Design Considerations for Solid State Relays

Application Note 5452

Introduction

For low voltage signaling applications or low power switching applications, optically isolated solid state relays (SSRs) with MOSFET outputs provide significant advantages over traditional electromechanical relays (EMRs).

In this application note, novel input LED drive current circuits that ensure proper SSR turn-on and turn-off are discussed. Design techniques for paralleling SSRs for higher load current or for stacking SSRs for higher load withstand voltages are also shown. Finally, example applications will show where the strengths of SSRs can be particularly well used.

Optically isolated solid state relays are classified as: Form A, single pole, single-throw, normally open; Form B, single pole, single throw, normally closed; and Form C, single pole, double throw with one contact closed and the other contact open. As an example, a dual channel SSR is described as 2 Form A, or 2 Form B, or 2 Form C.

Solid State Relay and Electromechanical Relay Comparison

A solid state relay offers significant advantages to the designer. Paramount amongst these advantages is the almost infinite switching cycles an SSR can perform since there are no mechanical parts or mechanisms to wear-out. The solid state reliability and billions of switching cycles are the SSRs most significant features. Other advantages include no contact bounce, the ability to handle relatively high inrush currents, and immunity to EMI and RFI. There are no mechanical parts inside SSRs and as a result they are essentially immune to shock, vibration and acceleration.

Some disadvantages of the SSR include a small but finite off-state leakage current and relatively higher output on resistance compared to EMRs. In addition, it is difficult to design multiple channels or various switch configurations within a single SSR package. Table 1 lists the advantages and disadvantages of SSRs.

Table 1. Advantages and disadvantages of solid state relays (SSRs)

Advantages: Solid state relays	Disadvantages: Solid state relays
No mechanical contacts or moving parts	Higher output resistance and on voltage than EMR
No acoustical noise	Multiple switch configurations are difficult
Long electrical life expectancy and high reliability: Over 10^9 operations	Higher unit cost than EMR
No contact bounce or arcing	Off-state leakage can affect the load or be hazardous
Low shock and vibration sensitivity	
Low EMI and RFI: No magnetic field or electrical noise	
High input-output isolation voltages	
Direct logic control	
Microprocessor compatible: Low input control current	
Low power and low operating voltages	
Design flexibility: Small, standard IC packages	
Easy SMT PCB manufacturing	

It is easy to find electromechanical relays with multiple contacts per package at relatively lower cost than SSR technology based solutions. In addition, an EMR has a very low contact voltage drop and there is no off state leakage to contend with.

However, EMRs do have significant disadvantages. The chief disadvantage is the relatively short life and low reliability associated with the contact wear out mechanism. Contact bounce must be considered by the system hardware and software designers. High inrush currents reduce contact life considerably. Capacitive loads have very high inrush currents.

Ideally, current should not begin to flow until the EMR's mechanical contacts are completely closed. In practice this never happens as the current begins to flow when the contact gap is small enough and the switched voltage is high enough. During this time the power dissipation in the contact can be high enough – even for resistive loads – to cause arcing, melting, and erosion of the relay contacts. Long term reliability suffers. In systems where maintenance is either difficult or very expensive to perform contact wear out or relay failure increases system downtime and operating costs.

Electromagnetic relay generates significant acoustic noise and are extremely sensitive to EMI and RFI. System designers that must focus on long term reliability, long operating life, and EMI and RFI immunity find solid state relays superior to electromechanical relays.

Table 2. Advantages and disadvantages of electromechanical relays(EMRs)

Advantages: Electromechanical Relay	Disadvantages: Electromechanical Relay
Cost	Slow response
Low contact voltage drop	Short life: contact wear
Heat sink not required	Random (non-zero) turn-on noise
No off-state leakage	Acoustical noise
Multiple contacts per package	Very high inrush current
Higher line power	Interface capability to microprocessors and logic is poor
	Sensitive to EMI and RFI
	Less reliable than solid state devices
	Contact bounce

Avago SSR Portfolio

Avago Technologies supplies both plastic solid state relays and hermetically sealed ceramic solid state relays. Hermetic sealed SSRs are used in high reliability military, aerospace, and harsh industrial environment applications.

Avago plastic optocoupler SSRs include parts with output withstand voltages up to 600 V (ASSR-5211) and with current ratings up to 2.5 A (ASSR-1611). A mid-range SSR like the ASSR-1510 has a 1 A and 60 V rating. A summary of the plastic SSR portfolio is shown in Table 3.

Low C(off) × R(on) relays such as the ASSR-321R have 250 V / 0.2 A ratings. The low output capacitance, low on resistance, and low output off-state leakage current of Avago's ASSR series give higher system throughput and reduced system errors.

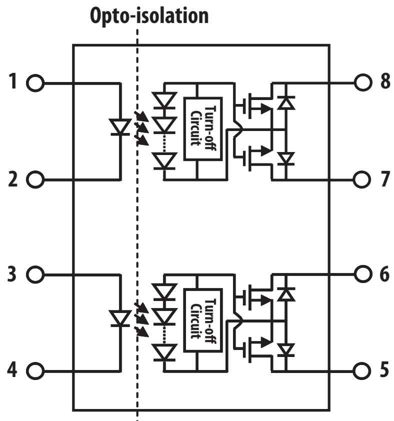
These and other solid state relays are available in normally open single-channel and dual-channel formats in 8-pin DIP, 6-pin DIP or 4-pin SO packages. In addition to their fast switching speeds, the ASSR series has a 3.75 kVac one minute UL insulation withstand specification, which is often required in industrial environments.

Also available are the ASSR-V621 and ASSR-V622 photovoltaic FET drivers that will drive external MOSFETs as SSRs.

