SGS-THOMSON
MICROELECTRONICS

APPLICATION NOTE

SCR and TRIAC THERMAL MANAGEMENT

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INTRODUCTION

The behaviour of a semiconductor device depends on the temperature of its silicon chip. It is why electrical parameters are given at a specified temperature.

To preserve the performance of a component and to avoid failure, the temperature has to be limited by managing the heat transfer between chip and the ambient atmosphere. The aim of this note is to show how to calculate a suitable heatsink for a semiconductor device and the precautions needed for mounting.

I - THERMAL RESISTANCE

1) Review

The thermal resistance of a semiconductor assembly is the parameter which characterizes its resistance to heatflow generated by the junction during operation. It means the thermal resistance has to be low to have a low junction temperature, resulting in good semiconductor performance.

The maximum dissipated power capability is :

$$P_{\max} = \frac{Tj_{\max} - Ta_{\max}}{Rth_{(j-a)}}$$

Where :

- Tj_{max} is maximum junction temperature of the semiconductor in degrees (°C).
- Ta_{max} is the maximum ambient air temperature in degrees (°C).
- $Rth_{(j-a)}$ is the thermal resistance between junction and ambient air in°C/W.

The Rth(j-a) takes into account all materials between the junction to ambient air.

2) Dissipated power in a thyristor

The maximum mean power dissipation versus average on-state current curve is given in the datasheet. But a more accurate result is obtained by using the Vto and Rt values, with the following calculation :

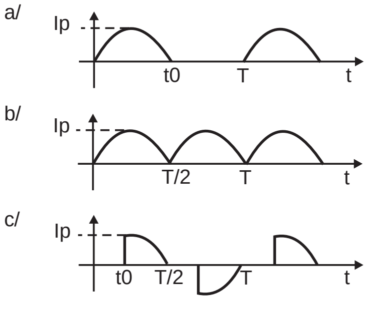
$$P = V_{to} \,.\, I_{T(AV)} + R_t \,.\, I_{T(RMS)}{}^2$$

Where :

- V_{to} is the threshold voltage specified in our datasheet
- R_t is the dynamic on-state resistance specified in our datasheet
- $I_{T(AV)}$ is the average on-state current
- $I_{T(RMS)}$ is the R_{MS} on-state current

The figure 1 shows the R_{MS} and average values for different waveforms of current :

Fig. 1 : RMS and average current.



a/ $IT(AV) = \frac{2.Ip.t0}{\pi.T}$ $\quad IT(RMS)^2 = \frac{Ip^2.t0}{2.T}$

b/ $IT(AV) = \frac{2.Ip}{\pi}$ $\quad IT(RMS) = \frac{Ip}{\sqrt{2}}$

c/ $IT(RMS)^2 = \frac{Ip^2}{2}\left(1 - \frac{2.t0}{T} + \frac{1}{2.\pi}\sin\left(\frac{4.\pi.to}{T}\right)\right)$

$$IT(AV) = \frac{1}{T}\int_0^T i(t)dt \qquad IT(RMS)^2 = \frac{1}{T}\int_0^T i^2(t)dt$$

3) Dissipated power in a triac

A triac is made up of two thyristors connected back to back. This means we consider the sum of the dissipated power of both thyristors.

The following formula gives us the total dissipated power versus $I_{T(RMS)}$ current though the triac :

$$P = \frac{2.\sqrt{2}}{\pi} . I_{T(RMS)} . Vto + Rt. I^2_{T(RMS)}$$

For a phase angle conduction the R_{MS} current is shown in figure I c (page 1).

Depending on the dissipated power in the component, two types of assembly are possible :

- In the air without external heatsink
- With heatsink

4) Component without external heatsink

The figure here after shows the thermal equivalent diagram for a component without external heatsink.

In practice the imposed parameters are :

- **Ta :** ambient air temperature where the triac is located.
- **Rth(j-a) :** Thermal resistance between junction and ambient air given in the datasheet.
- **P :** dissipated power in the triac depending on the used triac and on the load.

The following equation defines the junction temperature depending on these parameters.

$$Tj = P . Rth_{(j-a)} + Ta$$

If this temperature is higher than the maximum junction temperature specified, a heatsink has to be used.

