

## Solid Statements: Calculating the Internal Temperature of Solid-State Relays



In the previous edition we learned how to calculate the base plate temperature of a solid state relay using the formula below and given a few critical parameters. These were; power dissipation (load current x forward voltage drop), ambient temperature, and heat sink impedance.

### **T<sub>bp</sub> = T<sub>amb</sub> + (Power x R<sub>s-a</sub>)**

- \* T<sub>bp</sub> = base plate temp
- \* T<sub>amb</sub> = ambient temperature
- \* Power = SSR dissipation (Watts – V<sub>f</sub> x load current)
- \* R<sub>s-a</sub> = heat sink impedance

So now that we've learned how to calculate the actual base plate temperature of a solid state relay, what does this temperature actually tell us?

Well, basically it tells us the temperature of the warmest *external* surface of a solid state relay. As such, it gives us a reference for calculating the *internal* temperature of the solid state relay. And that, when it's all said and done, is the only thing we are really interested in learning here.

### **Internal vs External Impedance?**

A solid state relay mounted to a heat sink has both external and internal thermal impedances. The primary difference between the two is that the customer can control external impedances by adjusting the size of the heat sink (R<sub>s-a</sub>), changing ambient temperatures, airflow, etc. The internal impedance, however, is determined by the design and construction of the solid state relay's power assembly. This specification is provided by the manufacturer as R<sub>jb</sub> (thermal resistance, junction (SCR) to base plate) and measured, as with a heat sink, in °C per Watt of power dissipated.

The R<sub>jb</sub> of a solid state relay basically tells us how efficiently the relay transfers heat from the SCR die to the base plate. The lower the impedance, the more efficient the relay is at transferring heat. And, as we learned in calculating base plate temperature, the difference in temperature between the SCR die and the base plate is based on power dissipation and thermal impedance. Adding that differential to the previously calculated base plate temperature gives us an estimate of the

### **Crydom Inc.**

2320 Paseo de las Americas, Suite 201  
San Diego, CA 92154  
Tel: (619) 210-1550  
Fax: (619) 710-8544  
Email: sales@crydom.com  
Web: www.crydom.com

actual temperature of the SCR die in the application.

### To Calculate Base Plate Temperature (from last edition)

$$T_{bp} = T_{amb} + (\text{Power} \times R_{s-a})$$

- \*  $T_{bp}$  = max allowable base plate temp
- \*  $T_{amb}$  = ambient temperature
- \* Power = SSR dissipation (Watts –  $V_f \times$  load current)
- \*  $R_{s-a}$  = heat sink impedance

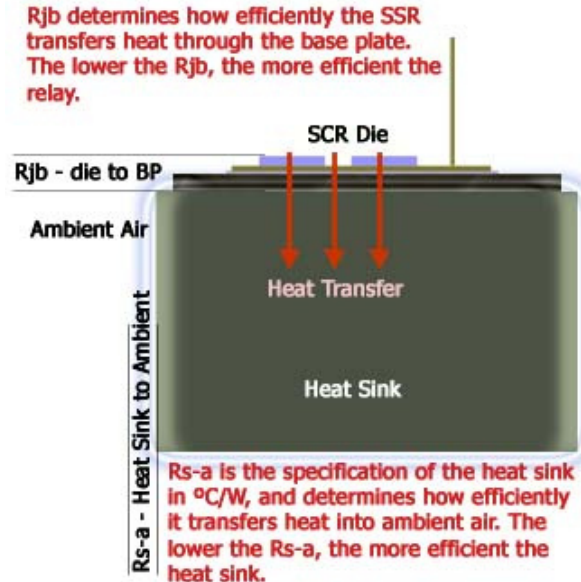
### To Calculate SCR Die Temperature

$$T_{scr} = T_{bp} + (\text{Power} \times R_{jb})$$

- \*  $T_{scr}$  = SCR die temp
- \*  $T_{bp}$  = base plate temp
- \* Power = SSR dissipation (Watts;  $V_f \times$  load current)
- \*  $R_{jb}$  = SSR thermal impedance, die to base plate

Using the formulas above we can begin to estimate the actual temperature of the SCR die inside a solid state relay given application parameters. For example, let's say we have a 90A CWD series SSR in a resistive heating application carrying 60 amps of load current. We'll assume an ambient of 40°C, a 100% duty cycle, and a 1.0°C/W heat sink, just to make things simple. The typical forward voltage drop of a CW series relay is 1.0Vrms, and the  $R_{jb}$  of a 90A CW is 0.13°C/W (per the specification).

One important point to note is that the forward voltage drop specifications in the catalog are in volts peak. We



convert this to the RMS value to calculate power dissipation, which in this case is 1.3Vpk or 0.9Vrms. However, for the sake of simplicity we'll use 1W per amp for such calculations. It gives us a little safety margin and, more importantly for us, makes it easier to do the math!

In this edition we will also add in the thermal interface material between the base plate and heat sink. This interface material fills the small air gaps between the base plate of the relay and the mounting surface, which allows heat to transfer more efficiently. Without a thermal pad or grease, the impedance of the air gap between the base plate and heat sink may be sufficient enough to cause the relay to over heat and fail. The additional impedance added by this material is quite low, but it must be accounted for to ensure calculation

#### **Crydom Inc.**

2320 Paseo de las Americas, Suite 201  
San Diego, CA 92154  
Tel: (619) 210-1550  
Fax: (619) 710-8544  
Email: sales@crydom.com  
Web: www.crydom.com

accuracy. In this case we'll say the customer is using a TP01 with a thermal impedance of  $\sim 0.1^{\circ}\text{C}/\text{W}$ .

