Measurement of Thermal Resistance of Power MOSFETs in Open Frame Amplifiers

SCOPE

This document will discuss and compare two (2) measurement techniques used to determine the thermal resistance junction to case, Θ_{JC}, of packaged power MOSFETs that are part of an open frame amplifier design. Method 1, a more popular method, requires no invasive action or preparation, while Method 2 exposes the actual device die.

METHOD ONE

This method uses the following procedure:

1. A thin coating of material with high emissivity is applied to the top of the packaged transistor.
2. The temperature at the top of the package is monitored with an infra-red thermal imaging camera and is designated "T_J".
3. A thermocouple is screwed through the heatsink, contacting the case directly beneath the transistor; the thermocouple output temperature, designated "T_C", is measured by DMM.
4. The voltage difference between V_{SUPPLY} to V_{OUTPUT} of the amplifier is measured, and output current is subsequently measured through a sense resistor. The power dissipated through the amplifier's output can now be determined by multiplying the differential voltage by output current.

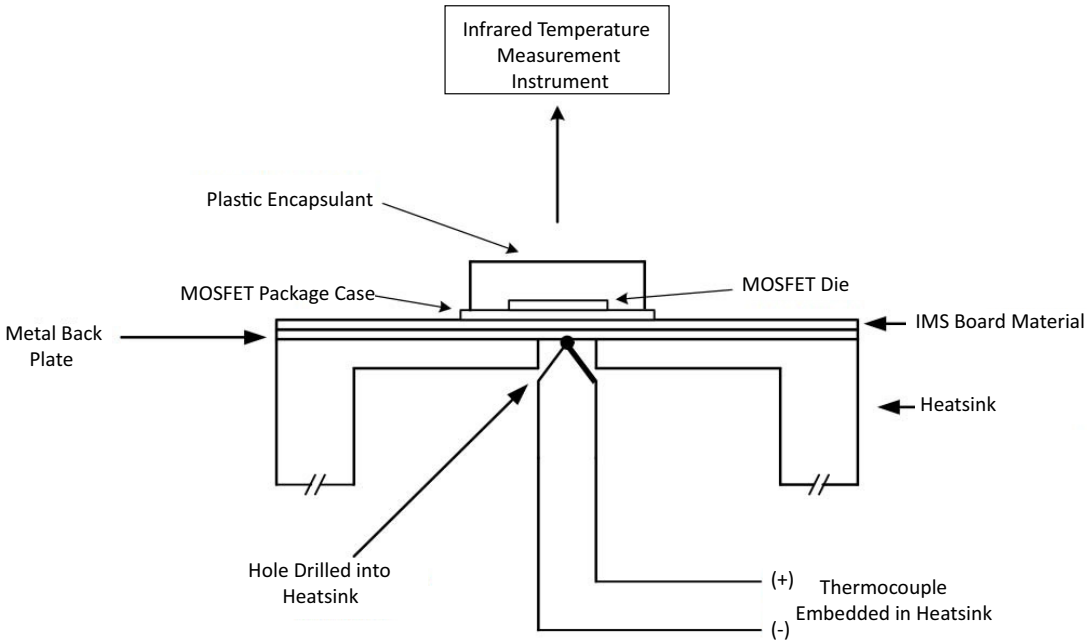
$$P_{DISS} = \begin{matrix} (+V_S - V_{OUT}) * I_{OUT} & for\ I_{OUT} > 0 \\ (-V_S - V_{OUT}) * I_{OUT} & for\ I_{OUT} < 0 \end{matrix}$$

5. The unit is turned on and the power in the transistor is ramped up until T_J = 150°C.
6. Once stable at that temperature, the unit is run for 300 seconds to ensure saturation of the temperature throughout the body of the MOSFET.
7. Thermal resistance is calculated as:

$$\Theta_{JC} = (T_J - T_C) / P_{DISS}\ [°C/W]$$

(See Figure 1)

Figure 1:


Infrared Temperature Measurement Instrument
Plastic Encapsulant
MOSFET Package Case
MOSFET Die
Metal Back Plate
IMS Board Material
Heatsink
Hole Drilled into Heatsink
(+)
Thermocouple Embedded in Heatsink
(-)

