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Application Note AN-1068 revA

Considerations for Designs Using Radiation-Hardened Solid State Relays

By Alan Tasker

Table of Contents

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International Rectifier • 233 Kansas Street, El Segundo, CA 90245 • USA

Considerations for Designs Using Radiation-Hardened Solid State Relays

By Alan Tasker,
SSR Product Line Manager, IR Hi-Rel Products Group

Introduction

Manufacturers of satellites, satellite launch vehicles, and tactical weapon systems face many challenges when designing electro-mechanical relays (EMR) into their systems. Some method of "cushioning" must be employed in order to prevent false relay operation when encountering shock and vibration. In addition, "hash filters" are sometimes necessary to debounce the contacts, thus adding space and weight. However, Solid State Relays (SSR) are immune to the shock and vibration levels normally encountered, and do not need contact filters. Hence, the use of Solid State Relays in place of the mechanical type leads to a more reliable end product.

Overview

In an SSR, various electronic elements are used to take the place of the electro-mechanical elements in a mechanical relay. These are described as follows.

The "Contact"

An SSR uses a MOSFET in place of the mechanical contact. This is why there is no contact bounce. However, if there is any significant power dissipation involved, then proper heat sinking will be necessary.

"Actuation"

The traditional relay uses an electromagnet in conjunction with other mechanical components to effect contact actuation. The SSR employs a photovoltaic isolator (PVI). As a minimum, a PVI consists of one or more LEDs and a photovoltaic array. When a current is run through the LED(s), the light output falls on the array, generating a voltage that charges the FET gate. This turns the SSR on. There must also be a gate discharge circuit present to insure that the MOSFET turns off in

a controlled manner when it is desired to turn the SSR off. An SSR constructed as described is shown in Figure 1. In relay terms, this particular configuration is called a Single Pole, Single Throw, Normally Open (SPST NO) type. It is also called a “Form A” relay. Since the MOSFET has a body diode, this arrangement does not block current flow in both directions, so it is used only in DC circuits.

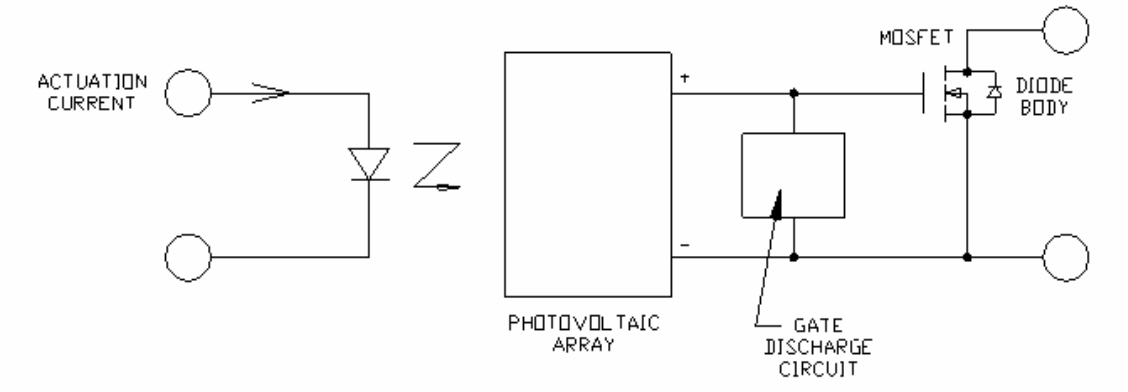


Figure 1.- SPST NO (Form A) DC SSR Circuit Schematic

Because of the physical separation between the LED(s) and the array, there is at least 1000 Volts of isolation between the input and the output of an SSR.

In order to handle AC, a second MOSFET is added, as shown in figure 2.