Keep in mind that this calculation has to be made in the worst case : with the maximum dissipated power taking into account the load and line voltage dispersions. We have to consider the maximum ambient temperature around the component i.e. inside the box where the triac is located. The most rigorous way is to know the thermal resistance between ambient air and the triac location.

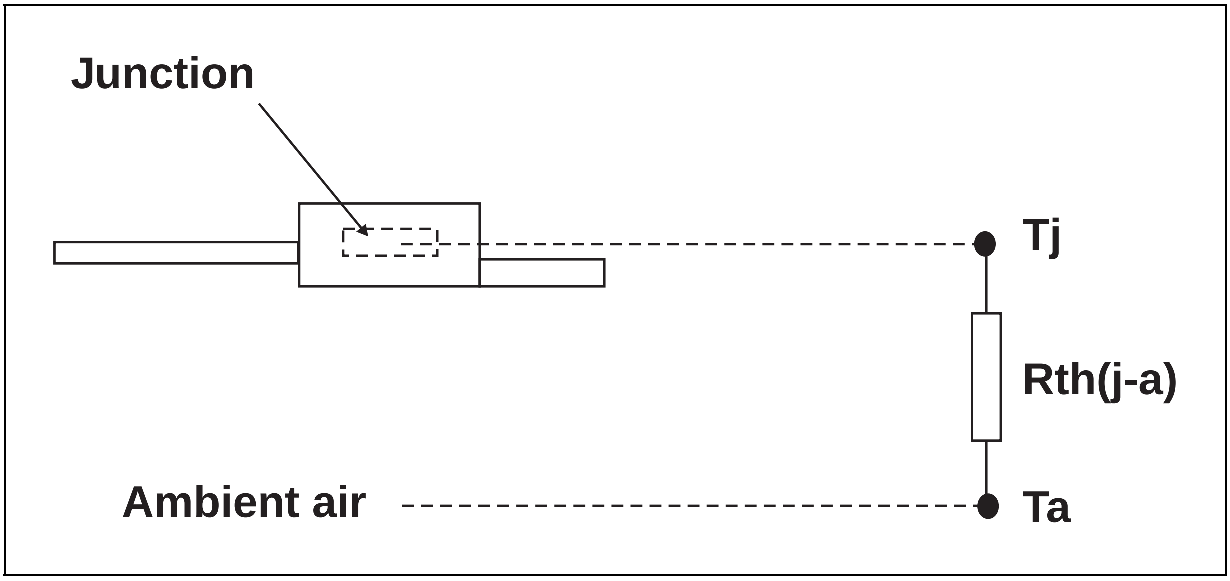
In most cases, ambient temperature is considered as the temperature around the triac which is the box temperature.
This has been done in this paper.

An analogy between Ohm's law and the thermal equivalent circuit can be made :

- Electrical resistance corresponds to thermal resistance
- Current corresponds to dissipated power
- Voltage corresponds to temperature

U = R.I corresponds to T = Rth.P

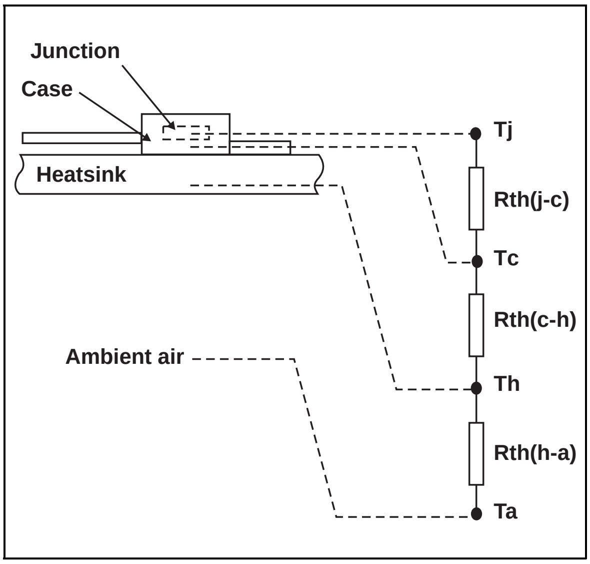
Fig. 2 : Thermal equivalent diagram.



