BTL Power Dissipation Calculation

National Semiconductor
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INTRODUCTION

Futurebus+ systems designed today have bus widths of 32 or 64. To support higher bandwidths in the future, Futurebus+ provides a data width extension of up to 256 bits. BTL (Backplane Transceiver Logic) is the electrical signaling environment for Futurebus+. The number of BTL transceivers in a system will increase as the bus width is extended to accommodate higher bandwidths. A total of 16 transceivers is required to implement a 64-bit data bus. Four 6-bit Handshake Transceivers (DS3884A) are used for the handshake, central arbitration, capability and serial bus lines. One 9-bit Arbitration Transceiver (DS3885) is used for the arbitration competition lines. Three 9-bit Data Transceivers (DS3883A or DS3886A) are used for the command, status and tag lines. A 64 wide bus with byte parity requires 8 data transceivers for the multiplexed address and data lines alone. A 256 wide bus requires 32 data transceivers. Including the other lines, the total number of transceivers on single board for a 256-bit data bus is 40. The power required and dissipated by these transceivers must be fully understood to design an efficient cooling and power supply system for the backplane. Power calculations differ depending on the assumptions made concerning supply and output power. This application note illustrates how to use graphs provided by manufacturers to obtain accurate power calculations. Power is calculated for these conditions; worst case, driver outputs high, driver outputs low and outputs switching.

POWER CALCULATION EQUATIONS AND DEFINITIONS

Table 1 summarizes the equations and terms used in following discussions.

CALCULATING BTL POWER USING THE STANDARD METHOD

The power equation may be divided into two parts. One part is the supply power (P_S) which is derived from the quiescent current flowing into the power pins. The other is output power (P_O) derived from current flowing into or out of the input and output pins. The standard method to calculate P_S and P_O is to use specifications available in the DC Electrical Characteristics of datasheets. I_{CC}(typ) and I_{CC}(max) are typical and maximum supply current which may be found directly within the DC Electrical Characteristics. Typical power dissipation (P_{S_Typ}) is equal to I_{CC}(typ) x V_{CC}(typ). Maximum power dissipation (P_{S_max}) is equal to I_{CC}(max) x V_{CC}(max). Output power is different when the output is low and when it is high. With the output high (the device is in high impedance) essentially zero current flows in or out of the device and P_O equals zero. With the output low, P_O is equal to V_{OL}(max) x I_{OL}(max). P_O is worst case when the output is low or asserted. Typical and Maximum power calculations are shown in *Table 2* for DS3886A. V_{OL} and I_{OL} will differ depending on the termination resistor and voltage used on the backplane which is not taken into account. Actual P_O for Futurebus+ is less and an accurate calculation of power dissipation is presented later.

TABLE 1. Power Calculation Equations and Terms

Parameter	Equation	Description
V_{CC}	$4.5V < V_{CC} < 5.5V$	Supply Voltage
I_{CC}	See DC Electrical Characteristics, Typical I_{CC} vs Temperature Curves or Typical I_{CC} vs Frequency	Supply Current
V_{OL}	See Typical I_{OL} vs V_{OL} Curves	Output Low Voltage For the BTL Driver V_{OL} will Depend on the Termination Resistance Used
I_{OL}	See Typical I_{OL} vs V_{OL} Curves	Output Low Current For the BTL Driver I_{OL} will Depend on the Termination Resistance Used
V_t	2.1V	Termination Voltage
P_S	I_{CC} x V_{CC}	Supply Power Power Dissipated Due to Quiescent Current Flowing into Power Pins
P_O	V_{OL} x I_{OL} $(V_{CC} - V_{OH})$ x I_{OH}	Output Power Power Dissipated per Channel at the Driver or Receiver Output when the Output is Low Power Dissipated per Channel at the Driver or Receiver Output when the Output is High; For BTL I_{OH} is Zero