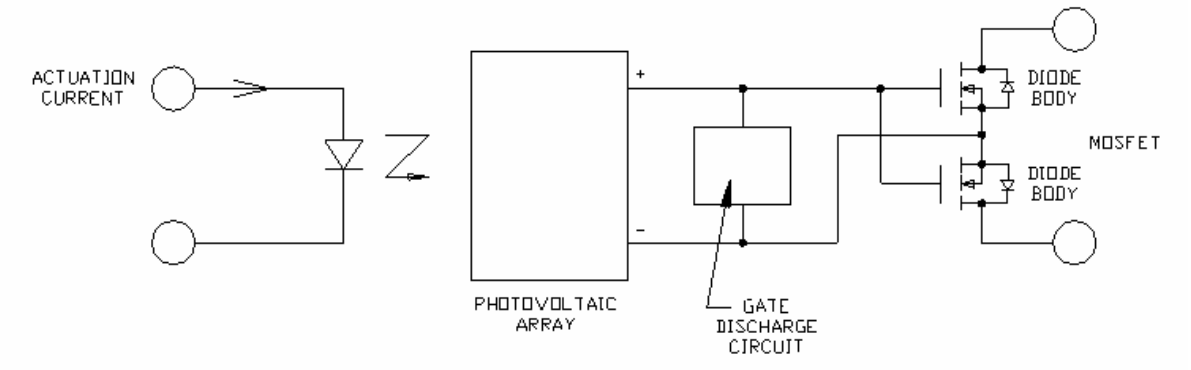


Figure 2.- SPST NO (Form A) AC SSR Circuit Schematic

The IR Advantage

1. "Input Buffer"

The coil in most mechanical relays has sufficient resistance such that it does not need an input buffer. Coils are usually constructed so that actuation occurs at reasonable currents when connected to its rated Voltage, such as 5, 12, 15, or 24 Volts. The LED in the SSR, however, is a low impedance device, so some method of current limiting must be employed. This can be built in, along with a logic level activated input buffer, as shown in Figure 3. This buffer, unlike a bipolar transistor buffer, draws no current from the logic driver, greatly simplifying the design.

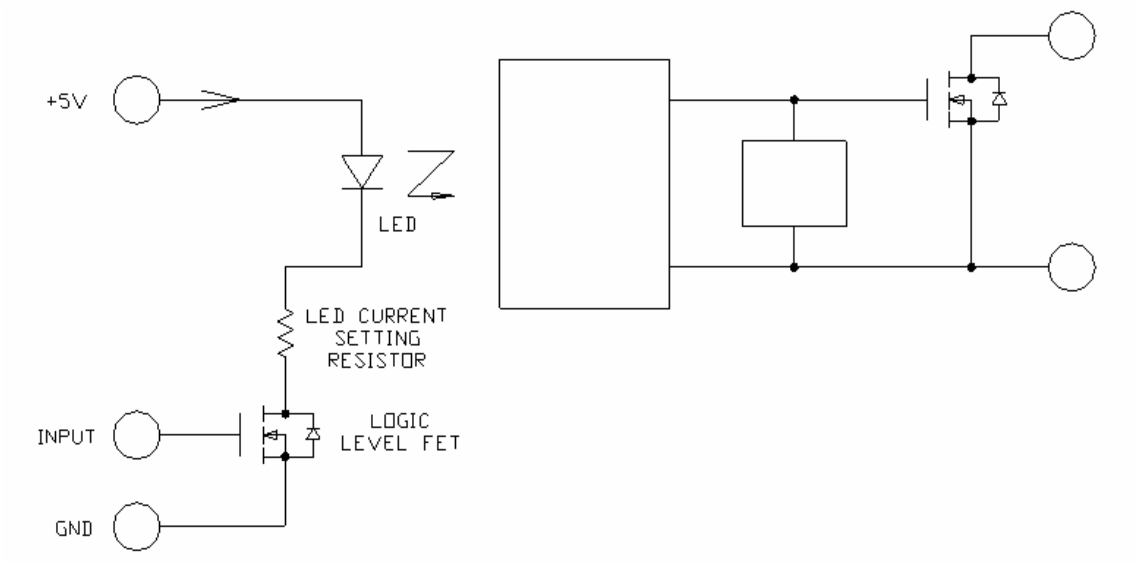


Figure 3.- One type of SSR Input Buffer

1. "Normally Closed Contacts"

Most MOSFETs are constructed by a process that leads to a normally off state, also called an enhancement mode device. The application of a gate voltage "enhances" the drain-to-source channel, turning the device on and allowing the channel to conduct current. This mode fulfills what is called a Normally Open (NO) or a Form A contact in an EMR.

