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IBM Federal Systems Division

THE IBM

4020 Military Computer

GENERAL INFORMATION

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**IBM Federal Systems Division
International Business Machines Corporation
New York, New York**

FOREWORD

Data processing -- in this age of ballistic missiles, underwater and space surveillance -- encompasses applications whose requirements for reliability, speed, and systems capability cannot be fulfilled by available data processors. These applications require that high-speed, long-distance communication links be integrated into a system which can accept tremendous masses of data from many input stations, classify, correlate and store this data, and perform precise computations in real time. Simultaneously, the system must monitor the computed results and, when necessary, initiate and transmit action messages in the form required for execution. In addition, the data processing system must satisfy military specifications for shock and vibration resistance and ease of maintenance.

With these requirements firmly established, the Federal Systems Division of the International Business Machines Corporation developed the IBM 4020 Military Computer. Conceived for defense, the IBM 4020 modular design provides the means for assembling a configuration of functional units tailored to the specific requirements of the application whether civilian or military. The IBM 4020 has been selected by the U. S. Air Force for today's most complex and challenging data processing applications.

RELIABILITY of a degree never before possible in a system of this complexity has been achieved by encapsulated component assemblies and error-detection circuitry and error-correction techniques.

SPEED has been substantially increased by complementing the inherent speed of the circuit components with simultaneous operations.

VERSATILITY of the system is accomplished by modular construction which allows the application's requirements to specify the configuration of functional units for the most efficient operation. Future expansion can be achieved by the addition of core and drum storage units, magnetic tapes, and various other conventional or real-time input-output units.

This modular construction philosophy permits the IBM 4020 to be adapted to a wide range of data processing applications. The following pages show how each building block contributes its share to the over-all capability of the system.

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CENTRAL PROCESSOR

- Instruction rate Up to 400,000 instructions per second
- Cycle time 2.5 microseconds
- Word size 48 bits plus 2 parities
- Core storage Up to 131,072 words

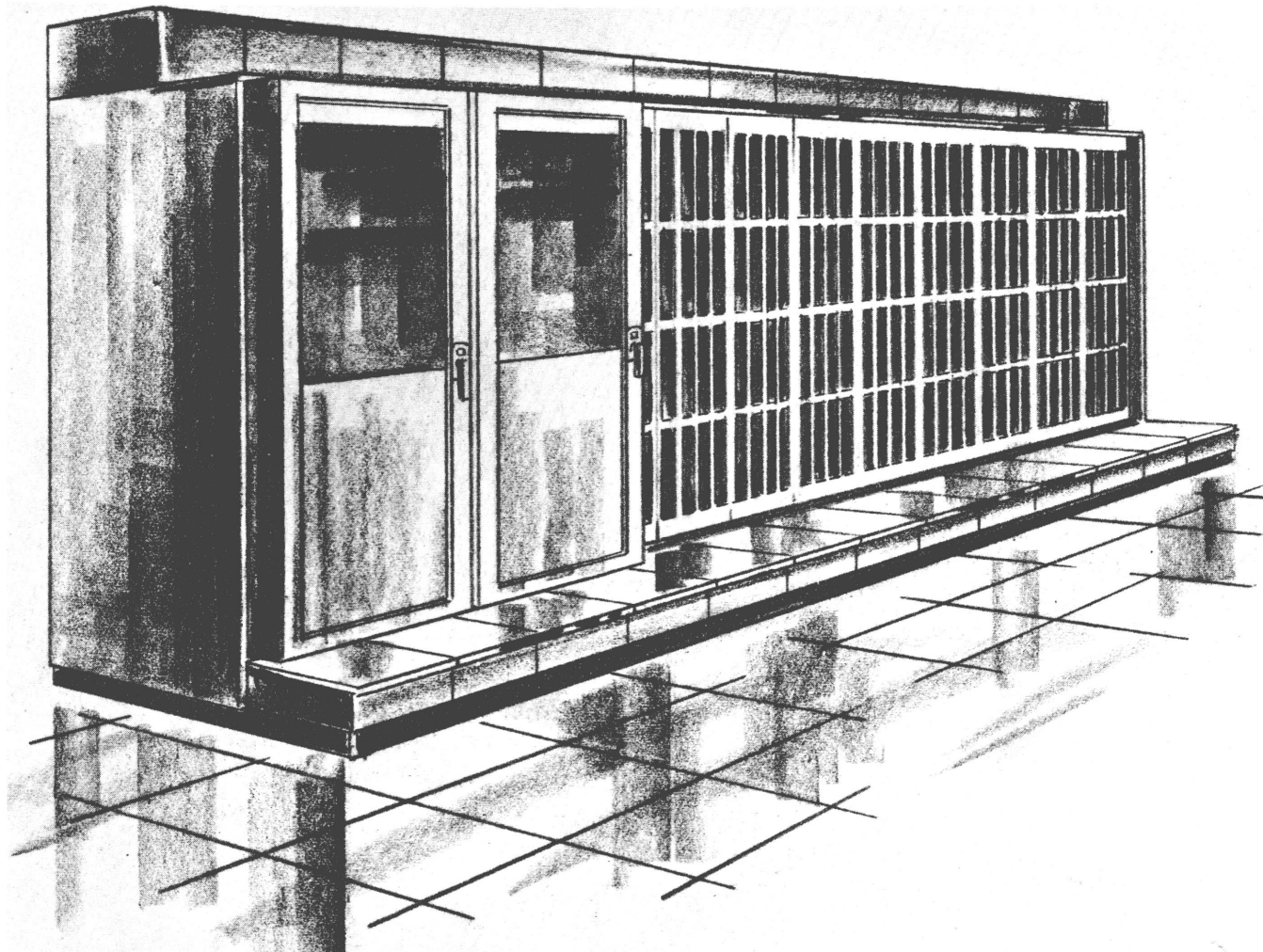
The IBM 4020 Military Computer operates in the parallel mode with single address instructions. This combination is a major factor in providing the high speed of instruction execution; e.g., add, subtract: 2.5 usec; multiply: average 24 microseconds (24 bit precision).

The speed and capacity of the IBM 4020 is enhanced by the array of input-output devices available for selection to satisfy the requirements of real-time applications as well as the conventional mode of operation. This flexibility, combined with the high degree of reliability specifically designed into the system, insures the efficient processing of the variety of applications requiring the capability of the IBM 4020.

To fully exploit the inherent capability of the IBM 4020, a comprehensive list of 69 instructions and many special programming features are included. Some of these features are described below.

AUTOMATIC PRIORITY PROCESSING

Automatic priority processing is a feature designed into the IBM 4020 which permits the processing of data immediately upon its entry into the system, regardless of its origin. Thus, a priority message has the ability to



Central Processor

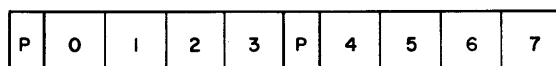
automatically interrupt the processing of low priority data immediately without waiting for a specific time in the program.

Automatic priority processing features also insure efficient utilization of the total system by permitting multi-processing. Multi-processing allows the processing of more than one application concurrently by utilizing systems components as they become available. Due to the features specifically designed into the 4020, a minimum amount of pre-planning for multi-processing is required for each program.