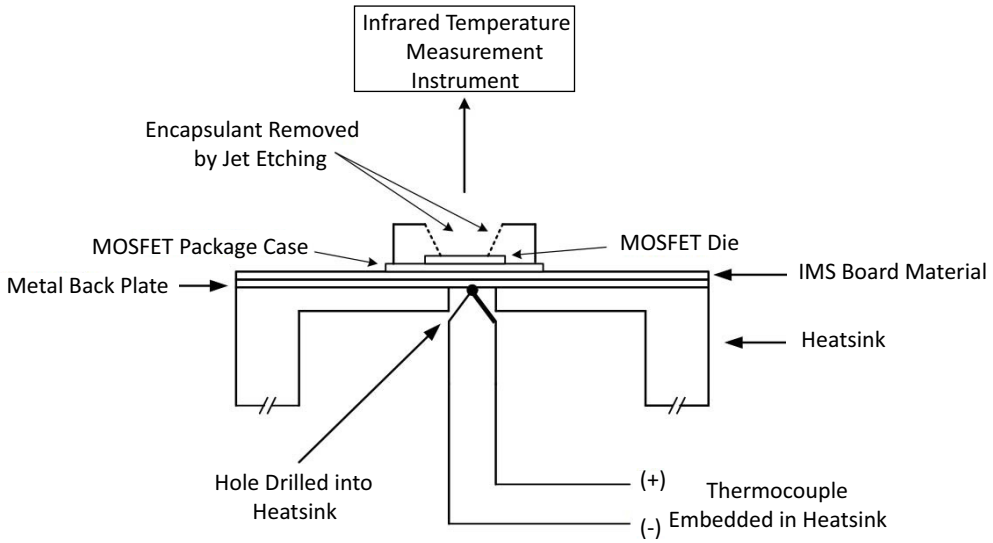
METHOD TWO

This method uses the following procedure:

1. The method is identical to that of Method One, except that the transistor is jet etched to reveal the transistor die itself for direct measurement of the transistor junction temperature.
2. Similar to Method One, a thin coating of the high emissivity material is applied directly to the top of the exposed die.
3. The die temperature itself is measured with the infrared camera, and that temperature is designated "T_J".
4. The thermal resistance calculation is identical to Method One except for the use of a direct T_J measurement.

(See Figure 2)

Figure 2:



ACTUAL TEST SET UP (METHOD 2)