TABLE 2. Standard Power Calculations for the DS3886A

Typical	Max
P_S = 5.0V x 55 mA = 275 mW	P_S = 5.5V x 62 mA = 341 mW
P_O = 1.0V x 65 mA = 65 mW	P_O = 1.1V x 80 mA = 88 mW
P_{total} = 275 mW + (65 mW x 9) = 860 mW	P_{total} = 341 mW + (88 mW x 9) = 1.13W

REVIEW OF BTL — BACKPLANE TRANSCEIVER LOGIC

A brief review of BTL is given to help the reader understand how the driver operates. A schematic of the BTL output stage is shown in *Figure 1*. The driver output is composed of a Schottky diode — DS2 in series with the collector of transistor Q1. DS2 shields the capacitance of Q1 from the bus to reduce capacitive loading. When the driver is asserted Q1 is "on", node a is approximately 0.4V, and node b is approximately 1V. Current flows from the 2.1V termination voltage through Rt/2, through DS2 and into the collector of Q1. When the driver is released Q1 is "off", a 12.5 kΩ resistor pulls node a which is clamped to 3V by four diode clamps (DC1 to DC4) in series. DS2 is reversed biased (node a is at a higher potential than node b), with node b at 2.1V which is equal to the termination voltage. Essentially zero current flows into or out of the driver output.

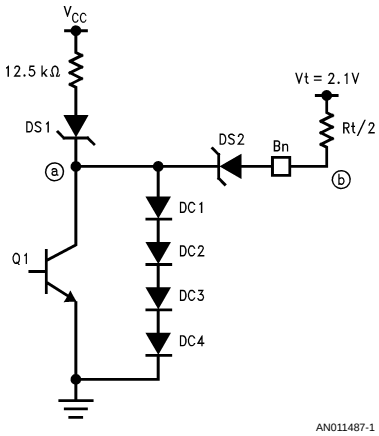


FIGURE 1. Futurebus+ BTL Driver Output Schematic

CALCULATION OF OUTPUT POWER USING LOAD LINES

IEEE 1194.1 BTL Electrical Characteristics define I_{OL} and V_{OL}. BTL devices are required to sink 80 mA (I_{OL}) within a specified V_{OL} range of 0.75V to 1.1V. This requirement was established to maintain compatibility between vendors offering BTL devices. The BTL devices offered by National conform to this specification. The actual I_{OL} flowing into the output is dependent on the termination resistor and voltage on the backplane. National's datasheets specify 12.5Ω in series with 2.1V to test AC and DC requirements which conform to an I_{OL} of 80 mA. The equivalent representation of a 12.5Ω load in a backplane environment is 25Ω at opposite ends. The Thevenin equivalent of two 25Ω resistors is 12.5Ω. Futurebus+ requires 33Ω termination resistors in series with 2.1V at each end of the backplane as shown on *Figure 2*. The Thevenin equivalent for the Futurebus+ termination of 33Ω is 16.5Ω in series with 2.1V which is shown in *Figure 3*. I_{OL} for a Futurebus+ termination will be less than 80 mA.

I_{OL} for a Futurebus+ termination is equal to the intersection point between the output V_{OL} vs I_{OL} curve and the resistor load line as shown on *Figure 4*. The intersection point for a Futurebus+ load line of 16.5Ω in series with 2.1V at 25˚C, is 65 mA and 1.025V. The intersection point for 12.5Ω in series with 2.1V is 83 mA and 1.075V. The intersection point for 9Ω in series with 2.1V is 110 mA and 1.125V. I_{OL} and V_{OL} may be obtained for any termination resistor and voltage using the load line intersection point.