However, normally on FETs are rare. IR, however, has a set of processes that enable us to make this type of FET as well, and these are called depletion mode devices. These fulfill the role of what is called a Normally Closed (NC) or a Form B contact. In addition, by packaging one of each type of contact in a single package, a Single Pole, Double Throw (SPDT) SSR can be made. This is also called a "Form C" contact.

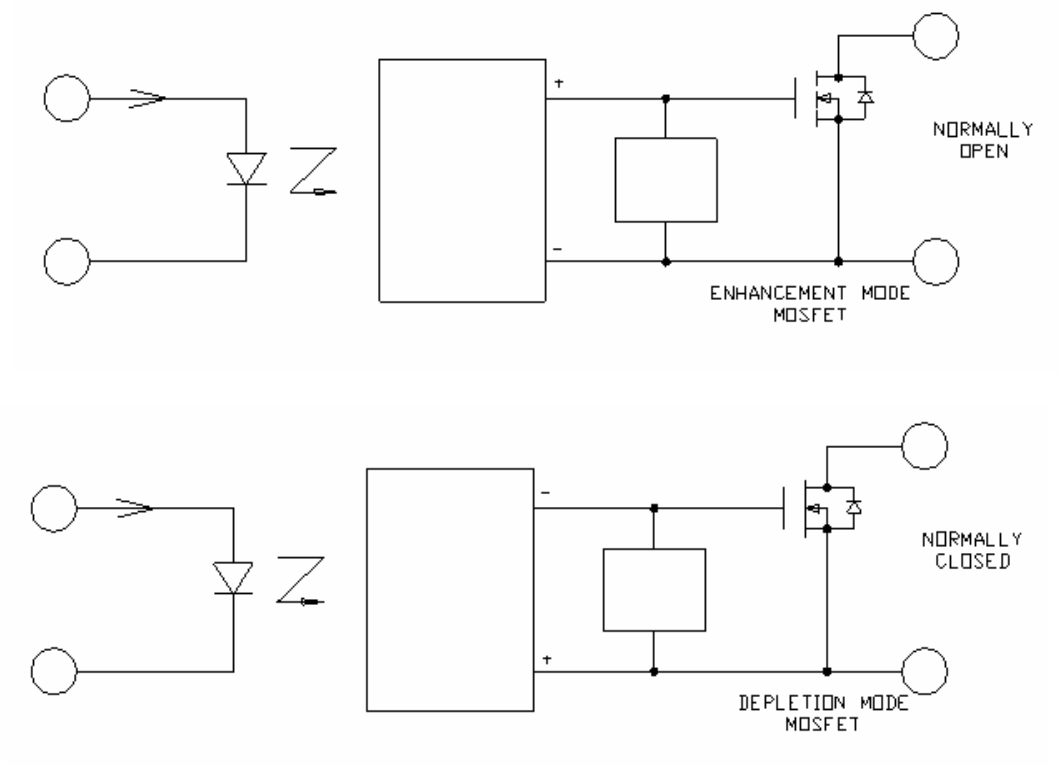


Figure 4.- RDHA718SD10C1BK Single Pole, Double Throw (Form C) DC SSR

Since the actuation voltage for each FET type is of the opposite polarity, two opto-couplers must be used. This leads to additional flexibility because the two sides (NO and NC) are independent and are not tied together as they would be in an EMR. Additional circuitry may be built in to accomplish Break-Before-Make (BBM), or Make-Before-Break (MBB) operation when the two inputs are driven simultaneously, another IR advantage.

The Product Line

At the time of this writing, the “A Series” product line consists of the following parts.

