Dynamic Power Dissipation Considerations for Solid State Relays

Application Note 5456

Introduction

For low-voltage signaling applications or low-power switching applications, optically isolated solid state relays (SSRs) with MOSFET outputs provide significant advant-ages over traditional electromechanical relays (EMRs). One of the primary challenges that a designer faces using SSRs is to determine and establish the maximum dynamic and static power dissipation experienced in the relay package. The frequency of operation ultimately imposes an upper limit on the total power dissipation. Therefore, it becomes imperative that both dynamic and static power dissipation be accurately calculated such that the maximum power dissipation allowed for the SSR is not exceeded. Finally, some typical and interesting application examples are shown where a SSR can be used in end applications with much advantage.

Solid State Relay Dynamic Power Dissipation Calculations

The instantaneous drain-to-drain voltage v(t) and drain current i(t) are both assumed to change in a linear fashion during the switching time interval Tsw. This linear transition change is an approximation but is good enough for all practical purposes.

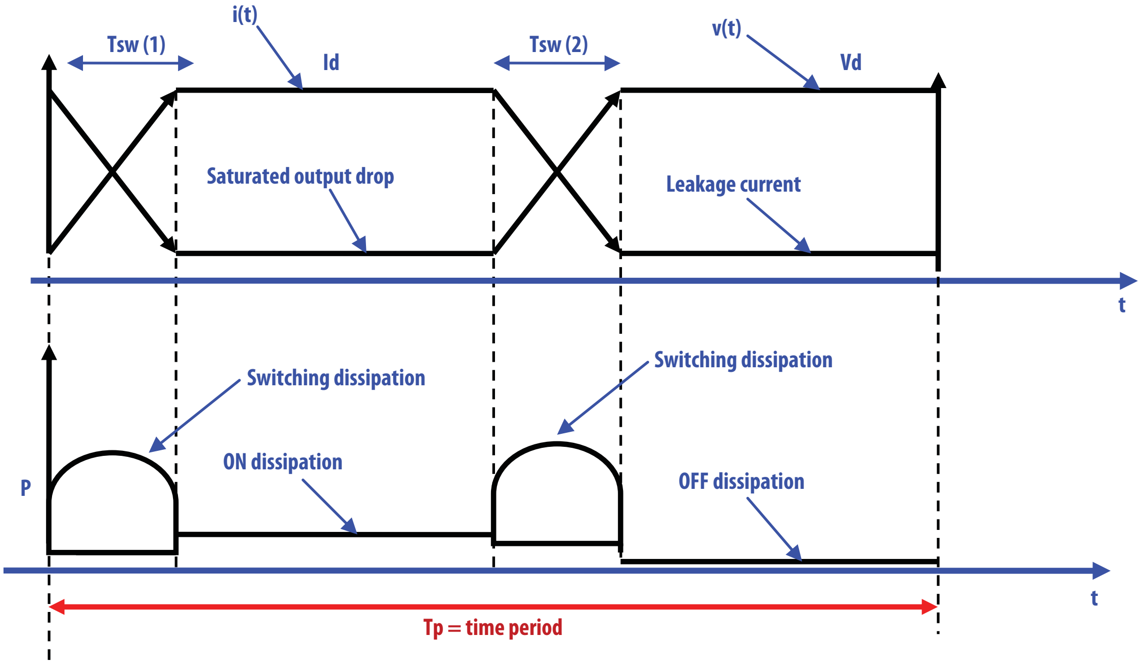


Figure 1. Switching waveforms and instantaneous power dissipation

The instantaneous power dissipation during the switching interval can be expressed as:

$$p(t)sw = v(t) \bullet i(t) \qquad \textbf{Eq (1)}$$

If a linear approximation is invoked, v(t) and i(t) are assumed to be a linear functions of time, as indicated in Figure 1. As such:

$$p(t)sw = [\ Vd\ (Tsw - t) / Tsw\ ] \bullet [\ (Id\ )\ (t) / Tsw\ ] \qquad \textbf{Eq (2)}$$

In Equation (2), the beginning of the switching cycle is assumed to be at t =0, and the switching takes place at a frequency f with a time period of Tp.