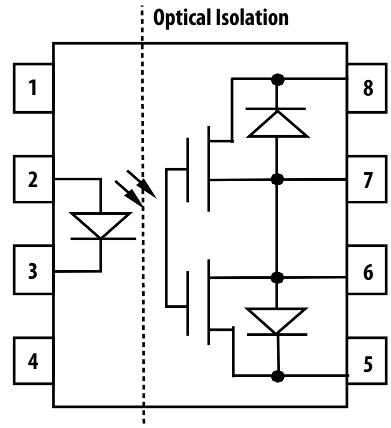
Avago's hermetic solid state relay series include the 90 V / 1 Ω HSSR-7110, HSSR-7111, HSSR-7112, and HSSR-711E. These relays can handle a steady state load current of 0.8 A in a connection "A" or 1.6 A in connection "B" (see relevant data sheet for the connection definition). The Hermetic SSR portfolio is shown in Table 4. Hermetic optocoupler reliability grades are described in Table 5.

Table 3. Avago Technologies plastic SSR portfolio summary

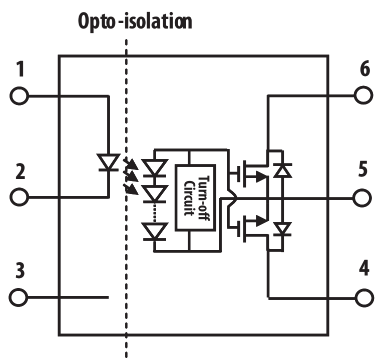
		Product Description		
Solid State Relay Family	**Function**	**Output Breakdown Voltage**	**Output Current**	**R(on)/C(on)**
ASSR-1218, ASSR-1219, ASSR-1228	Standard	60 V	0.2 A	10 Ω
ASSR-1410, ASSR-1411, ASSR-1420	General Purpose	60 V	0.6 A	1 Ω
ASSR-1510, ASSR-1511, ASSR-1520, ASSR-1530	High Power	60 V	1.0 A	0.5 Ω
ASSR-1611	High Power	60 V	2.5 A	0.1 Ω
ASSR-301C, ASSR-302C	Low C x R	250 V	0.05 A	15 pF
ASSR-3210, ASSR-3211, ASSR-3220	General Purpose	250 V	0.2 A	10 Ω
ASSR-321R, ASSR-322R	Low C x R	250 V	0.2 A	8.5 Ω
ASSR-401C, ASSR-402C	Low C x R	400 V	0.04 A	15 pF
ASSR-4118, ASSR-4119, ASSR-4128	Standard	400 V	0.1 A	35 Ω
ASSR-4110, ASSR-4111, ASSR-4120	General Purpose	400 V	0.12 A	25 Ω
ASSR-5211	High Power	600 V	0.2 A	16 Ω
ASSR-V621, ASSR-V622	Photo-Voltaic Driver for external MOSFTs	Minimum open circuit output voltage ≥ 6.5 V, and minimum short circuit output current ≥ 16 µA		



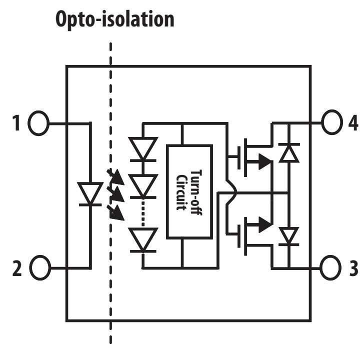
Dual Channel, SPST Relay, 2 Form A in 8-Pin DIP and Gull Wing Surface Mount Packages



Hermetic, Single Channel, SPST Relay, 1 Form A, in 8-Pin DIP and Gull Wing Surface Mount Packages



Single Channel, SPST Relay, 1 Form A in 6-Pin DIP and Gull Wing Surface Mount Packages



Single Channel, SPST Relay, 1 Form A in 4-Pin SO Packages

Table 4. Avago Technologies hermetic SSR portfolio summary

	Product Description			
Solid State Relay Family	**LED Drive Current**	**Output Breakdown Voltage**	**Output Current**	**Operating Temperature Range**
HSSR-7110 (Commercial Grade)	10mA (min)	90 V	0.8 A /1.6 A*	-55°C to 125°C
HSSR-7111 (MIL-PRF-38534 CLASS H)	10 mA (min)	90 V	0.8 A /1.6 A*	-55°C to 125°C
HSSR-7112 (MIL-PRF-38534 CLASS H)	5 mA (min)	90 V	0.8 A /1.6 A*	-55°C to 125°C
HSSR-711E (MIL-PRF-38534 CLASS E)	10 mA (min)	90 V	0.8 A /1.6 A*	-55°C to 125°C

* 0.8A (max) output load current in Connection (A) or the ac connection, 1.6A (max) output load current is in Connection (B) or the dc connection

Table 5. Hermetic Optocoupler Reliability Grades

Hermetic Reliability Grades	Description
Commercial Grade	Harsh Environments and Critical Applications
Class H	Military, Mission Critical Applications
Class K	Highest reliability for Space Applications
Class E	Highest reliability for Space Applications