BYTE CONTROL

Byte control is a method of selecting and positioning items of information which do not require a full word. The 48-bit word may be divided under program control into 6-bit increments called bytes. Some of the advantages of byte control are:

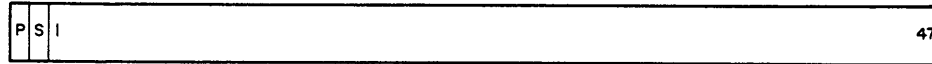
- Efficient handling of data represented by various codes such as Teletype or BCD commonly used for alphabetic or decimal information.
- Many arithmetic or logical operations accelerated by simultaneous positioning of the bytes while the desired operation is performed. This feature eliminates most of the extract, deposit, and cycle instructions.
- Increased versatility of each instruction. A load class instruction, for example, will transfer information from core storage to the selected register in any one of 2,048 possible byte configurations.



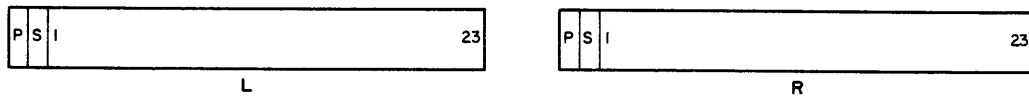
Byte Control

OPERATING MODE

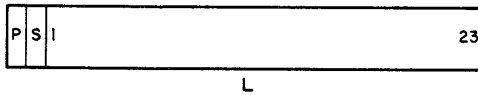
The mode selection bits (M) determine whether half- or full-word logic will be utilized.



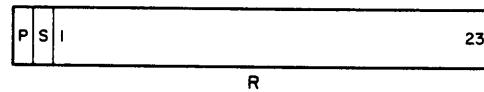
Full Word - For this mode of operation, the operand is treated as a signed quantity with 47 bits of magnitude.



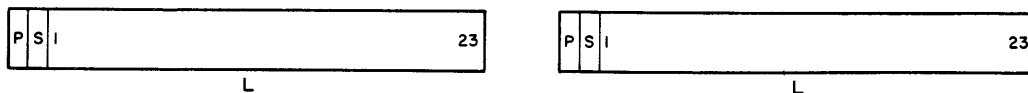
Dual Mode - The operand is treated as two independent values, each having a sign and 23 bits of magnitude.



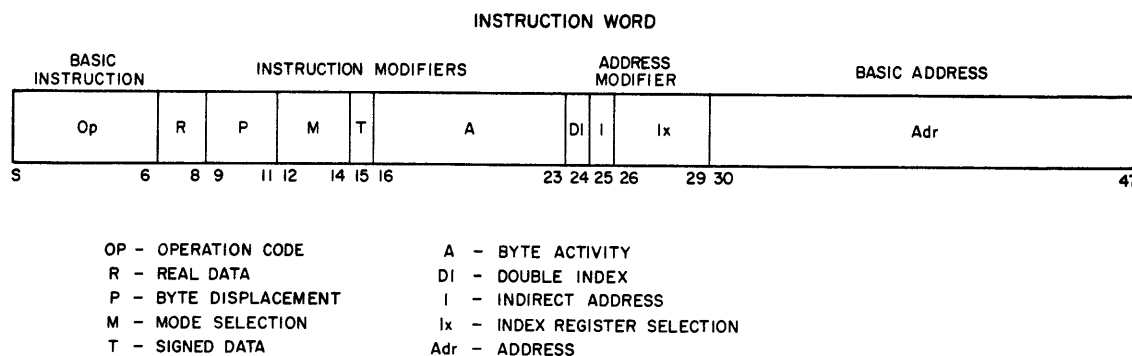
Left Mode - The instruction is executed only in the left arithmetic element.



Right Mode - The instruction is executed only in the right arithmetic element.



Twin Mode - The left half-word is executed in the left and right arithmetic element.



ADDRESSING

The IBM 4020 System provides three levels of addressing:

Direct Addressing (ADR) - Direct addressing uses the right-most 18 bits of the instruction word to specify the address of the operand.

Immediate Addressing (R) - Immediate or real data addressing specifies that the right half-word of the instruction is the operand. This feature simplifies programming routines by eliminating references to storage for a known constant.

Indirect Addressing (I) - The address portion of the instruction specifies an intermediate location which, in turn, contains the address of the information to be processed. This feature permits operands, referred to by several instructions, to be relocated without the necessity of rewriting the program.

INDEXING

Efficient utilization of the system does not permit the consistent placement of data into prefixed locations. Consequently, the instructions referring to this data must be modified quickly and simply. One method of achieving this address modification is called indexing. Indexing does not alter the instruction as retained in storage. There are 13 index registers, the right

accumulator, and the program counter which can be used for address modification. The IBM 4020 provides the programmer with several methods of indexing, thus simplifying the preparation of iterative routines and multi-programming.

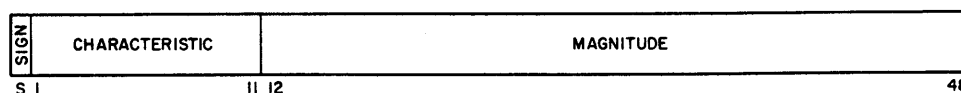
Direct Indexing (IX) - The contents of the location specified by the (IX) bits of the instruction word are used for address modification.

Double Indexing (DI) (IX) - Double indexing allows the base address of an instruction to be modified by the contents of two index registers. One important advantage of this feature is that all program routines are fully relocatable.

Relative Indexing (IX) - Relative indexing when specified by the (IX) uses the contents of the program counter for address modification. This technique eliminates the programming necessary to maintain separately the location of the executed instruction. This can be extremely helpful when branching within a subroutine or to a commonly used routine which may not be consistently located in the same area.

