AN-1179
APPLICATION NOTE

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Junction Temperature Calculation for Analog Devices RS-485/RS-422, CAN, and LVDS/M-LVDS Transceivers

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INTRODUCTION

The reliability of a semiconductor is determined by the junction temperature, which in turn is dependent on several factors including device power dissipation, package thermal resistance, printed circuit board (PCB) layout, heat sink interface, and ambient operating temperature. This application note describes these considerations, and provides guidance for determining the maximum junction temperature and power dissipated for isolated and nonisolated RS-485 and RS-422, controller area network (CAN), low voltage differential signaling (LVDS), and multipoint low voltage differential signaling (M-LVDS) transceivers from Analog Devices, Inc.

JUNCTION TEMPERATURE

The junction temperature refers to the temperature of the semiconductor in an integrated circuit (IC). By keeping the junction temperature low, the long-term reliability of the device improves. Use Equation 1 to estimate the junction temperature.

$$T_J = T_A + \theta_{JA} P_{DISS} \quad (1)$$

where:
T_J is the junction temperature (°C).
T_A is the ambient temperature (°C).
θ_{JA} is the junction to ambient thermal resistance (°C/W).
P_{DISS} is the total device power dissipation (W).

The maximum ambient operating conditions appear on all Analog Devices data sheets. The junction temperature, thermal resistance, and power dissipation are stated, or are calculable.

Equation 1 is one method of determining the junction temperature; other methods include complex, three-dimensional finite element analyses, as well as direct measurement of IC temperature using thermocouples.

THERMAL RESISTANCE

The junction to ambient thermal resistance, θ_{JA} (°C/W), defines the resistance when heat transfers from a hot IC junction to ambient air.

The thermal resistance values provided in Analog Devices data sheets assume a 4-layer JEDEC standard board with no cooling airflow, and no heat sink on the board. Airflow over the IC package reduces the package thermal resistance, and allows an increase in power dissipation for the rated maximum junction temperature. A heat sink allows heat removal and a lower thermal resistance for the IC by providing a conduction path from the device to the PCB and chassis.

MAXIMUM POWER DISSIPATION

The power dissipation of the bus interface (transceiver plus load) is key when evaluating the thermal and reliability characteristics of the transceiver device. The total power is the sum of the power dissipated in the transceiver due to the loading of the output and the transceiver quiescent power.

The maximum safe power dissipation for a particular device is limited by the associated rise in junction temperature on the die. Usually, the maximum rated junction temperature is 150°C. At a given ambient temperature operating condition and thermal resistance, the corresponding maximum power dissipation can be calculated. The maximum power dissipation may, in some cases, be much larger than the power dissipated for a typical transceiver application.

At a junction temperature of 150°C, the properties of the plastic of the device package change. Even temporarily exceeding this temperature limit may change the stresses the package exerts on the die, permanently shifting the parametric performance of the transceivers. Exceeding a junction temperature of 150°C for an extended period may result in a loss of functionality.

ABSOLUTE MAXIMUM RATINGS

Analog Devices data sheets provide absolute maximum ratings for isolated and nonisolated RS-485 and RS-422, CAN, and LVDS/M-LVDS transceivers. Stresses at or above those listed under the absolute maximum ratings may cause permanent damage to the device. Operation beyond the maximum operating conditions for extended periods may affect product reliability.

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DEVICE PORTFOLIO

CAN TRANSCEIVERS

Analog Devices CAN transceivers provide the differential physical layer interface between the data layer link, hardware protocoller, and the physical wiring of the CAN bus. The AN-1123 Application Note provides a CAN implementation guide. Analog Devices offers the isolated CAN ADM3052, ADM3053, and ADM3054 transceivers, and the nonisolated CAN ADM3051 transceiver. The isolated CAN devices include Analog Devices integrated *i*Coupler® and *iso*Power® isolation technology (see the *i*Coupler and *iso*Power Technology section).

The data sheets for these products specify a maximum junction temperature of 130°C or 150°C in the absolute maximum ratings table. The thermal impedance (junction to ambient) and ambient temperature operating conditions are also provided. Use Equation 1 to determine the maximum allowable power dissipation for a given ambient temperature operating condition, in this case 85°C or 125°C.

Table 1 provides the maximum allowable power dissipation. Alternatively, power dissipated by a CAN device is calculable under given loading conditions, with Equation 1 used to determine the corresponding junction temperature. As previously noted, the maximum power dissipation in Table 1 may be greater than the power dissipated for a typical transceiver application.