5) Component with external heatsink.

The same approach allows a suitable heatsink to be defined. The figure 3 shows the thermal diagram.

Fig. 3 : Thermal equivalent diagram with external heatsink.



The formula to calculate the thermal resistance between heatsink and ambient air is the following :

$$Rth_{(h-a)} = (Tj - Ta) / P - Rth_{(j-c)} - Rth_{(c-h)}$$

Where :

- T_j is the junction temperature in °C
- P is the maximum dissipated power in W
- $R_{th(j\text{-}c)}$ is the thermal resistance between junction and case in °C/W
- $R_{th(c\text{-}h)}$ is the thermal resistance between case and heatsink in °C/W, depending on the contact case/heasink.

For a triac, because the current is alternating, we have to consider the Rth(j-c) in AC which is different to the Rth(j-c) in DC.

This difference is due to the die of the triac. The first half of the silicon surface works when the current is positive, the second when the current is negative. Because of the thermal coupling between these two parts, Rth(j-c)AC is not equal to 50 % of Rth(j-c)DC.

$$Rth_{(j-c)}\ AC = 0.75 \ x \ Rth_{(j-c)}\ DC$$

II - ASSEMBLY

1) Without heatsink

For the example of a triac in TO220 package, the limit is :

$$P_{\max} = \frac{Tj_{\max} - Ta_{\max}}{Rth_{(j-a)}}$$

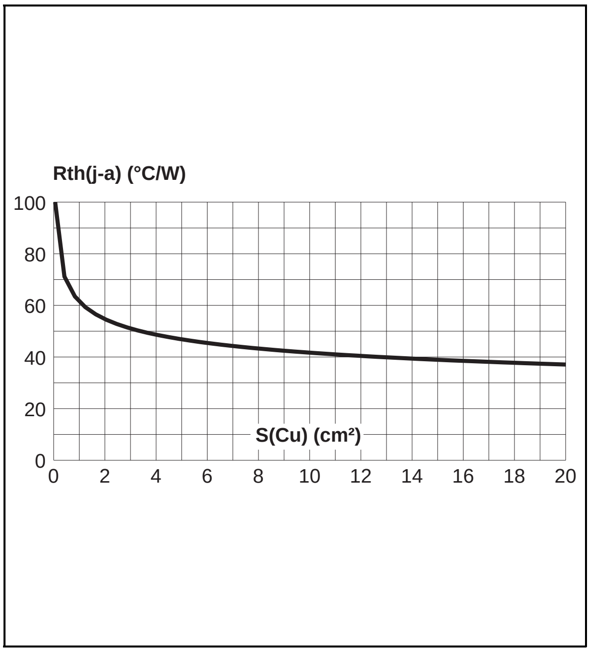
In this case, the cooling of the component is done due to :

- The case
- The leads

For a TO220, most of the power is evacuated by the case due to the metallic heatsink at the back of the package. Some packages, like SMD packages, required a copper area on the printed circuit board to better dissipate.

Figure 4 shows the thermal resistance versus copper area on the printed circuit board, for a DPAK package.

Fig. 4 : Thermal resistance junction to ambient versus copper area under tab (Epoxy printed circuit board FR4, copper thickness: 35µm).



2) With heatsink

To preserve all the performances of a component, the assembly is an important parameter. To master the junction temperature, certain rules have to be respected.

We can classify the assemblies in 2 families:

- Screw or rivet assembly
- Clip assembly

a) Assembly by screw :

The Rth(c-h) depends on the quality of the surface. This is why the screw hole or rivet must be milled to remove the burrs and decrease the Rth(c-h).

To improve the Rth(c-h), contact grease has to be used. The thickness has to be uniform and a gradual tightening is required to have a good distribution. This allows cambering of the package (TO220, TOP3, ...) to be avoided, due to a pile of contact grease between the case and the heatsink (see figures 5 and 6).

Fig. 5 : Bad assembly.