Part Number	Current Rating	Package	Voltage	Contacts	Channels per pkg	Input Buffer
RDHA718SE10A2QK	18	SMT	100 V	SPST NO (Form A)	2	5V, controlled
RDHA718FE10A2QK	“	Flange	“	“	“	“
RDHA718SE10A2SK	“	SMT	“	“	“	3.3V, controlled
RDHA718FE10A2SK	“	Flange	“	“	“	“
RDHA718SE13A2SK	“	SMT	130 V	“	“	“
RDHA718FE13A2SK	“	Flange	“	“	“	“
RDHA718SE10A2FK	“	SMT	100 V	“	“	3.3 V, fast
RDHA718FE10A2FK	“	Flange	“	“	“	”
RDHA718SE13A2FK	“	SMT	130 V	“	“	“
RDHA718FE13A2FK	“	Flange	“	“	“	“
RDHA720SF06A1NK	20	SMT	60 V	SPST NO (Form A)	1	No Buffer
RDHA720FF06A1NK	“	Flange	“	“	“	“
RDHA703NM10A1NK	3	SMD4	100	SPST NO (Form A)	1	No Buffer
RDHA701FP10A8CK	1.5 A	Flat Pack	100	SPST NO (Form A)	8	No Buffer
RDHA701FP10A8QK	“	“	“	“	“	5 V, controlled

Also in development are the following SPDT (Form C) types.

Part Number	Current Rating	Package	Voltage	Contacts	Channels per pkg	Input Buffer
RDHA718SD10C1BK	18	SMT	100	SPDT (Form C)	1	3.3 V
RDHA718FD10C1BK	"	Flange	"	"	"	"
RDHA718SD13C1BK	"	SMT	130	"	"	"
RDHA718FD13C1BK	"	Flange	"	"	"	"

For iterations on any of the above, or for something completely different, please contact your IR representative, your IR area Sales Manager, or the Leominster factory.

Application Hints

General Use

Because of the inherent isolation in the SSR, it can be used to drive either the high side or the low side, or even between sides, as in a solar array battery charger. Figures 5 through 7 show some typical applications:

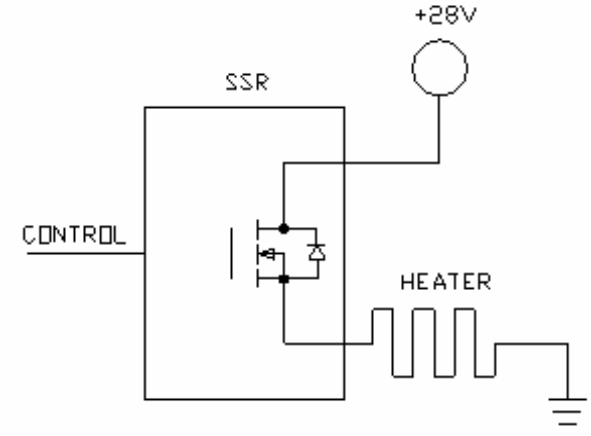


Figure 5.- One of Eight Channels in an RDHA701FP10A8QK Driving a Heater Element on the high side.

