

# **Characterizing Audio Amplifier Thermal Performance**

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## **ABSTRACT**

This application report discusses how to accurately measure the thermal performance of an audio amplifier IC at the system level.

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## 1 Introduction

Understanding the thermal limitations of an audio system is very important when designing for a maximum output power specification. The required equipment includes a temperature forcing system (or oven), several digital multimeters (DMM) for measuring current and voltage, a power supply with force/sense capabilities, and a current source.

Many IC vendors, including TI, specify a Theta Ja value for different package options. This value can be used to calculate the junction temperature of the IC for a known output power and ambient temperature. However, the Theta Ja presented in the datasheet depends on many printed circuit board (PCB) layout parameters. Limitations on this junction temperature are also specified in the datasheet and the system performance, i.e., maximum output power, is designed around these limitations. Exceeding these limitations can result in system shutdown from the integrated thermal protection on the IC or a decrease in device reliability. This application note discusses how to measure the Theta Ja of an IC in a system and how to calculate the junction temperature for each unique PCB design.

## 2 Definition of Theta Ja

Theta Ja is defined as the thermal resistance between the junction temperature, or die temperature, and the ambient temperature. The ambient temperature is defined as the temperature of the free air surrounding the device. If the device is in an enclosure, the ambient temperature would be measured in the enclosure. Equation 1 shows the dependency of the die temperature on the surrounding air temperature, Theta Ja, and the power dissipated in the device. If there were an ideal thermal transfer between the die and surrounding air, Theta Ja would equal zero and  $T_J = T_A$ . Or, if the IC is not dissipating any power when turned off,  $T_J = T_A$ . Many factors impede the thermal transfer and that is why Theta Ja is defined as a resistance. Again, Theta Ja is defined as a resistance to the transfer of heat between the surrounding air and the location of the die within a package. The units of Theta Ja are degrees Celsius per watt of power dissipated in the device. For example, if Theta Ja = 26°C/W, then the die temperature would increase 26°C for every 1 W of power dissipated in the device.

$$T_J = T_A + \theta_{ja} \times P_{dissipated} \quad (1)$$

## 3 Characterizing Internal Diode (Temperature Sensor)

If characterized properly, an internal diode is an excellent temperature sensor for measuring the internal die temperature. The forward voltage of a diode decreases linearly with an increase in temperature. Most terminals on an IC have an ESD protection circuit connected to them. The fundamental component in an ESD protection circuit is a diode connected between the IC terminal and GND. The cathode is connected to the terminal of the IC, whereas the anode is connected to device ground. A diode close to the output terminals is a good choice for the temperature-sensing diode.

The device must not be powered during the diode characterization. This ensures that the internal junction temperature of the die is equal to the surrounding air temperature. See Equation 1 when  $P_{\text{dissipated}} = 0 \text{ W}$ . The ambient temperature can be controlled by placing the PCB in a thermal chamber or by using a forced air hood placed directly over the device under test (DUT). A current source is used to forward bias the internal diode. The negative terminal of the current source must be connected to the terminal under test and the positive terminal must be connected to device ground. The current source must be set to 1 mA. If the current is set too high, excessive internal heating of the diode could result, or the device may be damaged. Internal leakage could skew the forward voltage measurement if the current is set too low. This current must be kept constant throughout the measurements. If a current source is not readily available, a voltage source can be used. Adjust the voltage until 1 mA of current flows through the internal diode. A standard multimeter with 3 digits of precision is used to measure the forward voltage. Figures 1 and 2 show the described test setups.