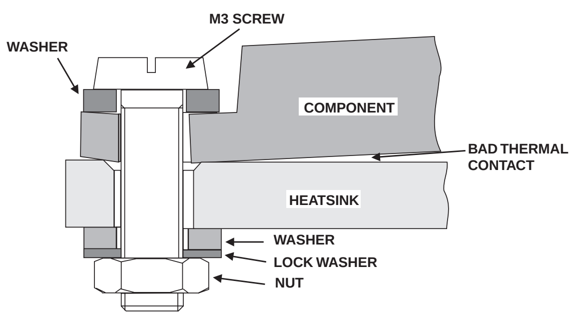
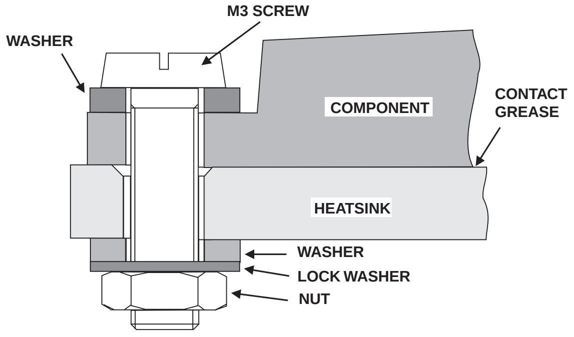
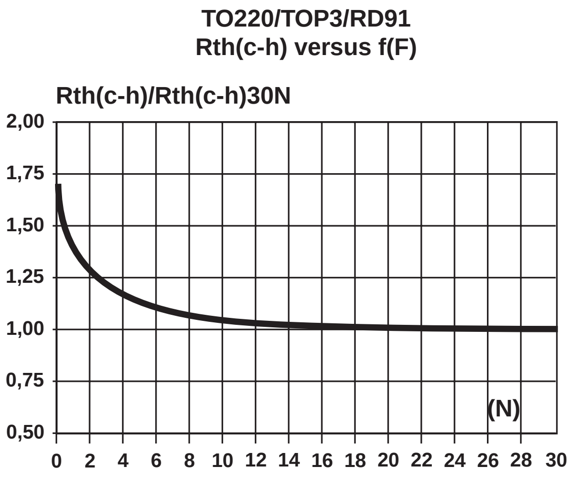


Fig. 6 : Correct assembly.



To avoid a distorsion of the shape, the use of a self-tapping screw is not recommended. If the tightening torque is too high, a distorsion of the shape is possible (see figure 5) and the Rth(c-h) increases. The relative variation of Rth(c-h) versus applied force is shown in figure 7.

Fig. 7 : Relative variation of Rth(c-h) versus pressure force for TO220, TOP3 and RD91.



The thermal contact resistance depends on the force generated by the applied torque on the screw :

$$F = \frac{2 \, . \, T \, . \, \pi}{P + r \, . \, D \, . \, \pi}$$

Where:

- **T :** applied torque on the screw in N.m
- **P :** pitch in m
- **D :** Screw diameter in m
- **r :** Rubbing factor: # 0.12 for steel-steel with grease and # 0.2 for steel-aluminium

Screw :

- Advantages :
  - possibility to insulate
  - easy and quick disassembly
- Disadvantages :
  - long assembly for mass production (high cost due to screw, nut, washers)
  - Master the tightening torque

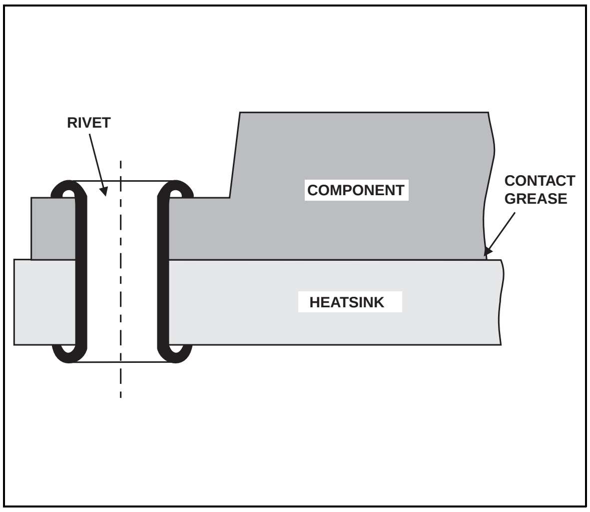
Rivet :

For riveted assembly, the force applied to the rivet should be controlled to avoid a distorsion of the shape and an increase of the Rth(c-h).

