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Thermal resistance characterization of Power MOSFETs

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I. Introduction

Power MOSFET junction temperature influences many operational parameters and device lifetime. To estimate device junction temperature in a circuit, or to compare MOSFETs for a target application, some basic data on thermal resistance is provided in the datasheet. In this article, we describe how the measurements are done and how the thermal resistance limits are set. We consider briefly both steady-state and transient thermal impedance of the MOSFET.

II. Measurement Method

To characterize the thermal resistance of a power MOSFET, we first obtain a calibration curve of the body diode forward drop V_F at a fixed test current (I_M=10mA) as a function of junction temperature. The device is first mounted to the standard fixture, for e.g., surface mount devices are mounted on 1sq inch of FR4 board. The device is then placed in a stirred liquid bath to achieve thermal equilibrium, with a thermocouple mounted on the case/lead. A typical plot of V_F vs. temperature T is shown in figure 1.

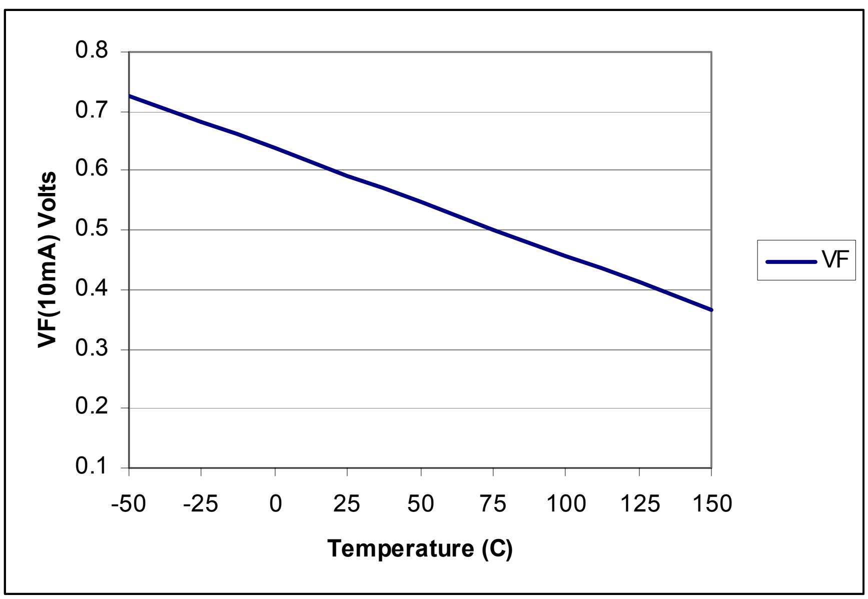

Figure 1: Variation of V_F(10mA) vs. temperature for a typical MOSFET

The steady-state thermal resistance is measured by heating the device to with a known amount of power. The device is placed in a still air environment, with a thermocouple placed to measure ambient temperature and another to measure temperature at the package leads. Two wires are used to force current I_F into the diode, and another two wires sense the forward drop V_F. The I_F*V_F product is the power dissipation. Once steady state is reached on the thermocouple connected to the leads, the power is cut off and the V_F is measured at the calibration current (I_M=10mA) within 10us, before the part can cool significantly. Figure 2 shows the concept behind this measurement.

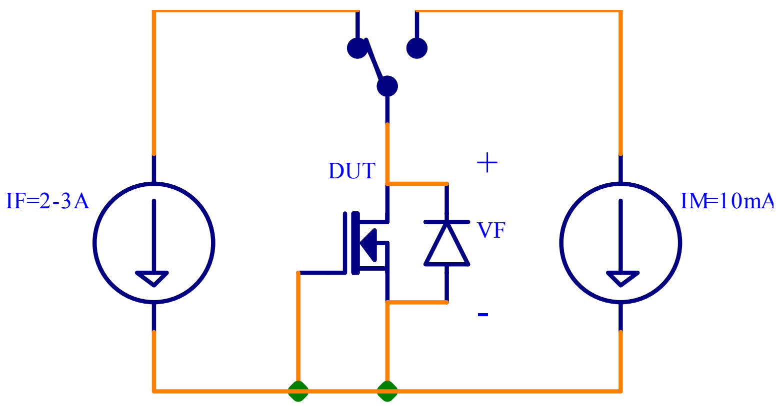

Figure 2: Circuit showing how thermal impedance is measured.

From the measured V_F(10mA), the calibration curve is used to determine the junction temperature T_J. The thermocouples are used to get the lead T_L and ambient T_A temperature. The steady-state thermal resistance is simply:

Pwr = I_F*V_F
$R_{\theta JA}$ = (T_J-TA)/Pwr {Junction-to-Ambient}
$R_{\theta JL}$= (T_J-T_L)/Pwr {Junction-to-Lead}

This gives the typical value for $R_{\theta JA}$ and $R_{\theta JL}$. A 20-30% margin is used to set the maximum specification, although devices are typically distributed within a few percent of the typical.