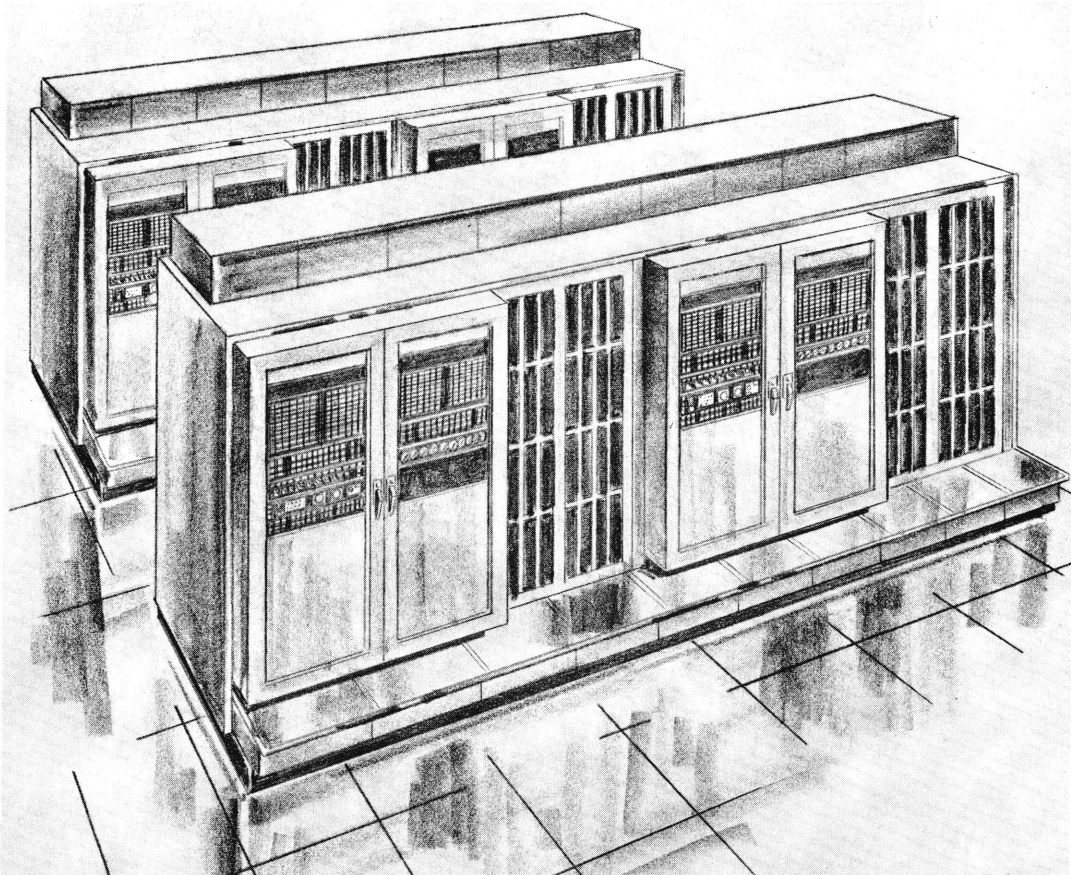
FLOATING-POINT ARITHMETIC

When the range of numbers which is anticipated during a calculation is either large or unpredictable, it may become extremely difficult to work with fixed-point arithmetic instructions. Therefore, floating-point notation has been included to simplify programming techniques by permitting automatic compilation of scaling factors. With this notation, a number is expressed as a proper fraction multiplied by some integral power of two. The range of possible numbers is more than $10^{\pm 300}$. Floating-point add or subtract is accomplished in 7.7 to 26 usec and multiply in 5 to 74 usec. Special instructions allow conversion from fixed- to floating-point notation.



Floating Point

CORE STORAGE



Core Storage

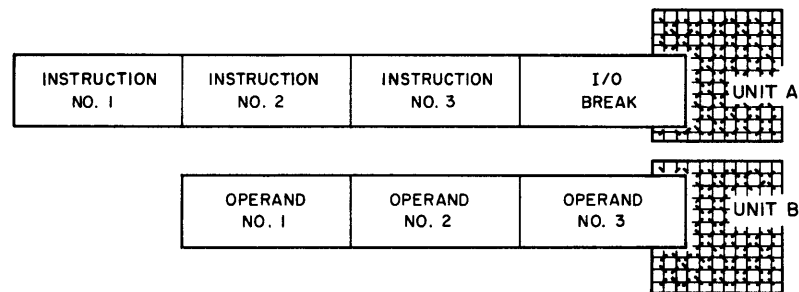
- Cycle time 2.5 microseconds
- Word size 48 bits plus 2 parities
- Words per unit 16,384
- Number of units 1 - 8

A data processing system is as efficient as its ability to accept data, determine its characteristics, process the data, and send it to its destina-

tion. The 2.5-usec core storage cycle time of the IBM 4020 is an ideal balance between the Central Processor and the various input-output devices.

The IBM 4020 core storage modularity was designed to offer a substantial saving in processing time by overlapping the accesses to data and instructions.

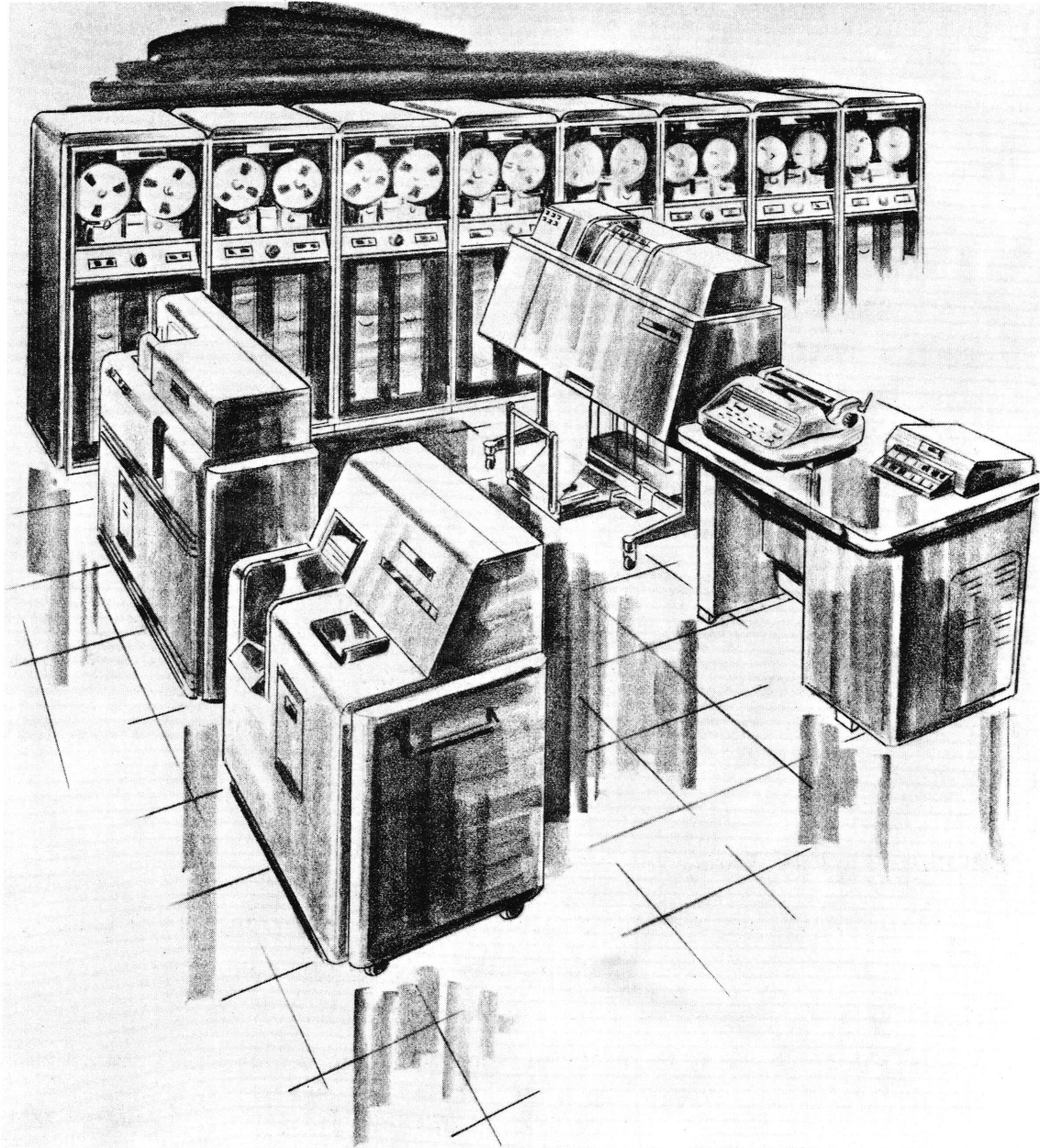
The Central Processor is capable of utilizing two core storage units simultaneously. The operand of a previous instruction is taken from unit B while a new instruction is being extracted from unit A, allowing the arithmetic element to operate continuously. With three or more storage units, input-output operations could also take place simultaneously under the control of the peripheral control unit.