Stacked Solid State Relays Increase Output Withstand Voltage

Solid state relays can be easily stacked when higher with-stand voltage is needed. The electrical parameters of the combined stacked relays that need to be considered are:

a) On resistance

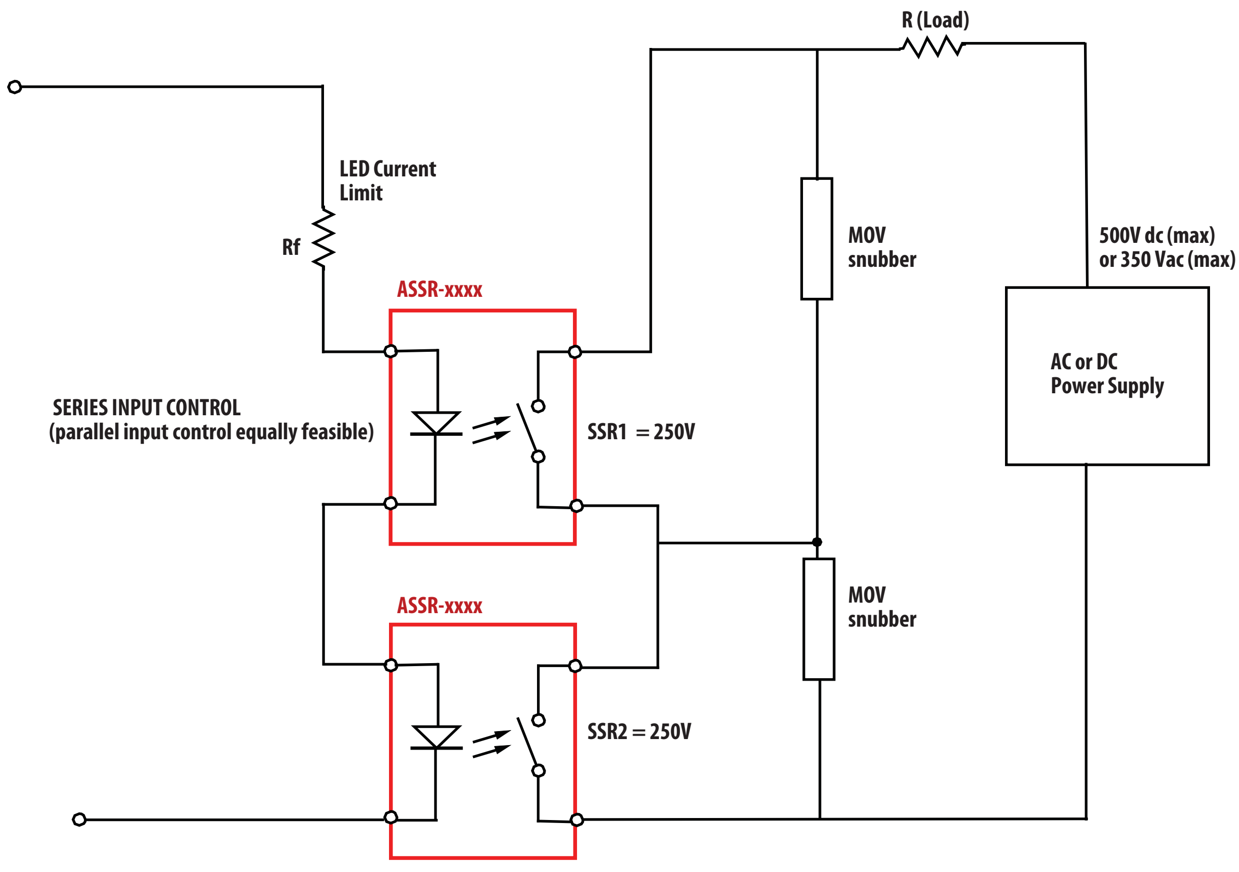
b) Load current

c) Load voltage.

The on resistance of the stacked relay circuit is simply the sum of the on resistances of the series relays. The load current of the stacked relay set by the series SSR with the lowest load current capability. The total blocking voltage of the series connected SSRs is the sum of the individual blocking voltages of the series relays.

When stacking SSRs, care must be taken to prevent avalanche breakdown of the individual relays. This protection is easily provided by placing metal oxide varistors (MOV) or transient voltage suppressors (TVS) across each SSR. The MOV or TVS transient breakdown voltage is selected to guarantee that a SSR is never brought into an avalanche breakdown.

The combined withstand capability of the SSR should be selected higher than the continuous worst case withstand for a particular application.



Note: MOV (Metal Oxide Varistor) snubber to prevent SSR avalanche breakdown

Figure 1. Metal Oxide Varistor (MOV) snubber prevents SSR avalanche breakdown

See notes 1, 2 and 3.

Parallel Solid State Relays for Higher Output Load Current

Unlike bipolar output or SCR output relays, a SSR with a MOSFET output is self balancing and can be easily paralleled to give higher load current capability. If we assume that the resistance of the two relays is equal, the current will divide in equal halves through each relay.

As another example, let us assume that the initial Ron of the two relays is not the same. Let the total load current that is carried by the combined SSR circuit be 2.5 A, as shown in Figure 2.

Let V1 (at 1.5 A) = 1 V

V2 (at 1 A) = 1.25 V

The series resistor that needs to be inserted in each SSR leg to balance the voltage is:

$Rx = \Delta V / \Delta I = (1.25\ V - 1.0\ V) / (1.5\ A - 1\ A)$

$= 0.25\ V / 0.5\ A$

$= 0.5\ \Omega$

As a check, we can see that this Rx equalizes the voltage drops:

$Vx = 1\ V + 0.5\ \Omega \times 1.5\ A = 1.75\ V$

and

$Vx = 1.25\ V + 0.5\ \Omega \times 1\ A = 1.75\ V$

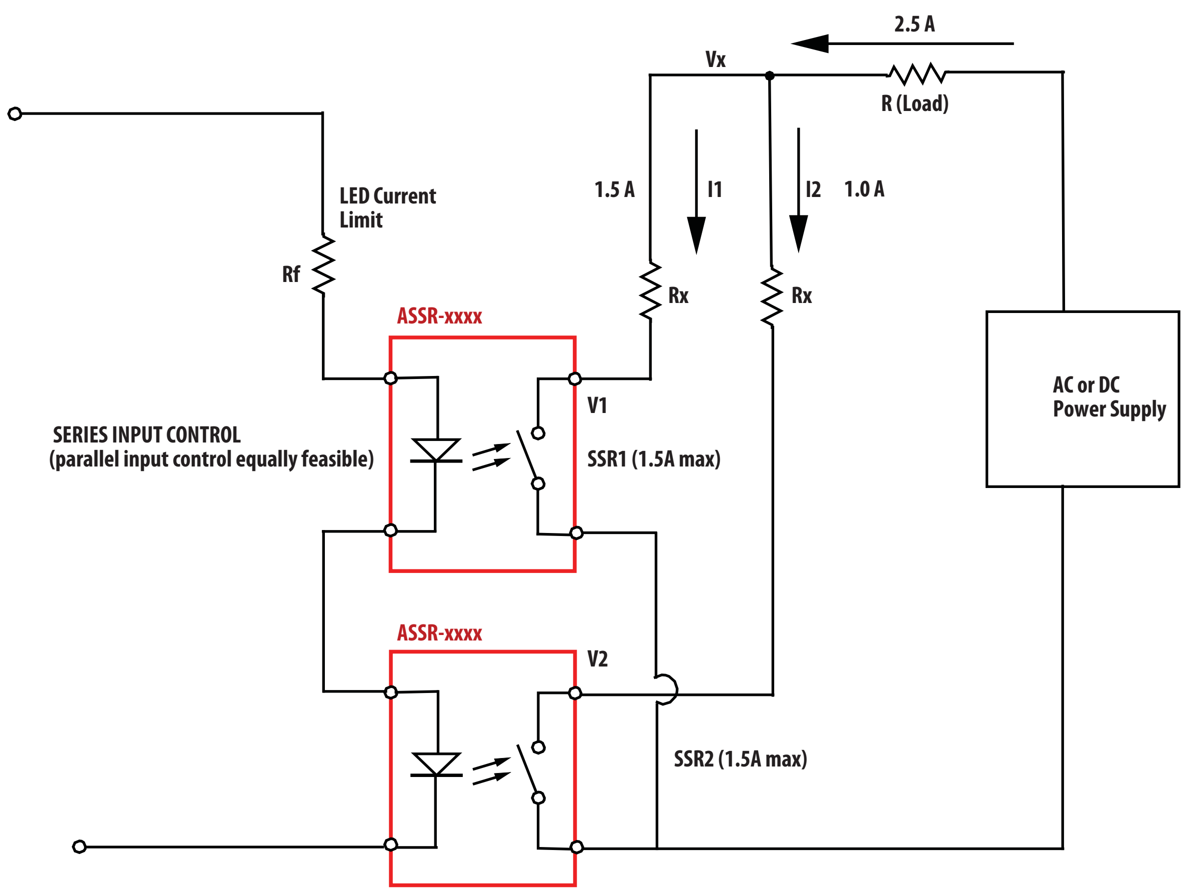


Figure 2. Parallel SSR to increase current

See notes 1, 2 and 3.

Peaking Drive Circuit Increases Operating Speed

SSR turn-on time is affected by LED drive current. If speed is not critical, the SSR can be operated at the minimum recommended drive current specified in the data sheet. If, however, the turn-on time must be low, then a current peaking drive circuit can be used. The circuit uses only two low cost components, as shown in Figure 3.

LED steady state drive current is set by the current limiting resistor, Rf. However, the transient peak current is set by the parallel combination of Rp and Rf. A higher steady state drive current is not advisable as it causes higher LED power dissipation. Higher power dissipation ultimately translates to a higher – thermal related – output offset voltage of the output MOSFET, which is caused by higher MOSFET on resistance. An LED drive current higher than necessary can degrade LED light output.

The resistors in Figure 3 are calculated as follows:

Rf = [Vcc –Vol – Vf(on)] / If(on)

Rx < Vf(off) / IOH

If(peak) = [Vcc – Vol – Vf (on)] / (Rf | | Rp)

The peak LED current must be limited to the absolute maximum peak current limit indicated in the SSR data sheet

Rp / Rf = If(on) / [(If(peak) – If(on)]

Resistor Rx is set to guarantee that Vf(off) of the LED is kept below 0.8 V with any driver leakage current. This assures that the LED is not inadvertently turned on by the drivers IOH leakage current when the driver is in the off (HIGH) state.

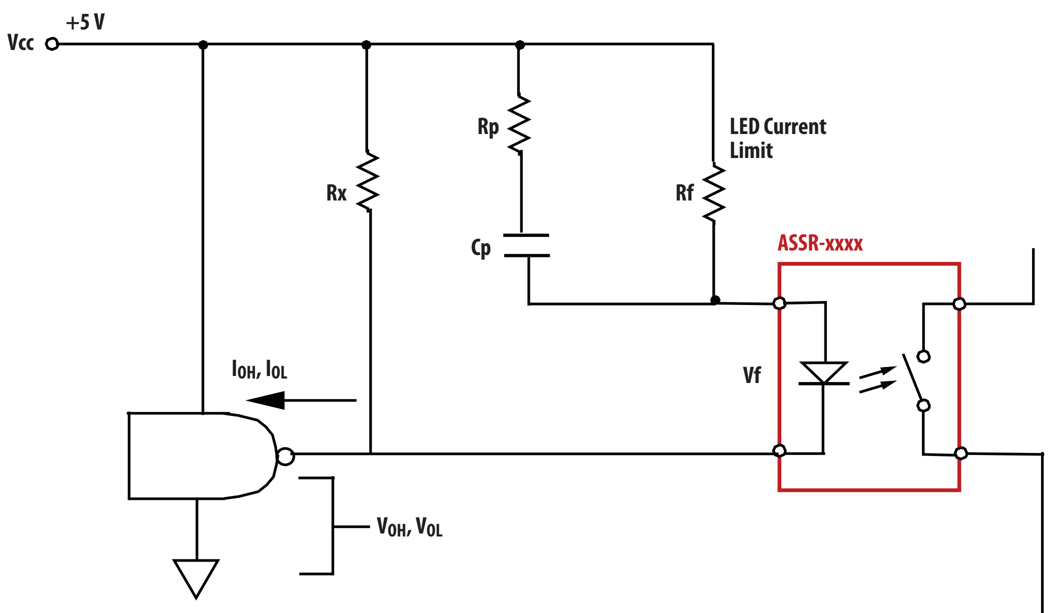


Figure 3. Input LED driver peaking gives faster turn-on time

Constant current drive SSR input driver

Figure 4 show a simple constant current source LED drive circuit. The LED current limiting resistor Rf sets the LED operating point at:

If = Vbe(on) / Rf

For a typical NPN transistor Vbe(on) is 0.6 V and with an LED current of 10 mA, Rf is 60 Ω. The driver voltage will be clamped at:

V(driver) = Vf (LED) + Vbe(on)

The typical forward voltage of the SSR LED, Vf, is approximately 1.5 V and with 0.6 V as the typical NPN Vbe (on) voltage, the driver voltage is clamped at 2.1 V. This assumes that there is no other resistance at the output of the driver other than Rf.

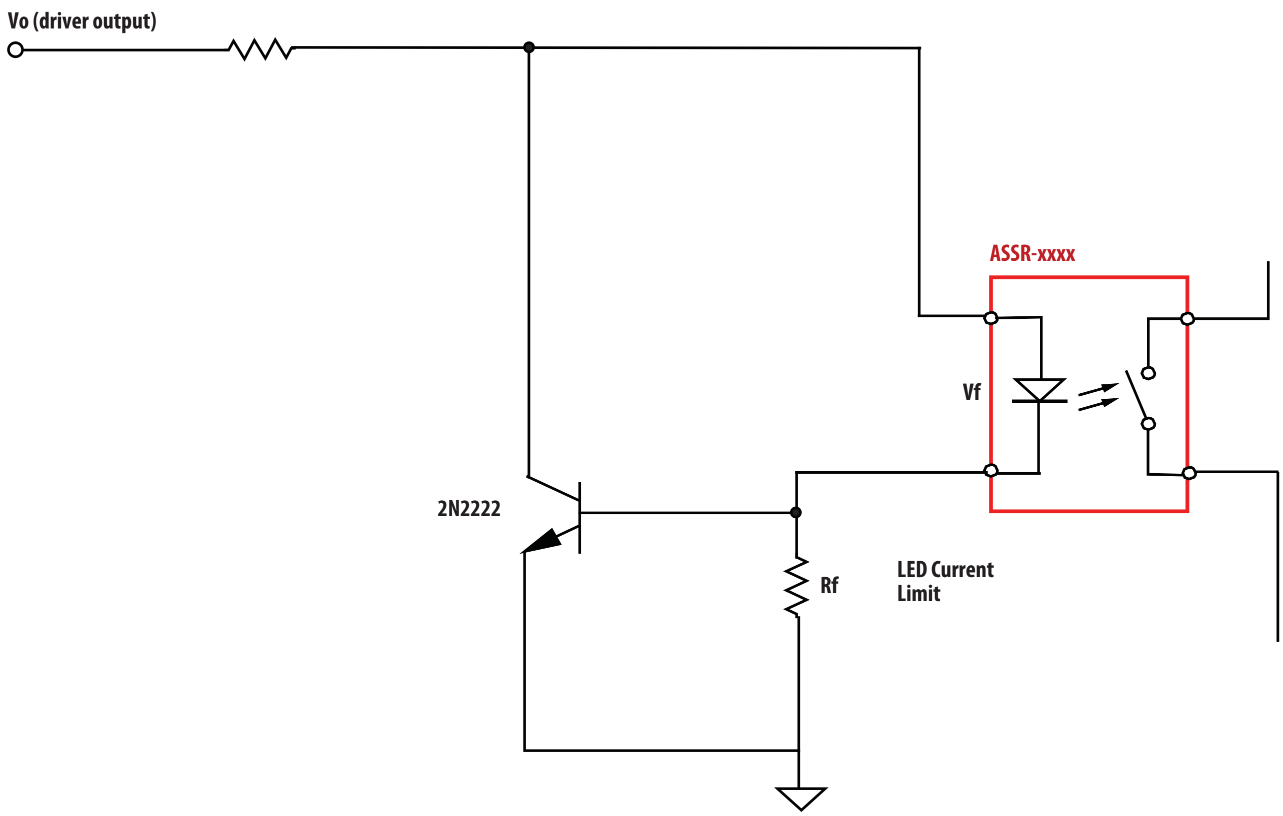


Figure 4. Constant current source drives input LED in solid state relay (SSR)

Prevent Inadvertent LED Turn On Caused by Leakage Current

The highly efficient photovoltaic powered photodiode stack within Avago's SSR FET driver is composed of twelve photo-detector diodes. This stack produces a typical voltage of 6 V and a typical photocurrent of 20 µA with an LED drive current of 10 mA. What this means is that the actual turn-on threshold current of the SSR is very low. The SSR may turn-on with LED drive currents in the range of 10 µA to 50 µA.

In order to assure that the SSR is not advertently turned on requires either zero LED current or that the maximum voltage across the LED be no more than 0.8 V, as indicated in the SSR data sheets. This maximum voltage of 0.8 V is tantamount to saying that the LED current is zero because the turn-on level of the LED is approximately 0.9 V.

In order to ensure that driver leakage current is not able to turn the SSR on, a shunt resistor is introduced in parallel with the LED. The value of this resistor is calculated by dividing the maximum turn-off voltage of 0.8 V by the driver leakage current. Assuming a maximum driver leakage current of 100 µA, the parallel resistor, Rx, is 8 kΩ.