In all cases, if there is a distorsion of the shape (especially for package like TO220, TOP33...) a risk of failure appears due to mechanical stress.

The figure 8 shows the assembly with rivet :

Fig. 8 : Assembly with rivet.



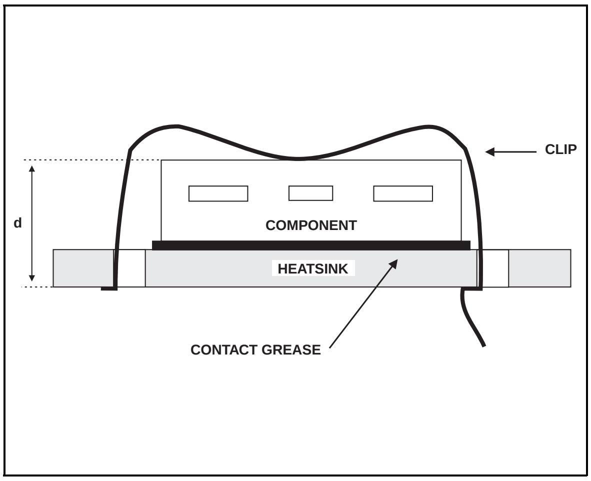
- Advantages:
  - fast assembly for mass production
- Disadvantages:
  - difficult to disassemble
  - difficult to master the force applied to the rivet
  - impossible to insulate with an interface (use of insulated component)

In order to avoid a distorsion of the package which would cause a degradation of the die, it is recommended to limit the applied force to 40 N.

b) Assembly by clip

Figure 9 shows how to assemble a component with a clip.

Fig. 9 : Clip assembly.



As we can see figure 9, the force applied to the component depends on the thickness (d) of the heatsink and the component.

The figure 10 gives the force applied to the component versus thickness of the heatsink.

Fig. 10 : Force applied to the component versus thickness of the heatsink.

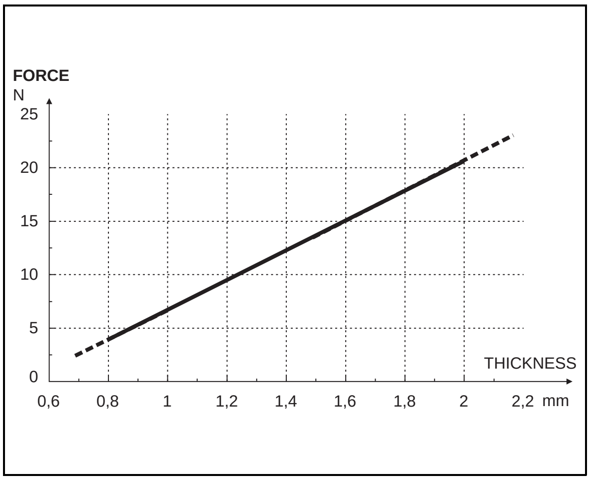
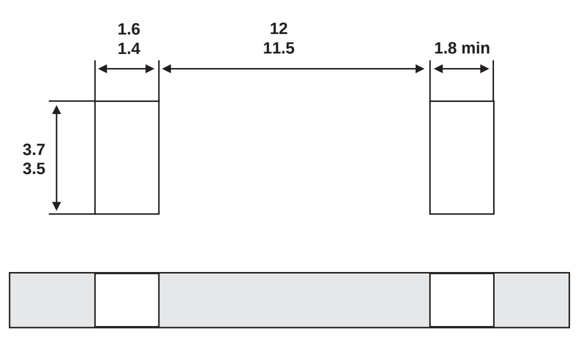


Figure 11 shows an example of the heatsink requirements to assemble a TO220 component with a clip.

Fig. 11 : Example of heatsink requirements.



This information is given by the manufacturer of clips.

