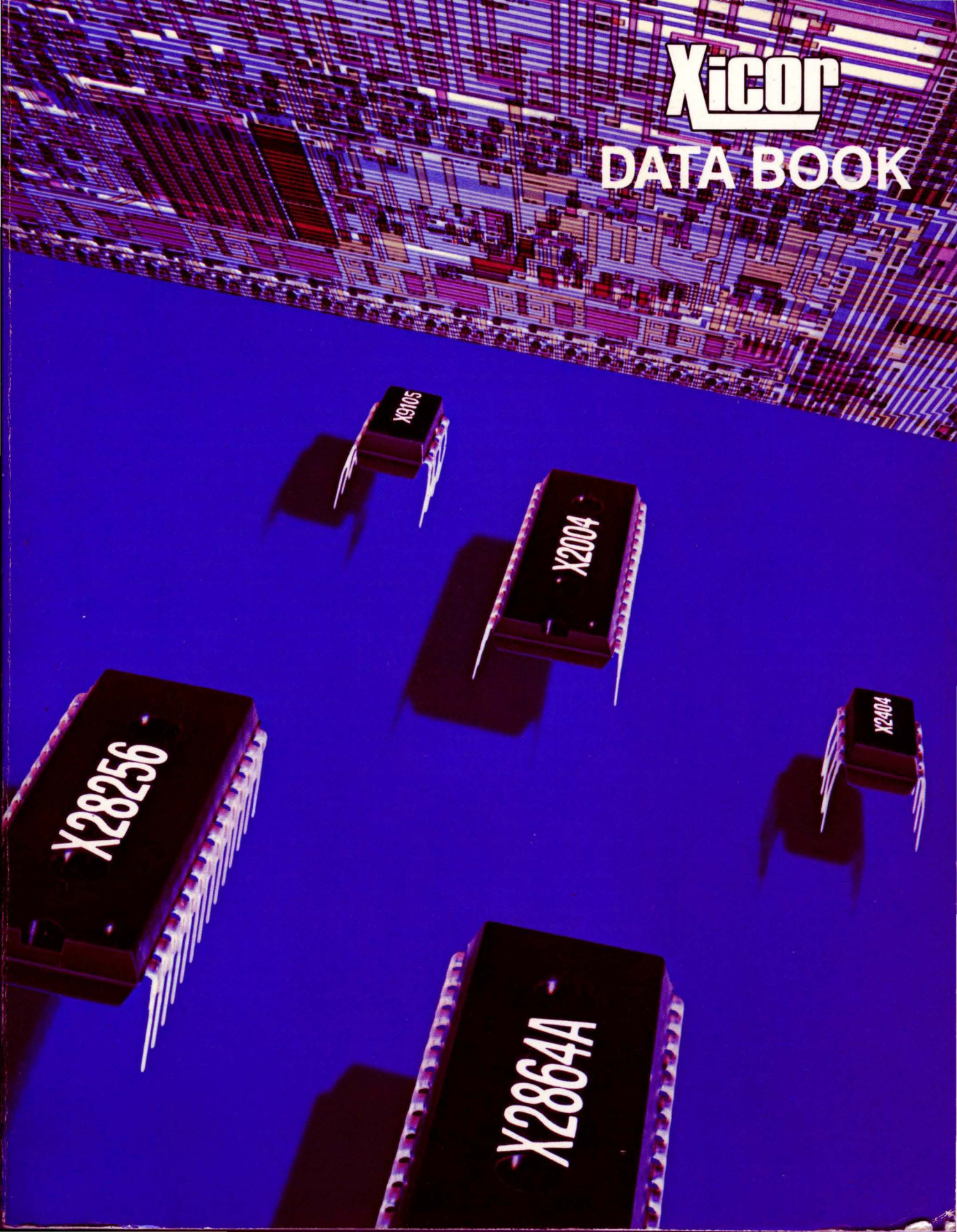
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Xicor

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*NOVRAM is Xicor's nonvolatile static RAM device.

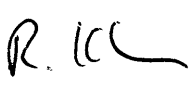
Xicor DATA BOOK

President's Message

Dear Customer:

As the leader of the exciting field of E^2PROM and NOVRAM memories, Xicor has charted a course to provide an extensive product offering. This catalog contains data sheets for NMOS and CMOS E^2PROMs and NMOS NOVRAMs. These products are available in a wide variety of speeds, package types and both parallel and serial interface configurations. The majority of the products are offered with extended temperature range, and many are built per Mil-Std-883 for Class B devices.

Xicor has shipped more than 10 million E^2PROM and NOVRAM memories to its customers. Our research and development budget is very substantial and will enable Xicor to continue to introduce innovative products. Our worldwide sales, marketing and applications organizations are dedicated to the support of your memory requirements. We appreciate your interest and look forward to supplying your present and future requirements.



Raphael Klein
President

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Fact Sheets contain information on products under development. Xicor reserves the right to change these specifications or modify the product at any time, without notice.

Advanced Data Sheets contain typical product specifications which are subject to change upon device characterization over the full specified temperature range. Xicor reserves the right to change these specifications or modify the product at any time, without notice.

Preliminary Data Sheets contain minimum and maximum limits specified over the full temperature range based upon initial production device characterization. Xicor reserves the right to change these specifications or modify the product at any time, without notice.

Final Data Sheets contain minimum and maximum limits specified over the full temperature range for production devices.

Contact your local Xicor sales representative to obtain the latest specifications prior to order placement.

E^2POT™ is a trademark of Xicor, Inc.
NOVRAM is Xicor's nonvolatile static RAM device.
COPS™ is a trademark of National Semiconductor, Corp.

LIMITED WARRANTY
Devices sold by Xicor, Inc. are covered by the warranty and patent indemnification provisions appearing in its Terms of Sale only. Xicor, Inc. makes no warranty, express, statutory, implied, or by description regarding the information set forth herein or regarding the freedom of the described devices from patent infringement. Xicor, Inc. makes no warranty of merchantability or fitness for any purpose. Xicor, Inc. reserves the right to discontinue production and change specifications and prices at any time and without notice.

Xicor, Inc. assumes no responsibility for the use of any circuitry other than circuitry embodied in a Xicor, Inc. product. No other circuits, patents, licenses are implied.

LIFE RELATED POLICY
In situations where semiconductor component failure may endanger life, system designers using this product should design the system with appropriate error detection and correction, redundancy and back-up features to prevent such an occurrence.

Xicor's products are not authorized for use as critical components in life support devices or systems.

1. Life support devices or systems are devices or systems which, (a) are intended for surgical implant into the body, or (b) support or sustain life, and whose failure to perform, when properly used in accordance with instructions for use provided in the labeling, can be reasonably expected to result in a significant injury to the user.
2. A critical component is any component of a life support device or system whose failure to perform can be reasonably expected to cause the failure of the life support device or system, or to affect its safety or effectiveness.

Precautions for the Handling of MOS Devices

Xicor products are designed with effective input protection to prevent damage to the devices under most conditions. However, any MOS circuit can be catastrophically damaged by excessive electrostatic discharge or transient voltages. The following procedures are recommended to avoid accidental circuit damage.

I. Testing MOS Circuits:

1. All units should be handled directly from the conductive or antistatic plastic tube in which they were shipped if possible. This action minimizes touching of individual leads.
2. If units are to be tested without using the tube carrier, the following precautions should be taken:
   a. Table surfaces which potentially will come in contact with the devices either directly or indirectly (such as through shipping tubes) must be metal or of another conductive material and should be electrically connected to the test equipment and to the test operator (a grounding bracelet is recommended).
   b. The units should be transported in bundled antistatic tubes or metal trays, both of which will assume a common potential when placed on a conductive table top.
   c. Do not band tubes together with adhesive tape or rubber bands without first wrapping them in a conductive layer.

II. Test Equipment (Including Environmental Equipment):

1. All equipment must be properly returned to the same reference potential (ground) as the devices, the operator, and the container for the devices.
2. Devices to be tested should be protected from high voltage surges developed by:
   a. Turning electrical equipment on or off.
   b. Relay switching.
   c. Transients from voltage sources (AC line or power supplies).

III. Assembling MOS Devices Onto P.C. Boards:

1. The MOS circuits should be mounted on the P.C. board last.
2. Similar precautions should be taken as in Item I above, at the assembly work station.
3. Soldering irons or solder baths should be at the same reference (ground) potential as the devices.
4. Plastic materials which are not antistatic treated should be kept away from devices as they develop and maintain high levels of static charge.

IV. Device Handling:

1. Handling of devices should be kept to a minimum. If handling is required, avoid touching the leads directly.

V. General:

1. The handler should take every precaution that the device will see the same reference potential when moved.
2. Anyone handling individual devices should develop a habit of first touching the container in which the units are stored before touching the units.
3. Before placing the units into a P.C. board, the handler should touch the P.C. board first.
4. Personnel should not wear clothing which will build up static charge. They should wear smocks and clothing made of 100% cotton rather than wool or synthetic fibers.
5. Be careful of electrostatic build up through the movement of air over plastic material. This is especially true of acid sinks.
6. Personnel or operators should always wear grounded wrist straps when working with MOS devices.
7. A 1 meg ohm resistance ground stap is recommended and will protect people up to 5,000 volts AC RMS or DC by limiting current to 5 milliamperes.
8. Antistatic ionized air equipment is very effective and useful in preventing electrostatic damage.
9. Low humidity maximizes potential static problems. Maintaining humidity levels above 45% is one of the most effective ways to guard against static handling problems.

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Reference Guide to Xicor Nonvolatile Memories

NOVRAMs

Part Number	Organization	Access Time	Power		Store Cycles	No. of Pins	Temp. Range(s)	Package			Data Sheet Page #	Order Info. Page #
			Active	Standby				P	D	E		
X2201A	1024 x 1	300ns	60mA	N/A	10,000	18	A		•		1-1	7-1
X2210A	64 x 4	250ns	50mA	N/A	10,000	18	A	•	•		1-9	7-1
X2210	64 x 4	300ns	50mA	N/A	10,000	18	A	•	•		1-17	7-1
X2210/5	64 x 4	300ns	50mA	N/A	50,000	18	A	•	•		1-17	7-1
X2210/10	64 x 4	300ns	50mA	N/A	100,000	18	A	•	•		1-17	7-1
X2210I	64 x 4	300ns	55mA	N/A	10,000	18	B	•	•		1-17	7-1
X2210I/5	64 x 4	300ns	55mA	N/A	50,000	18	B	•	•		1-17	7-1
X2210I/10	64 x 4	300ns	55mA	N/A	100,000	18	B	•	•		1-17	7-1
X2210M	64 x 4	300ns	55mA	N/A	10,000	18	C		•		1-25	7-1
X2210M/5	64 x 4	300ns	55mA	N/A	50,000	18	C		•		1-25	7-1
X2210M/10	64 x 4	300ns	55mA	N/A	100,000	18	C		•		1-25	7-1
X2212A	256 x 4	250ns	60mA	N/A	10,000	18	A	•	•		1-33	7-1
X2212	256 x 4	300ns	60mA	N/A	10,000	18	A	•	•		1-41	7-1
X2212/5	256 x 4	300ns	60mA	N/A	50,000	18	A	•	•		1-41	7-1
X2212/10	256 x 4	300ns	60mA	N/A	100,000	18	A	•	•		1-41	7-1
X2212I	256 x 4	300ns	70mA	N/A	10,000	18	B	•	•		1-41	7-1
X2212I/5	256 x 4	300ns	70mA	N/A	50,000	18	B	•	•		1-41	7-1
X2212I/10	256 x 4	300ns	70mA	N/A	100,000	18	B	•	•		1-41	7-1
X2212M	256 x 4	300ns	70mA	N/A	10,000	18	C		•		1-49	7-1
X2212M/5	256 x 4	300ns	70mA	N/A	50,000	18	C		•		1-49	7-1
X2212M/10	256 x 4	300ns	70mA	N/A	100,000	18	C		•		1-49	7-1

N/A = Not Applicable

A = Commercial = 0° to +70°C.
B = Industrial = –40° to +85°C.
C = Military = –55° to +125°C.

P = Plastic DIP
D = Cerdip
E = Ceramic LCC

NOVRAMs (Byte-Wide)

Part Number	Organization	Access Time	Power		Store Cycles	No. of Pins	Temp. Range(s)	Package			Data Sheet Page #	Order Info. Page #
			Active	Standby				P	D	E		
X2001-20	128 x 8	200ns	80mA	50mA	100,000	24	A	•	•		1-57	7-1
X2001-25	128 x 8	250ns	80mA	50mA	100,000	24	A	•	•		1-57	7-1
X2001	128 x 8	300ns	80mA	50mA	100,000	24	A	•	•		1-57	7-1
X2001I-20	128 x 8	200ns	100mA	65mA	100,000	24	B	•	•		1-57	7-1
X2001I-25	128 x 8	250ns	100mA	65mA	100,000	24	B	•	•		1-57	7-1
X2001I	128 x 8	300ns	100mA	65mA	100,000	24	B	•	•		1-57	7-1
X2002-20	256 x 8	200ns	90mA	55mA	100,000	28	A	•	•		1-65	7-1
X2002-25	256 x 8	250ns	90mA	55mA	100,000	28	A	•	•		1-65	7-1
X2002	256 x 8	300ns	90mA	55mA	100,000	28	A	•	•		1-65	7-1
X2002I-20	256 x 8	200ns	110mA	70mA	100,000	28	B	•	•		1-65	7-1
X2002I-25	256 x 8	250ns	110mA	70mA	100,000	28	B	•	•		1-65	7-1
X2002I	256 x 8	300ns	110mA	70mA	100,000	28	B	•	•		1-65	7-1
X2004-20	512 x 8	200ns	100mA	55mA	100,000	28	A	•	•	•	1-73	7-1
X2004-25	512 x 8	250ns	100mA	55mA	100,000	28	A	•	•	•	1-73	7-1
X2004	512 x 8	300ns	100mA	55mA	100,000	28	A	•	•	•	1-73	7-1
X2004I-20	512 x 8	200ns	120mA	90mA	100,000	28	B	•	•	•	1-73	7-1
X2004I-25	512 x 8	250ns	120mA	90mA	100,000	28	B	•	•	•	1-73	7-1
X2004I	512 x 8	300ns	120mA	90mA	100,000	28	B	•	•	•	1-73	7-1
X2004M-25	512 x 8	250ns	120mA	90mA	100,000	28	C		•	•	1-81	7-1
X2004M	512 x 8	300ns	120mA	90mA	100,000	28	C		•	•	1-81	7-1

A = Commercial = 0° to +70°C.
B = Industrial = −40° to +85°C.
C = Military = −55° to +125°C.

P = Plastic DIP
D = Cerdip
E = Ceramic LCC

Reference Guide to Xicor Nonvolatile Memories

SERIAL NOVRAMs

Part Number	Organization	Clk. Freq.	Power			Store Cycles	No. of Pins	Temp. Range(s)	Package			Data Sheet Page #	Order Info. Page #
			Active	Standby	Sleep				P	D	E		
X2444	16 x 16	1MHz	15mA	10mA	7mA	10,000	8	A	•	•		2-1	7-2
X2444/10	16 x 16	1MHz	15mA	10mA	7mA	100,000	8	A	•	•		2-1	7-2
X2444I	16 x 16	1MHz	25mA	15mA	10mA	10,000	8	B	•	•		2-1	7-2
X2444I/10	16 x 16	1MHz	25mA	15mA	10mA	100,000	8	B	•	•		2-1	7-2
X2444M	16 x 16	1MHz	25mA	15mA	10mA	10,000	8	C	•	•		2-9	7-2
X2444M/10	16 x 16	1MHz	25mA	15mA	10mA	100,000	8	C	•	•		2-9	7-2

SERIAL E^2PROMs

Part Number	Organization	Page Size (#Bytes)	Clk. Freq.	Power		No. of Pins	Temp. Range(s)	Package			Data Sheet Page #	Order Info. Page #
				Active	Standby			P	D	E		
X2404	512 x 8	8	100KHz	20mA	15mA	8	A	•	•		2-17	7-3
X2404I	512 x 8	8	100KHz	20mA	15mA	8	B	•	•		2-17	7-3
X2404M	512 x 8	8	100KHz	20mA	15mA	8	C	•	•		2-27	7-3
X24C04	512 x 8	8	100KHz	2mA	50μA	8	A, B	•	•		2-37	7-3
X24C16	2048 x 8	8	100KHz	2mA	50μA	8	A, B	•	•		2-45	7-3

A = Commercial = 0° to +70°C.
B = Industrial = -40° to +85°C.
C = Military = -55° to +125°C.

P = Plastic DIP
D = Cerdip
E = Ceramic LCC

Reference Guide to Xicor Nonvolatile Memories

4K E²PROMs

Part Number	Organization	Page Size (#Bytes)	Access Time	Power		No. of Pins	Temp. Range(s)	Package			Data Sheet Page #	Order Info. Page #
				Active	Standby			P	D	E		
X2804A-25	512 x 8	N/A	250ns	80mA	50mA	24	A	•	•		3-1	7-4
X2804A	512 x 8	N/A	300ns	80mA	50mA	24	A	•	•		3-1	7-4
X2804A-35	512 x 8	N/A	350ns	80mA	50mA	24	A	•	•		3-1	7-4
X2804A-45	512 x 8	N/A	450ns	80mA	50mA	24	A	•	•		3-1	7-4
X2804AI-25	512 x 8	N/A	250ns	100mA	60mA	24	B	•	•		3-1	7-4
X2804AI	512 x 8	N/A	300ns	100mA	60mA	24	B	•	•		3-1	7-4
X2804AI-35	512 x 8	N/A	350ns	100mA	60mA	24	B	•	•		3-1	7-4
X2804AI-45	512 x 8	N/A	450ns	100mA	60mA	24	B	•	•		3-1	7-4
X2804AM	512 x 8	N/A	300ns	100mA	60mA	24	C		•		3-7	7-4
X2804AM-35	512 x 8	N/A	350ns	100mA	60mA	24	C		•		3-7	7-4
X2804AM-45	512 x 8	N/A	450ns	100mA	60mA	24	C		•		3-7	7-4

16K E²PROMs

Part Number	Organization	Page Size (#Bytes)	Access Time	Power		No. of Pins	Temp. Range(s)	Package			Data Sheet Page #	Order Info. Page #
				Active	Standby			P	D	E		
X2816A-25	2048 x 8	N/A	250ns	110mA	50mA	24	A	•	•	•	3-13	7-4
X2816A	2048 x 8	N/A	300ns	110mA	50mA	24	A	•	•	•	3-13	7-4
X2816A-35	2048 x 8	N/A	350ns	110mA	50mA	24	A	•	•	•	3-13	7-4
X2816A-45	2048 x 8	N/A	450ns	110mA	50mA	24	A	•	•	•	3-13	7-4
X2816AI-25	2048 x 8	N/A	250ns	140mA	60mA	24	B	•	•	•	3-13	7-4
X2816AI	2048 x 8	N/A	300ns	140mA	60mA	24	B	•	•	•	3-13	7-4
X2816AI-35	2048 x 8	N/A	350ns	140mA	60mA	24	B	•	•	•	3-13	7-4
X2816AI-45	2048 x 8	N/A	450ns	140mA	60mA	24	B	•	•	•	3-13	7-4
X2816AM	2048 x 8	N/A	300ns	140mA	60mA	24	C		•	•	3-19	7-4
X2816AM-35	2048 x 8	N/A	350ns	140mA	60mA	24	C		•	•	3-19	7-4
X2816AM-45	2048 x 8	N/A	450ns	140mA	60mA	24	C		•	•	3-19	7-4
X2816B	2048 x 8	32	150ns	60mA	30mA	24	A, B	•	•	•	3-25	7-4
X2816H	2048 x 8	32	45ns	80mA	—	24	A, B	•	•	•	3-31	7-4
X2616	2048 x 8	N/A	45ns	80mA	—	24*	A, B	•	•	•	3-83	7-4

N/A = Not Applicable
*Industry Standard Bipolar PROM Pinout

A = Commercial = 0° to +70°C.
B = Industrial = -40° to +85°C.
C = Military = -55° to +125°C.

P = Plastic DIP
D = Cerdip
E = Ceramic LCC

Reference Guide to Xicor Nonvolatile Memories

64K E²PROMs

Part Number	Organization	Page Size (#Bytes)	Access Time	Power		No. of Pins	Temp. Range(s)	Package			Data Sheet Page #	Order Info. Page #
				Active	Standby			P	D	E		
X2864A-20	8192 x 8	16	200ns	140mA	60mA	28	A	•	•	•	3-33	7-4
X2864A-25	8192 x 8	16	250ns	140mA	60mA	28	A	•	•	•	3-41	7-4
X2864A	8192 x 8	16	300ns	140mA	60mA	28	A	•	•	•	3-41	7-4
X2864A-35	8192 x 8	16	350ns	140mA	60mA	28	A	•	•	•	3-41	7-4
X2864A-45	8192 x 8	16	450ns	140mA	60mA	28	A	•	•	•	3-41	7-4
X2864AI-20	8192 x 8	16	200ns	140mA	70mA	28	B	•	•	•	3-33	7-4
X2864AI-25	8192 x 8	16	250ns	140mA	70mA	28	B	•	•	•	3-41	7-4
X2864AI	8192 x 8	16	300ns	140mA	70mA	28	B	•	•	•	3-41	7-4
X2864AI-35	8192 x 8	16	350ns	140mA	70mA	28	B	•	•	•	3-41	7-4
X2864AI-45	8192 x 8	16	450ns	140mA	70mA	28	B	•	•	•	3-41	7-4
X2864AM-25	8192 x 8	16	250ns	140mA	70mA	28	C		•	•	3-49	7-4
X2864AM	8192 x 8	16	300ns	140mA	70mA	28	C		•	•	3-57	7-4
X2864AM-35	8192 x 8	16	350ns	140mA	70mA	28	C		•	•	3-57	7-4
X2864AM-45	8192 x 8	16	450ns	140mA	70mA	28	C		•	•	3-57	7-4
X2864B	8192 x 8	32	150ns	80mA	30mA	28	A, B	•	•	•	3-65	7-4
X2864H	8192 x 8	32	45ns	100mA	—	28	A, B	•	•	•	3-71	7-4
X28C64	8192 x 8	32	150ns	60mA	200μA	28	A, B	•	•	•	3-73	7-4
X2664	8192 x 8	N/A	45ns	100mA	—	24*	A, B	•	•	•	3-85	7-4

N/A = Not Applicable
*Industry Standard Bipolar PROM Pinout

256K E²PROMs

Part Number	Organization	Page Size (#Bytes)	Access Time	Power		No. of Pins	Temp. Range(s)	Package			Data Sheet Page #	Order Info. Page #
				Active	Standby			P	D	E		
X28256	32K x 8	64	150ns	100mA	50mA	28	A, B	•	•	•	3-75	7-4
X28C256	32K x 8	64	150ns	80mA	200μA	28	A, B	•	•	•	3-81	7-4

A = Commercial = 0° to +70°C.
B = Industrial = −40° to +85°C.
C = Military = −55° to +125°C.

P = Plastic DIP
D = Cerdip
E = Ceramic LCC

E^2POTENTIOMETERS (E^2POT™)

Part Number	Nominal Wiper Resistance	Incremental Resistance	Maximum Resistance	No. of Pins	Temp. Range(s)	Package			Data Sheet Page #	Order Info. Page #
						P	D	E		
X9103	40Ω	101Ω	10KΩ	8	A, B, C	•	•		4-1	4-2
X9203	40Ω	202Ω	20KΩ	8	A, B, C	•	•		4-1	4-2
X9503	40Ω	505Ω	50KΩ	8	A, B, C	•	•		4-1	4-2
X9104	40Ω	1.01KΩ	100KΩ	8	A, B, C	•	•		4-1	4-2
X9204	40Ω	2.02KΩ	200KΩ	8	A, B, C	•	•		4-1	4-2
X9504	40Ω	5.05KΩ	500KΩ	8	A, B, C	•	•		4-1	4-2
X9105	40Ω	10.1KΩ	1MΩ	8	A, B, C	•	•		4-1	4-2

A = Commercial = 0° to +70°C.
B = Industrial = -40° to +85°C.
C = Military = -55° to +125°C.

P = Plastic DIP
D = Cerdip
E = Ceramic LCC

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Uncompromising Features Hi-Lite the 5 Volt E^2PROM 5-96
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Memory Overview

Since its founding, Xicor has developed and placed into production a wide range of system-alterable nonvolatile memory devices. These devices, manufactured with Xicor's proprietary state-of-the-art textured triple-poly floating gate process, are available in a variety of architectures (NOVRAM and E²PROM), interfaces (nibble-wide, byte-wide and serial), densities, and speeds. Xicor's success as an innovator and leader in system-alterable nonvolatile memory is affirmed with an *Electronic Product Magazine* Product of the Year award in 1980 and again in 1982 for the first 5-volt only NOVRAM and the first 5-volt only full featured E²PROM, respectively.

Lower density E²PROMs and NOVRAMs have been readily available for a number of years and have provided unique niche applications solutions. Serial devices have replaced DIP switches in a wide range of products that offer user selectable operating parameters. Nibble-wide and byte-wide NOVRAMs and E²PROMs are being used in instrumentation and industrial control applications to store calibration data and control information. Communications equipment has implemented these same devices to store phone numbers in repertory dialers and antenna positioning equipment.

The list of first generation applications goes on at length; however, with the advent of the next generation of higher density E²PROM devices, such as the X2864A, the potential applications areas for E²PROMs has rapidly expanded.

As designers have gained experience implementing the denser E²PROM devices into system memories, they have given Xicor feedback on features they would like. Xicor has listened.

As Figures 1 and 2 illustrate, Xicor's response has been active. The issues addressed by the Xicor design team have been: faster read access time, faster write cycle time (Figure 1), denser memory devices and write protection mechanisms.

Xicor has also implemented added features via software control rather than "dedicated pin" hardware control for optional system use. Xicor is committed to providing solutions that neither hinder nor limit the memory designer's imagination. The products and features shown in Figures 1 and 2 and in the data sheets in this catalog illustrate Xicor's dedication to listening to you, the designer, in providing memory design solutions.

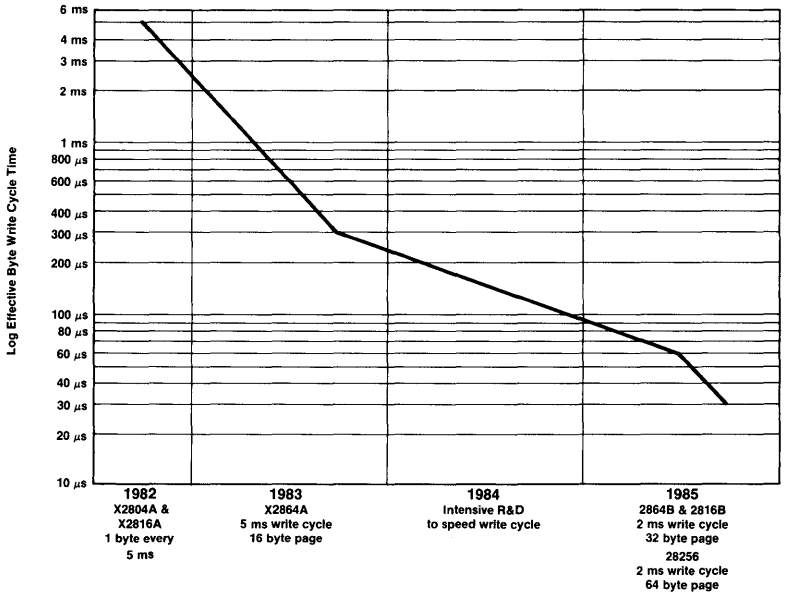
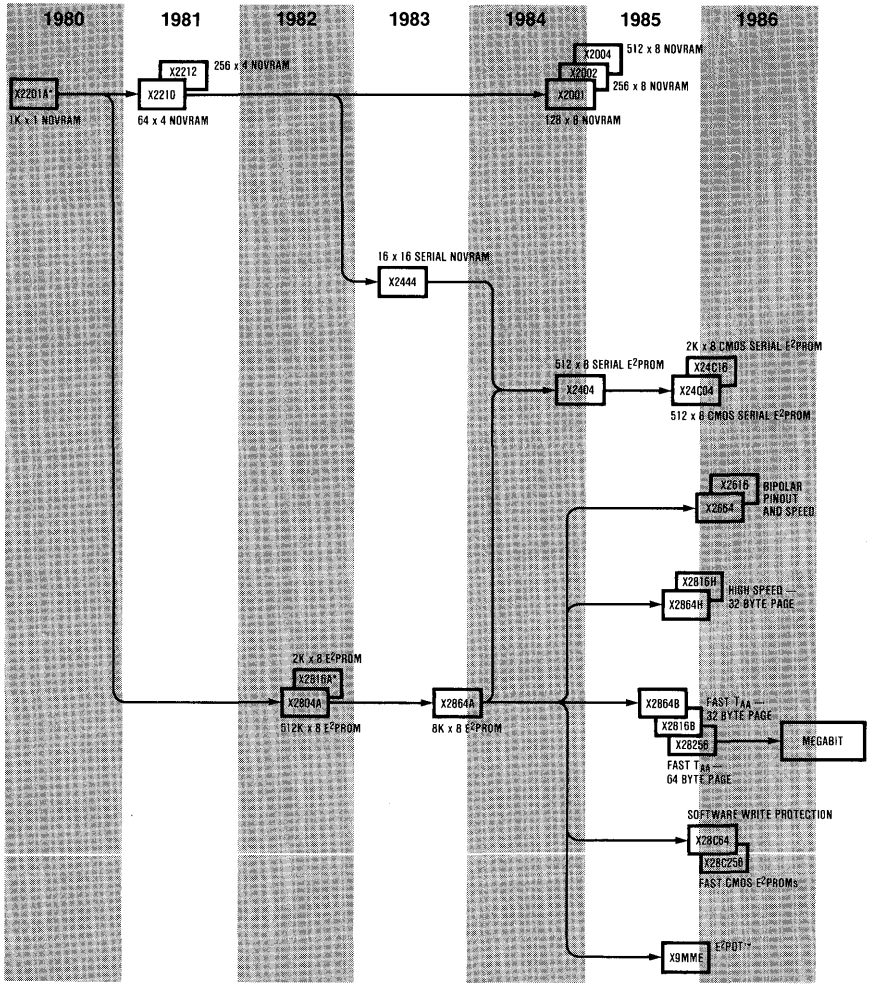


Figure 1: Xicor's E²PROM Write Cycle Time Reduction.
Effective byte write cycle time is calculated by dividing the device's internal write cycle time by the number of bytes per page.



*Product of the Year Award, *Electronic Product Magazine.*

1980 — First 5 volt only nonvolatile memory, sets new industry standard.
1981 — Expanded 5 volt only NOVRAM family.
1982 — First 5 volt only E²PROM. First E²PROM to offer latched address and data setting another industry standard.
1983 — First production E²PROM to feature page write capability and $\overline{\text{DATA}}$ Polling, becoming de facto industry standard for all E²PROMs. First Serial NOVRAM introduced.
1984 — Expansion of NOVRAM into byte-wide configurations. Introduction of Serial E²PROM family.
1985 — Banner year with introduction of high speed and higher density E²PROMs in both NMOS and CMOS technologies.

Figure 2: Xicor's Product Evolution.

NOVRAM* Data Sheets

1

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Nonvolatile Static RAM

FEATURES

- **Single 5 Volt Supply**
- **Fully TTL Compatible**
- **Infinite E²PROM Array Recall, RAM Read and Write Cycles**
- **Access Time of 300ns Max.**
- **Nonvolatile Store Inhibit: V_{CC} = 3v Typical**
- **100 Year Data Retention**

DESCRIPTION

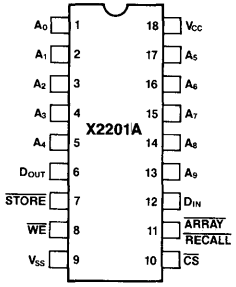
The Xicor X2201A is a 1024 x 1 NOVRAM* featuring a high-speed static RAM overlaid bit-for-bit with a nonvolatile E²PROM. The X2201A is fabricated with the same reliable N-channel floating gate MOS technology used in all Xicor 5 volt nonvolatile memories.

The NOVRAM design allows data to be easily transferred from RAM to E²PROM (store) and from E²PROM to RAM (recall). The store operation is completed in 10ms or less and the recall is typically completed in 1μs.

Xicor NOVRAMs are designed for unlimited write operations to RAM, either from the host or recalls from E²PROM. The E²PROM array is designed for a minimum 10,000 store cycles. Data retention is specified to be greater than 100 years.

*NOVRAM is Xicor's nonvolatile static RAM device.

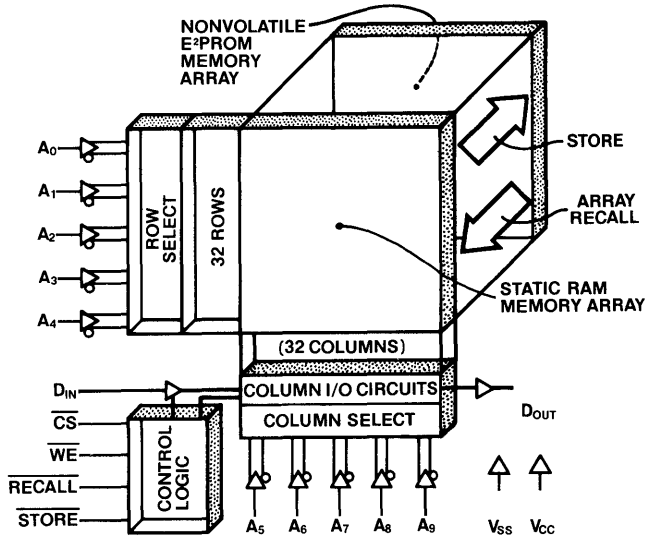
PIN CONFIGURATION



PIN NAMES

A_0–A_9	Address Inputs
D_{IN}	Data Input
D_{OUT}	Data Out
$\overline{WE}$	Write Enable
$\overline{CS}$	Chip Select
$\overline{ARRAY\ RECALL}$	Array Recall
$\overline{STORE}$	Store
V_{CC}	+5V
V_{SS}	Ground

FUNCTIONAL DIAGRAM



ABSOLUTE MAXIMUM RATINGS*

Temperature Under Bias ..... −10°C to +85°C
Storage Temperature ..... −65°C to +150°C
Voltage on any Pin with
Respect to Ground ..... −1.0V to +7V
D.C. Output Current ..... 5 mA
Lead Temperature (Soldering,
10 Seconds) ..... 300°C

*COMMENT

Stresses above those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. This is a stress rating only and the functional operation of the device at these or any other conditions above those indicated in the operational sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

D.C. OPERATING CHARACTERISTICS

T_A = 0°C to +70°C, V_{CC} = +5V ±10%, unless otherwise specified.

Symbol	Parameter	Limits		Units	Test Conditions
		Min.	Max.		
I_{CC}	Power Supply Current		60	mA	All Inputs = V_{CC} $I_{I/O}$ = 0 mA
I_{LI}	Input Load Current		10	µA	V_{IN} = GND to V_{CC}
I_{LO}	Output Leakage Current		10	µA	V_{OUT} = GND to V_{CC}
V_{IL}	Input Low Voltage	−1.0	0.8	V	
V_{IH}	Input High Voltage	2.0	V_{CC} +1.0	V	
V_{OL}	Output Low Voltage		0.4	V	I_{OL} = 4.2 mA
V_{OH}	Output High Voltage	2.4		V	I_{OH} = −2 mA

CAPACITANCE T_A = 25°C, f = 1.0 MHz, V_{CC} = 5V

Symbol	Test	Max.	Unit	Conditions
$C_{I/O}$[1]	Input/Output Capacitance	8	pF	$V_{I/O}$ = 0V
C_{IN}[1]	Input Capacitance	6	pF	V_{IN} = 0V

Note: (1) This parameter is periodically sampled and not 100% tested.

A.C. CONDITIONS OF TEST

Input Pulse Levels	0 to 3.0 Volts
Input Rise and Fall Times	10 nsec
Input and Output Timing Levels	1.5 Volts
Output Load	1 TTL Gate and C_L = 100 pF

MODE SELECTION

Inputs				Input Output	
CS	WE	ARRAY RECALL	STORE	I/O	Mode
H	X	H	H	Output High Z	Not Selected[2]
L	H	H	H	Output Data	Read RAM
L	L	H	H	Input Data High	Write "1" RAM
L	L	H	H	Input Data Low	Write "0" RAM
X	H	L	H	Output High Z	Array Recall
H	X	L	H	Output High Z	Array Recall
X	H	H	L	Output High Z	Nonvolatile Storing[3]
H	X	H	L	Output High Z	Nonvolatile Storing[3]

Notes: (2) Chip is deselected but may be automatically completing a store cycle.
(3) $\overline{\text{STORE}}$ = L is required only to initiate the store cycle, after which the store cycle will be automatically completed ($\overline{\text{STORE}}$ = X).

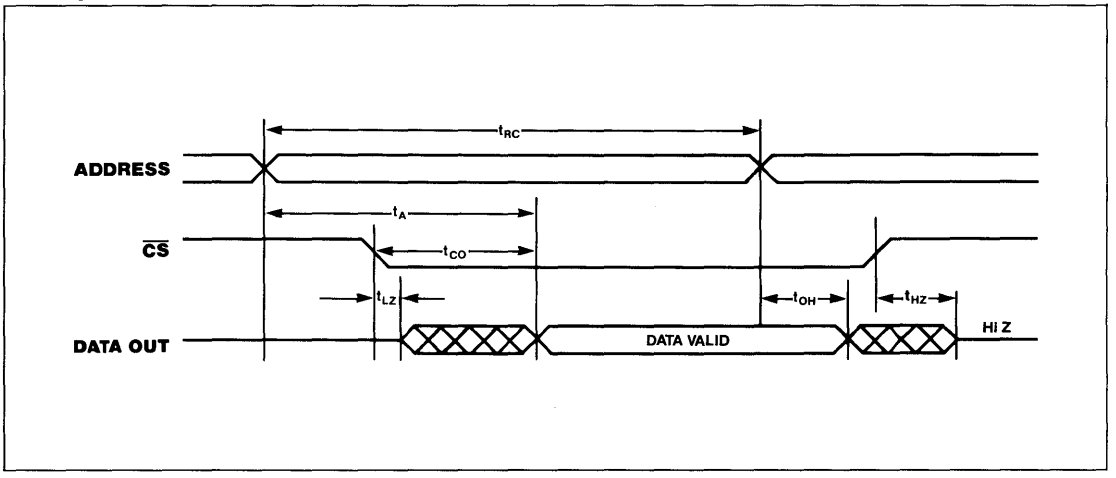
A.C. CHARACTERISTICS

T_A = 0°C to +70°C, V_{CC} = +5V ±10%, unless otherwise specified.

Read Cycle Limits

Symbol	Parameter	Min.	Max.	Units
t_{RC}	Read Cycle Time	300		ns
t_A	Access Time		300	ns
t_{CO}	Chip Select to Output Valid		200	ns
t_{OH}	Output Hold from Address Change	50		ns
t_{LZ}	Chip Select to Output in Low Z	10		ns
t_{HZ}	Chip Deselect to Output in High Z	10	100	ns

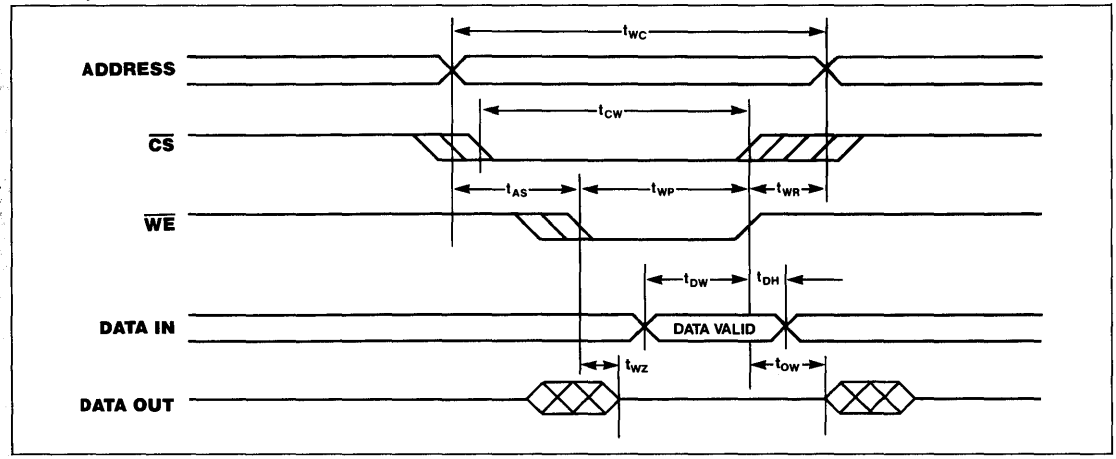
Read Cycle



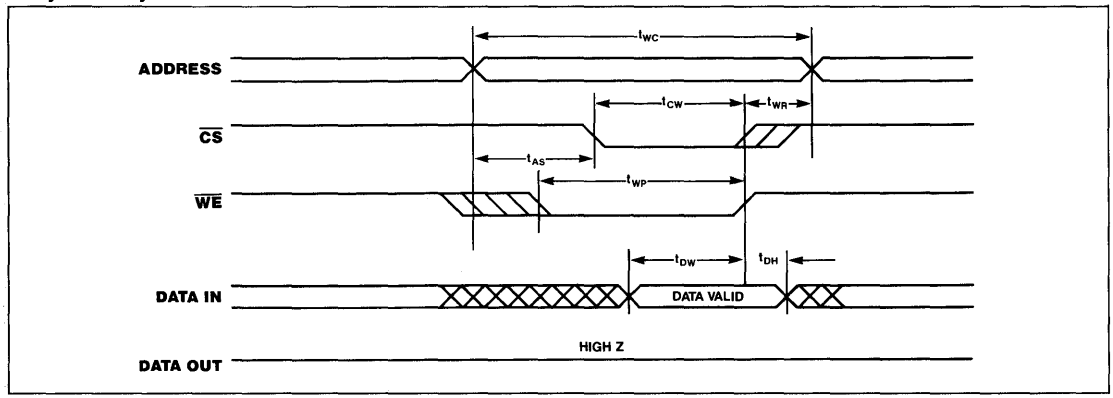
Write Cycle Limits

Symbol	Parameter	Min.	Max.	Units
t_{WC}	Write Cycle Time	300		ns
t_{CW}	Chip Select to End of Write	150		ns
t_{AS}	Address Set-up Time	50		ns
t_{WP}	Write Pulse Width	150		ns
t_{WR}	Write Recovery Time	25		ns
t_{DW}	Data Valid to End of Write	100		ns
t_{DH}	Data Hold Time	0		ns
t_{WZ}	Write Enable to Output in High Z	10	100	ns
t_{OW}	Output Active from End of Write	10		ns

Write Cycle



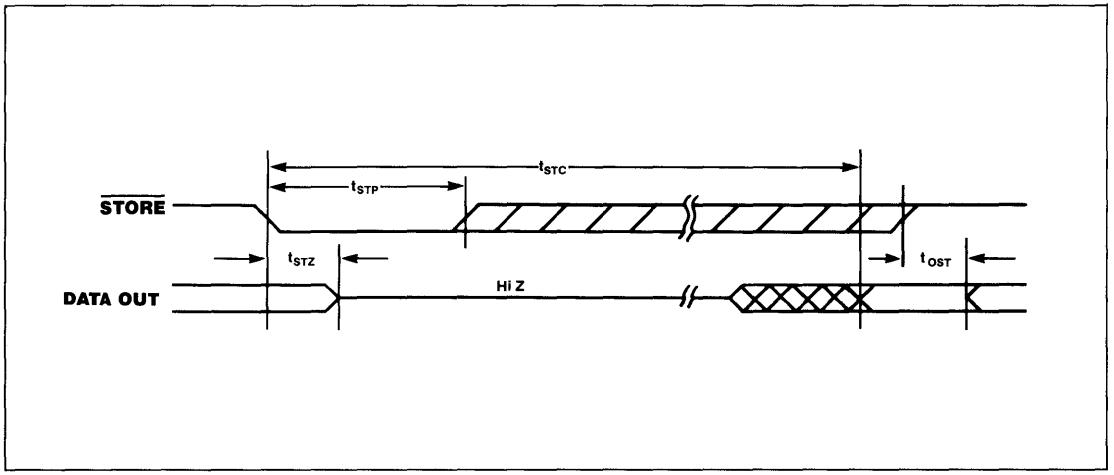
Early Write Cycle



Store Cycle Limits

Symbol	Parameter	Min.	Max.	Units
t_{STC}	Store Cycle Time		10	ms
t_{STP}	Store Pulse Width	100		ns
t_{STZ}	Store to Output in High Z		500	ns
t_{OST}	Output Active from End of Store	10		ns

Store Cycle

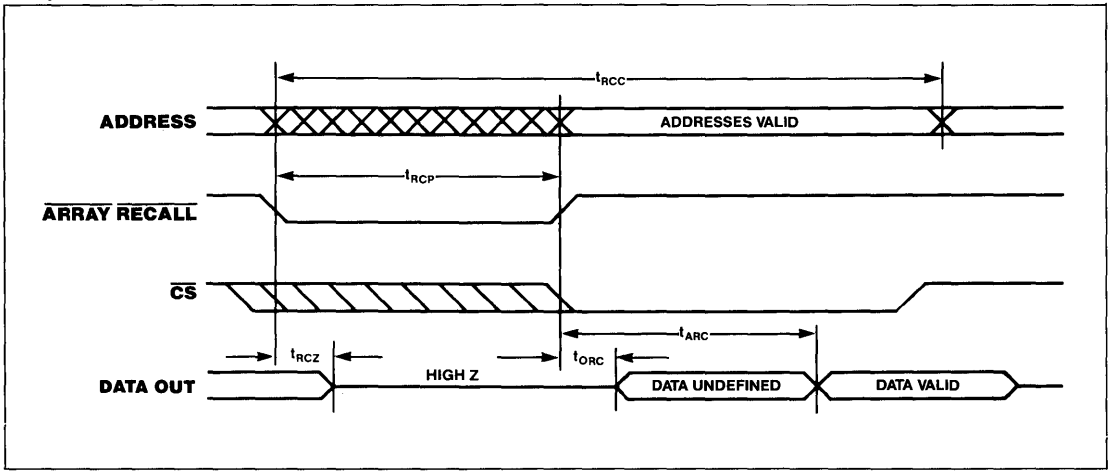


Array Recall Cycle Limits

Symbol	Parameter	Min.	Max.	Units
t_{RCC}	Array Recall Cycle Time	1200		ns
t_{RCP}	Recall Pulse Width(4)	450		ns
t_{RCZ}	Recall to Output in High Z		150	ns
t_{ORC}	Output Active from End of Recall	10		ns
t_{ARC}	Recalled Data Access Time from End of Recall		750	ns

Note: (4) Array Recall rise time must be less than 1 μs.

Array Recall Cycle



PIN DESCRIPTIONS AND DEVICE OPERATION

Addresses (A_0–A_9)

The address inputs select a memory location during a read or write operation.

Chip Select ($\overline{CS}$)

The Chip Select input must be LOW to enable read/write operations with the RAM array. $\overline{CS}$ HIGH will place the D_{OUT} in the high impedance state.

Write Enable ($\overline{WE}$)

The Write Enable input controls the D_{OUT} buffer, determining whether a RAM read or write operation is enabled. $\overline{WE}$ HIGH enables a read and $\overline{WE}$ LOW enables a write.

Data In (D_{IN})

Data is written into the device via the D_{IN} input.

Data Out (D_{OUT})

Data from a selected address is output on the D_{OUT} output. This pin is in the high impedance state when either $\overline{CS}$ is HIGH or when $\overline{WE}$ is LOW.

$\overline{STORE}$

The $\overline{STORE}$ input, when LOW, will initiate the transfer of the entire contents of the RAM array to the E^2PROM array. The $\overline{WE}$ and $\overline{ARRAY\ RECALL}$ inputs are inhibited during the store cycle. The store operation will be completed in 10ms or less.

A store operation has priority over RAM read/write operations. If $\overline{STORE}$ is asserted during a read operation, the read will be discontinued. If $\overline{STORE}$ is asserted during a RAM write operation, the write will be immediately terminated and the store performed. The data at the RAM address that was being written will be unknown in both the RAM and E^2PROM.

$\overline{ARRAY\ RECALL}$

The $\overline{ARRAY\ RECALL}$ input, when LOW, will initiate the transfer of the entire contents of the E^2PROM array to the RAM array. The transfer of data will typically be completed in 1μs or less.

An array recall has priority over RAM read/write operations and will terminate both operations when $\overline{ARRAY\ RECALL}$ is asserted. $\overline{ARRAY\ RECALL}$ LOW will also inhibit the $\overline{STORE}$ input.

WRITE PROTECTION

The X2201A has three write protect features that are employed to protect the contents of the nonvolatile memory.

- V_{CC} Sense—All functions are inhibited when V_{CC} is ≤ 3v, typically.
- Write Inhibit—Holding either $\overline{STORE}$ HIGH or $\overline{RECALL}$ LOW during power-up or power-down will prevent an inadvertent store operation and E^2PROM data integrity will be maintained.
- Noise Protection—A $\overline{STORE}$ pulse of less than 20ns will *not* initiate a store cycle.

ENDURANCE

The endurance specification of a device is characterized by the predicted *first* bit failure to occur in the entire memory (device or system) array rather than the average or typical value for the array. Since endurance is limited by the number of electrons trapped in the oxide during data changes, Xicor NOVRAMs are designed to minimize the number of changes an E^2PROM bit cell undergoes during store operations. Only those bits in the E^2PROM that are different from their corresponding location in the RAM will be "cycled" during a nonvolatile store. This characteristic reduces unnecessary cycling of any of the rest of the bits in the array, thereby increasing the potential endurance of each bit and increasing the potential endurance of the entire array. Reliability data documented in RR504, the *Xicor Reliability Report on Endurance*, and additional reports are available from Xicor.

Part Number	Store Cycles	Data Changes Per Bit
X2201A	10,000	1,000

NOTES

Nonvolatile Static RAM

FEATURES

- **Single 5 Volt Supply**
- **Fully TTL Compatible**
- **JEDEC Standard 18-Pin Package**
- **Infinite E^2PROM Array Recall, RAM Read and Write Cycles**
- **Access Time of 250ns Max.**
- **Nonvolatile Store Inhibit: V_{CC} = 3v Typical**
- **100 Year Data Retention**

DESCRIPTION

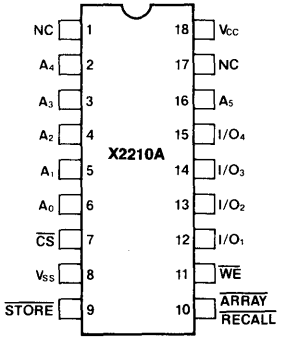
The Xicor X2210A is a 64 x 4 NOVRAM* featuring a high-speed static RAM overlaid bit-for-bit with a nonvolatile E^2PROM. The X2210A is fabricated with the same reliable N-channel floating gate MOS technology used in all Xicor 5 volt nonvolatile memories. The X2210A features the JEDEC approved pinout for 4-bit-wide memories, compatible with industry standard RAMs.

The NOVRAM design allows data to be easily transferred from RAM to E^2PROM (store) and from E^2PROM to RAM (recall). The store operation is completed in 10ms or less and the recall is typically completed in 1μs.

Xicor NOVRAMs are designed for unlimited write operations to RAM, either from the host or recalls from E^2PROM. The E^2PROM array is designed for a minimum 10,000 store cycles. Data retention is specified to be greater than 100 years.

*NOVRAM is Xicor's nonvolatile static RAM device.

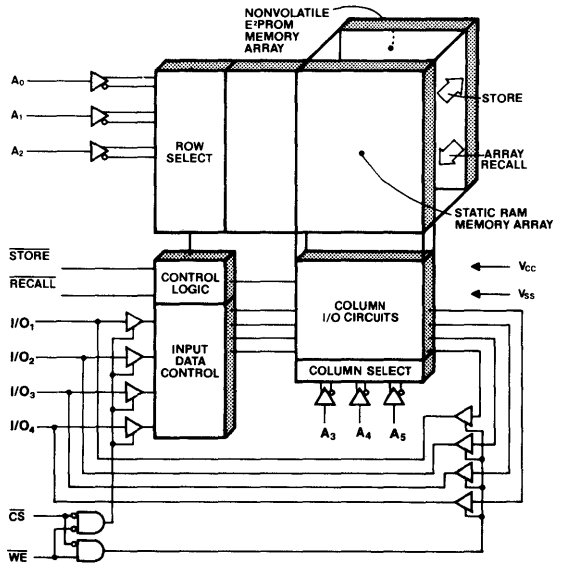
PIN CONFIGURATION



PIN NAMES

A_0–A_5	Address Inputs
I/O_1–I/O_4	Data Inputs/Outputs
$\overline{WE}$	Write Enable
$\overline{CS}$	Chip Select
$\overline{ARRAY\ RECALL}$	Array Recall
$\overline{STORE}$	Store
V_{CC}	+5V
V_{SS}	Ground
NC	No Connect

FUNCTIONAL DIAGRAM



ABSOLUTE MAXIMUM RATINGS*

Temperature Under Bias ..... −10°C to +85°C
Storage Temperature ..... −65°C to +150°C
Voltage on any Pin with
Respect to Ground ..... −1.0V to +7V
D.C. Output Current ..... 5 mA
Lead Temperature (Soldering,
10 Seconds) ..... 300°C

*COMMENT

Stresses above those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. This is a stress rating only and the functional operation of the device at these or any other conditions above those indicated in the operational sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

D.C. OPERATING CHARACTERISTICS

T_A = 0°C to +70°C, V_{CC} = +5V ±5%, unless otherwise specified.

Symbol	Parameter	Limits		Units	Test Conditions
		Min.	Max.		
I_{CC}	Power Supply Current		50	mA	All Inputs = V_{CC} $I_{I/O}$ = 0 mA
I_{LI}	Input Load Current		10	µA	V_{IN} = GND to V_{CC}
I_{LO}	Output Leakage Current		10	µA	V_{OUT} = GND to V_{CC}
V_{IL}	Input Low Voltage	−1.0	0.8	V	
V_{IH}	Input High Voltage	2.0	V_{CC} +0.5	V	
V_{OL}	Output Low Voltage		0.4	V	I_{OL} = 4.2 mA
V_{OH}	Output High Voltage	2.4		V	I_{OH} = −2 mA

CAPACITANCE T_A = 25°C, f = 1.0 MHz, V_{CC} = 5V

Symbol	Test	Max.	Unit	Conditions
$C_{I/O}$[1]	Input/Output Capacitance	8	pF	$V_{I/O}$ = 0V
C_{IN}[1]	Input Capacitance	6	pF	V_{IN} = 0V

Note: (1) This parameter is periodically sampled and not 100% tested.

A.C. CONDITIONS OF TEST

Input Pulse Levels	0 to 3.0 Volts
Input Rise and Fall Times	10 nsec
Input and Output Timing Levels	1.5 Volts
Output Load	1 TTL Gate and C_L = 100 pF

MODE SELECTION

Inputs				Input Output	
$\overline{CS}$	$\overline{WE}$	ARRAY $\overline{RECALL}$	$\overline{STORE}$	I/O	Mode
H	X	H	H	Output High Z	Not Selected[2]
L	H	H	H	Output Data	Read RAM
L	L	H	H	Input Data High	Write "1" RAM
L	L	H	H	Input Data Low	Write "0" RAM
X	H	L	H	Output High Z	Array Recall
H	X	L	H	Output High Z	Array Recall
X	H	H	L	Output High Z	Nonvolatile Storing[3]
H	X	H	L	Output High Z	Nonvolatile Storing[3]

Notes: (2) Chip is deselected but may be automatically completing a store cycle.
(3) $\overline{STORE}$ = L is required only to initiate the store cycle, after which the store cycle will be automatically completed ($\overline{STORE}$ = X).

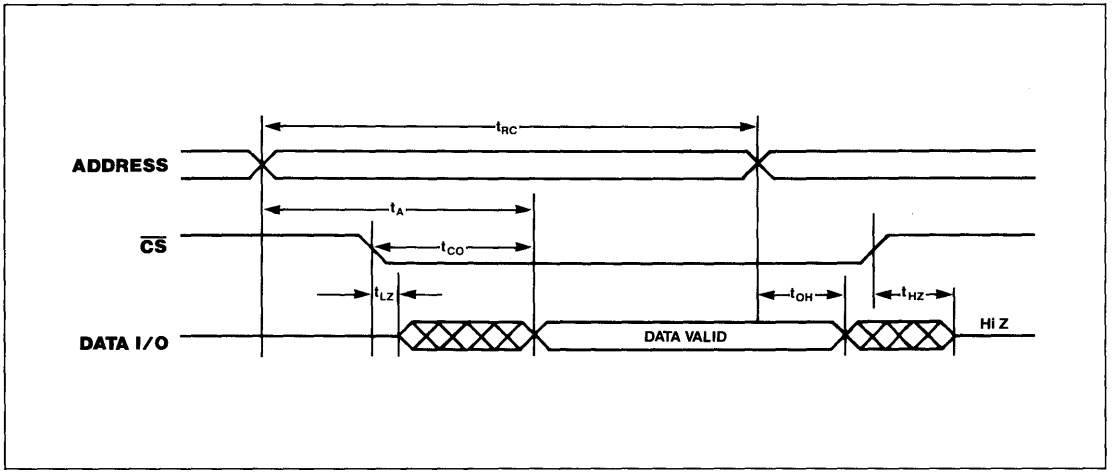
A.C. CHARACTERISTICS

T_A = 0°C to +70°C, V_{CC} = +5V ±5%, unless otherwise specified.

Read Cycle Limits

Symbol	Parameter	Min.	Max.	Units
t_{RC}	Read Cycle Time	250		ns
t_A	Access Time		250	ns
t_{CO}	Chip Select to Output Valid		200	ns
t_{OH}	Output Hold from Address Change	50		ns
t_{LZ}	Chip Select to Output in Low Z	10		ns
t_{HZ}	Chip Deselect to Output in High Z	10	100	ns

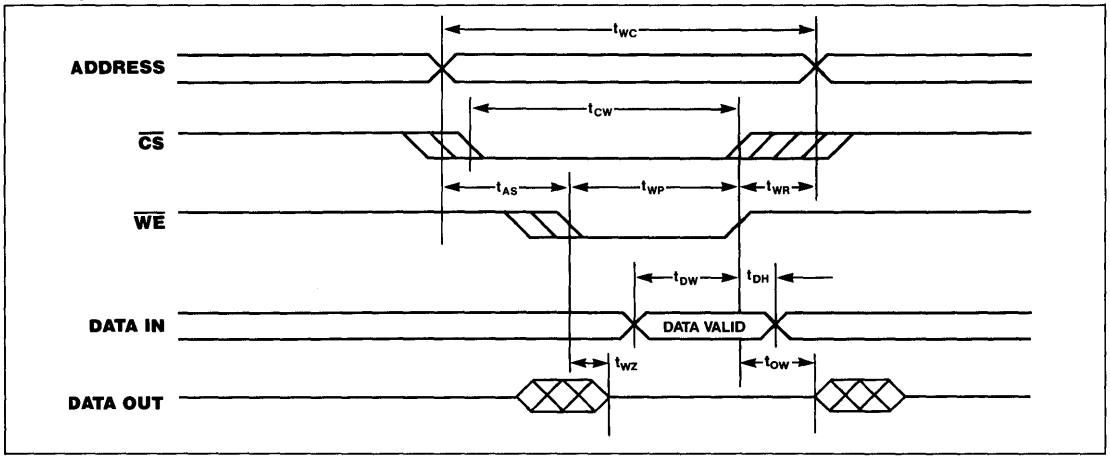
Read Cycle



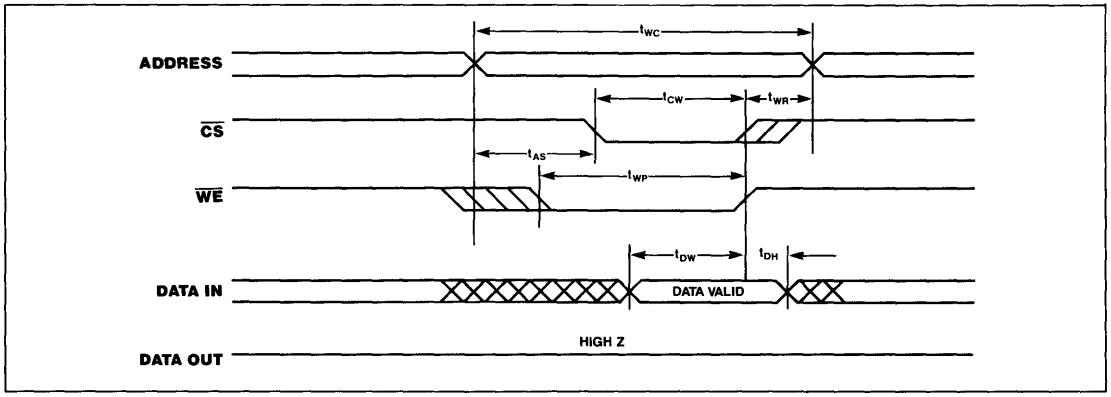
Write Cycle Limits

Symbol	Parameter	Min.	Max.	Units
t_{WC}	Write Cycle Time	250		ns
t_{CW}	Chip Select to End of Write	150		ns
t_{AS}	Address Set-up Time	50		ns
t_{WP}	Write Pulse Width	150		ns
t_{WR}	Write Recovery Time	25		ns
t_{DW}	Data Valid to End of Write	100		ns
t_{DH}	Data Hold Time	0		ns
t_{WZ}	Write Enable to Output in High Z	10	100	ns
t_{OW}	Output Active from End of Write	10		ns

Write Cycle



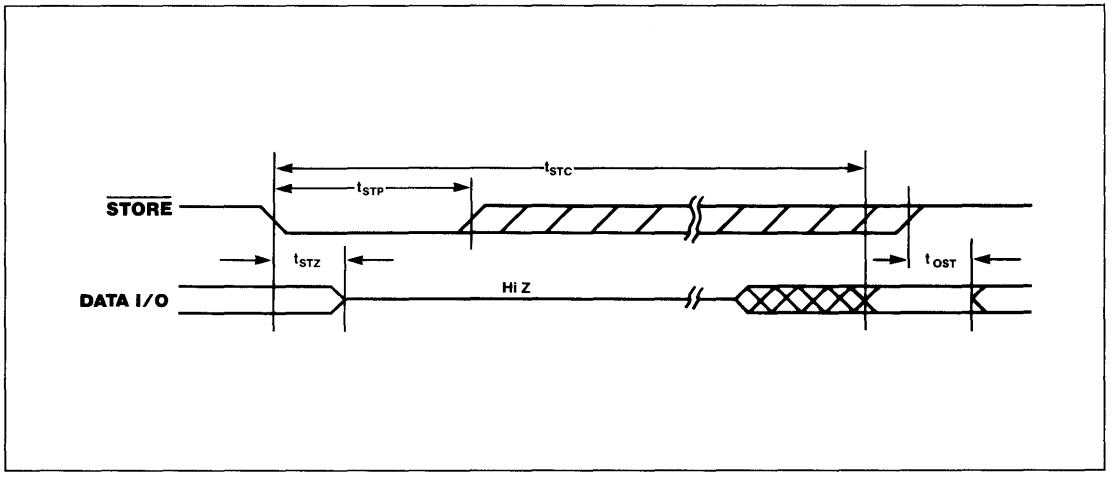
Early Write Cycle



Store Cycle Limits

Symbol	Parameter	Min.	Max.	Units
t_{STC}	Store Cycle Time		10	ms
t_{STP}	Store Pulse Width	100		ns
t_{STZ}	Store to Output in High Z		500	ns
t_{OST}	Output Active from End of Store	10		ns

Store Cycle

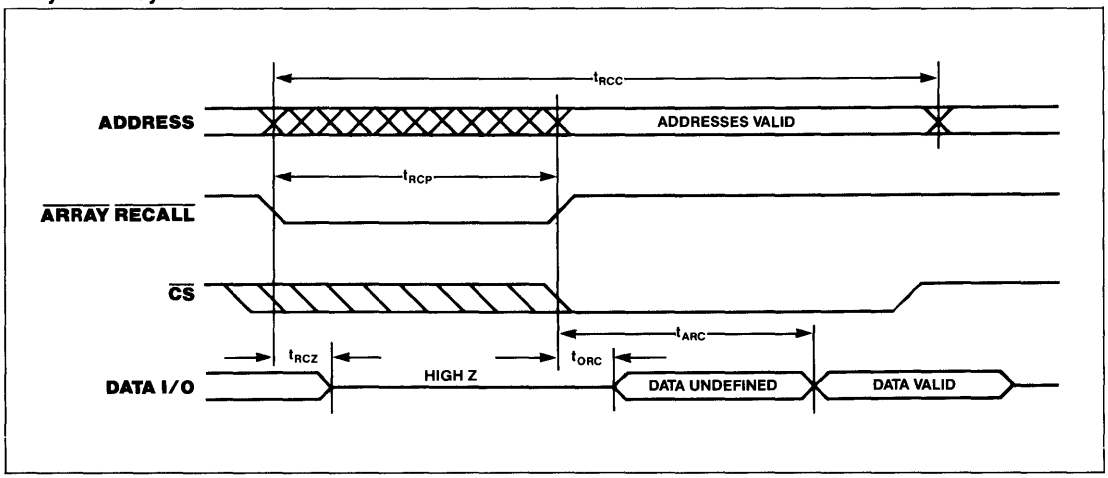


Array Recall Cycle Limits

Symbol	Parameter	Min.	Max.	Units
t_{RCC}	Array Recall Cycle Time	1200		ns
t_{RCP}	Recall Pulse Width[4]	450		ns
t_{RCZ}	Recall to Output in High Z		150	ns
t_{ORC}	Output Active from End of Recall	10		ns
t_{ARC}	Recalled Data Access Time from End of Recall		750	ns

Note: (4) Array Recall rise time must be less than 1 μs.

Array Recall Cycle



PIN DESCRIPTIONS AND DEVICE OPERATION

Addresses (A_0–A_5)

The address inputs select a 4-bit memory location during a read or write operation.

Chip Select ($\overline{CS}$)

The Chip Select input must be LOW to enable read/write operations with the RAM array. $\overline{CS}$ HIGH will place the I/O pins in the high impedance state.

Write Enable ($\overline{WE}$)

The Write Enable input controls the I/O buffers, determining whether a RAM read or write operation is enabled. $\overline{WE}$ HIGH enables a read and $\overline{WE}$ LOW enables a write.

Data In/Data Out (I/O_1–I/O_4)

Data is written to or read from the X2210A through the I/O pins. The I/O pins are placed in the high impedance state when either $\overline{CS}$ is HIGH or during either a store or recall operation.

$\overline{STORE}$

The $\overline{STORE}$ input, when LOW, will initiate the transfer of the entire contents of the RAM array to the E^2PROM array. The $\overline{WE}$ and $\overline{ARRAY\ RECALL}$ inputs are inhibited during the store cycle. The store operation will be completed in 10ms or less.

A store operation has priority over RAM read/write operations. If $\overline{STORE}$ is asserted during a read operation, the read will be discontinued. If $\overline{STORE}$ is asserted during a RAM write operation, the write will be immediately terminated and the store performed. The data at the RAM address that was being written will be unknown in both the RAM and E^2PROM.

$\overline{ARRAY\ RECALL}$

The $\overline{ARRAY\ RECALL}$ input, when LOW, will initiate the transfer of the entire contents of the E^2PROM array to the RAM array. The transfer of data will typically be completed in 1μs or less.

An array recall has priority over RAM read/write operations and will terminate both operations when $\overline{ARRAY\ RECALL}$ is asserted. $\overline{ARRAY\ RECALL}$ LOW will also inhibit the $\overline{STORE}$ input.

WRITE PROTECTION

The X2210A has three write protect features that are employed to protect the contents of the nonvolatile memory.

- V_{CC} Sense—All functions are inhibited when V_{CC} is ≤ 3v, typically.
- Write Inhibit—Holding either $\overline{STORE}$ HIGH or $\overline{RECALL}$ LOW during power-up or power-down will prevent an inadvertent store operation and E^2PROM data integrity will be maintained.
- Noise Protection—A $\overline{STORE}$ pulse of less than 20ns will *not* initiate a store cycle.

ENDURANCE

The endurance specification of a device is characterized by the predicted *first* bit failure to occur in the entire memory (device or system) array rather than the average or typical value for the array. Since endurance is limited by the number of electrons trapped in the oxide during data changes, Xicor NOVRAMs are designed to minimize the number of changes an E^2PROM bit cell undergoes during store operations. Only those bits in the E^2PROM that are different from their corresponding location in the RAM will be "cycled" during a nonvolatile store. This characteristic reduces unnecessary cycling of any of the rest of the bits in the array, thereby increasing the potential endurance of each bit and increasing the potential endurance of the entire array. Reliability data documented in RR504, the *Xicor Reliability Report on Endurance*, and additional reports are available from Xicor.

Part Number	Store Cycles	Data Changes Per Bit
X2210A	10,000	1,000

NOTES

Nonvolatile Static RAM

FEATURES

- **Single 5 Volt Supply**
- **Fully TTL Compatible**
- **JEDEC Standard 18-Pin Package**
- **Infinite E^2PROM Array Recall, RAM Read and Write Cycles**
- **Access Time of 300ns Max.**
- **Nonvolatile Store Inhibit: V_{CC} = 3v Typical**
- **100 Year Data Retention**

DESCRIPTION

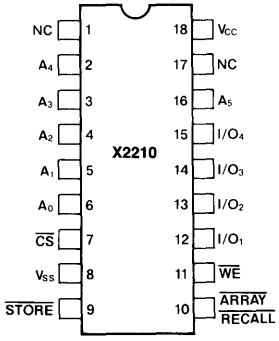
The Xicor X2210 is a 64 x 4 NOVRAM* featuring a high-speed static RAM overlaid bit-for-bit with a nonvolatile E^2PROM. The X2210 is fabricated with the same reliable N-channel floating gate MOS technology used in all Xicor 5 volt nonvolatile memories. The X2210 features the JEDEC approved pinout for 4-bit-wide memories, compatible with industry standard RAMs.

The NOVRAM design allows data to be easily transferred from RAM to E^2PROM (store) and from E^2PROM to RAM (recall). The store operation is completed in 10ms or less and the recall is typically completed in 1μs.

Xicor NOVRAMs are designed for unlimited write operations to RAM, either from the host or recalls from E^2PROM. The E^2PROM array is designed for a minimum 10,000 store cycles. Data retention is specified to be greater than 100 years.

*NOVRAM is Xicor's nonvolatile static RAM device.

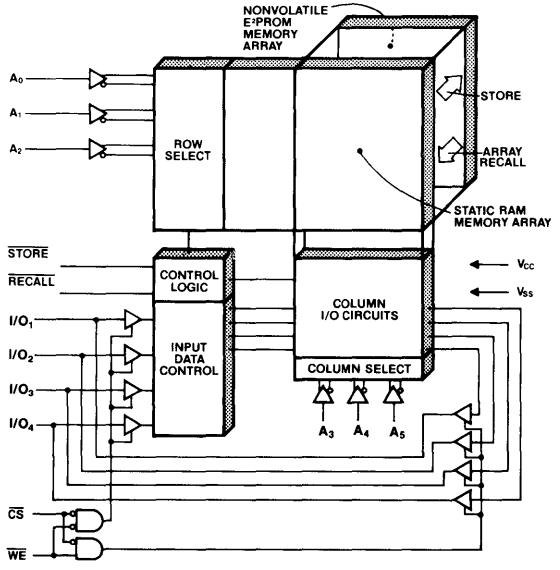
PIN CONFIGURATION



PIN NAMES

A_0–A_5	Address Inputs
I/O_1–I/O_4	Data Inputs/Outputs
$\overline{WE}$	Write Enable
$\overline{CS}$	Chip Select
$\overline{ARRAY\ RECALL}$	Array Recall
$\overline{STORE}$	Store
V_{CC}	+5V
V_{SS}	Ground
NC	No Connect

FUNCTIONAL DIAGRAM



ABSOLUTE MAXIMUM RATINGS*

Temperature Under Bias X2210 ..... −10°C to +85°C
X2210I ..... −65°C to +135°C
Storage Temperature ..... −65°C to +150°C
Voltage on any Pin with
Respect to Ground ..... −1.0V to +7V
D.C. Output Current ..... 5 mA
Lead Temperature (Soldering,
10 Seconds) ..... 300°C

*COMMENT

Stresses above those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. This is a stress rating only and the functional operation of the device at these or any other conditions above those indicated in the operational sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

D.C. OPERATING CHARACTERISTICS

X2210 T_A = 0°C to +70°C, V_{CC} = +5V ±10%, unless otherwise specified.
X2210I T_A = −40°C to +85°C, V_{CC} = +5V ±10%, unless otherwise specified.

		X2210 Limits		X2210I Limits			
Symbol	Parameter	Min.	Max.	Min.	Max.	Units	Test Conditions
I_{CC}	Power Supply Current		50		55	mA	All Inputs = V_{CC} $I_{I/O}$ = 0 mA
I_{LI}	Input Load Current		10		10	µA	V_{IN} = GND to V_{CC}
I_{LO}	Output Leakage Current		10		10	µA	V_{OUT} = GND to V_{CC}
V_{IL}	Input Low Voltage	−1.0	0.8	−1.0	0.8	V	
V_{IH}	Input High Voltage	2.0	V_{CC} +1.0	2.0	V_{CC} +1.0	V	
V_{OL}	Output Low Voltage		0.4		0.4	V	I_{OL} = 4.2 mA
V_{OH}	Output High Voltage	2.4		2.4		V	I_{OH} = −2 mA

CAPACITANCE T_A = 25°C, f = 1.0 MHz, V_{CC} = 5V

Symbol	Test	Max.	Unit	Conditions
$C_{I/O}$(1)	Input/Output Capacitance	8	pF	$V_{I/O}$ = 0V
C_{IN}(1)	Input Capacitance	6	pF	V_{IN} = 0V

Note: (1) This parameter is periodically sampled and not 100% tested.

A.C. CONDITIONS OF TEST

Input Pulse Levels	0 to 3.0 Volts
Input Rise and Fall Times	10 nsec
Input and Output Timing Levels	1.5 Volts
Output Load	1 TTL Gate and C_L = 100 pF

MODE SELECTION

Inputs				Input Output	
$\overline{CS}$	$\overline{WE}$	ARRAY RECALL	$\overline{STORE}$	I/O	Mode
H	X	H	H	Output High Z	Not Selected(2)
L	H	H	H	Output Data	Read RAM
L	L	H	H	Input Data High	Write "1" RAM
L	L	H	H	Input Data Low	Write "0" RAM
X	H	L	H	Output High Z	Array Recall
H	X	L	H	Output High Z	Array Recall
X	H	H	L	Output High Z	Nonvolatile Storing(3)
H	X	H	L	Output High Z	Nonvolatile Storing(3)

Notes: (2) Chip is deselected but may be automatically completing a store cycle.
(3) $\overline{STORE}$ = L is required only to initiate the store cycle, after which the store cycle will be automatically completed ($\overline{STORE}$ = X).

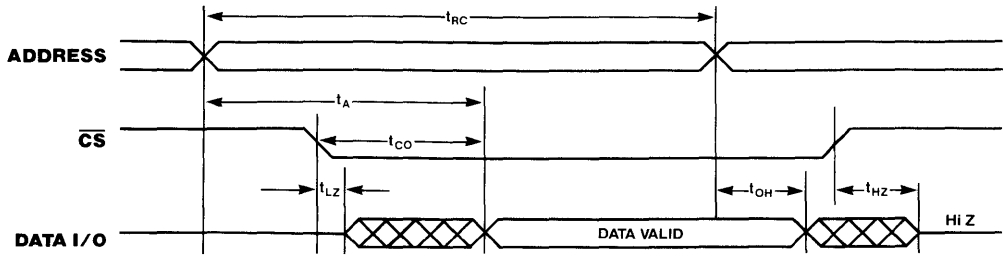
A.C. CHARACTERISTICS

X2210 T_A = 0°C to +70°C, V_{CC} = +5V ±10%, unless otherwise specified.
X2210I T_A = −40°C to +85°C, V_{CC} = +5V ±10%, unless otherwise specified.

Read Cycle Limits

Symbol	Parameter	Min.	Max.	Units
t_{RC}	Read Cycle Time	300		ns
t_A	Access Time		300	ns
t_{CO}	Chip Select to Output Valid		200	ns
t_{OH}	Output Hold from Address Change	50		ns
t_{LZ}	Chip Select to Output in Low Z	10		ns
t_{HZ}	Chip Deselect to Output in High Z	10	100	ns

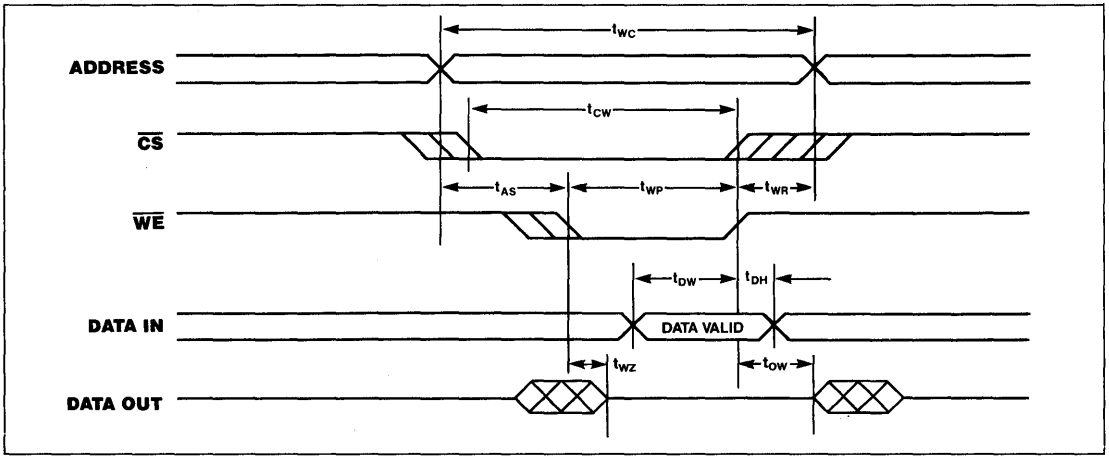
Read Cycle



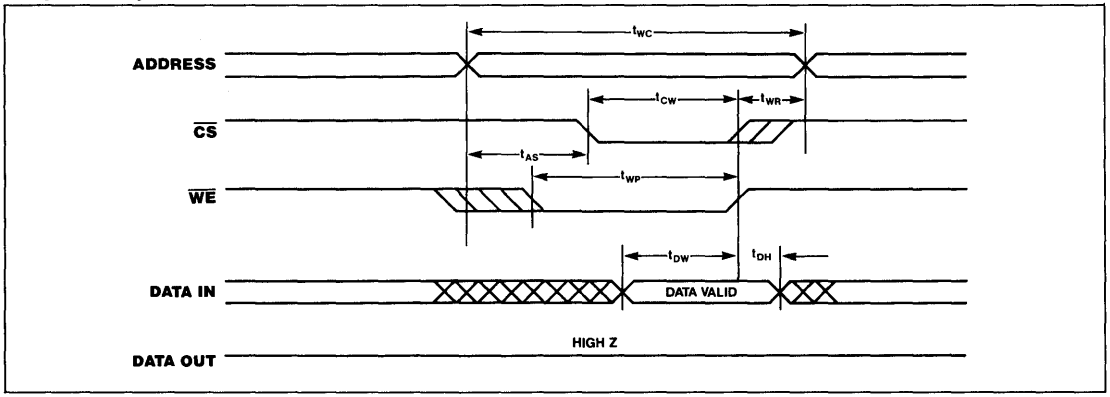
Write Cycle Limits

Symbol	Parameter		Min.	Max.	Units
t_{WC}	Write Cycle Time		300		ns
t_{CW}	Chip Select to End of Write		150		ns
t_{AS}	Address Set-up Time		50		ns
t_{WP}	Write Pulse Width		150		ns
t_{WR}	Write Recovery Time		25		ns
t_{DW}	Data Valid to End of Write		100		ns
t_{DH}	Data Hold Time	X2210	0		ns
		X2210I	20		ns
t_{WZ}	Write Enable to Output in High Z		10	100	ns
t_{OW}	Output Active from End of Write		10		ns

Write Cycle



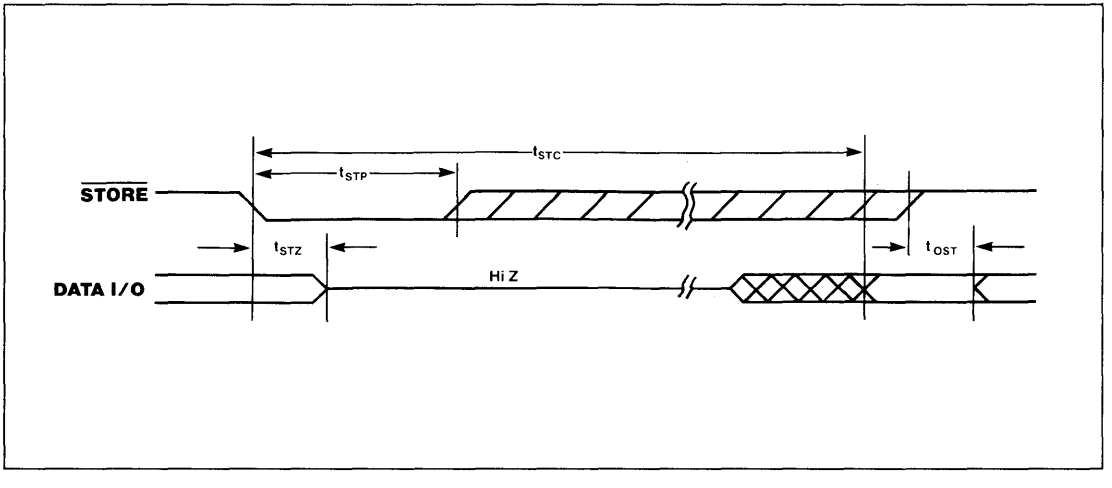
Early Write Cycle



Store Cycle Limits

Symbol	Parameter	Min.	Max.	Units
t_{STC}	Store Cycle Time		10	ms
t_{STP}	Store Pulse Width	100		ns
t_{STZ}	Store to Output in High Z		500	ns
t_{OST}	Output Active from End of Store	10		ns

Store Cycle

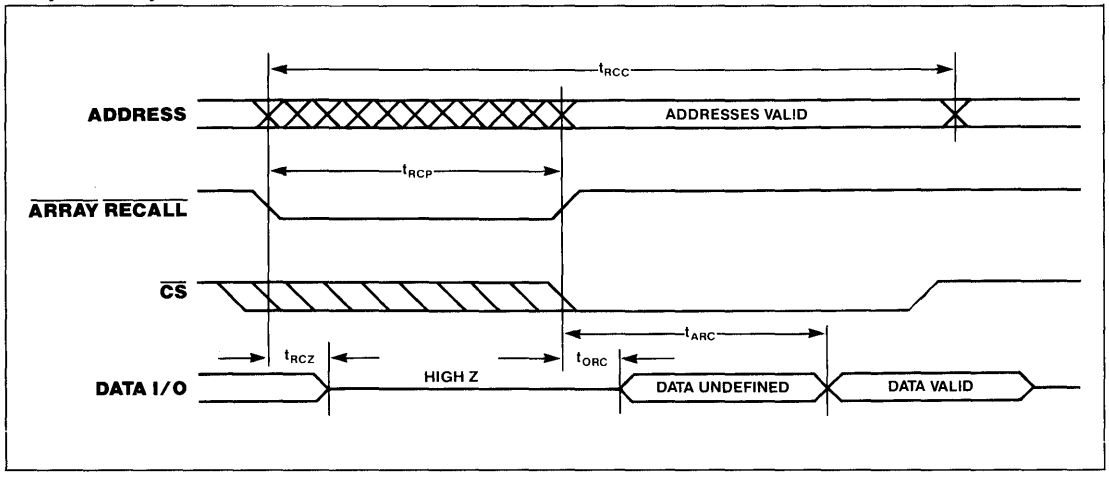


Array Recall Cycle Limits

Symbol	Parameter	Min.	Max.	Units
t_{RCC}	Array Recall Cycle Time	1200		ns
t_{RCP}	Recall Pulse Width[4]	450		ns
t_{RCZ}	Recall to Output in High Z		150	ns
t_{ORC}	Output Active from End of Recall	10		ns
t_{ARC}	Recalled Data Access Time from End of Recall		750	ns

Note: (4) Array Recall rise time must be less than 1 μs.

Array Recall Cycle



PIN DESCRIPTIONS AND DEVICE OPERATION

Addresses (A_0–A_5)

The address inputs select a 4-bit memory location during a read or write operation.

Chip Select ($\overline{CS}$)

The Chip Select input must be LOW to enable read/write operations with the RAM array. $\overline{CS}$ HIGH will place the I/O pins in the high impedance state.

Write Enable ($\overline{WE}$)

The Write Enable input controls the I/O buffers, determining whether a RAM read or write operation is enabled. $\overline{WE}$ HIGH enables a read and $\overline{WE}$ LOW enables a write.

Data In/Data Out (I/O_1–I/O_4)

Data is written to or read from the X2210 through the I/O pins. The I/O pins are placed in the high impedance state when either $\overline{CS}$ is HIGH or during either a store or recall operation.

$\overline{STORE}$

The $\overline{STORE}$ input, when LOW, will initiate the transfer of the entire contents of the RAM array to the E^2PROM array. The $\overline{WE}$ and $\overline{ARRAY\ RECALL}$ inputs are inhibited during the store cycle. The store operation will be completed in 10ms or less.

A store operation has priority over RAM read/write operations. If $\overline{STORE}$ is asserted during a read operation, the read will be discontinued. If $\overline{STORE}$ is asserted during a RAM write operation, the write will be immediately terminated and the store performed. The data at the RAM address that was being written will be unknown in both the RAM and E^2PROM.

$\overline{ARRAY\ RECALL}$

The $\overline{ARRAY\ RECALL}$ input, when LOW, will initiate the transfer of the entire contents of the E^2PROM array to the RAM array. The transfer of data will typically be completed in 1μs or less.

An array recall has priority over RAM read/write operations and will terminate both operations when $\overline{ARRAY\ RECALL}$ is asserted. $\overline{ARRAY\ RECALL}$ LOW will also inhibit the $\overline{STORE}$ input.

WRITE PROTECTION

The X2210 has three write protect features that are employed to protect the contents of the nonvolatile memory.

- V_{CC} Sense—All functions are inhibited when V_{CC} is ≤ 3v, typically.
- Write Inhibit—Holding either $\overline{STORE}$ HIGH or $\overline{RECALL}$ LOW during power-up or power-down will prevent an inadvertent store operation and E^2PROM data integrity will be maintained.
- Noise Protection—A $\overline{STORE}$ pulse of less than 20ns will *not* initiate a store cycle.

ENDURANCE

The endurance specification of a device is characterized by the predicted *first* bit failure to occur in the entire memory (device or system) array rather than the average or typical value for the array. Since endurance is limited by the number of electrons trapped in the oxide during data changes, Xicor NOVRAMs are designed to minimize the number of changes an E^2PROM bit cell undergoes during store operations. Only those bits in the E^2PROM that are different from their corresponding location in the RAM will be "cycled" during a nonvolatile store. This characteristic reduces unnecessary cycling of any of the rest of the bits in the array, thereby increasing the potential endurance of each bit and increasing the potential endurance of the entire array. Reliability data documented in RR504, the *Xicor Reliability Report on Endurance*, and additional reports are available from Xicor.

Part Number	Store Cycles	Data Changes Per Bit
X2210 X2210I	10,000	1,000
X2210/5 X2210I/5	50,000	5,000
X2210/10 X2210I/10	100,000	10,000

NOTES

Nonvolatile Static RAM

FEATURES

- **Single 5 Volt Supply**
- **Fully TTL Compatible**
- **JEDEC Standard 18-Pin Package**
- **Infinite E²PROM Array Recall, RAM Read and Write Cycles**
- **Access Time of 300ns Max.**
- **Nonvolatile Store Inhibit: V_{CC} = 3v Typical**
- **100 Year Data Retention**

DESCRIPTION

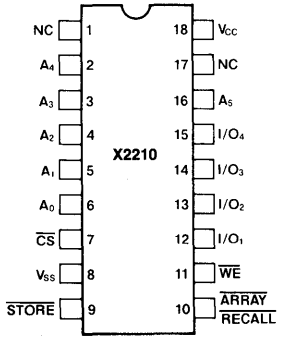
The Xicor X2210 is a 64 x 4 NOVRAM* featuring a high-speed static RAM overlaid bit-for-bit with a nonvolatile E²PROM. The X2210 is fabricated with the same reliable N-channel floating gate MOS technology used in all Xicor 5 volt nonvolatile memories. The X2210 features the JEDEC approved pinout for 4-bit-wide memories, compatible with industry standard RAMs.

The NOVRAM design allows data to be easily transferred from RAM to E²PROM (store) and from E²PROM to RAM (recall). The store operation is completed in 10ms or less and the recall is typically completed in 1μs.

Xicor NOVRAMs are designed for unlimited write operations to RAM, either from the host or recalls from E²PROM. The E²PROM array is designed for a minimum 10,000 store cycles. Data retention is specified to be greater than 100 years.

*NOVRAM is Xicor's nonvolatile static RAM device.

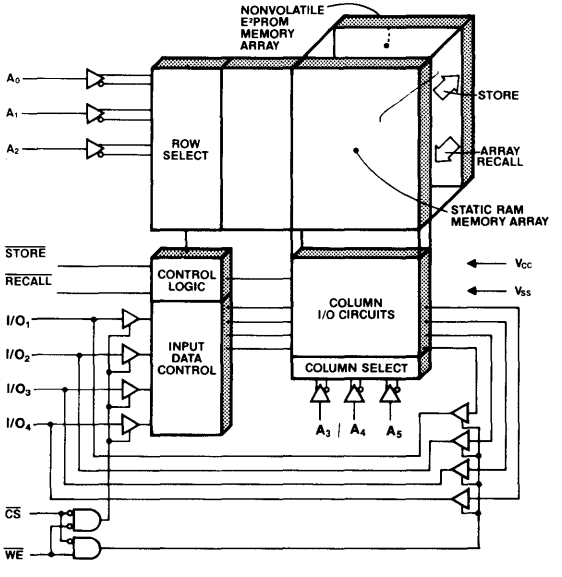
PIN CONFIGURATION



PIN NAMES

A_0–A_5	Address Inputs
I/O_1–I/O_4	Data Inputs/Outputs
$\overline{WE}$	Write Enable
$\overline{CS}$	Chip Select
$\overline{ARRAY\ RECALL}$	Array Recall
$\overline{STORE}$	Store
V_{CC}	+5V
V_{SS}	Ground
NC	No Connect

FUNCTIONAL DIAGRAM



ABSOLUTE MAXIMUM RATINGS*

Temperature Under Bias ..... −65°C to +135°C
Storage Temperature ..... −65°C to +150°C
Voltage on any Pin with
Respect to Ground ..... −1.0V to +7V
D.C. Output Current ..... 5 mA
Lead Temperature (Soldering,
10 Seconds) ..... 300°C

*COMMENT

Stresses above those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. This is a stress rating only and the functional operation of the device at these or any other conditions above those indicated in the operational sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

D.C. OPERATING CHARACTERISTICS

T_A = −55°C to +125°C, V_{CC} = +5V ±10%, unless otherwise specified.

Symbol	Parameter	Limits		Units	Test Conditions
		Min.	Max.		
I_{CC}	Power Supply Current		55	mA	All Inputs = V_{CC} $I_{I/O}$ = 0 mA
I_{LI}	Input Load Current		10	µA	V_{IN} = GND to V_{CC}
I_{LO}	Output Leakage Current		10	µA	V_{OUT} = GND to V_{CC}
V_{IL}	Input Low Voltage	−1.0	0.8	V	
V_{IH}	Input High Voltage	2.0	V_{CC} +1.0	V	
V_{OL}	Output Low Voltage		0.4	V	I_{OL} = 4.2 mA
V_{OH}	Output High Voltage	2.4		V	I_{OH} = −2 mA

CAPACITANCE T_A = 25°C, f = 1.0 MHz, V_{CC} = 5V

Symbol	Test	Max.	Unit	Conditions
$C_{I/O}$[1]	Input/Output Capacitance	8	pF	$V_{I/O}$ = 0V
C_{IN}[1]	Input Capacitance	6	pF	V_{IN} = 0V

Note: (1) This parameter is periodically sampled and not 100% tested.

A.C. CONDITIONS OF TEST

Input Pulse Levels	0 to 3.0 Volts
Input Rise and Fall Times	10 nsec
Input and Output Timing Levels	1.5 Volts
Output Load	1 TTL Gate and C_L = 100 pF

MODE SELECTION

Inputs				Input Output	
CS	WE	ARRAY RECALL	STORE	I/O	Mode
H	X	H	H	Output High Z	Not Selected[2]
L	H	H	H	Output Data	Read RAM
L	L	H	H	Input Data High	Write "1" RAM
L	L	H	H	Input Data Low	Write "0" RAM
X	H	L	H	Output High Z	Array Recall
H	X	L	H	Output High Z	Array Recall
X	H	H	L	Output High Z	Nonvolatile Storing[3]
H	X	H	L	Output High Z	Nonvolatile Storing[3]

Notes: (2) Chip is deselected but may be automatically completing a store cycle.
(3) $\overline{STORE}$ = L is required only to initiate the store cycle, after which the store cycle will be automatically completed ($\overline{STORE}$ = X).

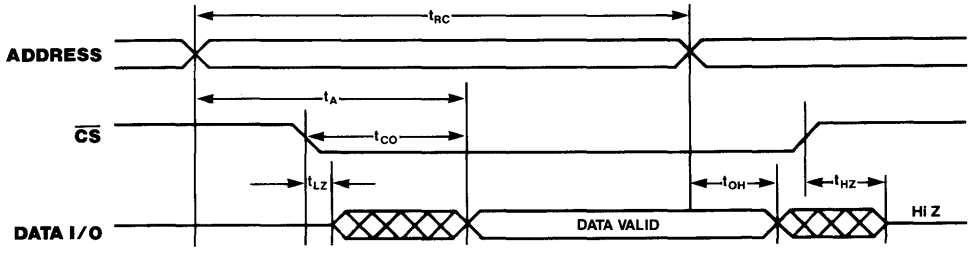
A.C. CHARACTERISTICS

T_A = −55°C to +125°C, V_{CC} = +5V ±10%, unless otherwise specified.

Read Cycle Limits

Symbol	Parameter	Min.	Max.	Units
t_{RC}	Read Cycle Time	300		ns
t_A	Access Time		300	ns
t_{CO}	Chip Select to Output Valid		200	ns
t_{OH}	Output Hold from Address Change	50		ns
t_{LZ}	Chip Select to Output in Low Z	10		ns
t_{HZ}	Chip Deselect to Output in High Z	10	100	ns

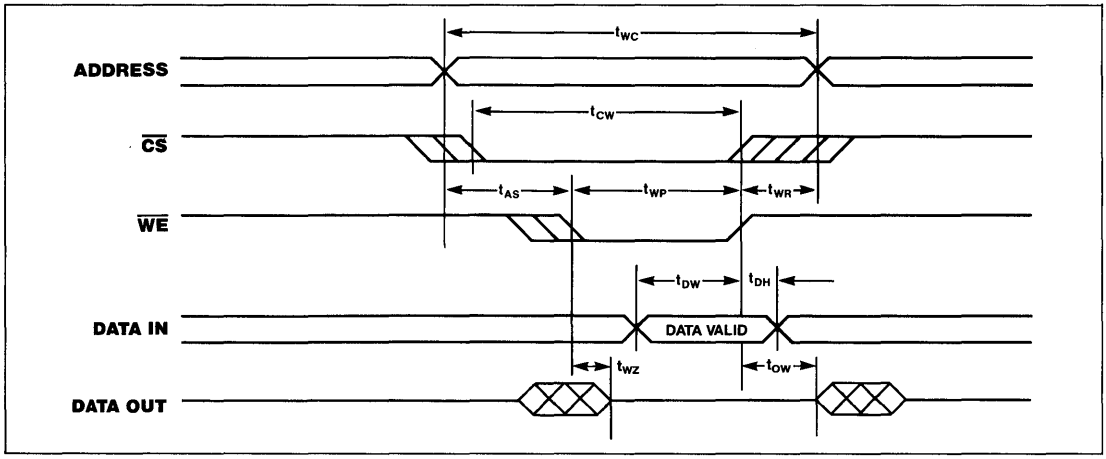
Read Cycle



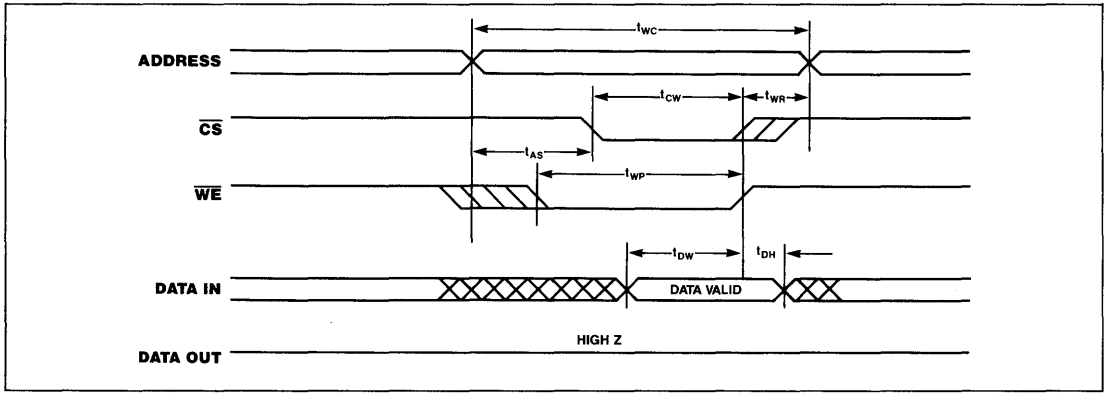
Write Cycle Limits

Symbol	Parameter	Min.	Max.	Units
t_{WC}	Write Cycle Time	300		ns
t_{CW}	Chip Select to End of Write	150		ns
t_{AS}	Address Set-up Time	50		ns
t_{WP}	Write Pulse Width	150		ns
t_{WR}	Write Recovery Time	25		ns
t_{DW}	Data Valid to End of Write	100		ns
t_{DH}	Data Hold Time	20		ns
t_{WZ}	Write Enable to Output in High Z	10	100	ns
t_{OW}	Output Active from End of Write	10		ns

Write Cycle



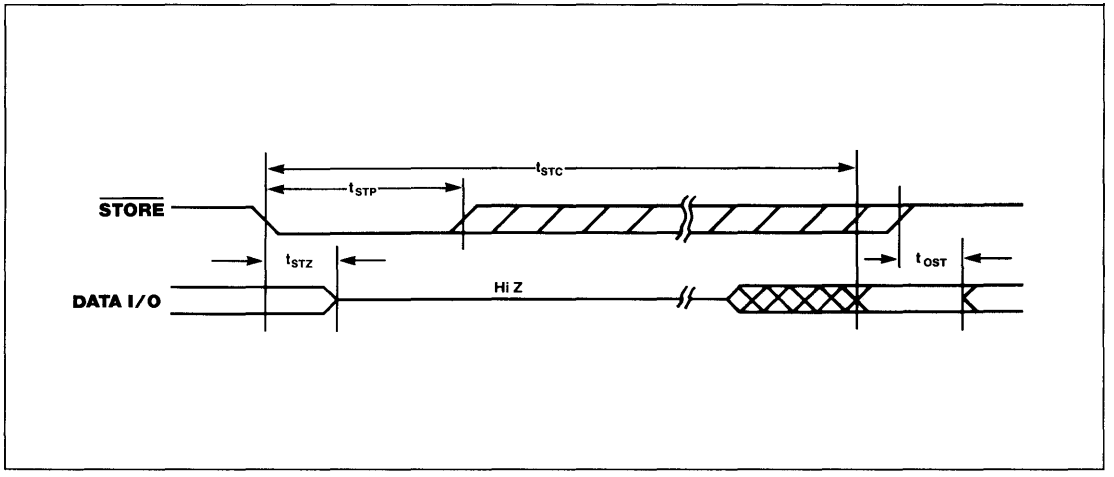
Early Write Cycle



Store Cycle Limits

Symbol	Parameter	Min.	Max.	Units
t_{STC}	Store Cycle Time		10	ms
t_{STP}	Store Pulse Width	100		ns
t_{STZ}	Store to Output in High Z		500	ns
t_{OST}	Output Active from End of Store	10		ns

Store Cycle

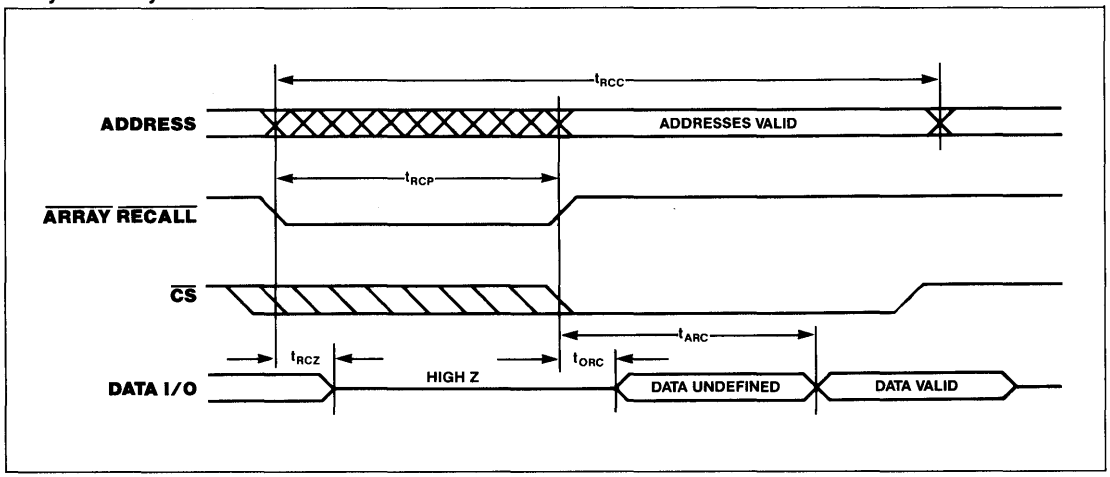


Array Recall Cycle Limits

Symbol	Parameter	Min.	Max.	Units
t_{RCC}	Array Recall Cycle Time	1200		ns
t_{RCP}	Recall Pulse Width[4]	450		ns
t_{RCZ}	Recall to Output in High Z		150	ns
t_{ORC}	Output Active from End of Recall	10		ns
t_{ARC}	Recalled Data Access Time from End of Recall		750	ns

Note: (4) Array Recall rise time must be less than 1 μs.

Array Recall Cycle



PIN DESCRIPTIONS AND DEVICE OPERATION

Addresses (A_0–A_5)

The address inputs select a 4-bit memory location during a read or write operation.

Chip Select ($\overline{CS}$)

The Chip Select input must be LOW to enable read/write operations with the RAM array. $\overline{CS}$ HIGH will place the I/O pins in the high impedance state.

Write Enable ($\overline{WE}$)

The Write Enable input controls the I/O buffers, determining whether a RAM read or write operation is enabled. $\overline{WE}$ HIGH enables a read and $\overline{WE}$ LOW enables a write.

Data In/Data Out (I/O_1–I/O_4)

Data is written to or read from the X2210 through the I/O pins. The I/O pins are placed in the high impedance state when either $\overline{CS}$ is HIGH or during either a store or recall operation.

$\overline{STORE}$

The $\overline{STORE}$ input, when LOW, will initiate the transfer of the entire contents of the RAM array to the E^2PROM array. The $\overline{WE}$ and $\overline{ARRAY\ RECALL}$ inputs are inhibited during the store cycle. The store operation will be completed in 10ms or less.

A store operation has priority over RAM read/write operations. If $\overline{STORE}$ is asserted during a read operation, the read will be discontinued. If $\overline{STORE}$ is asserted during a RAM write operation, the write will be immediately terminated and the store performed. The data at the RAM address that was being written will be unknown in both the RAM and E^2PROM.

$\overline{ARRAY\ RECALL}$

The $\overline{ARRAY\ RECALL}$ input, when LOW, will initiate the transfer of the entire contents of the E^2PROM array to the RAM array. The transfer of data will typically be completed in 1μs or less.

An array recall has priority over RAM read/write operations and will terminate both operations when $\overline{ARRAY\ RECALL}$ is asserted. $\overline{ARRAY\ RECALL}$ LOW will also inhibit the $\overline{STORE}$ input.

WRITE PROTECTION

The X2210 has three write protect features that are employed to protect the contents of the nonvolatile memory.

- V_{CC} Sense—All functions are inhibited when V_{CC} is ≤ 3v, typically.
- Write Inhibit—Holding either $\overline{STORE}$ HIGH or $\overline{RECALL}$ LOW during power-up or power-down will prevent an inadvertent store operation and E^2PROM data integrity will be maintained.
- Noise Protection—A $\overline{STORE}$ pulse of less than 20ns will *not* initiate a store cycle.

ENDURANCE

The endurance specification of a device is characterized by the predicted *first* bit failure to occur in the entire memory (device or system) array rather than the average or typical value for the array. Since endurance is limited by the number of electrons trapped in the oxide during data changes, Xicor NOVRAMs are designed to minimize the number of changes an E^2PROM bit cell undergoes during store operations. Only those bits in the E^2PROM that are different from their corresponding location in the RAM will be "cycled" during a nonvolatile store. This characteristic reduces unnecessary cycling of any of the rest of the bits in the array, thereby increasing the potential endurance of each bit and increasing the potential endurance of the entire array. Reliability data documented in RR504, the *Xicor Reliability Report on Endurance*, and additional reports are available from Xicor.

Part Number	Store Cycles	Data Changes Per Bit
X2210M	10,000	1,000
X2210M/5	50,000	5,000
X2210M/10	100,000	10,000

NOTES

Nonvolatile Static RAM

FEATURES

- **Single 5 Volt Supply**
- **Fully TTL Compatible**
- **JEDEC Standard 18-Pin Package**
- **Infinite E^2PROM Array Recall, RAM Read and Write Cycles**
- **Access Time of 250ns Max.**
- **Nonvolatile Store Inhibit: V_{CC} = 3v Typical**
- **100 Year Data Retention**

DESCRIPTION

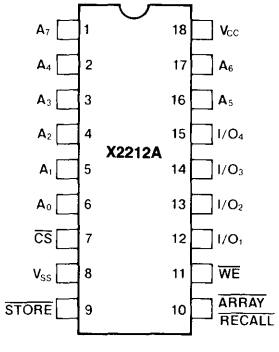
The Xicor X2212A is a 256 x 4 NOVRAM* featuring a high-speed static RAM overlaid bit-for-bit with a nonvolatile E^2PROM. The X2212A is fabricated with the same reliable N-channel floating gate MOS technology used in all Xicor 5 volt nonvolatile memories. The X2212A features the JEDEC approved pinout for 4-bit-wide memories, compatible with industry standard RAMs.

The NOVRAM design allows data to be easily transferred from RAM to E^2PROM (store) and from E^2PROM to RAM (recall). The store operation is completed in 10ms or less and the recall is typically completed in 1μs.

Xicor NOVRAMs are designed for unlimited write operations to RAM, either from the host or recalls from E^2PROM. The E^2PROM array is designed for a minimum 10,000 store cycles. Data retention is specified to be greater than 100 years.

*NOVRAM is Xicor's nonvolatile static RAM device.

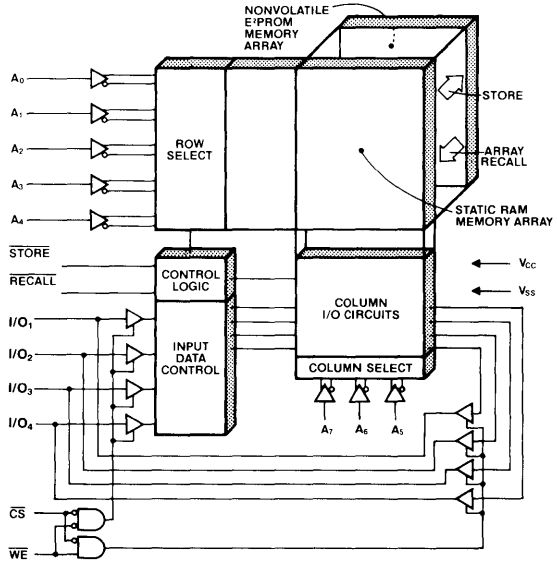
PIN CONFIGURATION



PIN NAMES

A_0–A_7	Address Inputs
I/O_1–I/O_4	Data Inputs/Outputs
$\overline{WE}$	Write Enable
$\overline{CS}$	Chip Select
$\overline{ARRAY\ RECALL}$	Array Recall
$\overline{STORE}$	Store
V_{CC}	+5V
V_{SS}	Ground
NC	No Connect

FUNCTIONAL DIAGRAM



ABSOLUTE MAXIMUM RATINGS*

Temperature Under Bias ..... −10°C to +85°C
Storage Temperature ..... −65°C to +150°C
Voltage on any Pin with
Respect to Ground ..... −1.0V to +7V
D.C. Output Current ..... 5 mA
Lead Temperature (Soldering,
10 Seconds) ..... 300°C

*COMMENT

Stresses above those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. This is a stress rating only and the functional operation of the device at these or any other conditions above those indicated in the operational sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

D.C. OPERATING CHARACTERISTICS

T_A = 0°C to +70°C, V_{CC} = +5V ±5%, unless otherwise specified.

Symbol	Parameter	Limits		Units	Test Conditions
		Min.	Max.		
I_{CC}	Power Supply Current		60	mA	All Inputs = V_{CC} $I_{I/O}$ = 0 mA
I_{LI}	Input Load Current		10	µA	V_{IN} = GND to V_{CC}
I_{LO}	Output Leakage Current		10	µA	V_{OUT} = GND to V_{CC}
V_{IL}	Input Low Voltage	−1.0	0.8	V	
V_{IH}	Input High Voltage	2.0	V_{CC} +0.5	V	
V_{OL}	Output Low Voltage		0.4	V	I_{OL} = 4.2 mA
V_{OH}	Output High Voltage	2.4		V	I_{OH} = −2 mA

CAPACITANCE T_A = 25°C, f = 1.0 MHz, V_{CC} = 5V

Symbol	Test	Max.	Unit	Conditions
$C_{I/O}$[1]	Input/Output Capacitance	8	pF	$V_{I/O}$ = 0V
C_{IN}[1]	Input Capacitance	6	pF	V_{IN} = 0V

Note: (1) This parameter is periodically sampled and not 100% tested.

A.C. CONDITIONS OF TEST

Input Pulse Levels	0 to 3.0 Volts
Input Rise and Fall Times	10 nsec
Input and Output Timing Levels	1.5 Volts
Output Load	1 TTL Gate and C_L = 100 pF

MODE SELECTION

Inputs				Input Output	
$\overline{CS}$	$\overline{WE}$	ARRAY $\overline{RECALL}$	$\overline{STORE}$	I/O	Mode
H	X	H	H	Output High Z	Not Selected[2]
L	H	H	H	Output Data	Read RAM
L	L	H	H	Input Data High	Write "1" RAM
L	L	H	H	Input Data Low	Write "0" RAM
X	H	L	H	Output High Z	Array Recall
H	X	L	H	Output High Z	Array Recall
X	H	H	L	Output High Z	Nonvolatile Storing[3]
H	X	H	L	Output High Z	Nonvolatile Storing[3]

Notes: (2) Chip is deselected but may be automatically completing a store cycle.
(3) $\overline{STORE}$ = L is required only to initiate the store cycle, after which the store cycle will be automatically completed ($\overline{STORE}$ = X).

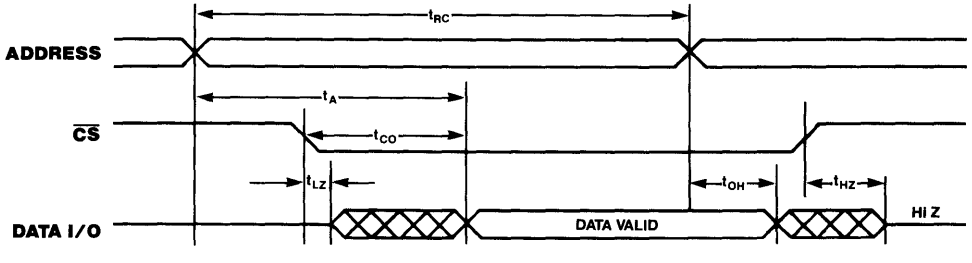
A.C. CHARACTERISTICS

T_A = 0°C to +70°C, V_{CC} = +5V ±5%, unless otherwise specified.

Read Cycle Limits

Symbol	Parameter	Min.	Max.	Units
t_{RC}	Read Cycle Time	250		ns
t_A	Access Time		250	ns
t_{CO}	Chip Select to Output Valid		200	ns
t_{OH}	Output Hold from Address Change	50		ns
t_{LZ}	Chip Select to Output in Low Z	10		ns
t_{HZ}	Chip Deselect to Output in High Z	10	100	ns

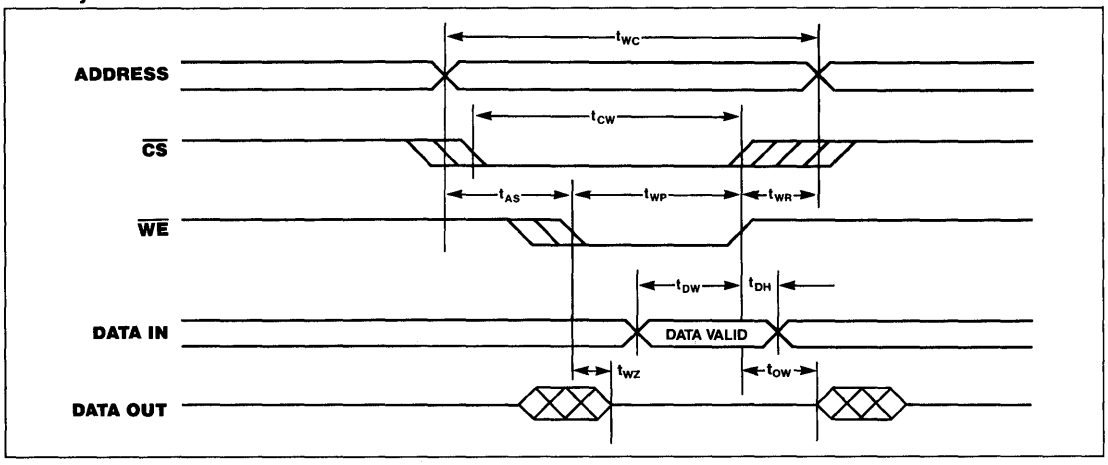
Read Cycle



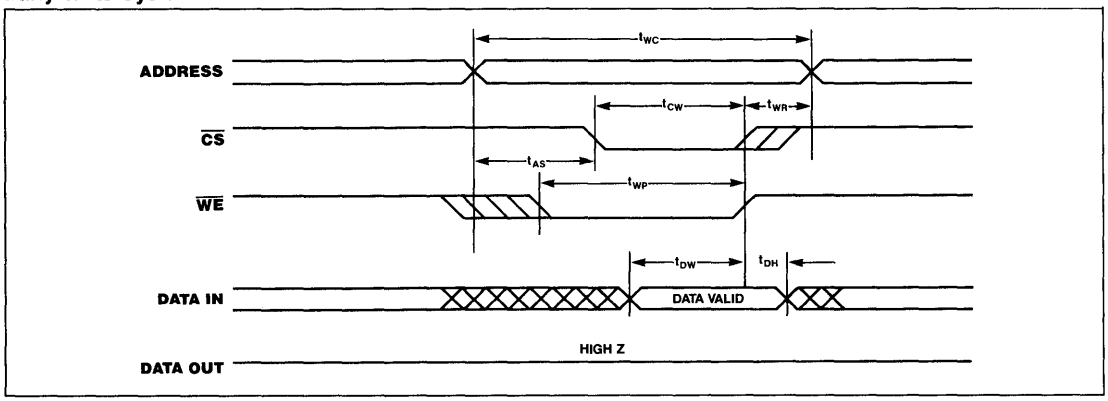
Write Cycle Limits

Symbol	Parameter	Min.	Max.	Units
t_{WC}	Write Cycle Time	250		ns
t_{CW}	Chip Select to End of Write	150		ns
t_{AS}	Address Set-up Time	50		ns
t_{WP}	Write Pulse Width	150		ns
t_{WR}	Write Recovery Time	25		ns
t_{DW}	Data Valid to End of Write	100		ns
t_{DH}	Data Hold Time	0		ns
t_{WZ}	Write Enable to Output in High Z	10	100	ns
t_{OW}	Output Active from End of Write	10		ns

Write Cycle



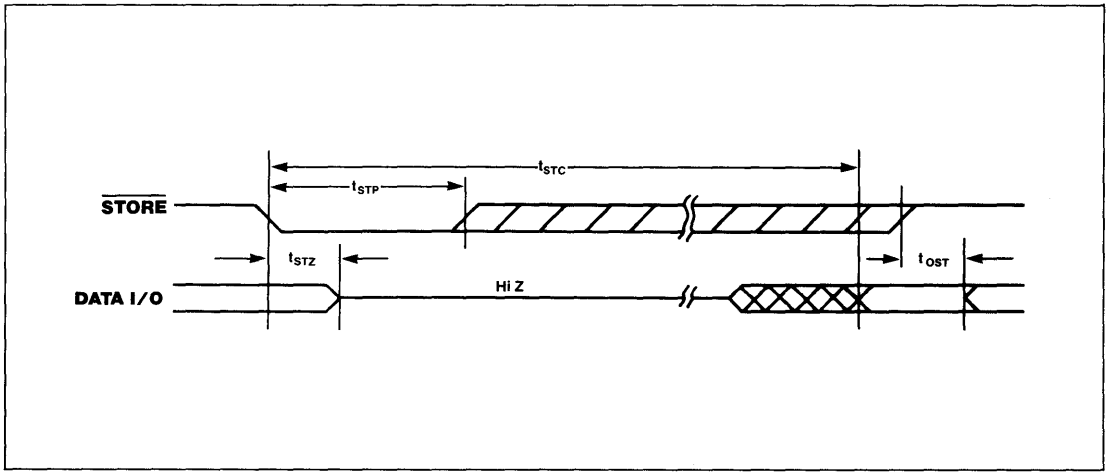
Early Write Cycle



Store Cycle Limits

Symbol	Parameter	Min.	Max.	Units
t_{STC}	Store Cycle Time		10	ms
t_{STP}	Store Pulse Width	100		ns
t_{STZ}	Store to Output in High Z		500	ns
t_{OST}	Output Active from End of Store	10		ns

Store Cycle

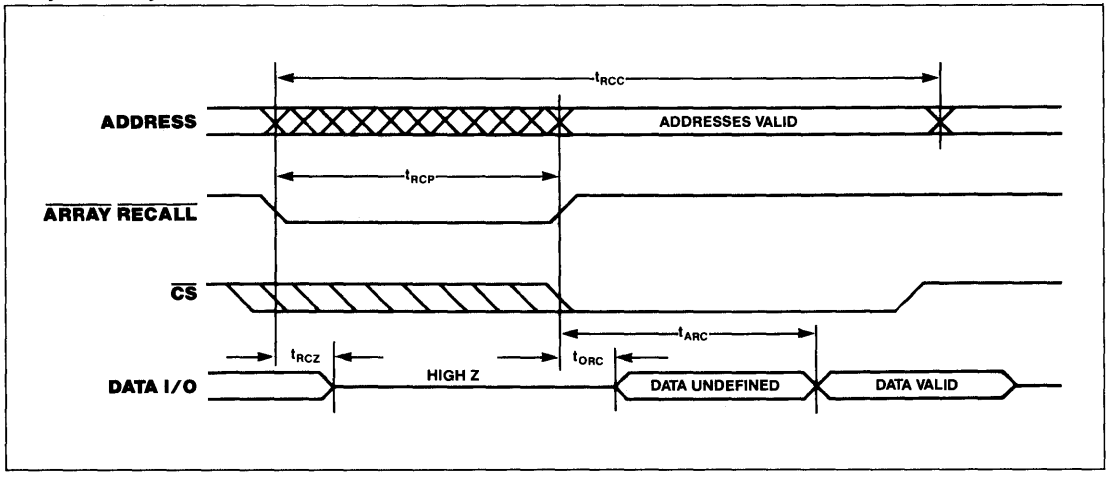


Array Recall Cycle Limits

Symbol	Parameter	Min.	Max.	Units
t_{RCC}	Array Recall Cycle Time	1200		ns
t_{RCP}	Recall Pulse Width[4]	450		ns
t_{RCZ}	Recall to Output in High Z		150	ns
t_{ORC}	Output Active from End of Recall	10		ns
t_{ARC}	Recalled Data Access Time from End of Recall		750	ns

Note: (4) Array Recall rise time must be less than 1 μs.

Array Recall Cycle



PIN DESCRIPTIONS AND DEVICE OPERATION

Addresses (A_0–A_7)

The address inputs select a 4-bit memory location during a read or write operation.

Chip Select ($\overline{CS}$)

The Chip Select input must be LOW to enable read/write operations with the RAM array. $\overline{CS}$ HIGH will place the I/O pins in the high impedance state.

Write Enable ($\overline{WE}$)

The Write Enable input controls the I/O buffers, determining whether a RAM read or write operation is enabled. $\overline{WE}$ HIGH enables a read and $\overline{WE}$ LOW enables a write.

Data In/Data Out (I/O_1–I/O_4)

Data is written to or read from the X2212A through the I/O pins. The I/O pins are placed in the high impedance state when either $\overline{CS}$ is HIGH or during either a store or recall operation.

$\overline{STORE}$

The $\overline{STORE}$ input, when LOW, will initiate the transfer of the entire contents of the RAM array to the E^2PROM array. The $\overline{WE}$ and $\overline{ARRAY\ RECALL}$ inputs are inhibited during the store cycle. The store operation will be completed in 10ms or less.

A store operation has priority over RAM read/write operations. If $\overline{STORE}$ is asserted during a read operation, the read will be discontinued. If $\overline{STORE}$ is asserted during a RAM write operation, the write will be immediately terminated and the store performed. The data at the RAM address that was being written will be unknown in both the RAM and E^2PROM.

$\overline{ARRAY\ RECALL}$

The $\overline{ARRAY\ RECALL}$ input, when LOW, will initiate the transfer of the entire contents of the E^2PROM array to the RAM array. The transfer of data will typically be completed in 1μs or less.

An array recall has priority over RAM read/write operations and will terminate both operations when $\overline{ARRAY\ RECALL}$ is asserted. $\overline{ARRAY\ RECALL}$ LOW will also inhibit the $\overline{STORE}$ input.

WRITE PROTECTION

The X2212A has three write protect features that are employed to protect the contents of the nonvolatile memory.

- V_{CC} Sense—All functions are inhibited when V_{CC} is ≤ 3v, typically.
- Write Inhibit—Holding either $\overline{STORE}$ HIGH or $\overline{RECALL}$ LOW during power-up or power-down will prevent an inadvertent store operation and E^2PROM data integrity will be maintained.
- Noise Protection—A $\overline{STORE}$ pulse of less than 20ns will *not* initiate a store cycle.

ENDURANCE

The endurance specification of a device is characterized by the predicted *first* bit failure to occur in the entire memory (device or system) array rather than the average or typical value for the array. Since endurance is limited by the number of electrons trapped in the oxide during data changes, Xicor NOVRAMs are designed to minimize the number of changes an E^2PROM bit cell undergoes during store operations. Only those bits in the E^2PROM that are different from their corresponding location in the RAM will be "cycled" during a nonvolatile store. This characteristic reduces unnecessary cycling of any of the rest of the bits in the array, thereby increasing the potential endurance of each bit and increasing the potential endurance of the entire array. Reliability data documented in RR504, the *Xicor Reliability Report on Endurance*, and additional reports are available from Xicor.

Part Number	Store Cycles	Data Changes Per Bit
X2212A	10,000	1,000

NOTES

Nonvolatile Static RAM

FEATURES

- **Single 5 Volt Supply**
- **Fully TTL Compatible**
- **JEDEC Standard 18-Pin Package**
- **Infinite E^2PROM Array Recall, RAM Read and Write Cycles**
- **Access Time of 300ns Max.**
- **Nonvolatile Store Inhibit: V_{CC} = 3v Typical**
- **100 Year Data Retention**

DESCRIPTION

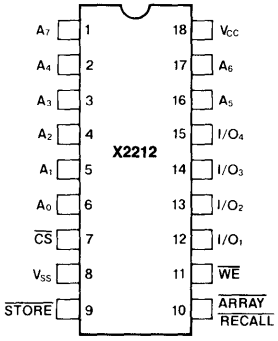
The Xicor X2212 is a 256 x 4 NOVRAM* featuring a high-speed static RAM overlaid bit-for-bit with a nonvolatile E^2PROM. The X2212 is fabricated with the same reliable N-channel floating gate MOS technology used in all Xicor 5 volt nonvolatile memories. The X2212 features the JEDEC approved pinout for 4-bit-wide memories, compatible with industry standard RAMs.

The NOVRAM design allows data to be easily transferred from RAM to E^2PROM (store) and from E^2PROM to RAM (recall). The store operation is completed in 10ms or less and the recall is typically completed in 1μs.

Xicor NOVRAMs are designed for unlimited write operations to RAM, either from the host or recalls from E^2PROM. The E^2PROM array is designed for a minimum 10,000 store cycles. Data retention is specified to be greater than 100 years.

*NOVRAM is Xicor's nonvolatile static RAM device.

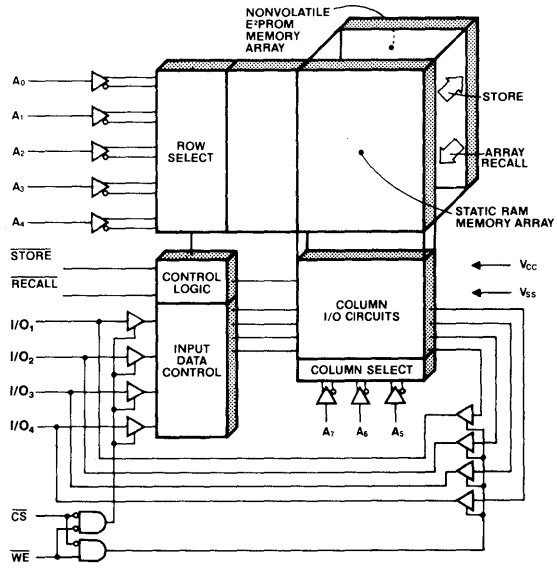
PIN CONFIGURATION



PIN NAMES

A_0–A_7	Address Inputs
I/O_1–I/O_4	Data Inputs/Outputs
$\overline{WE}$	Write Enable
$\overline{CS}$	Chip Select
$\overline{ARRAY\ RECALL}$	Array Recall
$\overline{STORE}$	Store
V_{CC}	+5V
V_{SS}	Ground
NC	No Connect

FUNCTIONAL DIAGRAM



ABSOLUTE MAXIMUM RATINGS*

Temperature Under Bias X2212 ..... −10°C to +85°C
X2212I ..... −65°C to +135°C
Storage Temperature ..... −65°C to +150°C
Voltage on any Pin with
Respect to Ground ..... −1.0V to +7V
D.C. Output Current ..... 5 mA
Lead Temperature (Soldering,
10 Seconds) ..... 300°C

*COMMENT

Stresses above those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. This is a stress rating only and the functional operation of the device at these or any other conditions above those indicated in the operational sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

D.C. OPERATING CHARACTERISTICS

X2212 T_A = 0°C to +70°C, V_{CC} = +5V ±10%, unless otherwise specified.
X2212I T_A = −40°C to +85°C, V_{CC} = +5V ±10%, unless otherwise specified.

Symbol	Parameter	X2212 Limits		X2212I Limits		Units	Test Conditions
		Min.	Max.	Min.	Max.		
I_{CC}	Power Supply Current		60		70	mA	All Inputs = V_{CC} $I_{I/O}$ = 0 mA
I_{LI}	Input Load Current		10		10	µA	V_{IN} = GND to V_{CC}
I_{LO}	Output Leakage Current		10		10	µA	V_{OUT} = GND to V_{CC}
V_{IL}	Input Low Voltage	−1.0	0.8	−1.0	0.8	V	
V_{IH}	Input High Voltage	2.0	V_{CC} +1.0	2.0	V_{CC} +1.0	V	
V_{OL}	Output Low Voltage		0.4		0.4	V	I_{OL} = 4.2 mA
V_{OH}	Output High Voltage	2.4		2.4		V	I_{OH} = −2 mA

CAPACITANCE T_A = 25°C, f = 1.0 MHz, V_{CC} = 5V

Symbol	Test	Max.	Unit	Conditions
$C_{I/O}$[1]	Input/Output Capacitance	8	pF	$V_{I/O}$ = 0V
C_{IN}[1]	Input Capacitance	6	pF	V_{IN} = 0V

Note: (1) This parameter is periodically sampled and not 100% tested.

A.C. CONDITIONS OF TEST

Input Pulse Levels	0 to 3.0 Volts
Input Rise and Fall Times	10 nsec
Input and Output Timing Levels	1.5 Volts
Output Load	1 TTL Gate and C_L = 100 pF

MODE SELECTION

Inputs				Input Output	
$\overline{CS}$	$\overline{WE}$	ARRAY $\overline{RECALL}$	$\overline{STORE}$	I/O	Mode
H	X	H	H	Output High Z	Not Selected[2]
L	H	H	H	Output Data	Read RAM
L	L	H	H	Input Data High	Write "1" RAM
L	L	H	H	Input Data Low	Write "0" RAM
X	H	L	H	Output High Z	Array Recall
H	X	L	H	Output High Z	Array Recall
X	H	H	L	Output High Z	Nonvolatile Storing[3]
H	X	H	L	Output High Z	Nonvolatile Storing[3]

Notes: (2) Chip is deselected but may be automatically completing a store cycle.
(3) $\overline{STORE}$ = L is required only to initiate the store cycle, after which the store cycle will be automatically completed ($\overline{STORE}$ = X).

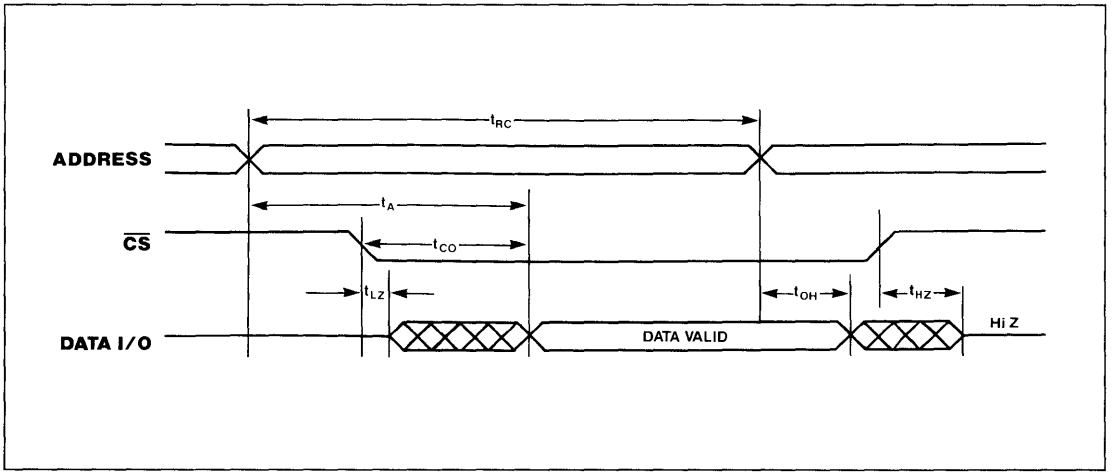
A.C. CHARACTERISTICS

X2212 T_A = 0°C to +70°C, V_{CC} = +5V ±10%, unless otherwise specified.
X2212I T_A = −40°C to +85°C, V_{CC} = +5V ±10%, unless otherwise specified.

Read Cycle Limits

Symbol	Parameter	Min.	Max.	Units
t_{RC}	Read Cycle Time	300		ns
t_A	Access Time		300	ns
t_{CO}	Chip Select to Output Valid		200	ns
t_{OH}	Output Hold from Address Change	50		ns
t_{LZ}	Chip Select to Output in Low Z	10		ns
t_{HZ}	Chip Deselect to Output in High Z	10	100	ns

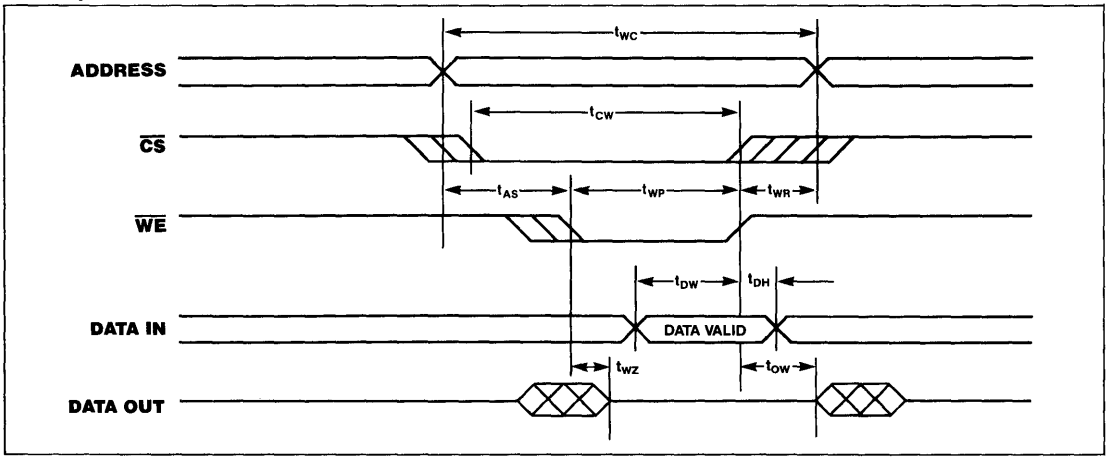
Read Cycle



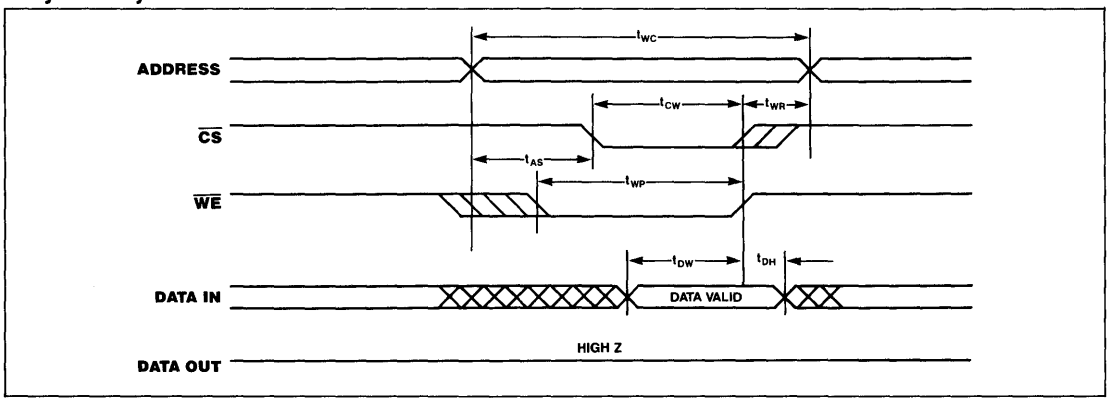
Write Cycle Limits

Symbol	Parameter		Min.	Max.	Units
t_{WC}	Write Cycle Time		300		ns
t_{CW}	Chip Select to End of Write		150		ns
t_{AS}	Address Set-up Time		50		ns
t_{WP}	Write Pulse Width		150		ns
t_{WR}	Write Recovery Time		25		ns
t_{DW}	Data Valid to End of Write		100		ns
t_{DH}	Data Hold Time	X2212	0		ns
		X2212I	20		ns
t_{WZ}	Write Enable to Output in High Z		10	100	ns
t_{OW}	Output Active from End of Write		10		ns

Write Cycle



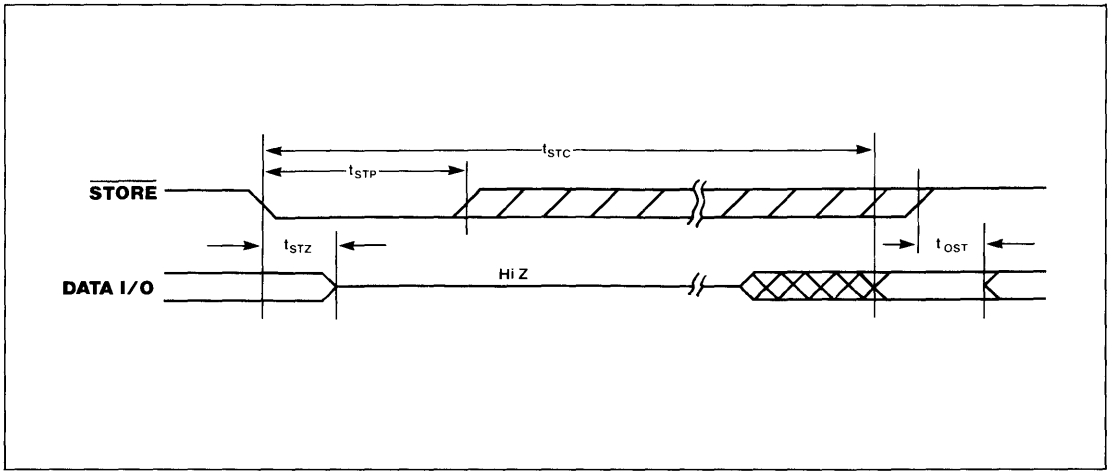
Early Write Cycle



Store Cycle Limits

Symbol	Parameter	Min.	Max.	Units
t_{STC}	Store Cycle Time		10	ms
t_{STP}	Store Pulse Width	100		ns
t_{STZ}	Store to Output in High Z		500	ns
t_{OST}	Output Active from End of Store	10		ns

Store Cycle

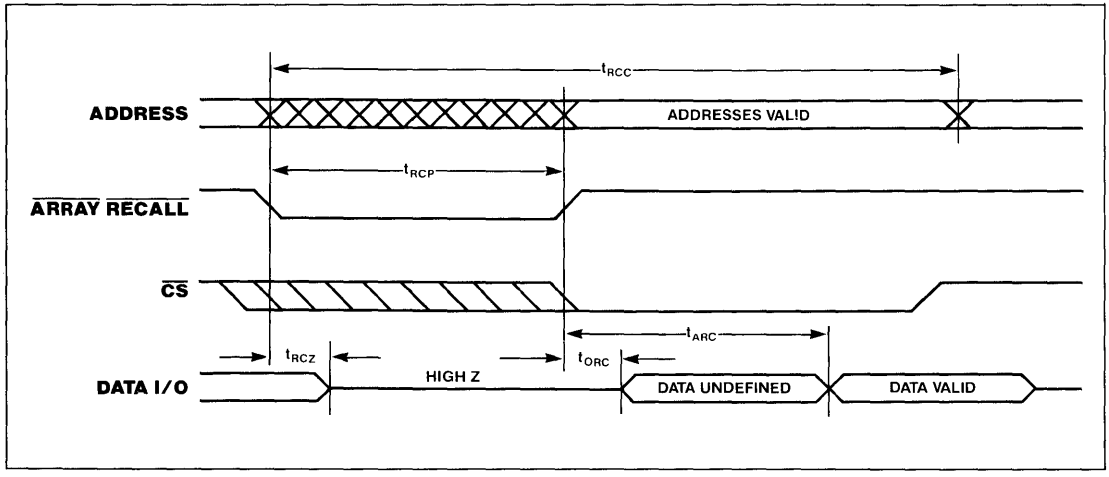


Array Recall Cycle Limits

Symbol	Parameter	Min.	Max.	Units
t_{RCC}	Array Recall Cycle Time	1200		ns
t_{RCP}	Recall Pulse Width(4)	450		ns
t_{RCZ}	Recall to Output in High Z		150	ns
t_{ORC}	Output Active from End of Recall	10		ns
t_{ARC}	Recalled Data Access Time from End of Recall		750	ns

Note: (4) Array Recall rise time must be less than 1 μs.

Array Recall Cycle



PIN DESCRIPTIONS AND DEVICE OPERATION

Addresses (A_0–A_7)

The address inputs select a 4-bit memory location during a read or write operation.

Chip Select ($\overline{CS}$)

The Chip Select input must be LOW to enable read/write operations with the RAM array. $\overline{CS}$ HIGH will place the I/O pins in the high impedance state.

Write Enable ($\overline{WE}$)

The Write Enable input controls the I/O buffers, determining whether a RAM read or write operation is enabled. $\overline{WE}$ HIGH enables a read and $\overline{WE}$ LOW enables a write.

Data In/Data Out (I/O_1–I/O_4)

Data is written to or read from the X2212 through the I/O pins. The I/O pins are placed in the high impedance state when either $\overline{CS}$ is HIGH or during either a store or recall operation.

$\overline{STORE}$

The $\overline{STORE}$ input, when LOW, will initiate the transfer of the entire contents of the RAM array to the E^2PROM array. The $\overline{WE}$ and $\overline{ARRAY\ RECALL}$ inputs are inhibited during the store cycle. The store operation will be completed in 10ms or less.

A store operation has priority over RAM read/write operations. If $\overline{STORE}$ is asserted during a read operation, the read will be discontinued. If $\overline{STORE}$ is asserted during a RAM write operation, the write will be immediately terminated and the store performed. The data at the RAM address that was being written will be unknown in both the RAM and E^2PROM.

$\overline{ARRAY\ RECALL}$

The $\overline{ARRAY\ RECALL}$ input, when LOW, will initiate the transfer of the entire contents of the E^2PROM array to the RAM array. The transfer of data will typically be completed in 1μs or less.

An array recall has priority over RAM read/write operations and will terminate both operations when $\overline{ARRAY\ RECALL}$ is asserted. $\overline{ARRAY\ RECALL}$ LOW will also inhibit the $\overline{STORE}$ input.

WRITE PROTECTION

The X2212 has three write protect features that are employed to protect the contents of the nonvolatile memory.

- V_{CC} Sense—All functions are inhibited when V_{CC} is ≤ 3v, typically.
- Write Inhibit—Holding either $\overline{STORE}$ HIGH or $\overline{RECALL}$ LOW during power-up or power-down will prevent an inadvertent store operation and E^2PROM data integrity will be maintained.
- Noise Protection—A $\overline{STORE}$ pulse of less than 20ns will *not* initiate a store cycle.

ENDURANCE

The endurance specification of a device is characterized by the predicted *first* bit failure to occur in the entire memory (device or system) array rather than the average or typical value for the array. Since endurance is limited by the number of electrons trapped in the oxide during data changes, Xicor NOVRAMs are designed to minimize the number of changes an E^2PROM bit cell undergoes during store operations. Only those bits in the E^2PROM that are different from their corresponding location in the RAM will be "cycled" during a nonvolatile store. This characteristic reduces unnecessary cycling of any of the rest of the bits in the array, thereby increasing the potential endurance of each bit and increasing the potential endurance of the entire array. Reliability data documented in RR504, the *Xicor Reliability Report on Endurance*, and additional reports are available from Xicor.

Part Number	Store Cycles	Data Changes Per Bit
X2212 X2212I	10,000	1,000
X2212/5 X2212I/5	50,000	5,000
X2212/10 X2212I/10	100,000	10,000

NOTES

Nonvolatile Static RAM

FEATURES

- **Single 5 Volt Supply**
- **Fully TTL Compatible**
- **JEDEC Standard 18-Pin Package**
- **Infinite E^2PROM Array Recall, RAM Read and Write Cycles**
- **Access Time of 300ns Max.**
- **Nonvolatile Store Inhibit: V_{CC} = 3v Typical**
- **100 Year Data Retention**

DESCRIPTION

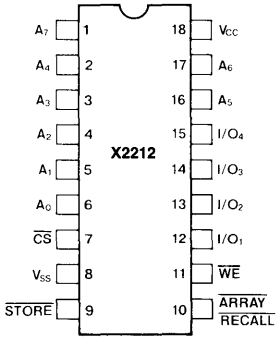
The Xicor X2212 is a 256 x 4 NOVRAM* featuring a high-speed static RAM overlaid bit-for-bit with a nonvolatile E^2PROM. The X2212 is fabricated with the same reliable N-channel floating gate MOS technology used in all Xicor 5 volt nonvolatile memories. The X2212 features the JEDEC approved pinout for 4-bit-wide memories, compatible with industry standard RAMs.

The NOVRAM design allows data to be easily transferred from RAM to E^2PROM (store) and from E^2PROM to RAM (recall). The store operation is completed in 10ms or less and the recall is typically completed in 1μs.

Xicor NOVRAMs are designed for unlimited write operations to RAM, either from the host or recalls from E^2PROM. The E^2PROM array is designed for a minimum 10,000 store cycles. Data retention is specified to be greater than 100 years.

*NOVRAM is Xicor's nonvolatile static RAM device.

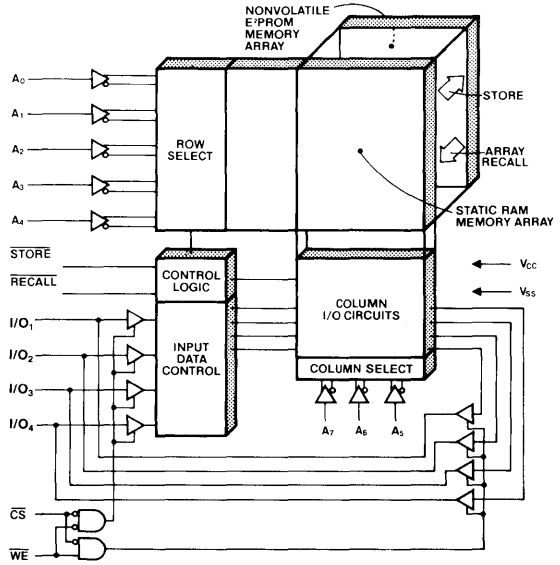
PIN CONFIGURATION



PIN NAMES

A_0–A_7	Address Inputs
I/O_1–I/O_4	Data Inputs/Outputs
$\overline{WE}$	Write Enable
$\overline{CS}$	Chip Select
$\overline{ARRAY\ RECALL}$	Array Recall
$\overline{STORE}$	Store
V_{CC}	+5V
V_{SS}	Ground
NC	No Connect

FUNCTIONAL DIAGRAM



ABSOLUTE MAXIMUM RATINGS*

Temperature Under Bias ..... −65°C to +135°C
Storage Temperature ..... −65°C to +150°C
Voltage on any Pin with
Respect to Ground ..... −1.0V to +7V
D.C. Output Current ..... 5 mA
Lead Temperature (Soldering,
10 Seconds) ..... 300°C

*COMMENT

Stresses above those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. This is a stress rating only and the functional operation of the device at these or any other conditions above those indicated in the operational sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

D.C. OPERATING CHARACTERISTICS

T_A = −55°C to +125°C, V_{CC} = +5V ±10%, unless otherwise specified.

Symbol	Parameter	Limits		Units	Test Conditions
		Min.	Max.		
I_{CC}	Power Supply Current		70	mA	All Inputs = V_{CC} $I_{I/O}$ = 0 mA
I_{LI}	Input Load Current		10	µA	V_{IN} = GND to V_{CC}
I_{LO}	Output Leakage Current		10	µA	V_{OUT} = GND to V_{CC}
V_{IL}	Input Low Voltage	−1.0	0.8	V	
V_{IH}	Input High Voltage	2.0	V_{CC} +1.0	V	
V_{OL}	Output Low Voltage		0.4	V	I_{OL} = 4.2 mA
V_{OH}	Output High Voltage	2.4		V	I_{OH} = −2 mA

CAPACITANCE T_A = 25°C, f = 1.0 MHz, V_{CC} = 5V

Symbol	Test	Max.	Unit	Conditions
$C_{I/O}$[1]	Input/Output Capacitance	8	pF	$V_{I/O}$ = 0V
C_{IN}[1]	Input Capacitance	6	pF	V_{IN} = 0V

Note: (1) This parameter is periodically sampled and not 100% tested.

A.C. CONDITIONS OF TEST

Input Pulse Levels	0 to 3.0 Volts
Input Rise and Fall Times	10 nsec
Input and Output Timing Levels	1.5 Volts
Output Load	1 TTL Gate and C_L = 100 pF

MODE SELECTION

Inputs				Input Output	
CS	WE	ARRAY RECALL	STORE	I/O	Mode
H	X	H	H	Output High Z	Not Selected[2]
L	H	H	H	Output Data	Read RAM
L	L	H	H	Input Data High	Write "1" RAM
L	L	H	H	Input Data Low	Write "0" RAM
X	H	L	H	Output High Z	Array Recall
H	X	L	H	Output High Z	Array Recall
X	H	H	L	Output High Z	Nonvolatile Storing[3]
H	X	H	L	Output High Z	Nonvolatile Storing[3]

Notes: (2) Chip is deselected but may be automatically completing a store cycle.
(3) $\overline{\text{STORE}}$ = L is required only to initiate the store cycle, after which the store cycle will be automatically completed ($\overline{\text{STORE}}$ = X).

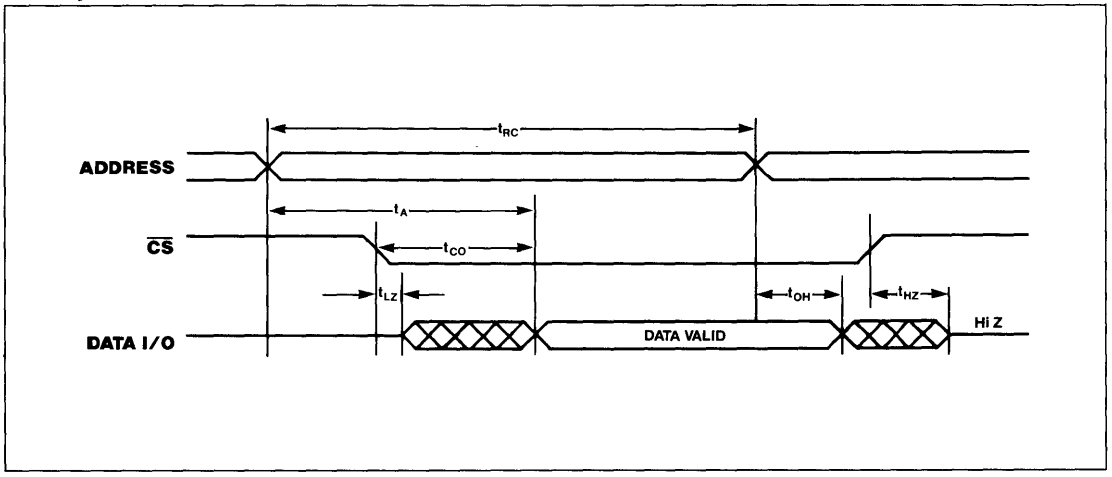
A.C. CHARACTERISTICS

T_A = −55°C to +125°C, V_{CC} = +5V ±10%, unless otherwise specified.

