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A PRACTICAL LOOK AT CURRENT RATINGS

Introduction

System designers are often faced with the task of selecting the most suitable power device from a wide array of products from different manufacturers with very similar ratings. While a detailed parameter by parameter comparison is technically the most correct way of selection, it is not the most practical and designers resort to making their first cut based on 3-4 simple parameters. Among these are package, voltage and current ratings, R_{dson} etc. In this article we will take a close and practical look at the current rating. For purposes of illustration we will focus on Mosfets in low and medium power packages, but the considerations can be applied to other technologies as well.

The definition of voltage rating is well accepted, it is measurable with a high degree of consistency, under conditions that are not far removed from the real world. It is reasonable to expect that the device can be subjected to its rated voltage continuously without causing failure. The situation is different for current ratings. There is no such thing as a measured value of rated current; it is always arrived at by indirect calculation. As a result, several versions of rated current can exist. The most common one is specified at case temperature T_c = 25 °C and another at T_c = 100 °C. For SMT packages they are also specified at ambient temperatures like 25 °C and 70 °C. We will focus on T_c based definitions for leaded packages; the conclusions can be easily extrapolated to other packages.

The usable current of any device is mainly limited by the heat it generates within the die and the maximum permissible junction temperature T_{jmax} for the silicon. Continuous DC current is assumed so rated current follows the formula

$$I_{dsrated} <= [(T_{jmax} - T_c) / (R_{dsmax} * R_{\theta jcmax})]^{1/2} \quad (1)$$

The inequality has its reasons. With low voltage Mosfets heading towards sub mΩ values of R_{ds}, at T_c = 25 °C the formula can yield hundreds of Amperes as rated current in a tiny DFN package. In such cases the mechanical construction of the package, such as the bond wires and pin size, become the limiting factors rather than silicon.

Even with the equality sign, this may not give any indication of usable current in the device. Most quick reference tables give the value for T_c = 25 °C which either requires a massive heatsink to maintain or theoretically impossible when the ambient is > 25 °C. Even if one were to look at the Tc = 100 °C definition, it assumes continuous DC current and zero switching losses, and excludes majority of today's applications. Most companies also set strict derating standards in design and limit the junction temperature to 125 °C even if the manufacturer claims a T_{jmax} of 175 °C. The usable current rating is then only 57.7% of the spec.

While ignoring the absolute value many users are tempted to use the current rating as a comparative benchmark for different devices. If R_{dson} values are close enough it reduces to a comparison of package thermal resistance. Technically this is a meaningless exercise as a number of variations are possible within the definition. Different manufacturers assume different tolerances on the thermal resistance for the same package; the number can vary from +15% to ±50%. Some of them do not even provide a maximum value and use the typical value to boost the current rating. If that is not enough many manufacturers use a creative version of "steady state" and limit it to 10 seconds. The power is applied and junction temperature is measured after only 10 seconds to calculate Rthjc. Not all datasheets are clear about exactly which definition of steady state is being used. As a result, for the same R_{dson} and case temperature the rated current can vary as much as 20% among essentially identical products. Given a specific application and operating current, the assumption that selecting a device touting a higher rated current somehow leads to better performance or reliability is misguided to say the least.

It is of course possible for devices with same R_{dson} and package to have thermal resistances that are actually and significantly different. The reason is that over the years Mosfet technology has been evolving and the silicon area required to achieve the same R_{dson} has been shrinking. As an example the R_{ds}-Area product, which indicates the area required for achieving a given value of R_{ds} at a specified voltage, has been shrinking by a factor of two every five years or so. For a given package and lead frame a larger die will invariably result in a lower value of $R_{\theta jc}$ and higher current rating. It then follows that if the current rating of a Mosfet is higher than that of identically rated competitors' devices the reason could very well be an older technology platform that demands larger die size to realise the same R_{dson}.

Whatever the reason, so long as the thermal resistance for one of them is genuinely lower, can it be used at a higher current? The answer will most likely be in the negative. Remember that the ultimate destination of heat generated in the junction is not the case but the ambient air surrounding the entire system. The amount of acceptable current in the device is not defined by its current rating but thermal management of the system. If the device is mounted on a heatsink of thermal resistance $R_{\theta HS}$ the case temperature is given by

$$T_c - T_A = P_d * R_{\theta HS} \qquad (2)$$

For simplicity we assume that $R_{\theta HS}$ includes heatsink-to-case interface and P_d is the power dissipation in the device. In other words,