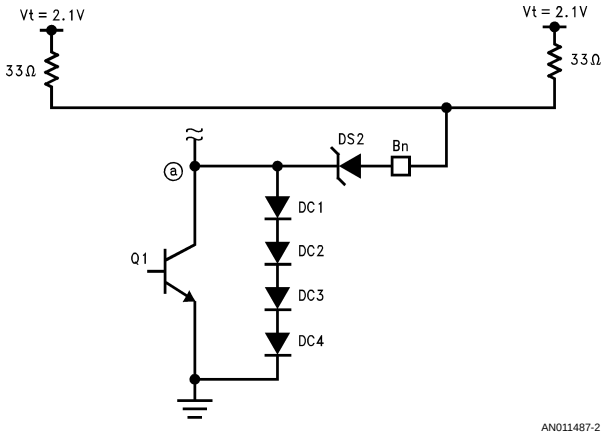


FIGURE 2. Futurebus+ Backplane Termination

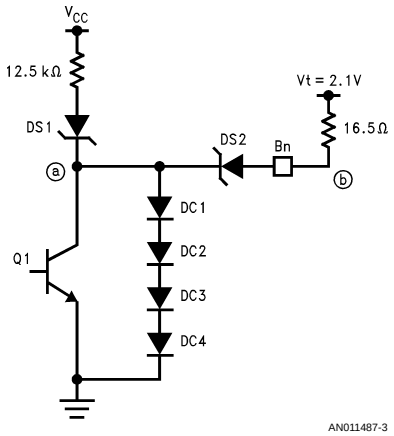


FIGURE 3. Thevenin Equivalent of Futurebus+ Backplane

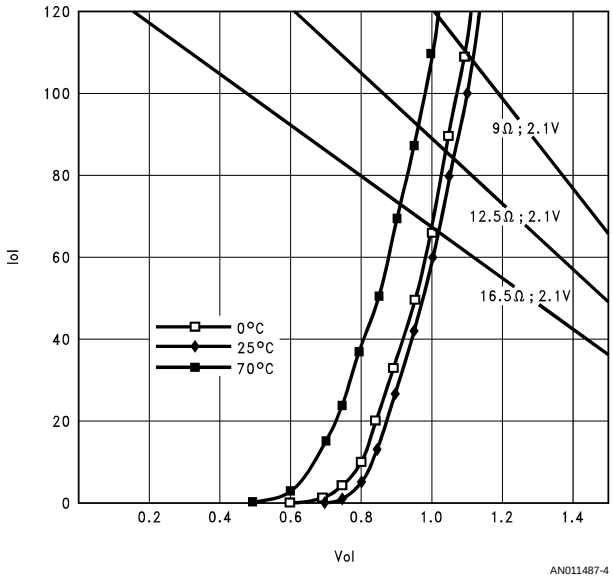


FIGURE 4. I_{OL} vs V_{OL} and Load Line

Output power (P_O) per channel is equal to the product of I_{OL} vs V_{OL} at the intersection point. For Futurebus+ with the driver asserted, the point of intersection is 65 mA and 1.025V which yields 66.6 mW for output power. Output power for a transceiver is directly proportional to the number of bits. A 9-bit transceiver (like the DS3886A, DS3883A or DS3885) with all outputs low will need to dissipate 599 mW, which is 66 mW times 9 bits. In addition to P_O, P_S must also be included for the total power. Calculations for P_S will be given later. Output power for different loads is shown on *Table 3*. Output power almost doubles when the resistor is reduced from 16.5Ω to 9Ω. When all drivers are released, the outputs are in a high impedance state and pulled high by the termination. At this state, essentially zero power is dissipated at the outputs.

Output power is also dependent on the duty cycle. The power dissipated at the output will equal the average power between the asserted and the released state. Assume that in a normal operation the drivers are high half of the time and low half of the time. This condition may be approximated to a 50% duty cycle. Power is calculated for a 50% duty cycle in *Table 3*. To calculate power for other duty cycles the equation below may be used:

$$P_{O(k)} = P_O \text{ (asserted)} \times k$$

where k is equal to the duty cycle.

For example, P_O is calculated for a 9-bit device terminated according to Futurebus+ specification with a 60% duty cycle.

$$P_{O(60\%)} = 600 \text{ mW} \times 0.60 = 360 \text{ mW}$$

CALCULATION OF TOTAL BTL TRANSCEIVER POWER

Total Power is equal to the sum of P_O and P_S. Using P_O from *Table 3* and P_S derived from *Figure 5*, *Figure 6*, *Figure 7*, *Table 4* shows total typical power for different conditions; all outputs high, all outputs low, 10 MHz and 20 MHz with 50% duty cycles. Supply power is equal to $I_{CC} \times V_{CC}$, where V_{CC} and I_{CC} were taken from *Figure 5*, *Figure 6*, *Figure 7*. *Table 5* shows Maximum power using I_{CC}(max) x V_{CC}(max) from the datasheet.