Table 1. Power Dissipation and Junction Temperature for Analog Devices CAN Transceivers

CAN Part Number	Junction Temperature (°C)	T_A Max (°C)	Thermal Impedance (°C/W)	Power Dissipation (W)
ADM3051	150	125	110	0.227
ADM3053	130	85	53	0.849
ADM3054	150	125	53	0.472

The ADM3054 data sheet provides logic and bus side currents for given loading conditions. The maximum logic side current is 3.0 mA, with the greatest bus side current of 75 mA for an output load resistance of 60 Ω. Use Equation 2 to determine the power dissipated for a voltage of 5 V.

$$P_{DISS} = VI - I^2 R_L$$
$$= (5\text{ V})(3.0\text{ mA}) + (5\text{ V})(75\text{ mA}) - (25\text{ mA})^2(60\ \Omega) = 352.5\text{ mW} \quad (2)$$

where:
V is the transceiver voltage (V).
I is the transceiver current (logic side, quiescent, bus side) (mA).
R_L is the typical load driven by a CAN application.

All bus side current does not flow through the R_L load resistor; therefore, only the current portion typically flowing through R_L is subtracted.

For a power dissipation of 352.5 mW and a thermal impedance of 53°C/W, the corresponding rise in junction temperature is approximately 18°C. Using Equation 1 for an ambient operating temperature of 125°C, the junction temperature is 143°C.

LVDS DRIVERS AND RECEIVERS

Analog Devices LVDS drivers (transmitters) and receivers provide high speed signaling single-ended to differential solutions for point-to-point applications. For example, the ADN4663 LVDS driver is capable of operating at up to 600 Mbps, and the ADN4664 LVDS receiver can operate at up to 400 Mbps. The LVDS portfolio from Analog Devices features enhanced ±15 kV ESD protection. The AN-1177 Application Note provides an LVDS and M-LVDS circuit implementation guide.

The LVDS data sheets provide the maximum junction temperature in the absolute maximum ratings table. For each of the LVDS devices, the maximum junction temperature is 150°C. The absolute maximum ratings table specifies thermal impedance, along with the maximum ambient operating temperature. Use Equation 1 to calculate the power dissipation. Table 2 details the maximum allowable power dissipation for the maximum ambient temperature operating condition for each of the LVDS devices.

Table 2. Power Dissipation and Junction Temperature for Analog Devices LVDS Drivers and Receivers

LVDS Part Number	Junction Temperature (°C)	T_A Max (°C)	Thermal Impedance (°C/W)	Power Dissipation (W)
ADN4661	150	85	149.5	0.435
ADN4662	150	85	149.5	0.435
ADN4663	150	85	149.5	0.435
ADN4664	150	85	149.5	0.435
ADN4665	150	85	150.4	0.432
ADN4666	150	85	150.4	0.432
ADN4667	150	85	150.4	0.432
ADN4668	150	85	150.4	0.432
ADN4670	150	85	59	1.102

As an alternative to the maximum power dissipation provided in Table 2, calculate the power dissipated by an LVDS device under typical conditions, and use Equation 1 to determine the corresponding junction temperature. As previously noted, the maximum power dissipation may be much greater than the power dissipated for a typical transceiver application. For example, the ADN4664 data sheet provides typical supply current for two channels switching at 47 mA. Use Equation 3 to calculate the power dissipated for a voltage of 3.3 V.

$$P_{DISS} = VI = (47\text{ mA})(3.3\text{ V}) = 155\text{ mW} \quad (3)$$

where:
V is the receiver voltage (V).
I is the receiver current (mA).

For a power dissipation of 155 mW and a thermal impedance of 149.5°C/W, the corresponding rise in junction temperature is 23°C. Using Equation 1 for an ambient operating temperature of 85°C, the junction temperature is 108°C.

M-LVDS TRANSCEIVERS

Analog Devices M-LVDS transceivers expand on the established LVDS signaling method by allowing bidirectional communication between more than two nodes. The ADN4690E, ADN4692E, ADN4694E, and ADN4695E are transceivers for transmitting and receiving M-LVDS at high speeds (data rates of up to 100 Mbps). The ADN4691E, ADN4693E, ADN4696E, and ADN4697E are capable of operating at data rates of up to 200 Mbps. The M-LVDS transceivers are available in full and half-duplex modes, with 8-lead and 14-lead SOIC packages. The AN-1177 Application Note provides an LVDS and M-LVDS circuit implementation guide.