Overlapped Operation

Up to eight core storage units of 16,384 words each can be attached to the 4020 initially, or subsequently at the installation.

LOCAL INPUT-OUTPUT



Local Input-Output

Number of tape units	1 - 48
Tape speed	62,500 characters per second
Card punch speed	100 cards per minute
Card reader speed	250 cards per minute
Line printer speed	600 lines per minute

The versatile Input-Output System of the IBM 4020 series includes the following peripheral equipment:

- Magnetic tapes for moderate speed, large-volume storage, and off-line data processing operations.
- Card equipment for instruction entry, maintenance operations, and off-line data processing.
- Printer for direct, high-speed hard-copy output.
- Input-output typewriter for computer inquiry, program modification, and intermediate reports.

SIMULTANEOUS OPERATION

The speed and flexibility of the computer has been extended by the use of a separate unit which controls the peripheral equipment independently of the Central Processor. One drum storage unit and many low-speed units, such as tapes, printer, typewriter, and card machines, may be operated simultaneously.

PERIPHERAL EQUIPMENT

The IBM 4020 series uses a card punch and reader capable of using either one of two card codes: conventional Hollerith or columnar binary. Columnar binary permits faster processing and is also, by increasing the information density per card, more compatible with off-line tape equipment.

The high-speed printer used may be switched for either on-line or off-line operations. In on-line operations, the printer requires only one instruction to print any number of words.

The 4020 uses a typewriter to enter information into or receive information from the computer. It is capable of inserting data in alphanumeric notation into a fixed number of locations in memory or data in octal notation into any memory location. The typewriter makes it possible to manually insert data or instructions into the computer: time of day, number of the program to be run next, program corrections in a debugging operation, etc. In addition, the typewriter can be used to query the computer for information needed by the programmer for subsequent decisions, thus completing the man-machine loop. A Comments switch gives the capability to add comments or notes to the record without entering them into the computer.

MAGNETIC TAPES

IBM 729 IV tape units provide a 62,500-characters-per-second read-write speed. Completely transistorized, they operate at a tape speed of 112.5 inches per second, and a bit density of 555 bits per linear inch. This high bit density has approximately doubled the word capacity of each tape unit to an average of 1,000,000 words (48-bit) per tape unit. An average figure is given since the tape capacity is dependent upon the number of end-of-record gaps. Facilities have been provided for a maximum of six permanent tape control units. Each unit can control a maximum of eight tape drives, resulting in a maximum of 48 tape units per computer. Six tapes, one with each control unit, can be used at one time.

NEW TAPE PROCESSING FEATURES

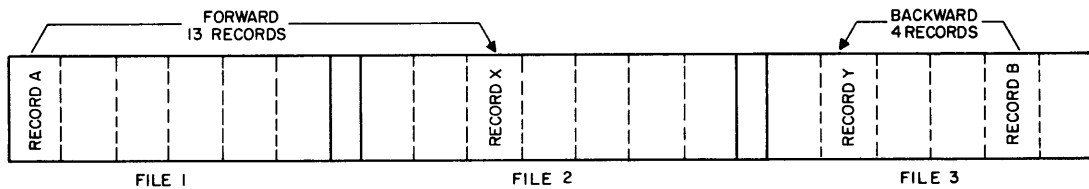
A reel of magnetic tape may contain a single sequence of data or it may contain many sequences of different data called files. The files are subdivided into units of information called records, as shown in the diagram below. It is often necessary to obtain data recorded on magnetic tape which, at the moment, is a considerable distance from the reading mechanism. To locate the desired information rapidly with a minimum of programming, two new features, Backspace-by-File and Read-by-Identity, have been included.

Read-by-Identity

The first word of each record can be used for identification. The Read-by-Identity feature permits each tape record to be interrogated independently of the Central Processor. Thus, while searching for the desired information at full tape speed, the Central Processor is free to perform other functions.

Backspace-by-File

The Backspace-by-File instruction causes the tape to move in the reverse direction through an entire file at normal tape speed. This instruction, together with the Backspace-by-Record instruction, greatly simplifies the location of information in the reverse direction.



TO MOVE TAPE FROM

Record A to X

Previous Systems - 86 instructions
4020 - two instructions, one
Read-by-Identity for each file

Record B to Y

Previous Systems - 31 instructions
4020 - two instructions, one
Backspace-by-File, one Read-by-Identity

FASTER RECORD LOCATION: USING LESS INSTRUCTIONS

Compatibility

The 729 IV tape unit can also read and write with a character density of 200 characters per inch. This facility to use tapes having lower character density makes the new tape system compatible with existing IBM equipment which may be used for program debugging, assembly, and data reduction.

REMOTE INPUT-OUTPUT

Number of input channels	108
Number of output channels	58
Input core storage	Up to 32,768 words

Additional input-output capacity is available if required.

MACHINE-TO-MACHINE INPUT

High-speed communication between computing systems is primarily limited by data transmission facilities. Generally, the cost of the communication facilities dictates that serial transmission of information shall be used. Effective communication between the systems then becomes more a matter of compatible data links and less a problem of computer design.

Some form of buffer storage must be used to assemble messages and provide temporary storage until the data can be transferred to the Central Processor. The IBM 4020 uses a common core storage unit to service all input channels. The incoming information is placed in the core storage unit, a bit at a time, as received from the telephone lines. When a complete message has been received, it is transferred to the Central Processor as 48-bit words. Transfer of a word from input storage to the Central Processor is accomplished in 2.5 usec.