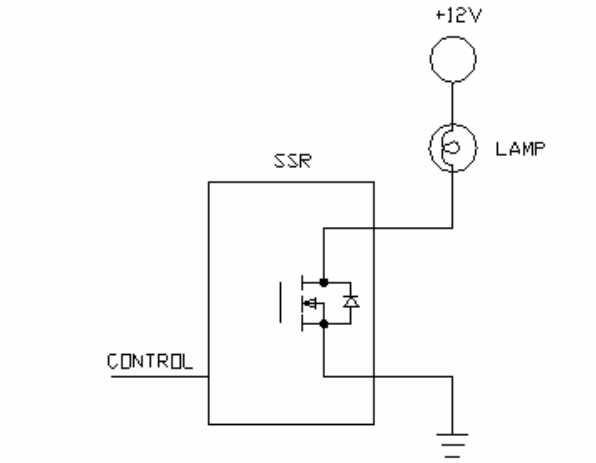


Figure 6.- An RDHA703NM10A1K Driving a Lamp on the Low Side

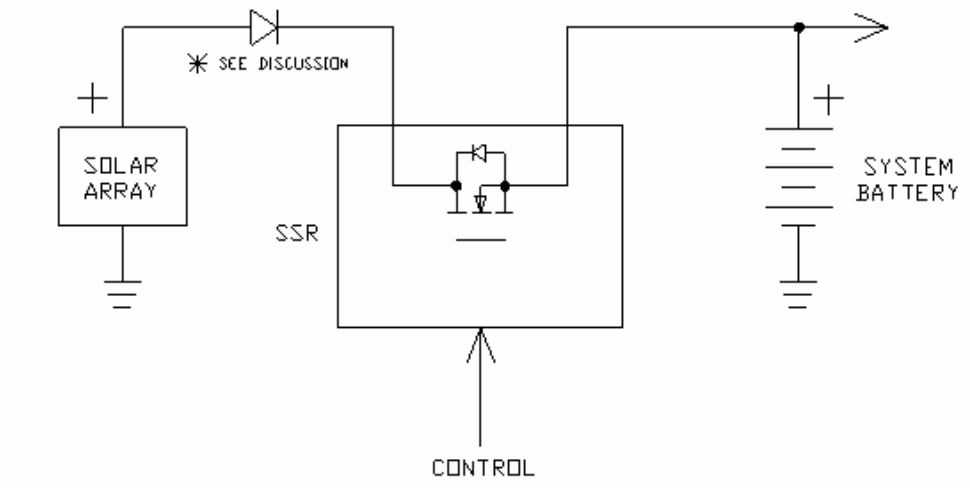


Figure 7.- An RDHA718SE10A2QK Being Used to Control Battery Charging

In Figure 7, an isolation diode must be used to prevent battery discharge into the solar array through the FET body diode when off, i.e. not charging. Another way to accomplish the same thing with less power dissipation is to use an AC SSR (or to use both channels of a dual DC SSR connected in series, source to source) in place of the DC SSR/diode combination shown above.

SSR Switching Times

EMRs do not switch very fast, perhaps in the neighborhood of 5-20 milliseconds. The switching time of a normally constructed SSR is in the same ballpark, due primarily to the poor current transfer ratio of the PVI. (The PVI output current has to charge the gate capacitance of the output FET, and this takes time.) For most applications, this medium speed response is acceptable.

In other applications, system designers may be concerned with dV/dt and/or dI/dt. Keeping these values low helps keep system interference at acceptable levels. Some SSRs are constructed with additional internal circuitry that keep dV/dt and dI/dt at “controlled” levels, thus helping to reduce system RFI and EMI. One consequence of this controlled (i.e. slow) switching is that the MOSFET transitions its active region slowly. If turn-on transients are expected (i.e. due to a capacitive load, for instance), an analysis must be performed to ensure that the design does not violate the MOSFET Safe Operating Area (SOA) limits. One method of limiting the current surge is to provide a small resistor in series with the load. Figure 8 shows one way of accomplishing this. The 1-Ohm resistor limits surges to 28 Amps peak, well within the capabilities of an 18 Amp rated SSR.

