Thermal Calculation of Power Semiconductor Devices

Abstract:

Power Semiconductor Devices (such as MOSFET, IGBT ,Traic) are widely used in various applications. But there are power losses while switching & conduction, which causes temperature rise of device junction, while temperature rise is limited by maximum junction temperature. So, a designer should be familiar with thermal characteristic of Power Semiconductor Devices and working temperature of device junctions. This paper introduces concept of thermal resister for power device, and gives junction calculation method and formula of power device in steady state and instantaneous conditions.

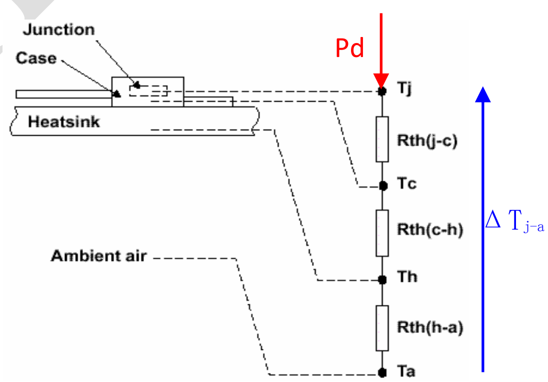
Conception of Thermal Resistance and Relevant Parameter

Rth_{j-c}: Thermal Resistance between the junction and the Case (related with die size & package of chip, and is a fixed value)

Rth_{j-a}： Thermal Resistance between the junction and the ambient (related with die size & package of chip and external heat-sink condition, and is dependent with external conditions)

Rth_{c-h}: Thermal Resistance between the Case and the heat-sink (this value depends on the interface material used.）

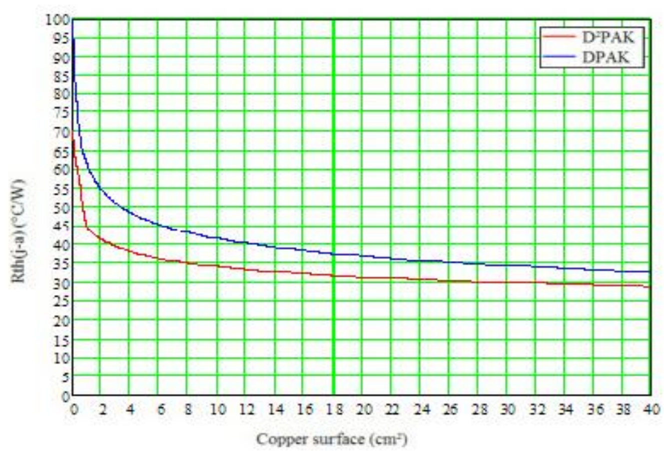
Rth_{h-a}： Thermal Resistance between the heat sink and the ambient (related with size of external heat-sink and its material)



Picture1. **Thermal resister model**

For SMD package, the thermal resistance between junction and ambient Rth_{j-a}, depends on the copper surface used under the tab. In case of an infinite heat-ink, the Rth_{j-a} will be limited by the value of the junction to case, junction to tab or junction to lead thermal resistance, depending on the package used.

Below, are the curves giving the relation between Rth_{j-a} and the copper surface



Picture2. Rth_{j-a} VS. copper

(Cu) under the tab for a FR4 board – 35 µm copper thickness:

Calculation Formula For Temperature Rise

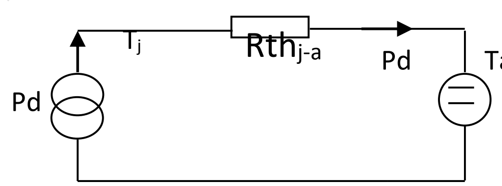
1. under Steady-State Condition

$Rth_{j-a}=Rth_{j-c}+Rth_{c-h}+Rth_{h-a}$

$T_j=Pd*Rth_{j-a}+T_a$

$\Delta T_{j-a}=T_{jmax}-T_a$

$Pd_{max}=\Delta T_{j-a}/ Rth_{j-a}$



Picture3. **Thermal model for steady state**

For Example:

Suppose: T_{jmax}=125℃, T_a=50℃，Rth_{j-a}=30℃/W

Then, Max. allowed Power Losses：Pd_{max}=（T_{jmax} - T_a）/ Rth_{j-a}=（125-50）/30=2.5w

If real power losses are 4w, then need parallel device (eg. MOSFET, DIODE that can be paralleled) and add heat sink & fan to reduce Rth_{j-a} .

Usually Rth_{j-a} is not a fixed value, but is a Rth_{j-c} is a fixed one. After calculating power loss of the device, according to ambient temperature, we can also calculate the thermal resistance of heat sink, that helps us to choose heat sink .

For Example:

Suppose: T_{jmax}=125℃, T_a=50℃，Rth_{j-c}=2℃/W, Pd=2.5w

Then, we can calculate the thermal resistance from junction to the ambient :

Rth_{j-a} =（T_{jmax} - T_a）/ Pd_{max} =（125-50）/2.5=30℃/W

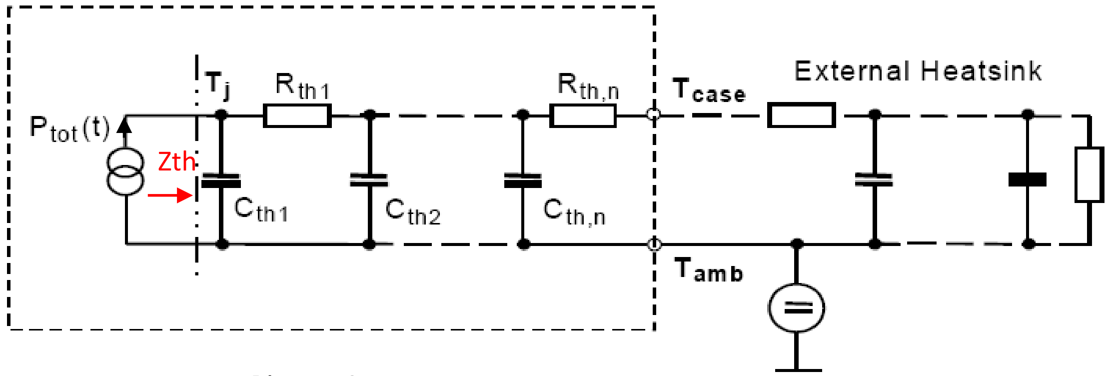
Further, we can get thermal resistance of the heat sink:

Rth_{c-h}+Rth_{h-a}= Rth_{j-a}- Rth_{j-c}=30-2=28℃/W

2. Under Instantaneous Condition

In some application, for example: hot swap and start-up of motor, power device need withstand large voltage & current in short time, then voltage & current reduce and recover to normal state. During this short period of time, Power dissipations is usually tens of times higher than normal work. Can the power device withstand so high temperature caused by the instantaneous power? We can count the junction temperature by instantaneous resistance.

Under instantaneous condition, we need consider of the existence of thermal capacity. Thermal resistance here is called Zth. Usually Zth is less than the thermal resistance under steady state. Below picture is the equivalent circuit of instantaneous thermal resistance.



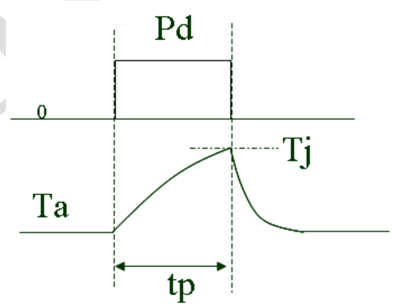
Picture4. **Thermal model for instantaneous**

Currently, power device is usually provided with curve of instantaneous thermal resistance, below is the curve of MOSFET and Traic.

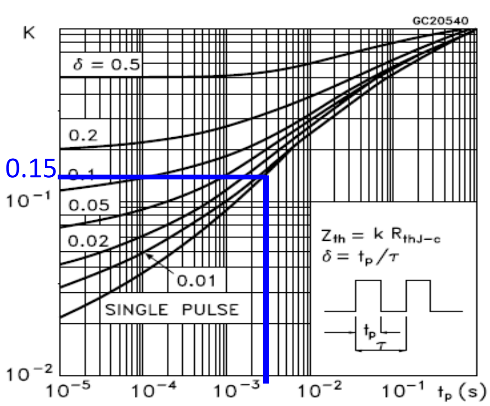
1) Single Pulse (In Short time)

$T_{j(tp)}=T_a+Pd*Zth_{j-a(tp)}$ $Zth_{j-a(tp)}=K*Rth_{j-a}$

or $T_{j(tp)}=T_c+Pd*Zth_{j-c(tp)}$ $Zth_{j-c(tp)}=K*Rth_{j-c}$

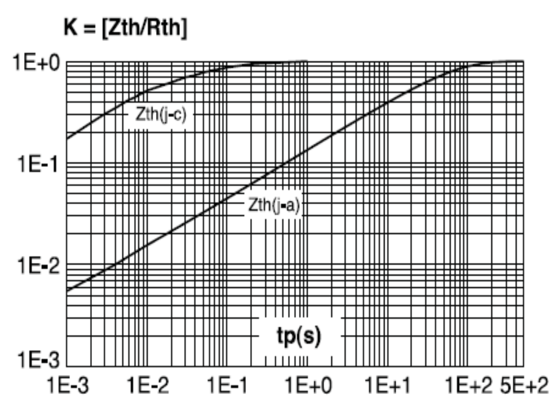


Thermal impedance for TO-220 / D²PAK / TO-247



MOSFET

Relative variation of thermal impedance junction to ambient versus pulse duration (recommended pad layout, FR4 PC board) for DPAK.



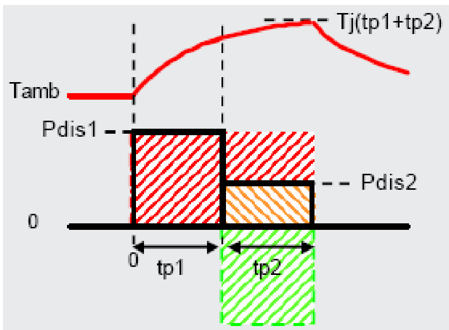
Traic

Picture5. **Instantaneous thermal factor**

For short time single pulse (<1s) or with large heat-sink condition, case temperature of power device can not change within short time, so we can think case temperature is same as ambient temperature. If there is no $Zth_{j-a(tp)}$ curve, we can use: $T_{j(tp)}=T_c+Pd*Zth_{j-c(tp)}$ to calculate junction temperature.

From figure 5, thermal resister of 3ms pulse K=0.15， Rthj-c=3.6℃/W(TO220FP), Suppose ambient temperature T_a=60℃， T_{jmax}=150℃ , then Max. allowed Power Loss is $Pd=(T_{jmax}-T_a)/(K*Rth_{j-c})=(150-60)/(0.15*3.6)=166.7W$

2) Composite waveform



Using Superposition principle:

$T_{j(tp1+tp2)}=T_a+Pdis1*Zth_{j-a(tp1+tp2)}-Pdis1*Zth_{j-a(tp2)}+Pdis2*Zth_{j-a(tp2)}$

Conclusion

Steady and instantaneous thermal resistance can be obtained from datasheet of power device, and then we cam calculate maximum junction temperature under different conditions which help us to choose power device and make it work safely.