TABLE 3. Calculation of BTL Output Power (T = 25˚C)

Termination Voltage (V)	Termination in Parallel (Ω)	Output Low Current — I_{OL} (mA)	Output Low Voltage — V_{OL} (V)	Output Power (mW)	Output Power 6-Bits (mW)	Output Power 9-Bits (mW)
BTL OUTPUT POWER PER CHANNEL WHEN DRIVERS ARE ASSERTED						
2.1	16.5	65	1.025	66.6	400	600
2.1	12.5	83	1.050	87.2	523	784
2.1	9	110	1.125	123.8	743	1,114
BTL OUTPUT POWER PER CHANNEL WHEN DRIVERS ARE RELEASED						
2.1	16.5, 12.5 or 9	0	2.1V	0	0	0
BTL OUTPUT POWER PER CHANNEL WHEN DRIVERS @ 50% DUTY CYCLE						
2.1	16.5	65	1.025	66.6/2	200	300

TABLE 3. Calculation of BTL Output Power (T = 25˚C) (Continued)

Termination Voltage (V)	Termination in Parallel (Ω)	Output Low Current — I_{OL} (mA)	Output Low Voltage — V_{OL} (V)	Output Power (mW)	Output Power 6-Bits (mW)	Output Power 9-Bits (mW)
BTL OUTPUT POWER PER CHANNEL WHEN DRIVERS @ 50% DUTY CYCLE						
2.1	12.5	83	1.050	87.2/2	262	392
2.1	9	110	1.125	123.8/2	372	557

TABLE 4. DS3886 Typical Power with Futurebus+ Termination

Parameter	Supply Power	Output Power	Total Power
All Outputs Low (25˚C and 5V)	210 mW	600 mW	810 mW
All Outputs High (25˚C and 5V)	140 mW	0 mW	140 mW
Switching at 10 MHz (25˚C and 5V)	230 mW	300 mW	530 mW
Switching at 20 MHz (25˚C and 5V)	235 mW	300 mW	535 mW

TABLE 5. DS3886 Maximum Power with Futurebus+ Termination

Parameter	Supply Power	Output Power	Total Power
All Outputs Low	341 mW	600 mW	941 mW

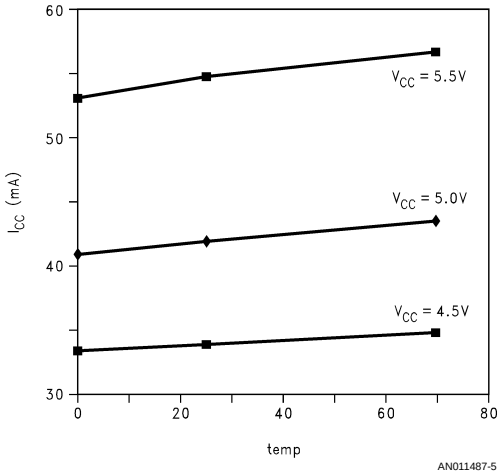


FIGURE 5. DS3886A I_{CC} vs Temperature (All Bn Outputs Low)

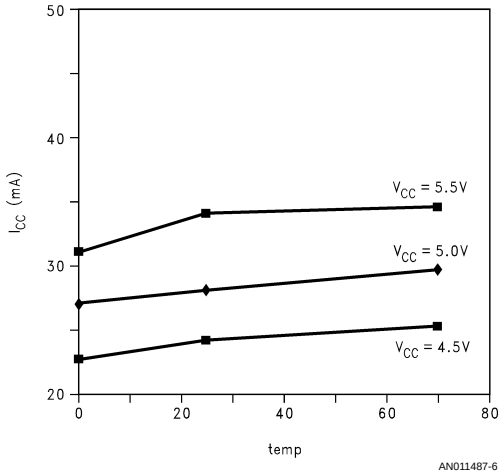


FIGURE 6. DS3886A I_{CC} vs Temperature (All Bn Outputs High)

