
AN1100

Usage of Steady State Thermal Values in Semiconductor Datasheets

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The ever increasing demand for higher power density is increasing the ambiguity of on board thermal conditions and this call for a thorough understanding of datasheet thermal information to evaluate the thermal performance of semiconductor devices.

This application notes explains the different steady state thermal information provided in the datasheet. It also highlights the inaccuracies in using the thermal information, provided in the datasheet, to calculate the junction temperature and suggests a tool to accurately determine the junction temperature.

Heat is generated in semi-conductor devices due to the power losses in the die during conduction and switching. Once generated, the three mechanisms through which this heat is removed from the package are:

- 1) Conduction
- 2) Convection
- 3) Radiation

The Majority of the heat in electronic devices is transferred out of the package through conduction, followed by convection and radiation respectively. Thermal resistance is the opposition to this heat flow from the source point (semi-conductor junction of the device) to the environment outside the package. The package thermal resistance figure is useful to determine the amount of power that can be safely dissipated inside the device without raising the junction temperature (T_j) above the maximum specified junction temperature. Manufacturers normally provide the junction to ambient thermal resistance value as a design aid to help determine the power handling capability of the package.

For example, for a device operating in an ambient temperature (T_a) of 25°C that has an $R_{th}(JA)$ of 150°C/W with a specified T_j maximum of 150°C, the maximum power (P_{max}) can be calculated using the following formula;

$$P_{max} = (T_j(\text{max}) - T_a) / R_{th}(JA) = (150-25) / 150 = 0.83W$$

Using the above formula, T_j can be calculated by knowing the power being dissipated inside the device, $R_{th}(JA)$ and T_a values.

On some occasions, manufacturers may provide the Junction to case (top of the package) value, $R_{th}(JC)$ and the junction to lead value(junction to the soldering point of the lead frame), $R_{th}(JL)$. These values can be used in the similar way to calculate the operating junction temperature.

The power dissipated at the semi-conductor junction leaves the package through a number of parallel heat flow paths each with a specific thermal resistance, and the value of the thermal resistance depends on the dimensions and the thermal conductivity of the heat flow path. Hence while trying to measure the thermal resistance of a specific heat flow path like junction to case or junction to lead, the ability to measure the temperature difference between the measuring points accurately and determining the fraction of the total heat generated that is flowing between these points, are important.

Though the temperature difference between the measuring points can be measured to a certain level of accuracy using non-contact thermocouples (IR thermocouples), determining the fraction of the heat flow between the measuring points accurately is difficult in practise. Therefore while determining the values for JC or JL thermal resistance values, one of the two following JEDEC (JESD51-12) standards/methods are used;

Method 1 : Rth(JX_Θ)

Rth(JX) → Thermal resistance of the heat flow path between junction and a measuring point 'X'.

This value is measured by forcing all the dissipated power at the junction through the point of interest, 'X' (which could be top of the package, soldering point etc.) and measuring the temperature at the point 'X', the accuracy of this measurement depends on a proper heat sinking arrangement at point 'X' and an accurate measurement of temperature at point 'X'.

$$R_{th}(JC_{\Theta}) = (T_j - T_x) / P$$

P is the part of the chip power (heat) that flows from the junction to the point 'X'. Ideally, during this measurement, close to 100% of the power should flow from the junction to the point 'X'. This figure ideally depends only on the physical properties of the heat flow path and it is independent of the amount of power dissipated and board size.

The Rth(JL) values provided by diodes is measured using this method. This value is independent of the board size. This value helps to compare the thermal performance of the lead frame of various packages.

Method 2: Rth(JX_Ψ)

This value is a thermal characterisation parameter (not to be confused as thermal resistance). It is calculated using an equation similar to the one used in method one;

$$R_{th}(JX_{\Psi}) = (T_j - T_x) / P$$

In this method, because no additional heat sinking arrangement is used to divert most/all of the generated heat through the heat flow path of interest, the total dissipated power value is used in the calculation instead of the fraction of the total power generated that is flowing between Junction and point 'X'. This results in a lower absolute value for Rth(JX_Ψ).

The Junction to case value given by diodes is measured using method 2 and hence it depends on the heat sink properties and can be used to compare the thermal performance of various packages.