Clip :

- Advantages
  - quick assembly and disassembly
  - easy to control the applied pressure
- Disadvantages :
  - difficult to place the component
  - problem with insulation

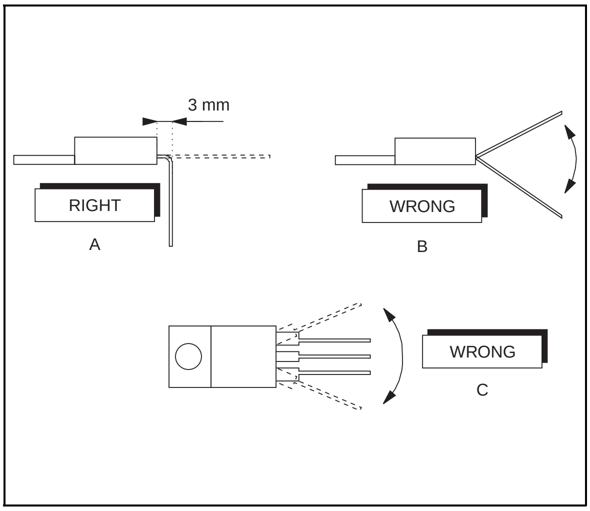
With screw, rivet or clip the order of assembly is the following :

1) Put the component on the heatsink
2) Solve the connections

This is done to avoid mechanical stress on the component due to bad lead cambering.

See (figure 12).

Fig. 12 : Lead bending.



III - INSULATING MATERIAL-CONTACT GREASE

In spite of careful packaging and heatsinking, the surfaces are not perfect. This is why an interface between case and heatsink is needed to decrease thermal contact resistance.

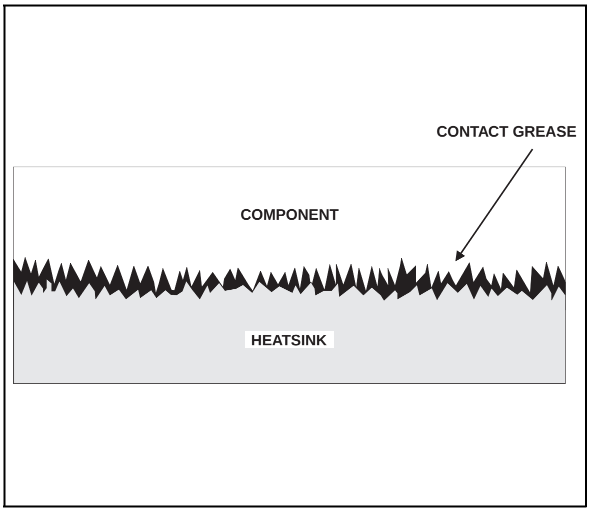
The most commonly used is the contact grease made from silicone.

Furthemore it is sometimes needed to insulate the package and the heatsink.

1) Contact grease

Because of the bad contact between component and heatsink, an interface is needed to reduce the Rth(c-h) as shown in the figure 13 :

Fig. 13 : The interface.



Due to the high thermal conductivity compared to that of air, the use of contact grease between component and heatsink allows the thermal contact resistance to be decreased.

This causes problems.

The time needed to apply it uniformly to avoid cambering of the package (due to a pile of grease) and the difficulty to clean it are common problems posed by using contact grease. Once it has been applied, cleaning baths have to be avoided to prevent washout of the grease.

2) Insulating materials

We can classify them in 3 types as follows :

a) - Mica insulators

This has been the most commonly used insulator for many years. Its insulating quality is good, but due to its rigidity, the thermal interface is not very good and needs contact grease on both sides. Because of its rigidity it can be easily broken.

b) - Ceramic insulators

More expensive than mica, their thermal resistances are lower. Due to their rigidity, they also need contact grease. They can be easily broken, however, as they are less fragile than mica.

c) - Silicon insulators

These materials are not rigid and therefore do not need contact grease. They assume the shape of the component and of the heatsink if sufficient pressure is applied. The problems previously explained disappear. According to the manufacturers, the stability in time is much better than with contact grease. However the thermal resistance is higher than the combination of the mica + grease.

Fig. 14 : Rth(c-h) for different materials for TO220 package.

	CONTACT GREASE	MICA + GREASE e=80µm	MICA DRY e=80µm	SILICONE INSULATOR
Rth(c-h) °C/W	0.1	1.7	4	2.6

Figure 14 shows the thermal resistance for different TO220 insulators and for a given pressure (F = 30N).

