MOSFET Thermal Characterization in the Application

Wharton McDaniel

INTRODUCTION

The use of surface-mount packages for power MOSFETs has progressed dramatically over the past 10 years. Today, power MOSFETs are widely available in packages that continue to get smaller. Now the question is how to choose best device in the smallest package and make a space-critical design as effective as possible. A major part of the problem is determining the thermal performance of the device on the printed circuit board (PCB) where it is mounted. Fortunately, a simple test method can be used to establish thermal performance of a MOSFET in a particular application.

THERMAL CHARACTERIZATION DATA

The main piece of thermal data provided by MOSFET suppliers is typically $R_{\Theta JA,}$ or junction-to-ambient thermal resistance. The basic thermal circuit (Figure 1) for this parameter consists of two components: the thermal resistance of the package and the thermal resistance of the PCB it is mounted on. The problem with the PCB component in $R_{\Theta JA}$ is that the characterization board used to create data sheet specifications does not accurately represent the boards used in actual applications. The PCB area is different, the copper patterns are different, many applications use multilayer board, and actual applications have many different components mounted on the board along with the MOSFET. All these things create thermal performance that tends to be different, and in most cases better than the performance of the characterization board. More recently, suppliers have added $R_{\Theta JF}$ to the characterization data, which defines the thermal performance of the package itself. This is an excellent parameter to use to compare package performance and to use in determining actual device performance.

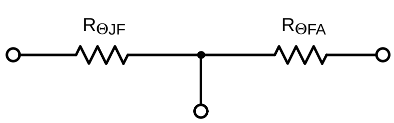

FIGURE 1. Basic Thermal Circuit

THERMAL PERFORMANCE IN THE APPLICATION

For any given application, the ideal MOSFET is the smallest device that provides the electrical and thermal performance that is required. The thermal performance is the most difficult to predict since, as previously described, the thermal characteristics of each PCB are different. Although there is data published showing the relationship between thermal resistance and the copper area used to spread heat, it is accurate only for the PCB where it is mounted. When trying to optimize the thermal performance, this is not good enough.

The most practical method of optimizing thermal performance is to characterize the MOSFET on the PCB where it will be used, or on a board that is very similar. This characterization can be performed using the same techniques used for the datasheet characterization, although the datasheet characterization is performed by a dedicated thermal analyzer. The basis of this method is to dissipate a known amount of power in the MOSFET, and to measure the amount of temperature rise this causes in the junction, giving the data required to calculate the junction to ambient thermal resistance in °C/W. The following procedure provides a simple method of determining the steady-state thermal resistance of a MOSFET on the PC board where it will be used.

THERMAL CHARACTERIZATION PROCEDURE

The procedure has two main steps. First is the characterization of the body diode. Second is the temperature rise measurements and calculation of the thermal resistance.

Diode Characterization

Characterization of the body diode is important because the body diode is used to measure the junction temperature of the MOSFET. As an inherent part of the MOSFET structure, the body diode makes the ideal sensor for this purpose. The forward voltage, V_F, of the diode varies with temperature, therefore the diode's temperature coefficient is needed to get an accurate representation of the junction temperature. The forward voltage is measured with a low level current flowing through it to insure there is no self heating, which would make the junction temperature measurement inaccurate. If it is not possible to perform the measurements of V_F, the generic V_F temperature coefficient of –2mV/°C for a diode can be used at the cost of accuracy.

For characterization of the diode, the MOSFET can be mounted on a PCB or just connected with wires. Electrically, the gate should be connected to the source to insure the MOSFET cannot turn on.

The characterization is performed as follows:

- Measure room temperature T_{room}
- Measure V_F of body diode with I_F of 10 mA at room temperature
- Measure V_F of body diode with I_F of 10 mA at 100°C
- Calculate the diode temperature coefficient using

$$\frac{T_C = V_{F\,@\,100^\circ C} - V_{F\,@\,room}}{100 - T_{room}\,(mV/^\circ C)}$$