The ADN4690E/ADN4692E/ADN4694E/ADN4695E data sheet provides information for calculating the power dissipated and junction temperature, depending on the package type. Table 3 provides the thermal impedance values for 8-lead and 14-lead SOIC packages.

Table 3. Information for 100 Mbps M-LVDS Transceivers

M-LVDS Part Number	T_A Max (°C)	Thermal Impedance (°C/W)	SOIC Package Type	Duplex
ADN4690E	85	121	8-lead	Half
ADN4694E	85	121	8-lead	Half
ADN4692E	85	86	14-lead	Full
ADN4695E	85	86	14-lead	Full

The ADN4690E/ADN4692E/ADN4694E/ADN4695E data sheet specifies 94 mW transceiver power dissipation.

For a power dissipation of 94 mW and a thermal impedance of 121°C/W, the corresponding rise in junction temperature is 11°C. Using Equation 1 for an ambient operating temperature of 85°C, the junction temperature is 96°C. For a power dissipation of 94 mW and a thermal impedance of 86°C/W, the corresponding rise in junction temperature is 8°C. Using Equation 1 for an ambient operating temperature of 85°C, the junction temperature is 93°C.

The ADN4691E/ADN4693E/ADN4696E/ADN4697E data sheet provides information for calculating the power dissipated and the junction temperature, depending on the package type. Table 4 provides the thermal impedance values for 8-lead and 14-lead SOIC packages.

Table 4. Information for 200 Mbps M-LVDS Transceivers

M-LVDS Part Number	T_A Max (°C)	Thermal Impedance (°C/W)	SOIC Package Type	Duplex
ADN4691E	85	121	8-lead	Half
ADN4696E	85	121	8-lead	Half
ADN4693E	85	86	14-lead	Full
ADN4697E	85	86	14-lead	Full

The ADN4691E/ADN4693E/ADN4696E/ADN4697E data sheet provides the maximum supply current with both the driver and receiver enabled at 25 mA. The typical load (R_L) driven by the transceiver is 50 Ω. Use Equation 4 to calculate the total power dissipated.

$$P_{DISS} = VI - I^2 R_L = (3.3\ V)(25\ mA) - (10\ mA)^2(50\ \Omega) = 77\ mW \quad (4)$$

All bus side current does not flow through the R_L load resistor; therefore, only the current portion typically flowing through R_L is subtracted.

For a power dissipation of 77 mW and a thermal impedance of 121°C/W, the corresponding rise in junction temperature is 9°C. Using Equation 1 for an ambient operating temperature of 85°C, the junction temperature is 94°C.

For a power dissipation of 77 mW and a thermal impedance of 86°C/W, the corresponding rise in junction temperature is 7°C. Using Equation 1 for an ambient operating temperature of 85°C, the junction temperature is 92°C.

RS-485/RS-422 TRANSCEIVERS

Analog Devices offers a wide range of standard RS-485/RS-422 transceivers and *i*Coupler isolated RS-485/RS-422 transceivers to suit many applications. RS-485 transceivers allow bidirectional communication over long distances (maximum of 4000 ft), with differential transmission lines increasing noise immunity. The AN-960 Application Note provides an RS-485/RS-422 circuit implementation guide. Table 5 provides data for Analog Devices isolated RS-485 transceivers, which include integrated *i*Coupler and *iso*Power isolation technology (see the *i*Coupler and *iso*Power Technology section).

Equation 5 and Equation 6 are example calculations for the power dissipated in the ADM2587E and ADM2582E, respectively, using data gathered from the device data sheet for a typical 54 Ω loading condition.

$$P_{DISS} = VI - I^2 R_L = (5\ V)(98\ mA) + (3.3\ V)(35\ mA) - (27\ mA)^2(54\ \Omega) = 567\ mW \quad (5)$$

$$P_{DISS} = VI - I^2 R_L = (5\ V)(200\ mA) + (3.3\ V)(50\ mA) - (27\ mA)^2(54\ \Omega) = 1.13\ W \quad (6)$$

All bus side current does not flow through the R_L load resistor; therefore, only the current portion typically flowing through R_L is subtracted.

For the ADM2587E, with a power dissipation of 0.567 W and a thermal impedance of 50°C/W, the corresponding rise in junction temperature is 28°C. Using Equation 1 for an ambient operating temperature of 85°C, the junction temperature is 113°C. Use a similar calculation for the ADM2582E.