Simplifying Equation (2):

$$p(t)sw = [\{\ (Vd)\ (Id)\ (Tsw\text{-}t)\ (t)\ \} / Tsw^2\ ] \qquad \textbf{Eq (3)}$$

It is now possible to calculate the average power dissipated over the switching time interval Tsw:

$$P(Tsw) = (1/ Tsw\ ) \int_{t=0}^{t=Tsw} v(t) \bullet i(t)\ dt \qquad \textbf{Eq (4)}$$

Combining equation (3) with (4):

$$P(Tsw) = (Vd)\ (Id) / Tsw^3 \bullet \int_{t=0}^{t\,=\,Tsw} (\ Tsw\text{-}t)\ t\ dt \qquad \textbf{Eq (4a)}$$

By solving this integral, the average power dissipation through the switching period Tsw is:

$$P(Tsw) = [\ (Vd\ )\ (Id) / 6\ ] \qquad \textbf{Eq (5)}$$

We are now able to readily calculate the total average power dissipation in a time period Tp . Also note that Tsw(1) is the fall time, t(f), transition of the output of the solid state relay, and Tsw(2) is the rise time, t(r), transition of the output of the solid state relay:

$$P\ (\text{Total average over Tp}) = [\ (Vd)\ (Id) / 6]\ Tsw(1) / Tp + [\ (Vd)\ (Id) /6\ ]\ Tsw(2) / Tp$$

$$+ [\ (Ron)\ (Id)^{\ 2}]\ t(\text{on-state})] / Tp + [\ (Vd)\ (Ioff)\ t(\text{off-state})\ ] / Tp \qquad \textbf{Eq (6)}$$

Since f = 1/Tp, Eq (6) can be formulated in terms of frequency by substituting Tsw(1) = t(f), or output fall time of the solid state relay, and Tsw(2) = t(r), or output rise time of the solid state relay, giving:

$$P(\text{Total average over Tp}) = [\ (Vd)\ (Id) / 6]\ t(f)\ (f) + [\ (Vd)\ (Id) /6]\ t(r)\ (f)$$

$$+ [(Ron)\ (Id)^{\ 2}\ t(\text{on-state})\ (f) + [\ (Vd)\ (Ioff)\ t(\text{off-state})\ (f) \qquad \textbf{Eq (7)}$$

Equation (6) underscores that if Tsw is small compared to the time period Tp the power dissipated during the switching period is relatively small. This is explained in the next example.

Equation (7) also underscores that as frequency increases the fraction of power dissipated over the switching period, Tsw, also increases. This ultimately sets the maximum operating frequency limit.

Input power dissipation is easily calculated. The average input power dissipated over a time period Tp is:

$$P(\text{input}) = [(Vf \bullet\ If\ )\ t(\text{on state})] / Tp \qquad \textbf{Eq (8)}$$

or in terms of frequency:

$$P(\text{input}) = [(Vf \bullet If\ )\ t(\text{on state}]\ (\ f\ ) \qquad \textbf{Eq (9)}$$