#### Example Application

- CW Series SSR
- 60A load @ 100% duty-cycle
- $V_f = 1.3\text{Vpk}$  ( $\sim 1.0\text{Vrms}$ )
- $1.0^{\circ}\text{C}/\text{W}$  heat sink
- TP01 thermal pad =  $0.1^{\circ}\text{C}/\text{W}$
- $R_{jb} = 0.13^{\circ}\text{C}/\text{W}$
- $40^{\circ}\text{C}$  ambient

**A) First we must calculate base plate temperature, as learned in the first edition:**

- 1)  $T_{bp} = 40^{\circ}\text{C} + ((1.0\text{Vrms} \times 60\text{A load current}) \times (1.0^{\circ}\text{C}/\text{W heat sink} + 0.1^{\circ}\text{C}/\text{W thermal pad}))$
- 2)  $T_{bp} = 40^{\circ}\text{C} + (66.0^{\circ}\text{C})$
- 3)  $T_{bp} = 106.0^{\circ}\text{C}$

**B) Then we add this to the calculated internal temperature differential to estimate the SCR die temperature.**

- 4)  $T_{scr} = 106.0^{\circ}\text{C} + ((1.0\text{Vrms} \times 60\text{A load current}) \times 0.13^{\circ}\text{ specified } R_{jb})$
- 5)  $T_{scr} = 106.0^{\circ}\text{C} + (7.8^{\circ}\text{C})$
- 6)  $T_{scr} = 113.8^{\circ}\text{C}$

In this example the die will reach approximately  $114^{\circ}\text{C}$  once the temperature has stabilized. The maximum SCR die temperature in a Crydom AC output SSR is  $125^{\circ}\text{C}$ , so we are within the parameters of the relay. However, there are a few points of

caution that one must always consider when calculating die temperature for their application;

- 1) Always confirm heat sink impedance and double-check your math! If you look at the formula above you can see the impact the heat sink has on the overall temperature rise. Miscalculate the  $R_{jb}$  by 20% and you have a mistake of roughly  $\pm 1.6^{\circ}\text{C}$ . However, make the same 20% mistake in estimating heat sink impedance and you have a variation of roughly  $\pm 12^{\circ}\text{C}$  in the overall temperature rise.
- 2) Always confirm that the ambient used in the calculation is actually the temperature surrounding the SSR / heat sink inside the panel. This is a common mistake. Also, the temperature increase of the heat sink itself may increase the ambient inside the panel. This must also be considered.
- 3) Round up your calculations, just to be safe. A little safety margin within the application is always a good thing to have.
- 4) If something bad can happen, then assume that it will!! As mentioned in point #3, a little safety margin is good to have. So, if it's possible that ambient temperatures can significantly increase, then assume that they will and design accordingly. This is common in applications that have electrical panels located outdoors and impacted by seasonal conditions. The same goes for loss

#### **Crydom Inc.**

2320 Paseo de las Americas, Suite 201  
San Diego, CA 92154  
Tel: (619) 210-1550  
Fax: (619) 710-8544  
Email: sales@crydom.com  
Web: www.crydom.com

January 2009

of airflow, increased load currents, etc. Design for the worst case scenario and you will avoid unpleasant surprises.

- 5) When in doubt, ask! Unfortunately, the thermal calculations are not always as straight forward as we show in these examples. That's why we're here. Let us help!

### In Conclusion:

Now that you've learned to calculate the SCR die temperature in a solid state relay, we can let you in on the fact that this information is, for the most part, already provided in our specification sheet derate curves. Of course, it's not nearly as fun as doing the math, but it does tell you what heat sink to use for a given load current and a given ambient temperature. So, you ask, why did we bother teaching you the long way around? Well basically, because if you've read this far then you're the type of person that needs to know how things work! Just seeing the answer isn't good enough! Furthermore, sometimes the short answer isn't always the most efficient. Maybe a smaller heat sink could be used to save time and space, or a slight reduction in ambient temperature could allow us to use that smaller heat sink. What you've learned here will help you make those decisions yourself.

However, as we stated before... we are here to help you throughout this process. More information on heat sinks and thermal management can be found

on our website at [www.crydom.com](http://www.crydom.com). Or, simply send us an e-mail with all of your application information and we will gladly help you select the appropriate heat sink for your application. Again, if a heat sink is even necessary...

Other useful formulas;

### To Calculate SCR Die Temperature

$$T_{scr} = T_{amb} + (\text{Power} \times R_{s-a}) + (\text{Power} \times R_{j-b}) + (\text{Power} \times .1^{\circ}\text{C/W} (R_{t-p}))$$

### To Calculate Minimum Required Rs-a

$$R_{s-a} = (125^{\circ}\text{C} - T_{amb} - (R_{j-b} \times \text{Power})) / \text{Power}$$

### To Calculate Maximum Load Current on a Given Heat Sink

$$I_{max} = (125^{\circ}\text{C} - T_{amb}) / ((R_{s-a} \times V_f) + (R_{j-b} \times V_f))$$

### To Calculate Heat Sink Thermal Impedance:

$$R_{s-a} = (T_{bp} - T_{amb}) / \text{Power}$$

$$R_{s-a} = ((T_{die} - (R_{j-b} \times \text{Power})) - T_{amb}) / \text{Power}$$

*Doug Sherman*  
*Field Sales Application Engineering Manager (EMEA)*  
[doug.sherman@crydom.com](mailto:doug.sherman@crydom.com)

### **Crydom Inc.**

2320 Paseo de las Americas, Suite 201  
San Diego, CA 92154  
Tel: (619) 210-1550  
Fax: (619) 710-8544  
Email: [sales@crydom.com](mailto:sales@crydom.com)  
Web: [www.crydom.com](http://www.crydom.com)