IV - INSULATED COMPONENTS

Most of the thyristors and triacs are available in insulated or uninsulated packages. In an insulated component, insulation can be done in two different ways, either by a ceramic between the die and the heatsink of the component (TO220 package) or by the resin of the package like for the ISOWATT 220 package. This added material increases the thermal resistance between junction and case but simplifies the assembly.

For two 12-Amp triacs in TO220 package, Rth(j-c)AC are the following :

BTA12-600SW (insulated version)	BTB12-600SW + mica + grease
2.5 °C/W	2 °C/W
+ 0.1 °C/W	+ 1.7 °C/W
2.6 °C/W	3.7 °C/W

and for two 4-Amp triacs :

T410-600S (ISOWATT)	T410-600F (TO220) + mica + grease Uninsulated version
4 °C/W	2.6 °C/W
+ 0.2 °C/W	+ 1.7 °C/W
4.2 °C/W	4.3 °C/W

The use of an insulated component results in a low thermal resistance between junction and heatsink and a reduced assembly cost.

V - HEATSINK

The choice of a heatsink depends on several parameters : the thermal characteristic, the shape and the cost.

However in some applications a flat heatsink can be sufficient. Figure 15 on next page shows the curve Rth(h-a) versus the length of a flat square heatsink for different materials and thicknesses.

Some applications need heatsinks with a very optimised shape where thermal resistances are not known.

For this, the best solution consists of measuring the case temperature of the component in the worst case and to check the following formula :

$$Tc < Tj_{\max} - P\,.\,Rth_{(j-c)}$$

Where:

- Tc is the case temperature
- Tjmax is the maximum junction temperature
- P is the dissipated power in the component
- Rth(j-c) is the thermal resistance between junction and case.