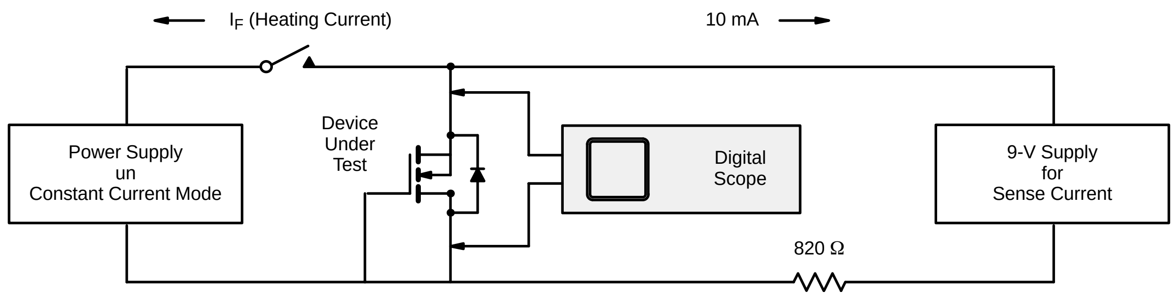

FIGURE 2. Connection Diagram

Temperature Rise Measurement and Calculation of Thermal Resistance

The MOSFET being characterized is mounted on the application PCB and has the gate shorted to the source, with the drain and source connected to two power supplies (Figure 2). The first power supply is configured as a constant current source, which forces current through the body diode to heat the junction when the switch is closed. The second power supply provides the sensing current for measuring the junction temperature. This supply is connected to the drain and source, forcing 10 mA though the body diode, with the V_F of the body diode indicating the junction temperature. Also, it stays connected throughout the test in order that the sensing current will flow immediately upon removal of the heating current.

The measurement procedure is as follows:

- Close the switch.
- Source current through the body diode such that approximately 1 W is dissipated after reaching equilibrium. Equilibrium has been reached when V_F stabilizes.
- Power is defined as $P_D = V_F \times I_F$.
- Open the switch, dropping I_F to 10 mA. Measure V_F immediately using a digital scope triggered on the negative slope of V_F.

Calculation of $R_{\Theta JA}$

- Calculate ΔV_F, result will be negative
- Calculate ΔT_J using $\Delta T_J = \Delta V_F / T_C$
- $R_{\Theta JA} = \Delta T_J / P_D$

Verification of the Method

This method was verified using an Si4410DY mounted on the standard thermal characterization board. The forward voltage of the body diode, V_F, was measured to be 0.586 V at a room temperature of 21.3°C. The device was placed in an oven, the oven temperature raised to 100°C, and V_F measured to be 0.394 V. This yields

$$T_C = \frac{0.394\ \text{V} - 0.586\ \text{V}}{100^\circ\text{C} - 21.3^\circ\text{C}} = -2.4\ \frac{\text{mV}}{^\circ\text{C}}$$

With the device connected according to Figure 2, 0.94 W was dissipated in the body diode. The starting value was measured to be 0.582 V. A digital oscilloscope was used to measure V_F immediately after the heating current was turned off. This gave a V_F of 0.402 mV. ΔV_F is –180 mV. Therefore,

$$\Delta T_J = \frac{\Delta V_F}{T_C} = \frac{-180\ \text{mV}}{-2.4\ \frac{\text{mV}}{^\circ\text{C}}}$$

$$\Delta T_J = 75^\circ\text{C}$$

and

$$R_{\Theta JA} = \frac{\Delta T_J}{P_D} = \frac{75^\circ\text{C}}{0.94\ \text{W}}$$

$$R_{\Theta JA} = 79.8\ \frac{^\circ\text{C}}{\text{W}}$$

This value compares well with the measured value of 75.7°C/W, measured using an AnaTech Phase 10 analyzer.

With $R_{\Theta JA}$ calculated, junction temperature can be predicted for any given power dissipation level using the equation as previously mentioned.

$$T_J = P_D \times R_{\Theta JA} + T_A$$

It should be noted that if other components on the PCB generate heat, the effective $R_{\Theta JA}$ will be higher since the temperature of the PCB will be raised by those components. If those components can be made to dissipate their typical power while performing the characterization above, the value of $R_{\Theta JA}$ will reflect this additional heating.

CONCLUSION

The process of selecting a power MOSFET on the basis of electrical parameters must be done with care. Close attention must be paid to the thermal performance of the MOSFET as part of the PCB assembly. Characterization of the MOSFET being used on the PCB being used can help insure that the correct device is chosen on the basis of both electrical and thermal performance.