Solid State Relays – Application Data

Definition: A SSR (solid state relay) can perform many tasks that an EMR (electromechanical relay) can perform. The SSR differs in that it has no moving mechanical parts within it. It is essentially an electronic device that relies on the electrical, magnetic and optical properties of semiconductors, and electrical components to achieve its isolation and relay switching function.

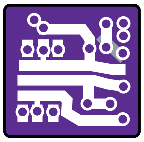
Principle of Operation: Solid State Relays are similar to electromechanical relays, in that both use a control circuit and a separate circuit for switching the load. When voltage is applied to the input of the SSR, the relay is energized by a light emitting diode. The light from the diode is beamed into a light sensitive semiconductor which, in the case of zero voltage crossover relays, conditions the control circuit to turn on the output solid state switch at the next zero voltage crossover. In the case of nonzero voltage crossover relays, the output solid state switch is turned on at the precise voltage occurring at the time. Removal of the input power disables the control circuit and the solid state switch is turned off when the load current passes through the zero point of its cycle.

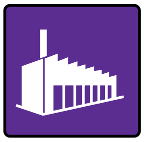
Applications: Since its introduction the SSR, as a technology, has gained acceptance in many areas, which had previously been the sole domain of the EMR or the Contactor. The major growth areas have come from Industrial Process Control applications; particularly heat/cool temperature control, motors, lamps, solenoids, valves, and transformers. The list of applications for the SSR is almost limitless.

The following are typical examples of SSR applications: industrial automation, electronic appliances, industrial appliances, packaging machines, tooling machines, manufacturing equipment, food equipment, security systems, industrial lighting, fire and security systems, dispensing machines, production equipment, on-board power control, traffic control, instrumentation systems, vending machines, test systems, office machines, medical equipment, display lighting, elevator control, metrology equipment, and entertainment lighting.

INDUSTRIAL AUTOMATION


ALARM SYSTEMS


ELECTRONIC APPLIANCES


INDUSTRIAL APPLIANCES


MEDICAL EQUIPMENT


PACKING MACHINES


TOOLING MACHINES


Advantages: When used correctly in the intended application, the SSR provides many of the characteristics that are often difficult to find in the EMR; a high degree of reliability, long service life, significantly reduced electromagnetic interference, fast response and high vibration resistance are significant benefits of the SSR. The SSR has no moving parts to wear out or arcing contacts to deteriorate, which are often the primary cause of failure with an EMR.

- Long life (reliability) > 10^9 operations
- Zero voltage turn on, low EMI / RFI
- Shock and Vibration resistant
- Random turn-on, proportional control
- No contact bounce
- Arc-less switching
- No acoustical noise
- Microprocessor compatible
- Fast response
- No moving parts

Thermal Considerations: One of the major considerations when using a SSR is properly managing the heat that is generated when switching currents higher than about 5 amps. In this scenario one must mount the base plate of the SSR onto a good heat conductor, typically aluminum; along with utilizing a good thermal transfer medium such as thermal grease or heat transfer pad. Using this technique, the SSR case to heat sink thermal resistance is reduced to a negligible value of 0.1 °C/W.

Thermal Calculations: To understand the thermal relationship between the output semiconductor junction (T_J) and the surrounding ambient temperature (T_A) one has to look at the temperature gradient or drop of temperature from junction to ambient (TJ - TA); which simply equals the sum of the thermal resistances multiplied by the junction power dissipation.

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

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 of the semiconductor must be known, typically 125 ˚C, along with the actual power dissipation. When these two parameters are known, the third can be found as shown in the following examples:

1.) Determine the maximum allowable ambient temperature, for 1 ˚C/W heat sink and 10 amp load (12 watts) with a maximum allowable junction temperature (T_J) of 100 ˚C and assume thermal resistance from junction to case ($R_{\Theta JC}$) of 1.3:

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

hence,

$$\begin{aligned} T_A &= T_J - 28.8 \\ &= 100 - 28.8 \\ &= 71.2\ ˚C \end{aligned}$$