The ADM2486 data sheet specifies a logic side current of 4 mA with a 5 V power supply. The corresponding 58 mA bus side current and 5 V bus side voltage (at a data rate of 20 Mbps) provide a power dissipation value of 271 mW (see Equation 7).

$$P_{DISS} = VI - I^2 R_L = (5\ V)(4\ mA) + (5\ V)(58\ mA) - (27\ mA)^2(54\ \Omega) = 271\ mW \quad (7)$$

All bus side current does not flow through the R_L load resistor; therefore, only the current portion typically flowing through R_L is subtracted.

With the ADM2486 power dissipation of 271 mW and a thermal impedance of 73°C/W, the corresponding rise in junction temperature is 19.8°C. Using Equation 1 for an ambient operating temperature of 85°C, the junction temperature is 105.4°C.

Table 5. Junction Temperature Corresponding to Typical Loading for Analog Devices Isolated RS-485/RS-422 Transceivers

Part Number	Junction Temperature (°C)	T_A Max. (°C)	Thermal Impedance (°C/W)	Power Dissipation (W)
ADM2481	102	85	65	0.256
ADM2482E	95	85	61	0.156
ADM2483	104	85	73	0.256
ADM2484E	93	85	73	0.103
ADM2485	104	85	73	0.266
ADM2486	105	85	73	0.271
ADM2487E	91	85	61	0.103
ADM2490E	102	105	60	0.291
ADM2491E	100	85	60	0.241
ADM2582E	141	85	50	1.13
ADM2587E	113	85	50	0.567
ADM2682E	143	85	52	1.13
ADM2687E	114	85	52	0.567

The ADM2682E/ADM2687E data sheet provides power supply currents for typical bus loading conditions. The power dissipation calculation is similar to that of the ADM2587E and ADM2582E.

The ADM2482E, ADM2487E, ADM2485, ADM2490E, ADM2491E, ADM2481, ADM2483, and the ADM2484E have a similar calculation to the ADM2486 for transceiver power dissipation at typical bus loading. After the power dissipation is calculated, the junction temperature can be determined using Equation 1 for a given thermal impedance and ambient operating temperature (see Table 5).

HEAT SINKS AND THERMAL DESIGN

For guidelines regarding heat sinks, PCB layout, and other good practices for thermal design, refer to the Analog Devices MT-093 Tutorial (see the References section). This tutorial provides a guide to PCB layout for applications where power dissipation requires consideration.

*i*COUPLER AND *iso*POWER TECHNOLOGY

Isolation between circuit components in a typical customer application improves system safety and data integrity. Isolation can protect sensitive circuit components on the system side from dangerous voltage levels present on the bus side, where high voltage equipment typically resides. Isolation can also mitigate or even eliminate common-mode noises and ground loops that affect data acquisition accuracy in a system.

For options and solutions for isolating power in isolated RS-485 nodes, refer to Analog Devices Technical Article MS-2155 (see the References section). Technical Article MS-2155 illustrates Analog Devices *iso*Power isolated dc-to-dc converter technology as used in the ADM2587E RS-485 transceiver. The ADM2587E also features Analog Devices *i*Coupler data isolation technology.

Isolated RS-485 and CAN transceivers with *i*Coupler technology enables designers to implement isolation in designs without the cost, size, power, performance, and reliability constraints found with optocouplers.

REFERENCES

MT-093 Tutorial. *Thermal Design Basics.* Analog Devices, Inc., 2009.

Ronan, Colm. Technical Article MS-2155. *Options and Solutions for Partitioning Isolated Power in Isolated RS-485 Nodes.* Analog Devices, Inc., 2011.

RELATED LINKS

Resource	Description
LVDS/MLVDS Webpage	Links to product pages and resources for LVDS drivers, receivers, and M-LVDS transceivers
RS-485/RS-422 Webpage	Links to product pages and resources for isolated and nonisolated RS-485/RS-422 transceivers
CAN Webpage	Links to product pages and resources for isolated and nonisolated CAN transceivers
Isolated Transceiver Portfolio from Analog Devices	Link to isolated transceiver portfolio resources
AN-960	Application Note, RS-485/RS-422 Circuit Implementation Guide
AN-1123	Application Note, Control Area Network (CAN) Implementation Guide
AN-1177	Application Note, LVDS and M-LVDS Circuit Implementation Guide