Figure 3: Overall System

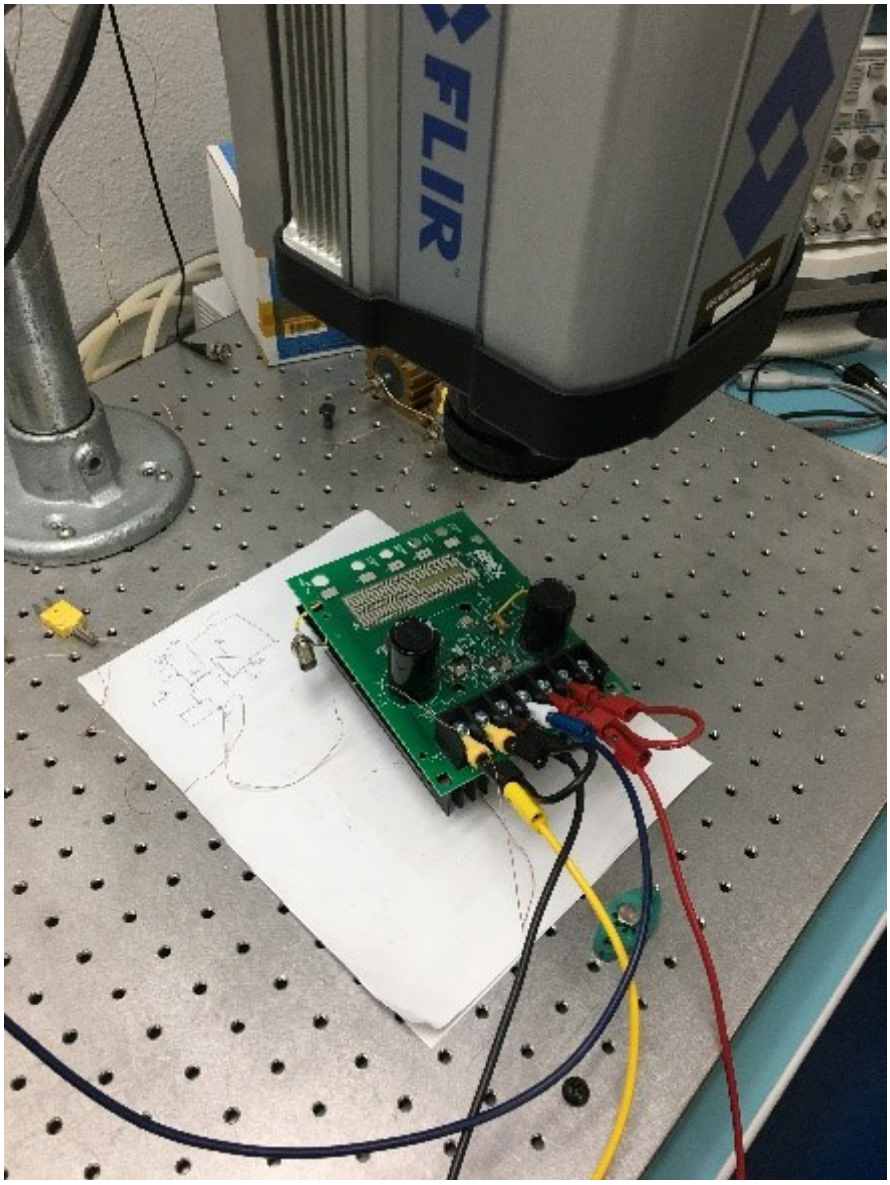
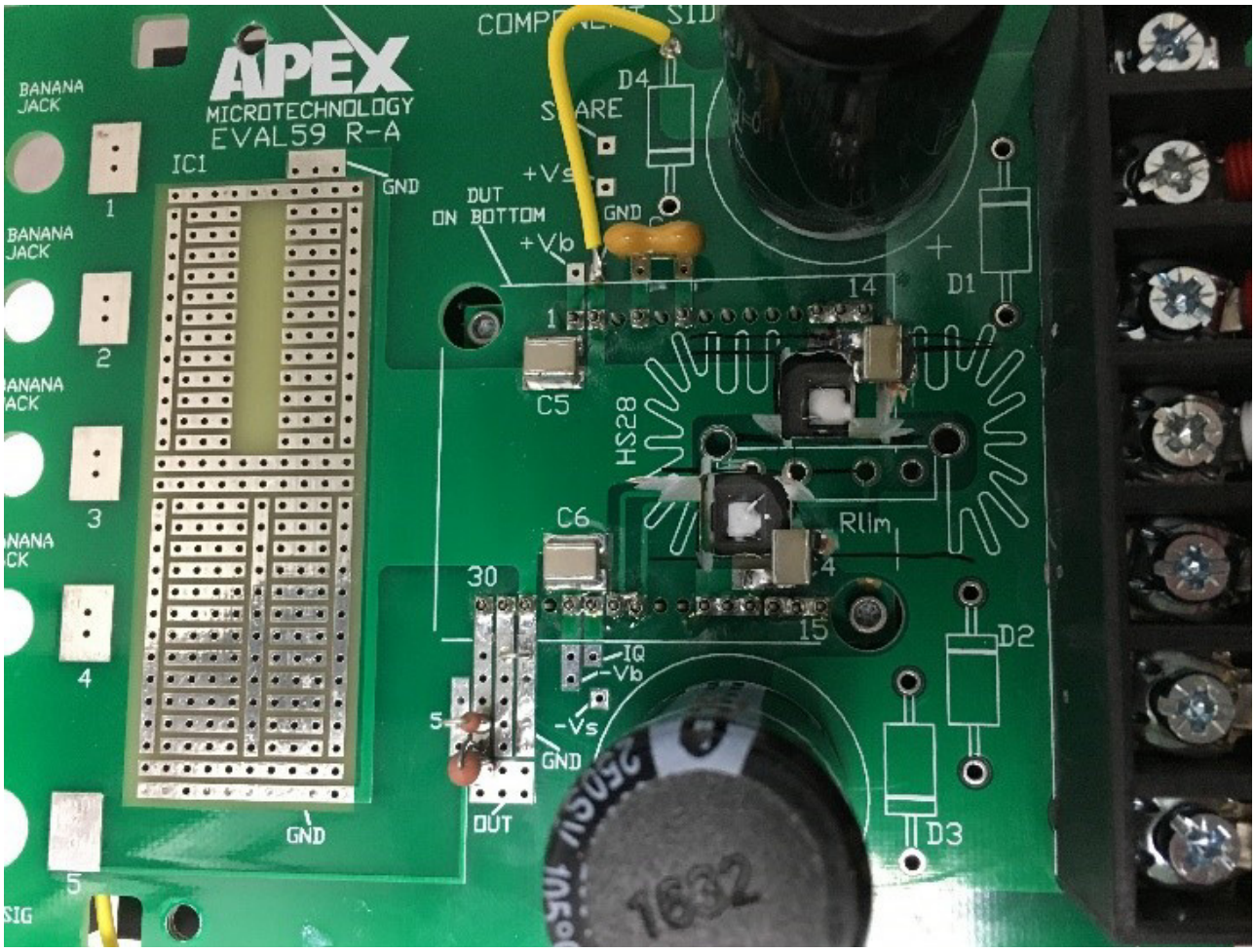