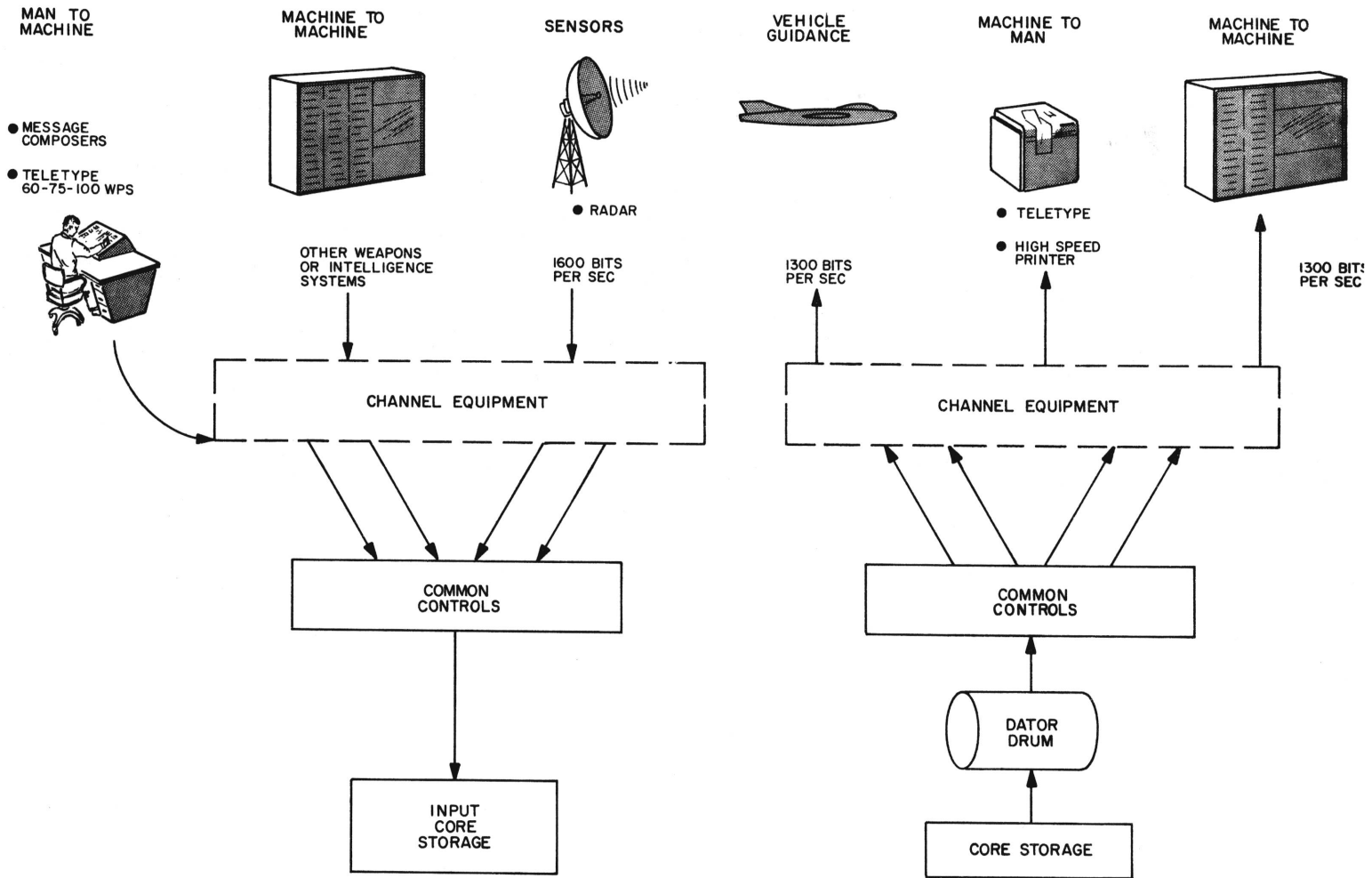
The quantity of data arriving on each input channel varies with time. Therefore, to insure optimum utilization of the available input storage, the number of locations assigned to each input channel is variable. Assignments are constantly revised by the computer to meet current requirements.

MAN-TO-MACHINE INPUT

Data entered into the system by operators at remote keyboards is automatically assembled into computer words and sent directly to the computer. This man-to-machine link extends the data collection capability of the computer to meet the requirements of systems using information from many and varied sources.

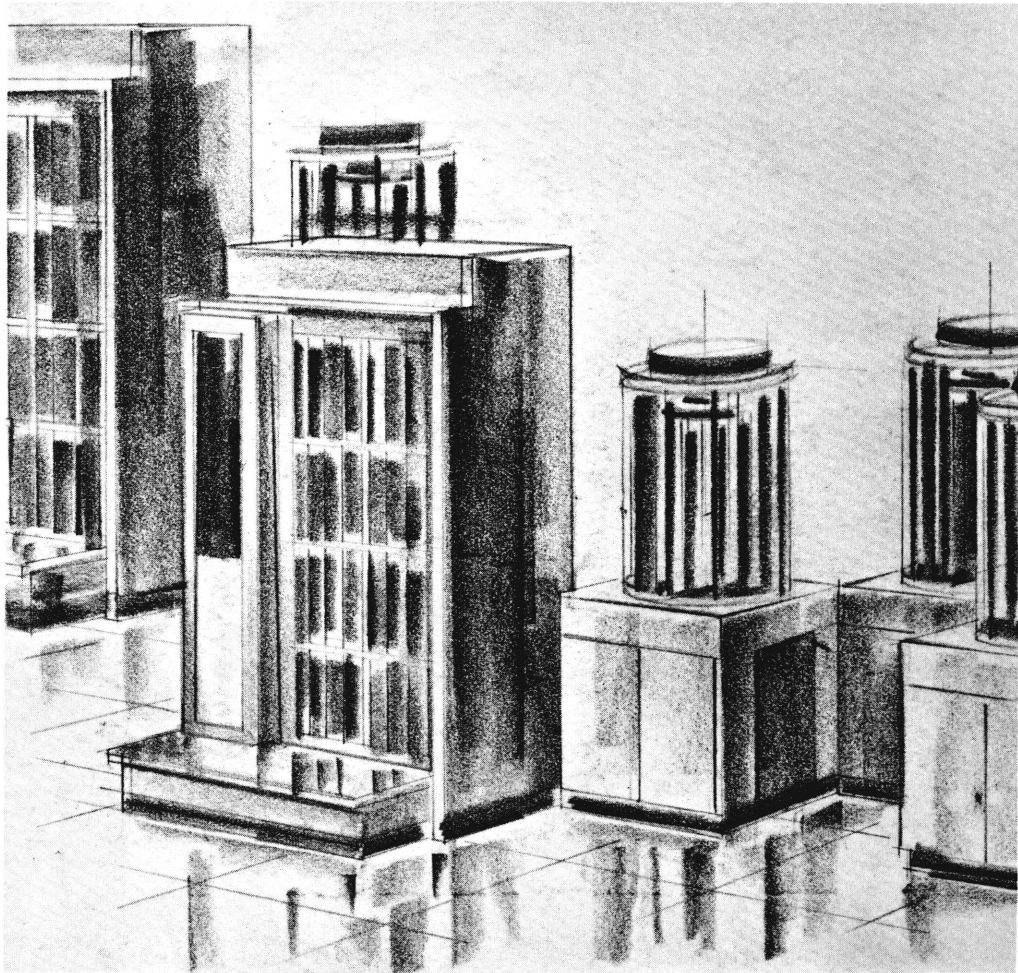
OUTPUT SYSTEM

The Output System translates computer words into phone-line messages and provides buffering between the computer and the relatively slow telephone line equipment. Simplicity and reliability are achieved by extensive use of magnetic core logic.



A Typical Remote Input-Output System

DRUM STORAGE



Drum Storage

Number of drums

1 - 4 auxiliary storage and
one Dator drum

or

1 - 8 auxiliary storage
drums

Number of words per drum	139,264
Number of words (48 bit) per field	8,192
Number of fields per drum	17
Average access time	11 ms
Data transfer rate	363,000 words per second

The Drum System fulfills a unique storage requirement by combining large storage capacity with a high data transfer rate. Auxiliary storage drums are efficiently used to store and retrieve large blocks of data or program subroutines which exceed the capacity of core storage. A second important function is performed by the Dator drum – accommodation of low-data-rate peripheral equipment. For example, information can be supplied by the computer approximately 20,000 times faster than it can be accepted by a telephone line. Therefore, during output operations, messages are stored on the drums, freeing the Central Processor for other activities.

DRUM CHARACTERISTICS

Dimensions	Length	27 inches
	Diameter	10.7 inches
Rotor speed	2,674 rpm	
Bit density	10,000 bits per square inch	

The magnetic drum is mounted vertically, with rotor and motor comprising an integral unit. A recently developed nickel-cobalt drum surface .0002 inch thick has made possible this high density storage and resolution. Drum tracks are packed 40 per linear inch with a bit density per track of 250 bits per inch.