Read Cycle Limits

Symbol	Parameter	Min.	Max.	Units
t_{RC}	Read Cycle Time	300		ns
t_A	Access Time		300	ns
t_{CO}	Chip Select to Output Valid		200	ns
t_{OH}	Output Hold from Address Change	50		ns
t_{LZ}	Chip Select to Output in Low Z	10		ns
t_{HZ}	Chip Deselect to Output in High Z	10	100	ns

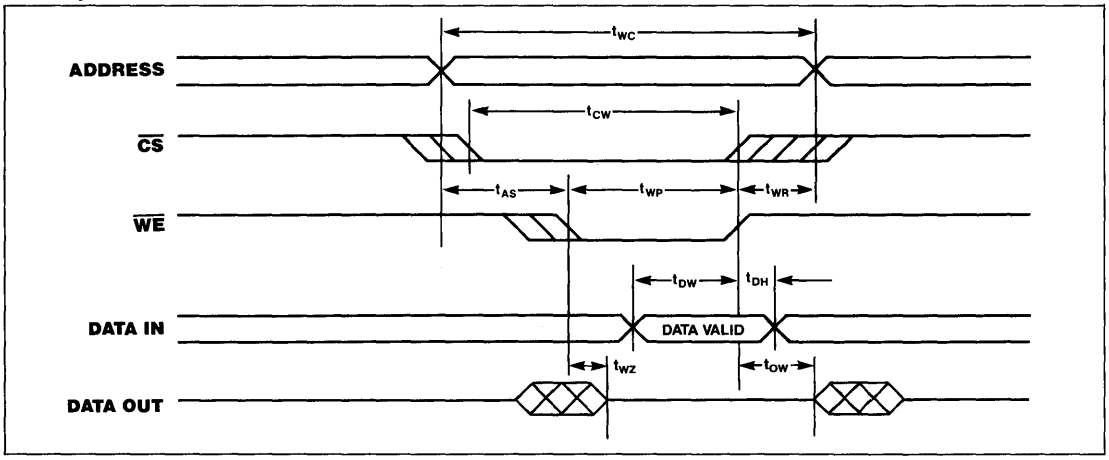
Read Cycle



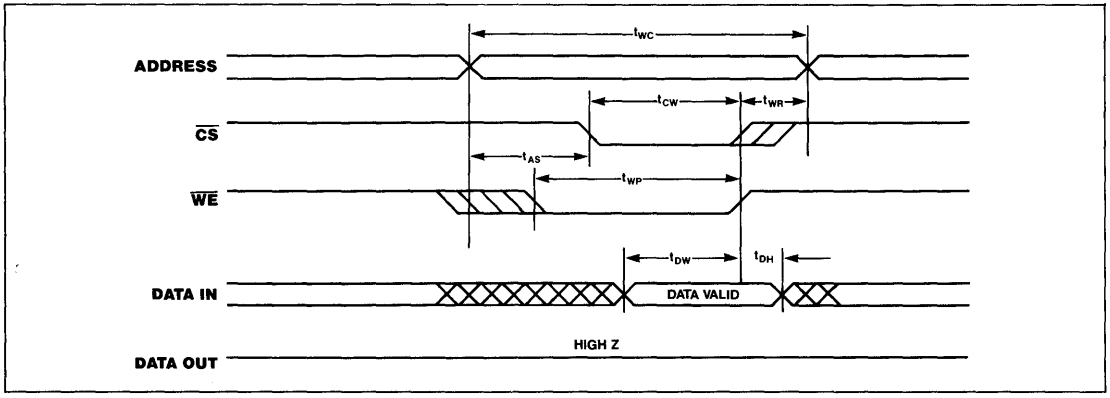
Write Cycle Limits

Symbol	Parameter	Min.	Max.	Units
t_{WC}	Write Cycle Time	300		ns
t_{CW}	Chip Select to End of Write	150		ns
t_{AS}	Address Set-up Time	50		ns
t_{WP}	Write Pulse Width	150		ns
t_{WR}	Write Recovery Time	25		ns
t_{DW}	Data Valid to End of Write	100		ns
t_{DH}	Data Hold Time	20		ns
t_{WZ}	Write Enable to Output in High Z	10	100	ns
t_{OW}	Output Active from End of Write	10		ns

Write Cycle



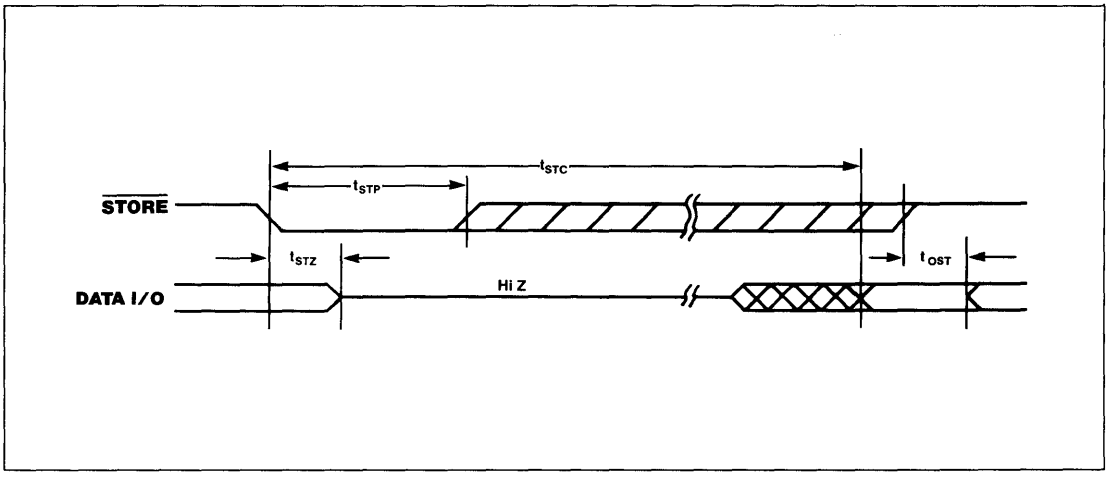
Early Write Cycle



Store Cycle Limits

Symbol	Parameter	Min.	Max.	Units
t_{STC}	Store Cycle Time		10	ms
t_{STP}	Store Pulse Width	100		ns
t_{STZ}	Store to Output in High Z		500	ns
t_{OST}	Output Active from End of Store	10		ns

Store Cycle

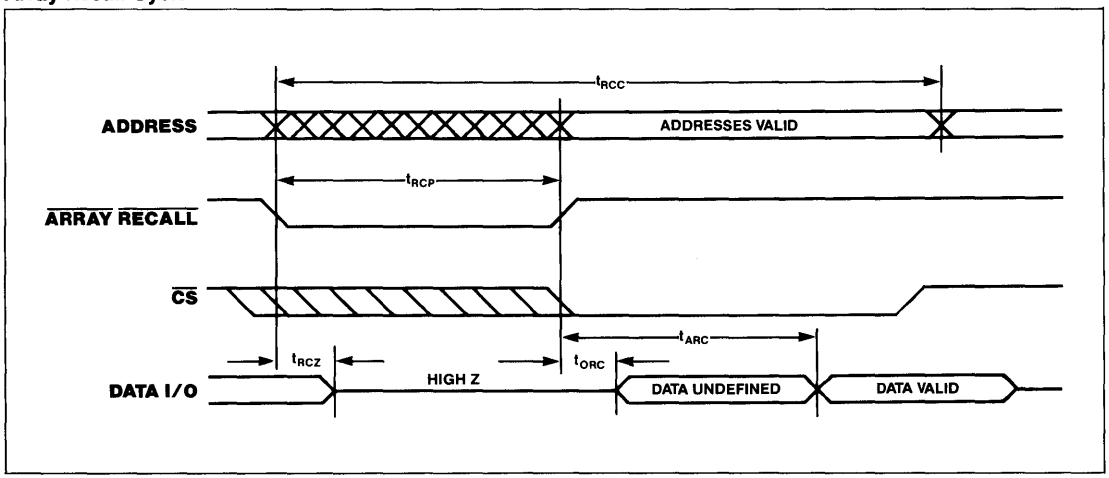


Array Recall Cycle Limits

Symbol	Parameter	Min.	Max.	Units
t_{RCC}	Array Recall Cycle Time	1200		ns
t_{RCP}	Recall Pulse Width[4]	450		ns
t_{RCZ}	Recall to Output in High Z		150	ns
t_{ORC}	Output Active from End of Recall	10		ns
t_{ARC}	Recalled Data Access Time from End of Recall		750	ns

Note: (4) Array Recall rise time must be less than 1 μs.

Array Recall Cycle



PIN DESCRIPTIONS AND DEVICE OPERATION

Addresses (A_0–A_7)

The address inputs select a 4-bit memory location during a read or write operation.

Chip Select ($\overline{CS}$)

The Chip Select input must be LOW to enable read/write operations with the RAM array. $\overline{CS}$ HIGH will place the I/O pins in the high impedance state.

Write Enable ($\overline{WE}$)

The Write Enable input controls the I/O buffers, determining whether a RAM read or write operation is enabled. $\overline{WE}$ HIGH enables a read and $\overline{WE}$ LOW enables a write.

Data In/Data Out (I/O_1–I/O_4)

Data is written to or read from the X2212 through the I/O pins. The I/O pins are placed in the high impedance state when either $\overline{CS}$ is HIGH or during either a store or recall operation.

$\overline{STORE}$

The $\overline{STORE}$ input, when LOW, will initiate the transfer of the entire contents of the RAM array to the E^2PROM array. The $\overline{WE}$ and $\overline{ARRAY\ RECALL}$ inputs are inhibited during the store cycle. The store operation will be completed in 10ms or less.

A store operation has priority over RAM read/write operations. If $\overline{STORE}$ is asserted during a read operation, the read will be discontinued. If $\overline{STORE}$ is asserted during a RAM write operation, the write will be immediately terminated and the store performed. The data at the RAM address that was being written will be unknown in both the RAM and E^2PROM.

$\overline{ARRAY\ RECALL}$

The $\overline{ARRAY\ RECALL}$ input, when LOW, will initiate the transfer of the entire contents of the E^2PROM array to the RAM array. The transfer of data will typically be completed in 1μs or less.

An array recall has priority over RAM read/write operations and will terminate both operations when $\overline{ARRAY\ RECALL}$ is asserted. $\overline{ARRAY\ RECALL}$ LOW will also inhibit the $\overline{STORE}$ input.

WRITE PROTECTION

The X2212 has three write protect features that are employed to protect the contents of the nonvolatile memory.

- V_{CC} Sense—All functions are inhibited when V_{CC} is ≤ 3v, typically.
- Write Inhibit—Holding either $\overline{STORE}$ HIGH or $\overline{RECALL}$ LOW during power-up or power-down will prevent an inadvertent store operation and E^2PROM data integrity will be maintained.
- Noise Protection—A $\overline{STORE}$ pulse of less than 20ns will *not* initiate a store cycle.

ENDURANCE

The endurance specification of a device is characterized by the predicted *first* bit failure to occur in the entire memory (device or system) array rather than the average or typical value for the array. Since endurance is limited by the number of electrons trapped in the oxide during data changes, Xicor NOVRAMs are designed to minimize the number of changes an E^2PROM bit cell undergoes during store operations. Only those bits in the E^2PROM that are different from their corresponding location in the RAM will be "cycled" during a nonvolatile store. This characteristic reduces unnecessary cycling of any of the rest of the bits in the array, thereby increasing the potential endurance of each bit and increasing the potential endurance of the entire array. Reliability data documented in RR504, the *Xicor Reliability Report on Endurance*, and additional reports are available from Xicor.

Part Number	Store Cycles	Data Changes Per Bit
X2212M	10,000	1,000
X2212M/5	50,000	5,000
X2212M/10	100,000	10,000

NOTES

PRELIMINARY

1K Commercial Industrial X2001 X2001I 128 x 8 Bit

Nonvolatile Static RAM

1

FEATURES

- **Nonvolatile Data Integrity**
- **Automatic Store Timing**
- **Store and Array Recall Combined on One Line ($\overline{NE}$)**
- **Enhanced Store Protection**
- **Infinite E^2PROM Array Recall, and RAM Read and Write Cycles**
- **Single 5V Supply**
- **100 Year Data Retention**
- **JEDEC Approved Pinout for Byte-Wide Memories**
- **Fast Access Time: 200ns Max.**
- **Automatic Recall on Power-Up**

DESCRIPTION

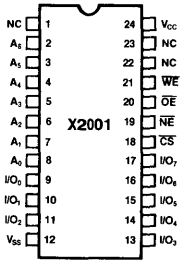
The Xicor X2001 is a byte-wide NOVRAM* featuring a high-speed static RAM overlaid bit-for-bit with a nonvolatile electrically erasable PROM (E^2PROM). The X2001 is fabricated with the same reliable N-channel floating gate MOS technology used in all Xicor 5 volt programmable nonvolatile memories. The X2001 features the JEDEC approved pinout for byte-wide memories, compatible with industry standard RAMs, ROMs, EPROMs and E^2PROMs.

The NOVRAM design allows data to be easily transferred from RAM to E^2PROM (store) and E^2PROM to RAM (recall). With $\overline{NE}$ LOW, these functions are performed in the same manner as RAM read and write operations. The store operation is completed in 10ms or less and the recall operation is completed in 5μs or less.

Xicor NOVRAMs are designed for unlimited write operations to RAM, either from the host or recalls from E^2PROM, and a minimum 100,000 store operations to the E^2PROM. Data retention is specified to be greater than 100 years.

*NOVRAM is Xicor's nonvolatile static RAM device.

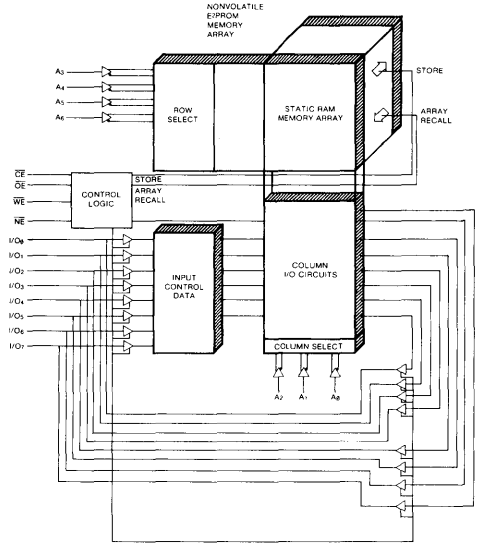
PIN CONFIGURATION



PIN NAMES

A_0–A_6	Address Inputs
I/O_0–I/O_7	Data Inputs/Outputs
$\overline{CE}$	Chip Enable
$\overline{OE}$	Output Enable
$\overline{WE}$	Write Enable
$\overline{NE}$	Nonvolatile Enable
V_{CC}	+5V
V_{SS}	Ground
NC	No Connect

FUNCTIONAL DIAGRAM



May 1985

ABSOLUTE MAXIMUM RATINGS*

Temperature Under Bias X2001 ..... −10°C to +85°C
X2001I ..... −65°C to +135°C
Storage Temperature ..... −65°C to +150°C
Voltage on any Pin with
Respect to Ground ..... −1.0V to +7V
D.C. Output Current ..... 5 mA
Lead Temperature (Soldering,
10 Seconds) ..... 300°C

*COMMENT

Stresses above those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. This is a stress rating only and the functional operation of the device at these or any other conditions above those indicated in the operational sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

D.C. OPERATING CHARACTERISTICS

X2001 T_A = 0°C to +70°C, V_{CC} = +5V ±5%, unless otherwise specified.
X2001I T_A = −40°C to +85°C, V_{CC} = +5V ±10%, unless otherwise specified.

Symbol	Parameter	X2001 Limits		X2001I Limits		Units	Test Conditions
		Min.	Max.	Min.	Max.		
I_{CC}	V_{CC} Current (Active)		80		100	mA	$\overline{CE}$ = V_{IL}, All Other Inputs = V_{CC} $I_{I/O}$ = 0 mA
I_{SB}	V_{CC} Current (Standby)		50		65	mA	All Inputs = V_{CC} $I_{I/O}$ = 0 mA
I_{LI}	Input Leakage Current		10		10	µA	V_{IN} = GND to V_{CC}
I_{LO}	Output Leakage Current		10		10	µA	V_{OUT} = GND to V_{CC}
V_{IL}	Input Low Voltage	−1.0	0.8	−1.0	0.8	V	
V_{IH}	Input High Voltage	2.0	V_{CC} +0.5	2.0	V_{CC} +1.0	V	
V_{OL}	Output Low Voltage		0.4		0.4	V	I_{OL} = 2.1 mA
V_{OH}	Output High Voltage	2.4		2.4		V	I_{OH} = −400 µA

CAPACITANCE T_A = 25°C, f = 1.0 MHz, V_{CC} = 5V

Symbol	Test	Max.	Unit	Conditions
$C_{I/O}$[1]	Input/Output Capacitance	10	pF	$V_{I/O}$ = 0V
C_{IN}[1]	Input Capacitance	6	pF	V_{IN} = 0V

Note: (1) This parameter is periodically sampled and not 100% tested.

A.C. CONDITIONS OF TEST

Input Pulse Levels	0 to 3.0 Volts
Input Rise and Fall Times	10 nsec
Input and Output Timing Levels	1.5 Volts
Output Load	1 TTL Gate and C_L = 100 pF

MODE SELECTION

$\overline{CE}$	$\overline{WE}$	$\overline{NE}$	$\overline{OE}$	Mode	I/O	Power
H	X	X	X	Not Selected	Output High Z	Standby
L	H	H	L	Read RAM	Output Data	Active
L	L	H	X	Write "1" RAM	Input Data High	Active
L	L	H	X	Write "0" RAM	Input Data Low	Active
L	H	L	L	Array Recall	Output High Z	Active
L	L	L	H	Nonvolatile Storing	Output High Z	Active
L	H	H	H	Output Disabled	Output High Z	Active
L	L	L	L	No Operation	Output High Z	Active
L	H	L	H	No Operation	Output High Z	Active

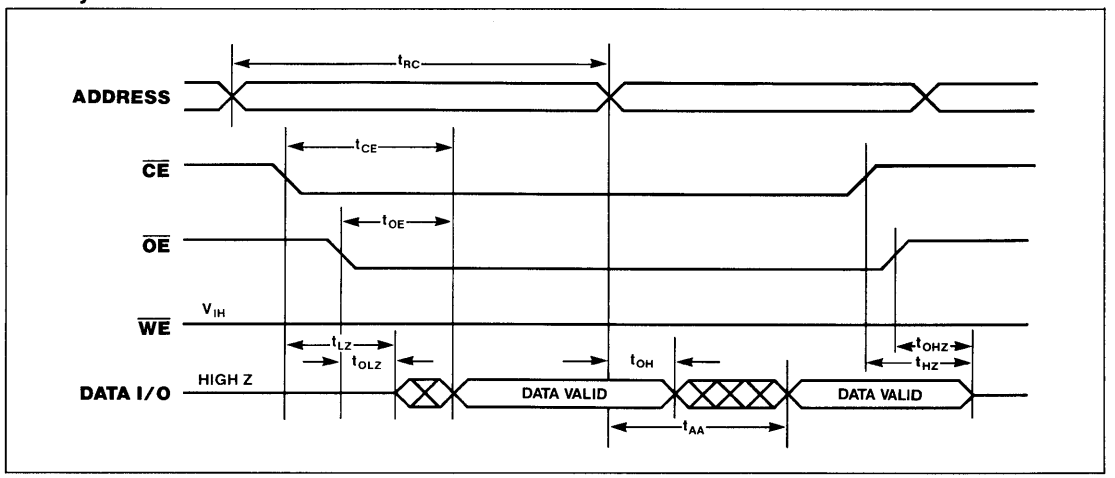
A.C. CHARACTERISTICS

X2001 T_A = 0°C to +70°C, V_{CC} = +5V ±5%, unless otherwise specified.
X2001I T_A = −40°C to +85°C, V_{CC} = +5V ±10%, unless otherwise specified.

Read Cycle Limits

Symbol	Parameter	X2001-20 X2001I-20		X2001-25 X2001I-25		X2001 X2001I		Units
		Min.	Max.	Min.	Max.	Min.	Max.	
t_{RC}	Read Cycle Time	200		250		300		ns
t_{CE}	Chip Enable Access Time		200		250		300	ns
t_{AA}	Address Access Time		200		250		300	ns
t_{OE}	Output Enable Access Time		70		100		150	ns
t_{LZ}	Chip Enable to Output in Low Z	10		10		10		ns
t_{HZ}	Chip Disable to Output in High Z	10	100	10	100	10	100	ns
t_{OLZ}	Output Enable to Output in Low Z	10		10		10		ns
t_{OHZ}	Output Disable to Output in High Z	10	100	10	100	10	100	ns
t_{OH}	Output Hold from Address Change	0		0		0		ns

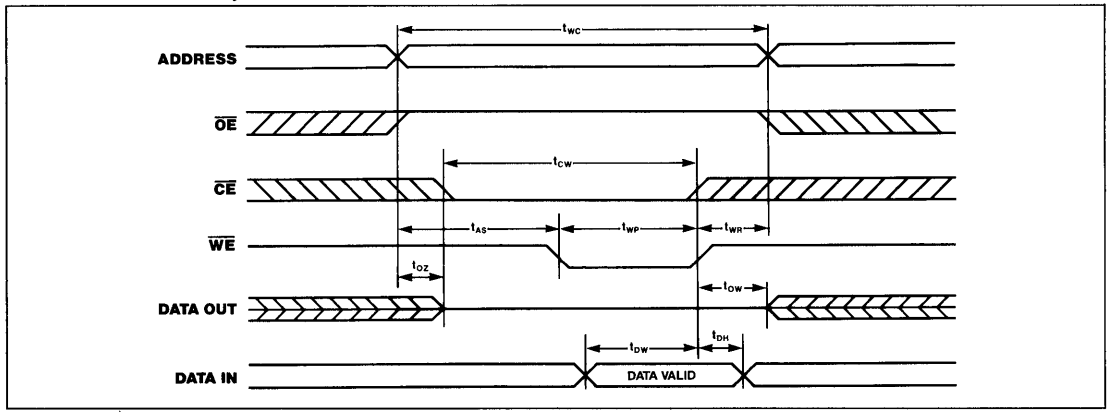
Read Cycle



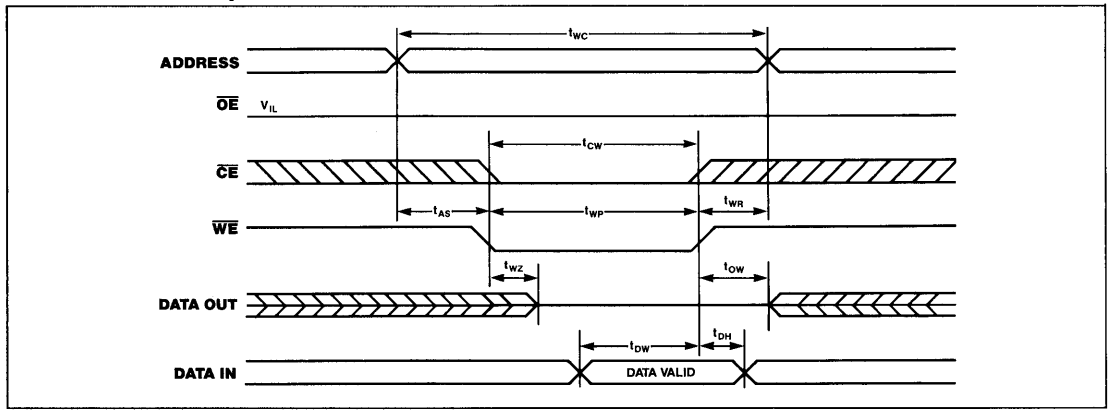
Write Cycle Limits

Symbol	Parameter	X2001-20 X2001I-20		X2001-25 X2001I-25		X2001 X2001I		Units
		Min.	Max.	Min.	Max.	Min.	Max.	
t_{WC}	Write Cycle Time	200		250		300		ns
t_{CW}	Chip Enable to End of Write Input	200		250		300		ns
t_{AS}	Address Set-Up Time	0		0		0		ns
t_{WP}	Write Pulse Width	120		150		200		ns
t_{WR}	Write Recovery Time	0		0		0		ns
t_{DW}	Data Valid to End of Write	120		150		200		ns
t_{DH}	Data Hold Time	0		0		0		ns
t_{WZ}	Write Enable to Output in High Z	10	100	10	100	10	100	ns
t_{OW}	Output Active from End of Write	10		10		10		ns
t_{OZ}	Output Enable to Output in High Z	10	100	10	100	10	100	ns

$\overline{WE}$ Controlled Write Cycle



$\overline{CE}$ Controlled Write Cycle

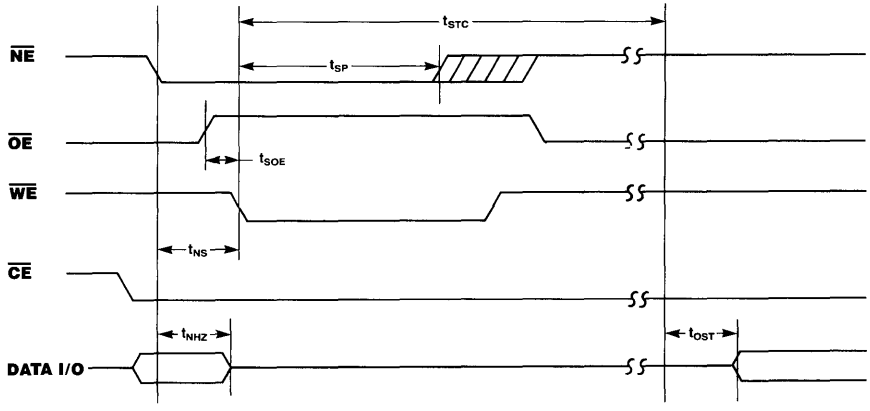


Store Cycle Limits

Symbol	Parameter	X2001-20 X2001I-20		X2001-25 X2001I-25		X2001 X2001I		Units
		Min.	Max.	Min.	Max.	Min.	Max.	
t_{STC}	Store Cycle Time		10		10		10	ms
t_{SP}[2]	Store Pulse Width	120		150		200		ns
t_{NHZ}	Nonvolatile Enable to Output in High Z		100		100		100	ns
t_{OST}	Output Active from End of Store	10		10		10		ns
t_{SOE}	$\overline{OE}$ Disable to STORE Function	20		20		20		ns
t_{NS}	$\overline{NE}$ Setup Time from $\overline{WE}$	0		0		0		ns

Note: (2) Once t_{SP} has been satisfied by ($\overline{NE}$, $\overline{OE}$, $\overline{WE}$, $\overline{CE}$) the store cycle is completed automatically, while ignoring all inputs.

Store Cycle

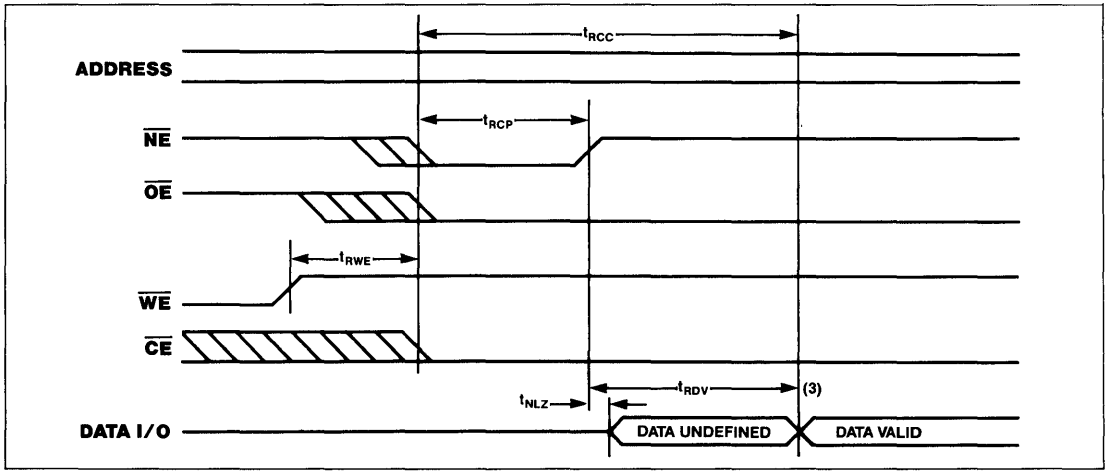


Array Recall Cycle Limits

Symbol	Parameter	X2001-20 X2001I-20		X2001-25 X2001I-25		X2001 X2001I		Units
		Min.	Max.	Min.	Max.	Min.	Max.	
t_{RCC}	Array Recall Cycle Time		5.0		5.0		5.0	µs
t_{RCP}(3)	Recall Pulse Width to Initiate Recall	120		150		200		ns
t_{NLZ}	Recall to Output in Low Z	0		0		0		ns
t_{RWE}	$\overline{WE}$ Setup Time to $\overline{NE}$	0		0		0		ns
t_{RDV}(3)	Recall to Data Valid	0.1	4.9	0.1	4.9	0.1	4.9	µs

Note: (3) The X2001 features internal control of the Recall Cycle time. t_{RCP} is the minimum input pulse width required to initiate a recall. Once initiated the Recall Cycle will have a completion time of t_{RDV} which varies. As t_{RCP} is increased above its minimum value, the cycle time t_{RCC} remains constant and t_{RDV} is reduced accordingly until reaching its minimum value. If t_{RCP} is increased further, t_{RDV} remains constant and the entire cycle time will increase.

Array Recall Cycle



PIN DESCRIPTIONS

Addresses (A_0–A_6)

The address inputs select an 8-bit word during a read or write operation.

Chip Enable ($\overline{CE}$)

The Chip Enable input must be LOW to enable all read/write operations. When $\overline{CE}$ is HIGH, power consumption is reduced.

Output Enable ($\overline{OE}$)

The Output Enable input controls the data output buffers and is used to initiate read and recall operations. Output Enable LOW disables a store operation regardless of the state of $\overline{CE}$, $\overline{WE}$ or $\overline{NE}$.

Data In/Data Out (I/O_0–I/O_7)

Data is written to or read from the X2001 through the I/O pins. The I/O pins are placed in the high impedance state when either $\overline{CE}$ or $\overline{OE}$ is HIGH or when $\overline{NE}$ is LOW.

Write Enable ($\overline{WE}$)

The Write Enable input controls the writing of data to both the static RAM and stores to the E^2PROM.

Nonvolatile Enable ($\overline{NE}$)

The Nonvolatile Enable input controls all accesses to the E^2PROM array (store and recall functions).

DEVICE OPERATION

The $\overline{CE}$, $\overline{OE}$, $\overline{WE}$ and $\overline{NE}$ inputs control the X2001 operation. The X2001 byte-wide NOVRAM uses a 2-line control architecture to eliminate bus contention in a system environment. The I/O bus will be in a high impedance state when either $\overline{OE}$ or $\overline{CE}$ is HIGH, or when $\overline{NE}$ is LOW.

RAM OPERATIONS

RAM read and write operations are performed as they would be with any static RAM. A read operation requires $\overline{CE}$ and $\overline{OE}$ to be LOW with $\overline{WE}$ and $\overline{NE}$ HIGH. A write operation requires $\overline{CE}$ and $\overline{WE}$ to be LOW with $\overline{NE}$ HIGH. There is no limit to the number of read or write operations performed to the RAM portion of the X2001.

NONVOLATILE OPERATIONS

With $\overline{NE}$ LOW, recall and store operations are performed in the same manner as RAM read and write operations. A recall operation causes the entire contents of the E^2PROM to be written into the RAM array. The time required for the operation to complete is 5µs or less. A store operation causes the entire contents of the RAM array to be stored in the nonvolatile E^2PROM. The time for the operation to complete is 10ms or less, typically 5ms.

POWER-UP RECALL

Upon power-up (V_{CC}), the X2001 performs an automatic array recall. When V_{CC} minimum is reached, the recall is initiated, regardless of the state of $\overline{CE}$, $\overline{OE}$, $\overline{WE}$ and $\overline{NE}$.

WRITE PROTECTION

The X2001 has four write protect features that are employed to protect the contents of both the nonvolatile memory and the RAM.

- Noise Protection—A $\overline{WE}$ pulse of less than 20ns will *not* initiate a write cycle.
- Combined Signal Noise Protection—A combined $\overline{WE}$ and $\overline{NE}$ ($\overline{WE} \cdot \overline{NE}$) pulse of less than 20ns will *not* initiate a store cycle.
- V_{CC} Sense—All functions are inhibited when V_{CC} is $\leq$ 3v, typically.
- Write Inhibit—Holding either $\overline{OE}$ LOW, $\overline{WE}$ HIGH, $\overline{CE}$ HIGH or $\overline{NE}$ HIGH during power-up or power-down, will prevent an inadvertent store operation.

ENDURANCE

The endurance specification of a device is characterized by the predicted *first* bit failure to occur in the entire memory (device or system) array rather than the average or typical value for the array. Since endurance is limited by the number of electrons trapped in the oxide during data changes, Xicor NOVRAMs are designed to minimize the number of changes an E^2PROM bit cell undergoes during store operations. Only those bits in the E^2PROM that are different from their corresponding location in the RAM will be "cycled" during a nonvolatile store. This characteristic reduces unnecessary cycling of any of the rest of the bits in the array, thereby increasing the potential endurance of each bit and increasing the potential endurance of the entire array. Reliability data documented in RR504, the *Xicor Reliability Report on Endurance,* and additional reports are available from Xicor.

Part Number	Store Cycles	Data Changes Per Bit
X2001	100,000	10,000
X2001I	100,000	10,000

NOTES

PRELIMINARY

2K Commercial Industrial — X2002 X2002I — 256 x 8 Bit

Nonvolatile Static RAM

1

FEATURES

- **Nonvolatile Data Integrity**
- **Automatic Store Timing**
- **Store and Array Recall Combined on One Line ($\overline{NE}$)**
- **Enhanced Store Protection**
- **Infinite E^2PROM Array Recall, and RAM Read and Write Cycles**
- **Single 5V Supply**
- **100 Year Data Retention**
- **JEDEC Approved Pinout for Byte-Wide Memories**
- **Fast Access Time: 200ns Max.**
- **Automatic Recall on Power-Up**

DESCRIPTION

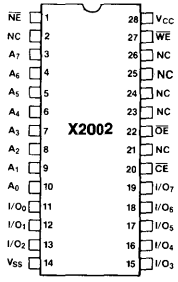
The Xicor X2002 is a byte-wide NOVRAM* featuring a high-speed static RAM overlaid bit-for-bit with a nonvolatile electrically erasable PROM (E^2PROM). The X2002 is fabricated with the same reliable N-channel floating gate MOS technology used in all Xicor 5 volt programmable nonvolatile memories. The X2002 features the JEDEC approved pinout for byte-wide memories, compatible with industry standard RAMs, ROMs, EPROMs and E^2PROMs.

The NOVRAM design allows data to be easily transferred from RAM to E^2PROM (store) and E^2PROM to RAM (recall). With $\overline{NE}$ LOW, these functions are performed in the same manner as RAM read and write operations. The store operation is completed in 10ms or less and the recall operation is completed in 5μs or less.

Xicor NOVRAMs are designed for unlimited write operations to RAM, either from the host or recalls from E^2PROM, and a minimum 100,000 store operations to the E^2PROM. Data retention is specified to be greater than 100 years.

*NOVRAM is Xicor's nonvolatile static RAM device.

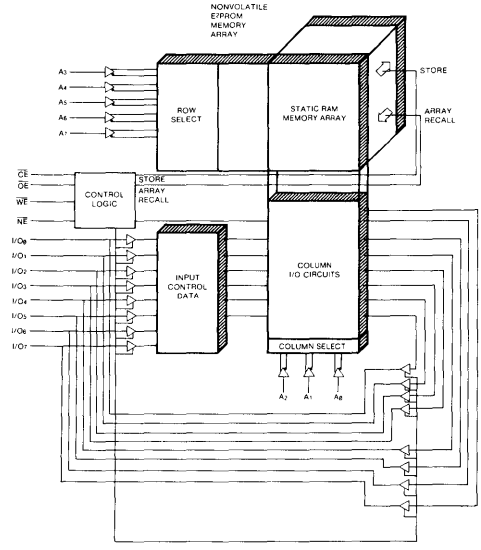
PIN CONFIGURATION



PIN NAMES

A_0–A_7	Address Inputs
I/O_0–I/O_7	Data Inputs/Outputs
$\overline{CE}$	Chip Enable
$\overline{OE}$	Output Enable
$\overline{WE}$	Write Enable
$\overline{NE}$	Nonvolatile Enable
V_{CC}	+5V
V_{SS}	Ground
NC	No Connect

FUNCTIONAL DIAGRAM



May 1985

ABSOLUTE MAXIMUM RATINGS*

Temperature Under Bias X2002 ..... −10°C to +85°C
X2002I ..... −65°C to +135°C
Storage Temperature ..... −65°C to +150°C
Voltage on any Pin with
Respect to Ground ..... −1.0V to +7V
D.C. Output Current ..... 5 mA
Lead Temperature (Soldering,
10 Seconds) ..... 300°C

*COMMENT

Stresses above those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. This is a stress rating only and the functional operation of the device at these or any other conditions above those indicated in the operational sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

D.C. OPERATING CHARACTERISTICS

X2002 T_A = 0°C to +70°C, V_{CC} = +5V ±5%, unless otherwise specified.
X2002I T_A = −40°C to +85°C, V_{CC} = +5V ±10%, unless otherwise specified.

Symbol	Parameter	X2002 Limits		X2002I Limits		Units	Test Conditions
		Min.	Max.	Min.	Max.		
I_{CC}	V_{CC} Current (Active)		90		110	mA	$\overline{CE}$ = V_{IL}, All Other Inputs = V_{CC} $I_{I/O}$ = 0 mA
I_{SB}	V_{CC} Current (Standby)		55		70	mA	All Inputs = V_{CC} $I_{I/O}$ = 0 mA
I_{LI}	Input Leakage Current		10		10	µA	V_{IN} = GND to V_{CC}
I_{LO}	Output Leakage Current		10		10	µA	V_{OUT} = GND to V_{CC}
V_{IL}	Input Low Voltage	−1.0	0.8	−1.0	0.8	V	
V_{IH}	Input High Voltage	2.0	V_{CC} +0.5	2.0	V_{CC} +1.0	V	
V_{OL}	Output Low Voltage		0.4		0.4	V	I_{OL} = 2.1 mA
V_{OH}	Output High Voltage	2.4		2.4		V	I_{OH} = −400 µA

CAPACITANCE T_A = 25°C, f = 1.0 MHz, V_{CC} = 5V

Symbol	Test	Max.	Unit	Conditions
$C_{I/O}$[1]	Input/Output Capacitance	10	pF	$V_{I/O}$ = 0V
C_{IN}[1]	Input Capacitance	6	pF	V_{IN} = 0V

Note: (1) This parameter is periodically sampled and not 100% tested.

A.C. CONDITIONS OF TEST

Input Pulse Levels	0 to 3.0 Volts
Input Rise and Fall Times	10 nsec
Input and Output Timing Levels	1.5 Volts
Output Load	1 TTL Gate and C_L = 100 pF

MODE SELECTION

$\overline{CE}$	$\overline{WE}$	$\overline{NE}$	$\overline{OE}$	Mode	I/O	Power
H	X	X	X	Not Selected	Output High Z	Standby
L	H	H	L	Read RAM	Output Data	Active
L	L	H	X	Write "1" RAM	Input Data High	Active
L	L	H	X	Write "0" RAM	Input Data Low	Active
L	H	L	L	Array Recall	Output High Z	Active
L	L	L	H	Nonvolatile Storing	Output High Z	Active
L	H	H	H	Output Disabled	Output High Z	Active
L	L	L	L	No Operation	Output High Z	Active
L	H	L	H	No Operation	Output High Z	Active

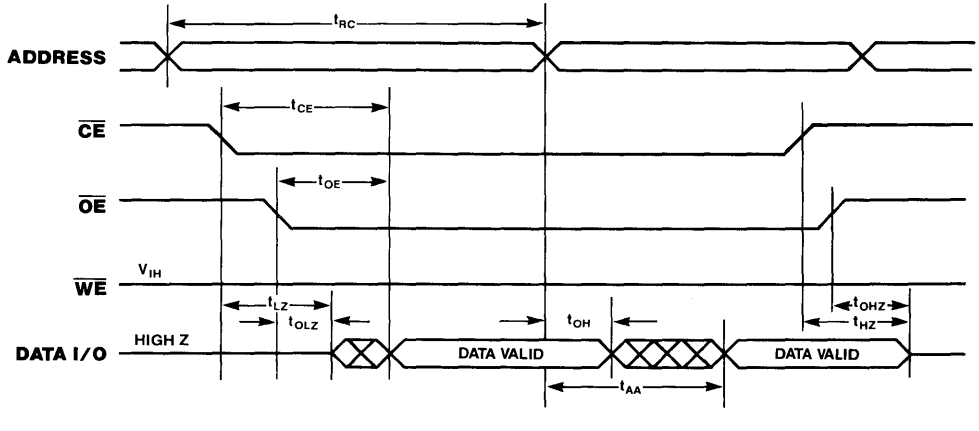
A.C. CHARACTERISTICS

X2002 T_A = 0°C to +70°C, V_{CC} = +5V ±5%, unless otherwise specified.
X2002I T_A = −40°C to +85°C, V_{CC} = +5V ±10%, unless otherwise specified.

Read Cycle Limits

Symbol	Parameter	X2002-20 X2002I-20		X2002-25 X2002I-25		X2002 X2002I		Units
		Min.	Max.	Min.	Max.	Min.	Max.	
t_{RC}	Read Cycle Time	200		250		300		ns
t_{CE}	Chip Enable Access Time		200		250		300	ns
t_{AA}	Address Access Time		200		250		300	ns
t_{OE}	Output Enable Access Time		70		100		150	ns
t_{LZ}	Chip Enable to Output in Low Z	10		10		10		ns
t_{HZ}	Chip Disable to Output in High Z	10	100	10	100	10	100	ns
t_{OLZ}	Output Enable to Output in Low Z	10		10		10		ns
t_{OHZ}	Output Disable to Output in High Z	10	100	10	100	10	100	ns
t_{OH}	Output Hold from Address Change	0		0		0		ns

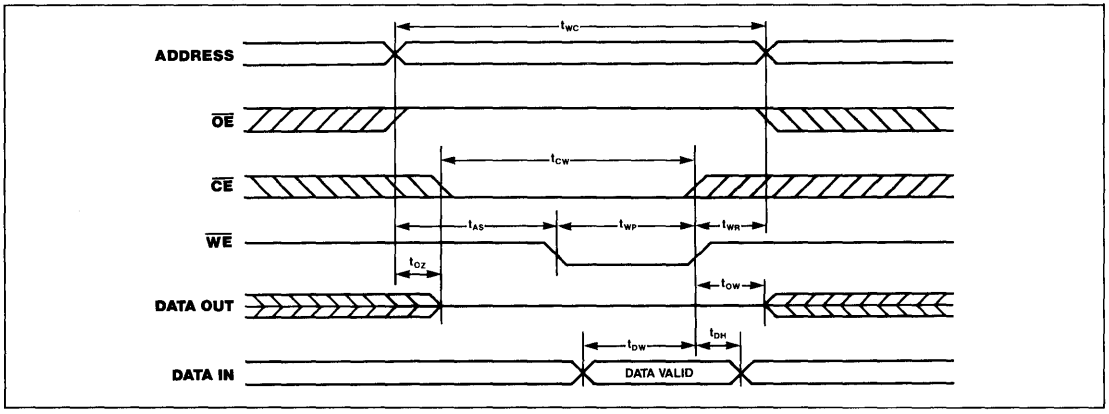
Read Cycle



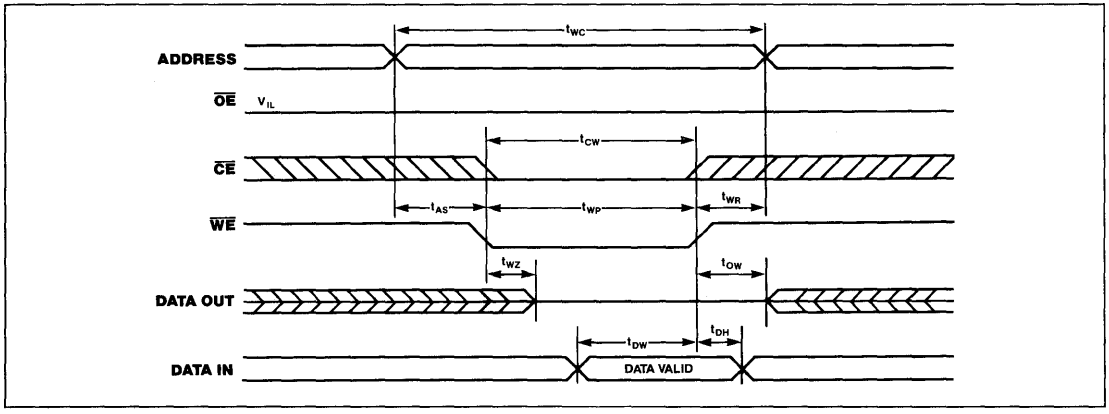
Write Cycle Limits

Symbol	Parameter	X2002-20 X2002I-20		X2002-25 X2002I-25		X2002 X2002I		Units
		Min.	Max.	Min.	Max.	Min.	Max.	
t_{WC}	Write Cycle Time	200		250		300		ns
t_{CW}	Chip Enable to End of Write Input	200		250		300		ns
t_{AS}	Address Set-Up Time	0		0		0		ns
t_{WP}	Write Pulse Width	120		150		200		ns
t_{WR}	Write Recovery Time	0		0		0		ns
t_{DW}	Data Valid to End of Write	120		150		200		ns
t_{DH}	Data Hold Time	0		0		0		ns
t_{WZ}	Write Enable to Output in High Z	10	100	10	100	10	100	ns
t_{OW}	Output Active from End of Write	10		10		10		ns
t_{OZ}	Output Enable to Output in High Z	10	100	10	100	10	100	ns

$\overline{WE}$ Controlled Write Cycle



$\overline{CE}$ Controlled Write Cycle

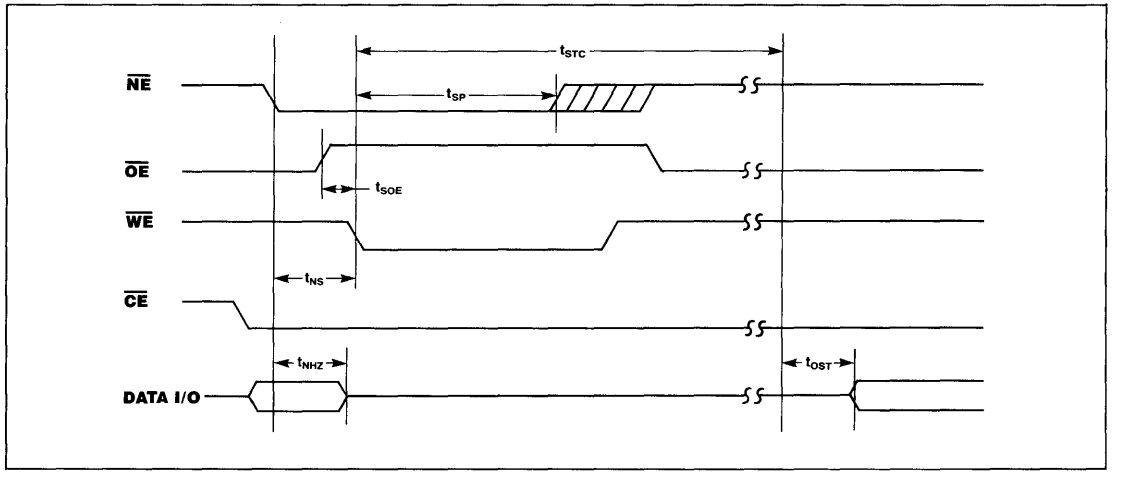


Store Cycle Limits

Symbol	Parameter	X2002-20 X2002I-20		X2002-25 X2002I-25		X2002 X2002I		Units
		Min.	Max.	Min.	Max.	Min.	Max.	
t_{STC}	Store Cycle Time		10		10		10	ms
t_{SP}[2]	Store Pulse Width	120		150		200		ns
t_{NHZ}	Nonvolatile Enable to Output in High Z		100		100		100	ns
t_{OST}	Output Active from End of Store	10		10		10		ns
t_{SOE}	$\overline{OE}$ Disable to STORE Function	20		20		20		ns
t_{NS}	$\overline{NE}$ Setup Time from $\overline{WE}$	0		0		0		ns

Note: (2) Once t_{SP} has been satisfied by ($\overline{NE}$, $\overline{OE}$, $\overline{WE}$, $\overline{CE}$) the store cycle is completed automatically, while ignoring all inputs.

Store Cycle

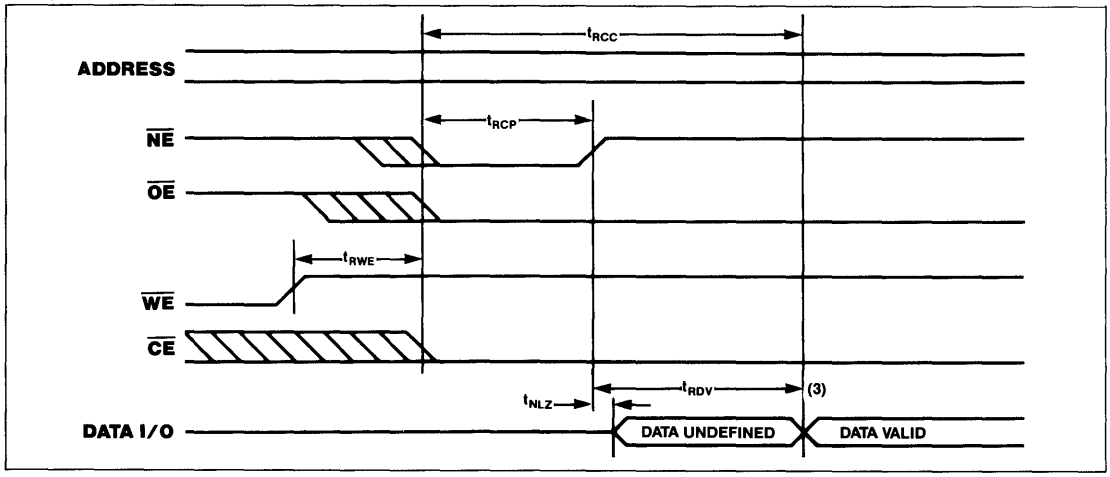


Array Recall Cycle Limits

Symbol	Parameter	X2002-20 X2002I-20		X2002-25 X2002I-25		X2002 X2002I		Units
		Min.	Max.	Min.	Max.	Min.	Max.	
t_{RCC}	Array Recall Cycle Time		5.0		5.0		5.0	µs
t_{RCP}(3)	Recall Pulse Width to Initiate Recall	120		150		200		ns
t_{NLZ}	Recall to Output in Low Z	0		0		0		ns
t_{RWE}	$\overline{WE}$ Setup Time to $\overline{NE}$	0		0		0		ns
t_{RDV}(3)	Recall to Data Valid	0.1	4.9	0.1	4.9	0.1	4.9	µs

Note: (3) The X2002 features internal control of the Recall Cycle time. t_{RCP} is the minimum input pulse width required to initiate a recall. Once initiated the Recall Cycle will have a completion time of t_{RDV} which varies. As t_{RCP} is increased above its minimum value, the cycle time t_{RCC} remains constant and t_{RDV} is reduced accordingly until reaching its minimum value. If t_{RCP} is increased further, t_{RDV} remains constant and the entire cycle time will increase.

Array Recall Cycle



PIN DESCRIPTIONS

Addresses (A_0–A_7)

The address inputs select an 8-bit word during a read or write operation.

Chip Enable ($\overline{CE}$)

The Chip Enable input must be LOW to enable all read/write operations. When $\overline{CE}$ is HIGH, power consumption is reduced.

Output Enable ($\overline{OE}$)

The Output Enable input controls the data output buffers and is used to initiate read and recall operations. Output Enable LOW disables a store operation regardless of the state of $\overline{CE}$, $\overline{WE}$ or $\overline{NE}$.

Data In/Data Out (I/O_0–I/O_7)

Data is written to or read from the X2002 through the I/O pins. The I/O pins are placed in the high impedance state when either $\overline{CE}$ or $\overline{OE}$ is HIGH or when $\overline{NE}$ is LOW.

Write Enable ($\overline{WE}$)

The Write Enable input controls the writing of data to both the static RAM and stores to the E^2PROM.

Nonvolatile Enable ($\overline{NE}$)

The Nonvolatile Enable input controls all accesses to the E^2PROM array (store and recall functions).

DEVICE OPERATION

The $\overline{CE}$, $\overline{OE}$, $\overline{WE}$ and $\overline{NE}$ inputs control the X2002 operation. The X2002 byte-wide NOVRAM uses a 2-line control architecture to eliminate bus contention in a system environment. The I/O bus will be in a high impedance state when either $\overline{OE}$ or $\overline{CE}$ is HIGH, or when $\overline{NE}$ is LOW.

RAM OPERATIONS

RAM read and write operations are performed as they would be with any static RAM. A read operation requires $\overline{CE}$ and $\overline{OE}$ to be LOW with $\overline{WE}$ and $\overline{NE}$ HIGH. A write operation requires $\overline{CE}$ and $\overline{WE}$ to be LOW with $\overline{NE}$ HIGH. There is no limit to the number of read or write operations performed to the RAM portion of the X2002.

NONVOLATILE OPERATIONS

With $\overline{NE}$ LOW, recall and store operations are performed in the same manner as RAM read and write operations. A recall operation causes the entire contents of the E^2PROM to be written into the RAM array. The time required for the operation to complete is 5µs or less. A store operation causes the entire contents of the RAM array to be stored in the nonvolatile E^2PROM. The time for the operation to complete is 10ms or less, typically 5ms.

POWER-UP RECALL

Upon power-up (V_{CC}), the X2002 performs an automatic array recall. When V_{CC} minimum is reached, the recall is initiated, regardless of the state of $\overline{CE}$, $\overline{OE}$, $\overline{WE}$ and $\overline{NE}$.

WRITE PROTECTION

The X2002 has four write protect features that are employed to protect the contents of both the nonvolatile memory and the RAM.

- Noise Protection—A $\overline{WE}$ pulse of less than 20ns will *not* initiate a write cycle.
- Combined Signal Noise Protection—A combined $\overline{WE}$ and $\overline{NE}$ ($\overline{WE} \cdot \overline{NE}$) pulse of less than 20ns will *not* initiate a store cycle.
- V_{CC} Sense—All functions are inhibited when V_{CC} is $\leq$ 3v, typically.
- Write Inhibit—Holding either $\overline{OE}$ LOW, $\overline{WE}$ HIGH, $\overline{CE}$ HIGH or $\overline{NE}$ HIGH during power-up or power-down, will prevent an inadvertent store operation.

ENDURANCE

The endurance specification of a device is characterized by the predicted *first* bit failure to occur in the entire memory (device or system) array rather than the average or typical value for the array. Since endurance is limited by the number of electrons trapped in the oxide during data changes, Xicor NOVRAMs are designed to minimize the number of changes an E^2PROM bit cell undergoes during store operations. Only those bits in the E^2PROM that are different from their corresponding location in the RAM will be "cycled" during a nonvolatile store. This characteristic reduces unnecessary cycling of any of the rest of the bits in the array, thereby increasing the potential endurance of each bit and increasing the potential endurance of the entire array. Reliability data documented in RR504, the *Xicor Reliability Report on Endurance,* and additional reports are available from Xicor.

Part Number	Store Cycles	Data Changes Per Bit
X2002	100,000	10,000
X2002I	100,000	10,000

NOTES

Nonvolatile Static RAM

FEATURES

- **Nonvolatile Data Integrity**
- **Automatic Store Timing**
- **Store and Array Recall Combined on One Line ($\overline{NE}$)**
- **Enhanced Store Protection**
- **Infinite E^2PROM Array Recall, and RAM Read and Write Cycles**
- **Single 5V Supply**
- **100 Year Data Retention**
- **JEDEC Approved Pinout for Byte-Wide Memories**
- **Fast Access Time: 200ns Max.**
- **Automatic Recall on Power-Up**

DESCRIPTION

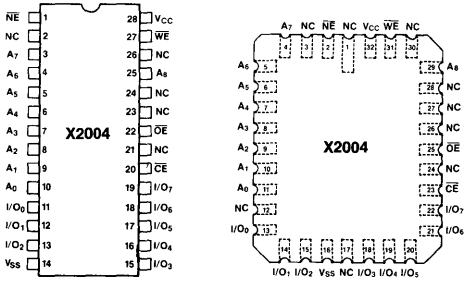
The Xicor X2004 is a byte-wide NOVRAM* featuring a high-speed static RAM overlaid bit-for-bit with a nonvolatile electrically erasable PROM (E^2PROM). The X2004 is fabricated with the same reliable N-channel floating gate MOS technology used in all Xicor 5 volt programmable nonvolatile memories. The X2004 features the JEDEC approved pinout for byte-wide memories, compatible with industry standard RAMs, ROMs, EPROMs and E^2PROMs.

The NOVRAM design allows data to be easily transferred from RAM to E^2PROM (store) and E^2PROM to RAM (recall). With $\overline{NE}$ LOW, these functions are performed in the same manner as RAM read and write operations. The store operation is completed in 10ms or less and the recall operation is completed in 5μs or less.

Xicor NOVRAMs are designed for unlimited write operations to RAM, either from the host or recalls from E^2PROM, and a minimum 100,000 store operations to the E^2PROM. Data retention is specified to be greater than 100 years.

*NOVRAM is Xicor's nonvolatile static RAM device.

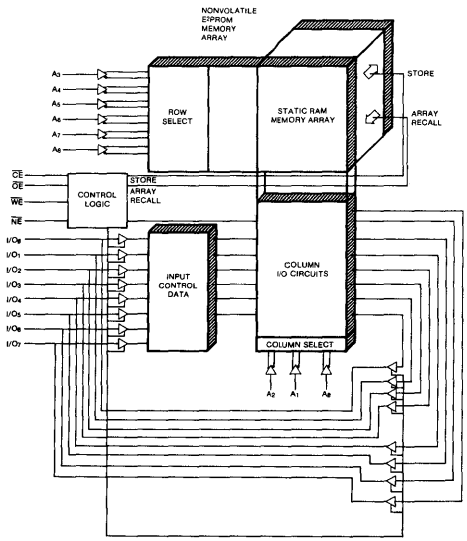
PIN CONFIGURATIONS



PIN NAMES

A_0–A_8	Address Inputs
I/O_0–I/O_7	Data Inputs/Outputs
$\overline{CE}$	Chip Enable
$\overline{OE}$	Output Enable
$\overline{WE}$	Write Enable
$\overline{NE}$	Nonvolatile Enable
V_{CC}	+5V
V_{SS}	Ground
NC	No Connect

FUNCTIONAL DIAGRAM



ABSOLUTE MAXIMUM RATINGS*

Temperature Under Bias X2004 ..... −10°C to +85°C
X2004I ..... −65°C to +135°C
Storage Temperature ..... −65°C to +150°C
Voltage on any Pin with
Respect to Ground ..... −1.0V to +7V
D.C. Output Current ..... 5 mA
Lead Temperature (Soldering,
10 Seconds) ..... 300°C

*COMMENT

Stresses above those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. This is a stress rating only and the functional operation of the device at these or any other conditions above those indicated in the operational sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

D.C. OPERATING CHARACTERISTICS

X2004 T_A = 0°C to +70°C, V_{CC} = +5V ±5%, unless otherwise specified.
X2004I T_A = −40°C to +85°C, V_{CC} = +5V ±10%, unless otherwise specified.

Symbol	Parameter	X2004 Limits		X2004I Limits		Units	Test Conditions
		Min.	Max.	Min.	Max.		
I_{CC}	V_{CC} Current (Active)		100		120	mA	$\overline{CE}$ = V_{IL}, All Other Inputs = V_{CC} $I_{I/O}$ = 0 mA
I_{SB}	V_{CC} Current (Standby)		55		90	mA	All Inputs = V_{CC} $I_{I/O}$ = 0 mA
I_{LI}	Input Leakage Current		10		10	µA	V_{IN} = GND to V_{CC}
I_{LO}	Output Leakage Current		10		10	µA	V_{OUT} = GND to V_{CC}
V_{IL}	Input Low Voltage	−1.0	0.8	−1.0	0.8	V	
V_{IH}	Input High Voltage	2.0	V_{CC} +0.5	2.0	V_{CC} +1.0	V	
V_{OL}	Output Low Voltage		0.4		0.4	V	I_{OL} = 2.1 mA
V_{OH}	Output High Voltage	2.4		2.4		V	I_{OH} = −400 µA

CAPACITANCE T_A = 25°C, f = 1.0 MHz, V_{CC} = 5V

Symbol	Test	Max.	Unit	Conditions
$C_{I/O}$[1]	Input/Output Capacitance	10	pF	$V_{I/O}$ = 0V
C_{IN}[1]	Input Capacitance	6	pF	V_{IN} = 0V

Note: (1) This parameter is periodically sampled and not 100% tested.

A.C. CONDITIONS OF TEST

Input Pulse Levels	0 to 3.0 Volts
Input Rise and Fall Times	10 nsec
Input and Output Timing Levels	1.5 Volts
Output Load	1 TTL Gate and C_L = 100 pF

MODE SELECTION

$\overline{CE}$	$\overline{WE}$	$\overline{NE}$	$\overline{OE}$	Mode	I/O	Power
H	X	X	X	Not Selected	Output High Z	Standby
L	H	H	L	Read RAM	Output Data	Active
L	L	H	X	Write "1" RAM	Input Data High	Active
L	L	H	X	Write "0" RAM	Input Data Low	Active
L	H	L	L	Array Recall	Output High Z	Active
L	L	L	H	Nonvolatile Storing	Output High Z	Active
L	H	H	H	Output Disabled	Output High Z	Active
L	L	L	L	No Operation	Output High Z	Active
L	H	L	H	No Operation	Output High Z	Active

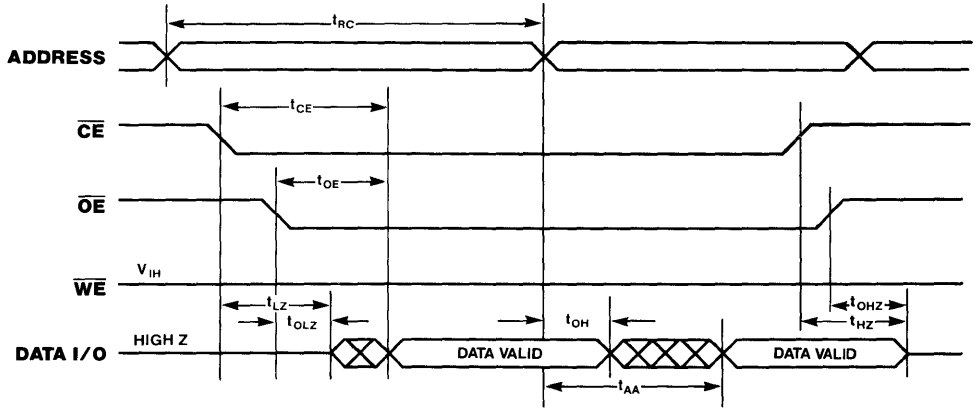
A.C. CHARACTERISTICS

X2004 T_A = 0°C to +70°C, V_{CC} = +5V ±5%, unless otherwise specified.
X2004I T_A = −40°C to +85°C, V_{CC} = +5V ±10%, unless otherwise specified.

Read Cycle Limits

Symbol	Parameter	X2004-20 X2004I-20		X2004-25 X2004I-25		X2004 X2004I		Units
		Min.	Max.	Min.	Max.	Min.	Max.	
t_{RC}	Read Cycle Time	200		250		300		ns
t_{CE}	Chip Enable Access Time		200		250		300	ns
t_{AA}	Address Access Time		200		250		300	ns
t_{OE}	Output Enable Access Time		70		100		150	ns
t_{LZ}	Chip Enable to Output in Low Z	10		10		10		ns
t_{HZ}	Chip Disable to Output in High Z	10	100	10	100	10	100	ns
t_{OLZ}	Output Enable to Output in Low Z	10		10		10		ns
t_{OHZ}	Output Disable to Output in High Z	10	100	10	100	10	100	ns
t_{OH}	Output Hold from Address Change	0		0		0		ns

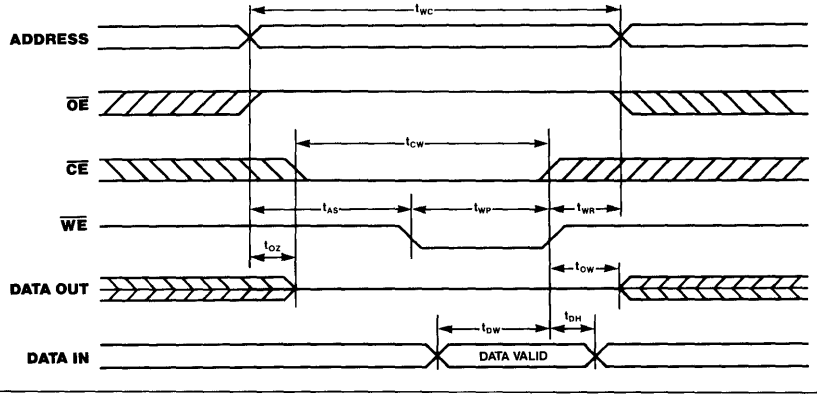
Read Cycle



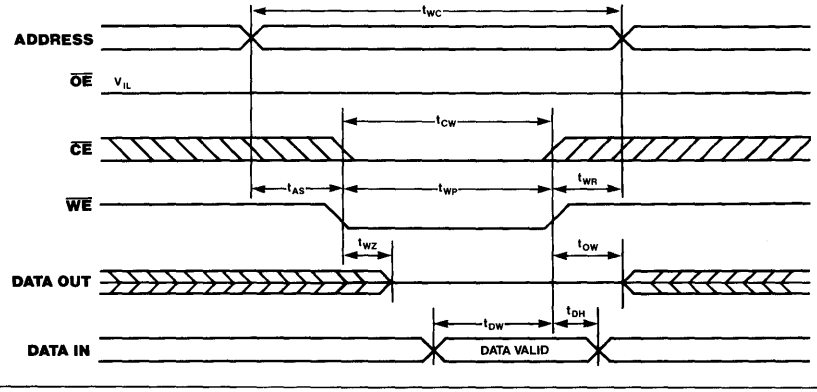
Write Cycle Limits

Symbol	Parameter	X2004-20 X2004I-20		X2004-25 X2004I-25		X2004 X2004I		Units
		Min.	Max.	Min.	Max.	Min.	Max.	
t_{WC}	Write Cycle Time	200		250		300		ns
t_{CW}	Chip Enable to End of Write Input	200		250		300		ns
t_{AS}	Address Set-Up Time	0		0		0		ns
t_{WP}	Write Pulse Width	120		150		200		ns
t_{WR}	Write Recovery Time	0		0		0		ns
t_{DW}	Data Valid to End of Write	120		150		200		ns
t_{DH}	Data Hold Time	0		0		0		ns
t_{WZ}	Write Enable to Output in High Z	10	100	10	100	10	100	ns
t_{OW}	Output Active from End of Write	10		10		10		ns
t_{OZ}	Output Enable to Output in High Z	10	100	10	100	10	100	ns

$\overline{WE}$ Controlled Write Cycle



$\overline{CE}$ Controlled Write Cycle

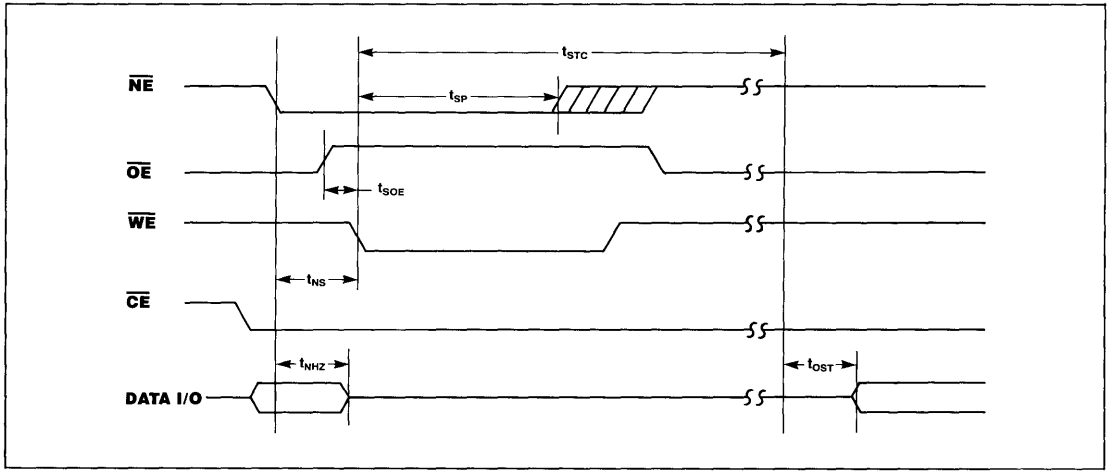


Store Cycle Limits

Symbol	Parameter	X2004-20 X2004I-20		X2004-25 X2004I-25		X2004 X2004I		Units
		Min.	Max.	Min.	Max.	Min.	Max.	
t_{STC}	Store Cycle Time		10		10		10	ms
t_{SP}[2]	Store Pulse Width	120		150		200		ns
t_{NHZ}	Nonvolatile Enable to Output in High Z		100		100		100	ns
t_{OST}	Output Active from End of Store	10		10		10		ns
t_{SOE}	$\overline{OE}$ Disable to STORE Function	20		20		20		ns
t_{NS}	$\overline{NE}$ Setup Time from $\overline{WE}$	0		0		0		ns

Note: (2) Once t_{SP} has been satisfied by ($\overline{NE}$, $\overline{OE}$, $\overline{WE}$, $\overline{CE}$) the store cycle is completed automatically, while ignoring all inputs.

Store Cycle

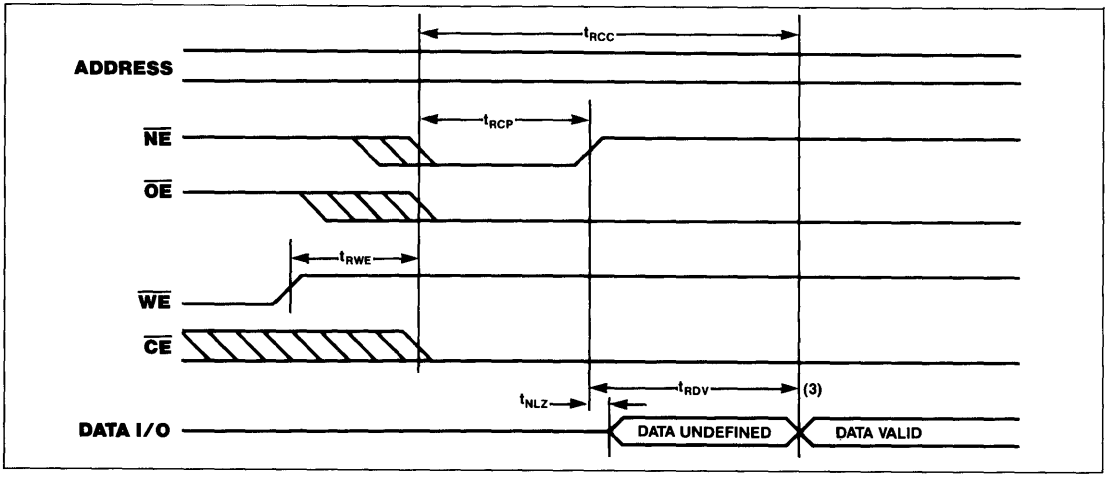


Array Recall Cycle Limits

Symbol	Parameter	X2004-20 X2004I-20		X2004-25 X2004I-25		X2004 X2004I		Units
		Min.	Max.	Min.	Max.	Min.	Max.	
t_{RCC}	Array Recall Cycle Time		5.0		5.0		5.0	µs
t_{RCP}(3)	Recall Pulse Width to Initiate Recall	120		150		200		ns
t_{NLZ}	Recall to Output in Low Z	0		0		0		ns
t_{RWE}	$\overline{WE}$ Setup Time to $\overline{NE}$	0		0		0		ns
t_{RDV}(3)	Recall to Data Valid	0.1	4.9	0.1	4.9	0.1	4.9	µs

Note: (3) The X2004 features internal control of the Recall Cycle time. t_{RCP} is the minimum input pulse width required to initiate a recall. Once initiated the Recall Cycle will have a completion time of t_{RDV} which varies. As t_{RCP} is increased above its minimum value, the cycle time t_{RCC} remains constant and t_{RDV} is reduced accordingly until reaching its minimum value. If t_{RCP} is increased further, t_{RDV} remains constant and the entire cycle time will increase.

Array Recall Cycle



PIN DESCRIPTIONS

Addresses (A_0–A_8)

The address inputs select an 8-bit word during a read or write operation.

Chip Enable ($\overline{CE}$)

The Chip Enable input must be LOW to enable all read/write operations. When $\overline{CE}$ is HIGH, power consumption is reduced.

Output Enable ($\overline{OE}$)

The Output Enable input controls the data output buffers and is used to initiate read and recall operations. Output Enable LOW disables a store operation regardless of the state of $\overline{CE}$, $\overline{WE}$ or $\overline{NE}$.

Data In/Data Out (I/O_0–I/O_7)

Data is written to or read from the X2004 through the I/O pins. The I/O pins are placed in the high impedance state when either $\overline{CE}$ or $\overline{OE}$ is HIGH or when $\overline{NE}$ is LOW.

Write Enable ($\overline{WE}$)

The Write Enable input controls the writing of data to both the static RAM and stores to the E^2PROM.

Nonvolatile Enable ($\overline{NE}$)

The Nonvolatile Enable input controls all accesses to the E^2PROM array (store and recall functions).

DEVICE OPERATION

The $\overline{CE}$, $\overline{OE}$, $\overline{WE}$ and $\overline{NE}$ inputs control the X2004 operation. The X2004 byte-wide NOVRAM uses a 2-line control architecture to eliminate bus contention in a system environment. The I/O bus will be in a high impedance state when either $\overline{OE}$ or $\overline{CE}$ is HIGH, or when $\overline{NE}$ is LOW.

RAM OPERATIONS

RAM read and write operations are performed as they would be with any static RAM. A read operation requires $\overline{CE}$ and $\overline{OE}$ to be LOW with $\overline{WE}$ and $\overline{NE}$ HIGH. A write operation requires $\overline{CE}$ and $\overline{WE}$ to be LOW with $\overline{NE}$ HIGH. There is no limit to the number of read or write operations performed to the RAM portion of the X2004.

NONVOLATILE OPERATIONS

With $\overline{NE}$ LOW, recall and store operations are performed in the same manner as RAM read and write operations. A recall operation causes the entire contents of the E^2PROM to be written into the RAM array. The time required for the operation to complete is 5μs or less. A store operation causes the entire contents of the RAM array to be stored in the nonvolatile E^2PROM. The time for the operation to complete is 10ms or less, typically 5ms.

POWER-UP RECALL

Upon power-up (V_{CC}), the X2004 performs an automatic array recall. When V_{CC} minimum is reached, the recall is initiated, regardless of the state of $\overline{CE}$, $\overline{OE}$, $\overline{WE}$ and $\overline{NE}$.

WRITE PROTECTION

The X2004 has four write protect features that are employed to protect the contents of both the nonvolatile memory and the RAM.

- Noise Protection—A $\overline{WE}$ pulse of less than 20ns will *not* initiate a write cycle.
- Combined Signal Noise Protection—A combined $\overline{WE}$ and $\overline{NE}$ ($\overline{WE} \cdot \overline{NE}$) pulse of less than 20ns will *not* initiate a store cycle.
- V_{CC} Sense—All functions are inhibited when V_{CC} is $\leq$ 3v, typically.
- Write Inhibit—Holding either $\overline{OE}$ LOW, $\overline{WE}$ HIGH, $\overline{CE}$ HIGH or $\overline{NE}$ HIGH during power-up or power-down, will prevent an inadvertent store operation.

ENDURANCE

The endurance specification of a device is characterized by the predicted *first* bit failure to occur in the entire memory (device or system) array rather than the average or typical value for the array. Since endurance is limited by the number of electrons trapped in the oxide during data changes, Xicor NOVRAMs are designed to minimize the number of changes an E^2PROM bit cell undergoes during store operations. Only those bits in the E^2PROM that are different from their corresponding location in the RAM will be "cycled" during a nonvolatile store. This characteristic reduces unnecessary cycling of any of the rest of the bits in the array, thereby increasing the potential endurance of each bit and increasing the potential endurance of the entire array. Reliability data documented in RR504, the *Xicor Reliability Report on Endurance,* and additional reports are available from Xicor.

Part Number	Store Cycles	Data Changes Per Bit
X2004	100,000	10,000
X2004I	100,000	10,000

NOTES

4K Military X2004M 512 x 8 Bit

Nonvolatile Static RAM

FEATURES

- **Nonvolatile Data Integrity**
- **Automatic Store Timing**
- **Store and Array Recall Combined on One Line ($\overline{NE}$)**
- **Enhanced Store Protection**
- **Infinite E^2PROM Array Recall, and RAM Read and Write Cycles**
- **Single 5V Supply**
- **100 Year Data Retention**
- **JEDEC Approved Pinout for Byte-Wide Memories**
- **Fast Access Time: 250ns Max.**
- **Automatic Recall on Power-Up**

DESCRIPTION

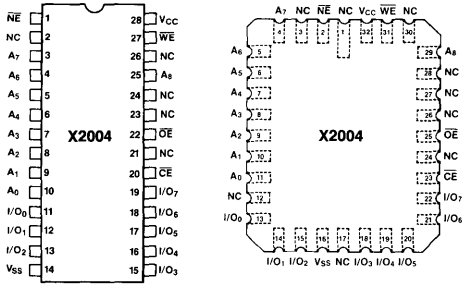
The Xicor X2004 is a byte-wide NOVRAM* featuring a high-speed static RAM overlaid bit-for-bit with a nonvolatile electrically erasable PROM (E^2PROM). The X2004 is fabricated with the same reliable N-channel floating gate MOS technology used in all Xicor 5 volt programmable nonvolatile memories. The X2004 features the JEDEC approved pinout for byte-wide memories, compatible with industry standard RAMs, ROMs, EPROMs and E^2PROMs.

The NOVRAM design allows data to be easily transferred from RAM to E^2PROM (store) and E^2PROM to RAM (recall). With $\overline{NE}$ LOW, these functions are performed in the same manner as RAM read and write operations. The store operation is completed in 10ms or less and the recall operation is completed in 5μs or less.

Xicor NOVRAMs are designed for unlimited write operations to RAM, either from the host or recalls from E^2PROM, and a minimum 100,000 store operations to the E^2PROM. Data retention is specified to be greater than 100 years.

*NOVRAM is Xicor's nonvolatile static RAM device.

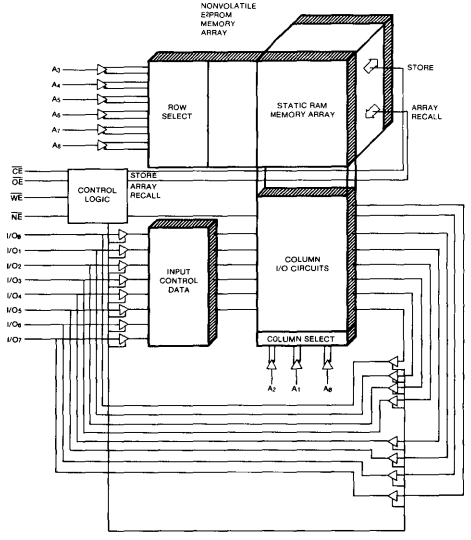
PIN CONFIGURATIONS



PIN NAMES

A_0–A_8	Address Inputs
I/O_0–I/O_7	Data Inputs/Outputs
$\overline{CE}$	Chip Enable
$\overline{OE}$	Output Enable
$\overline{WE}$	Write Enable
$\overline{NE}$	Nonvolatile Enable
V_{CC}	+5V
V_{SS}	Ground
NC	No Connect

FUNCTIONAL DIAGRAM



ABSOLUTE MAXIMUM RATINGS*

Temperature Under Bias ..... −65°C to +135°C
Storage Temperature ..... −65°C to +150°C
Voltage on any Pin with
Respect to Ground ..... −1.0V to +7V
D.C. Output Current ..... 5 mA
Lead Temperature (Soldering,
10 Seconds) ..... 300°C

*COMMENT

Stresses above those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. This is a stress rating only and the functional operation of the device at these or any other conditions above those indicated in the operational sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

D.C. OPERATING CHARACTERISTICS

T_A = −55°C to +125°C, V_{CC} = +5V ±10%, unless otherwise specified.

Symbol	Parameter	Limits		Units	Test Conditions
		Min.	Max.		
I_{CC}	V_{CC} Current (Active)		120	mA	$\overline{CE}$ = V_{IL}, All Other Inputs = V_{CC} $I_{I/O}$ = 0 mA
I_{SB}	V_{CC} Current (Standby)		90	mA	All Inputs = V_{CC} $I_{I/O}$ = 0 mA
I_{LI}	Input Leakage Current		10	µA	V_{IN} = GND to V_{CC}
I_{LO}	Output Leakage Current		10	µA	V_{OUT} = GND to V_{CC}
V_{IL}	Input Low Voltage	−1.0	0.8	V	
V_{IH}	Input High Voltage	2.0	V_{CC} +1.0	V	
V_{OL}	Output Low Voltage		0.4	V	I_{OL} = 2.1 mA
V_{OH}	Output High Voltage	2.4		V	I_{OH} = −400 µA

CAPACITANCE T_A = 25°C, f = 1.0 MHz, V_{CC} = 5V

Symbol	Test	Max.	Unit	Conditions
$C_{I/O}$[1]	Input/Output Capacitance	10	pF	$V_{I/O}$ = 0V
C_{IN}[1]	Input Capacitance	6	pF	V_{IN} = 0V

Note: (1) This parameter is periodically sampled and not 100% tested.

A.C. CONDITIONS OF TEST

Input Pulse Levels	0 to 3.0 Volts
Input Rise and Fall Times	10 nsec
Input and Output Timing Levels	1.5 Volts
Output Load	1 TTL Gate and C_L = 100 pF

MODE SELECTION

$\overline{CE}$	$\overline{WE}$	$\overline{NE}$	$\overline{OE}$	Mode	I/O	Power
H	X	X	X	Not Selected	Output High Z	Standby
L	H	H	L	Read RAM	Output Data	Active
L	L	H	X	Write "1" RAM	Input Data High	Active
L	L	H	X	Write "0" RAM	Input Data Low	Active
L	H	L	L	Array Recall	Output High Z	Active
L	L	L	H	Nonvolatile Storing	Output High Z	Active
L	H	H	H	Output Disabled	Output High Z	Active
L	L	L	L	No Operation	Output High Z	Active
L	H	L	H	No Operation	Output High Z	Active

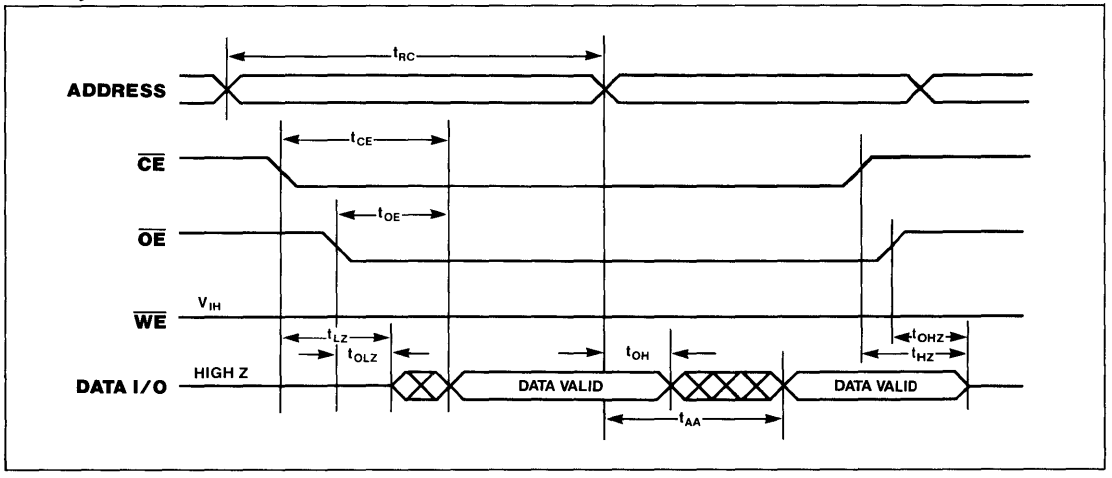
A.C. CHARACTERISTICS

T_A = −55°C to +125°C, V_{CC} = +5V ±10%, unless otherwise specified.

Read Cycle Limits

Symbol	Parameter	X2004M-25		X2004M		Units
		Min.	Max.	Min.	Max.	
t_{RC}	Read Cycle Time	250		300		ns
t_{CE}	Chip Enable Access Time		250		300	ns
t_{AA}	Address Access Time		250		300	ns
t_{OE}	Output Enable Access Time		100		150	ns
t_{LZ}	Chip Enable to Output in Low Z	10		10		ns
t_{HZ}	Chip Disable to Output in High Z	10	100	10	100	ns
t_{OLZ}	Output Enable to Output in Low Z	10		10		ns
t_{OHZ}	Output Disable to Output in High Z	10	100	10	100	ns
t_{OH}	Output Hold from Address Change	0		0		ns

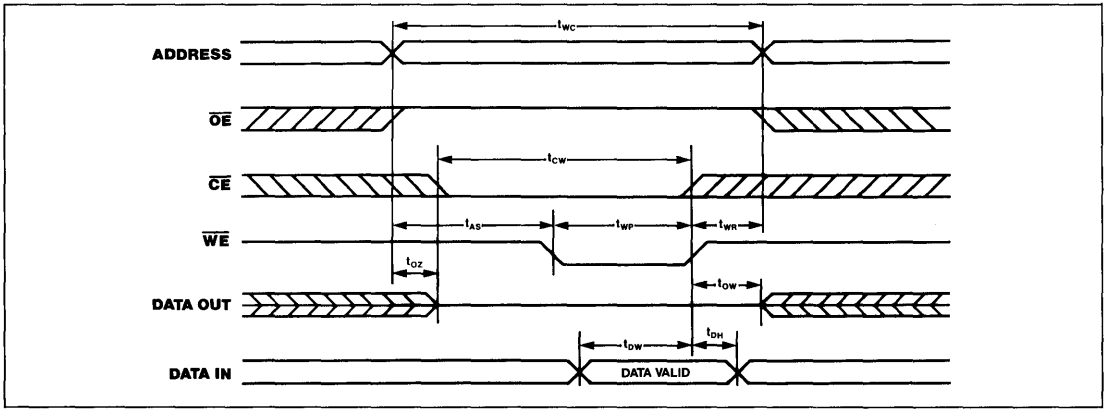
Read Cycle



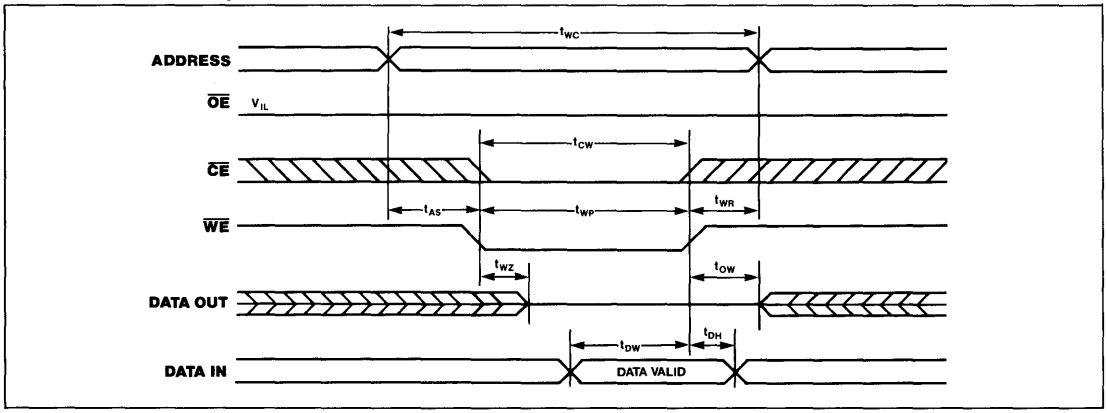
Write Cycle Limits

Symbol	Parameter	X2004M-25		X2004M		Units
		Min.	Max.	Min.	Max.	
t_{WC}	Write Cycle Time	250		300		ns
t_{CW}	Chip Enable to End of Write Input	250		300		ns
t_{AS}	Address Set-Up Time	0		0		ns
t_{WP}	Write Pulse Width	150		200		ns
t_{WR}	Write Recovery Time	0		0		ns
t_{DW}	Data Valid to End of Write	150		200		ns
t_{DH}	Data Hold Time	0		0		ns
t_{WZ}	Write Enable to Output in High Z	10	100	10	100	ns
t_{OW}	Output Active from End of Write	10		10		ns
t_{OZ}	Output Enable to Output in High Z	10	100	10	100	ns

$\overline{WE}$ Controlled Write Cycle



$\overline{CE}$ Controlled Write Cycle

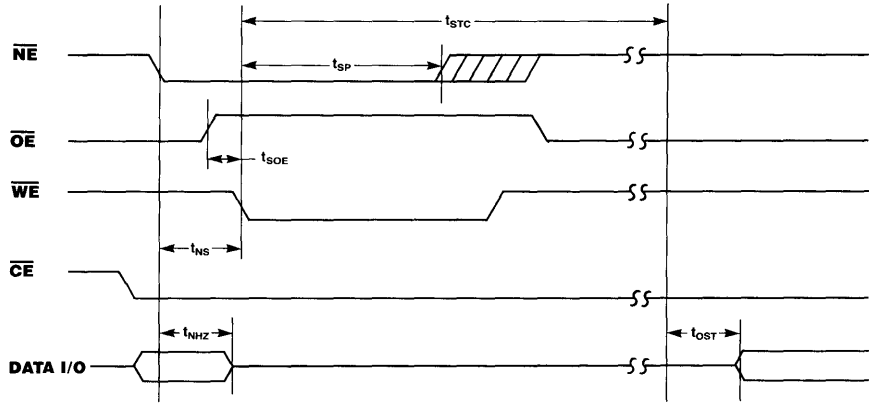


Store Cycle Limits

Symbol	Parameter	X2004M-25		X2004M		Units
		Min.	Max.	Min.	Max.	
t_{STC}	Store Cycle Time		10		10	ms
t_{SP}(2)	Store Pulse Width	150		200		ns
t_{NHZ}	Nonvolatile Enable to Output in High Z		100		100	ns
t_{OST}	Output Active from End of Store	10		10		ns
t_{SOE}	$\overline{OE}$ Disable to STORE Function	20		20		ns
t_{NS}	$\overline{NE}$ Setup Time from $\overline{WE}$	0		0		ns

Note: (2) Once t_{SP} has been satisfied by ($\overline{NE}$, $\overline{OE}$, $\overline{WE}$, $\overline{CE}$) the store cycle is completed automatically, while ignoring all inputs.

Store Cycle

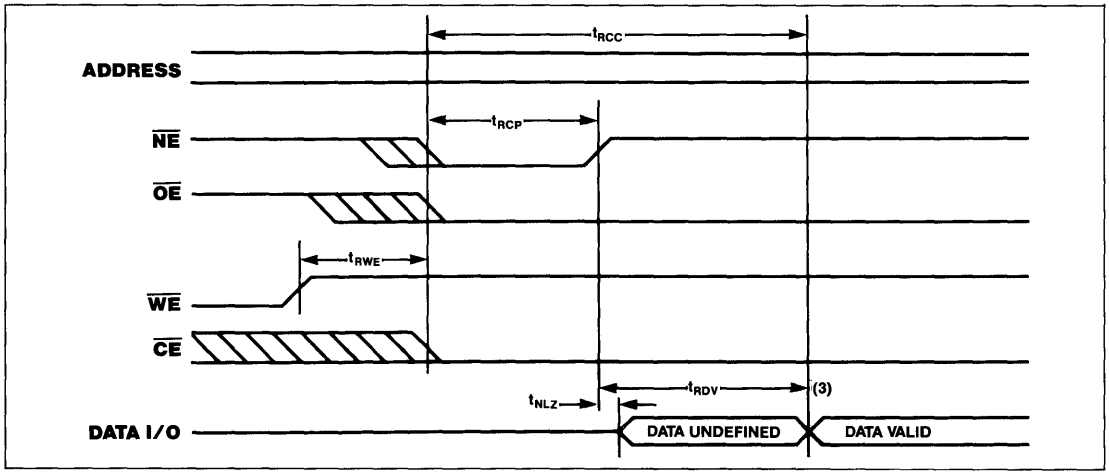


Array Recall Cycle Limits

Symbol	Parameter	X2004M-25		X2004M		Units
		Min.	Max.	Min.	Max.	
t_{RCC}	Array Recall Cycle Time		5.0		5.0	µs
t_{RCP}(3)	Recall Pulse Width to Initiate Recall	150		200		ns
t_{NLZ}	Recall to Output in Low Z	0		0		ns
t_{RWE}	$\overline{WE}$ Setup Time to $\overline{NE}$	0		0		ns
t_{RDV}(3)	Recall to Data Valid	0.1	4.9	0.1	4.9	µs

Note: (3) The X2004 features internal control of the Recall Cycle time. t_{RCP} is the minimum input pulse width required to initiate a recall. Once initiated the Recall Cycle will have a completion time of t_{RDV} which varies. As t_{RCP} is increased above its minimum value, the cycle time t_{RCC} remains constant and t_{RDV} is reduced accordingly until reaching its minimum value. If t_{RCP} is increased further, t_{RDV} remains constant and the entire cycle time will increase.

Array Recall Cycle



PIN DESCRIPTIONS

Addresses (A_0–A_8)

The address inputs select an 8-bit word during a read or write operation.

Chip Enable ($\overline{CE}$)

The Chip Enable input must be LOW to enable all read/write operations. When $\overline{CE}$ is HIGH, power consumption is reduced.

Output Enable ($\overline{OE}$)

The Output Enable input controls the data output buffers and is used to initiate read and recall operations. Output Enable LOW disables a store operation regardless of the state of $\overline{CE}$, $\overline{WE}$ or $\overline{NE}$.

Data In/Data Out (I/O_0–I/O_7)

Data is written to or read from the X2004 through the I/O pins. The I/O pins are placed in the high impedance state when either $\overline{CE}$ or $\overline{OE}$ is HIGH or when $\overline{NE}$ is LOW.

Write Enable ($\overline{WE}$)

The Write Enable input controls the writing of data to both the static RAM and stores to the E^2PROM.

Nonvolatile Enable ($\overline{NE}$)

The Nonvolatile Enable input controls all accesses to the E^2PROM array (store and recall functions).

DEVICE OPERATION

The $\overline{CE}$, $\overline{OE}$, $\overline{WE}$ and $\overline{NE}$ inputs control the X2004 operation. The X2004 byte-wide NOVRAM uses a 2-line control architecture to eliminate bus contention in a system environment. The I/O bus will be in a high impedance state when either $\overline{OE}$ or $\overline{CE}$ is HIGH, or when $\overline{NE}$ is LOW.

RAM OPERATIONS

RAM read and write operations are performed as they would be with any static RAM. A read operation requires $\overline{CE}$ and $\overline{OE}$ to be LOW with $\overline{WE}$ and $\overline{NE}$ HIGH. A write operation requires $\overline{CE}$ and $\overline{WE}$ to be LOW with $\overline{NE}$ HIGH. There is no limit to the number of read or write operations performed to the RAM portion of the X2004.

NONVOLATILE OPERATIONS

With $\overline{NE}$ LOW, recall and store operations are performed in the same manner as RAM read and write operations. A recall operation causes the entire contents of the E^2PROM to be written into the RAM array. The time required for the operation to complete is 5μs or less. A store operation causes the entire contents of the RAM array to be stored in the nonvolatile E^2PROM. The time for the operation to complete is 10ms or less, typically 5ms.

POWER-UP RECALL

Upon power-up (V_{CC}), the X2004 performs an automatic array recall. When V_{CC} minimum is reached, the recall is initiated, regardless of the state of $\overline{CE}$, $\overline{OE}$, $\overline{WE}$ and $\overline{NE}$.

WRITE PROTECTION

The X2004 has four write protect features that are employed to protect the contents of both the nonvolatile memory and the RAM.

- Noise Protection—A $\overline{WE}$ pulse of less than 20ns will *not* initiate a write cycle.
- Combined Signal Noise Protection—A combined $\overline{WE}$ and $\overline{NE}$ ($\overline{WE} \cdot \overline{NE}$) pulse of less than 20ns will *not* initiate a store cycle.
- V_{CC} Sense—All functions are inhibited when V_{CC} is $\leq$ 3v, typically.
- Write Inhibit—Holding either $\overline{OE}$ LOW, $\overline{WE}$ HIGH, $\overline{CE}$ HIGH or $\overline{NE}$ HIGH during power-up or power-down, will prevent an inadvertent store operation.

ENDURANCE

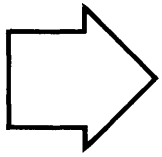
The endurance specification of a device is characterized by the predicted *first* bit failure to occur in the entire memory (device or system) array rather than the average or typical value for the array. Since endurance is limited by the number of electrons trapped in the oxide during data changes, Xicor NOVRAMs are designed to minimize the number of changes an E^2PROM bit cell undergoes during store operations. Only those bits in the E^2PROM that are different from their corresponding location in the RAM will be "cycled" during a nonvolatile store. This characteristic reduces unnecessary cycling of any of the rest of the bits in the array, thereby increasing the potential endurance of each bit and increasing the potential endurance of the entire array. Reliability data documented in RR504, the *Xicor Reliability Report on Endurance,* and additional reports are available from Xicor.

Part Number	Store Cycles	Data Changes Per Bit
X2004M	100,000	10,000

NOTES

Xicor

NOVRAM* Data Sheets 1



Serial I/O Data Sheets 2

X2444, X2444I 2-1
X2444M 2-9
X2404, X2404I 2-17
X2404M 2-27
X24C04 2-37
X24C16 2-45

Nonvolatile Static RAM

FEATURES

- **Low Cost 8-Pin Mini-Dip**
- **Ideal for use with Single Chip Microcomputers**
  - **— Static Timing**
  - **— Minimum I/O Interface**
  - **— Serial Port Compatible (COPS™, 8051)**
  - **— Easily Interfaces to Microcontroller Ports**
  - **— Minimum Support Circuits**
- **Software and Hardware Control of Nonvolatile Functions**
  - **— Maximum Store Protection**
- **TTL Compatible**
- **16 x 16 Organization**
- **Low Power Dissipation**
  - **— Active Current: 15mA Typ.**
  - **— Store Current: 8mA Typ.**
  - **— Standby Current: 6mA Typ.**
  - **— Sleep Current: 5mA Typ.**

DESCRIPTION

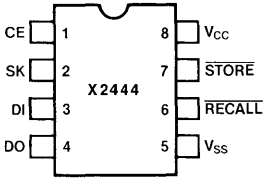
The Xicor X2444 is a serial 256 bit NOVRAM* featuring a static RAM configured 16 x 16, overlaid bit for bit with a nonvolatile E^2PROM array. The X2444 is fabricated with the same reliable N-channel floating gate MOS technology used in all Xicor 5 volt nonvolatile memories.

The Xicor NOVRAM design allows data to be transferred between the two memory arrays by means of software commands or external hardware inputs. A store operation (RAM data to E^2PROM) is completed in 10ms or less and a recall operation (E^2PROM data to RAM) is completed in 2.5μs or less.

Xicor NOVRAMs are designed for unlimited write operations to RAM, either from the host or recalls from E^2PROM and a minimum 100,000 store operations. Data retention is specified to be greater than 100 years.

*NOVRAM is Xicor's nonvolatile static RAM device.
COPS™ is a trademark of National Semiconductor Corp.

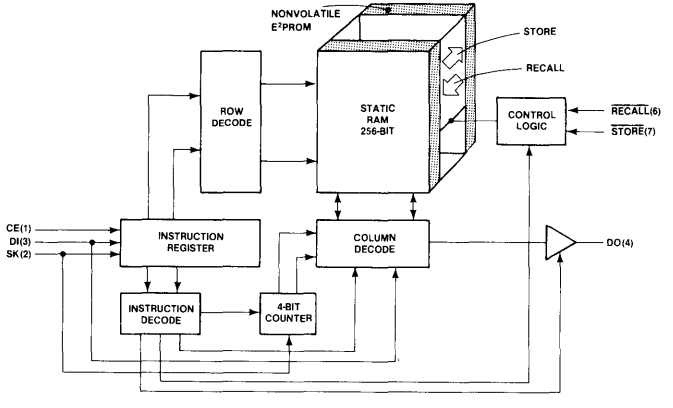
PIN CONFIGURATION



PIN NAMES

CE	Chip Enable
SK	Serial Clock
DI	Serial Data In
DO	Serial Data Out
$\overline{RECALL}$	Recall
$\overline{STORE}$	Store
V_{CC}	+5V
V_{SS}	Ground

FUNCTIONAL DIAGRAM



ABSOLUTE MAXIMUM RATINGS*

Temperature Under Bias X2444 ..... −10°C to +85°C
X2444I ..... −65°C to +135°C
Storage Temperature ..... −65°C to +150°C
Voltage on any Pin with
Respect to Ground ..... −1.0V to +7V
D.C. Output Current ..... 5 mA
Lead Temperature (Soldering,
10 Seconds) ..... 300°C

*COMMENT

Stresses above those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. This is a stress rating only and the functional operation of the device at these or any other conditions above those indicated in the operational sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

D.C. OPERATING CHARACTERISTICS

X2444 T_A = 0°C to +70°C, V_{CC} = +5V ±5%, unless otherwise specified.
X2444I T_A = −40°C to +85°C, V_{CC} = +5V ±10%, unless otherwise specified.

Symbol	Parameter	X2444 Limits		X2444I Limits		Units	Conditions
		Min.	Max.	Min.	Max.		
I_{CC}	Power Supply Current		15		25	mA	All Inputs=V_{CC}, $I_{I/O}$= 0 mA
I_{SL}	Sleep Current		7		10	mA	
I_{SB}	Standby Current		10		15	mA	CE=V_{IL}
I_{STO}	Store Current		12		15	mA	
I_{LI}	Input Load Current		10		10	µA	V_{IN} = V_{CC}
I_{LO}	Output Leakage Current		10		10	µA	V_{OUT} = V_{CC}
V_{IL}	Input Low Voltage	−1.0	0.8	−1.0	0.8	V	
V_{IH}	Input High Voltage	2.0	V_{CC} +0.5	2.0	V_{CC} +1.0	V	
V_{OL}	Output Low Voltage		0.4		0.4	V	I_{OL} = 2.4 mA
V_{OH}	Output High Voltage	2.4		2.4		V	I_{OH} = −0.8 mA

CAPACITANCE T_A = 25°C, f = 1.0 MHz, V_{CC} = 5V

Symbol	Test	Max.	Unit	Conditions
$C_{I/O}$[1]	Input/Output Capacitance	8	pF	$V_{I/O}$ = 0V
C_{IN}[1]	Input Capacitance	6	pF	V_{IN} = 0V

Note: (1) This parameter is periodically sampled and not 100% tested.

A.C. CONDITIONS OF TEST

Input Pulse Levels	0 to 3.0 Volts
Input Rise and Fall Times	10 nsec
Input and Output Timing Levels	1.5 Volts
Output Load	1 TTL Gate and C_L = 100 pF

NONVOLATILE OPERATIONS

Operation	$\overline{\text{STORE}}$	$\overline{\text{RECALL}}$	INST	WRITE ENABLE LATCH	Previous RECALL
Hardware Recall	1	0	NOP(2)	X	X
Software Recall	1	1	RCL	X	X
Hardware Store	0	1	NOP(2)	SET	True
Software Store	1	1	STO	SET	True

Note: (2) NOP designates when the X2444 is not currently executing an instruction.

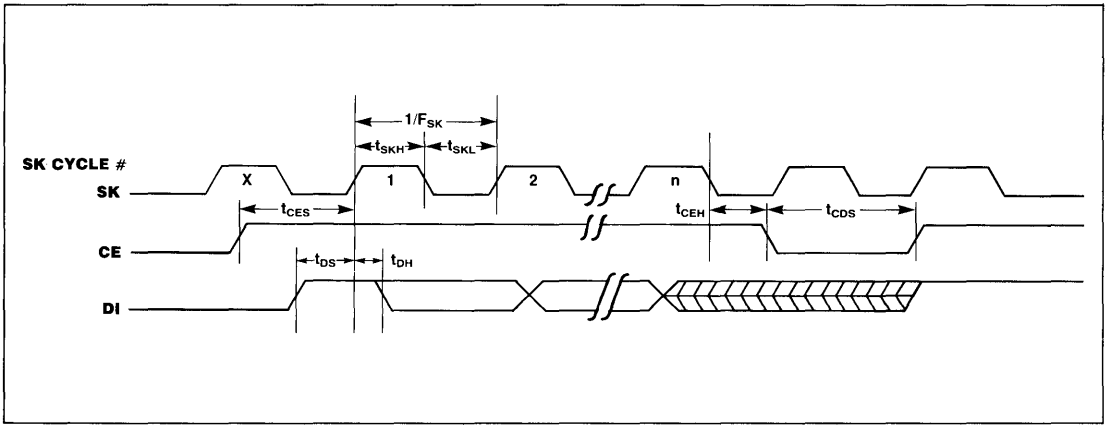
A.C. CHARACTERISTICS

X2444 T_A = 0°C to +70°C, V_{CC} = +5V ±5%, unless otherwise specified.
X2444I T_A = −40°C to +85°C, V_{CC} = +5V ±10%, unless otherwise specified.

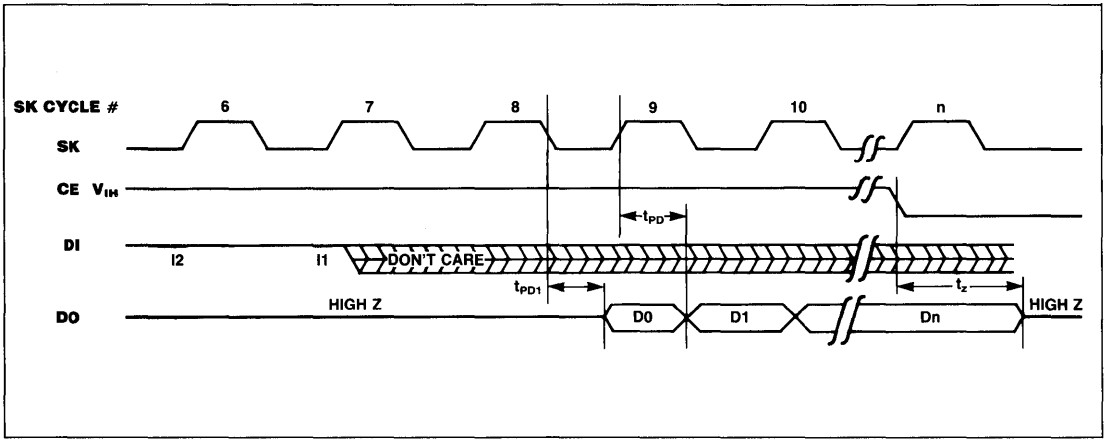
Read and Write Cycle Limits

Symbol	Parameter	Min.	Max.	Units
F_{SK}	SK Frequency		1.0	MHz
t_{SKH}	SK Positive Pulse Width	0.4		µs
t_{SKL}	SK Negative Pulse Width	0.4		µs
t_{DS}	Data Setup Time	0.4		µs
t_{DH}	Data Hold Time	0.08		µs
t_{PD1}	SK ↓ to Data 0 Valid		375	ns
t_{PD}	SK ↑ to Data Valid		375	ns
t_Z	Chip Enable to Output High Z		1.0	µs
t_{CES}	Chip Enable Setup	0.8		µs
t_{CEH}	Chip Enable Hold	0.4		µs
t_{CDS}	Chip De-select	0.8		µs

Write Cycle



Read Cycle

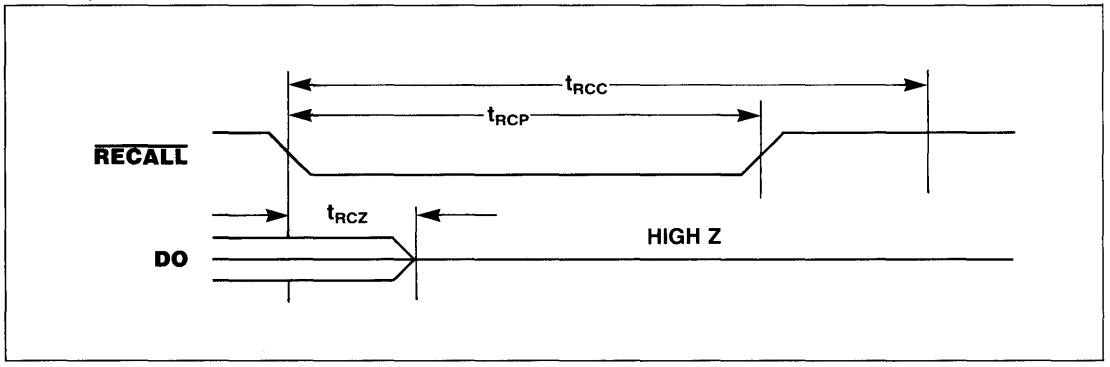


Array Recall Cycle Limits

Symbol	Parameter	Min.	Max.	Units
t_{RCC}	Recall Cycle Time	2.5		µs
t_{RCP}	Recall Pulse Width(3)	1.0		µs
t_{RCZ}	Recall to Output High Z		0.5	µs

Note: (3) Recall rise time must be <10µs.

Recall Cycle



Store Cycle Limits

Symbol	Parameter	Min.	Typ.(4)	Max.	Units
t_{ST}	Store Time		5	10	ms
t_{STP}	Store Pulse Width	0.2			µs
t_{STZ}	Store To Output High Z			1.0	µs
V_{CC}	Store Inhibit		3		V

Note: (4) Typical values are for T_A=25°C and nominal supply voltage.

Hardware Store

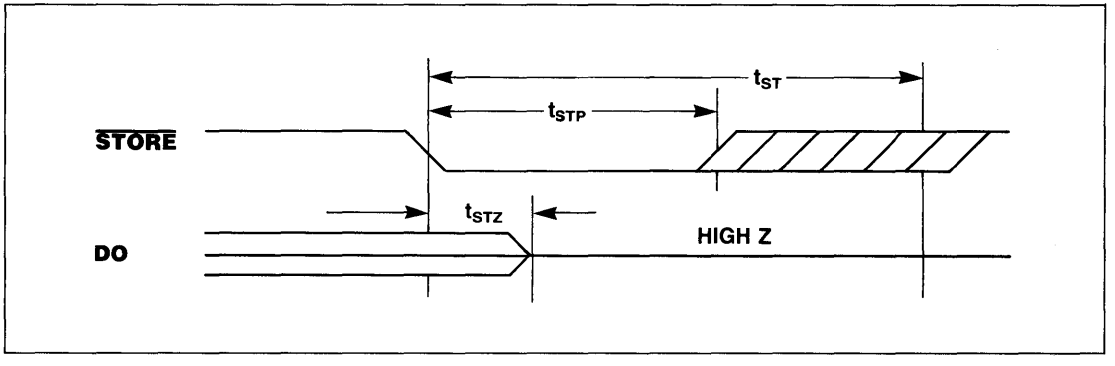


Figure 1: RAM Read

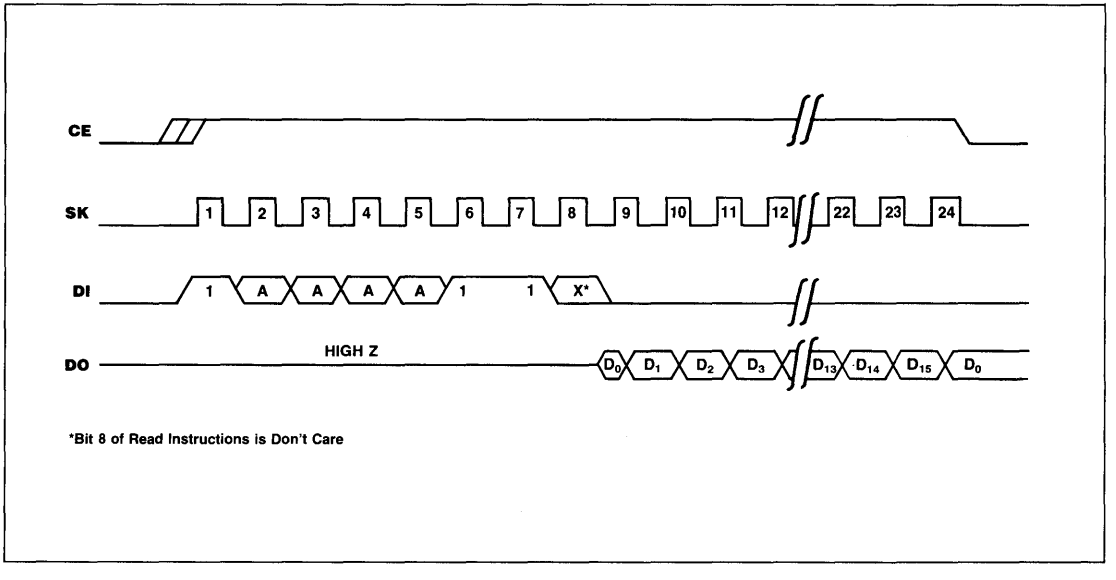


Figure 2: RAM Write

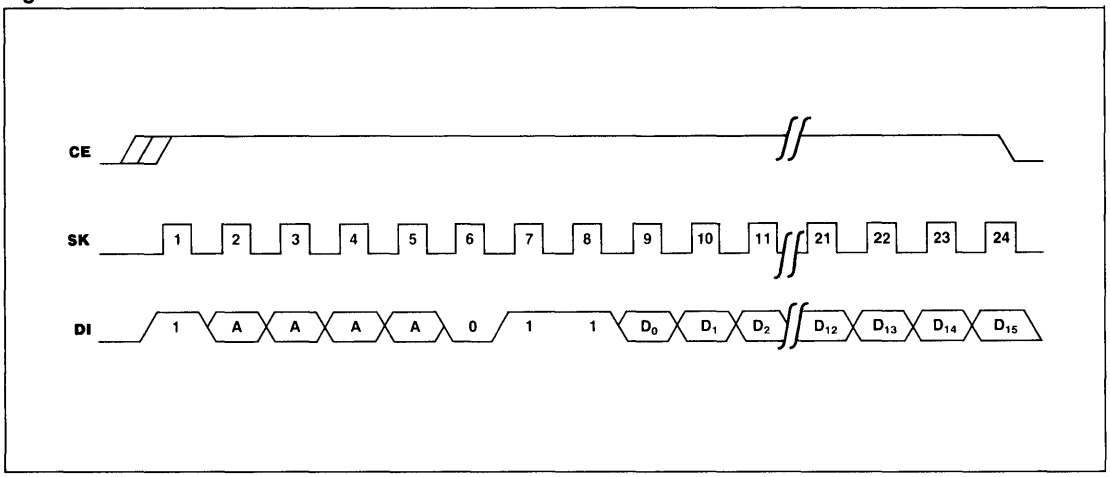


Figure 3: Non-Data Operations

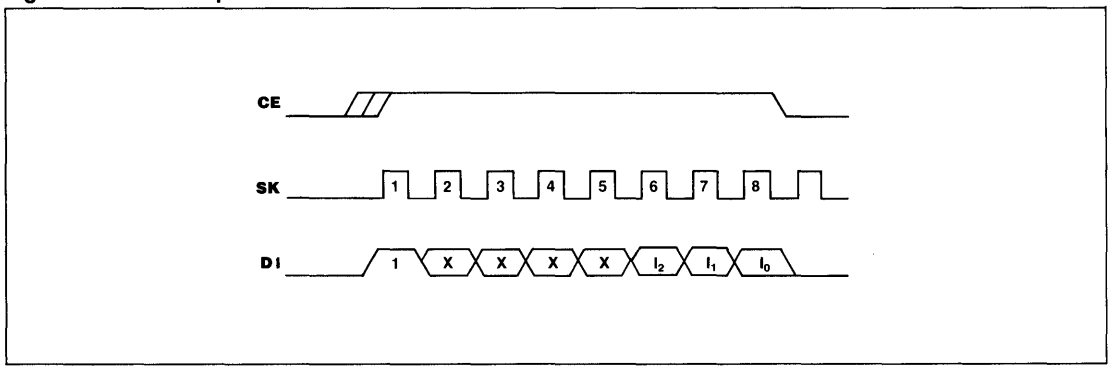


TABLE 1: INSTRUCTION SET

Instruction	Format, I_2 I_1 I_0	Operation
WRDS (Figure 3)	1XXXX000	Reset Write Enable Latch (Disables writes and stores)
STO (Figure 3)	1XXXX001	Store RAM data in E^2PROM
SLEEP (Figure 3)	1XXXX010	Enter SLEEP Mode
WRITE (Figure 2)	1AAAA011	Write Data into RAM Address AAAA
WREN (Figure 3)	1XXXX100	Set Write Enable Latch (Enables writes and stores)
RCL (Figure 3)	1XXXX101	Recall E^2PROM Data into RAM
READ (Figure 1)	1AAAA11X	Read Data from RAM Address AAAA

X=Don't Care
A=Address Bit

PIN DESCRIPTIONS

Chip Enable (CE)

The Chip Enable input must be HIGH to enable all read/write operations. CE LOW resets the instruction register and places the X2444 in the standby low power mode.

Serial Clock (SK)

The Serial Clock input is used to clock all data into and out of the device.

Data In (DI)

Data In is the serial data input.

Data Out (DO)

Data Out is the serial data output. It is in the high impedance state except during data output cycles in response to a READ instruction.

$\overline{\text{STORE}}$

$\overline{\text{STORE}}$ LOW will initiate an internal transfer of data from RAM to E^2PROM.

$\overline{\text{RECALL}}$

$\overline{\text{RECALL}}$ LOW will initiate an internal transfer of data from E^2PROM to RAM.

DEVICE OPERATION

The X2444 contains an 8-bit instruction register. It is accessed via the DI input, with data being clocked in on the rising edge of SK. CE must be HIGH during the entire data transfer operation.

Table 1 contains a list of the instructions and their operation codes. The most significant bit (MSB) of all instructions is a one, bits 6 through 3 are either RAM address (A) or don't care (X) and bits 2 through 0 are the operation codes. The X2444 requires the instruction to be shifted in with the MSB first.

After CE is HIGH, the X2444 will not begin to interpret the data stream until a one has been shifted in on DI. Therefore, CE may be brought HIGH with SK running and DI LOW. DI must then go HIGH to indicate the start condition of an instruction before the X2444 will begin any action.

In addition, the SK clock is totally static. The user can completely stop the clock and data shifting will be stopped. Restarting the clock will resume shifting of data.

WRDS and WREN

Internally the X2444 contains a "write enable" latch. This latch must be set for either writes to the RAM or store operations to the E^2PROM. The WREN instruction sets the latch and the WRDS instruction resets the latch, disabling *both* RAM writes and E^2PROM stores. The write enable latch is automatically reset on power-up.

SLEEP

The SLEEP instruction removes power from the RAM, placing the X2444 in a very low power quiescent state. Data in the RAM is lost once a SLEEP instruction is issued; however, data from the last store operation is retained in the E^2PROM. The sleep mode can be exited by either a software or hardware recall operation.

RCL and $\overline{\text{RECALL}}$

Either the RCL instruction or a LOW on the $\overline{\text{RECALL}}$ input will initiate a transfer of E^2PROM data into RAM. A recall operation must be performed after a power-up before any store or RAM write operation can be enabled. This recall operation and the recall recovery from the sleep mode guarantees a known state of data in RAM. Both recall operations set an internal "previous recall" latch which must be set to enable any write or store operations.

STO and $\overline{\text{STORE}}$

Either the STO instruction or a LOW on the $\overline{\text{STORE}}$ input will initiate the transfer of data from RAM to E^2PROM. In order to safeguard against unwanted store operations, the following conditions must be true:

1. STO instruction issued or $\overline{\text{STORE}}$ input is LOW;
2. The internal write enable latch must be set (WREN instruction issued);
3. The "previous recall" latch must be set.

Once the store cycle is initiated, all other device functions are inhibited. Upon completion of the store cycle, the write enable latch is reset.

WRITE

The write instruction contains the 4 bit address of the word to be written. The write instruction is immediately followed by the 16-bit word to be written. CE must remain HIGH during the entire operation. If CE is brought LOW prematurely (after the instruction but before 16 bits of data are transferred), the instruction register will be reset and the data that was shifted in will be written to RAM. If CE is kept HIGH for more than 24 SK clock cycles (8-bit instruction plus 16-bit data) the data already shifted in will be overwritten.

READ

The read instruction contains the 4 bit address of the word to be accessed. Unlike the other six instructions, I_0 is a "don't care" for the read instruction. This provides two advantages. In a design that ties both DI and DO together, the absence of an eighth bit in the instruction allows the host time to convert an I/O line from an output to an input. Secondly, it allows for valid data output during the ninth SK clock cycle.

DO, the first bit output during a read operation, is truncated. That is, it is internally clocked by the falling edge of the eighth SK clock; whereas, all succeeding bits are clocked by the rising edge of SK (refer to Read Cycle Diagram).

WRITE PROTECTION

The X2444 provides four hardware and software write protection mechanisms to prevent inadvertent stores of unknown data.

Power-down Condition

(when "write enable" latch and "previous recall" latch are not in the reset state):

- V_{CC} Sense—All functions are inhibited when V_{CC} is ≤3v, typically.
- Write Inhibit—Holding either $\overline{\text{RECALL}}$ LOW, CE LOW or $\overline{\text{STORE}}$ HIGH during power-down will prevent an inadvertent store.

Power-up Condition

- Write Enable Latch—Upon power-up the "write enable" latch is in the reset state, disabling any store operation.

Unknown Data Store

- Previous Recall Latch—The "previous recall" latch must be reset after power-up and after exiting the sleep mode. It may be reset only by performing a recall operation, which assures that data in all RAM locations is valid.

LOW POWER MODES

The X2444 provides two power conservation modes. When CE is LOW, non-critical internal devices are powered-down, placing the device in the standby power mode. Entering the sleep mode removes power from the entire RAM array, placing the device in a very low power quiescent state (sleep mode).

ENDURANCE

The endurance specification of a device is characterized by the predicted *first* bit failure to occur in the entire memory (device or system) array rather than the average or *typical* value for the array. Since endurance is limited by the number of electrons trapped in the oxide by data changes, Xicor NOVRAMs are designed to minimize the number of changes an E^2PROM bit cell undergoes during store operations. Only those bits in the E^2PROM that are different from their corresponding location in RAM will be "cycled" during a nonvolatile store. This characteristic reduces unnecessary cycling of any of the rest of the bits in the array, thereby increasing the potential endurance of each bit and increasing the potential endurance of the entire array. Reliability data documented in RR504, the *Xicor Reliability Report on Endurance*, and additional reports are available from Xicor.

Part Number	Store Cycles	Data Changes Per Bit
X2444	100,000	1,000
X2444/10	100,000	10,000

PRELIMINARY

256 Bit Military X2444M 16 x 16 Bit

Nonvolatile Static RAM

FEATURES

- **Low Cost 8-Pin Mini-Dip**
- **Ideal for use with Single Chip Microcomputers**
  - **— Static Timing**
  - **— Minimum I/O Interface**
  - **— Serial Port Compatible (COPS™, 8051)**
  - **— Easily Interfaces to Microcontroller Ports**
  - **— Minimum Support Circuits**
- **Software and Hardware Control of Nonvolatile Functions**
  - **— Maximum Store Protection**
- **TTL Compatible**
- **16 x 16 Organization**
- **Low Power Dissipation**
  - **— Active Current: 25mA Typ.**
  - **— Store Current: 15mA Typ.**
  - **— Standby Current: 15mA Typ.**
  - **— Sleep Current: 10mA Typ.**

DESCRIPTION

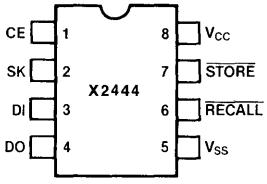
The Xicor X2444 is a serial 256 bit NOVRAM* featuring a static RAM configured 16 x 16, overlaid bit for bit with a nonvolatile E^2PROM array. The X2444 is fabricated with the same reliable N-channel floating gate MOS technology used in all Xicor 5 volt nonvolatile memories.

The Xicor NOVRAM design allows data to be transferred between the two memory arrays by means of software commands or external hardware inputs. A store operation (RAM data to E^2PROM) is completed in 10ms or less and a recall operation (E^2PROM data to RAM) is completed in 2.5μs or less.

Xicor NOVRAMs are designed for unlimited write operations to RAM, either from the host or recalls from E^2PROM and a minimum 100,000 store operations. Data retention is specified to be greater than 100 years.

*NOVRAM is Xicor's nonvolatile static RAM device.
COPS™ is a trademark of National Semiconductor Corp.

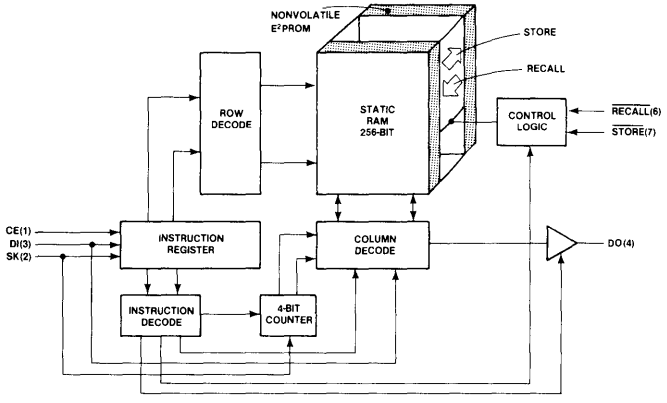
PIN CONFIGURATION



PIN NAMES

CE	Chip Enable
SK	Serial Clock
DI	Serial Data In
DO	Serial Data Out
$\overline{RECALL}$	Recall
$\overline{STORE}$	Store
V_{CC}	+5V
V_{SS}	Ground

FUNCTIONAL DIAGRAM



ABSOLUTE MAXIMUM RATINGS*

Temperature Under Bias ..... −65°C to +135°C
Storage Temperature ..... −65°C to +150°C
Voltage on any Pin with
Respect to Ground ..... −1.0V to +7V
D.C. Output Current ..... 5 mA
Lead Temperature (Soldering,
10 Seconds) ..... 300°C

*COMMENT

Stresses above those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. This is a stress rating only and the functional operation of the device at these or any other conditions above those indicated in the operational sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

D.C. OPERATING CHARACTERISTICS

T_A = −55°C to +125°C, V_{CC} = +5V ±10%, unless otherwise specified.

Symbol	Parameter	Limits		Units	Conditions
		Min.	Max.		
I_{CC}	Power Supply Current		25	mA	All Inputs=V_{CC}, $I_{I/O}$= 0 mA
I_{SL}	Sleep Current		10	mA	
I_{SB}	Standby Current		15	mA	CE=V_{IL}
I_{STO}	Store Current		15	mA	
I_{LI}	Input Load Current		10	µA	V_{IN} = V_{CC}
I_{LO}	Output Leakage Current		10	µA	V_{OUT} = V_{CC}
V_{IL}	Input Low Voltage	−1.0	0.8	V	
V_{IH}	Input High Voltage	2.0	V_{CC} +1.0	V	
V_{OL}	Output Low Voltage		0.4	V	I_{OL} = 2.0 mA
V_{OH}	Output High Voltage	2.4		V	I_{OH} = −0.8 mA

CAPACITANCE T_A = 25°C, f = 1.0 MHz, V_{CC} = 5V

Symbol	Test	Max.	Unit	Conditions
$C_{I/O}$[1]	Input/Output Capacitance	8	pF	$V_{I/O}$ = 0V
C_{IN}[1]	Input Capacitance	6	pF	V_{IN} = 0V

Note: (1) This parameter is periodically sampled and not 100% tested.

A.C. CONDITIONS OF TEST

Input Pulse Levels	0 to 3.0 Volts
Input Rise and Fall Times	10 nsec
Input and Output Timing Levels	1.5 Volts
Output Load	1 TTL Gate and C_L = 100 pF

NONVOLATILE OPERATIONS

Operation	$\overline{\text{STORE}}$	$\overline{\text{RECALL}}$	INST	WRITE ENABLE LATCH	Previous RECALL
Hardware Recall	1	0	NOP(2)	X	X
Software Recall	1	1	RCL	X	X
Hardware Store	0	1	NOP(2)	SET	True
Software Store	1	1	STO	SET	True

Note: (2) NOP designates when the X2444 is not currently executing an instruction.

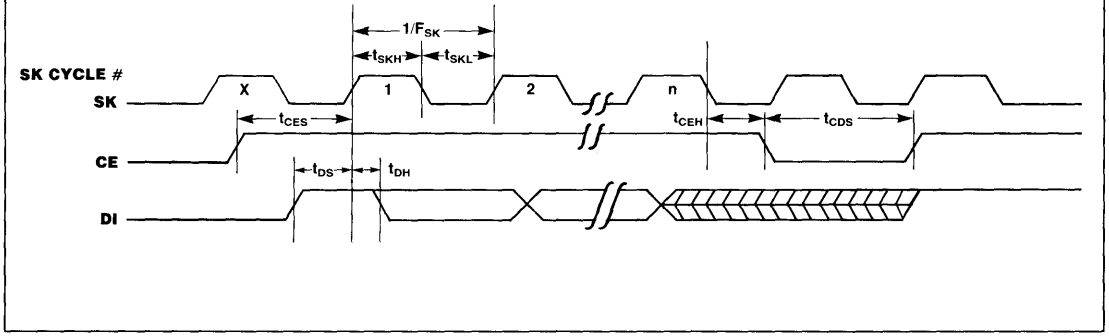
A.C. CHARACTERISTICS

T_A = −55°C to +125°C, V_{CC} = +5V ±10%, unless otherwise specified.

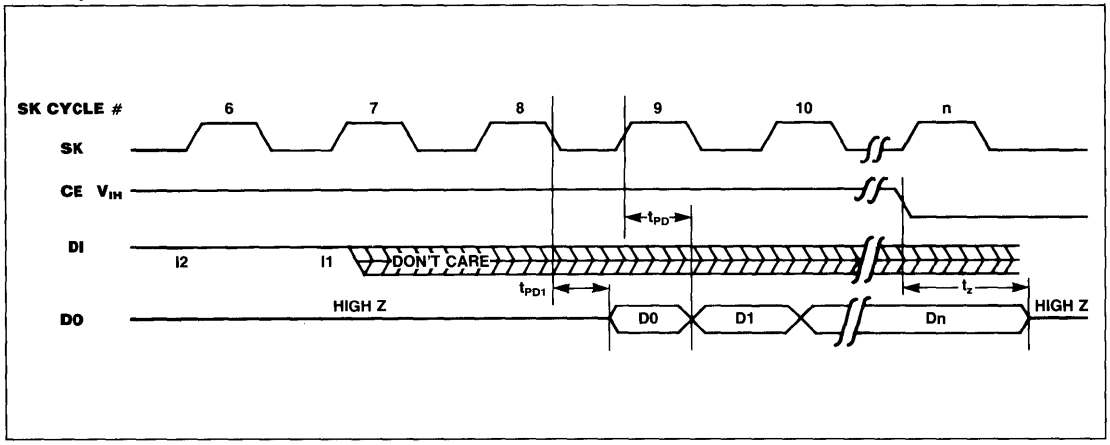
Read and Write Cycle Limits

Symbol	Parameter	Min.	Max.	Units
F_{SK}	SK Frequency		1.0	MHz
t_{SKH}	SK Positive Pulse Width	0.4		µs
t_{SKL}	SK Negative Pulse Width	0.4		µs
t_{DS}	Data Setup Time	0.4		µs
t_{DH}	Data Hold Time	0.08		µs
t_{PD1}	SK ↓ to Data 0 Valid		375	ns
t_{PD}	SK ↑ to Data Valid		375	ns
t_Z	Chip Enable to Output High Z		1.0	µs
t_{CES}	Chip Enable Setup	0.8		µs
t_{CEH}	Chip Enable Hold	0.4		µs
t_{CDS}	Chip De-select	0.8		µs

Write Cycle



Read Cycle

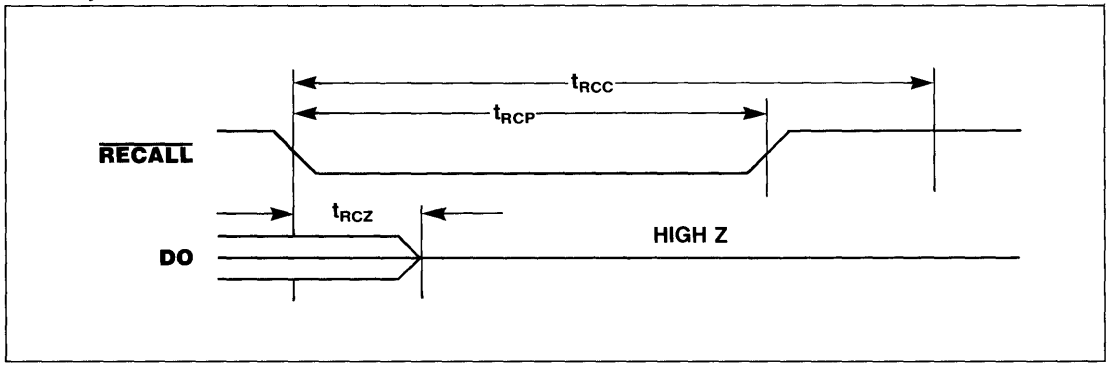


Array Recall Cycle Limits

Symbol	Parameter	Min.	Max.	Units
t_{RCC}	Recall Cycle Time	2.5		µs
t_{RCP}	Recall Pulse Width(3)	1.0		µs
t_{RCZ}	Recall to Output High Z		0.5	µs

Note: (3) Recall rise time must be <10µs.

Recall Cycle



Store Cycle Limits

Symbol	Parameter	Min.	Typ.(4)	Max.	Units
t_{ST}	Store Time		5	10	ms
t_{STP}	Store Pulse Width	0.2			µs
t_{STZ}	Store To Output High Z			1.0	µs
V_{CC}	Store Inhibit		3		V

Note: (4) Typical values are for T_A=25°C and nominal supply voltage.

Hardware Store

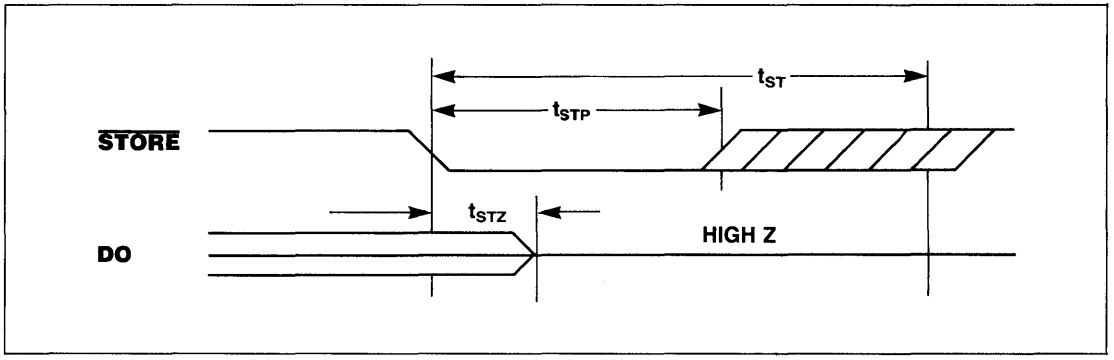


Figure 1: RAM Read

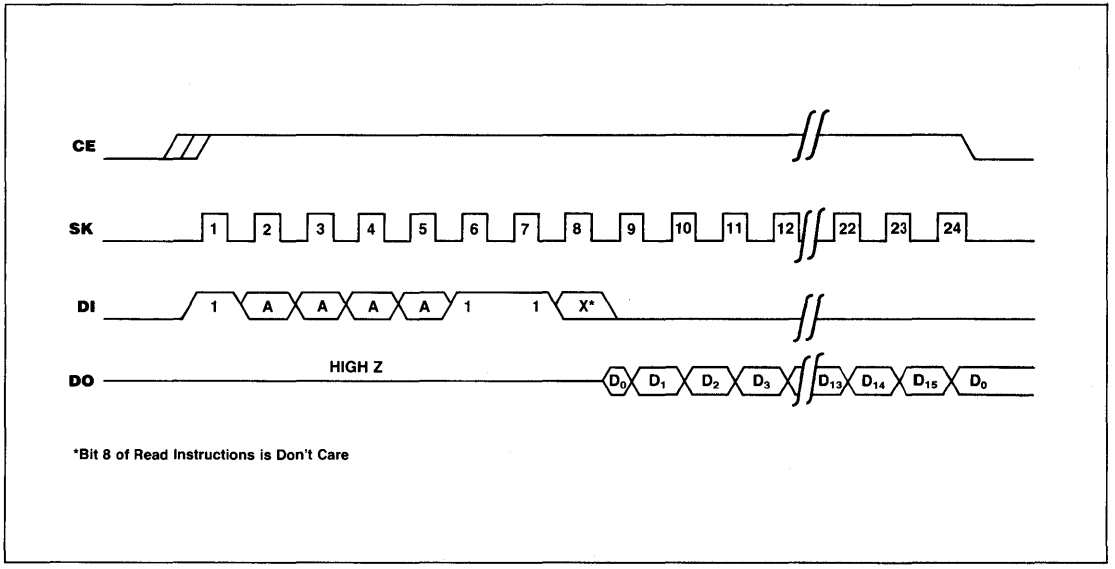


Figure 2: RAM Write

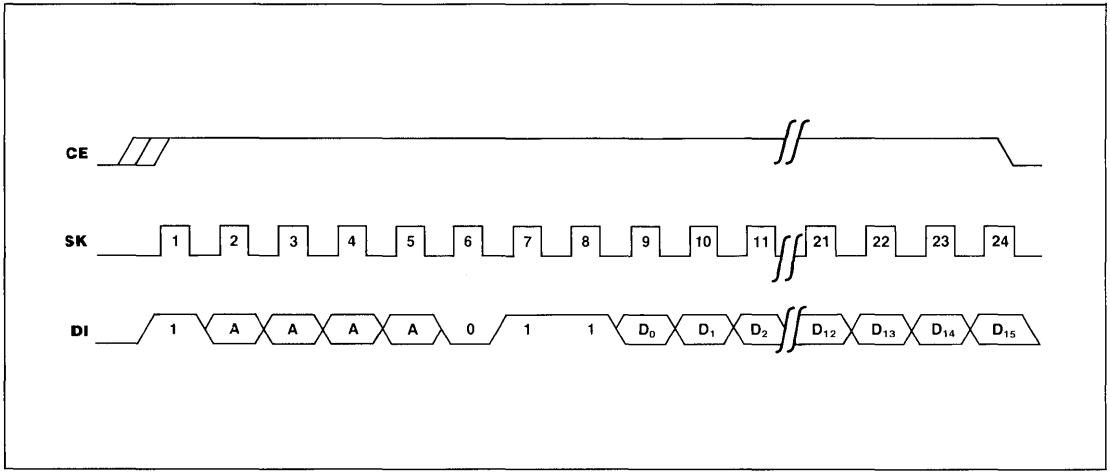


Figure 3: Non-Data Operations

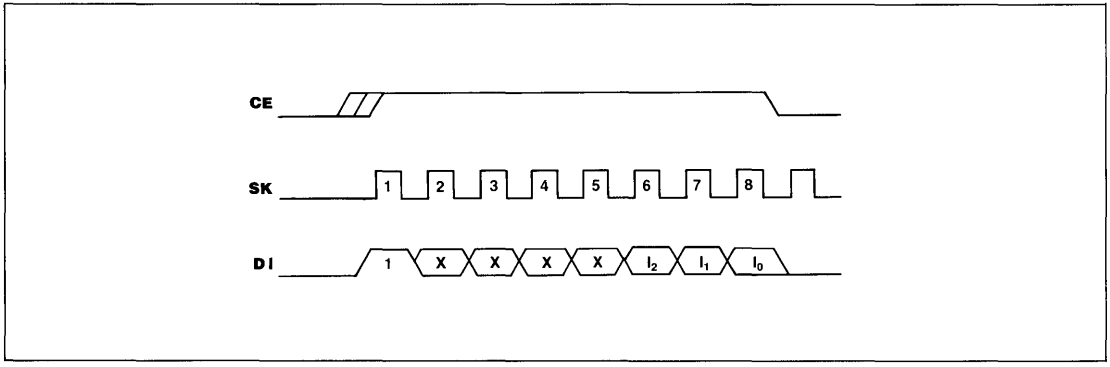


TABLE 1: INSTRUCTION SET

Instruction	Format, I_2 I_1 I_0	Operation
WRDS (Figure 3)	1XXXX000	Reset Write Enable Latch (Disables writes and stores)
STO (Figure 3)	1XXXX001	Store RAM data in E^2PROM
SLEEP (Figure 3)	1XXXX010	Enter SLEEP Mode
WRITE (Figure 2)	1AAAA011	Write Data into RAM Address AAAA
WREN (Figure 3)	1XXXX100	Set Write Enable Latch (Enables writes and stores)
RCL (Figure 3)	1XXXX101	Recall E^2PROM Data into RAM
READ (Figure 1)	1AAAA11X	Read Data from RAM Address AAAA

X=Don't Care
A=Address Bit

PIN DESCRIPTIONS

Chip Enable (CE)

The Chip Enable input must be HIGH to enable all read/write operations. CE LOW resets the instruction register and places the X2444 in the standby low power mode.

Serial Clock (SK)

The Serial Clock input is used to clock all data into and out of the device.

Data In (DI)

Data In is the serial data input.

Data Out (DO)

Data Out is the serial data output. It is in the high impedance state except during data output cycles in response to a READ instruction.

$\overline{\text{STORE}}$

$\overline{\text{STORE}}$ LOW will initiate an internal transfer of data from RAM to E^2PROM.

$\overline{\text{RECALL}}$

$\overline{\text{RECALL}}$ LOW will initiate an internal transfer of data from E^2PROM to RAM.

DEVICE OPERATION

The X2444 contains an 8-bit instruction register. It is accessed via the DI input, with data being clocked in on the rising edge of SK. CE must be HIGH during the entire data transfer operation.

Table 1 contains a list of the instructions and their operation codes. The most significant bit (MSB) of all instructions is a one, bits 6 through 3 are either RAM address (A) or don't care (X) and bits 2 through 0 are the operation codes. The X2444 requires the instruction to be shifted in with the MSB first.

After CE is HIGH, the X2444 will not begin to interpret the data stream until a one has been shifted in on DI. Therefore, CE may be brought HIGH with SK running and DI LOW. DI must then go HIGH to indicate the start condition of an instruction before the X2444 will begin any action.

In addition, the SK clock is totally static. The user can completely stop the clock and data shifting will be stopped. Restarting the clock will resume shifting of data.

WRDS and WREN

Internally the X2444 contains a "write enable" latch. This latch must be set for either writes to the RAM or store operations to the E^2PROM. The WREN instruction sets the latch and the WRDS instruction resets the latch, disabling *both* RAM writes and E^2PROM stores. The write enable latch is automatically reset on power-up.

SLEEP

The SLEEP instruction removes power from the RAM, placing the X2444 in a very low power quiescent state. Data in the RAM is lost once a SLEEP instruction is issued; however, data from the last store operation is retained in the E^2PROM. The sleep mode can be exited by either a software or hardware recall operation.

RCL and $\overline{\text{RECALL}}$

Either the RCL instruction or a LOW on the $\overline{\text{RECALL}}$ input will initiate a transfer of E^2PROM data into RAM. A recall operation must be performed after a power-up before any store or RAM write operation can be enabled. This recall operation and the recall recovery from the sleep mode guarantees a known state of data in RAM. Both recall operations set an internal "previous recall" latch which must be set to enable any write or store operations.

STO and $\overline{\text{STORE}}$

Either the STO instruction or a LOW on the $\overline{\text{STORE}}$ input will initiate the transfer of data from RAM to E^2PROM. In order to safeguard against unwanted store operations, the following conditions must be true:

1. STO instruction issued or $\overline{\text{STORE}}$ input is LOW;
2. The internal write enable latch must be set (WREN instruction issued);
3. The "previous recall" latch must be set.

Once the store cycle is initiated, all other device functions are inhibited. Upon completion of the store cycle, the write enable latch is reset.

WRITE

The write instruction contains the 4 bit address of the word to be written. The write instruction is immediately followed by the 16-bit word to be written. CE must remain HIGH during the entire operation. If CE is brought LOW prematurely (after the instruction but before 16 bits of data are transferred), the instruction register will be reset and the data that was shifted in will be written to RAM. If CE is kept HIGH for more than 24 SK clock cycles (8-bit instruction plus 16-bit data) the data already shifted in will be overwritten.

READ

The read instruction contains the 4 bit address of the word to be accessed. Unlike the other six instructions, I_0 is a "don't care" for the read instruction. This provides two advantages. In a design that ties both DI and DO together, the absence of an eighth bit in the instruction allows the host time to convert an I/O line from an output to an input. Secondly, it allows for valid data output during the ninth SK clock cycle.

DO, the first bit output during a read operation, is truncated. That is, it is internally clocked by the falling edge of the eighth SK clock; whereas, all succeeding bits are clocked by the rising edge of SK (refer to Read Cycle Diagram).

WRITE PROTECTION

The X2444 provides four hardware and software write protection mechanisms to prevent inadvertent stores of unknown data.

Power-down Condition

(when "write enable" latch and "previous recall" latch are not in the reset state):

- V_{CC} Sense—All functions are inhibited when V_{CC} is ≤3v, typically.
- Write Inhibit—Holding either $\overline{\text{RECALL}}$ LOW, CE LOW or $\overline{\text{STORE}}$ HIGH during power-down will prevent an inadvertent store.

Power-up Condition

- Write Enable Latch—Upon power-up the "write enable" latch is in the reset state, disabling any store operation.

Unknown Data Store

- Previous Recall Latch—The "previous recall" latch must be reset after power-up and after exiting the sleep mode. It may be reset only by performing a recall operation, which assures that data in all RAM locations is valid.

LOW POWER MODES

The X2444 provides two power conservation modes. When CE is LOW, non-critical internal devices are powered-down, placing the device in the standby power mode. Entering the sleep mode removes power from the entire RAM array, placing the device in a very low power quiescent state (sleep mode).

ENDURANCE

The endurance specification of a device is characterized by the predicted *first* bit failure to occur in the entire memory (device or system) array rather than the average or *typical* value for the array. Since endurance is limited by the number of electrons trapped in the oxide by data changes, Xicor NOVRAMs are designed to minimize the number of changes an E^2PROM bit cell undergoes during store operations. Only those bits in the E^2PROM that are different from their corresponding location in RAM will be "cycled" during a nonvolatile store. This characteristic reduces unnecessary cycling of any of the rest of the bits in the array, thereby increasing the potential endurance of each bit and increasing the potential endurance of the entire array. Reliability data documented in RR504, the *Xicor Reliability Report on Endurance*, and additional reports are available from Xicor.

Part Number	Store Cycles	Data Changes Per Bit
X2444M	100,000	1,000
X2444M/10	100,000	10,000

4K Commercial / Industrial — **X2404 / X2404I** — **512 x 8 Bit**

Electrically Erasable PROM

TYPICAL FEATURES

- **Low Cost**
- **Internally Organized as Two Pages**
  - **— Each 256 x 8**
- **2 Wire Serial Interface**
- **Provides Bidirectional Data Transfer Protocol**
- **Eight Byte Page Write Mode**
  - **— Minimizes Total Write Time per Byte**
- **Self Timed Write Cycle**
  - **— Typical Write Cycle Time of 5ms**
- **Data Retention Greater Than 100 Years**

DESCRIPTION

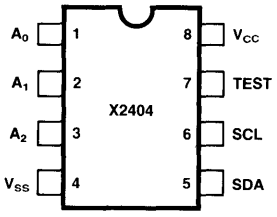
The X2404 is a 4096 bit serial E^2PROM, internally organized as two 256 x 8 pages. The X2404 is fabricated with the same reliable N-channel floating gate MOS technology used in all Xicor 5 volt programmable nonvolatile memories.

The X2404 features a serial interface and software protocol allowing operation on a two wire bus.

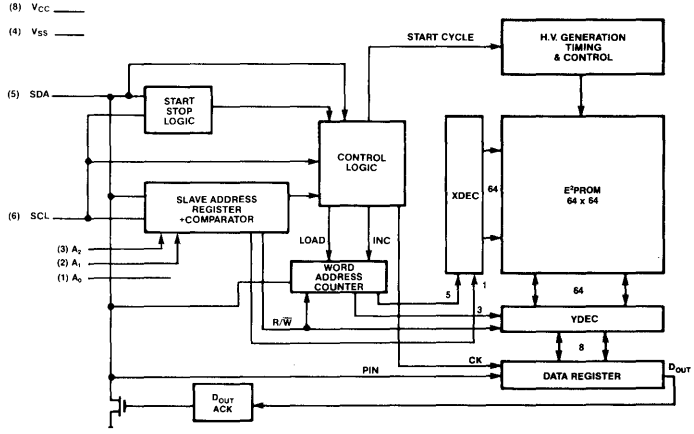
Xicor E^2PROMs are designed and tested for applications requiring extended endurance. Refer to Device Operation for further endurance information. Data retention is specified to be greater than 100 years.

2

PIN CONFIGURATION



FUNCTIONAL DIAGRAM



PIN NAMES

1 to 3	A_0 to A_2 Address Inputs
4	V_{SS}
5	SDA Serial Data
6	SCL Serial Clock
7	**Test Input → to V_{SS}**
8	V_{CC}

ABSOLUTE MAXIMUM RATINGS*

Temperature Under Bias X2404 ..... −10°C to +85°C
X2404I ..... −65°C to +135°C
Storage Temperature ..... −65°C to +150°C
Voltage on any Pin with
Respect to V_{SS} ..... −1.0V to +7V
D.C. Output Current ..... 5 mA
Lead Temperature (Soldering,
10 Seconds) ..... 300°C

*COMMENT

Stresses above those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. This is a stress rating only and the functional operation of the device at these or any other conditions above those indicated in the operational sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

D.C. OPERATING CHARACTERISTICS

X2404 T_A = 0°C to +70°C, V_{CC} = +5V ±5%, unless otherwise specified.
X2404I T_A = −40°C to +85°C, V_{CC} = +5V ±10%, unless otherwise specified.

Symbol	Parameter	Limits			Units	Test Conditions
		Min.	Typ.(1)	Max.		
I_{CC}	Power Supply Current		20		mA	
I_{SB}	Standby Current		15		mA	
I_{LI}	Input Leakage Current		0.1	10	µA	V_{IN} = GND to V_{CC}
I_{LO}	Output Leakage Current		0.1	10	µA	V_{OUT} = GND to V_{CC}
I_{TP}(2)	Test Pin Pull Down Current		16		µA	V_{IN} = V_{CC}
V_{IL}	Input Low Voltage	−1.0		0.8	V	
V_{IH}	Input High Voltage	2.0		V_{CC} +0.5	V	
V_{OL}	Output Low Voltage			0.4	V	I_{OL} = 3 mA

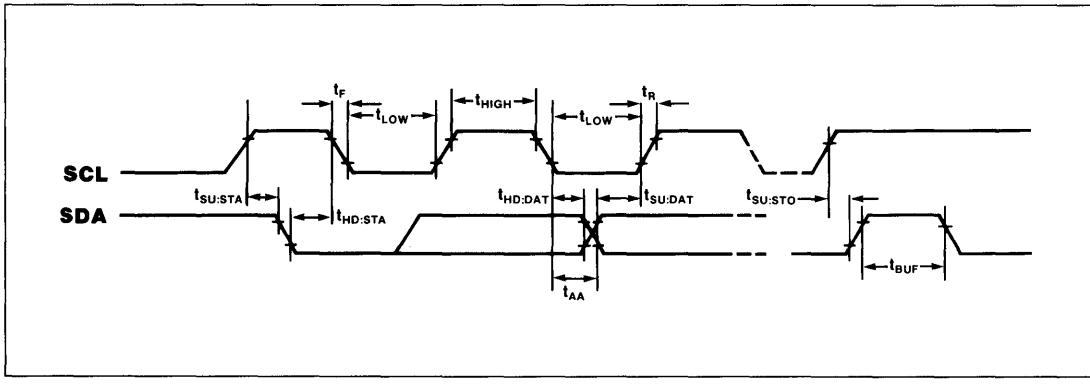
Note: (1) Typical values are for T_A = 25°C and nominal supply voltage.
(2) Test pin has on chip pull down device which sinks 16µA (typical) to V_{SS}.

CAPACITANCE T_A = 25°C, f = 1.0 MHz, V_{CC} = 5V

Symbol	Test	Max.	Unit	Conditions
$C_{I/O}$(3)	Input/Output Capacitance (SDA)	8	pF	$V_{I/O}$ = 0V
C_{IN}(3)	Input Capacitance (A_0, A_1, A_2, SCL)	6	pF	V_{IN} = 0V

Note: (3) This parameter is periodically sampled and not 100% tested.

Bus Timing



A.C. CHARACTERISTICS

X2404 T_A = 0°C to +70°C, V_{CC} = +5V ±5%, unless otherwise specified.
X2404I T_A = −40°C to +85°C, V_{CC} = +5V ±10%, unless otherwise specified.

Read & Write Cycle Limits

Symbol	Parameter	Min.	Typ.(1)	Max.	Units	Test Conditions
f_{SCL}	SCL clock frequency	0		100	KHz	
T_I	Noise suppression time constant at SCL, SDA inputs		1		µs	
t_{AA}	SCL low to SDA data out valid	0.3	1.5	3.5	µs	
t_{BUF}	Time the bus must be free before a new transmission can start	4.7			µs	
$t_{HD:STA}$	Start condition hold time	4.0			µs	
t_{LOW}	Clock low period	4.7			µs	
t_{HIGH}	Clock high period	4.0			µs	
$t_{SU:STA}$	Start condition set-up time (for a repeated start condition)	4.7			µs	
$t_{HD:DAT}$	Data in hold time	0			µs	
$t_{SU:DAT}$	Data in set-up time	250			ns	
t_R	SDA and SCL rise time			1	µs	
t_F	SDA and SCL fall time			300	ns	
$t_{SU:STO}$	Stop condition set-up time	4.7			µs	

Note: (1) Typical values are for T_A=25°C and nominal supply voltage.

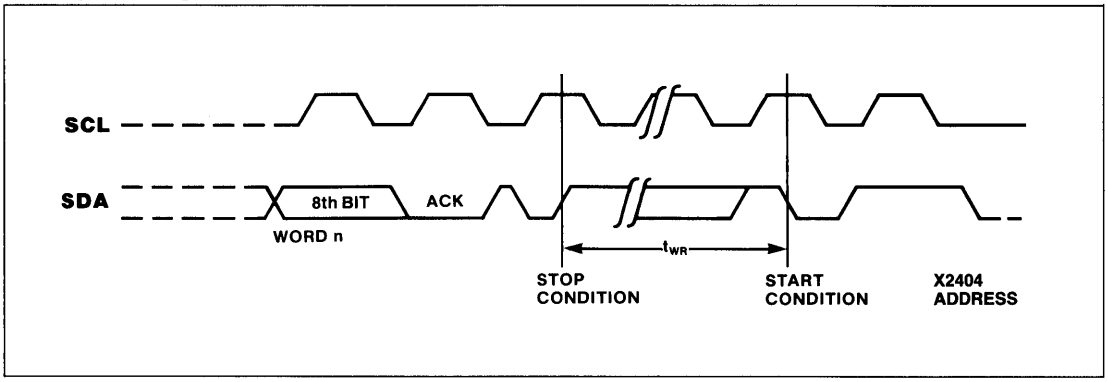
Write Cycle Limits

Symbol	Parameter	Min.	Typ.(1)	Max.	Units
t_{WR}	Write Cycle Time	—	5	10	ms

Note: (1) Typical values are for T_A=25°C and nominal supply voltage.