Rx < Vf(off) / IOH (maximum driver leakage)

Rx(maximum) = 0.8 V/100 µA = 8 kΩ

Assuming a 5 mA LED drive current, If, the LED current setting resistor, Rf, is 620 Ω.

Rf = [Vcc – VOL (logic gate) – Vf(on)] / If(on)

Let Vcc = 5 V, Vol = 0.4 V, Vf(on) = 1.5 V (typical), and If(on) = 5 mA

Rf= [5 V – 0.4 V – 1.5 V] / 5 mA

Rf = 620 Ω

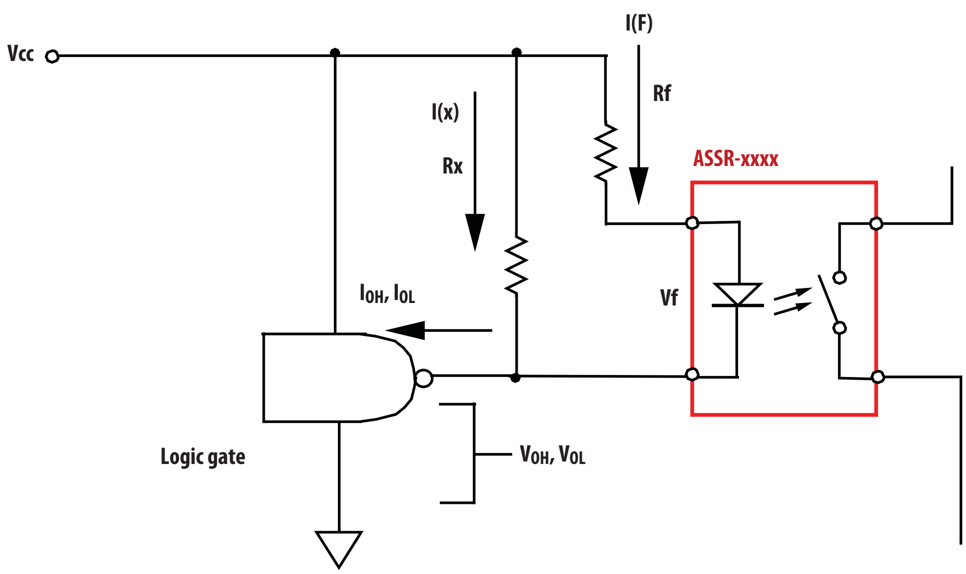


Figure 5. Input drive circuit eliminates driver leakage current effects

Solid State Relay Application Circuits

Solid state relays can be used in a wide range of communications, automotive, instrumentation, and test and measurement applications. The system block diagrams in Figure 6 through Figure 9 show applications that can benefit from the primary features of solid state relay technology: reliability, EMI and RFI immunity, long operating life, high speed operation, easy control from microcontrollers and higher input-output isolation.