PROGRAMMING FEATURES

Field stepping simplifies programming by permitting the reading of data from consecutive drum fields with the use of one instruction.

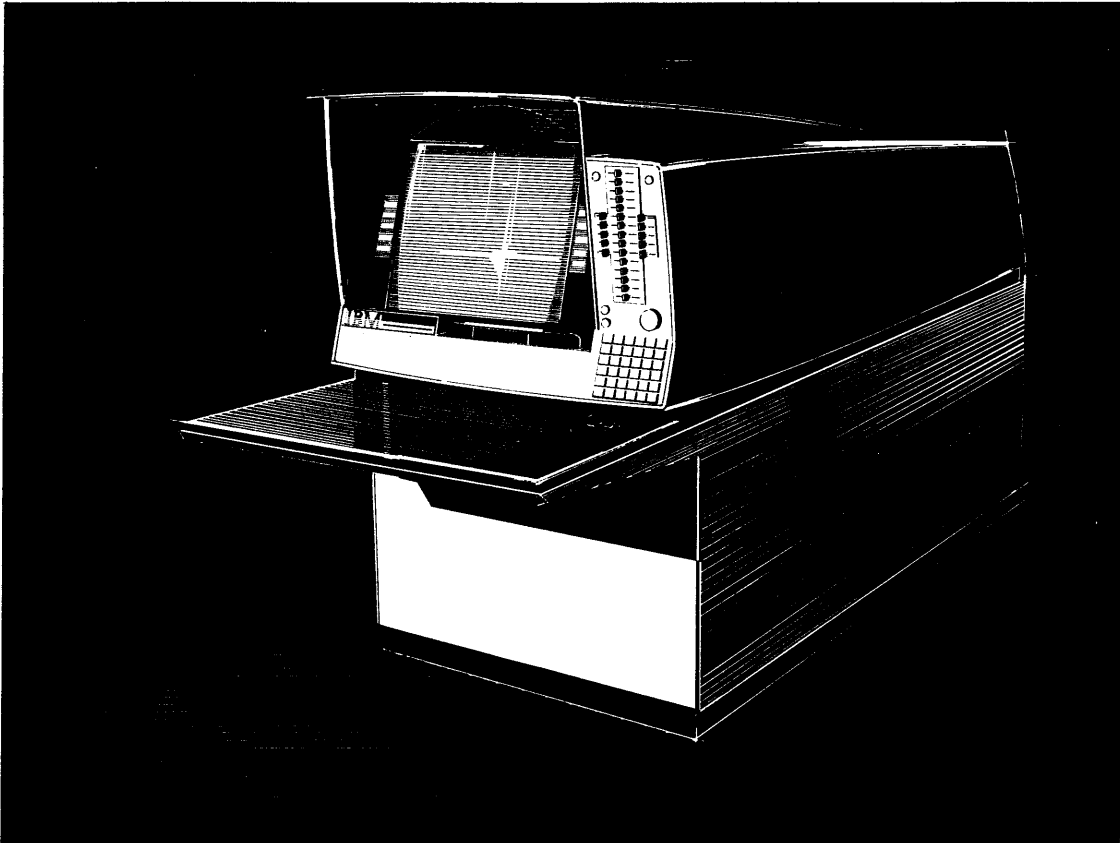
Interleaving, a method of reading or writing in nonconsecutive addresses, provides varying data transfer rates. This in effect makes the drum system compatible with the processing times of various equipments.

When a complete field of information is to be transferred (block transfer), the drum access time is effectively zero since the transfer begins with the first available drum word. The transfer is effected at the rate of 2.5 usec per word.

FLOATING DRUM HEADS

Bit density on the drum surface is in part dependent upon the head-to-surface spacing. To realize minimum spacing, a new floating head has been developed which maintains an extremely small uniform gap. As an additional benefit, this floating head minimizes the effects of temperature and humidity variations and drum eccentricity, thus eliminating the necessity for manual adjustment.

VISUAL DISPLAY



The Advanced Display Console

Command control centers concerned with the processing and control of vital data require a sophisticated system of man-machine communication. "Decision-makers" must be immediately and constantly apprised of trends as well as the current status of vital data. Much of this data is in a form not readily understood by humans; therefore, special output devices have been developed to effect the necessary man-machine relationship.

Since the particular application will dictate the specifications of visual displays, only general characteristics of some of the displays available with the IBM 4020 will be discussed.

OPERATIONAL ADVANTAGES OF THE ADVANCED DISPLAY SYSTEM

- Data is presented on the screen of a shaped beam cathode ray tube with an intensity which allows the level of lighting in the operational areas to approach normal room illumination. The increased clarity of the presentation results in the use of a display tube with greater light output and the addition of storage in the console which permits the data to be presented at a high repetition rate.
- Fast response time to changes in display selection made by the computer program and the operator have been provided. In the case of most operator changes the response is immediate.
- A flexible selection of data is provided to permit an operator to view only that information needed for a given decision.
- It is possible to remove one or the other of a pair of overlapping symbologies if an overlap should occur.
- With the exception of the cathode ray tube, solid-state circuitry is used exclusively. The storage capabilities and circuitry provided in each console will result in a decrease in the complexity of the common equipment. Reliability is therefore enhanced through a lessening of incidence of failure in the common equipment.
- Capability is provided for unlimited expansion in the number of consoles and their remote location. Consoles can be added to the system without changes to the common equipment.
- Expansion capabilities as high as X 32 are provided. These expansion capabilities will permit close examination of

critical areas, when required, without sacrificing any capability to view the over-all situation.

MAN-MACHINE COMMUNICATIONS

Visual displays for effective decision-making control are limited unless they provide adequate means for man to communicate with the system. Special devices were developed to provide this man-to-machine link.