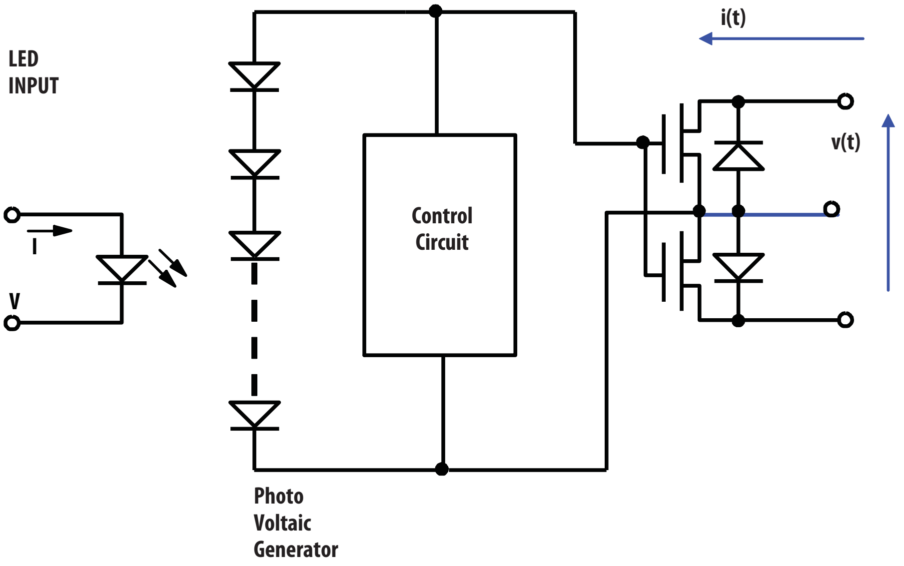


Figure 2. SSR functional diagram

Practical Example for Calculating Power Dissipations

In this example the ASSR-1510 solid state relay is being used to switch a load of 1 A at a Vd of 60 V . The switching frequency is 100 Hz at a duty cycle of 50%. The input drive current of the SSR is 5 mA.

(a) Calculate the output power dissipation, input power dissipation and total package power dissipation.

From the ASSR-1510 data sheet:

Vf (max) = 1.7 V
Frequency (f) = 100 Hz,
R(ON) = 0.5 Ω
t(f) = output fall time = 200 μsec (estimated, because this is not a data sheet parameter)
t(r) = output rise time = 2 μsec (estimated, because this is not a data sheet parameter)
Time period Tp = 1/f = 10 msec
50% duty cycle means that t(On state) = 5 msec
t(off state) = 5 msec

From Equation (7):

P(Total Average over Tp) = [(Vd) (Id) / 6] t(f) (f) + [(Vd) (Id) /6] t(r) (f)

+ [(Ron) (Id)^2 t(on-state) (f) + [(Vd) (Ioff) t(off-state) (f) **Eq (7)**

Calculating each of the above power dissipation components separately:

(a) [(Vd) (Id) /6] t(f) (f) = [60 V x 1 A]/6 x 200 μsec x 100 Hz = 200 mW

(b) [(Vd)(Id) / 6] t (r) (f) = [60 V x 1A]/6 x 2 μsec x 100 Hz = 2 mW

(c) [R(ON) (Id) ^{2}] t(on-state) (f) = 0.5 Ω x (1A)^2 x 5 msec x 100 Hz = 250 mW

(d) [(Vd) (Ioff)] t(off-state) (f) = 60 V x 1 μA x 5 msec x 100 Hz = 30 μW

Adding the above power dissipation components, gives the total output power dissipation as 452 mW.

The input power dissipation is calculated from **Eq (9)**:

P(input) = [(Vf • If) t(on state] (f) = 1.7 V x 5 mA x 5 msec x 100 Hz = 4.25 mW

Thus, total average package power dissipation per switching period is:

4.25 mW + 452 mW = 456.25 mW

This power dissipation is lower than the absolute maximum allowed for the ASSR-1510 (540 mW). Therefore, the operating conditions do not require power derating.

