1. Introduction

When power semiconductor devices conduct electrical current there is power dissipated in the semiconductor chip. The heat generated is concentrated in small regions of the chip and the temperature of the chip rises. This heat generated diffuses outward towards the lower temperature regions of the chip, the package and the environment. The flow of this heat is governed by the laws of thermodynamics and the principles of heat transfer. The temperature within the package is at its highest at the heat generating regions of the chip and higher chip temperatures are usually associated with reduced operating life for the device.

Thermal characterization of packaged devices is the determination of the temperature response of the chip due to this internal self-heating. Using the important information provided by this characterization can facilitate a designer to ensure safe chip operating temperatures for packaged power devices. This ensures enhanced reliability and reduced thermally induced failures for the electronic systems into which power devices are placed.

The parameter used in datasheets to describe this characterization is called "thermal resistance", $\mathbf{R_{th}}$. This datasheet note looks at the way this parameter is defined and described.

2. Defining R_{th}

The quality of the internal chip attachment to the leadframe of the package, package design, materials used, pad thickness for the chip on the leadframe and how this pad is exposed to the environment are factors under the control of the semiconductor manufacturer. It is important to define a measurement of $\mathbf{R_{th}}$ that most closely reflects the capability of a device with respect to these factors which are controlled by the supplier. Such a definition is the measurement of $\mathbf{R_{th}}$ from the heat generating region of the chip (junction) to the nearest external measurable point on the package. Any measurement of $\mathbf{R_{th}}$ to an external point beyond the package, such as the ambient environment will necessarily involve factors under the control of the user and not the supplier (e.g. air-flow).

Fig.1 Examples TO3, TO5 and DO5 – older metal can power packages

In previous years, power devices were typically supplied by manufacturers in metal can packages such as TO3, TO5, DO5 etc., (see Fig. 1). The "nearest external measurable point" at which temperature can be accurately measured and defined was the "metal can". This meant that suppliers defined thermal resistance as $\mathbf{R_{th(j-c)}}$ i.e. thermal resistance from junction to "can" or "case".

These days such metal can packages have been replaced by plastic encapsulated packages such as TO220, IITO220, TO220F, SOT223, I²PAK, D²PAK, DPAK, SMA, SMB, SMC, TO3P, TO3PF, TO247 etc., (see Fig 2).

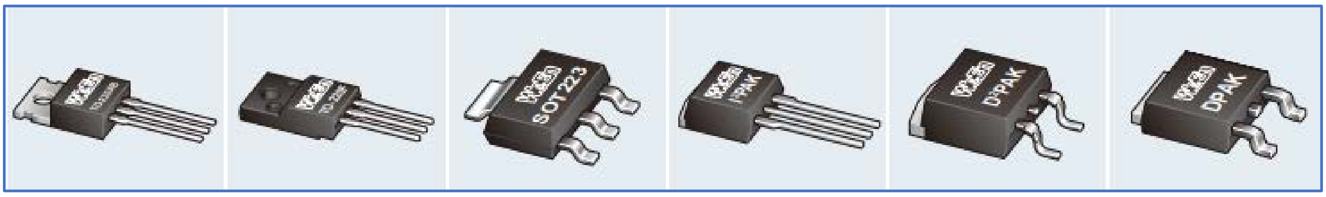

Fig.2 Examples of some recent power packages

Some packages have part of the leadframe on which the chip is attached exposed to the outside world as a metal "tab" or "mounting base". This is the "nearest external measurable point" where temperature can be accurately measured and so the most meaningful measurement of thermal resistance for these packages is $\mathbf{R_{th(j-mb)}}$ i.e. thermal resistance from junction to "mounting base".

Thermal resistance from junction to mounting base is the common parameter guaranteed and used by most manufacturers to characterise these packages, but some suppliers still use the old historic terminology of $\mathbf{R_{th(j-c)}}$. Strictly, this not accurate because such plastic encapsulated packages do not have a "case" that encloses the whole device.