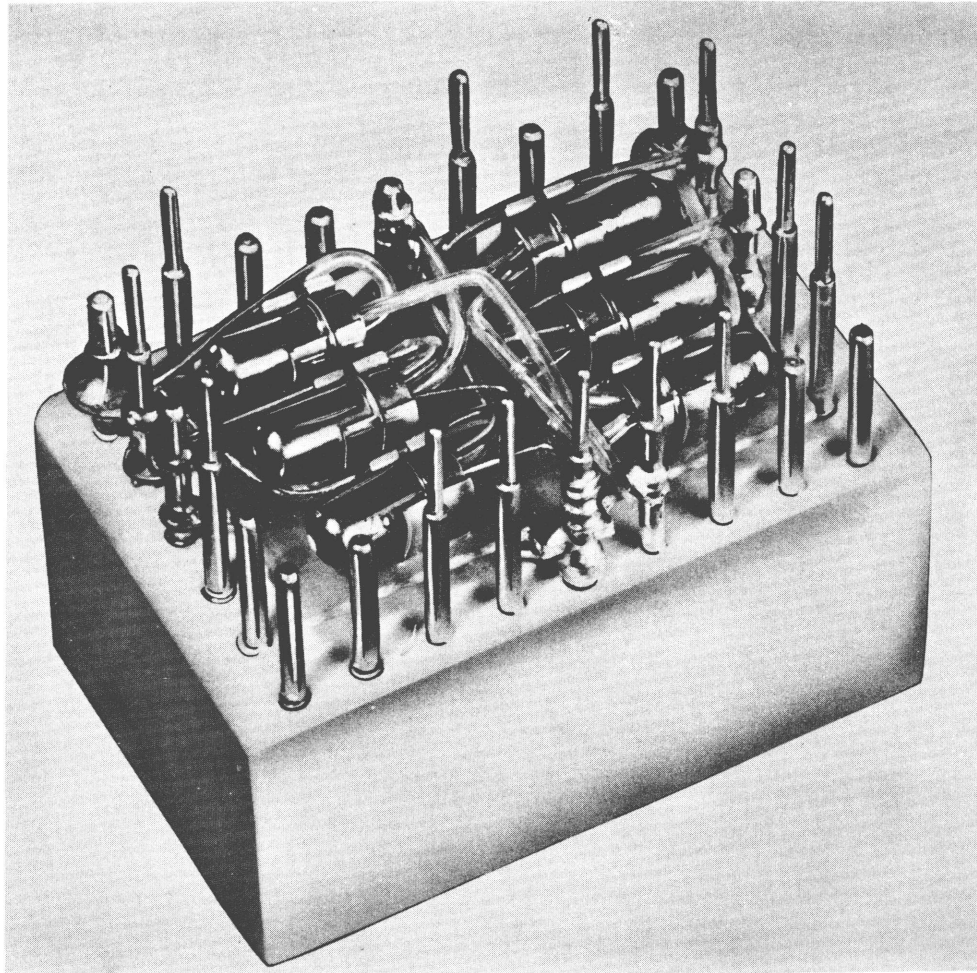
LIGHT GUN

The light gun is a hand-held photoelectric device which indicates a specific area or object. It can be used to request additional information or to specify an area to be expanded.

MESSAGE COMPOSER

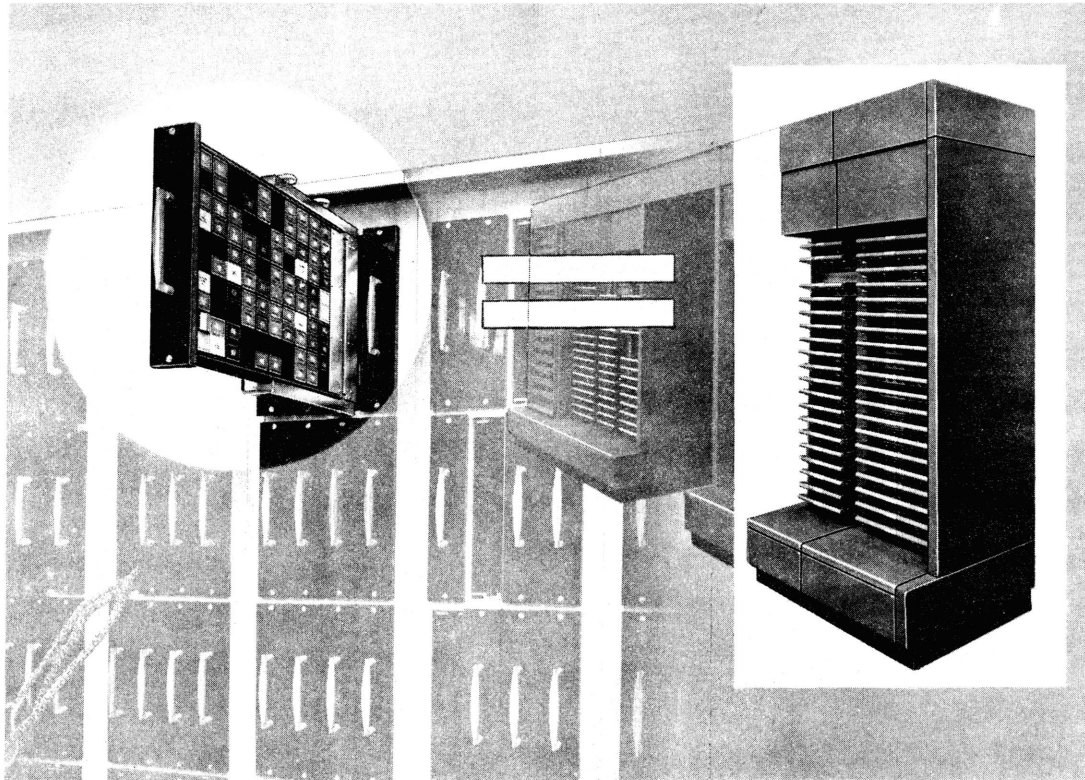
A Message Composer will be provided for the entry of input information. It will offer a simplified keyboard system which will allow rapid insertion of the information by the operator. The composed message may be viewed on a reserved area of the display before entry into the system.

PACKAGING



Physical Considerations

The primary purpose of packaging is to achieve volume efficiency and material economy. Packaging of electronic equipment for military applications dictates further requirements of MIL-SPEC ruggedness, rapid replacement, logistic compatibility, and resistance to the effects of nuclear blast.



Present Method vs. Old Method

These stringent requirements are met in the IBM 4020 by an extension of the rapid replacement concept: the use of pluggable, encapsulated circuit packages called Q-Pacs. The majority of all logic requirements can be met by seven basic types of Q-Pacs, each containing from one to four circuits. The use of transistors and semiconductor diodes, together with miniaturized components, has reduced circuit volume to 1/40 of equivalent vacuum tube equipment. To facilitate heat dissipation and replacement, these transistors and diodes are soldered outside the encapsulated portion of the package.

As many as 96 Q-Pacs may be mounted in the vertical sliding drawer, shown in the photograph. This drawer, occupying 0.8 cubic foot, contains the circuit equivalent of approximately 200 vacuum tubes, depending on type of circuit. Finally, 16 sliding drawers are mounted in a module, which constitutes a major logic section of the computer.

IBM's RESPONSIBILITY

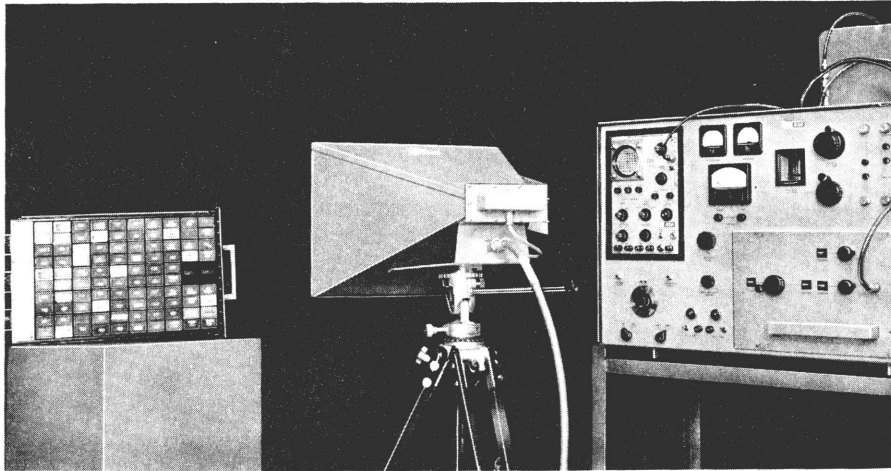
As a military contractor, IBM has assumed a commitment to develop and produce equipment on which the nation can depend for its defense. To fulfill this responsibility, the Federal Systems Division has evolved a reliability discipline: a step-by-step process from design to delivery that assures the inherent reliability of each piece of equipment. The major steps in this discipline are discussed briefly below.