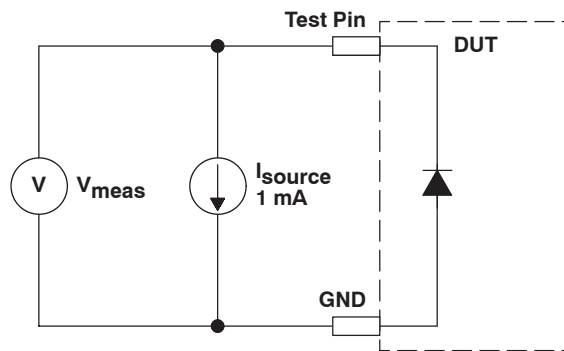


Figure 1. Diode Characterization Test Setup With External Current Source

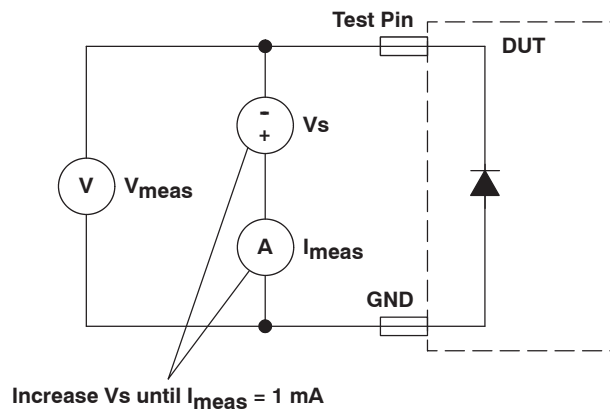
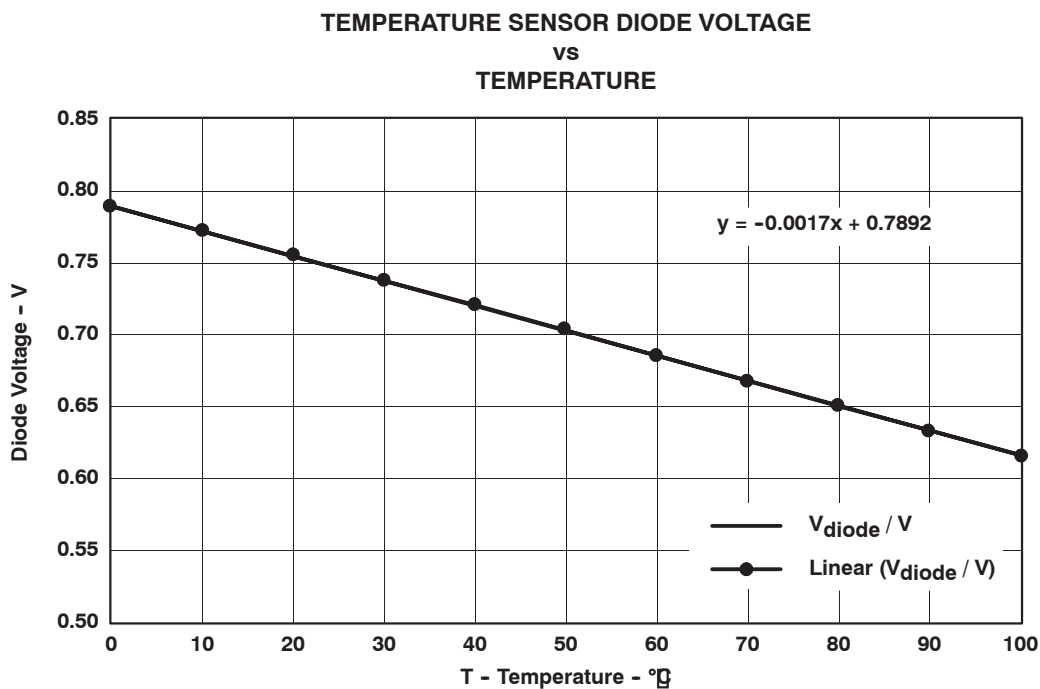


Figure 2. Diode Characterization Test Setup With External Voltage Source

Note that the device must not be powered. Powering the device introduces error in the measurement results due to the internal heating of the device with quiescent current flowing through it. Carefully increase the temperature of the thermal forcing system in 10-degree increments. Smaller steps can be chosen, but multiple measurements with 10-degree increments are adequate for calculating the slope of the linear dependency. If smaller temperature steps are chosen, the voltage change between steps may be too small to measure accurately. After 5 to 10 minutes of soak time at each step, the diode voltage stabilizes. Once the voltage is stable, record it and increment the temperature by the next 10-degree step.

Figure 3 shows an example of some actual measurements. This data was collected from a TPA3001D1 device. The GAIN1 terminal, chosen for characterization, is a logic input for setting the gain of the device. Figure 3 shows the actual data and corresponding best-fit line. The best-fit line then was calculated with the slope shown on the graph,  $-1.7 \text{ mV}/^\circ\text{C}$ .