The write cycle time is the time from a valid stop condition of a write sequence to the end of the internal erase/program cycle. During the write cycle, the X2404 bus interface circuits are disabled, SDA is allowed to remain high, and the device does not respond to its slave address.

Write Cycle Timing



PIN DESCRIPTIONS

Serial Clock (SCL)

The SCL input is used to clock all data into and out of the device.

Serial Data (SDA)

SDA is a bidirectional pin used to transfer data into and out of the device. It is an open drain output and may be wire-ANDed with any number of open drain or open collector outputs.

Address (A_0)

A_0 is unused by the X2404, however, it must be tied to V_{SS} to ensure proper device operation.

Address (A_1, A_2)

The Address inputs are used to set the least significant two bits of the six bit slave address. The inputs are static, and should be tied HIGH or LOW, forming one unique address per device.

DEVICE OPERATION

The X2404 supports a bidirectional bus oriented protocol. The protocol defines any device that sends data onto the bus as a transmitter, and the receiving device as the receiver. The device controlling the transfer is a master and the device being controlled is the slave. The master will always initiate data transfers, and provide the clock for both transmit and receive operations. Therefore, the X2404 will be considered a slave in all applications.

Clock and Data Conventions

Data states on the SDA line can change only during SCL LOW. SDA state changes during SCL HIGH are reserved for indicating start and stop conditions. Refer to Figures 1 and 2.

Figure 1: Data Validity

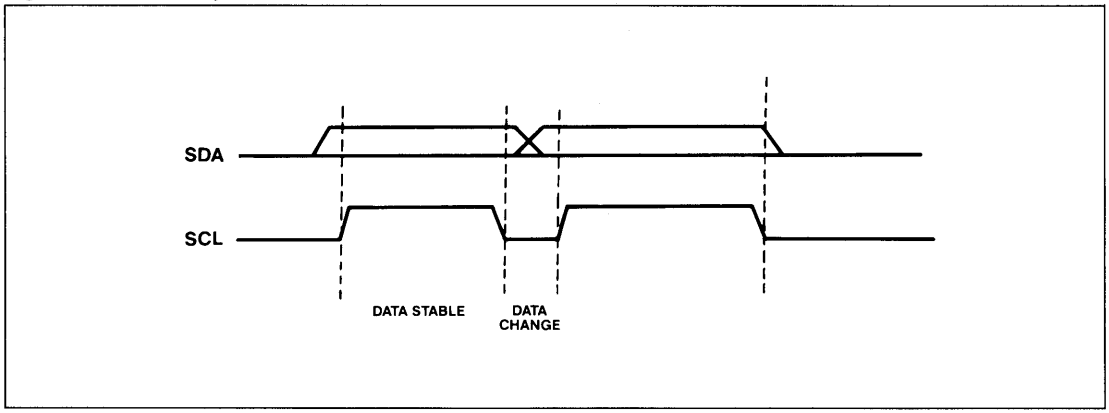
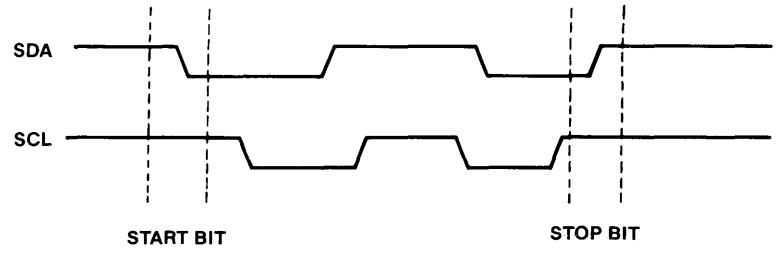


Figure 2: Definition of Start and Stop



Start Condition

All commands are preceded by the start condition, which is a HIGH to LOW transition of SDA when SCL is HIGH. The X2404 continuously monitors the SDA and SCL lines for the start condition and will not respond to any command until this condition has been met.

Stop Condition

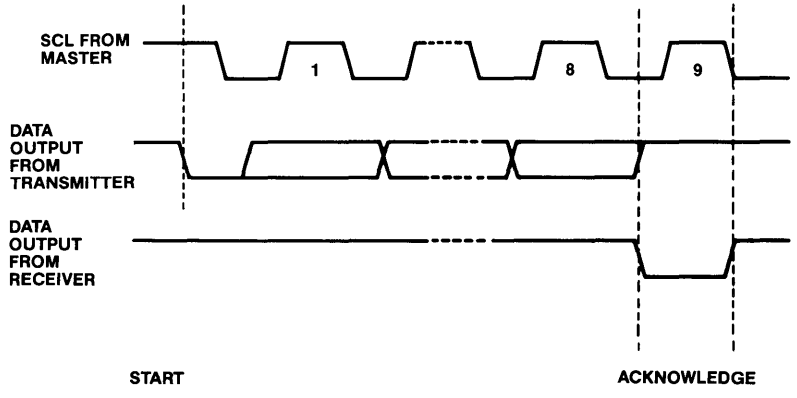
All communications are terminated by a stop condition, which is a LOW to HIGH transition of SDA when SCL is HIGH.

Acknowledge

Acknowledge is a software convention used to indicate successful data transfers. The transmitting device, either master or slave, will release the bus after transmitting eight bits. During the ninth clock cycle the receiver will pull the SDA line LOW to acknowledge that it received the eight bits of data. Refer to Figure 3.

The X2404 will always respond with an acknowledge after recognition of a start condition and its slave address. If both the device and a write operation have been selected, the X2404 will respond with an acknowledge after the receipt of each subsequent eight bit word.

Figure 3: Acknowledge Response From Receiver

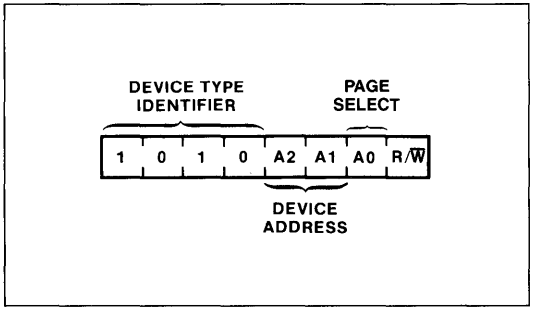


In the read mode the X2404 will transmit eight bits of data, release the SDA line and monitor the line for an acknowledge. If an acknowledge is detected and no stop condition is generated by the master, the X2404 will continue to transmit data. If an acknowledge is not detected, the X2404 will terminate further data transmissions and await the stop condition.

DEVICE ADDRESSING

Following a start condition the bus master must output the address of the slave it is accessing. The most significant four bits of the slave address are the device type identifier (see Figure 4). For the X2404 this is fixed as 1010[B].

Figure 4: Slave Address



The next two significant bits address a particular device. A system could have up to four X2404 devices on the bus (see Figure 10). The four addresses are defined by the state of the A_1 and A_2 inputs.

The next bit of the slave address field (bit 1) is the page select bit. It is used by the host to toggle between the two 256 word pages of memory.

The last bit of the slave address defines the operation to be performed. When set to one a read operation is selected; when set to zero a write operation is selected.

Following the start condition, the X2404 monitors the SDA bus comparing the slave address being transmitted with its address (device type and state of A_1, and A_2 inputs). Upon a compare the X2404 outputs an acknowledge on the SDA line. Depending on the state of the R/$\overline{W}$ bit, the X2404 will execute a read or write operation.

WRITE OPERATIONS

Byte Write

For a write operation, the X2404 requires a second address field. This address field is the word address, comprised of eight bits, providing access to any one of the 256 words of memory. Upon receipt of the word address the X2404 responds with an acknowledge and awaits the next eight bits of data, again responding with an acknowledge. The master then terminates the transfer by generating a stop condition, at which time the X2404 begins the internal write cycle to the nonvolatile memory. While the internal write cycle is in progress the X2404 inputs are disabled, and the device will not respond to any requests from the master. Refer to Figure 5 for the address, acknowledge and data transfer sequence.

Page Write

The X2404 is capable of an eight byte page write operation. It is initiated in the same manner as the byte write operation, but instead of terminating the write cycle after the first data word is transferred, the master can transmit up to seven more words. After the receipt of each word, the X2404 will respond with an acknowledge.

After the receipt of each word, the three low order address bits are internally incremented by one. The high order five bits of the address remain constant. If the master should transmit more than eight words prior to generating the stop condition, the address counter will "roll over" and the previously written data will be overwritten. As with the byte write operation, all inputs are disabled until completion of the internal write cycle. Refer to Figure 6 for the address, acknowledge and data transfer sequence.

Figure 5: Byte Write

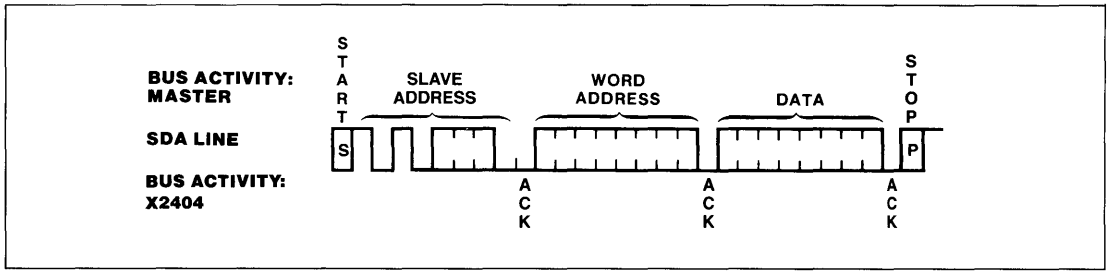
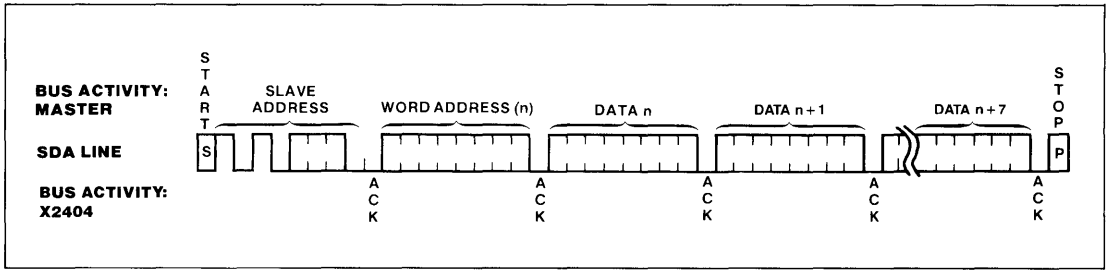


Figure 6: Page Write



Acknowledge Polling

The disabling of the inputs can be used to take advantage of the typical 5ms write cycle time. The bus master can continually transmit the slave address and no acknowledge will be returned if the X2404 is internally writing to the E^2PROM array. As soon as the internal cycle is complete the X2404 will respond to its slave address.

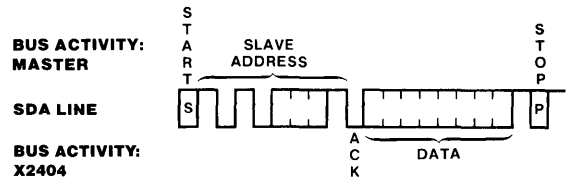
Read Operations

Read operations are initiated in the same manner as write operations with the exception that the R/$\overline{W}$ bit of the slave address is set to a one. There are three basic read operations: current address read, random read and sequential read.

Current Address Read

Internally the X2404 contains an address counter that maintains the address of the last word accessed, incremented by one. Therefore, if the last access (either a read or write) was to address n, the next read operation would access data from address n+1. Upon receipt of the slave address with R/$\overline{W}$ set to one, the X2404 issues an acknowledge and transmits the eight bit word. The master does not acknowledge the transfer but does generate a stop condition and the X2404 discontinues transmission. Refer to Figure 7 for the sequence of address, acknowledge and data transfer.

Figure 7: Current Address Read



Random Read

Random read operations allow the master to access any memory location in a random manner. Prior to issuing the slave address with the R/$\overline{W}$ bit set to one, the master must first perform a "dummy" write operation. The master issues the start condition, and the slave address followed by the word address it is to read. After the word address acknowledge, the master immediately reissues the start condition and the slave address with the R/$\overline{W}$ bit set to one. This will be followed by an acknowledge from the X2404 and then by the eight bit word. The master does not acknowledge the transfer but does generate a stop condition and the X2404 discontinues transmission. Refer to Figure 8 for the address, acknowledge and data transfer sequence.

Sequential Read

Sequential reads can be initiated as either a current address read or random access read. The first word is transmitted as with the other read modes, however, the master now responds with an acknowledge, indicating it requires additional data. The X2404 continues to output data for each acknowledge received. The read operation is terminated by the master not responding with an acknowledge and generating a stop condition.

The data output is sequential, with the data from address n followed by the data from n+1. The address counter for read operations increments all eight address bits, allowing the entire memory contents of the current 256 word page to be serially read during one operation. If more than 256 words are read, the counter "rolls over" and the X2404 continues to output data from the same 256 word page for each acknowledge received. Refer to Figure 9 for the address, acknowledge and data transfer sequence.

ENDURANCE

Xicor E^{2}PROMs are designed and tested for applications requiring extended endurance. The process average for endurance of Xicor E^{2}PROMs is approximately 1/2 million cycles, as documented in RR504, the *Xicor Reliability Report on Endurance*. Included in that report is a method for determining the expected endurance of the device based upon the specific application environment. RR504 and additional reliability reports are available from Xicor.

Figure 8: Random Read

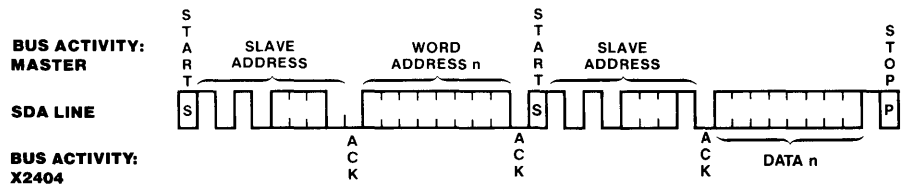


Figure 9: Sequential Read

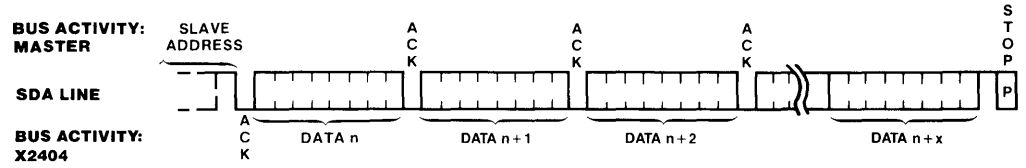
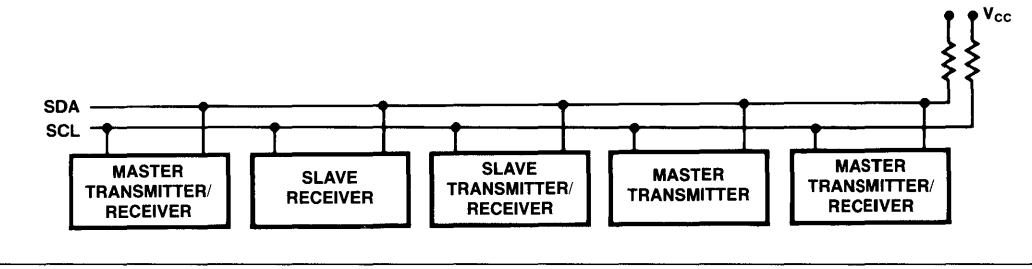


Figure 10: Typical System Configuration



2

NOTES

FACT SHEET

4K Military X2404M 512 x 8 Bit

Electrically Erasable PROM

TYPICAL FEATURES

- **Low Cost**
- **Internally Organized as Two Pages**
  — Each 256 x 8
- **2 Wire Serial Interface**
- **Provides Bidirectional Data Transfer Protocol**
- **Eight Byte Page Write Mode**
  — Minimizes Total Write Time per Byte
- **Self Timed Write Cycle**
  — Typical Write Cycle Time of 5ms
- **Data Retention Greater Than 100 Years**

DESCRIPTION

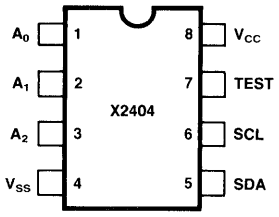
The X2404 is a 4096 bit serial E^2PROM, internally organized as two 256 x 8 pages. The X2404 is fabricated with the same reliable N-channel floating gate MOS technology used in all Xicor 5 volt programmable nonvolatile memories.

The X2404 features a serial interface and software protocol allowing operation on a two wire bus.

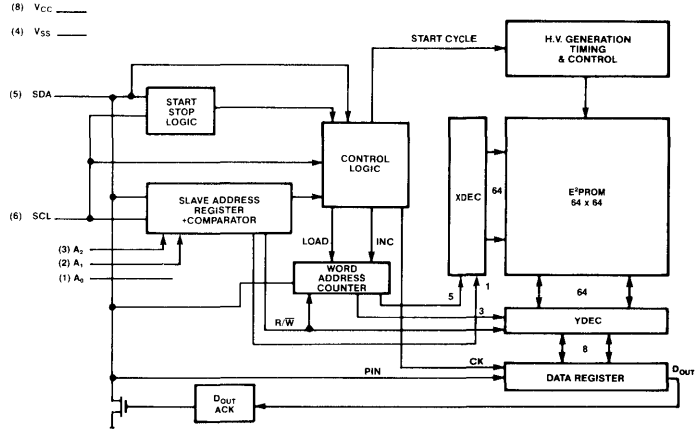
Xicor E^2PROMs are designed and tested for applications requiring extended endurance. Refer to Device Operation for further endurance information. Data retention is specified to be greater than 100 years.

2

PIN CONFIGURATION



FUNCTIONAL DIAGRAM



PIN NAMES

1 to 3	A_0 to A_2 Address Inputs
4	V_{SS}
5	SDA Serial Data
6	SCL Serial Clock
7	**Test Input → to V_{SS}**
8	V_{CC}

ABSOLUTE MAXIMUM RATINGS*

Temperature Under Bias ..... −65°C to +135°C
Storage Temperature ..... −65°C to +150°C
Voltage on any Pin with
Respect to V_{SS} ..... −1.0V to +7V
D.C. Output Current ..... 5 mA
Lead Temperature (Soldering,
10 Seconds) ..... 300°C

*COMMENT

Stresses above those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. This is a stress rating only and the functional operation of the device at these or any other conditions above those indicated in the operational sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

D.C. OPERATING CHARACTERISTICS

T_A = −55°C to +125°C, V_{CC} = +5V ±10%, unless otherwide specified.

Symbol	Parameter	Limits			Units	Test Conditions
		Min.	Typ.(1)	Max.		
I_{CC}	Power Supply Current		20		mA	
I_{SB}	Standby Current		15		mA	
I_{LI}	Input Leakage Current		0.1	10	µA	V_{IN} = GND to V_{CC}
I_{LO}	Output Leakage Current		0.1	10	µA	V_{OUT} = GND to V_{CC}
I_{TP}(2)	Test Pin Pull Down Current		16		µA	V_{IN} = V_{CC}
V_{IL}	Input Low Voltage	−1.0		0.8	V	
V_{IH}	Input High Voltage	2.0		V_{CC} +1.0	V	
V_{OL}	Output Low Voltage			0.4	V	I_{OL} = 3 mA

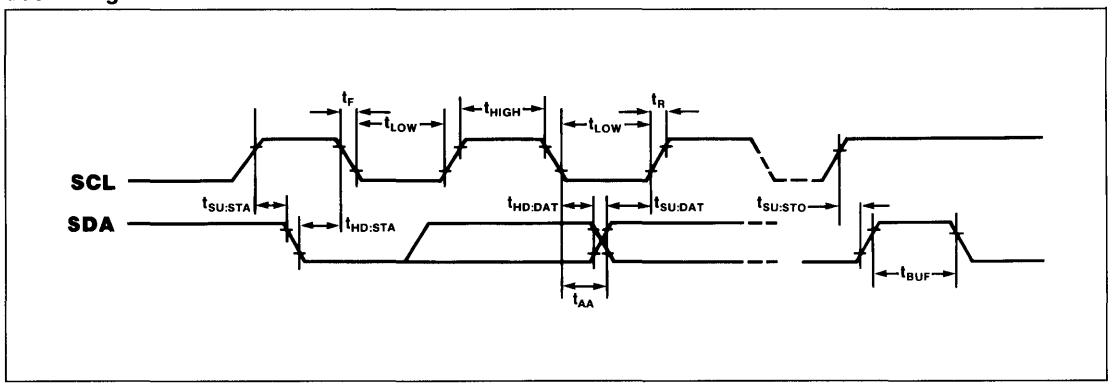
Note: (1) Typical values are for T_A = 25°C and nominal supply voltage.
(2) Test pin has on chip pull down device which sinks 16µA (typical) to V_{SS}.

CAPACITANCE T_A = 25°C, f = 1.0 MHz, V_{CC} = 5V

Symbol	Test	Max.	Unit	Conditions
$C_{I/O}$(3)	Input/Output Capacitance (SDA)	8	pF	$V_{I/O}$ = 0V
C_{IN}(3)	Input Capacitance (A_0, A_1, A_2, SCL)	6	pF	V_{IN} = 0V

Note: (3) This parameter is periodically sampled and not 100% tested.

Bus Timing



A.C. CHARACTERISTICS

Read & Write Cycle Limits

T_A = −55°C to +125°C, V_{CC} = +5V ±10% unless otherwise specified.

Symbol	Parameter	Min.	Typ.(1)	Max.	Units	Test Conditions
f_{SCL}	SCL clock frequency	0		100	KHz	
T_I	Noise suppression time constant at SCL, SDA inputs		1		µs	
t_{AA}	SCL low to SDA data out valid	0.3	1.5	3.5	µs	
t_{BUF}	Time the bus must be free before a new transmission can start	4.7			µs	
$t_{HD:STA}$	Start condition hold time	4.0			µs	
t_{LOW}	Clock low period	4.7			µs	
t_{HIGH}	Clock high period	4.0			µs	
$t_{SU:STA}$	Start condition set-up time (for a repeated start condition)	4.7			µs	
$t_{HD:DAT}$	Data in hold time	0			µs	
$t_{SU:DAT}$	Data in set-up time	250			ns	
t_R	SDA and SCL rise time			1	µs	
t_F	SDA and SCL fall time			300	ns	
$t_{SU:STO}$	Stop condition set-up time	4.7			µs	

Note: (1) Typical values are for T_A = 25°C and nominal supply voltage.

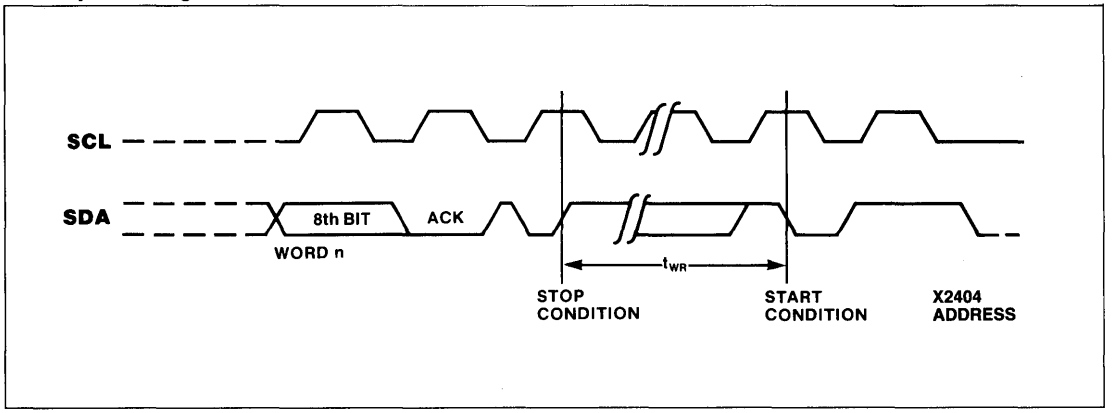
Write Cycle Limits

Symbol	Parameter	Min.	Typ.(1)	Max.	Units
t_{WR}	Write Cycle Time	—	5	10	ms

Note: (1) Typical values are for T_A = 25°C and nominal supply voltage.

The write cycle time is the time from a valid stop condition of a write sequence to the end of the internal erase/program cycle. During the write cycle, the X2404 bus interface circuits are disabled, SDA is allowed to remain high, and the device does not respond to its slave address.

Write Cycle Timing



PIN DESCRIPTIONS

Serial Clock (SCL)

The SCL input is used to clock all data into and out of the device.

Serial Data (SDA)

SDA is a bidirectional pin used to transfer data into and out of the device. It is an open drain output and may be wire-ANDed with any number of open drain or open collector outputs.

Address (A_0)

A_0 is unused by the X2404, however, it must be tied to V_{SS} to insure proper device operation.

Address (A_1, A_2)

The Address inputs are used to set the least significant two bits of the six bit slave address. The inputs are static, and should be tied HIGH or LOW, forming one unique address per device.

DEVICE OPERATION

The X2404 supports a bidirectional bus oriented protocol. The protocol defines any device that sends data onto the bus as a transmitter, and the receiving device as the receiver. The device controlling the transfer is a master and the device being controlled is the slave. The master will always initiate data transfers, and provide the clock for both transmit and receive operations. Therefore, the X2404 will be considered a slave in all applications.

Clock and Data Conventions

Data states on the SDA line can change only during SCL LOW. SDA state changes during SCL HIGH are reserved for indicating start and stop conditions. Refer to Figures 1 and 2.

Figure 1: Data Validity

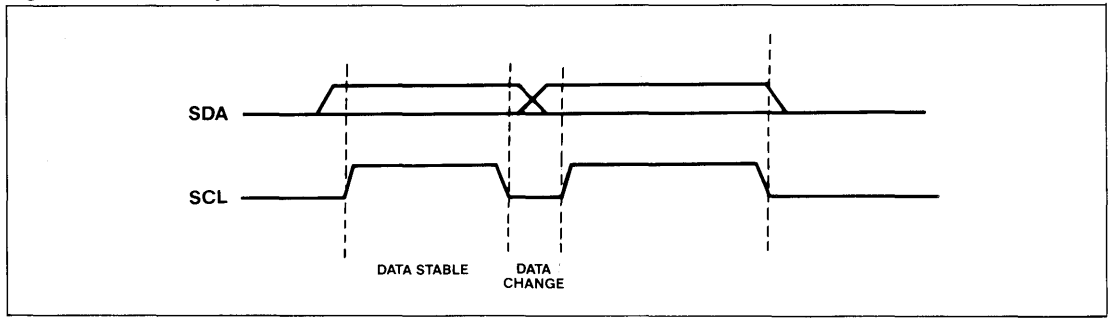
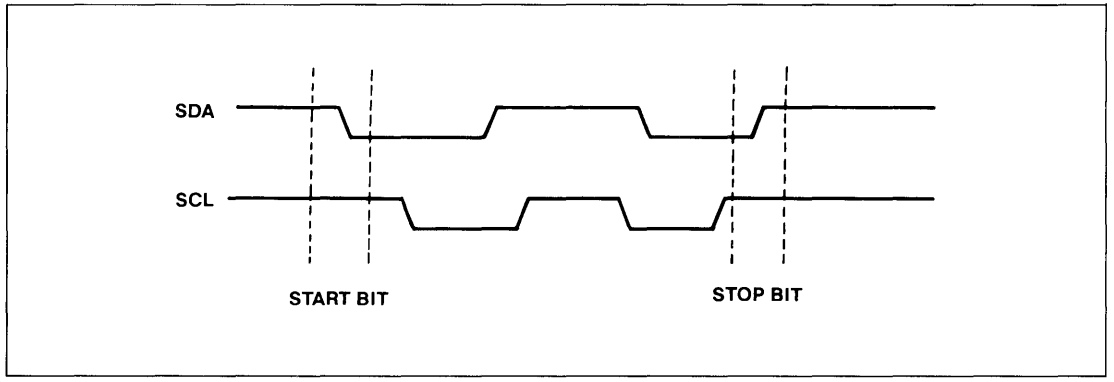


Figure 2: Definition of Start and Stop



Start Condition

All commands are preceded by the start condition, which is a HIGH to LOW transition of SDA when SCL is HIGH. The X2404 continuously monitors the SDA and SCL lines for the start condition and will not respond to any command until this condition has been met.

Stop Condition

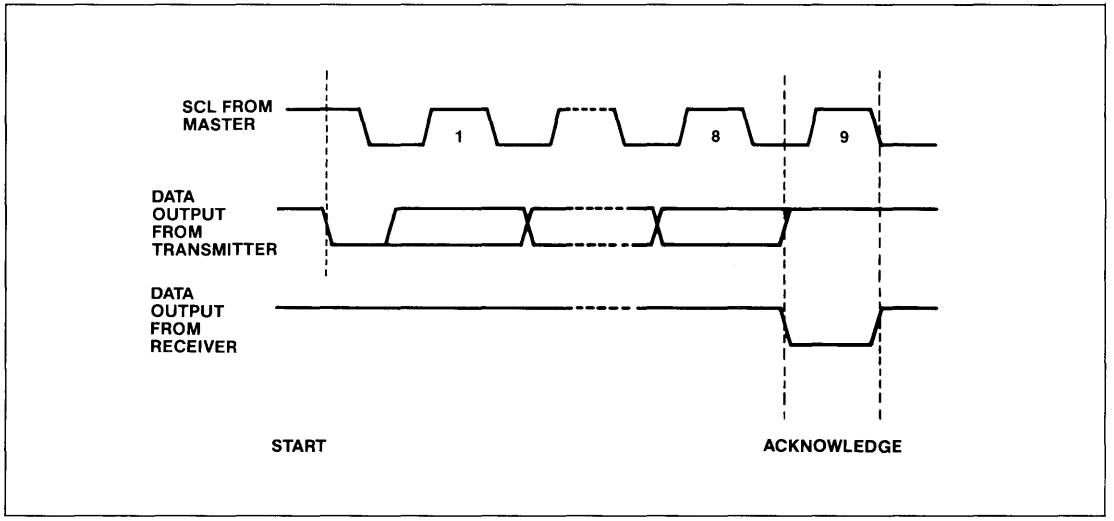
All communications are terminated by a stop condition, which is a LOW to HIGH transition of SDA when SCL is HIGH.

Acknowledge

Acknowledge is a software convention used to indicate successful data transfers. The transmitting device, either master or slave, will release the bus after transmitting eight bits. During the ninth clock cycle the receiver will pull the SDA line LOW to acknowledge that it received the eight bits of data. Refer to Figure 3.

The X2404 will always respond with an acknowledge after recognition of a start condition and its slave address. If both the device and a write operation have been selected, the X2404 will respond with an acknowledge after the receipt of each subsequent eight bit word.

Figure 3: Acknowledge Response From Receiver

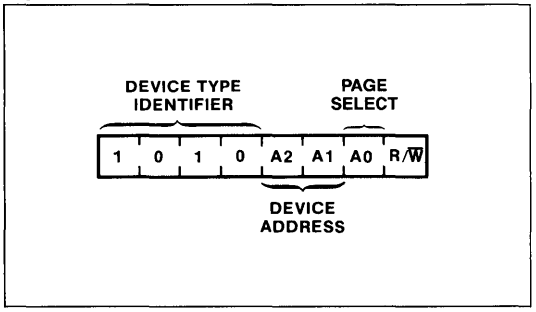


In the read mode the X2404 will transmit eight bits of data, release the SDA line and monitor the line for an acknowledge. If an acknowledge is detected and no stop condition is generated by the master, the X2404 will continue to transmit data. If an acknowledge is not detected, the X2404 will terminate further data transmissions and await the stop condition.

DEVICE ADDRESSING

Following a start condition the bus master must output the address of the slave it is accessing. The most significant four bits of the slave address are the device type identifier (see Figure 4). For the X2404 this is fixed as 1010[B].

Figure 4: Slave Address



The next two significant bits address a particular device. A system could have up to four X2404 devices on the bus (see Figure 10). The four addresses are defined by the state of the A_1 and A_2 inputs.

The next bit of the slave address field (bit 1) is the page select bit. It is used by the host to toggle between the two 256 word pages of memory.

The last bit of the slave address defines the operation to be performed. When set to one a read operation is selected; when set to zero a write operation is selected.

Following the start condition, the X2404 monitors the SDA bus comparing the slave address being transmitted with its address (device type and state of A_1, and A_2 inputs). Upon a compare the X2404 outputs an acknowledge on the SDA line. Depending on the state of the R/$\overline{W}$ bit, the X2404 will execute a read or write operation.

WRITE OPERATIONS

Byte Write

For a write operation, the X2404 requires a second address field. This address field is the word address, comprised of eight bits, providing access to any one of the 256 words of memory. Upon receipt of the word address the X2404 responds with an acknowledge and awaits the next eight bits of data, again responding with an acknowledge. The master then terminates the transfer by generating a stop condition, at which time the X2404 begins the internal write cycle to the nonvolatile memory. While the internal write cycle is in progress the X2404 inputs are disabled, and the device will not respond to any requests from the master. Refer to Figure 5 for the address, acknowledge and data transfer sequence.

Page Write

The X2404 is capable of an eight byte page write operation. It is initiated in the same manner as the byte write operation, but instead of terminating the write cycle after the first data word is transferred, the master can transmit up to seven more words. After the receipt of each word, the X2404 will respond with an acknowledge.

After the receipt of each word, the three low order address bits are internally incremented by one. The high order five bits of the address remain constant. If the master should transmit more than eight words prior to generating the stop condition, the address counter will "roll over" and the previously written data will be overwritten. As with the byte write operation, all inputs are disabled until completion of the internal write cycle. Refer to Figure 6 for the address, acknowledge and data transfer sequence.

Figure 5: Byte Write

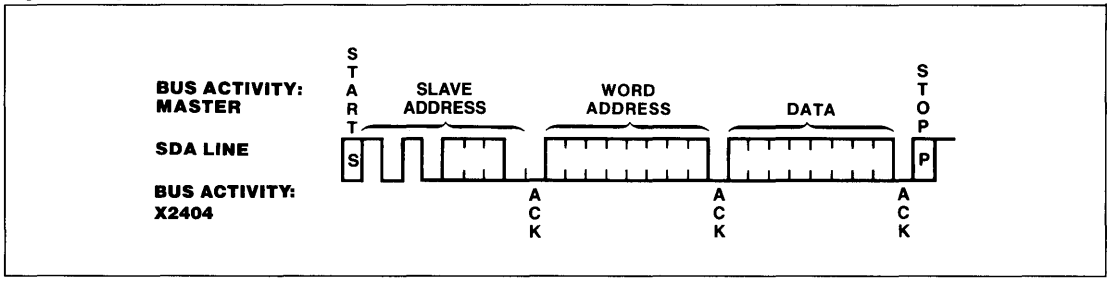
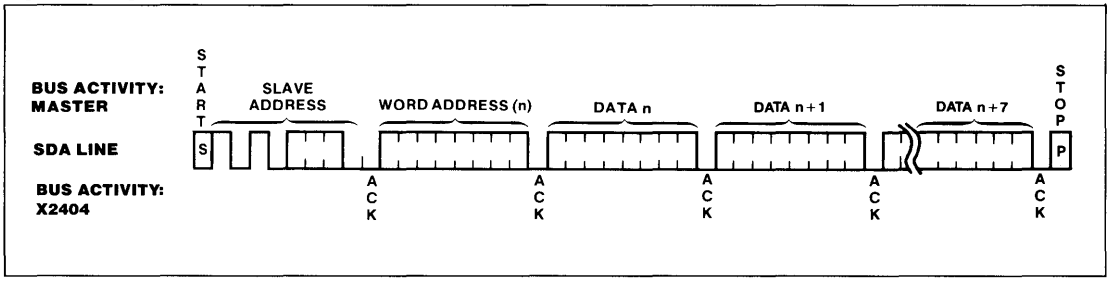


Figure 6: Page Write



Acknowledge Polling

The disabling of the inputs can be used to take advantage of the typical 5ms write cycle time. The bus master can continually transmit the slave address and no acknowledge will be returned if the X2404 is internally writing to the E^2PROM array. As soon as the internal cycle is complete the X2404 will respond to its slave address.

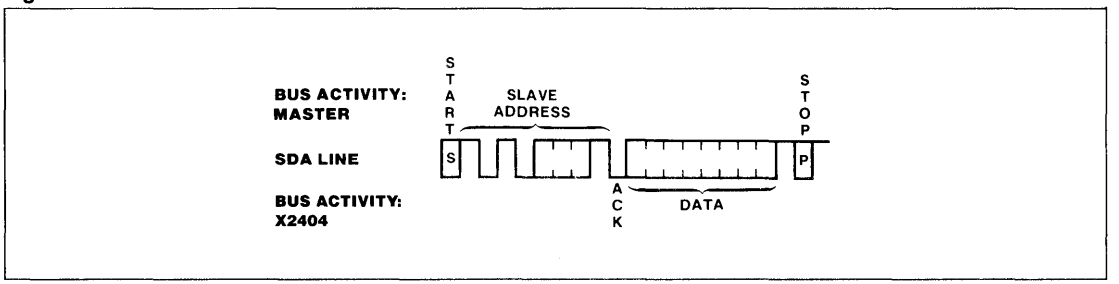
Read Operations

Read operations are initiated in the same manner as write operations with the exception that the R/$\overline{W}$ bit of the slave address is set to a one. There are three basic read operations: current address read, random read and sequential read.

Current Address Read

Internally the X2404 contains an address counter that maintains the address of the last word accessed, incremented by one. Therefore, if the last access (either a read or write) was to address n, the next read operation would access data from address n+1. Upon receipt of the slave address with R/$\overline{W}$ set to one, the X2404 issues an acknowledge and transmits the eight bit word. The master does not acknowledge the transfer but does generate a stop condition and the X2404 discontinues transmission. Refer to Figure 7 for the sequence of address, acknowledge and data transfer.

Figure 7: Current Address Read



Random Read

Random read operations allow the master to access any memory location in a random manner. Prior to issuing the slave address with the R/$\overline{W}$ bit set to one, the master must first perform a "dummy" write operation. The master issues the start condition, and the slave address followed by the word address it is to read. After the word address acknowledge, the master immediately reissues the start condition and the slave address with the R/$\overline{W}$ bit set to one. This will be followed by an acknowledge from the X2404 and then by the eight bit word. The master does not acknowledge the transfer but does generate a stop condition and the X2404 discontinues transmission. Refer to Figure 8 for the address, acknowledge and data transfer sequence.

Sequential Read

Sequential reads can be initiated as either a current address read or random access read. The first word is transmitted as with the other read modes, however, the master now responds with an acknowledge, indicating it requires additional data. The X2404 continues to output data for each acknowledge received. The read operation is terminated by the master not responding with an acknowledge and generating a stop condition.

The data output is sequential, with the data from address n followed by the data from n+1. The address counter for read operations increments all eight address bits, allowing the entire memory contents of the current 256 word page to be serially read during one operation. If more than 256 words are read, the counter "rolls over" and the X2404 continues to output data from the same 256 word page for each acknowledge received. Refer to Figure 9 for the address, acknowledge and data transfer sequence.

ENDURANCE

Xicor E^{2}PROMs are designed and tested for applications requiring extended endurance. The Process average for endurance of Xicor E^{2}PROMs is approximately 1/2 million cycles, as documented in RR504, the *Xicor Reliability Report on Endurance*. Included in that report is a method for determining the expected endurance of the device based upon the specific application environment. RR504 and additional reliability reports are available from Xicor.

Figure 8: Random Read

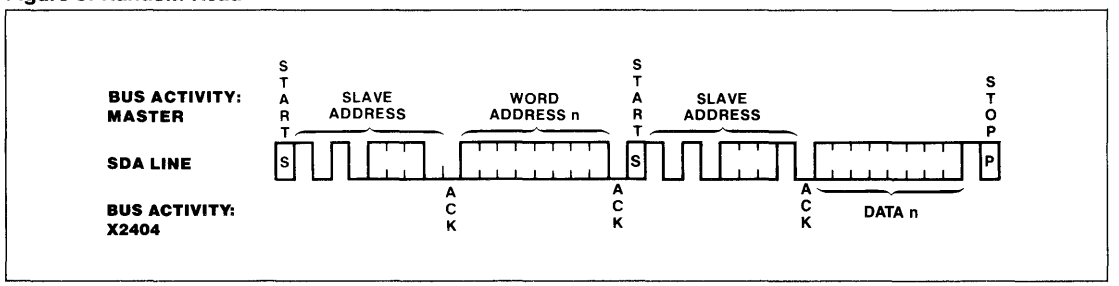


Figure 9: Sequential Read

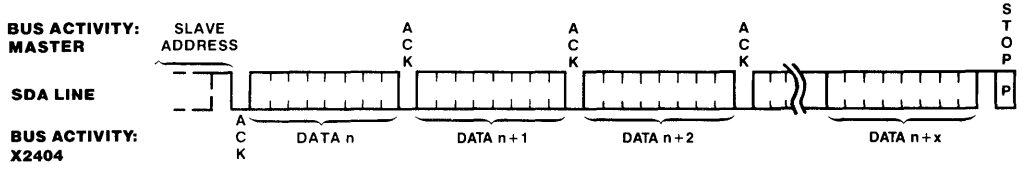
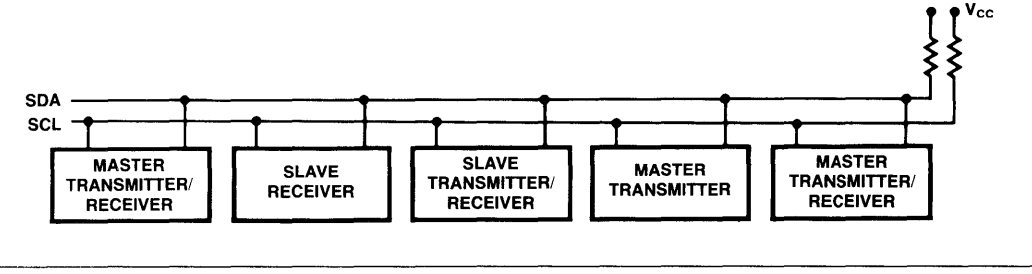


Figure 10: Typical System Configuration



NOTES

4K X24C04 512 x 8 Bit

Electrically Erasable PROM

TYPICAL FEATURES

- **Low Cost**
- **Low Power CMOS**
  - **— 2mA Active Current**
  - **— 50μA Standby Current**
- **Internally Organized as Two Pages**
  - **— Each 256 x 8**
- **2 Wire Serial Interface**
- **Provides Bidirectional Data Transfer Protocol**
- **Eight Byte Page Write Mode**
  - **— Minimizes Total Write Time per Byte**
- **Self Timed Write Cycle**
  - **— Typical Write Cycle Time of 5ms**
- **Data Retention Greater Than 100 Years**

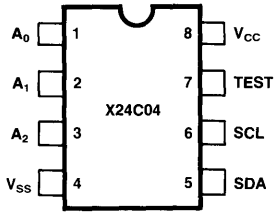
DESCRIPTION

The X24C04 is a CMOS 4096 bit serial E^2PROM, internally organized as two 256 x 8 pages. The X24C04 features a serial interface and software protocol allowing operation on a two wire bus.

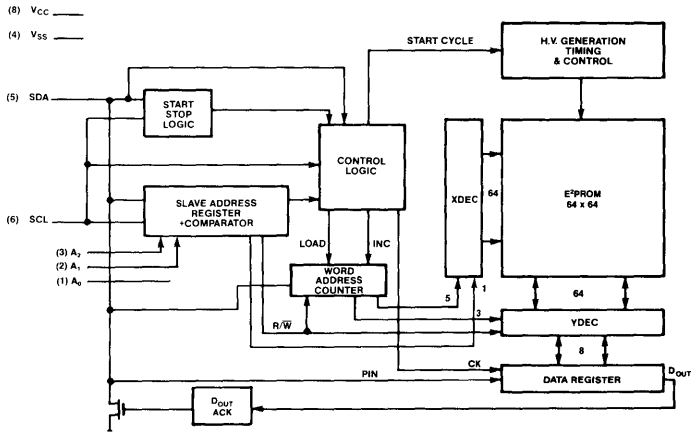
Xicor E^2PROMs are designed and tested for applications requiring extended endurance. Data retention is specified to be greater than 100 years.

2

PIN CONFIGURATION



FUNCTIONAL DIAGRAM



PIN NAMES

1 to 3	A_0 to A_2 Address Inputs
4	V_{SS}
5	SDA Serial Data
6	SCL Serial Clock
7	**Test Input → to V_{SS}**
8	V_{CC}

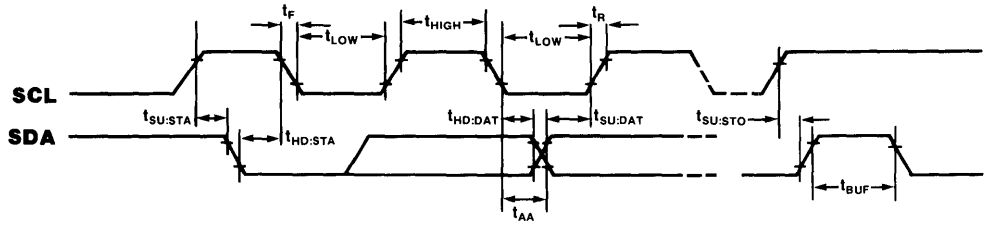
ABSOLUTE MAXIMUM RATINGS*

Temperature Under Bias ..... −10°C to +85°C
Storage Temperature ..... −65°C to +150°C
Voltage on any Pin with
Respect to V_{SS} ..... −1.0V to +7V
D.C. Output Current ..... 5 mA
Lead Temperature (Soldering,
10 Seconds) ..... 300°C

*COMMENT

Stresses above those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. This is a stress rating only and the functional operation of the device at these or any other conditions above those indicated in the operational sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

Bus Timing



A.C. CHARACTERISTICS LIMITS

Symbol	Parameter	Min.	Typ.(1)	Max.	Units	Test Conditions
f_{SCL}	SCL clock frequency	0		100	KHz	
T_I	Noise suppression time constant at SCL, SDA inputs		1		µs	
t_{AA}	SCL low to SDA data out valid	0.3	1.5	3.5	µs	
t_{BUF}	Time the bus must be free before a new transmission can start	4.7			µs	
$t_{HD:STA}$	Start condition hold time	4.0			µs	
t_{LOW}	Clock low period	4.7			µs	
t_{HIGH}	Clock high period	4.0			µs	
$t_{SU:STA}$	Start condition set-up time (for a repeated start condition)	4.7			µs	
$t_{HD:DAT}$	Data in hold time	0			µs	
$t_{SU:DAT}$	Data in set-up time	250			ns	
t_R	SDA and SCL rise time			1	µs	
t_F	SDA and SCL fall time			300	ns	
$t_{SU:STO}$	Stop condition set-up time	4.7			µs	

Note: (1) Typical values are for T_A = 25°C and nominal supply voltage (5v).

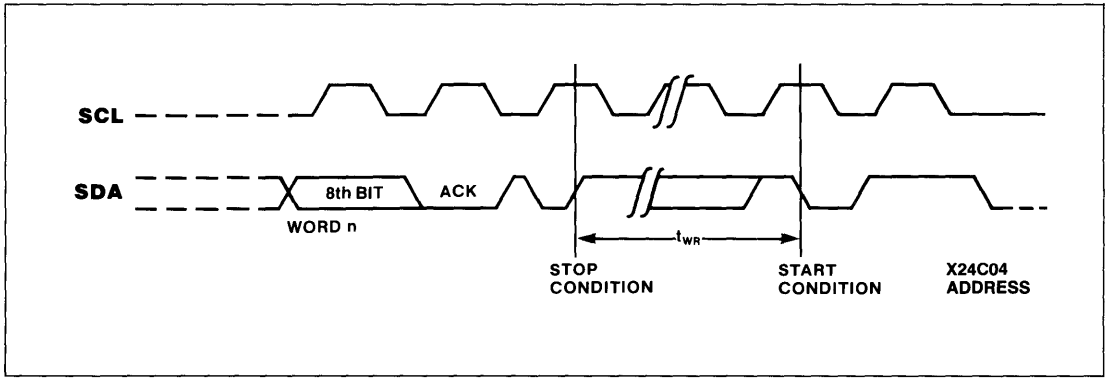
Write Cycle Limits

Symbol	Parameter	Min.	Typ.(1)	Max.	Units
t_{WR}	Write Cycle Time	—	5	10	ms

Note: (1) Typical values are for T_A = 25°C and nominal supply voltage (5v).

The write cycle time is the time from a valid stop condition of a write sequence to the end of the internal erase/program cycle. During the write cycle, the X24C04 bus interface circuits are disabled, SDA is allowed to remain high, and the device does not respond to its slave address.

Write Cycle Timing



PIN DESCRIPTIONS

Serial Clock (SCL)

The SCL input is used to clock all data into and out of the device.

Serial Data (SDA)

SDA is a bidirectional pin used to transfer data into and out of the device. It is an open drain output and may be wire-ANDed with any number of open drain or open collector outputs.

Address (A_0)

A_0 is unused by the X24C04, however, it must be tied to V_{SS} to insure proper device operation.

Address (A_1, A_2)

The Address inputs are used to set the least significant two bits of the six bit slave address. The inputs are static, and should be tied HIGH or LOW, forming one unique address per device.

DEVICE OPERATION

The X24C04 supports a bidirectional bus oriented protocol. The protocol defines any device that sends data onto the bus as a transmitter, and the receiving device as the receiver. The device controlling the transfer is a master and the device being controlled is the slave. The master will always initiate data transfers, and provide the clock for both transmit and receive operations. Therefore, the X24C04 will be considered a slave in all applications.

Clock and Data Conventions

Data states on the SDA line can change only during SCL LOW. SDA state changes during SCL HIGH are reserved for indicating start and stop conditions. Refer to Figures 1 and 2.

Start Condition

All commands are preceded by the start condition, which is a HIGH to LOW transition of SDA when SCL is HIGH. The X24C04 continuously monitors the SDA and SCL lines for the start condition and will not respond to any command until this condition has been met.

Figure 1: Data Validity

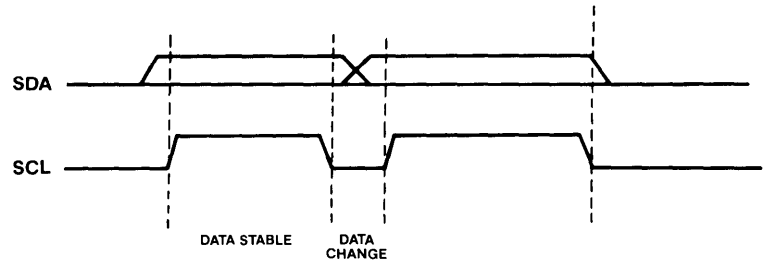
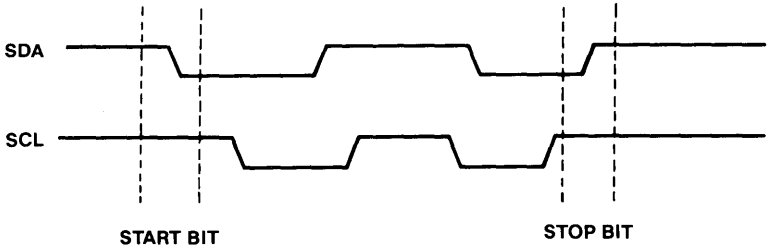


Figure 2: Definition of Start and Stop



Stop Condition

All communications are terminated by a stop condition, which is a LOW to HIGH transition of SDA when SCL is HIGH. The stop condition is also used by the X24C04 to place the device in the standby power mode.

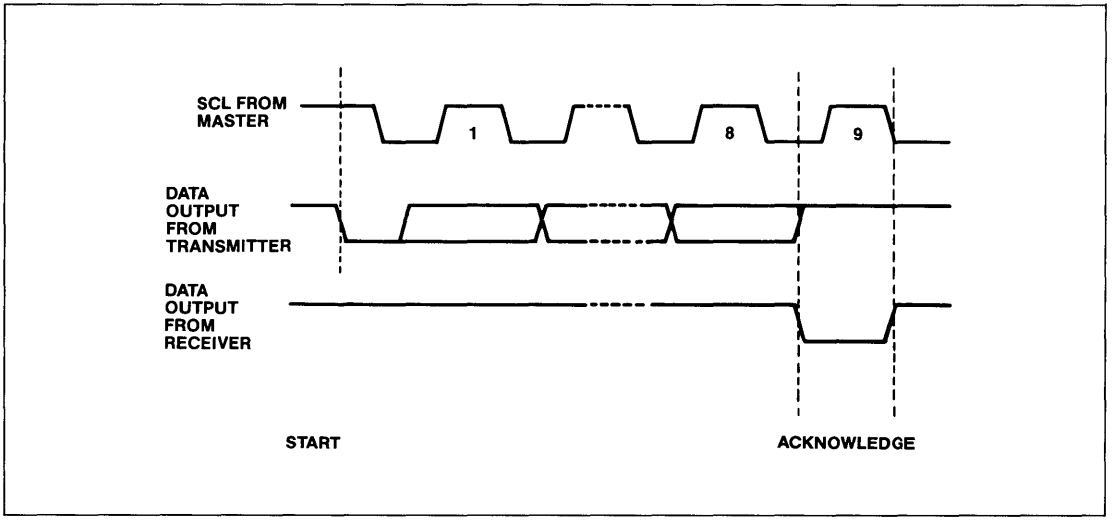
Acknowledge

Acknowledge is a software convention used to indicate successful data transfers. The transmitting device, either master or slave, will release the bus after transmitting eight bits. During the ninth clock cycle the receiver will pull the SDA line LOW to acknowledge that it received the eight bits of data. Refer to Figure 3.

The X24C04 will always respond with an acknowledge after recognition of a start condition and its slave address. If both the device and a write operation have been selected, the X24C04 will respond with an acknowledge after the receipt of each subsequent eight bit word.

In the read mode the X24C04 will transmit eight bits of data, release the SDA line and monitor the line for an acknowledge. If an acknowledge is detected and no stop condition is generated by the master, the X24C04 will continue to transmit data. If an acknowledge is not detected, the X24C04 will terminate further data transmissions and await the stop condition to return to the standby power mode.

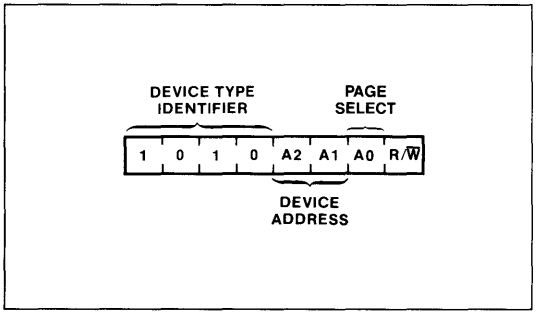
Figure 3: Acknowledge Response From Receiver



DEVICE ADDRESSING

Following a start condition the bus master must output the address of the slave it is accessing. The most significant four bits of the slave address are the device type identifier (see Figure 4). For the X24C04 this is fixed as 1010[B].

Figure 4: Slave Address



The next two significant bits address a particular device. A system could have up to four X24C04 devices on the bus (see Figure 10). The four addresses are defined by the state of the A_1 and A_2 inputs.

The next bit of the slave address field (bit 1) is the page select bit. It is used by the host to toggle between the two 256 word pages of memory.

The last bit of the slave address defines the operation to be performed. When set to one a read operation is selected, when set to zero a write operation is selected.

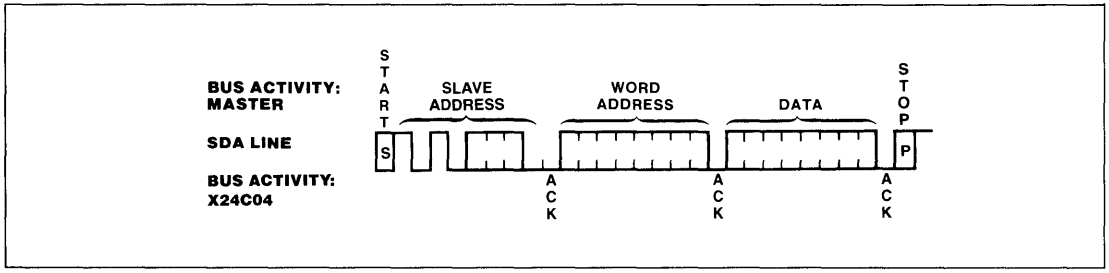
Following the start condition, the X24C04 monitors the SDA bus comparing the slave address being transmitted with its address (device type and state of A_1, and A_2 inputs). Upon a compare the X24C04 outputs an acknowledge on the SDA line. Depending on the state of the R/$\overline{W}$ bit, the X24C04 will execute a read or write operation.

WRITE OPERATIONS

Byte Write

For a write operation, the X24C04 requires a second address field. This address field is the word address, comprised of eight bits, providing access to any one of the 256 words of memory. Upon receipt of the word address the X24C04 responds with an acknowledge, and awaits the next eight bits of data, again responding with an acknowledge. The master then terminates the transfer by generating a stop condition, at which time the X24C04 begins the internal write cycle to the nonvolatile memory. While the internal write cycle is in progress the X24C04 inputs are disabled, and the device will not respond to any requests from the master. Refer to Figure 5 for the address, acknowledge and data transfer sequence.

Figure 5: Byte Write



Page Write

The X24C04 is capable of an eight byte page write operation. It is initiated in the same manner as the byte write operation, but instead of terminating the write cycle after the first data word is transferred, the master can transmit up to seven more words. After the receipt of each word, the X24C04 will respond with an acknowledge.

After the receipt of each word, the three low order address bits are internally incremented by one. The high order five bits of the address remain constant. If the master should transmit more than eight words prior to generating the stop condition, the address counter will "roll over" and the previously written data will be overwritten. As with the byte write operation, all inputs are disabled until completion of the internal write cycle. Refer to Figure 6 for the address, acknowledge and data transfer sequence.

Acknowledge Polling

The disabling of the inputs can be used to take advantage of the typical 5ms write cycle time. The bus master can continually transmit the slave address and no acknowledge will be returned if the X24C04 is internally writing to the E^2PROM array. As soon as the internal cycle is complete the X24C04 will respond to its slave address.

Read Operations

Read operations are initiated in the same manner as write operations with the exception that the bit of the slave address is set to a one. There are three basic read operations: current address read, random read and sequential read.

Current Address Read

Internally the X24C04 contains an address counter that maintains the address of the last word accessed, incremented by one. Therefore, if the last access (either a read or write) was to address n, the next read operation would access data from address n+1. Upon receipt of the slave address with $R/\overline{W}$ set to one, the X24C04 issues an acknowledge and transmits the eight bit word. The master does not acknowledge the transfer but does generate a stop condition and the X24C04 discontinues transmission. Refer to Figure 7 for the sequence of address, acknowledge and data transfer.

Figure 6: Page Write

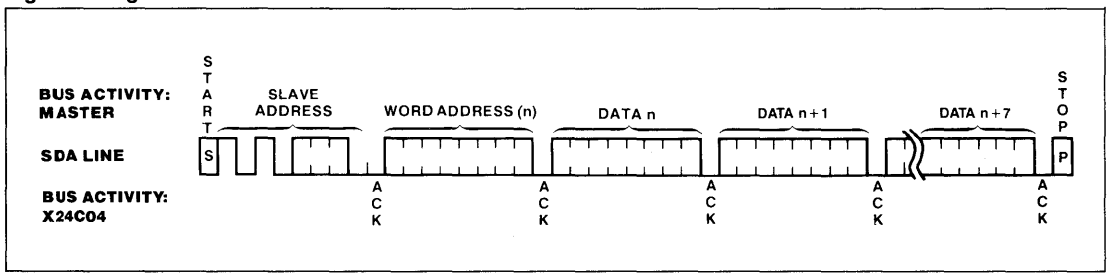
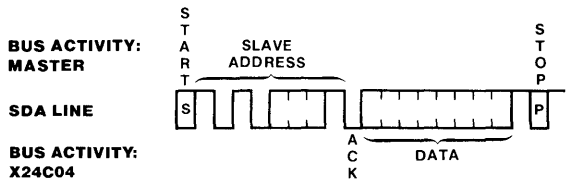


Figure 7: Current Address Read



Random Read

Random read operations allow the master to access any memory location in a random manner. Prior to issuing the slave address with the R/$\overline{W}$ bit set to one, the master must first perform a "dummy" write operation. The master issues the start condition, and the slave address followed by the word address it is to read. After the word address acknowledge, the master immediately reissues the start condition and the slave address with the R/$\overline{W}$ bit set to one. This will be followed by an acknowledge from the X24C04 and then by the eight bit word. The master does not acknowledge the transfer but does generate a stop condition and the X24C04 discontinues transmission. Refer to Figure 8 for the address, acknowledge and data transfer sequence.

Sequential Read

Sequential reads can be initiated as either a current address read or random access read. The first word is transmitted as with the other read modes, however, the master now responds with an acknowledge, indicating it requires additional data. The X24C04 continues to output data for each acknowledge received. The read operation is terminated by the master not responding with an acknowledge and generating a stop condition.

The data output is sequential, with the data from address n followed by the data from n+1. The address counter for read operations increments all eight address bits, allowing the entire memory contents of the current 256 word page to be serially read during one operation. If more than 256 words are read, the counter "rolls over" and the X24C04 continues to output data from the same 256 word page for each acknowledge received. Refer to Figure 9 for the address, acknowledge and data transfer sequence.

Figure 8: Random Read

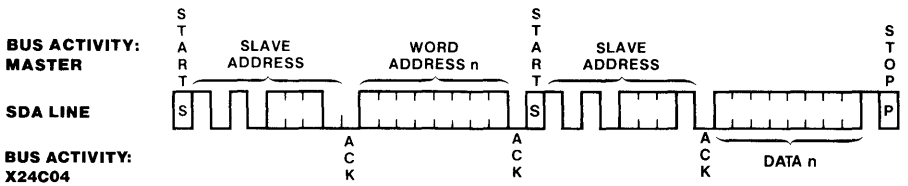


Figure 9: Sequential Read

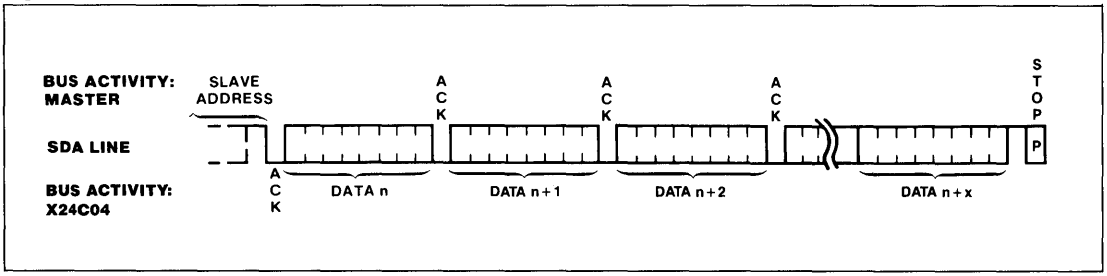
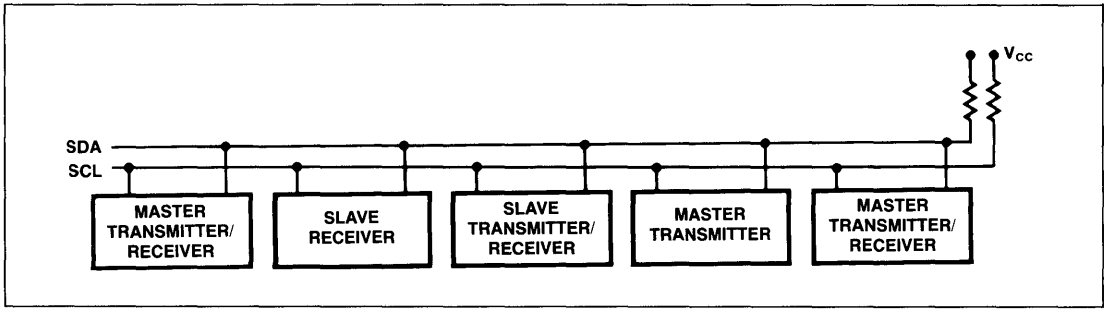


Figure 10: Typical System Configuration



16K X24C16 2048 x 8 Bit

Electrically Erasable PROM

TYPICAL FEATURES

- **Low Cost**
- **Low Power CMOS**
  - **— 2mA Active Current**
  - **— 50μA Standby Current**
- **Internally Organized as Eight Pages**
  - **— Each 256 x 8**
- **2 Wire Serial Interface**
- **Provides Bidirectional Data Transfer Protocol**
- **Eight Byte Page Write Mode**
  - **— Minimizes Total Write Time per Byte**
- **Self Timed Write Cycle**
  - **— Typical Write Cycle Time of 5ms**
- **Data Retention Greater Than 100 Years**

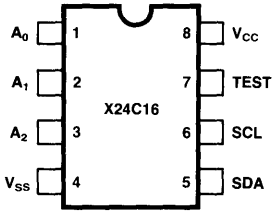
DESCRIPTION

The X24C16 is a CMOS 16,384 bit serial E^2PROM, internally organized as eight 256 x 8 pages. The X24C16 features a serial interface and software protocol allowing operation on a two wire bus.

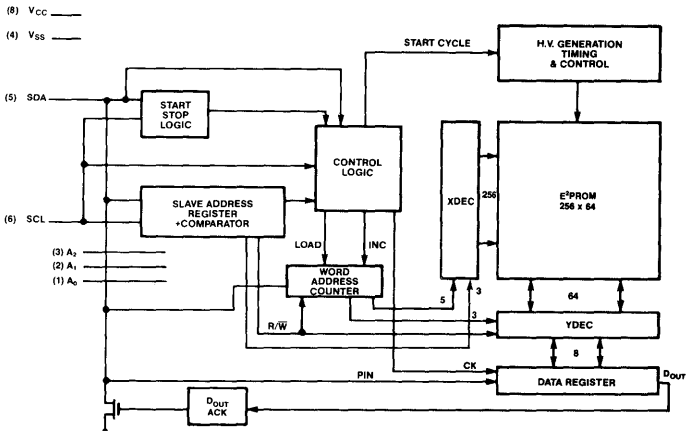
Xicor E^2PROMs are designed and tested for applications requiring extended endurance. Data retention is specified to be greater than 100 years.

2

PIN CONFIGURATION



FUNCTIONAL DIAGRAM



PIN NAMES

1 to 3	A_0 to A_2 Address Inputs
4	V_{SS}
5	SDA Serial Data
6	SCL Serial Clock
7	**Test Input → to V_{SS}**
8	V_{CC}

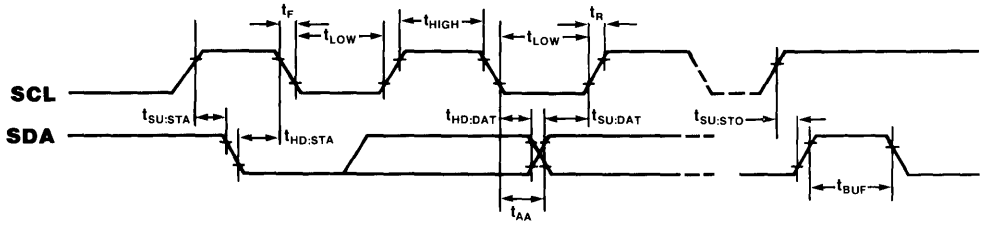
ABSOLUTE MAXIMUM RATINGS*

Temperature Under Bias ..... −10°C to +85°C
Storage Temperature ..... −65°C to +150°C
Voltage on any Pin with
Respect to V_{SS} ..... −1.0V to +7V
D.C. Output Current ..... 5 mA
Lead Temperature (Soldering,
10 Seconds) ..... 300°C

*COMMENT

Stresses above those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. This is a stress rating only and the functional operation of the device at these or any other conditions above those indicated in the operational sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

Bus Timing



A.C. CHARACTERISTICS LIMITS

Symbol	Parameter	Min.	Typ.(1)	Max.	Units	Test Conditions
f_{SCL}	SCL clock frequency	0		100	KHz	
T_I	Noise suppression time constant at SCL, SDA inputs		1		µs	
t_{AA}	SCL low to SDA data out valid	0.3	1.5	3.5	µs	
t_{BUF}	Time the bus must be free before a new transmission can start	4.7			µs	
$t_{HD:STA}$	Start condition hold time	4.0			µs	
t_{LOW}	Clock low period	4.7			µs	
t_{HIGH}	Clock high period	4.0			µs	
$t_{SU:STA}$	Start condition set-up time (for a repeated start condition)	4.7			µs	
$t_{HD:DAT}$	Data in hold time	0			µs	
$t_{SU:DAT}$	Data in set-up time	250			ns	
t_R	SDA and SCL rise time			1	µs	
t_F	SDA and SCL fall time			300	ns	
$t_{SU:STO}$	Stop condition set-up time	4.7			µs	

Note: (1) Typical values are for T_A = 25°C and nominal supply voltage (5v).

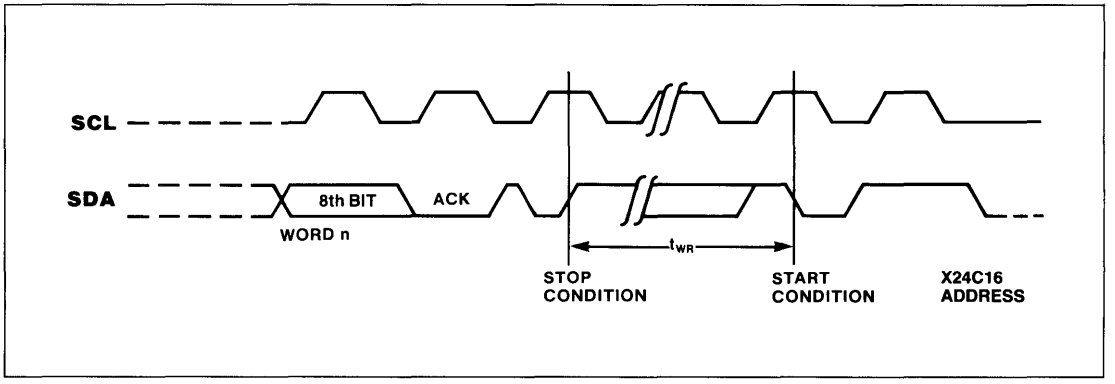
Write Cycle Limits

Symbol	Parameter	Min.	Typ.(1)	Max.	Units
t_{WR}	Write Cycle Time	—	5	10	ms

Note: (1) Typical values are for T_A = 25°C and nominal supply voltage (5v).

The write cycle time is the time from a valid stop condition of a write sequence to the end of the internal erase/program cycle. During the write cycle, the X24C16 bus interface circuits are disabled, SDA is allowed to remain high, and the device does not respond to its slave address.

Write Cycle Timing



PIN DESCRIPTIONS

Serial Clock (SCL)

The SCL input is used to clock all data into and out of the device.

Serial Data (SDA)

SDA is a bidirectional pin used to transfer data into and out of the device. It is an open drain output and may be wire-ANDed with any number of open drain or open collector outputs.

Address (A_0, A_1, A_2)

The A_0, A_1 and A_2 inputs are unused by the X24C16, however, they must be tied to V_{SS} to insure proper device operation.

DEVICE OPERATION

The X24C16 supports a bidirectional bus oriented protocol. The protocol defines any device that sends data onto the bus as a transmitter, and the receiving device as the receiver. The device controlling the transfer is a master and the device being controlled is the slave. The master will always initiate data transfers, and provide the clock for both transmit and receive operations. Therefore, the X24C16 will be considered a slave in all applications.

Clock and Data Conventions

Data states on the SDA line can change only during SCL LOW. SDA state changes during SCL HIGH are reserved for indicating start and stop conditions. Refer to Figures 1 and 2.

Start Condition

All commands are preceded by the start condition, which is a HIGH to LOW transition of SDA when SCL is HIGH. The X24C16 continuously monitors the SDA and SCL lines for the start condition and will not respond to any command until this condition has been met.

Figure 1: Data Validity

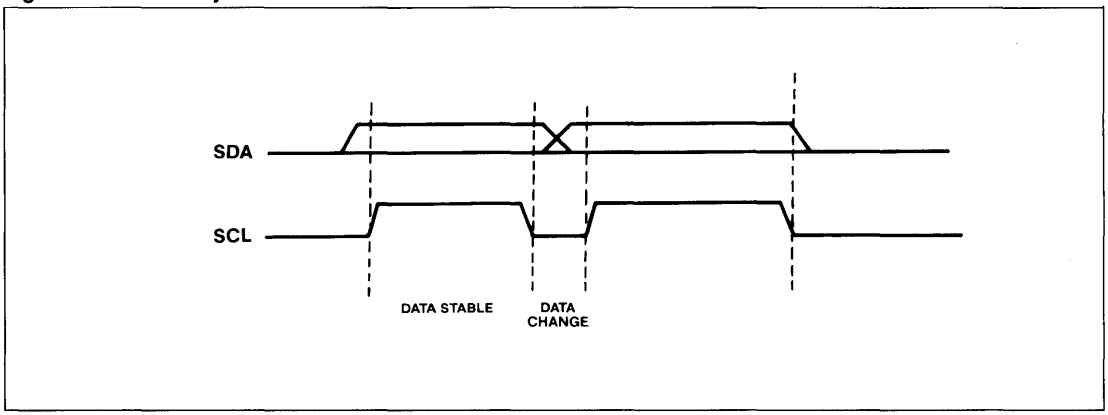
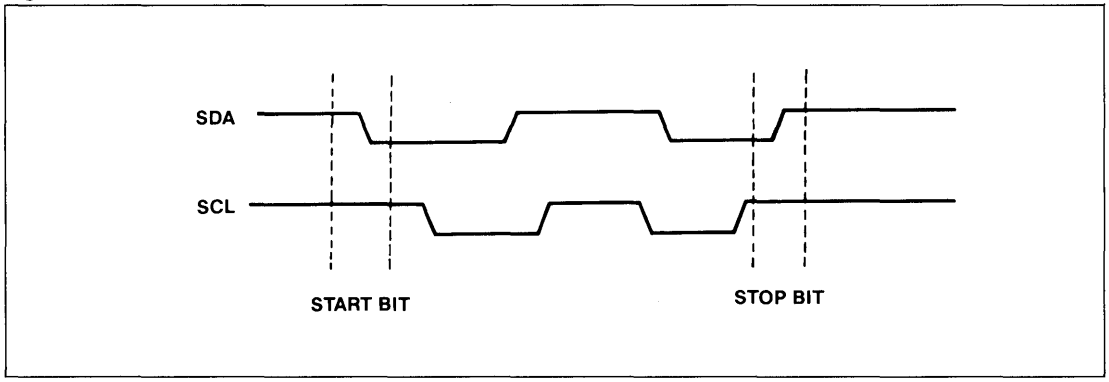


Figure 2: Definition of Start and Stop



Stop Condition

All communications are terminated by a stop condition, which is a LOW to HIGH transition of SDA when SCL is HIGH. The stop condition is also used by the X24C16 to place the device in the standby power mode.

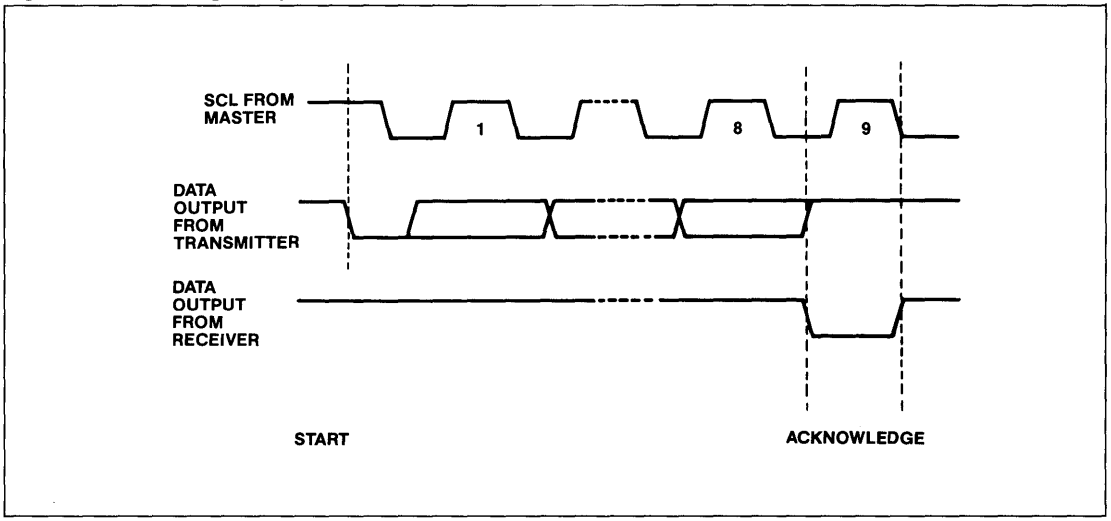
Acknowledge

Acknowledge is a software convention used to indicate successful data transfers. The transmitting device, either master or slave, will release the bus after transmitting eight bits. During the ninth clock cycle the receiver will pull the SDA line LOW to acknowledge that it received the eight bits of data. Refer to Figure 3.

The X24C16 will always respond with an acknowledge after recognition of a start condition and its slave address. If both the device and a write operation have been selected, the X24C16 will respond with an acknowledge after the receipt of each subsequent eight bit word.

In the read mode the X24C16 will transmit eight bits of data, release the SDA line and monitor the line for an acknowledge. If an acknowledge is detected and no stop condition is generated by the master, the X24C16 will continue to transmit data. If an acknowledge is not detected, the X24C16 will terminate further data transmissions and await the stop condition to return to the standby power mode.

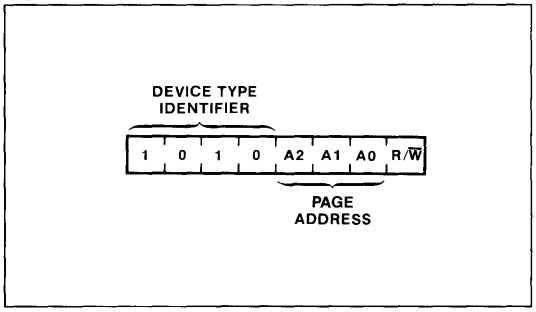
Figure 3: Acknowledge Response From Receiver



DEVICE ADDRESSING

Following a start condition the bus master must output the address of the slave it is accessing. The most significant four bits of the slave address are the device type identifier (see Figure 4). For the X24C16 this is fixed as 1010[B].

Figure 4: Slave Address



The next three bits of the slave address field are the page select bits. They are used by the master device to select which of the eight 256 word pages of memory are to be accessed. It should be noted, the protocol limits the size of memory to eight pages of 256 words; therefore, the protocol can support only one X24C16 per system.

The last bit of the slave address defines the operation to be performed. When set to one a read operation is selected, when set to zero a write operation is selected.

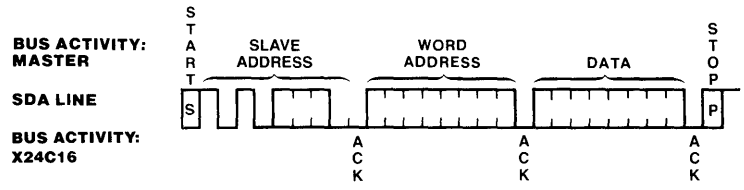
Following the start condition, the X24C16 monitors the SDA bus comparing the slave address being transmitted with its slave address. Upon a compare the X24C16 outputs an acknowledge on the SDA line. Depending on the state of the R/$\overline{W}$ bit, the X24C16 will execute a read or write operation.

WRITE OPERATIONS

Byte Write

For a write operation, the X24C16 requires a second address field. This address field is the word address, comprised of eight bits, providing access to any one of the 256 words in the selected page of memory. Upon receipt of the word address the X24C16 responds with an acknowledge, and awaits the next eight bits of data, again responding with an acknowledge. The master then terminates the transfer by generating a stop condition, at which time the X24C16 begins the internal write cycle to the nonvolatile memory. While the internal write cycle is in progress the X24C16 inputs are disabled, and the device will not respond to any requests from the master. Refer to Figure 5 for the address, acknowledge and data transfer sequence.

Figure 5: Byte Write



Page Write

The X24C16 is capable of an eight byte page write operation. It is initiated in the same manner as the byte write operation, but instead of terminating the write cycle after the first data word is transferred, the master can transmit up to seven more words. After the receipt of each word, the X24C16 will respond with an acknowledge.

After the receipt of each word, the three low order address bits are internally incremented by one. The high order five bits of the word address remain constant. If the master should transmit more than eight words prior to generating the stop condition, the address counter will "roll over" and the previously written data will be overwritten. As with the byte write operation, all inputs are disabled until completion of the internal write cycle. Refer to Figure 6 for the address, acknowledge and data transfer sequence.

Acknowledge Polling

The disabling of the inputs can be used to take advantage of the typical 5ms write cycle time. The bus master can continually transmit the slave address and no acknowledge will be returned if the X24C16 is internally writing to the E^2PROM array. As soon as the internal cycle is complete the X24C16 will respond to its slave address.

Read Operations

Read operations are initiated in the same manner as write operations with the exception that the R/$\overline{W}$ bit of the slave address is set to a one. There are three basic read operations: current address read, random read and sequential read.

Current Address Read

Internally the X24C16 contains an address counter that maintains the address of the last word accessed, incremented by one. Therefore, if the last access (either a read or write) was to address n, the next read operation would access data from address n+1. Upon receipt of the slave address with R/$\overline{W}$ set to one, the X24C16 issues an acknowledge and transmits the eight bit word. The master will not acknowledge the transfer but does generate a stop condition and the X24C16 discontinues transmission. Refer to Figure 7 for the sequence of address, acknowledge and data transfer.

Figure 6: Page Write

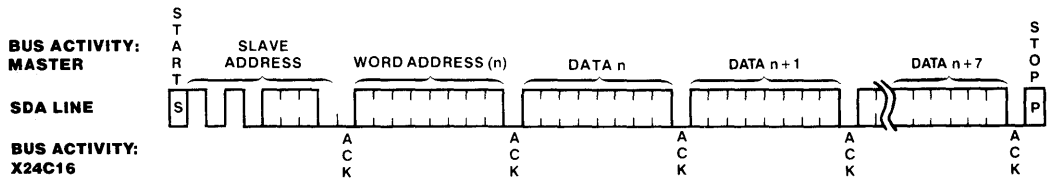
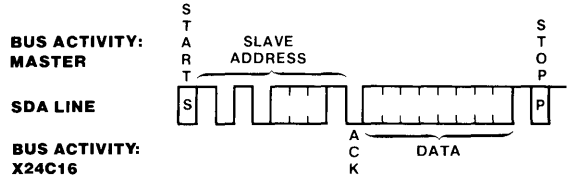


Figure 7: Current Address Read



Random Read

Random read operations allow the master to access any memory location in a random manner. Prior to issuing the slave address with the R/$\overline{W}$ bit set to one, the master must first perform a "dummy" write operation. The master issues the start condition, and the slave address followed by the word address it is to read. After the word address acknowledge, the master immediately reissues the start condition and the slave address with the R/$\overline{W}$ bit set to one. This will be followed by an acknowledge from the X24C16 and then by the eight bit word. The master will not acknowledge the transfer but does generate the stop condition and the X24C16 discontinues transmission. Refer to Figure 8 for the address, acknowledge and data transfer sequence.

Sequential Read

Sequential reads can be initiated as either a current address read or random access read. The first word is transmitted as with the other read modes, however, the master now responds with an acknowledge, indicating it requires additional data. The X24C16 continues to output data for each acknowledge received. The read operation is terminated by the master not responding with an acknowledge and generating a stop condition.

The data output is sequential, with the data from address n followed by the data from n+1. The address counter for read operations increments all eight word address bits, allowing the entire memory contents of the current 256 word page to be serially read during one operation. If more than 256 words are read the counter "rolls over" and the X24C16 continues to output data from the same 256 word page for each acknowledge received. Refer to Figure 9 for the address, acknowledge and data transfer sequence.

Figure 8: Random Read

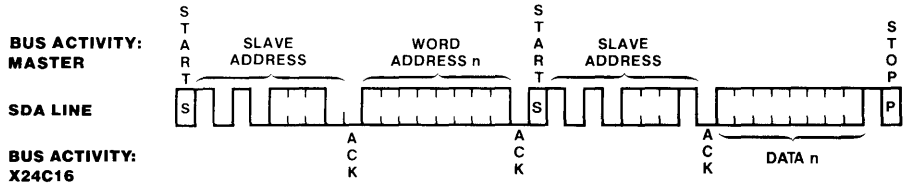


Figure 9: Sequential Read

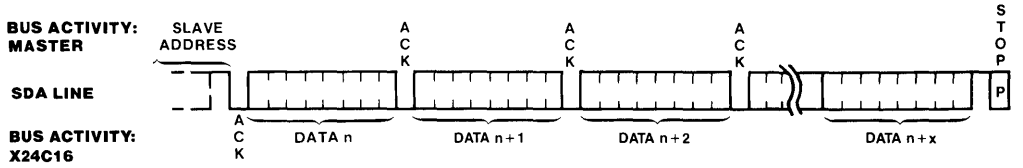
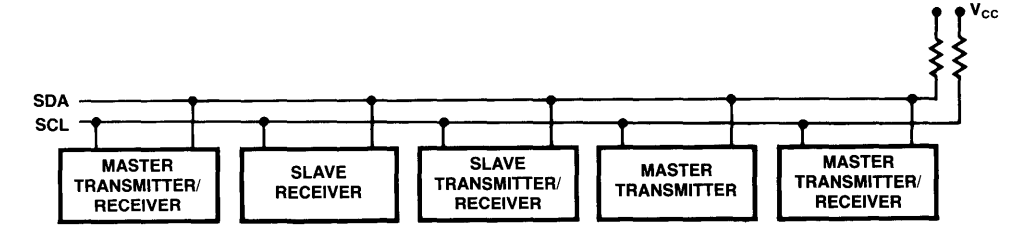


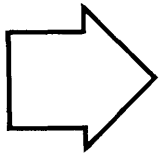
Figure 10: Typical System Configuration



Xicor

NOVRAM* Data Sheets 1

Serial I/O Data Sheets 2



E^2PROM Data Sheets 3

X2804A, X2804AI 3-1
X2804AM 3-7
X2816A, X2816AI 3-13
X2816AM 3-19
X2816B 3-25
X2816H 3-31
X2864A-20, X2864AI-20 3-33
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X2864B 3-65
X2864H 3-71
X28C64 3-73
X28256 3-75
X28C256 3-81
X2616 3-83
X2664 3-85

Electrically Erasable PROM

FEATURES

- **Simple Byte Write Operation**
  - **— No High Voltages Necessary**
  - **— Single TTL Level $\overline{WE}$ Signal Modifies Data**
  - **— Internally Latched Addresses and Data**
  - **— Self Timed Write**
  - **— Noise Protected $\overline{WE}$ Pin**
- **JEDEC Approved Pinout for Byte-Wide Memories**
- **Reliable N-Channel Floating Gate MOS Technology**
- **Single 5 Volt Supply**
- **Byte Write Time: 10ms Max.**
- **Fast Access Time: 250ns Max.**
- **Low Power Dissipation**
  - **— Active Current: 80mA Max.**
  - **— Standby Current: 50mA Max.**

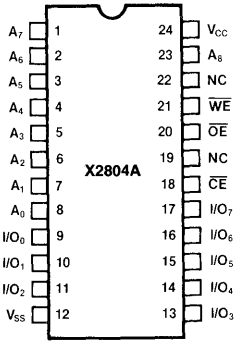
DESCRIPTION

The Xicor X2804A is a 512 x 8 E^2PROM, fabricated with the same reliable N-channel floating gate MOS technology used in all Xicor 5 volt programmable nonvolatile memories. The X2804A features the JEDEC approved pinout for byte-wide memories, compatible with industry standard RAMs, ROMs and EPROMs.

Xicor E^2PROMs are designed and tested for applications requiring extended endurance. Refer to Device Operation for further endurance information. Data retention is specified to be greater than 100 years.

3

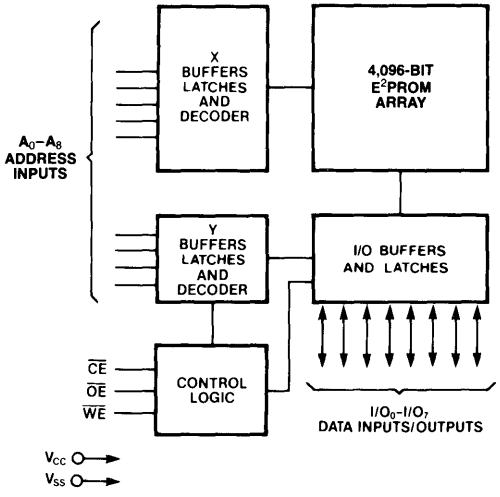
PIN CONFIGURATION



PIN NAMES

A_0–A_8	Address Inputs
I/O_0–I/O_7	Data Input/Output
$\overline{WE}$	Write Enable
$\overline{CE}$	Chip Enable
$\overline{OE}$	Output Enable
V_{CC}	+5V
V_{SS}	Ground
NC	No Connect

FUNCTIONAL DIAGRAM



ABSOLUTE MAXIMUM RATINGS*

Temperature Under Bias X2804A ..... −10°C to +85°C
X2804AI ..... −65°C to +135°C
Storage Temperature ..... −65°C to +150°C
Voltage on any Pin with
Respect to Ground ..... −1.0V to +7V
D.C. Output Current ..... 5 mA
Lead Temperature (Soldering,
10 Seconds) ..... 300°C

*COMMENT

Stresses above those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. This is a stress rating only and the functional operation of the device at these or any other conditions above those indicated in the operational sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

D.C. OPERATING CHARACTERISTICS

X2804A T_A = 0°C to +70°C, V_{CC} = +5V ±5%, unless otherwise specified.
X2804AI T_A = −40°C to +85°C, V_{CC} = +5V ±10%, unless otherwise specified.

Symbol	Parameter	X2804A Limits		X2804AI Limits		Units	Test Conditions
		Min.	Max.	Min.	Max.		
I_{CC}	V_{CC} Current (Active)		80		100	mA	$\overline{CE}$ = $\overline{OE}$ = V_{IL} All I/O's = Open Other Inputs = V_{CC}
I_{SB}	V_{CC} Current (Standby)		50		60	mA	$\overline{CE}$ = V_{IH}, $\overline{OE}$ = V_{IL} All I/O's = Open Other Inputs = V_{CC}
I_{LI}	Input Leakage Current		10		10	µA	V_{IN} = GND to V_{CC}
I_{LO}	Output Leakage Current		10		10	µA	V_{OUT} = GND to V_{CC}
V_{IL}	Input Low Voltage	−1.0	0.8	−1.0	0.8	V	
V_{IH}	Input High Voltage	2.0	V_{CC} +0.5	2.2	V_{CC} +1.0	V	
V_{OL}	Output Low Voltage		0.4		0.4	V	I_{OL} = 2.1 mA
V_{OH}	Output High Voltage	2.4		2.4		V	I_{OH} = −400 µA

CAPACITANCE T_A = 25°C, f = 1.0 MHz, V_{CC} = 5V

Symbol	Test	Max.	Unit	Conditions
$C_{I/O}$[1]	Input/Output Capacitance	10	pF	$V_{I/O}$ = 0V
C_{IN}[1]	Input Capacitance	6	pF	V_{IN} = 0V

Note: (1) This parameter is periodically sampled and not 100% tested.

A.C. CONDITIONS OF TEST

Input Pulse Levels	0 to 3.0 Volts
Input Rise and Fall Times	10 nsec
Input and Output Timing Levels	1.5 Volts
Output Load	1 TTL Gate and C_L = 100 pF

MODE SELECTION

$\overline{CE}$	$\overline{OE}$	$\overline{WE}$	Mode	I/O	Power
L	L	H	Read	D_{OUT}	Active
L	H	L	Write	D_{IN}	Active
H	X	X	Standby and Write Inhibit	High Z	Standby
X	L	X	Write Inhibit	—	—
X	X	H	Write Inhibit	—	—

A.C. CHARACTERISTICS

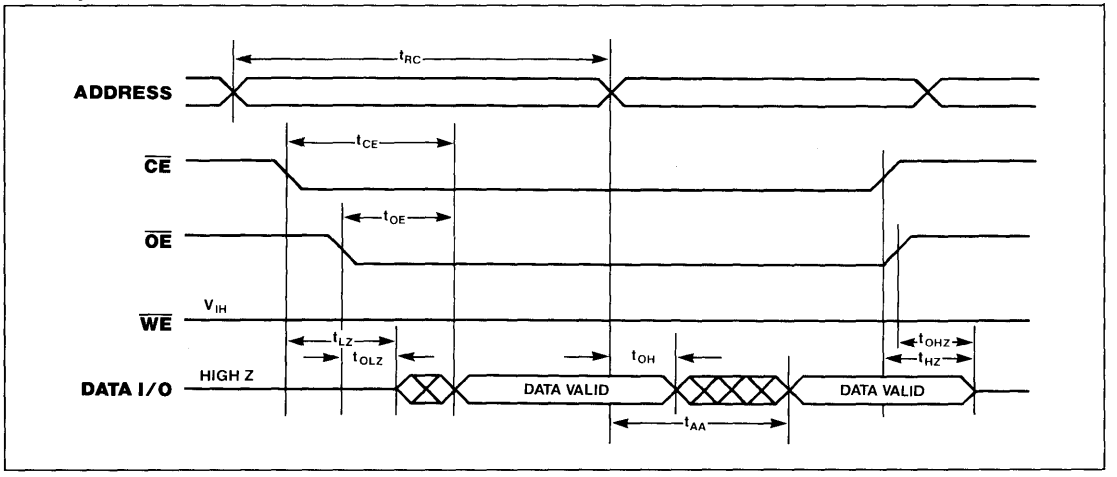
X2804A T_A = 0°C to +70°C, V_{CC} = +5V ±5%, unless otherwise specified.
X2804AI T_A = −40°C to +85°C, V_{CC} = +5V ±10%, unless otherwise specified.

Read Cycle Limits

Symbol	Parameter	X2804A-25 X2804AI-25		X2804A X2804AI		X2804A-35 X2804AI-35		X2804A-45 X2804AI-45		Units
		Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	
t_{RC}	Read Cycle Time	250		300		350		450		ns
t_{CE}	Chip Enable Access Time		250		300		350		450	ns
t_{AA}	Address Access Time		250		300		350		450	ns
t_{OE}	Output Enable Access Time		120		120		135		150	ns
t_{LZ}	Chip Enable to Output in Low Z	10		10		10		10		ns
t_{HZ}	Chip Disable to Output in High Z	10	100	10	100	10	100	10	100	ns
t_{OLZ}	Output Enable to Output in Low Z	50		50		50		50		ns
t_{OHZ}	Output Disable to Output in High Z	10	100	10	100	10	100	10	100	ns
t_{OH}	Output Hold from Address Change	20		20		20		20		ns

3

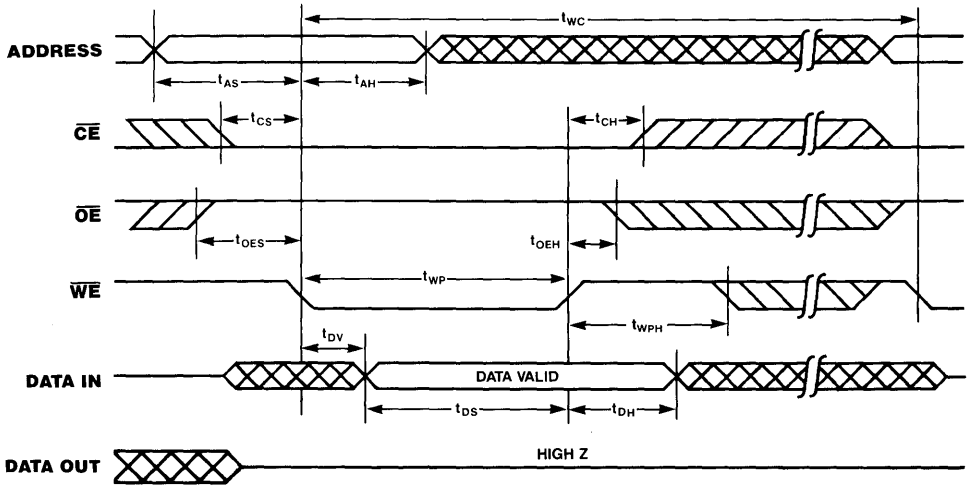
Read Cycle



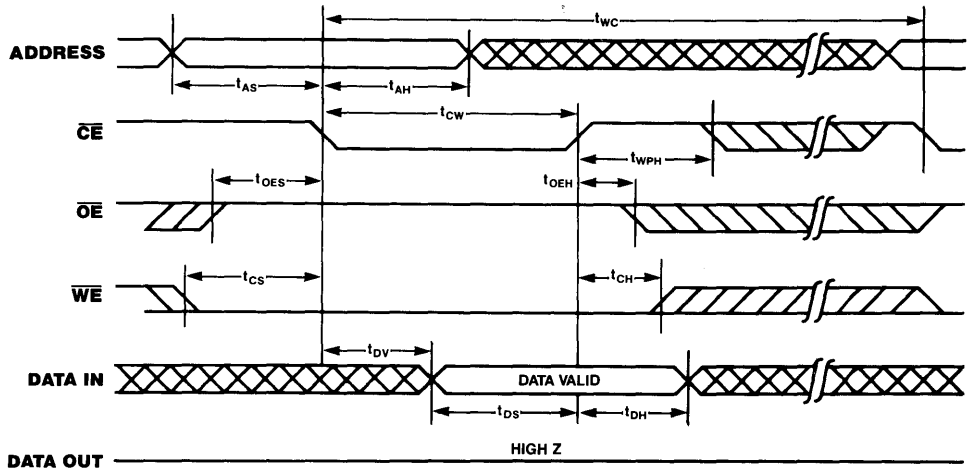
Write Cycle Limits

Symbol	Parameter	X2804A-25 X2804AI-25		X2804A X2804AI		X2804A-35 X2804AI-35		X2804A-45 X2804AI-45		Units
		Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	
t_{WC}	Write Cycle Time	10		10		10		10		ms
t_{AS}	Address Set-Up Time	10		10		10		10		ns
t_{AH}	Address Hold Time	120		120		150		150		ns
t_{CS}	Write Set-Up Time	0		0		0		0		ns
t_{CH}	Write Hold Time	0		0		0		0		ns
t_{CW}	Chip Enable to End of Write Input	150		150		175		230		ns
t_{OES}	Output Enable Set-Up Time	10		10		10		10		ns
t_{OEH}	Output Enable Hold Time	10		10		10		10		ns
t_{WP}	Write Pulse Width	150		150		175		230		ns
t_{WPH}	Write Control Recovery	50		50		50		50		ns
t_{DV}	Data Valid Time		1		1		1		1	µs
t_{DS}	Data Set-Up Time	120		135		175		230		ns
t_{DH}	Data Hold Time	15		15		20		30		ns

$\overline{WE}$ Controlled Write Cycle



$\overline{CE}$ Controlled Write Cycle



PIN DESCRIPTIONS

Addresses (A_0–A_8)

The Address inputs select an 8-bit memory location during a read or write operation.

Chip Enable ($\overline{CE}$)

The Chip Enable input must be LOW to enable all read/write operations. When $\overline{CE}$ is HIGH, power consumption is reduced.

Output Enable ($\overline{OE}$)

The Output Enable input controls the data output buffers and is used to initiate read operations.

Data In/Data Out (I/O_0–I/O_7)

Data is written to or read from the X2804A through the I/O pins.

Write Enable ($\overline{WE}$)

The Write Enable input controls the writing of data to the X2804A.

DEVICE OPERATION

READS

Read operations are initiated by both $\overline{OE}$ and $\overline{CE}$ LOW. The read operation is terminated by either $\overline{CE}$ or $\overline{OE}$ returning HIGH. This 2-line control architecture eliminates bus contention in a system environment. The data bus will be in a high impedance state when either $\overline{OE}$ or $\overline{CE}$ is HIGH.

WRITES

Write operations are initiated when both $\overline{CE}$ and $\overline{WE}$ are LOW and $\overline{OE}$ is HIGH. The X2804A supports both a $\overline{CE}$ and $\overline{WE}$ controlled write cycle. That is, the address is latched by the falling edge of either $\overline{CE}$ or $\overline{WE}$, whichever occurs last. Similarly, the data is latched internally by the rising edge of either $\overline{CE}$ or $\overline{WE}$, whichever occurs first.

A byte write operation, once initiated, will automatically continue to completion, typically within 5ms. In order to take advantage of the typical write time as opposed to the maximum specified time, the user can poll the X2804A. The I/O pins are placed in the high impedance state during the internal programming cycle. Once the internal cycle is complete, the X2804A may be accessed without any limitations. Therefore, the host can poll an address with known data (preferably with zeroes), as soon as a compare is true, the X2804A is ready for another write cycle.

WRITE PROTECTION

There are three features that protect the nonvolatile data from inadvertent writes.

- Noise Protection—A $\overline{WE}$ pulse of less than 20ns will not initiate a write cycle.
- V_{CC} Sense—All functions are inhibited when V_{CC} is $\leq$3v, typically.
- Write Inhibit—Holding either $\overline{OE}$ LOW, $\overline{WE}$ HIGH or $\overline{CE}$ HIGH during power-on and power-off, will inhibit inadvertent writes.

ENDURANCE

Xicor E^2PROMs are designed and tested for applications requiring extended endurance. The Process average for endurance of Xicor E^2PROMs is approximately 1/2 million cycles, as documented in RR504, the *Xicor Reliability Report on Endurance.* Included in that report is a method for determining the expected endurance of the device based upon the specific application environment. RR504 and additional reliability reports are available from Xicor.

MASS PROGRAM

Mass chip program and erase modes may be used to accelerate test time when performing tests that require a large number of writes, such as device endurance testing. Additional information is available, upon request, from Xicor regarding these test modes.

Electrically Erasable PROM

FEATURES

- **Simple Byte Write Operation**
  - **No High Voltages Necessary**
  - **Single TTL Level $\overline{WE}$ Signal Modifies Data**
  - **Internally Latched Addresses and Data**
  - **Self Timed Write**
  - **Noise Protected $\overline{WE}$ Pin**
- **JEDEC Approved Pinout for Byte-Wide Memories**
- **Reliable N-Channel Floating Gate MOS Technology**
- **Single 5 Volt Supply**
- **Byte Write Time: 10ms Max.**
- **Fast Access Time: 300ns Max.**
- **Low Power Dissipation**
  - **Active Current: 100mA Max.**
  - **Standby Current: 60mA Max.**

DESCRIPTION

The Xicor X2804A is a 512 x 8 E^2PROM, fabricated with the same reliable N-channel floating gate MOS technology used in all Xicor 5 volt programmable nonvolatile memories. The X2804A features the JEDEC approved pinout for byte-wide memories, compatible with industry standard RAMs, ROMs and EPROMs.

Xicor E^2PROMs are designed and tested for applications requiring extended endurance. Refer to Device Operation for further endurance information. Data retention is specified to be greater than 100 years.

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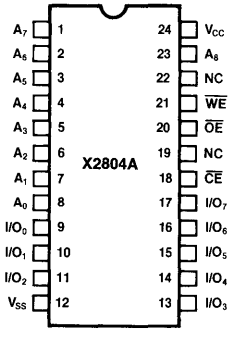
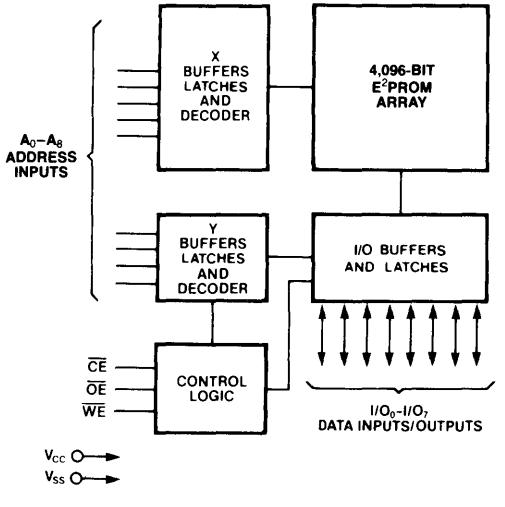
PIN CONFIGURATION



PIN NAMES

A_0–A_8	Address Inputs
I/O_0–I/O_7	Data Input/Output
$\overline{WE}$	Write Enable
$\overline{CE}$	Chip Enable
$\overline{OE}$	Output Enable
V_{CC}	+5V
V_{SS}	Ground
NC	No Connect

FUNCTIONAL DIAGRAM



ABSOLUTE MAXIMUM RATINGS*

Temperature Under Bias ..... −65°C to +135°C
Storage Temperature ..... −65°C to +150°C
Voltage on any Pin with
Respect to Ground ..... −1.0V to +7V
D.C. Output Current ..... 5 mA
Lead Temperature (Soldering,
10 Seconds) ..... 300°C

*COMMENT

Stresses above those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. This is a stress rating only and the functional operation of the device at these or any other conditions above those indicated in the operational sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

D.C. OPERATING CHARACTERISTICS

T_A = −55°C to +125°C, V_{CC} = +5V ±10%, unless otherwise specified.

Symbol	Parameter	Limits		Units	Test Conditions
		Min.	Max.		
I_{CC}	V_{CC} Current (Active)		100	mA	$\overline{CE}$ = $\overline{OE}$ = V_{IL} All I/O's = Open Other Inputs = V_{CC}
I_{SB}	V_{CC} Current (Standby)		60	mA	$\overline{CE}$ = V_{IH}, $\overline{OE}$ = V_{IL} All I/O's = Open Other Inputs = V_{CC}
I_{LI}	Input Leakage Current		10	µA	V_{IN} = GND to V_{CC}
I_{LO}	Output Leakage Current		10	µA	V_{OUT} = GND to V_{CC}
V_{IL}	Input Low Voltage	−1.0	0.8	V	
V_{IH}	Input High Voltage	2.2	V_{CC} +1.0	V	
V_{OL}	Output Low Voltage		0.4	V	I_{OL} = 2.1 mA
V_{OH}	Output High Voltage	2.4		V	I_{OH} = −400 µA

CAPACITANCE T_A = 25°C, f = 1.0 MHz, V_{CC} = 5V

Symbol	Test	Max.	Unit	Conditions
$C_{I/O}$(1)	Input/Output Capacitance	10	pF	$V_{I/O}$ = 0V
C_{IN}(1)	Input Capacitance	6	pF	V_{IN} = 0V

Note: (1) This parameter is periodically sampled and not 100% tested.

A.C. CONDITIONS OF TEST

Input Pulse Levels	0 to 3.0 Volts
Input Rise and Fall Times	10 nsec
Input and Output Timing Levels	1.5 Volts
Output Load	1 TTL Gate and C_L = 100 pF

MODE SELECTION

$\overline{CE}$	$\overline{OE}$	$\overline{WE}$	Mode	I/O	Power
L	L	H	Read	D_{OUT}	Active
L	H	L	Write	D_{IN}	Active
H	X	X	Standby and Write Inhibit	High Z	Standby
X	L	X	Write Inhibit	—	—
X	X	H	Write Inhibit	—	—

A.C. CHARACTERISTICS

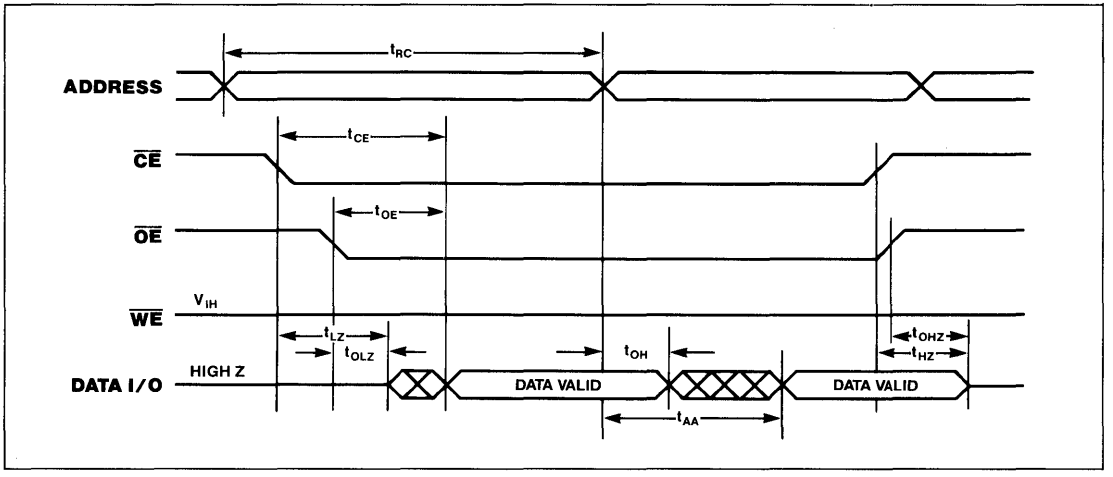
T_A = −55°C to +125°C, V_{CC} = +5V ±10%, unless otherwise specified.

Read Cycle Limits

Symbol	Parameter	X2804AM		X2804AM-35		X2804AM-45		Units
		Min.	Max.	Min.	Max.	Min.	Max.	
t_{RC}	Read Cycle Time	300		350		450		ns
t_{CE}	Chip Enable Access Time		300		350		450	ns
t_{AA}	Address Access Time		300		350		450	ns
t_{OE}	Output Enable Access Time		120		135		150	ns
t_{LZ}	Chip Enable to Output in Low Z	10		10		10		ns
t_{HZ}	Chip Disable to Output in High Z	10	100	10	150	10	150	ns
t_{OLZ}	Output Enable to Output in Low Z	50		50		50		ns
t_{OHZ}	Output Disable to Output in High Z	10	100	10	150	10	150	ns
t_{OH}	Output Hold from Address Change	20		20		20		ns

3

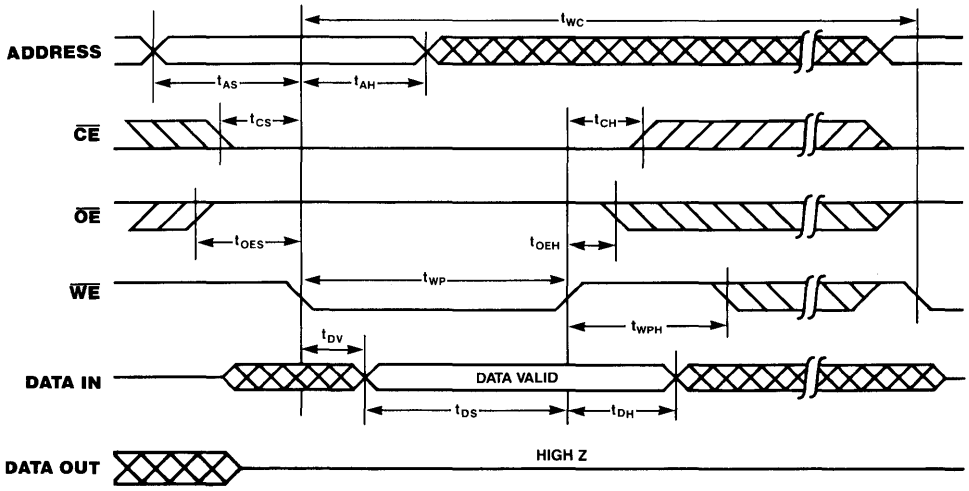
Read Cycle



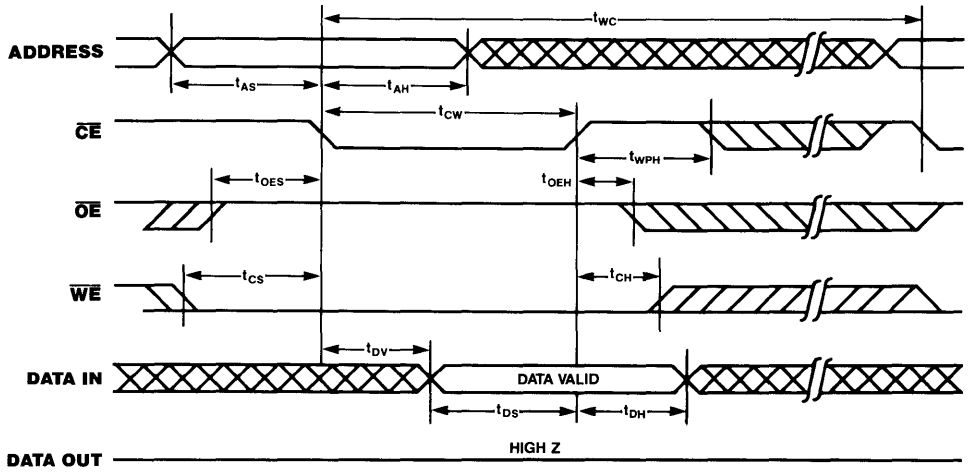
Write Cycle Limits

Symbol	Parameter	X2804AM		X2804AM-35		X2804AM-45		Units
		Min.	Max.	Min.	Max.	Min.	Max.	
t_{WC}	Write Cycle Time	10		10		10		ms
t_{AS}	Address Set-Up Time	10		10		10		ns
t_{AH}	Address Hold Time	150		150		150		ns
t_{CS}	Write Set-Up Time	0		0		0		ns
t_{CH}	Write Hold Time	0		0		0		ns
t_{CW}	Chip Enable to End of Write Input	150		175		230		ns
t_{OES}	Output Enable Set-Up Time	10		10		10		ns
t_{OEH}	Output Enable Hold Time	10		10		10		ns
t_{WP}	Write Pulse Width	150		175		230		ns
t_{WPH}	Write Control Recovery	50		50		50		ns
t_{DV}	Data Valid Time		1		1		1	µs
t_{DS}	Data Set-Up Time	135		175		230		ns
t_{DH}	Data Hold Time	15		20		30		ns

$\overline{WE}$ Controlled Write Cycle



$\overline{CE}$ Controlled Write Cycle



PIN DESCRIPTIONS

Addresses (A_0–A_8)

The Address inputs select an 8-bit memory location during a read or write operation.

Chip Enable ($\overline{CE}$)

The Chip Enable input must be LOW to enable all read/write operations. When $\overline{CE}$ is HIGH, power consumption is reduced.

Output Enable ($\overline{OE}$)

The Output Enable input controls the data output buffers and is used to initiate read operations.

Data In/Data Out (I/O_0–I/O_7)

Data is written to or read from the X2804A through the I/O pins.

Write Enable ($\overline{WE}$)

The Write Enable input controls the writing of data to the X2804A.

DEVICE OPERATION

READS

Read operations are initiated by both $\overline{OE}$ and $\overline{CE}$ LOW. The read operation is terminated by either $\overline{CE}$ or $\overline{OE}$ returning HIGH. This 2-line control architecture eliminates bus contention in a system environment. The data bus will be in a high impedance state when either $\overline{OE}$ or $\overline{CE}$ is HIGH.

WRITES

Write operations are initiated when both $\overline{CE}$ and $\overline{WE}$ are LOW and $\overline{OE}$ is HIGH. The X2804A supports both a $\overline{CE}$ and $\overline{WE}$ controlled write cycle. That is, the address is latched by the falling edge of either $\overline{CE}$ or $\overline{WE}$, whichever occurs last. Similarly, the data is latched internally by the rising edge of either $\overline{CE}$ or $\overline{WE}$, whichever occurs first.

A byte write operation, once initiated, will automatically continue to completion, typically within 5ms. In order to take advantage of the typical write time as opposed to the maximum specified time, the user can poll the X2804A. The I/O pins are placed in the high impedance state during the internal programming cycle. Once the internal cycle is complete, the X2804A may be accessed without any limitations. Therefore, the host can poll an address with known data (preferably with zeroes), as soon as a compare is true, the X2804A is ready for another write cycle.

WRITE PROTECTION

There are three features that protect the nonvolatile data from inadvertent writes.

- Noise Protection—A $\overline{WE}$ pulse of less than 20ns will not initiate a write cycle.
- V_{CC} Sense—All functions are inhibited when V_{CC} is $\leq$3v, typically.
- Write Inhibit—Holding either $\overline{OE}$ LOW, $\overline{WE}$ HIGH or $\overline{CE}$ HIGH during power-on and power-off, will inhibit inadvertent writes.

ENDURANCE

Xicor E^2PROMs are designed and tested for applications requiring extended endurance. The Process average for endurance of Xicor E^2PROMs is approximately 1/2 million cycles, as documented in RR504, the *Xicor Reliability Report on Endurance*. Included in that report is a method for determining the expected endurance of the device based upon the specific application environment. RR504 and additional reliability reports are available from Xicor.

MASS PROGRAM

Mass chip program and erase modes may be used to accelerate test time when performing tests that require a large number of writes, such as device endurance testing. Additional information is available, upon request, from Xicor regarding these test modes.

Electrically Erasable PROM

FEATURES

- **Simple Byte Write Operation**
  - **No High Voltages Necessary**
  - **Single TTL Level $\overline{WE}$ Signal Modifies Data**
  - **Internally Latched Addresses and Data**
  - **Self Timed Write**
  - **Noise Protected $\overline{WE}$ Pin**
- **JEDEC Approved Pinout for Byte-Wide Memories**
- **Reliable N-Channel Floating Gate MOS Technology**
- **Single 5 Volt Supply**
- **Byte Write Time: 10ms Max.**
- **Fast Access Time: 250ns Max.**
- **Low Power Dissipation**
  - **Active Current: 110mA Max.**
  - **Standby Current: 50mA Max.**

DESCRIPTION

The Xicor X2816A is a 2K x 8 E^2PROM, fabricated with the same reliable N-channel floating gate MOS technology used in all Xicor 5 volt programmable nonvolatile memories. The X2816A features the JEDEC approved pinout for byte-wide memories, compatible with industry standard RAMs, ROMs and EPROMs.

Xicor E^2PROMs are designed and tested for applications requiring extended endurance. Refer to Device Operation for further endurance information. Data retention is specified to be greater than 100 years.

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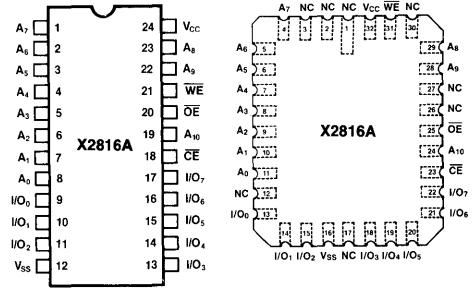
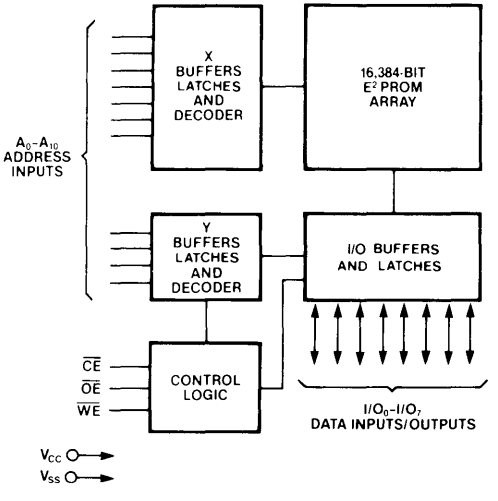
PIN CONFIGURATIONS



PIN NAMES

A_0–A_{10}	Address Inputs
I/O_0–I/O_7	Data Input/Output
$\overline{WE}$	Write Enable
$\overline{CE}$	Chip Enable
$\overline{OE}$	Output Enable
V_{CC}	+5V
V_{SS}	Ground
NC	No Connect

FUNCTIONAL DIAGRAM



ABSOLUTE MAXIMUM RATINGS*

Temperature Under Bias X2816A ..... −10°C to +85°C
X2816AI ..... −65°C to +135°C
Storage Temperature ..... −65°C to +150°C
Voltage on any Pin with
Respect to Ground ..... −1.0V to +7V
D.C. Output Current ..... 5 mA
Lead Temperature (Soldering,
10 Seconds) ..... 300°C

*COMMENT

Stresses above those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. This is a stress rating only and the functional operation of the device at these or any other conditions above those indicated in the operational sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

D.C. OPERATING CHARACTERISTICS

X2816A T_A = 0°C to +70°C, V_{CC} = +5V ±5%, unless otherwise specified.
X2816AI T_A = −40°C to +85°C, V_{CC} = +5V ±10%, unless otherwise specified.

Symbol	Parameter	X2816A Limits		X2816AI Limits		Units	Test Conditions
		Min.	Max.	Min.	Max.		
I_{CC}	V_{CC} Current (Active)		110		140	mA	$\overline{CE}$ = $\overline{OE}$ = V_{IL} All I/O's = Open Other Inputs = V_{CC}
I_{SB}	V_{CC} Current (Standby)		50		60	mA	$\overline{CE}$ = V_{IH}, $\overline{OE}$ = V_{IL} All I/O's = Open Other Inputs = V_{CC}
I_{LI}	Input Leakage Current		10		10	µA	V_{IN} = GND to V_{CC}
I_{LO}	Output Leakage Current		10		10	µA	V_{OUT} = GND to V_{CC}
V_{IL}	Input Low Voltage	−1.0	0.8	−1.0	0.8	V	
V_{IH}	Input High Voltage	2.0	V_{CC} +0.5	2.2	V_{CC} +1.0	V	
V_{OL}	Output Low Voltage		0.4		0.4	V	I_{OL} = 2.1 mA
V_{OH}	Output High Voltage	2.4		2.4		V	I_{OH} = −400 µA

CAPACITANCE T_A = 25°C, f = 1.0 MHz, V_{CC} = 5V

Symbol	Test	Max.	Unit	Conditions
$C_{I/O}$[1]	Input/Output Capacitance	10	pF	$V_{I/O}$ = 0V
C_{IN}[1]	Input Capacitance	6	pF	V_{IN} = 0V

Note: (1) This parameter is periodically sampled and not 100% tested.

A.C. CONDITIONS OF TEST

Input Pulse Levels	0 to 3.0 Volts
Input Rise and Fall Times	10 nsec
Input and Output Timing Levels	1.5 Volts
Output Load	1 TTL Gate and C_L = 100 pF

MODE SELECTION

$\overline{CE}$	$\overline{OE}$	$\overline{WE}$	Mode	I/O	Power
L	L	H	Read	D_{OUT}	Active
L	H	L	Write	D_{IN}	Active
H	X	X	Standby and Write Inhibit	High Z	Standby
X	L	X	Write Inhibit	—	—
X	X	H	Write Inhibit	—	—

A.C. CHARACTERISTICS

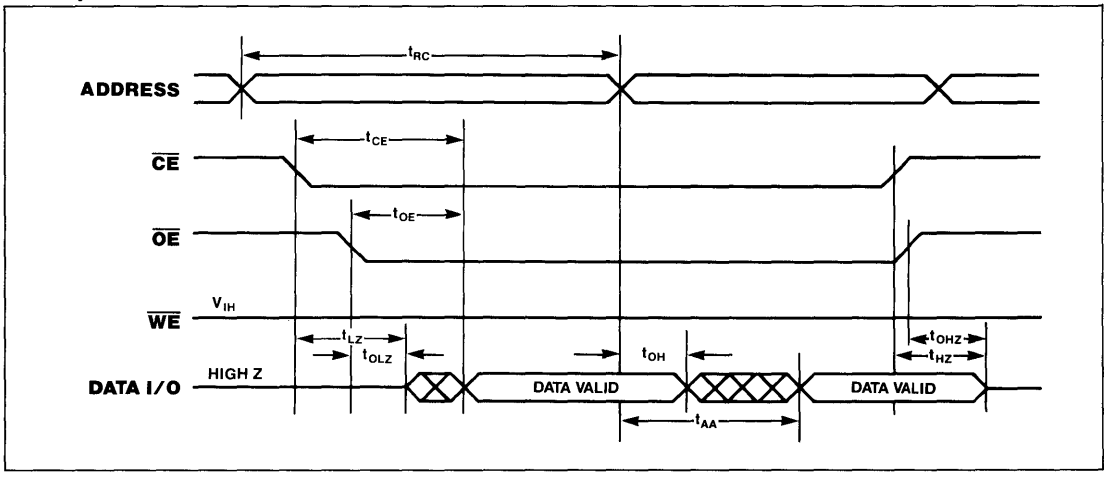
X2816A T_A = −0°C to +70°C, V_{CC} = +5V ±5%, unless otherwise specified.
X2816AI T_A = −40°C to +85°C, V_{CC} = +5V ±10%, unless otherwise specified.

Read Cycle Limits

Symbol	Parameter	X2816A-25 X2816AI-25		X2816A X2816AI		X2816A-35 X2816AI-35		X2816A-45 X2816AI-45		Units
		Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	
t_{RC}	Read Cycle Time	250		300		350		450		ns
t_{CE}	Chip Enable Access Time		250		300		350		450	ns
t_{AA}	Address Access Time		250		300		350		450	ns
t_{OE}	Output Enable Access Time		120		120		135		150	ns
t_{LZ}	Chip Enable to Output in Low Z	10		10		10		10		ns
t_{HZ}	Chip Disable to Output in High Z	10	100	10	100	10	150	10	150	ns
t_{OLZ}	Output Enable to Output in Low Z	50		50		50		50		ns
t_{OHZ}	Output Disable to Output in High Z	10	100	10	100	10	150	10	150	ns
t_{OH}	Output Hold from Address Change	20		20		20		20		ns

3

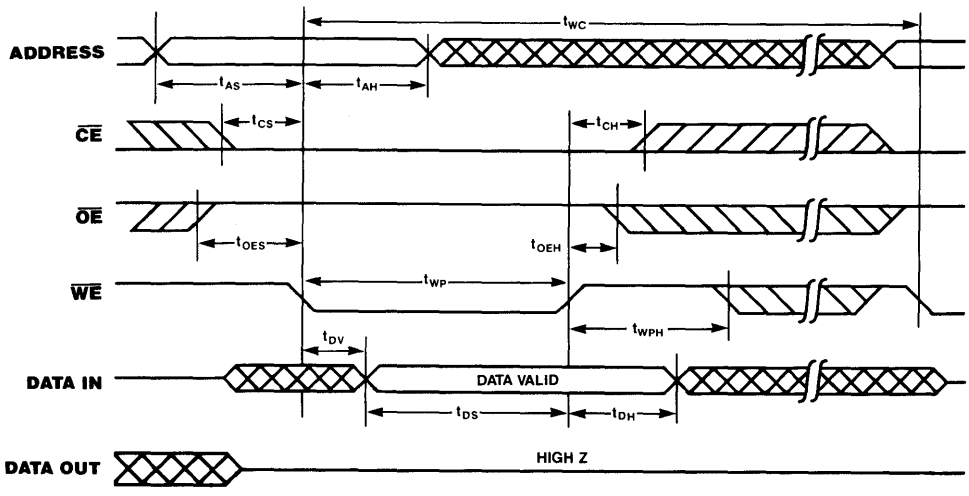
Read Cycle



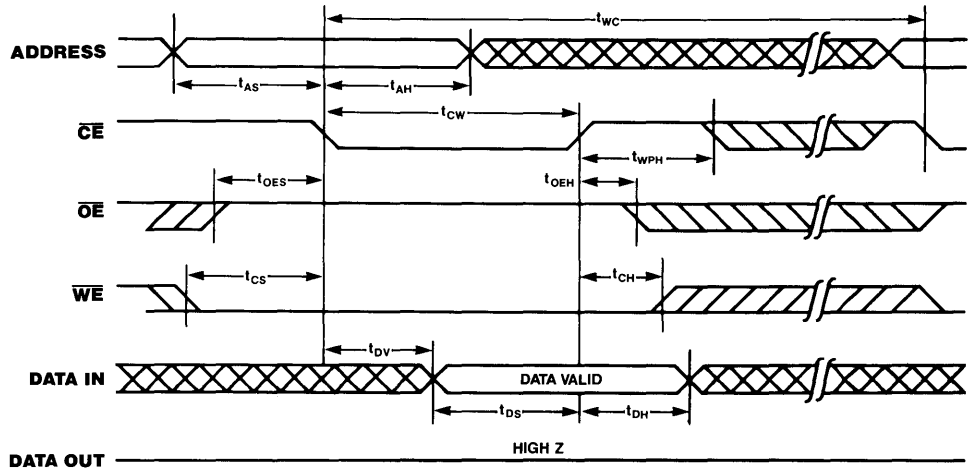
Write Cycle Limits

Symbol	Parameter	X2816A-25 X2816AI-25		X2816A X2816AI		X2816A-35 X2816AI-35		X2816A-45 X2816AI-45		Units
		Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	
t_{WC}	Write Cycle Time	10		10		10		10		ms
t_{AS}	Address Set-Up Time	10		10		10		10		ns
t_{AH}	Address Hold Time	120		120		150		150		ns
t_{CS}	Write Set-Up Time	0		0		0		0		ns
t_{CH}	Write Hold Time	0		0		0		0		ns
t_{CW}	Chip Enable to End of Write Input	150		150		175		230		ns
t_{OES}	Output Enable Set-Up Time	10		10		10		10		ns
t_{OEH}	Output Enable Hold Time	10		10		10		10		ns
t_{WP}	Write Pulse Width	150		150		175		230		ns
t_{WPH}	Write Control Recovery	50		50		50		50		ns
t_{DV}	Data Valid Time		1		1		1		1	µs
t_{DS}	Data Set-Up Time	120		135		175		230		ns
t_{DH}	Data Hold Time	15		15		20		30		ns

$\overline{WE}$ Controlled Write Cycle



$\overline{CE}$ Controlled Write Cycle



3

PIN DESCRIPTIONS

Addresses (A_0–A_{10})

The Address inputs select an 8-bit memory location during a read or write operation.

Chip Enable ($\overline{CE}$)

The Chip Enable input must be LOW to enable all read/write operations. When $\overline{CE}$ is HIGH, power consumption is reduced.

Output Enable ($\overline{OE}$)

The Output Enable input controls the data output buffers and is used to initiate read operations.

Data In/Data Out (I/O_0–I/O_7)

Data is written to or read from the X2816A through the I/O pins.

Write Enable ($\overline{WE}$)

The Write Enable input controls the writing of data to the X2816A.

DEVICE OPERATION

READS

Read operations are initiated by both $\overline{OE}$ and $\overline{CE}$ LOW. The read operation is terminated by either $\overline{CE}$ or $\overline{OE}$ returning HIGH. This 2-line control architecture eliminates bus contention in a system environment. The data bus will be in a high impedance state when either $\overline{OE}$ or $\overline{CE}$ is HIGH.

WRITES

Write operations are initiated when both $\overline{CE}$ and $\overline{WE}$ are LOW and $\overline{OE}$ is HIGH. The X2816A supports both a $\overline{CE}$ and $\overline{WE}$ controlled write cycle. That is, the address is latched by the falling edge of either $\overline{CE}$ or $\overline{WE}$, whichever occurs last. Similarly, the data is latched internally by the rising edge of either $\overline{CE}$ or $\overline{WE}$, whichever occurs first.

A byte write operation, once initiated, will automatically continue to completion, typically within 5ms. In order to take advantage of the typical write time as opposed to the maximum specified time, the user can poll the X2816A. The I/O pins are placed in the high impedance state during the internal programming cycle. Once the internal cycle is complete, the X2816A may be accessed without any limitations. Therefore, the host can poll an address with known data (preferably with zeroes), as soon as a compare is true, the X2816A is ready for another write cycle.

WRITE PROTECTION

There are three features that protect the nonvolatile data from inadvertent writes.

- Noise Protection—A $\overline{WE}$ pulse of less than 20ns will not initiate a write cycle.
- V_{CC} Sense—All functions are inhibited when V_{CC} is $\leq$3v, typically.
- Write Inhibit—Holding either $\overline{OE}$ LOW, $\overline{WE}$ HIGH or $\overline{CE}$ HIGH during power-on and power-off, will inhibit inadvertent writes.

ENDURANCE

Xicor E^2PROMs are designed and tested for applications requiring extended endurance. The Process average for endurance of Xicor E^2PROMs is approximately 1/2 million cycles, as documented in RR504, the *Xicor Reliability Report on Endurance.* Included in that report is a method for determining the expected endurance of the device based upon the specific application environment. RR504 and additional reliability reports are available from Xicor.

MASS PROGRAM

Mass chip program and erase modes may be used to accelerate test time when performing tests that require a large number of writes, such as device endurance testing. Additional information is available, upon request, from Xicor regarding these test modes.

Electrically Erasable PROM

FEATURES

- **Simple Byte Write Operation**
  - **— No High Voltages Necessary**
  - **— Single TTL Level $\overline{WE}$ Signal Modifies Data**
  - **— Internally Latched Addresses and Data**
  - **— Self Timed Write**
  - **— Noise Protected $\overline{WE}$ Pin**
- **JEDEC Approved Pinout for Byte-Wide Memories**
- **Reliable N-Channel Floating Gate MOS Technology**
- **Single 5 Volt Supply**
- **Byte Write Time: 10ms Max.**
- **Fast Access Time: 300ns Max.**
- **Low Power Dissipation**
  - **— Active Current: 140mA Max.**
  - **— Standby Current: 60mA Max.**

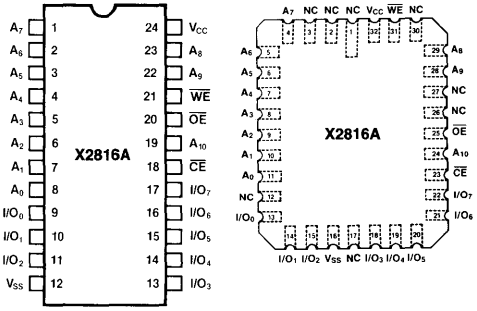
DESCRIPTION

The Xicor X2816A is a 2K x 8 E^2PROM, fabricated with the same reliable N-channel floating gate MOS technology used in all Xicor 5 volt programmable nonvolatile memories. The X2816A features the JEDEC approved pinout for byte-wide memories, compatible with industry standard RAMs, ROMs and EPROMs.

Xicor E^2PROMs are designed and tested for applications requiring extended endurance. Refer to Device Operation for further endurance information. Data retention is specified to be greater than 100 years.

3

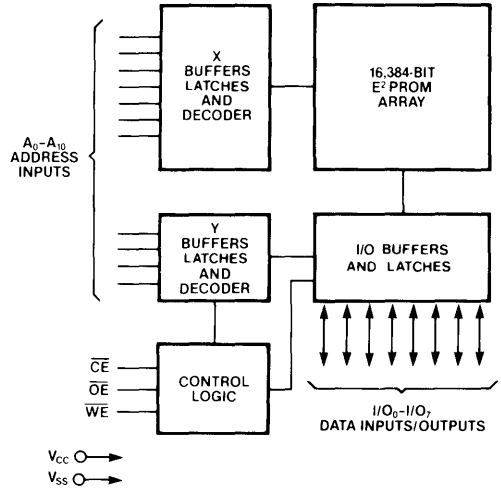
PIN CONFIGURATIONS



PIN NAMES

A_0–A_{10}	Address Inputs
I/O_0–I/O_7	Data Input/Output
$\overline{WE}$	Write Enable
$\overline{CE}$	Chip Enable
$\overline{OE}$	Output Enable
V_{CC}	+5V
V_{SS}	Ground
NC	No Connect

FUNCTIONAL DIAGRAM



ABSOLUTE MAXIMUM RATINGS*

Temperature Under Bias ..... −65°C to +135°C
Storage Temperature ..... −65°C to +150°C
Voltage on any Pin with
Respect to Ground ..... −1.0V to +7V
D.C. Output Current ..... 5 mA
Lead Temperature (Soldering,
10 Seconds) ..... 300°C

*COMMENT

Stresses above those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. This is a stress rating only and the functional operation of the device at these or any other conditions above those indicated in the operational sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

D.C. OPERATING CHARACTERISTICS

T_A = −55°C to +125°C, V_{CC} = +5V ±10%, unless otherwise specified.

Symbol	Parameter	Limits		Units	Test Conditions
		Min.	Max.		
I_{CC}	V_{CC} Current (Active)		140	mA	$\overline{CE}$ = $\overline{OE}$ = V_{IL} All I/O's = Open Other Inputs = V_{CC}
I_{SB}	V_{CC} Current (Standby)		60	mA	$\overline{CE}$ = V_{IH}, $\overline{OE}$ = V_{IL} All I/O's = Open Other Inputs = V_{CC}
I_{LI}	Input Leakage Current		10	µA	V_{IN} = GND to V_{CC}
I_{LO}	Output Leakage Current		10	µA	V_{OUT} = GND to V_{CC}
V_{IL}	Input Low Voltage	−1.0	0.8	V	
V_{IH}	Input High Voltage	2.2	V_{CC} +1.0	V	
V_{OL}	Output Low Voltage		0.4	V	I_{OL} = 2.1 mA
V_{OH}	Output High Voltage	2.4		V	I_{OH} = −400 µA

CAPACITANCE T_A = 25°C, f = 1.0 MHz, V_{CC} = 5V

Symbol	Test	Max.	Unit	Conditions
$C_{I/O}$[1]	Input/Output Capacitance	10	pF	$V_{I/O}$ = 0V
C_{IN}[1]	Input Capacitance	6	pF	V_{IN} = 0V

Note: (1) This parameter is periodically sampled and not 100% tested.

A.C. CONDITIONS OF TEST

Input Pulse Levels	0 to 3.0 Volts
Input Rise and Fall Times	10 nsec
Input and Output Timing Levels	1.5 Volts
Output Load	1 TTL Gate and C_L = 100 pF

MODE SELECTION

$\overline{CE}$	$\overline{OE}$	$\overline{WE}$	Mode	I/O	Power
L	L	H	Read	D_{OUT}	Active
L	H	L	Write	D_{IN}	Active
H	X	X	Standby and Write Inhibit	High Z	Standby
X	L	X	Write Inhibit	—	—
X	X	H	Write Inhibit	—	—

A.C. CHARACTERISTICS

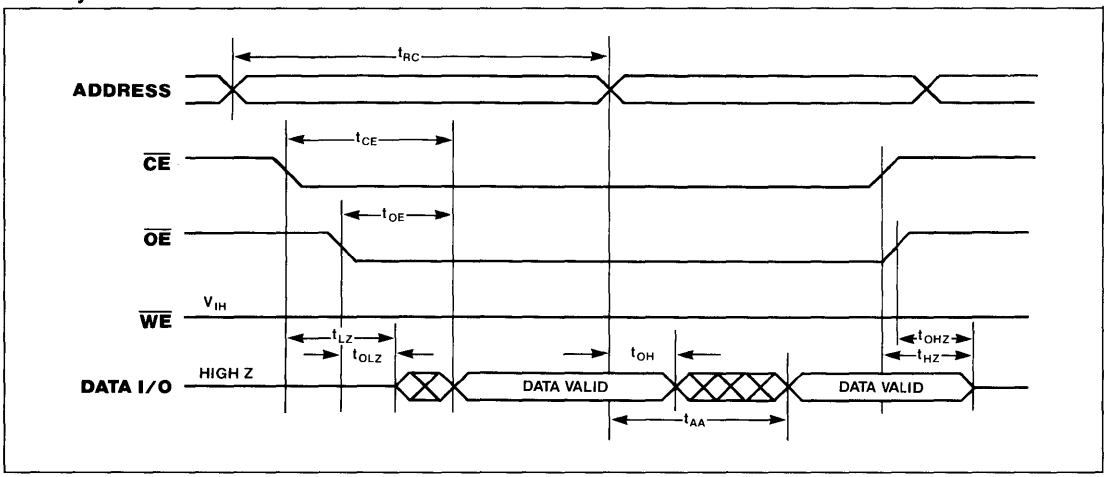
T_A = −55°C to +125°C, V_{CC} = +5V ±10%, unless otherwise specified.

Read Cycle Limits

Symbol	Parameter	X2816AM		X2816AM-35		X2816AM-45		Units
		Min.	Max.	Min.	Max.	Min.	Max.	
t_{RC}	Read Cycle Time	300		350		450		ns
t_{CE}	Chip Enable Access Time		300		350		450	ns
t_{AA}	Address Access Time		300		350		450	ns
t_{OE}	Output Enable Access Time		120		135		150	ns
t_{LZ}	Chip Enable to Output in Low Z	10		10		10		ns
t_{HZ}	Chip Disable to Output in High Z	10	100	10	150	10	150	ns
t_{OLZ}	Output Enable to Output in Low Z	50		50		50		ns
t_{OHZ}	Output Disable to Output in High Z	10	100	10	150	10	150	ns
t_{OH}	Output Hold from Address Change	20		20		20		ns

3

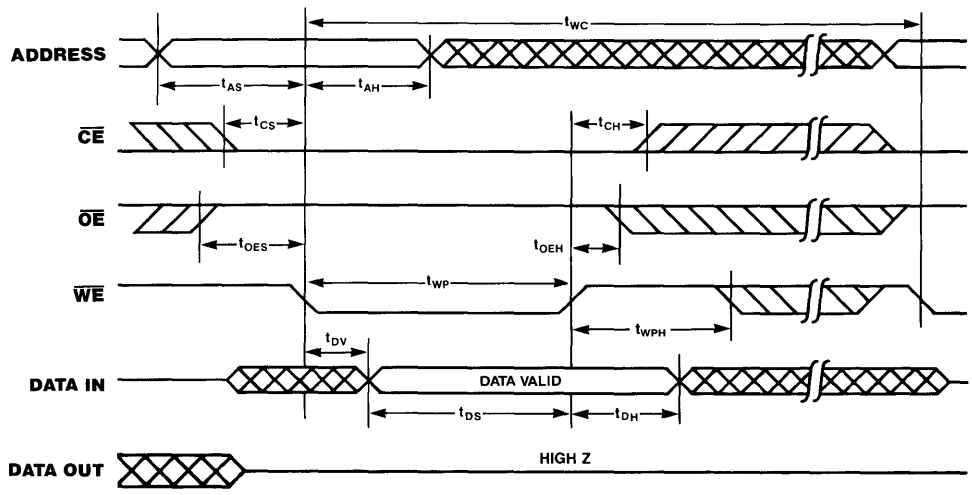
Read Cycle



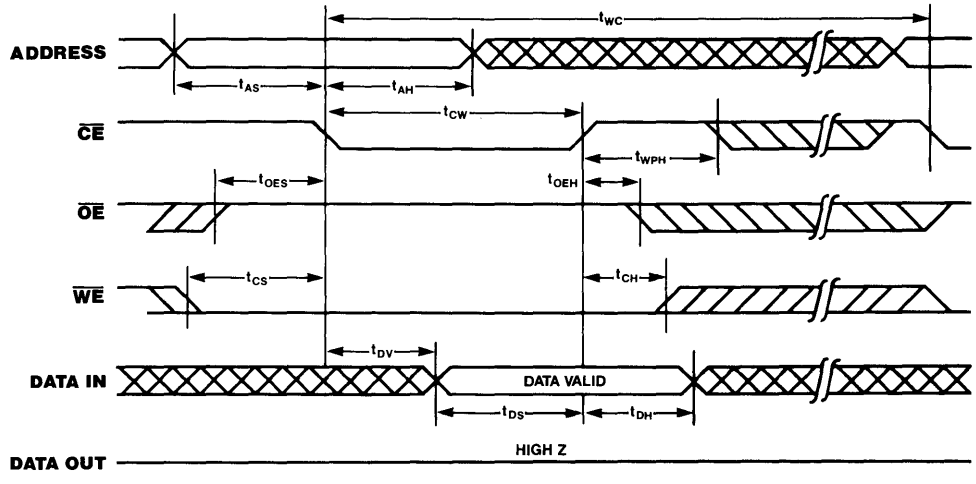
Write Cycle Limits

Symbol	Parameter	X2816AM		X2816AM-35		X2816AM-45		Units
		Min.	Max.	Min.	Max.	Min.	Max.	
t_{WC}	Write Cycle Time	10		10		10		ms
t_{AS}	Address Set-Up Time	10		10		10		ns
t_{AH}	Address Hold Time	150		150		150		ns
t_{CS}	Write Set-Up Time	0		0		0		ns
t_{CH}	Write Hold Time	0		0		0		ns
t_{CW}	Chip Enable to End of Write Input	150		175		230		ns
t_{OES}	Output Enable Set-Up Time	10		10		10		ns
t_{OEH}	Output Enable Hold Time	10		10		10		ns
t_{WP}	Write Pulse Width	150		175		230		ns
t_{WPH}	Write Control Recovery	50		50		50		ns
t_{DV}	Data Valid Time		1		1		1	µs
t_{DS}	Data Set-Up Time	135		175		230		ns
t_{DH}	Data Hold Time	15		20		30		ns

$\overline{WE}$ Controlled Write Cycle



$\overline{CE}$ Controlled Write Cycle



PIN DESCRIPTIONS

Addresses (A_0–A_{10})

The Address inputs select an 8-bit memory location during a read or write operation.

Chip Enable ($\overline{CE}$)

The Chip Enable input must be LOW to enable all read/write operations. When $\overline{CE}$ is HIGH, power consumption is reduced.

Output Enable ($\overline{OE}$)

The Output Enable input controls the data output buffers and is used to initiate read operations.

Data In/Data Out (I/O_0–I/O_7)

Data is written to or read from the X2816A through the I/O pins.

Write Enable ($\overline{WE}$)

The Write Enable input controls the writing of data to the X2816A.

DEVICE OPERATION

READS

Read operations are initiated by both $\overline{OE}$ and $\overline{CE}$ LOW. The read operation is terminated by either $\overline{CE}$ or $\overline{OE}$ returning HIGH. This 2-line control architecture eliminates bus contention in a system environment. The data bus will be in a high impedance state when either $\overline{OE}$ or $\overline{CE}$ is HIGH.

WRITES

Write operations are initiated when both $\overline{CE}$ and $\overline{WE}$ are LOW and $\overline{OE}$ is HIGH. The X2816A supports both a $\overline{CE}$ and $\overline{WE}$ controlled write cycle. That is, the address is latched by the falling edge of either $\overline{CE}$ or $\overline{WE}$, whichever occurs last. Similarly, the data is latched internally by the rising edge of either $\overline{CE}$ or $\overline{WE}$, whichever occurs first.

A byte write operation, once initiated, will automatically continue to completion, typically within 5ms. In order to take advantage of the typical write time as opposed to the maximum specified time, the user can poll the X2816A. The I/O pins are placed in the high impedance state during the internal programming cycle. Once the internal cycle is complete, the X2816A may be accessed without any limitations. Therefore, the host can poll an address with known data (preferably with zeroes), as soon as a compare is true, the X2816A is ready for another write cycle.

WRITE PROTECTION

There are three features that protect the nonvolatile data from inadvertent writes.

- Noise Protection—A $\overline{WE}$ pulse of less than 20ns will not initiate a write cycle.
- V_{CC} Sense—All functions are inhibited when V_{CC} is $\leq$3v, typically.
- Write Inhibit—Holding either $\overline{OE}$ LOW, $\overline{WE}$ HIGH or $\overline{CE}$ HIGH during power-on and power-off, will inhibit inadvertent writes.

ENDURANCE

Xicor E^2PROMs are designed and tested for applications requiring extended endurance. The Process average for endurance of Xicor E^2PROMs is approximately 1/2 million cycles, as documented in RR504, the *Xicor Reliability Report on Endurance*. Included in that report is a method for determining the expected endurance of the device based upon the specific application environment. RR504 and additional reliability reports are available from Xicor.

MASS PROGRAM

Mass chip program and erase modes may be used to accelerate test time when performing tests that require a large number of writes, such as device endurance testing. Additional information is available, upon request, from Xicor regarding these test modes.

16K X2816B 2048 x 8 Bit

Electrically Erasable PROM

TYPICAL FEATURES

- 150ns Access Time
- High Performance Advanced NMOS Technology
- Fast Write Cycle Times
  - — Byte or Page Write Cycle: 2ms Typical
  - — 32 Byte Page Write Operation
  - — Complete Memory Rewrite: 128ms
  - — Effective Byte Write Cycle Time of 63μs
- $\overline{\text{DATA}}$ Polling
  - — Allows User to Minimize Write Cycle Time
- Reduced Power
  - — 60mA Active Current
  - — 30mA Standby Current
- JEDEC Approved Byte-wide Pinout
- Direct Replacement for X2816A

DESCRIPTION

The Xicor X2816B is a 2K x 8 E^2PROM, fabricated with an advanced, high performance N-channel floating gate MOS technology. Like all Xicor programmable nonvolatile memories it is a 5 volt only device. The X2816B features the JEDEC approved pinout for byte-wide memories, compatible with industry standard RAMs, ROMs and EPROMs.

The X2816B supports a 32-byte page write operation, effectively providing a 63μs/byte write cycle and enabling the entire memory to be written in less than 128ms. The X2816B also features $\overline{\text{DATA}}$ Polling, a system software support scheme used to indicate the early completion of a write cycle.

Xicor E^2PROMs are designed and tested for applications requiring extended endurance. Data retention is specified to be greater than 100 years.

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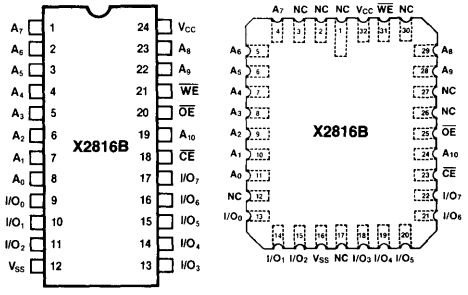
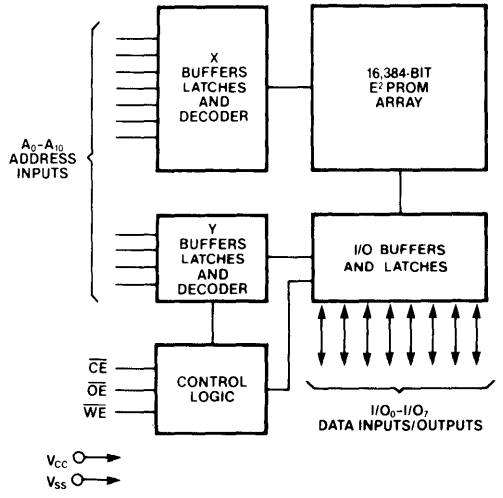
PIN CONFIGURATIONS



PIN NAMES

A_0–A_{10}	Address Inputs
I/O_0–I/O_7	Data Input/Output
$\overline{WE}$	Write Enable
$\overline{CE}$	Chip Enable
$\overline{OE}$	Output Enable
V_{CC}	+5V
V_{SS}	Ground
NC	No Connect

FUNCTIONAL DIAGRAM



ABSOLUTE MAXIMUM RATINGS*

Temperature Under Bias X2816B ..... −10°C to +85°C
Storage Temperature ..... −65°C to +150°C
Voltage on any Pin with
Respect to Ground ..... −1.0V to +7V
D.C. Output Current ..... 5 mA
Lead Temperature (Soldering,
10 Seconds) ..... 300°C

*COMMENT

Stresses above those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. This is a stress rating only and the functional operation of the device at these or any other conditions above those indicated in the operational sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

D.C. OPERATING CHARACTERISTICS

T_A = 0°C to +70°C, V_{CC} = +5V ±10%, unless otherwise specified.

Symbol	Parameter	Limits			Units	Test Conditions
		Min.	Typ.(1)	Max.		
I_{CC}	V_{CC} Current (Active)		60		mA	$\overline{CE}$ = $\overline{OE}$ = V_{IL} All I/O's = Open Other Inputs = V_{CC}
I_{SB}	V_{CC} Current (Standby)		30		mA	$\overline{CE}$ = V_{IH}, $\overline{OE}$ = V_{IL} All I/O's = Open Other Inputs = V_{CC}
I_{LI}	Input Leakage Current			10	µA	V_{IN} = GND to V_{CC}
I_{LO}	Output Leakage Current			10	µA	V_{OUT} = GND to V_{CC}, $\overline{CE}$ = V_{IH}
V_{IL}	Input Low Voltage	−1.0		0.8	V	
V_{IH}	Input High Voltage	2.0		V_{CC} +1.0	V	
V_{OL}	Output Low Voltage			0.4	V	I_{OL} = 2.1 mA
V_{OH}	Output High Voltage	2.4			V	I_{OH} = −400 mA

Note: (1) Typical values are for T_A = 25°C and nominal supply voltage.

CAPACITANCE T_A = 25°C, f = 1.0 MHz, V_{CC} = 5V

Symbol	Test	Max.	Unit	Conditions
$C_{I/O}$(2)	Input/Output Capacitance	10	pF	$V_{I/O}$ = 0V
C_{IN}(2)	Input Capacitance	6	pF	V_{IN} = 0V

Note: (2) This parameter is periodically sampled and not 100% tested.

A.C. CONDITIONS OF TEST

Input Pulse Levels	0 to 3.0 Volts
Input Rise and Fall Times	10 nsec
Input and Output Timing Levels	1.5 Volts
Output Load	1 TTL Gate and C_L = 100 pF

MODE SELECTION

$\overline{CE}$	$\overline{OE}$	$\overline{WE}$	Mode	I/O	Power
L	L	H	Read	D_{OUT}	Active
L	H	L	Write	D_{IN}	Active
H	X	X	Standby and Write Inhibit	High Z	Standby
X	L	X	Write Inhibit	—	—
X	X	H	Write Inhibit	—	—

A.C. CHARACTERISTICS

T_A = −0°C to +70°C, V_{CC} = +5V ±10%, unless otherwise specified.

Read Cycle Limits

Symbol	Parameter	Min.	Typ.(1)	Max.	Units
t_{RC}	Read Cycle Time		150		ns
t_{CE}	Chip Enable Access Time		150		ns
t_{AA}	Address Access Time		150		ns
t_{OE}	Output Enable Access Time		100		ns
t_{LZ}	$\overline{CE}$ Low to Active Output	0			ns
t_{OLZ}	$\overline{OE}$ Low to Active Output	0			ns
t_{HZ}	$\overline{CE}$ High to High Z Output		50		ns
t_{OHZ}	$\overline{OE}$ High to High Z Output		50		ns
t_{OH}	Output Hold From Address Change		20		ns

Note: (1) Typical values are for T_A = 25°C and nominal supply voltage.