Figure 4: Exposed MOSFET Die



TECHNICAL DISCUSSION

Method One Makes the following assumption:

The thermal resistance of ambient air is much greater than the thermal resistance of the plastic encapsulation. So, after some time of operation the temperature of the top of the package equals the junction temperature. This, however, ignores the thermal resistance of the plastic encapsulation.

To determine the extent of the influence of the thermal conductivity of the plastic encapsulation, it became necessary to calculate the actual thermal resistance of a specific MOSFET device. However, the thermal resistance required in this case is that of junction-to-top of the package.

This is designated as Ψ_{JT}.

From the MOSFET data sheets and other sources we obtain the following information for a D-PAK package.

Length = 10.16 mm

Width = 9.015 mm

Area = 91.592 mm^2

Thickness = 2.25 mm (die to package top)

k = 0.58 - 0.70 W/m-K (Encapsulation Thermal Conductivity)[1]

h = 5W/m^2-K (Heat Transfer Convection Coefficient)[2]

Θ_{JA} = 31 °C/W (typ)[3]

1. Intel, “Physical Constants of IC Package Material, “Package Data Book, 2000
2. IDT, Application Note AN-842
3. International Rectifier, Application Note AN-0994

With this data, we can now determine the thermal resistance from the junction to the top of the package:

$$\Psi_{JT} = (h * \Theta_{JA} * \text{thickness})/k$$ [1]

$$\Psi_{JT} = 0.45 - 0.65\ °C/W \text{ (with tolerance of dimensions and constants)}$$

1. Electronics Cooling, March 2018

This indicates that there will be a small variation of temperature from the actual junction to the top of the MOSFET package top.

Actual measurements using both methods were carried out. Method One was used on two(2) samples and Method Two was carried out on five (5) samples. The results were as follows:

$$\text{Method One} \quad \Theta_{JC(AVG)} = 1.092\ °C/W$$

$$\text{Method Two} \quad \Theta_{JC(AVG)} = 1.488\ °C/W$$

$$\Delta\ \Theta_{JC(AVG)} = 0.396\ °C/W$$

This compares favorably with the calculated additional thermal resistance of the plastic encapsulating material. However, please be aware that instrumentation accuracy may affect the results. Also, note that the thermal conductivity for plastic encapsulation material varies with manufacturer and device type. The range of values used is typical for this application, and power devices tend to have thermal conductivity values at the high side of the range used here, 0.70 W/m-K or slightly larger.

The absolute accuracy of the IR measurement instrument is not an issue. Rather it is the repeatability and relative accuracy that is important since we are looking at differential temperature measurements to determine the thermal characteristics.

CONCLUSION

Method Two would appear to be the most accurate method of determining the thermal resistance, Θ_{JC}. This is justified by the fact that the actual die temperature was measured via the IR instrument and that the addition of the calculated thermal resistance of the plastic encapsulation material to the thermal resistance determined by Method One corresponds to the true thermal resistance as determined by Method Two.

One can say that, although Method One is non-invasive and does not reduce the later usefulness of the device under test, it will give somewhat more optimistic and erroneous results than what is true.

Please note that while some manufacturers still use Method One, Apex Microtechnology uses Method Two for a more accurate thermal resistance rating.

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