$$R_{\theta HS} = R_{\theta\ c\text{-}hs} + R_{\theta\ hs\text{-}a}$$

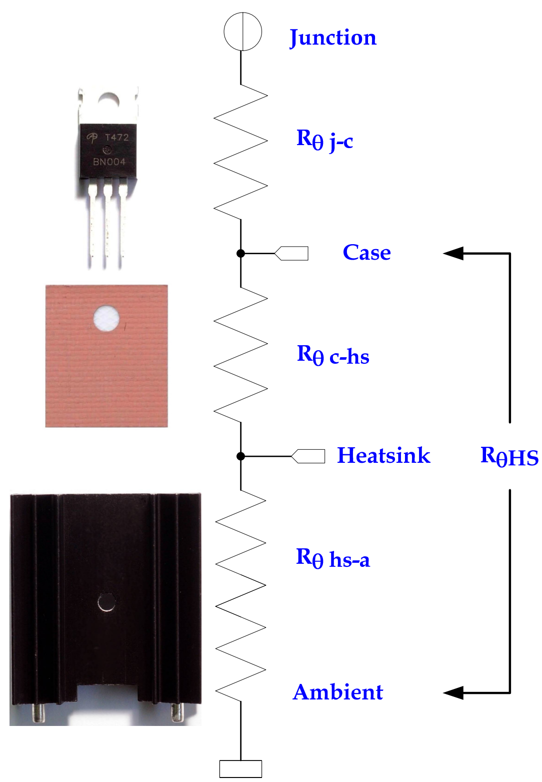

Fig 1: Thermal resistance chain from junction to ambient

Combining (1) and (2) we can write the "system limited" current rating of the same device as

$$I_{dssystem} = \frac{(T_{jmax} - T_c) + (T_c - T_A)}{[R_{dsmax} * (R_{\theta jcmax} + R_{\theta HS})]^{1/2}} \quad (3)$$

As before power dissipation is assumed to occur only due to conduction. To illustrate the issue further we assume a typical high voltage Mosfet in TO-220 package with an R_{dsmax} of 1Ω and $R_{\theta jcmax}$ of 1 °C/W. The datasheet would show a current rating of 7.07A DC @ T_c = 100 °C which results in a power dissipation of 50W in the device. Since industrial products must work at an ambient of 50 °C at the least, we also need a heatsink with a $R_{\theta HS}$ of 1 °C/W to maintain the case at 100 °C. But a heatsink of this thermal resistance would be quite large in its size. As an example consider Aavid Thermalloy 530002B02500G with a PCB footprint of 1000 sq mm. We will need 166 mm of this extrusion and the overall volume would be impractical for any system that is being designed with this Mosfet. One can choose a more practical piece like the 513002B00000G with a 1" height but the $R_{\theta HS}$ will be 13.4 °C / W. Substituting these values in (3) gives a $I_{dssystem}$ rating of less than 2.63A. These calculations of course are quite elementary and known to every power designer. But the point here is that with the heatsink fixed by the thermal design of the system, the usable current of <u>any</u> 1 Ohm Mosfet is limited to 2.63A *no matter what its current rating says.*

In equation (3) the temperature differentials are split as $T_j - T_c$ and $T_c - T_A$ instead of the single term $T_j - T_A$. The reason is that thermal design of the system could also restrict the permissible Tc. Operating just one device at higher case temperature to utilise its lower $R_{\theta jc}$ is invariably ruled out when sharing heatsink or PCB copper as a common coolant. When all power devices share a common heatsink no single component will be allowed to dump too much heat and raise T_c for all the others. This is even more true in case of POL converters built on PCBs. The PCB copper is shared by rest of the electronics including sensitive ICs. The maximum PCB temperature is collectively set by the ICs and in turn limits the allowed dissipation for power devices. In our example above, if the heatsink temperature has to be clamped at 100 °C, the device current gets limited to 1.9A.

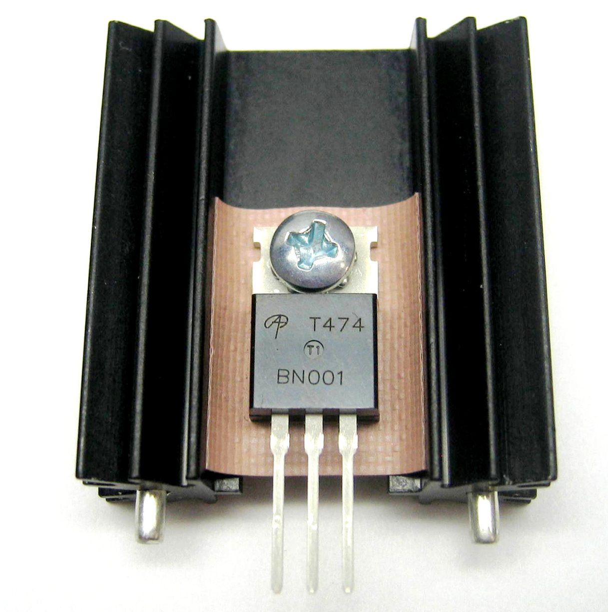

Fig 2: The usable current of small packages is determined by the heatsink they are mounted on

