SSR Thermal Considerations

One of the major considerations when using a SSR, which cannot be stressed too strongly, is that an effective method of removing heat from the SSR package must be employed. The most common method is to employ a heat sink. SSR's have a relatively high "contact" dissipation, in excess of 1 watt per amp.

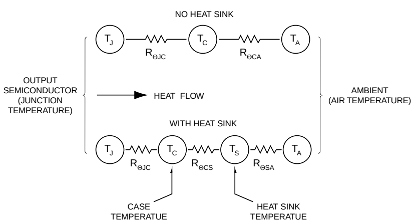

Fig. 18 A simplified thermal model

With loads of less than 5 amps, cooling by free flowing air or forced air current around the SSR is usually sufficient. At higher currents it will become necessary to make sure the radiating surface is in good contact with a heat sink. Essentially this involves mounting the base plate of the SSR onto a good heat conductor, usually aluminum. Good thermal transfer between the SSR and the heat sink can be achieved with thermal grease or heat sink compound. Using this technique, the SSR case to heat sink thermal resistance ($R_{\Theta CS}$) is reduced to a negligible value of 0.1°C/W (celsius per watt) or less. This is usually presumed and included in the thermal data. The simplified thermal model in Fig. 18 indicates the basic elements to be considered in the thermal design. The values that are determinable by the user are the case to heat sink interface ($R_{\Theta CS}$), as previously mentioned, and the heat sink to ambient interface ($R_{\Theta SA}$).

Thermal Calculations

Fig. 18 illustrates the thermal relationships between the output semiconductor junction and the surrounding ambient. $T_J - T_A$ is the temperature gradient or drop from junction to ambient, which is the sum of the thermal resistances multiplied by the junction power dissipation (P watts). Hence

$$T_J - T_A = P(R_{\Theta JC} + R_{\Theta CS} + R_{\Theta SA})$$

where

- T_J = Junction temperature, °C
- T_A = Ambient temperature, °C
- P = Power dissipation (I_{LOAD} x E_{DROP}) watts
- $R_{\Theta JC}$ = Thermal resistance, junction to case °C/W
- $R_{\Theta CS}$ = Thermal resistance, case to sink. °C/W
- $R_{\Theta SA}$ = Thermal resistance, sink to ambient °C/W

To use the equation, the maximum junction temperature must be known, typically 125°C, together with the actual power dissipation, say 12 watts for a 10 amp SSR, assuming a 1.2 volt effective (not actual) voltage drop across the output semiconductor. The power dissipation (P watts) is determined by multiplying the effective voltage drop (E_{DROP})

Assuming a thermal resistance from junction to case ($R_{\Theta JC}$) of, say, 1.3°C/W and inserting the above typical values into the equation, solutions can be found for unknown parameters, such as maximum load current, maximum operating temperature, and the appropriate heat sink thermal resistance. Where two of these parameters are known the third can be found as shown in the following examples:

(a) To determine the maximum allowable ambient temperature for 1°C/W heat sink and 10 amp load (12 watts) with a maximum allowable T_3 of 100°C:

$$T_J - T_A = P(R_{\Theta JC} + R_{\Theta CS} + R_{\Theta SA})$$
$$= 12\ (1.3 + 0.1 + 1.0)$$
$$= 28.8$$

hence,

$$T_A = T_J - 28.8$$
$$= 100 - 28.8$$
$$= 71.2°C$$

(b) To determine required heat sink thermal resistance, for 71.2C maximum ambient temperature and a 10 amp load (12 watts):

$$R_{\Theta SA} = \frac{T_J - T_A}{P} - (R_{\Theta JC} + R_{\Theta CS})$$
$$= \frac{100 - 71.2}{12} - (1.3 + 0.1)$$
$$= 1°C/W$$

(c). To determine maximum load current, for 1°C/W heat sink and 71.2°C ambient temperature:

$$P = \frac{T_J - T_A}{R_{\Theta JC} + R_{\Theta CS} + R_{\Theta SA}}$$
$$= \frac{100 - 7.2}{1.3 + 0.1 + 1.0}$$
$$= 12 \text{ watts}$$

hence,

$$I_{LOAD} = \frac{P}{E_{DROP}}$$
$$= \frac{12}{1.2}$$
$$= 10 \text{ amperes}$$

Regardless of whether the SSR is used on a heat sink or the case is cooled by other means, it is possible to confirm proper operating conditions by making a direct base plate temperature measurement when certain parameters are known. The same basic equation is used except that base plate temperature (T_C) is substituted for ambient temperature (T_A) and $R_{\Theta CS}$ and $R_{\Theta SA}$ are deleted. The temperature gradient now becomes $T_J - T_C$ that is the thermal resistance ($R_{\Theta JC}$) multiplied by the junction power dissipation (P watts). Hence:

$$T_J - T_C = P(R_{\Theta JC})$$

Parameter relationships are similar in that solutions can be found for maximum allowable case temperature, maximum load current, and required junction to case ($R_{\Theta JC}$) thermal resistance. Again, where two parameters are known, the third can be found as shown in the following examples (using previous values).