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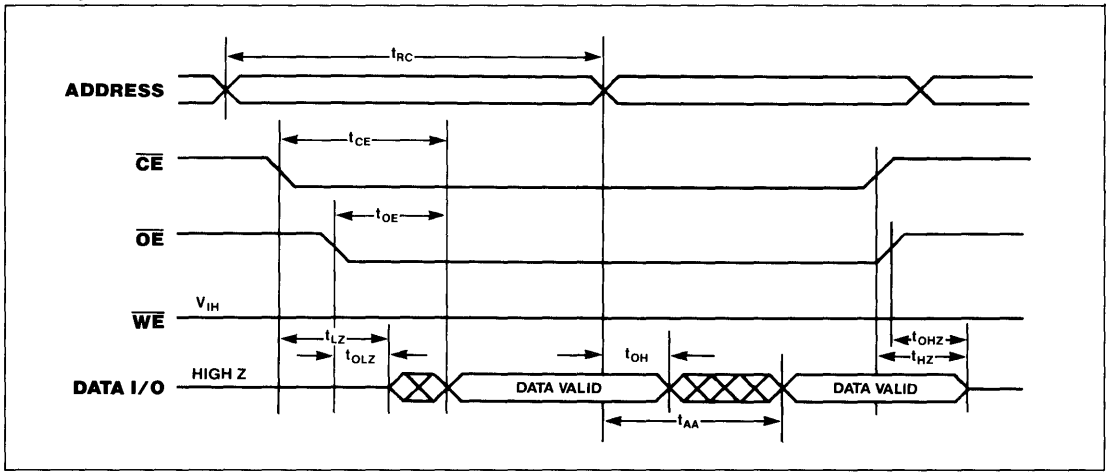
Read Cycle

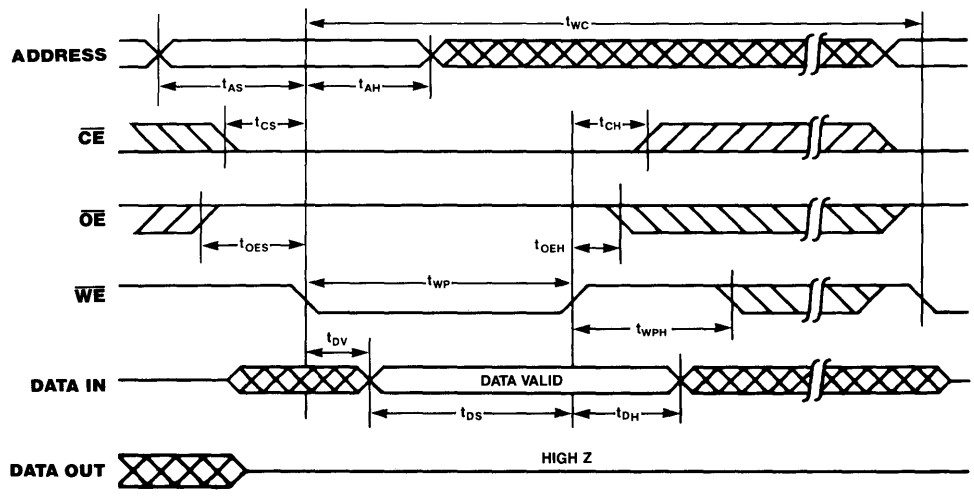


Write Cycle Limits

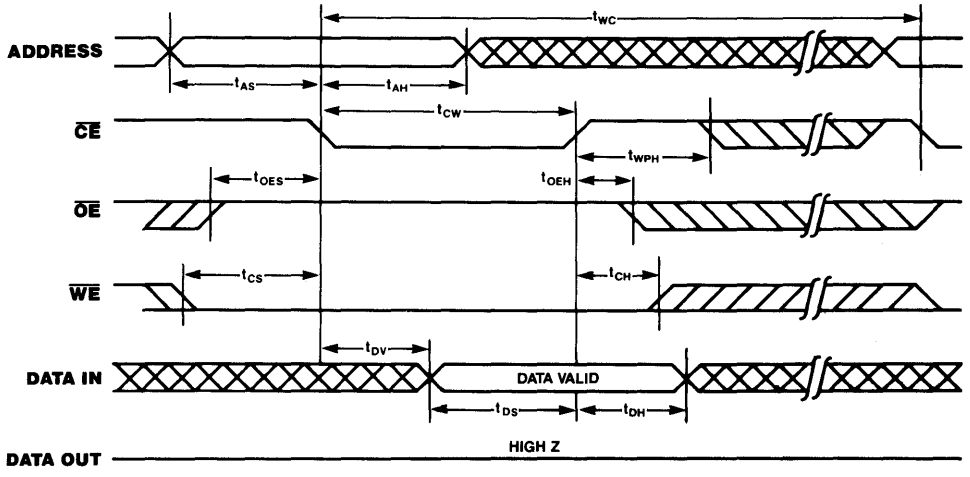
Symbol	Parameter	Min.	Typ.(1)	Max.	Units
t_{WC}	Write Cycle Time		2		ms
t_{AS}	Address Set-up Time	0			ns
t_{AH}	Address Hold Time		100		ns
t_{CS}	Write Set-up Time	0			ns
t_{CH}	Write Hold Time	0			ns
t_{CW}	$\overline{CE}$ Pulse Width		100		ns
t_{OES}	$\overline{OE}$ High Set-up Time		10		ns
t_{OEH}	$\overline{OE}$ High Hold Time		10		ns
t_{WP}	$\overline{WE}$ Pulse Width		100		ns
t_{WPH}	$\overline{WE}$ High Recovery		50		ns
t_{DV}	Data Valid		1		µs
t_{DS}	Data Set-up		50		ns
t_{DH}	Data Hold		0		ns
t_{BLC}	Byte Load Cycle	1		100	µs

Note: (1) Typical values are for T_A = 25°C and nominal supply voltage.

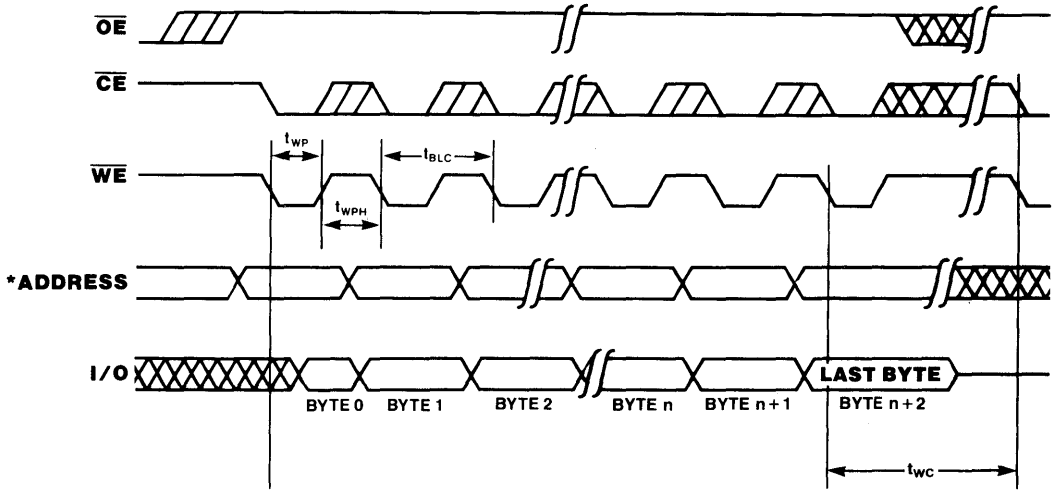
$\overline{WE}$ Controlled Write Cycle



$\overline{CE}$ Controlled Write Cycle



Page Mode Write Cycle



*The page address, addresses A_5–A_{10}, must remain the same throughout the page write cycle (t_{PLW}). If a page violation occurs, writes to an unknown address could result.

PIN DESCRIPTIONS

Addresses (A_0–A_{10})

The Address inputs select an 8-bit memory location during a read or write operation.

Chip Enable ($\overline{CE}$)

The Chip Enable input must be LOW to enable all read/write operations. When $\overline{CE}$ is HIGH, power consumption is reduced.

Output Enable ($\overline{OE}$)

The Output Enable input controls the data output buffers and is used to initiate read operations.

Data In/Data Out (I/O_0–I/O_7)

Data is written to or read from the X2816B through the I/O pins.

Write Enable ($\overline{WE}$)

The Write Enable input controls the writing of data to the X2816B.

DEVICE OPERATION

READ

Read operations are initiated by both $\overline{OE}$ and $\overline{CE}$ LOW. The read operation is terminated by either $\overline{CE}$ or $\overline{OE}$ returning HIGH. This 2-line control architecture eliminates bus contention in a system environment. The data bus will be in a high impedance state when either $\overline{OE}$ or $\overline{CE}$ is HIGH.

WRITE

Write operations are initiated when both $\overline{CE}$ and $\overline{WE}$ are LOW *and* $\overline{OE}$ is HIGH. The X2816B supports both a $\overline{CE}$ and $\overline{WE}$ controlled write cycle. That is, the address is latched by the falling edge of either $\overline{CE}$ or $\overline{WE}$, whichever occurs last. Similarly, the data is latched internally by the rising edge of either $\overline{CE}$ or $\overline{WE}$, whichever occurs first. A byte write operation, once initiated, will automatically continue to completion, typically within 2ms.

PAGE WRITE OPERATION

The page write feature of the X2816B allows the entire memory to be written in 128ms. Page write allows two to thirty-two bytes of data to be consecutively written to the X2816B prior to the commencement of the internal programming cycle. The destination addresses for a page write operation must reside on the same page; that is, A_5 through A_{10} must not change.

The page write mode can be entered during any write operation. Following the initial byte write cycle, the host can write an additional one to thirty-one bytes in the same manner as the first byte was written. Each successive byte load cycle, started by the $\overline{WE}$ HIGH to LOW transition, must begin within 100µs of the falling edge of the preceding $\overline{WE}$. If a subsequent $\overline{WE}$ HIGH to LOW transition is not detected within 100µs the internal automatic programming cycle will commence. There is no page write window limitation. The page write window is infinitely wide so long as the host continues to access the device within the byte load cycle time of 100µs.

$\overline{DATA}$ POLLING

The X2816B features $\overline{DATA}$ Polling as a method to indicate to the host system that the byte write or page write cycle has completed. $\overline{DATA}$ Polling allows a simple bit test operation to determine the status of the X2816B, eliminating additional interrupt inputs or external hardware. During the internal programming cycle, any attempt to read the last byte written will produce the complement of that data on I/O_7 (i.e., write data = 0xxx xxxx, read data = 1xxx xxxx). Once the programming cycle is complete, I/O_7 will reflect true data.

PROGRAMMABLE V_{CC} SENSE

All Xicor products have a default V_{CC} Sense set point. This inhibits all device operations during power transitions and is typically 3v. The X2816B provides an additional V_{CC} Sense feature that allows the user to program the set point at which *write* operations are disabled. This feature allows a user to program the sense level in the range of +3v to V_{CC} +1v. The set point is nonvolatile and reprogrammable.

16K X2816H 2048 x 8 Bit

Electrically Erasable PROM

TYPICAL FEATURES

- **45ns Access Time**
- **High Performance Advanced NMOS Technology**
- **Fast Write Cycle Times**
  - **— Byte or Page Write Cycle: 2ms Typical**
  - **— 32 Byte Page Write Operation**
  - **— Complete Memory Rewrite: 128ms**
  - **— Effective Byte Write Cycle Time of 63μs**
- **DATA Polling**
  - **— Allows User to Minimize Write Cycle Time**
- **Low Power Operation**
  - **— 80mA Active Current**
- **JEDEC Approved Byte-wide Pinout**

DESCRIPTION

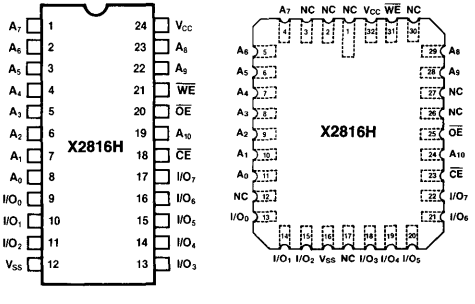
The Xicor X2816H is a high speed 2K x 8 E^2PROM, fabricated with Xicor's advanced, high performance N-channel floating gate MOS technology. The X2816H features the JEDEC approved pinout for byte-wide memories, compatible with industry standard RAMs, ROMs and EPROMs.

The X2816H supports a 32-byte page write operation, effectively providing a 63μs/byte write cycle and enabling the entire memory to be written in less than 128ms. The X2816H also features DATA Polling, a system software support scheme used to indicate the early completion of a write cycle.

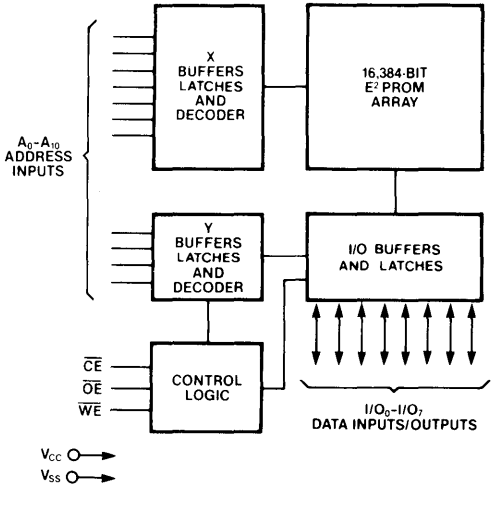
Xicor E^2PROMs are designed and tested for applications requiring extended endurance. Data retention is specified to be greater than 100 years.

3

PIN CONFIGURATIONS



FUNCTIONAL DIAGRAM



PIN NAMES

A_0–A_{10}	Address Inputs
I/O_0–I/O_7	Data Input/Output
$\overline{WE}$	Write Enable
$\overline{CE}$	Chip Enable
$\overline{OE}$	Output Enable
V_{CC}	+5V
V_{SS}	Ground
NC	No Connect

May 1985

PIN DESCRIPTIONS

Addresses (A_0–A_{10})

The Address inputs select an 8-bit memory location during a read or write operation.

Chip Enable ($\overline{CE}$)

The Chip Enable input must be LOW to enable all read/write operations.

Output Enable ($\overline{OE}$)

The Output Enable input controls the data output buffers and is used to initiate read operations.

Data In/Data Out (I/O_0–I/O_{10})

Data is written to or read from the X2816H through the I/O pins.

Write Enable ($\overline{WE}$)

The Write Enable input controls the writing of data to the X2816H.

DEVICE OPERATION

READ

Read operations are initiated by both $\overline{OE}$ and $\overline{CE}$ LOW. The read operation is terminated by either $\overline{CE}$ or $\overline{OE}$ returning HIGH. This 2-line control architecture eliminates bus contention in a system environment. The data bus will be in a high impedance state when either $\overline{OE}$ or $\overline{CE}$ is HIGH.

WRITE

Write operations are initiated when both $\overline{CE}$ and $\overline{WE}$ are LOW *and* $\overline{OE}$ is HIGH. The X2816H supports both a $\overline{CE}$ and $\overline{WE}$ controlled write cycle. That is, the address is latched by the falling edge of either $\overline{CE}$ or $\overline{WE}$, whichever occurs last. Similarly, the data is latched internally by the rising edge of either $\overline{CE}$ or $\overline{WE}$, whichever occurs first. A byte write operation, once initiated, will automatically continue to completion, typically within 2ms.

PAGE WRITE OPERATION

The page write feature of the X2816H allows the entire memory to be written in 128ms. Page write allows two to thirty-two bytes of data to be consecutively written to the X2816H prior to the commencement of the internal programming cycle. The destination addresses for a page write operation must reside on the same page; that is, A_5 through A_{10} must not change.

The page write mode can be entered during any write operation. Following the initial byte write cycle, the host can write an additional one to thirty-one bytes in the same manner as the first byte was written. Each successive byte load cycle, started by the $\overline{WE}$ HIGH to LOW transition, must begin within 100µs of the falling edge of the preceding $\overline{WE}$. If a subsequent $\overline{WE}$ HIGH to LOW transition is not detected within 100µs the internal automatic programming cycle will commence. There is no page write window limitation. The page write window is infinitely wide, so long as the host continues to access the device within the 100µs byte load cycle time.

$\overline{DATA}$ POLLING

The X2816H features $\overline{DATA}$ Polling as a method to indicate to the host system that the byte write or page write cycle has completed. $\overline{DATA}$ Polling allows a simple bit test operation to determine the status of the X2816H, eliminating additional interrupt inputs or external hardware. During the internal programming cycle, any attempt to read the last byte written will produce the complement of that data on I/O_7 (i.e., write data = 0xxx xxxx, read data = 1xxx xxxx). Once the programming cycle is complete, I/O_7 will reflect true data.

PROGRAMMABLE V_{CC} SENSE

All Xicor products have a default V_{CC} Sense set point. This inhibits all device operations during power transitions and is typically 3v. The X2816H provides an additional V_{CC} Sense feature that allows the user to program the set point at which *write* operations are disabled. This feature allows a user to program the sense level in the range of +3v to V_{CC} +1v. The set point is nonvolatile and reprogrammable.

ADVANCED INFORMATION

64K	Commercial Industrial	X2864A-20 X2864AI-20	8192 x 8 Bit

Electrically Erasable PROM

FEATURES

- **Simple Byte and Page Write**
  - **— Single TTL Level $\overline{WE}$ Signal**
  - **— Latched Address and Data**
  - **— Automatic Write Timing**
  - **— $\overline{DATA}$ Polling Verification**
- **Fast Byte Write: 5ms Typical**
- **Automatic Page Write**
  - **— 5ms Typical per page**
  - **— Chip Rewrite in 2.6 sec Typical**
  - **— Effective 300 μsec/Byte**
- **Fast Access Time: 200ns Max.**
- **Single 5 Volt Supply**
- **JEDEC Approved Pinout for Byte-Wide Memories**

DESCRIPTION

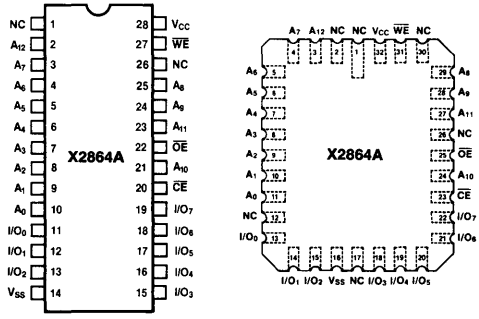
The Xicor X2864A is an 8K x 8 E^2PROM, fabricated with the same reliable N-channel floating gate MOS technology used in all Xicor 5 volt programmable nonvolatile memories. The X2864A features the JEDEC approved pinout for byte-wide memories, compatible with industry standard RAMs, ROMs and EPROMs.

The X2864A supports a 16-byte page write operation, effectively providing a 300μs/byte write and enabling the entire memory to be written in less than 2.6 seconds. The X2864A also features $\overline{DATA}$ Polling, a system software support scheme used to indicate the early completion of a write cycle.

Xicor E^2PROMs are designed and tested for applications requiring extended endurance. Refer to Device Operation for further endurance information. Data retention is specified to be greater than 100 years.

3

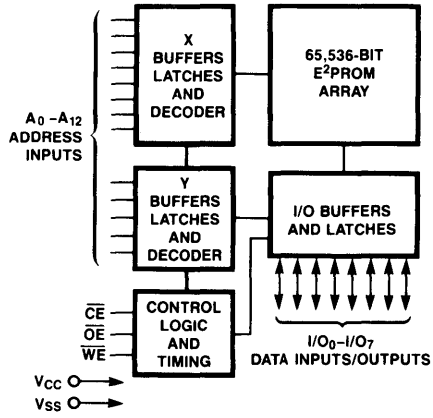
PIN CONFIGURATIONS



PIN NAMES

A_0–A_{12}	Address Inputs
I/O_0–I/O_7	Data Input/Output
$\overline{WE}$	Write Enable
$\overline{CE}$	Chip Enable
$\overline{OE}$	Output Enable
V_{CC}	+5V
V_{SS}	Ground
NC	No Connect

FUNCTIONAL DIAGRAM



ABSOLUTE MAXIMUM RATINGS*

Temperature Under Bias X2864A-20 ..... −10°C to +85°C
X2864AI-20 ..... −65°C to +135°C
Storage Temperature ..... −65°C to +150°C
Voltage on any Pin with
Respect to Ground ..... −1.0V to +7V
D.C. Output Current ..... 5 mA
Lead Temperature (Soldering,
10 Seconds) ..... 300°C

*COMMENT

Stresses above those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. This is a stress rating only and the functional operation of the device at these or any other conditions above those indicated in the operational sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

D.C. OPERATING CHARACTERISTICS

X2864A-20 T_A = 0°C to +70°C, V_{CC} = +5V ±5%, unless otherwise specified.
X2864AI-20 T_A = −40°C to +85°C, V_{CC} = +5V ±5%, unless otherwise specified.

Symbol	Parameter	X2864A-20 Limits		X2864AI-20 Limits		Units	Test Conditions
		Min.	Max.	Min.	Max.		
I_{CC}	V_{CC} Current (Active)		140		140	mA	$\overline{CE}$ = $\overline{OE}$ = V_{IL} All I/O's = Open Other Inputs = V_{CC}
I_{SB}	V_{CC} Current (Standby)		60		70	mA	$\overline{CE}$ = V_{IH}, $\overline{OE}$ = V_{IL} All I/O's = Open Other Inputs = V_{CC}
I_{LI}	Input Leakage Current		10		10	µA	V_{IN} = GND to V_{CC}
I_{LO}	Output Leakage Current		10		10	µA	V_{OUT} = GND to V_{CC}, $\overline{CE}$ = V_{IH}
V_{IL}	Input Low Voltage	−1.0	0.8	−1.0	0.8	V	
V_{IH}	Input High Voltage	2.0	V_{CC} +0.5	2.0	V_{CC} +0.5	V	
V_{OL}	Output Low Voltage		0.4		0.4	V	I_{OL} = 2.1 mA
V_{OH}	Output High Voltage	2.4		2.4		V	I_{OH} = −400 µA

CAPACITANCE T_A = 25°C, f = 1.0 MHz, V_{CC} = 5V

Symbol	Test	Max.	Unit	Conditions
$C_{I/O}$[1]	Input/Output Capacitance	10	pF	$V_{I/O}$ = 0V
C_{IN}[1]	Input Capacitance	6	pF	V_{IN} = 0V

Note: (1) This parameter is periodically sampled and not 100% tested.

A.C. CONDITIONS OF TEST

Input Pulse Levels	0 to 3.0 Volts
Input Rise and Fall Times	10 nsec
Input and Output Timing Levels	1.5 Volts
Output Load	1 TTL Gate and C_L = 100 pF

MODE SELECTION

$\overline{CE}$	$\overline{OE}$	$\overline{WE}$	Mode	I/O	Power
L	L	H	Read	D_{OUT}	Active
L	H	L	Write	D_{IN}	Active
H	X	X	Standby and Write Inhibit	High Z	Standby
X	L	X	Write Inhibit	—	—
X	X	H	Write Inhibit	—	—

A.C. CHARACTERISTICS

X2864A-20 T_A = 0°C to +70°C, V_{CC} = +5V ±5%, unless otherwise specified.
X2864AI-20 T_A = −40°C to +85°C, V_{CC} = +5V ±5%, unless otherwise specified.

Read Cycle Limits

Symbol	Parameter	X2864A-20 X2864AI-20 Min.	Max.	Units
t_{RC}	Read Cycle Time	200		ns
t_{CE}	Chip Enable Access Time		200	ns
t_{AA}	Address Access Time		200	ns
t_{OE}	Output Enable Access Time		150	ns
t_{LZ}	Chip Enable to Output in Low Z	10		ns
t_{HZ}	Chip Disable to Output in High Z	10	60	ns
t_{OLZ}	Output Enable to Output in Low Z	10		ns
t_{OHZ}	Output Disable to Output in High Z	10	60	ns
t_{OH}	Output Hold from Address Change	20		ns

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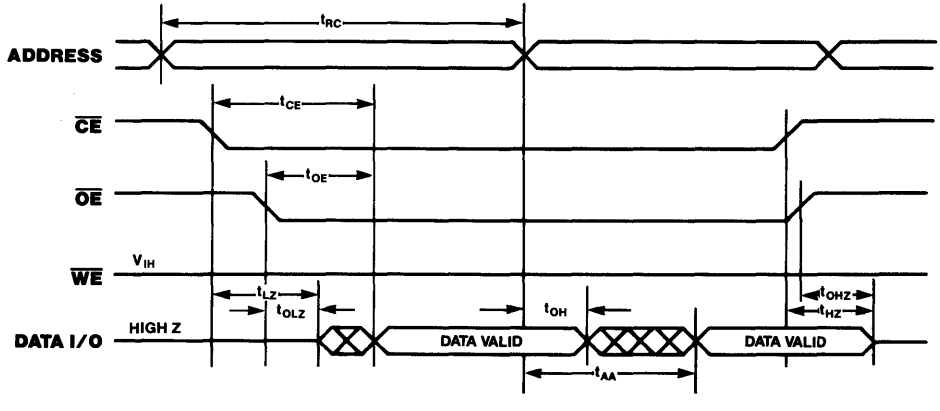
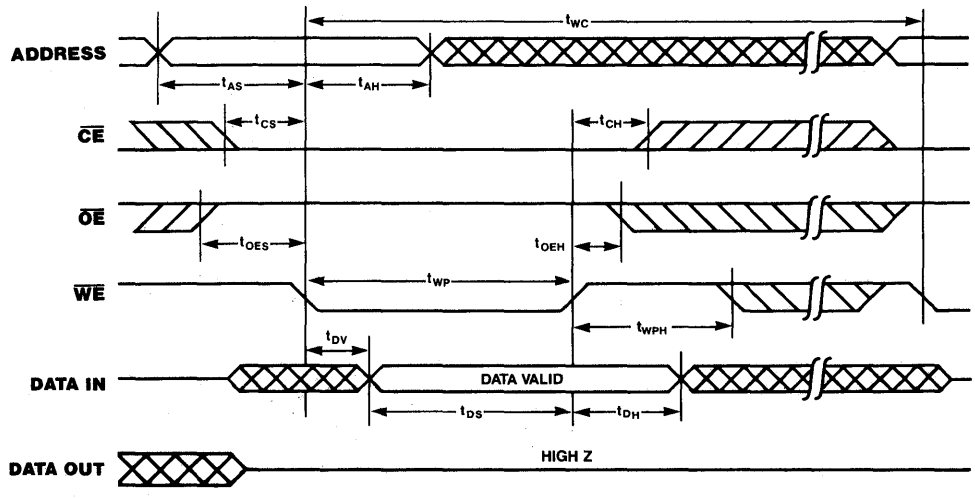
Read Cycle



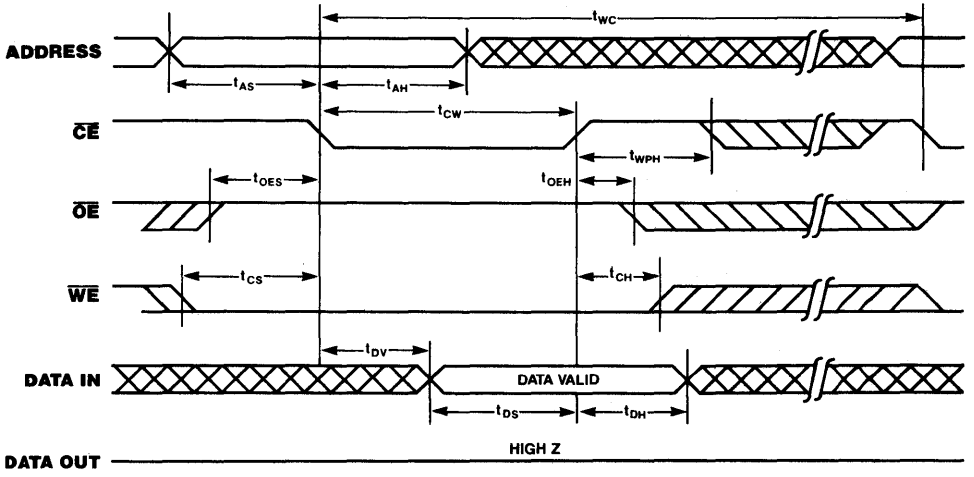
Byte Write Cycle Limits

Symbol	Parameter	Min.	Max.	Units
t_{WC}	Write Cycle Time	10		ms
t_{AS}	Address Set-Up Time	10		ns
t_{AH}	Address Hold Time	200		ns
t_{CS}	Write Set-Up Time	0		ns
t_{CH}	Write Hold Time	0		ns
t_{CW}	Chip Enable to End of Write Input	150		ns
t_{OES}	Output Enable Set-Up Time	10		ns
t_{OEH}	Output Enable Hold Time	10		ns
t_{WP}	Write Pulse Width	150		ns
t_{WPH}	Write Control Recovery	50		ns
t_{DV}	Data Valid Time		300	ns
t_{DS}	Data Set-Up Time	100		ns
t_{DH}	Data Hold Time	20		ns

$\overline{WE}$ Controlled Write Cycle



$\overline{CE}$ Controlled Write Cycle

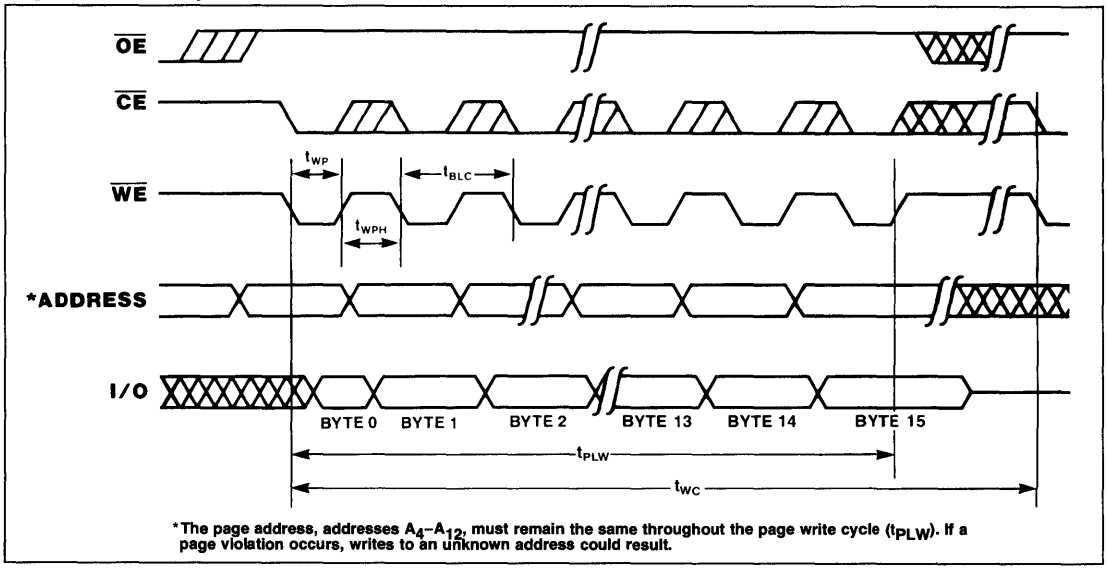


Page Mode Write Cycle Limits

Symbol	Parameter	Min.	Typ.(2)	Max.	Units
t_{WC}	Write Cycle Time		5	10	ms
t_{WP}	Write Pulse Width	150			ns
t_{BLC}	Byte Load Cycle	3		20	µs
t_{PLW}	Page Load Width			150	µs
t_{WPH}	Write Pulse Width High	50			ns

Note: (2) Typical values are for T_A = 25°C and nominal supply voltage.

Page Mode Write Cycle



*The page address, addresses A_4–A_{12}, must remain the same throughout the page write cycle (t_{PLW}). If a page violation occurs, writes to an unknown address could result.

PIN DESCRIPTIONS

Addresses (A_0–A_{12})

The Address inputs select an 8-bit memory location during a read or write operation.

Chip Enable ($\overline{CE}$)

The Chip Enable input must be LOW to enable all read/write operations. When $\overline{CE}$ is HIGH, power consumption is reduced.

Output Enable ($\overline{OE}$)

The Output Enable input controls the data output buffers and is used to initiate read operations.

Data In/Data Out (I/O_0–I/O_7)

Data is written to or read from the X2864A through the I/O pins.

Write Enable ($\overline{WE}$)

The Write Enable input controls the writing of data to the X2864A.

DEVICE OPERATION

READS

Read operations are initiated by both $\overline{OE}$ and $\overline{CE}$ LOW. The read operation is terminated by either $\overline{CE}$ or $\overline{OE}$ returning HIGH. This 2-line control architecture eliminates bus contention in a system environment. The data bus will be in a high impedance state when either $\overline{OE}$ or $\overline{CE}$ is HIGH.

WRITES

Write operations are initiated when both $\overline{CE}$ and $\overline{WE}$ are LOW *and* $\overline{OE}$ is HIGH. The X2864A supports both a $\overline{CE}$ and $\overline{WE}$ controlled write cycle. That is, the address is latched by the falling edge of either $\overline{CE}$ or $\overline{WE}$, whichever occurs last. Similarly, the data is latched internally by the rising edge of either $\overline{CE}$ or $\overline{WE}$, whichever occurs first. A byte write operation, once initiated, will automatically continue to completion, typically within 5ms.

PAGE WRITE OPERATION

The page write feature of the X2864A allows the entire memory to be written in 2.6 seconds. Page write allows two to sixteen bytes of data to be consecutively written to the X2864A prior to the commencement of the internal programming cycle. The destination addresses for a page write operation must reside on the same page; that is, A_4 through A_{12} must not change.

The page write mode can be entered during any write operation. Following the initial byte write cycle, the host can write an additional one to fifteen bytes in the same manner as the first byte was written. Each successive byte write cycle must begin within 20μs of the falling edge of $\overline{WE}$ of the preceding cycle. If a subsequent $\overline{WE}$ HIGH to LOW transition is not detected within 20μs the internal automatic programming cycle will commence.

$\overline{DATA}$ POLLING

The X2864A features $\overline{DATA}$ Polling as a method to indicate to the host system that the byte write or page write cycle has completed. $\overline{DATA}$ Polling allows a simple bit test operation to determine the status of the X2864A, eliminating additional interrupt inputs or external hardware. During the internal programming cycle, any attempt to read the last byte written will produce the complement of that data on I/O_7 (i.e., write data = 0xxx xxxx, read data = 1xxx xxxx). Once the programming cycle is complete, I/O_7 will reflect true data.

WRITE PROTECTION

There are three features that protect the nonvolatile data from inadvertent writes.

- Noise Protection—A $\overline{WE}$ pulse of less than 20ns will not initiate a write cycle.
- V_{CC} Sense—All functions are inhibited when V_{CC} is ≤3v, typically.
- Write Inhibit—Holding either $\overline{OE}$ LOW, $\overline{WE}$ HIGH or $\overline{CE}$ HIGH during power-on and power-off, will inhibit inadvertent writes.

ENDURANCE

Xicor E²PROMs are designed and tested for applications requiring extended endurance. The Process average for endurance of Xicor E²PROMs is documented in RR504, the *Xicor Reliability Report on Endurance.* Included in that report is a method for determining the expected endurance of the device based upon the specific application environment. RR504 and additional reliability reports are available from Xicor.

MASS PROGRAM

Mass chip program and erase modes may be used to accelerate test time when performing tests that require a large number of writes, such as device endurance testing. Additional information is available from Xicor regarding these test modes.

NOTES

Electrically Erasable PROM

FEATURES

- **Simple Byte and Page Write**
  - **— Single TTL Level $\overline{WE}$ Signal**
  - **— Latched Address and Data**
  - **— Automatic Write Timing**
  - **— $\overline{DATA}$ Polling Verification**
- **Fast Byte Write: 5ms Typical**
- **Automatic Page Write**
  - **— 5ms Typical per page**
  - **— Chip Rewrite in 2.6 sec Typical**
  - **— Effective 300 μsec/Byte**
- **Fast Access Time: 250ns Max.**
- **Single 5 Volt Supply**
- **JEDEC Approved Pinout for Byte-Wide Memories**

DESCRIPTION

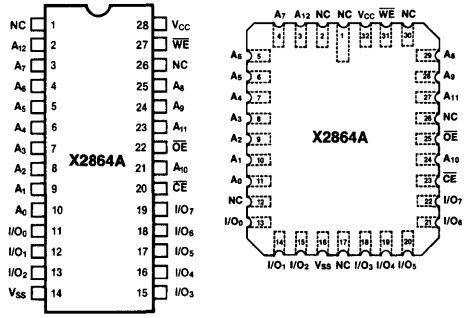
The Xicor X2864A is an 8K x 8 E^2PROM, fabricated with the same reliable N-channel floating gate MOS technology used in all Xicor 5 volt programmable nonvolatile memories. The X2864A features the JEDEC approved pinout for byte-wide memories, compatible with industry standard RAMs, ROMs and EPROMs.

The X2864A supports a 16-byte page write operation, effectively providing a 300μs/byte write and enabling the entire memory to be written in less than 2.6 seconds. The X2864A also features $\overline{DATA}$ Polling, a system software support scheme used to indicate the early completion of a write cycle.

Xicor E^2PROMs are designed and tested for applications requiring extended endurance. Refer to Device Operation for further endurance information. Data retention is specified to be greater than 100 years.

3

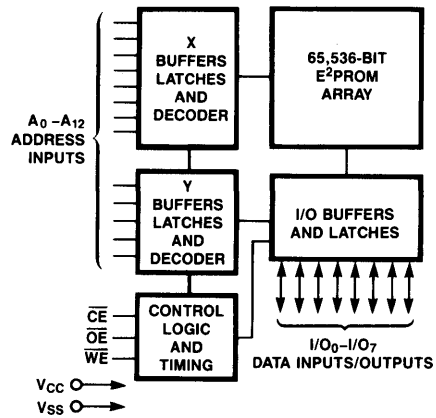
PIN CONFIGURATIONS



PIN NAMES

A_0–A_{12}	Address Inputs
I/O_0–I/O_7	Data Input/Output
$\overline{WE}$	Write Enable
$\overline{CE}$	Chip Enable
$\overline{OE}$	Output Enable
V_{CC}	+5V
V_{SS}	Ground
NC	No Connect

FUNCTIONAL DIAGRAM



ABSOLUTE MAXIMUM RATINGS*

Temperature Under Bias X2864A ..... −10°C to +85°C
X2864AI ..... −65°C to +135°C
Storage Temperature ..... −65°C to +150°C
Voltage on any Pin with
Respect to Ground ..... −1.0V to +7V
D.C. Output Current ..... 5 mA
Lead Temperature (Soldering,
10 Seconds) ..... 300°C

*COMMENT

Stresses above those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. This is a stress rating only and the functional operation of the device at these or any other conditions above those indicated in the operational sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

D.C. OPERATING CHARACTERISTICS

X2864A T_A = 0°C to +70°C, V_{CC} = +5V ±5%, unless otherwise specified.
X2864AI T_A = −40°C to +85°C, V_{CC} = +5V ±5%, unless otherwise specified.

Symbol	Parameter	X2864A Limits		X2864AI Limits		Units	Test Conditions
		Min.	Max.	Min.	Max.		
I_{CC}	V_{CC} Current (Active)		140		140	mA	$\overline{CE}$ = $\overline{OE}$ = V_{IL} All I/O's = Open Other Inputs = V_{CC}
I_{SB}	V_{CC} Current (Standby)		60		70	mA	$\overline{CE}$ = V_{IH}, $\overline{OE}$ = V_{IL} All I/O's = Open Other Inputs = V_{CC}
I_{LI}	Input Leakage Current		10		10	µA	V_{IN} = GND to V_{CC}
I_{LO}	Output Leakage Current		10		10	µA	V_{OUT} = GND to V_{CC}, $\overline{CE}$ = V_{IH}
V_{IL}	Input Low Voltage	−1.0	0.8	−1.0	0.8	V	
V_{IH}	Input High Voltage	2.0	V_{CC} +0.5	2.0	V_{CC} +0.5	V	
V_{OL}	Output Low Voltage		0.4		0.4	V	I_{OL} = 2.1 mA
V_{OH}	Output High Voltage	2.4		2.4		V	I_{OH} = −400 µA

CAPACITANCE T_A = 25°C, f = 1.0 MHz, V_{CC} = 5V

Symbol	Test	Max.	Unit	Conditions
$C_{I/O}$[1]	Input/Output Capacitance	10	pF	$V_{I/O}$ = 0V
C_{IN}[1]	Input Capacitance	6	pF	V_{IN} = 0V

Note: (1) This parameter is periodically sampled and not 100% tested.

A.C. CONDITIONS OF TEST

Input Pulse Levels	0 to 3.0 Volts
Input Rise and Fall Times	10 nsec
Input and Output Timing Levels	1.5 Volts
Output Load	1 TTL Gate and C_L = 100 pF

MODE SELECTION

$\overline{CE}$	$\overline{OE}$	$\overline{WE}$	Mode	I/O	Power
L	L	H	Read	D_{OUT}	Active
L	H	L	Write	D_{IN}	Active
H	X	X	Standby and Write Inhibit	High Z	Standby
X	L	X	Write Inhibit	—	—
X	X	H	Write Inhibit	—	—

A.C. CHARACTERISTICS

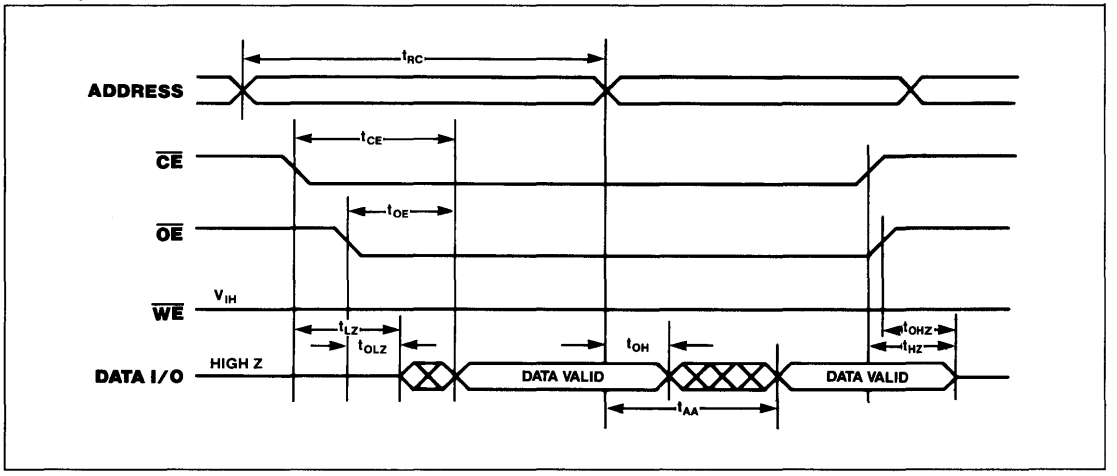
X2864A T_A = 0°C to +70°C, V_{CC} = +5V ±5%, unless otherwise specified.
X2864AI T_A = −40°C to +85°C, V_{CC} = +5V ±5%, unless otherwise specified.

Read Cycle Limits

		X2864A-25 X2864AI-25		X2864A X2864AI		X2864A-35 X2864AI-35		X2864A-45 X2864AI-45		
Symbol	**Parameter**	**Min.**	**Max.**	**Min.**	**Max.**	**Min.**	**Max.**	**Min.**	**Max.**	**Units**
t_{RC}	Read Cycle Time	250		300		350		450		ns
t_{CE}	Chip Enable Access Time		250		300		350		450	ns
t_{AA}	Address Access Time		250		300		350		450	ns
t_{OE}	Output Enable Access Time		150		150		150		150	ns
t_{LZ}	Chip Enable to Output in Low Z	10		10		10		10		ns
t_{HZ}	Chip Disable to Output in High Z	10	60	10	80	10	80	10	100	ns
t_{OLZ}	Output Enable to Output in Low Z	10		10		10		10		ns
t_{OHZ}	Output Disable to Output in High Z	10	60	10	80	10	80	10	100	ns
t_{OH}	Output Hold from Address Change	20		20		20		20		ns

3

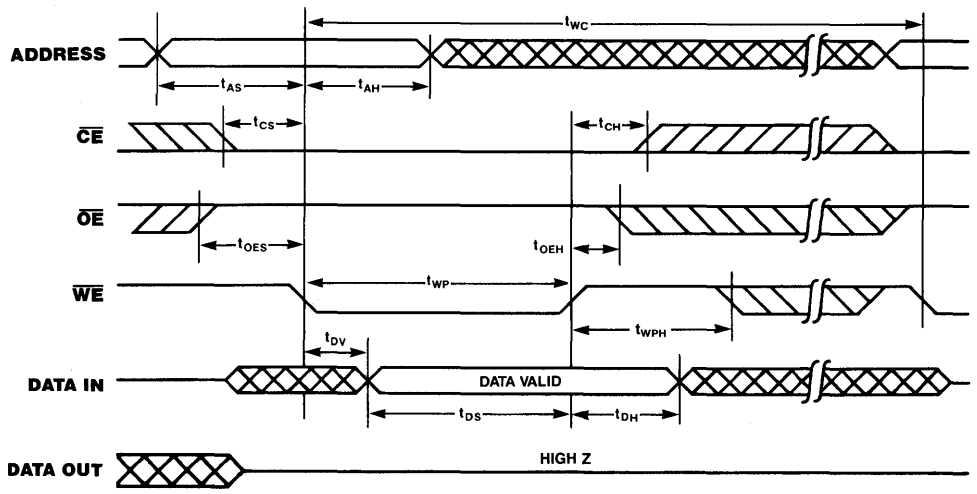
Read Cycle



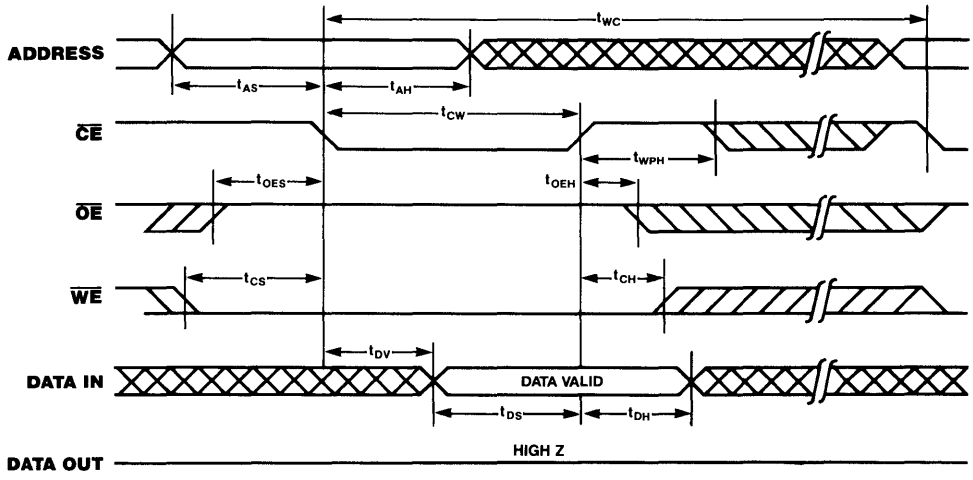
Byte Write Cycle Limits

Symbol	Parameter	Min.	Max.	Units
t_{WC}	Write Cycle Time	10		ms
t_{AS}	Address Set-Up Time	10		ns
t_{AH}	Address Hold Time	200		ns
t_{CS}	Write Set-Up Time	0		ns
t_{CH}	Write Hold Time	0		ns
t_{CW}	Chip Enable to End of Write Input	150		ns
t_{OES}	Output Enable Set-Up Time	10		ns
t_{OEH}	Output Enable Hold Time	10		ns
t_{WP}	Write Pulse Width	150		ns
t_{WPH}	Write Control Recovery	50		ns
t_{DV}	Data Valid Time		300	ns
t_{DS}	Data Set-Up Time	100		ns
t_{DH}	Data Hold Time	20		ns

$\overline{WE}$ Controlled Write Cycle



$\overline{CE}$ Controlled Write Cycle



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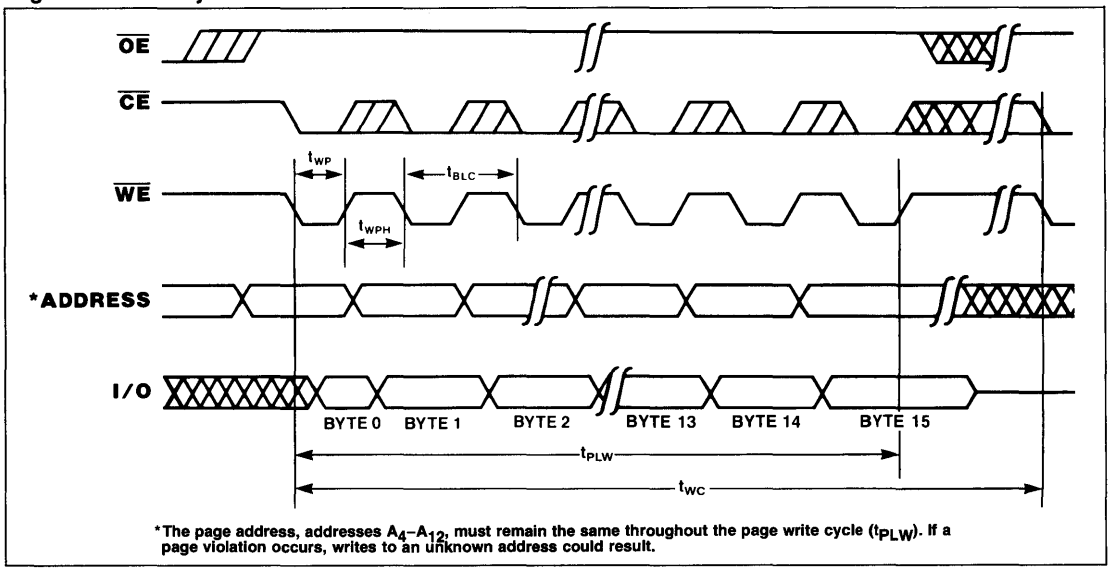
Page Mode Write Cycle Limits

Symbol	Parameter	Min.	Typ.(2)	Max.	Units
t_{WC}	Write Cycle Time		5	10	ms
t_{WP}	Write Pulse Width	150			ns
t_{BLC}	Byte Load Cycle	3		20	µs
t_{PLW}	Page Load Width			150	µs
t_{WPH}	Write Pulse Width High	50			ns

Note: (2) Typical values are for T_A = 25°C and nominal supply voltage.

Page Mode Write Cycle



*The page address, addresses A_4–A_{12}, must remain the same throughout the page write cycle (t_{PLW}). If a page violation occurs, writes to an unknown address could result.

PIN DESCRIPTIONS

Addresses (A_0–A_{12})

The Address inputs select an 8-bit memory location during a read or write operation.

Chip Enable ($\overline{CE}$)

The Chip Enable input must be LOW to enable all read/write operations. When $\overline{CE}$ is HIGH, power consumption is reduced.

Output Enable ($\overline{OE}$)

The Output Enable input controls the data output buffers and is used to initiate read operations.

Data In/Data Out (I/O_0–I/O_7)

Data is written to or read from the X2864A through the I/O pins.

Write Enable ($\overline{WE}$)

The Write Enable input controls the writing of data to the X2864A.

DEVICE OPERATION

READS

Read operations are initiated by both $\overline{OE}$ and $\overline{CE}$ LOW. The read operation is terminated by either $\overline{CE}$ or $\overline{OE}$ returning HIGH. This 2-line control architecture eliminates bus contention in a system environment. The data bus will be in a high impedance state when either $\overline{OE}$ or $\overline{CE}$ is HIGH.

WRITES

Write operations are initiated when both $\overline{CE}$ and $\overline{WE}$ are LOW *and* $\overline{OE}$ is HIGH. The X2864A supports both a $\overline{CE}$ and $\overline{WE}$ controlled write cycle. That is, the address is latched by the falling edge of either $\overline{CE}$ or $\overline{WE}$, whichever occurs last. Similarly, the data is latched internally by the rising edge of either $\overline{CE}$ or $\overline{WE}$, whichever occurs first. A byte write operation, once initiated, will automatically continue to completion, typically within 5ms.

PAGE WRITE OPERATION

The page write feature of the X2864A allows the entire memory to be written in 2.6 seconds. Page write allows two to sixteen bytes of data to be consecutively written to the X2864A prior to the commencement of the internal programming cycle. The destination addresses for a page write operation must reside on the same page; that is, A_4 through A_{12} must not change.

The page write mode can be entered during any write operation. Following the initial byte write cycle, the host can write an additional one to fifteen bytes in the same manner as the first byte was written. Each successive byte write cycle must begin within 20μs of the falling edge of $\overline{WE}$ of the preceding cycle. If a subsequent $\overline{WE}$ HIGH to LOW transition is not detected within 20μs the internal automatic programming cycle will commence.

$\overline{DATA}$ POLLING

The X2864A features $\overline{DATA}$ Polling as a method to indicate to the host system that the byte write or page write cycle has completed. $\overline{DATA}$ Polling allows a simple bit test operation to determine the status of the X2864A, eliminating additional interrupt inputs or external hardware. During the internal programming cycle, any attempt to read the last byte written will produce the complement of that data on I/O_7 (i.e., write data = 0xxx xxxx, read data = 1xxx xxxx). Once the programming cycle is complete, I/O_7 will reflect true data.

WRITE PROTECTION

There are three features that protect the nonvolatile data from inadvertent writes.

- Noise Protection—A $\overline{WE}$ pulse of less than 20ns will not initiate a write cycle.
- V_{CC} Sense—All functions are inhibited when V_{CC} is ≤3v, typically.
- Write Inhibit—Holding either $\overline{OE}$ LOW, $\overline{WE}$ HIGH or $\overline{CE}$ HIGH during power-on and power-off, will inhibit inadvertent writes.

ENDURANCE

Xicor E²PROMs are designed and tested for applications requiring extended endurance. The Process average for endurance of Xicor E²PROMs is documented in RR504, the *Xicor Reliability Report on Endurance*. Included in that report is a method for determining the expected endurance of the device based upon the specific application environment. RR504 and additional reliability reports are available from Xicor.

MASS PROGRAM

Mass chip program and erase modes may be used to accelerate test time when performing tests that require a large number of writes, such as device endurance testing. Additional information is available from Xicor regarding these test modes.

NOTES

64K Military **X2864AM-25** **8192 x 8 Bit**

Electrically Erasable PROM

FEATURES

- **Simple Byte and Page Write**
  - **— Single TTL Level $\overline{WE}$ Signal**
  - **— Latched Address and Data**
  - **— Automatic Write Timing**
  - **— $\overline{DATA}$ Polling Verification**
- **Fast Byte Write: 5ms Typical**
- **Automatic Page Write**
  - **— 5ms Typical per page**
  - **— Chip Rewrite in 2.6 sec Typical**
  - **— Effective 300 μsec/Byte**
- **Fast Access Time: 250ns Max.**
- **Single 5 Volt Supply**
- **JEDEC Approved Pinout for Byte-Wide Memories**

DESCRIPTION

The Xicor X2864A is an 8K x 8 E^2PROM, fabricated with the same reliable N-channel floating gate MOS technology used in all Xicor 5 volt programmable nonvolatile memories. The X2864A features the JEDEC approved pinout for byte-wide memories, compatible with industry standard RAMs, ROMs and EPROMs.

The X2864A supports a 16-byte page write operation, effectively providing a 300μs/byte write and enabling the entire memory to be written in less than 2.6 seconds. The X2864A also features $\overline{DATA}$ Polling, a system software support scheme used to indicate the early completion of a write cycle.

Xicor E^2PROMs are designed and tested for applications requiring extended endurance. Refer to Device Operation for further endurance information. Data retention is specified to be greater than 100 years.

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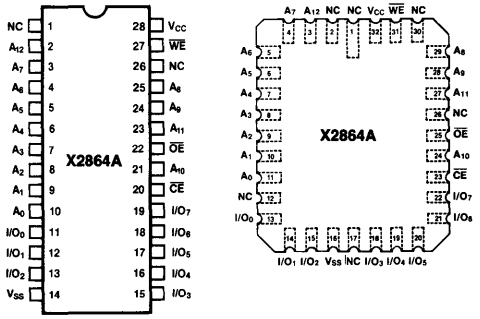
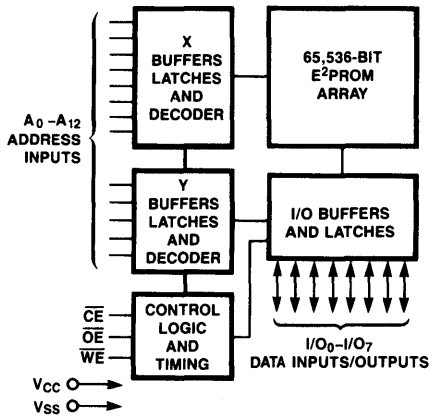
PIN CONFIGURATIONS



PIN NAMES

A_0–A_{12}	Address Inputs
$\overline{I/O_0}$–I/O_7	Data Input/Output
$\overline{WE}$	Write Enable
$\overline{CE}$	Chip Enable
$\overline{OE}$	Output Enable
V_{CC}	+5V
V_{SS}	Ground
NC	No Connect

FUNCTIONAL DIAGRAM



ABSOLUTE MAXIMUM RATINGS*

Temperature Under Bias ..... −65°C to +135°C
Storage Temperature ..... −65°C to +150°C
Voltage on any Pin with
Respect to Ground ..... −1.0V to +7V
D.C. Output Current ..... 5 mA
Lead Temperature (Soldering,
10 Seconds) ..... 300°C

*COMMENT

Stresses above those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. This is a stress rating only and the functional operation of the device at these or any other conditions above those indicated in the operational sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

D.C. OPERATING CHARACTERISTICS

T_A = −55°C to +125°C, V_{CC} = +5V ±5%, unless otherwise specified.

Symbol	Parameter	Limits		Units	Test Conditions
		Min.	Max.		
I_{CC}	V_{CC} Current (Active)		140	mA	$\overline{CE}$ = $\overline{OE}$ = V_{IL} All I/O's = Open Other Inputs = V_{CC}
I_{SB}	V_{CC} Current (Standby)		70	mA	$\overline{CE}$ = V_{IH}, $\overline{OE}$ = V_{IL} All I/O's = Open Other Inputs = V_{CC}
I_{LI}	Input Leakage Current		10	µA	V_{IN} = GND to V_{CC}
I_{LO}	Output Leakage Current		10	µA	V_{OUT} = GND to V_{CC}, $\overline{CE}$ = V_{IH}
V_{IL}	Input Low Voltage	−1.0	0.8	V	
V_{IH}	Input High Voltage	2.0	V_{CC} +0.5	V	
V_{OL}	Output Low Voltage		0.4	V	I_{OL} = 2.1 mA
V_{OH}	Output High Voltage	2.4		V	I_{OH} = −400 µA

CAPACITANCE T_A = 25°C, f = 1.0 MHz, V_{CC} = 5V

Symbol	Test	Max.	Unit	Conditions
$C_{I/O}$[1]	Input/Output Capacitance	10	pF	$V_{I/O}$ = 0V
C_{IN}[1]	Input Capacitance	6	pF	V_{IN} = 0V

Note: (1) This parameter is periodically sampled and not 100% tested.

A.C. CONDITIONS OF TEST

Input Pulse Levels	0 to 3.0 Volts
Input Rise and Fall Times	10 nsec
Input and Output Timing Levels	1.5 Volts
Output Load	1 TTL Gate and C_L = 100 pF

MODE SELECTION

$\overline{CE}$	$\overline{OE}$	$\overline{WE}$	Mode	I/O	Power
L	L	H	Read	D_{OUT}	Active
L	H	L	Write	D_{IN}	Active
H	X	X	Standby and Write Inhibit	High Z	Standby
X	L	X	Write Inhibit	—	—
X	X	H	Write Inhibit	—	—

A.C. CHARACTERISTICS

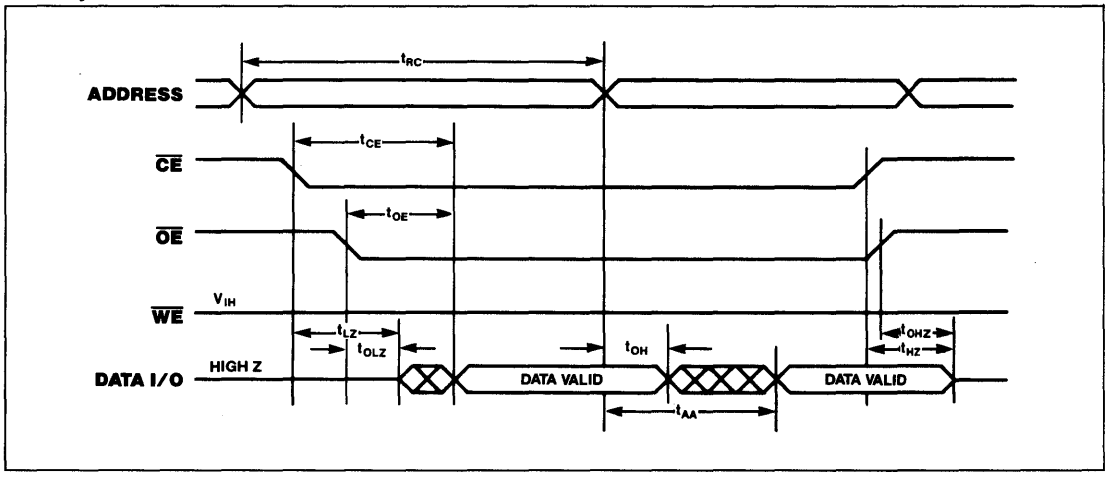
T_A = −55°C to +125°C, V_{CC} = +5V ±5%, unless otherwise specified.

Read Cycle Limits

Symbol	Parameter	Min.	Max.	Units
t_{RC}	Read Cycle Time	250		ns
t_{CE}	Chip Enable Access Time		250	ns
t_{AA}	Address Access Time		250	ns
t_{OE}	Output Enable Access Time		150	ns
t_{LZ}	Chip Enable to Output in Low Z	10		ns
t_{HZ}	Chip Disable to Output in High Z	10	60	ns
t_{OLZ}	Output Enable to Output in Low Z	10		ns
t_{OHZ}	Output Disable to Output in High Z	10	60	ns
t_{OH}	Output Hold from Address Change	20		ns

3

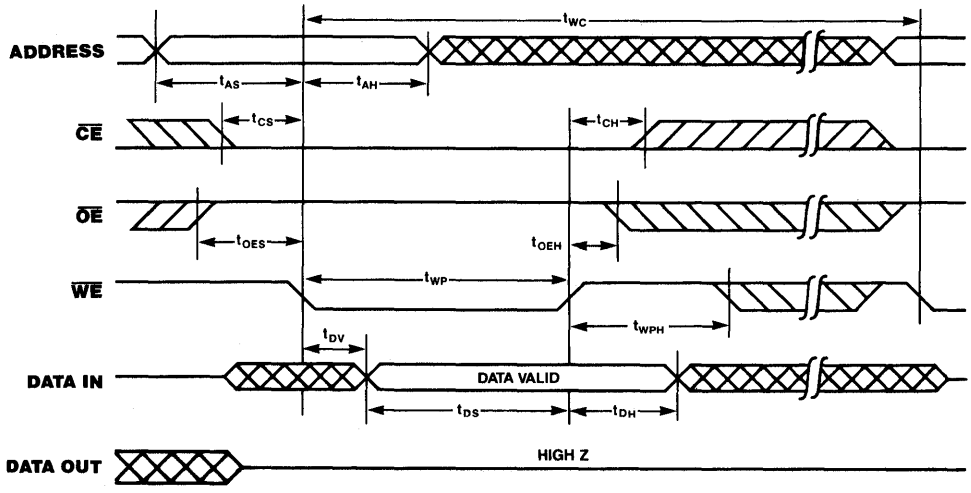
Read Cycle



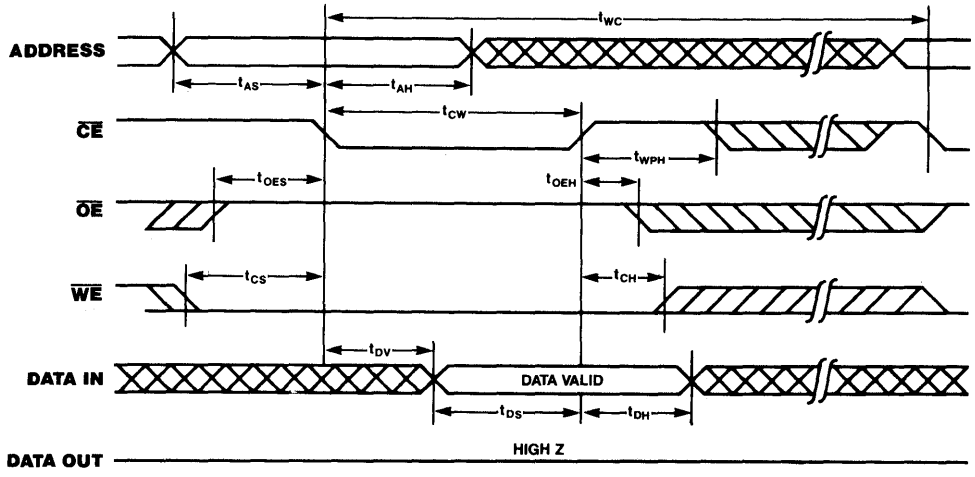
Byte Write Cycle Limits

Symbol	Parameter	Min.	Max.	Units
t_{WC}	Write Cycle Time	10		ms
t_{AS}	Address Set-Up Time	10		ns
t_{AH}	Address Hold Time	200		ns
t_{CS}	Write Set-Up Time	0		ns
t_{CH}	Write Hold Time	0		ns
t_{CW}	Chip Enable to End of Write Input	150		ns
t_{OES}	Output Enable Set-Up Time	10		ns
t_{OEH}	Output Enable Hold Time	10		ns
t_{WP}	Write Pulse Width	150		ns
t_{WPH}	Write Control Recovery	50		ns
t_{DV}	Data Valid Time		300	ns
t_{DS}	Data Set-Up Time	100		ns
t_{DH}	Data Hold Time	20		ns

$\overline{WE}$ Controlled Write Cycle



$\overline{CE}$ Controlled Write Cycle

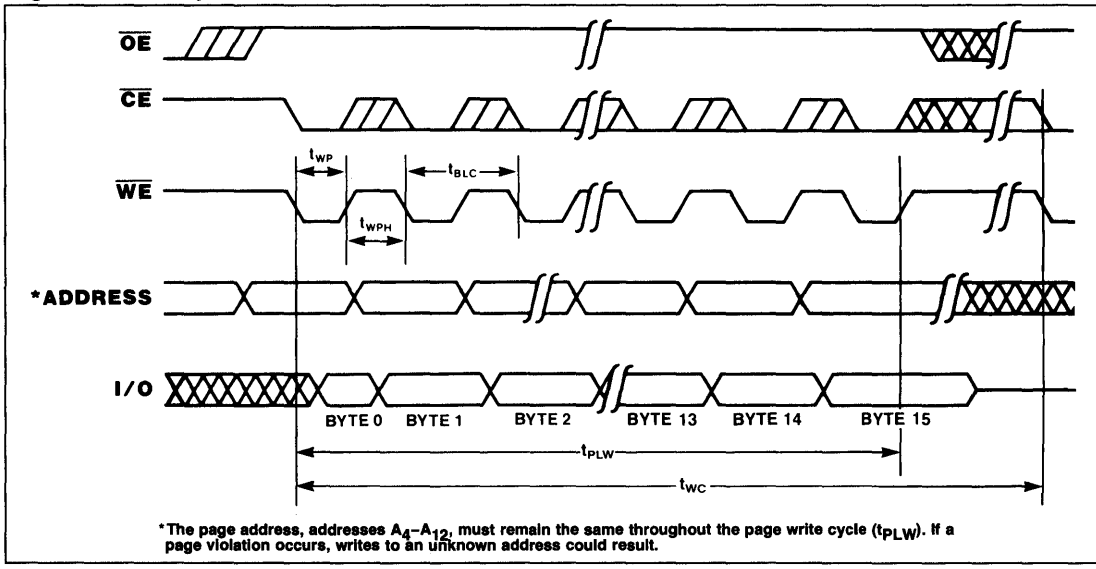


Page Mode Write Cycle Limits

Symbol	Parameter	Min.	Typ.(2)	Max.	Units
t_{WC}	Write Cycle Time		5	10	ms
t_{WP}	Write Pulse Width	150			ns
t_{BLC}	Byte Load Cycle	3		20	µs
t_{PLW}	Page Load Width			150	µs
t_{WPH}	Write Pulse Width High	50			ns

Note: (2) Typical values are for T_A = 25°C and nominal supply voltage.

Page Mode Write Cycle



*The page address, addresses A_4–A_{12}, must remain the same throughout the page write cycle (t_{PLW}). If a page violation occurs, writes to an unknown address could result.

PIN DESCRIPTIONS

Addresses (A_0–A_{12})

The Address inputs select an 8-bit memory location during a read or write operation.

Chip Enable ($\overline{CE}$)

The Chip Enable input must be LOW to enable all read/write operations. When $\overline{CE}$ is HIGH, power consumption is reduced.

Output Enable ($\overline{OE}$)

The Output Enable input controls the data output buffers and is used to initiate read operations.

Data In/Data Out (I/O_0–I/O_7)

Data is written to or read from the X2864A through the I/O pins.

Write Enable ($\overline{WE}$)

The Write Enable input controls the writing of data to the X2864A.

DEVICE OPERATION

READS

Read operations are initiated by both $\overline{OE}$ and $\overline{CE}$ LOW. The read operation is terminated by either $\overline{CE}$ or $\overline{OE}$ returning HIGH. This 2-line control architecture eliminates bus contention in a system environment. The data bus will be in a high impedance state when either $\overline{OE}$ or $\overline{CE}$ is HIGH.

WRITES

Write operations are initiated when both $\overline{CE}$ and $\overline{WE}$ are LOW *and* $\overline{OE}$ is HIGH. The X2864A supports both a $\overline{CE}$ and $\overline{WE}$ controlled write cycle. That is, the address is latched by the falling edge of either $\overline{CE}$ or $\overline{WE}$, whichever occurs last. Similarly, the data is latched internally by the rising edge of either $\overline{CE}$ or $\overline{WE}$, whichever occurs first. A byte write operation, once initiated, will automatically continue to completion, typically within 5ms.

PAGE WRITE OPERATION

The page write feature of the X2864A allows the entire memory to be written in 2.6 seconds. Page write allows two to sixteen bytes of data to be consecutively written to the X2864A prior to the commencement of the internal programming cycle. The destination addresses for a page write operation must reside on the same page; that is, A_4 through A_{12} must not change.

The page write mode can be entered during any write operation. Following the initial byte write cycle, the host can write an additional one to fifteen bytes in the same manner as the first byte was written. Each successive byte write cycle must begin within 20μs of the falling edge of $\overline{WE}$ of the preceding cycle. If a subsequent $\overline{WE}$ HIGH to LOW transition is not detected within 20μs the internal automatic programming cycle will commence.

$\overline{DATA}$ POLLING

The X2864A features $\overline{DATA}$ Polling as a method to indicate to the host system that the byte write or page write cycle has completed. $\overline{DATA}$ Polling allows a simple bit test operation to determine the status of the X2864A, eliminating additional interrupt inputs or external hardware. During the internal programming cycle, any attempt to read the last byte written will produce the complement of that data on I/O_7 (i.e., write data = 0xxx xxxx, read data = 1xxx xxxx). Once the programming cycle is complete, I/O_7 will reflect true data.

WRITE PROTECTION

There are three features that protect the nonvolatile data from inadvertent writes.

- Noise Protection—A $\overline{WE}$ pulse of less than 20ns will not initiate a write cycle.
- V_{CC} Sense—All functions are inhibited when V_{CC} is ≤3v, typically.
- Write Inhibit—Holding either $\overline{OE}$ LOW, $\overline{WE}$ HIGH or $\overline{CE}$ HIGH during power-on and power-off, will inhibit inadvertent writes.

ENDURANCE

Xicor E^2PROMs are designed and tested for applications requiring extended endurance. The Process average for endurance of Xicor E^2PROMs is documented in RR504, the *Xicor Reliability Report on Endurance*. Included in that report is a method for determining the expected endurance of the device based upon the specific application environment. RR504 and additional reliability reports are available from Xicor.

MASS PROGRAM

Mass chip program and erase modes may be used to accelerate test time when performing tests that require a large number of writes, such as device endurance testing. Additional information is available from Xicor regarding these test modes.

NOTES

Electrically Erasable PROM

FEATURES

- **Simple Byte and Page Write**
  - **Single TTL Level $\overline{WE}$ Signal**
  - **Latched Address and Data**
  - **Automatic Write Timing**
  - **$\overline{DATA}$ Polling Verification**
- **Fast Byte Write: 5ms Typical**
- **Automatic Page Write**
  - **5ms Typical per page**
  - **Chip Rewrite in 2.6 sec Typical**
  - **Effective 300 μsec/Byte**
- **Fast Access Time: 300ns Max.**
- **Single 5 Volt Supply**
- **JEDEC Approved Pinout for Byte-Wide Memories**

DESCRIPTION

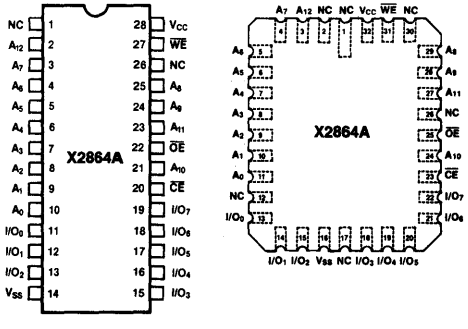
The Xicor X2864A is an 8K x 8 E^2PROM, fabricated with the same reliable N-channel floating gate MOS technology used in all Xicor 5 volt programmable nonvolatile memories. The X2864A features the JEDEC approved pinout for byte-wide memories, compatible with industry standard RAMs, ROMs and EPROMs.

The X2864A supports a 16-byte page write operation, effectively providing a 300μs/byte write and enabling the entire memory to be written in less than 2.6 seconds. The X2864A also features $\overline{DATA}$ Polling, a system software support scheme used to indicate the early completion of a write cycle.

Xicor E^2PROMs are designed and tested for applications requiring extended endurance. Refer to Device Operation for further endurance information. Data retention is specified to be greater than 100 years.

3

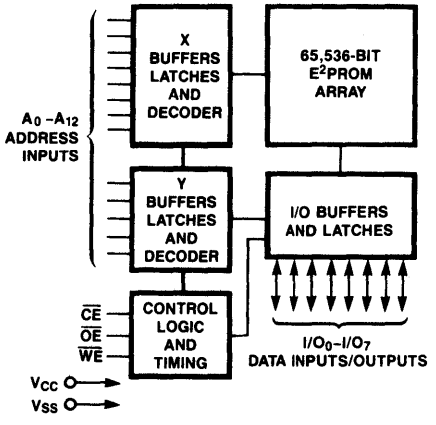
PIN CONFIGURATIONS



PIN NAMES

A_0–A_{12}	Address Inputs
I/O_0–I/O_7	Data Input/Output
$\overline{WE}$	Write Enable
$\overline{CE}$	Chip Enable
$\overline{OE}$	Output Enable
V_{CC}	+5V
V_{SS}	Ground
NC	No Connect

FUNCTIONAL DIAGRAM



ABSOLUTE MAXIMUM RATINGS*

Temperature Under Bias ..... −65°C to +135°C
Storage Temperature ..... −65°C to +150°C
Voltage on any Pin with
Respect to Ground ..... −1.0V to +7V
D.C. Output Current ..... 5 mA
Lead Temperature (Soldering,
10 Seconds) ..... 300°C

*COMMENT

Stresses above those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. This is a stress rating only and the functional operation of the device at these or any other conditions above those indicated in the operational sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

D.C. OPERATING CHARACTERISTICS

T_A = −55°C to +125°C, V_{CC} = +5V ±5%, unless otherwise specified.

Symbol	Parameter	Limits		Units	Test Conditions
		Min.	Max.		
I_{CC}	V_{CC} Current (Active)		140	mA	$\overline{CE}$ = $\overline{OE}$ = V_{IL} All I/O's = Open Other Inputs = V_{CC}
I_{SB}	V_{CC} Current (Standby)		70	mA	$\overline{CE}$ = V_{IH}, $\overline{OE}$ = V_{IL} All I/O's = Open Other Inputs = V_{CC}
I_{LI}	Input Leakage Current		10	µA	V_{IN} = GND to V_{CC}
I_{LO}	Output Leakage Current		10	µA	V_{OUT} = GND to V_{CC}, $\overline{CE}$ = V_{IH}
V_{IL}	Input Low Voltage	−1.0	0.8	V	
V_{IH}	Input High Voltage	2.0	V_{CC} +0.5	V	
V_{OL}	Output Low Voltage		0.4	V	I_{OL} = 2.1 mA
V_{OH}	Output High Voltage	2.4		V	I_{OH} = −400 µA

CAPACITANCE T_A = 25°C, f = 1.0 MHz, V_{CC} = 5V

Symbol	Test	Max.	Unit	Conditions
$C_{I/O}$[1]	Input/Output Capacitance	10	pF	$V_{I/O}$ = 0V
C_{IN}[1]	Input Capacitance	6	pF	V_{IN} = 0V

Note: (1) This parameter is periodically sampled and not 100% tested.

A.C. CONDITIONS OF TEST

Input Pulse Levels	0 to 3.0 Volts
Input Rise and Fall Times	10 nsec
Input and Output Timing Levels	1.5 Volts
Output Load	1 TTL Gate and C_L = 100 pF

MODE SELECTION

$\overline{CE}$	$\overline{OE}$	$\overline{WE}$	Mode	I/O	Power
L	L	H	Read	D_{OUT}	Active
L	H	L	Write	D_{IN}	Active
H	X	X	Standby and Write Inhibit	High Z	Standby
X	L	X	Write Inhibit	—	—
X	X	H	Write Inhibit	—	—

A.C. CHARACTERISTICS

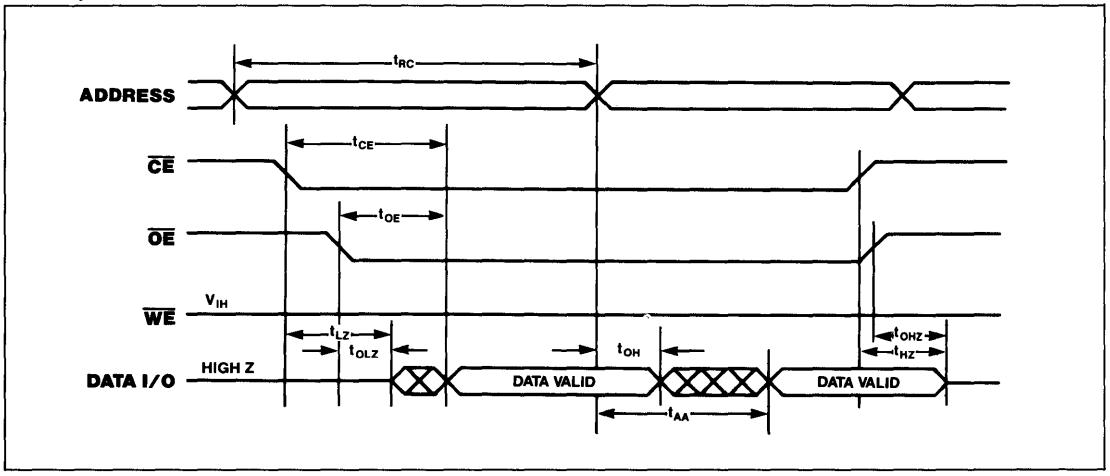
T_A = −55°C to +125°C, V_{CC} = +5V ±5%, unless otherwise specified.

Read Cycle Limits

Symbol	Parameter	X2864AM		X2864AM-35		X2864AM-45		Units
		Min.	Max.	Min.	Max.	Min.	Max.	
t_{RC}	Read Cycle Time	300		350		450		ns
t_{CE}	Chip Enable Access Time		300		350		450	ns
t_{AA}	Address Access Time		300		350		450	ns
t_{OE}	Output Enable Access Time		150		150		150	ns
t_{LZ}	Chip Enable to Output in Low Z	10		10		10		ns
t_{HZ}	Chip Disable to Output in High Z	10	80	10	80	10	100	ns
t_{OLZ}	Output Enable to Output in Low Z	10		10		10		ns
t_{OHZ}	Output Disable to Output in High Z	10	80	10	80	10	100	ns
t_{OH}	Output Hold from Address Change	20		20		20		ns

3

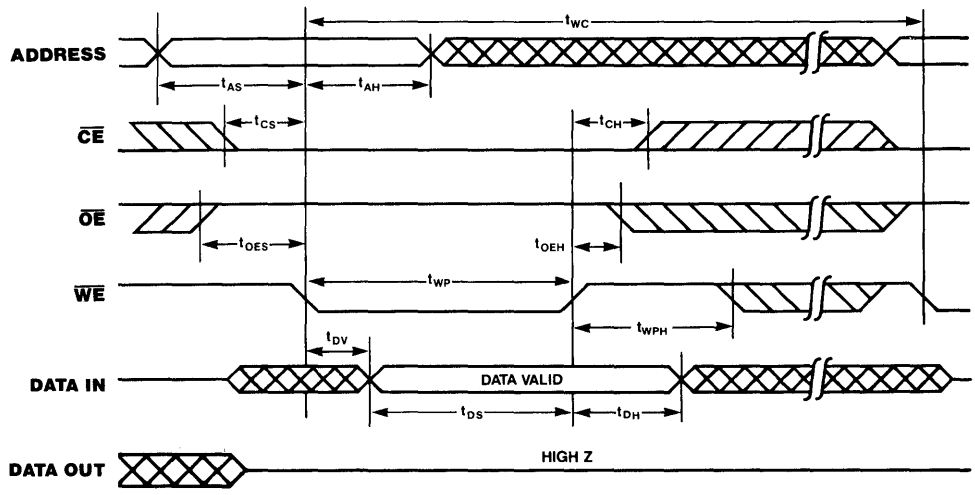
Read Cycle



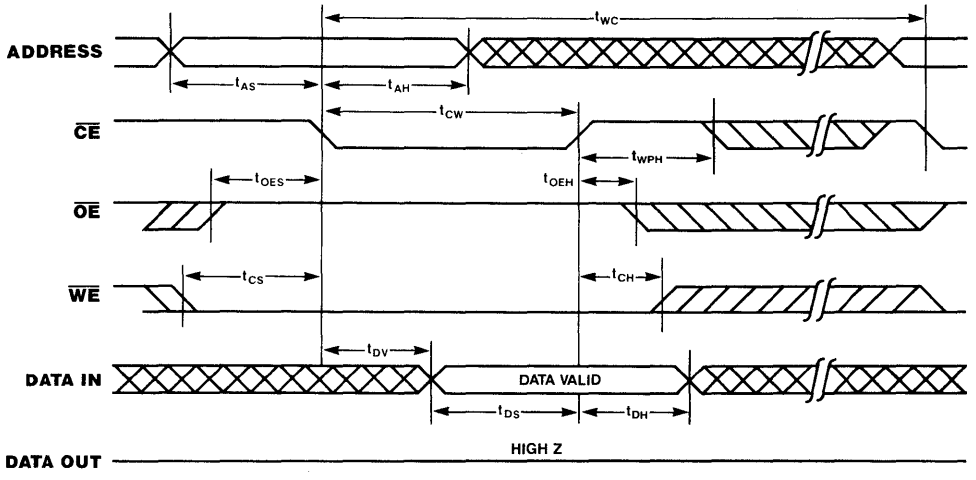
Byte Write Cycle Limits

Symbol	Parameter	Min.	Max.	Units
t_{WC}	Write Cycle Time	10		ms
t_{AS}	Address Set-Up Time	10		ns
t_{AH}	Address Hold Time	200		ns
t_{CS}	Write Set-Up Time	0		ns
t_{CH}	Write Hold Time	0		ns
t_{CW}	Chip Enable to End of Write Input	150		ns
t_{OES}	Output Enable Set-Up Time	10		ns
t_{OEH}	Output Enable Hold Time	10		ns
t_{WP}	Write Pulse Width	150		ns
t_{WPH}	Write Control Recovery	50		ns
t_{DV}	Data Valid Time		300	ns
t_{DS}	Data Set-Up Time	100		ns
t_{DH}	Data Hold Time	20		ns

$\overline{WE}$ Controlled Write Cycle



$\overline{CE}$ Controlled Write Cycle



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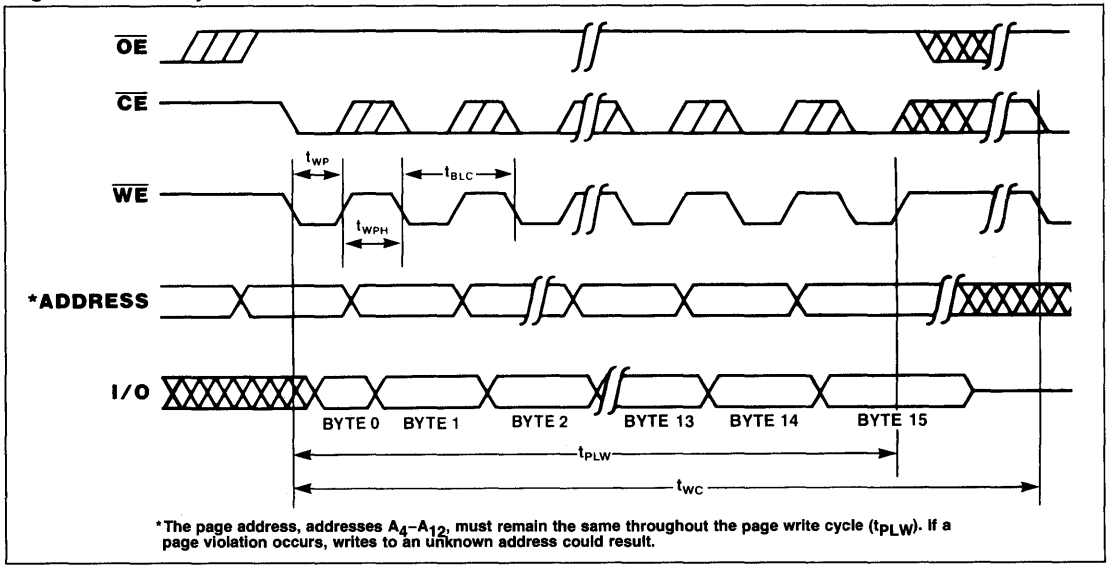
Page Mode Write Cycle Limits

Symbol	Parameter	Min.	Typ.(2)	Max.	Units
t_{WC}	Write Cycle Time		5	10	ms
t_{WP}	Write Pulse Width	150			ns
t_{BLC}	Byte Load Cycle	3		20	µs
t_{PLW}	Page Load Width			150	µs
t_{WPH}	Write Pulse Width High	50			ns

Note: (2) Typical values are for T_A = 25°C and nominal supply voltage.

Page Mode Write Cycle



*The page address, addresses A_4–A_{12}, must remain the same throughout the page write cycle (t_{PLW}). If a page violation occurs, writes to an unknown address could result.

PIN DESCRIPTIONS

Addresses (A_0–A_{12})

The Address inputs select an 8-bit memory location during a read or write operation.

Chip Enable ($\overline{CE}$)

The Chip Enable input must be LOW to enable all read/write operations. When $\overline{CE}$ is HIGH, power consumption is reduced.

Output Enable ($\overline{OE}$)

The Output Enable input controls the data output buffers and is used to initiate read operations.

Data In/Data Out (I/O_0–I/O_7)

Data is written to or read from the X2864A through the I/O pins.

Write Enable ($\overline{WE}$)

The Write Enable input controls the writing of data to the X2864A.

DEVICE OPERATION

READS

Read operations are initiated by both $\overline{OE}$ and $\overline{CE}$ LOW. The read operation is terminated by either $\overline{CE}$ or $\overline{OE}$ returning HIGH. This 2-line control architecture eliminates bus contention in a system environment. The data bus will be in a high impedance state when either $\overline{OE}$ or $\overline{CE}$ is HIGH.

WRITES

Write operations are initiated when both $\overline{CE}$ and $\overline{WE}$ are LOW *and* $\overline{OE}$ is HIGH. The X2864A supports both a $\overline{CE}$ and $\overline{WE}$ controlled write cycle. That is, the address is latched by the falling edge of either $\overline{CE}$ or $\overline{WE}$, whichever occurs last. Similarly, the data is latched internally by the rising edge of either $\overline{CE}$ or $\overline{WE}$, whichever occurs first. A byte write operation, once initiated, will automatically continue to completion, typically within 5ms.

PAGE WRITE OPERATION

The page write feature of the X2864A allows the entire memory to be written in 2.6 seconds. Page write allows two to sixteen bytes of data to be consecutively written to the X2864A prior to the commencement of the internal programming cycle. The destination addresses for a page write operation must reside on the same page; that is, A_4 through A_{12} must not change.

The page write mode can be entered during any write operation. Following the initial byte write cycle, the host can write an additional one to fifteen bytes in the same manner as the first byte was written. Each successive byte write cycle must begin within 20µs of the falling edge of $\overline{WE}$ of the preceding cycle. If a subsequent $\overline{WE}$ HIGH to LOW transition is not detected within 20µs the internal automatic programming cycle will commence.

$\overline{DATA}$ POLLING

The X2864A features $\overline{DATA}$ Polling as a method to indicate to the host system that the byte write or page write cycle has completed. $\overline{DATA}$ Polling allows a simple bit test operation to determine the status of the X2864A, eliminating additional interrupt inputs or external hardware. During the internal programming cycle, any attempt to read the last byte written will produce the complement of that data on I/O_7 (i.e., write data = 0xxx xxxx, read data = 1xxx xxxx). Once the programming cycle is complete, I/O_7 will reflect true data.

WRITE PROTECTION

There are three features that protect the nonvolatile data from inadvertent writes.

- Noise Protection—A $\overline{WE}$ pulse of less than 20ns will not initiate a write cycle.
- V_{CC} Sense—All functions are inhibited when V_{CC} is ≤3v, typically.
- Write Inhibit—Holding either $\overline{OE}$ LOW, $\overline{WE}$ HIGH or $\overline{CE}$ HIGH during power-on and power-off, will inhibit inadvertent writes.

ENDURANCE

Xicor E^2PROMs are designed and tested for applications requiring extended endurance. The Process average for endurance of Xicor E^2PROMs is documented in RR504, the *Xicor Reliability Report on Endurance.* Included in that report is a method for determining the expected endurance of the device based upon the specific application environment. RR504 and additional reliability reports are available from Xicor.

MASS PROGRAM

Mass chip program and erase modes may be used to accelerate test time when performing tests that require a large number of writes, such as device endurance testing. Additional information is available from Xicor regarding these test modes.

NOTES

ADVANCED INFORMATION

64K Commercial X2864B 8192 x 8 Bit

Electrically Erasable PROM

TYPICAL FEATURES

- 150ns Access Time
- High Performance Scaled NMOS Technology
- Fast Write Cycle Times
  - — Byte or Page Write Cycle: 2ms Typical
  - — 32 Byte Page Write Operation
  - — Complete Memory Rewrite: 500ms
  - — Effective Byte Write Cycle Time of 63μs
- $\overline{\text{DATA}}$ Polling
  - — Allows User to Minimize Write Cycle Time
- Reduced Power
  - — 80mA Active Current
  - — 30mA Standby Current
- JEDEC Approved Byte-wide Pinout

DESCRIPTION

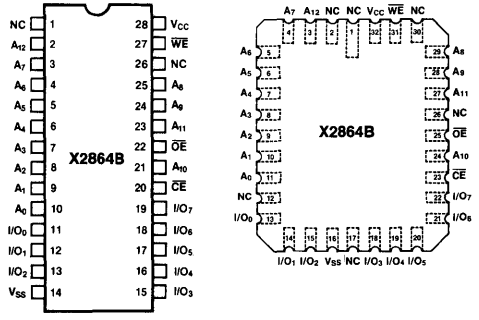
The Xicor X2864B is an 8K x 8 E^2PROM, fabricated with an advanced, high performance N-channel floating gate MOS technology. Like all Xicor programmable nonvolatile memories it is a 5 volt only device. The X2864B features the JEDEC approved pinout for byte-wide memories, compatible with industry standard RAMs, ROMs and EPROMs.

The X2864B supports a 32-byte page write operation, effectively providing a 63μs/byte write cycle and enabling the entire memory to be written in less than 500ms. The X2864B also features $\overline{\text{DATA}}$ Polling, a system software support scheme used to indicate the early completion of a write cycle.

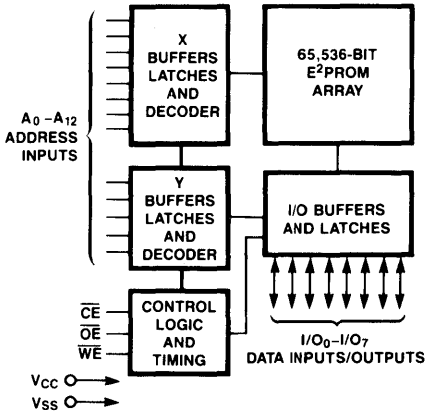
Xicor E^2PROMs are designed and tested for applications requiring extended endurance. Data retention is specified to be greater than 100 years.

3

PIN CONFIGURATIONS



FUNCTIONAL DIAGRAM



PIN NAMES

A_0–A_{12}	Address Inputs
I/O_0–I/O_7	Data Input/Output
$\overline{WE}$	Write Enable
$\overline{CE}$	Chip Enable
$\overline{OE}$	Output Enable
V_{CC}	+5V
V_{SS}	Ground
NC	No Connect

ABSOLUTE MAXIMUM RATINGS*

Temperature Under Bias X2864B ..... −10°C to +85°C
Storage Temperature ..... −65°C to +150°C
Voltage on any Pin with
Respect to Ground ..... −1.0V to +7V
D.C. Output Current ..... 5 mA
Lead Temperature (Soldering,
10 Seconds) ..... 300°C

*COMMENT

Stresses above those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. This is a stress rating only and the functional operation of the device at these or any other conditions above those indicated in the operational sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

D.C. OPERATING CHARACTERISTICS

T_A = 0°C to +70°C, V_{CC} = +5V ±10%, unless otherwise specified.

Symbol	Parameter	Limits			Units	Test Conditions
		Min.	Typ.(1)	Max.		
I_{CC}	V_{CC} Current (Active)		80		mA	$\overline{CE}$ = $\overline{OE}$ = V_{IL} All I/O's = Open Other Inputs = V_{CC}
I_{SB}	V_{CC} Current (Standby)		30		mA	$\overline{CE}$ = V_{IH}, $\overline{OE}$ = V_{IL} All I/O's = Open Other Inputs = V_{CC}
I_{LI}	Input Leakage Current			10	µA	V_{IN} = GND to V_{CC}
I_{LO}	Output Leakage Current			10	µA	V_{OUT} = GND to V_{CC}, $\overline{CE}$ = V_{IH}
V_{IL}	Input Low Voltage	−1.0		0.8	V	
V_{IH}	Input High Voltage	2.0		V_{CC} +1.0	V	
V_{OL}	Output Low Voltage			0.4	V	I_{OL} = 2.1 mA
V_{OH}	Output High Voltage	2.4			V	I_{OH} = −400 mA

Note: (1) Typical values are for T_A = 25°C and nominal supply voltage.

CAPACITANCE T_A = 25°C, f = 1.0 MHz, V_{CC} = 5V

Symbol	Test	Max.	Unit	Conditions
$C_{I/O}$(2)	Input/Output Capacitance	10	pF	$V_{I/O}$ = 0V
C_{IN}(2)	Input Capacitance	6	pF	V_{IN} = 0V

Note: (2) This parameter is periodically sampled and not 100% tested.

A.C. CONDITIONS OF TEST

Input Pulse Levels	0 to 3.0 Volts
Input Rise and Fall Times	10 nsec
Input and Output Timing Levels	1.5 Volts
Output Load	1 TTL Gate and C_L = 100 pF

MODE SELECTION

$\overline{CE}$	$\overline{OE}$	$\overline{WE}$	Mode	I/O	Power
L	L	H	Read	D_{OUT}	Active
L	H	L	Write	D_{IN}	Active
H	X	X	Standby and Write Inhibit	High Z	Standby
X	L	X	Write Inhibit	—	—
X	X	H	Write Inhibit	—	—

A.C. CHARACTERISTICS

T_A = −0°C to +70°C, V_{CC} = +5V ±10%, unless otherwise specified.

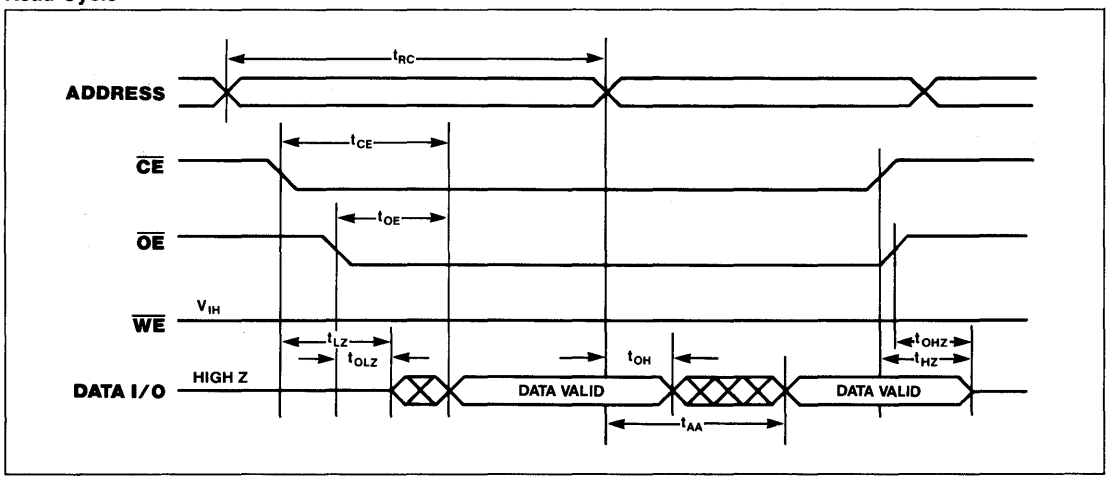
Read Cycle Limits

Symbol	Parameter	Min.	Typ.(1)	Max.	Units
t_{RC}	Read Cycle Time		150		ns
t_{CE}	Chip Enable Access Time		150		ns
t_{AA}	Address Access Time		150		ns
t_{OE}	Output Enable Access Time		100		ns
t_{LZ}	$\overline{CE}$ Low to Active Output	0			ns
t_{OLZ}	$\overline{OE}$ Low to Active Output	0			ns
t_{HZ}	$\overline{CE}$ High to High Z Output		50		ns
t_{OHZ}	$\overline{OE}$ High to High Z Output		50		ns
t_{OH}	Output Hold From Address Change		20		ns

Note: (1) Typical values are for T_A = 25°C and nominal supply voltage.

3

Read Cycle

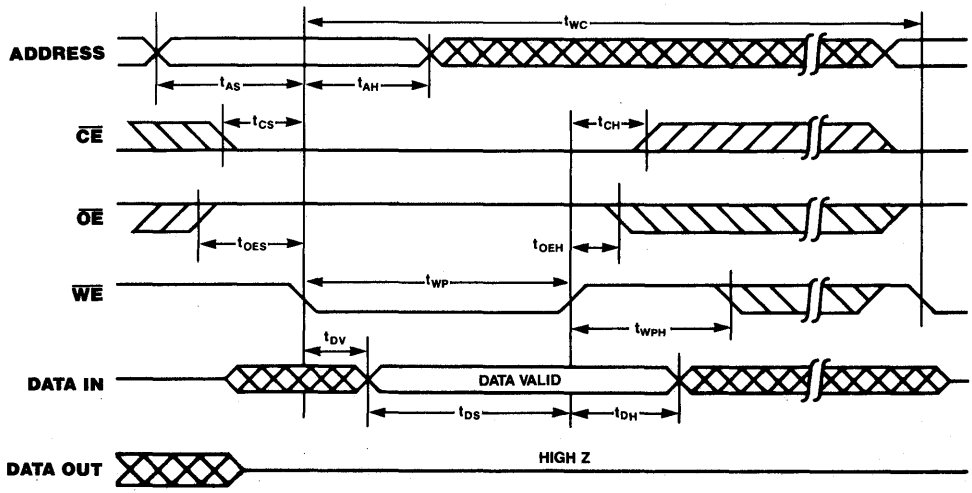


Write Cycle Limits

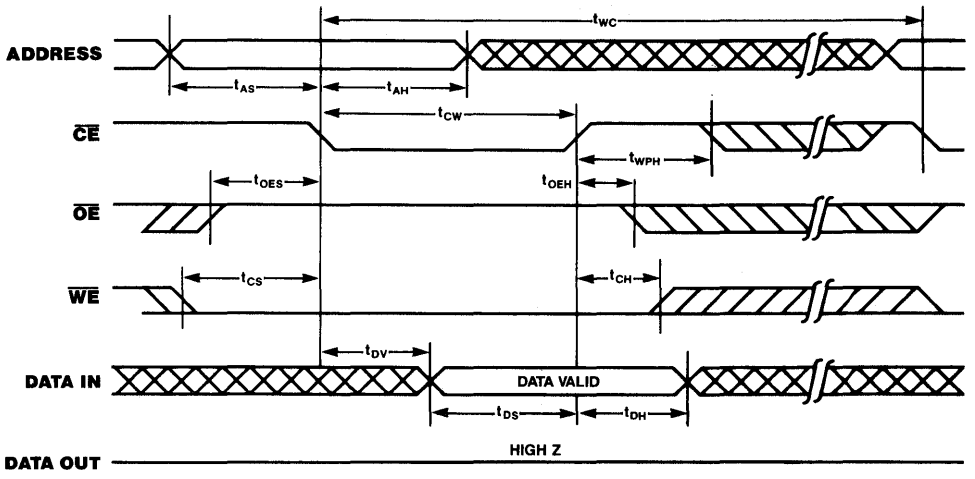
Symbol	Parameter	Min.	Typ.(1)	Max.	Units
t_{WC}	Write Cycle Time		2		ms
t_{AS}	Address Set-up Time	0			ns
t_{AH}	Address Hold Time		100		ns
t_{CS}	Write Set-up Time	0			ns
t_{CH}	Write Hold Time	0			ns
t_{CW}	$\overline{CE}$ Pulse Width		100		ns
t_{OES}	$\overline{OE}$ High Set-up Time		10		ns
t_{OEH}	$\overline{OE}$ High Hold Time		10		ns
t_{WP}	$\overline{WE}$ Pulse Width		100		ns
t_{WPH}	$\overline{WE}$ High Recovery		50		ns
t_{DV}	Data Valid		1		µs
t_{DS}	Data Set-up		50		ns
t_{DH}	Data Hold		0		ns
t_{BLC}	Byte Load Cycle	1		100	µs

Note: (1) Typical values are for T_A = 25°C and nominal supply voltage.

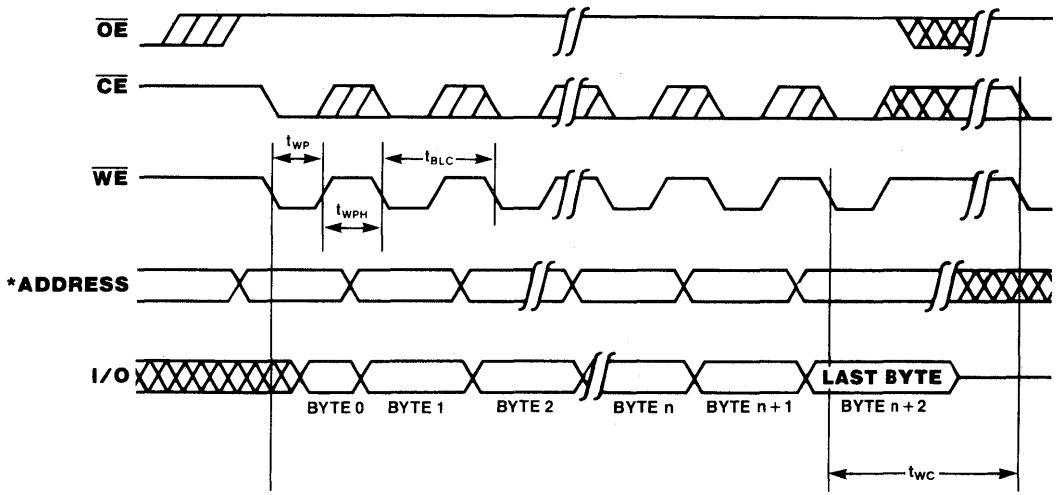
$\overline{WE}$ Controlled Write Cycle



$\overline{CE}$ Controlled Write Cycle



Page Mode Write Cycle



*The page address, addresses A_5-A_{12}, must remain the same throughout the page write cycle (t_{PLW}). If a page violation occurs, writes to an unknown address could result.

PIN DESCRIPTIONS

Addresses (A_0–A_{12})

The Address inputs select an 8-bit memory location during a read or write operation.

Chip Enable ($\overline{CE}$)

The Chip Enable input must be LOW to enable all read/write operations. When $\overline{CE}$ is HIGH, power consumption is reduced.

Output Enable ($\overline{OE}$)

The Output Enable input controls the data output buffers and is used to initiate read operations.

Data In/Data Out (I/O_0–I/O_7)

Data is written to or read from the X2864B through the I/O pins.

Write Enable ($\overline{WE}$)

The Write Enable input controls the writing of data to the X2864B.

DEVICE OPERATION

READ

Read operations are initiated by both $\overline{OE}$ and $\overline{CE}$ LOW. The read operation is terminated by either $\overline{CE}$ or $\overline{OE}$ returning HIGH. This 2-line control architecture eliminates bus contention in a system environment. The data bus will be in a high impedance state when either $\overline{OE}$ or $\overline{CE}$ is HIGH.

WRITE

Write operations are initiated when both $\overline{CE}$ and $\overline{WE}$ are LOW *and* $\overline{OE}$ is HIGH. The X2864B supports both a $\overline{CE}$ and $\overline{WE}$ controlled write cycle. That is, the address is latched by the falling edge of either $\overline{CE}$ or $\overline{WE}$, whichever occurs last. Similarly, the data is latched internally by the rising edge of either $\overline{CE}$ or $\overline{WE}$, whichever occurs first. A byte write operation, once initiated, will automatically continue to completion, typically within 2ms.

PAGE WRITE OPERATION

The page write feature of the X2864B allows the entire memory to be written in 500ms. Page write allows two to thirty-two bytes of data to be consecutively written to the X2864B prior to the commencement of the internal programming cycle. The destination addresses for a page write operation must reside on the same page; that is, A_5 through A_{12} must not change.

The page write mode can be entered during any write operation. Following the initial byte write cycle, the host can write an additional one to thirty-one bytes in the same manner as the first byte was written. Each successive byte load cycle, started by the $\overline{WE}$ HIGH to LOW transition, must begin within 100μs of the falling edge of the preceding $\overline{WE}$. If a subsequent $\overline{WE}$ HIGH to LOW transition is not detected within 100μs the internal automatic programming cycle will commence. There is no page write window limitation. The page write window is infinitely wide so long as the host continues to access the device within the byte load cycle time of 100μs.

$\overline{DATA}$ POLLING

The X2864B features $\overline{DATA}$ Polling as a method to indicate to the host system that the byte write or page write cycle has completed. $\overline{DATA}$ Polling allows a simple bit test operation to determine the status of the X2864B, eliminating additional interrupt inputs or external hardware. During the internal programming cycle, any attempt to read the last byte written will produce the complement of that data on I/O_7 (i.e., write data = 0xxx xxxx, read data = 1xxx xxxx). Once the programming cycle is complete, I/O_7 will reflect true data.

WRITE PROTECTION

There are four features that protect the nonvolatile data from inadvertent writes.

- Noise Protection—A $\overline{WE}$ pulse of less than 20ns will not initiate a write cycle.
- V_{CC} Sense—All functions are inhibited when V_{CC} is ≤3v, typically.
- Write Inhibit—Holding either $\overline{OE}$ LOW, $\overline{WE}$ HIGH or $\overline{CE}$ HIGH during power-on and power-off, will inhibit inadvertent writes.
- **Programmable V_{CC} Sense**—All Xicor products have a default V_{CC} Sense set point. This inhibits all device operations during power transitions and is typically 3v. The X2864B provides an additional V_{CC} Sense feature that allows the user to program the set point at which *write* operations are disabled. This feature allows a user to program the sense level in the range of +3v to V_{CC} +1v. The set point is nonvolatile and reprogrammable.

64K X2864H 8192 x 8 Bit

Electrically Erasable PROM

TYPICAL FEATURES

- **45ns Access Time**
- **High Performance Scaled NMOS Technology**
- **Fast Write Cycle Times**
  - **— Byte or Page Write Cycle: 2ms Typical**
  - **— 32 Byte Page Write Operation**
  - **— Complete Memory Rewrite: 500ms Typical**
  - **— Effective Byte Write Cycle Time of 63μs**
- **$\overline{\text{DATA}}$ Polling**
  - **— Allows User to Minimize Write Cycle Time**
- **100mA Active Current**
- **JEDEC Approved Byte-wide Pinout**

DESCRIPTION

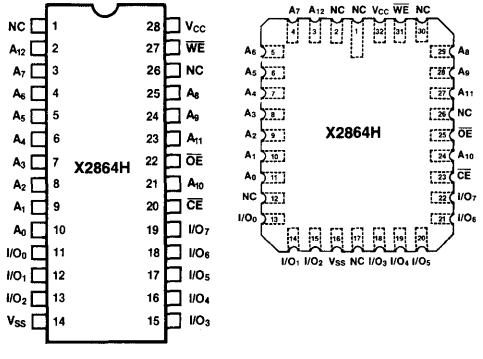
The Xicor X2864H is a high speed 8K x 8 E^2PROM, fabricated with Xicor's proprietary, high performance, N-channel floating gate MOS technology. The X2864H features the JEDEC approved pinout for byte-wide memories, compatible with industry standard RAMs, ROMs and EPROMs.

The X2864H supports a 32-byte page write operation, effectively providing a 63μs/byte write cycle and enabling the entire memory to be written in less than 500ms. The X2864H also features $\overline{\text{DATA}}$ Polling, a system software support scheme used to indicate the early completion of a write cycle.

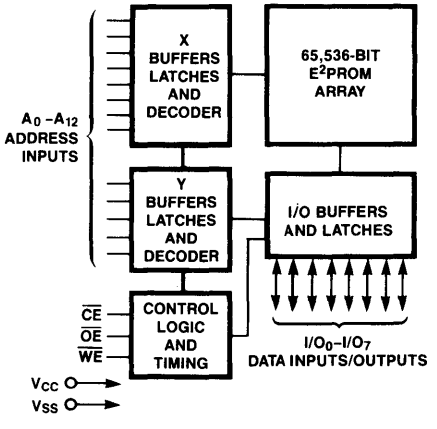
Xicor E^2PROMs are designed and tested for applications requiring extended endurance. Data retention is specified to be greater than 100 years.

3

PIN CONFIGURATIONS



FUNCTIONAL DIAGRAM



PIN NAMES

A_0–A_{12}	Address Inputs
I/O_0–I/O_7	Data Input/Output
$\overline{WE}$	Write Enable
$\overline{CE}$	Chip Enable
$\overline{OE}$	Output Enable
V_{CC}	+5V
V_{SS}	Ground
NC	No Connect

May 1985

PIN DESCRIPTIONS

Addresses (A_0–A_{12})

The Address inputs select an 8-bit memory location during a read or write operation.

Chip Enable ($\overline{CE}$)

The Chip Enable input must be LOW to enable all read/write operations. When $\overline{CE}$ is HIGH, power consumption is reduced.

Output Enable ($\overline{OE}$)

The Output Enable input controls the data output buffers and is used to initiate read operations.

Data In/Data Out (I/O_0–I/O_7)

Data is written to or read from the X2864H through the I/O pins.

Write Enable ($\overline{WE}$)

The Write Enable input controls the writing of data to the X2864H.

DEVICE OPERATION

READ

Read operations are initiated by both $\overline{OE}$ and $\overline{CE}$ LOW. The read operation is terminated by either $\overline{CE}$ or $\overline{OE}$ returning HIGH. This 2-line control architecture eliminates bus contention in a system environment. The data bus will be in a high impedance state when either $\overline{OE}$ or $\overline{CE}$ is HIGH.

WRITE

Write operations are initiated when both $\overline{CE}$ and $\overline{WE}$ are LOW *and* $\overline{OE}$ is HIGH. The X2864H supports both a $\overline{CE}$ and $\overline{WE}$ controlled write cycle. That is, the address is latched by the falling edge of either $\overline{CE}$ or $\overline{WE}$, whichever occurs last. Similarly, the data is latched internally by the rising edge of either $\overline{CE}$ or $\overline{WE}$, whichever occurs first. A byte write operation, once initiated, will automatically continue to completion, typically within 2ms.

PAGE WRITE OPERATION

The page write feature of the X2864H allows the entire memory to be written in 500ms. Page write allows two to thirty-two bytes of data to be consecutively written to the X2864H prior to the commencement of the internal programming cycle. The destination addresses for a page write operation must reside on the same page; that is, A_5 through A_{12} must not change.

The page write mode can be entered during any write operation. Following the initial byte write cycle, the host can write an additional one to thirty-one bytes in the same manner as the first byte was written. Each successive byte load cycle, started by the $\overline{WE}$ HIGH to LOW transition, must begin within 100µs of the falling edge of the preceding $\overline{WE}$. If a subsequent $\overline{WE}$ HIGH to LOW transition is not detected within 100µs the internal automatic programming cycle will commence. There is no page write window limitation. Effectively the page write window is infinitely wide, so long as the host continues to access the device within the 100µs byte load cycle time.

$\overline{DATA}$ POLLING

The X2864H features $\overline{DATA}$ Polling as a method to indicate to the host system that the byte write or page write cycle has completed. $\overline{DATA}$ Polling allows a simple bit test operation to determine the status of the X2864H, eliminating additional interrupt inputs or external hardware. During the internal programming cycle, any attempt to read the last byte written will produce the complement of that data on I/O_7 (i.e., write data = 0xxx xxxx, read data = 1xxx xxxx). Once the programming cycle is complete, I/O_7 will reflect true data.

WRITE PROTECTION

There are four features that protect the nonvolatile data from inadvertent writes.

- Noise Protection—A $\overline{WE}$ pulse of less than 15ns will not initiate a write cycle.
- V_{CC} Sense—All functions are inhibited when V_{CC} is ≤3v, typically.
- Write Inhibit—Holding $\overline{OE}$ LOW, $\overline{WE}$ HIGH or $\overline{CE}$ HIGH during power-on and power-off, will inhibit inadvertent writes.
- Programmable V_{CC} Sense—All Xicor products have a default V_{CC} Sense set point. This inhibits all device operations during power transitions and is typically 3v. The X2864H provides an additional V_{CC} Sense feature that allows the user to program the set point at which *write* operations are disabled. This feature allows a user to program the sense level in the range of +3v to V_{CC} +1v. The set point is nonvolatile and reprogrammable.

64K X28C64 8192 x 8 Bit

Electrically Erasable PROM

TYPICAL FEATURES

- **150ns Access Time**
- **Low Power CMOS Technology**
  - **— 60mA Active Current**
  - **— 75μA Standby Current**
- **Advance High Performance CMOS**
- **Fast Write Cycle Times**
  - **— Byte or Page Write Cycle: 2ms Typical**
  - **— 32 Byte Page Write Operation**
  - **— Complete Memory Rewrite: 500ms**
  - **— Effective Byte Write Cycle Time of 63μs**
- **$\overline{\text{DATA}}$ Polling**
  - **— Allows User to Minimize Write Cycle Time**
- **JEDEC Approved Byte-wide Pinout**

DESCRIPTION

The Xicor X28C64 is an 8K x 8 E^2PROM, fabricated with Xicor's proprietary high performance CMOS process, providing high speed operation with low power consumption. The X28C64 features the JEDEC approved pinout for byte-wide memories, compatible with industry standard RAMs, ROMs and EPROMs.

The X28C64 supports a 32-byte page write operation, effectively providing a 63μs/byte write cycle and enabling the entire memory to be written in less than 500ms. The X28C64 also features $\overline{\text{DATA}}$ Polling, a system software support scheme used to indicate the early completion of a write cycle.

Xicor E^2PROMs are designed and tested for applications requiring extended endurance. Data retention is specified to be greater than 100 years.

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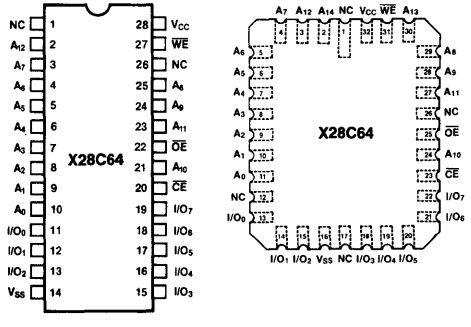
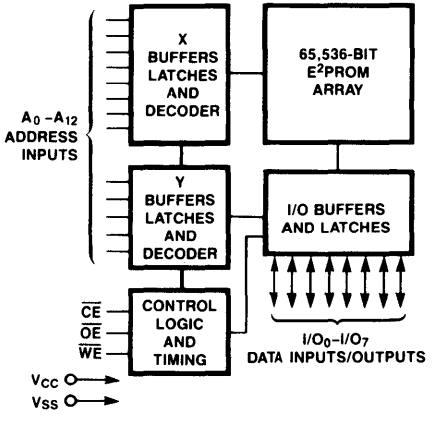
PIN CONFIGURATIONS



FUNCTIONAL DIAGRAM



PIN NAMES

A_0–A_{12}	Address Inputs
I/O_0–I/O_7	Data Input/Output
$\overline{WE}$	Write Enable
$\overline{CE}$	Chip Enable
$\overline{OE}$	Output Enable
V_{CC}	+5V
V_{SS}	Ground
NC	No Connect

PIN DESCRIPTIONS

Addresses (A_0–A_{12})

The Address inputs select an 8-bit memory location during a read or write operation.

Chip Enable ($\overline{CE}$)

The Chip Enable input must be LOW to enable all read/write operations. When $\overline{CE}$ is HIGH, power consumption is reduced.

Output Enable ($\overline{OE}$)

The Output Enable input controls the data output buffers and is used to initiate read operations.

Data In/Data Out (I/O_0–I/O_7)

Data is written to or read from the X28C64 through the I/O pins.

Write Enable ($\overline{WE}$)

The Write Enable input controls the writing of data to the X28C64.

DEVICE OPERATION

READ

Read operations are initiated by both $\overline{OE}$ and $\overline{CE}$ LOW. The read operation is terminated by either $\overline{CE}$ or $\overline{OE}$ returning HIGH. This 2-line control architecture eliminates bus contention in a system environment. The data bus will be in a high impedance state when either $\overline{OE}$ or $\overline{CE}$ is HIGH.

WRITE

Write operations are initiated when both $\overline{CE}$ and $\overline{WE}$ are LOW *and* $\overline{OE}$ is HIGH. The X28C64 supports both a $\overline{CE}$ and $\overline{WE}$ controlled write cycle. That is, the address is latched by the falling edge of either $\overline{CE}$ or $\overline{WE}$, whichever occurs last. Similarly, the data is latched internally by the rising edge of either $\overline{CE}$ or $\overline{WE}$, whichever occurs first. A byte write operation, once initiated, will automatically continue to completion, typically within 2ms.

PAGE WRITE OPERATION

The page write feature of the X28C64 allows the entire memory to be written in 500ms. Page write allows two to thirty-two bytes of data to be consecutively written to the X28C64 prior to the commencement of the internal programming cycle. The destination addresses for a page write operation must reside on the same page; that is, A_5 through A_{12} must not change.

The page write mode can be entered during any write operation. Following the initial byte write cycle, the host can write an additional one to thirty-one bytes in the same manner as the first byte was written. Each successive byte load cycle, started by the $\overline{WE}$ HIGH to LOW transition, must begin within 100µs of the falling edge of the preceding $\overline{WE}$. If a subsequent $\overline{WE}$ HIGH to LOW transition is not detected within 100µs the internal automatic programming cycle will commence. There is no page write window limitation. The page write window is infinitely wide, so long as the host continues to access the device within the byte load cycle time of 100µs.

$\overline{DATA}$ POLLING

The X28C64 features $\overline{DATA}$ Polling as a method to indicate to the host system that the byte write or page write cycle has completed. $\overline{DATA}$ Polling allows a simple bit test operation to determine the status of the X28C64, eliminating additional interrupt inputs or external hardware. During the internal programming cycle, any attempt to read the last byte written will produce the complement of that data on I/O_7 (i.e., write data = 0xxx xxxx, read data = 1xxx xxxx). Once the programming cycle is complete, I/O_7 will reflect true data.

PROGRAMMABLE V_{CC} SENSE

All Xicor products have a default V_{CC} Sense set point. This inhibits all device operations during power transitions and is typically 3v. The X28C64 provides an additional V_{CC} Sense feature that allows the user to program the set point at which *write* operations are disabled. This feature allows a user to program the sense level in the range of +3v to V_{CC} +1v. The set point is nonvolatile and reprogrammable.

256K X28256 32K x 8 Bit

Electrically Erasable PROM

TYPICAL FEATURES

- **150ns Access Time**
- **High Performance Advanced NMOS Technology**
- **Fast Write Cycle Times**
  - **— Byte or Page Write Cycle: 2ms Typical**
  - **— 64 Byte Page Write Operation**
  - **— Complete Memory Rewrite: 1 sec**
  - **— Effective Byte Write Cycle Time of 31 μs**
- **Software Write Protection**
- **DATA Polling**
  - **— Allows User to Minimize Write Cycle Time**
- **Reduced Power**
  - **— 100mA Active Current**
  - **— 50mA Standby Current**
- **JEDEC Approved Byte-wide Pinout**

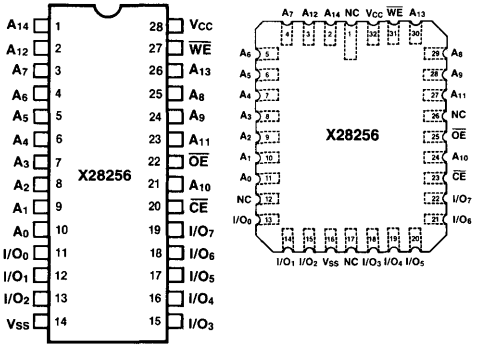
DESCRIPTION

The Xicor X28256 is a 32K x 8 E^2PROM, fabricated with Xicor's proprietary, high performance, N-channel floating gate MOS technology. Like all Xicor programmable nonvolatile memories the X28256 is a 5 volt only device. The X28256 features the JEDEC approved pinout for byte-wide memories, compatible with industry standard RAMs, ROMs and EPROMs.

The X28256 supports a 64-byte page write operation, effectively providing a 31 μs/byte write cycle and enabling the entire memory to be written in less than 1 second. The X28256 also features DATA Polling, a system software support scheme used to indicate the early completion of a write cycle. In addition, the X28256 includes a unique software write protect scheme that further enhances Xicor's hardware write protect capability.

Xicor E^2PROMs are designed and tested for applications requiring extended endurance. Data retention is specified to be greater than 100 years.

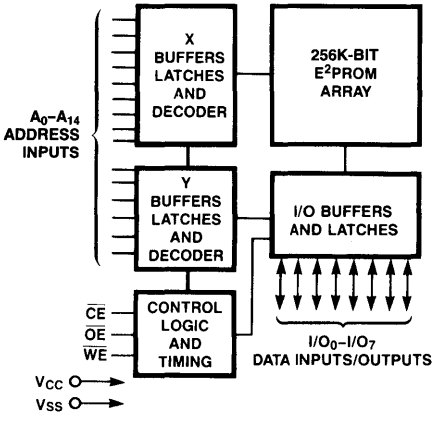
PIN CONFIGURATIONS



PIN NAMES

A_0–A_{14}	Address Inputs
I/O_0–I/O_7	Data Input/Output
$\overline{WE}$	Write Enable
$\overline{CE}$	Chip Enable
$\overline{OE}$	Output Enable
V_{CC}	+5V
V_{SS}	Ground
NC	No Connect

FUNCTIONAL DIAGRAM



ABSOLUTE MAXIMUM RATINGS*

Temperature Under Bias X28256 ..... −10°C to +85°C
Storage Temperature ..... −65°C to +150°C
Voltage on any Pin with
Respect to Ground ..... −1.0V to +7V
D.C. Output Current ..... 5 mA
Lead Temperature (Soldering,
10 Seconds) ..... 300°C

*COMMENT

Stresses above those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. This is a stress rating only and the functional operation of the device at these or any other conditions above those indicated in the operational sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

D.C. OPERATING CHARACTERISTICS

T_A = −0°C to +70°C, V_{CC} = +5V ±5%, unless otherwise specified.

Symbol	Parameter	Limits			Units	Test Conditions
		Min.	Typ.(1)	Max.		
I_{CC}	V_{CC} Current (Active)		100		mA	$\overline{CE}$ = $\overline{OE}$ = V_{IL} All I/O's = Open Other Inputs = V_{CC}
I_{SB}	V_{CC} Current (Standby)		50		mA	$\overline{CE}$ = V_{IH}, $\overline{OE}$ = V_{IL} All I/O's = Open Other Inputs = V_{CC}
I_{LI}	Input Leakage Current			10	µA	V_{IN} = GND to V_{CC}
I_{LO}	Output Leakage Current			10	µA	V_{OUT} = GND to V_{CC}, $\overline{CE}$ = V_{IH}
V_{IL}	Input Low Voltage	−1.0		0.8	V	
V_{IH}	Input High Voltage	2.0		V_{CC} +0.5	V	
V_{OL}	Output Low Voltage			0.4	V	I_{OL} = 2.1 mA
V_{OH}	Output High Voltage	2.4			V	I_{OH} = −400 mA

Note: (1) Typical values are for T_A = 25°C and nominal supply voltage.

CAPACITANCE T_A = 25°C, f = 1.0 MHz, V_{CC} = 5V

Symbol	Test	Max.	Unit	Conditions
$C_{I/O}$(2)	Input/Output Capacitance	10	pF	$V_{I/O}$ = 0V
C_{IN}(2)	Input Capacitance	6	pF	V_{IN} = 0V

Note: (2) This parameter is periodically sampled and not 100% tested.

A.C. CONDITIONS OF TEST

Input Pulse Levels	0 to 3.0 Volts
Input Rise and Fall Times	10 nsec
Input and Output Timing Levels	1.5 Volts
Output Load	1 TTL Gate and C_L = 100 pF

MODE SELECTION

$\overline{CE}$	$\overline{OE}$	$\overline{WE}$	Mode	I/O	Power
L	L	H	Read	D_{OUT}	Active
L	H	L	Write	D_{IN}	Active
H	X	X	Standby and Write Inhibit	High Z	Standby
X	L	X	Write Inhibit	—	—
X	X	H	Write Inhibit	—	—

A.C. CHARACTERISTICS

T_A = −0°C to +70°C, V_{CC} = +5V ±5%, unless otherwise specified.

Read Cycle Limits

Symbol	Parameter	Min.	Typ.(1)	Max.	Units
t_{RC}	Read Cycle Time		150		ns
t_{CE}	Chip Enable Access Time		150		ns
t_{AA}	Address Access Time		150		ns
t_{OE}	Output Enable Access Time		100		ns
t_{LZ}	$\overline{CE}$ Low to Active Output	0			ns
t_{LOZ}	$\overline{OE}$ Low to Active Output	0			ns
t_{HZ}	$\overline{CE}$ High to High Z Output		50		ns
t_{OHZ}	$\overline{OE}$ High to High Z Output		50		ns
t_{OH}	Output Hold From Address Change		10		ns

Note: (1) Typical values are for T_A = 25°C and nominal supply voltage.

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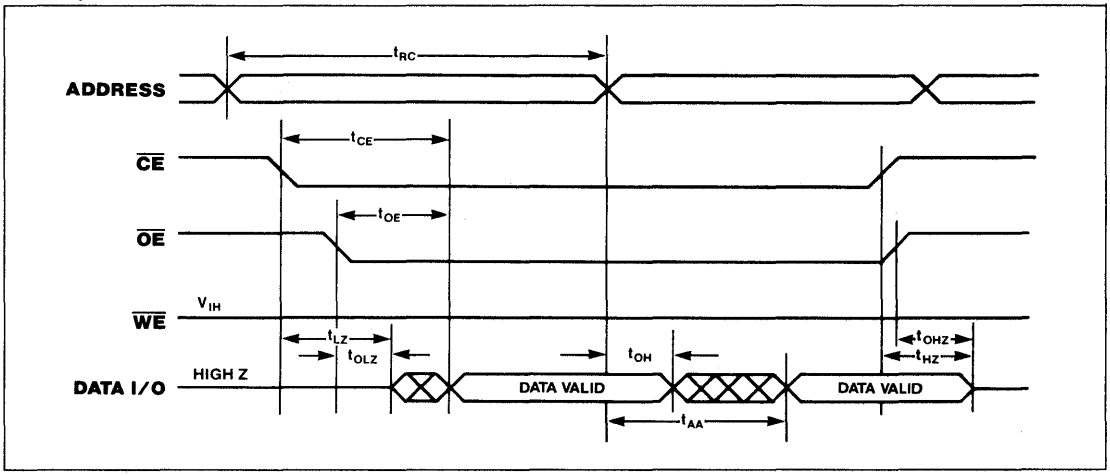
Read Cycle

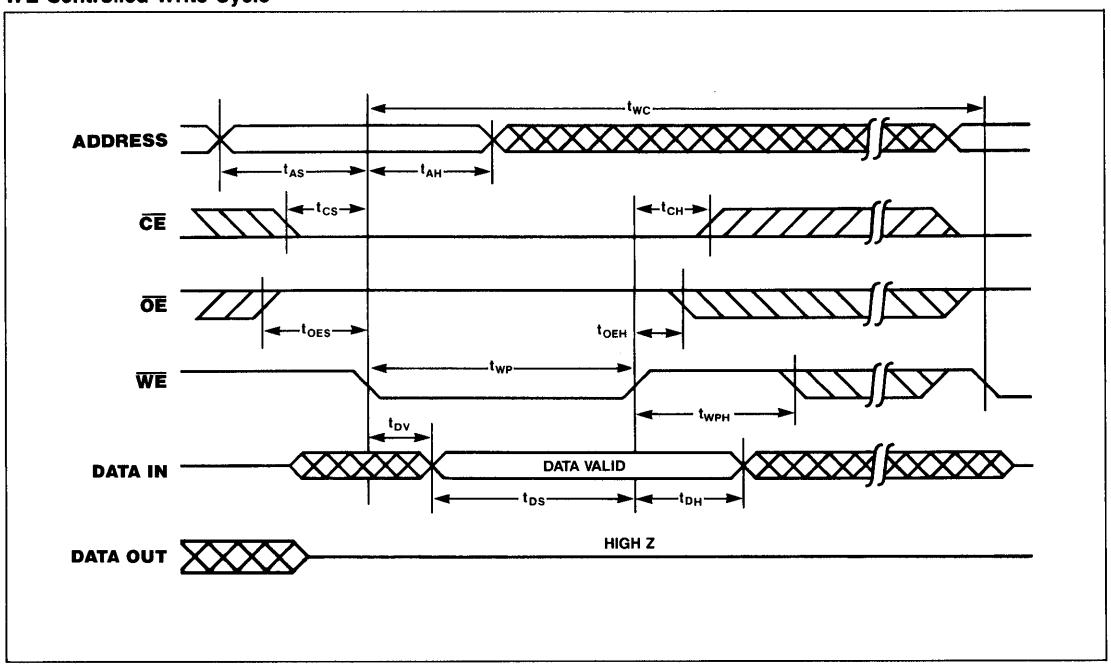


Write Cycle Limits

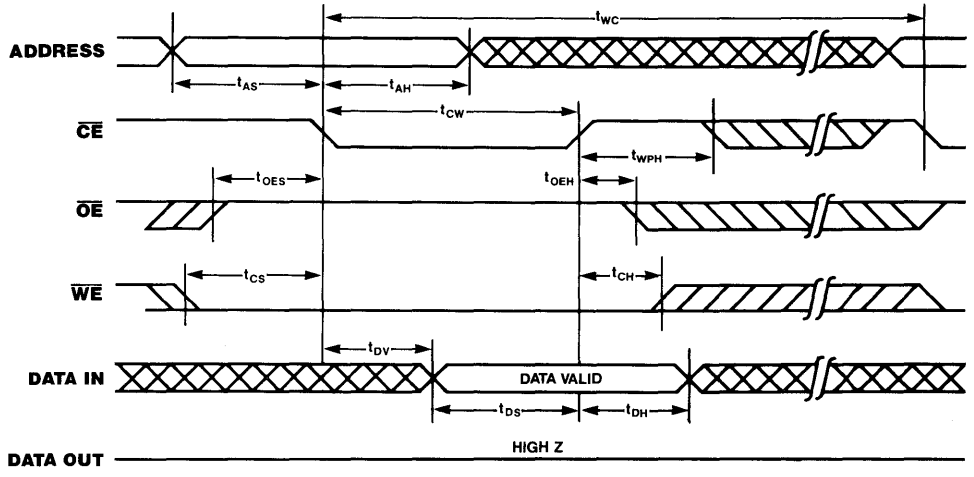
Symbol	Parameter	Min.	Typ.(1)	Max.	Units
t_{WC}	Write Cycle Time		2		ms
t_{AS}	Address Set-up Time	0			ns
t_{AH}	Address Hold Time		100		ns
t_{CS}	Write Set-up Time	0			ns
t_{CH}	Write Hold Time	0			ns
t_{CW}	$\overline{CE}$ Pulse Width		100		ns
t_{OES}	$\overline{OE}$ High Set-up Time		10		ns
t_{OEH}	$\overline{OE}$ High Hold Time		10		ns
t_{WP}	$\overline{WE}$ Pulse Width		100		ns
t_{WPH}	$\overline{WE}$ High Recovery		50		ns
t_{DV}	Data Valid		1		µs
t_{DS}	Data Set-up		50		ns
t_{DH}	Data Hold		10		ns
t_{BLC}	Byte Load Cycle	1		100	µs

Note: (1) Typical values are for T_A = 25°C and nominal supply voltage.

$\overline{WE}$ Controlled Write Cycle



$\overline{CE}$ Controlled Write Cycle



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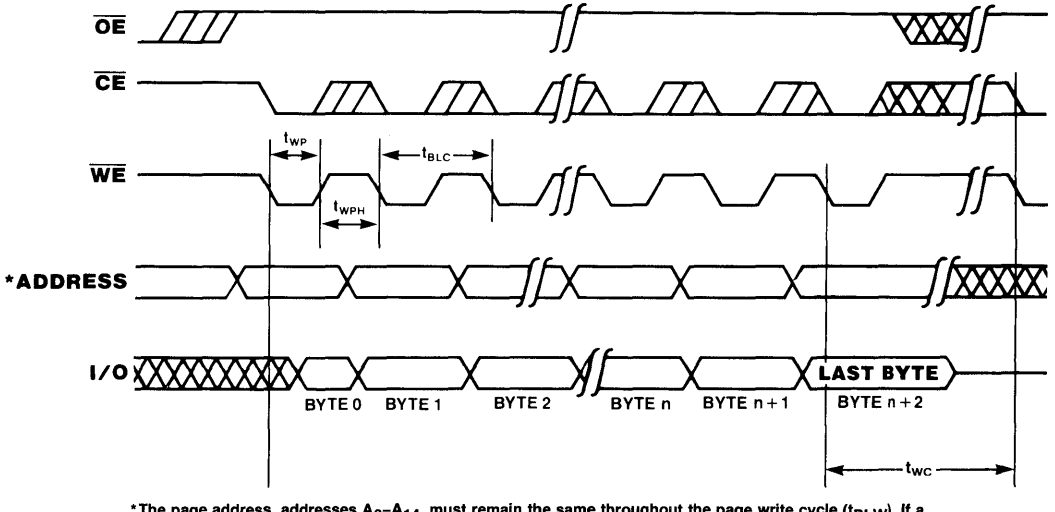
Page Mode Write Cycle



*The page address, addresses A_6–A_{14}, must remain the same throughout the page write cycle (t_{PLW}). If a page violation occurs, writes to an unknown address could result.

PIN DESCRIPTIONS

Addresses (A_0–A_{14})

The Address inputs select an 8-bit memory location during a read or write operation.

Chip Enable ($\overline{CE}$)

The Chip Enable input must be LOW to enable all read/write operations. When $\overline{CE}$ is HIGH, power consumption is reduced.

Output Enable ($\overline{OE}$)

The Output Enable input controls the data output buffers and is used to initiate read operations.

Data In/Data Out (I/O_0–I/O_7)

Data is written to or read from the X28256 through the I/O pins.

Write Enable ($\overline{WE}$)

The Write Enable input controls the writing of data to the X28256.

DEVICE OPERATION

READS

Read operations are initiated by both $\overline{OE}$ and $\overline{CE}$ LOW. The read operation is terminated by either $\overline{CE}$ or $\overline{OE}$ returning HIGH. This 2-line control architecture eliminates bus contention in a system environment. The data bus will be in a high impedance state when either $\overline{OE}$ or $\overline{CE}$ is HIGH.

WRITES

Write operations are initiated when both $\overline{CE}$ and $\overline{WE}$ are LOW *and* $\overline{OE}$ is HIGH. The X28256 supports both a $\overline{CE}$ and $\overline{WE}$ controlled write cycle. That is, the address is latched by the falling edge of either $\overline{CE}$ or $\overline{WE}$, whichever occurs last. Similarly, the data is latched internally by the rising edge of either $\overline{CE}$ or $\overline{WE}$, whichever occurs first. A byte write operation, once initiated, will automatically continue to completion, typically within 5ms.

PAGE WRITE OPERATION

The page write feature of the X28256 allows the entire memory to be written in 1 second. Page write allows two to sixty-four bytes of data to be consecutively written to the X28256 prior to the commencement of the internal programming cycle. The destination addresses for a page write operation must reside on the same page; that is, A_6 through A_{14} must not change.

The page write mode can be entered during any write operation. Following the initial byte write cycle, the host can write an additional one to sixty-three bytes in the same manner as the first byte was written. Each successive byte load cycle, started by the $\overline{WE}$ HIGH to LOW transition, must begin within 100µs of the falling edge of the preceding $\overline{WE}$. If a subsequent $\overline{WE}$ HIGH to LOW transition is not detected within 100µs, the internal automatic programming cycle will commence. There is no page write window limitation. Effectively the page write window is infinitely wide, so long as the host continues to access the device within the byte load cycle time of 100µs.

$\overline{DATA}$ POLLING

The X28256 features $\overline{DATA}$ Polling as a method to indicate to the host system that the byte write or page write cycle has completed. $\overline{DATA}$ Polling allows a simple bit test operation to determine the status of the X28256, eliminating additional interrupt inputs or external hardware. During the internal programming cycle, any attempt to read the last byte written will produce the complement of that data on I/O_7 (i.e., write data = 0xxx xxxx, read data = 1xxx xxxx). Once the programming cycle is complete, I/O_7 will reflect true data.

SOFTWARE WRITE PROTECT

Software write protection provides certain options to the designer in selecting the level of protection required by the application. In the default mode the device is accessible (once V_{CC} is stable) at all times, the write protection feature is transparent. Protection can be enabled at anytime by performing a short (three byte write operation) software algorithm. Once enabled, the system is allowed to perform one write operation, either a single byte write or page write operation. At the conclusion of the write cycle the X28256 will disable any further write operations until the device is reenabled through the software algorithm. If a total memory rewrite is necessary, the protection mode can be exited allowing unrestrained write access to the X28256.

HARDWARE WRITE PROTECTION

The X28256 provides four additional hardware features that protect nonvolatile data from inadvertent writes.

- Noise Protection—A $\overline{WE}$ pulse less than 20ns will not initiate a write cycle.
- V_{CC} Sense—All functions are inhibited when V_{CC} is ≤3v, typically.
- Write Inhibit—Holding either $\overline{OE}$ LOW, $\overline{WE}$ HIGH, or $\overline{CE}$ HIGH will prevent an inadvertent write cycle during power-on and power-off, maintaining data integrity.
- **Programmable V_{CC} Sense**—All Xicor products have a default V_{CC} Sense set point. This inhibits all device operations during power transitions and is typically 3v. The X28256 provides an additional V_{CC} Sense feature that allows the user to program the set point at which *write* operations are disabled. This feature allows a user to program the sense level in the range of +3v to V_{CC} +1v. The set point is nonvolatile and reprogrammable.

256K X28C256 32K x 8 Bit

Electrically Erasable PROM

TYPICAL FEATURES

- **150ns Access Time**
- **LOW Power CMOS**
  - **— 80mA Active Current**
  - **— 100μA Standby Current**
- **High Performance**
- **Fast Write Cycle Times**
  - **— Byte or Page Write Cycle: 2ms Typical**
  - **— 64 Byte Page Write Operation**
  - **— Complete Memory Rewrite: 1 sec Typical**
  - **— Effective Byte Write Cycle Time of 31μs**
- **Software Write Protection**
- **$\overline{\text{DATA}}$ Polling**
  - **— Allows User to Minimize Write Cycle Time**
- **JEDEC Approved Byte-wide Pinout**

DESCRIPTION

The Xicor X28C256 is a 32K x 8 E^2PROM, fabricated with Xicor's proprietary, high performance, floating gate CMOS technology. Like all Xicor programmable nonvolatile memories the X28C256 is a 5 volt only device. The X28C256 features the JEDEC approved pinout for byte-wide memories, compatible with industry standard RAMs, ROMs and EPROMs.

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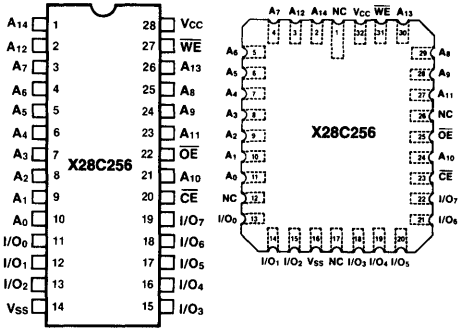

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V_{CC}	+5V
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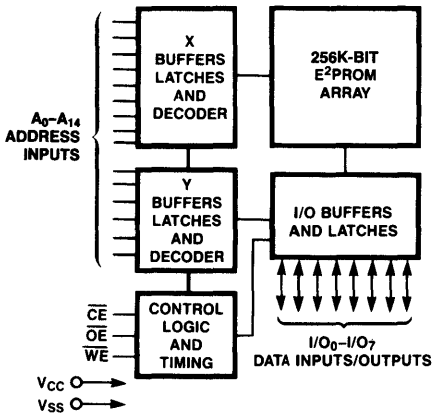

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The Output Enable input controls the data output buffers and is used to initiate read operations.

Data In/Data Out (I/O_0–I/O_7)

Data is written to or read from the X28C256 through the I/O pins.

Write Enable ($\overline{WE}$)

The Write Enable input controls the writing of data to the X28C256.

DEVICE OPERATION

READ

Read operations are initiated by both $\overline{OE}$ and $\overline{CE}$ LOW. The read operation is terminated by either $\overline{CE}$ or $\overline{OE}$ returning HIGH. This 2-line control architecture eliminates bus contention in a system environment. The data bus will be in a high impedance state when either $\overline{OE}$ or $\overline{CE}$ is HIGH.

WRITE

Write operations are initiated when both $\overline{CE}$ and $\overline{WE}$ are LOW *and* $\overline{OE}$ is HIGH. The X28C256 supports both a $\overline{CE}$ and $\overline{WE}$ controlled write cycle. That is, the address is latched by the falling edge of either $\overline{CE}$ or $\overline{WE}$, whichever occurs last. Similarly, the data is latched internally by the rising edge of either $\overline{CE}$ or $\overline{WE}$, whichever occurs first. A byte write operation, once initiated, will automatically continue to completion, typically within 5ms.

PAGE WRITE OPERATION

The page write feature of the X28C256 allows the entire memory to typically be written in 1 second. Page write allows one to sixty-four bytes of data to be consecutively written to the X28C256 prior to the commencement of the internal programming cycle. The destination addresses for a page write operation must reside on the same page; that is, A_6 through A_{14} must not change.

The page write mode can be entered during any write operation. Following the initial byte write cycle, the host can write an additional one to sixty-three bytes in the same manner as the first byte was written. Each successive byte load cycle, started by the $\overline{WE}$ HIGH to LOW transition, must begin within 100μs of the falling edge of the preceding $\overline{WE}$. If a subsequent $\overline{WE}$ HIGH to LOW transition is not detected within 100μs, the internal automatic programming cycle will commence. There is no page write window limitation. The page write window is infinitely wide, so long as the host continues to access the device within the byte load cycle time of 100μs.

$\overline{DATA}$ POLLING

The X28C256 features $\overline{DATA}$ Polling as a method to indicate to the host system that the byte write or page write cycle has completed. $\overline{DATA}$ Polling allows a simple bit test operation to determine the status of the X28C256, eliminating additional interrupt inputs or external hardware. During the internal programming cycle, any attempt to read the last byte written will produce the complement of that data on I/O_7 (i.e., write data = 0xxx xxxx, read data = 1xxx xxxx). Once the programming cycle is complete, I/O_7 will reflect true data.

SOFTWARE WRITE PROTECT

Software write protection provides certain options to the designer in selecting the level of protection required by the application. In the default mode the device is accessible (once V_{CC} is stable) at all times and the write protection feature is transparent. Protection can be enabled at anytime by performing a short (three byte write operation) software algorithm. Once enabled, the system is allowed to perform one write operation, either a single byte write or page write operation. At the conclusion of the write cycle the X28C256 will disable any further write operations until the device is reenabled through the software algorithm. If a total memory rewrite is necessary, the protection mode can be exited allowing unrestrained write access to the X28C256.

PROGRAMMABLE V_{CC} SENSE

All Xicor products have a default V_{CC} Sense set point. This inhibits all device operations during power transitions and is typically 3v. The X28C256 provides an additional V_{CC} Sense feature that allows the user to program the set point at which *write* operations are disabled. This feature allows a user to program the sense level in the range of +3v to V_{CC} +1v. The set point is nonvolatile and reprogrammable.

16K X2616 2048 x 8 Bit

Electrically Erasable PROM
High Speed Bipolar PROM Replacement

TYPICAL FEATURES

- **45ns Access Time**
- **Reprogrammable Bipolar PROM Replacement**
- **High Performace NMOS Technology**
- **Low Power**
  - **— 80mA Active Current**
- **JEDEC Approved 2K x 8 Bipolar PROM Pinout**

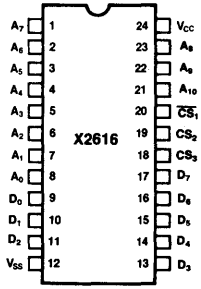
DESCRIPTION

The Xicor X2616 is a very high speed 2K x 8 E^2PROM. It is fabricated with Xicor's proprietary, high performance, N-channel floating gate MOS technology. The X2616 features the industry standard bipolar PROM pinout.

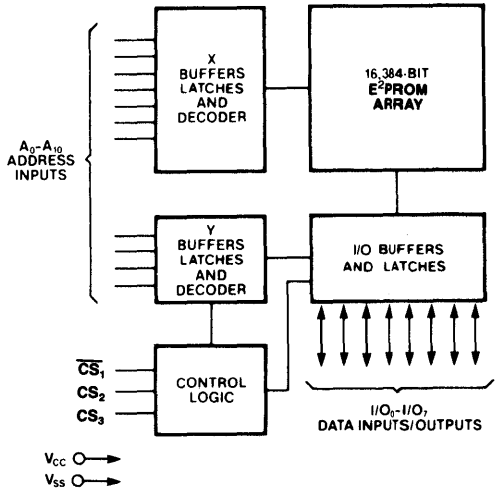
Xicor E^2PROMs are designed and tested for applications requiring extended endurance. Data retention is specified to be greater than 100 years.

3

PIN CONFIGURATION



FUNCTIONAL DIAGRAM



PIN NAMES

A_0–A_{10}	Address Inputs
D_0–D_7	Data Outputs
$\overline{CS}_1$, CS_2, CS_3	Chip Selects

PIN DESCRIPTIONS

Addresses (A_0–A_{10})

The address inputs select an 8-bit memory location during a read operation.

Chip Selects ($\overline{CS}_1$, CS_2, CS_3)

$\overline{CS}_1$ must be LOW and both CS_2 and CS_3 must be HIGH to enable a read operation.

DATA (D_0–D_7)

Data is read from the X2616 on the Data pins.

DEVICE OPERATION

After programming, stored information is read on outputs D_0–D_7 by applying binary addresses to A_0–A_{10} and holding $\overline{CS}_1$ LOW and CS_2 and CS_3 HIGH. All other input combinations on the Chip Select inputs place the Data lines in the high impedance state.

DEVICE PROGRAMMING

The X2616 is an E^2PROM allowing it to be reprogrammed. There are no fuseable links to be blown, therefore the programming operation is similar to a standard E^2PROM write operation. Reprogramming operations are initiated by selecting the memory location to be altered with the address inputs. Then $\overline{CS}_1$ is raised above 12v, CS_2 and CS_3 to a TTL HIGH and then presenting TTL levels at the Data pins. The entire write cycle is typically completed in 2ms.

64K X2664 8192 x 8 Bit

Electrically Erasable PROM
High Speed Bipolar PROM Replacement

TYPICAL FEATURES

- **45ns Access Time**
- **Reprogrammable Bipolar PROM Replacement**
- **High Performance NMOS Technology**
- **Low Power**
  - **— 80mA Active Current**
- **JEDEC Approved 8K x 8 Bipolar PROM Pinout**

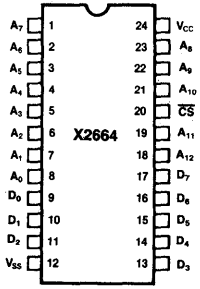
DESCRIPTION

The Xicor X2664 is a very high speed 8K x 8 E^2PROM. It is fabricated with Xicor's proprietary, high performance, N-channel floating gate MOS technology. The X2664 features the industry standard bipolar PROM pinout.

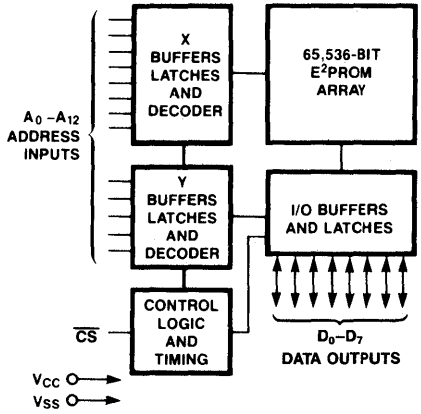
Xicor E^2PROMs are designed and tested for applications requiring extended endurance. Data retention is specified to be greater than 100 years.

3

PIN CONFIGURATION



FUNCTIONAL DIAGRAM



PIN NAMES

A_0–A_{12}	Address Inputs
D_0–D_7	Data Outputs
$\overline{CS}$	Chip Select

PIN DESCRIPTIONS

Addresses (A_0–A_{12})

The address inputs select an 8-bit memory location during a read operation.

Chip Select ($\overline{CS}$)

$\overline{CS}$ must be LOW to enable a read operation.

DATA (D_0–D_7)

Data is read from the X2664 on the Data pins.

DEVICE OPERATION

After programming, stored information is read on outputs D_0 –D_7 by applying binary addresses to A_0–A_{12} and holding $\overline{CS}$ LOW. Chip Select HIGH places the Data lines in the high impedance state.

DEVICE PROGRAMMING

The X2664 is an E^2PROM allowing it to be reprogrammed. There are no fuseable links to be blown, therefore the programming operation is similar to a standard E^2PROM write operation. Reprogramming operations are initiated by selecting the memory location to be altered with the address inputs. Then $\overline{CS}$ is raised above 12v, and TTL levels are presented at the Data pins. The entire write cycle is typically completed within 2ms.

Xicor

NOVRAM* Data Sheets 1

Serial I/O Data Sheets 2

E²PROM Data Sheets 3

E²POT™ Data Sheets 4

X9MME 4-1

X9MME

E²POT™

Digitally Controlled Potentiometer

DEVICE DESCRIPTION

The Xicor X9MME is a family of solid state nonvolatile potentiometers. Each device is packaged in an 8 pin mini-dip and is ideal for digitally controlled resistance trimming.

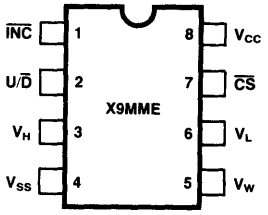
There are 100 tap points on a serial array composed of 99 resistive elements. Each tap point increments the wiper value by 1/99th of the total value of the device. The X9MME uses a single 5 volt supply.

The X9MME is controlled through the $\overline{CS}$, U/$\overline{D}$ and $\overline{INC}$ inputs. These inputs are used to select a value of resistance within the range of the device. The desired resistance value is automatically stored in a nonvolatile array. The V_H (High Terminal), V_W (Wiper Terminal), and V_L (Low Terminal) outputs are equivalent to the three pins of a trim-pot. Additionally, the X9MME resistance is internally temperature compensated.

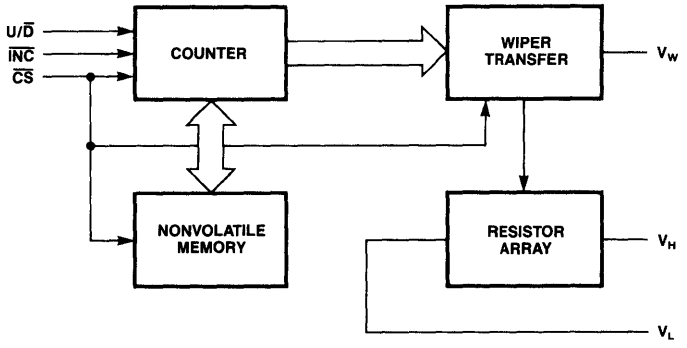
The resolution of the X9MME is equal to the maximum resistance value (refer to Device Numbering Diagram) divided by 99. For the X9503 (50K ohms) each tap point represents 505 ohms. The wiper location is controlled with the use of the three control inputs and an internal nonvolatile counter. The U/$\overline{D}$ input is TTL level sensitive and controls the direction of the wiper movement. The $\overline{INC}$ input is used to move the wiper a desired number of tap points. The wiper moves on falling edges of the input to the $\overline{INC}$ pin. The $\overline{CS}$ input controls the operational state of the device.