APPLIED EXPERIENCE

IBM's responsibility does not end with the delivery of the equipment. A continuous performance analysis is carried out on each operating system. As a result, the operational data from the SAGE System, the world's largest high-speed data handling system, has been invaluable in designing the IBM 4020.

COMPONENT EVALUATION

One of the most important factors contributing to system reliability is the long, uniform life expectancy of common components. Critical components are subjected to a design evaluation that includes electrical measurements, accelerated tests-to-failure, and physical analysis (dissections, X-ray examinations, and photomicrograph studies). A component surviving the design tests is then subjected to environmental tests covering heat, humidity, shock, vibration, dust, salt spray, fungus, and radiation. Only after successfully completing both design and environmental tests is a component approved for use by the circuit designers.



Component Evaluation

CIRCUIT DESIGN

The goal of the circuit designers is to develop basic building blocks which will have long life regardless of end-of-life variations in power supplies and components. Circuit optimization has been advanced by the evolution of the Margin Diagram technique, which locates the design center of two or more variable parameters.

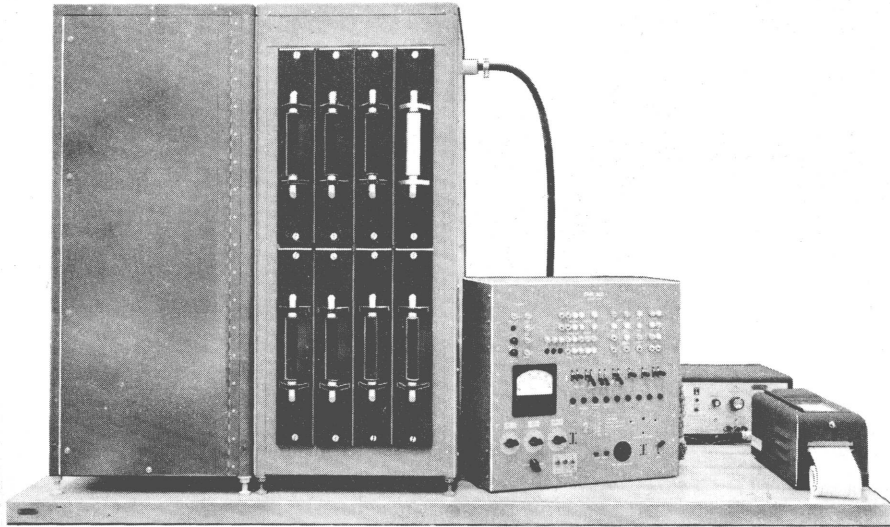
CIRCUIT FEASIBILITY MODEL

An intermediate step in the IBM 4020 program was the design, construction, and test of a 600-transistor bench model to prove the feasibility of the new transistor circuits when placed in the environment of the equally new electronic packaging. The successful operation of the Circuit Feasibility Model (CFM) proved the validity of the component selection, circuits, packaging, and logic.

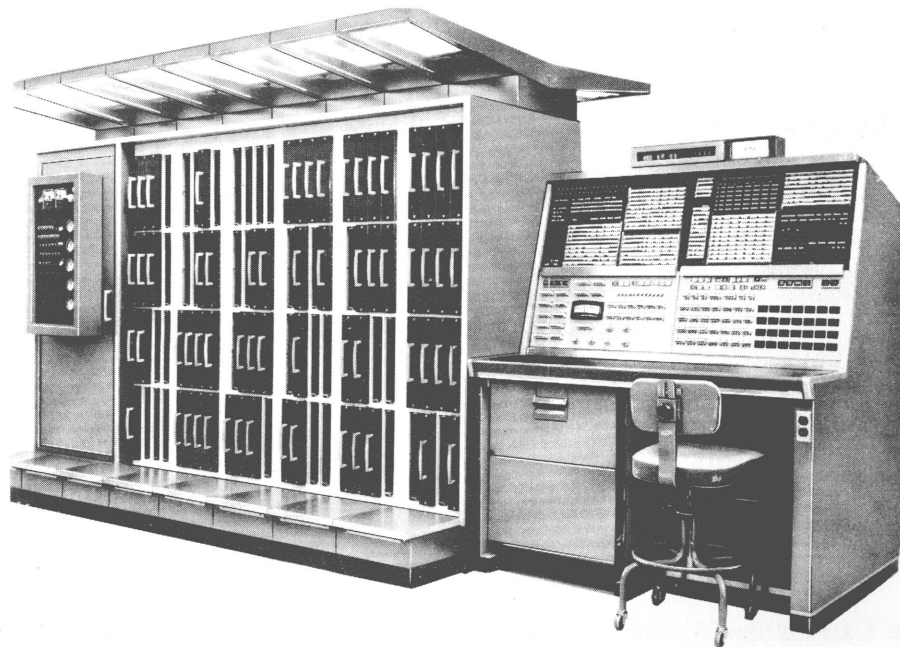
RELIABILITY TEST ASSEMBLY

The CFM was followed by the Reliability Test Assembly (RTA) which combines into one machine the components, circuits, logic, and packaging

developed under various engineering projects. A prototype computer, RTA was constructed to test and evaluate advanced logic design and circuitry in a realistic environment.



Circuit Feasibility Model



Reliability Test Assembly

IBM 4020 SYSTEMS

Each step of the reliability discipline has prepared IBM Federal Systems Division engineers for a new endeavor in the computer field – the IBM 4020 Military Computer. Some of the outstanding reliability features of this system are:

Transistors and Semiconductor Diodes - Transistors and semiconductor diodes have been used almost exclusively to improve the over-all reliability of the system. It is expected that this feature alone will substantially increase reliability over vacuum tube systems.

Error Detection - Optimum error detection circuitry is employed throughout the computer to detect parity errors and register transfer errors, illegal address selection, timing errors, missing or extra pulses, etc. This self-checking ability and appropriate diagnostic programs will indicate the location of an error to a small group of replaceable Q-Pacs, permitting correction with minimum delay. To facilitate maintenance procedures, certain portions of the computer, such as drums and tapes, have the capability to carry out self-checking routines, independently of the Central Processor.

Error Correction - During real-time operations, random or intermittent errors may impair the efficiency of the system. An extension of Priority Processing, previously described in the Central Processor section, enables the computer to remain in operation during critical periods. When an error is indicated, processing is momentarily suspended and program control branched to an error correction routine. Pertinent data and the detail nature of the error are automatically analyzed, and, with few exceptions, the erroneous information is automatically corrected. This information is printed out for performance history or audit, and control is returned to the original program.

SUMMARY

The IBM 4020 advances the art of data processing by increasing the system's capability and reliability. The Q-Pac, for example, is an ingenious method of packaging components to insure reliability and long life. This, coupled with the automatic error detection and correction techniques included in the 4020, insures the operation of the system for remarkably long periods of time.

In achieving the stringent design objectives of the IBM 4020, new horizons of system capability are now available. This system capability permits present applications to be processed more efficiently while providing the characteristics necessary for mechanizing or improving applications concerned with the processing of vital data.

Further information may be obtained by contacting the local IBM office or by writing to Federal Systems Division - WHQ, 590 Madison Avenue, New York 22, New York.

IBM[®]