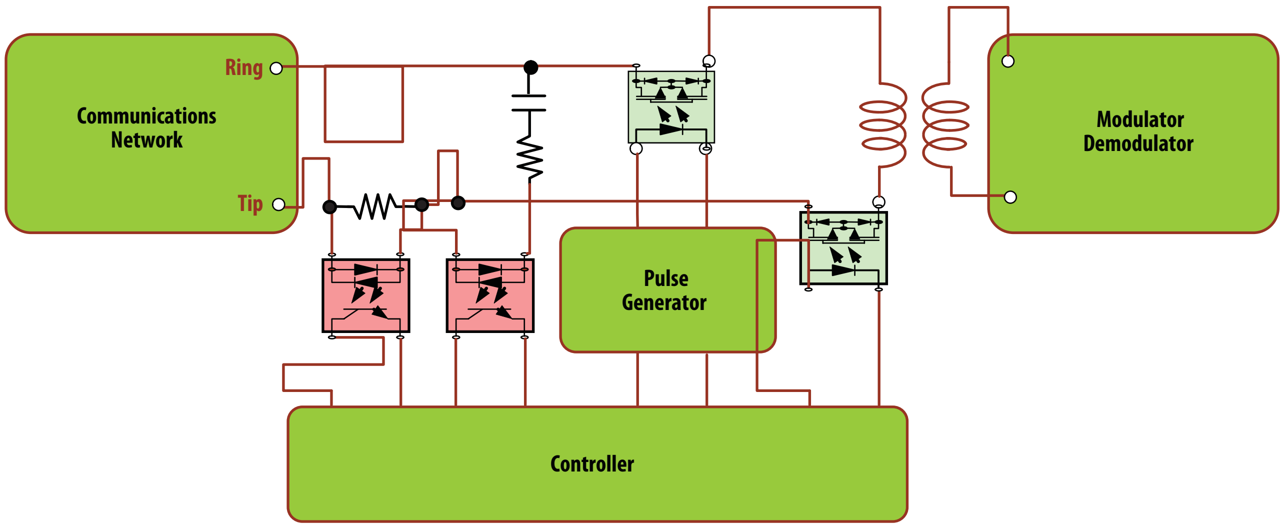


Figure 6. Telecommunication modem application

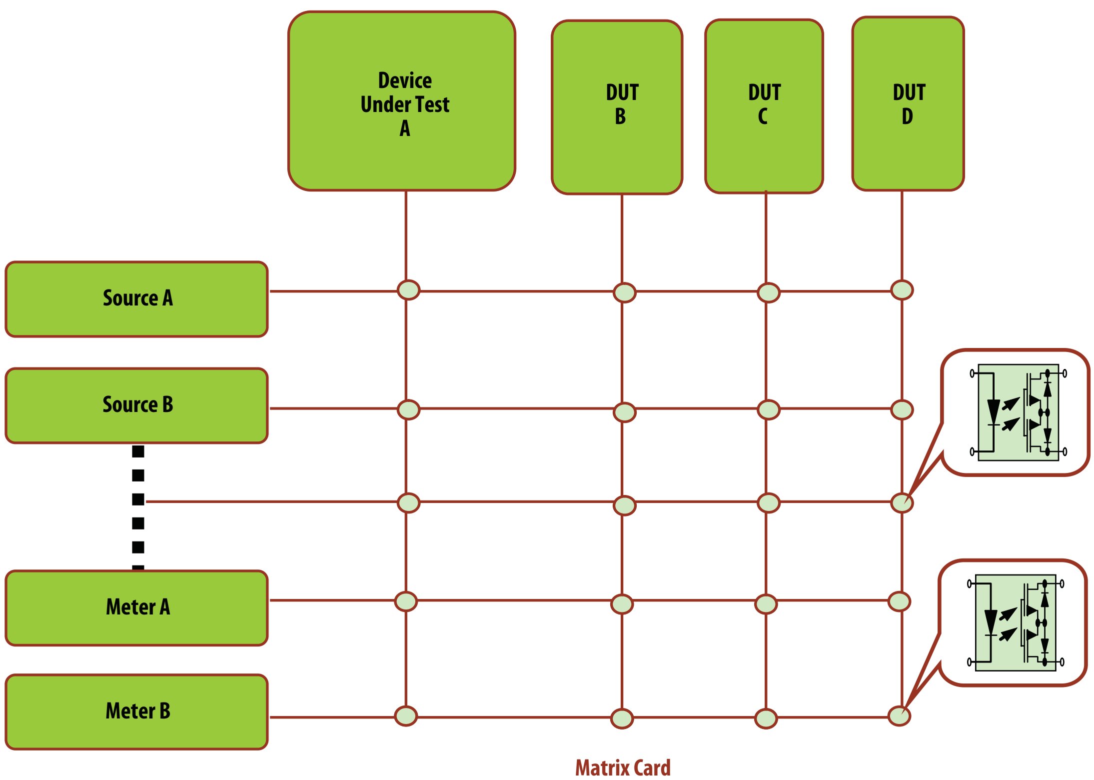


Figure 7. Industrial controller with matrix switches

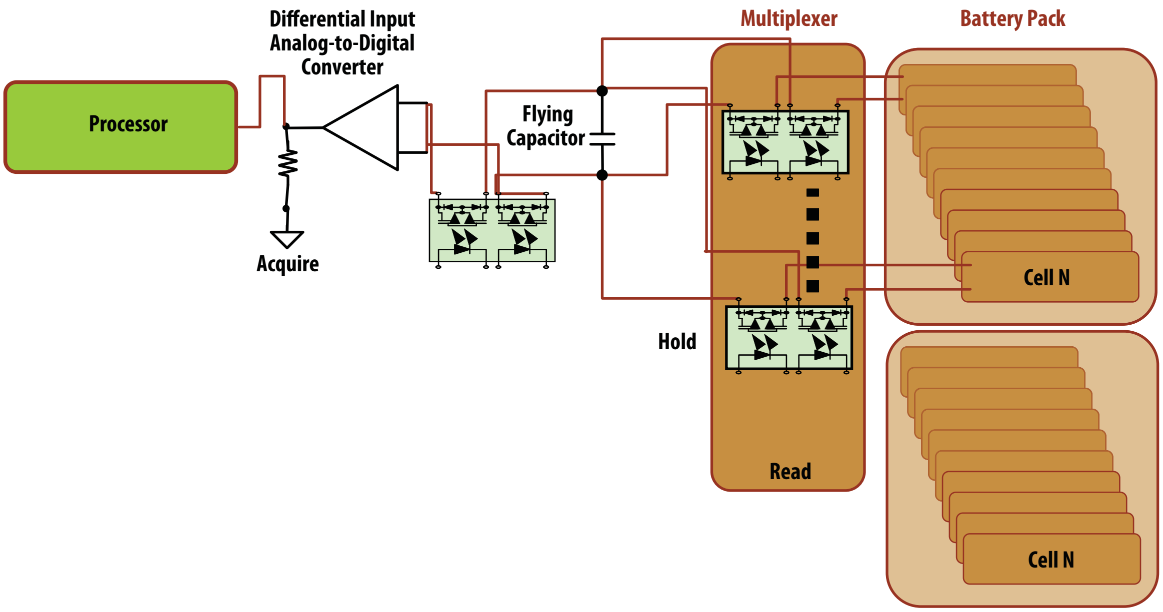


Figure 8. Automotive battery pack management

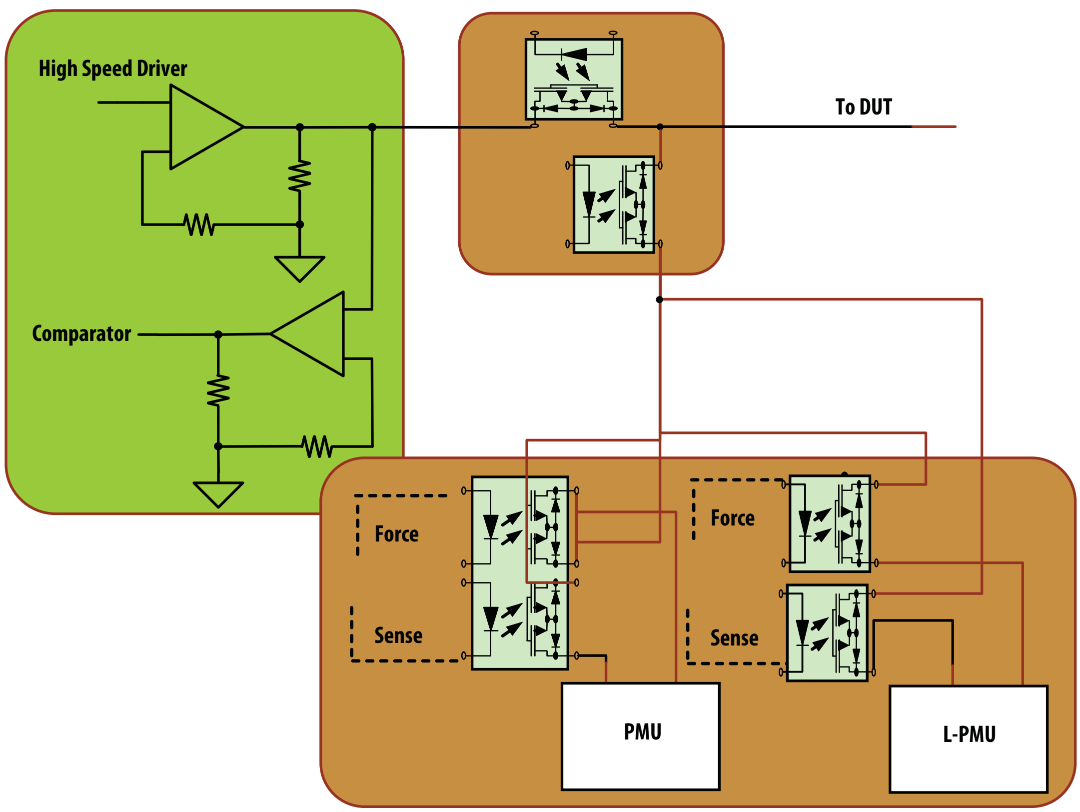


Figure 9. Semiconductor test and measurement pin driver electronics

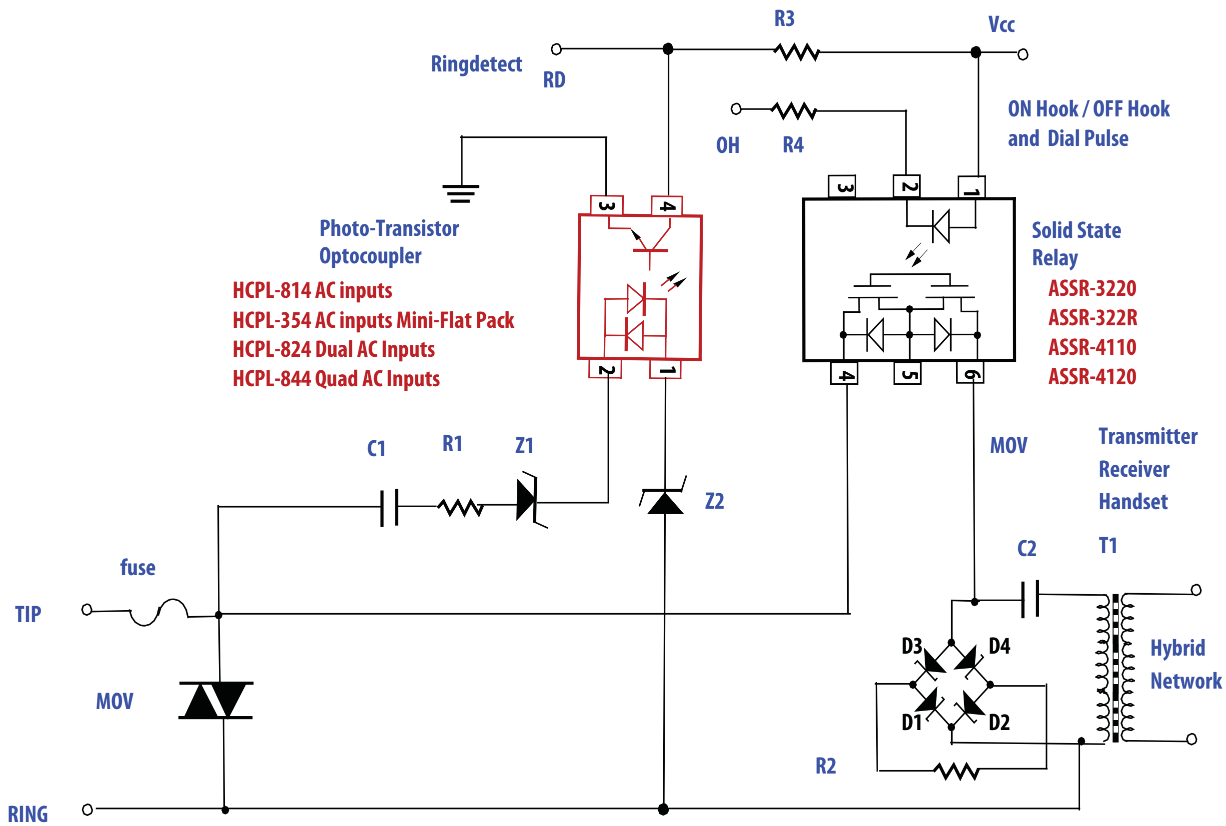


Figure 10. Telecommunication Switch Application – Ring Detection, On-Hook, and Pulse Dialer

Summary

Compared to electromechanical relays, solid state relays have significantly higher reliability levels with very high mean time to failure (MTTF) and very low failures in time (FITs). With no moving mechanical components inside, SSRs also withstand shock, vibration, and acceleration significantly better than EMRs. SSRs are also significantly more immune to electromagnetic interference.

In addition, a current of a few milliamps controls the input LED of the SSR, making microcontroller interface or control easy. Other advantages include the elimination of contact bounce and no acoustical noise. SSRs have no wear out mechanism to limit the number of operations and require no minimum contact "wetting" current. They are also free from magnetic fields, do not generate electrical noise, and are not sensitive to electromagnetic interference.

Complete SSRs are available as well as photovoltaic drivers for use with external MOSFETs.

Avago's SSRs are available in standard IC packages that are compatible with standard pick-and-place SMT manufacturing processes.

Notes:

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