2.) Determine **required heat sink thermal resistance**, for 71.2 ˚C maximum ambient temperature and a 10 amp load (12 watts):

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

3.) Determine **maximum load current**, for 1 ˚C/W heat sink and 71.2 ˚C ambient temperature:

$$\begin{aligned} P &= \frac{T_J - T_A}{(R_{\Theta JC} + R_{\Theta CS} + R_{\Theta SA})} \\ &= \frac{100 - 71.2}{1.3 + 0.1 + 1.0} \\ &= 12\ \text{watts} \end{aligned}$$

hence,

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

Load Considerations: The major cause of application problems with SSRs is improper heat sinking. Following that, are problems which result from operating conditions which specific loads impose upon an SSR. The surge characteristics of the load should be carefully considered when designing in an SSR as a switching solution.

Resistive Loads: Loads of constant value of resistance are the simplest application of SSRs. Proper thermal consideration along with attention to the steady state current ratings will result in trouble free operation.

DC Loads: This type of load should be considered inductive and a diode should be placed across the load to absorb any surges during turn off.

Lamp loads: Incandescent lamp loads, though basically resistive, present some special problems. Because the resistance of the cold filament is about 5 to 10 percent of the heated value, a large inrush current can occur. It is essential to verify that this inrush current is within the surge specifications of the SSR. One must also check that the lamp rating of the SSR is not exceeded. This is a UL rating based on the inrush of a typical lamp. Due to the unusually low filament resistance at the time of turn-on, a zero voltage turn on characteristic is particularly desirable with incandescent lamps.

Capacitive Loads: These types of loads can also prove to be problematic because of their initial appearance as short circuits. High surge currents can occur while charging, limited only by circuit resistance. Caution must be used with low impedance capacitive loads to verify that the di/dt capabilities are not exceeded. Zero voltage turn on is a particularly valuable means of limiting di/dt with capacitive loads.

Motors and Solenoids: Motor and solenoid loads can create special problems for reliable SSR functionality. Solenoids have high initial surge currents because their stationary impedance is very low. Motors also frequently have severe inrush currents during starting and can impose unusually high voltages during turn off. As a motor's rotor rotates, it creates a back EMF that reduces the flow of current. This back EMF can add to the applied line voltage and create an over voltage condition during turn off. Likewise, the inrush currents associated with mechanical loads having high starting torque or inertia, such as fans and flywheels, should be carefully considered to verify that they are within the surge capabilities of the SSR. A current shunt and oscilloscope should be used to examine the duration of the inrush current.

Transformers: In controlling transformers, the characteristics of the secondary load should be considered because they reflect the effective load on the SSR. Voltage transients from secondary loads circuits, similarly, are frequently transformer and can be imposed on the SSR. Transformers present a special problem in that, depending on the state of the transformer flux at the time of turn off, the transformer may saturate during the first half-cycle of subsequently applied voltage. This saturation can impose a very large current (10 to 100 times rated typical) on the SSR which far exceeds its half cycle surge rating. SSRs having random turn on may have a better chance of survival than a zero cross turn on device for they commonly require the transformer to support only a portion of the first half cycle of the voltage. On the other hand, a random turn on device will frequently close at the zero cross point and then the SSR must sustain the worst case saturation current. A zero cross turn on device has the advantage that it turns on in a known mode and will immediately demonstrate the worst case condition. The use of a current shunt and an oscilloscope is recommended to verify that the half cycle surge capability is not exceeded.

A rule of thumb in applying an SSR to a transformer load is to select an SSR having a half cycle current surge rating greater than the maximum applied line voltage divided by the transformer primary resistance. The primary resistance is usually easily measured and can be relied on as a minimum impedance limiting the first half cycle of inrush current. The presence of some residual flux plus the saturated reactance of the primary will then further limit, in the worst case, the half cycle surge safely within the surge rating of the SSR.