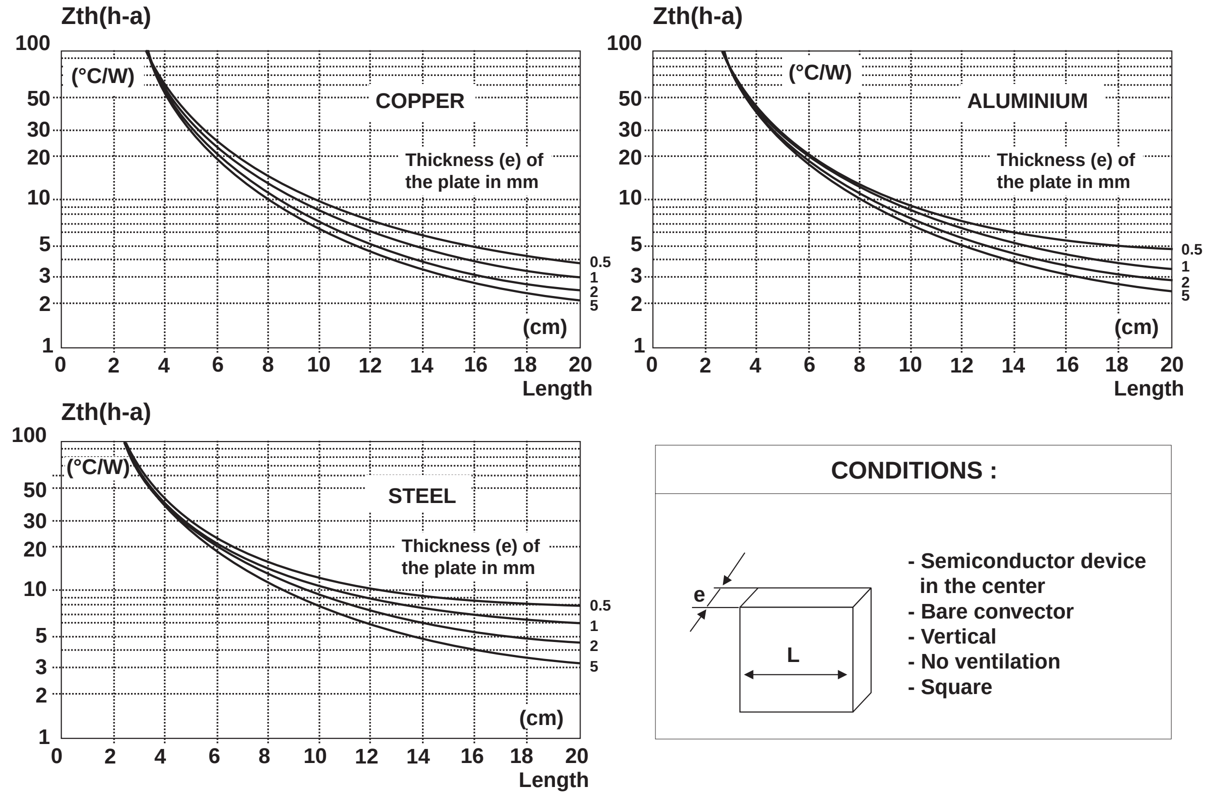
VI - FORCED COOLING

For high power or very high power, an air-forced or liquid cooling may be needed. Heatsink manufacturers give a coefficient depending on the air or liquid flow.

However in some applications like vacuum cleaners, dissipated power is only a few watts and there is air flow. This allows a very small heatsink to be used, very often a flat aluminium heatsink. In this case it is necessary to measure the case temperature in the worst case and to check the formula :

$$Tc < Tj_{\max} - P\,.\,Rth_{(j-c)}$$

Fig. 15 : Rth(h-a) versus the length of a flat square heatsink.



VII - THERMAL IMPEDANCE

In steady state, a thermal equivalent circuit can be done only with thermal resistances. However for pulse operation it can be useful to consider the thermal capacitance, especially when the component is on during a time lower than the time to reach the thermal resistance. The thermal impedance value versus duration is given in the data sheet (see an example fig.16)

For example BTA08-600SW is able to dissipate 21 W without heating during 1s :

$$P = \frac{Tj_{\max} - Ta_{\max}}{Zth_{(j-a)}}$$

$$P = \frac{110 - 25}{4}$$

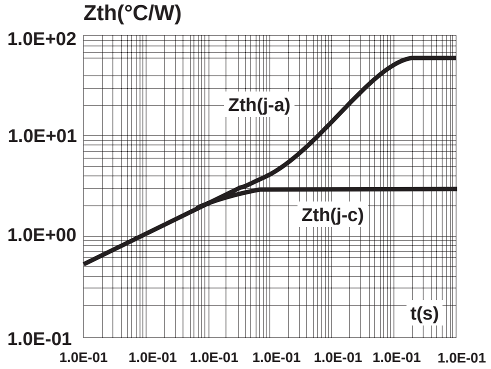
$$P = 21\ W$$

In steady state, with the same ambient temperature the triac is able to dissipate :

$$P = \frac{110 - 25}{60}$$

$$P = 1.4\ W$$

Fig. 16 : Thermal transient impedance of a BTA08-600SW.



VIII - SUMMARY

To preserve the performance of a component, the temperature has to be limited by applying simple rules.

1) Dissipated power :

Thyristor : $P = I_{T(AV)} \,.\, Vto + Rt \,.\, I^2_{T(RMS)}$

Triac : $P = \frac{2\,.\,\sqrt{2}}{\pi} \,.\, I_{T(RMS)} \,.\, Vto + RT \,.\, I^2_{T(RMS)}$

2) Junction temperature :

$Tj = P \,.\, Rth(j\text{–}a) + Ta$

3) External heatsink :

needed if : $Tj > Tj_{max}$

4) Thermal resistance between case and heatsink :

This thermal contact resistance has to be as small as possible. This is done by adding contact grease between case and heatsink.

5) Insulation :

If insulation is needed, we recommend an insulated component instead of external insulation.

6) Heatsink thermal resistance :

$$Rth_{(h-a)} = \frac{Tj - Ta}{P} - Rth_{(j-c)} - Rth_{(c-h)}$$

7) Screw, rivet or clip :

Screw :

- Advantages :
  - Possibility to insulate, easy and fast disassembly
- Disadvantages :
  - Slow assembly for mass production, high cost
  - Difficult to control the tightening force

Rivet :

- Advantages :
  - Fast assembly for mass production.
- Disadvantages:
  - Difficult to disassemble.
  - Difficult to control the force applied to the rivet

Clip :

- Advantages :
  - Fast assembly and disassembly
  - Easy to control the applied pressure
- Disadvantages:
  - Difficult to place the component

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