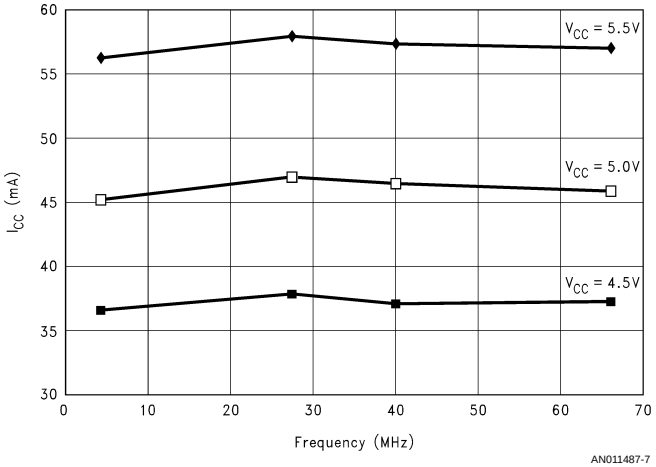


FIGURE 7. DS3886A I_{CC} vs Switching Frequency (A_n to B_n) (All Channels Switching at Room Temperature)

The maximum power dissipation result shown in *Table 5* is 1.315W compared to 1.51W in *Table 2* derived from the standard method. Power calculated using the standard method is 15% higher than actual maximum of 1.315W. I_{OL} of 80 mA and V_{OL} of 1.1V was used in the standard method yielding the higher P_O. The results derived in *Table 5* take into account the Futurebus+ termination specification in the calculation of P_O. There are four typical power calculations in *Table 4* reflecting different conditions. Typical power varied from 325 mW when all outputs are high to 990 mW when all outputs are low. The typical power calculated in *Table 2* is 1.08W which is 10% higher than that calculated in *Table 4*. These different power calculations are important when determining the total power of a system. A Futurebus+ backplane may contain several modules. Only one module may transmit data on the bus while others receive. It is important to know how to calculate power dissipation for modules in the transmit mode as well as modules in the receive mode to derive accurate system power.

CALCULATION OF SYSTEM POWER REQUIREMENTS

In a backplane, one board will normally be active and driving the bus while other modules are receiving or in standby. If all lines were asserted, the termination voltage must be able to supply enough current to all the lines. To determine the current requirement from the termination voltage, use this equation;

I_{OL} x Number of Lines = Termination Current

In a 32-bit Futurebus+ backplane the total number of lines will be 89 which includes all the required lines in addition to the 32-bit address/data lines. The current requirement from the termination supply will be;

65 mA x 89 Lines = 5.79A

A 64-bit Futurebus+ backplane requires;

65 mA x (89 + 32 + 4) = 8.13A

Calculation of typical system power is shown below. Two assumptions are made for the given equation. First, one module transmits while others receive. Second, the transmitting module will have an average duty cycle equal to 50% and running at 20 MHz. Power per bit allows easy calculation of total power for different number of lines. Dividing the total transceiver power by the number of bits on the transceiver will yield power/bit. The total number of modules on the backplane minus one gives the number of receiving modules. The receiving modules will have their outputs in a high state.