E²POT is a trademark of Xicor, Inc.

PIN CONFIGURATION



FUNCTIONAL DIAGRAM



PIN NAMES

V_H	High Terminal of Pot
V_W	Wiper Terminal of Pot
V_L	Low Terminal of Pot
V_{SS}	Ground
V_{CC}	System Power
U/$\overline{D}$	Up/Down Control
$\overline{INC}$	Wiper Movement Control
$\overline{CS}$	Chip Select for Wiper Movement

PIN DESCRIPTIONS

V_H

The high terminal of the X9MME is capable of handling an input voltage from 0 to 5 volts.

V_L

The low terminal input is limited from −5 to V_H−1 volts.

V_W

The wiper terminal series resistance is typically less than 40 ohms. The value of the wiper is controlled by the use of $U/\overline{D}$ and $\overline{INC}$.

UP/DOWN ($U/\overline{D}$)

The $U/\overline{D}$ input controls the direction of the wiper movement and the value of the nonvolatile counter.

INCREMENT ($\overline{INC}$)

The $\overline{INC}$ input is negative-edge triggered. Toggling $\overline{INC}$ will move the wiper and either increment or decrement the counter in the direction indicated by the logic level on the $U/\overline{D}$ input.

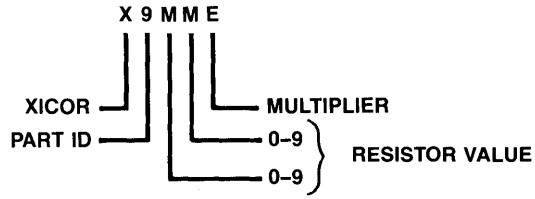
CHIP SELECT ($\overline{CS}$)

The device is selected when the $\overline{CS}$ input is LOW. The current counter value is stored when $\overline{CS}$ is returned HIGH.

Standard Parts

Minimum Resistance	Wiper Increments	Maximum Resistance	Part Number
40 ohm	101 ohm	10K ohm	X9103
40 ohm	202 ohm	20K ohm	X9203
40 ohm	505 ohm	50K ohm	X9503
40 ohm	1010 ohm	100K ohm	X9104
40 ohm	2020 ohm	200K ohm	X9204
40 ohm	5050 ohm	500K ohm	X9504
40 ohm	10.1K ohm	1Meg ohm	X9105

Device Numbering



For example; a 33,000 ohm full resistance device the number would be X9333

NOVRAM* Data Sheets 1

Serial I/O Data Sheets 2

E²PROM Data Sheets 3

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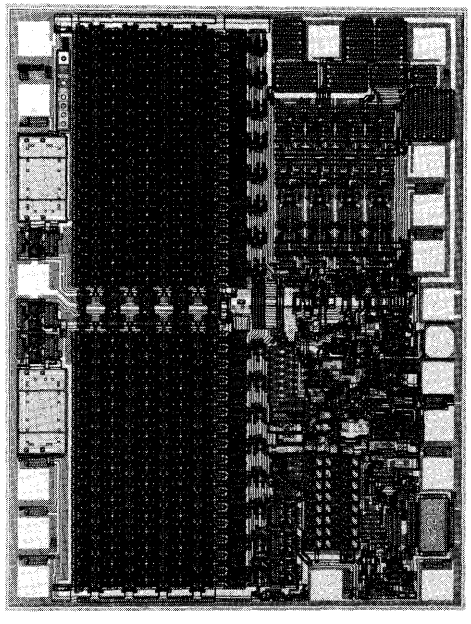
Applications 5



XICOR NOVRAM FAMILY, EASIER THAN EVER TO USE

BY APPLICATIONS STAFF

Introduction

The purpose of this application note is to take the user through the internal operation of NOVRAMs as well as their external operation. These devices are finding their way into many diverse applications due to their ease of use. The major features of the XICOR family of NOVRAMs are 1) only 5 volts is required for all operations including programming, 2) only TTL signals are required and 3) all pulse widths are short (< 450 ns).

Basically a NOVRAM is a memory device that has a static RAM overlaid with an EEPROM (Electrically Erasable Programmable ROM). The operation of the RAM is identical with other popular static RAMs such as the 2102A and the 2114. Figure 1 shows the block diagram of the XICOR NOVRAM family. NOVRAMs have $\overline{CS}$ and $\overline{WE}$ pins in common with their standard static RAM cousins but also have two additional control pins: $\overline{STORE}$ and $\overline{RECALL}$. The $\overline{STORE}$ and $\overline{RECALL}$ pins control movement of data between the RAM and the EEPROM.

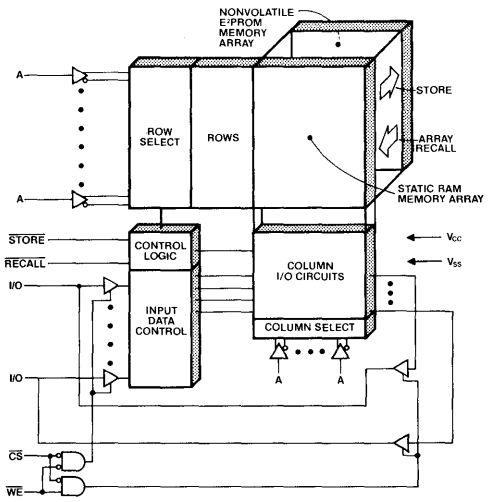


Figure 1) Block diagram of the XICOR NOVRAM family.

The $\overline{STORE}$ pin is used to transfer the contents of the RAM to the EEPROM in a single operation. The entire contents of the RAM are transferred with one STORE operation. After a STORE operation is completed the original data is still in the RAM as well as the EEPROM.

The $\overline{RECALL}$ pin is used to transfer the contents of the EEPROM back to the RAM. When this is done, whatever data were in the RAM prior to the RECALL operation are totally replaced by the contents of the EEPROM. The STORE and RECALL operations function on the entire contents of the memory and not on a word by word basis. After either operation the contents of both the RAM and the EEPROM will be the same.

This may seem too good to be true; however, with XICOR's family of NOVRAMs the life of the systems designer is made even easier. Only a single five volt power supply is required for all operations including the STORE and RECALL operations. All addresses, data lines and control pins are TTL compatible and all pulse widths are short enough that most microprocessors do not require wait states. There are no high voltages or long pulse widths required which will inhibit the designer from designing a system with clean operation.

Technology

The XICOR NOVRAM stores its nonvolatile data during periods of power off by the absence or presence of charges on floating polysilicon gates. This is the same structure that is widely used in UV-EPROMS. The floating gate is an island of polysilicon surrounded by oxides with thicknesses of about 800 A°. Charge can be injected or removed from the floating gate by applying electric fields of sufficient strength to cause electron tunneling through the oxides. At normal field strengths the charges are permanently trapped on the floating gate even when power is removed.

The XICOR family of NOVRAMs uses three layers of polysilicon; the second layer is the floating gate. This structure employs a phenomenon known as Fowler-Nordheim tunneling. This form of tunneling is described in Vol. 40 No. 1 (Jan. 1969, pg. 278) of the Journal of Applied Physics and Vol. 27 No. 9 (Nov. 1975, pg. 505) of the Applied Physics Letters. In XICOR NOVRAMs this tunneling is enhanced by the use of textured polysilicon surfaces to generate higher field strengths at the surface to enhance electron injection into the oxide. The alternative to field enhancement by textured surfaces is to use ultrathin oxide layers in order to conduct the charge. The use by XICOR of standard oxide thickness gives XICOR a very manufacturable product, thus ensuring its low cost and volume delivery.

Figure 2. shows the circuit of the NOVRAM cell containing a conventional 6 transistor static RAM cell and a floating gate EEPROM cell with 2 additional transistors to control the action of data transfer. The floating gate (POLY 2) is connected to the rest of the circuit only through capacitance. Electrons are moved to the floating gate by tunneling from POLY 1 to POLY 2 and removed by tunneling from POLY 2 to POLY 3.

The capacitance ratios are the key to the operation of the transfer of data from RAM to EEPROM. If node

N1 is LOW, transistor Q7 is turned OFF. This allows the junction between CC2 and CC3 to float. Since the combined capacitance of CC2 and CC3 are larger than CP the floating gate follows the Internal Store Voltage node. When the voltage on the floating gate is high enough electrons are tunneled from POLY 1 to POLY 2 and the floating gate is negatively charged.

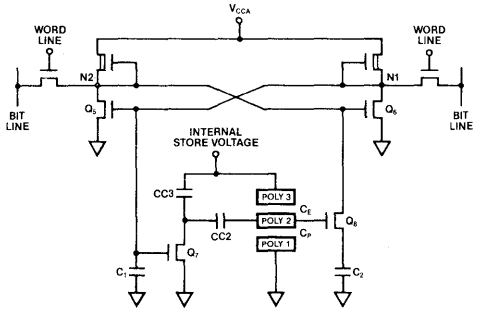


Figure 2) Circuit diagram of a NOVRAM cell.

If node N1 is HIGH, transistor Q7 is turned ON which grounds the junction between CC2 and CC3. Since CC2 is larger than CE, CC2 holds the floating gate near ground when the Internal Store Voltage node is pulled HIGH. This creates a sufficient field between POLY 2 and POLY 3 to tunnel electrons away from the floating gate leaving it with a positive charge.

The RECALL operation also takes advantage of capacitance ratios. The value of C2 in Figure 2 is larger than that of C1. When the external RECALL command is received, the internal power supply, VCCA, is first pulled LOW to equalize the voltage on N1 and N2. When the internal power node is allowed to rise, the node which has the lighter loading will rise more rapidly and the gain of the flip-flop will cause it to latch HIGH and the opposite node to latch LOW. If the floating gate has a positive charge C2, is connected to N2 through Q8 and N2 will latch LOW. If the floating gate has a negative charge Q8, is turned OFF and N1 will have the heavier loading.

The Xicor NOVRAM Family

XICOR's family of NOVRAMs contains three members with identical operating characteristics. The three parts offer the designer a choice of memory organization. The X2201A, X2210 andX2212 are organized 1024 x 1, 64 x 4 and 256 x 4 respectively. All three devices are packaged in 18 pin DIPs with 300 mil centers. Figure 3 shows the pin configuration of the three different NOVRAMs.

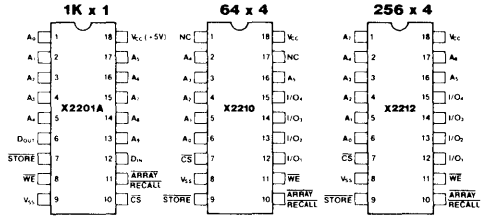


Figure 3) Pin configuration of the XICOR NOVRAM family.

The only functional difference between the three devices is that the X2201A has separate Data I/O lines while the two 4 bit wide parts have common I/O. Additionally, the X2210 and the X2212 are pin compatible. The two unused pins on the X2210 are used for the two higher order addresses on the X2212. The control pins $\overline{STORE}$, $\overline{RECALL}$, $\overline{CS}$ and $\overline{WE}$ operate identically on all three parts.

Write Operation

The WRITE operation is initiated by applying valid addresses followed by both $\overline{CS}$ and $\overline{WE}$ going LOW. On the 300ns version access time version, at least one of these two signals must remain HIGH until the addresses are valid. $\overline{CS}$ and $\overline{WE}$ must remain LOW simultaneously for 100ns.

An easy way to look at this is to consider the internal write command as the simultaneous LOW of $\overline{CS}$ and $\overline{WE}$. The internal write command is started by the last edge down and terminated by the first edge up. Valid addresses must overlap this internal write command. Data must be referenced to the first positive edge of $\overline{CS}$ or $\overline{WE}$. The timing required for writing to the RAM is shown in Figure 4.

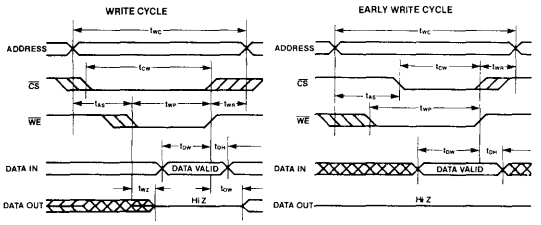


Figure 4) Timing diagram for Writing to the RAM.

Read Operation

The READ operation is the easiest of the four operations performed by the NOVRAM. In the case of the 300ns access time version, data will be valid at the outputs 300ns after valid addresses or 200ns after $\overline{CS}$ goes LOW, whichever is later.

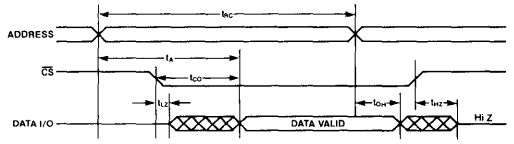


Figure 5) Timing diagram for Reading from the RAM.

Store Operation

The STORE operation is initiated by the application of an active LOW TTL pulse of 100ns or greater on the $\overline{STORE}$ pin. As long as the power supply remains within its specification for 10ms after the beginning of the STORE pulse the contents of the RAM will have been transferred to the EEPROM in total. The STORE operation cannot be terminated once initiated except by removing the power supply. This can not be counted upon to rapidly terminate the STORE operation since the user cannot determine how far the STORE operation the device has progressed. Additionally, if the power supply drops below the specification during the 10ms the integrity of the STORE operation is not assured. Figure 6 shows the timing diagram for transferring data from the RAM to the EEPROM.

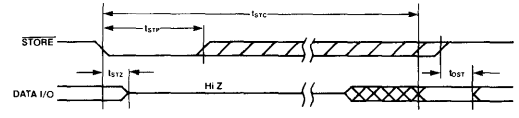


Figure 6) Timing diagram for the STORE operation where data is transferred from the RAM to the EEPROM.

The STORE operation takes precedence over all other operations except the RECALL operation. If the RECALL operation has begun, any STORE command is ignored as long as the $\overline{RECALL}$ pin remains LOW. Once the STORE operation has started, taking the $\overline{RECALL}$ pin LOW has no effect and the STORE operation will be completed. If a READ or WRITE cycle is in progress when a STORE command is received, that cycle is terminated. The data in the selected RAM address during an interrupted WRITE cycle would be indeterminate.

During the 10ms of the STORE operation the NOVRAM should not be accessed for any other operation as it would not be known if the internal STORE operation was completed or not. If the internal STORE operation was completed before the 10ms and another operation command was entered, that command would be executed. However, if the internal STORE operation was not completed and another operation command was received, the later command would be ignored. During the STORE operation the outputs of the NOVRAM are in the floating state.

Recall Operation

The RECALL operation is initiated by the application of an active LOW TTL pulse of 450ns or greater on the $\overline{RECALL}$ pin. The positive going edge of this pulse determines when it is possible to read data from the RAM. Valid data from the RAM can be viewed on the outputs of the NOVRAM 750ns after the rising edge of $\overline{RECALL}$ or 300ns after application of valid addresses, whichever comes latest. FIGURE 7 shows the timing requirements for transferring data from the EEPROM to the RAM.

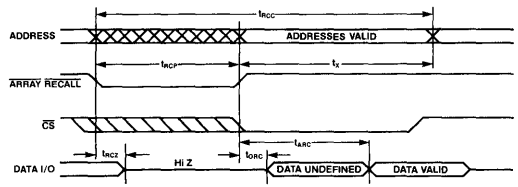


Figure 7) Timing diagram for the RECALL operation.

The RECALL operation takes precedence over all other operations. RECALL will terminate a READ or WRITE cycle if applied in the middle of either cycle. The RECALL operation can take precedence over the STORE operation only if the RECALL command was received prior to the STORE command.

Hooking up the NOVRAM

Now that the basics of the four NOVRAM operations have been described, we may discuss using these unique parts in a system. Let's first discuss a system in in which we connect the NOVRAMs to a 6502. We'll assume that the system powers up and down cleanly. The problem of systems where this does not occur will be dealt with later.

The 6502 microprocessor uses memory space for I/O functions. The design uses one set of addresses for the READ and WRITE operations and other blocks of addresses to initiate the STORE and RECALL operations. An APPLE II* computer was used as the 6502 computer because it has address space already decoded for I/O functions and convenient card slots to communicate with these decoder outputs.

The RAM was placed in the address space starting at HEX address $C800 by connecting pin 20 on the APPLE II peripheral connector to the $\overline{CS}$ on the NOVRAM. This pin is activated when any of the 2048 bytes starting at $C800 are accessed. Peripheral slot 2 was selected for the NOVRAM design. On slot 2 pin 41 is activated whenever the 16 bytes located at HEX address $C0A0 are accessed. This address space is sent only to slot 2 and was tied to the $\overline{STORE}$ pin on the NOVRAM. PIN 1 also has a unique address space for slot 2 and was tied to the RECALL pin. This space is the 256 bytes starting at HEX address $C200.

Figure 8 shows the connections of the card to be plugged into peripheral card slot 2. Reading and writing are accomplished from the BASIC programming language by PEEK and POKE instructions to HEX addresses starting at $C800. The STORE operation is called by either a PEEK or a POKE instruction to any of the 16 addresses starting at $C0A0. $\overline{RECALL}$ is initiated by accessing any of the 256 bytes starting at $C200.

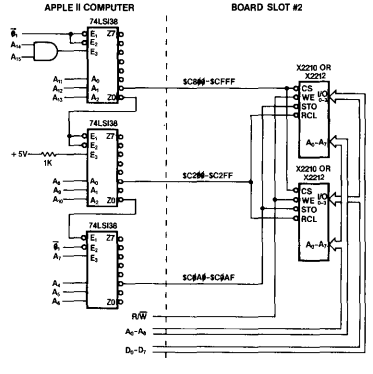


Figure 8) Connections for operating the NOVRAM on the I/O Bus of an APPLE II computer.

The APPLESOFT* program in Table 1 demonstrates how a NOVRAM can be accessed easily. The statement 210 is a Write operation to HEX address $C200 while statement 310 is a Write to HEX address $C0A0. The $\overline{CS}$ pin is activated with statement 430 and statement 580 respectively. This program was written for the X2210 but it could be easily modified for the X2212 or even eight X2201s.

```
5  TEXT : HOME
10 A$ = "#1 WELCOME TO THE WORLD'
    S EASIEST TO USENONVOLATILE
    STATIC RAM!!"
20 B$ = "#2 ONLY A SINGLE 5 VOLT
    POWER SUPPLY IS REQUIRED FOR
    OPERATIONS!"
30 C$ = "#3 ALL INPUTS AND OUTPUT
    S REQUIRE ONLY  TTL INTERFAC
    E SIGNALS!!!"
40 F$ = "#4 ALL TIMING SIGNALS AR
    E MICROPROCESSORCOMPATIBLE-N
    O STRECHING!"
50 G$ = "#5 3 SIZES AVAILABLE:(X2
    201)1024X1,    (X2212)256X4
    ,(X2210)64X4"
60  VTAB 5: HTAB 11: PRINT "XICOR
    'S X2210 DEMO"
75  PRINT : PRINT : HTAB 5: PRINT
    "1=RECALL": HTAB 25: PRINT
    "3=READ"
80  PRINT : HTAB 5: PRINT "2=STOR
    E": HTAB 25: PRINT "4=WRITE
    "
85  PRINT : HTAB 17: PRINT "5=EXI
    T"
90  VTAB 15: HTAB 12: INPUT "SELE
    CT ONE?,"A
100  IF A < 1 OR A > 5 THEN  HOME
    : VTAB 5: HTAB 5: PRINT "ONL
    Y 1-5 ALLOWED---TRY AGAIN": GOTO
     75
110  ON A GOTO 200,300,400,500,60
    0
200  REM  ***********************
201  REM  * RECALL SUBROUTINE *
202  REM  ***********************
210  POKE  - 15872,0
215  HOME : VTAB 5: HTAB 14
216  PRINT "RECALL COMPLETE"
218  FOR I = 1 TO 1000: NEXT I
220  HOME : GOTO 60
300  REM  ***********************
301  REM  * STORE SUBROUTINE *
302  REM  ***********************
310  POKE  - 16224,0
315  HOME : VTAB 5: HTAB 14: PRINT
    "STORE COMPLETE"
320  FOR I = 1 TO 1000: NEXT I
325  HOME : GOTO 60
400  REM  ***********************
401  REM  * READ SUBROUTINE *
402  REM  ***********************
422  HOME
423  VTAB 5: HTAB 12: PRINT "RESU
    LTS FROM RAM": PRINT : PRINT

425  FOR I = 1 TO 64
430  PRINT  CHR$ ( PEEK ( - 14336
    + I));
435  NEXT I
440  FOR I = 1 TO 5000: NEXT I
445  HOME : GOTO 60
500  REM  ***********************
501  REM  * WRITE SUBROUTINE *
502  REM  ***********************
505  HOME : VTAB 5: HTAB 6: PRINT
    "PRESELECTED MESSAGES (1-5)"
    : PRINT : PRINT
515  PRINT : PRINT : HTAB 4: PRINT
    "ENTER MESSAGE FROM KEYBOARD
    (6)"
520  PRINT : PRINT : HTAB 11: INPUT
    "SELECT ONE (1-6)?"A
525  ON A GOTO 531,532,533,534,53
    5,540
531  Q$ = A$: GOTO 548
532  Q$ = B$: GOTO 548
533  Q$ = C$: GOTO 548
534  Q$ = F$: GOTO 548
535  Q$ = G$: GOTO 548
540  PRINT : PRINT : HTAB 5: PRINT
    "INPUT MESSAGE-64CHARACTERS
    MAX": INPUT Q$
545  Q$ = Q$ + "

548  HOME : VTAB 5: HTAB 12: PRINT
    "WRITTEN INTO RAM": PRINT : PRINT

550  Q$ =  LEFT$ (Q$,64)
570  FOR I = 1 TO 64
575  Z$ = MID$ (Q$,I,1):Z = ASC
    (Z$)
580  POKE  - 14336 + I,Z
582  PRINT Z$;
585  NEXT I
590  FOR I = 1 TO 5000: NEXT I
595  HOME : GOTO 60
600  END
```

Table 1) An APPLESOFT BASIC program for demonstrating the four operations of NOVRAMs.

*APPLE II and APPLESOFT are trademarks of Apple Computers.

Protection Against Inadvertent Store

The circuit described in the previous section assumes that the system is powered up and down in an orderly manner. This would mean that the microprocessor would never generate addresses unless they were part of the program. Unfortunately real systems do not operate in this ideal manner. Although the circuit described above has not produced a fault during extensive testing, the possibility exists that the hex addresses $C0A0-$C0AF could come up during power up, or during a brown out when the supply dropped below the operating specification, or during a power failure.

Several methods can be used to insure that the NOVRAM does not react to errors produced by the system when it is out of its operating specification. Setting the $\overline{\text{RECALL}}$ pin LOW to block a STORE operation is the easiest. Holding the $\overline{\text{STORE}}$ pin between VIH MIN and the falling power supply is another.

Most microprocessors are not totally under control for the first few cycles after power up. Their early addresses depend on what is in the registers after the System Reset pulse terminates. There is a possibility that these registers can cause one of the early addresses to be the same selected for a STORE operation. In this case the circuit shown in Figure 8 could cause the EEPROM to be written with false data during the power up operation. Figure 8 allows the STORE operation to be initiated if any of 16 addresses is selected for either a read or a write.

Although microprocessors can put out uncontrolled addresses they do not put out uncontrolled write commands. By ANDing the System Write line with the System STORE command, the NOVRAM would recognize a STORE operation only on a machine write cycle.

A potential danger in the use of the above schemes is the fact that three state TTL gates are not under total control while the power supply is coming up. This could produce glitches on the STORE pin even though no Write command was received at the input of the gate. A more positive way to insure that the $\overline{\text{STORE}}$ pin follows the power supply as the voltage increases is to use an open collector NAND gate with one of the inputs provided by a signal that determines power supply status (Circuitry for power supply status will be covered later in this application note). If one input of an open collector NAND gate is held LOW the output transistor is turned OFF since it can not receive base current. Pulling the output of this gate to the power supply of the NOVRAM through a pullup resistor will then insure that the output follows the power supply with no glitches.

Carrying the use of a power supply status signal one step further, would be to use it to hold the $\overline{\text{RECALL}}$ pin LOW in addition to holding the $\overline{\text{STORE}}$ pin HIGH. A direct connection of this status signal to the $\overline{\text{RECALL}}$ pin is all that is necessary as shown in Figure 9. This circuit has a more positive control of the NOVRAM since it takes two actions to prevent an inadvertent STORE operation.

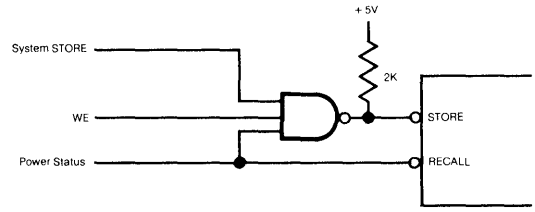


Figure 9) A power supply status line held LOW can insure that both the $\overline{\text{RECALL}}$ pin is held LOW and the $\overline{\text{STORE}}$ pin is held HIGH.

An example of a basic circuit to monitor the power supply status is shown in Figure 10. The output of this two-stage circuit is held LOW whenever the power supply is below 4.5 Volts. This same technique can be used with a Zener diode and an operational amplifier. The designer is cautioned to consider temperature effects.

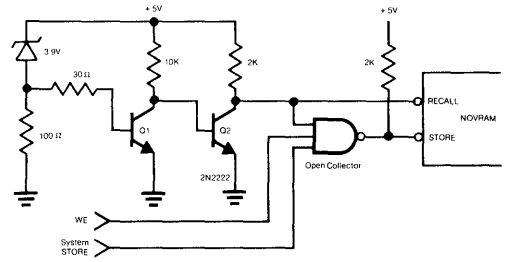


Figure 10) The Zener power supply detector is used in combination with the open collector on the $\overline{\text{STORE}}$ pin to provide protection against an inadvertent STORE operation during power up and power down.

Another method of power supply status is to assume that the only power supply fault which requires insuring that wrong data is not stored is the loss of the AC line voltage. Many commercially available AC line fault monitors are on the market. Two of these line fault monitors are the MID 400 Power Line Monitor from General Instrument and the SG1547 from Silicon General. Additionally, many commercially available power supplies have a power fail signal either as a standard feature or as an option.

The circuit shown in Figure 11 shows another type of power supply status detector. This circuit is a low cost solution but it should be used only to take the $\overline{\text{RECALL}}$

pin LOW because it does not provide adequate drive for a TTL gate.

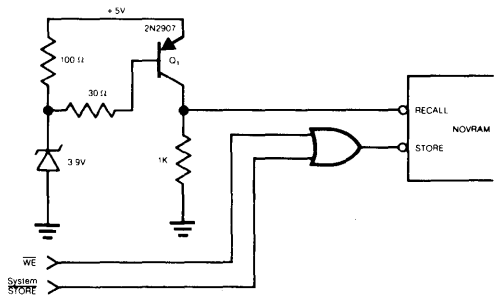


Figure 11) Another form of power supply status detector to drive the RECALL pin LOW when the supply drops below 4.5Volts.

Some other schemes to protect against inadvertent STORE operations are the use of jumpers, cables and/or switches. The STORE signal is transmitted through the jumper or switch which is normally open unless it is desired to change the data in the EEPROM. During normal operation the only component attached to the STORE pin is a resistor to the power supply.

A more comprehensive discussion of power supply status circuitry can be found in XICOR's Ap Note #102. This note covers those requirements that STORE data at power failure.

Applications

Most microprocessor systems have need for some form of nonvolatile memory to store important data such as:

1) Calibration constants
2) Set-up configuration information
3) User system ID
4) Changeable programs/firmware
5) System status
6) Accounting information
7) Error conditions

The types of equipment that are today being designed to include NOVRAMs vary through the complete line of electronic equipment. Some of these systems are:

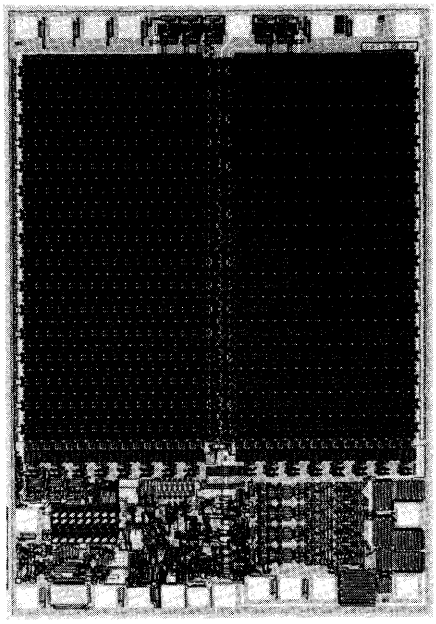
1) Computer peripherals/terminals etc.
2) Automatic tellers/transaction terminals
3) Point-of-sale terminals
4) Smart scales
5) Vending machines and games (i.e. arcade games, slot machines)
6) Meters (i.e. utilities, taxi, gas pumps)
7) Process control
8) Robots
9) Instruments (musical, medical, test, avionics)
10) Communications
11) Transducers/load cells
12) Automotive: odometers, engine control
13) Office equipment: copiers, word processors
14) Military products

Some of the competitive products being replaced by NOVRAMs in systems are:

1) DIP switches
2) Thumbwheel switches
3) CMOS with batteries
4) EAROM
5) EEPROM
6) Potentiometers

One should let his imagination soar when thinking applications for these unique NOVRAMs. XICOR is always interested in application ideas that represent both normal and off-beat uses of these NOVRAMs. Any ideas sent to XICOR will be greatly appreciated.

NOTES



STORING DATA IN XICOR NOVRAMS DURING POWER FAILURE

BY APPLICATIONS STAFF

Introduction

Many systems require that some data be saved at the time of a power failure. This can be a wide variety of data such as accounting information, system status, program counter or register contents, or security information. The XICOR NOVRAM family is ideal for applications of this type as a NOVRAM* memory can save the entire contents of its RAM into an on-chip EEPROM in only 10ms and with a single 5V power supply.

This application note addresses several methods of detecting a power failure and insuring that the regulated +5 Volts supply remains within specification for at least the 10ms required to complete the STORE operation. Various schemes of detecting the absence of ac and the decline of unregulated dc are discussed. The use of either hardware or software control is also covered. Since each system and power supply has individual requirements, it will be up to the system designer to select the circuit approach best suited to the application. None of the circuits shown are necessarily better in all cases and indeed the ideal circuit for a particular situation may not even be shown.

Store Requirements

The requirements to save data in the NOVRAM memory are very straightforward. It is only required that a low level TTL pulse, 100ns or greater duration, be applied to the $\overline{\text{STORE}}$ pin and the power supply remain above 4.5 Volts for 10ms after the beginning of the STORE pulse. Figure 1 shows the relationship between the STORE pulse and the +5 Volt power supply. Once the STORE operation has started it can not be terminated unless the supply drops below +4.5V.

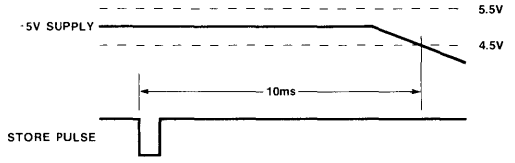


Figure 1) The +5 Volt power supply must remain above +4.5 Volts for 10ms after the STORE pulse starts.

During the STORE operation, the NOVRAM memory is not on the bus allowing the microprocessor to complete other tasks that may be required by the system for an orderly shutdown. The STORE operation is determined by the falling edge of the STORE pulse. If the $\overline{\text{STORE}}$ pin is held LOW, another STORE cycle will not be started. The $\overline{\text{STORE}}$ pin must be brought HIGH before another STORE operation can occur.

Since the regulated +5 Volt power supply must remain above +4.5 Volts for 10ms, some other point must be monitored for power failure. The detection of regulated dc dropping is already too late to provide an assured 10ms of at least +4.5 Volts. Two possible points to monitor for an early indication of declining power are the ac to the power supply and/or the raw or unregulated dc to the regulator itself.

Detecting the absence of ac can be performed either before or after the transformer. If it is done in front of the transformer, it is necessary that the signal be electrically decoupled from the dc portions of the system. This can be accomplished by using optoelectronic components which transmit light signals between two points with differing electrical references.

If detection is accomplished after the transformer, it needs to be isolated from the heavily filtered unregulated dc of the main power supply as the response time there is very slow. This is done by using either a separate transformer tap or two extra diodes to isolate the signal from the bridge. Figure 2 shows the relationship necessary between the ac, the +5 Volt supply and the STORE pulse.

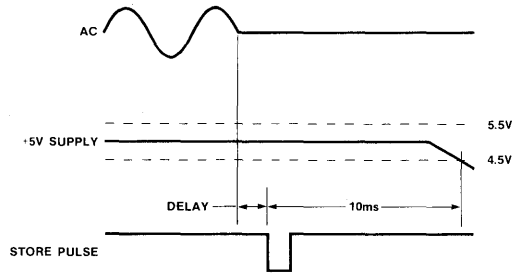


Figure 2) Missing ac must trigger a STORE pulse at least 10ms prior to the regulated dc dropping below specification.

The other technique for early detection of failing power is to sense the unregulated or raw dc in front of the regulator. The regulator has a range of input voltage for which it will maintain the output within fixed limits. If a trip point is set up below the normal input voltage, a STORE signal can be sent to the NOVRAM memory with enough time to insure that the +5 Volts stays within specification for at least 10ms as shown in Figure 3.

*NOVRAM is Xicor's nonvolatile static RAM device.

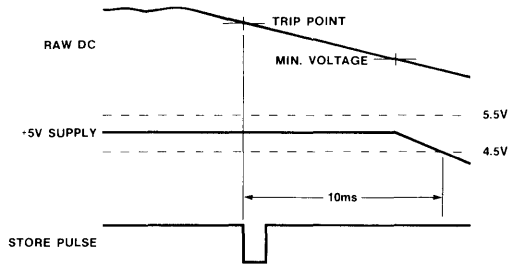


Figure 3) Falling dc is detected to trigger a STORE pulse at least 10ms before the +5 Volt supply drops below 4.5 Volts.

AC Power Failure Detect Circuits

It is possible to detect the loss of ac power with some very simple circuits. Four differing approaches are discussed in this section. These include a simple transistor zero crossing detector, two optoelectronic detectors and a CMOS Schmitt trigger method.

The circuit shown in Figure 4 is a low cost technique for detecting the loss of ac. It uses two diodes to isolate the circuit from the filter capacitor in front of the regulator. The resistor R2 is selected to limit the base current of Q1 and is dependent on the value of the ac signal.

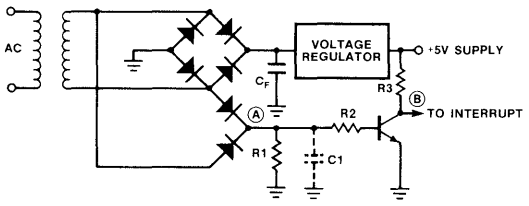


Figure 4) A circuit to detect the absence of ac.

When the full wave rectified ac drops toward zero, the transistor Q1 loses base current and the output goes HIGH. If the capacitor is not used, the circuit produces a short HIGH pulse every 8.3ms. This signal is then used to interupt the microprocessor. Since the ac has probably not been lost, the microprocessor starts a subroutine to determine if this is a true power loss event. This subroutine produces a short delay (2ms) and looks at the detector again. If the output of the detector is still HIGH the power loss is real and the microprocessor issues to the NOVRAM memory a STORE pulse. The waveform produced by the circuit without the capacitor is shown in Figure 5.

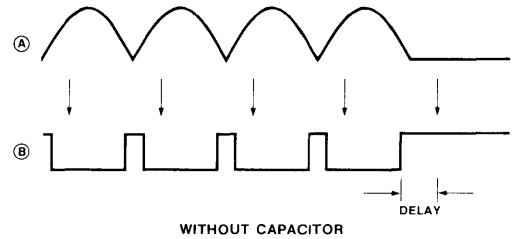


Figure 5) Waveforms in the circuit of Figure 4 without the capacitor. The microprocessor is interupted every 8.3ms and must check 2ms later to determine if the power loss is real.

The disadvantage of using an interupt every half cycle is that the available processing time is reduced by nearly 25%. In many applications this is undesirable. A capacitor in the circuit of Figure 4 eliminates the pulses every half cycle. The value of that capacitor depends on many factors. Among these are the holdup time of the power supply, the desired delay of missing ac before triggering STORE and the values of R1 and R2. Figure 6 shows the signals under these conditions. In the lab circuit the values were R1 = 33K Ohms, R2 = 10K Ohms, C1 = .1 microfarad and a full wave rectified ac of 20 volts peak. This combination produced a delay of 2ms from the time that a half cycle was missing.

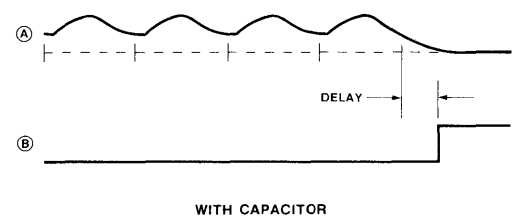


Figure 6) A capacitor in the circuit of Figure 4 fills in the valley in the rectified ac to produce a pulse only when ac disappears.

Care should be taken to insure that the time rise of the output of any detector circuit is fast enough for the microprocessor. Extra logic gates can be used to improve the time rise.

An approach that allows direct connection to the ac power line is shown in Figure 7. In this circuit the ac line is connected through a resistor to two optoelectronic isolators connected with their diodes back to back.

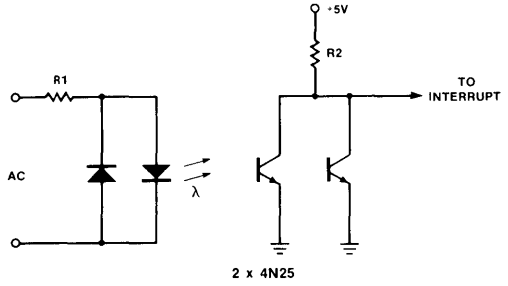


Figure 7) Two optoelectronic isolators are connected with their diodes back to back to provide an interupt signal.

This circuit produces a positive pulse each time that ac line has a zero crossing as shown in Figure 8.

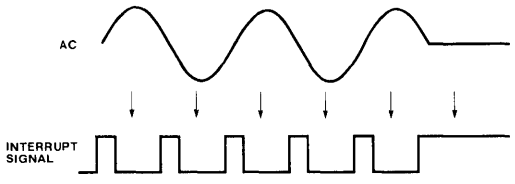


Figure 8) The circuit of Figure 7 produces positive pulses every 8.3ms until ac power failure and then remains HIGH until the dc decays.

This circuit is similar to the one in Figure 4 in that it produces an interupt every 8.3 ms. This ties up the microprocessor during the delay time when the output of the detector must be resampled. In addition to the method of adding a capacitor to the circuit in Figure 4, a missing pulse detector similar to that shown in Figure 9 can be used.

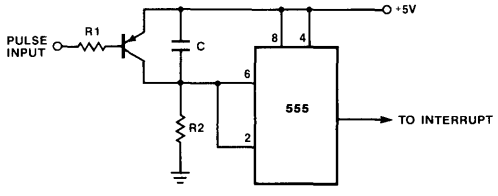


Figure 9) A 555 timer connected as a missing pulse detector.

Another circuit for connecting directly to the ac power line is shown in Figure 10. This circuit uses the MID400 from General Instruments. It requires only two resistors to provide a clean interupt signal.

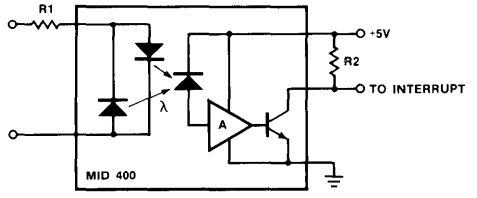


Figure 10) The MID400 requires only two resistors to connect directly to the ac power line.

The waveforms are shown in Figure 11. The turn on and turn off delays can be adjusted with a capacitor. (see the G.I. data sheet for details)

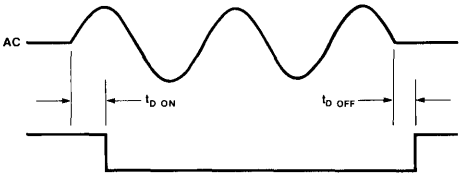


Figure 11) Waveforms for the MID400.

The last ac detect circuit to be discussed uses a CMOS Schmitt Trigger as both a full wave ac low voltage detector and a missing pulse detector. This circuit is shown in Figure 12.

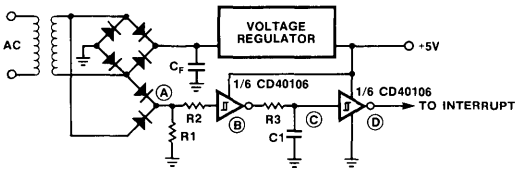


Figure 12) Two CMOS Schmitt Triggers are used to detect the absence of ac.

Care should be taken to insure that the input voltage of the CMOS Schmitt Triggers does not exceed the 5 Volt power supply. If this occurs, the possibility of latch-up exists which can be destructive to the CMOS cir-

cuits. A resistor in series between the bridge and R1 will limit the input voltage.

The ac input voltage should be as high as possible to provide narrow pulsewidths out of the first gate. The values of R3 and C1 determine the delay from the output. The waveforms can be seen in Figure 13.

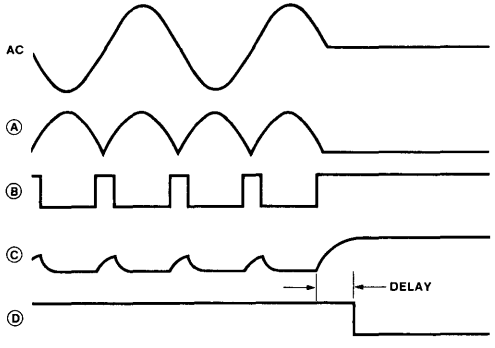


Figure 13) The delay established by R3 and C1 must be longer than the pulsewidth out of the first gate.

DC Power Failure Detect Circuits

Detecting the decline of the raw dc does not involve missing pulses or capacitor delays. The first circuit shown in Figure 14 uses a Zener diode to set a trigger point. This trigger point should be as high as possible without being high enough for the normal range of unregulated dc to trip it. The value of the diode should be selected to be equal to the trip point desired minus .7 volts for the base-emitter drop.

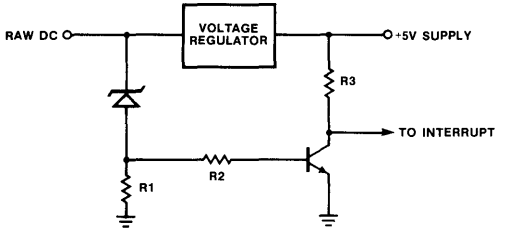


Figure 14) A Zener diode in series with a base-emitter diode establishes the trip point of this dc detector.

A PNP transistor can be used as shown in Figure 15. In this circuit the value of the Zener diode is the desired trip point minus 5 Volts plus .7 Volts for the base-emitter drop.

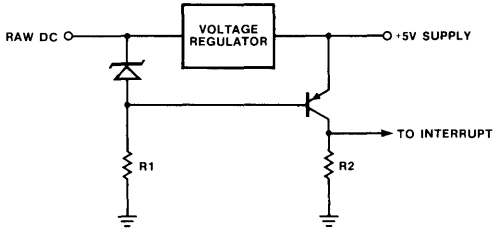


Figure 15) A dropping unregulated dc turns on the PNP transistor.

Care should be used with these last two circuits to insure that all tolerances and temperature coefficients have been considered.

The last circuit that will be discussed in this application note uses an operational amplifier and a Zener diode with some resistors as shown in Figure 16. The circuit trips when the raw dc drops the junction of R1 and R2 to the value of the Zener diode. This circuit can provide either a positive or negative interupt signal depending on the connection of the two amplifier inputs.

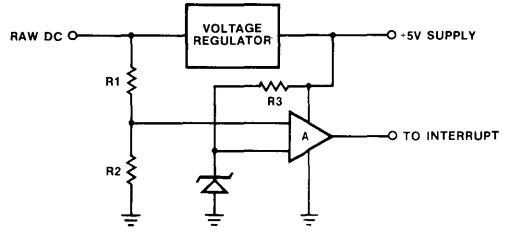


Figure 16) R1 and R2 with the Zener diode determine the trip point of this circuit.

5

Notes On Filter Capacitors

The value of the filter capacitor on the unregulated dc to ground should be high enough to ensure that the regulator remains in regulation for at least 10ms after the STORE pulse has been sent. This is dependent on the value of the trip point, the lowest input voltage to the regulator and the load. For an example consider a system with a 300mA load, a 15 Volt trip point and a 7 Volt lowest regulation voltage. Using the $I = CdV/dT$ equation we have: $C = 300 \times (10/8) \times 10^{-6} =$ 375microfarads.

Notes On Software

When using a microprocessor interupt to issue the STORE command, the program should branch to a STORE subroutine. This subroutine contains a short delay followed by a test of the power supply detector to insure that the power failure is valid. This can be seen in Figure 17.

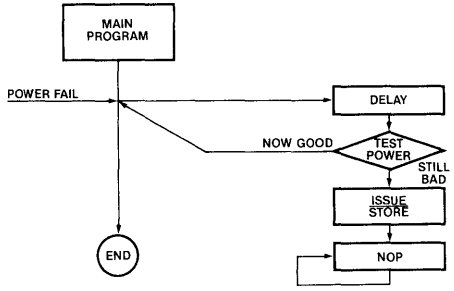
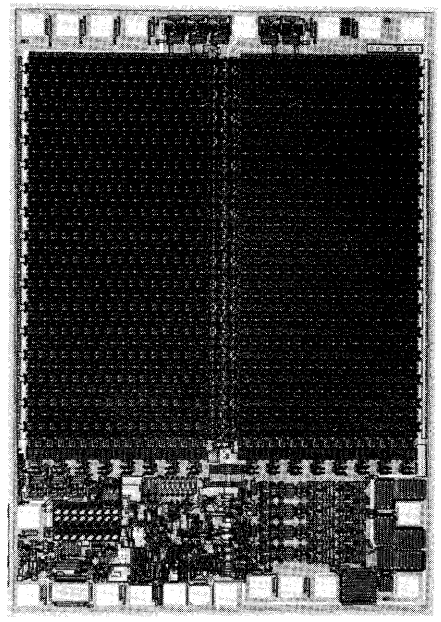


Figure 17) The program branches to a STORE subroutine when a power failure is detected.

Note: The exact values of components in the preceding drawings depend on system conditions such as secondary AC voltage and power supply hold-up time.

Some lab values for the drawings to use as starting points are as follows:

Figure 7. $R_1 = 12k\Omega$, $R_2 = 2k\Omega$, AC = 120V
Figure 9. $R_1 = 5k\Omega$, $R_2 = 3.3k\Omega$, $C = 1\mu F$, Time delay = 2msec
Figure 10. $R_1 = 22k\Omega$, $R_2 = 2k\Omega$, AC = 120V
Figure 12. $R_1 = 20k\Omega$, $R_2 = 20k\Omega$, $R_3 = 10k\Omega$, $C_1 = .2\mu F$, Rectified AC = 20V, Time Delay = 2msec
Figure 14. Zener = 10V, $R_1 = 1k\Omega$, $R_2 = 2k\Omega$, $R_3 = 2k\Omega$, Trip Point = 10.7V
Figure 15. Zener = 10V, $R_1 = 2k\Omega$, $R_2 = 2k\Omega$, Trip Point = 14.3V
Figure 16. Zener = 3.3V, $R_1 = 20k\Omega$, $R_2 = 6k\Omega$, $R_3 = 2k\Omega$, Trip Point = 14.3V



XICOR REPLACES DIP SWITCHES AND TRIMMERS WITH NOVRAM MEMORIES

BY APPLICATIONS STAFF

Introduction

The desire to replace mechanical components in electronic systems for purposes of increased reliability, lower costs and ease of maintainability has spread to DIP switches and trimming potentiometers or trimmers. The component that makes this replacement possible is the NOVRAM memory from Xicor. The NOVRAM memory is a device that has two memories in parallel, a standard static RAM and a nonvolatile electrically erasable programmable read only memory (EEPROM). The EEPROM portion of the NOVRAM memory holds data that is equivalent to the settings of the now obsolete DIP switches and trimmers.

What Is A NOVRAM Memory?

A NOVRAM memory, as stated previously, is two memories in a single unit. The standard static RAM has a nonvolatile EEPROM cell associated with each RAM cell. Figure 1 shows a block diagram of a typical NOVRAM memory.

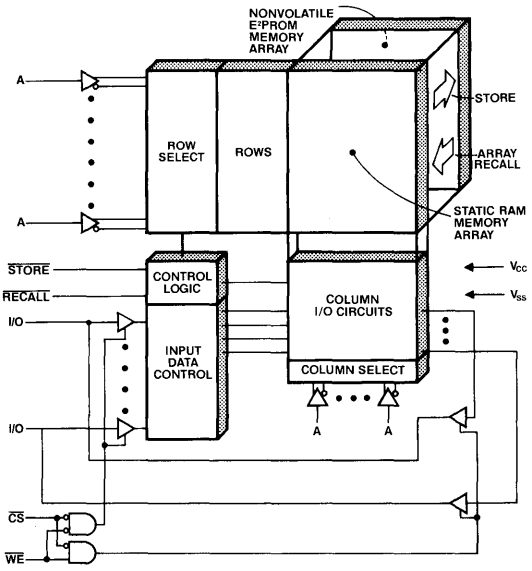


Figure 1) NOVRAM memory block diagram.

There are two additional pins on a NOVRAM memory device that do not appear on an ordinary static RAM. These two pins are called $\overline{\text{STORE}}$ and $\overline{\text{RECALL}}$. The $\overline{\text{STORE}}$ pin is used to transfer the entire contents of the RAM to the EEPROM as a single block. This operation is performed in parallel. The $\overline{\text{RECALL}}$ pin is used to transfer the entire contents of the EEPROM back to the RAM. At the end of either operation, the contents of the two memories are identical.

Access to the EEPROM data is through the RAM portion. To alter the contents of the EEPROM, the data must first be written into the RAM and then transferred to the EEPROM with a Store operation. To use the contents of the EEPROM in the system, perform a Recall operation and then the contents of the RAM may be read. Once data is stored in the EEPROM, the RAM can be used as an entirely separate and independent memory. Some users put configuration data into the EEPROM and then use the RAM as a separate scratchpad.

Besides these operational features, the NOVRAM memory has some unique electrical features. These devices are the world's easiest-to-use nonvolatile components in that they operate with only a single 5-volt power supply, simple TTL level pulses and short pulse widths (<450 ns). Even for operations such as the Store operation, which takes 10 ms to complete, it only requires a low level TTL pulse of 100 ns or greater to initiate. During the remaining time, the NOVRAM memory is not on the bus, which frees the microprocessor and the bus for other tasks. Complete details of the operation of NOVRAM memories can be found in the individual data sheets and application note AN101.

Replacing DIP Switches With NOVRAM Memories

DIP switches and thumbwheel switches have been used in systems to provide alterable, nonvolatile data. Some uses of this data are to set up configuration parameters and to provide calibration constants. The apparent low cost of these components is one of their attractive features. The drawback is that costs of these components do not end with installation.

The biggest cost of these mechanical, nonvolatile components is in post-installation service. A simple change of a DIP switch setting can require a technician to visit the equipment, disassemble the unit, throw the switch and reassemble the equipment. This could easily run the total use costs to well over 10 times the installed cost. A solution to the problems presented by DIP switches is to use a NOVRAM memory to hold valuable configuration or calibration data. In addition to a lower-cost, easier, and more secure method of changing data, NOVRAM memories cost less at the installed level.

The disadvantages of using DIP switches in modern electronic systems accumulate through each step of the manufacturing process. The first stage of NOVRAM memory advantages starts right at system concept and design. Since the density of NOVRAM memories is significantly greater (up to 1024 switches in a single low-cost DIP package), more functional options can be added to enhance the total value of the system. Features such as electronic unit type signature can be added for a small software cost, with no extra components. No special access needs to be provided to change the NOVRAM memory, as all changes can be made from a keyboard or over phone lines. This can not be said for DIP switches, which require disassembly or special doors or hatches to provide access.

At incoming inspection it is difficult to completely test a package of DIP switches for all possible combinations, or even as individual switches. The NOVRAM memory, on the other hand is tested by automatic test equipment both quickly and thoroughly. The NOVRAM memories are 100% tested by Xicor and can be further tested at whatever levels the user desires, including the quick testing of all the options that were designed into the equipment. In the case of the DIP switch, this would require manually setting each option, rather than have the final system test equipment take care of the task.

The assembly operation is made more difficult when trying to wave solder or clean a board containing DIP switches. These operations can cause contamination in the degreasing step. This is true, even on the components that have tape or other cover for protection, as these are extra items to handle or become lost. Again, the NOVRAM memory exhibits none of these problems in that they are in sealed packages like the rest of the semiconductor components that make up the bulk of the system.

Once the system is in the field, the advantages of the NOVRAM memory are further enhanced. The basic reliability improvement of semiconductors over mechanical components is well known. Equipment warranties can be enforced since there is no need for a customer to open the equipment. The greatest advantage of all comes in service. No longer is it necessary for a technician to travel to the users site to change the setting on DIP switches as this can be accomplished over a phone hookup.

In addition to all of the above cost savings and system benefits in using NOVRAM memories, the basic component cost is also very low. Figure 2 shows a typical interface for DIP switches in a microprocessor system. Each package of 8 switches requires a decoder port and 8 diodes to provide isolation from other switches.

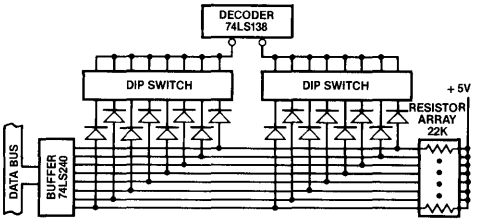


Figure 2) Typical DIP switch interface for multiple packages.

An octal buffer and 8 pull up resistors are required for any quantity of switch packages in a given system. Matrix schemes could be applied to reduce the decoder ports at the cost of more buffers but, by then, the costs will be much greater than those of using NOVRAM memories.

The assembly costs include incoming inspection, handling, inventory, board real estate, and final inspection. These costs are variable depending on volume and other factors.

The interface of a NOVRAM memory to a microprocessor is shown in Figure 3.

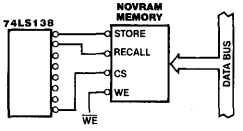


Figure 3) The typical NOVRAM memory interface requires only 3 decoder ports for any number of switches up to 1024.

This setup requires 3 decoder ports for any number of switches up to 1024 and then starts adding a single port for each additional package of 256 or 1024 switches.

The plot in Figure 4 shows that system costs using NOVRAM memories remain constant as the equivalent packages of DIP switches required are increased. These costs include the costs of all associated components, assembly and testing.

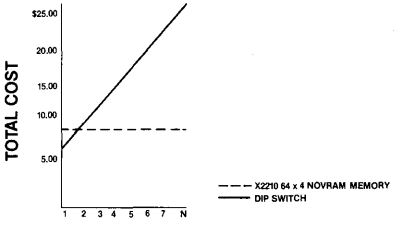


Figure 4) Relative costs of using NOVRAM memories as opposed to DIP switches as a function of packages of 8 switches required.

The plot shows that whenever the required number of DIP switch packages of 8 switches exceeds 1, the NOVRAM approach is lower in cost at the systems level.

The cost of using DIP switches rises constantly as the number of required packages increases. An actual cost crossover occurs between 1 and 2 packages of 8 switches. Designers can derive their actual costs by calculating the two approaches based on the costs at their firm. These costs should include, in addition to the component costs, all costs associated with incoming inspection, warehousing, assembly and system tests. One will find that the crossover between 1 and 2 packages of 8 switches is consistent and favors the NOVRAM memory approach.

Where And Why Trimmers Are Used

The trimming potentiometer or trimmer is a 3-terminal device that can be connected in many different configurations. The purpose of the trimmer in the analog circuit is to make a fine adjustment of a current or a voltage. This current or voltage is then used in analog circuits to compensate for component variations in frequency, gain, offset, voltage or current.

Like the DIP switch, the trimmer appears quite inexpensive when one considers only the purchased price. In actuality it can be one of the most expensive components on the card when the costs of field calibration are taken into consideration. It takes only one service call (considered by some to cost approximately $200) due to a changed setting caused by vibration, humidity or even well-intentioned user tampering, to run the cost of using the trimmer to high levels. In addition, the trimmer requires equipment disassembly and the skilled use of a screwdriver. This skill adds to the cost of owning the equipment.

Taking an 'all costs considered' approach is one way manufacturers are reducing the cost of equipment ownership as a function of performance. Although the end customer wants equipment that is low in purchase price and service costs while delivering a high level of performance, they will purchase a more expensive piece of equipment if they believe that the service costs and possible downtime will be reduced.

The functions of the trimmer can be duplicated quite well by a NOVRAM memory combined with a Digital-to-Analog Converter (DAC). A DAC is a device that delivers a voltage at the output that is a function of a digital signal at the input. In a microprocessor system, this is a variable voltage source that is under the control of the program. While the DAC cannot exactly duplicate the 3 terminals of the trimmer, the circuit can be modified to provide equivalent results.

The NOVRAM memory provides settings for the DAC that are free from problems of humidity and vibration, as well as holding onto those settings during times of no power. Once the NOVRAM memory/DAC combination is in the circuit, the calibration can be made automatic by closing the loop since all mechanical adjustments are eliminated. A self-calibrating system can eliminate all expensive service calls for recalibration.

Duplicating The Function Of The Trimmer

This section will demonstrate a few simple concepts for using a NOVRAM memory and a DAC in combination to modify important circuit parameters. As previously mentioned, a trimmer adjusts small variations of frequency, gain, offset, voltage or current. By properly interfacing the output voltage of a DAC in the analog circuit, these functions can be easily duplicated.

The first example shown will demonstrate how to effect a small adjustment in voltage that can be used as a reference or for some other need. Figure 5 shows an operational amplifier connected to provide a small amount of trim to the output. The 9.9k and 100 ohm resistors provide a division by 100 of the DAC output.

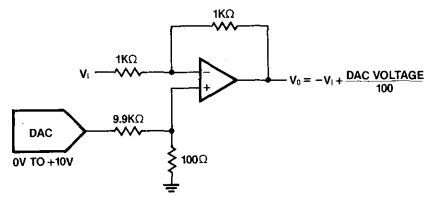


Figure 5) The DAC output provides up to 100 millivolts of trim for the operational amplifier output voltage.

If the DAC can be adjusted from 0 to 10 volts, this voltage divider provides an offset of up to 100 millivolts. The operational amplifier offset adds this amount to the output, providing up to 100 millivolts of reference voltage trim.

The next example will show how to provide a small offset for a fixed gain amplifier. Figure 6 shows the operational amplifier connected as an inverting amplifier with a gain of 10.

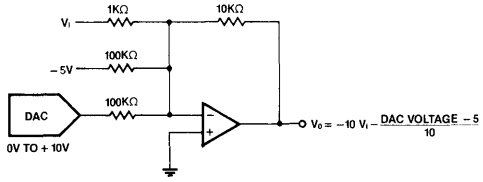


Figure 6) The DAC output provides an offset of 0.5 volt for a fixed gain amplifier.

The fixed gain is established by the 1K and 10K resistors. As the DAC output is varied from 0 through 10 volts, this voltage, combined with the −5 volts, reduces the amplifier output by $^1/_{10}$ of the difference. This gives a fixed offset of up to 0.5 volt in either direction.

The third example will show a different use of a DAC to change the operational amplifier gain. This example uses a CMOS DAC with the ladder network in the amplifier feedback loop.

A short course in CMOS DACs is in order at this time. Figure 7 shows a simple 3-switch CMOS DAC.

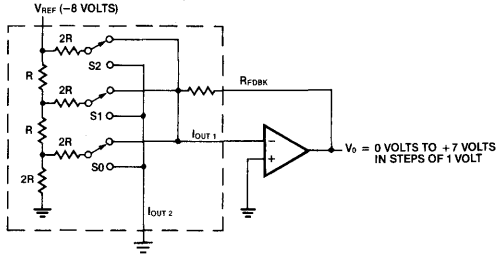


Figure 7) A simplified 3-switch CMOS DAC.

The outputs of a CMOS DAC are in the form of current. The sum of the two output currents is always a constant. In the case of Figure 7, this sum is $^7/_8$ x V_{REF}/R. Both current outputs must look into a ground potential. In Figure 7 the I_{OUT1} pin is tied to the summing junction of an operational amplifier while the I_{OUT2} pin is tied to system ground. The internally provided feedback resistor should be used with an amplifier since its temperature coefficient is identical to the other resistors on the DAC chip. The DAC switches are operated by standard 5 volt logic levels. The amplifier output in Figure 7 will vary from 0 to 7 volts in 1 volt increments depending on the setting of switches S0, S1 and S2. These switches in the 'up' position add 1, 2 and 4 volts, respectively, to the amplifier output. In the positions shown, the amplifier output is 7 volts.

Figure 8 shows the CMOS DAC of Figure 7 in a slightly different configuration.

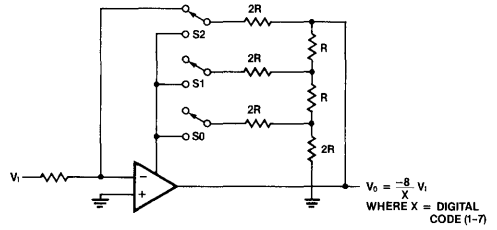


Figure 8) A CMOS DAC used in the amplifier feedback loop to adjust the amplifier gain.

The ladder network provides the feedback to the amplifier while the internal feedback resistor is used as the input resistor. If one goes through the equations, the result for Figure 8 is VO = VI x 8/X, where X is the digital code for the switch settings from 1 to 7. The circuit gain runs from a low of $^8/_7$ for the switches in the indicated position, to a gain of 8 when S0 is high and the other switches are low. Table 1 shows a listing of the gains obtainable.

S2	S1	S0	GAIN
L	L	H	8
L	H	L	4
L	H	H	$2^2/_3$
H	L	L	2
H	L	H	$1^3/_5$
H	H	L	$1^1/_3$
H	H	H	$1^1/_7$

Table 1) Gains of the circuit in Figure 5 as a function of the switch settings.

Analog Circuit Examples

This section will present some actual circuit examples for using a NOVRAM memory combined with a DAC. The circuits that appear in this section have been built and tested. The concepts presented may be useful to stimulate ideas which will help to solve the reader's system problems and may even be of immediate use. Figure 9 shows how the NOVRAM memory/DAC combination provides a voltage or a current for the application.

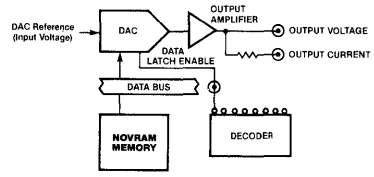


Figure 9) A NOVRAM memory DAC combination provides a voltage or a current to correct analog circuits.

It is, of course, possible for a single NOVRAM memory to provide the address setting for multiple DACs. The DAC size used is selected for the user's application, depending on the accuracy and resolution required. There are even multiple DACs available in a single package such as the SAB 3013 from Philips for more cost sensitive applications.

Tuneable Crystal Oscillator

The first application example of a NOVRAM memory used in combination with a DAC is that of a quartz crystal oscillator. These circuits find application in many areas, including aviation and nautical navigation, as well as time measuring due to high stability. The oscillator is normally trimmed with a small padding capacitor in shunt or series with the crystal. This trim is used to 'pull' the resonance point of the crystal by a few parts per million (PPM) to set the operating frequency of the circuit. The capacitor may have to be adjusted in the field to retrim for the aging effects of the crystal and its associated circuitry.

The circuit in Figure 10 uses a NOVRAM memory/ DAC combination to provide the trim voltage for a varactor.

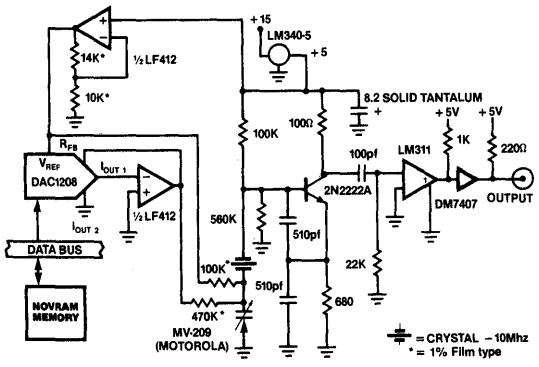


Figure 10) Tuneable crystal oscillator.

A varactor is a diode whose capacitance is a function of the applied voltage. This varactor in series with the crystal provides the actual trim function. The fixed operating point for the varactor is supplied through the 100K resistor. Variable bias for the diode is supplied by the DAC through the 470K resistor. Figure 11 shows that a 50 PPM frequency trim range is achievable with the 12-bit DAC used.

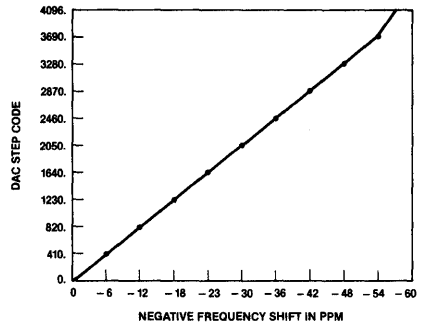


Figure 11) Tuning range of the tuneable crystal oscillator of Figure 10.

The frequency shift is down so it is recommended to specify the crystal approximately 25 PPM higher than the desired frequency. Initial trimming and re-trimming is easily accomplished by changing the DAC address settings as stored in the NOVRAM memory.

Software Programmable Voltage Reference

Many systems (such as DVMs, test equipment, data acquisition systems and most forms of measurement and control apparatus) require a voltage reference that places a limit on total system performance. Figure 12 shows how a NOVRAM memory/DAC combination can provide a means of adjusting the ouput of a precision 10 volt reference.

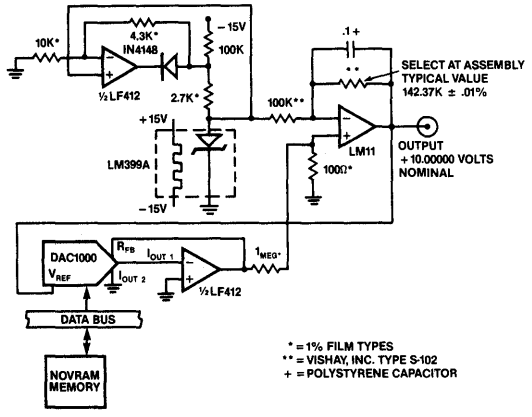


Figure 12) Software programmable voltage reference.

An LM399A 6.95 volt reference is used in a bootstrap configuration to supply bias to the LF412 amplifier which in turn drives the LM399A. The 100K resistor insures start-up. The reference supplies bias to the LM11 amplifier, which supplies the circuit's output.

The NOVRAM memory/DAC-1000 combination supplies an offset voltage for the LM11 of 1 millivolt full scale in 1 microvolt increments. The 0.1 µF capacitor insures dynamic stability and low noise at the LM11 output. To calibrate the output to within 1 microvolt, one sets the DAC to half scale and selects the feedback resistor of the LM11 until the output is within a few hundred microvolts of the desired value. Then the RAM portion of the NOVRAM memory is exercised, providing new inputs for the DAC until the desired value is achieved. This setting is then stored in the EEPROM portion of the NOVRAM memory. If a wider trim range is desired, the 1 megohm resistor can be reduced, but this degrades the setpoint resolution appropriately.

Self-Calibrating, Interchangeable Probe Thermometer

A standard industrial temperature sensor with high linearity and long term stability is obtained using platinum resistance temperature detectors (RTDs). The RTD is specified in terms of its resistance at 0° centigrade (as this is a function of the manufacturing process), while the gain slope is relatively constant from unit to unit. A constant gain amplifier with an offset to compensate for the changing impedance at 0° centigrade is shown in Figure 13.

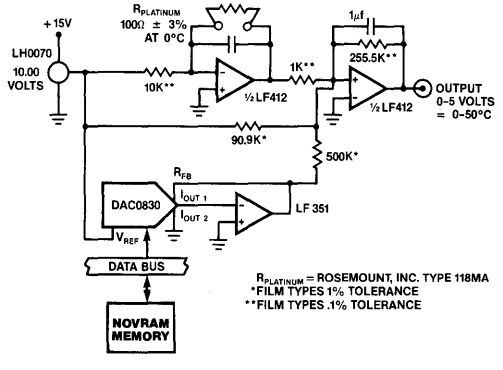


Figure 13) Self-calibrating, interchangeable probe thermometer.

The NOVRAM memory/DAC combination is used to modify the offset voltage of the amplifier to allow full interchangeability of probes in the field.

The plantinum RTD shown has a ±3% tolerance at 0°C (±7.5°C) and is driven with a 1 milliampere constant current source by placing it in the feedback loop of the LF412 amplifier. The constant current is provided by the 10 volt reference IC. The amplifier output will be a linear function of the sensed temperature at the RTD. The 1 µF capacitor limits noise pickup and also insures that the RTD, a wirewound device with parasitic inductance, does not cause amplifier oscillations. The second half of the LF412 provides a fixed gain to the signal.

The 90.9K resistor provides a current to the summing junction of the amplifier to move beyond the correction for the worst case sensor. The NOVRAM memory/DAC pair then pull enough current from the summing junction to correct for the inserted RTD. Over a 0°C to 55°C range, this circuit is accurate to within ±0.25°C while allowing the use of probes with a ±7.5°C tolerance specification.

Automatic Scale Calibration

The scale normally does not worry about a zero-level reading from its sensor, since it may have a wide variety of items on the platform such as wrapping paper or containers. An algorithm is usually required to automatically zero the scale before loading the material into the container. The transducer used in scale applications has a large variation in gain slope which must be corrected before shipping the scale or when changing the load cell. Figure 14 shows a circuit for providing these necessary corrections for the gain slope of the sensor.

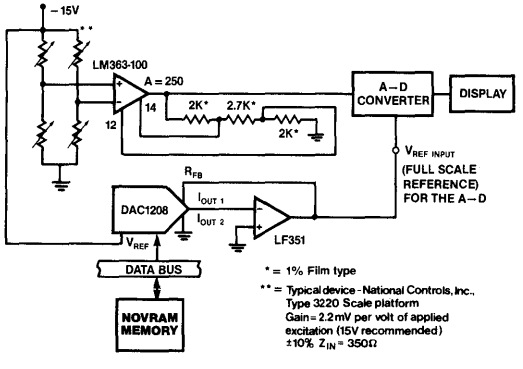


Figure 14) Automatic scale calibration.

The transducer shown, combined with the fixed gain amplifier, can produce outputs of 7.424 volts to 9.075 volts for full load depending on the transducer selected. To bring this result to the required value, the NOVRAM memory/DAC combination is used to vary the reference of an analog-to-digital converter. Since the DAC and the platform bridge are driven from the same supply, the measurement is ratiometric and no stable voltages are necessary. As the −15 volt supply changes, the readout on the display will not vary. To calibrate a new platform, the scale is first zeroed out using the internal algorithm and then a fixed known weight is added to the platform. Then the NOVRAM memory/DAC unit is exercised until the correct readout is obtained. This calibration can be called from the scale's keyboard. Security for this adjustment can be in a software access code which is also stored in the NOVRAM memory.

Gain Trimming For Photomultiplier Tube

The last example handles gain variations in a slightly different manner. The gain of a photomultiplier tube varies over time, temperature and power supply for a given input level. The output is a current from a high impedance source. A circuit to trim the changing gain is shown in Figure 15.

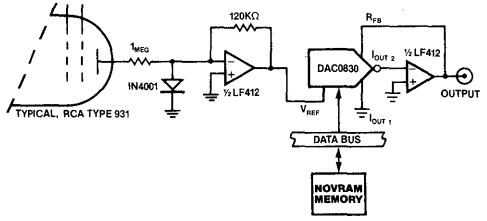


Figure 15) Gain trimming for photomultiplier tubes.

This current is converted to a voltage by the amplifier on the left side of the figure. For a full scale current of 100 μA, the output voltage of this amplifier is 12 volts. This voltage output is used as the reference input for a NOVRAM memory/8-bit DAC combination which amplifies the reference from $^1/_{256}$ through 1 depending on DAC setting. This gain can be varied in steps of $^1/_{256}$. The currents out of the photomultiplier tube are normally accurate to only 1% once the calibration is complete. Some applications, however, may require smaller steps in resolution. If this is the case, one could use a 10-bit DAC. Another method of obtaining fine resolution is to use an 8-bit DAC connected as shown in Figure 8 in place of the DAC arrangement of Figure 15. If the feedback resistor of the left-hand amplifier is changed to 50K, very fine tuning (around a voltage gain of 2) is possible. This gain of 2 is established when the DAC is set for midrange of the digital value which gives a fine tuning range.

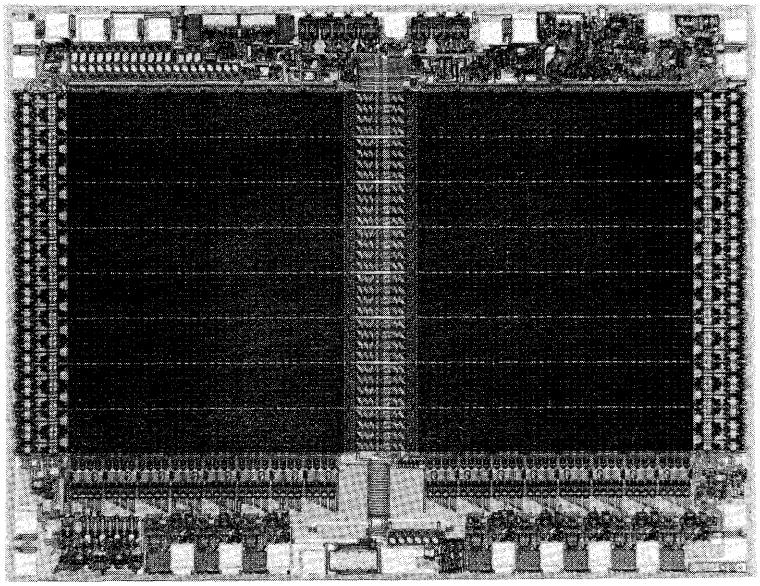
Conclusion

This application note has shown how the NOVRAM memory can be used to replace commonly used mechanical components such as trimmers and DIP switches. This replacement improves reliability and reduces service costs for recalibration and resetting. In addition, actual equipment costs can be reduced.

Once a single NOVRAM memory is in the system, it is easy to include additional features in the unused portions. For example, a system designer could use a NOVRAM memory to replace DIP switches used for configuration data and then place calibration data for DACs in the unused memory. If even more unused space exists, storage of other desired data such as ID numbers or a service log would be possible.

The possible uses of NOVRAM memories are limitless. The designer is encouraged to build upon the ideas presented by this application note.

NOVRAM is a trademark of Xicor, Inc., for its nonvolatile RAM devices.



THE WORLD'S EASIEST-TO-USE EEPROMS ARE HERE

BY APPLICATIONS STAFF

Introduction

The EEPROM has been available for several years and performs the very useful function of storing data or programs on a nonvolatile basis, while still allowing alteration of that information in the system. Many designers have wanted to use EEPROMs, but have been limited by the support circuitry needed by currently available products. With the announcement of 'The World's Easiest-To-Use EEPROM', Xicor has removed these limitations. This new product family operates with the simplicity of a standard static RAM.

Much has been said about the ease-of-use of EEPROMs. Most EEPROMs are indeed very easy to use during the read operation but, when it comes to the write operation, the term 'easy-to-use' applies only loosely. All EEPROMs introduced prior to the Xicor components described in this application note require one or more of the following during the write operation:

1. One or more high voltage power supplies may be required in addition to the +5 volt power supply.
2. A specially shaped high voltage pulse may be needed.
3. Addresses and data may be required for the entire write time.
4. It may be necessary for data stored in an address location to be preconditioned before writing new information.
5. Additional timing components such as capacitors may be necessary.

The Xicor EEPROMs require none of these for operation, and exhibit the following features:

1. Only a single +5 volt power supply is required for any operation including the write operation.
2. Only TTL level signals are required to control the part.
3. The write operation requires that addresses and data be stable for less than 200nsec to initiate the self controlled 10msec internal write cycle.
4. The write operation accepts random data to be changed to random data with no preconditioning.
5. An optional mode is available that allows the Xicor parts to plug into an existing socket for some of the older EEPROMs requiring shaped high voltage pulses.

The Xicor EEPROM Family

The Xicor family of EEPROMs presently consists of two pin-compatible members: the X2816A, which is organized 2048 x 8 and the X2804A, which is organized 512 x 8. Figure 1 shows the pinouts of these two components.

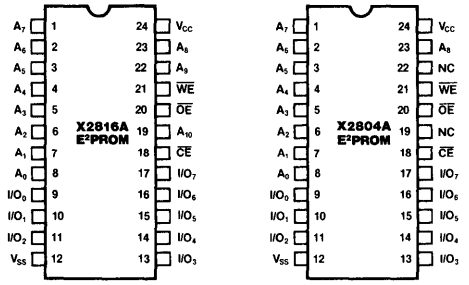


Figure 1) Pinouts of the Xicor family of EEPROMs.

Parts conform to the JEDEC standard pinouts for byte-wide memories. These two different chips use the same design rules. The smaller chip was designed in response to many requests for a smaller, more cost effective part for those applications requiring fewer bytes of storage.

The X2816A and the X2804A are manufactured using the same proven process used in Xicor's popular 5 volt programmable NOVRAM™ memories. The process is a reliable n-channel floating gate MOS technology using triple polysilicon. The method of data storage utilizes charge trapped on a floating gate, similar to the popular 2716 UV-EPROM. The charge is added and removed from the floating gate utilizing Fowler-Nordheim tunneling, enhanced by textured polysilicon surfaces. This enhancement allows fabrication with thicker oxides than other EEPROMs which don't employ textured emission surfaces. A more thorough treatment of positive reliability and data retention implications of textured surfaces is available in Xicor Reliability Report RR501.

Operation of the Xicor EEPROMs

The X2816A will be used to demonstrate the use and features of the Xicor EEPROM family. The X2804A works identically to the X2816A and fits all those applications that require smaller segments of memory. The X2816A uses a three line control structure to ease interface requirements. These three lines are:

$\overline{CE}$: Chip Enable is activated (LOW) whenever it is desired to access the part for a read or a write operation. When $\overline{CE}$ is HIGH the power is reduced to a standby level.

$\overline{WE}$: Write Enable is activated (LOW) whenever it is desired to write new data into a byte. $\overline{OE}$ must be HIGH to allow a write to start.

$\overline{OE}$: Output Enable is activated (LOW) whenever it is desired to read data from a byte. This eliminates all chances of data bus contention.

The mode selection chart in Figure 2 shows the required setting of the control signals to select the various modes of operation.

$\overline{CE}$	$\overline{OE}$	$\overline{WE}$	MODE	I/O	POWER
H	X	X	Standby	High Z	Standby
L	L	H	Read	D_{OUT}	Active
L	H	L	Byte Write	D_{IN}	Active
L	H	H	Read and Write Inhibit	High Z	Active

Figure 2) Mode selection chart for the Xicor EEPROM family.

The one possible state of the inputs not shown (all three control lines LOW) is also an inhibit mode.

Read Cycle

The read cycle for the X2816A is shown in Figure 3.

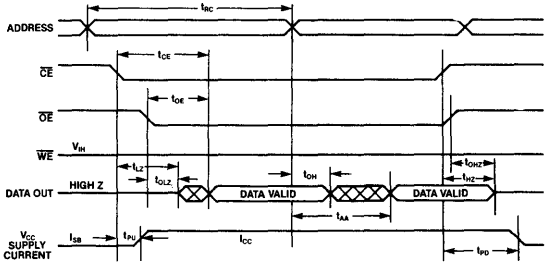


Figure 3) Timing diagram for the Xicor EEPROM read cycle.

This cycle is totally static. It is level sensitive and requires no clocking. Addresses must be stable for the entire read cycle. If $\overline{CE}$ and $\overline{OE}$ are both LOW, a change of address produces new data on the output buffers. The $\overline{CE}$ pin also controls the power level. When $\overline{CE}$ is HIGH, the power dissipation is at a standby level increasing to operating level only during the time that the $\overline{CE}$ pin is LOW. Most EEPROMs on the market operate in a similar manner.

Write Cycle

The byte write cycle on the Xicor X2816A gives new meaning to the term 'easy-to-use' regarding EEPROMs. A standard microprocessor write cycle, a single +5 volt power supply and TTL level signals are the only requirements to write new data to a selected byte. No other hardware support is necessary. Most systems will not require extra wait states for this operation, because times required are short. All timing can be completed within 200nsec. The addresses, data and controls can be removed entirely as the chip latches addresses, data and the write command at the end of the 200nsec. The X2816A takes 10msec to complete the internal byte write cycle but, once initiated, is totally self timed and does not use the data bus. This latching feature allows the microprocessor to use the bus for other purposes during these self timed write cycles. During the internal write cycle, power consumption is at the operating level.

All byte write cycle timing is referenced to an internal write pulse, which is generated by the simultaneous LOW of both $\overline{CE}$ and $\overline{WE}$. Figure 4 shows the internal write cycle timing for all possible combinations of $\overline{CE}$ and $\overline{WE}$.

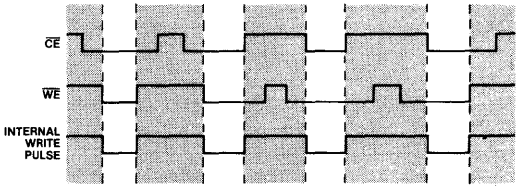


Figure 4) The internal write pulse is generated by the simultaneous LOW of both $\overline{CE}$ and $\overline{WE}$.

The internal write pulse is initiated by the last edge of $\overline{CE}$ or $\overline{WE}$ to go LOW and is terminated by the first of those two edges to go HIGH. The specific relationship of each of the two symbols is not important. Timing depends on the last edge down and the first edge up.

Figure 5 shows the byte write cycle for the X2816A with the internal write pulse used as the timing reference.

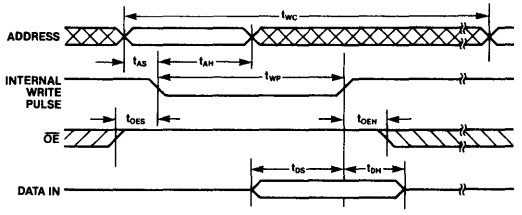


Figure 5) Timing diagram for the Xicor EEPROM byte write cycle.

The addresses are latched by the falling edge of the internal write pulse, while data is latched by the rising

edge. Once the addresses and data are latched on-chip, all further tasks are self timed. The internal byte write cycle, averaging 4 to 6msec, takes a maximum of 10msec to complete. Any attempt to read the X2816A during the internal write cycle will result in open state outputs. The last internal write cycle action releases control of the output buffers to the three control lines. It is necessary that the power supply remain within specification during the entire internal write cycle time. Once initiated, the internal byte write cycle cannot be terminated by any signal and will complete under its own control.

The write cycle is inhibited by holding either the $\overline{OE}$ pin LOW or $\overline{CE}$ HIGH. Write protection can be achieved during power-up and power-down by holding $\overline{OE}$ pin LOW. If $\overline{OE}$ goes LOW after the write has started, the write cycle will complete.

Unlike most other EEPROMs, it is not necessary to precondition the byte prior to writing new data. The byte write cycle allows the change from random data directly to random data. Separate byte erase and program cycles are unnecessary. To change data, one writes as in a static RAM.

It is necessary to refer to the data sheet for the latest timings; however, Table 1 shows the byte write cycle timing for the 300nsec part.

Symbol	Parameter	Limits		Units
		Min.	Max.	
t_{WC}	Write Cycle Time	10		ms
t_{AS}	Address Set-Up Time	10		ns
t_{AH}	Address Hold Time	120		ns
t_{WP}	Write Pulse Width	150		ns
t_{OES}	Output Enable Set-Up Time	10		ns
t_{OEH}	Output Enable Hold Time	10		ns
t_{DV}	Data Valid Time		1	μs
t_{DS}	Data Set-Up Time	50		ns
t_{DH}	Data Hold Time	10		ns

Table 1) Timing requirements for the 300 nsec X2816A.

Optional High Voltage Write Cycle

Although high voltage power supplies and/or pulses are not necessary for the X2816A, Xicor has added an additional mode for customer convenience. This is the optional high voltage write mode. The Xicor X2816A option provides a plug-in replacement for the Intel 2816, NMC 2816, NMC 9716 and similar devices, with no extra interfacing required. The Xicor X2816A eliminates complicated timing required by similar devices as shown in Figure 6.

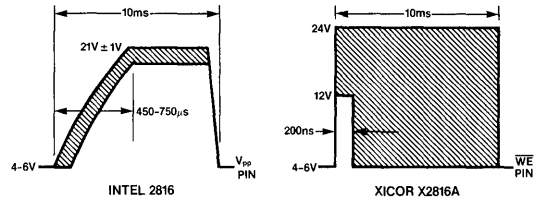


Figure 6) Comparison of timing and level requirements of the high voltage pulse between the Intel 2816 and the Xicor X2816A. The shaded portion indicates the operating range of each part.

The X2816A uses no current from the high voltage pulse. Bringing pin 21 above 12 volts is sufficient to trigger the internal byte write cycle. All actual timing is executed by the part itself. Since the X2816A can write directly from random data to random data without an intervening erase, the user can make software changes to shorten the code by removing the preceding byte erase cycle, although this is not necessary if complete compatibility is desired.

Optional Chip Erase Cycle

Another mode available on the X2816A as a user option is the chip erase cycle, during which all bytes are simultaneously changed to 1's or HIGH. Since the part does not require that data in the byte be preconditioned, the only use for a chip erase is for setting the unused bytes to a known HIGH state. This operation requires that high voltage pulses be applied to $\overline{OE}$ and $\overline{WE}$. The high voltage provides a third state on the $\overline{OE}$ pin, enabling an extra function without adding pins. This function is provided tc make the X2816A compatible to all modes of operation on the high voltage 2816. It is not a required mode for the majority of applications. No time is saved by using the chip erase mode. It takes 20sec total to write every byte on the Xicor X2816A, regardless of whether the chip is totally erased or not. On the other hand, the Intel or similar 2816 requires 20 sec to completely write an erased chip and up to 40 sec to overwrite a chip with random data.

Implications of the X2816A Improvements

In the introduction of this application note there were five major features listed for the Xicor X2816A. These were:

1. 5 volts only
2. TTL level signals
3. Short signals

4. Random data to random data
5. Optional high voltage mode

The implications of each one will be discussed in this section. One of the major goals of Xicor is to design as much support requirement into the chip as practical.

5 Volts Only

The only power supply requirement for the Xicor X2816A is a single +5 volt supply. No other power supply is required, either by the chip or any support circuitry that may be used. This makes the board design considerably easier and less costly. Many EEPROMs require one or more high voltage supplies to provide necessary signal levels for writing. This high voltage is applied either as dc voltage directly to the chip or as the source of the levels for an external pulse. Xicor has chosen to make the designer's task easier by including the necessary high voltage levels for tunneling on-chip. This high voltage, generated on command during the internal byte write cycle, is totally transparent to the user.

High voltage is present on the X2816A only during the time of an actual internal byte write cycle. This considerably reduces the quiescent field strengths, thereby decreasing the stress on internal nodes and oxides. Figure 7 shows a comparison of the on-chip voltages using internal or external high voltage pulses as opposed to a high voltage power supply.

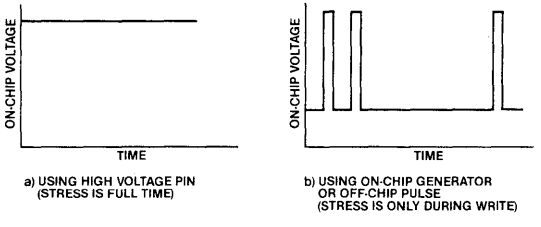


Figure 7) Comparison of on-chip voltages between an EEPROM using a) high voltage power supplies and b) internal or external high voltage pulses.

Since constant high voltage on the chip has deleterious reliability implications, an EEPROM with a high voltage pulse generator on-chip offers two benefits. These being the elimination of boardspace and design time for external components, and reduced stress-time levels on the chip to avoid a potential reliability hazard. In addition, parts requiring multiple power supplies can lead to power supply sequencing problems. If the high voltage supply is present without the lower voltage supply the part may be destroyed.

TTL Level Signals

Some EEPROMs require specially shaped high voltage pulses. These pulses usually last the entire period of the write cycle. The Xicor X2816A provides on-chip all necessary high voltage functions totally transparent to the user. When an external high voltage pulse is required by an EEPROM, it may require controlled rise and fall times (which may be different, as well as requiring unusual signal levels). Taking this external pulse requirement away saves design complexity, costs and reliability problems.

Short Signals

Some EEPROMs require that address and data be held valid during the entire write cycle. This may require the use of wait states or, more usually, external latches to capture the addresses and data as well as the control signals. The Xicor X2816A requires only a 200nsec signal to initiate the internal byte write cycle. Once started it will complete by itself. The elimination of external latches saves considerable cost and boardspace.

These first three feature advantages can be seen in the evolution of EEPROMs shown in Figure 8.

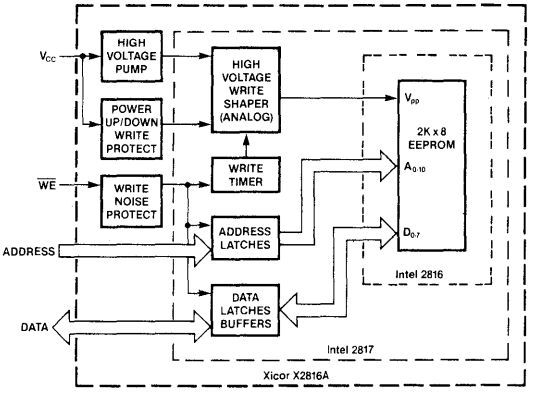


Figure 8) Evolution of easy-to-use EEPROMs from the Intel 2816 and 2817 to the Xicor X2816A.

From requiring an external high voltage pulse and latches, to a high voltage power supply, this evolution shows finally, no external support requirement (other than possible optional buffering in layer systems).

Internal latches also allow tremendous write time savings for large systems. Different data may be programmed into multiple parts. Multiple parts may be programmed in parallel instead of sequentially. In a system using 100 parts without latches, 2000sec would be required to write all locations, as opposed to 20sec for a system using the X2816A, because, while the first part is on its internal write cycle, the other parts may be written simultaneously.

Random Data To Random Data

Some EEPROMs require that the byte be preconditioned to a specific state before writing new data into the byte. Again, this is not the case for the Xicor X2816A. All byte erase requirements are performed transparently as part of the internal byte write cycle. When data must be preconditioned, a full write cycle to the required starting data must be performed. This leads to extra software to reduce as much time as possible. An example of possible extra software is shown in Figure 9.

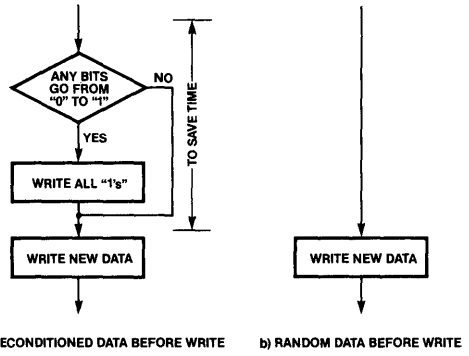


Figure 9) Comparison of software requirements for minimum write time systems between a) preconditioned data and b) random data prior to the write cycle.

Optional High Voltage Mode

In addition to all aforementioned benefits, the Xicor X2816A can also substitute directly for the Intel or similar 2816 as shown in Figure 10.

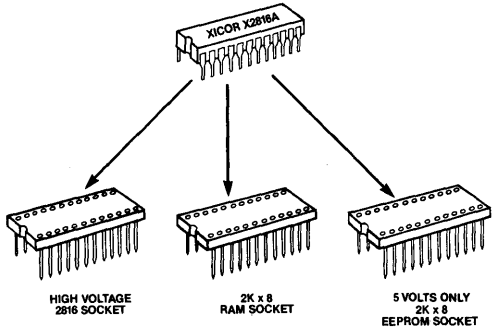


Figure 10) The Xicor X2816A works equally well in three environments.

Designers have the option of using the Xicor X2816A in a standard low voltage RAM socket, or a high voltage EEPROM socket, designed for the high voltage 2816. No other EEPROM offers such flexibility. It is important to keep pin 21 above 2.4 volts in this mode. Otherwise, a second false write can be triggered at the completion of the high voltage pulse.

The X2816A Can Be Used Like A RAM

The only EEPROM currently able to plug into a standard 2K x 8 RAM socket is the Xicor X2816A. The X2816A will operate with all signals provided by that conventional socket. The device becomes fully functional with a simple read or write operation. The only restriction being to wait at least 10msec, or until the internal byte write cycle is completed, whichever comes first, before starting another EEPROM cycle. It is possible, however, to use the bus for other tasks during this wait.

Programming Optimization

Several methods can be used to determine when one can command another EEPROM cycle. The system designer can use either a software or hardware time-out or use an interrogation scheme. The time-out can be derived from a software loop, a 16.7msec AC marker or some other timed interrupt.

It is possible to speed up writing blocks of data into the X2816A by using the interrogation method. Since the average part completes its internal byte write cycle in 4 to 6msec, it is quicker to initiate the next write cycle as soon as control of the output buffers is turned back to the $\overline{CE}$ and $\overline{OE}$ pins. The output buffers go to the high impedance mode during write and can return to the low impedance mode, under control of $\overline{CE}$ and $\overline{OE}$, only after the internal write cycle completes. In this manner, the part can signal the system that a write cycle has finished.

Interfacing To Microprocessors

Since the Xicor X2816A will operate in a 2K x 8 RAM socket, interface to a microprocessor is simple. The connections to an 8085 microprocessor are shown in Figure 11.

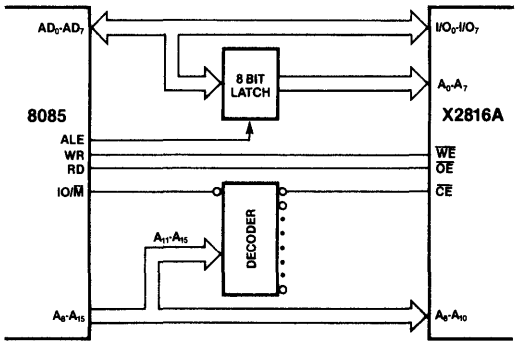


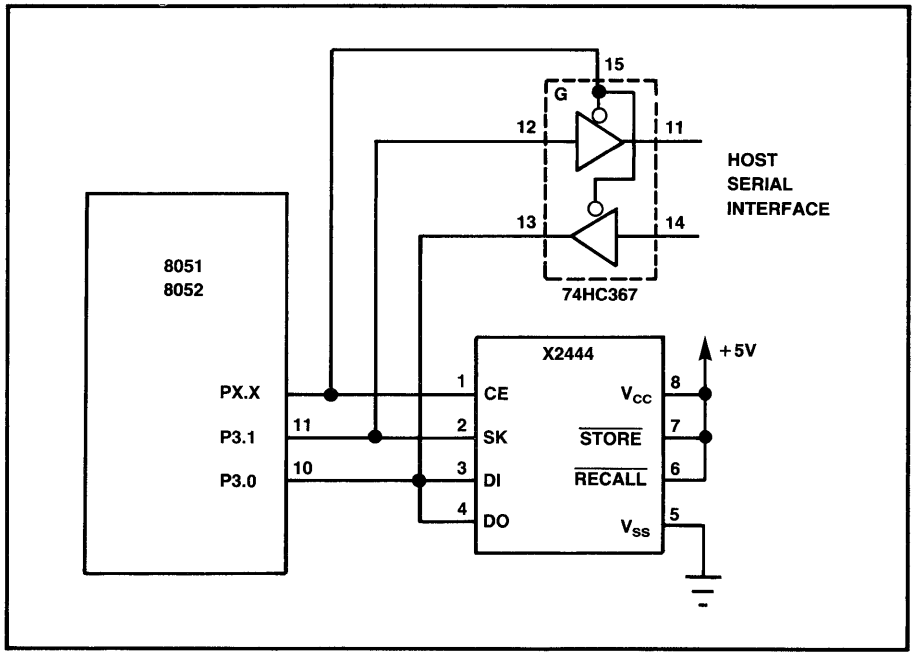
Figure 11) Interfacing the X2816A to the 8085 microprocessor.

The 8 bit latch captures the low order addresses from the combined address/data bus. The latch and a decoder are the only additional circuitry required for this interface, normally found in any system using standard RAM or ROM. These are the same connections required by a fully static RAM.

Conclusion

Each improvement made in EEPROMs provides extended potential applications. By eliminating the need for any hardware support, the Xicor family of EEPROMs makes it as easy to alter nonvolatile data as it is to write to a static RAM. Clearly, this unprecedented ease-of-use widens standard EEPROM applications through lower costs and reduced boardspace. A 5 volt power supply requirement improves reliability and lowers the damage risk to other components, unlike EEPROMs that require a fixed high voltage power supply. In addition to download type applications, where a remote system is reprogrammed over a phone line, these smarter EEPROMs will eventually be used in machines that adjust themselves to their particular environment. The Xicor EEPROM family allows designers freedom from former limitations.

NOTES



THE X2444 SERIAL NOVRAM TEAMS UP WITH THE 8051 MICROCONTROLLER FAMILY

5

Add scratch pad RAM and nonvolatile parameter store via the 8051 serial port and still maintain full use of the serial port as a UART.

Application from Rick Orlando
Written by Richard Palm

INTRODUCTION

The X2444 is a 256 bit serial NOVRAM internally configured as sixteen 16-bit words of RAM overlaid bit for bit with a nonvolatile E^2PROM. The X2444 has the standard hardware RECALL and STORE inputs plus the ability to perform these same operations under software control, thereby freeing two microcontroller port pins for other tasks. The serial interface allows the X2444 to be packaged in a low cost space saving 8-pin mini DIP.

When teamed with the 8051 family of microcontrollers, the X2444's small physical size, software instruction set and serial interface make it an ideal parameter store and scratch pad memory while maintaining full use of the 8051 serial port as a UART.

SCOPE

This application note describes interfacing the X2444 with the 8051 family of microcontrollers. Emphasis will be placed on the timing considerations of the interface, and explaining the modifications to the instruction words for normal device operation. This note assumes the reader has access to a Xicor Data Book and Intel *Microcontroller Handbook.*

SERIAL PORT OPERATION

Port 3 on the 8051 provides a serial port that can be used in two basic configurations, full duplex and half duplex. This note examines the half duplex (mode 0) operation in interfacing to the X2444. Port 3 pin 1 (P3.1) is the clock output for both transmit and receive modes and Port 3 pin 0 (P3.0) is used for bidirectional data transfers.

The clock output frequency is 1/12 of the XTAL oscillator input frequency. To simplify timing calculations this note will assume an input frequency of 12 MHz resulting in a symmetrical 1 MHz output on P3.1.

The P3.1 and P3.0 pins when inactive (neither transmitting nor receiving) are always a logic 1 (HIGH). When a data transfer commences P3.1 will be LOW during machine cycle states S3, S4 and S5 and will be HIGH during states S6, S1 and S2. When transmitting, data is shifted out on P3.0 during S6P2 (state 6 phase 2) LSB first. When receiving, data is sampled during S5P2. Refer to Figure 1 for the basic 8051 serial port timing.

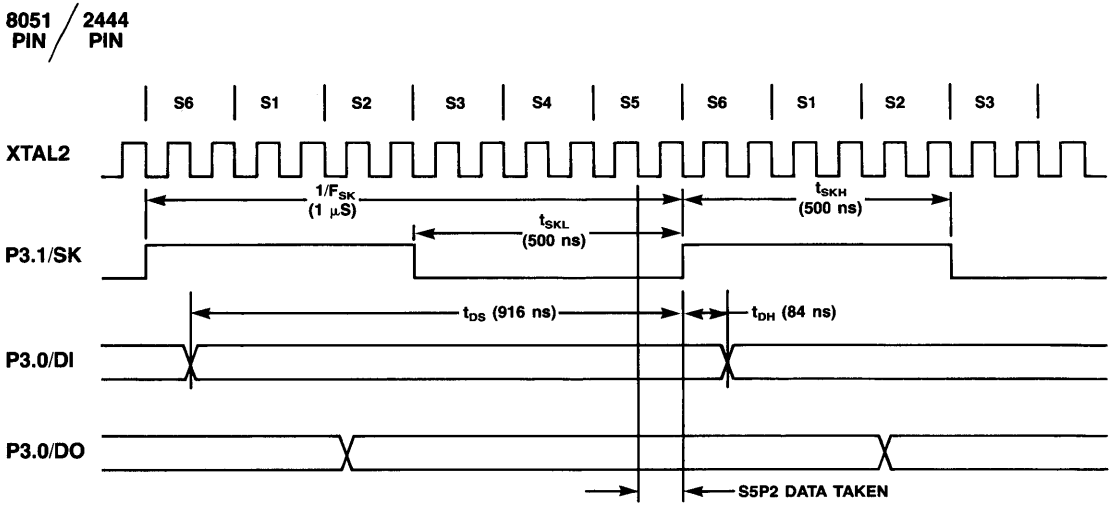


Figure 1. 12 MHz 8051 Serial Port Mode 0 and X2444 Timing

HARDWARE CONNECTIONS

The X2444 directly interfaces with the 8051 with no external circuitry required. DI and DO of the X2444 are both tied to P3.0, SK is tied to P3.1, CE is tied to any free port pin configured as an output and STORE and RECALL are tied to V_{CC} (see Figure 2).

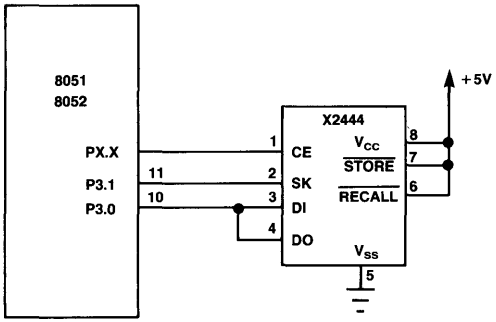


Figure 2. Basic Configuration

X2444 OPERATIONS REVIEW

The X2444 is a serial device and in this application all chip functions are handled via the software instructions. The 8051 transmits data LSB first but the instruction format for the X2444 shows the instruction to be transmitted MSB first. This requires a simple transposition of the instruction, MSB for LSB. The memory is effectively a FIFO, so the data to be stored need not be transposed.

Internally the X2444 increments a bit (clock) counter. This is used to indicate the end of an instruction and if a read or write instruction is received, to increment a bit position pointer. This pointer enables individual RAM cells for writing and reading. The counter for the pointer increments from zero to fifteen. If CE remains HIGH and SK continues to clock, the counter will rollover from fifteen to zero. The word address does not increment; therefore, during a write operation if SK continues to clock and CE is HIGH, a 25th rising clock edge (8 edges for instruction + 16 edges for the data word + 1) would cause bit position zero to be overwritten.

SYSTEM CHARACTERISTICS

Under normal operating conditions the X2444 expects CE to transition LOW to HIGH when SK is LOW in order that the first bit of data can be clocked into the X2444 on the first rising edge of SK. The data is sampled to see if it is "0" (a don't care state) or a "1" which is recognized as an instruction start. The 8051, however, places both P3.1 and P3.0 in the HIGH state when not actively transmitting. *THIS IS* ***OK.*** The X2444 internally gates CE and SK; therefore, toggling the port pin controlling CE to a HIGH effectively generates the first rising edge of SK, and also clocks in the HIGH present at P3.0 (DI).

What this does is clock a "1" into the X2444 indicating the start of an instruction prior to any shifting operation by the 8051 serial port. This will require dropping the leading "1" from the instruction. See Table 1 for the WAS/IS conditions for the equivalent instructions to be used by the 8051.

INSTRUCTION	WAS								IS							
	7	6	5	4	3	2	1	0	7	6	5	4	3	2	1	0
WRDS	1	X	X	X	X	0	0	0	X	0	0	0	X	X	X	X
STO	1	X	X	X	X	0	0	1	X	1	0	0	X	X	X	X
SLEEP	1	X	X	X	X	0	1	0	X	0	1	0	X	X	X	X
WRITE	1	A	A	A	A	0	1	1	X	1	1	0	A	A	A	A
WREN	1	X	X	X	X	1	0	0	X	0	0	1	X	X	X	X
RCL	1	X	X	X	X	1	0	1	X	1	0	1	X	X	X	X
READ*	1	A	A	A	A	1	1	X	1	X	1	1	A	A	A	A

*Note: bit 7 of the READ command should be a "1" to avoid bus contention.

Table 1. Reconfigured Instruction Format

The 8051 will still generate eight rising clock edges on P3.1 for each byte loaded into the shift register (SBUF), effectively providing the X2444 with nine clocks for the first byte. For the single byte instructions the ninth clock and data are ignored by the X2444. Refer to Figure 3 for the single byte instruction timing.

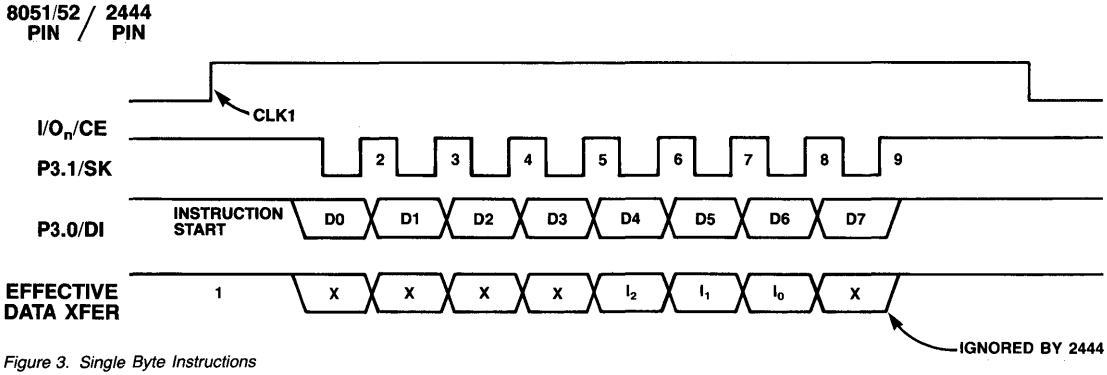


Figure 3. Single Byte Instructions

WRITING

Writing to the RAM array is straightforward. The write instruction is issued by the 8051 in the same manner as the single byte instructions. The MSB (eighth bit) of the instruction byte is clocked in on the equivalent ninth clock rising edge. This bit is recognized as the first data bit transfer and is initially written into the addressed word's bit position zero. The 8051 will continue to transmit two more bytes of actual data. The LSB (bit "0") of the first byte will be physically located in bit position "1" and all subsequent bits will also be offset by one. The MSB (sixteenth data bit) of the word will be written into bit position zero, overwriting the last bit of the instruction byte. Refer to Figure 4 for the sequence of operations.

READING

Reading data back from the RAM array is quite similar. The X2444 begins to shift data out during the instruction cycle (more on this later). After the instruction is shifted out, the 8051 must turn around P3.0 and configure it as an input. CE and SK are static during this period and the DO output will remain unchanged until after the rising edge of the first 8051 receive data clock. Therefore, the first data shifted into the 8051 will be from bit position "1", equivalent to the LSB originally written. Refer to Figure 5 for the sequence of operations.

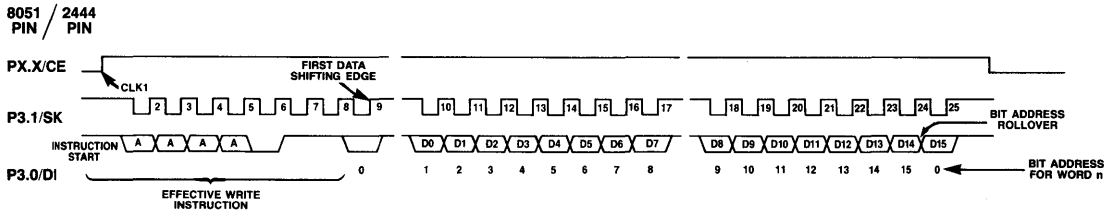


Figure 4. Write Cycle Sequence

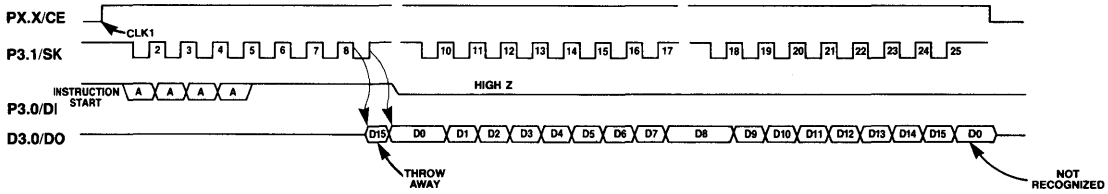


Figure 5. Read Cycle Sequence

BUS CONTENTION

There will not be any bus contention for single byte instructions or the write command. However, for the Read command there could be contention. While the 8051 is still shifting out the instruction byte the X2444 begins to output data on the same line. Refer to Figure 5, just after the falling edge of clock eight.

The 8051 shifts out data at S6P2. If the data changes state from "0" to "1" a high current enhancement FET is turned on for two 8051 system clock cycles. This is used to provide a fast rise time. At the end of this two cycle period, the enhancement FET is turned off and the output is held HIGH by a depletion mode FET that essentially looks like a resistor pullup (Refer to Intel's *Microcontroller Handbook* [1984] pages 6-6 and 6-7). Note that the high drive circuit is enabled only for data state changes from "0" to "1"; therefore, if the output is already a "1" and another "1" is shifted out on P3.0, the high drive will *not* be turned on. This depletion FET can source a maximum of 250μA if the port pin is grounded.

The instruction table indicates that bit seven for the READ instruction should be a "1". The reason for this is to guarantee that the high drive period is off before the X2444 begins to output data. If bit seven were a "0", the 8051 would turn on the high drive circuit to return P3.0 to the inactive state, possibly generating a high current contention problem with the DO output of the X2444. Figure 6 illustrates the timing involved during clock eight. The high drive period of the 8051 is turned off well before the X2444 begins to output data.

VERSATILITY

The DO output of the X2444 is always in the high impedance state unless it is outputting data in response to a READ command. Therefore, the serial port of the 8051 need not be dedicated solely to a serial memory interface.

Figure 7 illustrates the versatility this affords. This figure depicts the basic system components required in a remote location controller. Notice that the 8051 serial port has access to both the X2444 and through the use of the CE control line maintains full use of the serial port as a UART. Therefore, it can receive downloaded parameters from a host, re-enable the serial port for X2444 communication, then store the data either temporarily in the X2444 RAM array or permanently in the X2444 E^2PROM array.

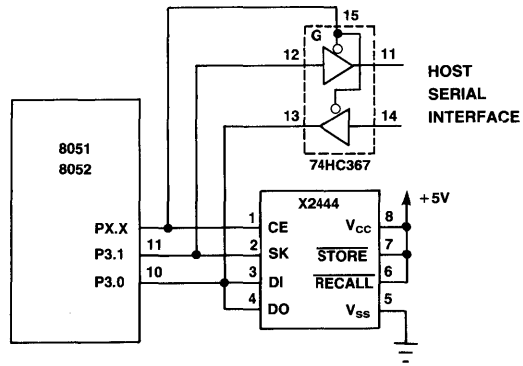


Figure 7. Shared Serial Port

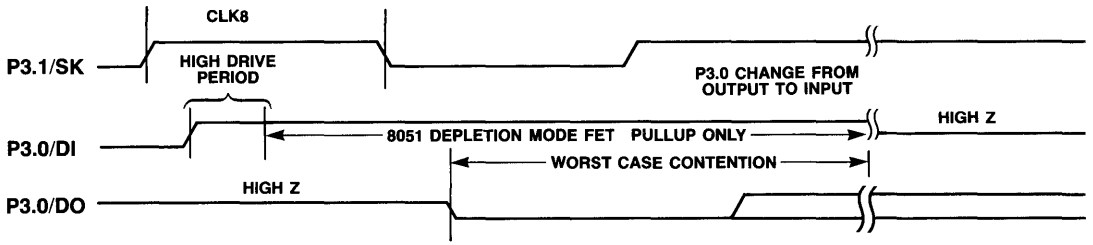


Figure 6. Worst Case Bus Contention

5

CONCLUSION

This application note has shown that with no extra hardware the X2444 interfaces directly with the 8051 family of microcontrollers, providing a non-volatile memory store and scratch pad memory and maintaining full 8051 UART capabilities. It is the ideal solution for applications where extra memory is required but few port pins are available for implementation.

Xicor Application Brief

NONVOLATILE DATA INTEGRITY: INADVERTENT WRITE/STORE ELIMINATION

By Applications Staff

Vol. 1, No. 1

Xicor's nonvolatile memory products are backed by designed-in protection features which ensure data integrity. These include:

- **Onboard V_{CC} Sensor**
  All operations inhibited when $V_{CC} \leq 3.0V$.
- **Noise Filter**
  A feature which blocks noise spikes on control lines.
- **Orderly Power Transition**
  The device will not self-generate inadvertent write/store operations.
- **Write/Store Inhibited Control Pins**
  Multi-pin write/store command signal requirements provide both data security *and* design flexibility.

New Design Features

- Software Write Protection
- Previous Recall Latch
- Command Sequence

With Xicor nonvolatile memories, data is maintained through power-on, power-off, power-down, system crash, and the entire range of system conditions when some simple design rules are observed. Often nonvolatile system designers are frustrated by inadvertent system command signals during power-up and power-down operations. Being nonperiodic in nature, these elusive culprits can lead the designers to the false conclusion that the memory device is malfunctioning. This, however, is rarely the case. The system is more often sending an unintended write/store command. This problem can be easily resolved as shown in this application brief.

GIGO[1] Going to Sleep

Just as a person falling asleep at the wheel can inadvertently command his vehicle into an undesirable situation, digital systems transitioning from normal operation to a power-off state or vice versa can distribute random data, addresses, and control signals along the way.

Since Xicor nonvolatile memories accurately and reliably store data as instructed, data stored at power-down will be impeccably retained and available upon power-up. (That's nonvolatile GIGO.)

Protection-Conscious Design

Data integrity is a major criterion with Xicor products and several superb features were designed into Xicor's memories to ensure it.

- **V_{CC} Sensor**
  An onboard sensor establishes a threshold supply voltage of 3.0V below which write operations on E^2PROMs and store operations on NOVRAMs are blocked. Above this voltage, write and store operations are available and therefore must be protected from unplanned instructions.
- **Orderly Supply Transitions**
  As a system powers up or down, the possibility of unintentional, internally generated control signals increases dramatically. The Xicor nonvolatile memory family has designed-in protection to eliminate self-generated write/store commands.
- **Noise Filter**
  An additional feature designed into Xicor's E^2PROM family is a noise filter to prevent glitches on the $\overline{WE}$ line from initiating a write cycle. This feature filters pulses of less than 20ns duration insuring noise spikes are not misconstrued as write commands.

- **Write/Store Inhibit Control Pins**
  Xicor nonvolatile memories require combinational control pin conditions in order to execute a write/store command. By disallowing any one of the required pin conditions, the user can prevent unplanned nonvolatile data changes so that data integrity is maintained.

Write/Store Pin Conditions

$\overline{\text{ARRAY RECALL}}$[2]	$\overline{\text{STORE}}$	STORE CAPABILITY
X	H	STORE OPERATION DISABLED
L	X	ARRAY RECALL BLOCKS STORE INITIATION (SEE FOOTNOTE 2)
H	L	STORE OPERATION EXECUTED[3]

Figure 1: X2200 NOVRAM Family

$\overline{\text{CE}}$	$\overline{\text{OE}}$	$\overline{\text{WE}}$	WRITE CAPABILITY
X	X	H	($\overline{\text{WE}}$) WRITE INHIBIT
X	L	X	($\overline{\text{OE}}$) WRITE INHIBIT
H	X	X	($\overline{\text{CE}}$) WRITE INHIBIT
L	H	L	WRITE OPERATION EXECUTED[3]

Figure 2: E²PROM Family

External Hardware Implementations

Solution I—"Hold-Low" Protection

The simplest solution is to pull the $\overline{\text{OE}}$ (or ARRAY RECALL) to a logic "0" whenever the supply voltage is below the (5.0-10%) system threshold.

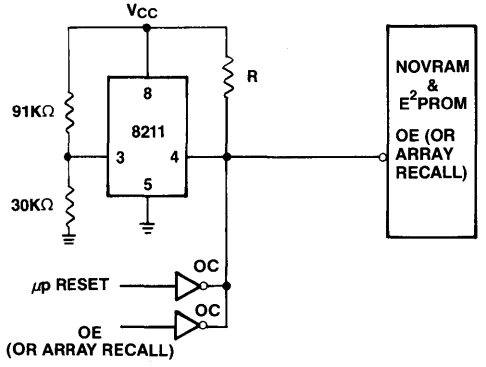


Figure 3: "Hold-Low" Protection

The Intersil[4] ICL 8211 programmable voltage reference is an inexpensive 8-pin mini DIP which will sense a selected voltage threshold and output a logic "0" when the supply is below that threshold. Conversely, as the sensed voltage rises above the selected threshold, the 8211 outputs a logic "1" following its supply voltage level.

Solution II—"Hold-High" Protection

The second method of data protection during power supply transitions is to keep the NOVRAM $\overline{\text{STORE}}$ pin (or the $\overline{\text{WE}}$ and/or $\overline{\text{CE}}$ pins in the E²PROM family) near the power supply voltage. By preventing the low condition of these pins which is necessary for a write or store operation, inadvertent stores will be eliminated.

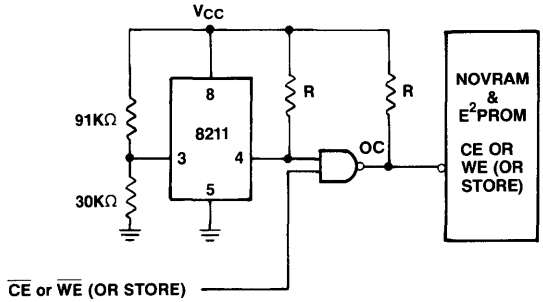


Figure 4: "Hold-High" Protection

The graph in Figure 5 shows the performance of the Intersil ICL 8211. The top plot is a sawtooth which is connected to "5V supply" as shown in the Solution I and Solution II schematic diagrams. The bottom plot is the output of the ICL 8211. Note that when the supply is above 4.50V, the ICL 8211 output tracks it at logic "1". When the supply sawtooth is below 1.56V, the ICL 8211 output tracks the power supply. However, since the Xicor memory family has internal protection inhibiting write/store operations when V_{CC} is below 3V, no inadvertent write/stores will occur in this range. In the critical range between 3V, where internal protection stops, and 4.5V, where normal operation begins, the ICL 8211 insures a 0V output.

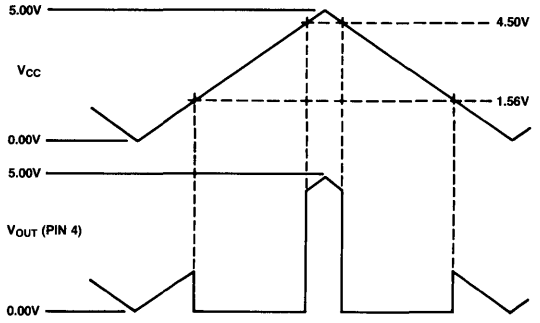


Figure 5: Intersil ICL 8211 Programmable Voltage Reference/Supply and Output Waveforms

As an alternate approach to the 8211, some designers may prefer to incorporate the SGS L487. This device is a 500 mA precision 5V voltage regulator which includes an open collector power-on, power-off reset output pin, which can protect the nonvolatile memories just as the 8211 does. The timing diagram in Figure 6 shows the voltage on this reset output pin as the supply voltage transitions through power-up and power-down.

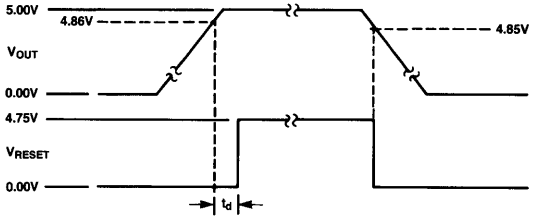


Figure 6: SGS L487 Precision Voltage Regulator/Output and Reset Waveforms

New Protect Features

Serial Device Protection X2444

A Previous Recall latch and Write Enable latch have been incorporated in the X2444 Serial NOVRAM.

Upon power-up, both latches will be in the reset state. Both latches must be set in order to enable either a write RAM operation or store to E^2PROM operation.

A recall operation copies data from the E^2PROM array into the RAM array. This operation places known data in all RAM locations and sets the previous recall latch. This prevents the user from inadvertently writing one word to RAM and performing a store operation with unknown data in all other locations.

The WREN instruction sets the Write Enable latch, enabling (if the Previous Recall latch is set) write and store operations. The WRDS instruction resets the latch, disabling write and store operations.

Therefore, total data integrity can be maintained through the use of software commands. The device is inherently protected during power-up and, through proper software control, is protected during power-down.

X2404 Serial E^2PROM

Due to the nature of the software protocol involved in writing to the X2404, inadvertent stores are highly unlikely. During power-up or power-down the possibility of the bus duplicating the start condition, slave address and transmitting data successfully is so remote as to be unmeasurable.

Software Write Protection

Future E^2PROM products will contain a register which is accessible through a software sequence algorithm. This feature provides the user control in selecting the level of write protection required by their application.

Mode Selection

Write Lock-Out

In the lock-out mode, all write operations will be disabled.

Open Access Writes

In the open access write mode, the lock-out is disabled, and the host system can write in both byte and page modes unimpeded.

Single Write

In the single write mode the host can execute only one byte or page mode write cycle. When the internal write cycle is completed, the device will automatically reset the register, disabling any further attempts to write.

Figure 7 indicates the write protection features incorporated in all Xicor products.

GENERIC DEVICE TYPE	V_{CC} SENSE	NOISE FILTER	SELF-GENERATE PROTECT	INHIBIT CONTROL	PREVIOUS RECALL	SOFTWARE PROTECTION	COMMAND SEQUENCE
X2201A	X	X	X	X			
X2210	X	X	X	X			
X2212	X	X	X	X			
X2001	X	X	X	X			
X2002	X	X	X	X			
X2004	X	X	X	X			
X2444	X	X	X	X	X		
X2804A	X	X	X	X			
X2816A	X	X	X	X			
X2816B	X	X	X	X			
X2816H	X	X	X	X			
X2616	X	X	X	X			
X2864A	X	X	X	X			
X2864B	X	X	X	X			
X2864H	X	X	X	X			
X2664	X	X	X	X			
X28C64	X	X	X	X		X	
X28256	X	X	X	X		X	
X28C256	X	X	X	X		X	
X2404	X	X	X	X			X
X24C04	X	X	X	X			X
X24C16	X	X	X	X			X

Figure 7: Product Protection Matrix

Footnotes

[1] GIGO is an acronym popular in the computer world for "Garbage In Garbage Out".

[2] ARRAY RECALL blocks all control inputs but does not halt a store in process.

[3] These are the *only conditions* allowing nonvolatile data change.

[4] See Intersil ICL 8211, ICL 8212 Programmable voltage reference data sheet in Intersil Data Book.

Xicor Application Brief

$\overline{\text{DATA}}$ POLLING AND PAGE WRITE COMBINE TO OFFER IMPROVED WRITE TIMING CHARACTERISTICS

By Applications Staff

Vol. 1, No. 2

$\overline{\text{DATA}}$ Polling

Xicor E^2PROMs normally complete the nonvolatile Write Cycle substantially faster than the maximum time specified on the data sheet. In order to take advantage of this faster Write Cycle potential, Xicor developed $\overline{\text{DATA}}$ Polling.

$\overline{\text{DATA}}$ Polling provides a simple software technique of testing for the early completion of a nonvolatile Write Cycle. $\overline{\text{DATA}}$ Polling uses the most significant bit (MSB) of the last byte written to indicate to the microprocessor when the write operation is complete. During the internal nonvolatile Write Cycle. I/O_7 is the complement of the last D_7 written. Thus, the microprocessor can simply read the last byte written and compare the result with the actual data written (generally stored in a register or RAM location). When the values are equal, the Write Cycle is complete.

The flow chart below shows the minimal software necessary to "Poll" for "Data", thereby testing for nonvolatile Write Cycle completion.

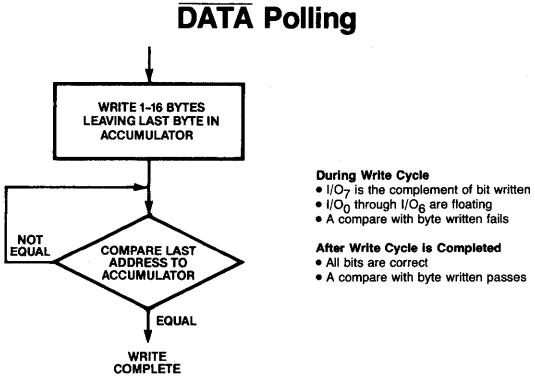


Figure 1: Testing for Nonvolatile Write Cycle Completion

Prior to nonvolatile Write Cycle completion, the comparison test will continue. When the Write Cycle is complete, the comparison test will succeed and control will fall out of the loop. The user may then access the memory for the next read or write operation.

```
8080/8085 Microprocessor Instructions
Retain last byte written in the accumulator and the
last address written to in HL

XXX CMP M              COMPARE MEMORY TO ACCUMULATOR
    JNZ XXX            JUMP IF NO MATCH
    RET                RETURN FROM SUBROUTINE
```

```
6502 Microprocessor Instructions
Retain the last byte written in the accumulator

XXX CMP (LAST),Y       COMPARE MEMORY TO ACCUMULATOR
    BNE XXX            BRANCH IF NO MATCH
    RTS                RETURN FROM SUBROUTINE
```

Figure 2: $\overline{\text{DATA}}$ Polling Subroutine Examples

Growth Path

$\overline{\text{DATA}}$ Polling has a side benefit in that no additional pins are required to implement the feature. Therefore, a board populated with X2864's can easily accommodate the X28256 when the user needs to expand their system.

5

The X2864 package shown in Figure 3 reveals the two unconnected pins on the 28 pin package. This allows for board designs which accommodate the 64K E²PROM to upgrade to 256K with the only change being the addition of high order address signals.

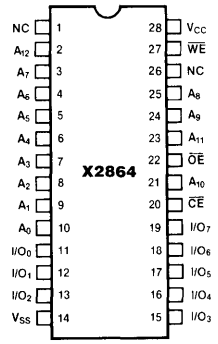


Figure 3: X2864 64K E²PROM

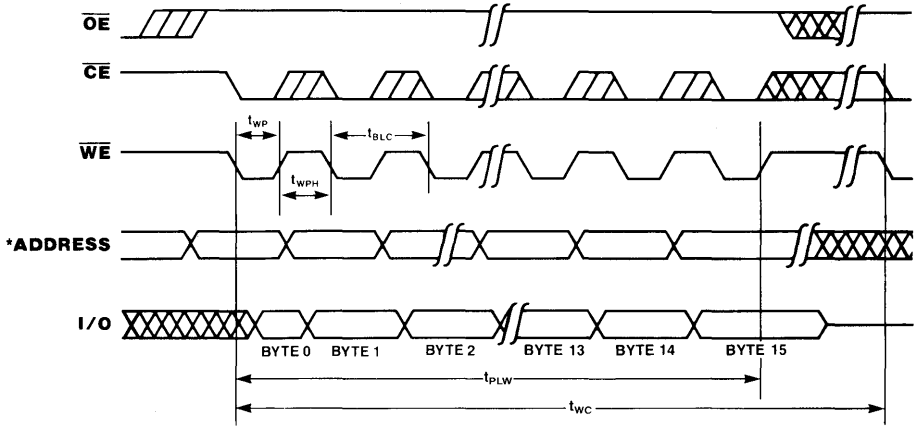
Page Write Operation

Xicor E²PROMs currently feature Page Write operation. It was first implemented by Xicor to enhance the effective byte Write Cycle time. As Xicor's experience in the design of nonvolatile memories has increased, so has the capability of the Page Write feature.

The X2864A currently supports a 16-byte Page Write feature. The manner in which this was implemented provides a host processor a 150μs window in which to write one to sixteen bytes of data. Refer to Figure 4 for the sequence of an X2864A Page Write operation. Using the worst case Write Cycle time of 10ms, this method of writing data to the X2864A yields an effective byte Write Cycle of 625μs. The effective Write Cycle time can typically be halved by implementing DATA Polling, yielding a byte write time of 312μs.

The next generation of E²PROMs (X2864B, X2864H, X2816B etc.) have been implemented with the latest Xicor proprietary technology, speeding the Write Cycle time. They have also been designed to expand the page size. For example, the X2864B maximum Write Cycle time is 2ms, and the page size has been increased to 32 bytes, yielding an effective byte Write Cycle of 62μs. This too, can typically be halved by implementing a DATA Polling software routine, yielding a 32μs byte Write Cycle time.

In addition the Page Write window has been eliminated on the new generation. For example, the X2864B page size is defined as 32 bytes, the host can theoretically perform as many writes to that one page as it requires. In order to keep the page window open the host must initiate subsequent write operations, WE falling edge, within 20μs of the previous WE falling edge. Refer to Figure 5 for an illustration of AC Page Write characteristics.



*The page address, addresses A_4–A_{12}, must remain the same throughout the page write cycle (t_{PLW}). If a page violation occurs, writes to an unknown address could result.

Figure 4: X2864A Page Write Timing Diagram

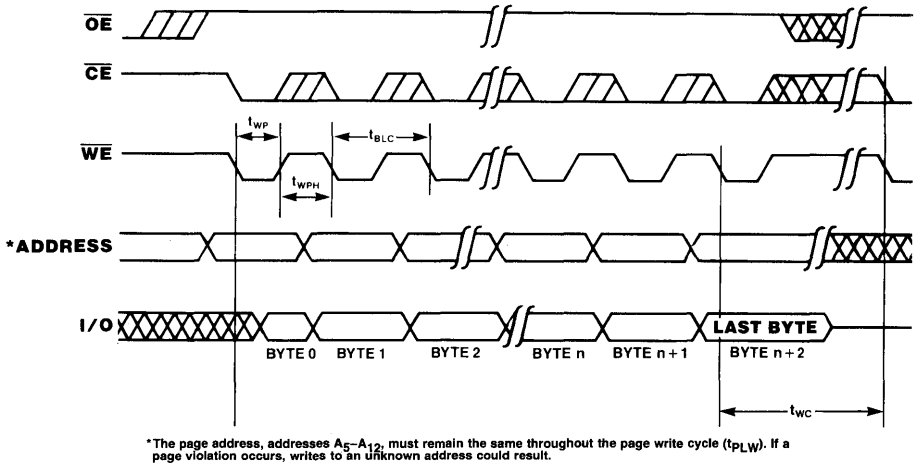


Figure 5: X2864B Page Write Timing Diagram

Figure 6 is a cross reference table for Xicor products featuring Page Write operation. For each device the maximum and typical byte Write Cycle times are listed, and effective byte Write Cycle times for page mode and page mode with $\overline{DATA}$ Polling implemented. As a further comparison, entire device rewrite times are listed for single byte maximum cycle time and page write using $\overline{DATA}$ Polling.

Device Type	Byte Write		Page Size	Effective Byte Write		Device Rewrite	
				Polling		Single Byte Without Polling	Page With Polling
	Max.	Typical		No	Yes		
X2864A	10ms	5ms	16	625μs	312μs	82sec	2.5sec
X2816B	2ms	1ms	32	62μs	31μs	4.1sec	64ms
X2864B	2ms	1ms	32	62μs	31μs	16.4sec	256ms
X2864H	2ms	1ms	32	62μs	31μs	16.4sec	256ms
X28256	5ms	2ms	64	78μs	31μs	163sec	1sec

Figure 6: Cross Reference for Xicor Products Featuring Page Write Operation

Xicor Application Brief

X2816A DESIGN ALLOWS UPGRADE TO X2864A AND BEYOND

By Rick Orlando

Vol. 1, No. 5

With the announcement of the X2864A, customers have expressed a desire to design an X2816A socket that can be upgraded to accept the X2864A. The 28-pin footprint of the X2864A allows eventual migration up to the 256K bit level. If a board design is done properly, the socket can accept the entire product family.

First, let us look at the "universal socket".

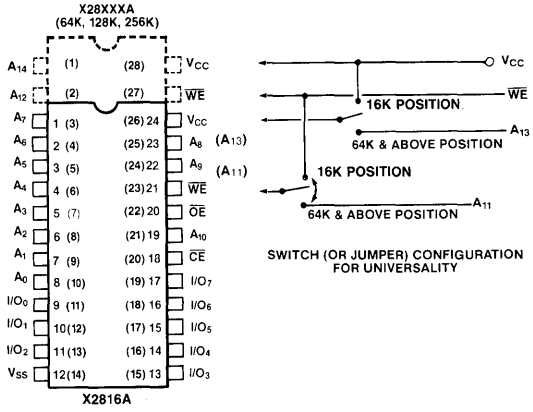


Figure 1. Universal Socket for 16K Thru 256K E²PROMs

One can see that the socket will accept Xicor E²PROMs from the 16K level through the 256K level with essentially two jumpers determining which footprint the socket is to be.

The next question is how can one minimize the address decoding logic for a board populated with the above "universal" sockets. We will assume that we have a board with eight "universal" sockets. We would like to design the address decoding logic to allow the eight X2816A's to be replaced by two X2864A's.

Now, we look at the addresses that each chip will be mapped into:

	Chip #	Address Range
X2816A	(1)	0000 - 07FF
	(2)	0800 - 0FFF
	(3)	1000 - 17FF
	(4)	1800 - 1FFF
	(5)	2000 - 27FF
	(6)	2800 - 2FFF
	(7)	3000 - 37FF
	(8)	3800 - 3FFF

	Chip #	Address Range
X2864A	(1)	0000 - 1FFF
	(2)	2000 - 3FFF

Figure 2. Address Map Comparison

The breakdown of the decoding for such a scheme is listed as follows:

					X2816A Chip Selects*								X2864A Chip Selects*	
A_{15}	A_{14}	A_{13}	A_{12}	A_{11}	1	2	3	4	5	6	7	8	1	2
0	0	0	0	0	0	1	1	1	1	1	1	1	0	1
0	0	0	0	1	1	0	1	1	1	1	1	1	0	1
0	0	0	1	0	1	1	0	1	1	1	1	1	0	1
0	0	0	1	1	1	1	1	0	1	1	1	1	0	1
0	0	1	0	0	1	1	1	1	0	1	1	1	1	0
0	0	1	0	1	1	1	1	1	1	0	1	1	1	0
0	0	1	1	0	1	1	1	1	1	1	0	1	1	0
0	0	1	1	1	1	1	1	1	1	1	1	0	1	0

*Chip Select is active low.

Figure 3. Address Decode Comparison

One possible solution is to use two 74LS138's with one being wired for the X2816A and one for the X2864A. If the X2816A's are used in the board, LS138-A is installed and LS138-B is omitted. Conversely, if X2864A's are being used, LS138-B is installed and LS138-A is omitted.

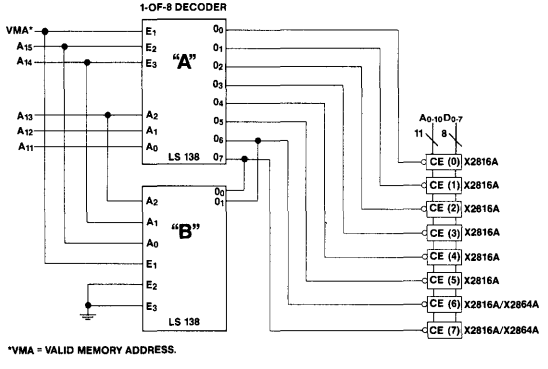


Figure 4. 74LS138 Decode Wiring Option

The two X2864A's are placed in sockets 6 and 7.

Another solution for the address mapping questions is to use a 32x8 bipolar PROM for address decoding.

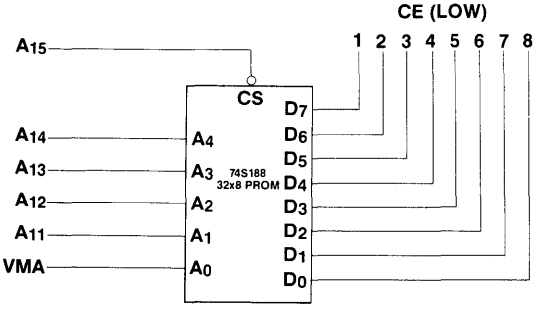


Figure 5. Bipolar PROM Mapping

One simply changes the PROM for replacing the X2816A's with X2864A's.

Another related case is where the designer would like to increase the memory capacity of the board by upgrading to the X2864A. In this case, we need to replace the eight X2816A's (128K bits/board) with eight X2864A's (512K bits/board).

Using the "universal" sockets, this is relatively easy. We use the following circuit, again using a 32x8 bipolar PROM.

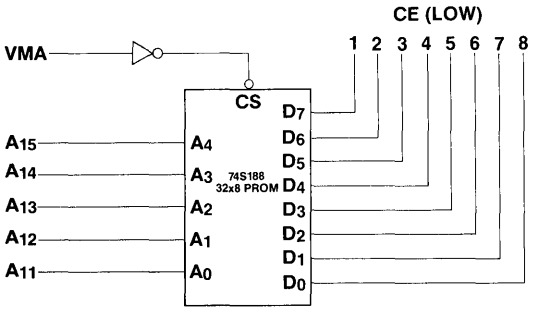


Figure 6. Bipolar PROM Mapping for Memory Expansion

One simply changes the program in the PROM to go from using X2816A's to X2864A's. The listing below shows the PROM program for the X2816A's and the X2864A's.

The PROM decode method allows a mixed combination of X2816A's and X2864A's to be used on the same board. It also allows different types of memory to be used such as X2816A's and 64K CMOS RAMs on the board. If the board is to be used with either 16K or larger devices, then only two jumpers are needed per board to configure all of the "universal" sockets.

The address decoding can be extended even further to incorporate expansion to the 256K bit E^2PROM.

One can see that through using foresight in design, a modern designer can implement a memory socket that is truly universal in allowing the use of the most cost-effective E^2PROM densities available.

					16K Bytes X2816A Program 0000 - 3FFF								**64K Bytes X2864A Program 0000 - FFFF**							
A_{11}	A_{12}	A_{13}	A_{14}	A_{15}	D_0	D_1	D_2	D_3	D_4	D_5	D_6	D_7	D_0	D_1	D_2	D_3	D_4	D_5	D_6	D_7
0	0	0	0	0	0	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1
1	0	0	0	0	1	0	1	1	1	1	1	1	0	1	1	1	1	1	1	1
1	1	0	0	0	1	1	0	1	1	1	1	1	0	1	1	1	1	1	1	1
1	1	0	0	0	1	1	1	0	1	1	1	1	0	1	1	1	1	1	1	1
0	0	1	0	0	1	1	1	1	0	1	1	1	1	0	1	1	1	1	1	1
1	0	1	0	0	1	1	1	1	1	0	1	1	1	0	1	1	1	1	1	1
0	1	1	0	0	1	1	1	1	1	1	0	1	1	0	1	1	1	1	1	1
1	1	1	0	0	1	1	1	1	1	1	1	0	1	0	1	1	1	1	1	1
0	0	0	1	0	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1
1	0	0	1	0	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1
0	1	0	1	0	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1
1	1	0	1	0	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1
0	0	1	1	0	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1
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0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0
1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0
0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0

Figure 7. PROM Contents for Memory Expansion Mapping

REPLACING DIP SWITCHES WITH NONVOLATILE TECHNOLOGY

By Rick Orlando

Vol. 1, No. 7

One of the most prevalent applications for small nonvolatile memories is that of replacing DIP switches. The advantages of the nonvolatile memories is clear. They take up less room, are easier to use, and lend themselves to automated board assembly. 256 bits of information, or the equivalent of 32, 8-bit DIP switches can be implemented in a single package.

Xicor's new X2444 Serial NOVRAM adds yet another feature—low cost. When coupled with the serial device's minimal interface requirements, the X2444 takes DIP switches head on, and is obviously the cost/performance leader. The purpose of this brief is to describe how easy it is to replace a DIP switch with an X2444 NOVRAM.

DIP Switch Interface

There are two common types of DIP switch interfaces.

I/O Port

The first uses an I/O port with internal pullup resistors. Figure 1a shows a typical circuit that could be used either with a single chip microcomputer or with an I/O port on a microprocessor bus. In either case, the internal pullups present a logic "1" to the input as long as the DIP switch is open. To use an X2444 Serial NOVRAM in the DIP switch socket, one only needs to tie pins 14, 15, and 16 of the 16-pin socket to V_{CC}.

One then plugs an X2444 part in the uppermost half of the socket, and the circuit becomes that shown in Figure 1b. V_{CC}, STORE, and RECALL are tied hard to 5 volts, so that all nonvolatile operations are controlled through software. The four interface lines from the X2444 are connected to the four least significant I/O lines of the port.

5

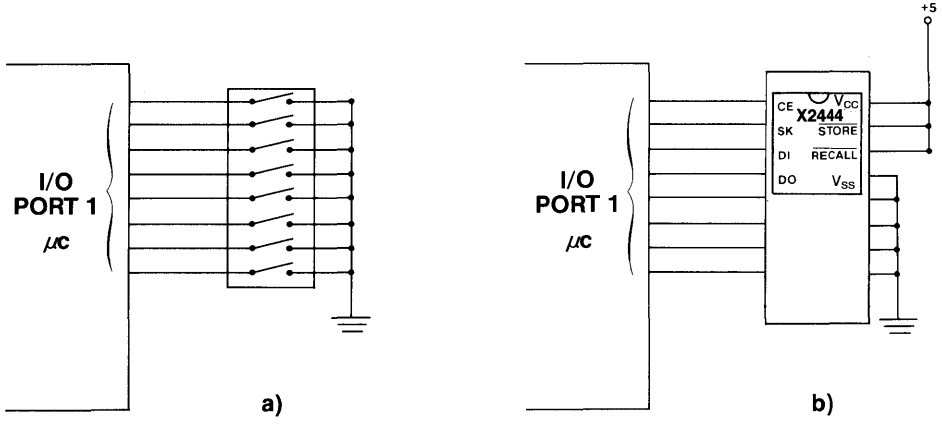

Figure 1. Microcomputer with Internal Pullups

No Internal Pullups

The second type of interface uses ports which do not have internal pullups. In this instance, the X2444 can be plugged into the top section of the pullup resistor socket, with a jumper from pin 13 of the 16-pin site to ground, for the V_{SS} on the serial part. Again, V_{CC}, STORE, and RECALL are tied to +5V through the connections used for the resistor pack. The DIP switch socket simply remains empty. See Figure 2.

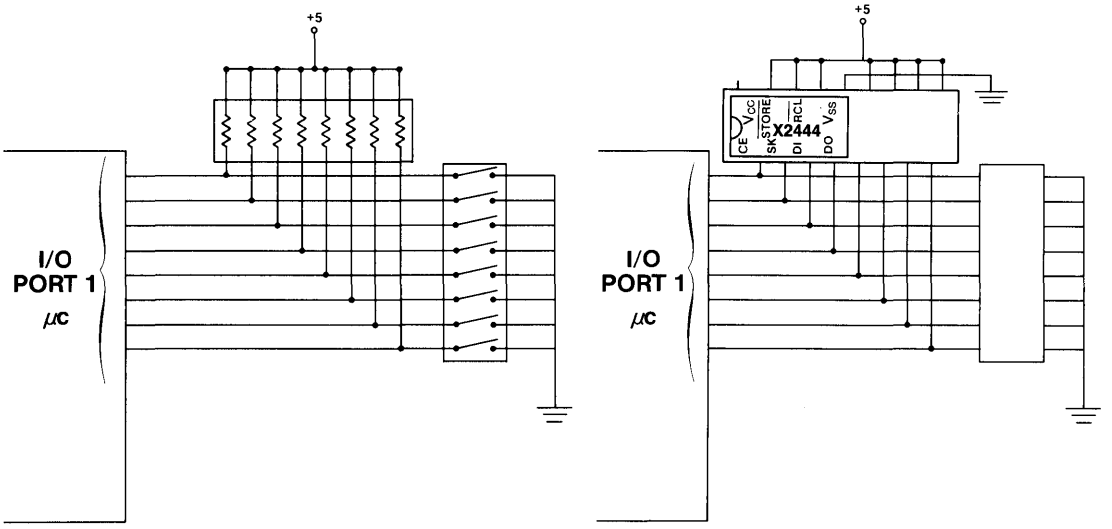

Figure 2. Microcomputer without Internal Pullups

Both of these implementations free up four more I/O lines to be used elsewhere. They also require the same software to drive the X2444.

Assume that the processor is a 6801 with the X2444 replacing a DIP switch. The procedure "INIT" initializes the port (see Section 1, "X2444 Driver Program for 6801").

Serial output is accomplished by loading the data to be output into the A Accumulator. A loop routine then shifts a bit into the carry, sets the serial data out (Data in for X2444) to either a "1" or "0" depending upon the state of the carry and toggles the clock. (See Section 2 Procedure "SHIFT1" of X2444 Driver Program for further details).

The serial input is performed by a loop which examines the state of the serial data in, (Data out for X2444) sets the carry accordingly, shifts the carry into the accumulator and toggles the clock. (See Section 3 Procedure "SHIFTIN" of X2444 Driver Program for further details).

The complete software is as follows, and it occupies about 100 bytes of code. As one can see, the X2444 is indeed a value replacement for DIP switches.

```
;*****************************************************************************
;                          6801 X2444 DRIVER
;       ASSUME THAT PORT1 IS USED AS THE 2444 INTERFACE
;       PORT1'S REGISTERS ARE LOCATED AS FOLLOWS
;                DATA DIRECTION              HEX  0000
;                PORT                        HEX  0002
;                                 PORT1              X2444
;       I/O 0                     SERIAL CLOCK       SERIAL CLOCK
;       I/O 1                     SERIAL OUT         SERIAL IN
;       I/O 2                     SERIAL IN          SERIAL OUT
;       I/O 3                     2444 SELECT        CHIP SELECT
;
;       COMMANDS ARE PASSED TO THE X2444 ROUTINE BY A PARAMETER IN THE
;       A ACCUMULATOR, WHILE THE ADDRESS IF NEEDED IS PASSED ON THE STACK
;       SERIAL DATA IN OR OUT USES THE TEMPORARY LOCATION TEMP1,
;       WHICH IS A SIXTEEN BIT WORSD.  THE X2444 COMMANDS ARE ENCRYPTED AS
;       FOLLOWS.
;       COMMAND CODE                INSTRUCTION          OPCODE
;       0                           READ                 1AAAA11X
;       1                           WRITE                1AAAA011
;       2                           RESET WRITE ENABLE   11111000
;       3                           STORE                11111001
;       4                           SLEEP                11111010
;       5                           SET WRITE ENABLE     11111100
;       6                           RECALL               11111101
;  "1"s ARE USED INSTEAD OF DON'T CARE TO DISTINGUISH BETWEEN DATA AND
;   NON DATA OPERATIONS.
;*****************************************************************************

DIRECTION1      .EQU        00.
PORT1           .EQU        02.
TEMP1           .EQU        080H    ;RAM STORAGE FOR DATA
COUNT           .EQU        082H    ;COUNTER VARIABLE
DATUM           .EQU        084H    ;DATA STORAGE
ADDRESS         .EQU        086H    ;ADDRESS STORAGE
ERRORDATA       .EQU        088H     ;ERROR DATA

;*****************************************************************************
;                   PROCEDURE INIT
;       THIS PROCEDURE INITIALIZES THE X2444 INTERFACE
;*****************************************************************************
INIT    LDAA    #10H            ; B=10.1, I/O 0,1 AND 3 OUTPUTS, 2 INPUT
        STAA    DIRECTION1      ; WRITE TO DATA DIRECTION REGISTER
        CLRA                    ;SET CE TO 0(INACTIVE), DOUT AND SK TO 0
        STAA    PORT1           ;AND STORE IN DATA PORT
        RTS                     ;

;*****************************************************************************
;       SHIFTER ROUTINE- SHIFT1
; THIS ROUTINE TAKES THE DATA IN THE A ACCUMULATOR AND CLOCKS IT MOST
; SIGNIFICANT BIT FIRST INTO THE X2444.  THE FLOW IS SHIFT A BIT, TOGGLE
; THE SERIAL OUTPUT(6801) ACCORDING TO STATE, AND TOGGLE SERIAL CLOCK
;*****************************************************************************

SHIFTOUT LDAB   #08.            ;LOAD THE BIT COUNT WITH 8
        STAB    COUNT           ;STORE IN COUNTER
SHIFT1  ROLA                    ;SHIFT BIT INTO CARRY BIT
        LDAB    #14H            ;WE SET DATA OUT TO ZERO, WHILE SETTING CHIP
                                ;ENABLE.  SERIAL CLOCK IS LOW.
        BCC     TRANS           ;IF BIT IS A ZERO, THEN TRANSMIT
        ORAB    #02H            ;IF IT IS A ONE, THEN SET DATA OUT
TRANS   STAB    PORT1           ;STORE THE DATA INTO THE PORT
        ORAB    #01H            ;AND SET THE CLOCK FOR A TRANSITION
        STAB    PORT1           ;BY WRITING A 1 TO SERIAL CLOCK
        ANDB    #1AH            ;KEEP THE DATA VALID, BUT SET SK TO ZERO
        STAB    PORT1           ;AND STORE IN THE PORT
        LDAB    #14H            ;TOGGLE CLOCK DOWN, SET DOUT TO 0, BUT KEEP
        STAB    PORT1           ;X2444 SELECTED
        DEC     COUNT           ; DECREMENT THE BIT COUNTER
        BNE     SHIFT1          ;IF COUNT IS NOT ZERO, TRANSMIT NEXT BIT
        ROLA                    ;ONE MORE ROTATE TO PRESERVE INSTRUCTION
        RTS                     ;RETURN FROM SUBROUTINE
;*****************************************************************************
;                   SHIFTIN ROUTINE
; THIS SUBROUTINE SHIFTS IN 8 BITS OF DATA INTO THE A ACCUMULATOR FROM THE
; X2444. THE METHOD IS TO ENTER WITH THE CLOCK LOW, TOGGLE THE SERIAL CLOCK,
; EXAMINE THE INPUT DATA, AND SHIFT IT INTO THE A ACCUMULATOR.  THIS IS DONE
; 8 TIMES.  THE ROUTINE IS EXITED WITH THE CHIP DESELECTED, AND THE BYTE
; READ FROM THE CHIP IN THE A ACCUMULATOR
;*****************************************************************************
SHIFTIN LDAB    #8.             ;LOAD THE BIT COUNT
        STAB    COUNT           ;AND STORE IT IN THE COUNTER
                                ;AT THIS POINT THE X2444 SHOULD BE SELECTED
                                ;THEREFORE, WE DO NOT NEED TO SELECT CHIP
NEXT    LDAB    #04             ;MASK BIT FOR I/O 2 OF PORT
        BITB    PORT1           ;CHECK TO SEE IF INPUT IS A ONE OR ZERO
        CLC                     ;CLEAR THE CARRY
        BEQ     CLOCK           ;IF IT IS A ZERO, LEAVE CARRY AT 0
        SEC                     ;OTHERWISE SET CARRY TO LOAD INTO A
CLOCK   LDAB    #15H            ;SEND A CLOCK TO X2444,BUT KEEP CHIP SELECT HIGH
        STAB    PORT1           ;BY WRITING A 1 TO SERIAL CLOCK OUTPUT
SHIFT   LDAB    #14H            ;SET UP TO CLEAR CLOCK, BUT KEEP X2444 SELECTED
        STAB    PORT1           ;AND STORE
        ROLA                    ;ROTATE CARRY INTO LSB OF ACCUMULATOR A
        DEC     COUNT           ;DECREMENT COUNTER
        BNE     NEXT            ;IF NOT ZERO, THEN WE ARE NOT DONE, GET NEXT
        RTS                     ;AND RETURN FROM SUBROUTINE
```

Section 1

Section 2

Section 3

```
;*****************************************************************************
;       X2444 DRIVER ROUTINE
; IT IS ASSUMED THAT THE INSTRUCTION IS PASSED IN THE A ACCUMULATOR,  AN
; ADDRESS, IF NEEDED, IS PASSED ON THE STACK(CURRENT SP-2)
; DATA TO BE READ OR WRITTEN WILL BE HELD IN TEMP1
;*****************************************************************************
DRIVE   CMPA    #0F8H           ;CHECK TO SEE IF IT IS READ OR WRITE
        BGE     NONDATA         ;IF NOT, THEN BRANCH AROUND
        TSX                     ;TRANSFER STACK TO INDEX REGISTER
        ORAA    2,X             ;THE ADDRESS SHOULD BE SP+2
        JSR     SHIFTOUT        ;OUTPUT THE INSTRUCTION
        ANDA    #04H            ;CHECK TO SEE IF IT IS A READ OR WRITE
        BNE     RD              ;IF AC3=1, IT IS A READ

WRT     LDAA    TEMP1           ;IF IT IS A WRITE, GET THE FIRST BYTE
        JSR     SHIFTOUT        ;WRITE THE FIRST BYTE
        LDAA    TEMP1+1         ;GET THE SECOND BYTE
        JSR     SHIFTOUT        ;WRITE THE SECOND BYTE
        BRA     DONE            ;WRITE INSTRUCTION COMPLETE
RD      JSR     SHIFTIN         ;GET THE FIRST BYTE
        STAA    TEMP1           ;STORE IN TEMP1
        JSR     SHIFTIN         ;GET THE SECOND BYTE
        STAA    TEMP1+1         ;STORE IN TEMP1+1
        BRA     DONE            ;READ COMPLETE
NONDATA JSR     SHIFTOUT        ;OUTPUT THE INSTRUCTION
DONE    CLRA
        STAA    PORT1           ;DESELECT THE X2444 BY MAKING CS 0
        RTS                     ;RETURN FROM SUBROUTINE
;*****************************************************************************
;               MAIN INSTRUCTION ROUTINES- COULD BE MACROS
;*****************************************************************************
;*****************************************************************************
;       READ ROUTINE
; ASSUMES THAT THE ADDRESS IS IN THE A ACCUMULATOR, DATA IS LEFT IN X REGISTER
;*****************************************************************************
READ    ASLA                    ;SHIFT THE ADDRESS 3 TIMES TO LINE IT
        ASLA                    ;UP WITH THE INSTRUCTION FIELD
        ASLA
        PSHA                    ;PUSH ADDRESS ON THE STACK
        LDAA    #087H           ;LOAD INSTRUCTION INTO A ACCUMULATOR
        JSR     DRIVE           ;PERFORM INSTRUCTION
        LDX     TEMP1           ;GET THE RESULT IN THE INDEX REGISTER
        PULA                    ;CLEAN UP THE STACK
        RTS                     ;AND RETURN
;*****************************************************************************
;                               WRITE ROUTINE
; ASSUMES THAT THE ADDRESS IS IN THE A ACCUMULATOR, DATA TO WRITE IS IN THE
; X REGISTER.
; ALSO CALLS SET WRITE ENABLE LATCH ROUTINE(SWREN) TO ENABLE THE WRITE OPERATION
;*****************************************************************************
WRITE   ASLA                    ;SHIFT THE ADDRESS 3 TIMES
        ASLA
        ASLA
        PSHA                    ;PUSH ADDRESS ONTO THE STACK
        JSR     SWREN           ;SET THE WRITE ENABLE LATCH
        LDAA    #083H           ;LOAD WRITE INSTRUCTION
        STX     TEMP1           ;STORE DATA IN TEMP1
        JSR     DRIVE           ;PERFORM INSTRUCTION
        PULA                    ;CLEAN UP STACK
        RTS
;*****************************************************************************
RWREN   LDAA    #0F8H           ;LOAD THE INSTRUCTION
        JSR     DRIVE           ;AND EXECUTE
        RTS
;*****************************************************************************
STORE   LDAA    #0F9H           ;LOAD THE INSTRUCTION
        JSR     DRIVE           ;PERFROM OPERATION
        RTS                     ;AND RETURN
;*****************************************************************************
SLEEP   LDAA    #0FAH           ;LOAD THE INSTRUCTION
```

THE NINE MOST FREQUENT NOVRAM QUESTIONS

By Rick Orlando

Vol. 2, No. 10

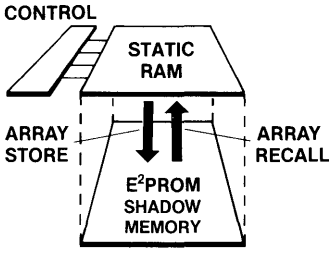

Figure 1: Xicor NOVRAM SRAM Functionality with Nonvolatile E²PROM

The NOVRAM (Nonvolatile RAM) from Xicor is being utilized in a multitude of systems and applications today. As engineers throughout the industry become aware of its availability, their appreciation for this state of the art technology, and the design flexibility which it affords them, is demonstrated by its rapidly expanding use. NOVRAMs have become the "secret" of many winning product designs by providing the technical edge which defines the industry leader.