FET Driver and Solid State Relay Operation

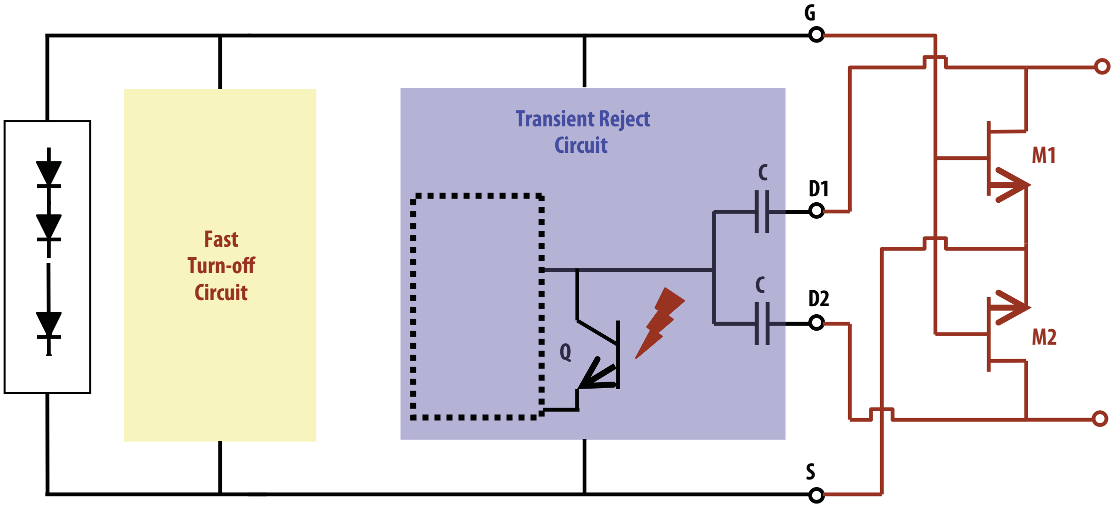


Figure 3. Avago FET driver and SSR function

The FET driver within the SSR is powered through photo-voltaic power alone. The LED photo-flux received by the FET driver is the only energy that powers the FET driver that drives the output MOSFETs. The photo-voltaic voltage is generated by a stack of twelve photo-diodes stacked one on top of the other. Each photo-diode generates approximately 0.5 V typical. The total voltage generated by the photo-diodes is 0.5 V x 12 = 6 V (typical).

The photo current generated is the peak current that charges up the gate capacitance of the output MOSFETs. The larger the photo-current, the faster is the gate voltage that is charged to the photo-diode stack photo-voltaic voltage. With an LED drive current of 10 mA, the typical photo-current generated by the stack voltage is in the range of 20 µA.

The FET driver design includes a fast turn-off circuit. The purpose of this circuit is to instantaneously discharge the gate capacitance once the SSR has been turned OFF by bringing the LED current to zero. This circuit momentarily turns on when the photo-voltaic voltage is collapsing. This fast turn-off circuit guarantees the turn-off time of the SSR is much shorter than the turn-ON time of the SSR. The power dissipated in the FET driver is negligible, as the photo-current generated is typically 20 µA and the generated stack voltage is 6 V (typical) with a 10 mA drive current.

The Avago Technologies FET driver design also includes an output transient reject circuit that assures the very high dVo/dt parameter specified in data sheets. The circuit operates as follows. When the SSR is in the off-state, any transient, high-voltage perturbation on the contacts of the SSR is capacitively coupled into the base of the transient reject transistor. This causes the transistor to momentarily turn-ON and keeps the gate discharged, guaranteeing that the output MOSFETs do not turn-ON when a transient high voltage pulse is present at the output contacts of the SSR.

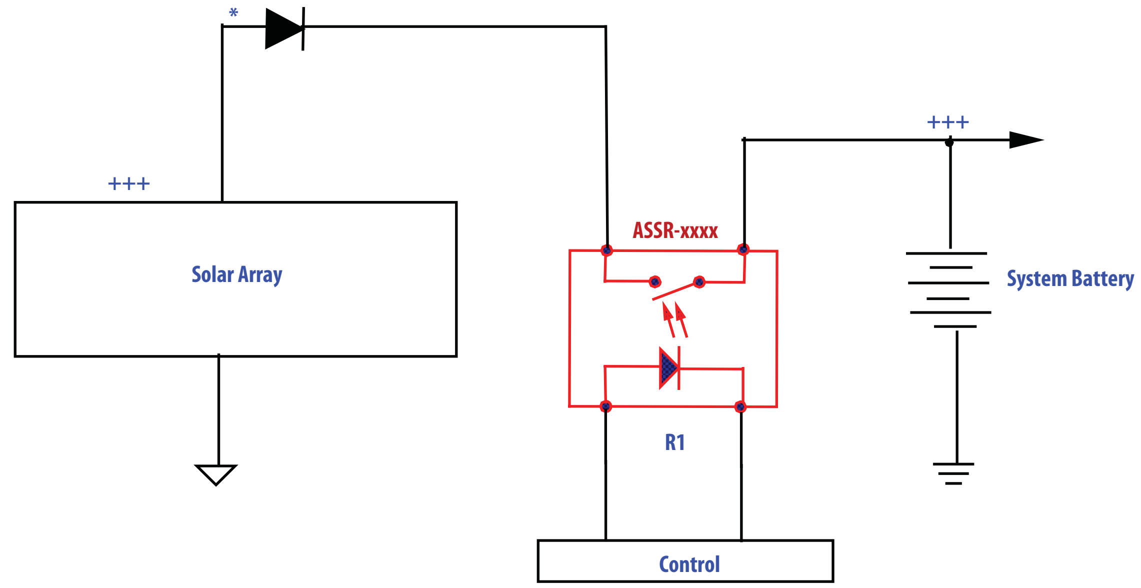
Application Examples for the Solid State Relays