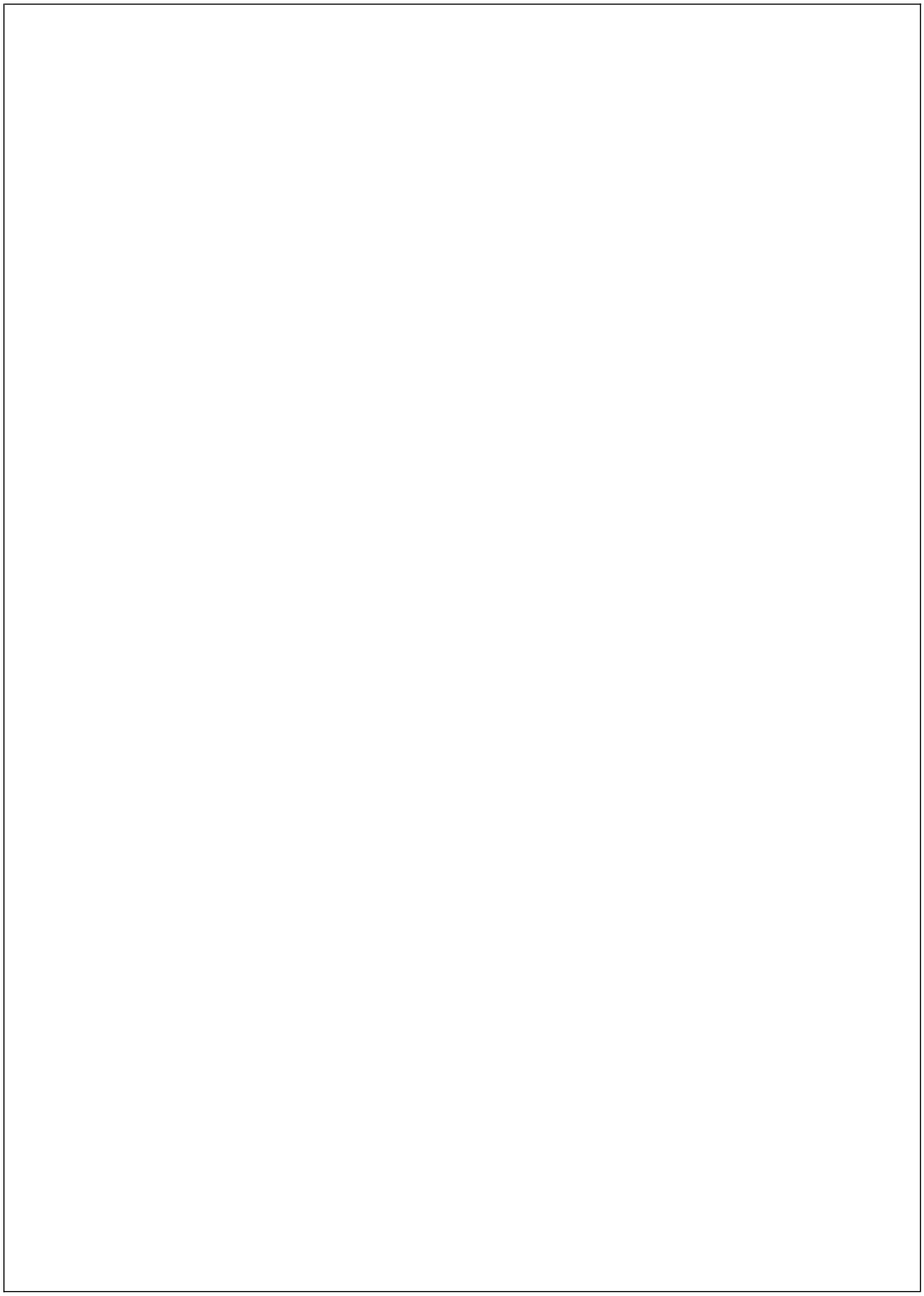
(Power/bit with 50% Duty Cycle @ 20 MHz x # of Lines) + (# Boards − 1) (Power/Bit with all Outputs High x # of Lines) = Transceiver System Power

For a 32-bit Futurebus+ Interface with 14 boards the transceiver system power required will be;

(725 mW/9 x 89) + (14 − 1) (325 mW/9 x 89) = 49W

CONCLUSION

There are several ways of calculating power dissipation. The results of these calculations will greatly vary depending on the assumptions. An error in calculating output power will be multiplied when extending the results to determine overall system power. A thorough understanding of how to calculate power will yield accurate power calculations. A preferred method of calculating output power is to use the load line intersection point. Typical power dissipation calculation should use duty cycle approximation. Typical device curves are provided with datasheets. Refer to individual datasheets for most up to date information. With this background, the designer will be able to make accurate thermal and power analysis of the interface which may ultimately reduce cost.



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