If we define the whole external surface of the package as the "case", then $\mathbf{R_{th(j-c)}}$ is ambiguous because the temperature measured on the front of the plastic can be very different from that measured on the metal tab. The high thermal conductivity of metal means we can approximately say that all points on the continuous metal surface have the same temperature (similar as in the historic "can" or "case" of a hermetically sealed metal package). This cannot be said of a plastic package such as TO220F.

Most suppliers that use the term $\mathbf{R_{th(j-c)}}$ are actually describing the thermal resistance from junction to the metal part of the "case", i.e. the metal tab, the mounting base.

In WeEn datasheets, the more accurate and unambiguous parameter, $\mathbf{R_{th(j-mb)}}$, thermal resistance from junction to "mounting base", is always used, the mounting base being defined as the back-metal surface of the package.

For packages such as the TO220F "full-pack", where the whole body of the device is encased in plastic, $\mathbf{R_{th(j-mb)}}$ is also not the correct term to use because there is no external metal "mounting base" with a well-defined temperature. It cannot be assumed, even approximately, that all points on the plastic surface have the same temperature, so any $\mathbf{R_{th}}$ from junction to the "plastic surface" (if this is called "the case") is not well-defined. For this reason, for the TO220F "full-pack" devices, the metal heatsink on which the device is mounted is considered to be the "nearest external measurable point" with a measurable temperature. This measurement of thermal resistance is called, $\mathbf{R_{th(j-h)}}$, thermal resistance from junction to heatsink.

This measurement of $\mathbf{R_{th(j-h)}}$ is now not entirely governed by the device itself since the measurement can be affected by how the user mounts the package on the heatsink. It is for this reason the conditions, "with heatsink compound" or "without heatsink compound" are often seen in datasheets for this thermal resistance parameter - pointing out the fact that some factors affecting thermal resistance are under user control.

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8. Thermal characteristics

Table 5. Thermal characteristics

Symbol	Parameter	Conditions		Min	Typ	Max	Unit
$R_{th(j-mb)}$	thermal resistance from junction to mounting base	full cycle; Fig. 6		-	-	2.3	K/W
$R_{th(j-a)}$	thermal resistance from junction to ambient free air	in free air		-	60	-	K/W

Fig.3 Example of WeEn datasheet for $R_{th(j-mb)}$

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8. Thermal characteristics

Table 5. Thermal characteristics

Symbol	Parameter	Conditions		Min	Typ	Max	Unit
$R_{th(j-h)}$	thermal resistance from junction to heatsink	full cycle or half cycle; with heatsink compound; Fig. 6		-	-	4	K/W
		full cycle or half cycle; without heatsink compound; Fig. 6		-	-	5.5	K/W
$R_{th(j-a)}$	thermal resistance from junction to ambient free air	in free air		-	55	-	K/W

Fig.3 Example of WeEn datasheet for $R_{th(j-h)}$

As mentioned, some suppliers continue to use the historic term $\mathbf{R_{th(j-c)}}$, thermal resistance from junction to "case", even for TO220F "full-pack" packaged and similar devices. The best interpretation of what is meant when $\mathbf{R_{th(j-c)}}$ is quoted for such packages is $\mathbf{R_{th(j-h)}}$ having the condition "with heatsink compound".

This understanding is on the basis that, with a good heatsink compound, the temperature of the heatsink will be very close to the ***average*** temperature of the back-plastic surface of the package.

3. Conclusion

Thermal resistance is an important parameter for designers to understand in order to ensure the reliability of packaged power devices and the electronic systems into which they are placed.

The parameters and the history underpinning the definition of thermal resistance has been described so that designers may understand thermal resistance values quoted by various suppliers and what is meant by the terms $\mathbf{R_{th}}$, $\mathbf{R_{th(j\text{-}mb)}}$, $\mathbf{R_{th(j\text{-}h)}}$, and $\mathbf{R_{th(j\text{-}c)}}$.

$\mathbf{R_{th(j\text{-}c)}}$ has been shown to be effectively the same parameter as $\mathbf{R_{th(j\text{-}mb)}}$ and $\mathbf{R_{th(j\text{-}h)}}$ with heatsink compound.

Revision history

Rev	Date	Description
v.1	20190905	initial version

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