III. Transient Thermal Impedance

The transient thermal impedance is a measure of how the device behaves when pulsed power is applied to it. This is important for determining the behavior of low duty cycle, low frequency pulsed loads. A typical transient thermal impedance curve from the datasheet is shown in figure 3.

The test setup is the same as for the steady state thermal resistance. To get the single pulse curve, and single pulse of power is applied to the device, and the V_F(10mA) is measured with 10us of the end of the pulse. For e.g., a 20us pulse is applied, and then V_F is read at 10mA within 10us of the end of the pulse. This is repeated for whole range of pulse widths shown on the x-axis. At each point the values of thermal impedance are given by:

$Pwr = I_F * V_F$

$Z_{\theta JA} = (T_J - T_A)/Pwr$ {Junction-to-Ambient}

$Z_{\theta JL} = (T_J - T_L)/Pwr$ {Junction-to-Lead}

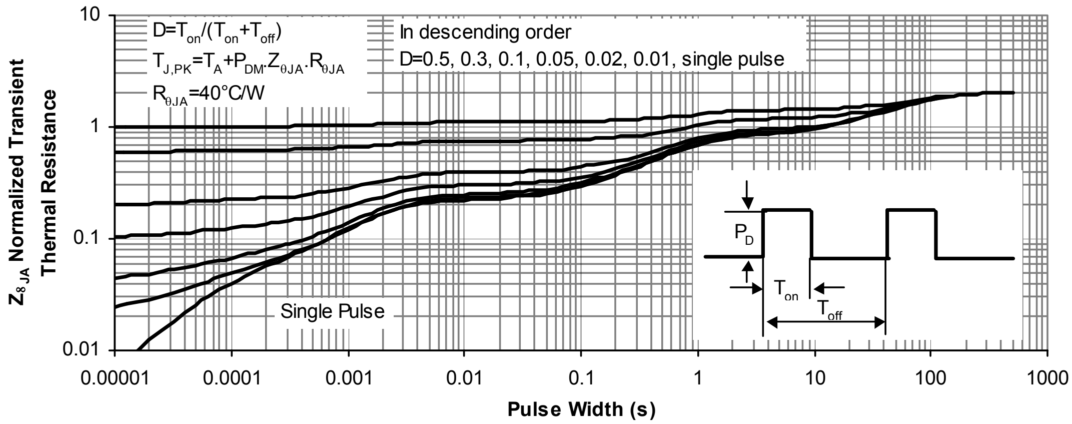

Figure 3: Normalized Maximum Transient Thermal Impedance

As one might expect, for low values of pulse width, the junction temperature is smaller because the thermal capacity of the die, package and FR4 fixture board impose various time constants on the rate at which junction temperature can rise. Therefore, for the same power level, at short durations, the thermal impedance appears to be smaller. This results in the kind of curve shown in figure 3. This explains why the Safe-Operating-Area SOA is so much larger for short pulse widths.

The different duty cycle curves may be done in similar fashion. With a fixed duty cycle, pulse width for the applied current is varied to trace the transient thermal curve. The device is allowed to reach steady state at each condition before the V_F(10mA) is measured within 10us of cutting of the heating current pulse.

However, we may also extract these curves from a model of the thermal network derived to fit the single pulse curve. From an equivalent circuit point of view, the thermal network may be modeled effectively as a third or fourth order RC network as shown in figure 4 below. The values of R and C for each stage are determined by curve fitting the measured single pulse curve. This model is then used to derive the thermal impedance curves for various duty cycles as a function of pulse width. (Electrically, temperature is equivalent to voltage and power to current).

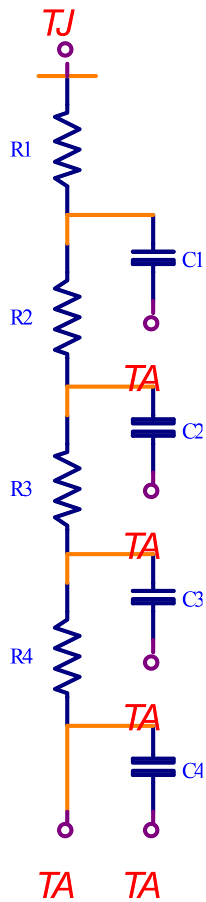

Figure 4: Model for the transient thermal impedance of the power MOSFET

IV. Conclusion

This concludes our brief introduction to thermal impedance characterization. Please note that for surface mount devices, the effective thermal resistance is influenced by many factors, including copper area and layout, heating from adjacent devices, thermal mass of adjacent devices on the PCB, air flow around the device, power dissipation level, quality of solder joint between board and device lead/tabs. It is best to characterize thermal resistance directly in the application circuit, if the temperature rise needs to be estimated accurately for design.