Determining the junction temperature (T_j):

At times the intention may be to determine the T_j using the $R_{th}(JA)$ or $R_{th}(JL)$ or $R_{th}(JC)$, but when not measured under the datasheet conditions none of these values can provide an accurate T_j value. In practise the device is often mounted on a circuit board crowded with a number of other devices and there may be an ambiguity in ambient temperature, the usefulness of these parameters to serve this purpose is discussed below:

$R_{th}(JA)$ depends on Cu size and ambient temperature. Hence, in the application, along with this information an $R_{th}(JA)$ value measured under similar conditions is required to determine the T_j .

$R_{th}(JL)$ this value can only be used if heat flow in every other path is made insignificant. Accuracy in the measurement of Lead temperature is important.

$R_{th}(JC)$, by the virtue of the formula used, this value depends on $(T_j - T_c)$ and P_{total} . Just like $R_{th}(JA)$ this value also depends on Cu area and P. Though the variation in the absolute value of $R_{th}(JC)$ may be little w.r.t to the operating T_j and heat sinking, it still cannot be used for calculating T_j , unconditionally. Also, $R_{th}(JC)$ value is sensitive to the measurement method and the point on the case at which this measurement is made. Charts 1 to 3, measured on a PD5 package, shows the variation of $R_{th}(JC)$ for different Cu areas and operating T_j along with $R_{th}(JA)$ and $R_{th}(JL)^*$. Refer to figure 1 for measurement points.

*The fact that no arrangement was made to direct all the heat through the measurement point, makes $R_{th}(JL)$ dependant on heat sinking.

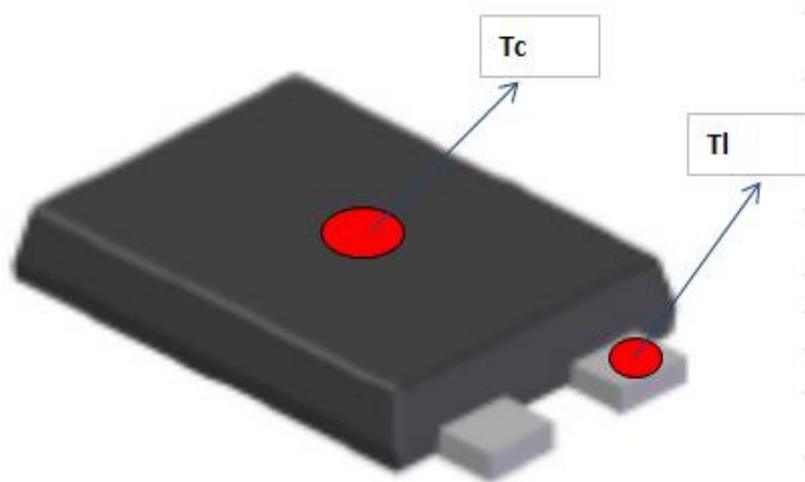


Figure 1: PD5 package with measurement points.