Typical applications for SSRs include:

- Fire and Alarm Systems
- Lighting Controls
- Instrument Systems
- Dispensing Machines
- Vending Machines
- Test and Measurement
- Traffic Controls
- Temperature Controls
- Security Systems
- Medical Equipment
- Elevator Controls
- Production Equipment
- Commercial Laundry
- Office / Business Machines
- Navigation Systems
- Defense / Military Hardware

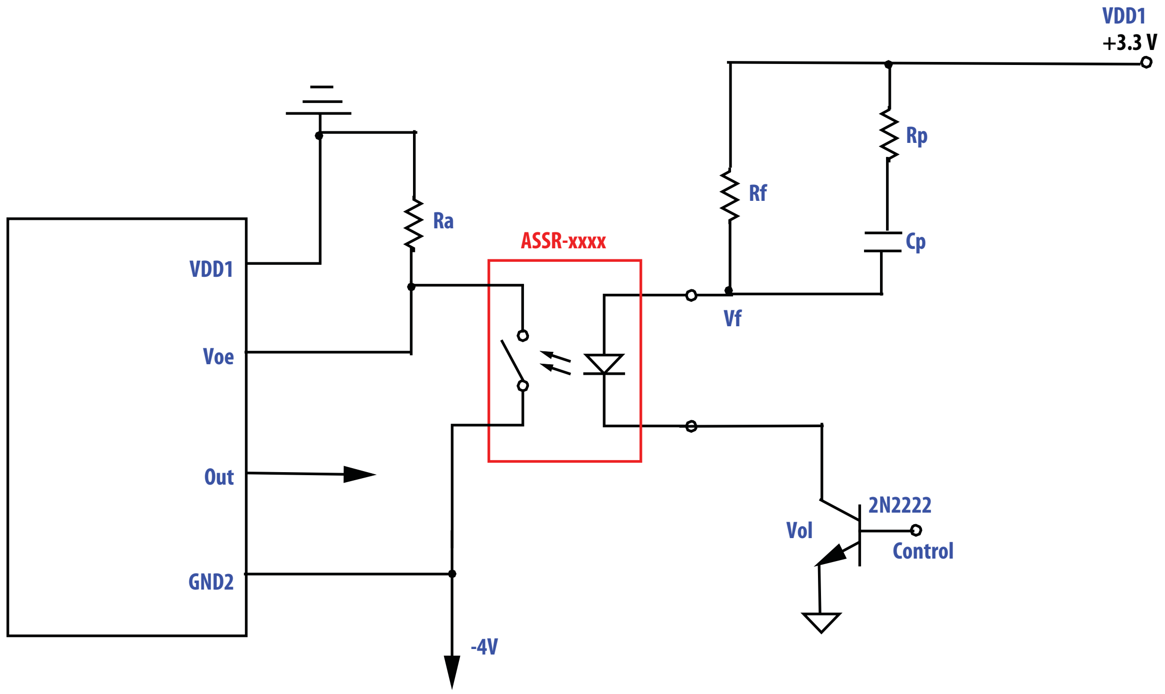
Typical SSR application block diagrams are shown in Figure 4 (a)-(f):