Although the X2200 series NOVRAMs are very easy to use, the possibilities created by their simplicity and versatility bring forth questions regarding their more subtle characteristics. Frequently, the clarification of these points provides creative engineers with insights into new and unique applications.

Question No. 1: Will the RAM portion of the NOVRAM be accessible during the 10ms Store cycle?

Answer: No. From initiation of the Store cycle until its completion, the data outputs are in a high impedance state and the control inputs are inhibited. This provides a completely free bus, so that the processor can utilize the store cycle period performing other tasks. In order to maximize NOVRAM accessibility, the actual Store cycle completion can be detected by monitoring this high impedance condition. For example, if using a "pulled-up" bus, a specific RAM location can be repeatedly read until its non-FF contents are acquired. At that point, the system knows that the Store cycle is complete and the NOVRAM is accessible.

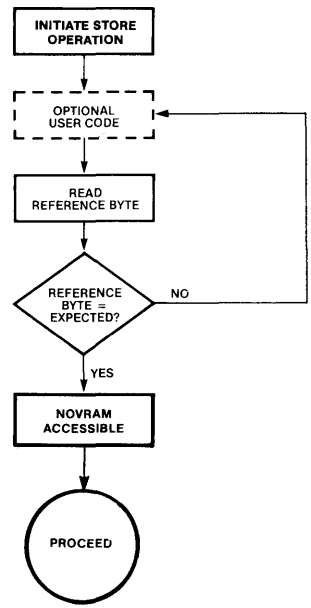

Figure 2: Early Write Completion Flowchart

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Question No. 2: Will the application of voltage to pins marked NC (Not Connected) damage the part?

Answer: No. The pins are literally not electrically connected to the die.

Question No. 3: Will the RAM be accessible for either reading or writing while the $\overline{\text{ARRAY RECALL}}$ pin is held low protecting the nonvolatile data?

Answer: No. While $\overline{\text{ARRAY RECALL}}$ is low, the data outputs are placed in a high impedance state and all control inputs are inhibited. This feature is particularly useful for preventing inadvertent Store operations during power transitions. Pulling $\overline{\text{ARRAY RECALL}}$ low in these periods prevents unintentional data changes. See Application Brief No. 1: Nonvolatile Data Integrity.

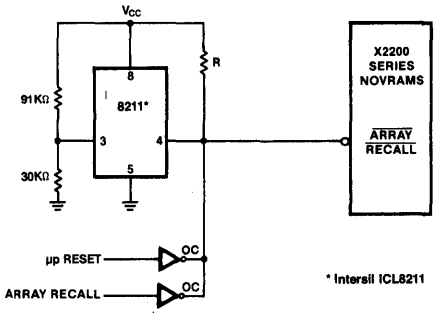

Figure 3: Power-up/Power-down Write Protection Circuit

Question No. 4: What happens if V_{CC} falls below 4.50V before the Store cycle is complete?

Answer: A complete and accurate Store operation is only guaranteed while V_{CC} is within spec (i.e., 5.0V + 10%). If the supply voltage drops out of that range during a Store operation, the result of the Store is not predictable. The Store operation typically completes in less than 5ms, and if it is completed before V_{CC} falls out of range, the data will be secure. However, the many internal system factors involved as the supply voltage diminishes make Storing without sufficient time a potential catastrophy. Always allow at least 10ms between the Store cycle initiation and V_{CC} dropping below 4.50V for certainty in your "data perfect" system crash designs.

Question No. 5: How does Store time vary with device temperature?

Answer: The duration of the Store cycle time is a function of the operating temperature. In general, higher temperatures cause a longer store cycle time, but, within specified limits, does not exceed 10ms.

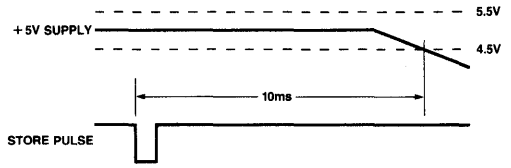

Figure 4: Initiate Store to Power-down Condition Timing

Question No. 6: We found the NOVRAM to be the perfect memory device for our plug-in cartridge application. Is any precaution necessary to protect the data while the cartridge is handled out of the system?

Answer: The best protection is simply to use a pull-down resistor in the cartridge tying $\overline{\text{ARRAY RECALL}}$ to the V_{SS} pin. This will prevent any unanticipated cartridge power (like decaying capacitors and external static voltages) from modifying NOVRAM data.

Although in a strictly 5V environment, "hot socket" insertion will not harm the NOVRAM, precautions should be taken to ensure that cartridge insertion and removal does not generate inadvertent Write or Store commands.

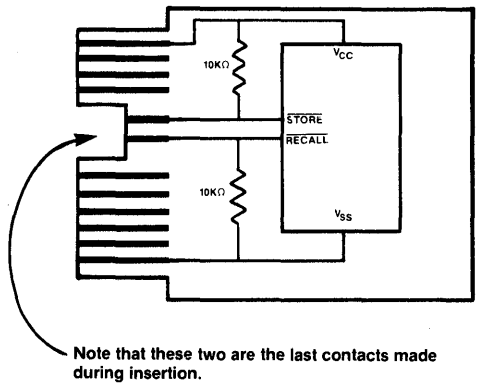

Figure 5: Typical Cartridge Write Protect Scheme

Question No. 7: Two distinct "endurance" parameters are specified on the NOVRAM data sheet. What is the difference between them, and how may this distinction be advantageously used?

Answer: The X2200 data sheets specify a minimum of 10,000 Store cycles and 1000 changes per bit. Xicor NOVRAM technology is implemented differently than standard E^2PROM technology. E^2PROMs generally require an erase before write cycle (Xicor E^2PROMs automatically perform the chore.) This can unnecessarily cycle a bit cell: i.e., when a cell

currently programmed as "0" and new data is also a "0", would require the cell to be erased to a "1" then back to a "0". This is equivalent to two write cycles that effect no change.

The Xicor NOVRAM design "cycles" only those bits in the E^2PROM array that are in a different state than their corresponding bit in the RAM array, reducing the average cycling of individual bit cells per Store operation. Therefore, the 10,000 store operations and 1000 bit changes specified are not contradictory.

Question No. 8: The imminent-power-failure signal in my system is designed to pull $\overline{\text{STORE}}$ low and keep it there throughout the power-down. Will subsequent store cycles be initiated once the first one completes?

Answer: No. The $\overline{\text{STORE}}$ input is falling edge sensitive, so the pin would have to be raised through V_{IH} and lowered through V_{IL} to start another cycle.

Question No. 9: The X2212 features are perfect for my application. However, the 8048 μP has separate $\overline{R}$ and $\overline{W}$ pins and uses a multiplexed data bus which creates bus contention between the higher order address bits and the X2212 output. How can I interface these two?

Answer: By conditioning the $\overline{CS}$ of the NOVRAMs with an active $\overline{R}$ or $\overline{W}$ signal, the built-in NOVRAM output buffer may be utilized. Figure 6 shows the simple NAND gate logic required. The NOVRAM $\overline{CS}$ is only low when the device is selected and $\overline{R}$ or $\overline{W}$ are low $\overline{CS} \cdot (\overline{R} + \overline{W})$. This way the NOVRAM data buffer is tri-stated unless it is being accessed. This makes NOVRAMs static-RAM-simple even in a multiplexed bus environment.

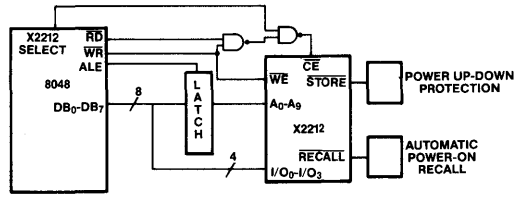

Figure 6: 8048 Microcontroller Implementation

The tremendous versatility of these X2200 dual array memory devices has yet to be fully utilized. Xicor applications engineers are available to address any questions regarding NOVRAMs that you might have.

5

NOTES

Xicor Application Brief

USING $\overline{\text{DATA}}$ POLLING IN AN INTERRUPT DRIVEN ENVIRONMENT

By Rick Orlando

Vol. 2, No. 12

The use of interrupt driven system design has become increasingly popular in many applications. Interrupt driven systems usually can achieve higher performance and improved user friendliness. An interrupt driven system can perform a variety of tasks while waiting for a certain condition to occur, rather than constantly looping and waiting for the occurrence. Writing to E^2PROMs is no exception. Since the devices take a relatively long period to complete a Write Cycle, the system could perform a variety of tasks in the meantime.

$\overline{\text{DATA}}$ Polling was introduced on the X2864A to allow notification to the processor of Write Cycle completion. The manner in which it works is quite simple. The processor first writes a byte of data into the E^2PROM. Any subsequent reads to any location of the chip will produce the complement of the data last written (hence, the name $\overline{\text{DATA}}$ Polling) until the E^2PROM's internal Write Cycle is complete. At this point, reads to any location in the E^2PROM will result in the valid data at that location. It can be seen that one can simply write a byte, and then perform frequent compares of the data in the location just written. The data will not be correct until the chip has completed its internal Write Cycle, and the $\overline{\text{Data}}$ circuitry is disabled.

In applications where the processor does not have anything to do during the Write Cycle, the software can simply perform compare loops until the Write Cycle is complete, and then write the next byte. In applications which are more processing time limited, a test loop can be placed in the main program loop, which will check the status of a previous Write Cycle on each pass through the main or outermost software loop. Almost all microprocessor applications software has such a top level loop. $\overline{\text{DATA}}$ Polling is obviously adequate in these environments.

The interrupt intensive applications may not have a main control loop nor can they usually afford the processing time for the processor to sit and loop until the Write Cycle is complete. In these applications, it would be ideal if the Write Cycle completion notification could be interrupt controlled. Although it is not obvious, $\overline{\text{DATA}}$ Polling can be used in these applications as well.

It should be noted that the whole reason for Write Cycle notification is because the typical write times for the E^2PROMs are substantially shorter than the specified maximums. The magnitude of the delta between the typical and the maximum values determines the importance of the Write Cycle notification. One can easily see that if the maximum Write Cycle time and the typical were equal, one would only have to time a fixed interval for each Write Cycle, either from a software loop or a hardware timer. The hardware timer would generate an interrupt 10 msec after the Write Cycle was initiated, and the next byte could be written. Keep in mind that the discussion of write times for E^2PROMs are in terms of msec rather than the μsec in which the processor executes instructions. A few μsecs here or there are not important when compared to the Write Cycle time of about 10 msec.

$\overline{\text{DATA}}$ Polling does not require any additional hardware interface in order to be used. It is an exclusively software oriented method for determining Write Cycle completion. Even in an interrupt environment, no additional circuitry is required, since all of the interface to the chip occurs through the data and address bus.

In order to use $\overline{\text{DATA}}$ Polling in an interrupt driven system, one only needs a time-based interrupt generator. This could be a programmable timer or even something as simple as an AC frequency interrupt. The key is that the processor does not check to see if the device has completed the Write Cycle until the interrupt occurs. The interrupt routine simply compares the data last written to the E^2PROM to the data coming from the E^2PROM. If the two match, the device can be written again. If not, the processor simply returns from the interrupt routine to where it was and continues processing until the next interrupt. The interrupt source is maskable which prevents the overhead of servicing the periodic interrupt during the intervals when a write has not been performed.

A programmable timer or counter is the most elegant solution. Figure 1 shows the hardware configuration of a typical system with the E^2PROM and the programmable timer on the bus. It should be noted that no unusual circuitry is needed from the E^2PROM socket, which preserves its usefulness as a truly universal socket. The timer interrupt output drives one of the processor's interrupt lines. Many systems already have such a timer on the bus, and as a result require no additional hardware changes to implement this method.

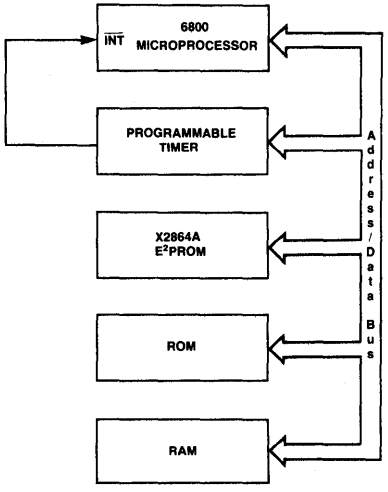

Figure 1: Hardware Configuration of a Typical System with the E^2PROM and the Programmable Timer on the Bus

The software implementation is rather simple. Figure 2 shows an example of how it might be done using a 6800 microprocessor and a simple timer. The timer control and data registers are mapped into the memory locations described in the initial header along with the temporary RAM variables, which are used to store the last data written and its address.

The write routine (WEEPROM) initially checks to see if the E^2PROM is ready to perform a write. If not, it simply exits with an error code to show that the write has not taken place. If the write is performed, the timer is loaded with the initial count for 4 msec, and the timer interrupt is enabled. The processor then goes off and performs its normal duties until the interrupt takes place. At that point, the interrupt routine (CKEEP) is entered. It first checks for the proper data that was written to see if the write is complete, using $\overline{\text{DATA}}$ Polling. If it is, the ready flag is set, and the routine is exited. If not, the counter is loaded with a smaller increment, such as 500 μsec until the chip's Write Cycle is completed. This essentially allows the majority of the Write time to pass (4 msec) before the processor checks at the more frequent interval of every 500 μsec.

Five hundred μsec has been chosen in this example for the interrupt granularity. The value used for a particular application should be chosen based upon the actual system requirements.

One can see that this implementation is rather easy and can be performed with hardware that already may exist in the system. By using the periodic interface approach, the system has the advantage of using an interrupt driven write algorithm, while maintaining only a software interface to the E^2PROM. Most of the "bookkeeping" sections of the example code are the same as one would use with any method of write termination notification. The end result of using $\overline{\text{DATA}}$ Polling in an interrupt environment is optimization of the Write Cycle period as well as preservation of the pinout of the universal 28-pin socket for expansion through the 256K bit level for E^2PROMs.

```
PAGE -   1  DATA_COD
File: :DATA_CODE.TEXT                CODE FOR DATA POLLING IN INTERRUPT ENVIRONMENT, 6800 VERSION

0000:                                          .PROC DATA_CODE
Current memory available:     4380
0000:                        ;*********************************************************************
0000:                        ;       SAMPLE CODE FOR USING DATA POLLING IN INTERRUPT ENVIRONMENT
0000:                        ;   THIS CODE SHOWS AN EXAMPLE OF HOW TO USE DATA POLLING IN A
0000:                        ; INTERRUPT DRIVEN WRITE MODE
0000:                        ;*********************************************************************
0000:                        ;                MEMORY LOCATIONS
0000: 0100                   TIMER   .EQU     0100H   ;LOCATION OF TIMER DATA REGISTER(COUNT DOWN VALUE)
0000:                                                ;16 BIT VALUE(2 BYTES)
0000: 0102                   CTIMER  .EQU     0102H   ;TIMER CONTROL REGISTER
0000: 0103                   LASTA   .EQU     0103H   ;RAM LOCATION FOR LAST WRITTEN DATA
0000: 0104                   TEMP    .EQU     0104H   ;RAM LOCATION FOR LAST ADDRESS WRITTEN
0000: 0106                   ERROR   .EQU     0106H   ;ERROR FLAG FOR WRITE
0000: 0107                   READY   .EQU     0107H   ;MEMORY READY FOR NEXT WRITE FLAG
0000: 0108                   CONFIG  .EQU     0108H   ;TIMER CONFIGURATION BYTE
0000:
0000:                                .ORG 0F000H
F000:                        ;*********************************************************************
F000:                        ;                EEPROM WRITE ROUTINE
F000:                        ;   THIS ROUTINE WRITES A BYTE OF DATA PASSED IN THE A ACCUMULATOR INTO
F000:                        ; THE EEPROM AT LOCATION POINTED TO BY THE VALUE IN THE X INDEX REGISTER.
F000:                        ; THE ROUTINE THEN INITIALIZES THE DATA IN THE COUNTER TO 4096, SINCE THE TIMER
F000:                        ; COUNTS AT A 1 MHZ FREQUENCY.  THIS WILL TIME OUT THE INITIAL 4 MSEC OF THE WRI
F000:                        ; WRITE CYCLE.  THE ROUTINE THEN ENABLES THE INTERRUPTS AN RETURNS CONTROL TO
F000:                        ; THE CALLING ROUTINE
F000:                        ;*********************************************************************
F000: C6 00                  WEEPROM LDAB    #00H    ;COMPARE TO SEE IF THE MEMORY IS READY FOR WRITE
F002: F1 0107                        CMPB    READY   ;CHECK MEMORY LOCATION READY
F005: 27 **                          BEQ     WRITE   ;IF READY THEN WRITE
F007: C6 00                          LDAB    #00H    ;OTHERWISE SET THE ERROR FLAG
F009: F7 0106                        STAB    ERROR   ;AND STORE IT IN ERROR
F00C: 20 **                          BRA     EXIT    ;AND EXIT
F00E: A7 00                  WRITE   STAA    0,X     ;WRITE THE DATA IN A TO LOCATION X
F010: B7 0103                        STAA    LASTA   ;STORE DATA IN RAM AT LASTA
F013: FF 0104                        STX     TEMP    ;AND STORE LOCATION IN EEPROM AT TEMP
F016: C6 10                          LDAB    #10H    ;LOAD THE FIRST BYTE OF 4096 HEX INTO B ACCUMULATOR
F018: F7 0100                        STAB    TIMER   ;WRITE TO TIMER DATA REGISTER
F01B: C6 00                          LDAB    #00H    ;LOAD THE SECOND BYTE OF 4096 HEX
F01D: F7 0101                        STAB    TIMER+1 ;STORE IN THE LSB OF TIMER REGISTER
F020: F6 0108                        LDAB    CONFIG  ;GET THE TIMER INITIALIZATION CODE
F023: F7 0102                        STAB    CTIMER  ;STORE IT IN THE TIMER CONTROL REGISTER
F026: 0E                             CLI             ;CLEAR INTERRUPT MASK TO LET TIMER INTERRUPT
F027: 39                     EXIT    RTS             ;RETURN FROM SUBROUTINE
F028:                        ;*********************************************************************
F028:                        ;           CHECK EEPROM ROUTINE
F028:                        ;   THIS ROUTINE CHECKS TO SEE IF THE EEPROM IS DONE.  IT IS ENTERRED
F028:                        ; EVERY TIME THAT THE INTERRUPT IS GENERATED FROM THE TIMER.  IT COMPARES
F028:                        ; THE DATA AT LOCATION TEMP IN THE EEPROM WITH THE DATA THAT IS STORED IN
F028:                        ; LASTA LOCATION IN RAM.  IF THE COMPARISON FAILS, THEN THE EEPROM IS NOT
F028:                        ; DONE  YET , ADN THE TIMER IS RESET TO TIME 1/2 MSEC(OR 512 USEC).  THE
F028:                        ; ROUTINE IS THEN EXITED.
F028:                        ;*********************************************************************
F028: B6 0103                CKEEP   LDAA    LASTA   ;GET THE LAST DATA WRITTEN
F02B: FE 0104                        LDX     TEMP    ;GET THE ADDRESS FOR THE BYTE IN EEPROM
F02E: A1 00                          CMPA    0,X     ;COMPARE TO SEE IF THE WRITE IS COMPLETE
```

```
PAGE -   2  DATA_COD
File: :DATA_CODE.TEXT                CODE FOR DATA POLLING IN INTERRUPT ENVIRONMENT, 6800 VERSION

F030: 26 **                                  BNE     REINIT  ;IF NOT EQUAL REINITIALIZE THE TIMER
F032: 86 00                                  LDAA    #00     ;SET THE READY FLAG
F034: B7 0107                                STAA    READY   ;AND STORE IT IN READY
F037: 20 **                                  BRA     RET     ;AND RETURN FROM SUBROUTINE
F039: 86 02                          REINIT  LDAA    #02H    ;LOAD THE FIRST BYTE FOR COUNTER
F03B: B7 0100                                STAA    TIMER   ;WRITE TO TIMER DATA REGISTER
F03E: 86 00                                  LDAA    #00H    ;LOAD THE SECOND BYTE
F040: B7 0101                                STAA    TIMER+1 ;WRITE TO LSB OF TIMER DATA REGISTER
F043: 3B                             RET     RTI             ;RETURN FROM INTERRUPT
F044:                                ;*********************************************************************
F044:                                    .END
```

```
SYMBOL TABLE DUMP
       CODE FOR DATA POLLING IN INTERRUPT ENVIRONMENT, 6800 VERSION

AB - Absolute      LB - Label       UD - Undefined     MC - Macro
RF - Ref           DF - Def         PR - Proc          FC - Func
PB - Public        PV - Private     CS - Consts        RS - Residents

CKEEP     LB F028:  CONFIG   AB 0108:  CTIMER
LASTA     AB 0103:  READY    AB 0107:  REINIT
WEEPROM   LB F000:  WRITE    LB F00E:

AB 0102:  DATA_COD PR -----:  ERROR    AB 0106:  EXIT     LB F027
LB F039:  RET      LB F043:  TEMP     AB 0104:  TIMER    AB 0100
```

Figure 2: Software Implementation for 6800 Microprocessor and a Simple Timer

NOTES

E²PROM PROVIDES THE SOLUTION TO FIELD ALTERABLE SOFTWARE

By Rick Orlando

Vol. 2, No. 15

The advent of the 5-volt E²PROM has brought about many changes in the manner in which the designer views his software. Such devices allow for in-field reprogrammability, which greatly reduces the cost and impact of software changes or upgrades. The 5 volt E²PROM allows the designer the capability to completely upgrade or change his software from a remote location rather than through the replacement of the system ROMs or EPROMs, a costly and inconvenient method at best. Complete infield programmability requires that the entire program store of the system be implemented in E²PROM. An alternative is a "hybrid" system.

A "hybrid" approach refers to a design which utilizes both EPROMs or ROMs in conjunction with E²PROMs to yield a design which features the best of both approaches: the low cost of a full ROM implementation, while maintaining the flexibility of a full E²PROM approach.

The secret to this approach is to analyze the software requirements of the end system from two distinct levels. That of the machine code routines which perform the simple tasks, and that of the higher level routines which call the lower level routines to perform an algorithm. The order in which the low level routines are called is determined by the higher level routines or program flow. This "Top-Down" programming approach is more efficient and structured, and is the basis for many high level languages. The fact that it can be used in machine language coding should not come as a surprise to designers, since the decomposition of a complex task into many simple tasks is quickly learned in programming, even if it is not called "structured programming" per se. The decomposition of the end task can sometimes lead to many different levels of program structure, but for the simplicity of discussion, this brief will limit itself to the most simple approach, that of two level program structure.

The lower level code consists of the machine dependent routines such as that required to fetch a character from an I/O link. The buffering of multiple characters from this link might also be a low level routine. The interpretation of the buffered character string will be implemented in the higher level code, since it simply calls the lower level routines and determines the action to take based upon their results.

A basic example is that of the executing of multiple character command entered by the operator from a keyboard. The lowest level routine simply gets a character from the keyboard if a key is depressed. The next level of the software "buffers" the input to make the system more "user-friendly". This routine looks at the input string, eliminates misplaced blanks or other characters, and forms a character string which the high level program can understand. As a result, the "parsing" task is broken into three distinct levels.

The first involves the inputting of a single character from the keyboard into a character buffer. The second level continually calls the first routine until an end-of-input character is detected (such as a Carriage Return). The top most level of the code takes the parsed command and determines if it is a valid command by searching a table of valid commands. If the command is valid, the address of the routine to execute is fetched out of the table, and the processor performs a jump. Most of the input processing is handled at the lowest level, thereby reducing the overhead in the outermost routine.

As more and more of the processing tasks are pushed "down" into low level routines, the main procedure in the high-level segment becomes very short and simple. In fact, it can be reduced to a simple list of jump-to-subroutine instructions. This structured approach not only eases the software development task, but it also minimizes the debugging time required for the software since it is built upon other routines which have already been debugged.

If one completely decomposes the task to be performed by a particular segment of the systems main program, it becomes a list of procedure calls to lower level segments. This method lends itself very well to a system which can use E²PROM. Since the "outermost" program store is quite compact, it can be implemented in E²PROM while the majority of the machine code in the lower levels can be implemented in ROM or EPROM. Changes to the software then become as simple as changing the jump location in the E²PROM, and the order of execution of the lower level routines can be altered in such a manner.

Using this method, one can also reserve a section of the E²PROM for low-level "patch" alterations to the software. If a low level routine is found to be in error or needs updating, the new version of the machine code is loaded into the reserved section of the E²PROM. The jump instructions in the high level code in the E²PROM are simply changed to "jumps" to the new routine now residing in the E²PROM as opposed to the old routine in the ROM or EPROM. Figure 1 shows a typical memory map where the E²PROM is used to store the high-level routines which perform a variety of jump to subroutines to control the program flow. The low level machine language routines are stored in the EPROM as shown. Figure 2 shows how a patch is made to replace the old routine in EPROM called "PARSE" with a new version loaded into the E²PROM. The jump-to-subroutine addresses in the E²PROM are updated to point to the new routine in E²PROM. The actual update or "patch" can be performed remotely, thereby eliminating the need for in field EPROM replacements for both the remedying of software bugs as well as the upgrading of systems in the field to take advantage of new features or capabilities.

Since both the valid character and the valid command tables reside in the E²PROM, new entries can be made to allow for additional command selection. New command character strings are simply added to the valid command list. The low-level code for the new command can either be loaded into the E²PROM patch area or utilize routines which already exist in the ROM or EPROM. The appropriate address is appended to the new command string.

If an error is discovered in an existing command, the valid command list is updated to point to the new command routine which is loaded into the patch area of the E²PROM. Figure 3 depicts the memory map after such a change has been made.

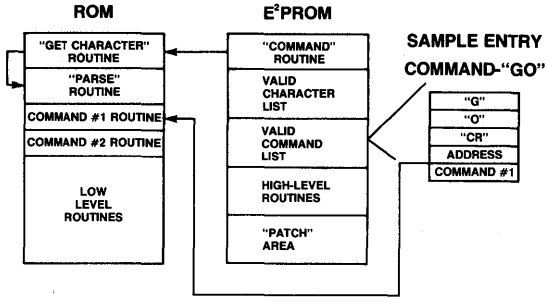

Figure 1: Memory Map Original Configuration

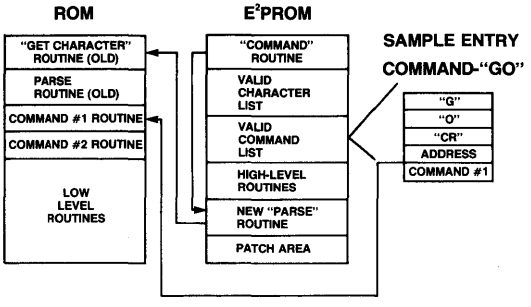

Figure 2: Memory Map After Routine Patch

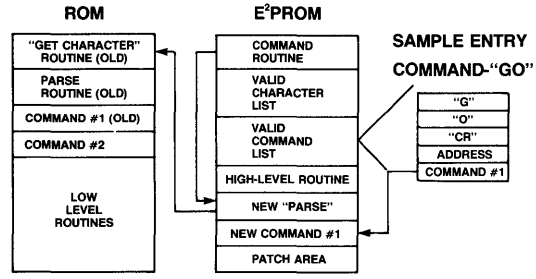

Figure 3: Memory Map After New Command Patch

Ultimate flexibility can be attained through a complete E²PROM design. It can also be shown that a minimal amount of E²PROM can add great flexibility to the system not only in terms of software alteration, but also in its intrinsic ability to store user alterable parameters such as configuration data. The actual ratio of EPROM to E²PROM must be determined based upon the systems' requirements. The advantage of the "hybrid" approach is that it requires that only the "top level" portion of the code be resident in E²PROM, and as such is usually limited to a series of procedure calls, which are very code efficient.

In the cases where the software is to be updated remotely, perhaps through the use of a modem, certain factors must be considered. The key point is that while the processor is executing programs in the E²PROM, it is unadvisable to write into that particular device. The reason for this is that while the device is performing the write cycle, any reads, such an opcode fetch, will result in a high impedance bus.

The important issue is that the download of the new code must not reside in the E²PROM to be modified.

This can be accomplished in two different ways. The first implements the download program segment in the low level ROM or EPROM. In this case, the actual instructions will be present from the memory throughout the download sequence. Figure 4 shows such an approach where the download software is kept in the ROM. This routine writes the new bytes into the E²PROM and then enters a software loop to time out the E²PROM write cycle.

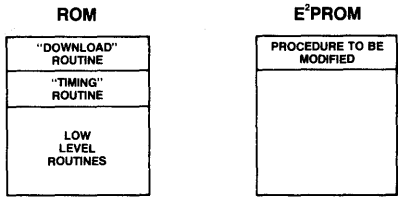

Figure 4: Memory Map-Download and Timing Resident in ROM

In some applications, this method may not be adequate, especially if the actual download routine is to be modified. In these cases, this program segment must be stored in the E²PROM, and hence, cannot be directly executed from the E²PROM to be modified. In this situation, a possible approach is to copy the download program segment from the E²PROM into RAM. The program then jumps to the RAM location, where the copy of the old code resides. This RAM routine loads the new program segment into the proper E²PROM locations, timing out the necessary E²PROM write cycle. Once the download is complete, the program executing out of the RAM then jumps back to the main program, and the download routine section of the E²PROM will contain the new code. Figure 5 shows the various stages of this operation in terms of the contents of the various memories and the program execution flow.

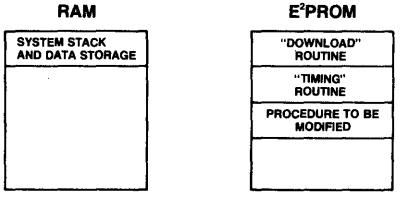

Figure 5a: Memory Map Prior to Download

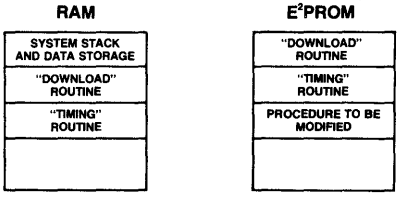

Figure 5b: Memory Map Download Routine Transferred to RAM

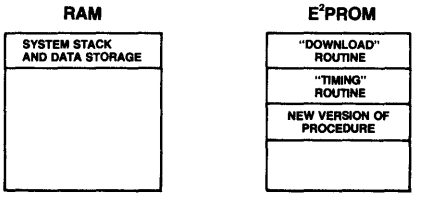

Figure 5c: Memory Map RAM Erased After Transfer Complete

As one can see, the "hybrid" approach to software design, utilizing a combination of both E²PROMs and ROMs or EPROMs, can result in a system which exhibits the advantages of the field alterability of E²PROMs. As the cost of the development and maintenance of the system software becomes more dominant in the overall cost of the system, such methods as those presented in this brief will become more commonplace in system design.

NOTES

Xicor Application Brief

FIFTEEN COMMON E²PROM QUESTIONS ANSWERED

By Rick Orlando

Vol. 2, No. 17

The wide variety of applications for E²PROM devices includes remotely alterable control stores and look up tables, calibration parameters, configuration data, nonvolatile counters, user programmable software storage, and artificial intelligence systems which update their algorithms as they learn. The E²PROM device features making these applications easier to implement include:

- 5 Volt Only Operation
- TTL Compatible Interface
- Noise Filtered Control Inputs
- 10 Year Nonvolatile Data Retention
- Self-Timed Write Cycle with On-Chip Latches
- Inadvertent Write Protection (V_{CC} Sensor)
- Transparent Byte Erase (Automated in Write Cycle)

This brief includes fifteen common E²PROM questions asked of the Xicor applications department. Frequently, the clarification of these points provides creative engineers with insights into new and unique applications. Should you need additional information, don't hesitate to contact us.

Question No. 1: I am concerned about the possibility of inadvertent Write commands being generated on my system bus during power transitions. Is there an easy way to protect the data in the E²PROM device?

Answer: YES!! Xicor E²PROM devices protect against this occurence. First, there is an on-chip V_{CC} sensor which inhibits the control inputs when the supply voltage drops below 3 volts. Second, noise protection is standard on the $\overline{WE}$ input pins. This blocks out spikes and glitches that might otherwise indicate a Write Cycle. Third, a control pin combination is required so external power-up/down protection is easy to implement. For detailed information on data protection, please refer to Application Brief Vol. 1, No. 1, NONVOLATILE DATA INTEGRITY: Inadvertent Write/Store Elimination.

Question No. 2: The Write Cycle timing diagrams on the X2804A and X2816A data sheets show that the internal data latch secures the data upon the first rising edge of $\overline{WE}$ or $\overline{CE}$. In an existing design, external latches supporting the E²PROM socket hold these two control signals LOW for the full 10ms period. How can the X2804A and X2816A devices be used without hardware changes to my system?

Answer: The Xicor E²PROM family is compatible with existing industry standard sockets. The internal data latches on the X2804A and X2816A devices are transparent so that, while not latched, the data on their inputs is passed directly through. This feature makes X2804A and X2816A use in externally latched sockets plug-in simple. Data may be held constant by an external latch, along with the control signals, and the Xicor devices will write perfectly. An economizing suggestion in this case would be to leave the external latches and timers off the board and jumper the control, data, and address busses directly to the E²PROM socket. Since Xicor designed all of these functions on-chip, the expense of support hardware required by some competing E²PROM manufacturers is eliminated.

Question No. 3: The Standby current requirements of the X2804A and X2816A devices is too great for our portable CMOS system. If the V_{CC} line is switched open, will the E²PROM I/O lines load the bus?

Answer: No. The output driver for each I/O pin is composed of a matched series pair of enhancement mode NMOS FETs as shown in Figure 1. During normal power-up operation, these drivers are in the HIGH-Z mode whenever the E²PROM is not selected.

While the device has no power applied, these FETs are not conducting so the output pin presents a HIGH-Z load to the bus. The device input pins are simply V and I protected FET gates, so there is no loading beyond the input capacitance, and minimal leakage current. The Zener diode input protection allows for signals to be applied to the X2804A and X2816A when the V_{CC} line is open. The internal V_{CC} sensor designed into the X2804A and X2816A E^2PROMs ensures that the control inputs are inhibited whenever V_{CC} = 3V. Therefore, data integrity is maintained even while V_{CC} is switched open.

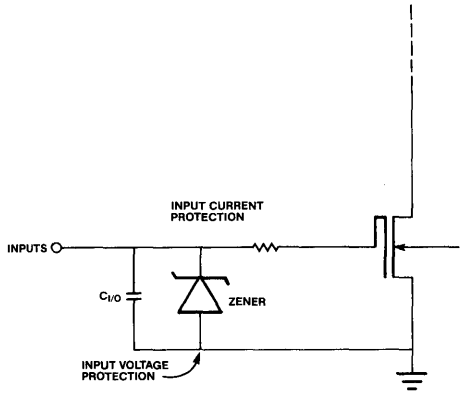

Figure 1a: Input Circuit Model

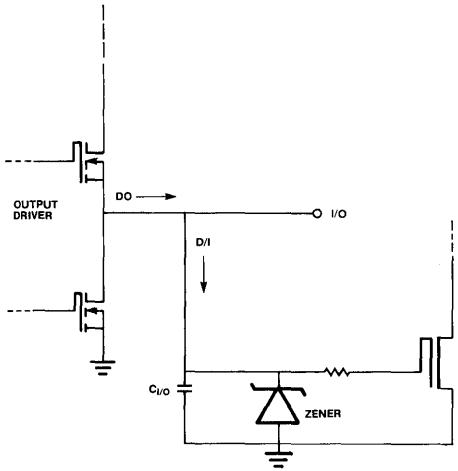

Figure 1b: I/O Circuit Model

Many remote and portable system designs have taken advantage of E^2PROM nonvolatility through the use of a low on-resistance Power FET which switches supply current to the V_{CC} line as shown in Figure 2a. The algorithm is shown in Figure 2b. Note that the Power FET must remain enabled for at least 10ms after the initialization of the most recent Write Cycle so that the E^2PROM power supply remains in-spec for the duration of the nonvolatile Write Cycle. Since the device is off the bus during this period, the system may optionally perform other tasks while the nonvolatile Write Cycle completes. Where maximum power conservation is necessary, the 10ms power-up period may be reduced to typical (5ms) nonvolatile Write periods by polling the E^2PROM for HIGH-Z 10ms I/O lines on the X2804A and X2816A (see next question) or utilizing the $\overline{DATA}$ Polling feature designed into the X2864A see Application Brief Vol. 1, No. 2, $\overline{DATA}$ Polling and Page Write Combine to Offer Improved Write Timing Characteristics.

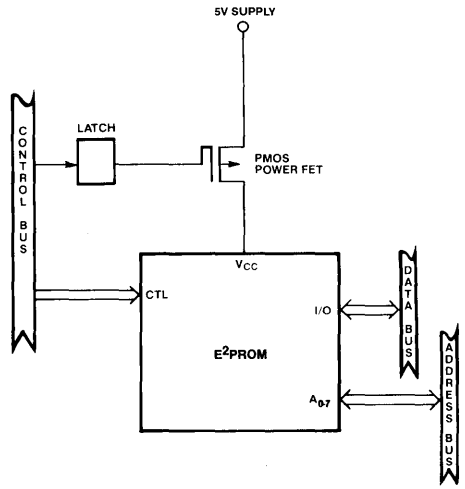

Figure 2a: Use of Low On-Resistance Power FET

Question No. 4: The maximum nonvolatile Write Cycle period is specified over the temperature range as 10ms on the X2804A and X2816A E^2PROMs. What is the typical time required and how might it be utilized?

Answer: Typically, these devices complete the non-volatile Write Cycle in less than 5ms. The cycle is initiated by a standard microprocessor write cycle. As the last of $\overline{CE}$ or $\overline{WE}$ falls LOW, the address to be written to is latched into the on-chip address latches. When the first of $\overline{CE}$ or $\overline{WE}$ transitions back to HIGH, the data latches lock the data to-be-written on board the chip (see Figure 3). These features make the Xicor E^2PROM appear as a standard static RAM to the system. The on board timer is initiated when the address is latched and once the data is latched, the device inputs are inhibited and the outputs placed in their HIGH-Z mode, thereby freeing the system to perform other tasks. The E^2PROM outputs remain floating until the internal operations are complete, at which point, the X2804A and X2816A are immediately available for access.

To take advantage of typical Write times and maximize the multiple byte Write speeds, simply poll the E^2PROM looping until the floating outputs are no longer detected (see Figure 4). For example, in a

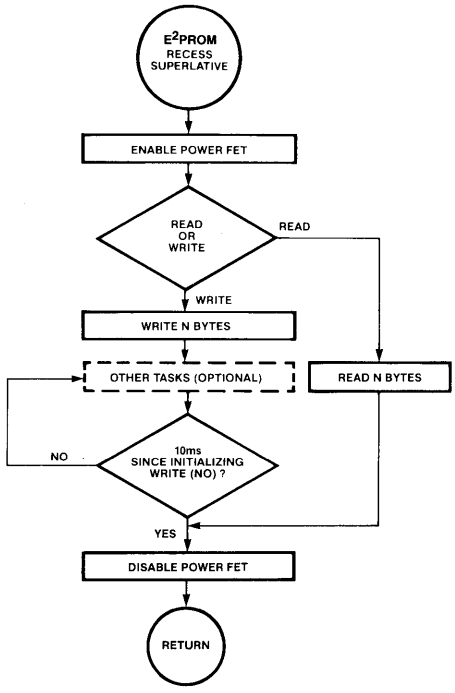

Figure 2b: Algorithm

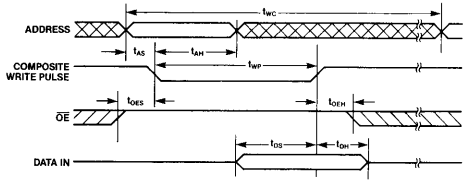

Figure 3: E²PROM Timing

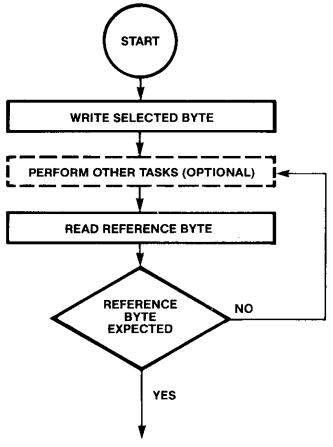

Figure 4: Flow Chart for Interrogation

system with a pulled up bus, 00 (Hex) could be permanently stored in the last address in the E²PROM. After the nonvolatile Write Cycle is initiated, the system attempts to read the last location. While the device is still internally occupied, the pullup resistors combined with the HIGH-Z state of the E²PROM output buffer, will provide FF (Hex) in response. Immediately upon completion of the nonvolatile Write Cycle, the inputs are again enabled and the Read Cycle will provide valid data from the E²PROM. In this example, the software would loop until the data acquired is 00 (Hex).

The X2864A has a software feature designed into it for this purpose. $\overline{\text{DATA}}$ Polling inverts D_7 of the last byte written, and routes it to the output buffer while the device is internally occupied. This way the user simply reads the last address written, comparing the data to the last data written, until they match indicating nonvolatile Write Cycle completion. Refer to Application Brief Vol. 1, No. 2, $\overline{\text{DATA}}$ Polling and Page Write Combine to Offer Improved Write Timing Characteristics for details.

Question No. 5: How do the Read Access and Write Cycle times change as the E²PROM operating temperature varies?

Answer: Xicor maximum and minimum specifications are guaranteed over the full operating temperature range of the device. These values are established under worst case conditions and specified with a conservative margin. This means that, invariably in a systems environment, Xicor products perform much better than the data sheet indicates. In terms of actual parameter variation, Read Access time varies proportionately to temperature, and Write Cycle time varies inversely with temperature. They each stay well within their respective maximum specifications throughout the allowable temperature range of the device.

Question No. 6: Will signals applied to E²PROM pins designated NC (not connected) damage the devices?

Answer: No. NC pins have no connections to the device.

Question No. 7: How much drive current is required to hold the $\overline{\text{CE}}$, $\overline{\text{OE}}$, and $\overline{\text{WE}}$ inputs low?

Answer: The input configuration of Xicor E²PROMs is shown in Figure 1a and is standard NMOS. Only the leakage current (max 10μa) and enough charge for the 6 pF input must be capacitance driven.

Question No. 8: Can the E²PROM be read during the 10ms nonvolatile Write Cycle?

Answer: No. During the internally timed write, the device inputs are inhibited and its outputs are in a

high impedance state. However, once the nonvolatile Write Cycle is complete, (typically <5ms), normal data access may be resumed.

Question No. 9: The X2804A and X2816A data sheets make no mention of the standard byte-erase cycle which precedes an E^2PROM byte-write. Is there something about Xicor E^2PROMs which eliminates this requirement?

Answer: Yes! On Xicor E^2PROMs, an automatic and user transparent byte erase cycle is initiated as a normal part of the nonvolatile Write Cycle. This feature eliminates the extra time and software required by the other E^2PROMs.

Question No. 10: When interfacing the Xicor E^2PROMs with a CMOS system are pullup resistors required?

Answer: Yes. The V_{OH} min specification on the Xicor devices is 2.4V, and the V_{IH} min for CMOS technology (when V_{DD} = 5V) is 3.5V. To ensure that E^2PROM HIGH outputs are recognized by the CMOS inputs, pullup resistors are necessary. Of course, CMOS outputs can drive the E^2PROM inputs directly with no pullup assistance.

Question No. 11: We are using an entire bank of military X2864A devices on a common bus. If some of these are enabled and some not when high voltage chip erase cycle is executed, will the not-enabled devices be affected?

Answer: No. Those chips which are not enabled will not be modified.

Question No. 12: During the Read cycle, the Xicor E^2PROM outputs go low before stabilizing with valid data. Although the data is valid long before the specified access time, I wonder if this phenomenon is normal?

Answer: This operation is perfectly normal when clocking with $\overline{CE}$. While $\overline{CE}$ is HIGH, the device is in a standby state with the power to the output buffers and sense amps turned off. When $\overline{CE}$ goes LOW, the output buffers are turned on and the sense amps are reading a LOW until the actual cell-data reaches them. Therefore, with $\overline{OE}$ LOW and $\overline{WE}$ HIGH, when $\overline{CE}$ falls LOW valid data will be preceded by a brief LOW output.

Question No. 13: I have a mature product design using 2816 high voltage E^2PROM which I'd like to replace with the Xicor X2816A. How may I minimize expenses in this conversion?

Answer: The X2816A was designed with this replacement in mind. The 21V V_{PP} pin on the older part (pin 21) is named $\overline{WE}$ on the X2816A. This pin recognizes TTL HIGH and LOW values as well as the 21V V_{PP} pulse applied in older 2816 sockets with multi voltage sensing circuitry. Assuming $\overline{OE}$ is HIGH and $\overline{CE}$ is LOW, the Write Cycle can be initiated either by pulling $\overline{WE}$ down to V_{IL} or up to 21V. This versatility allows you the option of directly replacing the older 2816 with the X2816A or of reducing costs by eliminating the extra power supply, latches and software required to support the older 2816.

Question No. 14: We are using the high voltage Chip Erase function on the military E^2PROMs to Bulk Erase data so that the data is unavailable to unauthorized copying. Could a highly skilled technologist detect what the data was prior to erasure given enough resources?

Answer: No. The floating gate storage mechanism is driven to complete saturation when programmed, and all free electrons are removed upon erasure. Therefore, no trace of a previous state is left when a cell moves to the opposite state. This is one of the features of Xicor nonvolatile technology that makes it perfect for high security military applications.

Question No. 15: I am using several X2816As which form contiguous address spaces in my system. Does the "self-timed" feature on these devices mean that I can write to each of them independently during a single 10ms Write Cycle?

Answer: EXACTLY! The on-chip timer frees the busses (and therefore the system) for the duration of the write cycle. The on-chip latches are essential for this to be possible. A quick look at the data sheet Write Cycle timing diagram shows that the system can shake hands with the Xicor E^2PROMs for as little as (t_{AS} + t_{WP} + t_{DH} =) 170ns. The other 99.98% of the 10ms write cycle can be spent executing other system tasks which could include initiating write cycles to the other X2816As. This "gang programming" is one simple method of achieving very high effective-byte-write speeds in multiple device systems.

XICOR E²PROMS VS BATTERY BACKED-UP CMOS RAMs NONVOLATILE MEMORY SYSTEMS

By Applications Staff

Vol. 3, No. 19

Introduction

System designers are increasingly facing the requirements of providing for nonvolatile memory in the system design. This nonvolatile memory may be required for program control, data acquisition, system configuration, or a host of other uses. Once the requirement for nonvolatile memory is established, the next hurdle faced by the system designer is the choice of the technology to be used to implement the nonvolatile memory. This means the system designers are faced with many tradeoffs when selecting a technology to implement the memory portion of their design. Tradeoffs between technologies such as bipolar, NMOS, CMOS, bubble, etc. depend in large part on overall system factors—such as requirements for density, cost, power-dissipation, availability, reliability, etc. Such tradeoffs are generally evaluated in the "time-constrained" design environment leaving little time for the system designer to complete a thorough investigation of the tradeoffs and their impact on the system design and reliability. The implementation of nonvolatile memory systems using battery backed-up CMOS RAMs has raised questions regarding the comparison of these technologies with E²PROM devices. The purpose of this Application Brief is to discuss the tradeoffs between implementing nonvolatile memory designs with E²PROM devices and/or the twin technologies of batteries and CMOS static RAMs.

E²PROM/Battery Back-up CMOS Technology Comparison

CMOS static RAMs used in conjunction with batteries to achieve nonvolatile memory have the following characteristics in comparison with E²PROMs:

1.) Microprocessor compatible write cycle times
2.) Unlimited write cycles
3.) Low standby power
4.) Unknown battery/RAM data retention characteristics
5.) Temperature limitations

System reliability considerations and battery/CMOS design interface are the major issues between implementing nonvolatile memory systems with CMOS/battery combination and E²PROM devices. E²PROM devices are specified to reliably operate over a wide range of operating temperatures, altitudes, pressures and moisture. In addition, E²PROM devices can be subjected to extreme temperatures (>300°C) to accelerate data retention failure mechanisms and determine the probability of retaining data at the lower operating temperatures. Although CMOS devices can be subjected to the same tests—*the CMOS/battery combination cannot.* The result is the CMOS/battery combination cannot be evaluated *TOGETHER* to determine the failure rates for data retention.

Reliability

When choosing a memory device or technology, reliability factors should be carefully considered. Factors such as the environment in which it will be used, data retention time, etc. should all be considered.

In a forgiving environment (such as room temperature, low humidity and pressure) battery backed-up CMOS RAM has a respectable data retention time (although still not statistically measurable). Outside this environment, the performance of this combination decays rapidly. Most solid state memory devices (including CMOS RAMs and E²PROMs) have the capability of operating easily over the temperature range of −55°C to +125°C. But combined with a battery, a CMOS device can only operate within the temperature constraints of the additional technology—the battery. Most popular external onboard batteries spec a maximum operating temperature of 70°C. Xicor E²PROM devices guarantee a minimum retention time of 10 years at the worst case operating temperature (e.g. from −55°C to +125°C). Some CMOS RAM/battery combinations (contained in the same package) specify the "Expected Data Retention Time" of 10 years at 25°C. *This ten year data retention time is measured from the date of manufacture of the combination*

technologies. Non-operating specifications such as storage temperatures, also become a consideration. Battery backed-up RAM technologies (with the battery integral to the device) cannot be put into storage without the batteries. Since the batteries supply power to the RAM when V_{CC} is not present, there is no true storage mode (i.e. non-operating mode). This limits the storage temperature to the operating temperature specification of the combination. By comparison, E^2PROMs have specified storage temperature ranges from −65°C to +165°C. These storage temperatures apply whether the device is in the system or on the shelf.

Types of Battery Backed CMOS

There are two basic types of battery backed-up CMOS RAM technology implementations available on the market today:

1.) Battery internal to the IC package
2.) Battery external to the IC package

In the first type, the battery is permanently attached to the device inside the IC package. This type of implementation has its advantages when board space is at a premium. *It is noted, however, that this type of device is non-standard in height (approximately 300 mils taller than conventional DIP packages) which limits or eliminates the possibility of automated device insertion.* The battery internal to the device is generally of primary type in that it cannot be recharged. The second type of CMOS RAM system implementation requires an external battery to provide the required standby power for nonvolatile data retention. For this type of implementation, additional circuitry is required for the detection of a power failure and interconnection between the "normal" power supply and the battery—thereby significantly increasing board space requirements.

Battery Characteristics

Lithium and Nickel-Cadmium (Nicad) are two of the most commonly used batteries for back-up with CMOS RAM. Each has unique advantages in the system environment. Both can handle temperature variations of approximately 70°C over "some" time duration. Negative current spikes of greater than 10μA in the system can damage the device.

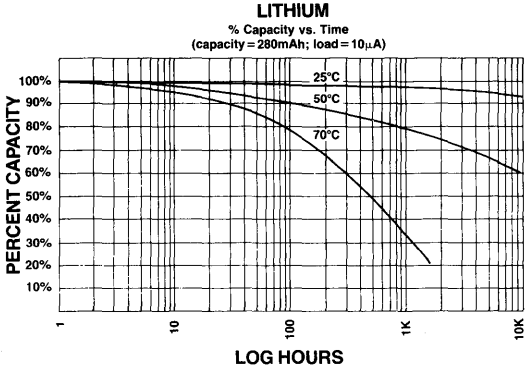

Figure 1: Lithium-Capacity vs. Time with Varying Temperatures

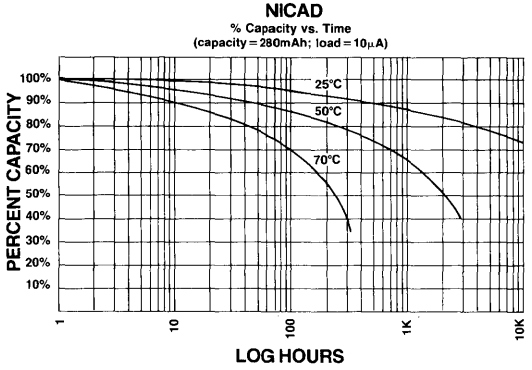

Figure 2: Nicad-Capacity vs. Time with Varying Temperatures

Lithium batteries, although not rechargable, have a greater life expectancy than Nicad batteries and generally have a shelf life of 10 years at room temperature. When used in a system as a battery back-up, where temperatures vary, the output of the battery becomes sporadic. This causes a decrease in capacity and unstable circuit voltages. Figure 1 shows a typical characteristic curve of a lithium battery's capacity vs. temperature. Drawing a current of only 10μA, the capacity could easily be reached in a very short time.

Additional concerns should be noted with transportation and disposal of lithium batteries. Because of the toxicity of lithium, the Department of Transportation regulates their transportation. Lithium cells containing greater than 0.5g must carry warning labels, and be transported by approved land, sea or air methods (document # DOT-E-7052). Generally, lithium batteries with more than 0.5g are restricted from passenger aircraft. Also the EPA requires special disposal of lithium batteries to secured landfill areas.

Nickel-Cadmium's most advantageous feature is the ability to recharge the battery once its output becomes low. Nicads can generally be charged many times without damage. Nicads tend to have a short shelf life so recharging is necessary. Figure 2 is a characteristic curve of a Nicad battery's capacity when being operated over various temperatures with a current draw of 10μA. When comparing Figure 1 and Figure 2 it is obvious that a Nicad doesn't have the capacity of a lithium battery.

Memory Densities

Xicor's NMOS floating gate technology has one transistor per storage cell. CMOS devices have four or six transistors per storage cell. This means that

the potential memory density of the E²PROM device is greater than for the comparable CMOS device.

Physical Dimensions

The size and number of devices on a board have often times been a determining factor in designing circuitry. Xicor has numerous possibilities in minimizing the necessary circuitry. First, within the same package constraints the memory density of E²PROMs that are available is eight times greater than that of CMOS static RAMs. Besides the typical dual-in line-package (DIP), Xicor also offers LCC packaging. Users have also used the E²PROM in its die form for various applications, including the use of X2864A for core memory in military applications. This conserves enormous amounts of space (i.e. the X2864A die is 0.215in by 0.170in, and the X2816A die is 0.185in by 0.151in. in die form). When physical size is an important factor, E²PROM devices have a clear cut advantage.

Applications

There are various optimum uses of E²PROMs for data and information storage. One such use is in the application of a portable data base where a large amount of memory is stored into a portable module. The memory module is plugged into the computer, data transferred bi-directionally, and then removed. The portable module can be transported or stored for long periods of time without the requirements of additional power. If battery backed CMOS were used in such an application, battery capacity could be a limiting factor for reliably maintaining data integrity.

In applications where data retention is critical, such as the boot-up storage area in a computer system, true nonvolatile memory is a must. With E²PROMs the data is nonvolatile, and allows any necessary changes to the boot-up routine. If batteries and CMOS RAM are used, critical "start-up" routines can be lost when the battery is replaced.

There are many other applications where E²PROMs are the technology of choice. These applications generally are exposed to harsh environments such as temperatures, changing pressure and altitude, or in high humidity environments.

The following is a partial list of typical applications which are ideal for E²PROM devices:

System Parameter Set-up
Configuration Data
Calibration Data
Constants Storage
Industrial and Process Controllers
Traffic Control Equipment
High Altitude Meterological Data Storage
Telemetry
Satellite Communication Equipment
Navigational Reference System
Digital Positioning Machinery
Measuring Instruments
Temperature Monitoring Equipment
Field Data Acquisition
Electronic Musical Instruments
Radio and TV Program Control
Disc Drive Servo
Robotics
Depth Recorders
Oil Field Drilling Systems
Core Memory for Military Use
Single Chip Microcontroller Applications

Cost and Availability

Design costs with CMOS RAM are another consideration. The added time to design low power detection and switching circuitry adds to engineering costs. The added circuitry increases component and stocking costs and increases board test time.

Xicor E²PROMs enable the designer to minimize the cost of designing, the cost of components and the cost of "time-to-market." By minimizing or eliminating the additional circuitry required for data retention integrity, system cost and reliability are enhanced. Xicor is the leading manufacturer of E²PROMs, having sold more 5-volt only E²PROM devices (NOVRAMs & E²PROMs) than all other manufacturers combined. This experience allows Xicor to maintain leadership in this key emerging market segment by providing reliable cost-effective nonvolatile devices. This "learning curve" characteristic is shown in Figure 4. This figure shows the price curve as a function of time for the X2864A, an 8K x 8 E²PROM.

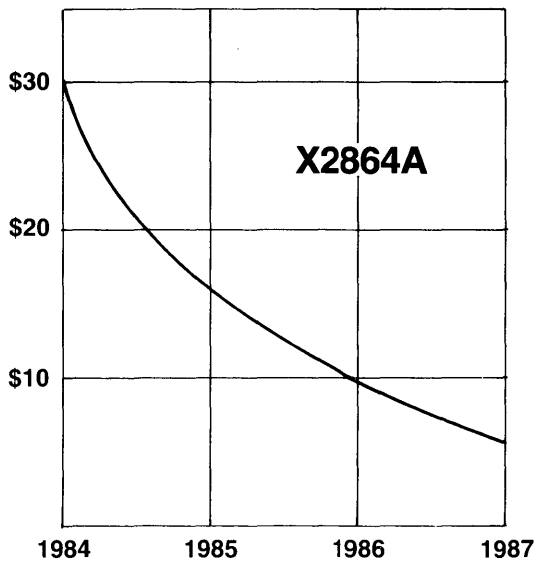

Figure 3: Price Curve as a Function of Time for the X2864A

NOTES

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5-volt-only EE-PROM mimics static-RAM timing

By Applications Staff, Xicor Inc., Milpitas, CA

5

5-volt-only EE-PROM mimics static-RAM timing

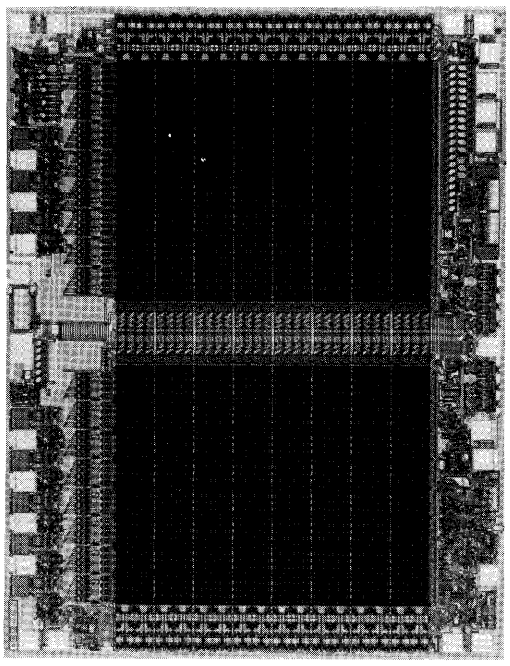
On-chip charge pump, interface latches simplify designs; textured polysilicon enhances tunneling through thick oxides

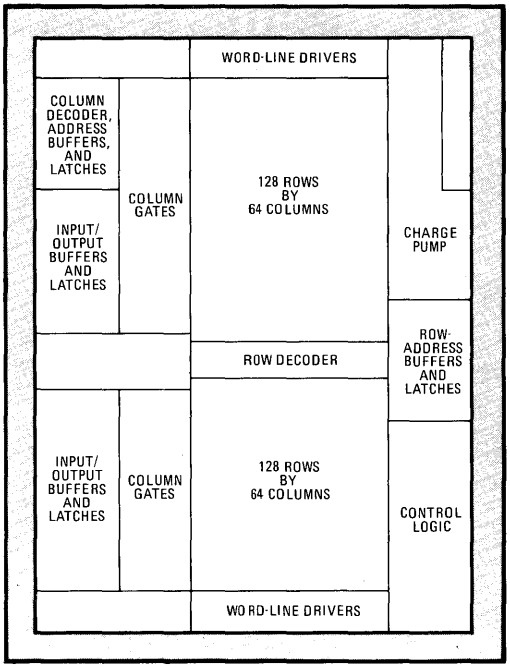
By Applications Staff, Xicor Inc., Milpitas, CA

☐ The approaching mastery in fabricating electrically erasable programmable read-only memory conjures up dramatically different system designs. On the most mundane—but perhaps most immediately valuable—level, alterable nonvolatile semiconductor memory will soon banish routine service calls by allowing remote changing of system software. Not far away, if still somewhat tinged with the aura of science fiction, is the vision of self-programmable systems that adapt themselves to a changing operating environment. The catalyst for these advances is an EE-PROM that is simple to incorporate in microprocessor-based systems.

Now being launched by Xicor is a family of EE-PROMs that is the first to do away completely with external supporting hardware (Fig. 1). The chips contain the charge pump that generates a high programming voltage from a 5-volt supply. Further, latches on chip hold the data, address, and control signals during alteration of the cells, which typically takes 5 milliseconds per byte and is timed internally. The part marks the debut of an EE-PROM that can simply be dropped into a standard 24-pin static random-access-memory socket.

The 5-micrometer n-channel MOS technology applied to produce the X2816A 2-K-by-8-bit EE-PROM and the X2804A, a 512-by-8-bit version, is the same as that being used to build the devices in the Novram line of static RAMs with nonvolatile backup arrays [*Electronics*, Oct. 11, 1979, p. 111]. Recently, however, theoretical





1. All aboard. This 16-K electrically erasable programmable read-only memory integrates all its support circuits. A charge pump generates the programming voltage from a 5-V supply; latches hold addresses and data during the internally timed write cycle.

Shedding light on electron tunneling

The present generation of electrically erasable programmable read-only memories using floating-gate structures draws on a reservoir of process development, circuit design, and basic physics. The floating-gate process has been in production for many years and forms the building block of EE-PROMs. The next step toward a practical 5-volt programmable EE-PROM centers on removing the high currents typically used to alter data by avalanche or hot-electron injection. A high voltage can be generated on chip as long as only minute currents are required, as with the new circuit designs.

As far as the underlying physics, the tunneling processes found in most floating-gate EE-PROM devices are described by a theory introduced in the 1920s by Fowler and Nordheim. As shown in the theory, if the emitting surface is flat, very thin oxides of around 100 angstroms are necessary for significant tunneling currents at reasonable voltages of 15 to 20 volts. To the continued puzzlement of researchers, experimental data has fit the theory roughly, but not especially closely.

Xicor purposely fabricates textured emitting surfaces that are covered with low-lying bumps or hills formed during the oxidation of the polysilicon surface. Recently, tunneling theory has been extended to describe this textured-surface geometry with the result that conventional devices are now better understood as well.

The low-lying hills, which serve as the electron emitters, are less than 150 Å high and more than 500 Å across their base. The figure on the right shows the triple-polysilicon tunneling strucfure in cross section, a scanning-electron-microscope photograph of a typical textured tunneling surface, and the geometry of a typical bump on the polysilicon surface.

Because the oxidation is a well-controlled step, the properties of the emitters are exceptionally regular. The shape of the emitters tends to increase the electric field at the crest of the hills, enhancing the emission of electrons substantially, which allows the use of thick oxide layers of approximately 800 Å. As indicated in the figure, increasing the voltage not only increases the emission, but enlarges the area from which it occurs. This effect explains the discrepancies between experiments and the earlier tunneling theory. The thick oxides have important practical advantages: they are easier to manufacture and lead to increased retention of data.

Until recently, the theoretical work on Fowler-Nordheim tunneling had solved only the limited case of perfectly flat plates. Roger Ellis and H. A. R. Wegener of Xicor recently presented measurements and calculations that agree over a range of eight orders of magnitude in the current. With the aid of the methods of differential geometry, the tunneling characteristics of a textured surface were calculated for the first time. As the scale of the texturing is reduced, the solution naturally reduces to the familiar flat-plate case. The figure on the far right compares the tunneling currents for flat and textured surfaces.

The two structures were designed for the same operating point—a current density of 10^{-4} amperes per square centimeter at 17 V. At low fields, such as are applied to read data, the thick oxide used with the textured surface has only about a thousandth the current of a flat surface. As a result, data retention would be expected to be far longer.

The current from a flat emitter in fact can be modeled much more closely by considering some texturing of its surface. Even single-crystal polished silicon wafers have surface features on the order of 5 Å, and normally processed polysilicon has even larger variations. Thus, Xicor's tunneling structures accentuate features that are always present in floating-gate devices.

work has significantly added to the understanding of the tunneling of electrons from textured polysilicon, the mechanism exploited in all these products (see "Shedding light on electron tunneling," above).

This work explains how a textured surface emits more electrons than a smooth one for a given voltage and oxide thickness. (Scanning-electron-microscope studies of the polysilicon surface show that the texturing consists of low-lying bumps about 150 angstroms high and 500 Å across.) This enhanced emission allows the use of typically 800-Å-thick oxides, instead of very thin, 100-Å layers that are much harder to produce reliably.

Besides being easier to manufacture, thicker oxides lead to increased retention of data. What's more, a 16-K EE-PROM with 5-μm linewidths and 800-Å-thick oxides promises to be more readily scaled down for denser memory arrays than one with, for example, 3-μm lines and 100-Å-thick oxides.

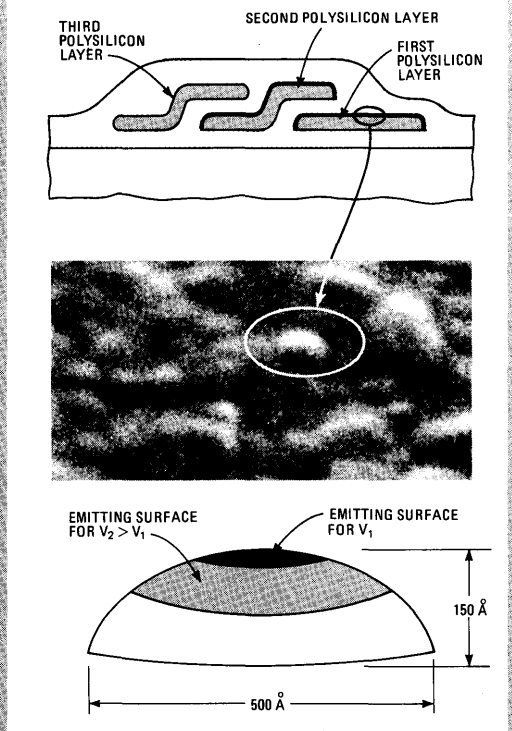
Floating-gate technology along with the architectural features making the parts simple to use present the state of the art in EE-PROMs after a decade of development. Metal-nitride-oxide-semiconductor structures yielded the first nonvolatile memories that were electronically alterable. These devices store data by trapping electrons within the nitride and oxide dielectrics. Besides the problems these devices encounter—data disturbance during the read operation and the loss of data over time—they require multiple power supplies, one of which is often negative, and signal swings beyond TTL levels. All this complicates their incorporation within microprocessor-based systems that work with a single 5-V power supply and TTL levels.

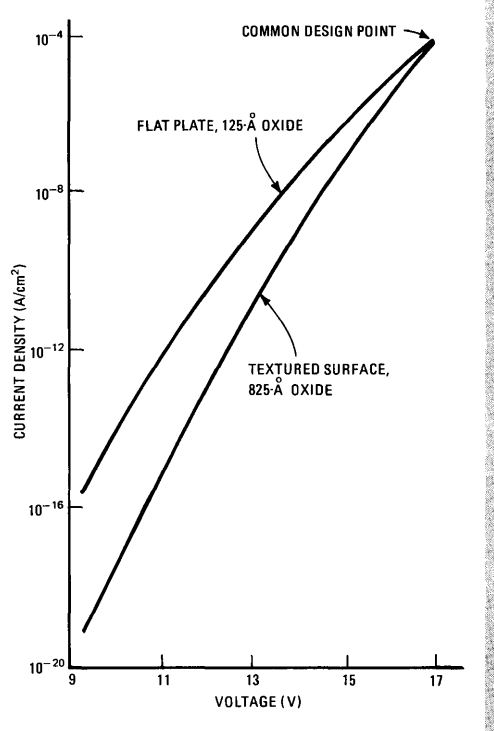
Further complicating their use is the fact that the addresses and data must be stable for the entire write cycle, lasting up to 40 ms. It takes extra hardware to capture these signals and to time the write interval in order to free the processor for other tasks.

Comparing EE-PROMs

The second generation in EE-PROMs was ushered in by the 2816 from Intel Corp. of Santa Clara, Calif. This part stores data by trapping charge on floating polysilicon gates, as is done in ultraviolet-light–erasable PROMs, or E-PROMs, and improves the data integrity compared with MNOS parts. Although the 2816 has a standard pin configuration and uses TTL signal levels, it still requires an externally generated high-voltage pulse for altering data, not to mention latches for holding the address and data signals.

Measured against the 2816, recently introduced third-





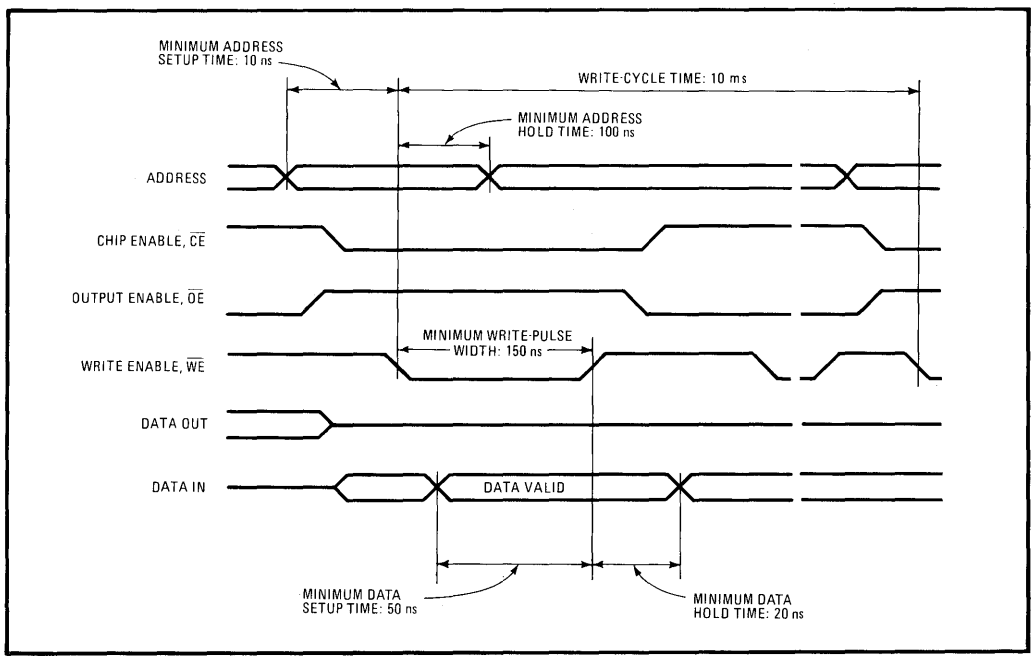
generation parts incorporate some or all of the required supporting hardware on chip (see table). The 2817 from Intel moves the external high-voltage pulse generator onto the chip, so that a fixed 21-V supply is all the user must provide. Though it does include the necessary interface latches, it still requires an external capacitor to time the write cycle. More recently, the 5213 from Seeq Technology Inc., San Jose, Calif., operates from a single 5-V power supply, but still needs latches and external timing. Only the X2816A completely eliminates the external components.

COMPARISON OF RECENT ELECTRICALLY ERASABLE PROGRAMMABLE READ-ONLY MEMORIES

Part	Intel 2816	Intel 2817	Seeq 5213	Xicor X2816A
On-chip charge pump				
Address and data latches				
Automatic erase				
Internal timing of write cycle				
Internal control of write-pulse shape		needs external capacitor		
Maximum erase-write cycle time (ms)	20	75	20	10

All the X2816A's input and output signals are TTL-compatible and the addresses and data are latched so that they need be stable for only 200 nanoseconds to initiate the 10-ms write cycle. Once the write cycle starts, the part self-times the remainder of the operation, freeing the microprocessor and the data bus for other tasks. Freedom from an external timing capacitor or other hardware leads to considerable savings in component and assembly expense as well as in board space. In addition, the cost of design is lower because the part is far simpler to operate.

As can be seen in Fig. 2, the timing of a write cycle for the X2816A is as simple as that for a static RAM. The latches are active only during a write cycle, when they hold the addresses and data to allow the microprocessor to use the bus for other tasks. A write cycle is activated by both chip-enable and write-enable lines going low while output-enable is high. The addresses are latched on the last low-going edge of either the chip-enable or write-enable signal. The data inputs are latched by the



2. Like a static RAM. The write-cycle timing for the X2816A EE-PROM looks much like that for a static random-access memory. Although the write cycle takes a maximum of 10 ms, latches hold the address and data signals, freeing the processor for other tasks.

first of those two signals to return to the high level.

Unlike with most EE-PROMs, there is no need to precondition the data at the desired address before the write cycle, for the X2816A automatically performs an erase function immediately after the cycle starts. Both the erase and write of the data occur during the 10-ms write cycle. The condition requiring the output-enable signal to be high to initiate the write cycle ensures that the part will not be mistakenly programmed when the power is switched on or off.

A compatible part

Conveniently, a socket designed for one of the earlier EE-PROMs can accept an X2816A as well. An internal detector on the write-enable pin senses a signal above 12 V and initiates the internal write cycle (and thus the part may second-source the 2816). This high-voltage signal is used only to detect the system's request to write data—otherwise, the part draws virtually no current from the high-voltage supply.

Further, because of their internal control over the write cycle, the Xicor EE-PROMs can plug into the standard sockets of 2-K-by-8-bit static RAMs. They will operate with the signals normally applied to a RAM, with the only restriction being the delay of 10 ms after starting a write cycle before accessing data. As mentioned already, the X2816A is not on the bus and requires no servicing or supervision during this 10-ms wait. Since the parts time their own write cycle, other EE-PROMs may be updated while a write cycle is continuing on the first unit.

The 10 ms quoted is the maximum delay for writing—the typical delay is only half that. By polling the part during its write cycle, a user can usually reduce the waiting time. One method is to place a particular byte of data at some address and then ask for data from that address during the write cycle. If the data that is retrieved checks against the data written, the part has finished its cycle.

With the cost of a single service call to modify a system in the field mounting toward $200, no doubt the system that can be serviced from afar will be an early development goal. With an EE-PROM plus a modem or other communication method, a telephone call suffices to download the program and configuration data pertaining to all or some of the systems tied together in a network.

A prime application for this technique would be a system of point-of-sale terminals for a market chain. Pricing for items could be dumped to all terminals in the system by calling each store and modifying the price look-up table in each terminal. Similarly, gasoline prices at computer-controlled service-station pumps may be remotely updated.

Indeed, from here it is only a simple step to imagine writing programs that learn as they go. A terminal might analyze the way it was being used and adjust itself for optimum performance in a particular application. By the same token, the next wave of automated manufacturing systems may calibrate themselves, hold information about the steps that have been completed, then interrogate themselves to determine their point in the manufacturing process. □

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Publisher's letter

Though nonvolatile semiconductor memories have been commercially available for a decade or so, the early versions were no joy to work with—multiple power supplies, high voltages, and slow writing discouraged potential users. The push to create a simpler part is yielding noteworthy results, particularly the 16-K electrically erasable programmable read-only memory that Xicor Inc. describes on page 2.

Solid state editor Rod Beresford first heard about the company's new chip back in January. "At the time," he recalls, "we had just published our annual markets forecast, in which we were projecting that consumption of EE-PROMs would nearly quadruple by 1985, to over $330 million. Many of those parts will be going into microprocessor-based systems, where 5-volt power supplies and TTL signal levels are the only way of life."

Xicor's X2816A gets high marks for ease of use. In fact, it's not only microprocessor-compatible, it's a truly self-supporting EE-PROM that's as simple to use as a static random-access memory. Beyond those features, though, our editor was struck by the research at Xicor on the electron tunneling that provides the storage mechanism in EE-PROMs. "I studied tunneling in school," notes Rod, "and can appreciate what the Xicor researchers were up against in trying to get a better fit between theory and experiments. I think they succeed admirably."

Xicor

Understand your application in choosing NOVRAM, EEPROM

Richard Orlando, Xicor Inc., Milpitas, CA

As appeared in EDN Magazine

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Understand your application in choosing NOVRAM, EEPROM

Examining how NOVRAMs and EEPROMs serve various applications illustrates the memory devices' capabilities and simplifies device selection.

Richard Orlando, Xicor Inc

If your system design calls for electrically erasable nonvolatile data storage, you can simplify the selection of semiconductor memory for that task by choosing from among four basic types—NOVRAM, EEPROM, EAROM and battery-backed CMOS RAM. Assuming that you've examined the system-level tradeoffs among these memory types (EDN, April 14, pg 135) and have narrowed your choice to the first two, use the information presented here to understand the detailed tradeoffs and design considerations underlying NOVRAM and EEPROM use. In some application classes, either memory type functions adequately; in others, you have a clearcut choice. And in still others, consider taking advantage of both—an approach that often results in cost reductions and enhanced features.

NOVRAMs use multiple technologies

First, however, understand how each memory type works. Nonvolatile static RAM (NOVRAM) combines two memory technologies on one monolithic chip. In **Fig 1,** the NOVRAM shown contains 1k bits of static RAM and 1k bits of electrically erasable PROM (EEPROM). The device comprises cells that in turn each contain one cell of each memory type, rather than housing two separate memory arrays (see **box,** "Anatomy of a NOVRAM cell").

In this NOVRAM, data gets read and written exactly as in a standard static RAM. In addition, the $\overline{\text{Store}}$ signal transfers each RAM cell's data into a shadowing EEPROM cell; EEPROM-stored data gets reloaded into the RAM via the $\overline{\text{Recall}}$ signal. Note that the EEPROM-cell portion is accessible only through the RAM portion.

One of this device type's most powerful features is its ability to transfer the entire RAM contents into nonvolatile storage in one operation, initiated by bringing the TTL-compatible $\overline{\text{Store}}$ LOW. The operation takes less than 10 msec, and once data is stored in this manner, only another store operation can alter it—even if the chip loses power.

Generating $\overline{\text{Store}}$ in the event of a power failure therefore saves the RAM contents, subject only to power remaining on the chip for the next 10 msec. RAM data can also be changed without disturbing the shadowing EEPROM, allowing the system to manipulate two separate groups of data.

EEPROMs offer greater density, fewer features

EEPROM, your other major memory choice, resembles UV-erasable EPROM. Unlike EPROM, however, it can be written electrically in circuit; it needs no prior erasure by exposure to ultraviolet radiation.

First-generation EEPROMs are merely electrically

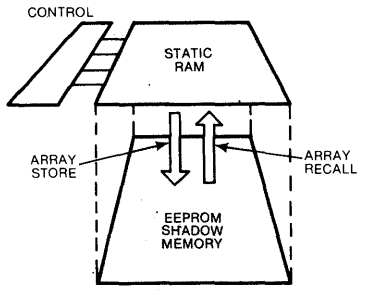


Fig 1—Nonvolatile static RAM (NOVRAM) *is organized so that each static-RAM bit is overlaid on a bit of nonvolatile electrically erasable PROM (EEPROM).*

Careful analysis simplifies the EEPROM vs NOVRAM choice

alterable ROMs (EAROMs). They're reprogrammable only after an entire memory array (or at least one page) is electrically erased. Similarly, second-generation devices require erasure of individual bytes before programming. Third-generation EEPROMs, however, automatically and internally erase a to-be-written byte as part of the write cycle; they also contain much of the required voltage-generating and pulse-shaping functions on chip.

Two examples of third-generation EEPROMs currently in production are the Intel 2817 and the Seeq 5213. The 2817 latches the data to be written and eliminates the need for prewrite erasure. However, it requires an external high-voltage supply as well as a timing capacitor for deriving internal timing signals.

TABLE 1—EEPROM/NOVRAM COMPARISONS

	NOVRAM (X2212)	EEPROM (X2816A)
Density (bits)	1024	16,384
Price (1k level)	$9.00	$23.00
Cost/bit	$0.0088	$0.0014

The 5213 generates the high voltage on chip but requires external latches that hold the data and address valid during erase and write operations.

Fourth-generation EEPROMs are characterized by

Anatomy of a NOVRAM cell

NOVRAM-cell operation depends on a phenomenon termed Fowler-Nordheim tunneling. In the NOVRAM, a layer of oxide isolates a gate from an underlying section of polysilicon. Applying a large positive voltage to this floating gate while holding the underlying polysilicon near ground programs the gate.

Specifically, electrons attracted to the floating gate's significantly higher potential tunnel across the separating oxide. As a result, the floating gate acquires a net negative charge from the tunneled electrons.

The cell is erased in a similar manner: The floating gate is held at a low potential while the potential of the top polysilicon layer is raised; the electrons then tunnel across the oxide from the floating gate to the neighboring polysilicon sandwich.

The EEPROM technology employed in Xicor's NOVRAM uses a 3-layer polysilicon sandwich that, when coupled with a 6-transistor static-RAM cell, results in the NOVRAM circuit shown in **Fig A.** The state of the static-RAM cell determines whether the EEPROM cell is programmed or erased during a store cycle.

Capacitance ratios are the key to the data transfer from RAM to EEPROM. If node N_1 is LOW, Q_7 is turned off, allowing the junction between capacitors C_3 and C_4 to float. Because the combined capacitance of C_3 and C_4 is larger than C_P, the floating gate follows the Store-node voltage. When the voltage on the floating gate is sufficiently high, electrons tunnel from $POLY_1$ to $POLY_2$, and the

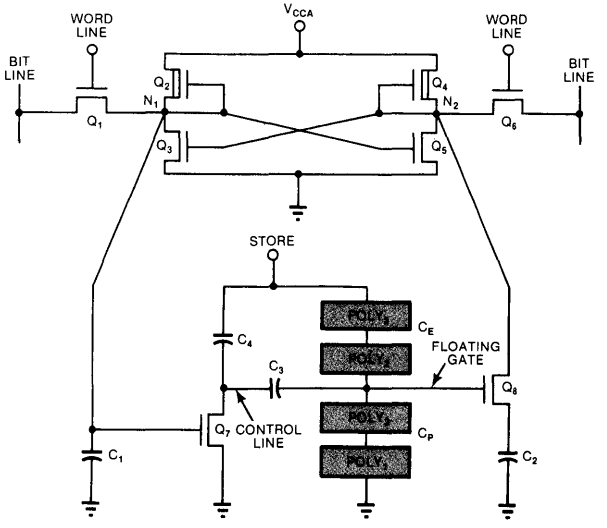


Fig A—A NOVRAM cell *consists of two sections: a 6-transistor RAM and a shadowing 2-transistor EEPROM.*

5

on-chip generation of all high-voltage and wave-shaping functions in addition to their use of on-chip latches and self-timing features. Their byte-write requirements are identical to those of static RAM except that the EEPROM write cycle, once initiated by normal static-RAM timings, takes as long as 10 msec. Once a byte-write operation begins, the EEPROM is self supporting, freeing the processor and all external circuitry for other tasks. Read timing to the EEPROM is identical to that of a standard EPROM, RAM or ROM.

An important feature of a fourth-generation EEPROM is its compatibility with currently used RAM, EPROM and ROM. An EPROM- or ROM-based system needs only an additional Write Enable line to each socket to provide retrofitting for EEPROM. This control line allows the changing of data tables and program store without removing the component from the system, as required with EPROMs.

Choosing between NOVRAM and EEPROMs

Many application requirements can be satisfied by either of the two memory types. However, note that although NOVRAM is the most versatile in terms of features and capabilities, the price you pay for its greater intelligence is increased cell size.

Specifically, a fourth-generation EEPROM's cell is small and simple, allowing much higher density storage than in a NOVRAM. The EEPROM is also more efficient as memory-array area increases, thanks to the gate becomes negatively charged.

If node N_1 is HIGH, Q_7 turns on, grounding the junction between C_3 and C_4. C_3, larger than C_E, holds the floating gate near ground when the Store node gets pulled HIGH. This action creates a sufficiently large field between $POLY_2$ and $POLY_3$ to tunnel electrons away from the floating gate, leaving it with a positive charge.

The recall operation also depends on capacitance ratios. C_2 is larger than C_1. When the cell receives the external $\overline{\text{Recall}}$ command, the internal power supply (V_{CCA}) first goes LOW to equalize the voltages on N_1 and N_2. When V_{CCA} is allowed to rise, the node with the lighter capacitive load rises more rapidly. The flip flop's gain causes the lightly loaded node to latch HIGH and the opposite side to latch LOW. If the floating gate has a positive charge, C_2 is connected to N_2 through Q_8, and N_2 latches LOW. If the floating gate has a negative charge, Q_8 gets turned off and N_1 experiences the heavier loading.

A major task in the development of the NOVRAM was to reduce the amplitude and simplify the waveform of external voltages needed for programming or erasure. Earlier devices required carefully shaped pulses with amplitudes exceeding 20V.

The first step in the cell design was to reduce the internal voltage level presented to the cell to initiate electron tunneling. The voltage magnitude required for programming a floating gate is related to the intensity of the electric field generated at the oxide-polysilicon interface by that voltage.

Electric-field strength at the oxide-polysilicon interface can be increased by using an extremely thin oxide, on the order of 100Å. A second technique uses textured polysilicon to locally enhance the field at the surface and achieve Fowler-Nordheim tunneling. It achieves better data retention.

Once the internal voltage-level requirement was reduced, a key achievement in device design was the on-chip generation of the high-voltage pulses needed to program or erase an individual cell. A Store-voltage generator **(Fig B)** provides the solution; it uses a 32-stage capacitor/transistor charge pump.

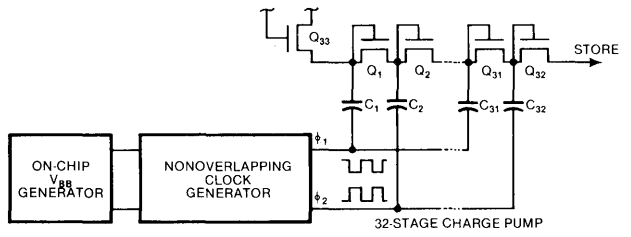


Fig B—A 32-stage charge pump *internally generates a NOVRAM's high Store voltage, allowing the device's NOVRAM and EEPROM sections to operate from 5V.*

Each NOVRAM cell combines RAM and EEPROM

TABLE 2—EEPROM/NOVRAM DATA-CAPTURE SPEEDS

	NOVRAM (X2212)	EEPROM (X2816A)
Byte-Write Time	256 × 1 μsec	256 × 10 msec
Store Time	10 msec	0
Total Time	10.26 msec	2.56 sec

decrease in the relative proportion of support-circuitry area required. Therefore, EEPROMs are more likely to be the device of choice if your application needs large amounts of memory.

The larger cell size and more extensive on-chip support that gives NOVRAM its added capabilities also results in a higher cost per bit, which might not be justified in applications that don't require all of a NOVRAM's features. Consider, for example, the cost-per-bit comparison between the X2212 256×4-bit NOVRAM and the X2816A 2k×8-bit EEPROM (**Table 1**): NOVRAM cost per bit is more than six times greater than that of EEPROM.

However, cost-per-bit ratios can be deceiving for systems requiring a minimum amount of nonvolatile memory. Lower density nonvolatile memories often are more cost effective in a NOVRAM configuration. The smallest NOVRAM currently available, the 64×4 X2210, is also the least expensive 5V device.

Another selection factor to consider is the required write time. An EEPROM requires a relatively long write time (10 msec/byte max), while NOVRAM write time is that of a typical static RAM. Therefore, NOVRAMs are more suited for applications requiring frequent memory-data changes, while EEPROMs most suit applications calling for infrequent memory writes.

A NOVRAM is also better suited to data-capture applications. **Table 2** compares two 256×4-bit NOVRAMs organized in a byte-wide configuration with a 2k×8 EEPROM in terms of the time needed to store 256 bytes of information. These times assume a 1-μsec/byte max processor write-cycle time. You can see that the NOVRAM's single-store operation makes it much faster. A NOVRAM system can update and store 10,000 bytes of data in the time needed to store two bytes of EEPROM information.

Another important NOVRAM feature is the device's ability to initiate and complete a nonvolatile store of data under external-signal control. This feature can be a key decision criterion in real-time applications such as power-fail re-entrant systems.

Both types serve power-fail-tolerant controllers

As noted, however, many applications can profitably use either device type. One common application in this class centers on retaining important system information in the event of a power loss. In most systems, power failures require reinitialization of the entire system, necessitating the temporary loss of system operation. In real-time control applications, this loss of control can cause expensive and sometimes dangerous failures of the process or equipment being controlled.

Such an application's main requirement is therefore some type of nonvolatile storage upon power failure. A prime consideration in this type of environment is the storage of a fixed amount of data upon receipt of an

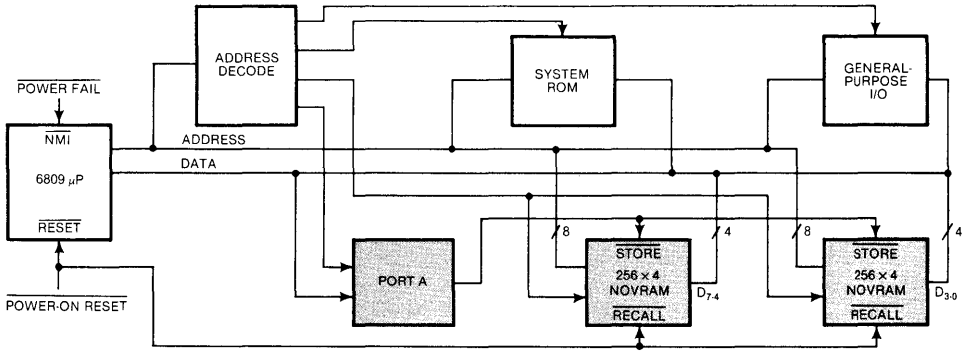


Fig 2—In this controller, *a NOVRAM retains the μP state in the event of a power failure.*

```
;*************************************************************************
; AN EXAMPLE OF THE POWER-DOWN AND POWER-ON CODE FOR THE 6809 USING
; THE NOVRAM FOR PROCESSOR STATUS STORAGE.
;*************************************************************************
; LOCATION DEFINITIONS
NURAMLO         .EQU    0000H
NURAMHI         .EQU    NURAMLO + 256.
; THE NOVRAM IS LOCATED AT THE BOTTOM OF THE 6809 MEMORY MAP
DIRTY           .EQU    NURAMHI ;TEST BYTE FOR POWER FAIL CONDITION
OLDSTK          .EQU    NURAMHI-6 ;STACK POINTER NONVOLATILE LOCATION
STACK           .EQU    NURAMHI-7 ;PROCESSOR STACK BEGINNING LOCATION
TEMP1           .EQU    NURAMHI-1 ;IMPORTANT PROCESS PARAMETERS
TEMP2           .EQU    NURAMHI-2
TEMP3           .EQU    NURAMHI-3
PORTA           .EQU    8000H   ;LOCATION OF DATA REGISTER FOR PORT
                .ORG 0F800H
;*************************************************************************
;                       POWER FAILURE ROUTINE
;*************************************************************************
PFAIL           STS     OLDSTK  ;WRITE CURRENT STACK POINTER INTO NOVRAM
; AT THIS POINT, THE POWER FAIL INTERRUPT HAS PUSHED ALL OF THE
; CURRENT VALUES OF THE PROCESSOR REGISTERS ONTO THE STACK. THE
; STACK POINTER POINTS TO THESE VALUES.
                LDA     #0A5H   ;LOAD ACCUMULATOR WITH POWER FAIL FLAG
                STA     DIRTY   ;STORE FLAG IN NOVRAM
                LDA     #00.    ;WRITING A 0 TO THE PORT GENERATES
                STA     PORTA   ;A STORE SIGNAL TO THE NOVRAM
LOOP            BRA     LOOP    ;SIT AND WAIT UNTIL POWER DISAPPEARS
;*************************************************************************
;                       POWER-ON RESET ROUTINE
;*************************************************************************
RESET           LDA     #0FFH   ;SET ALL OUTPUTS TO A "1"
                STA     PORTA   ;WRITE TO PORT TO KEEP STORE HIGH
                LDA     DIRTY   ;LOAD FLAG TO SEE IF POWER FAILED
                CMPA    #0A5H   ;IT WILL BE A 0A5H IF IT DID
                BNE     INIT    ;IF NOT DO NORMAL INITIALIZATION
                LDA     #00H    ;CLEAR THE POWER FAILURE FLAG
                STA     DIRTY   ;IN THE NOVRAM
                LDA     #00H    ;AND GIVE A STORE SIGNAL
                STA     PORTA   ;TO STORE THE NEW FLAG
                LDA     #0FFH   ;RESET PORT.
                LDS     OLDSTK  ;LOAD OLD STACK VALUES
                RTI             ;RETURN FROM POWER FAIL INTERRUPT
INIT  ;NORMAL INITIALIZATION CODE
;                       .

;                       .

;                       .

                .ORG 0FFFCH
                .WORD   PFAIL   ;POWER FAILURE INTERRUPT VECTOR
                .WORD   RESET   ;POWER-ON RESET INTERRUPT VECTOR
                .END
```

Fig 3—A power-failure-tolerant controller's 6809-μP assembly-language routines *handle both failure store and recovery. NOVRAM handles the stack and other temporary storage.*

NOVRAM doubles as bootstrap and global memory

external $\overline{\text{Power Fail}}$ signal. You can use an EEPROM for this purpose if the processor has sufficient time to recognize the power failure and respond by writing the data into memory. Otherwise, a NOVRAM is the device of choice because it captures data in one nonvolatile store operation.

Fig 2 shows a simple controller that uses a NOVRAM to retain the state of a μP in the event of a power failure. The $\overline{\text{Power Fail}}$ signal generates a μP interrupt, and the NOVRAM stores the contents of all RAM including the μP stack.

Upon interrupt acknowledgement, the μP registers are pushed onto the stack as program control branches to the interrupt routine **(Fig 3)**. The routine writes the current stack pointer and a test byte to the NOVRAM, signifying that a power failure has occurred, and then generates a $\overline{\text{Store}}$ signal. The power supply is designed to ensure that the V_C level remains above 4.5V for 10 msec after it generates the $\overline{\text{Power Fail}}$ signal.

Once power is restored, the $\overline{\text{Power-On Reset}}$ signal generates a $\overline{\text{Recall}}$ signal to the NOVRAM. The power-on routine in the μP checks the state of the test byte to see if a process was interrupted by a power failure. If so, the stack pointer gets loaded with the address of the saved processor state, a return from interrupt is executed, and the process resumes.

NOVRAM stores terminal configurations

An application in which NOVRAM is the device of choice lies in the storage of terminal-configuration information, consisting of such parameters as baud rate, data format and parity method. The conventional approach to this task **(Fig 4)** stores data in DIP switches on a pc board somewhere in the terminal; the user must have a terminal manual handy for decoding switch settings to change any of the preset features.

One alternative uses menu-driven configuration modes to set the terminal and a NOVRAM to store the terminal-configuration parameters. The user can easily change the configuration information for specific tasks and retain this data until the terminal loses power.

Upon power-up, a set of predefined default parameters stored in the NOVRAM's EEPROM section goes to RAM, and the terminal is configured. The NOVRAM also allows the user to change default parameters for subsequent sessions by transferring the modified RAM data to EEPROM—in either a general or privileged user environment. The NOVRAM's ability to manipulate two sets of data proves important here because the terminal software operates on the data in the NOVRAM's RAM section, regardless of whether the terminal is in the default configuration or a user-entered one.

In **Fig 4**'s conventional approach, an 8-section DIP switch holds the configuration information. If a switch position is open, the pull-up resistor causes a ONE to appear at the buffer input; a closed switch denotes a ZERO. Decoding the buffer's address and reading the data provides the switch information. If the system needs more than eight bits, the design requires additional switches, resistors, buffers and logic.

If a block of memory addresses is reserved for configuration information, the granularity of the address decoding increases with the number of DIP

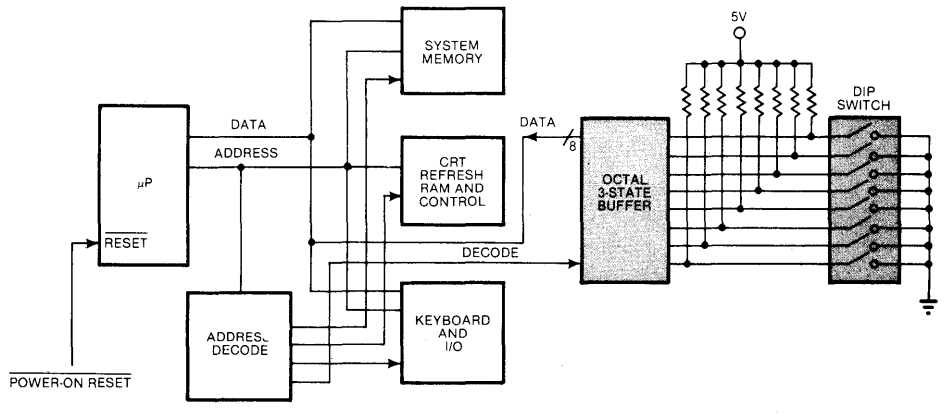


Fig 4—A conventional terminal configuration *uses an 8-section DIP switch to program the terminal's operating parameters.*

In-system data modifications make EEPROMs more versatile than EPROMs

switches required. And you can change the default data only by altering individual switch positions.

The NOVRAM implementation of this system (**Fig 5**) permits the storage of 1k bits of configuration information in one 18-pin X2212. If you reserve an 8k memory-address block for configuration storage, the NOVRAM requires only a single chip-select decode. The only restriction in this arrangement is that four parameter bits get read simultaneously, rather than eight. Note that storing the same amount of information using the conventional approach calls for 128 DIP switches and octal buffers, 1024 resistors and sufficient address decoding to provide 128 separate locations within the 8k field—an address granularity of 64.

A terminal user employs the keyboard to enter operational parameters into the NOVRAM. The user enters a configuration mode when the terminal is in the off-line or local mode. A menu display shows the current terminal configuration; the user moves the cursor and/or strikes a control key to alter the current values. Once the configuration is established, the user exits the configuration mode, and the terminal operates according to the new parameters. The user can also change the default parameters by entering a control signal that places the new configuration mode in the NOVRAM's EEPROM section.

In this application, very few terminals would ever require the NOVRAM's full storage capacity for configuration information. You could therefore employ the unused portion to store other operational and maintenance parameters.

NOVRAM loader provides reusable memory

A system that employs a bootstrap loader during initialization is another prime NOVRAM application candidate. Examples of such applications include single-chip μCs operating in external-memory modes and full-blown systems requiring the maximum allowable memory space. A common approach to this requirement stores the bootstrap program in ROM or EPROM. However, the program occupies memory space that might be used for other purposes during system operation. Because most initialization routines use a relatively small amount of memory space, this approach can be particularly wasteful in space-limited systems.

As an alternative, you can preprogram the bootstrap into the EEPROM section of a NOVRAM. Upon reset, the system generates a $\overline{\text{Recall}}$ signal to the NOVRAM, loading the bootstrap into RAM. The bootstrap program executes, and the NOVRAM RAM section then becomes free for other uses. This design feature even allows bootstrap-program alteration via external control for servicing or software updates.

Fig 6 shows a simple disk-oriented system that uses NOVRAM as a bootstrap memory. After booting, the NOVRAM becomes a global RAM. The device—and

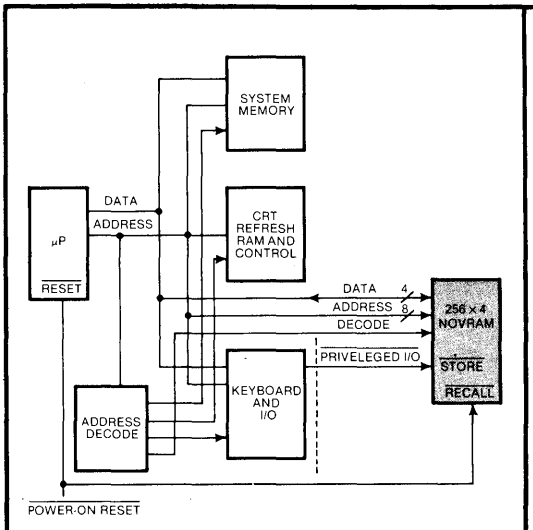


Fig 5—Replacing a DIP switch with a NOVRAM *results in greater versatility for programming terminal operating parameters.*

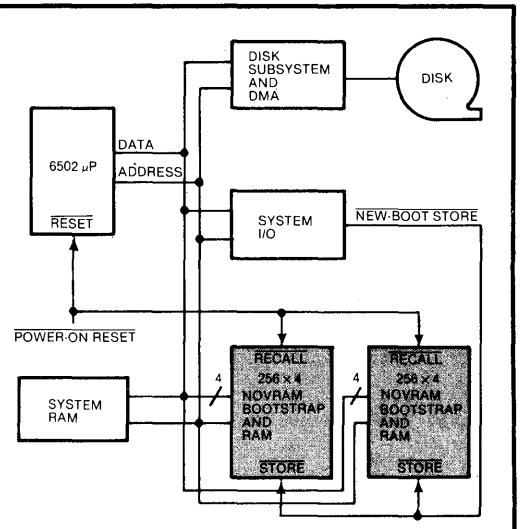


Fig 6—This disk-oriented system uses two NOVRAMs *as bootstrap memory. Once loading is complete, the NOVRAM functions as global RAM.*

```
;*****************************************************************************
; THIS PROGRAM SEGMENT DEMONSTRATES THE OPERATION OF A SYSTEM WHICH
; USES A BOOTSTRAP PROGRAM PRELOADED INTO THE NOVRAM'S EEPROM. UPON
; POWER-ON RESET, THIS BOOT IS RECALLED INTO THE EEPROM'S RAM. THE
; BOOTSTRAP PORGRAM CONFIGURES THE SYSTEM, AND THEN USES THE NOVRAM'S
; RAM AS REGULAR RAM. THE NOVRAM IS LOCATED AT THE BOTTOM OF THE
; 6502'S MEMORY MAP SO THAT THE HIGHEST LOCATIONS CAN CONTAIN THE
; PROCESSOR'S INTERRUPT VECTORS. ACTUAL LOADING OF THE OPERATING
; SYSTEM INTO MAIN MEMORY IS ACCOMPLISHED BY A DMA CONTROLLER, WHICH
; LOADS THE PROGRAM FROM THE DISK.
;*****************************************************************************
DMADATA         .EQU    0C000H  ;DMA DATA REGISTER
DMACTRL         .EQU    0C001H  ;DMA CONTROL REGISTER
PROGRAM         .EQU    00200H  ;START OF PROGRAM MEMORY

                .ORG    0FF00H
; THIS PROGRAM SECTION IS LOADED INTO THE EEPROM SECTION OF THE
; NOVRAM, AND IS RECALLED UPON POWER-UP.
BOOT            LDX     #0FFH   ;LOAD THE X INDEX REGISTER WITH FF
                TXS             ;TRANSFER TO STACK POINTER AT 01FF
CONFIGUR        ; THIS CODE SECTION CONFIGURES THE DMA CONTROLLER,
                ; AND SETS THE INITIAL LOAD LOCATION AT 0200H, SO
                ; THAT PROGRAM DATA WILL NOT OVERWRITE THE STACK.
SEEK            ; THIS CODE SECTION TELLS THE DMA CONTROLLER WHAT
                ; DISK SECTION IT SHOULD GET THE PROGRAM FROM, AS
                ; WELL AS HOW MUCH DATA TO LOAD.
GO              LDA     #01.    ; 01 IN THE DMA CONTROL REGISTER
                                ; WILL INDICATE DISK DATA LOADING
                STA     DMADATA ; STORE IN THE DMA CONTROL REGISTER
                LDA     #0A5H   ; WRITE TO TEST BYTE TO SIGNIFY BOOT
                STA     TEST    ; IF WE SEE A #0A5H,WE ARE IN BOOT
LOOP            JMP     LOOP    ; LOOP UNTIL DMA CONTROLLER INTERRUPTS
;*****************************************************************************
; NMI FROM DMA INTERRUPT WILL VECTOR HERE. THIS ROUTINE CHECKS THE
; STATUS FROM THE DISK SUBSYSTEM AND DMA CONTROLLER TO INSURE THAT
; THE REQUESTED DATA HAS BEEN LOADED. ONCE A SUCCESSFUL BOOT HAS
; TAKEN PLACE, THE SYSTEM CAN CHANGE THE NMI VECTOR SINCE THE NOVRAM
; NOW FUNCTIONS AS A REGULAR RAM.
;*****************************************************************************
INTERRUPT       LDA     DMACTRL ; CHECK TO SEE IF THE DESIRED PROGRAM
                                ; HAS BEEN SUCCESSFULLY LOADED. IF SO,
                                ; ALL WILL BE ZEROES EXCEPT D0 WHICH
                                ; WILL BE SET TO SIGNIFY THAT AN
                                ; INTERRUPT WAS GIVEN.
                CMP     #01     ; ARE WE LOADED?
                BNE     BOOT    ; IF NOT, WE'HAVE AN ERROR, RE-BOOT.
                LDA     TEST    ; GET TEST BYTE TO SEE IF IN A BOOT.
                CMP     #0A5H   ; IF SO, TEST BYTE WILL BE A5 HEX.
                BEQ     PROGRAM ; AND JUMP TO PROGRAM BEGINNING.
ERROR           ;OTHERWISE WE HAVE AN ERROR.
TEST            .BYTE   00.     ; A ZERO IS STORED IN TEST INITIALLY.
                .ORG    0FFFAH
NMI             .WORD   INTERRUPT; NMI WILL GO TO SYSTEM START ROUTINE.
RESET           .WORD   BOOT    ; POWER-ON RESET WILL CAUSE AUTO BOOT.
```

Fig 7—A 6502-μP assembly-language boot routine *is located temporarily in NOVRAM, which forms the highest 256 bytes of memory in this system.*

5

hence the bootstrap routine—is in the highest memory segment so it can hold all the interrupt vectors. μPs such as the 6502 and 6800 use these locations for reset and interrupt pointers.

In the bootstrap program (**Fig 7**), the reset vector for the 6502 μP points to the boot routine. **Fig 6**'s two NOVRAMs reside in the highest 256 bytes of the address map. Upon power-up, the NOVRAM's EEPROM section gets loaded into the device's RAM section. The μP then initializes the stack pointer, and the DMA controller begins a data transfer from the disk. A test byte gets set to show that a boot process is under way.

Once the DMA transfer begins, the μP loops until an interrupt signifies that the operation is complete. The μP vectors to the interrupt-handling routine, which determines if a valid DMA has occurred. If an error has occurred, the program causes a jump to location Program, where the first byte of the loaded program resides. The NOVRAM RAM is then free for general use. Note that you must take care not to accidentally overwrite the interrupt and reset vectors, located in the highest memory locations.

EEPROM stores controller parameters

Turn now to some applications in which an EEPROM is the device of choice. One such task is the storage of coefficients in PID (proportional integral-differential) controllers.

Modern control applications such as the PID algorithm are characterized by two basic qualities. First, they are computationally intense. Second, their ability to precisely control a set condition is based on their knowledge of the effects of their outputs. This knowledge results from deriving the various controller coefficients via calculations: Each controller output must be calculated with reference to the previously defined term.

If a PID system loses power, it must resynthesize all data before it approaches the level of performance exhibited before the power loss. The data tables for each control task are fairly large and require a substantial amount of memory. Therefore, a controller might use EEPROM for algorithm-coefficient storage.

Note also that most PID-controller deviations result from the sensitivity of the system's sensors as well as the response time and accuracy of the control outputs. These variables might change in a particular unit but are usually the same when power returns to the controller; they need only be updated occasionally as the system runs. An EEPROM's slow write time and fast read time make it ideally suited for this infrequent-write application.

Finally, note that parameters stored in EEPROM are available to the system whenever it's running—whether programmed into the system during initialization or resulting from previous system operation. An EEPROM implementation of such a system thus results in shorter system-interrupt recovery time as well as self-recalibration upon component replacement.

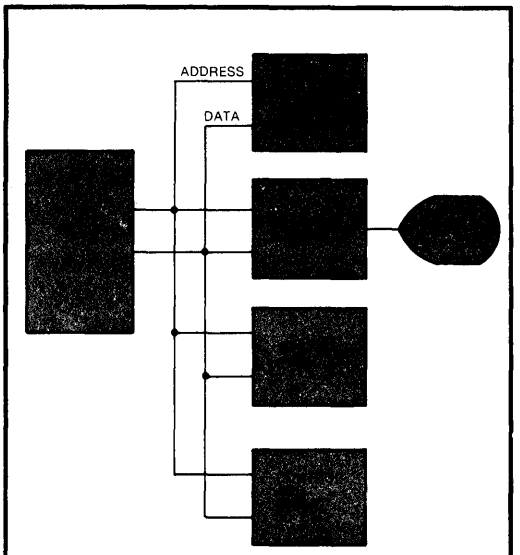


Fig 8—A self-learning video game uses EEPROM *to change difficulty levels after play is completed.*

Self-learning video games use EEPROMs

Another potential EEPROM application centers on the storage of self-teaching or self-modifying code, through which a process or algorithm can tailor itself based on the results of previous executions. Such applications are characterized by updates to program storage, which usually occur relatively infrequently. This high read-to-write ratio of memory access, as well as the densities required in the program store, generally dictate an EEPROM implementation.

An example of this application category is a self-learning video game (**Fig 8**). Such a game's success depends largely on its ability to keep a player interested by continually increasing the level of challenge after repeated plays.

At the end of a certain period (**Fig 9**), the game analyzes the scores and modifies its program (including timing loops and difficulty factors) to present a more complex play to the next group of players. The learning algorithm also makes the game easier to play under

certain conditions, preventing unwarranted increases in difficulty.

The initial game code includes several routines that make the game progressively more difficult to play. These routines get bypassed in the initial program execution by always-executable branch instructions. At

```
;*****************************************************************************
; THIS IS AN EXAMPLE OF 6809 GAME CODE WITH BRANCH NEVERS
;*****************************************************************************
PLAY            ;THIS SECTION OF CODE IS THE EASIEST
;                       .
;                       .
SECT1           BRA     SECT2   ;WE START OUT BY BYPASSING THIS SECTION
                ;THIS SECTION OF CODE IS MORE DIFFICULT
SECT2           BRA     SECTN   ;WE ALSO BYPASS THIS SECTION
;                       .
SECTN           BRA     ENPLAY  ;WE HAVE N DIFFICULT ROUTINES
;                       .
ENPLAY          LDA     TEST    ;CHECK THE END OF GAME FLAG
                CMPA    #0FFH   ;IT WILL BE AN FF IF GAME IS OVER
                BNE     PLAY    ;IF GAME NOT OVER, GO BACK TO MAIN LOOP
                BRA     FINISH  ;IF IT IS, GO TO FINISH SECTION

FINISH          ;THIS IS THE AREA FOR THE END OF THE GAME CODE. IT MAY
                ;CALL PROCEDURES TO MAKE THE GAME HARDER IF THE
                ;ANALYSIS OF PAST SCORES WARRANTS.
;*****************************************************************************
; THIS SECTION OF CODE INCREASES THE DIFFICULTY LEVEL OF THE GAME BY
; REPLACING ONE OF THE BRANCHES AROUND THE MOST DIFFICULT ROUTINES
; WITH A DUMMY BRANCH OR BRANCH NEVER INSTRUCTION. THIS ROUTINE ALSO
; INCREASES A GLOBAL DIFFICULTY FACTOR, ON WHICH MANY OF THE GAME
; PLAYING ALGORITHMS ARE COMPUTED, BY ONE.
;*****************************************************************************
DIFCULT         .BYTE   00      ;DIFFICULTY FACTOR
;               TABLE OF BRANCH LOCATIONS
TABLE           .WORD   SECT1
                .WORD   SECT2
;                       .
;                       .
TABLEND         .WORD   SECTN

MAKEHARD        LDX     #TABLE  ;START LOOKING THROUGH TABLE AT THE TOP
LOOK            CMPX    #TABLEND  ;ARE WE AT THE END OF THE TABLE?
                BEQ     NEXT    ;IF SO, GAME CAN'T BE MADE HARDER!
                LDA     [X++]   ;LOOK AT THE OPCODE AT THE BRANCH, AND
                                ;INCREMENT INDEX REGISTER FOR NEXT LOOK
                                ;(AUTO INCREMENT BY 2 INDEXED)
                CMPA    #21H    ;CHECK TO SEE IF IT IS A BRANCH NEVER
                BNE     LOOK    ;IF NOT, THEN CHECK THE NEXT ONE
                STA     [0,X]   ;OTHERWISE MAKE THE GAME HARDER BY
                                ;INCLUDING A ROUTINE BY STORING A BRANCH
                                ;NEVER (INDEXED INDIRECT)
                INC     DIFCULT ;INCREMENT DIFFICULTY FACTOR
ATTRACT         ;ENTER THE ATTRACT MODE FOR THE GAME
;                       .
;                       .
NEXT            ;WE CAN'T MAKE THE GAME HARDER, SO WHAT DO WE DO??
                .END
```

Fig 9—Written in 6809-μP assembly language, *this self-learning video-game program changes branch instructions based on previously obtained scores.*

the end of each play, the system determines from the score whether to make the algorithm more difficult. If so, it eliminates some of the branches around difficult parts of the game software. A simple table stores all of these branches. Other features, including speed parameters and energy levels, can also be stored to make the game more difficult as scores improve. Storing them in EEPROM provides the additional advantage of easy updates and changes in the basic table.

EEPROM and NOVRAM team up

As a final example, consider how you might combine EEPROM and NOVRAM in an automobile navigational system that could direct a driver to a location within a specific city or area. Proponents of this approach envision beacons located throughout an area, notifying each in-car computer of the car's current location. Provided with this information, a local electronic map and the desired destination, the computer would direct the driver along the most efficient route.

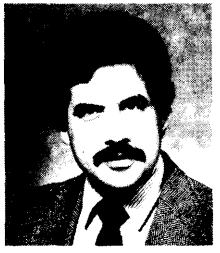
Data-storage requirements would be extensive, implying the use of EEPROM. After all, the system must not only be programmed with a map of the area roads but must also be able to select between many possible alternatives based upon continuously changing factors such as time of day and known construction areas. Using EEPROM would allow the car's driver to load the navigational computer upon entering a location such as a filling station.

A NOVRAM would also prove critical to this application. It would contain rapidly changing current information, which would get transferred to the NOVRAM's EEPROM section upon reaching a destination. The approach allows power removal from the system while the car is parked, eliminating battery drain. Restarting the vehicle would transfer the current data from the NOVRAM's EEPROM section back to its RAM section.

Fig 10 shows how the hardware could be implemented. Map information, stored in EEPROM, gets changed as necessary via the map-download controller, a serial interface over which the data is transmitted. The transmission rate is low because the map data is written into EEPROM, which specs a slow write cycle.

The system has two main interfaces—to the driver and to the vehicle. The former consists of a keyboard for input and a CRT for display of the map and other information. The latter receives data such as mileage and speed so that the system can monitor the driver's progress along a given route. **EDN**

Author's biography



Richard Orlando is product marketing manager at Xicor (Milpitas, CA), where his duties include product development. He is a member of the IEEE Computer Society, the ACM, Tau Beta Pi and Eta Kappa Nu. Rick holds a BS degree in computer-systems engineering from the University of Massachusetts at Amherst. His interests include research in the areas of distributed processing, reconfigurable processor architectures and μP applications.

Article Interest Quotient (Circle One)
***High* 476 *Medium* 477 *Low* 478**

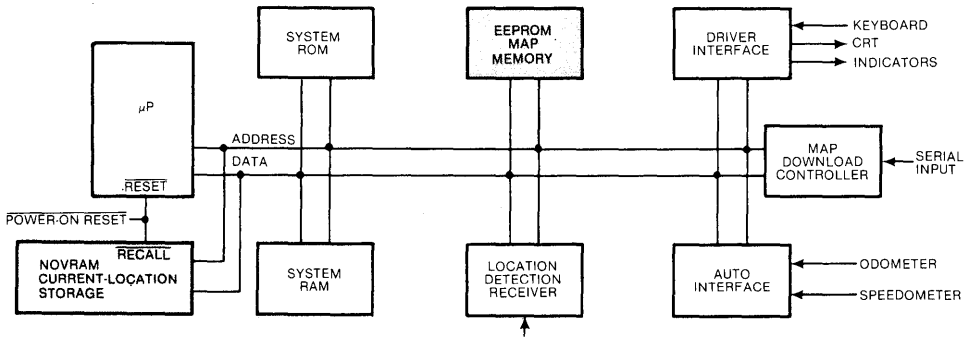


Fig 10—A hypothetical automobile navigational system *uses EEPROM to store extensive map information and NOVRAM to handle rapidly changing current-location information.*

Non-volatile memories keep appliances out of the dark

Richard Orlando, Xicor Inc., Milpitas, CA

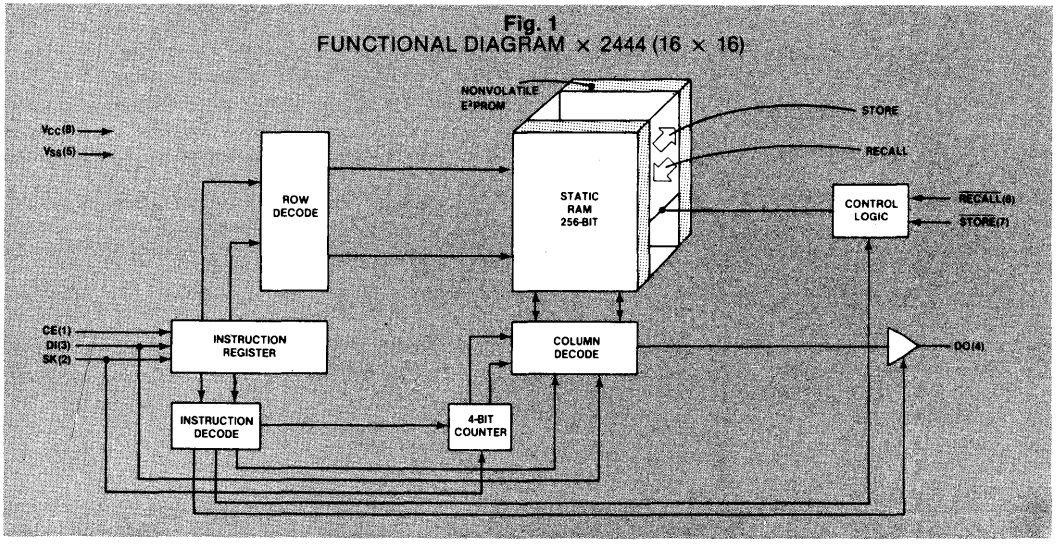
Appliance design has undergone a revolution in recent years. The advent of the low-cost, single-chip microcomputer has opened many applications for these small computers in the appliance market. Initial applications were based upon new types of appliances where digital control was a necessity. Today one sees even the venerable "white goods" using single-chip microcomputers to add features and capabilities to the end products. With this migration to digital control, a need for non-volatile memory has developed, and many new non-volatile memory devices have been made available to the designer.

Appliance control applications have gone through an orderly evolution. The design methods of the past used electromechanical devices, such as switches, relays, mechanical timers and, of course, wafer switches. The requirements of older appliances could be easily satisfied by these devices. Washing machines, for example, using multiplane wafer switches driven by a simple timer could initiate, time and terminate the different cycles of the laundry washing process. And the electronic range allowed simple electromechanical timing of a cooking cycle.

Since the appliance industry has been subject to the whims and attitudes of the consumer, the desired capabilities of appliances have grown as a function of added features. A simple example is the evolution of the home stove controller: first, accurate control over cooking temperature, then the ability to turn off the oven after a programmed time, and, finally, the complete programmable oven that not only turns itself off after a programmed time has elapsed, but also initiates the cooking cycle at a certain time of day.

The increased capabilities of the appliances coupled with the availability of low-cost, single-chip micro-

Fig. 1
FUNCTIONAL DIAGRAM × 2444 (16 × 16)



5

computers has led to the final step in the evolution, that of full digital control. The use of the microcomputer as a control mechanism allows the designer increased flexibility, reliability and precision in the control process, not easily attainable with the older design methods. Decreased development costs are also possible since a flexible digital controller can be used in a variety of different products, or models of the same product.

Microcomputer designs were not free of their own unique problems, however. The microcomputer interface required to perform the actual control functions was somewhat complex. New issues had to be addressed in terms of product reliability, since the semiconductor devices introduced different failure modes than those exhibited by electromechanical devices. The microcomputer also had a major disadvantage over prior design techniques due to its inherent volatile nature: when the power was removed from the appliance, the microcomputer not only stopped functioning, it lost any data it had maintained based upon the current state of the system.

One advantage that the older electromechanical timers possessed was that if the power went off to the appliance, the control system would maintain the state it was in when the power was interrupted. When the power was restored to the appliance, it would continue from where it left off. One can easily appreciate the irritation of a homemaker who, having left a roast in the oven, returns from errands to find that it had not resumed cooking after a blackout.

Emergence of non-volatility

With many appliance designs, there is a definite need to prevent such untoward situations. Some type of non-volatility is a necessity in appliance design. Since the cost of the appliance is a great concern, this non-volatility must be cost-effective. One of the earlier approaches was that of battery backup on the microcomputer itself, or on a separate CMOS memory in the system. The disadvantages of this approach are based simply on the limitations of batteries and the cost of implementation. Unfortunately, there were not many alternatives until now.

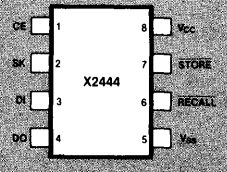
The past five years have seen a remarkable evolution in the emergence of semiconductor non-volatile memories. Unlike the battery backup of the data in either on-board or external RAM, these devices were able to retain data without the external power, in a manner similar to that of an EPROM. The main difference between these devices and the EPROM was their ability to be "rewritten" in-circuit, as opposed to being removed from the circuit, erased, and then "reprogrammed" before they were put back into the circuit.

Unfortunately, these early devices were expensive and difficult to use. They required multiple "programming" voltages, extensive support circuitry, and were quite unreliable. These devices, for the most part, were organized for microprocessor "bus" applications, and as such required too many I/O lines for efficient interfacing to single-chip microcomputers, where I/O lines are a precious commodity.

The development of 5v floating-gate, NMOS non-volatile memories eliminated many of the disadvantages of semiconductor non-volatile devices. These devices not only decreased the support circuitry required for their use, but increased the reliability of the devices. Unfortunately, these devices were also designed for "bus" applications and were relatively expensive due to their large densities (>1K bits). A need was recognized in the appliance and other industries for an inexpensive and reliable non-volatile memory designed exclusively for interfacing to single-chip microcomputers.

The Xicor X2444 answers this need. The device is a low-cost 16 × 16 non-volatile static RAM (NOVRAM for short) which features serial interface designed for interfacing to a single-chip microcomputer with a minimum requirement for both I/O

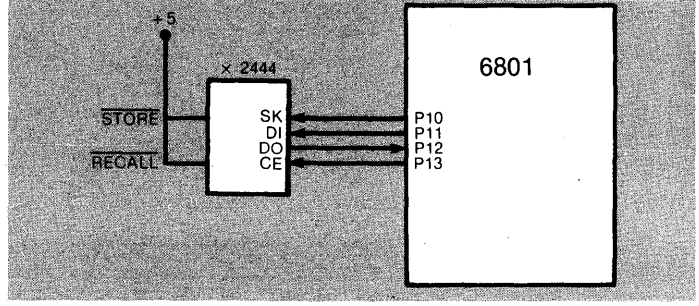
Fig. 2
PIN CONFIGURATION
8-PIN DIP, 300"



PIN NAMES

CE	CHIP ENABLE
SK	SERIAL CLOCK
DI	SERIAL DATA IN
DO	SERIAL DATA OUT
$\overline{\text{RECALL}}$	RECALL
$\overline{\text{STORE}}$	STORE
V_{CC}	+5V
V_{SS}	GROUND

Fig. 3
× 2444-6801 INTERFACE



lines and software. Housed in an eight-pin mini-DIP, the X2444 provides inexpensive non-volatile data storage for both operational and configuration parameters. Its low cost (less than $4.00 in unit quantities) makes it the least expensive non-volatile storage on the market, even rivalling the DIP switch in unit cost, while providing the equivalent of 32 DIP switches in terms of data capacity.

The NOVRAM concept

The NOVRAM idea is not new. Xicor invented this type of memory more than three years ago. The concept is quite simple. Figure 1 shows a block diagram of the X2444. It consists of a 256-bit (16 × 16) static RAM with a 256-bit 5v E^2PROM array overlaid bit for bit in a "shadow" type manner. Two signals, $\overline{\text{STORE}}$ and $\overline{\text{RECALL}}$, control the transfer of data between the E^2PROM array and the static RAM. The STORE function replicates the data which is currently in the RAM into the non-volatile E^2PROM array. In a similar manner, the RECALL function transfers the non-volatile data in the E^2PROM array into the RAM. One can see that by simply performing a STORE during power failure, the data is then retained in the non-volatile E^2PROM , and can be restored to the RAM using the RECALL once power is returned to the system.

The X2444's serial interface method is ideal for microcomputer applications. Figure 2 shows the pinout and signal designation for the X2444. The four-line serial interface consists of a Chip Select (CS), a Serial Clock (SC), a Data In (DI) line, and a Data Out (DO) line. The Data In and Data Out timings are designed to allow the implementation of a single Serial Data line by typing both Data In and Data Out to a single I/O line from the microcomputer, reducing the I/O lines to three. All data transfer to and from the X2444 are performed over this serial interface by either synchronous 8-bit instructions or 16-bit data operations. The X2444 has two external pins, $\overline{\text{STORE}}$ and $\overline{\text{RECALL}}$, for performing the non-volatile operations via hardware control in the event of power failure. The X2444 also includes distinct STORE and RECALL instructions over the serial interface to allow only software control over the non-volatile operations.

The serial interface is accomplished using discrete "bit-banging" from the single-chip micro. An instruction is performed by loading an accumulator with the proper bit pattern, and shifting it out through an I/O line while toggling the serial clock low and then high again between each bit.

The software for this interface is simple, and an example of a 6801 implementation is shown in Figure 3. The software assumes that the X2444 is connected to bits 0, 1, 2 and 3 of the 6801 I/O Port 1. The interconnect between the 6801 and the X2444 is shown in Figure 4. The three main parts of the software segment are three subroutines, SHIFTIN, SHIFTOUT and DRIVE. The SHIFTOUT routine takes the eight bits of data in the A accumulator, and shifts it out through Bit 1 of Port 1. Between each data bit output the clock is toggled. This routine is used for either instruction or data output to the X2444.

The SHIFTIN subroutine gives the X2444 eight clock cycles, and shifts the data from the X2444 into the A accumulator. This routine is used only in the READ instruction. The DRIVE subroutine actually provides the driver to interpret the desired operation and issue the proper sequence of commands to the X2444. It should be noted that this sample interface uses the software-controlled STORE and RECALL commands and leaves the X2444 STORE and RECALL inputs tied to Vcc.

E.g. . . . microwave oven controller

One of the newest appliances in the consumer environment is the microwave oven. This also proves to be an ideal example for the application of a non-volatile memory.

The microwave oven started with a control mechanism which was no more than the simple electromechanical timer borrowed from electric ranges. Since the microwave oven cooks in times which are orders-of-magnitude faster than a conventional stove, it became apparent that an accurate and precise control mechanism was needed. The microwave was one of the first appliances to embrace full digital control using a single-chip microcomputer.

Figure 5 shows a typical microwave oven control system based upon the 6801 microcomputer. The user interface includes a keyboard, alarm and display, while the oven interface includes the magnetron control, door interlock, and an optional temperature probe. Non-volatile memory has been added to the system design through the use of an X2444. The interface method to the 6801 and the driving software are similar to that above. The key difference to note is the addition of an external signal to drive the $\overline{\text{STORE}}$ input. This allows the controller to automatically store the data in the RAM into the E^2PROM upon Power-Failure. The circuitry in the power supply senses a loss of power by monitoring either the ac or unregulated dc levels. Once a power failure has been detected, the power supply circuitry pulls the $\overline{\text{STORE}}$ input low. The power supply circuitry need only ensure that Vcc is held valid to the X2444 for 10 msec, and all of the data in the RAM will be stored into the E^2PROM array. Upon Power-on-Reset, the 6801 issues a RECALL command to the X2444, and all of the data is restored.

The remainder of the microwave control circuitry is fairly standard. A 4 × 4 keyboard provides an input mechanism for the user, while the status indicators and display provide visual feedback. A two-line magnetron control allows the use of variable power levels in the cooking process. Timing is performed using the 6801's internal 16-bit timer which is driven off the 60-Hz reference from the power supply. Standard features include a safety door

interlock and alarm. Optional features are provisions for a temperature probe for magnetron control or temperature-based cooking algorithms. The a-d converter used for temperature sensing has a serial interface similar to that of the X2444, and is placed on the same serial bus. Distinct chip selects enable the X2444 or the a-d converter to be accessed. Many such devices are currently on the market including the new TLC540 from Texas Instruments.

The X2444's non-volatile memory serves many functions in this application. Frequently used recipes or cooking sequences can be stored so that the microwave will sequence through a complex cooking algorithm automatically. The X2444's ability to store the data currently in the RAM into the E^2PROM is very useful here. As the cooking process takes place, the 6801 keeps a copy of the preset time and power setting in the X2444's RAM. As cooking time elapses, a location in the X2444 is updated to show the elapsed time. In the event of a power failure, the current values of these variables are automatically stored into the E^2PROM section of the X2444. Once power is restored to the microwave, the data in the E^2PROM is loaded into the RAM section of the X2444, and cooking continues from where it was interrupted. Intelligence can be added to the control algorithm to compensate for the continued cooking (due to retained heat) that occurs after the power outage.

The X2444's unique NOVRAM architecture makes such an application feasible. Since current E^2PROM technology has limitations on the number of times that the non-volatile data can be changed, one would not want to change the contents of the E^2PROM each time the timer was incremented. If one were to use a typical E^2PROM with a write limitation of 10,000 writes, the device would be worn out in a relatively short period of time at a write rate of one per second. Instead, the X2444 allows the system to update the E^2PROM section of the chip only in the event of a power failure while using the unlimited RAM write capability of the X2444 every time the counter value changes.

The X2444's can also be used for a variety of other purposes in microwave design. As was mentioned earlier, one can save development time and money if a universal controller is designed. Many different models could use the same controller simply by adding circuitry

Fig. 5
6801 MICROWAVE CONTROLLER

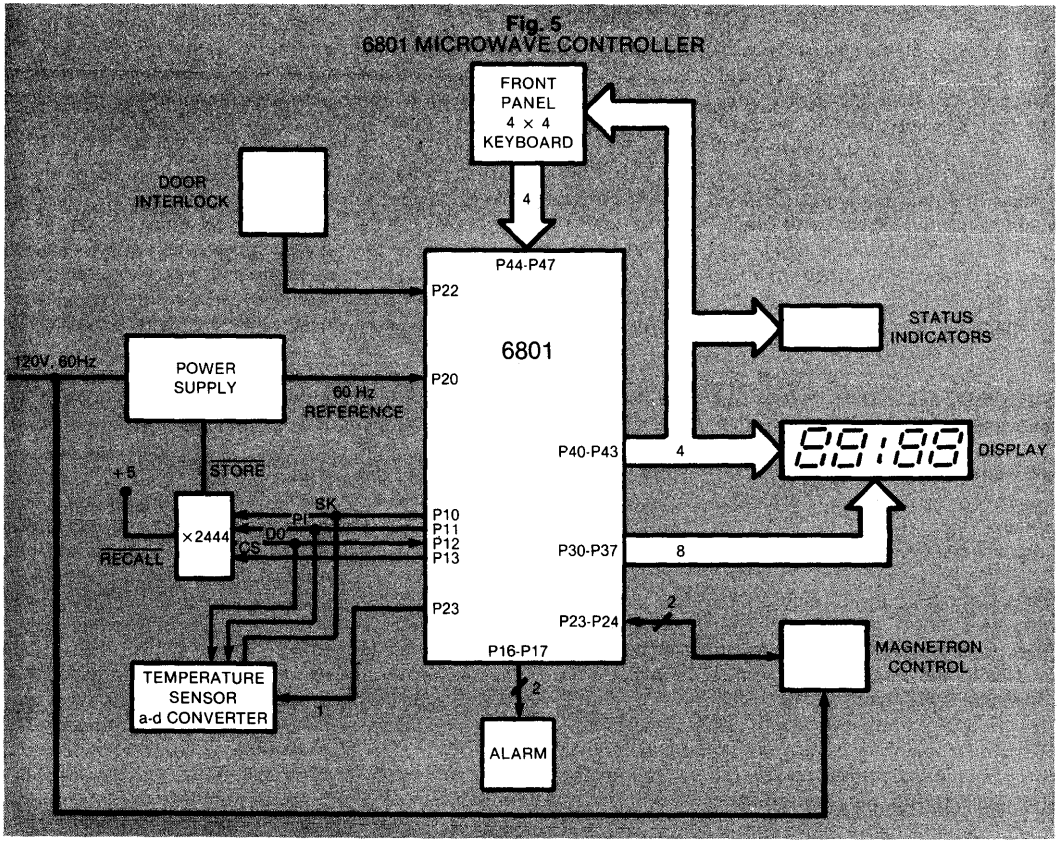


Fig. 4
X2444 DRIVER PROGRAM FOR 6801

```
PAGE -  1
File: X2444                CODE AS OF AUGUST 22, 1983   Minimal Driver for X2444, 6801 Version 3.0

0000:                              .TITLE "X2444 DRIVER PROGRAM FOR 6801"
0000:                              .ABSOLUTE
Z blocks for procedure code  7440 words left
0000:                              .PROC X2444
Current memory available:    7992
0000:                              .ORG  1000H
1000:                         ;*********************************************************************************
1000:                         ;                          6801 X2444 DRIVER
1000:                         ;       ASSUME THAT PORT1 IS USED AS THE 2444 INTERFACE
1000:                         ;       PORT1'S REGISTERS ARE LOCATED AS FOLLOWS
1000:                         ;                    DATA DIRECTION          HEX  0000
1000:                         ;                    PORT                    HEX  0002
1000:                         ;                                    PORT1          X2444
1000:                         ;       I/O 0                        SERIAL CLOCK   SERIAL CLOCK
1000:                         ;       I/O 1                        SERIAL OUT     SERIAL IN
1000:                         ;       I/O 2                        SERIAL IN      SERIAL OUT
1000:                         ;       I/O 3                        2444 SELECT    CHIP SELECT
1000:                         ;
1000:                         ;       COMMANDS ARE PASSED TO THE X2444 ROUTINE BY A PARAMETER IN THE
1000:                         ;       A ACCUMULATOR, WHILE THE ADDRESS IF NEEDED IS PASSED ON THE STACK
1000:                         ;       SERIAL DATA IN OR OUT USES THE TEMPORARY LOCATION TEMP1,
1000:                         ;       WHICH IS A SIXTEEN BIT WORD.  THE X2444 COMMANDS ARE ENCRYPTED AS
1000:                         ;       FOLLOWS.
1000:                         ;       COMMAND CODE                 INSTRUCTION    OPCODE
1000:                         ;       0                            READ           1AAAA11X
1000:                         ;       1                            WRITE          1AAAA011
1000:                         ;       2                            RESET WRITE ENABLE  11111000
1000:                         ;       3                            STORE          11111001
1000:                         ;       4                            SLEEP          11111010
1000:                         ;       5                            SET WRITE ENABLE    11111100
1000:                         ;       6                            RECALL         11111101
1000:                         ; '1'S ARE USED INSTEAD OF DON'T CARE TO DISTINGUISH BETWEEN DATA AND
1000:                         ;  NON DATA OPERATIONS.
1000:                         ;*********************************************************************************
1000: 0000                    DIRECTION1          .EQU          00.
1000: 0002                    PORT1               .EQU          02.
1000: 0080                    TEMP1               .EQU          080H    ;RAM STORAGE FOR DATA
1000: 0082                    COUNT               .EQU          082H    ;COUNTER VARIABLE
1000: 0084                    DATUM               .EQU          084H    ;DATA STORAGE
1000: 0086                    ADDRESS             .EQU          086H    ;ADDRESS STORAGE
1000: 0088                    ERRORDATA           .EQU          088H    ;ERROR DATA
1000:                         ;*********************************************************************************
1000:                         ;                          PROCEDURE INIT
1000:                         ;       THIS PROCEDURE INITIALIZES THE X2444 INTERFACE
1000:                         ;*********************************************************************************
1000: 86 1B                   INIT      LDAA      #1BH              ; B=1011, I/O 0,1 AND 3 OUTPUTS, 2 INPUT
1002: 97 00                             STAA      DIRECTION1        ; WRITE TO DATA DIRECTION REGISTER
1004: 4F                                CLRA                        ;SET CE TO 0(INACTIVE), DOUT AND SK TO 0
1005: 97 02                             STAA      PORT1             ;AND STORE IN DATA PORT
1007: 39                                RTS                         ;
1008:
1008:                         ;*********************************************************************************
1008:                         ;       SHIFTER ROUTINE- SHIFT1
1008:                         ; THIS ROUTINE TAKES THE DATA IN THE A ACCUMULATOR AND CLOCKS IT MOST
1008:                         ; SIGNIFICANT BIT FIRST INTO THE X2444.  THE FLOW IS SHIFT A BIT, TOGGLE
1008:                         ; THE SERIAL OUTPUT(6801) ACCORDING TO STATE, AND TOGGLE SERIAL CLOCK
1008:                         ;*********************************************************************************
PAGE -  2  X2444              X2444 DRIVER PROGRAM FOR 6801
File: X2444                CODE AS OF AUGUST 22, 1983   Minimal Driver for X2444, 6801 Version 3.0

1008: C6 08                   SHIFTOUT  LDAB      #08.              ;LOAD THE BIT COUNT WITH 8
100A: D7 82                             STAB      COUNT             ;STORE IN COUNTER
100C: 49                      SHIFT1    ROLA                        ;SHIFT BIT INTO CARRY BIT
100D: C6 14                             LDAB      #14H              ;WE SET DATA OUT TO ZERO, WHILE SETTING CHIP
100F:                                                               ;ENABLE.  SERIAL CLOCK IS LOW.
100F: 24 xx                             BCC       TRANS             ;IF BIT IS A ZERO, THEN TRANSMIT
1011: CA 02                             ORAB      #02H              ;IF IT IS A ONE, THEN SET DATA OUT
1013: D7 02                   TRANS     STAB      PORT1             ;STORE THE DATA INTO THE PORT
1015: CA 01                             ORAB      #01H              ;AND SET THE CLOCK FOR A TRANSITION
1017: D7 02                             STAB      PORT1             ;BY WRITING A 1 TO SERIAL CLOCK
1019: C4 1A                             ANDB      #1AH              ;KEEP THE DATA VALID, BUT SET SK TO ZERO
101B: D7 02                             STAB      PORT1             ;AND STORE IN THE PORT
101D: C6 14                             LDAB      #14H              ;TOGGLE CLOCK DOWN, SET DOUT TO 0, BUT KEEP
101F: D7 02                             STAB      PORT1             ;X2444 SELECTED
1021: 7A 0082                           DEC       COUNT             ; DECREMENT THE BIT COUNTER
1024: 26 E6                             BNE       SHIFT1            ;IF COUNT IS NOT ZERO, TRANSMIT NEXT BIT
1026: 49                                ROLA                        ;ONE MORE ROTATE TO PRESERVE INSTRUCTION
1027: 39                                RTS                         ;RETURN FROM SUBROUTINE
1028:                         ;*********************************************************************************
1028:                         ;                          SHIFTIN ROUTINE
1028:                         ; THIS SUBROUTINE SHIFTS IN 8 BITS OF DATA INTO THE A ACCUMULATOR FROM THE
1028:                                    IS TO ENTER WITH THE CLOCK LOW
                                                    OUTPUT IT INTO
```

external to the 6801 microcomputer. Configuration information can be stored in the X2444 at time of manufacture which the 6801 can then determine upon Power-on-Reset to control the features and functions of its particular microwave. Additional X2444s can be added on the serial bus as user or model options. These optional X2444s require only an additional chip select, and can be used for such features as increased recipe storage or operational modes. The X2444's non-volatile memory also can be used for calibrating the temperature probe and storing the response time of the magnetron to allow quick calibrations or more complex and precise temperature-control algorithms.

General applications

There are many other areas in the appliance field which are natural applications for the X2444. Since most electronic appliance controllers utilize the single-chip microcomputer, the X2444's serial bus is the ideal solution their non-volatile storage needs.

"User-programmable" parameters such as favorite stations, cooking algorithms or preset time-of-day events all make the appliances more "user-friendly" especially if these parameters are retained in the event of power loss. System configuration parameters can be stored in the X2444 to allow the design of appliances in a modular fashion, substantially reducing development costs while increasing the reliability of each new product. System status saved in the X2444 in the event of a power failure is restored upon Power-On so that the system can complete interrupted tasks as well as ensure that the appliance is left in a safe and stable state.

The availability of the new 5V non-volatile memories allows the appliance designer to add more features and capabilities for a minimum cost. Whether it be used for power-failure data storage, or as user set-up information, the X2444 will make appliance designs less complex, more cost-effective, more fault-tolerant, and easier to use. □

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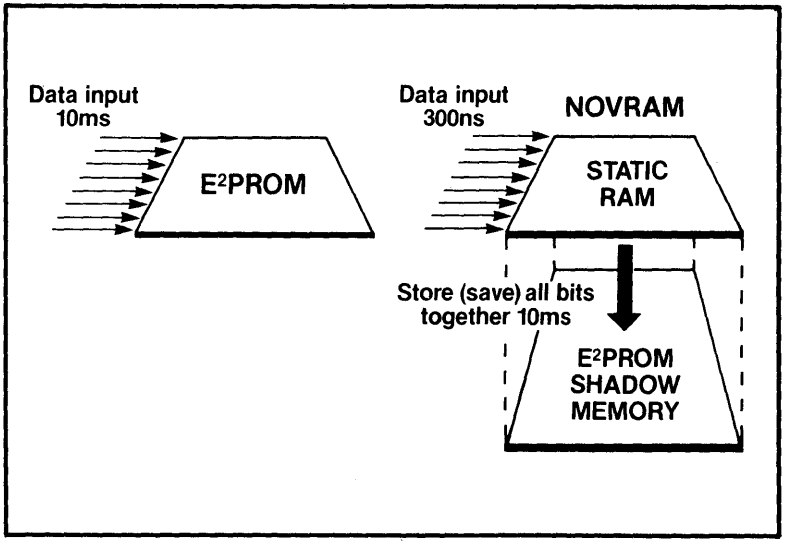


UNCOMPROMISING FEATURES HI-LITE THE 5 VOLT E²PROM

RICHARD V. ORLANDO

5

THE NOVRAM FAMILY A NEW DOMAIN OF SYSTEM POSSIBILITIES

JULIE BENNETTS CONKLIN

UNCOMPROMISING FEATURES HI-LITE THE 5 VOLT E²PROM

RICHARD V. ORLANDO

INTRODUCTION

In 1982 Xicor introduced the first full featured E²PROM, the X2816A. This device incorporated virtually all of the support requirements that had previously been needed by E²PROMs, placing this circuitry on chip. Interface requirements were thus minimized, and the door was opened to the perception of the E²PROM as a writable memory, as opposed to an electrically erasable EPROM. This new perception of the E²PROM has led to its rapid infiltration into all areas of product design. In addition, the end users of these devices have required that all manufacturers include these "writable memory" features into their new E²PROMs.

The purpose of this paper is to specify the minimum feature set for 5 volt E²PROMs, and show how these features can be used in different applications. A discussion of endurance is also included in terms of its measurement, characterization and variation in different applications.

THE HISTORICAL EVOLUTION OF THE 5 VOLT E²PROM STANDARD FEATURE SET

The X2816A was the first fully integrated E²PROM to appear on the market. The device, along with its smaller brother the X2804A, pioneered the concept of the E²PROM as a writable memory. As such, the device's interface requirements were tailored to the most common of the writable memories, the static RAM. The high voltages which were needed to perform the Fowler-Nordheim tunneling were generated on-chip through a multi-stage charge pump. This high voltage was then passed through a variety of control circuitry to shape the internal programming pulses. The complex timing for the automatic write cycle was controlled by an on-chip ring oscillator and many stages of counters. Last, but not least, to make the device as much "RAM-like" as possible, latches were added on the address and data inputs to hold the information during the E²PROM's write cycle. These internal latches also allowed the X2816A to perform an automatic byte erase cycle prior to each byte write, eliminating the need for the processor in the system to do so. Both devices are packaged in the JEDEC standard 24-pin DIP packages as well as the JEDEC standard 32 pad LCC in the case of the X2816A. Figure 1 shows the pinouts for the various packages.

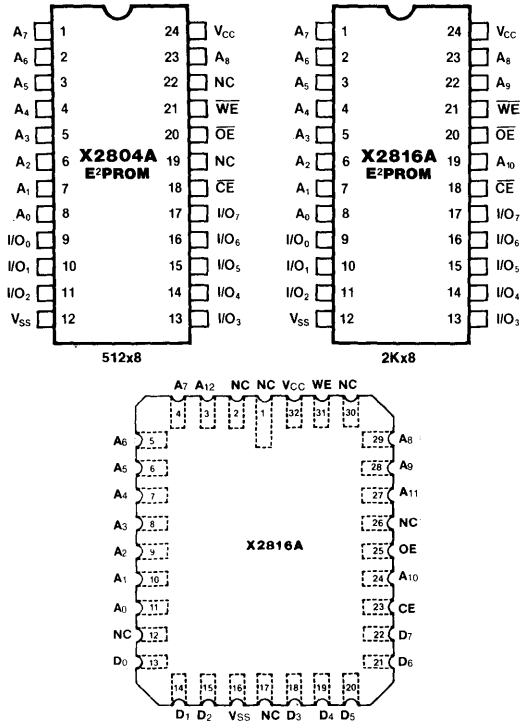


Figure 1. Pinouts for X2804A and X2816A in DIP and LCC.

The X2816A design anticipated an issue which is an important one in 5 volt nonvolatile memory applications: that of inadvertent write protection. Since the device is capable of writing to different locations with only a 5 volt level, care must be taken that the external circuitry surrounding the chip does not initiate a write sequence during power-up or power-down. To facilitate this task, the X2816A incorporates three important features. The first of these is an internal V_{CC} sensor. When V_{CC} falls below 3 volts, all write operations are automatically disabled. The Write Enable input on the X2816A is noise protected to insure that a glitch on the Write Enable input will not trigger a write cycle. In addition, the control circuitry of the device is such that the Output Enable signal will disable any writes to the part if it is asserted. By holding down the Output Enable signal whenever V_{CC} is below say 4.75 volts, inadvertent write operations will be eliminated.

Figure 2 shows a block diagram of the X2816A. As one can see, the basic building block is the 16K E²PROM array similar to that found in the old 2816 device. On-chip integration of the support circuitry required by previous generations of E²PROMs led to the widespread acceptance of the X2816A feature set as the "de-facto" industry standard.

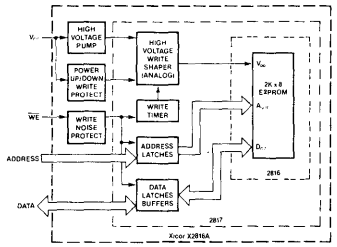


Figure 2. X2816A Block Diagram.

It can be easily seen that virtually all of the manufacturers currently participating in the E²PROM market have included all of these features on their current or next generation products.

Whereas the X2816A set the standard for the E²PROM feature set, the X2864A device from Xicor has refined it. In addition to the features of the X2816A, the X2864A incorporates two additional features: DATA Polling and Page Mode Write.

The Page Mode Write feature on the X2864A allows the system to write 1-16 bytes into the E²PROM in a single 5 msec write cycle. The only requirement is that all of the bytes reside on the same page in the device and that the bytes in the page are latched within the first 200 μsec after the initial Write Enable. Page Mode Write reduces the time required for a complete device re-write to a total of 2.5 seconds.

DATA Polling is a method for determining the completion of the internal E²PROM write cycle. Since the memory is self-timed, this is only of benefit in those applications where time is of the essence in writing to the device. DATA Polling insures that any reads to any location in the E²PROM during the 10 msec write cycle will yield the complement of the data bit #7 currently being written. Hence the name DATA Polling. Since the typical X2864A completes the write cycle in less than 5 msec, some speed may be gained if the entire part is to be written, but the improvement in the chip write time gained through the automatic page write feature greatly overshadows any improvement that can be gained through the use of DATA Polling.

The V_{CC} sensing capabilities of the X2816A were enhanced in the X2864A through the use of a programmable V_{CC} sensor. This circuit consists of a separate floating gate which is charged to a given voltage level. This voltage level provides the reference voltage for the V_{CC} sensor. This technique insures that the reference level compared to V_{CC} is stable over temperature and manufacturing variances.

Figure 3 shows a block diagram for the X2864A and the enhanced features that were added to the X2816A's feature set.

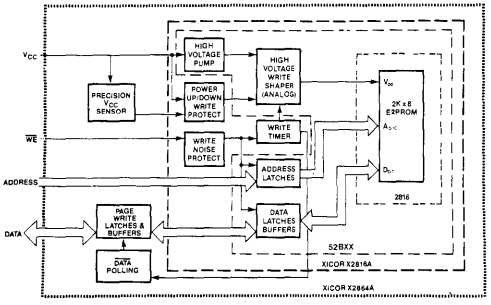


Figure 3. X2864A Block Diagram.

The X2816A established the feature set for the state-of-the-art E²PROMs. This can be seen in the standardization of the various manufacturers offerings at both the 16K and 64K densities. This standard feature set consists of:

1. 5-Volt operation
2. Latched address, data and write enable inputs
3. Automatic erase-before-write
4. Self-timed write operation
5. On-chip V_{CC} sensing

All of the above features have a common characteristic. They all make the E²PROM more "RAM-like" in its operation and interface requirements. Indeed, the new generation of E²PROMs exhibiting the above features can be used interchangeably with many other types of memory devices including ROMs, EPROMs and RAMs. This trend towards more universal E²PROMs has greatly simplified the task of the design engineer trying to use E²PROM. The design engineer spends less time trying to design the socket for the E²PROM and more time trying to conceptualize how the new nonvolatile devices can be used to enhance the end product. DATA Polling and Page Mode are certain to be "standard" features on future parts from other manufacturers.