(d). To determine maximum allowable case temperature, for

$R_{\Theta JC}$ = 1.3°C/W and 10 amp load (12 watts):

$$T_J - T_C = P(R_{\Theta JC})$$
$$= 12 \times 1.3$$
$$= 15.6$$

hence,

$$T_C = T_J - 15.6$$
$$= 100 - 15.6$$
$$= 84.4°C$$

(e). To determine maximum load current for $R_{\Theta JC}$ = 1.3°C/W and 84.4°C case temperature:

$$P = \frac{T_J - T_C}{R_{\Theta JC}}$$
$$= \frac{100 - 84.4}{1.3}$$
$$= 12 \text{ watts}$$

hence,

$$I_{LOAD} = \frac{P}{E_{DROP}}$$
$$= \frac{12}{1.2}$$
$$= 10 \text{ amperes}$$

(f). To determine required thermal resistance ($R_{\Theta JC}$) for 84.4°C case temperature and 10 amp load (12 watts):

$$R_{\Theta JC} = \frac{T_J - T_C}{P}$$
$$= \frac{100 - 84.4}{12}$$
$$= 1.3°C/W$$

In examples (a) through (c) SSR operating conditions are determined as they relate to ambient air temperature using a heat sink. Similarly, conditions can be determined for an SSR operating in free air without a heat sink, provided that a value is given for the radiating characteristics of the package ($R_{\Theta CA}$). This value is rarely given

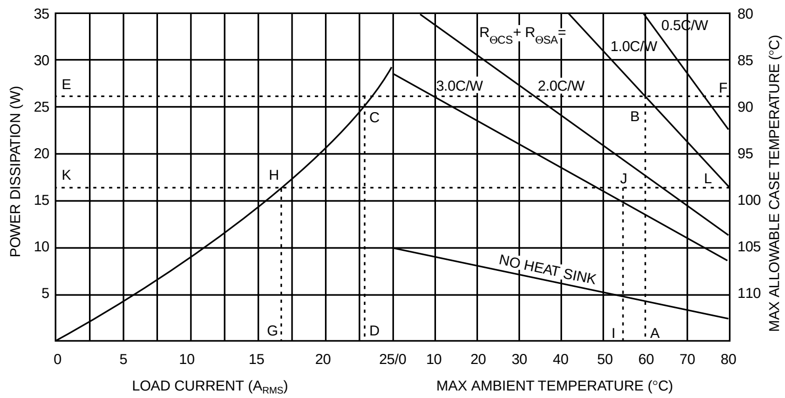

Fig. 19 Thermal operating curves (25 A SSR)

and when it is, it is more commonly combined with ($R_{\Theta JC}$) and stated as ($R_{\Theta JA}$) The equation would appear as follows:

$$T_J - T_A = P(R_{\Theta JC} + R_{\Theta CA})$$

Or

$$T_J - T_A = P(R_{\Theta JA})$$

Where

$R_{\Theta CA}$ = Thermal resistance, case to ambient, °C/W

$R_{\Theta JA}$ = Thermal resistance, junction to ambient, °C/W

The equation can be used to calculate maximum load current and maximum ambient temperature as before. However, the resultant values are inclined to be less precise due to the many variables that affect the case to air relationship (i.e... positioning, mounting, stacking, air movement, etc).

Generally, free air performance is associated with PCB or plug-in SSR's of 5 amps or less, which have no metallic base to measure. The question is often raised as to where the air temperature is measured. There is no clear-cut answer for this. Measurement is made more difficult when the SSR's are closely stacked, each creating a false environment for its neighbor. One suggested approach is to place a temperature probe or thermocouple in the horizontal plane approximately 1 inch away from the subject SSR. This technique is reasonably accurate and permits repeatability.