(a) Solar cell array battery charging

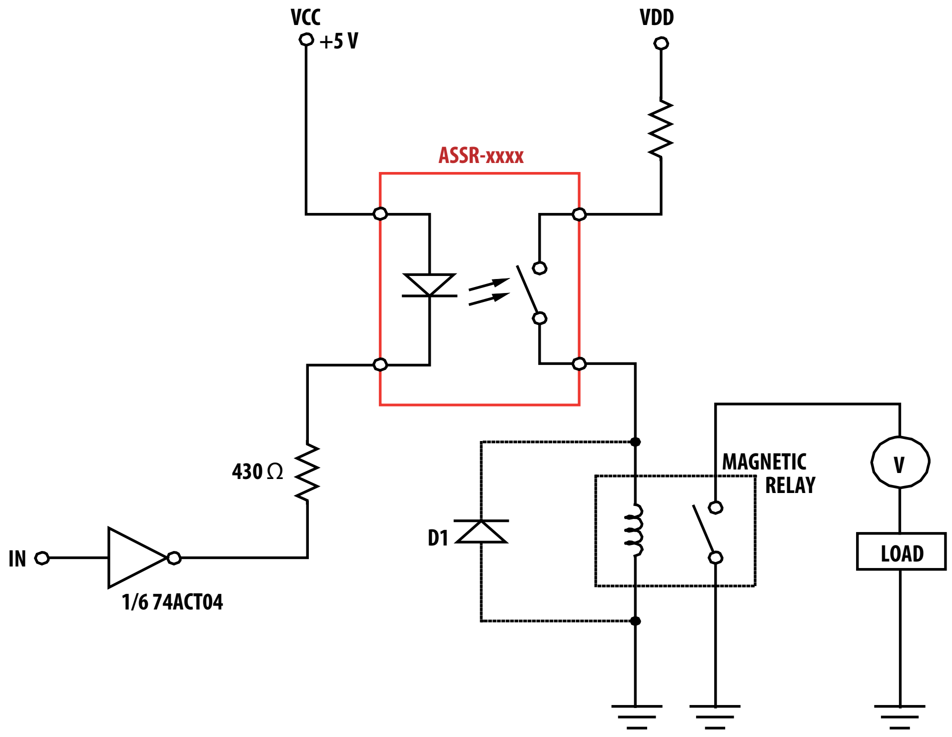


* Isolation diode prevents battery discharge into the solar array when SSR is off through any parasitic resistance or leakage current of the SSR