5

THE STANDARDIZATION OF SPECIFICATIONS

Once the design engineer accepts that there is a standard feature set available from a variety of manufacturer's E²PROMs, he can begin to compare the devices from a specification point of view to determine which device suits his needs best. Of course as with all memory devices the E²PROMs are available in a variety of access times and write cycle times. The power consumption on the devices currently in production are all comparable, although this will change as CMOS versions of the devices become available. Aside from these minor changes, the specifications of the various devices are almost identical.

The biggest "gray" area in the specifications of these devices in in terms of endurance. Endurance and data retention are the key reliability issues in the nonvolatile area. Suffice it to say that the various technologies in production today can all achieve the "10 year" data retention requirement. Although many of the technologies, such as Xicor's exhibit data retention, are many orders of magnitude larger than 10 years, this number seems to be sufficient for most applications. Unfortunately, the question of endurance is not so easily satisfied.

The main problem is that endurance cannot be directly tested. Granted, one can generate tests which will weed out the weak bits, or "freaks," but endurance testing by definition is a destructive test. The problem is similar to that faced by a light bulb manufacturer. One cannot burn each light bulb for 1000 hours to guarantee that the bulbs will burn 1000 hours. The bulb's ability to reach a certain endurance level only proves that the part *did* achieve that level, and does not prove absolutely the bulb's *future* longevity.

Of course, one could take a sample of the devices and test them for a specific endurance level. This data could be used statistically to predict the endurance of the remainder of the devices. Unfortunately, this data is usually based upon the "average" cell in the device and is not significant from an applications point-of-view. Figure 4 shows a graph of the endurance of a "typical" bit in a Xicor E²PROM, and as one can see there is not significant cell margin reduction until 10^7 cycles. Many manufacturers use such a graph to describe the endurance of their devices.

This graph is worth little to the design engineer. The design engineer always has to be concerned about worst case parameters or operation, not

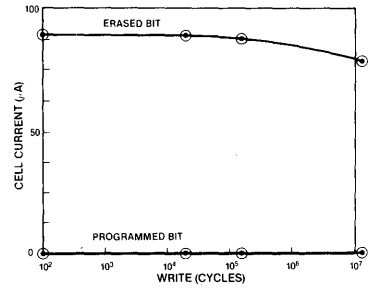
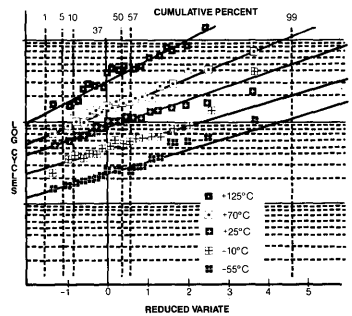


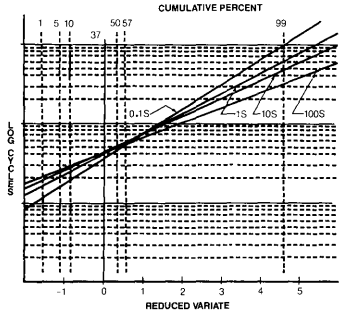
Figure 4. Endurance of a "Typical" E²PROM.

the overall average or typical values. No design engineer worth his salt would design around a "typical" access time; why should he design around a "typical" endurance? A new definition for endurance is needed, and Xicor has found such a definition.

Several definitions are in order. The endurance of a single nonvolatile bit is defined as the number of times that the bit can be changed from one state to a different state before it can no longer be changed. In a similar manner, the endurance of a memory array is defined as the endurance of the weakest bit (i.e., one that fails first). Finally, the endurance of a wafer lot of devices is described by the statistical distribution of the endurance of these devices. It should be pointed out that endurance is wafer lot dependent in floating gate nonvolatile memories. Unfortunately, a simple bell curve type of distribution tells very little as to the endurance of a group of devices. In devices of the same type, the weakest bit has the lowest endurance from the same fixed number of cells in the array. For this reason, it can be expected that the endurance of a group of parts will be distributed according to the "Extreme Value" distribution.



5a



5b

Figure 5a and 5b. Example Extreme Value Distribution Plots.

Figure 5a and 5b show two typical extreme value distribution graphs. The y-axis is the log cycles scale. Each point represents the endurance of an individual device as defined above. The x-axis is a function of the rank of the endurance of the particular device as compared with the rest of the devices in the sample. By picking a set predicted failure rate on the top axis, one can guarantee a certain level of endurance. As one would expect, since the 100% of the devices are not actually being tested for an endurance level, there cannot be a 100% guarantee, but one can get quite close.

The "Extreme Value" distribution not only allows for the specification and guarantee of a certain endurance level, it also allows one to study the effects of external conditions on the endurance of the devices. It can be seen that in Figure 5a identical material will exhibit different endurance levels when operated at different temperatures. Indeed, the devices actually achieve a higher endurance when cycled at 125° C. One explanation for this phenomenon may be the change in the rate with which the tunneling electrons are trapped and de-trapped in the insulating oxide. In a similar manner, the rate at which the cycles are put on the device will also influence the endurance for identical devices. A simple change in cycling rate from .1 seconds to 100 seconds has a marked effect on the endurance of the devices as is shown in the plot of Figure 5b. In actual applications, this data change rate would be even slower, usually in days. Unfortunately, cycling devices in intervals measured in days takes a very long time, but the scientists at Xicor are doing it to learn more about effects of applications specific parameters on endurance.

There exists a pressing need for a standardized method for specifying and characterizing the endurance in nonvolatile memories. The "Extreme Value" distribution is the best one that Xicor has found, and there is a move to make it the industry standard approach. Only after there is such a method in place can the end users ever be sure that they are comparing "apples-to-apples" when studying the endurance specifications of nonvolatile memories.

STANDARD FEATURE SET E²PROMs SIMPLIFY DESIGNS

The appearance of a variety of multiple sourced full-featured E²PROMs has led to their rapid acceptance by the design engineering community. Such standardization was required to change E²PROMs from scientific curiousity to a high volume low-cost memory alternative.

The "RAM-like" nature of the new E²PROMs greatly simplifies their use in all areas of microprocessor-based design. The elimination of complex timing and voltage requirements allow the designer to incorporate nonvolatile capabilities into his design with minimal effort.

One of the key advantages of the E²PROM is its abilty to be re-written in circuit. The initial E²PROM offerings were at the 16K and smaller density level. For this reason, they were not quite dense enough to be seriously considered as a program storage medium. As a result, most of the initial E²PROM applications used the E²PROM for data storage, such as set-up, configuraiton, or calibration parameters. The only applications which did use the E²PROM for program store were those who could afford the cost and board space implications of such a design method.

The availability of the 64K E²PROM along with the reduction in cost of the 16K devices has led to a new awareness among design engineers. The E²PROM is now looked at as a viable software carrier, either by itself or in conjunction with other nonvolatile memory devices such as ROMs and EPROMs.

The use of E²PROMs for program storage has many significant advantages. At time of manufacture, the program for an individual system can be loaded into the E²PROM either on the assembly line or in the test stage. Many different versions of a product can use the same basic board design and be configured at time of assembly through the loading of different programs into the E²PROM.

This method could have been used in the past, but it required the use of PROM programmers and multiple program selections in the manufacturing environment. The use of the standard feature set E²PROMs allows the entire process to be automated in the following way.

Initially, each board is assembled with the E²PROM containing a diagnostic program. The entire board is then tested on an automated board tester which will use the trace execution of the diagnostic program in the E²PROM. Once the board has been tested, the test system holds the processor in a quiescent state, such as Reset, and takes control of the bus. The program for the specific system under test is then loaded into the E²PROM by the test system. The unit leaves the test stage fully tested and configured for the end customer.

E²PROMs also allow the system's software to be updated remotely, either through a field service interface or a modem link to a main computer. The cost of performing a software update in the field is extremely expensive. A service technician must go to the site, often in a remote area, and replace the system's EPROMs or ROMs. E²PROMs make this scenario much less painful since the new software can be loaded electrically, as opposed to physically. These software updates are attractive for a variety of reasons, including the fixing of software bugs, updating an older version of the system software, or changing the system's configuration or capabilities.

The ultimate flexibility from a systems point of view is through the use of only E²PROM for software storage. Unfortunately, this can get quite expensive since E²PROMs are still more costly than EPROMs or ROMS. A "hybrid" approach is the best solution in many applications, since it balances the flexibility of the E²PROM with the low cost of EPROM or ROM. Using both E²PROM and ROM also eases the update method since the download software can be stored in the ROM. The reason for this is as follows. With any of the full-featured E²PROMs, there is a period of time during the internal write cycle that the device is inaccessable for either subsequent writes or reads. If the processor is executing code out of the same E²PROM to which it is writing, the next instruction fetch will yield a high-impedance bus, and the processor will get lost. In the case of a ROM/E²PROM hybrid design, the actual download routine can reside in ROM as shown in Figure 6.

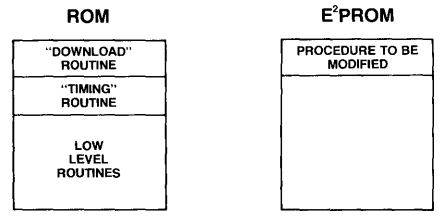


Figure 6. Memory Map for ROM/E²PROM *Hybrid*

If only E²PROM is used for the program storage, the download situation becomes a little trickier. If the code to be modified is a different chip than the one that the processor is executing out of, everything is fine. In the case of a single E²PROM design, the following approach needs to be used. The memory map in Figure a, b, and c graphically depicts the different stages.

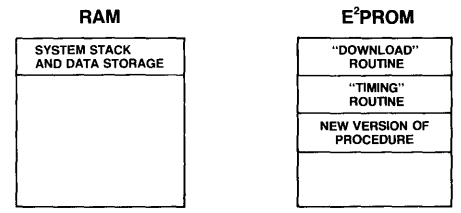


Figure 7a.

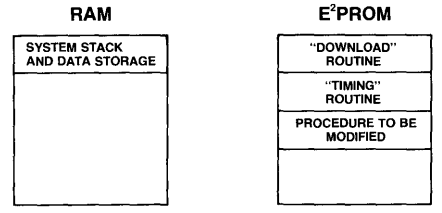


Figure 7b.

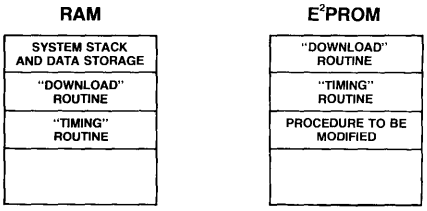


Figure 7a, 7b and 7c. Memory Maps for E²PROM *Only Implementation.*

In the first step, the download and E²PROM write procedures are stored in E²PROM. Once the system realizes that a new version of internal code is to be downloaded, the system copies the download and timing routine into system RAM. At this point, Figure 7b shows the memory map. The processor then jumps to the download routine and executes out of RAM until the download is complete. The processor then jumps back to the main program in E²PROM and continues its normal tasks. The RAM is freed up for other uses, and the new copy of the downloaded routine is in the E²PROM as is shown in Figure 7c. It is left as an exercise for the readers to determine how this technique could be used if the procedure to be updated is the actual download procedure. This can be handled by a simple extension of the above technique.

Now that we have discussed the manner in which a system utilizing E²PROM for program storage can be remotely updated, it is pertinent to determine how the maximum flexibility can be attained in a "hybrid" design. As was mentioned before, the ultimate flexibility can be attained if all of the program memory is E²PROM since any portion of it can be changed in the field; while an all ROM approach features virtually no flexibility. The secret is through the use of intelligent software design to maximize the flexibility of a set amount of E²PROM storage.

Top-down or structured programming has received much attention in the software world due to its inherent ease of implementation and subsequent modification. The key characteristic of such an approach is that the task to be performed is broken down into smaller and smaller sub-tasks, eventually leading to the "bottom" level of the program. This "bottom" level is composed of many short and simple machine language routines, which in themselves are simple to code and debug, while together they perform the desired complex "uppermost" task. As one can see, this method of software development lends itself well to the maximization of flexibility in a "hybrid" system.

As an example, we will use a software segment which performs commands as they are entered on a keyboard. The task of interpretation and execution of the entered commands is broken down into three routines. The "bottom" level routine "Get-Character" simply waits for a character to be entered, and then places the character into a buffer. The next level routine is called "Parse," and this routine calls "Get-Character" continuously until a "Carriage Return" is detected. The "Parse" routine also eliminates illegal or superfluous characters. The end result is a syntactically correct command string in the command buffer. The "uppermost" level takes the parsed command, searches a table to see if it is valid, and fetches the appropriate routine's address.

Figure 8a shows the address map for a hybrid system which uses the software described above. The outermost level, "Command" is stored in the E²PROM as is the Valid Character List and the Valid Command List. A sample entry into the valid command list is shown for the command "GO." The entry includes the valid command format as well as the address of the routine to be executed upon reception of the "GO" command. The E²PROM also contains many other High-Level routines as well as a patch area that will be explained shortly.

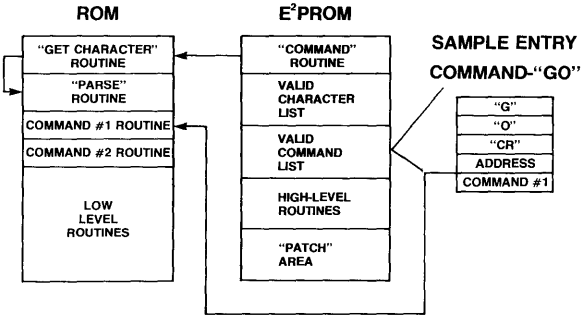


Figure 8a. Address Map for Hybrid-Initial Configuration.

The ROM contains the "low-level" routines including the "Get-Character," "Parse" and the routines for the different commands. Since these routines are the "lowest" level of the program, it is assumed that these are relatively stable and will not need to be changed.

The use of the E²PROM for the storage of the Valid Character and Valid Command Lists allows them to be easily updated as the system's vocabulary is expanded.

One of the characteristics of a "top" level routine, such as the "command" routine, is that it mainly consists of calls to other routines. If an error is found in the "command" routine, it can be easily changed to execute the called routines in a different order, etc. . .

If one of the lower level routines needs updating, such as "Parse," the new version of the routine can be loaded into the "patch" area of the E²PROM. Any references to the "Parse" routine are then changed to point to the new version in the E²PROM rather than the old version still in ROM. Figure 8b shows the address map after such a "patch" has been performed.

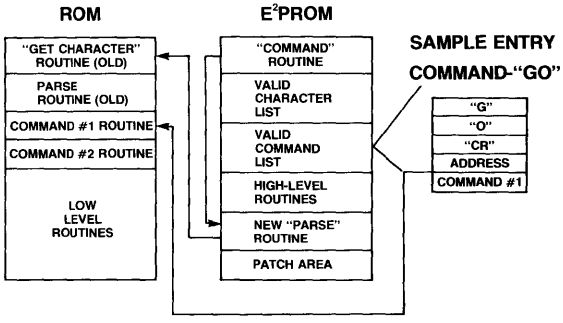


Figure 8b. Memory Map After "Parse" has been Patched.

In a similar fashion, if one of the command routines is found to be in error, the new routine is loaded into the "patch" area of the E²PROM, and the reference to the routine in the Valid Command List is updated to point to the new routine. Figure 8c shows the address map after a patch has been made to command routine #1.

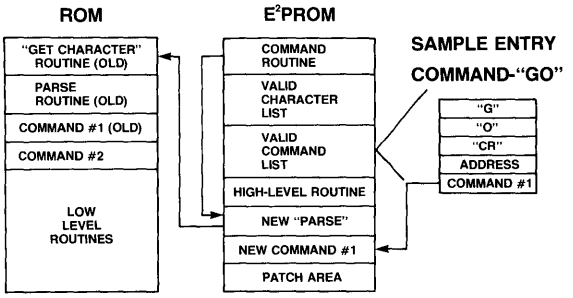


Figure 8c. Address Map After "Parse" and "Command #1" are Patched.

It can be seen that this implementation is quite flexible in terms of remote software alteration. This is a direct result of the "Top-Down" structure of the software. The added benefit of this software technique is that it is easier to create, more modular, easier to debug and easier to verify. One can extend the concepts discussed here even further into the E²PROM's impact on threaded-code interpretive algorithm implementations, but that is beyond the scope of this paper.

The impact of the standard feature-set E²PROMs has not yet been fully seen. One can see that the availability of such devices will influence not only the hardware aspects of a system design, but the software aspects as well. The present generation of E²PROMs has finally reached the density level and feature set that allows it to become a medium for use in program storage applications. Once the final unresolved issue of endurance specification is cleared up and designers understand the benefit that can be realized in all areas of system design, manufacturing and maintenance, the E²PROM will be perceived as one of the most important advances in semiconductor history.

THE NOVRAM FAMILY A NEW DOMAIN OF SYSTEM POSSIBILITIES

JULIE BENNETTS CONKLIN

INTRODUCTION

The first nonvolatile memory device to be designed and manufactured by Xicor was the X2201A, a 1K x 1 NOVRAM. The design concept of the NOVRAM evolved from the combined talents of Richard Simko and William Owen, two of Xicor's founders. Simko was the process developer of the Intel double-poly FAMOS 2708 ultra-violet EPROM and Owen was the circuit designer of the Intel HMOS 2147 RAM.

The NOVRAM is a static volatile RAM overlaid bit for bit with a nonvolatile E²PROM "shadow" memory. The NOVRAM is reprogrammable in circuit using a single 5 volt supply. Figure 1 shows the functional layout of the NOVRAM.

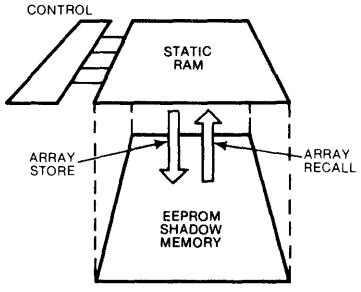


Figure 1.

Data is written to and read from the static RAM portion as if the device were a RAM. Data is transferred between the RAM and nonvolatile E²PROM memories in parallel in one store or recall operation.

Xicor was founded in 1978, and the first X2201A was shipped in 1980. In 1981, the NOVRAM family was expanded to include an X2210 (64 x 4) and an X2212 (256 x 4). In 1983, the X2400 series (16 x 16) of serial input/output NOVRAMs was introduced. And, 1984 brings the "byte-wide" series — the X2001 (128 x 8), the X2002 (256 x 8), and the X2004 (512 x 8).

In addition, Xicor also manufactures a family of nonvolatile E²PROMs — the X2804A (512 x 8), the X21816A (2K x 8), and the X2864A (8K x 8). Xicor E²PROMs also are reprogrammable in circuit using a single 5 volt supply.

THE NOVRAM TODAY

Xicor NOVRAMs are manufactured using the same reliable triple polysilicon floating gate N-channel MOS technology pioneered with Xicor's X2201A.

5V Only

The NOVRAM is read to and written from as if it were a static RAM. The device is fully TTL compatible and needs no high voltages — a single 5 V power supply is all that is needed for any function. The nonvolatile E²PROM stores data via Fowler-Nordheim electron tunneling. This function is performed by the device in circuit using only the 5 V chip power supply. An onboard charge pump provides the internal store voltage.

Nonvolatile Data Storage

The nonvolatile E²PROM polysilicon floating gate is isolated by a thick oxide layer (approximately 800 Å) and the programming surface of the poly layers are textured to enhance tunneling. Figure 2 shows a cross section of a floating gate, and these textured programming surfaces.

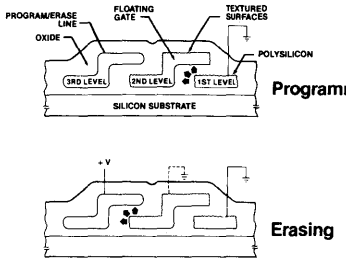


Figure 2.

Data is stored and erased in the nonvolatile E²PROM via Fowler-Nordheim electron tunneling between these layers. An erase leaves Poly 2 positively charged; programming leaves Poly 2 negatively charged.

The NOVRAM cell is composed of a 6 transistor volatile static RAM and a nonvolatile "shadow" E²PROM. The RAM portion acts as a latch holding data for storage and receiving data when it is recalled from the E²PROM. See Figure 3.

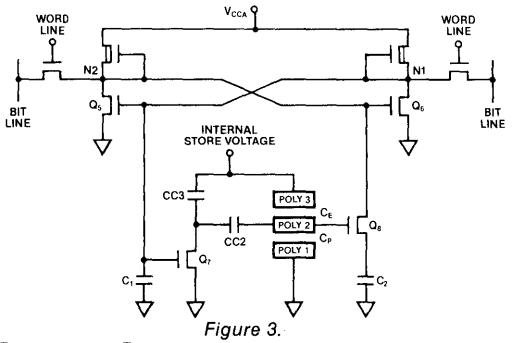


Figure 3.

Store Operation

A STORE cycle is initiated by a low signal on the STORE input to the NOVRAM. Once initiated, the STORE cycle will automatically time out until completed. A STORE transfers data bit for bit from the volatile static RAM to the nonvolatile E²PROM. The internal storage voltage is generated on-chip.

There are two types of storage mechanisms which will occur during the STORE operation, and each bit will experience only one. This is determined by the state of each bit (floating gate) prior to the STORE and the desired state after the STORE.

If the state of a particular bit is to remain unchanged by the STORE operation, no tunneling will occur at that location. Xicor NOVRAMs detect charge or lack of charge on the floating gate and will not perform a repetitive function, thereby extending the endurance of each bit.

Should the state of the floating gate need to be changed, it will either be programmed (charged) or erased (discharged).

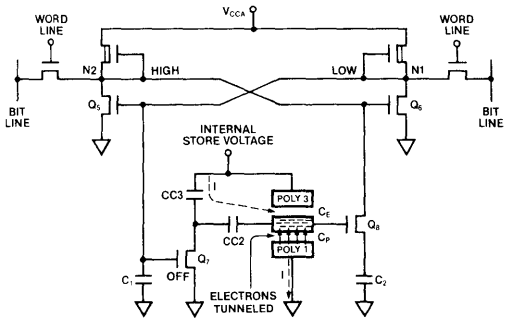


Figure 4.

As shown in Figure 4, when programming a cell, N_1 goes low and Q_7 is off causing the junction between CC_2 and CC_3 to float. The combined capacitance of CC_2 and CC_3 is greater than C_P (the capacitance between Poly 1 and Poly 2). This causes the floating gate to follow the internal store voltage when it goes high. Poly 2 then becomes negatively charged due to the tunneling of electrons from Poly 1 to Poly 2 and the floating gate is programmed.

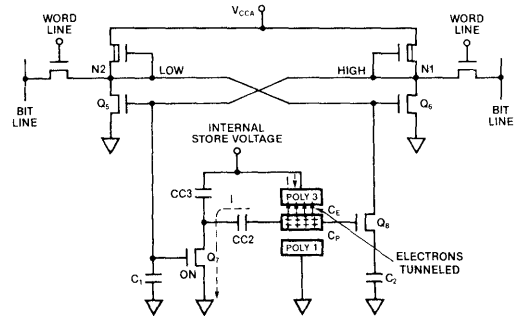


Figure 5.

As shown in Figure 5, when erasing a cell, N_1 goes high and Q_7 is turned on causing the junction between CC_2 and CC_3 to go to ground. The capacitance of CC_2 is greater than that of CE (the capacitance between Poly 2 and Poly 3). Poly 2 remains low and Poly 3 now follows the internal store voltage when it goes high. Poly 2 then becomes positively charged (discharges) due to the tunneling of electrons from Poly 2 to Poly 3 and the floating gate is erased.

Recall Operation

To recall data from the nonvolatile E²PROM array to the volatile static RAM, a low level signal is sent on the ARRAY RECALL input to the NOVRAM. As with the STORE operation, two types of Recall mechanisms will occur depending upon the state of each bit/cell:

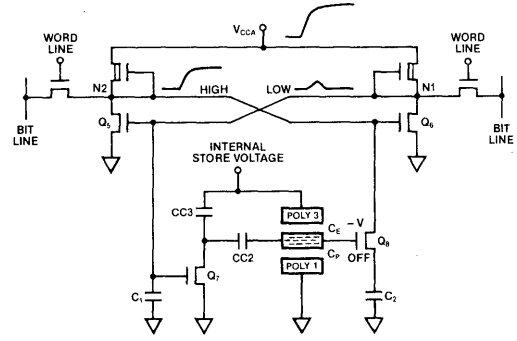


Figure 6.

As shown in Figure 6, when recalling a programmed cell, the memory array voltage VCC_A goes low momentarily to equalize the voltages at nodes N1 and N2. Then, VCC_A is allowed to rise. If the floating gate on a particular bit cell is programmed (negatively charged), Q8 is off. This allows N2 to rise more rapidly than N1 to the VCC_A level and the "latch" (the static RAM) is set with N2 high and N1 low.

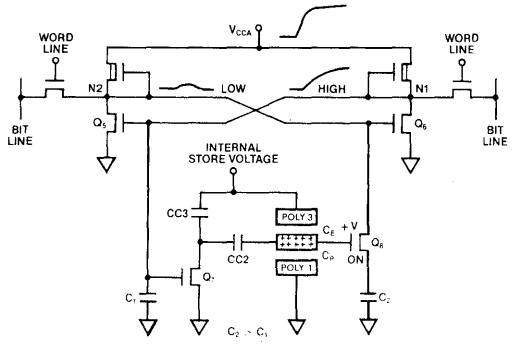


Figure 7.

Again, VCC_A goes low momentarily to equalize N1, and N2 is then allowed tdo rise. In this instance (Figure 7), the bit cell is erased (positively charged) and Q8 is on. With Q8 on, C2 and N2 are connected. N1 is then able to rise more quickly to VCC_A than N2 and the latch is set with N1 high and N2 low.

Both the STORE and RECALL operations transfer the data array from one memory location (RAM or E²PROM) to the other in one operation.

TECHNOLOGY AND RELIABILITY

There are two aspects of nonvolatile memory reliability that are of concern:

1) Data Retention = time elapsed before first bit in array fails.
2) Endurance.

Xicor technology excels in both aspects as shown by the following data:

Data Retention

The combination of thick oxide (800 Å) and textured programming surfaces in the floating gate cells creates an environment that is ideal for Fowler-Nordheim tunneling. The textured ("bumpy") poly surface concentrates the electric fields near the regions of high positive curvature (i. e., near the tops of the "bumps") as shown in Figure 8.

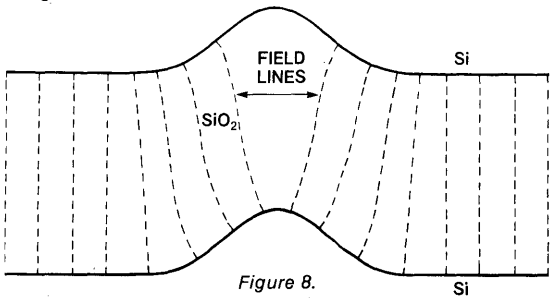


Figure 8.

Fowler-Nordheim tunneling current increases exponentially with increasing electric field applied to the emitting surface area. Research done at Xicor has established an equation that characterizes tunneling current as a function of the amount of texture on the programming surface. The current comparison of flatplate (125 Å) and textured (825 Å) surfaces is shown in Figure 9 below.

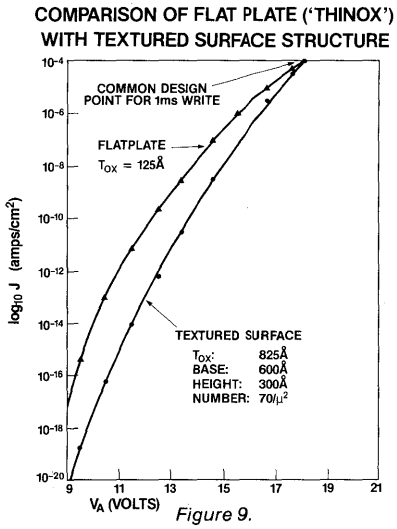


Figure 9.

This figure illustrates that the two surface types do achieve a common design point at the higher current levels where programming occurs.

The data retention characteristics of a textured emitting surface versus a flatplate emitting surface become an issue at the lower values of applied voltage. These lower values are representative of

typical read and store operations. As shown in Figure 9, the current emitted by the textured surface (tunneling) is approximately four orders of magnitude lower than that of the flatplate surface at the lower values (9-13 volts) of appled voltage. This suggests that the textured surface is less likely to experience tunneling during read and store operations, and during power up and down situations than the flatplate surface. The thicker textured Xicor technology provides better data retention.

Xicor has performed extensive testing on NOVRAMs using high temperature bakes with the units stressed and not stressed to support the statements above with manufactured units.

Figure 10 below shows the results of 100 units of an X2210 tested for data retention over three extended temperatures.

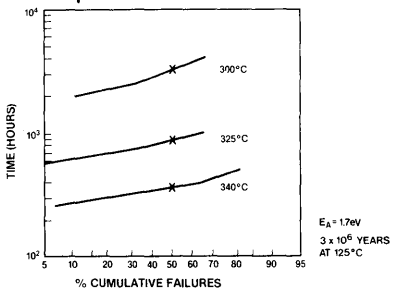


Figure 10.

As shown, the first bit failure occured at 300° C only after 2000 hours of testing.

This same data was used to calculate expected failure rates in time. This data is shown in Figure 11 below.

The Mean Time Between Failures is extrapolated to 3 million years at 125° C with any activation energy of 1.7 eV for this sample group.

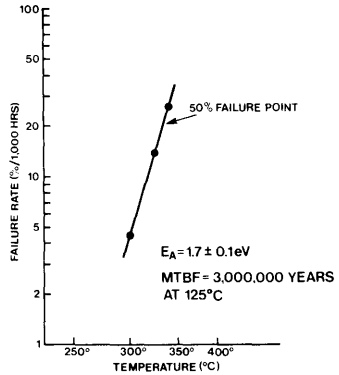


Figure 11.

Endurance

As discussed earlier, Xicor devices sense the state of the nonvolatile E²PROM floating gate prior to performing a store operation. This characteristic reduces unnecessary cycling of a given bit in the array and increases the potential endurance of that bit. This is a critical point since the endurance limit of a given device is determined by the first bit failure that occurs for that device, not the average or typical value for the memory.

Xicor specifies endurance for NOVRAMs as two values:

1) Data changes per bit
2) Store cycles

Xicor's goal is to specify the maximum number of data changes per bit possible based upon sampling data taken from every lot for every NOVRAM.

Xicor data shows that endurance is affected by:

1) Temperature
2) Frequency at which data is changed.

Xicor has recently characterized data endurance as a function of each of these parameters. The easiest way to look at this data is using graphs using 'Extreme Value Distribution.' The following graphs each show data collected from X2212 sample lots.

Figure 12 below shows the results of temperature tests on five 20 unit samples subjected to data changes at a rate of one per second until each device failed. Each point marked on the graph is the first bit failure point for each device tested. Two points are made by these tests results — the maximum endurance increases with temperature and the dispersion of maximum endurance cycles achieved increases with temperature.

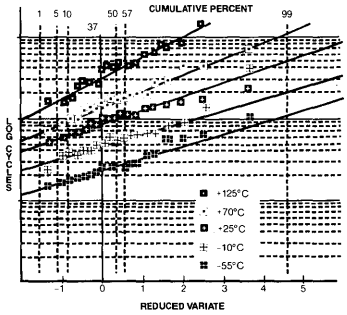


Figure 12.

Figure 13 shows the results of four 20 unit samples subjected to four different fixed delays between data changes. The dispersion of maximum endurance levels for each fixed delay (0.1 sec, 1 sec, 10 sec, and 100 sec) is represented by the slope of each line on the graph. Note that as the time delay is increased, the dispersion decreases, as demonstrated by the differing line slopes graphed. Although most applications allow much more than 100 sec between cycles, this information is useful for endurance testing of devices. Decreasing the time delay between cycles speeds the testing process and requires less cycles to reach the maximum endurance of the device.

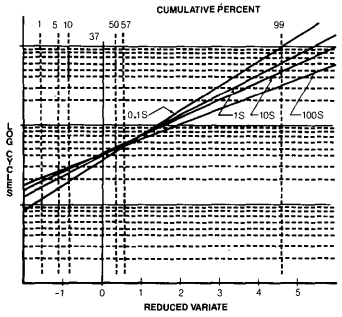
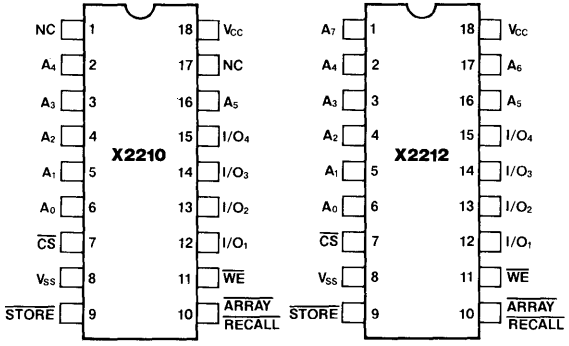


Figure 13.

PRODUCTS

The Xicor family of NOVRAMs can be used with nibble wide (by 4), byte-wide (by 8), and serial I/O microprocessors:

By 4's



64x4 *Figure 14.* 256x4

- 18 pin plastic and cerdip packages
- 300 nsec Read Access time
- 300 nsec Read and Write Cycle times
- Latched and self timed
- Unlimited RAM data changes
- Endurance specs for nonvolatile array:
  1,000 data changes per bit; 10,000 store cycles
  5,000 data changes per bit; 50,000 store cycles
  10,000 data changes per bit; 100,000 store cycles
- Infinite Recall cycles
- Hardware control over nonvolatile operations

By 8's

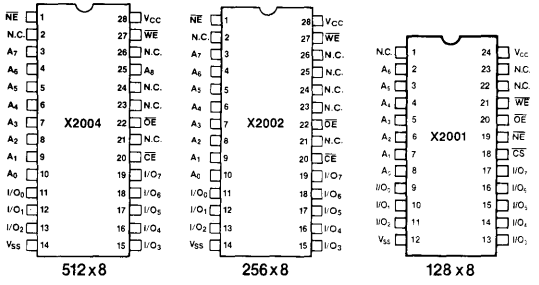


Figure 15.

- Plastic package
- 300 nsec Read Access time
- 300 nsec Read and Write Cycles times
- Unlimited RAM data changes
- Latched and Self timed
- Software Control over nonvolatile operations
- Endurance Specs:
  1,000 data changes per bit; 10,000 STORE cycles
  10,000 data changes per bit; 100,000 STORE cycles

Serial I/O — X2400 Series

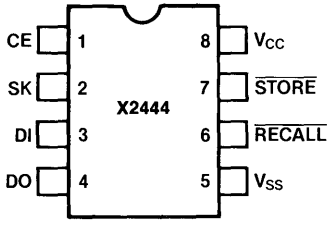


Figure 16.

- Serial Interface, three pin control
- Low power Standby and Sleep Modes
- Unlimited RAM data changes
- Low cost
- Static timing
- Complete store protection

5

- Endurance Specs:
  1,000 data changes per bit; 10,000 STORE cycles
  10,000 data changes per bit; 100,000 STORE cycles
- Hardware and software controls over nonvolatile operations

APPLICATIONS

NOVRAMs are traditionally thought of as ideal nonvolatile memory devices in systems requiring frequent updates to the Static RAM and nonvolatile storage or "data capture" of the RAM data in the E²PROM in the event of system power loss.

There are other application environments also ideally suited to the NOVRAM since it is actually two memory arrays in one device.

Dip Switch Replacement

A typical CRT terminal uses dip switches to set up the terminal configuration data each time the terminal is turned on. These mechanical switches take up board space, are vulnerable to contamination since they are not sealed and must be replaced once worn out from frequent updates if their application calls for such updating. Because these devices are subject to updating, the terminal itself often cannot be a completely sealed unit, thus end users may be permitted access to other portions of the unit's circuitry.

The Xicor X2400 series of serial interface NOVRAMs offers dip switch users a low cost, compact and reliable alternative. One X2400 device can replace up to 32 8-bit dip switches. Figure 17 shows a conventional terminal configuration using one 8-bit dip switch and pullup resistors.

As shown in Figure 18, the X2400 device can be plugged into the top section of the pullup resistor socket and the dip switch socket is no longer needed.

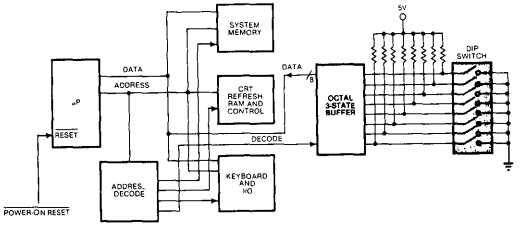


Figure 17.

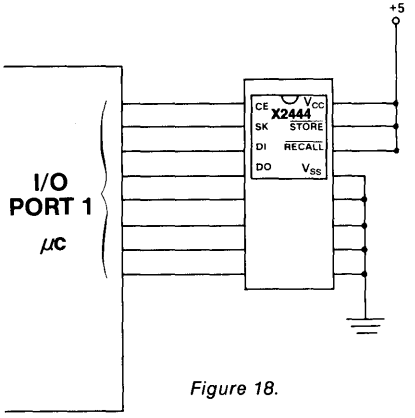


Figure 18.

Ex: Terminal Configuration.

Because one X2400 series 8 pin minidip device can replace up to 32 8-bit dip switches (256 bits), and associated circuitry, the terminal board designer needs much less board space on which to provide configuration storage capability. And, the end user need not be concerned with access to the devices for updates since the NOVRAM contents can be observed via the terminal keyboard. And, because the contents can only be changed via the keyboard, it is less likely that terminal configuration information will be changed accidentally or without the knowledge of the terminal user.

By using the nonvolatile E²PROM portion of the NOVRAM for storage of the terminal default parameters, the terminal user can use the RAM portion for temporary parameters. These temporary parameters can then be stored in the nonvolatile E²PROM at the user's option (see Figure 18).

Power Fail Tolerant System

Ex: Industrial Controller

In the event of power failure, many industrial controllers must be stopped and restarted at specific program locations to prevent damage to work in process or to users of the machinery under control. The NOVRAM can be used in such an application as both system memory (RAM portion) and a nonvolatile memory (E²PROM portion) storage location for the microprocessor program status in

the event of system power loss. This is a classic example of data capture and storage at power loss. Figure 19 shows an X2212 used for this purpose.

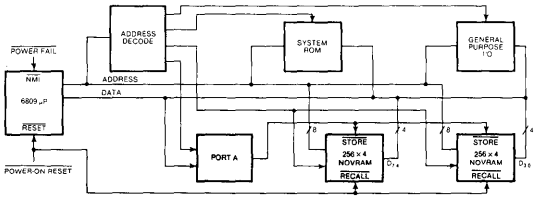


Figure 19.

Upon power loss, a Power Fail signal causes the microprocessor to generate an interrupt. The system memory contents and the µP stack, which are both in the RAM portion of the NOVRAM, are then stored on the nonvolatile E²PROM portion of the NOVRAM.

Upon return of power, Power On/Reset also generates a RECALL at the NOVRAM. A power-on routine verifies that an interrupt did occur at power loss and a return from interrupt is performed, returning the program to a known function.

Self Calibrating Systems

Ex: Tape drive

Mechanical systems require some method of measuring, recording and correcting for wear of mechanical system components. The most common method of doing this is calibration of potentiometers. A repair/service person must make a service call, take apart the unit to reach the potentiometer(s), adjust spec components to compensate for mechanical wear and then reassemble the unit. This service call must occur on a periodic basis and the expense of these service calls and machine down time can be costly.

An alternative to the calibration of potentiometers is the use of Xicor NOVRAMs in place of the potentiometer in applications under microprocessor control. Once such application is a computer tape drive for which potentiometers are traditionally used to calibrate the drive heads, motor and recording levels. Figure 20 shows a microprocessor controlled tape drive using an X2210.

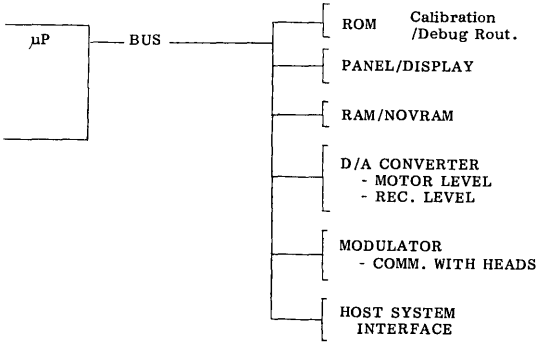


Figure 20.

As shown in Figure 20, the X2210 is part of the system memory. A debug/calibration routine can be initiated by a service person via a terminal keyboard panel. The motor and recording setting levels at which the host system is currently operating can be read via the D/A converter, reset to compensate for wear if necessary, and the new setting values can be written into their corresponding address locations in the RAM portion of the NOVRAM. Similarly, the modulator provides information about the drive heads and these too are self calibrated.

Once the information is in the NOVRAM, at any time this information can be read from the NOVRAM via the keyboard. The unit does not have to be disassembled unless something must be mechanically repaired. The data in the NOVRAM can be read in seconds, unlike the more time consuming task of field calibration of potentiometers. And, the data is stored in the nonvolatile E²PROM during machine downtime.

SUMMARY

Xicor NOVRAMs are a compact, reliable, cost competitive and easy to use nonvolatile memory for use in applications requiring frequent memory updates or rapid data capture at power down. The RAM portion of the NOVRAM has unlimited data change capability. The nonvolatile E²PROM is cycled only when a STORE operation is performed. Xicor NOVRAM endurance limits are specified in terms of data change per bit as well as array STORE cycles. E²PROM bit locations are "written to" only if a data change is required, thereby greatly increasing the potential endurance limit of the device. Xicor has set the standard for the NOVRAM in terms of ease of use, reliability, and specifying maximum device endurance.

These papers were first presented at

Electronic Show & Convention
May 15-17, 1984
Boston, Massachusetts

NONVOLATILE MEMORY GIVES NEW LIFE TO OLD DESIGNS

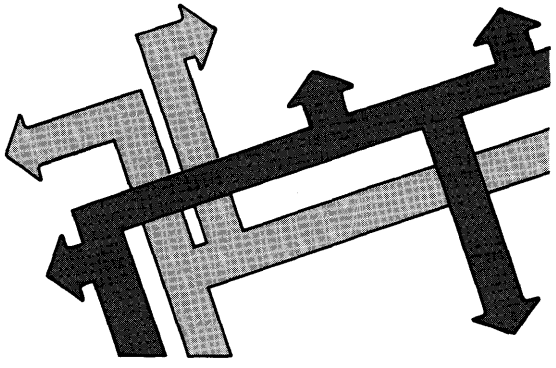
Terminals and other equipment can be made more flexible, and product life can be extended by upgrading and customizing with NOVRAMs and EEPROMs.

by Richard Orlando, *Xicor, Inc., Milpitas, Calif.*

The recent appearance of low cost, 5-V nonvolatile memories has led to design applications that can be broken into two distinct classes. One class uses nonvolatile memory to store such data as configuration or calibration parameters. This information can be updated and then stored in the device for access on power-up. The second application uses nonvolatile memory for program storage. Here, the nonvolatile memory's main advantage is that content can be updated or changed remotely, rather than by device replacement.

Unfortunately, many end products completed prior to the availability of these devices are threatened by newer designs. The latter take advantage of the added flexibility and features afforded by nonvolatile memory. There are, however, ways to add nonvolatile memory to existing designs without a major redesign.

For example, consider the schematic of an intelligent terminal design, which will be used to illustrate methods that improve the flexibility of almost any microprocessor-based design (Fig 1). Here, the 6800 processor is the source of the "intelligence" in the design. The serial communication channel is through a 6551 asynchronous communication interface adapter (ACIA), which features an onchip baud rate generator. A 2716 erasable PROM is the program store for the 6800, and the two 2114 RAMs provide 1 Kbyte each of buffer, stack, and parameter storage. The keyboard is an ASCII-encoded type whose inputs are fed through one port of a 6821 peripheral interface adapter (PIA). The other port of the 6821 receives the dual inline package (DIP) switch settings for such user-defined operational parameters as baud rate, parity, and protocol selections.



Video control is provided by a 68045 (or 6845) CRT controller. The display RAM interface is set up as a tightly coupled, shared RAM interface. The timing

Richard Orlando is product marketing manager at Xicor, 851 Buckeye Ct, Milpitas, CA 95035. He holds a BS in computer systems engineering from the University of Massachusetts at Amherst.

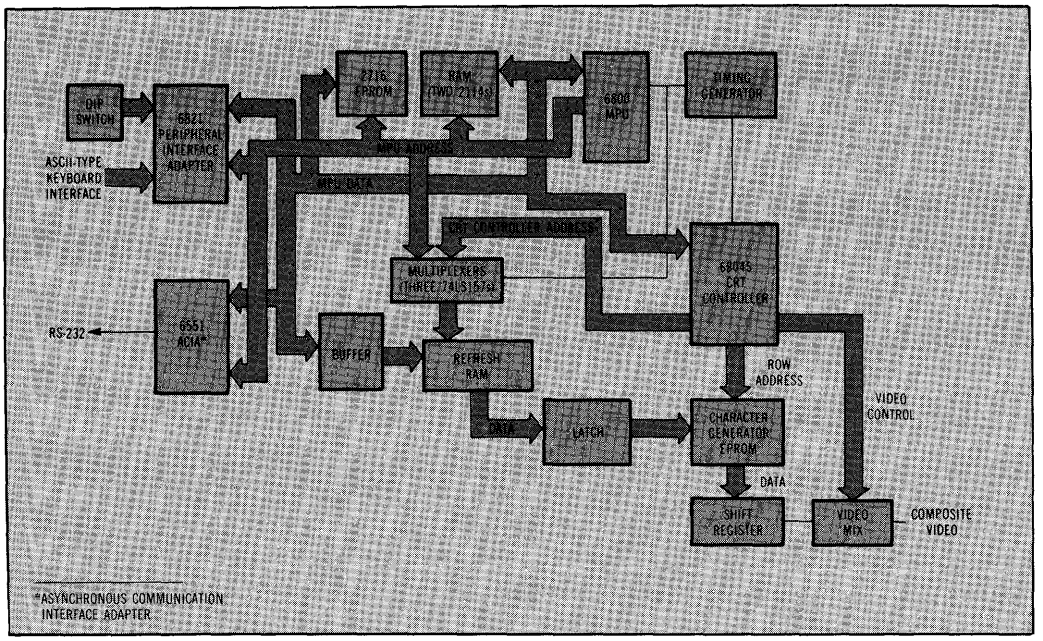


Fig 1 The original terminal design has dual inline package (DIP) switch settings that must be read by the processor. They are then parsed to determine setup parameters invoked from the terminal program contained in the EPROM.

is such that the CRT controller only accesses the data in the display RAM during the bus "dead" time of the 6800. This allows the processor to access the data in the display RAM at any time, regardless of the state of the CRT controller. The CRT controller can access the RAM transparent to the processor, and thus can relieve the processor of any access arbitration tasks.

Improving the design

Although the design serves its initial purpose, several areas, which will make it more flexible and possibly extend the life of the product, can be improved. Intended for use in a variety of applications, the original design relies primarily on software for its characteristics and "feature set." Simple changes to the erasable PROM containing the 6800's software allow such terminal "customization." This approach is adequate when end-user needs are known prior to manufacture. However, if a user wants to upgrade an existing terminal, someone must perform a costly EPROM change in the field. The same penalty applies to the manufacturer who wishes to "upgrade" the software of the existing units in the field, in order to increase performance or to eliminate possible errors.

The second area in need of improvement is the DIP switch used for the input of user-definable parameters. It creates many manufacturing problems, since most DIP switches cannot be handled by automated assembly equipment, such as insertion machines and wave solderers. Additionally, because someone must manually toggle the switch through a sequence of positions in order to fully test the boards, DIP switches slow down automated board testing. Also, to change parameters, a DIP switch requires the terminal user to remove an access panel and manipulate switch toggles while referring to a manual. As the range of user-definable parameters expands to include such features as emulation modes, the problem becomes even more awkward.

In the example terminal, added features and enhancements can be made in two ways. The first involves replacing the DIP switch with an X2443 serial NOVRAM, which is used to store user-defined setup and configuration parameters. The second replaces the EPROM with an electrically erasable PROM.

The NOVRAM, a 256-bit serial device, is organized as 16 words of 16 bits each. All communication between the device and the processor is done in a bit-serial fashion using the data in input, data out output, and the synchronous clock lines shown in Fig 2. All operations are controlled by the microprocessor through the serial interface. Read and write operations are executed through the transmission of a specific 8-bit instruction code with an embedded address of the word to be accessed. In the write operation, the processor follows the write command with 16 bits of data to be written. In the

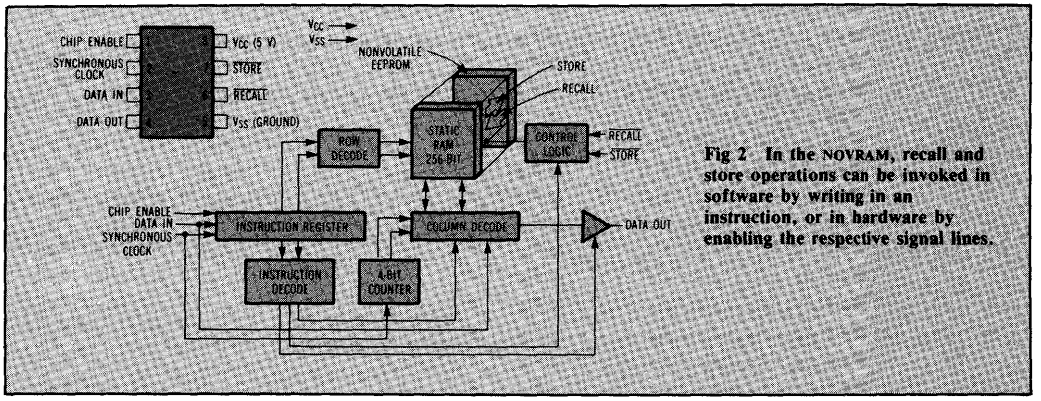


Fig 2 In the NOVRAM, recall and store operations can be invoked in software by writing in an instruction, or in hardware by enabling the respective signal lines.

read operation, the processor supplies the read instruction, and then gives the X2443 16 clock cycles, which the device uses to output the data to be read. The NOVRAM also includes several non-data types of instructions to control the nonvolatile operation of the part, the part's power consumption, and the write/store lockout feature.

The X2443 is designed to interface with single-chip microcomputers when the main consideration is minimizing I/O lines and software overhead. This device also works well in microprocessor-based designs requiring upgrading with minimal design changes. It consists of a serial static RAM overlaid or "shadowed" bit-for-bit with a 5-V EEPROM array, as shown in Fig 2. The execution of a store operation, either from the input $\overline{\text{STORE}}$ or by the execution of the software store instruction, transfers the current contents of the SRAM *en masse* into the nonvolatile EEPROM array. In a similar manner, the execution of a recall operation, via the $\overline{\text{RECALL}}$ input, transfers the contents of the nonvolatile EEPROM array into the SRAM array. On power-up, the contents of the EEPROM array are automatically loaded into the RAM array for a default configuration.

When using the X2443 to replace an existing DIP switch, it is advantageous to drop the NOVRAM into the existing switch "footprint." Fig 3 shows the simple conversion of the existing site or socket (a) to accept the X2443 (b). Four of the eight 6821 I/O lines used to read the DIP switch are already mapped into pins 1 through 4 of the NOVRAM.These lines originally input the current settings of the DIP switches, but can be configured through the 6821's data direction register to serve as the three outputs and one input needed for interfacing the NOVRAM. Since hardware $\overline{\text{STORE}}$ and $\overline{\text{RECALL}}$ signals are not needed in this application, they are simply tied to V_{CC}. All nonvolatile operations occur through software control, whose requirements are relatively

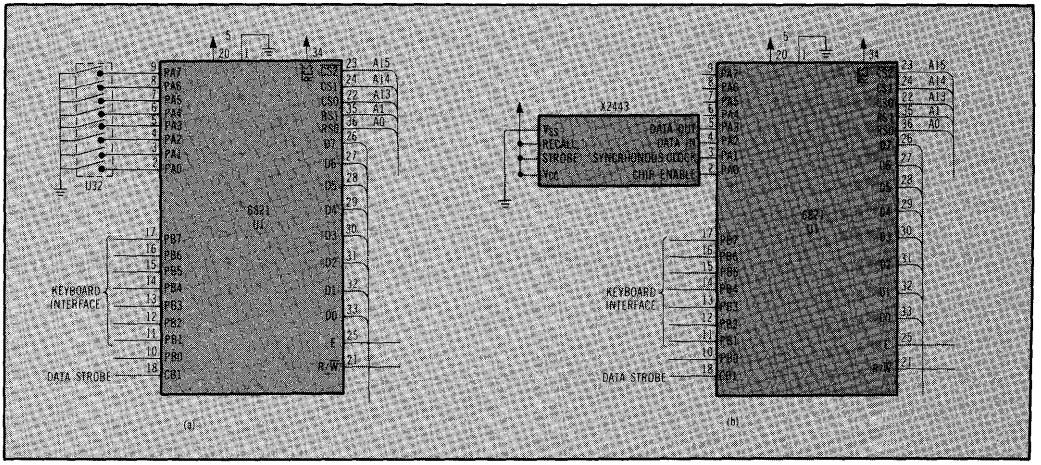


Fig 3 Within both the original DIP interface (a) and the X2443 implementation (b), the interface is serial. Therefore, only the clock, enable, data input, and data output lines need to be used.

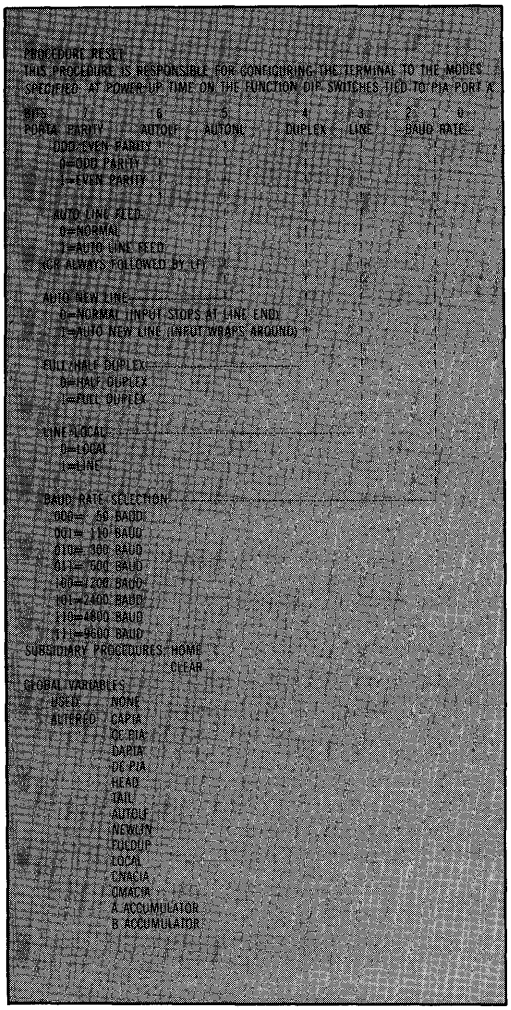


Fig 4 When using a header for a parsing program used with the DIP switch configuration, the possible parameters are limited to 8 bits, and an elaborate software routine is needed to interpret them.

straightforward (as described). With this software in place, the communication between the processor and the device simply becomes a series of reads or writes to the appropriate serial device locations.

The original design only allowed eight user-definable inputs, since only one DIP switch is used in the terminal. The meaning of the various input conditions is shown in the DIP switch map portion of the program header in Fig 4. Since the single 8-bit input is used for so many functions, parsing the input byte into the appropriate setup parameters requires an extensive piece of code. The problem with this implementation is the extensive software required to make switch operation straightforward in the user's manual.

Replacing the DIP switch with the NOVRAM has several significant advantages. The 256-bit nonvolatile storage leaves adequate room for storing an "image" of all interface circuit registers. Thus, the parsing problem of the DIP switch implementation is eliminated. Even the control registers that do not need to be user-programmable can benefit from this imaging, since they can be changed remotely in the field for hardware or software updates. This method simplifies field upgrading when compared with the usual method of storing these register images in the program store ROM or EPROM.

New images can either be down-loaded remotely or loaded through a diagnostic mode using a direct-connect RS-232 interface. Examples of where this capability is beneficial are numerous, and include changing interface protocols, data formats, or other hardware, interface, or networking options.

The use of the device for storing setup parameters also allows a more user-friendly operator interface. Software in the original design includes routines that allow random placement of the cursor or text through the use of a "go to X-Y" routine. It becomes a fairly trivial task to implement a menu-driven setup mode. After entering a certain escape sequence, the user is placed in the configuration mode, which presents an English menu.

The return key increments the cursor position to the next setup area where the current setting is displayed, and the spacebar key increments that setting through all possible choices. Once the user has set up the parameters for a particular session, depressing the escape key writes the current settings into the RAM section of the NOVRAM. With this operation, the user can set up a temporary configuration without changing the default parameters in the EEPROM section of the NOVRAM. Default settings are changed only when the user executes a certain control sequence (such as control X and then the escape). In some applications, it may be desirable to allow only certain users to change these default parameters before entering a special code.

Replacing the DIP switch with the NOVRAM allows increased design flexibility, as well as reduced manufacturing and testing costs.

Since the X2443 has a much larger capacity than actually needed for this application, the remainder of the nonvolatile storage can hold such data as serial number of the individual unit, revision level, and hardware configuration diagnostic parameters. Otherwise, it can be reserved for future expansion. The Table shows a sample address map for the

NOVRAM Address Map

Location	Bit map	Interpretation
0	XXXXXXXSWWXBBBB	S = Stop Bit Control WW = Word Length BBBB = Baud Rate
1	XXXXXXXPPPETTRD	PPP = Parity Check Controls E = Normal/Echo Mode TT = Transmit Controls R = Receiver Interrupt Enable D = Data Terminal Ready Control
2	XXXXXXXXEEEEEEEE	E = Emulation Designator (1 of 256)
3	SSSSSSSSSSSSSSSS	S = Serial Number
4	RRRRRRRRRRRRRRRR	R = Revision Level
5	XXXXXXXXXXXXXXXX	L = Latch data from keyboard on high-to-low or low-to-high

X = Don't Care

device, with the associated data stored in each of the 16-bit locations. The end results of replacing the DIP switch with the NOVRAM are increased design flexibility, as well as reduced manufacturing and testing costs.

Program storage considerations

The second aspect of improving the terminal design involves the program store for the 6800 microprocessor. The original design uses a 2716 EEPROM since the software requirements for the terminal are not extensive. The feature set of the X2816A EEPROM makes the replacement easier because EEPROMs of the X2816A generation incorporate high voltage generation, address and data latching, and the write-cycle timing circuitry on the memory chip. During read operations, the device functions just like the 2716 EPROM in its use of chip enable ($\overline{CE}$) and output enable ($\overline{OE}$) signals. During a write operation, the X2816A latches the addresses on the bus during the high to low transition of the write enable ($\overline{WE}$) signal, and then latches the data to be written on the rising edge of the $\overline{WE}$ signal.

The duration of this signal is not important, since the EEPROM only uses it to initiate the write cycle; the timing for the write operation is generated on-chip. The processor needs only to ignore the EEPROM for 10 ms during the write cycle, and the device does the rest. The latched and self-timed nature of the X2816A allows it to be placed in a 16-K SRAM socket and be read and written with the same signals used for the SRAM.

The read operation of the X2816A is the same as that of the 2716 EPROM, so this part of the EEPROM operation is of no concern. The only changes required to the existing circuitry involve the write operation. The first change allows the processor to write to the EEPROM, and the second protects the EEPROM from unwanted write operations during power-up and power-down.

The memory map for the original design was not very full, so only large blocks of the address map are decoded for each memory device and I/O chip on the bus. The 2716 logically resides at addresses F800 through FFFF since the 6800 reset vectors must be included. The physical decoding for the 2716 includes the address range of F000-FFFF since only the microprocessor's two most significant address lines A15 and A14 are used for the decoding.

Since line A14 is used to drive the $\overline{OE}$ line of the 2716, the EPROM is selected whenever A15 is a logical one. Possible conflict with the system RAM residing at 8000-81FF is avoided by restricting the processor's access to the 2716 in the logical F800-FFFF range. Since the processor can now read and write to the logical address range of the 2716 socket, the $\overline{CE}$ must also be derived from the A15 and A14 address lines. And, since $\overline{CE}$ is active low and the address line is active high, a simple NAND gate will suffice (Fig 5). Luckily, an extra NAND gate in the

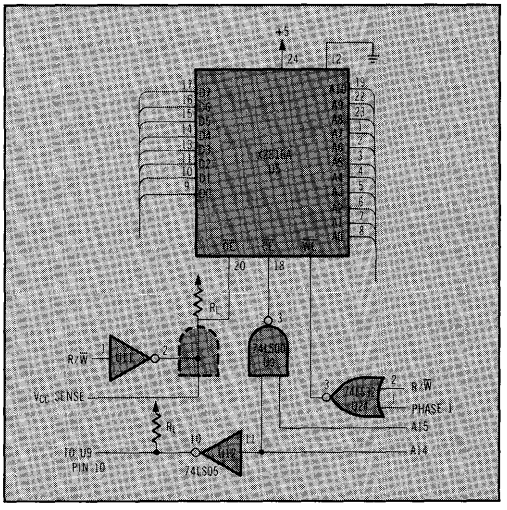


Fig 5 The EEPROM control logic uses the processor's high order address lines to map the device into the proper address range and enable it at the same time.

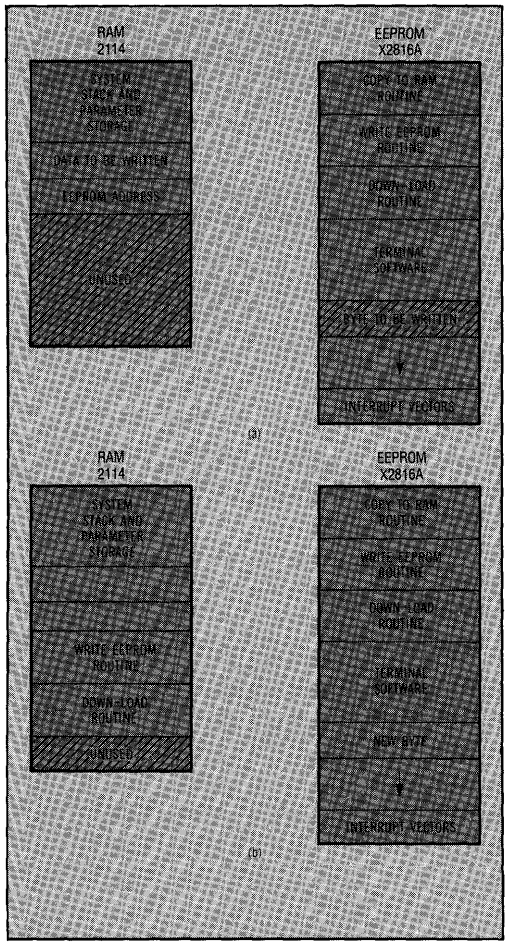


Fig 6 Address maps for updating EEPROM software are kept in EEPROM (a) and copied to RAM (b) when needed.

design can be used as an inverter. The inverter used for the $\overline{CE}$ is no longer needed, and therefore can replace the NAND gate. The inverter on A14 must remain intact since it is used in the 2114 RAM decode circuit.

The $\overline{WE}$ line for the X2816A EEPROM can be derived from the composite RAM write signal used for the 2114 RAMs. This signal is the logical OR or the R/$\overline{W}$ output from the 6800 and the Phase 1 clock signal. This qualification of the R/$\overline{W}$ line ensures that the addresses are valid on the high to low transition of the $\overline{WE}$ signal. Therefore, they can be latched into the EEPROM. This ORing connection also guarantees that the data to be written is valid on the rising edge of the composite $\overline{WE}$ signal. The $\overline{OE}$ signal on the EEPROM can simply be driven from the complement of the R/$\overline{W}$ signal from the processor. This technique requires that all accesses to the EEPROM be made in the logical address range of F800-FFFF to avoid bus contention with the system RAM.

Discussion of the circuitry needed for the $\overline{OE}$ signal also must include another important issue: ensuring that the chip does not experience an accidental write cycle during power-up or power-down. Even though the chance of $\overline{CE}$ and $\overline{WE}$ going low during power-up or power-down is rather remote, the possibility must be eliminated.

The EEPROM simplifies write protection by including an onchip voltage sensor that monitors the V_{CC} input level and automatically disables writes from occurring when V_{CC} falls below 3 V. Also, a noise filter on the $\overline{WE}$ input prevents a write from being initiated by a low spike. Functional interaction of the control inputs on the chip allows a low level on the $\overline{OE}$ to disable any write operations regardless of the state of the $\overline{CE}$ and $\overline{WE}$ inputs. By holding $\overline{OE}$ low while V_{CC} is between 3 and 4.75 V, inadvertent write cycles are inhibited.

The power supply must be modified to generate an active low signal whenever V_{CC} is below a specific level. This signal disables the write operation during both power-up and power-down. Because this signal is wire-ANDed with the control signal driving the $\overline{OE}$ signal, all writes to the chip are disabled when V_{CC} is below the 4.75-V limit.

Software modification

Once hardware changes have been made, in-factory modifications and in-field modifications must be addressed in order to take full advantage of an X2816A. In-factory modifications can be handled in many ways. If the terminal configuration is known at assembly time, the appropriate software can be loaded into the EEPROM through the use of a standard PROM programmer. However, this method does not take full advantage of the features of the in-circuit reprogrammability inherent in the X2816A. A more advanced approach also makes automated board testing easier.

For example, the EEPROM can be initially installed with a diagnostic program for testing the completed terminal board with an automated test system. Once the board has been tested, the tester controls the 6800 processor by holding it in a quiescent state such as reset or halt. The tester then assumes control over the terminal bus and writes the actual terminal software into the EEPROM. This greatly reduces the overhead required to manufacture a variety of different configurations or "models" on a single assembly line. In-line programming also allows for the verification of the EEPROM write operation and control circuitry.

The real advantages of the EEPROM surface when it comes to modifying software in the field. In this case, the terminal is placed in a down-load mode,

and the software revision is loaded through the RS-232 interface, either from a service "box" or remotely via a modem. The X2816A allows the terminals in the field to be called over phone lines for loading new operating software, thereby greatly reducing the cost and impact of a software update.

Although full-featured EEPROMs such as the X2816A simplify this task significantly, there remains one software issue to be resolved. While the EEPROM is performing its internal write cycle, it is unavailable for further writes or reads. For example, the processor, executing out of a program stored in the EEPROM, might perform a write cycle to the chip and then fetch the next instruction. Since the X2816A is occupied with its internal write cycle, the next instruction fetch will yield a high impedance bus. The processor will take this data as its next instruction and enter the "catch fire and die" mode of operation.

To avoid this situation, a very compact routine fetches the byte to be written into the EEPROM from a given location, writes the byte into the EEPROM, and then enters a timing loop to wait the 10-ms period required to complete the write. Since the RS-232 interface supports full handshaking, there is no chance of overrun from the down-loaded data. This routine is initially loaded into the EEPROM, but it is never executed from this device. Instead, another "copy to RAM" routine copies the routine from EEPROM into RAM, from which it is executed.

Since the terminal has 1 Kbyte of RAM capacity, there is ample room for storing such a routine during the EEPROM write cycle. Fig 6 shows address maps for both the EEPROM (a) and the RAM (b) prior to and during the execution of the EEPROM write routine. This method works especially well with the 6800 since its architecture is that of a von Neumann machine, and can therefore execute program segments out of the memory space reserved for RAM data storage.

In-field terminal upgradeability has two important benefits. If the terminal software is upgraded or revised after the unit is sold, the new software can be added to the existing units in the field at minimal cost. This method also eases the addition of optional hardware in the field, since the new software supporting the hardware option can be down-loaded instead of replacing the terminal EPROM.

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NOTES

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ELECTRONIC TECHNOLOGY FOR ENGINEERS AND ENGINEERING MANAGERS

Save volatile data during power loss

5

Save volatile data during power loss

Nonvolatile-storage devices give you a medium in which to store data during power loss. By combining these devices with power-sensing circuits and supplying the necessary control signals, you can design a system that transfers data securely between volatile and nonvolatile memory during power loss.

Christopher Lopes, *Xicor Corp*

To protect volatile data during power loss, you need to transfer that data reliably to nonvolatile memory during the transient and return it to RAM after power is restored. A system that performs this function includes two subsystems. The first reports power status, indicating when power is lost and when it is restored; the second handles the data transfer, using the power-status signal to generate the appropriate store and retrieve commands.

Sense power failure

To transfer data reliably after power loss, a system must have enough time to copy data from RAM to nonvolatile memory before the supply voltage drops below a certain level. The sensing circuit must recognize the power loss and generate a power-loss signal promptly, giving the storage subsystem enough time to effect the data transfer. In fact, in some systems, you may have to complete your transfer within a single write cycle to ensure a reliable transfer.

Your first step in designing the sensing subsystem is to choose a sensing point. You could use the 5V regulator's output as a sensing point, but this output will not indicate power loss as quickly as will either the ac input line to the power supply or the unregulated dc voltage supplied to the regulator.

To sense ac loss on the power supply's ac input line, you can monitor either the input or the output to the power transformer. If you monitor the transformer's input side, you must electrically decouple the sensing circuit's signal from the system's dc portions (by using optoelectronic isolators, for example). If you monitor

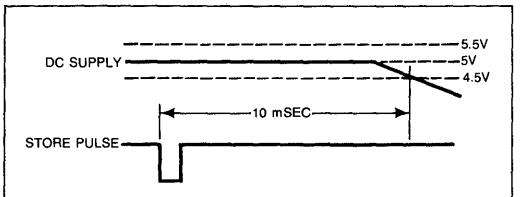

Fig 1—The system characterized by this timing diagram *must detect a power loss early enough to allow it to generate a store pulse 10 msec before the dc supply drops to 4.5V.*

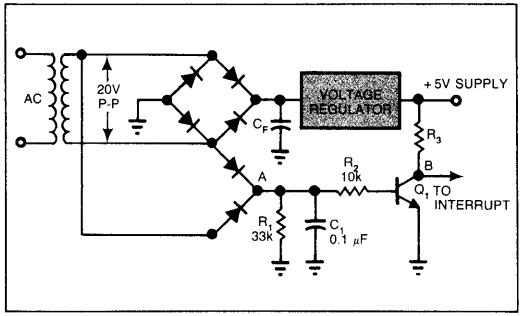

Fig 2—This zero-crossing detector *monitors power-supply status at the transformer's ac output. The two diodes isolate the detector from the main power supply's unregulated dc bus.*

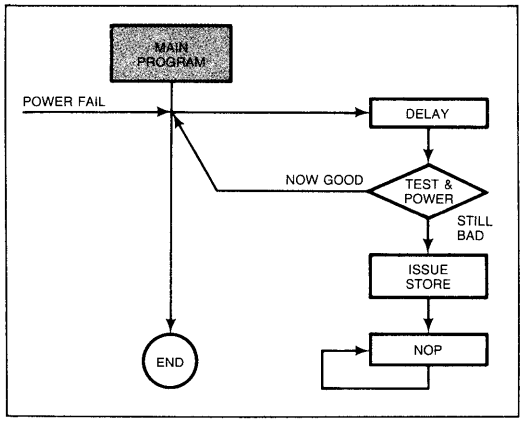

Fig 3—In a typical μP system *that tests for power loss, once the processor receives an interrupt indicating a power loss, the system initiates a subroutine that tests for a true power loss. The subroutine first produces a delay of about 2 msec; then the system looks again at the power detector's output. If that output is still asserted, the system decides that the power loss is real and sends a store pulse to the nonvolatile RAM.*

the output side, you must isolate the detector circuit from the main power supply's filtered unregulated dc circuit, because that circuit's response to a line fault is slow. To isolate the circuit, you can use either a separate transformer tap or two extra diodes between the bridge and the detector.

Alternatively, you can use the unregulated dc voltage ahead of the regulator as a sensing point. The regulator maintains its regulated output as long as its input voltage remains within a certain range. To make sure that the system will have time to respond to a power loss, you should set your trip point below the normal input voltage. This allows you to send your store signal early enough to ensure a reliable transfer to nonvolatile memory. Consider, for example, the timing diagram in **Fig 1** and assume that the minimum reliable write voltage of the memory in the system it characterizes is 4.5V. Because this system's dc supply drops to 4.5V 10 msec after initiation of the store pulse, the system must complete a write operation to nonvolatile memory within this 10-msec period.

Once you've chosen a sensing point, you must choose a detector. If you've chosen to detect ac loss, consider one of the following four methods. The first is a low-cost zero-crossing detector (**Fig 2**), in which two diodes isolate the detector circuit from the filter capacitor (C_F) that's ahead of the regulator. When a power loss occurs, the full wave's rectified ac drops to zero, inhibiting base current to transistor Q_1. This causes Q_1's output to go high, thereby generating an interrupt signal at point B.

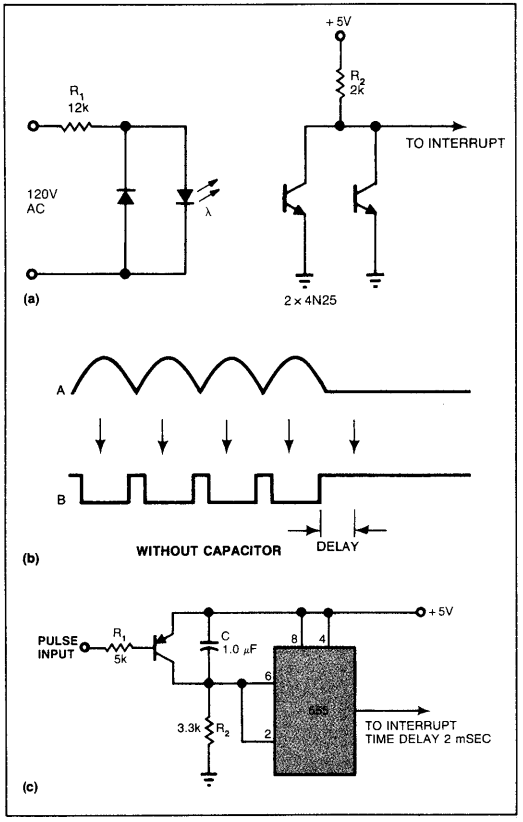

Fig 4—You can connect a detector like this one, *(which contains optoelectronic isolators with their diodes connected back-to-back) directly to the ac line through a resistor* ***(a).*** *The circuit produces an output pulse that can interrupt a μP each time the input waveform crosses zero, or every 8.3 msec* ***(b).*** *Instead of allowing the sensor to interrupt the μP every 8.3 msec, you can feed these pulses first to a 555 timer that's configured as a missing-pulse detector. It issues an interrupt only when the input pulse train is interrupted* ***(c).***

To ensure that you'll be able to transfer data reliably from RAM to EEPROM, you need to maintain power for at least 10 msec after a power loss.

When it receives an interrupt, the system initiates a subroutine that tests for a true power loss (**Fig 3**). The subroutine delays the store signal for about 2 msec and then looks at the detector again. If the output is still high, the system decides that the power loss is real, and it sends a store pulse to the nonvolatile RAM. Resistor R_2 in **Fig 2** limits the transistor base current.

Capacitor C_1 is essential in this circuit because it filters the power supply's half-cycle pulses before they're applied to Q_1. (If you were to fail to filter these pulses, the μP would receive an interrupt signal every 8.3 msec, whether or not a power loss had occurred. Without C_1, as much as 25% of your available processor time would be spent responding to false interrupts generated by the power-loss detector.) The value that you choose for C_1 depends on the power supply's holdup time, the values of R_1 and R_2, and the delay that you want between the loss of ac and the triggering of the store signal.

Use optoisolators

The second technique for sensing ac power loss uses two optoelectronic isolators between the detector and the ac power line (**Fig 4a**). This technique produces a positive output pulse at each zero crossing on the ac line, or at 8.3-msec intervals (**Fig 4b**). The problem with Fig 4a's circuit is that the interrupt signal occupies the μP's time while the rest of the system is resampling the detector's output. To solve this problem, you can add a missing-pulse detector similar to the one shown in **Fig 4c.**

A third detector that relies on direct ac-line connection uses General Instrument's MID 400 power-line monitor. When you use this device, you need to add only two resistors to ensure a clean interrupt signal (**Fig 5**). You can adjust turn-on and turn-off delays by adding a capacitor across R_2.

The fourth detector (**Fig 6**) uses a CMOS Schmitt trigger as a full-wave, low-voltage, missing-pulse detector. To avoid latch-up, and possible damage to the CMOS circuits, you must make sure that the input voltage to the CMOS Schmitt trigger does not exceed the 5V supply voltage. You can meet this requirement by inserting a resistor between the Schmitt trigger and the bridge's output. To obtain narrow pulse widths from the first gate, keep the ac input voltage as high as possible. R_3 and C_1 determine the output's delay, which must be longer than the first gate's pulse width.

Sensing dc power loss

If you've decided to sense dc loss instead of ac loss, you don't have to worry about capacitor delays or missing pulses. Consider the sensor in **Fig 7a,** for instance. The sensor generates a negative interrupt pulse when it senses dc loss; it uses a zener diode to set the trigger point. On one hand, you should set the

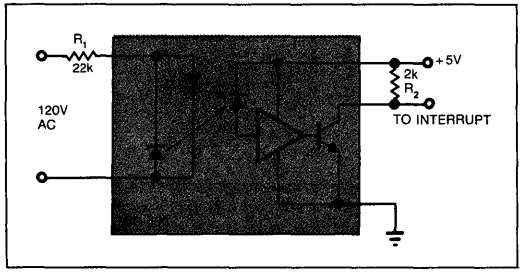

Fig 5—To incorporate the MID 400 detector *in your sensing subsystem, you need to add only two external resistors that you connect directly to the ac line. You can control the on and off delays at the output by connecting a capacitor across R_2.*

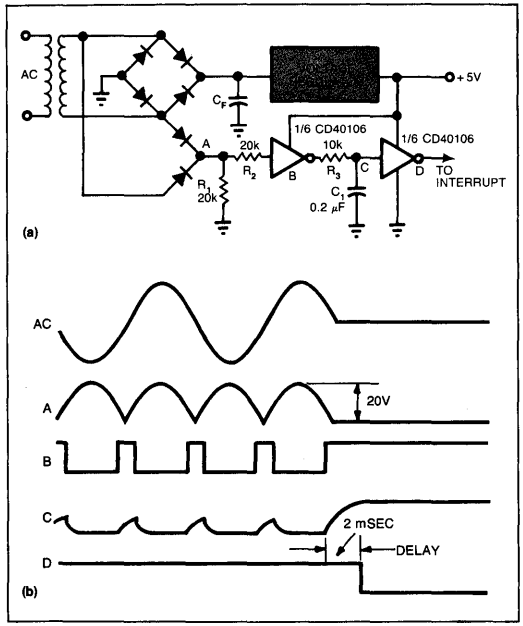

Fig 6—When you use two Schmitt triggers *to detect ac loss* ***(a)****, the delay produced by R_3 and C_1 must be longer than the first gate's output pulse width. The timing diagram* ***(b)*** *shows the circuit waveforms.*

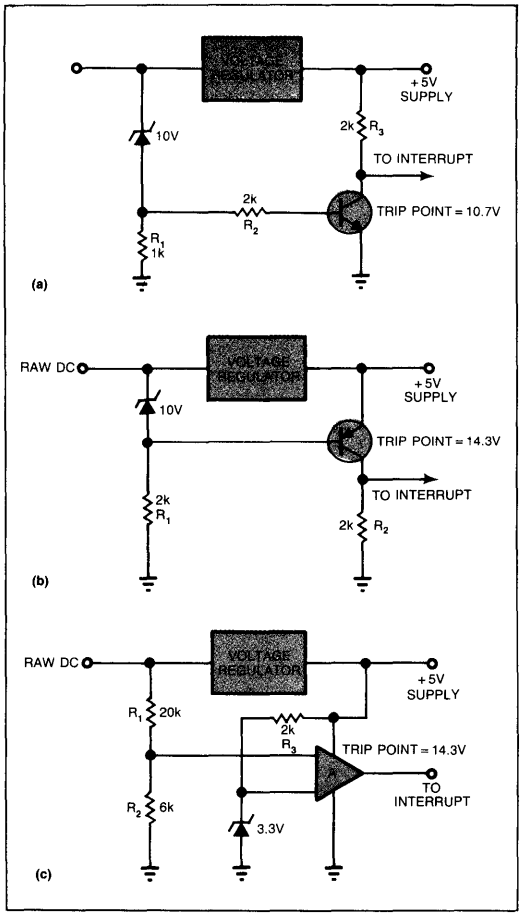

Fig 7—Using zener diodes *you can configure a power-supply detector circuit to produce either a negative* ***(a)*** *or a positive* ***(b)*** *interrupt pulse when the trigger point is reached. You can configure the op amp shown in* ***c*** *to produce either a positive or a negative output pulse polarity.*

trigger point as high as possible (to allow the circuit to sense the power loss as early as possible). On the other hand, you must still set the trigger point low enough to fall below the lower boundary of the supply's upper unregulated limit (to prevent false triggering). Remember that the diode's voltage rating should equal the desired trip-point voltage minus the 0.7V base-emitter drop.

In the dc detector circuit shown in **Fig 7b,** when the unregulated dc voltage drops, a pnp transistor turns on and produces a positive pulse. Here, the zener diode's rating is equal to the trip-point voltage minus 5V, plus 0.7V for the base-emitter drop.

The circuit in **Fig 7c** trips when the dc level at R_1's and R_2's junction drops to the zener's voltage rating. You can provide either a positive or a negative interrupt signal, depending on the operational amplifier's input configuration.

To ensure that the regulator operates long enough to perform a reliable transfer to nonvolatile memory once a store pulse is sent, you need to use a large filter capacitor. The capacitance depends on the desired trip point, the lowest input voltage to the regulator, and the load. For example, a system with a 10-msec transfer time, a 300-mA load, a 15V trip point, and a minimum regulator input of 7V requires a 375-μF capacitor; you can derive the capacitor's value from the equation $i=Cdv/dt$.

Once you've chosen a sensing point and a sensing circuit, the next step is to develop a subsystem that uses the power-status signal to generate save and

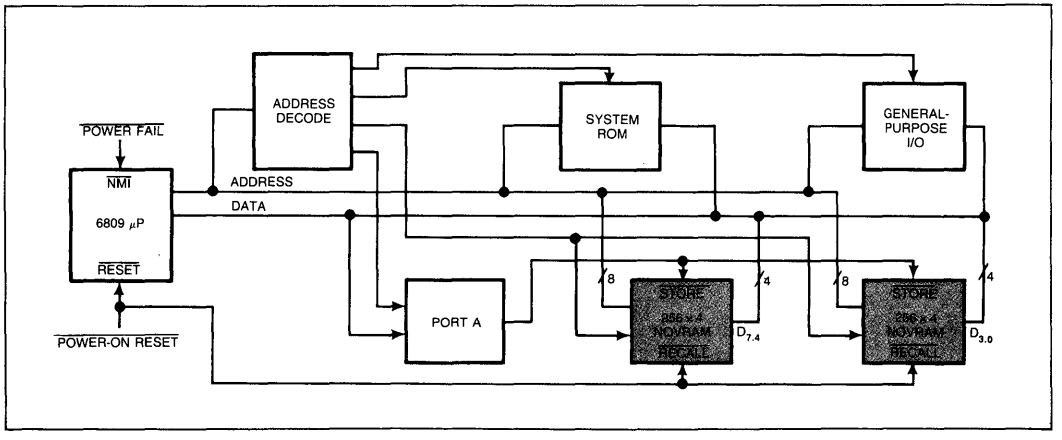

Fig 8—This industrial controller's storage architecture *uses a NOVRAM as both the volatile and nonvolatile system storage elements.*

Monitoring the ac line in front of the main supply's power transformer gives you the fastest warning of a power loss.

restore signals. These signals tell the storage subsystem to transfer data from RAM to nonvolatile memory during power loss and return data to RAM after power has been restored.

The type of system you design will depend largely on the type of nonvolatile storage that you plan to use with that system. For instance, you could use battery-backed RAM, or you could use a NOVRAM like the one used in the industrial controller shown in **Fig 8.** The industrial-controller design takes advantage of the nonvolatile RAM's ability to transfer data between RAM and EEPROM in a 10-msec single write cycle (see **box,** "NOVRAM architecture").

The nonvolatile RAM provides both the system storage (RAM portion) and the nonvolatile program storage (EEPROM portion) for power losses. The μP supplies a low-going TTL store signal (100-nsec min duration) to the nonvolatile RAM's store input. During the 10 msec that the nonvolatile RAM requires to complete its data transfer, you must keep the power supply's voltage within the specified operating tolerance. Once the system initiates a store cycle, the store cycle can't be terminated.

When the system loses power, the sensor sends a power-failure-detection interrupt to the μP. Once the processor acknowledges the interrupt, it branches to an interrupt routine that writes the current stack pointer and a test byte to the nonvolatile RAM (to signify that a power failure has occurred) and generates a store signal. The power supply holds V_{CC} above 4.5V for 10 msec after it generates the power-fail signal. During the store operation, the nonvolatile RAM I/O lines maintain high impedance, allowing the μP to complete other tasks. After the system completes a store operation, it must drive the store input high before performing subsequent store operations.

When power is restored, the power-on-reset routine sends a recall signal to the nonvolatile RAM. The routine in the μP then checks the nonvolatile RAM's test byte to see if the previous process had been interrupted by a power failure. If so, the processor saves the current processor state and loads the address

NOVRAM architecture

A NOVRAM (nonvolatile RAM) is a memory device comprising a static RAM overlaid bit for bit with an EEPROM (electrically erasable programmable ROM). A typical nonvolatile RAM, the Xicor X2212, contains 2k bits organized as a conventional 1k-byte static RAM overlaid with a 1k-byte EEPROM.

The operation of the RAM portion is identical to that of other static RAMs. However, in addition to CS (chip select) and WE (write enable) pins, nonvolatile RAMs also have store and recall pins that control data transfers between the RAM and EEPROM. Because the pulse widths of the control and data inputs are less than 450 nsec, most μP-based systems don't require wait states during the data transfers.

A store operation transfers the entire RAM contents to the EEPROM in a single 10-msec write cycle. After the NOVRAM completes the store operation, the original data will reside in both the RAM and the EEPROM.

The NOVRAM uses a recall operation to transfer data in the EEPROM to the RAM, replacing the RAM's prior content. Instead of moving data on a word-by-word basis, store and recall operations transfer the entire content of the memory simultaneously.

NOVRAMs don't require high-voltage pulses or high-voltage supplies: The devices operate from a single 5V power source and have no battery backup. All inputs and outputs are TTL compatible. The RAM portion's cycle time is 300 nsec, and the common data input/output is 4 bits wide.

On-chip protection

A built-in V_{CC} sensor protects the NOVRAM from spurious signals often initiated during power-up and power-down. The sensor establishes a threshold supply voltage of 3V. When the supply voltage falls below 3V, store operations to the EEPROM and write operations to the nonvolatile RAM are blocked.

A noise filter built into the EEPROM prevents glitches on the WE line from initiating a write cycle. This filter makes the device ignore pulses of less than 20 nsec so that noise spikes will not be interpreted as write commands.

An alternative to monitoring ac power at the power transformer is monitoring the unregulated dc power to the regulator.

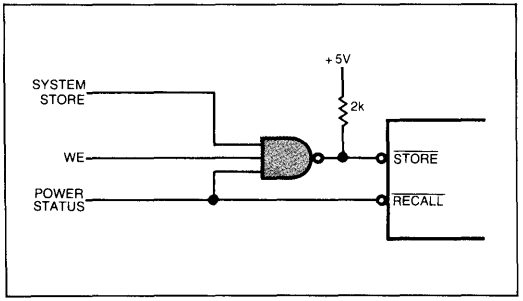

Fig 9—By NANDing the store, WE, and power-status signals *you can protect the NOVRAM from false store commands. In this configuration, all three inputs must be true for a store operation to occur.*

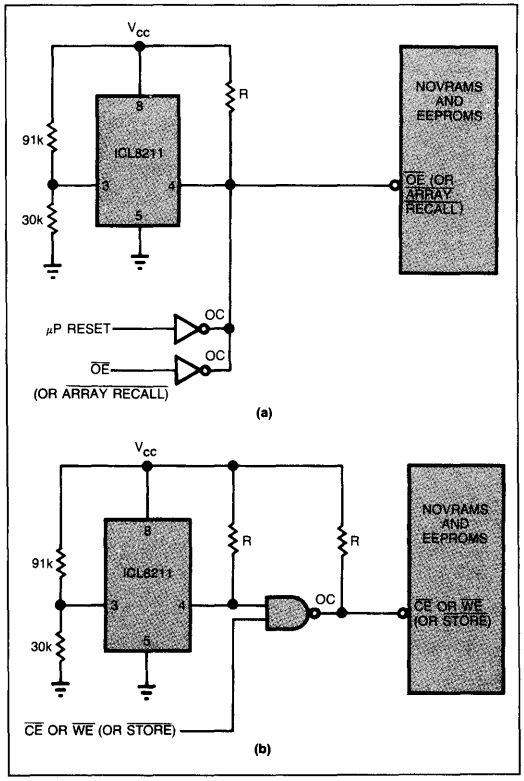

Fig 10—In a hold-low protection scheme (a), *a nonvolatile memory's array-recall pin is pulled to logical zero when the supply voltage falls below 5V. In hold-high protection* ***(b),*** *when power is lost, either the WE or CE pins are held high.*

of the saved processor state onto the stack. It then executes a return from interrupt and resumes the previously interrupted process.

Beware false commands

One of the biggest obstacles you'll face in deriving reliable store and save signals will be to avoid false store commands. Because most μP-based systems don't operate in ideal environments, they often generate false signals during power-ups, power-downs, brown-outs, and power failures. However, these signals are generally nonperiodic in nature, so the system usually recognizes them as by-products of a faulty memory device and disregards them.

Sometimes, however, these signals are periodic and turn out to be unintended write/store commands. After a system reset, for example, the μP's erratic behavior may cause the registers that usually contain the system information to contain false write-store commands instead. Therefore, when the system addresses those registers, those registers issue a false store command.

You can use several system techniques to avoid these errant commands. (For a discussion of on-chip protection features, see **box,** "NOVRAM architecture.") One technique for protecting the NOVRAM from errant commands takes advantage of the fact that even though most μPs can issue spurious addresses, they don't usually issue false write commands. By ANDing the system write command with the system store command, you can make sure that the nonvolatile RAM will respond to a store signal only during a write cycle.

Nevertheless, glitches can still appear at the store pin during power up, even if no write command is received at any of the 3-state TTL gate inputs. One way to solve this problem is to use an open-collector NAND gate, one of whose inputs indicates the power supply's status (**Fig 9**). This method ensures that the store pin's voltage follows the power supply's voltage as the voltage increases.

If you hold one NAND gate's open-collector input low, the output transistor is turned off. Pulling the gate's output voltage to the nonvolatile RAM's power supply through a pullup resistor ensures that the output follows the power supply with no glitches. You can also use the power supply's status signal to hold the recall pin low and the store pin high. This technique gives you better control over the nonvolatile RAM because it uses two conditions to prevent an inadvertent store operation. All you need to do is to connect the status signal directly to the recall pin.

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Two additional methods of preventing unintentional nonvolatile data changes during power transitions are hold-low and hold-high protection. When you use hold-low protection (**Fig 10a**), the array recall pin is pulled to logical zero whenever the supply voltage falls below the 5V−10% threshold. The Intersil ICL8211, an 8-pin miniature DIP, provides the voltage reference and gives a zero output whenever the supply falls below its threshold. When the sensed voltage rises above the selected threshold, the device produces a logical one.

(**Fig 10b**) gives an example of hold-high protection. ICL8211 keeps the voltage on the nonvolatile RAM's store pin (or the $\overline{WE}$ or $\overline{CE}$ pins) near the power supply's voltage level. This blocks the low pin voltage that's necessary for a write or store operation.

The power-supply output that ICL8211 senses is a sawtooth waveform. ICL8211's output is a logical 1 while the supply output is above 4.5 volts. Below 3V, the nonvolatile RAM's internal protection circuitry prevents inadvertent writes or stores. In the critical unprotected range between 3 and 4.5V, ICL8211 provides a zero output to prevent writes or stores.

An alternative to ICL8211 in these applications is the SGS L487. The SGS L487 is a 500-mA precision 5V voltage regulator that includes an open-collector power-on/power-off reset output pin that protects nonvolatile memory the same way the ICL8211 does.

Other schemes that protect systems from inadvertent store operations employ jumpers, cables, and switches. You transmit the store signal through a jumper or switch that you hold open unless you're changing data in the EEPROM. During normal operation, the only component attached to the store pin is a resistor to the power supply. **EDN**

Author's biography

Christopher Lopes is an applications engineer at Xicor (Milpitas, CA), where his duties include system-level evaluation, product-application development, and customer technical assistance. A member of the IEEE, Chris holds a BS in electrical and electronic engineering from California State University at Sacramento and is currently enrolled in the MBA program at the University of Santa Clara. He enjoys windsurfing, skiing, and tennis.

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Product Bit Maps

On the following pages are individual device bit maps. These bit maps are supplied to aid in the development of test programs.

Figures 1, 2 and 3 illustrate the physical proximity of individual bit cells within the memory array of the X2201A, X2210 and X2212 respectively.

Figures 4 and 5 illustrate the location of individual bits within a byte for columns 1-15 suppressed. The bit locations in these fifteen columns is identical to column 0.

Figure 6 is a bit map for the X2864A and illustrates the relative physical location of all bytes within the array. The actual bit locations within each byte are identical throughout the array.

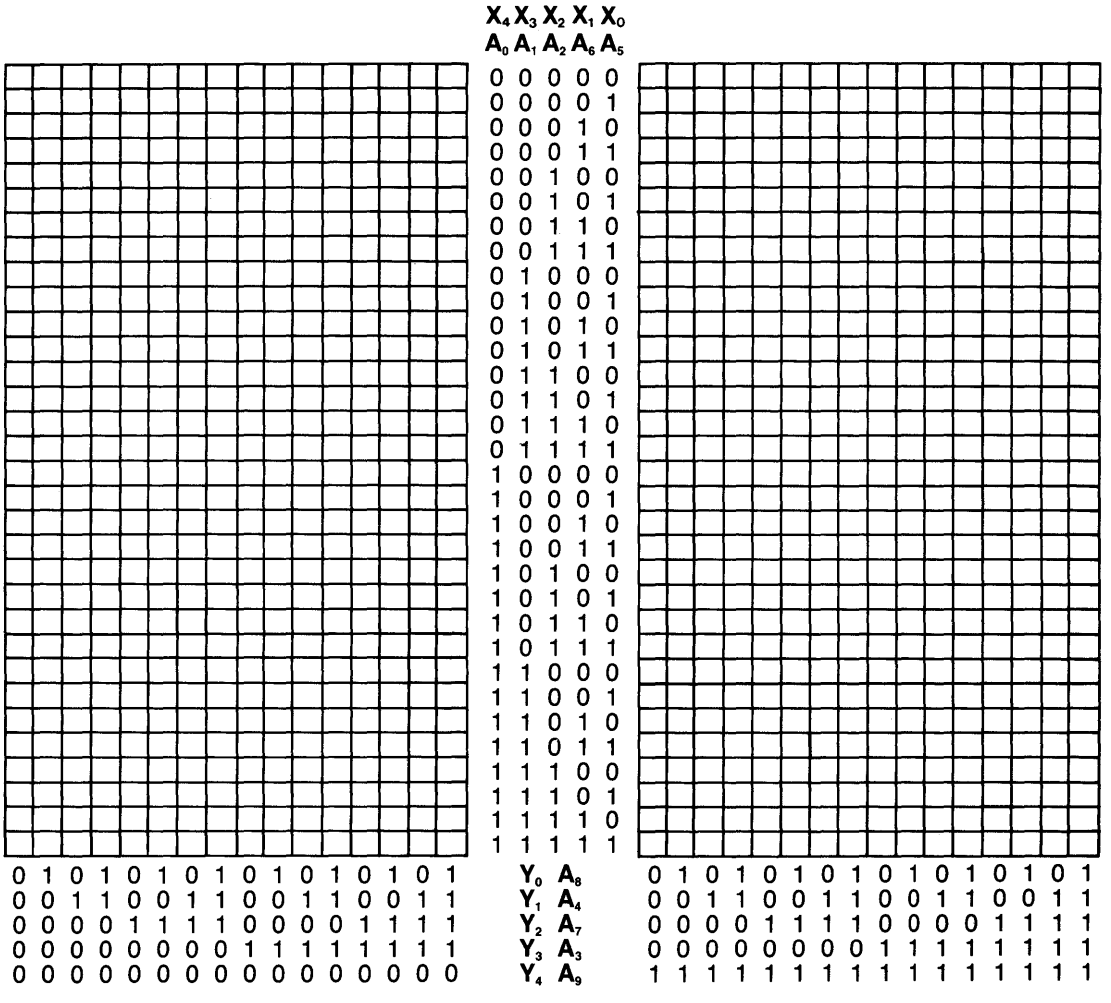

Figure 1: X2201A (1024 x 1) Bit Map

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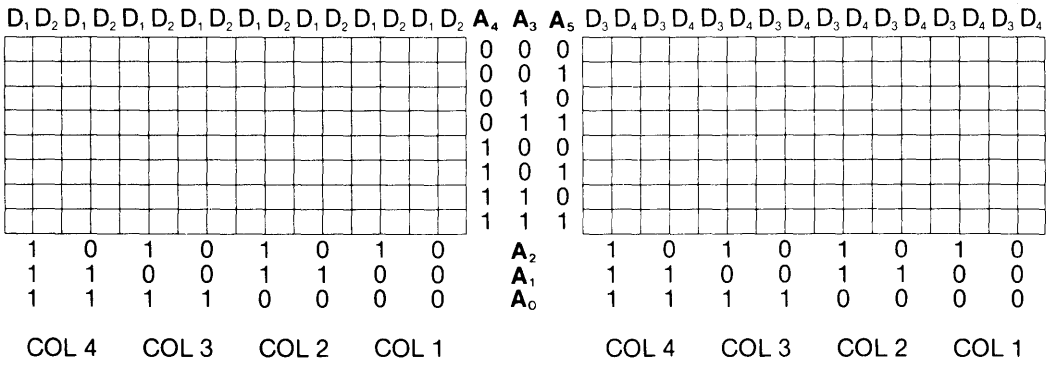
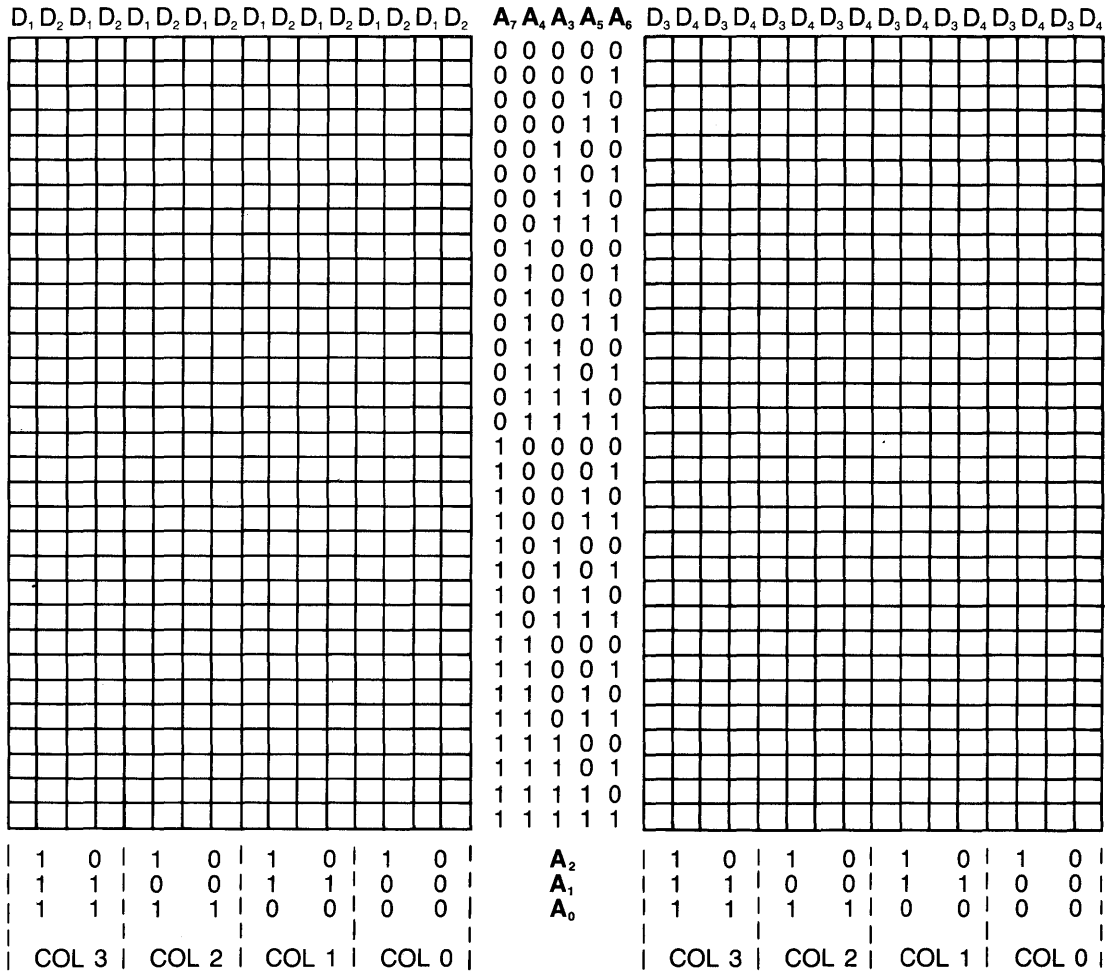


D_i = i^{th} Data Line (I/O Line)

Figure 2: X2210 (64 x 4) Bit Map



D = DATA LINE (I/O LINE)
1 BIT = 1 SQUARE

Figure 3: X2212 (256 x 4) Bit Map

5

Product Bit Maps

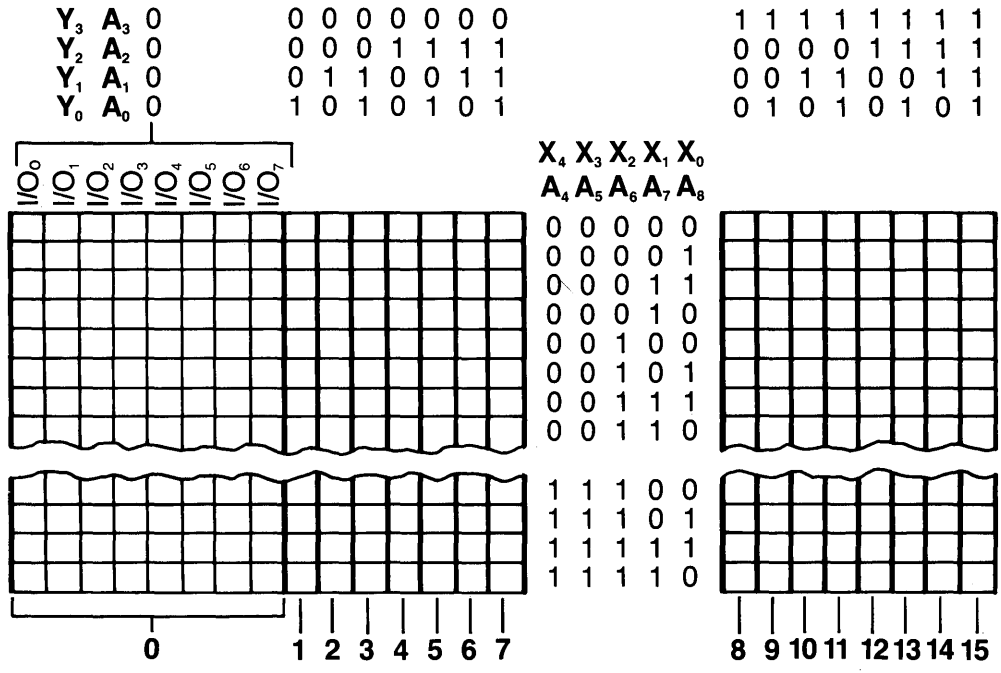


Figure 4: X2804A (512 x 8) Bit Map

Product Bit Maps

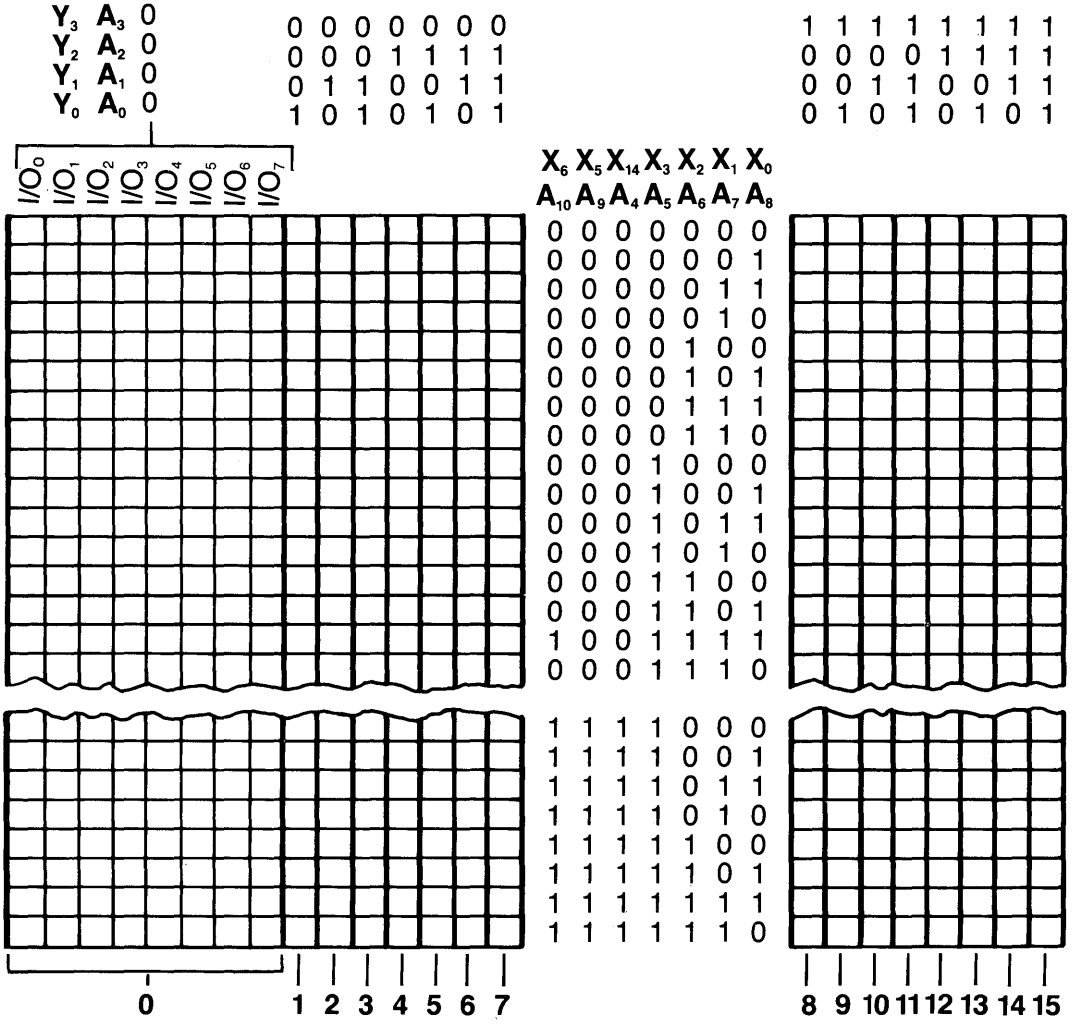


Figure 5: X2816A (2K x 8) Bit Map

Product Bit Maps

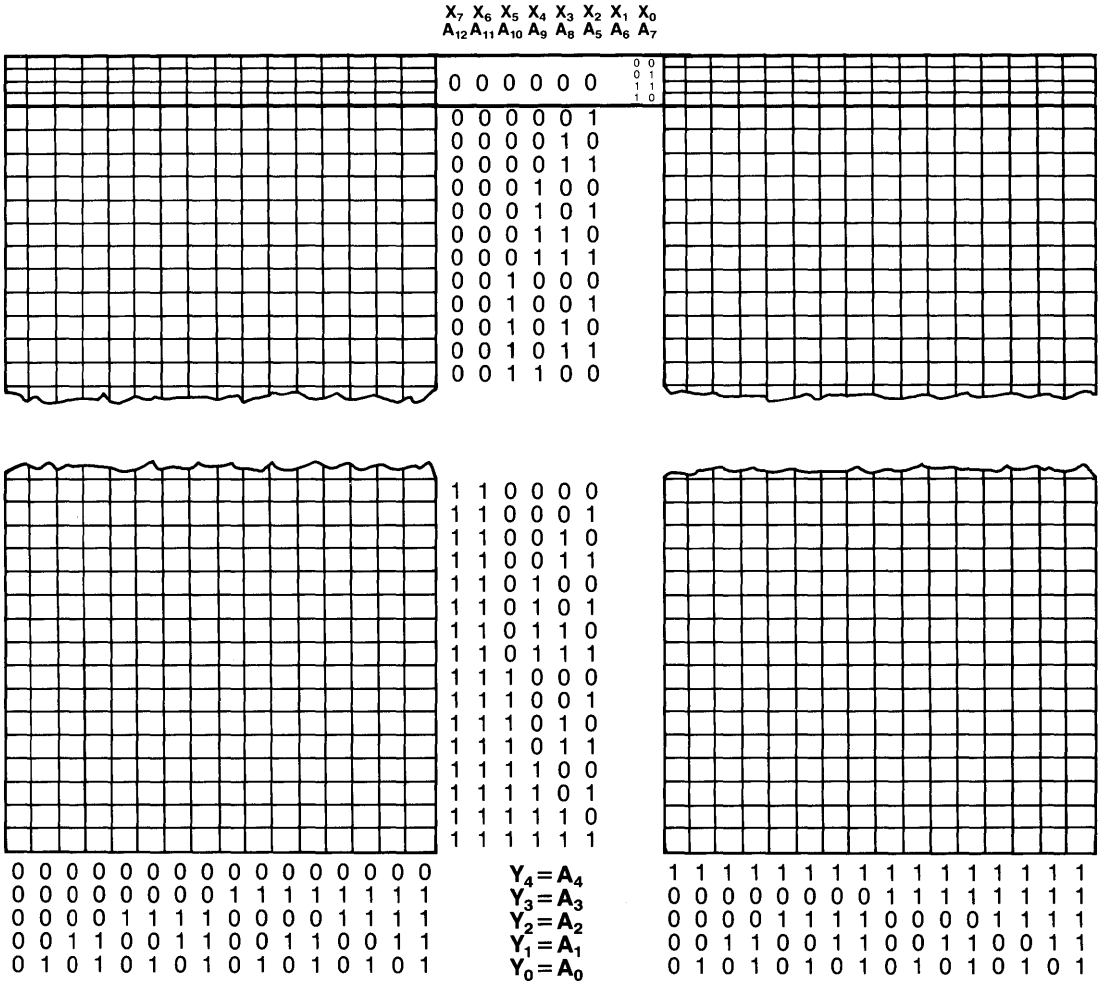


Figure 6: X2864A (8K x 8) Bit Map

Xicor

NOVRAM* Data Sheets 1

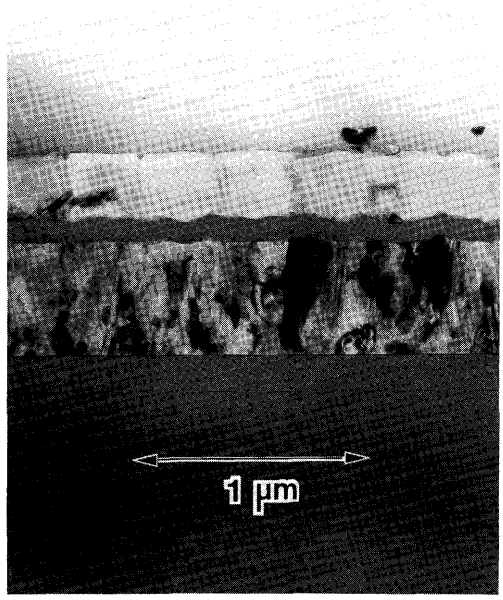
Serial I/O Data Sheets 2

E^2PROM Data Sheets 3

E^2POT™ Data Sheets 4

Applications 5

Reliability 6



NOVRAM* RELIABILITY REPORT

BY BILLY KWONG
& DR. JOHN CAYWOOD

*NOVRAM is Xicor's designation for its nonvolatile RAM memory

INTRODUCTION

This report is an accumulation of reliability testing data taken on the Xicor X2210 and X2212 NOVRAM memories. In these memories, each memory bit integrates one bit of static RAM and one bit of electrically erasable-programmable ROM (E^2PROM) into one cell. The controls STORE and RECALL cause the data to be transferred in parallel from all RAM bits into the associated E^2PROM bits and back again. These devices, which exemplify Xicor's innovative technology, require only a 5V power supply and TTL level signals for all operations, including STORE and RECALL. Both devices employ the same design and processes and are organized 64 x 4 and 256 x 4 for the X2210 and X2212, respectively. Figure 1 shows the pinout for the two parts, as well as for the X2201A (1K x 1) NOVRAM. Figure 2 shows the logic diagram for the X2212 (256 x 4); Figure 3a and 3b show the package dimensions for the packages which are common to the X2201A, X2210 and X2212. The bit maps for the three devices shown in Figures 4-6 illustrate the physical location of the various address bits.

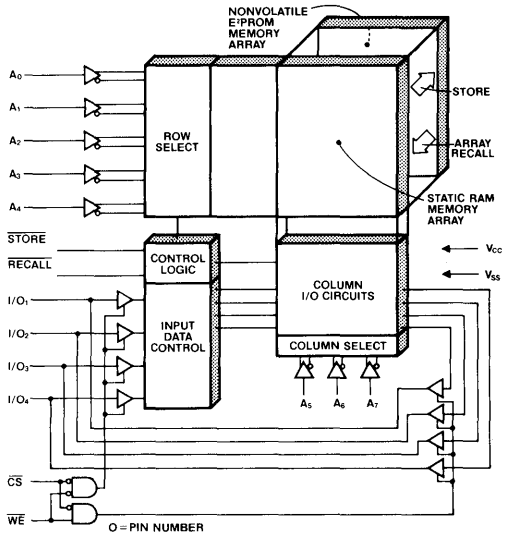
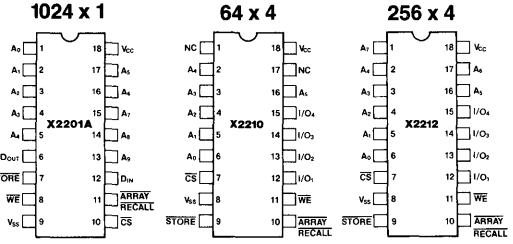


Figure 2: Functional diagram of X2212 memory



PIN NAMES

A_0–A_9	Address Inputs
I/O_1–I/O_4	Data Input/Output
$\overline{WE}$	Write Enable
$\overline{CS}$	Chip Select
$\overline{ARRAY\ RECALL}$	Array Recall
$\overline{STORE}$	Store
V_{CC}	+5V
V_{SS}	Ground
NC	No Connect

Figure 1: X2201A, X2210, and X2212 pin assignment drawings

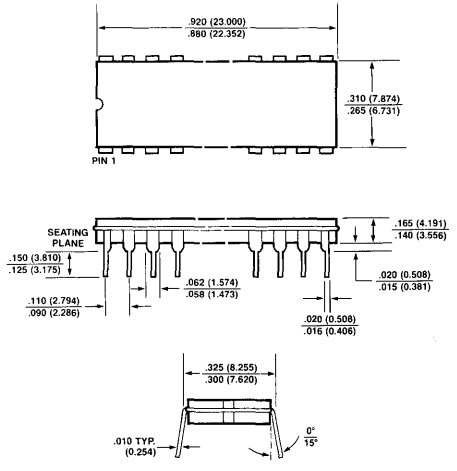


Figure 3a: Package outline drawing for memories in cerdip

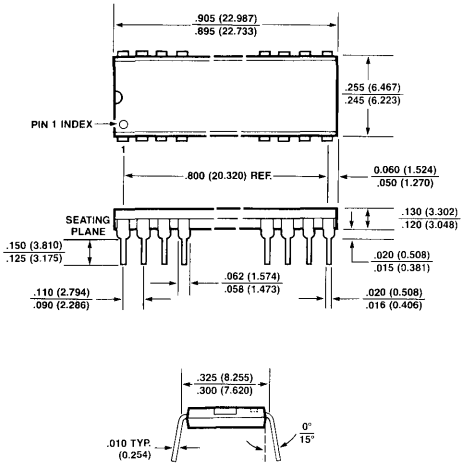


Figure 3b: Package outline drawing for memories in plastic

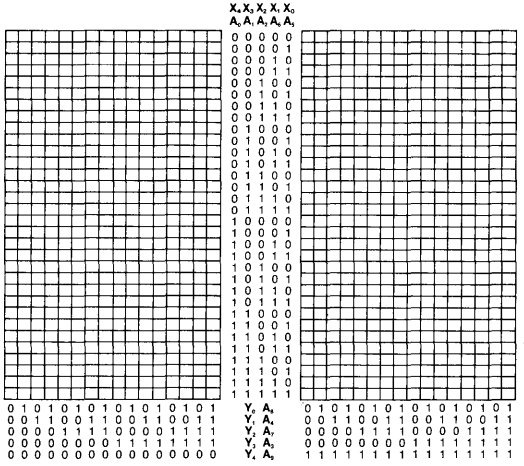


Figure 4: X2201A physical address map

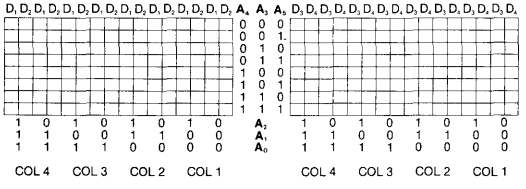


Figure 5: X2210 physical address map

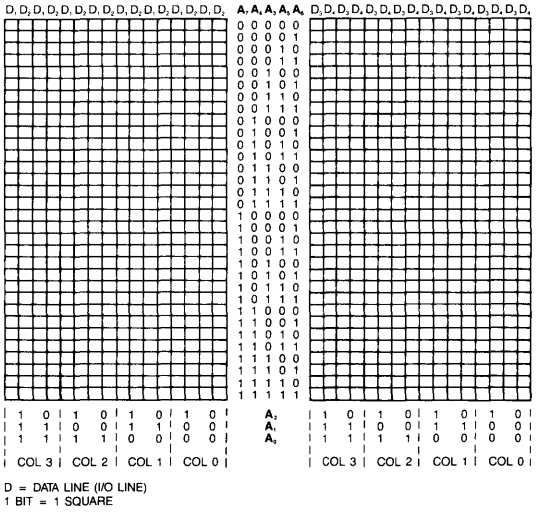


Figure 6: X2212 physical address map

TECHNOLOGY

Xicor NOVRAM memories store their nonvolatile data on electrically isolated polysilicon gates. These gates are islands of polysilicon surrounded by about 800Å of SiO_2, one of the best insulators known. This is similar to the structure used in UV light erasable PROMs (UVEPROMs).

Electrons once trapped on the floating (isolated) gates will remain there unless they receive a large energy input from an outside source (e.g., an ultraviolet photon in the case of UVEPROMs), or until a sufficiently high electric field is applied to distort the energy bands sufficiently to allow Fowler-Nordheim tunneling to occur.[1]

Fowler-Nordheim tunneling, which will be discussed in more detail later in this report, is the mechanism employed to charge and discharge the floating storage gate of Xicor's NOVRAM memories. The storage gate is formed in the second of three layers of polysilicon as illustrated in Figure 7. Electrons move to the floating gate by tunneling from POLY 1 to POLY 2. When the high fields which are used to cause the desired tunneling are not present, the electrons remain trapped on POLY 2.

As Figure 7 illustrates, the NOVRAM memory cell is a conventional six transistor static RAM cell to which a floating gate E^2PROM cell containing two transistors has been added. During the normal READ/WRITE operations, memory array power supply

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(V_{CCA}) is fixed at the positive supply level (nominally 5V) and the Internal Store Voltage is fixed at ground. Only the six transistors of the static RAM cell are effective and the operation is exactly that of a conventional six transistor static RAM.

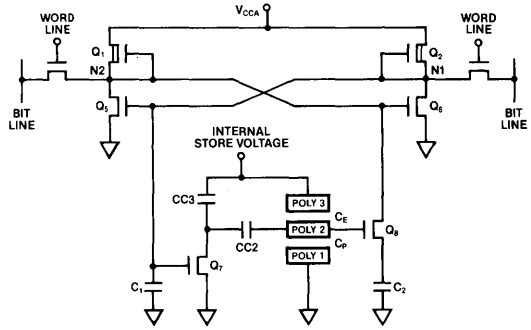

Figure 7: Schematic diagram of a NOVRAM memory cell showing how a standard six-transistor static RAM cell is merged with a floating gate E^2PROM cell.

The RECALL operation depends on capacitance ratios. The value of C_2 in Figure 7 is larger than that of C_1. When the external RECALL command is received, the memory array power supply (V_{CCA}) is initially pulled low to equalize the voltages on nodes N_1 and N_2. These nodes equalize quickly to V_{CCA} through the depletion transistors Q_1 and Q_2. When V_{CCA} is then allowed to rise, the node with the lighter capacitive loading will rise more quickly and turn on the pull down transistor on the opposing side, which will keep the more slowly rising node clamped low. If the floating gate is charged positively, Q_8 is turned on, which connects C_2 to N_2. Thus N_1, which is loaded by the smaller capacitor C_1, rises more rapidly, causing the latch to set with N_1 high and N_2 low. If the floating gate is charged negatively, Q_8 is turned off, which isolates C_2 from N_2 and allows N_2 to rise more rapidly than N_1. Thus the latch is set with N_2 high and N_1 low. During the RECALL operation the Internal Store Voltage remains at ground.

The STORE operation also utilizes capacitance differences to transfer data from RAM to E^2PROM. When node N_1 is low, transistor Q_7 is turned off. This allows the junction between capacitors CC_2 and CC_3 to float. Since the combined capacitance of CC_2 and CC_3 is larger than that of C_p, the capacitor between POLY 1 and POLY 2, the floating gate follows the potential of the Internal Store Voltage. Thus when the Internal Store Voltage becomes high (several times V_{CC}), a sufficient field exists between POLY 1 and POLY 2 to cause electron tunneling and the floating gate is charged negatively.

When node N_1 is high, transistor Q_7 is turned on which grounds the junction between CC_2 and CC_3. Since the capacitance of CC_2 is larger than that of C_E, the capacitor formed between POLY 2 and POLY 3, CC_2 holds the floating gate near ground when the Internal Store Voltage goes high. In this case the high field exists between POLY 2 and POLY 3 and electrons tunnel from POLY 2 to POLY 3, which discharges the floating gate.

The Internal Store Voltage is at ground except during the STORE operation. Moreover, during the STORE operation all bits are stored simultaneously, which is possible because the RAM bit associated with each E^2PROM bit acts as a data latch.

TUNNELING PHYSICS

Because the innovative aspects of the NOVRAM memory revolve around the nonvolatile storage procedure, it seems appropriate to discuss the storage phenomenon in more detail. As was mentioned above, the storage occurs via a tunneling mechanism first described by Fowler and Nordheim in 1928 and subsequently named after them.[1] The basic idea is illustrated in Figure 8. The energy difference between the conduction and valence bands in Si is about 1.1 eV; the energy difference between those bands in SiO_2 is approximately 9 eV. When the two materials are joined, the conduction band in SiO_2 is 3.25 eV above that in Si. The differences in valence band energies is even larger (approximately 4 eV). Since the thermal energy of an electron averages only 0.025 eV at room temperature, the chances of an electron in silicon gaining enough thermal energy to surmount the barrier and enter the conduction band in SiO_2 is exceedingly small. This case is illustrated in Figure 8.

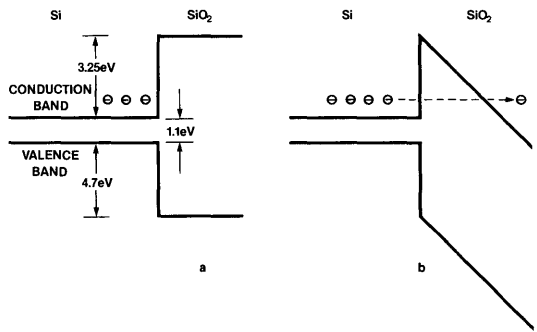

Figure 8: Energy band diagrams of the Si/SiO_2 system in the neutral state (a), and during the store operation (b).

Fowler and Nordheim pointed out that in the presence of a high electric field, the energy bands will be distorted as illustrated in Figure 8b. Under these conditions there is a small but finite probability that an electron in the conduction band in the silicon will tunnel through the energy barrier and emerge in the conduction band of the SiO_2, as illustrated in Figure 8a.

Fowler-Nordheim emission was observed early in this century for the case of electrons being emitted from metals into vacuum, and in 1969 Lenzlinger and Snow observed this phenomenon for the Si-SiO_2 system.[2] The Fowler-Nordheim current increases exponentially with applied field and becomes readily observable (i.e., $J \sim 10^{-6}$ A/cm^2) for the Si-SiO_2 system in which the Si surface is smooth for fields on the order of 10 MV/cm.

It has been known for some time that "enhanced" electron emission currents could be observed for Si-SiO_2 systems for which the Si surface has a texture. (Texture in this context means that the Si surface has features on the order of a few hundred angstroms.)[3-5] These enhanced currents occur at applied fields with values smaller than one quarter of those necessary for the same current from a smooth surface. It has been thought that the enhanced emission occurs because of locally enhanced fields near the top regions of the features on the surface.

Lewis attempted to model Fowler-Nordheim tunneling from a textured surface by calculating current from a number of hemispheres set in a plane.[6] Attempts to quantitatively fit experimentally observed currents with this model have not been very successful. Hu, et al, for example, found that to fit their data to existing theory it was necessary to assume an energy barrier of approximately 1 eV between conduction bands in Si and SiO_2.[7] Even with this assumption, the fit was poor because the measured current increased more rapidly than the calculated values, as is illustrated in Figure 9.

Because of the importance of tunneling to the operation of its products, Xicor decided to adequately characterize and model tunnel emission from textured polycrystalline silicon (poly) surfaces. One avenue of exploration was to characterize the physical topology of the tunneling structure. Figure 10 is a scanning electron micrograph (SEM) of the emitting (top) surface of a layer of polysilicon from which the oxide has been removed for clarity. As shown in the micrograph, this surface is composed of a densely packed array of features reminiscent of a cobblestone street. A count of these features on SEM photos of material from several lots determined that there is an average of about 50 features per square micron. A transmission electron microscope (TEM) cross-section of a tunneling structure is shown in Figure 11. This photo demonstrates the conformal nature of the structure. The top surface of the prior deposition of polysilicon is formed into a series of "hillocks" 200-300Å high and 1000-1500Å across the base. The free surface of the oxide grown on this silicon replicates the silicon surface. Thus, polysilicon deposited atop the prior polysilicon layer subsequent to oxidation has dimples on its undersurface occurring over the already existing "hillocks".

The topology of the polysilicon surfaces causes the electric field lines to no longer be parallel as in the case of parallel emitting and collecting surfaces, but rather to diverge and converge in response to the local topology as is illustrated in Figure 12. As shown, the field lines converge near surfaces of positive curvature (i.e., bumps) and diverge near surfaces of negative curvature (i.e., dimples). Since Fowler-Nordheim tunneling depends exponentially on the electric field at the surface of the polysilicon, a good model of the electron emission requires an accurate knowledge of the field over the complete surface.

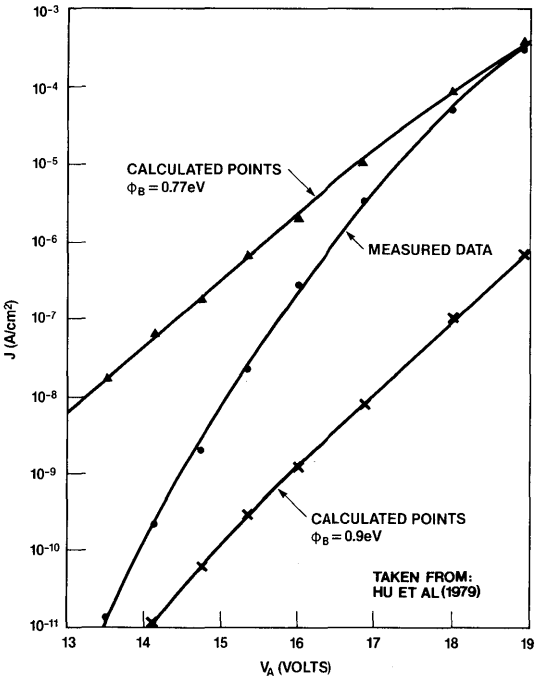

Figure 9: Current vs. applied voltage for current from textured poly surface emitted through 1760 Å of thermal SiO_2 compared with calculations based on previously available theory.

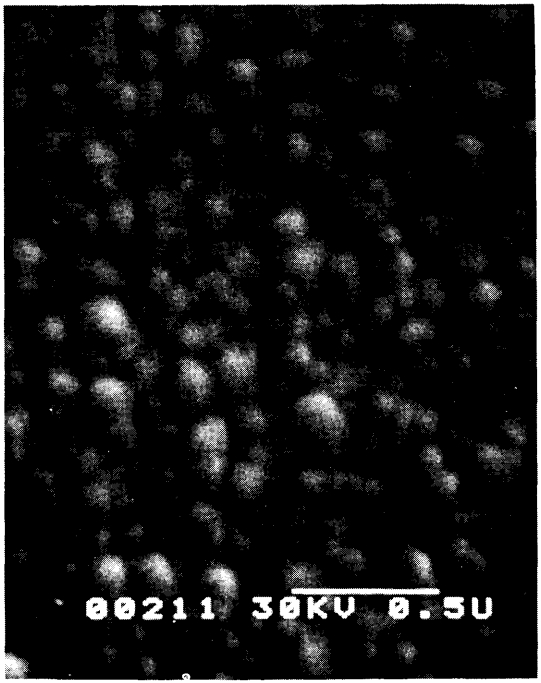

Figure 10: Scanning electron microscope (SEM) photograph of top emitting textured poly surface with oxide removed. The 0.5μ-long bar gives the scale.

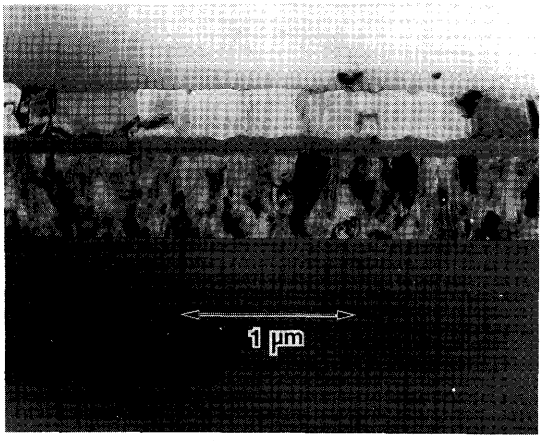

Figure 11: Transmission electron microscope (TEM) photograph of a cross-section through a textured tunneling structure. The one micron-long arrow shows the scale.

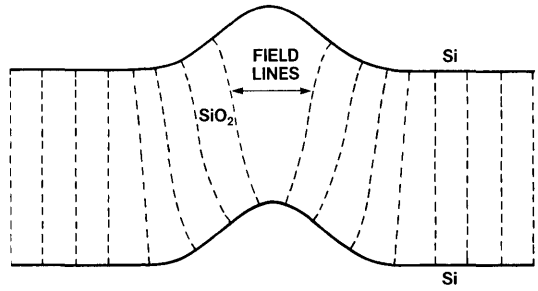

Figure 12: Sketch illustrating the manner in which field lines converge near convex feature and diverge near concave features.

Until recently, this field problem was one of the unsolved problems of mathematical physics. (It is classically known as the "lighting rod problem".) Roger Ellis, a member of the Xicor staff, has solved this problem.[8] The technique used differential geometry to transform Euclidean space into a space in which the field lines were parallel. The electrostatics problem was solved in this space and the solution transformed back into the original space. The tunnel current was found to be described in a spherical coordinate system by the equation:

$$J_{collecting} = \frac{\left[\int_S \frac{q^3E^2}{8\pi h\phi_B} \exp\left\{\frac{-4(2m)^{1/2}\phi_B^{3/2}}{3hqE}\right\} ds\right]_{emitting}}{\left[\int_S ds\right]_{collecting}} \quad (1)$$

where the electric field, E, is given by

$$E = \frac{V_A}{\xi(s_2) - \xi(s_1)} \left[\left(\frac{d\Theta^2}{dr}\right) + \frac{1}{r^2}\right]^{1/2} \frac{d\xi}{d\Theta} \quad (2)$$

and

$$\xi = \frac{1}{\left|\frac{d\vec{r}}{d\Theta}\right|} \frac{de_t}{d\Theta}(\vec{e}_t)$$

is the curvature of the surface at which the field is evaluated.[9]

This expression has several interesting properties. One is that the field depends on the difference of the curvatures of the emitting and collecting surfaces. Another is that the electric field also depends on the derivative of the curvature of the emitting surface.

To verify the accuracy of this expression, the current-voltage (J-V) characteristics of a textured polysilicon tunnel structure were experimentally determined and compared with those predicted by equation (1). Because of the field enhancement on

the bumps, a higher current is expected at a given applied voltage polarity which causes electron emission from the bumps than for that polarity which causes emission from the dimples. Thus, by analogy with a diode, the polarity with the bumps negative (higher current emitted) is called the forward bias direction and the other polarity is called the reverse bias direction.

Figure 13 shows the results of comparing experimental and calculated values for the forward bias condition. As can be seen, theory and experiment agree within about 20% over seven orders of magnitude in current. The parameters used in calculating the predicted currents were not arbitrarily chosen. The value of the oxide/silicon conduction band barrier, $\varnothing_B$, was taken to be 3.15 eV as measured by Weinberg[10]. The feature density $(50\mu)^2$ and the bump base and height are typical of those seen on SEMs and TEMs such as Figures 10 and 11, respectively. The dashed line in Figure 13 is the current which would be predicted if the top (i.e., collecting) electrode were flat rather than dimpled. This illustrates the effect of the collecting surface curvature on the field at the emitting surface.

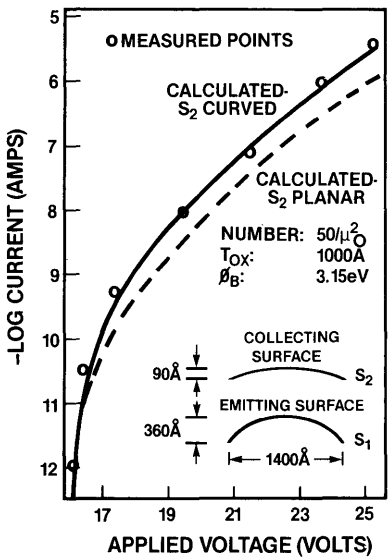

Figure 13: Forward tunneling characteristic comparing the measured data with curves calculated for a concave and a planar collecting surface.

To further verify equation (1), the reverse bias current was measured on the same device used for the forward bias case. The results are compared with the predicted current in Figure 14. This shows about 20% agreement over eight orders of magnitude in current with the same parameters used as in calculating the forward bias case. Clearly, the model does an excellent job of predicting the measured current.

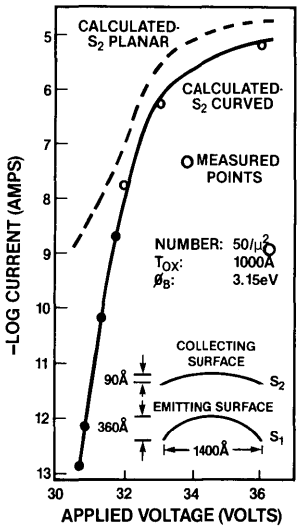

Figure 14: Reverse tunneling characteristic comparing the measured data with curves calculated for a concave and planar emitting surface.

Several points of interest can be observed in Figure 14. One point is that at a voltage at which the forward current is saturating (25V), the reverse current is unobservable (extrapolation of the measured current predicts $\sim 10^{-27}$ A). Another point is that the current emission predicted from a flat top surface is greater than that predicted from a dimpled top surface. Moreover, the current emitted from a flat top surface decreases more slowly with decreasing voltage than that from a dimpled flat surface. This latter fact is important for data retention as will be discussed in the next section.

In summary, Xicor is able to accurately model the tunnel current emitted from textured poly surfaces through SiO_2 layers. The magnitude of the tunnel current as well as its voltage dependence are dependent upon the surface topology. Thus, we have the means to optimize the emission characteristics. Lastly, the asymmetric nature of the tunnel emission makes possible cell designs which are better adapted to particular requirements than is possible with symmetric tunnel characteristics – just as a diode offers more design possibilities than does a resistor.

DATA RETENTION

As was suggested in the previous section, textured poly tunneling structures have a significant advantage in data retention, in comparison with those employing flat surfaces and thin oxides. One basis for this advantage is illustrated in Figure 15, in which the current-voltage (J-V) characteristics of a tunneling device which employs a thin oxide between planar surfaces is compared with a tunneling device which employs a thick oxide between textured silicon surfaces. For this comparison we match the currents in the high current region since most memories are designed to program in about the same time period (~ 10 msec). As can be seen, the same current can be obtained from a smooth surface with 125Å thick tunnel oxide or from a textured surface with an 825Å thick tunnel oxide. Note however, that at lower values of applied voltage typical of read and storage conditions, the current emitted from a textured surface is approximately four orders of magnitude lower than that from a smooth surface.

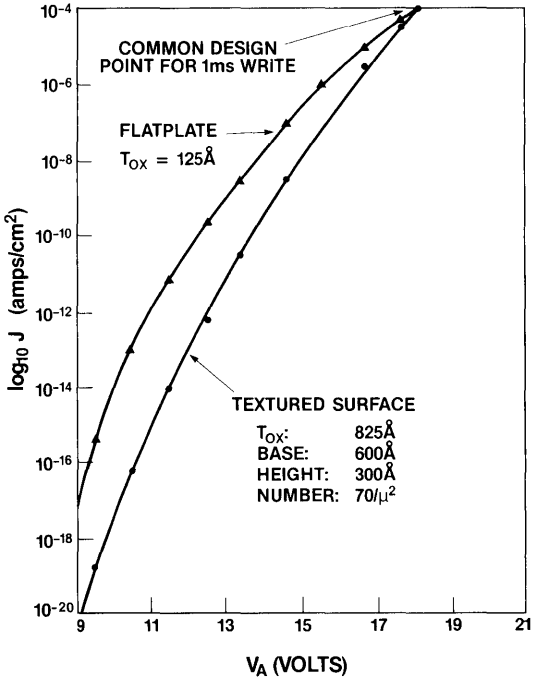

Figure 15: Comparison of calculated tunneling J-V curves for emission from a planar and a textured structure. The devices were designed to have the same emission in the high current regime where programming takes place.

These differences may become even more significant as devices are scaled. It is clear that, in order to scale the memory properly, lower programming voltages are needed so that the isolation widths and device channel lengths can be reduced both in the memory array and in the peripheral circuitry. However, for a typical part which stores data in 3 msec. and must retain it for 10 years, the tunneling current under storage and reading conditions must be at least 10^{11} times smaller than under programming conditions because the retention time is 10^{11} times longer than the storage time. Actually, for margin, one would design for a difference in currents of 10^{13} to 10^{14}. For planar surface tunneling structures, this may be a difficult design constraint because the slope of the J-V curve is fixed, which means that the maximum allowed read voltage drops with the programming voltage on a volt-for-volt basis, not proportionately. On the other hand, textured surface tunneling structures, in their current manifestation, have a steeper J-V characteristic than planar ones and the J-V characteristic of a textured structure can be tailored to yield a steeper curve if desired. This means that for a given maximum read voltage, a textured structure requires a lower programming voltage which leads to better scaling.

To verify the excellent data retention expected of Xicor NOVRAMs, a study was carried out to measure data loss as a function of temperature. Figure 16 shows log cumulative data loss vs. log time for 100 samples of X2210's at each of three temperatures. Data loss is defined as occurring when the first bit in the array loses data. As shown in Figure 16, high temperatures were required to obtain appreciable data loss in experimentally useful times. Note that even at 300° C, 2000 hours (~ 3 months) are required to begin to see data loss. Figure 17 shows the result of calculating failure rates based on these results and plotting vs. inverse temperature. Since the rates fall on a straight line, we can extract an activation energy and extrapolate to lower temperatures (see the next section for a discussion of activation energies). The result is that the experimental value of the activation energy is 1.7 eV and the mean time for data loss for this mechanism (which we believe to be the fundamental loss mechanism of this technology) is 3 million years for data retention at 125°C.

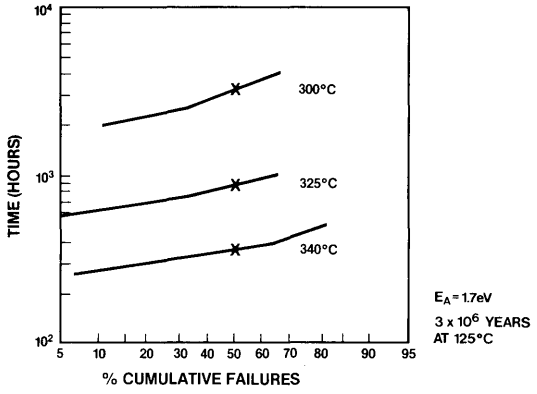

Figure 16: Log cumulative data loss vs. log time for three storage temperatures on samples of 100 X2210's. Data loss is defined to occur when the first bit in an array loses data.

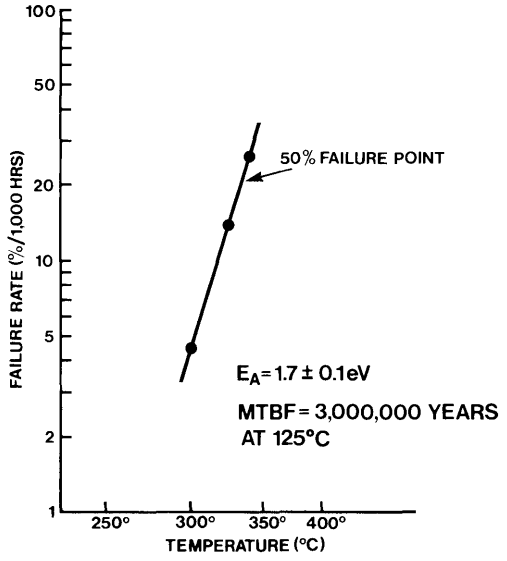

Figure 17: Log data loss rate vs. inverse temperature for X2210's.

BASIC RELIABILITY CONCEPTS

There are several concepts basic to most reliability work. One is the long established observation that failure rates follow the bathtub-shaped curve illustrated in Figure 18. There is an infant mortality region characterized by a rapidly declining failure rate as the "weak" parts are eliminated from the population, a random failure characterized by an invariant or slowly declining failure rate, and a wearout region characterized by an increasing failure rate as the units reach the end of life.

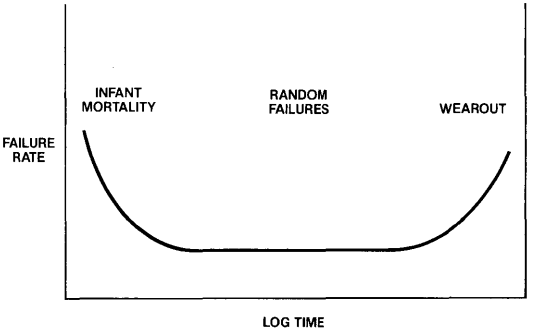

Figure 18: Illustration of bathtub curve of failure rates showing regions in which infant mortality, random failures, and wearout mechanisms dominate the failure rate.

Each region of the failure rate curve has specific failure modes which predominate. For example, the infant mortality region is dominated by failures which arise from manufacturing defects. Table I gives a summary of common failure mechanisms and stresses which may be used to accelerate the failure rates of the various mechanisms which have been culled from the literature.[11-14]

The classic parameter used to accelerate failure rates is temperature. It is known that a very broad class of failure mechanisms have a temperature dependence proportional to exp $(-E_a/kT)$ where E_a is called the activation energy, k is Boltzmann's constant, and T is the absolute temperature. This is true because a number of basic physical phenomena such as diffusion rates and chemical reaction rates have this dependence. The significance of this is that if the activation energy is known for the failure mechanisms in question, then the failure rates arising from these mechanisms can be measured at elevated temperature where they are high enough to be conveniently measured and extrapolated back to

lower operating temperatures where the failure rates may be so low as to require an inconveniently large number of device hours to measure. The relationship which allows one to translate failure rates from one temperature to another is known as the Arrhenius relation. Figure 19 illustrates this relation for a number of common values of activation energy.

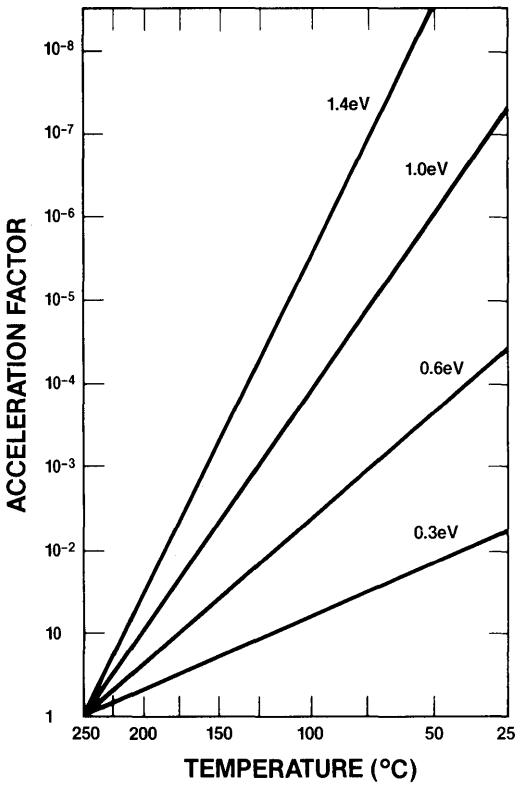

Figure 19: Acceleration factor vs. temperature calculated for various activation energies from Arrhenius relation.

RELIABILITY TESTING

Five types of tests were conducted to establish the reliabilty of the devices:

1. High temperature dynamic lifetest
2. Data retention bake
3. High temperature reverse bias
4. Lifetest monitor
5. Environmental

These tests are discussed after Table I.

Failure Mechanism	Type	Activation Energy	Detection Method
Ionic Contamination	Infant/ Random/ Wearout	1.0 eV	High Temp. Bias
Surface Charge	Wearout	0.5-1.0 eV	High Temp. Bias
Polarization	Wearout	1.0 eV	High Temp. Bias
Electro-migration	Wearout	1.0 eV	High Temp. Operating Life
Microcracks	Random	---	Temperature Cycling
Oxide Rupture	Infant/ Random	0.3 eV	High Temp. Operating Life
Silicon Defects	Infant/ Random	0.3 eV	High Temp. Bias
Oxide Defect Leakage	Infant/ Random	0.6 eV	High Temp. Operating Life
Electron Trapping In Oxide	Wearout	---	Low Temp., High Voltage Operating Life

Table I: MOS Failure Mechanisms

High Temperature Dynamic Lifetest

This is the usual data from which failure rate predictions are made. For this to be a valid predictor of failure rate, the parts must function as they would in normal operation. Thus, overly elevated temperatures at which the unit does not function internally are to be avoided since this may lead to overly optimistic predictions.

Xicor gathers this data at 125°C ambient which is within the known operating range of the units under test. The stimulus pattern consists of recalling a known pattern, writing an all one's pattern over the recalled pattern bit by bit, reading the all one's pattern, writing its complement, reading the complement and then beginning over again.

The units in lifetest are tested at 168, 500, 1000, and 2000 hours to verify that they are still within specification. The first step of the readout tests is to recall the information stored in the nonvolatile section of memory to verify that the previously stored pattern is still retained. If so, the memory is completely exercised over voltage including verification of the STORE function. Finally, the predetermined pattern is restored to memory for the next lifetest period.

Data Retention Bake

This test is sometimes referred to as a storage bake. The term "data retention bake" better describes the principal function it serves in the case of electrically programmable nonvolatile memories which is to measure how fast charge leaks away from the floating gate.

In this test, a pattern which represents all floating gates charged positive is stored and the devices are baked at 250°C for the cerdip (ceramic dual-in-line) package and 150°C for plastic (dual-in-line) package with no bias applied. At intervals the memory is removed from bake, and the nonvolatile data recalled and checked for accuracy. The data is not restored at readouts in order to ascertain the worst case retention. Since Xicor warrants cycling endurance of various values, this test was performed on parts specified for 1000 cycle endurance which had performed 1000 complete data alterations, as well as on parts which had not received this treatment.

HTRB

HTRB stands for High Temperature Reverse Bias, a term which originated with bipolar circuits, in which case the test reverse biased the junctions of all of the input stages. For MOS circuits, a better term would be high temperature static bias. In this stress, which Xicor carries out at 150°C, V_{SS} is grounded and a static positive voltage is applied to all of the inputs and outputs, as well as to V_{CC}. This has the effect of applying a static bias equal to the power supply across the gate oxides of the circuit transistors. This stress is intended to expose failures which might occur as a result of drift of mobile ionic contaminants or latent defects in the gate oxides.

It is known that many defects are accelerated by voltage as well as temperature. For example, it has been shown by Crook that the failure rate of oxide defects increases 10^7 times per MV/cm increase in the electric field.[15] For this reason, HTRB stresses were conducted with both 5.5V and 7.5V bias applied to the units under test.

Life Test Monitor

In order to assure a continuous supply of the highest quality and reliability possible to our customers, a weekly life test monitor is maintained.

This monitor is used at Xicor for two purposes. First, it is used to monitor the infant mortality rate which is an indicator of manufacturing defects. If an unusually high failure rate were to be observed, a corrective action could be taken before defective units are shipped to customers. Secondly, a long term failure rate is also monitored. This establishes a way to ensure that long term reliability is maintained.

Each week approximately 250 units of X2212 devices are placed in a dynamic life test at 125°C for 168 hours. Also, monitor units of the first week of each period remain in dynamic life test for up to 1000 hours.

Package Environmental Tests

MIL-M-35810 and MIL-STD-883, Method 5005, Group C and D have been the guide for environmental testing for the cerdip package. Table II lists the tests, the test conditions and test results. All lots passed the 883 qualification criteria.

Because of the nature of the plastic package, additional tests were done. These tests are 85°C/85% RH (both biased and unbiased) life test, temp cycling (200 cycles) and saturated storage test at 2 ATM (autoclave).

RESULTS

Tables IIIA and IIIB exhibit the results of dynamic life test of X2210 and X2212 in cerdip package and plastic package, respectively. Table IIIA shows zero failure result in 6×10^5 device hours on 1700 units of X2210 and X2212. Table IIIB shows two failure results in 1.7×10^6 device hours on 5055 units of X2210 and X2212. The causes of the failures were also listed in Table IIIB. In addition, Table IIIB includes life test monitor data since plastic units are used.

Tables IVA and IVB show the results of 150°C static life test at 5.5V for cerdip and plastic. No failures were detected on both package types, out of 121 units for cerdip and 245 units for plastic.

Tables VA and VB show the results of 150°C static life test at 7.5V applied bias. Increasing V_{CC} from 5.5V to 7.5V increases the field across the gate oxide from 6.875×10^5 V/cm to 9.375×10^5V/cm. According to Crook this increase in field should accelerate the failure rate by about 56 times. In cerdip, one failure was observed at the 48 hour readout. For oxide breakdown, out of 250 units tested in plastic, no failures were seen.