A common misconception is that for the same operating current, selecting a device with a higher tag somehow builds up a higher degree of derating in the design. In switching applications the ratio of operating current to the so called rated current is an illusion and has no relevance to reliability. The key parameters that define robustness are power loss and case temperature, neither of which is predicated by the current rating. The losses are set by measurable device parameters such as the R_{dson}, gate charges and body diode characteristics. The case temperature is dictated by the rest of the system, independently of current rating. Because of the lower $R_{\theta jc}$ there may be a marginal reduction in the junction temperature which has little influence on the overall reliability.

Manufacturers often design a standard silicon die and offer it in different packages. For example our 1Ω Mosfet above could be sold in TO-220, TO-220F and D-Pak, all marketed under the same datasheet. Since typical $R_{\theta jc}$ for these packages can vary in a 1:4 ratio we would expect their rated currents also to vary in the 1:2 range. However, the common datasheet may show identical values of rated current for all of them. Working backwards from $R_{\theta jc}$ one may even prove that there is no way some of the packages will carry the specified current continuously under any condition without exceeding T_{jmax}. The datasheet is not misrepresenting the facts here; it is just that the term "rated current" has a different connotation. It should neither be equated nor confused with the current carrying or power handling capabilities of the device.

At this point the end user might justifiably ask why this number is provided at all. Experienced power designers are known to dismiss the rated current as the "single most useless piece of information" printed on the datasheet. (The SOA curves are also strong contenders for that distinction.) There *are* cases where current rating is a useful indicator in device selection. The inequality of $R_{\theta HS} >> R_{\theta jcmax}$ in (3) is valid for relatively low power and/or low current applications. In industrial applications where a module can dissipate hundreds of watts of heat, relatively massive heatsinks are used for which $R_{\theta HS}$ and $R_{\theta jcmax}$ are quite comparable. The rated system current is responsive as much to $R_{\theta jcmax}$ as it is to $R_{\theta HS}$. A current rating of 150A could be a meaningful indicator for an IGBT module intended for multi kW inverter system. But when a low voltage Mosfet in D-PAK flaunts the same number, designers need to run a reality check.

In many consumer motor control applications the switching device is subject to very high currents for short durations. The designers can't and/or don't implement safe and precise current limits in the circuit and the device has to absorb all of the power losses associated with the spike and survive. The higher current rating, which is synonymous with lower $R_{\theta jc}$ for a given R_{dson}, implies that temperature rise will be lower under the pulse. T_{jmax} of course could be way above 150 °C in all the cases but the device with lower $R_{\theta jc}$ has a better survival rating.

Manufacturers also use the rated current as a point of reference for specifying other parameters such as the UIS, forward drop of the body diode, transconductance and so on. But just because the forward drop of the body diode is measured at a certain current does not mean that the diode, or the Mosfet for that matter, is capable of continuously carrying that current in real world.

When comparing two power devices the correct question is not which one of them has better current rating, but which of them will contribute less heat to the system. Remember that the answers to the questions are not related and can be contradictory as well. In a high current synchronous buck switching 15A at 500 kHz, a low side Mosfet with 70A current rating could very well be more efficient than an 80A device and therefore the better choice. Unfortunately it is easy to look up the answer to the wrong question in a short form catalog but there are no shortcuts to answering the right question. The losses have to be calculated separately for each application using several parameters distributed all over the datasheet. And rated current most certainly is not one of them.

Conclusion

The current rating of a power device is neither guaranteed by design nor tested in production. It is a secondary value computed from calculations using R_{dson}, R_{thjc} and T_{jmax}. Further the calculations are made under standard conditions that are not practically encountered. The manufacturers use it as a reference number to define and measure certain other characteristics, but to most end users it is not a meaningful parameter.

The proper way of evaluating a power device is to calculate how much loss it will generate based on the application conditions. While difficult, this is the only way to ensure that the most appropriate device is selected for the application. Comparing power devices from different manufacturers based on their current ratings is at best misleading.