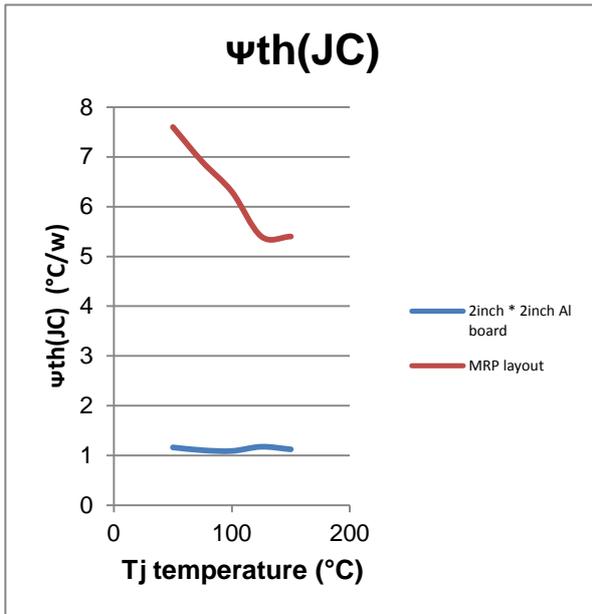


Chart 1: $\psi_{th}(JC)$ Vs T_j

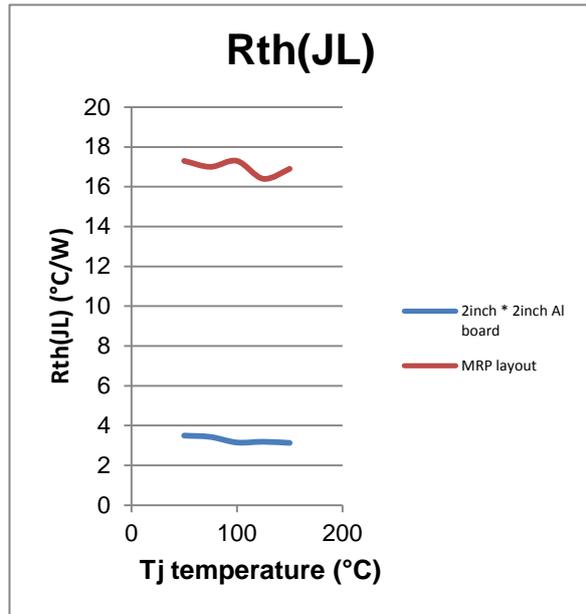


Chart 2: $R_{th}(JL)$ Vs T_j

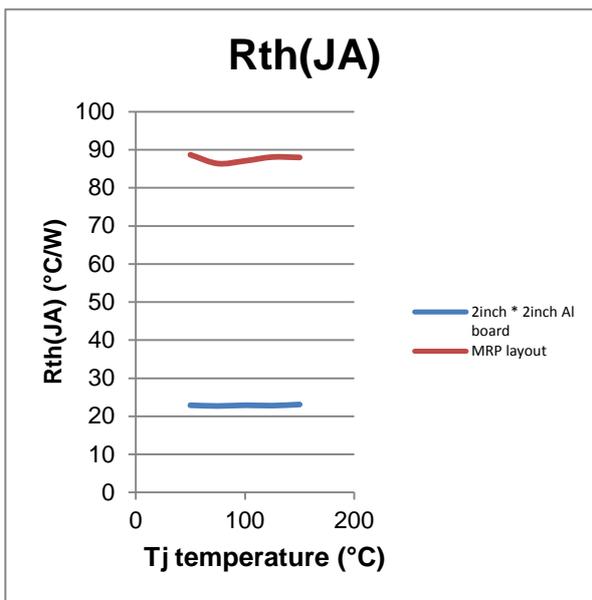


Chart 3: $R_{th}(JA)$ Vs T_j

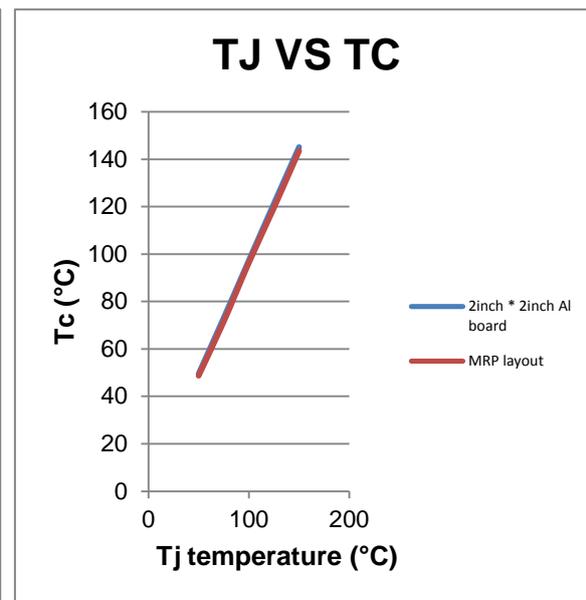


Chart 4: T_j Vs T_c

Conclusion:

As it can be seen, $R_{th}(JA)$, $R_{th}(JL)$ and $R_{th}(JC)$ are dependent on the heat sinking. Although the absolute variation on $R_{th}(JC-\psi)$ is smaller, it still cannot be used unconditionally. Hence, to determine the T_j accurately the best proposed tool is chart 4, a graph showing the variation of T_c w.r.t T_j , under still air conditions. When measured accurately, this graph is least dependent on heat sinking Cu size.