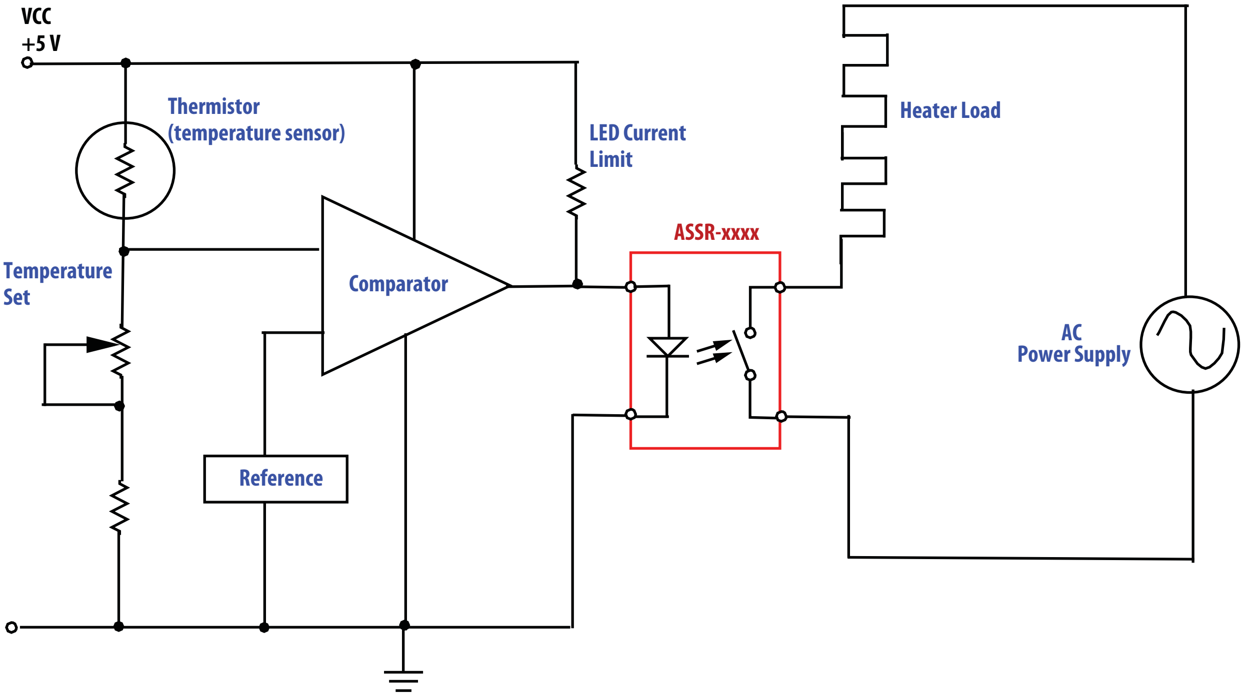
(b) Telephone pulse dialing



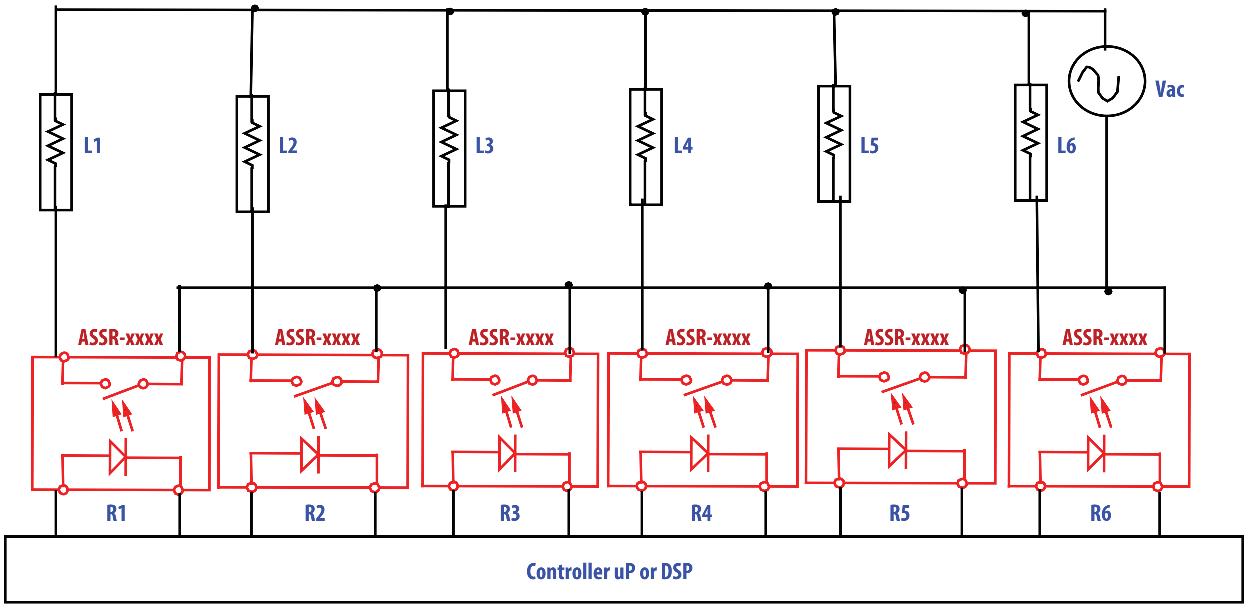
(c) Relay coil driver



(d) Temperature controller



(e) Multi-Channel AC load control module



Notes:

1. For transient protection devices such as TVS or MOV please see the following manufacturers:
    - ST Microelectronics (www.st.com)
    - Vishay (www.vishay.com)
    - Proteck Devices (www.proteckdevices.com)
2. Avago Technologies highly recommends that when paralleling or stacking solid state relays (SSRs) the two SSRs selected must be of the same kind to prevent any performance mismatch issues.
3. Avago Technologies highly recommends that when paralleling or stacking solid state relays (SSRs) the input LED drive selected should be a series drive versus parallel drive to prevent any performance mismatch issues.

References:

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4. Avago Technologies Application Note AN1036 "Small Signal Solid State Relays," publication number 5965-5980E, July 2007
5. Avago Technologies Application Note AN1046, "Low On Resistance Solid State Relays," publication number 5965-5978E, July 2007
6. Avago Technologies Application Note AN1047, "Low On Resistance Solid State Relay for High Reliability Applications, " publication number 5091-4502E, April 2007
7. Avago Technologies Application Note AN5302,"Solid State Relays, ASSR Series," publication number AV01-0527EN, October 2006
8. "Switching Handbook: A Guide to Signal Switching in Automated Test Systems," 5th Edition, Keithly Instruments, Inc.
9. "Low Level Measurements Handbook: Precision DC Current, Voltage, and Resistance Measurements," 6th Edition, Keithly Instruments, Inc.

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