Test	Mil-Std-883 Test Method	Conditions	LTPD	Accept #	Results
Temp. Cycling	1005	Test Condition C (10 cycle −65 to 125°C)	15	0/15	0/175
Constant Acceleration	2001	Test Condition E (30,000 g Y1 axis only)			0/175
Seal −Fine −Gross	1014	Test Condition B (5×10^{-8} cc/min) Test Condition C			0/175 0/175
Lead Integrity	2004	Test Condition B2 (Lead Fatigue)	15	0/15	0/213
Seal −Fine −Gross	1014	Test Condition B Test Condition C			0/213 1/213
Thermal Shock	1011	Test Condition B (15 cycles −55°C to 125°C)	15	0/15	0/203
Temp. Cycling	1010	Test Condition C (100 cycles)			0/203
Moisture Resistance	1004				0/203
Seal −Fine −Gross	1014	Test Condition B Test Condition C			0/203 0/203
Internal Water Vapor Content	1018	5,000 ppm max. water content at 100° C	—	0/3 or 1/5	0/6
Mechanical Shock	2002	Test Condition B (1500 g peak 3 axis)	15	0/15	0/192
Vibration Variable Frequency	2007	Test Condition A (20 g peak 3 axis)			0/192
Constant Acceleration	2001	Test Condition E			0/192
Seal −Fine −Gross	1014	Test Condition B Test Condition C			0/192 0/192
Salt Atmosphere	1009	Test Condition A	15	0/15	0/144
Seal −Fine −Gross	1014	Test Condition B Test Condition C			0/144 0/144
Adhesion of Lead Finish	2025		15	0/15 (# of leads from 3 devices)	0/18
Lid Torque	2024		—	0/5	0/15

Table II: Environmental Test for 18 Lead Cerdip Package

	48 Hr.		168 Hr.		500 Hr.		1000 Hr.		Total
	#Fail	#In	#Fail	#In	#Fail	#In	#Fail	#In	Hours
Lot #1 (2212)	0	403	0	383	0	99	0	97	1.3E5
Lot #2 (2212)	0	350	0	324	0	99	0	98	1.2E5
Lot #3 (2212)	0	338	0	334	0	99	0	98	1.2E5
Lot #4 (2210)	0	294	0	284	0	99	0	97	1.2E5
Lot #5 (2210)	0	315	0	312	0	99	0	98	1.2E5
TOTALS	0	1700	0	1637	0	495	0	488	6.0E5

Table IIIA: Stress Dynamic Life Test at 125°C – Cerdip Package

	48 Hr.		168 Hr.		500 Hr.		1000 Hr.		2000 Hr.		Total
	#Fail	#In	#Fail	#In	#Fail	#In	#Fail	#In	#Fail	#In	Hours
Lot #1 (2212)	0	575	0	573	0	99	0	97	0	97	2.5E5
Lot #2 (2212)	2[a]	570	0	565	0	99	0	98	0	98	2.5E5
Lot #3 (2212)	0	577	0	577	0	99	0	96	0	96	2.5E5
Lot #4 (2210)	0	573	0	570	0	99	0	99	0	98	2.5E5
Lot #5 (2212)	0	570	0	570	0	99	0	99	0	98	2.5E5
Lot #6 (Monit.)	0	2190	0	2183	0	297	0	297	—	—	5.1E5
TOTALS	2	5055	0	5038	0	792	0	786	0	487	1.7E6

a = one x-decoder failure due to blown oxide 0.3 eV
one word line failure due to blown oxide 0.3 eV

Table IIIB: Stress Dynamic Life Test at 125°C – Plastic Package

	48 Hr.		168 Hr.		500 Hr.		1000 Hr.		2000 Hr.		Total
	#Fail	#In	#Fail	#In	#Fail	#In	#Fail	#In	#Fail	#In	Hours
Lot #1 (2212)	0	25	0	23	0	23	0	23	0	23	44896
Lot #2 (2212)	0	25	0	25	0	25	0	25	0	25	48800
Lot #3 (2212)	0	25	0	23	0	23	0	23	0	23	44896
Lot #4 (2210)	0	25	0	25	0	25	0	25	0	25	48800
Lot #5 (2210)	0	25	0	25	0	25	0	25	0	25	48800
TOTALS	0	125	0	121	0	121	0	121	0	121	2.4E5

Table IVA: Stress 5.5V HTRB at 150°C – Cerdip Package

	48 Hr.		168 Hr.		500 Hr.		1000 Hr.		Total
	#Fail	#In	#Fail	#In	#Fail	#In	#Fail	#In	Hours
Lot #1 (2212)	0	50	0	49	0	49	0	49	46648
Lot #2 (2212)	0	50	0	50	0	50	0	49	47100
Lot #3 (2212)	0	50	0	50	0	50	0	50	47600
Lot #4 (2210)	0	50	0	50	0	50	0	50	47600
Lot #5 (2212)	0	50	0	49	0	47	0	47	44984
TOTALS	0	250	0	248	0	246	0	245	2.3E5

Table IVB: Stress 5.5V HTRB at 150°C – Plastic Package

	48 Hr.		168 Hr.		500 Hr.		1000 Hr.		Total
	#Fail	#In	#Fail	#In	#Fail	#In	#Fail	#In	Hours
Lot #1 (2212)	0	25	0	25	0	25	0	25	23800
Lot #2 (2212)	1[a]	25	0	24	0	24	0	24	22848
Lot #3 (2212)	0	25	0	25	0	25	0	25	23800
Lot #4 (2210)	0	25	0	25	0	25	0	25	23800
Lot #5 (2210)	0	25	0	25	0	25	0	25	23800
TOTALS	1	125	0	124	0	124	0	124	1.2E5

a = blown oxide 0.3eV

Table VA: Stress 7.5V HTRB at 150°C – Plastic Package

	48 Hr.		168 Hr.		500 Hr.		1000 Hr.		Total
	#Fail	#In	#Fail	#In	#Fail	#In	#Fail	#In	Hours
Lot #1 (2212)	0	50	0	48	0	48	0	48	45696
Lot #2 (2212)	0	50	0	50	0	50	0	48	46600
Lot #3 (2212)	0	50	0	50	0	50	0	50	47600
Lot #4 (2210)	0	50	0	50	0	50	0	50	47600
Lot #5 (2212)	0	50	0	48	0	48	0	48	45696
TOTALS	0	250	0	246	0	246	0	244	2.3E5

Table VB: Stress 7.5V HTRB at 150°C – Plastic Package

Tables VIA, VIB, VIIA and VIIB show the results of 250°C and 150°C retention bake for cerdip and plastic, respectively. Retention bake was done both before and after 1000 data change cycles on units that are rated for 1000 data change cycles. At 150°C no failures were detected before nor after 1000 data changes on a total of 125 units for 1000 hours. At 250°C, the data on uncycled devices shows 3 units failed from 250 units for 2000 hours. The data on cycled devices shows 4 units failed from 125 units for 2000 hours. These results do not have statistically significant differences in overall failure rate. Close examination shows a tendency for the cycled failures to be more scattered, while uncycled failures are more concentrated at 1000 and 2000 hour readouts. This kind of data should not be surprising, as an oxide defect, which had been accelerated by the high electric field, became manifest during store operation. The retention failure rate for 1000 hours at 250°C is at the range of 1 to 2%, which is about half of that previously reported for EPROMs.[16] Retention data reported for other E^2PROM technologies would indicate that the present NOVRAM retention results are greatly superior.[17]

Table VIII and IX represents 85/85 life test with and without voltage bias, respectively. As indicated by the data, no failures were observed in both the 5.5V biased and the unbiased groups for a total of 5×10^5 device hours.

	48 Hr.		168 Hr.		500 Hr.		1000 Hr.		2000 Hr.		Total
	#Fail	#In	#Fail	#In	#Fail	#In	#Fail	#In	#Fail	#In	Hours
Lot #1 (2212)	0	50	0	50	0	50	0	49	0	48	95100
Lot #2 (2212)	0	50	0	50	0	50	0	50	1	47	94600
Lot #3 (2212)	0	50	0	50	0	50	1	50	1	48	95600
Lot #4 (2210)	0	50	0	50	0	50	0	50	0	50	97600
Lot #5 (2210)	0	50	0	50	0	50	0	49	0	49	96100
TOTALS	0	250	0	250	0	250	1	248	2	242	4.8E5

Table VIA: Stress Bake at 250°C – Cerdip Package

	48 Hr.		168 Hr.		500 Hr.		1000 Hr.		Total
	#Fail	#In	#Fail	#In	#Fail	#In	#Fail	#In	Hours
Lot #1 (2212)	0	25	0	25	0	25	0	25	23800
Lot #2 (2212)	0	25	0	25	0	25	0	25	23800
Lot #3 (2212)	0	25	0	25	0	25	0	25	23800
Lot #4 (2210)	0	25	0	25	0	25	0	25	23800
Lot #5 (2212)	0	25	0	25	0	25	0	25	23800
TOTALS	0	125	0	125	0	125	0	125	1.2E5

Table VIB: Stress Retention Bake at 150°C – Plastic Package

	48 Hr.		168 Hr.		500 Hr.		1000 Hr.		2000 Hr.		Total
	#Fail	#In	#Fail	#In	#Fail	#In	#Fail	#In	#Fail	#In	Hours
Lot #1 (2212)	0	25	0	25	1	24	0	23	1	23	45468
Lot #2 (2212)	0	25	0	25	0	25	0	25	0	25	48800
Lot #3 (2212)	1	25	0	24	0	24	1	24	0	23	45848
Lot #4 (2210)	0	25	0	25	0	25	0	25	0	25	48800
Lot #5 (2210)	0	25	0	25	0	25	0	25	0	25	48800
TOTALS	1	125	0	124	1	123	1	122	1	121	2.4E5

Table VIIA: 250°C Retention Bake – Cycled Cerdip Unit

	48 Hr.		168 Hr.		500 Hr.		1000 Hr.		Total
	#Fail	#In	#Fail	#In	#Fail	#In	#Fail	#In	Hours
Lot #1 (2212)	0	25	0	25	0	25	0	25	23800
Lot #2 (2212)	0	25	0	25	0	25	0	25	23800
Lot #3 (2212)	0	25	0	25	0	25	0	25	23800
Lot #4 (2210)	0	25	0	25	0	25	0	25	23800
Lot #5 (2212)	0	25	0	25	0	25	0	25	23800
TOTALS	0	125	0	125	0	125	0	125	1.2E5

Table VIIB: 150°C Retention Bake – Cycled Plastic Unit

	500 Hr.		1000 Hr.		Total
	#Fail	#In	#Fail	#In	Hours
Lot #1 (2212)	0	50	0	50	41600
Lot #2 (2212)	0	50	0	50	41600
Lot #3 (2212)	0	50	0	50	41600
Lot #4 (2210)	0	50	0	50	41600
Lot #5 (2212)	0	50	0	50	41600
TOTALS	0	250	0	250	2.1E5

Table VIII: Biased 85/85 – Plastic Units with $V_{CC} = 5V$

	500 Hr.		1000 Hr.		Total
	#Fail	#In	#Fail	#In	Hours
Lot #1 (2212)	0	50	0	50	41600
Lot #2 (2212)	0	50	0	50	41600
Lot #3 (2212)	0	50	0	50	41600
Lot #4 (2210)	0	50	0	50	41600
Lot #5 (2212)	0	50	0	50	41600
TOTALS	0	250	0	250	2.1E5

Table IX: Biased 85/85 – Plastic Units with $V_{CC} = 0V$

	200 Cycles	
	#Fail	#In
Lot #1 (2212)	0	50
Lot #2 (2212)	0	50
Lot #3 (2212)	0	50
Lot #4 (2212)	0	50
Lot #5 (2210)	0	50
TOTAL	0	250

Table X: Temperature Cycles (Method 1010) – Plastic Package

	48 Hr.		168 Hr.		500 Hr.		1000 Hr.		Total
	#Fail	#In	#Fail	#In	#Fail	#In	#Fail	#In	Hours
Lot #1 (2212)	0	25	0	25	0	25	0	25	23800
Lot #2 (2212)	0	25	0	25	0	25	0	25	23800
Lot #3 (2212)	0	25	0	25	0	25	0	25	23800
Lot #4 (2210)	0	25	0	25	0	25	0	25	23800
Lot #5 (2212)	0	25	0	25	0	25	0	25	23800
TOTALS	0	125	0	125	0	125	0	125	1.2E5

Table XI: Dynamic Life Test at 10°C – Plastic Packaged Units

Figure 20 shows a bar graph of the autoclave results for plastic package. Cumulative failures steadily increased for the first 400 hours with sharp increase at approximately 500 hours. Figure 20 shows the 500 hour mark for the plastic package in the 24% range. The discrepancy between autoclave and 85°C/85% RH life test results can be explained by the two causes of failure. During the saturated storage (autoclave), failure rate is dependent on the galvanically induced ionic currents flowing in a layer of water on the surface of the die. This layer of water is accumulated after plastic has debonded from the die which causes corrosion to concentrate on the bonding pad. The 85°C/85% RH life test produced more widespread corrosion due to phosphorous in the passivations, and debonding is not a prerequisite for this type of failure.[21, 22] Since corrosion on the bonding pad is only one of the failure modes which can occur in 85°C/85% RH life test, it would be a better indicator for normal operation.[21]

Table X shows the result of the temperature cycling for plastic packages. No failures were observed. The test used 200 temperature cycles for +125°C to −65°C, air to air. (MIL-Std-883, Method 1010) indicates that the plastic packaged device would perform very well under normal temperature variations.

Table XI shows the results (no failures) of low temperature dynamic life test. The lack of failures indicates that typical semiconductor failure modes are not a factor in this technology.

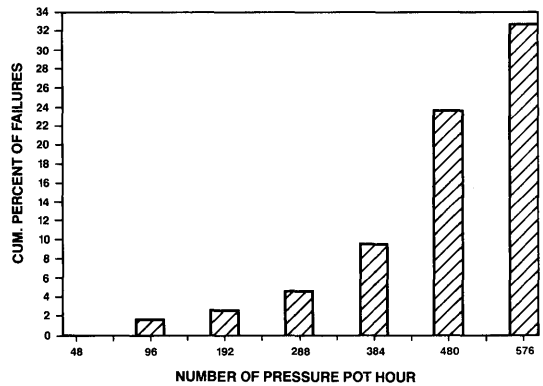

Figure 20: Pressure Pot Result

CALCULATION OF PREDICTED FAILURE RATE

There is no simple, one-step formula for inferring a predicted failure rate from the experimental data. Instead, the failures of each individual activation energy must be treated differently. The first step is to calculate the equivalent device hours at the ambient temperature of interest, utilizing the Arrhenius relationship discussed earlier on pages 8 & 9. This calculation should be carried out for every mechanism observed or expected. For example, the calculation for the 0.3 eV activation energy oxide rupture mechanism should be carried out whether this failure mechanism is observed or not, since this mechanism is always anticipated in MOS integrated circuits. The extrapolation should be carried out utilizing the junction temperature at the ambient temperature of interest and not the ambient temperature itself. The upper confidence limit is then calculated for the failure rate for each activation energy. The upper confidence limits for the various activation energies are then summed for a total failure rate prediction. The meaning of the "upper confidence level" is that with a certainty, or probability, of a certain level we can say that the true value is less than the stated value. Thus, the confidence level rate calculated is non-zero even for the case where no failures are observed because we can't be sure that there will be none.

Two calculations were performed to separate short term failure rates (infant mortality) and long term failure rate (expected failure rate). This was done to obtain a better picture of the expected failure rates.

Long term failure rates are tabulated in Table XII based on the data in Tables III-V. Voltage acceleration is applied for the 0.3 eV activation energy failure mode typical of oxide breakdown. No voltage acceleration is applied to the 0.6 eV and 1.0 eV failure modes because the dependence for these has not been established. These data lead to a predicted long term failure rate in plastic of 39 F.I.T. (0.0039%/1000 hr) at 60% UCL at 70°C ambient and 18 F.I.T. (0.0018%/1000 hr) at 60% UCL at 55°C ambient. In cerdip the corresponding values are 85 F.I.T. (0.0085%/1000 hr) at 60% UCL at 70°C ambient and 45 F.I.T. (0.0045%/1000 hr) at 60% UCL at 55°C ambient. From these numbers, it should not be concluded that the parts are more reliable in plastic than in cerdip but rather that since there are more hours in plastic than cerdip the uncertainty is reduced and hence the UCL (upper confidence level) is lower. The best single point estimate of the reliability of the part is probably obtained by combining the data on the units in plastic and cerdip packages. This leads to estimated failure rate of 39 F.I.T. (0.0039%/1000 hr) at 70°C ambient and 60% UCL and 16 F.I.T. (0.0016%/1000 hr) at 55°C ambient and 60% UCL.

The above calculations of long term failure rates were done excluding the data for the first 48 hours of

PLASTIC									
Activation Energy	**Hours at 125°C**	**Hours at 150°C**	**Number of Failures**	**Equivalent Hours at 70°C**	**Expected Value of Failure Rate at 70°C**	**60% UCL Failure Rate at 70°C**	**Equivalent Hours at 55°C**	**Expected Value of Failure Rate at 55°C**	**60% UCL Failure Rate at 55°C**
0.3 eV	1.75×10^6	4.91×10^5	0	$9.31 \times 10^{7*}$	—	9.8	1.40×10^8	—	7
0.6 eV	1.75×10^6	4.91×10^5	0	3.94×10^7	—	26	8.86×10^7	—	10
1.0 eV	1.75×10^6	4.91×10^5	0	3.07×10^8	—	3	1.19×10^9	—	1
TOTAL					—	39		—	18
CERDIP									
Activation Energy	**Hours at 125°C**	**Hours at 150°C**	**Number of Failures**	**Equivalent Hours at 70°C**	**Expected Value of Failure Rate at 70°C**	**60% UCL Failure Rate at 70°C**	**Equivalent Hours at 55°C**	**Expected Value of Failure Rate at 55°C**	**60% UCL Failure Rate at 55°C**
0.3 eV	6.05×10^5	3.66×10^5	1	$4.86 \times 10^{7*}$	—	41	7.45×10^7	—	27
0.6 eV	6.05×10^5	3.66×10^5	0	2.26×10^7	—	40	5.30×10^7	—	17
1.0 eV	6.05×10^5	3.66×10^5	0	2.11×10^8	—	4	8.75×10^8	—	1
TOTAL					—	85		—	45

*0.3 eV equivalent hours includes voltage acceleration for 7.5 eV stress.

Table XII: Long Term Failure Rate (Not Including 48 HR Data Point)

dynamic lifetest. (Note: all units going into other tests received this stress as a preconditioning.) The short term failure fraction, sometimes called infant mortality percentage, can be estimated from these data in Tables IIIA, B. In cerdip, no failures were observed from 1700 units. In plastic, there were 2 failures in 5055 units or 396 PPM. If the data from all packages is combined, a single point estimate is 296 PPM.

These results show that Xicor NOVRAMs have attained failure rates comparable, if not better, to those reported by major suppliers of standard volatile memory products.[18-20]

SUMMARY

The data presented in this reliability report show that the data retention of Xicor's NOVRAM technology is excellent. Even at a high temperature (300°C), only about 2% lose data in 1000 hours. Theoretical grounds for expecting this result are discussed. Two calculations were done, one for short term (48 hours) failure rate and one for long term expected failure rate. These show an overall long term failure rate of 16 F.I.T. at 55°C, 60% UCL and an infant mortality of less than 300 PPM. The cerdip packaging employed is shown to be capable of passing the Group D qualification requirements of MIL-Std-883, Method 5005. Finally, the plastic packaging employed shows excellent 85°C/85% RH result.

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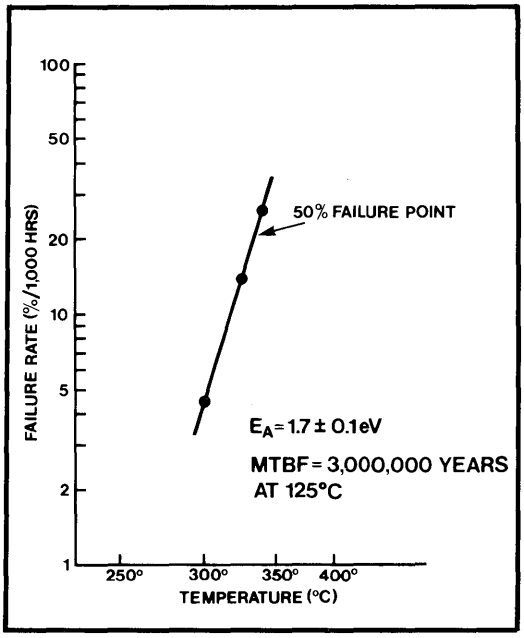
This report is based on data collected through February, 1985.



X2816A/04A PRELIMINARY RELIABILITY SUMMARY

By Bruce Prickett
& Dr. John Caywood

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Cover Photo: Figure 7 Data retention vs. temperature for memory arrays fabricated with Xicor's technology.

This report is based on data collected through September, 1983.

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X2816A/04A PRELIMINARY RELIABILITY SUMMARY

by Bruce Prickett &
John Caywood

Introduction

The X2804A and X2816A are 4K and 16K electrically erasable programmable read only memories (E^2PROMs) organized as 512 x 8 and 2K x 8. These memories operate on a single 5 volt power supply for all operations. Figures 1 and 2 show the pin configurations of the X2816A and X2804A and the functional diagram of the X2816A. Figure 3 is the package outline drawing for these parts. Figure 4 and 5 are bit maps which illustrate the physical location of the memory bits of the X2804A and X2816A respectively.

Although Xicor introduced its X2816A and X2804A E^2PROMs only recently, Xicor is an experienced manufacturer of E^2PROMs. This is because the family of NOVRAMs (X2201A,X2210 and X2212) which Xicor introduced earlier all contained E^2PROMs integrated together with static RAM on a bit-for-bit basis. The process technology and the 5 volt design techniques which had been developed for the NOVRAMs were carried over to the E^2PROM products. This experience enabled Xicor to introduce these 5-Volt only E^2 PROMs with a self timed write cycle that includes latched address and data buffers. By producing parts with these features in production quantities, Xicor has set the industry standard for E^2 PROMs.

Technology

These E^2PROMs employ the same triple poly n-channel process which Xicor developed previously for NOVRAMs. With this technology, data is stored as the presence or absence of charge on a piece of second-level polysilicon which acts as a gate for a readout transistor. This piece of polysilicon is completely surrounded by ~ 1000 Å of thermally grown SiO_2, one of the best electrical insulators known. Charge is transferred onto and off of the storage gate by means of a quantum mechanical phenomenon, called Fowler-Nordheim tunneling. This phenomenon has been described in detail in recent publications.[1-3]

The operation of the cell can be explained in terms of the schematic diagram shown in Figure 6. First consider the left-hand read section. When the word select line (which is fabricated in third level polysilicon) is de-selected (i.e., low), the READ transistor is off. When the word select line is selected (i.e., high), conduction through the READ transistor depends on the charge on the floating storage gate. If the floating gate is charged negatively, the channel beneath it is in accumulation and no conduction occurs. This is read as a "0". If the floating gate is charged positively, the channel beneath it is in depletion and the channel conducts. This is read as a "1". The floating gate is programmed (i.e., charged negatively) by taking the Word Select line and source lines high while the poly 1 WRITE BIT line is held low. The floating gate is erased (i.e., charged positively) by taking the word select line high while holding both the source and WRITE BIT lines low.

As was explained in an earlier publication, tunnel current emitted from a textured surface inherently decreases more rapidly with decreasing voltage than does emission through thin oxide grown on a planar surface.[3] This results in lower leakage currents from the floating gate during storage and during the read operation of the part. The excellent data retention which users may expect from Xicor E^2PROMs is shown in Figure 7 where the log of the measured data loss rate is plotted vs. inverse temperature. The slope of a straight line passing through these data gives the thermal activation energy for intrinsic data loss in Xicor's technology: 1.7 eV. Extrapolation of this line to lower temperatures suggests that the mean time before data loss should be 3,000,000 years at 125°C. Such extrapolations cannot be taken literally but clearly show that data will be retained as long as anyone cares for temperatures within the specified storage conditions.

Xicor's textured poly technology also yields E^2PROMs whose ability to be re-programmed (usually called "endurance") is good. Figure 8 shows the current conducted by a typical cell as a function of the number of times that cell had been programmed to a "0" or erased to a "1". As can be seen, the current conducted in the erased state begins declining noticeably at greater than a million cycles of data change, but after ten million cycles, the cell current in the erased state is still about 70 µA while the current in the programmed state is zero. These values provide good margin to the 50 µA value which is the nominal value at which the sense amplifier circuit distinguishes between "1" and "0".

Reliability Study and Results

As was mentioned above, Xicor's E^2PROMs use the same process technology and design techniques as the Xicor family of NOVRAMs. Additionally, these products are fabricated in the same wafer fab facility and assembled in the same assembly area with the same assembly technology and controls as the NOVRAMs. For these reasons, the E^2PROMs should be expected to exhibit the same excellent long term reliability already demonstrated by Xicor's NOVRAMs. The reliability studies reported here were designed to corroborate this assumption.

One further note is that the X2804A is a smaller version of the X2816A, created by designing a mask set which is just like the X2816A except that 3/4 of the array and two address buffers are removed (i.e., the X2804A is not a fallout die from the X2816A production). Thus, the reliability study focused on the X2816A as the more sensitive reliability indicator since it has four times as many memory bits and about twice the active silicon area.

Since the study illustrated in Figure 7 showed a strong acceleration in data loss at elevated temperatures, data retention was measured at 250°C. (For an activation energy of 1.7 eV, data loss at 250°C is accelerated 1.4×10^5 times with respect to 125°C.) Table 1 shows the results of data retention testing on two lots of material which was not intentionally cycled and on two lots after 10,000 program/erase cycles. Although the sample is small, in neither case was any data loss observed, which corroborates the results of Figure 7.

Two other types of stress tests which were conducted on the X2816A were high temperature reverse bias (HTRB) at 150°C and dynamic life test at

125°C. The bias and timing diagrams used for these stress tests are schematically illustrated in Figure 9 and 10. Tables II and III exhibit the results for the HTRB and dynamic life tests, respectively. As these results show, no failures were observed in these tests for HTRB, and three units failed in 890,000 device hours of 125°C dynamic life test.

The failure rate of the 2816 was estimated based on the data in Tables II and III. The method used is that discussed in some detail in RR502. The results, shown in Table IV, predict an expected failure rate of 15 F.I.T. (.0015%/1000 hr.) at 70°C and 3 F.I.T. (.00032%/1000 hr.) at 55°C. The extrapolated value for the 60% UCL of the failure rates are 260 F.I.T. (.026%/1000 hr.) and 140 F.I.T. (.014%/1000 hr) at 70°C and 55°C ambient, respectively. The large difference between expected failure rate and 60% confidence level for the failure rate are an indication of the enormous number of device hours necessary to confirm the low failure rates observed.

Summary

The technology used in producing the Xicor X2816A and X2804A are reviewed. The reasons for expecting excellent data retention and good endurance are discussed. Finally, data are shown which confirm that these E^2PROMs share the excellent long-term reliability already demonstrated by Xicor's NOVRAM family.

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Table I

250°C RETENTION BAKE

	48 HOUR		168 HOUR		500 HOUR		1000 HOUR		2000 HOUR		TOTAL HOURS
	#FAIL	#IN	#FAIL	#IN	#FAIL	#IN	#FAIL	#IN	#FAIL	#IN	
Lot #1	0	50	0	50	0	50	0	50	0	50	97600
Lot #2 (Cycled)	0	24	0	24	0	24	0	24	0	24	46848
Lot #3	0	20	0	20	0	20	0	20	0	20	39040
Lot #4 (Cycled)	0	55	0	55	0	55	0	55	0	55	1.1×10^5
TOTALS	0	149	0	149	0	149	0	149	0	149	2.9×10^5

Table II

STRESS 5.5V HTRB AT 150°C

	48 HOUR		168 HOUR		500 HOUR		1000 HOUR		TOTAL HOURS
	#FAIL	#IN	#FAIL	#IN	#FAIL	#IN	#FAIL	#IN	
Lot #1	0	25	0	25	0	25	0	25	23800
Lot #2	0	25	0	25	0	25	0	25	23800
Lot #3	0	105	0	105	0	105	0	104	99460
Lot #4	0	25	0	25	0	25	0	25	23800
TOTALS	0	180	0	180	0	180	0	179	1.7×10^5

Table III

DYNAMIC LIFE TEST AT 125°C

	168 HOUR		500 HOUR		1000 HOUR		2000 HOUR		TOTAL HOURS
	#FAIL	#IN	#FAIL	#IN	#FAIL	#IN	#FAIL	#IN	
Lot #1	0	159	0	84	0	84	0	84	1.7×10^5
Lot #2	0	152	0	93	0	93	1[a]	93	1.9×10^5
Lot #3	0	75	0	75	0	75	0	75	1.5×10^5
Lot #4	0	388	0	99	1[c]	99	0	98	1.3×10^5
Lot #5	1[b]	387	0	126	0	126	-	-	1.5×10^5
TOTALS	1	1161	0	477	1	477	1	350	8.9×10^5

a = column failure; ionic contamination;1 eV
b = stuck row; ionic contamination; 1 eV
c = single bit retention failure; non-repeatable ionic contamination; 1 eV

Table IV

Activation Energy (eV)	Hours at 125°C	Hours at 150°C	Number of Failures	Equivalent Hours at 70°C	Expected Value of Failure Rate at 70°C	60% UCL Failure Rate at 70°C	Equivalent Hours at 55°C	Expected Value of Failure Rate at 55°C	60% UCL Failure Rate at 55°C
.3	8.9×10^5	1.7×10^5	0	4.78×10^6	0%/1000	.0195%/1000	7.60×10^6	0%/1000hr	.012/1000hr
.6	8.9×10^5	1.7×10^5	0	2.26×10^7	0%/1000	.0041%/1000	5.73×10^7	0%/1000	.0016/1000hr
1.0	8.9×10^5	1.7×10^5	3	1.97×10^8	.0015%/1000	.0021%/1000	9.29×10^8	.00032%/1000	.00044/1000hr
TOTAL			3		.0015%/1000	.0257%1000hr		.00032%/1000	.014%/1000hr

Figure 1

E^2PROM pin assignments

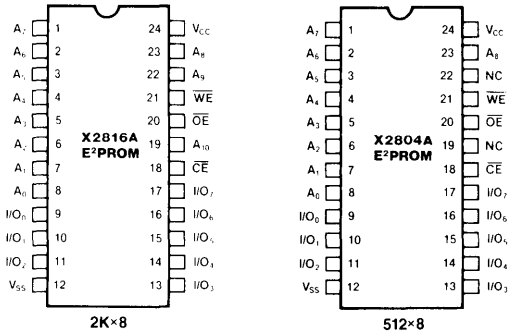

Figure 2

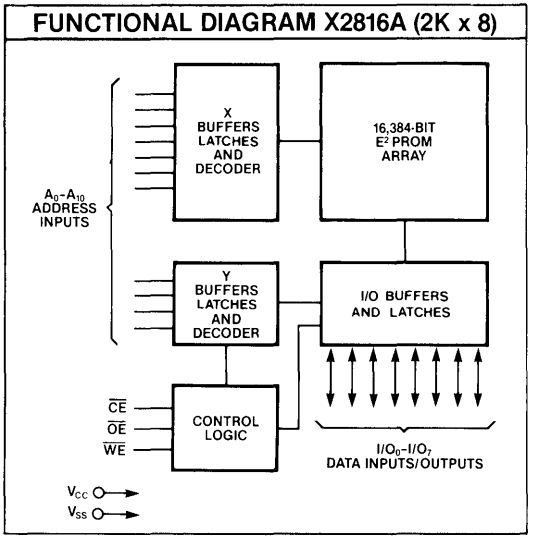

Figure 3

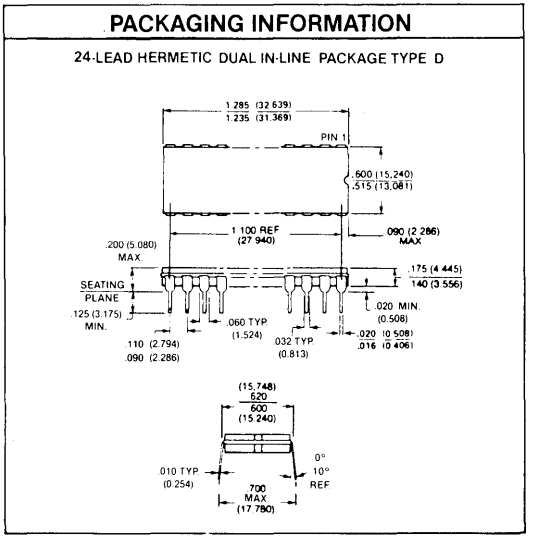

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Figure 4: X2804A physical bit map. The arrangement of bits within each byte are displayed for column Ø and suppressed for the other columns in which the arrangement of column Ø is duplicated.

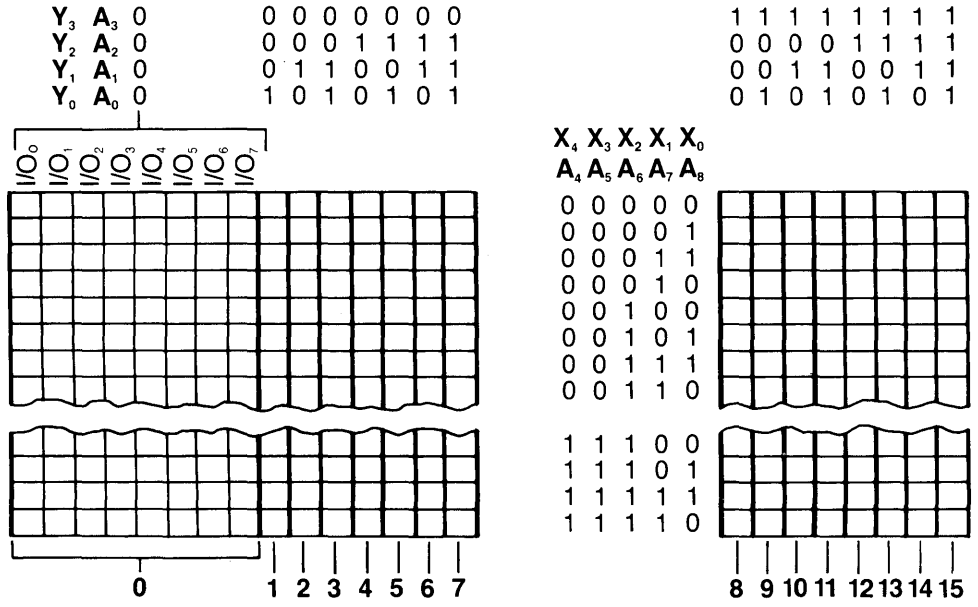


Figure 5: X2816A physical bit map. The arrangement of bits within each byte are displayed for column Ø and suppressed for the other columns.

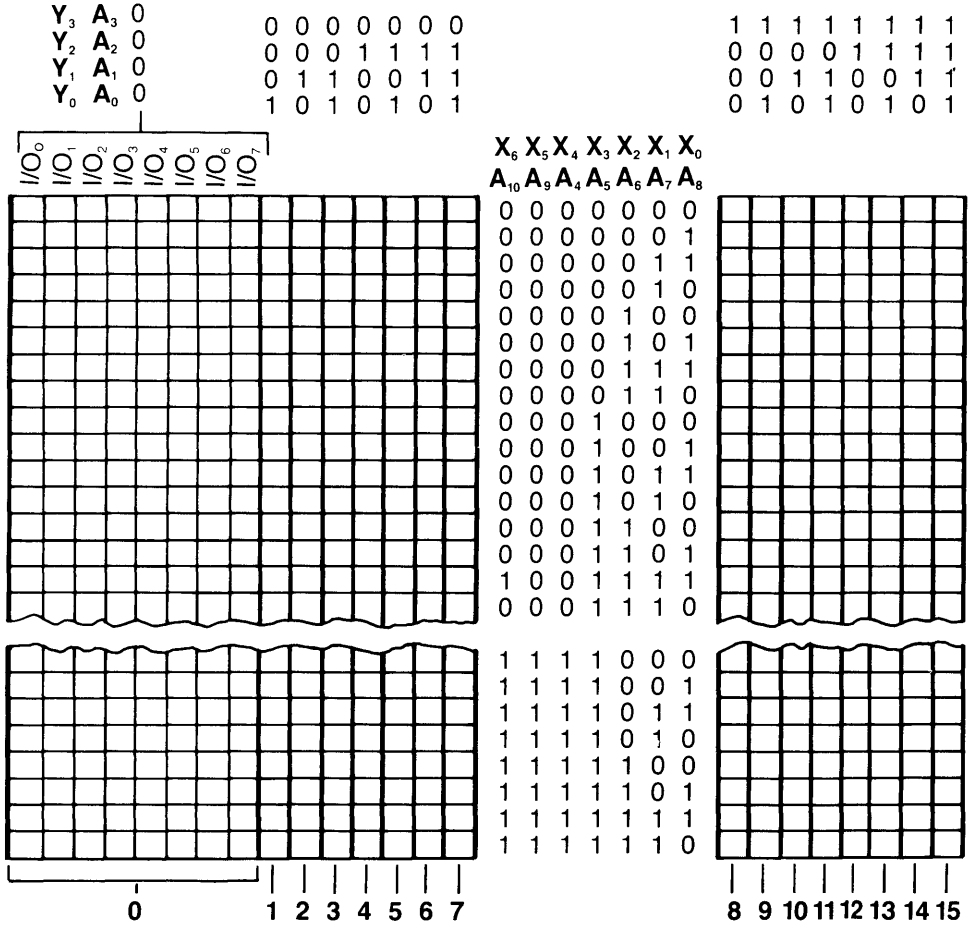


Figure 6: E^2 cell schematic

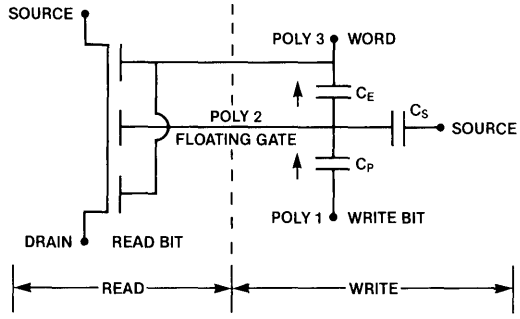


Figure 7: Data retention vs. temperature for memory arrays fabricated with XICOR's technology

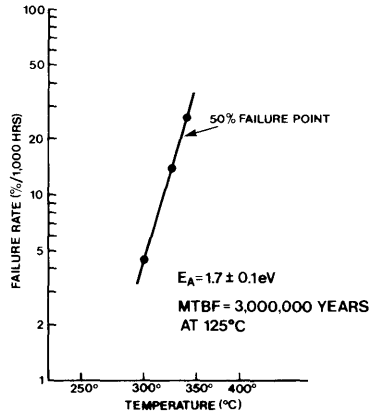


Figure 8: E^2 cell endurance data for a typical cell

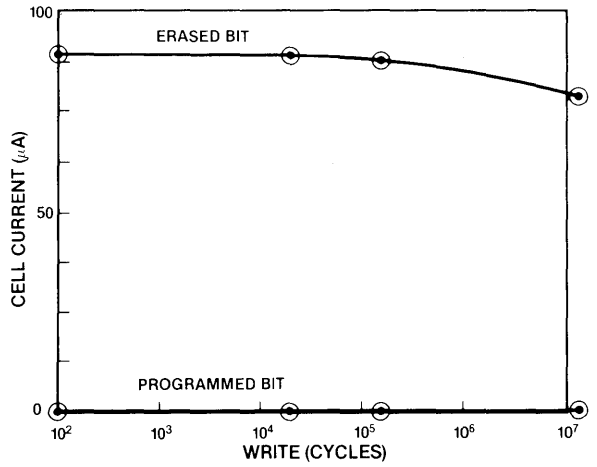
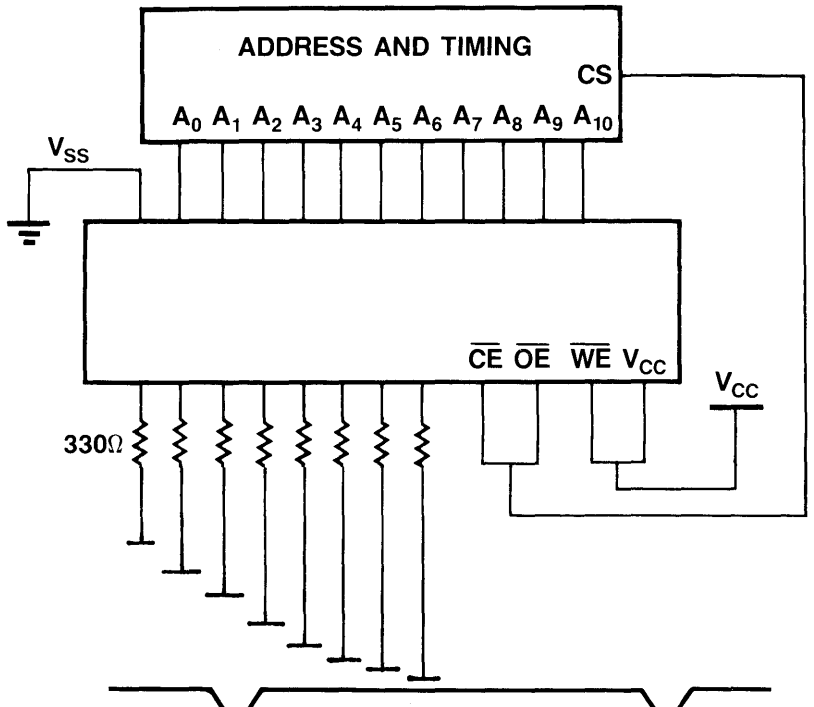


Figure 9: Dynamic life test set-up showing the circuit configuration (a) and the timing (b). The clock frequencies of higher order address signals are divided down in binary sequence from A_0.

a.



b.

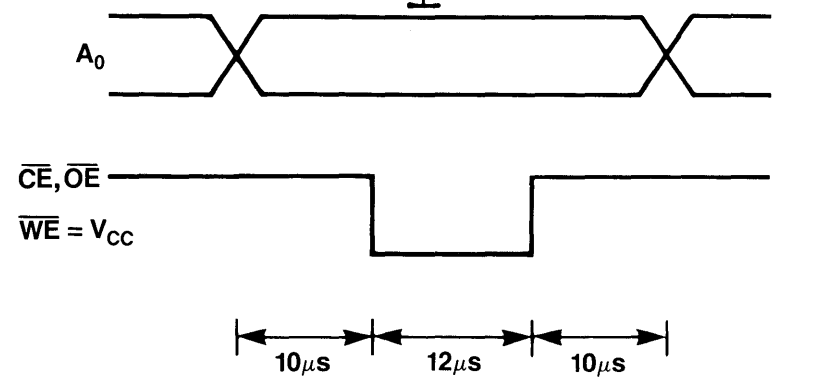
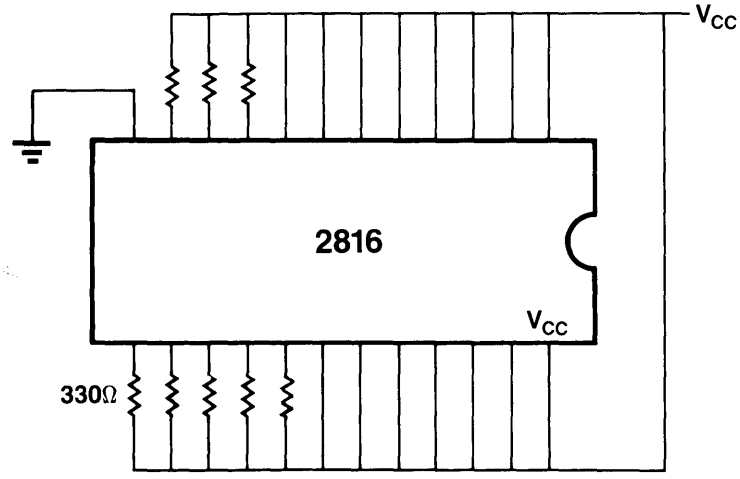
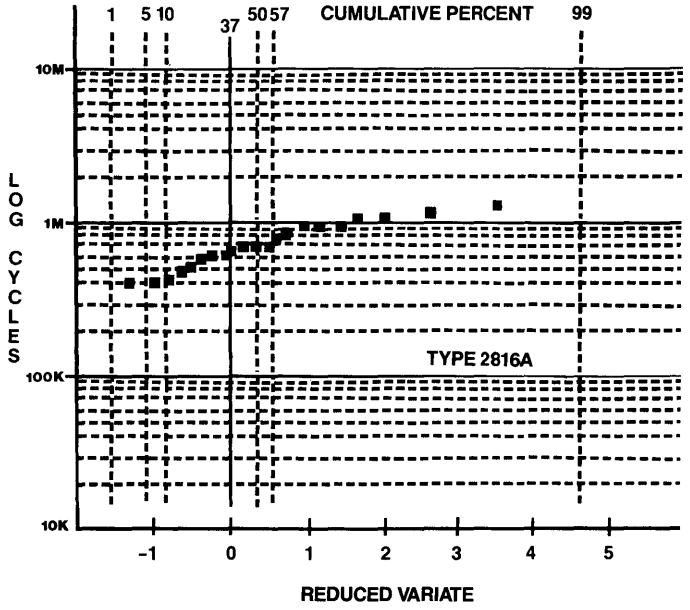


Figure 10: Static life test bias diagram





ENDURANCE OF XICOR E²PROMS AND NOVRAMS*

DR. H.A.R. WEGENER

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*NOVRAM is Xicor's designation for its nonvolatile RAM memory

This report is based on data collected through February, 1984.

Cover Photo: Figure 6. Endurance data from a lot of Xicor X2816A E^2PROMs.

INTRODUCTION

Endurance is a property unique to nonvolatile memories. It describes the ability of the nonvolatile memory section of the chip to sustain repeated data changes without failure. Such a data change occurs when a stored "1" is changed into a "0", or when a stored "0" is changed into a "1". Continual changes from "1" to "0" to "1" to "0" are called write-erase cycling, or just cycling.

In this work, endurance will first be defined. A quantitative method for characterizing endurance is described and applied to the characterization of endurance as a function of temperature and time between store events. Data on the endurance of a selection of Xicor's products is presented. Finally, the application of this information to the calculation of system failure rates is described. A general problem in discussions of endurance is that various people mean different things when they speak of endurance. One meaning which has been used is that endurance is the number of nonvolatile data changes to a "typical" cell before the cell dielectric fails or the programming window closes. Figure 1 shows such data for a typical Xicor E^2PROM cell showing that after greater than 10^7 data changes the cell still has good margin with respect to the 50 μA trip point of our sense amplifier. Many other suppliers have presented similar data. Unfortunately this data is of little help to the user who doesn't buy one "typical" cell, but rather an array containing a large number of cells, some of which will not be typical.

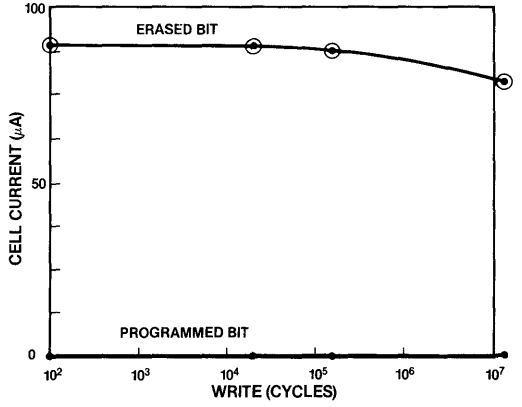

Figure 1. E^2PROM cell current vs. write/erase cycles. 50 μA is the trip point of the cell.

Xicor's definition of the endurance of an individual memory is that the limit of endurance is reached when, under conditions specified by the data sheet for normal operation, the first bit on any chip is found to be in error after a required data change. This limit of endurance, or endurance for short, is expressed in terms of cycles. By this definition then, endurance (in cycles) is the number of data changes per bit that occurred without error before the first failure took place.

When a nonvolatile memory chip is operating within a given application, it can be expected that some bits on that chip will experience more data changes than other bits, unless particular attention has been paid to even out their use throughout the chip. Within a given chip the endurances of individual bits have a small range of values, and it is pure chance whether a highly cycled bit has an endurance on the high end or the low end of that distribution.

Xicor's approach to this problem is that the lowest, the worst case endurance on any given cell in the array, defines the endurance of that chip. In order to test for the bit that causes the worst case endurance, each bit on that chip must be subjected to the same number of data changes during cycling. When the first bit on that chip fails, all other bits have been cycled without failure at least the same number of times. While these other bits may have much higher endurance limits, the endurance of the chip under test is defined as that of the one worst case bit.

Knowledge of the statistical distribution of the worst case bit from each of thousands of devices makes the endurance of a given chip statistically predictable. We have found that our endurance data fit a known statistical distribution — it is the logarithmic "Extreme Value" distribution. Its properties, and the handling of cycling data to derive its parameters for a given lot, are described in Appendix A.

The Measurement of Endurance

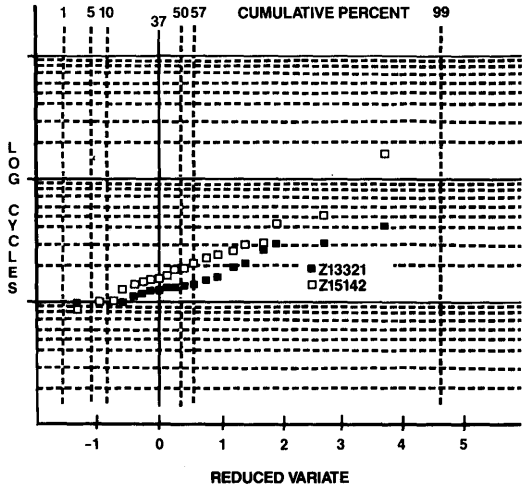

Figure 2. Typical endurance plots of two lots of Xicor X2212 NOVRAMs. The upper horizontal axis gives the cumulative percent of failures.

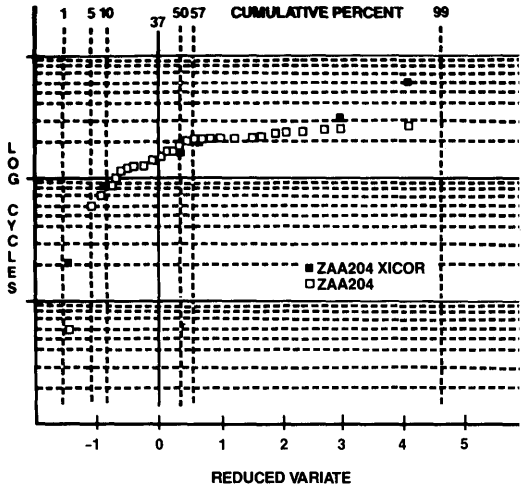

Figure 3. Correlation between endurance data obtained by Xicor and by one of Xicor's customers for Lot ZAA204. Each test is based on 28 data points. Most of Xicor's points are coincident with the customer's so that they are hidden.

The graph in Figure 2 shows the plots of endurances of two different lots of Xicor's X2212 NOVRAMs. This graph is an example of endurance plotted using an extreme value distribution. The meaning of the lower horizontal axis, the linear extreme value variate, is explained in Appendix A. The upper horizontal axis, however, has intuitive appeal. It is the cumulative failure percentage. The plots are well distributed around a straight line. This indicates that they originate from an Extreme Value distribution. They differ somewhat in slope (which is the measure of spread, or dispersion of the distribution). They are also offset in the vertical direction, which indicates that the maximum of each distribution is different. Since the cycles are plotted as their logarithms, this difference is about 40%.

Implicit in this discussion is the assumption that the endurance performance of lots can be described as the result of a relatively small sample. This has been proven correct experimentally and has been used to establish correlation between different pieces of equipment used for the determination of endurance. A successful application of this is shown in Figure 3.

The graph in Figure 3 shows the outcome of an endurance correlation exercise between Xicor and one of its customers. The first set of points (black squares) was established from a 30-device sample of X2212s from lot ZAA204 cycled out at Xicor. Overlying most of these original points are a second set (open squares) which were generated by endurance measurements on a separate 30-device sample from the same lot at the facility of the customer. It can be seen that the signatures of the two samples match faithfully, except at both extremes. At the left hand side, the difference can be explained by the increased scatter of any distribution at its extremes. At the right hand side, a slight difference was introduced when the customer stopped cycling before the last three devices had failed. Even if it is assumed that the match would not have improved by further cycling, the agreement for 27 out of 30 points, or between 5% and 95% of the sample, is excellent.

ENDURANCE VARIABLES

The existence of an inherent limit to endurance is a universal property of nonvolatile semiconductor memories. Regardless of the materials used and of the details of the cell design or the semiconductor manufacturer, there is a measurable upper limit to the number of data changes that such a memory cell can sustain and still meet the data retention specification. The exact number of cycles, however, is dependent on all the elements that go into the construction and operation of a given cell design.

The reason for an endurance limit arises from the basic physics of nonvolatile semiconductor memories. All such memories depend on the highly nonlinear conduction properties of the solid-state dielectrics employed to form the memory cells. At high electric fields, these dielectrics permit a predictable current to pass from one electrode to another. This is used to program or erase such a device. At low electric fields, essentially no electron is transmitted. Therefore charges transferred at high fields to locations isolated by this type of dielectric will remain there indefinitely. But during the transfer of charge at high fields, a very small fraction of the electrons passing through becomes trapped in the dielectric. The many thousands of times that this happens during the life of a memory contribute more and more trapped charge, creating an electric retarding potential in the dielectric, until the device cannot function as a memory any more. Then its endurance limit is reached.

The nonvolatile cells used in Xicor memories make use of the special characteristics of its microtextured surface. The many tiny regions of gently curved features are particularly effective as non-linear conduction elements. As a result of the combination of surface curvature and thick oxide, they require relatively low voltages for programming, and provide excellent retention of data. The physics of the programming process as well as the excellent data retention measured for Xicor memories have been described in a recent publication.[1]

If all these features were identical, if the thickness of the dielectric over them were the same, and if the details of the high voltage generator on the chip were precisely reproducible, then every device on the same silicon wafer, and in the same manufacturing lot would have identical endurance limits. In the real world, there are small variations in the results of the intricate fabrication steps of the silicon chip. These give rise to a range of endurance values for all the nonvolatile memory cells on the same chip. Additional small variations will occur from chip to chip over the whole silicon wafer, and from wafer to wafer. All of these define the details of the distribution that describes the endurances of all the memory cells in a device lot. Once the chips have been fabricated, the average and the dispersion of this distribution have been fixed by the interaction of cell design and the fabrication process with its small variations. These are the fixed internal parameters of endurance. The dispersion is an indicator of the process variation.

There are, however, variations that can be superimposed on the fixed characteristics by the conditions that accompany the normal use of the nonvolatile memory devices. The temperature of operation is one of these. Both the details of the charge transfer process in the nonvolatile memory cell, and the operation of the high voltage generating circuit should be affected in some way by this condition. Another externally controlled parameter is the frequency of the cycling process. At the end of a storage cycle the newly trapped electrons are in a relatively high free energy state. Longer periods between cycles give these charges and their environment more time to relax into a lower energy state. This should also affect the measured endurance parameters.

The control of these external parameters is essential when exact correlation of endurance data must be obtained. Their knowledge is also important to optimize performance and predict reliability in any application.

The Effect of Temperature on Endurance

The endurance of a lot of nonvolatile memories can be described concisely by the constants defining its statistical distribution. For the simple "Extreme Value" distribution pertinent here, these constants are its mode and its dispersion. This distribution can be used to assist in the characterization of endurance.

Five 20-device samples from the same lot of X2212 NOVRAMs were subjected to continuous data changes, each at a different temperature, until all devices had failed. The temperature levels were -55° C, -10° C, +25° C, +70° C, and +125° C. The delay between data changes for all devices was one second. The endurances of individual devices were plotted in the form of a probability plot, as shown in Figure 4.

[1]XICOR Reliability Report RR502.

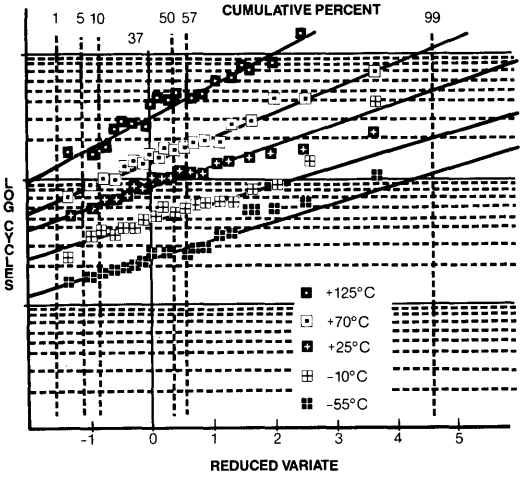

Figure 4. The effect of temperature on endurance: the endurance doubles for every increase in temperature by 50° C.

The y-axis gives the logarithm of the number of cycles that each unit had at the end of its endurance. The straight lines shown were least-squares fitted to each set of data. The correlation coefficients for lines ranged from 97% to 99%. The results can be summarized as follows:

1) There is an increase in the endurance with increasing temperature.

2) The dispersion is essentially constant at and below room temperature and increases somewhat above room temperature.

Over the range of the data, the logarithm of the endurance is linearly related with temperature. The coefficient is 0.0062/° C, but as a simple rule, the endurance doubles for every increase of temperature by 50° C.

The Effect of Data Change Delay on Endurance

The baseline values of endurance can also be modified by the length of the delay between consecutive data changes.

In the determination of the endurance of a lot there is a premium on getting the job done as rapidly as possible. This means that only minimum delays can be added between STORE signals. Typically, the devices in a lot of our current NOVRAMs have endurances between 10,000 and 100,000 cycles. The time to cycle a lot of devices will be 3 hours if the last device to fail had an endurance as low as 100,000 cycles for delays between data changes of 0.1 second even if all devices are cycled in parallel. This total cycling time increases to 28 hours for a delay of 1 second, to 12 days for a delay of 10 seconds, and 120 days for a delay of 100 seconds. Even a 1000 second delay is at the low end of the type of write frequency to be expected in most applications, and this would take in excess of three years to document. For this reason we have limited the experimental work on the effect on lot endurances to delays of 0.1, 1, 10, and 100 seconds. The shortest delay could not be reduced much below 100ms, since that is the time required by the microprocessor which was used in the test to handle addressing, reading and recording data of the many devices tested simultaneously.

Four 20-device samples were taken from the same lot of X2212 NOVRAMs and then they were cycled until all devices had failed. The endurance of each device was recorded. Each of the four samples had one of the four different data change delays in its cycling program. The data are summarized in Figure 5. Individual data points were not recorded on this graph, since there was much confusing overlap where the data point from the samples overlay each other. Instead, the points were replaced with least-squares fitted straight lines. The correlation coefficients for these lines were between 97 and 99%.

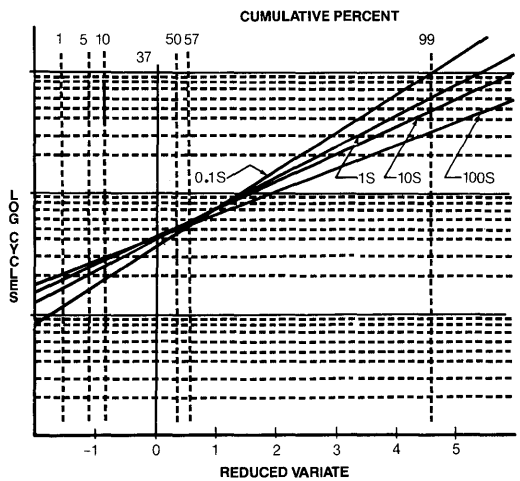

Figure 5. The effect of data change delay on endurance: the maximum of the distribution is unchanged, but it becomes tighter as the delay increases.

The results can be best expressed in terms of the constants of the distributions obtained:

1) The mode of the distribution did not change for the four orders of magnitude of delay tested. This is shown by the fact that the individual lines cross near 37% of the cumulative frequency.

2) The slope of the distribution decreased 15% per decade of cycles with each order of increase in delay. At first sight, this might appear to be a small change. But in the terms of the definition of endurance, they are quite important for many applications. This is because the endurance change in the region where the majority of the units have failed is irrelevant. The important region is that in which only a few per cent or less have failed. In this region, the effect of the longer time between store events at a constant endurance level is to decrease the fraction failing by an order of magnitude or more!

Endurance Status of XICOR Memories

Figure 4 and 5 lack vertical scales because they are intended to show general tendencies. The actual endurance observed on Xicor memories vary from product to product because of differences in cell design and to a lesser amount from lot to lot because of small processing variations. There is also a general tendency for the endurance to improve with time as a result of refinements in design and processing technique.

To give the user a sense of the status of endurance of Xicor memories as of the date of this report, distribution measurements for several product types are reported here. All of this data was measured at 25° C and rapid cycling rates. Figure 6 shows the endurance data measured on a lot of X2816As. The process average for this lot is about 500,000 cycles with the 5% point on the curve appearing at 200,000 cycles. In Figure 7 the measured endurance distribution of a lot of X2443s (a 256 bit serial NOVRAM) is displayed. For this device the process average was ~ 80,000 cycles and the 5% point appears at 30,000 cycles. The measured endurance distribution of a lot of X2212s is shown in Figure 8. This product exhibits a process average of about 100,000 cycles and the 5% point appears at 40,000 cycles.

The data reported here are intended as a status report. As we further refine our products and increase the endurance, we intend to issue updates to this report.

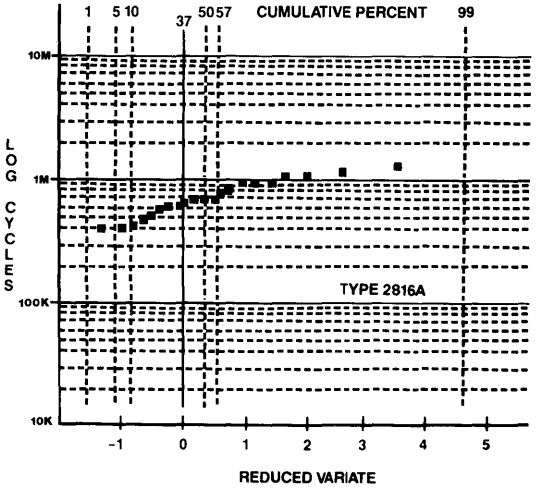

Figure 6. Endurance data from a lot of Xicor X2816A E^2PROMs.

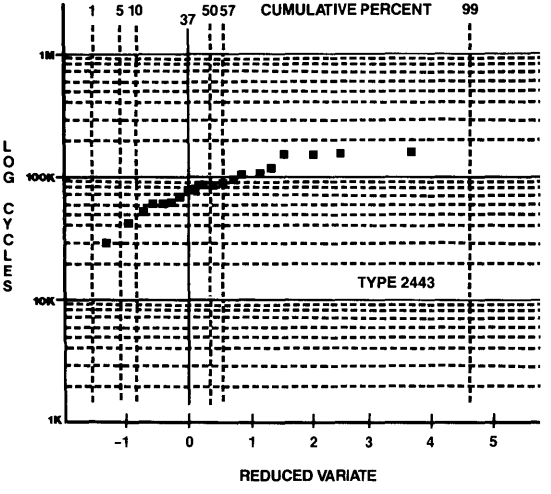

Figure 7. Endurance data from a lot of Xicor X2443 Serial NOVRAMs.

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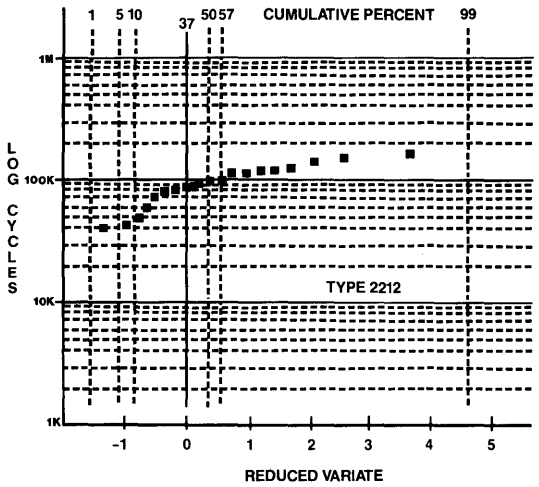

Figure 8. Endurance data from a lot of Xicor X2212 NOVRAMs.

QUALITY ASSURANCE APPLICATIONS

One problem any supplier of nonvolatile memory faces is how to define endurance and how to assure that the parts reaching the customer actually satisfy the endurance specification. This task is akin to assuring the lifetime of a light bulb. If the light bulb is specified to have a 1000 hour life, one can verify that the bulb lasts 1000 hours by burning it for that period. However, one now knows only that the bulb lasted 1000 hours, not that it will last another 1000 hours. The statistical technique discussed in this report allows Xicor to perform this difficult and exacting task. What a Xicor endurance specification means is that for any lot of memories shipped, fewer than 5% of the units will cease to cycle before the specified limit when cycled at room temperature and at the maximum frequency allowed by the specification. Xicor continually samples production lots to assure that this criterion is met.

Let's look at what this means in a typical application. Assume that the Xicor memory is used in an electronic system which contains a number of other components so that the average chip temperature is 50°C and that the average delay between store events is some minutes. Examination of Figure 3 shows that raising the chip temperature from 25°C to 50°C would decrease the fraction of units not exceeding the endurance value from 5% to 0.03%. For data change delays of 100 seconds and longer, the fraction of the lot not meeting the nominal endurance value further decreases to 0.001% or less.

Of course, in a given application the predicted behavior may be better or worse than that worked out in the example described above. However, the information supplied here should be sufficient for the user to compute the expected endurance failure rate in a particular application.

One last consideration is how endurance failures affect the overall device failure rate. Here again, the calculation is a little application-sensitive, but for simplicity assume that the system is designed to last 10^5 hours (~12 years) and that the device performs nonvolatile writes roughly uniformly over this period. If the application is designed to use the specified number of cycles over the life of the part, the additional endurance-related failure rate is the cumulative failed fraction divided by the time. For our previous example, this works out to $0.001\%/10^5$ hours or $10^{-5}\%/1000$ hours (0.1 FIT). As this illustrates, in most well-designed systems the endurance-related failures of Xicor product do not significantly increase the overall device failure rate.

In all discussions of endurance in this work NOVRAMs and E^2PROMs have been treated as if they behave the same. From a physical view of the nonvolatile storage element this is correct. However, there are two properties of the NOVRAM cell which may cause it to have significantly enhanced endurance in certain applications. One factor is that the NOVRAM allows the user to store data in the volatile latch during normal operation and only transfer data to the nonvolatile element prior to power down. In applications which require a high frequency of data changes but only relatively infrequent power interruptions this may be very useful. A second, if less obvious factor, is that unlike the E^2PROMs which automatically erase each byte prior to each write, the NOVRAMs only transfer electrons in the case of a change in nonvolatile data. This means that only those cells in which nonvolatile data is altered use up endurance. In some applications this fact can be used to greatly increase effective endurance of the memory.

SUMMARY

A method of characterizing endurance which is of general applicability has been described here. This method has been applied to the characterization of endurance as a function of temperature and time between store events. The meaning of Xicor's endurance specification is defined in the framework of this method. Based on the above, the fraction of Xicor product which is predicted to fail to store prior to attaining the specified endurance is predicted to be less than 0.001% in a typical system in which the devices experience a 50°C ambient temperature.

APPENDIX A

The Mathematics of Endurance Characterization

The mathematical characterization of endurance data arises most elegantly from the definition of endurance. In an individual device, the endurance is the minimum number of data changes that all memory cells can sustain until one cell gives rise to an erroneous output (due to a permanent change in its characteristics). The extreme characteristic from a fixed set of possible values forms a well-known distribution called the Extreme Value distribution. This distribution is independent of the distribution within that fixed set of values. Since by definition, the endurance of a chip containing 1024 memory cells is that of the cell with the minimum endurance, it can be expected that the endurances of the chips from the same device type will have the Extreme value distribution.

The formulations of the Extreme Value distribution are given in Table A. On the left hand side are the entries for the Extreme Value distribution, and on the right hand side the corresponding entries for the Normal distribution.

STATISTIC	EXTREME VALUE	NORMAL DISTRIBUTION
CUMULATIVE PROBABILITY	$\Phi_{EV} = EXP(-EXP(-Y))$	$\Phi_N = \int_{-\infty}^{Z} (2)^{-1/2} EXP(-T^2/2)\, \delta T$
VARIATE	$Y = \alpha (X-U)$	$Z = (X-M)/\sigma$
MAXIMUM	U at $\Phi = 0.37$	M at $\Phi = 0.50$
DISPERSION	$1/\alpha$	σ

Table A. MATHEMATICAL DEFINITIONS

The cumulative probability Φ is defined by a fraction of 1. It defines, towards one side of a distribution, the fraction of the population Φ that has a smaller value than the variate at that fraction, and towards the other side, the complement of that fraction which has a larger value than the variate at that fraction. This is quite often expressed as "fraction with more than..." or "fraction with less than...". It can be seen that the cumulative probability of the Extreme Value distribution Φ_{EV} has a much simpler functional relationship with its variate Y than the equivalent Φ_N with its variate Z of the Normal distribution. The Extreme Value variate Y is related by two constants to the distributed property X. One constant is the maximum of the distribution U, and the other the dispersion $1/\alpha$. The Extreme Value distribution is not symmetrical around its maximum (as the Normal distribution is). Instead, one side is stretched out more than the other. If the low cumulative probability fraction is on the narrower end, the maximum of that distribution is located at the value of 0.366, or 37%.

This is typical of the distributions of low extremes, and this is the distribution used for endurance values from NOVRAM chips of the same device type. There is one more empirical observation: it is not the number of cycles, but the logarithm of the number of cyles that has the form of the Extreme Value distribution. The X in the expression for the variate then is the logarithm of the observed cycles of individual chip endurances, α is the dispersion of the distribution of these endurances, and U is the observed or interpolated value of the log of the endurance at $\Phi = 0.366$.

The extraction of these two constants from the data could be a complex calculational procedure, but by linearizing the variate Y, it becomes as simple as plotting a straight line. The approach is summarized in Table B.

$\Phi_i = EXP\ (-EXP\ -Y_i)$ $Y_i = \alpha\ (X_i - U)$ $= -LN\ (-LN\ \Phi_i)$
$X_i = U + (1/\alpha)\ (-LN\ (-LN\Phi_i))$ BUT $X_i = LOG\ CY_i$ $U = LOG\ CY_m$
$LOG\ CY_i = LOG\ CY_m + (1/\alpha)\ (LV)$ CY_i = endurance of part$_i$ CY_m = maximum of distribution $(1/\alpha)$ = slope of line $(LV) = (-LN\ (-LN\Phi_i))$

Table B. LINEARIZED PLOT

The first line states once more the cumulative probability relationship between Φ and Y, and the second line the linear relationship between Y and X. The third line shows that the value of Y can be calculated from the double natural logarithm of Φ. The fourth line expresses the second line as a function of X, and substitutes its functional relationship with Φ. Identification of X with the logarithm of an individual observation, and U with the logarithm of the maximum of the distribution of cycles then leads to the seventh line which states the desired linear relationship. A typical plot is shown in Figure 9. There is clearly a straight line relationship. The value of the maximum occurs at Φ = 37%, and the slope of the line is the value of $1/\alpha$.

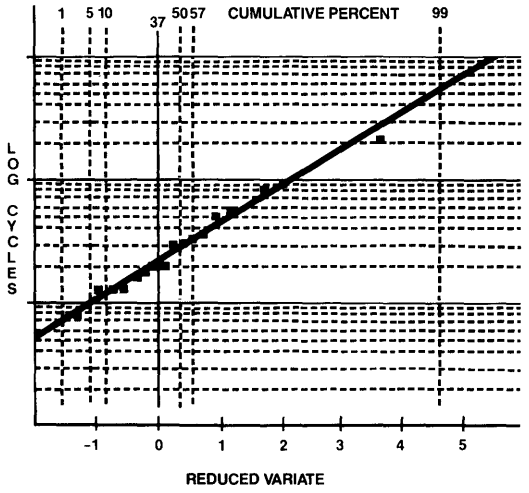

Figure 9. Straight line plot of the logarithm of endurance cycles vs. the reduced variate.

There remains one more problem, and that is how to associate the correct value of Φ with a given observed endurance. This is accomplished by taking all the endurances from a group of devices and writing them down in the order of increasing cycles (this is called "ranking"). Looking at the data in this way, any given endurance represents the borderline between a fraction of the lot that is higher than anything preceding it, and lower than anything following it. The approximate value of that fraction is found by assigning consecutive rank numbers to the ordered endurances: 1 to the lowest, 2 to the second lowest, and so on, until the highest endurance ends up with the rank equal to the total number of devices tested in that group. Dividing the rank numbers by the total number of the devices in the group then yields the "fraction lower than . . .". A slightly more exact value for Φ is found by the formula $\Phi = (i - 1/2)/N$, where i is the rank number and N the total number of devices tested.

RAW DATA (CY)	**RANKED DATA** (CY_i)	**RANK** (i)	**PLOTTING POSITION** (Φ_i=(i-.5)/n)
129.50	7.31	1	.025
35.95	12.10	2	.075
21.95	12.10	3	.125
7.31	12.10	4	.175
31.95	16.85	5	.225
19.65	19.65	6	.275
60.75	21.95	7	.325
33.95	22.45	8	.375
22.45	22.95	9	.425
85.75	31.45	10	.475
12.10	31.95	11	.525
22.95	33.95	12	.575
12.10	35.95	13	.625
79.25	48.25	14	.675
52.75	52.75	15	.725
209.50	60.75	16	.775
16.85	79.75	17	.825
12.10	85.75	18	.875
48.25	129.50	19	.925
31.45	290.50	20	.975
PLOT LOG (CY_i) vs. -LN(-LNΦ_i)			

Table C. DATA PREPARATION

DETERMINING SYSTEM RELIABILITY FROM E²PROM ENDURANCE DATA

By Richard Palm

Vol. 3, No. 20

Xicor has published numerous reliability reports regarding data retention and endurance; however, the relationship of this data to system reliability warrants further analysis and discussion. This paper will discuss two methods for determining the affect of endurance on system reliability. The first method will use actual data collected on the X2816A and the second method will use data collected on the X2864A.

Definition of Terms

Endurance - is the ability of a nonvolatile memory to sustain repeated data changes.

Endurance Failure (Level) - is the limit of endurance, expressed in number of write cycles, when the *first bit* of any memory device or memory system is found to be in error after a required data change.

Write Cycle - to reduce testing time Xicor uses a test method whereby the entire array of the device under test is written in a single write cycle. Therefore, all references to "write cycle" equate to every bit in the entire array (device or system array) being written.

Cumulative Failure (Probability) - the percentage of parts not expected to attain a particular goal; i.e., endurance level.

Note: all endurance data used in this report were collected at a cycling frequency of one cycle per 100ms and at +25°C.

Background

There are three reliability categories for nonvolatile memories: semiconductor, data retention and endurance.

- Semiconductor reliability pertains to several failure modes common to all semiconductor devices such as oxide rupture and micro-cracks.
- Data retention refers to the capability of a nonvolatile memory device to retain valid data under worst case conditions.
- Endurance is the ability of a nonvolatile memory device to sustain repeated data changes.

Xicor reliability reports, RR502A and RR504, detail these three categories for Xicor devices. Reliability is easily deduced for semiconductor failures and data retention. The affect of endurance on reliability is not so straightforward.

Because endurance screening is a destructive procedure, Xicor performs endurance life tests on a sample basis. The data collected from these tests are then plotted onto an extreme value distribution graph to determine the endurance distribution for a particular lot of devices.

Using the Extreme Value Distribution Data

Figure 1 is an extreme value distribution graph for twenty X2816A devices and Table 2 (located on the last page) is the raw data used to generate the straight line shown.

- In this sample lot the lowest ranked device (#1) exceeded 279,000 write cycles before the first bit failure occurred; however, the graph extends to the left to show that only ~ .01% of all devices from this manufacturing lot will fail before 200,000 cycles.
- The maximum of the extreme value distribution occurs at the 37% cumulative probability point (statistically, 37% of all devices will fail to reach this endurance level), indicating that the predicted most probable endurance of devices in this lot is 460,000 cycles.

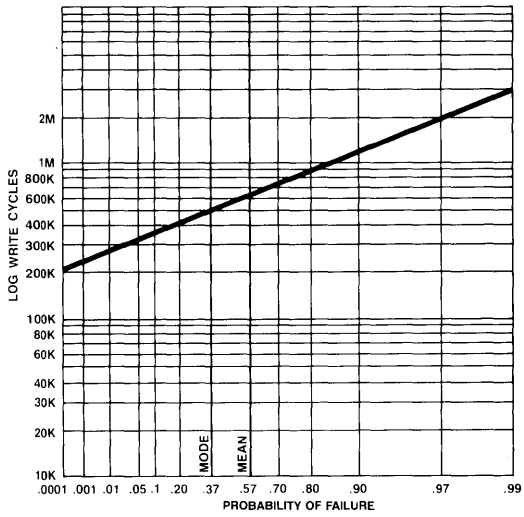

Figure 1: Extreme Value Distribution Graph for One Twenty Piece Lot of X2816As

Reliability data are generally stated in terms of percent failures per 1000 hrs. This can be easily derived from the extreme value graph in a two step procedure.

The system design parameters for this example are chosen as follows: the lifetime of the system is five years; and each X2816A will experience 250,000 write cycles over the lifetime of the system.

- The first step determines the failure rate per 1000 write cycles using the formula W = C/E where:

  W = failure rate in %/1000 write cycles

  E = endurance level chosen for the system (250,000 write cycles) divided by 1000.

  C = cumulative failure rate at E (in this case .5%).

  Therefore W = .5%/250 = .002%/1000 write cycles.

- Converting this to percent failures per 1000 hours requires H = W × A where:

  H = failure rate in %/1000 hrs.

  W = failure rate in %/1000 write cycles

  A = number of write cycles per hour. (i.e., 2.5×10^5 cycles/5 years)

In our case, H = .002 × 5.7 = .0114%/1000 hrs.

In the above example the entire X2816A is being rewritten at the rate of 5.7 times every hour. In some applications this could occur, but generally the frequency is much lower. Using the same graph and arbitrarily choosing the lowest cumulative failure rate depicted at 200,000 write cycles and performing the same calculations, the percent failures per 1000 hrs. drops dramatically.

W = .01/200 = .00005%/1000 write cycles

H = .00005 × 4.56 = .00022%/1000 hrs.

Predicting System Endurance Reliability Within Design Constraints

This next example is based on data collected on the X2864A. The system requirements for which the data were collected are defined as follows: the life expectancy of the system is ten years; the number of write cycles is 10,000. Therefore, Xicor cycled five lots of approximately three hundred devices each, for 10,000 write cycles. The data were collected by cycling the devices every 100ms at ~25°C. Table 1 summarizes the data collected.

LOT #	# OF UNITS	# OF FAILURES	% FAILURES
1	297	4	1.35
2	295	2	0.68
3	295	4	1.36
4	298	6	2.01
5	299	6	2.01
TOTAL	1484	22	1.48

Table 1: Raw Data From Cycling X2864A Devices 10,000 Times

The overall failure rate of devices unable to reach 10,000 write cycles is 1.48%. How does this relate to system reliability?

- The system is defined as having a life expectancy of ten years or 87.6×10^3 hours.

- The failure rate in percent per 1000 hours is determined by dividing the percent of parts unable to reach 10,000 write cycles by system's life expectancy in thousands of hours.

Therefore, reliability based on endurance for this system is:

1.5%/87.6 = 0.017%/1000 hrs.

Temperature

RR504 describes in detail the affect of temperature on endurance. In general, this report shows that for every 50°C rise in temperature the endurance rate doubles. The data collected for the above examples was taken at +25°C. Therefore, for systems operating at a more common +40°C the endurance will improve. Figure 2 illustrates the case for the X2816A.

- The line labeled +25°C is the same as that in Figure 1.
- The added line is for the predicted increase in endurance at +40°C.
- The cumulative failure rate at 250,000 write cycles moves from .5% to less than .01% and the endurance reliability increases as follows:
  W = .01%/250 = .00004%/1000 write cycles
  H = .00004% × 5.7 = .0002%/1000 hrs.

The failure rate for the X2864A sample lots can be expected to decrease by a factor of ~ 1.30, for the increase in operating temperature from +25°C to +40°C; yielding a failure rate of .013%/1000 hrs. vs. the unfactored .017%/1000 hrs.

Frequency of Writing

Xicor reliability report RR504 describes device operation and the affects of frequency of writing to a device. Figure 3 is a copy of a graph in RR504, depicting the relationship of write cycle frequency on the endurance of a Xicor nonvolatile memory.

There are two key relationships illustrated by the graph in Figure 3.

- As the frequency of writing decreases the slope of the plotted line, the extreme value, decreases.
- Although the most probable endurance (the 37% cumulative failure point) does not show appreciable change, the decreasing slope is significant in the region most concerned with predicting reliability, the .01% to 5% region (shaded area of Figure 3).

It is in this region that a system's reliability is determined. Arbitrarily choosing the .1% probability of failure point, Figure 3 shows:

- A write cycle frequency of 1 per 100 seconds increases the endurance level by a factor of 2 over a write cycle frequency of 1 per 100 milliseconds.

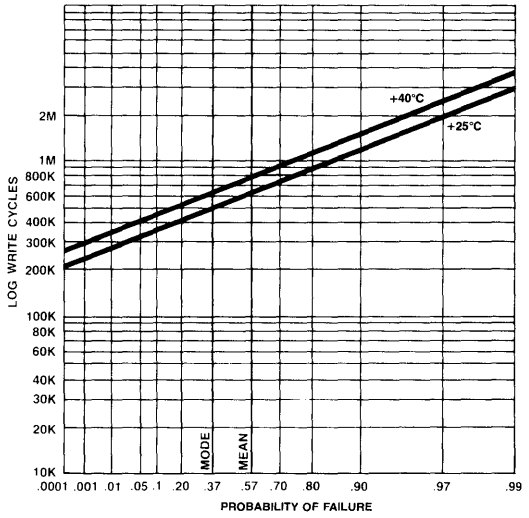

Figure 2: Affect of Ambient Temperature on Endurance

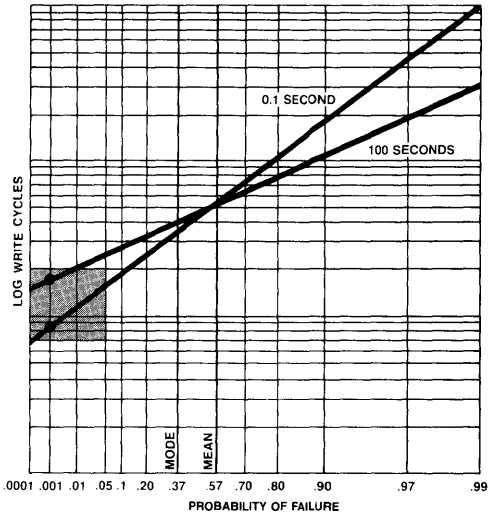

Figure 3: Affect of Write Cycle Frequency on Endurance

6

Conclusion

This paper has illustrated two methods for determining system reliability based on endurance. In the examples given, the failure rates due to endurance are well below industry standards for semiconductor failures.

Additionally, by factoring in the affects of both temperature and frequency of writing, the endurance failure rates for the X2816A system and X2864A system may be predicted specifically for the user's application.

DEVICE RANK	THOUSANDS OF WRITE CYCLES
1	297
2	315
3	355
4	365
5	400
6	410
7	450
8	450
9	510
10	572
11	620
12	620
13	650
14	680
15	800
16	820
17	940
18	952
19	992
20	1400

Table 2: Ranked Endurance Data for Twenty Pieces of X2816A Devices

RADIATION-INDUCED SOFT ERRORS AND FLOATING GATE MEMORIES

J.M. Caywood & B.L. Prickett

ABSTRACT

A new failure mechanism which may be induced in floating gate memories by ionizing radiation is discussed. This mechanism, which is designated a "firm error", is modeled in some detail. Calculations which show that the MTBF for alpha particles emitted by ceramic packaging materials is >100,000 years are verified experimentally. The effect of device scaling on this mechanism is also discussed.

INTRODUCTION

Ionizing radiation incident on floating gate nonvolatile memories can give rise to three types of observable effects. The radiation may induce damage in the peripheral circuitry (hard errors); it may cause upset of the sense/readout circuitry (soft errors); or it may cause data loss by transfer of charge from the floating gate. The first of these groups of effects is common to all MOS circuitry and has been investigated extensively over many years.[1] The second group of effects was first observed in dynamic RAMs and has since also been observed in static RAMs and microprocessors.[2-5]

The third effect, on which this paper will concentrate, is qualitatively different than the "soft errors" which are observed in volatile RAMs. In the soft error case, thermalized carriers are collected from relatively long (~10μm) distances in the Si substrate which can result in efficient collection of the charges generated by an alpha particle (~50%)[4]. In the case to be discussed here, the carriers collected on the floating gate may come from two sources. One source is carriers created by the ionizing radiation in the SiO_2 which lies between the floating gate and another electrode or the substrate when they are at a different potential. The second source is electrons excited in the floating gate which have enough kinetic energy to surmount the potential barrier between the conduction bands in Si and SiO_2. As will be developed in this paper, these effects are relatively inefficient (<1%). Unlike soft errors which are caused by a single ionizing particle, charge transfer to a floating gate is cumulative so that effects of many ionizing events occurring over an extended period of time must be considered.

To differentiate this phenomenon from soft errors which, if they occur in floating gate memories, are dependent upon the design of the readout circuitry and are temporary read errors which can be corrected by re-reading the floating gate, and from hard errors which render all or part of the memory inoperable, we shall call it "firm error". This firm error has the operational characteristics that it causes a read error which cannot be corrected by re-reading the floating gate, but it can be corrected by re-writing the cell or cells in question to provide a completely functional memory.

MODELING THE CHARGE TRANSFER

Figure 1a shows a typical cross-section through a floating gate memory structure where the + and − signs indicate that electron-hole pairs are created along the track. Figure 1b shows a potential diagram of the same structure. Clearly electron-hole pairs created in the oxides on both sides of the floating gates will drift apart and tend to discharge the gate. Similarly electrons injected from the floating gate into either oxide will discharge the gate. The problem can therefore be broken into that of computing the charge created in the oxide and that of estimating the charge injected from the Si into the oxide.

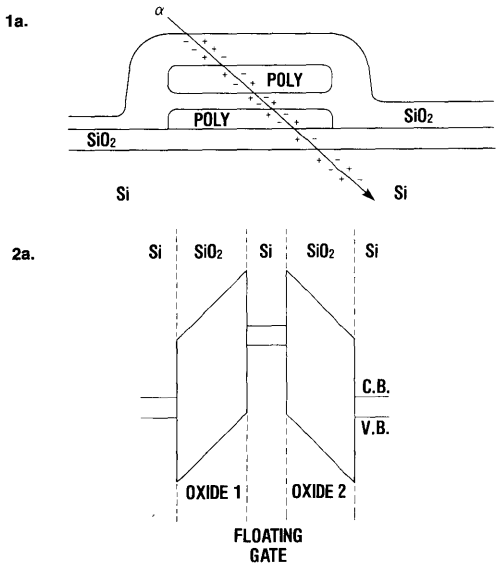

Figure 1: Cross section and potential diagram of a typical floating gate memory transistor; a) the cross section is cut through in the direction of current flow; b) the potential diagram is shown for the case that the floating gate is programmed and the access gate grounded.

INJECTION OF CHARGE FROM Si INTO SiO_2

Emission of excited electrons from Si into SiO_2 is a complex process. Some of the phenomena occurring are illustrated schematically in Figure 2. Hot electrons created by the ionizing particle may be scattered by acoustic or optical phonons, other electrons, or the surface itself. The requirement for electrons to reach the surface with sufficient crystal momentum, κ, normal to the surface to surmount the barrier ($\kappa_\perp^2/2m^* > \phi_B$ where $\kappa_\perp$ is the component of κ normal to the surface, m^* is the effective mass, and ϕ_B is the barrier height between the conduction bands in Si and SiO_2).[6] Phonon scattering may be considered to be elastic since the phonon energies are small with respect to the barrier height. However, an electron scattering off another electron may lose up to one-half of its kinetic energy. Hence, electron-electron scattering rapidly thermalizes hot electrons.[7] The escape length of electrons is long for energies near the fermi level but drops rapidly and forms a broad U between 20 Å and 5 Å over the energy range 10 eV to 1000 eV.[8] Escape depths of 25 Å and 12 Å are reported for electrons 5.8 eV and 11 eV above the valence band maximum, respectively.[9,10]

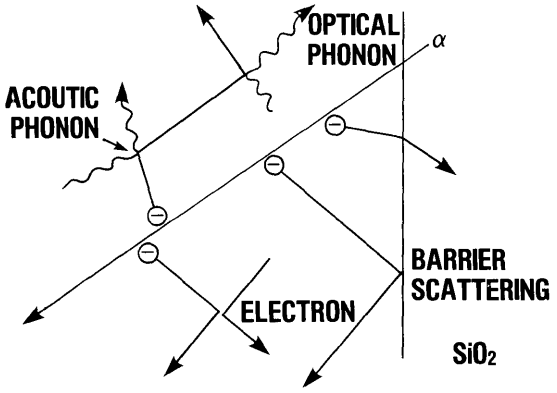

Figure 2: Schematic illustration of scattering process which contributes to small escape depth of electrons from Si.

The ideal situation would be to have electron yield curves as a function of energy for various charged particles of interest incident upon a biased oxidized silicon surface. Unfortunately, we lack such a complete data base, so we shall estimate the yields from data on optically stimulated emission. Figure 3 shows energy distribution curves (EDCs) for three photon energies plotted versus the energy of the states from which the electrons are excited for photons incident on clean Si.[11] By integrating the EDCs and dividing by the incident photon energy, the yields in terms of electrons emitted per electron volt of incident photon energy are found to be 6.7 x 10^{-4}, 8.9 x 10^{-4}, and 8.7 x 10^{-4} for photons with energies of 8.6 eV, 10.2 eV, and 11.8 eV, respectively. For lower energy photons, the yields drop precipitously.[6] It is known that the optical absorption length, $1/\alpha$, in Si is 80 Å for 12 eV photons.[12] Moreover, the electron escape depth at 11 eV is 12 Å.[10] This implies that one factor limiting the yield is that most of the electrons generated within the bulk of the Si relax via electron-electron scattering. Thus an estimate that a charged particle yields 10^{-3} electrons for every electron-volt of energy lost within 80 Å of the surface is probably an upper bound for emission from silicon into a vacuum.

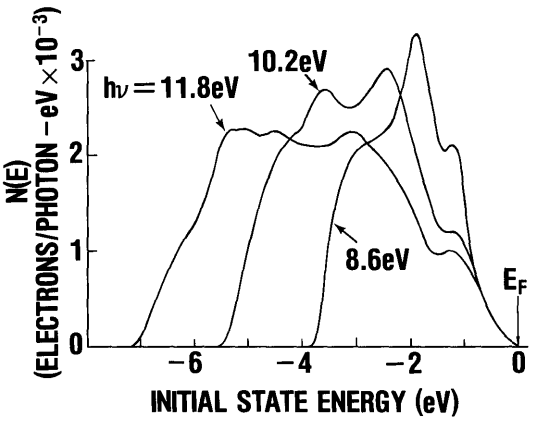

Figure 3: These energy distribution curves give electron yield vs. the energy of the initial state for photons incident on clean Si. (Data from Spicer, ref. 11).

Because the barrier between the conduction band in Si and the conduction band of SiO_2 is ~0.9 eV lower than that between the conduction band of silicon and the vacuum level, the yield in the Si/SiO_2 system should be higher than that estimated above.[6,13] The magnitude of the yield increase can be estimated two ways. Callcott measured the effect of applying 0.16 monolayer of Cs to a Si surface. He found that the vacuum barrier was lowered by 1 eV and the photon yield was increased by 2.6 times.[14] Another estimate comes from the observation that for 6 eV photons, Powell reports ~13 times higher quantum yield for the Si/SiO_2 system than does Broudy for the Si/vacuum system.[6,13] Since Powell applied a field of 3 x 10^6V/cm (~5x that present in a typical floating gate memory), the barrier between Si and SiO_2 was lowered by 0.45 eV. This implies that

the ratio of the Powell and Broudy results is clearly an overestimate of the yield enhancement. Based on these data, we shall use 10x as a generous estimate of the magnitude of the yield increase between the Si/SiO_2 system and the Si/vacuum system. Our estimate of the yield of electrons emitted over the Si/SiO_2 barrier as a result of an incident ionizing particle is 10^{-2} electrons for each eV of energy lost within 80 Å of the Si/SiO_2 interface.

COLLECTION OF CHARGE GENERATED IN THE SiO_2

The experimental evidence for collection of charge generated within SiO_2 is much more direct than for charge injected from the Si/SiO_2 interface. Measurements of Srour, Curtis, and Chiu show that the collection efficiency of electron-hole pairs generated by 4-5 keV electrons in SiO_2 varies from very low at low fields to ~20% at 5×10^5 V/cm to ~100% at 5×10^6 V/cm.[15] From calculations based on these measurements, Ausman and McLean have deduced that one electron pair is created for each 18 eV lost in the SiO_2.[16] Since typical fields occurring in floating gate memory devices during read or storage operations are 5×10^5 V/cm, we shall assume that one pair is created for each 18 eV of energy lost in the oxide and that 20% of the charges created are collected at the electrodes.

ENERGY DEPOSITED FROM IONIZING RADIATION

Ionizing radiation can be generally separated into that involving massless particles (X-ray, Gamma-rays, etc.) and those which have mass (mesons, electrons, protons, atomic ions, etc.). The absorption cross-sections of the massless particles are quite small and decrease with increasing energy. For example, the κ_α line of Mo occurring at 20.03 keV has a mass absorption coefficient of ~$4cm^2/g$.[17] This means that approximately 1mm of Si is required to absorb 63% of the energy of a Mo X-ray beam. Since the cross-section is proportional to the cube of the wavelength, high energy photons lose even less energy per unit of length traveled through a solid. Because of this, it is expected that large fluences of X-rays would be required to transfer significant charge from the gate of floating gate memory.

For particles with mass, the stopping cross-section varies in a systematic way. This is illustrated in Figure 4 where we have plotted calculated energy loss rates in silicon for particles of differing mass using the Bethe-Bloch formalism.[18] As can be seen, for each mass particle, there is a peak in the curve of stopping power vs. energy which shifts to higher energy and becomes larger as the particle mass increases. Because of the log-log nature of the plot shown in Figure 4, it implies that there will be a high density of carriers created at the end of the particle track. This feature is called the Bragg peak.

Since the charge generation rate is maximum for particles with energies in the neighborhood of the Bragg peak, it is illuminating to calculate the charge transferred from a fairly conventional floating gate for two of the particles shown in Figure 4.

Alpha particles are known to be the chief cause of soft errors in volatile memories so their effect will be calculated. The other particle we will consider is an A1 ion, both for itself, since it may be generated as a result of muon capture by Si, and as a proxy for both the Si recoil ions which may be generated in various nuclear reactions and Mg which may also result from muon capture.[19,20]

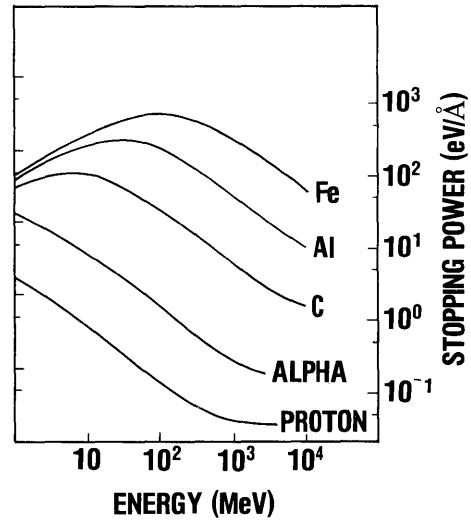

Figure 4: Energy loss rates vs. particle energy for particles with various masses calculated from Bethe-Bloch theory.

The Bragg peak for α's in Si occurs for particle energies in the neighborhood of 0.5 MeV. The energy loss rate for α's in Si is ~28 eV/Å in this range.[21] The energy loss rate for a compound such

as SiO_2 can be found from Bragg's rule which postulates the linear additivity of the energy loss cross-sections of the constituents of the compound, viz.

$$\varepsilon(X_mY_n) = m\,\varepsilon(x) + n\varepsilon(y)$$

Applying this to SiO_2 we find that the energy loss rate for alpha particles in SiO_2 near the Bragg peak is ~10.6 eV/Å.[22] Similar calculations for Al ions give approximate loss rates of 300 eV/Å and 110 eV/Å for Si and SiO_2, respectively.

Putting all of this together in the context of Figure 1, we can see that the total charge collected per incident particle should be given by:

$$Q_p = \frac{N_{ox}(\bar{\varepsilon})}{18} \int \frac{d_{ox1}}{\cos\theta} \left(\frac{dE}{dx}\right)_{SiO_2} dp$$

$$+ Y_{Si\text{-}SiO_2} \frac{\lambda_{esc}}{\cos\theta} \int \left[\left(\frac{dE}{dx}\right)_{Si} dp + \left(\frac{dE}{dx}\right)_{Si} \right] dp$$

$$+ \frac{\eta_{ox}(\varepsilon)}{18} \int \frac{d_{ox2}}{\cos\theta} \left(\frac{dE}{dx}\right)_{SiO_2} dp$$

where η_{ox} is the field dependent collection efficiency for pairs generated in the oxide, d_{ox1} and d_{ox2} are the thicknesses of the first and second oxides, λ_{esc} is the effect escape depth for electrons generated in the Si, θ is the angle of the particle path to the normal, $Y_{Si\text{-}SiO_2}$ is the yield (for normal incidence), and the integrals over path are needed because dE/dx is a function of energy and hence position.

SAMPLE CALCULATION

As one example, let's calculate the probability of a floating gate device similar to those in current production being upset by alpha particles emanating from the packaging material. We will assume that the floating gate poly measures 5μ x 14μ x 0.4μ, that the transistor gate size is 5μ x 5μ, that the gate oxide and interpoly oxides are both 1000 Å thick and that the field oxide is 1μm thick. We also assume that there is 2μ of SiO_2 deposited after the access gate is defined.

Figure 5 shows the alpha particle spectrum measured by Meieran et al.[23] The alpha spectrum is a result of the decay change of thorium and uranium which are present in the alumina which is used for hermetic packaging as trace impurities. For simplicity of calculation, we shall approximate this spectrum as two superimposed step functions. The high energy step begins at 8.6 MeV and the lower energy step at 7 MeV, the high and low energy steps have the relative weights of 3 to 7. Since it is known that the total emission rate of alumina ranges from 0.1 to 1.0 $\alpha/cm^2 \cdot hr.$, the integral over the approximation will be taken to be 1 $\alpha/cm^2 \cdot hr.$

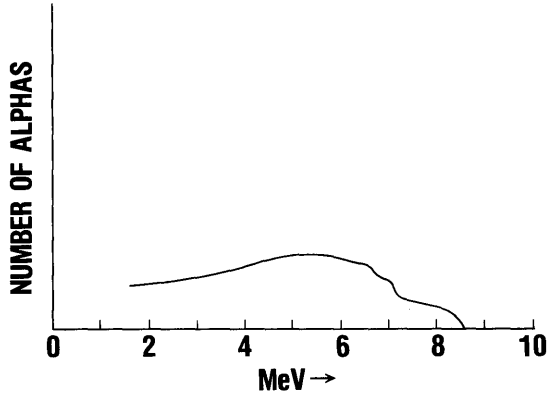

Figure 5: Spectrum of alpha particle emission rate vs. particle energy from an alumina lid. (Data from Meieran et al, ref. 23).

The maximum charge transfer which can occur as a result of a single particle is caused by a particle coming in at such an angle that the complete path length is within the gate oxide. (This requires that $\theta > 88.85°$. However, $\theta < 89.43°$ because for larger angles, the path length of the overglass is so long that no particles get through. Moreover, at $\theta = 89°$, the particle energy must be greater than 6.8 MeV to penetrate the glass.) If such a particle were to hit a cell so that 5μ of path length lay within the cell it could lose ~1.4 MeV. This implies a transfer of 15,550 electrons. The gate which is under consideration requires ~450,000 electrons to charge the state (assuming internal 2 V margin) or about 30 of these pathological alphas. Because the number of pathological alphas needed is >1, we can turn to a calculation of the average energy loss/particle.

We make the simplifying assumptions that the fraction of particles lost in the overglass from each of the two step functions contributing to the energy spectrum is given by the ratio of the path length in the overglass to the range of the highest energy particle in the step function, and that the energy loss rate in the effective charge collection region is that for 1 MeV. The first assumption causes an underestimation in the particles stopped in the overglass, and the second overestimates the energy contributed to charge generation. Under these assumptions the charge transferred from the floating gate by N_0 alpha particles is given by:

$$Q_t = 2N_0 \sum_i r_i \sum_j \ell_j \left(\frac{dE}{dx}\right)_j C_j \int_0^{\theta_{max}} \frac{\sin\theta}{\cos\theta} [1 - \beta_i/\cos\theta]\, d\theta$$

where r_i are the relative contribution of the two components in the spectrum; ℓ_j is the effective path length for charge generation; C_j is the conversion factor from energy loss to collected charges; β_i is the fraction lost in the overglass; and θ_{max} is taken to be the angle whose tangent is the gate length divided by the sum of the gate electrode and gate oxide thicknesses.

From this, one can find that the average alpha particle causes 580 electrons to be transferred from the floating gate. This means that about 750 alpha particles must hit the gate to change its state.

The problem becomes that of finding the probability that at least one cell has been hit 750 times, given that the average cell has been hit n times. Fortunately, the numbers are large enough that we can invoke the law of large numbers and approximate the distribution as normal with variance $\sqrt{n}$. If the array contains m cells then the probability that at least one cell is hit n_{crit} times is given by:

$$Q = \frac{m}{\sqrt{2\pi}} \int_z^\infty e^{-t^2/2} dt < \frac{m}{z} \sqrt{2\pi}\ e^{-z^2/2}$$

when $z = (n_{crit} - n) / \sqrt{n}$

as long as $Q<1$.[24]

If $n = 500$, then $Q < 1.84 \times 10^{-13}$ for a 16K chip and $Q<5.1 \times 10^{-12}$ for a 64K chip. For the chip size and alpha flux assumed, the expected period for the average alpha count per cell to reach 500 is 7×10^8 hours. Given the approximations we have made, this probably understates the actual time by about an order of magnitude.

Turning briefly to carriers created by Al ions, we note that very few ions have energies in excess of 3 MeV.[19] Since this energy is below the Bragg peak for Al in Si, the ions stop fairly quickly. Nonetheless, the maximum energy loss rate is ~120 eV/Å in SiO_2. Since the maximum energy of the Al ions is ~3 MeV, the maximum charge which would be collected from this ion is about 30,000 electrons which is still small enough that we can use normal statistics. Because of the small cross section for creation of these energetic ions, we can neglect this mode of charge generation for devices operating in normal terrestrial environments.

SCALING

The effect of scaling on the firm error rate on floating gate devices is interesting because it is very different from that which occurs in volatile memories. If we assume that both lateral and vertical dimensions are scaled by a factor λ, then the storage capacitance decreases as λ. However, since the charge collection is dominated by generation in the oxide, it decreases like λ^3. If the voltage margin decreases like λ, the expected time for upset increases as λ, if the voltage margin is held constant, the expected time for upset increases like λ^2. Thus, scaling should decrease the firm error rate.

EXPERIMENTAL RESULTS

To verify the theoretical results presented here, floating gate nonvolatile memories have been exposed to two types of radiation: gamma rays, representing massless particles, and alpha particles, representing massed particles. Table I gives the results. The devices tested contained a checkerboard pattern to look for firm error sensitivity for either bias of the floating gate.

As can be seen, no firm errors could be observed. The gamma radiation caused the devices to fail to meet the output leakage specification after 12,000 RAD. Measurement of the threshold of the output transistors showed that the thresholds had dropped from ~0.7V to ~0V.

The alpha particle fluence to which these devices were exposed was approximately that which would be seen after 200,000 years in a dirty package (1 $\alpha/cm^2 \cdot hr$) or 2,000,000 years in a clean (0.1 $\alpha/cm^2 \cdot hr$). These results are in good agreement with the predictions.

6

TABLE I

Radiation Type	Energy/ quantum	Integrated Surface Flux	#Units Tested	#Firm Errors	Part Type
Gamma Radiation	58.6 keV	12,000 RAD	10	0	X2212
Alpha Radiation	5.3 MeV	2.6×10^9 α/cm^2	5	0	X2816

SUMMARY

The question of "firm" errors in floating gate nonvolatile memories has been treated. A firm error is defined as a change of data occurring as the result of transfer of charge from the floating gate by ionizing radiation. The rate of charge transport by various forms of ionizing radiation is discussed. The case of alpha particles is worked out in some detail as an example. Experimental results of exposure of units to gamma and alpha radiation are shown which support the theoretical predictions. The units in test survived exposure to 12,000 RADs and 2.6×10^9 α/cm^2 without firm errors. The alpha fluence is equivalent to that emitted by a typical ceramic package in about a million years.

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ENDURANCE MODEL FOR TEXTURED-POLY FLOATING GATE MEMORIES

H.A. Richard Wegener

ABSTRACT

Textured Poly Floating Gate (TPFG) memories are beginning to dominate the commercial market. This is due to many of its inherent strengths. One of these is the consistency of its endurance. Its predictability is here developed theoretically. Starting with a model of emission from bumps based on the radial solutions of LaPlace's and Poisson's equation in spherical coordinates and the use of an Extreme Value distribution for the bump radii, an expression for charge build-up at constant current fits experimental data very well. This charge build-up is proportional to fluence. When these results are used in a model for continuous data changes, an expression is developed that relates endurance exponentially to a ratio of internal voltages.

INTRODUCTION

The basic features of the TPFG technology have been described in previous publications (1-4). The action of three polysilicon levels in charging and discharging the floating gate is shown in Figure 1.

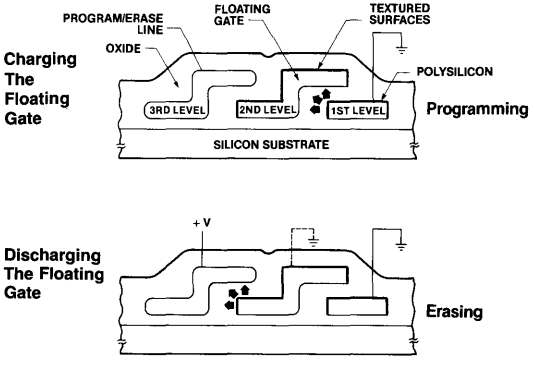

Figure 1: TPFG Cell Operation

Electron emission occurs only from a lower poly layer towards an upper poly layer. The oxide layers in between are in the 55 to 75 nm range, compared to the 8 to 11 nm required for the other common floating gate technology. The reason is simple: the surfaces of the poly layers are textured to form many small bump-like features, whose curved surfaces enhance applied fields by factors of 4 to 5. The modeling of these fields is an important part of the analysis to follow.

ENDURANCE

The term endurance has become accepted for a property common to all current nonvolatile memory technologies. It describes the number of data changes that a memory device can sustain without failure. In MNOS technologies, the failure is sometimes an inability to maintain the memory state for the required retention time; in thin oxide floating gate technologies it is often the breakdown of the fragile dielectric. In the TPFG technology, the end of endurance is generally caused by "trap-up", which prevents the transfer of charge to the floating gate. Trap-up is caused by the accumulation of trapped negative charge in the dielectric due to the repeated passage of current. These charges create a potential that opposes the potential necessary for tunneling. When this opposing potential reaches the voltage supplied on the chip, tunneling can no longer occur, resulting in the end of endurance. This paper describes a model for trapped charge build-up in TPFG devices.

FIELD MODEL

Electron emission by Fowler-Nordheim tunneling requires the knowledge of the field at the surface of the bump. This model assumes a bump with a spherical tip, which permits the use of solutions of LaPlace's and Poisson's equations in spherical coordinates. It is further assumed that the emitting surface (cathode) is radially conformal with the collecting electrode (anode), so that only the radial parts of both equations need to be employed. This leads to a solution of the form

$$(1)\quad E_c = -V_c/[R_c(1-R_c/R_a)] + (\sigma/K)\, R_d\, (1-R_d/R_a)/[R_c\,(1-R_c/R_a)]$$

where E is the field, R the radius, K the dielectric permittivity, σ a charge density per unit area, subscript c denotes a quantity at the cathode, and subscript a is a quantity at the anode. The first term describes the field in a dielectric free of charge, and the second has been cast in a form that the trapped charge distribution can be described by its charge density σ located at the centroid radius R_d.

FORMALISM FOR TRAP GENERATION

There is a body of experimental data for parallel plate structures (5,6) that clearly indicates that the amount of trapped charge is proportional to the amount of charge that has passed through as current:

(2) $Q_t = b \{\int J\, dt\} (4 \pi R^2_c)$ (s/4)

where Q_t is the charge trapped, and $\int J\, dt$ is the current density that passed through the dielectric integrated over time (termed "fluence"). The quantity b is the ratio of trapped charge to fluence. The second bracket converts charge density into charge, and (s/4) is the fraction of a full sphere that actually emits electrons. When this charge is concentrated at the centroid raduis R_d, then

(3) $Q_d = (\sigma) (4 \pi R^2_d)$ (s/4)

Equating Q_t with Q_d, solving for σ, substituting into eq (1), identifying the denominator of the second term of eq (1) as V_Q, and approximating R_d with $R_a/2$ results in

(4) $V_Q = \{\int J\, dt\}$ (b/K) (R^2_c/R_a)

FORMALISM FOR VARIATION OF BUMP SHAPES

All of the preceding derivations require two perfect concentric spherical shells to be applicable. To account for deviations from sphericity, and the distribution in the sizes of real bumps, as many as four constants might be necessary. But as a first approach it was decided to view the bumps as a distribution of perfectly spherical surfaces of limited area, with the hope that the dispersion parameter of the distribution of spherical radii would absorb the effects of contour variations. The distribution chosen was the Extreme Value distribution (7-9). Its sampling function has the form (10)

(5) $R_{ci} = R_m - BB\{\log [-\log (i - 0.5) /k]\}$

where R_m is the radius at the maximum of the distribution (the mode), BB is the dispersion parameter, k is the number of samples chosen, and i is the rank number of the particular item of k samples chosen.

CONSTANT CURRENT CHARACTERISTICS OF "TPFG" MEMORY TEST STRUCTURES

TPFG memory devices are operated by linear voltage ramps, which result in a forced constant current through the dielectric. A useful concept in this mode of operation is the "tunnel voltage" V_{TU}, which is the voltage that must be applied to sustain a specific constant current. For purposes of characterization, simple test structures are subjected to a set of forced constant currents, and the tunnel voltage V_{TU} is recorded vs fluence. Such a characteristic is shown in Figure 2.

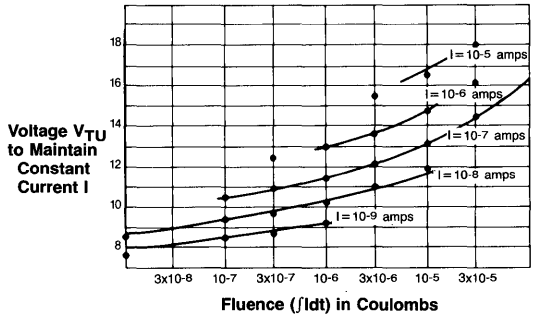

Figure 2: Tunnel Voltage vs. Fluence at Constant Current. Lines are experimental data, solid circles are calculated from eq (8).

With representative bump radii chosen by the sampling function the field at bump i is

(6) $E_{ci} = [-V_{TUi} + V_{Qi}]/[R_{ci} (1-R_{ci}/R_{ai})]$, where

(7) $V_{Qi} = \{\Sigma J_{FNi} \Delta t\}$ (b/K) (R^2_{ci}/R_{ai}).

Fluence is now expressed by its sum over time increments. The measured current is the sum of the currents from the number of all individual bumps G. The current density emitted by tunneling must be multiplied by the active spherical surface area. This leads to

(8) $I = (G/k) \sum_{i=1}^{k} (4 \pi R^2_{ci})$ (s/4) J_{FNi}, where

(9) $J_{FNi} = A E^2_{ci} \exp -B/E_{ci}$.

The initial modeling was done with a program in BASIC on a personal computer. The area of the structure was 0.1mm^2, the number of bumps per square micrometer was 50, the oxide thickness was 59 nm, which translated into a value for $R_{ai}=R_{ci}$ + 59 nm. Following (11) the Fowler-Nordheim constants were set at A=6.5E-7 amps - cm/V^2 - sec and B=2.52E + 8V/cm. The dielectric permittivity was K=3.5E-13. The best fit was obtained for R_m=15.4 nm, BB=4.8 nm, b-2.OE-8, and s=0.03. The calculated values are shown as circles against the continuous experimental data on Figure 2. The value R_m is consistent with values obtained from T.E.M. cross-sections, the calculated dispersion has an analog in the estimated dispersion of bump base diameters, and b agrees very well with data presented at IEDM81 (6) for parallel plate structures. There is now a good basis for describing the processes occurring in TPFG memories. A pertinent example is shown in Figure 3. Here a constant current plot was calculated as a function of the number of samples representing the same distribution. While it is an indication that, indeed, 1024 samples are necessary to accurately depict conduction at fluences as low as 1E-8, it also clearly shows that during the latter part of the life of the devices, all those different bumps can be represented by bumps of the same radius R_m. This should make the prediction of endurance somewhat less complex.

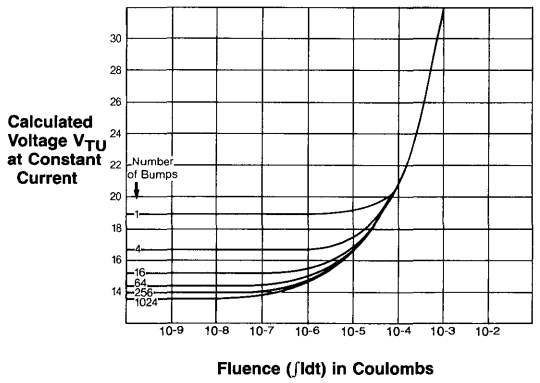

Figure 3: Effect of Number of Samples k on Calculated Tunnel Voltage

VOLTAGE-TIME RELATIONSHIPS DURING PROGRAM-ERASE CYCLING

This analysis is based on the assertion that trap-up is the cause of the end of endurance. Since the build-up of traps is the result of current through the tunnel dielectric, this analysis is concerned only with the time interval during which tunneling occurs. As an aid to understanding, reference may be made to Figure 4.

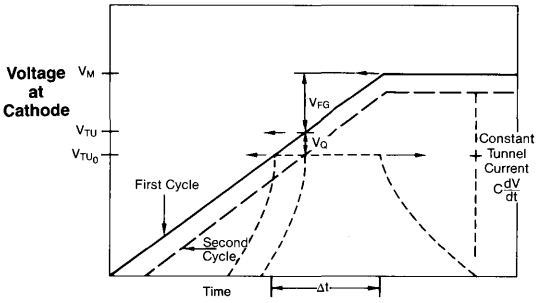

Figure 4: Voltage vs. Time Relationships at Floating Gate

The heavy line describes the (absolute) potential at the cathode (which may be poly 1 or poly 2) during the course of the first ramp to be applied to an untested structure. When the tunnel voltage V_{TUo} is reached, a current flows that remains constant until the maximum voltage (internal to the tunnel structure) V_M, is reached. The constant current is indicated by a superimposed plot in broken lines referenced to the right. When V_M is reached, the voltage stays constant for a "flat top" period. During this time, the current decreases exponentially, since any transferred charge reduces the tunnel potential. Since tunnel current flows during this first pulse, its fluence gives rise to trapped charge, which in turn causes an opposing voltage V_Q. Therefore, during the second pulse, the net potential on the cathode is reduced by V_Q. This can be indicated by a second ramp offset downwards by V_Q. The tunnel voltage for the same constant current is then reached later, and the time to reach the end of the ramp is shorter. As cycling proceeds, the time interval during which tunneling occurs becomes shorter and shorter. This simple picture neglects one important element of endurance cycling: each cycle of one polarity must be followed by a cycle of the opposite polarity. The charge stored during the previous cycle affects the

potential of the cathode during the following cycle. The amount of charge stored during each cycle can be picked off Figure 4 by looking at it in another way. Instead of offsetting all succeeding ramps, one may consider them all superimposed, and recognize that the tunnel voltage V_{TU} increases with each cycle. Then the tunnel voltage can be viewed as the sum of V_{TUo} and V_Q. Conversely, the charge transferred to the floating gate V_{FG} is the difference between V_M and V_{TU}.

ENDURANCE MODEL

The change in V_{TU} per programming pulse on one bump is

(10) $d V_{TU}/dn = \Delta V_Q = \{J_{FN} \Delta t\} (b/K) (R^2_c/R_a)$

where Δt is the total time during which current flows.

(11) $\Delta t = (V_{FGe} + V_{FTe} + V_{Mp} - V_{TUp} + V_{FTp})/r$,

where r is the ramp rate dV/dt, subscript p refers to the programming step, and e to the erase step. $V_{FGe} + V_{FTe}$ is the floating gate voltage left over from the erase step. V_{FTp} is the charge added to V_{FGp} during flat top. From previous analysis, $V_{FGe} = V_{Me} - V_{TUe} + V_{FTe}$. Let the structure be symmetrical so that all subscripts are interchangeable. Eq (11) be can now be written

(12) $dV_{TU}/d n = \alpha(V_M - V_{TU} + V_{FT})$ where

(13) $\alpha = 2b J_{FN} R^2_c/K r R_a$

Integrating (12), setting $V_{TU} = V_{TUo}$ when n=0, setting $V_M - V_{TU} + V_{FT} = V_{MS}$ when n = N, and rearranging, results in

(14) $N = (1/\alpha) [1n (V_M + V_{FT} - V_{TUo})/V_{MS}]$.

Here N is endurance expressed as the number of data changes before trap-up, and V_{MS} is the minimum voltage on the floating gate to be sensed as the correct state.

Near the end of endurance, according to Figure 3, after a fluence of about 1E-4 coulombs has been accumulated, the build-up of traps follows a path as if all bumps had the same radius R_m. This permits the exact substitution for R_c and R_a in Eq (13), and the calculation of V_{TUo} in Eq (14) with the help of Eq (9). V_{FT} can be calculated exactly, depending on flat top time and floating gate capacitance; it is of the order of 0.1-0.3 volts. V_M depends strictly on internal voltages and coupling ratios. V_{MS} depends on coupling ratios, the threshold voltage of the floating gate transistor, the minimum voltage required to accomplish sensing at the circuit sensing device. Memory cells operating within real circuits require the establishment of both programming and erase voltage quantities to fit in Eq (14). Endurance distributions as a function of temperature have been recorded experimentally for specific TPFG products (12). Their modes are consistent with tunneling currents as determined from the measured ramp rates in circuits operating at different temperatures.

CONCLUSION

There are three major results of this calculation. First, it indicates that textured surface emission can be modeled adequately by spherical geometrics, if modified by the dispersion of an Extreme Value distribution of the bump radii. Second, it confirms that TPFG memories are a part of the same universe as other silicon-to-silicon-dioxide tunneling structures, exhibiting the same mode of trapping (proportional to fluence), with a trapping ratio (b=2E-8) that is essentially identical to that for parallel plate structures. Finally, on the basis of these results, a model for TPFG endurance based on charge build-up has been developed that appears well supported by experimental results.

ACKNOWLEDGEMENTS

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NOTES

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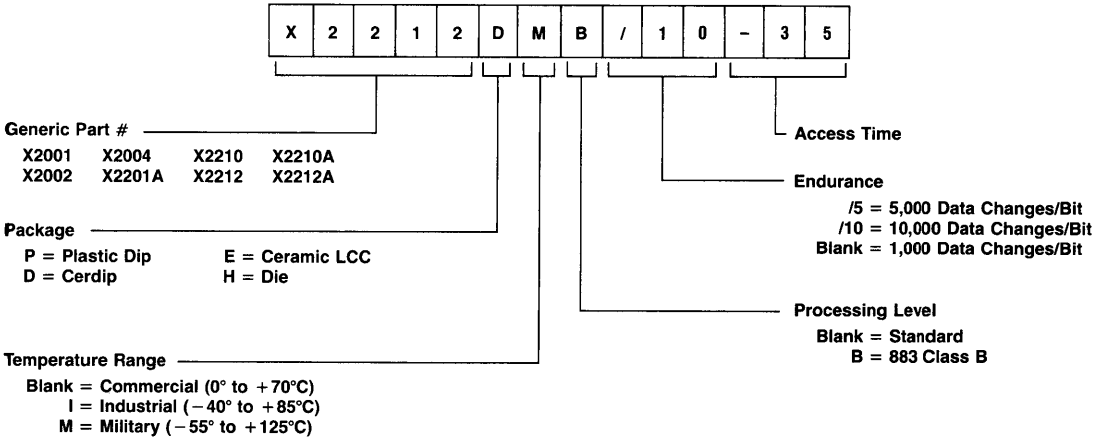

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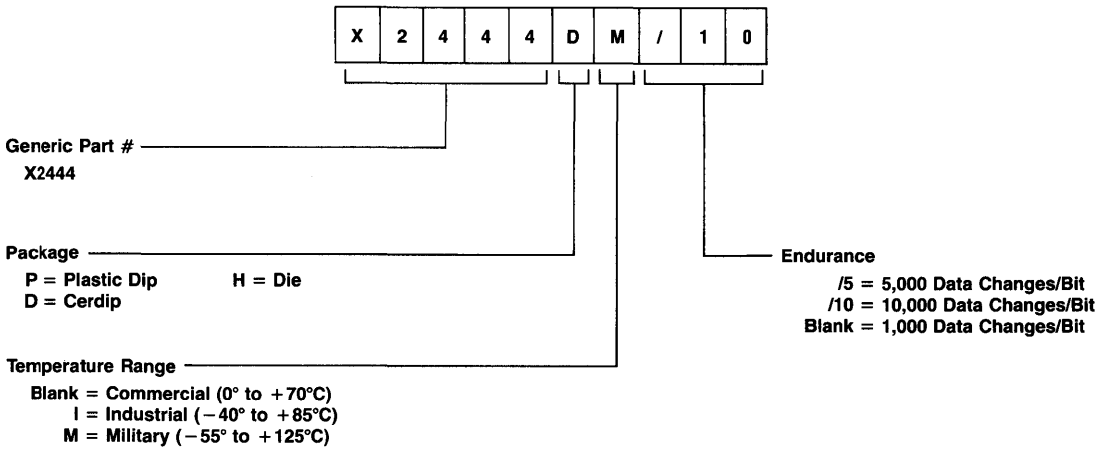

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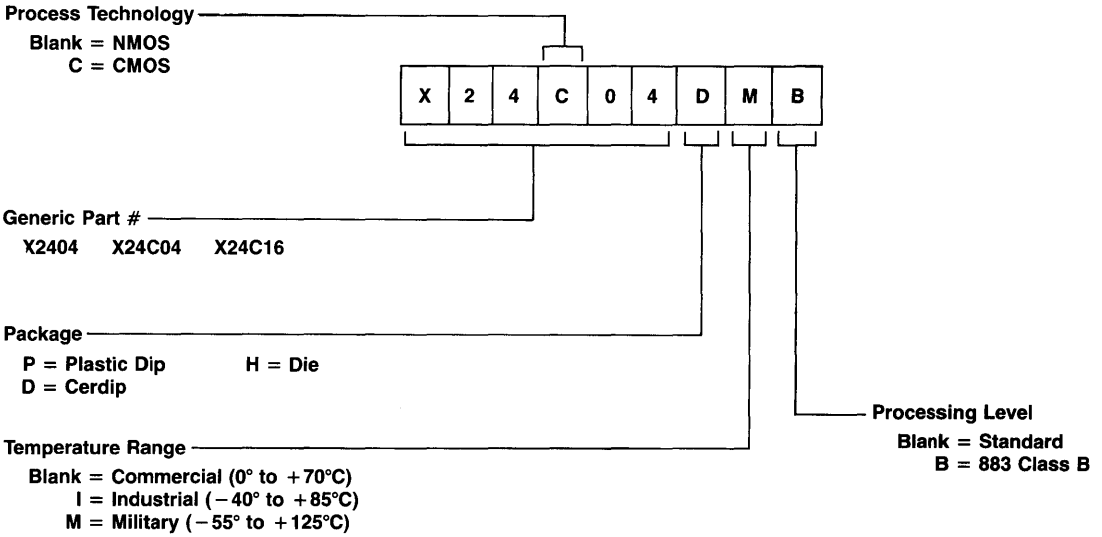

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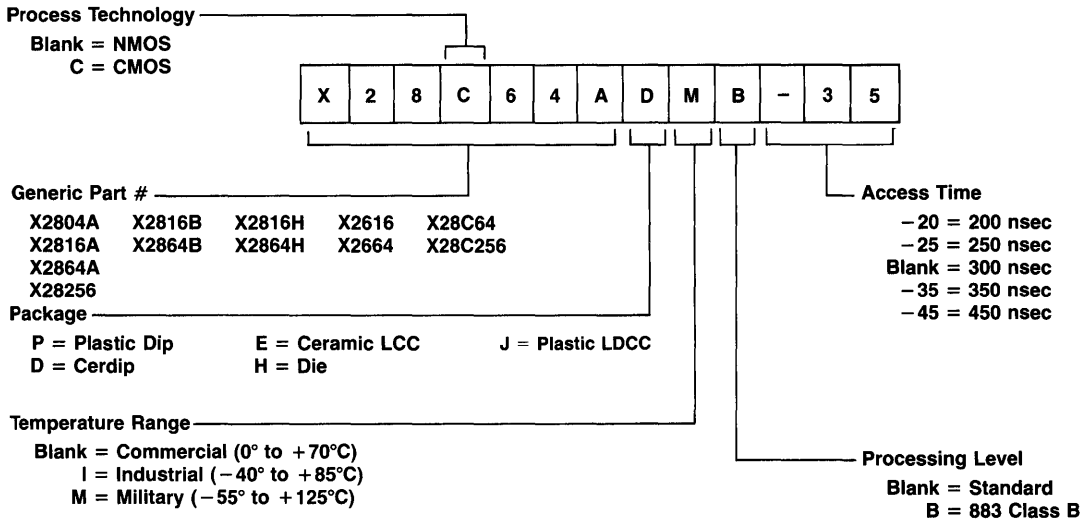

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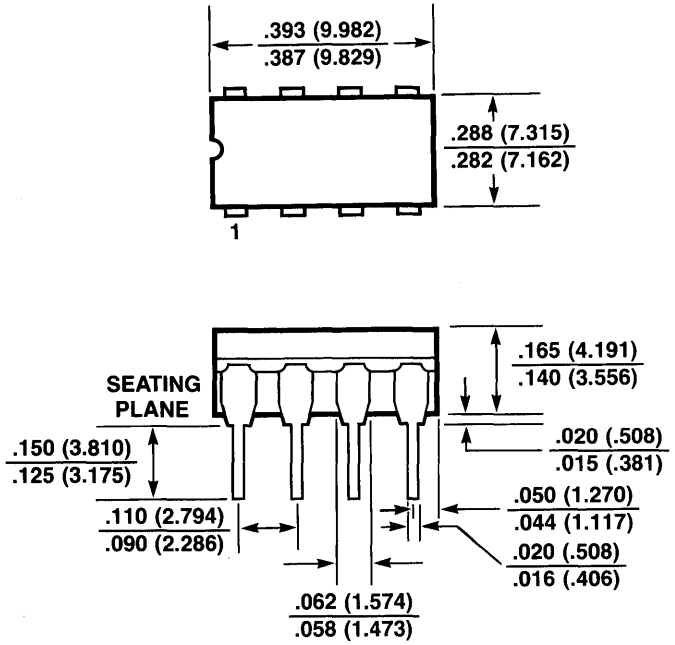
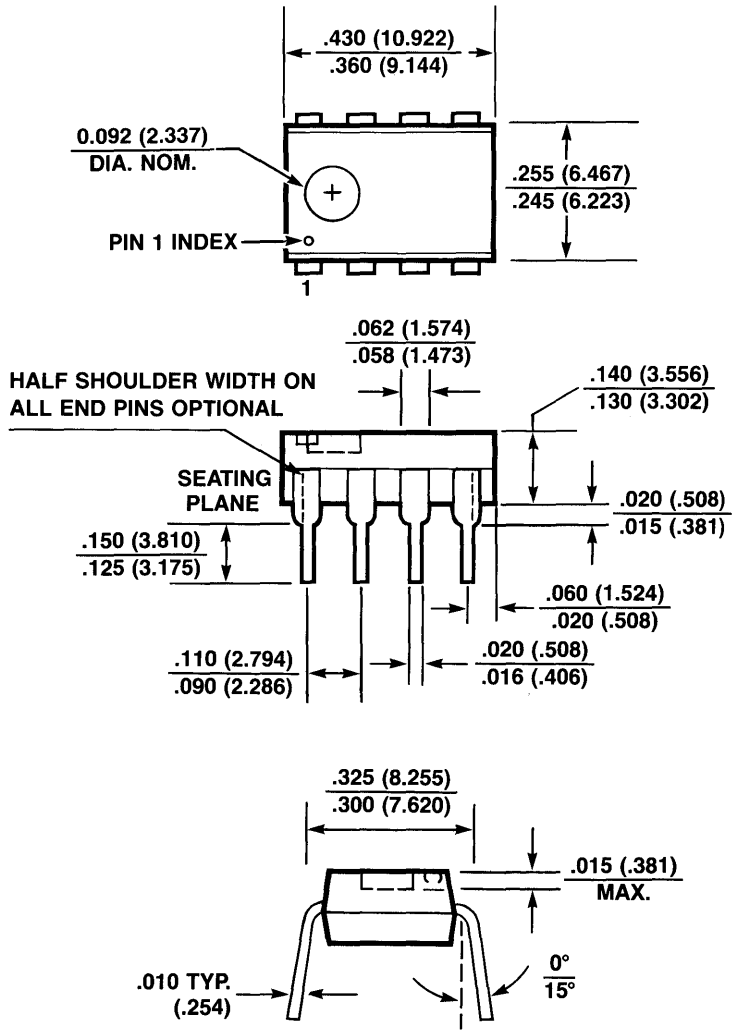


NOTE: ALL DIMENSIONS IN INCHES (IN PARENTHESES IN MILLIMETERS)

8-LEAD PLASTIC DUAL IN-LINE PACKAGE TYPE P

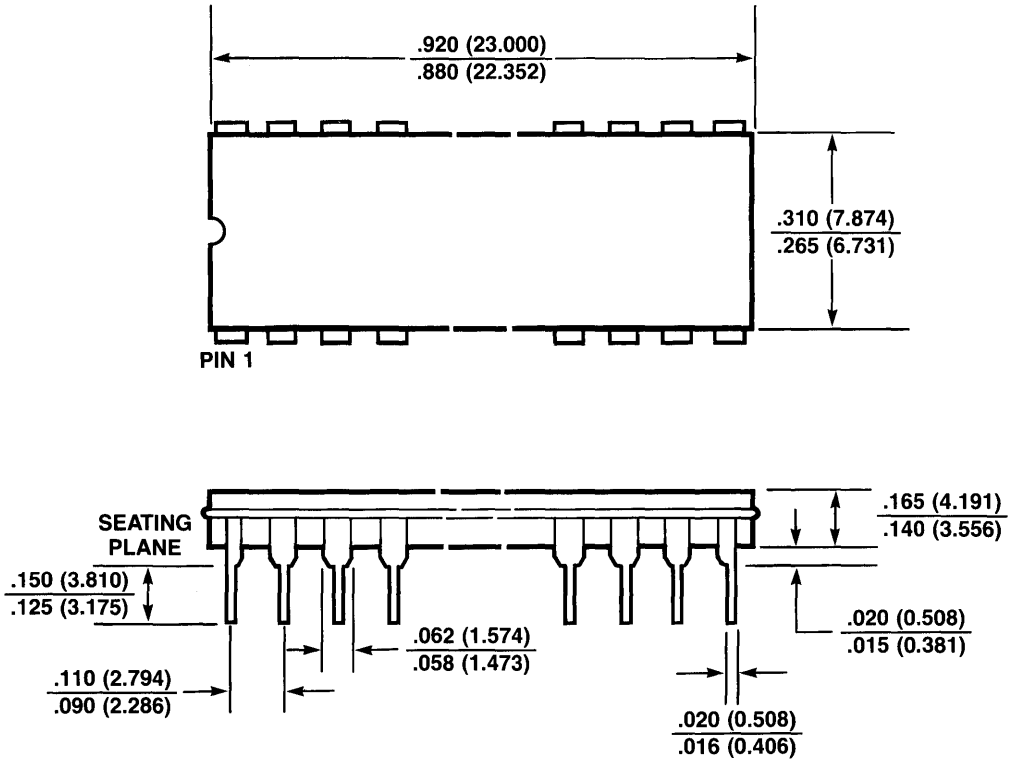


NOTE: ALL DIMENSIONS IN INCHES (IN PARENTHESES IN MILLIMETERS)

7

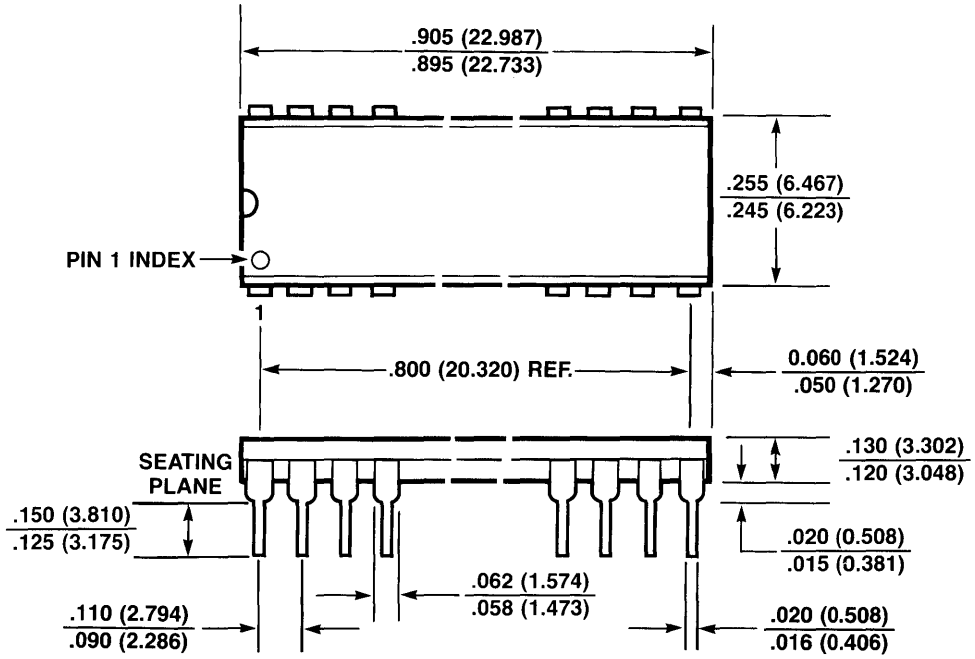
PACKAGING INFORMATION

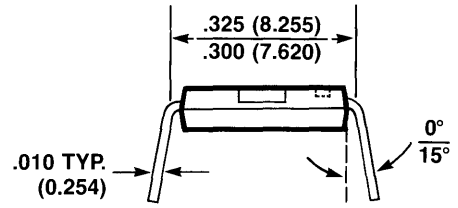
18-LEAD HERMETIC DUAL IN-LINE PACKAGE TYPE D



NOTE: ALL DIMENSIONS IN INCHES (IN PARENTHESES IN MILLIMETERS)

18-LEAD PLASTIC DUAL IN-LINE PACKAGE TYPE P



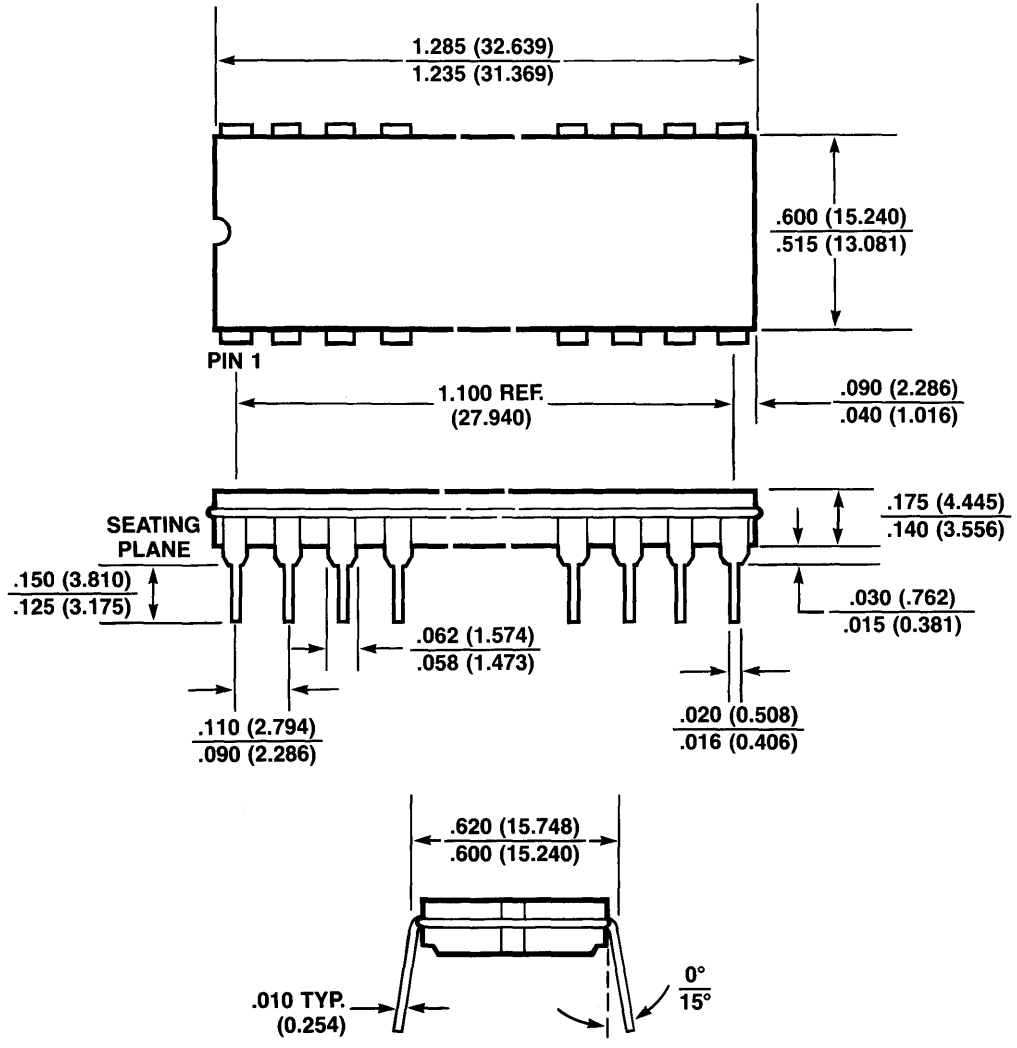


NOTE: ALL DIMENSIONS IN INCHES (IN PARENTHESES IN MILLIMETERS)

7

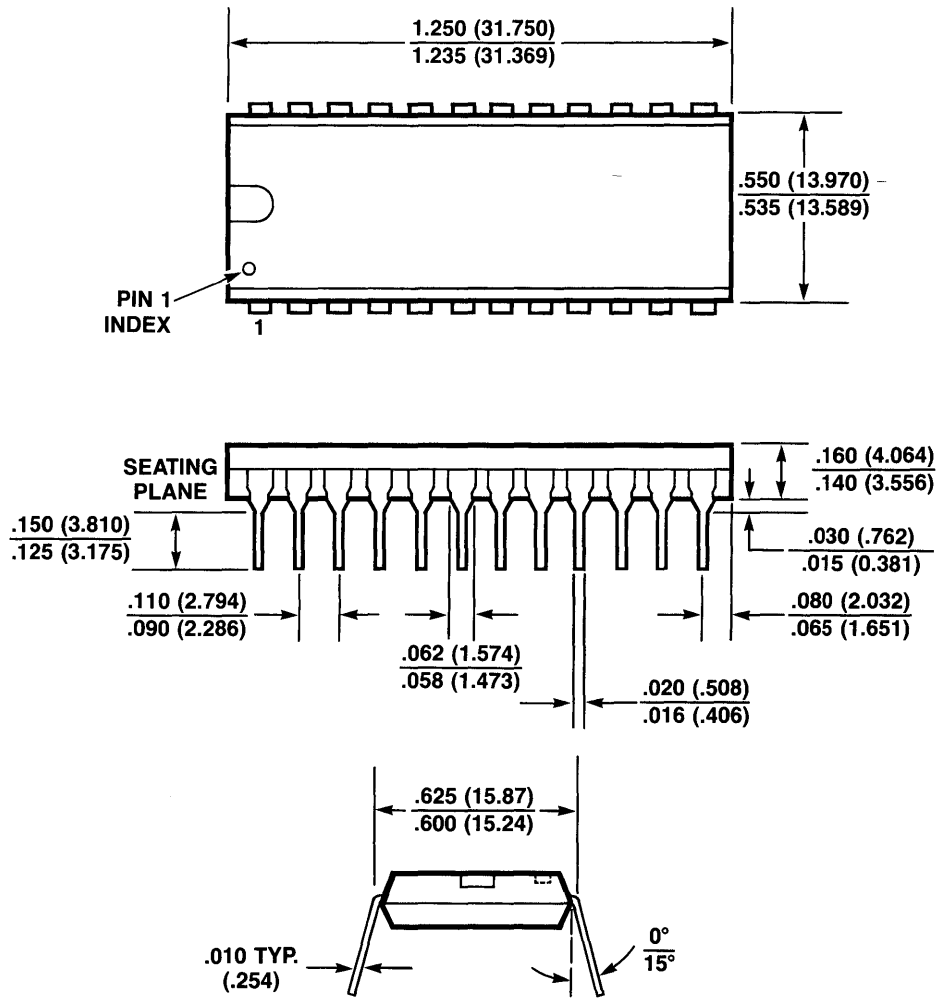
PACKAGING INFORMATION

24-LEAD HERMETIC DUAL IN-LINE PACKAGE TYPE D



NOTE: ALL DIMENSIONS IN INCHES (IN PARENTHESES IN MILLIMETERS)

24-LEAD PLASTIC DUAL IN-LINE PACKAGE TYPE P

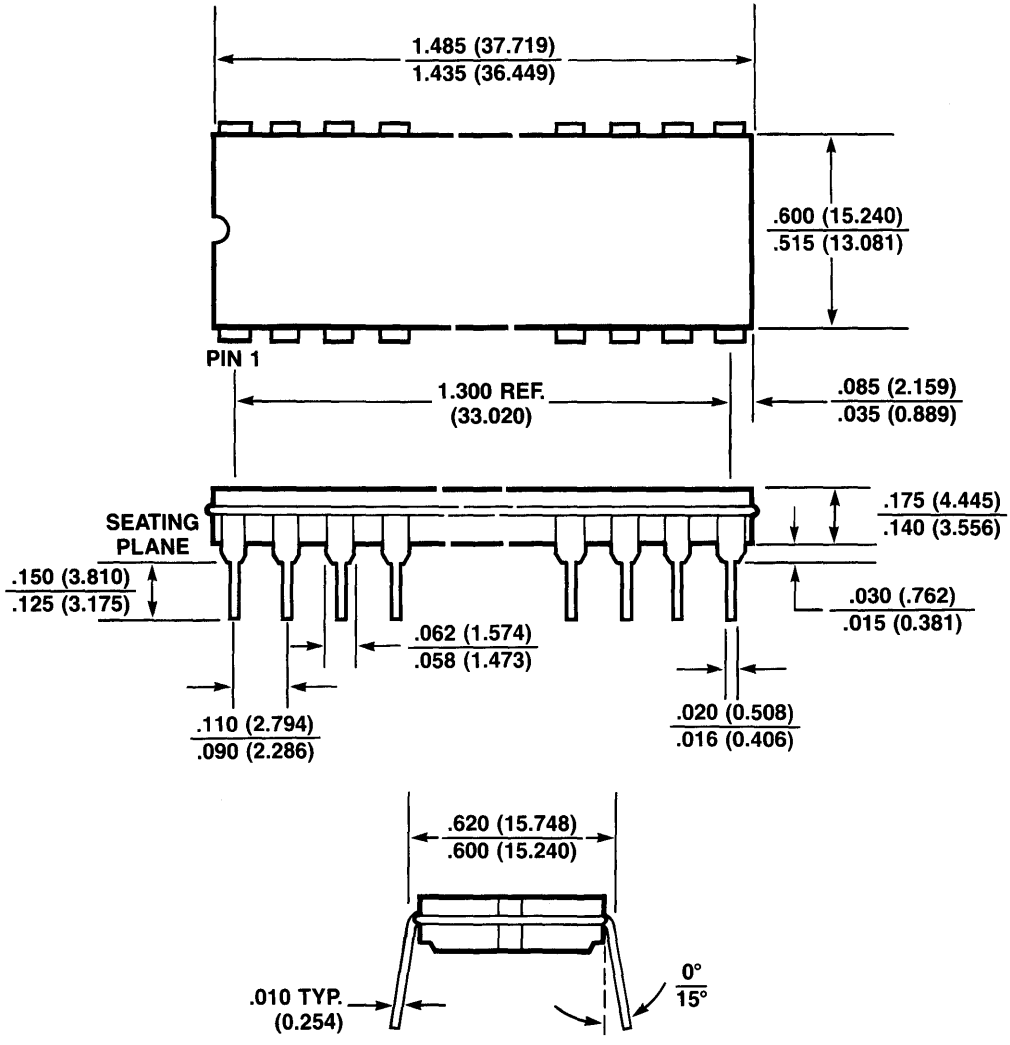


NOTE: ALL DIMENSIONS IN INCHES (IN PARENTHESES IN MILLIMETERS)

7

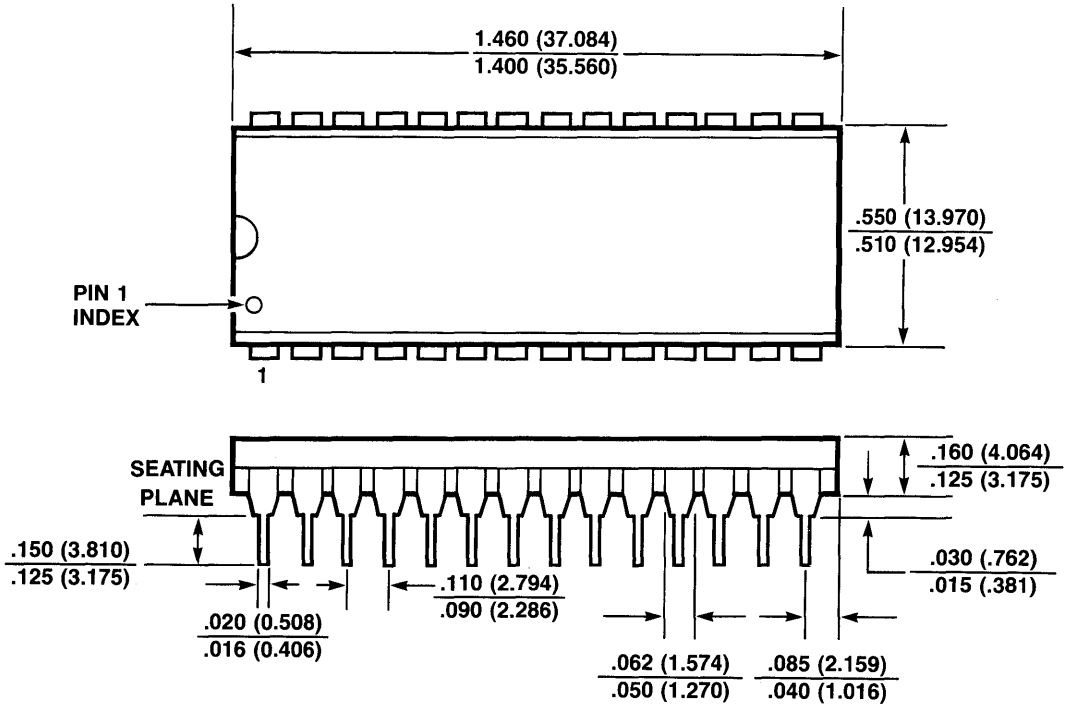
PACKAGING INFORMATION

28-LEAD HERMETIC DUAL IN-LINE PACKAGE TYPE D



NOTE: ALL DIMENSIONS IN INCHES (IN PARENTHESES IN MILLIMETERS)

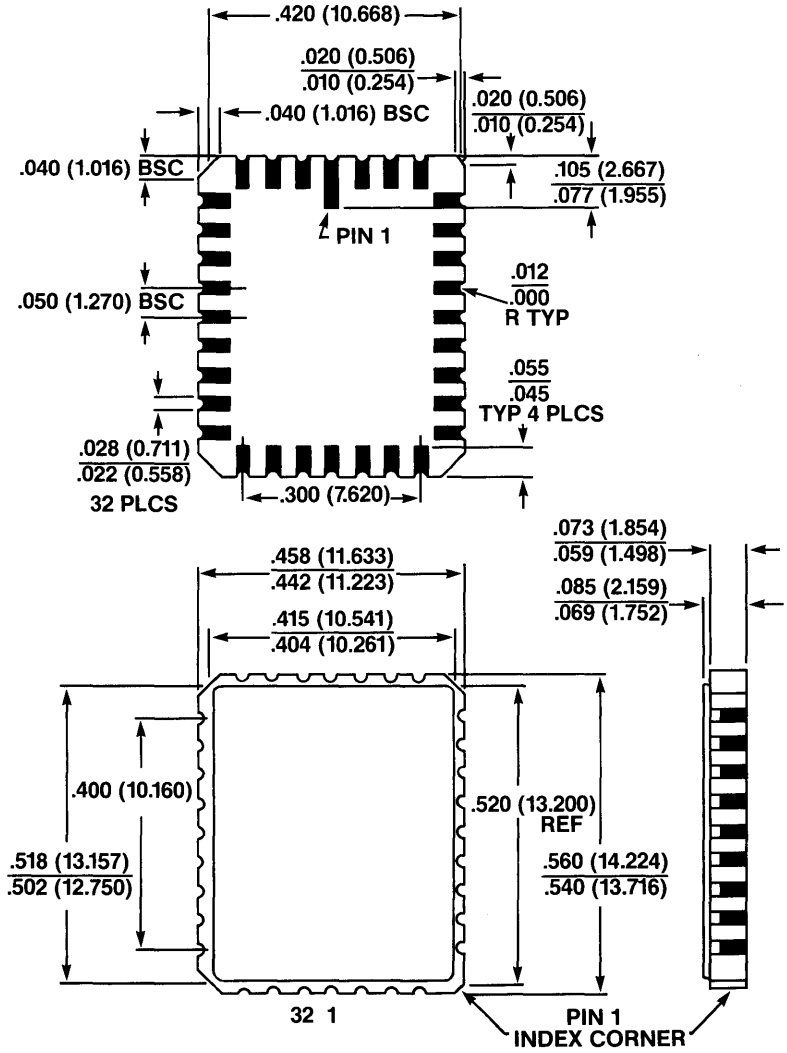
28-LEAD PLASTIC DUAL IN-LINE PACKAGE TYPE P



NOTE: ALL DIMENSIONS IN INCHES (IN PARENTHESES IN MILLIMETERS)

7

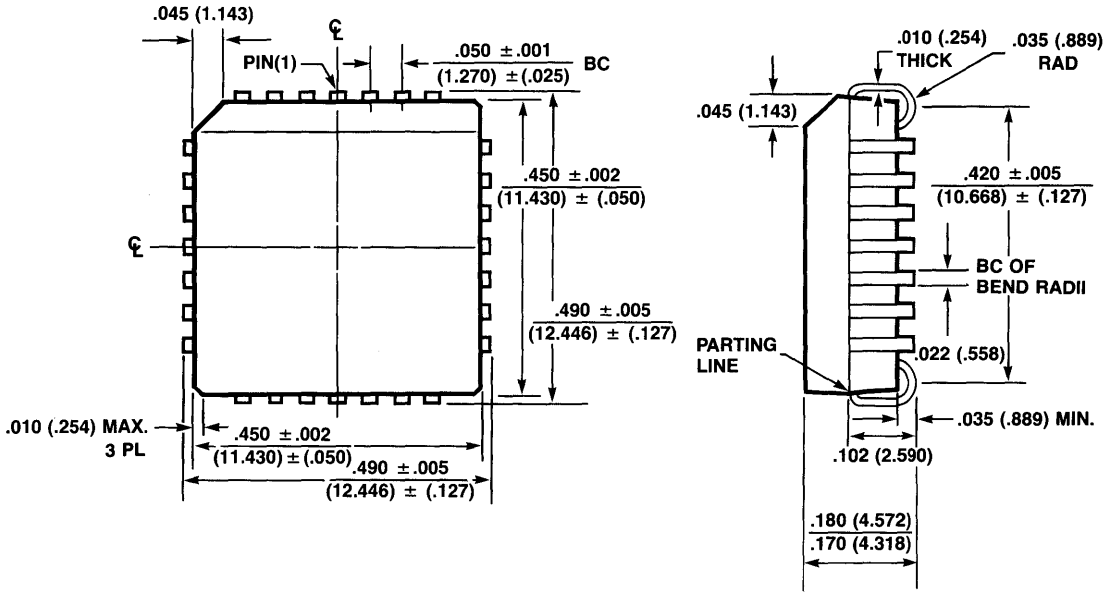
32-PAD CERAMIC LEADLESS CHIP CARRIER PACKAGE TYPE E



NOTES:

1. ALL DIMENSIONS IN INCHES (IN PARENTHESES IN MILLIMETERS)
2. TOLERANCE: ±1% NLT ±.005 (.127)

28-LEAD PLASTIC LEADED CHIP CARRIER TYPE J



NOTES:
1. ALL DIMENSIONS IN INCHES (IN PARENTHESES IN MILLIMETERS)
2. DIMENSIONS WITH NO TOLERANCE FOR REFERENCE ONLY.

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Sales Offices

U.S. Sales Offices

Eastern Area
Xicor, Inc.
Montvale Executive Park
91 Montvale Avenue
Stoneham, Massachusetts 02180
Phone: 617/279-0220
Telex: 322889

Southeast Area
Xicor, Inc.
201 Park Place
Suite 203
Altamonte Springs
Florida 32701
Phone: 305/767-8010
Twx: 510-100-7141

Mid-Atlantic Area
Xicor, Inc.
Patriot Square
39 Mill Plain Road
Danbury, Connecticut 06810
Phone: 203/743-1701
Telex: 853137

Central Area
Xicor, Inc.
943 North Plum Grove Road
Suite D
Schaumburg, Illinois 60195
Phone: 312/490-1310
Twx: 910-997-3663

South Central Area
Xicor, Inc.
9451 LBJ Freeway
Suite 220, Office 231
Dallas, Texas 75243
Phone: 214/669-2022
Telex: 758760

Southwest Area
Xicor, Inc.
4000 MacArthur Boulevard
Suite 3000
Newport Beach, California 92660
Phone: 714/752-8700
Telex: 182737

Northwest Area
Xicor, Inc.
851 Buckeye Court
Milpitas, California 95035
Phone: 408/946-6920
Twx: 910-379-0033

International Sales Offices

Northern Europe Area
Xicor, Inc.
29A, Market Square
Witney
Oxon 0X8 6PD
England
Phone: 011.44.993.5198
Telex: 946240

Southern Europe Area
Xicor, Inc.
Forsthausstrasse 1
D8013 Haar bei Muenchen
West Germany
Phone: 011.49.8946.3089
Telex: 5213883