Ratings

The free air performance of lower powered SSR's is usually defined in the catalogue by means of a single derating curve, current versus ambient temperature based on the foregoing formulas, which is adequate for most situations

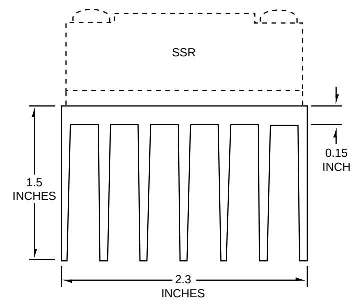

Fig. 20 Typical light duty aluminum heat sink extrusion (end view)

Heat Sinking

Under worst case conditions the SSR case temperature should not exceed the maximum allowable shown in the right hand vertical scales of Fig. 19.

A typical finned section of extruded aluminum heat sink material is shown in outline form in Fig. 20. A 2 inch length of this material would approximate the same thermal characteristics as curve (a) in Fig. 21, likewise, a 4 inch length would approximate curve (b). This is assuming the heat sink is positioned with the fins in the vertical plane, with an unimpeded air flow.

As a general rule, a heat sink with the proportions of the 2 inch length of extrusion (curve (a)) is suitable

SSR Thermal Considerations Cont'd

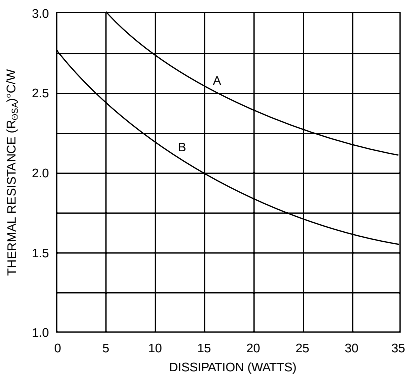

Fig. 21 Typical heat sink characteristics

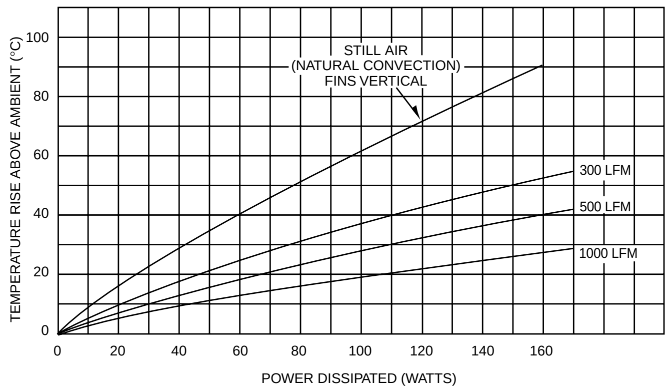

Fig. 23 Typical free-moving air characteristics of a heavy duty heat sink, temperature rise versus power dissipated

for SSR's rated up to 10 amps, while the 4 inch length (curve (b)) will serve SSR's rated up to 20 amps. For power SSR's with ratings greater than 20 amps, heavy duty heat sink of the type shown in Fig. 22 become necessary. The performance of a 5.5 inch length of the extrusion would approximate the characteristics shown in Fig. 23.

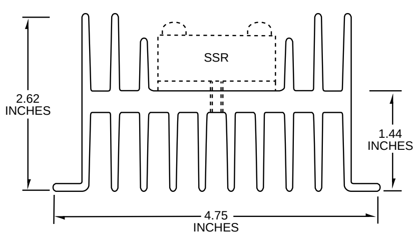

Fig. 22 An end view of a typical heavy duty aluminum heat sink extrusion

Not all heat sink manufacturers show their characteristics in terms of degrees C per watt (°C/W). Some show them as a temperature rise above ambient as shown in Fig. 23. In this case, a value for $R_{\Theta SA}$ is found by dividing power dissipation (watts) into the temperature rise (°C). For example, taking the 60 watt point on the dissipation scale the free air curve would indicate a 40 degree rise. Hence:

$$R_{\Theta SA} = \frac{T_{RISE}}{P}$$

$$= \frac{40}{60}$$

$$= 0.66°C/W$$

In many applications, the SSR is mounted to a panel or base plate which may also be more than adequate as a heat sink. By ensuring flatness, using thermal compound, and removing paint to maximize effectiveness, a base plate (SSR) temperature measurement at maximum ambient may be all that is necessary to confirm proper operation as previously mentioned.

If an SSR installation does not provide an adequate heat sink, a selection is made from the wide variety of commercial heat sink types that are available. Each configuration has its own unique thermal characteristics and are usually well documented with manufacturers' performance curves and application data.