**Figure 3. Diode Voltage vs. Temperature**

## 4 Measuring Internal Power Dissipation Versus Junction Temperature

Section 3 discussed the relationship between the forward voltage of an internal diode and the junction temperature. Using a slope equation like the one shown in Figure 3, the internal junction temperature can be calculated and inserted into Equation 2.

$$\theta_{ja} = \left[ \Delta T_j - \Delta T_a \right] \div \Delta P_{dissipated} \quad (2)$$

As Equation 2 shows, the most accurate way to determine Theta Ja is to take two readings of  $T_j$  at two different power dissipation points. Assuming that  $T_a$  remains constant, Theta Ja equals the change in  $T_j$  over the change in  $P_{dissipated}$ . This is a safe assumption if the two measurements are taken within a short time of each other. A room thermometer can be used to remove this source of error and to ensure that no airflow is moving over the device from an air-conditioning vent or similar source. Airflow also can introduce error by removing heat from the package.

The following steps describe a method for dissipating power in the device and accurately measuring the power dissipated.

1. Remove the PCB from the temperature chamber or temperature forcing device. Leave the diode connections intact from Section 3. Use the setup described in Section 3 to measure the change in junction temperature as power is dissipated in the DUT. The diode characterized in Section 3 is referred to as the Temp Sensor in the setup depicted in Figure 4.
2. Again, do not power the device during this measurement. The power supply pins can be left floating. Make only the connections to the DUT shown in Figure 4.
3. Connect a power supply across an output terminal and a power ground (PGND) terminal. This supply is used to force a voltage across the output diode connected across the output and GND. As the forced voltage is increased, the current increases. This creates the required power dissipation on chip for calculating Theta Ja. It is important that a force/sense connection be made close to the output and GND terminals of the DUT, because a significant amount of current is flowing through the supply wires and will result in a voltage drop between the supply and the DUT.

See Table 1 for example measurements and calculations. Note that the die temperature is calculated using the equation in Figure 3, and the diode voltage is measured during the experiment. For simplicity, three measurements are shown. More data can be taken so that any error can be averaged out over multiple measurements.

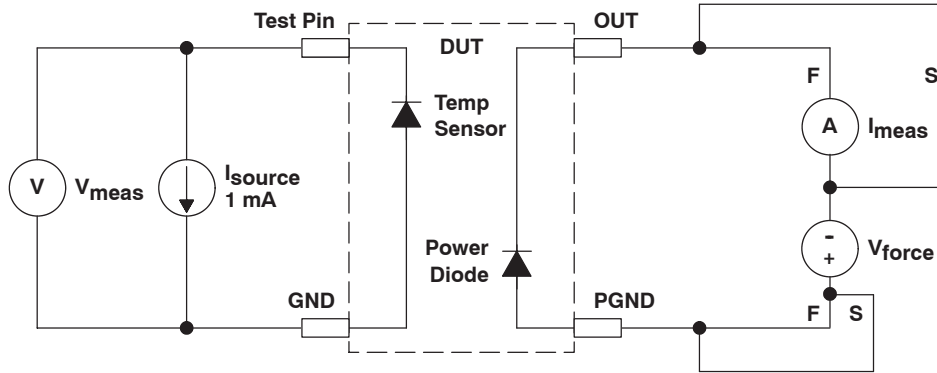


Figure 4. Complete Theta Ja Test Setup

Table 1. Worksheet for Theta Ja Calculations

Experimental Data			Calculated Data		
$V_{force} (V)$	$I_{meas} (A)$	$V_{diode}/V$	$P_{dissipated} (W)$ [ $V_{force} \times I_{meas}$ ]	Die Temperature ( $^{\circ}C$ ) [ $(V_{diode} - 0.7892) / -0.0017$ ]	Theta Ja ( $\Delta T/\Delta P$ )
0.771	0.550	0.7350	0.42405	31.88235294	
0.800	1.250	0.7110	1	46	24.51193169
0.820	1.861	0.6895	1.52602	58.64705882	24.04292389
				Average Theta Ja =	24.27742779

## 5 Conclusion

This application report defines a method for accurately measuring the thermal performance of an audio amplifier IC at the system level. This method is universal for determining the thermal limitations of any audio system. While there can be many sources of error, averaging multiple measurements minimizes the impact on the final calculated Theta Ja value.

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