Switching Devices: The thyristor family of semiconductors consists of several very useful devices. The most widely used of this family are metal-oxide semiconductor field effect transistors (MOSFETs), silicon controlled rectifiers (SCRs), Triac, and Alternistor Triac. In many applications these devices perform key functions and therefore it is imperative that one understand their advantages as well as their shortcomings to properly specify a reliable system. Once applied correctly thyristors are a real asset in meeting environmental, speed, and reliability specifications which their electro-mechanical counterparts could not fulfill.

MOSFET: The MOSFET is a semiconductor device that consists of two metal-oxide semiconductor field effect transistors (MOSFETs), one N-type and one P-type, integrated on a single silicon chip. The MOSFET is ideal for switching DC loads.

Triacs: A TRIAC, is an electronic component approximately equivalent to two silicon-controlled rectifiers joined in inverse parallel (paralleled but with the polarity reversed) and with their gates connected together. This results in a bidirectional electronic switch which can conduct current in either direction. The Triac is ideal for switching resistive AC loads.

Alternistor Triac: Used to switch AC loads; the Alternistor has been specifically designed for applications that switch highly inductive loads. A special chip offers similar performance as two SCRs wired inverse parallel (back-to-back), providing better turn-off behavior than a standard Triac. The Alternistor Triac is an economical solution; ideal for switching inductive AC loads.

SCR: The silicon-controlled rectifier is a 4-layer solid state device that controls current flow. The SCR acts as a switch, conducting when its gate receives a current pulse, and continue to conduct for as long as it is forward biased. The SCR is ideal for switching all types of AC loads.

Heat Sinking: Thermal management is a fundamental consideration in the design and use of solid state relays (SSRs) because of the contact dissipation (typically 1 W per amp). It is, therefore, vital that sufficient heat sinking is provided, or the life and switching reliability of the SSR will be compromised.

In order to properly size a heat sink one has to consider at what goes into getting the thermal resistance **Rth** (X° C/W) numbers in order to understand what it means.

Let's first begin by defining some variables.

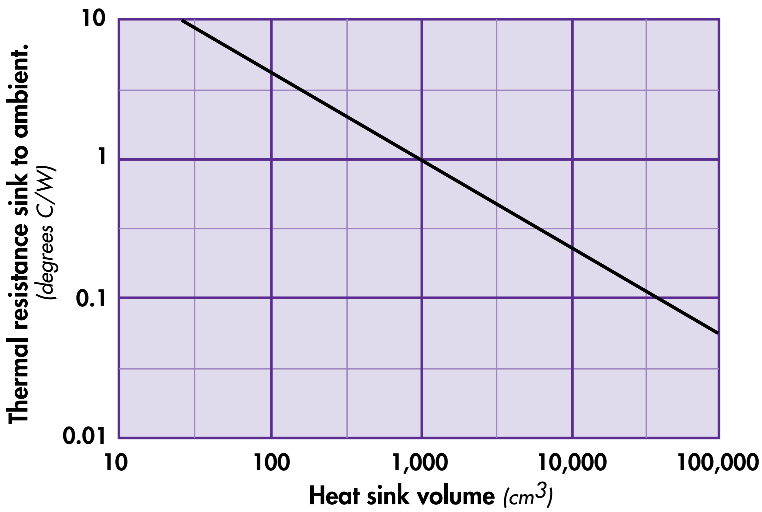
Tr - Temperature rise
Ta - Ambient temperature (example 22°C)
Th - Heat sink temperature (example 54°C)
Vh - Voltage to heater (example 12V)
Ih - Current to heater (example 3.5A)
Ph - Power applied to heat sink
Rth - Thermal resistance (in °C/W)

so…

Tr = Th - Ta = 54 - 22 = 32°C
Ph = Vh * Ih = 12 * 3.5 = 42W
Rth = Tr / Ph = 32 / 42 = 0.76°C/W

Okay, now that we have calculated the Thermal Resistance **(Rth)** we can look at the Thermal resistance vs. Heat sink volume curve.

Thermal resistance vs. Heat sink volume.
Natural convection at 50C rise above ambient.



Using the attached curve, one can see that in our example one would need around 1000 cm cubed sized heat sink in order to successfully sink the amount of heat generated by the device.