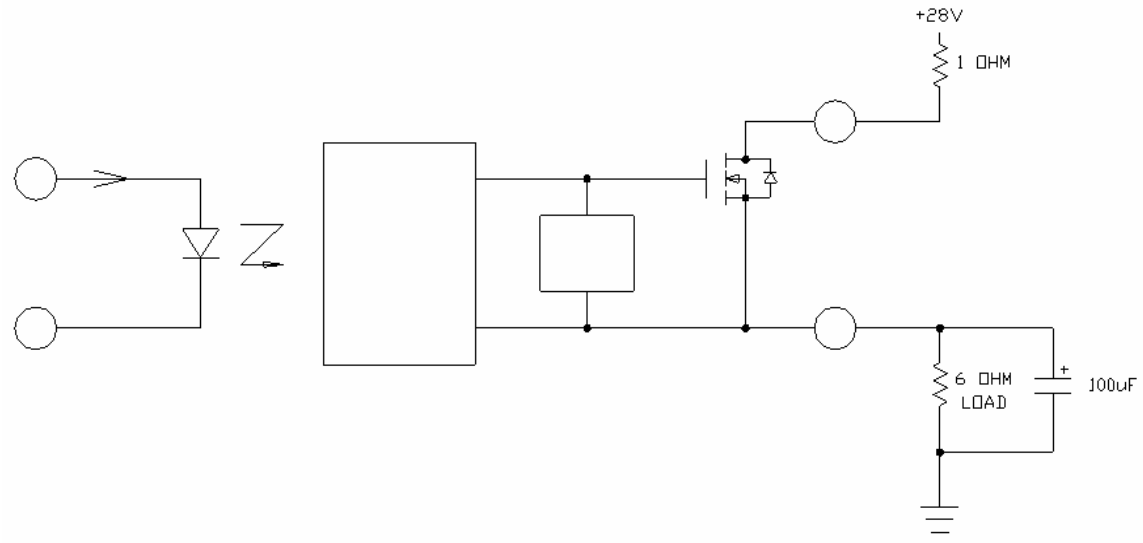


Figure 8.- Surge Current Limiting Using a 1-Ohm Resistor

If proper circuit operation does not permit leaving the current limiting resistor in the circuit permanently, it can be bypassed by a second SSR. The second SSR turns on slightly delayed from the main load SSR. This is shown in Figure 9.

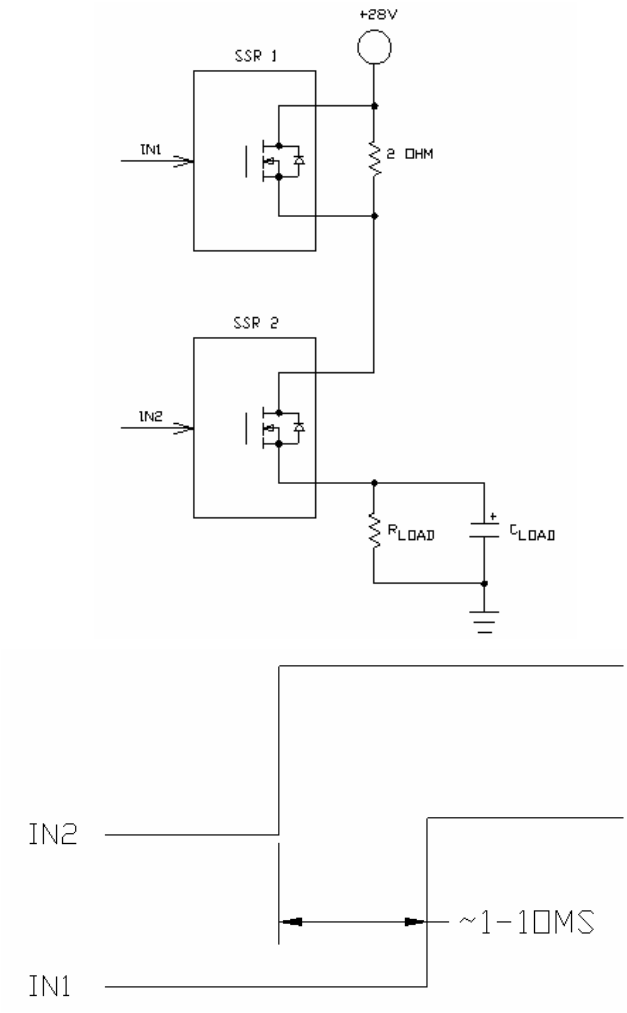


Figure 9.- Sequenced Switching Out of a Current Limiting Resistor

Some SSRs have a multi-purpose input circuit. These can be configured for automatic bypassing of the current limiting resistor. This is shown in Figure 10. The current limiting resistor for the second (bypass) SSR sets the input LED current in the 10-20 mA region.

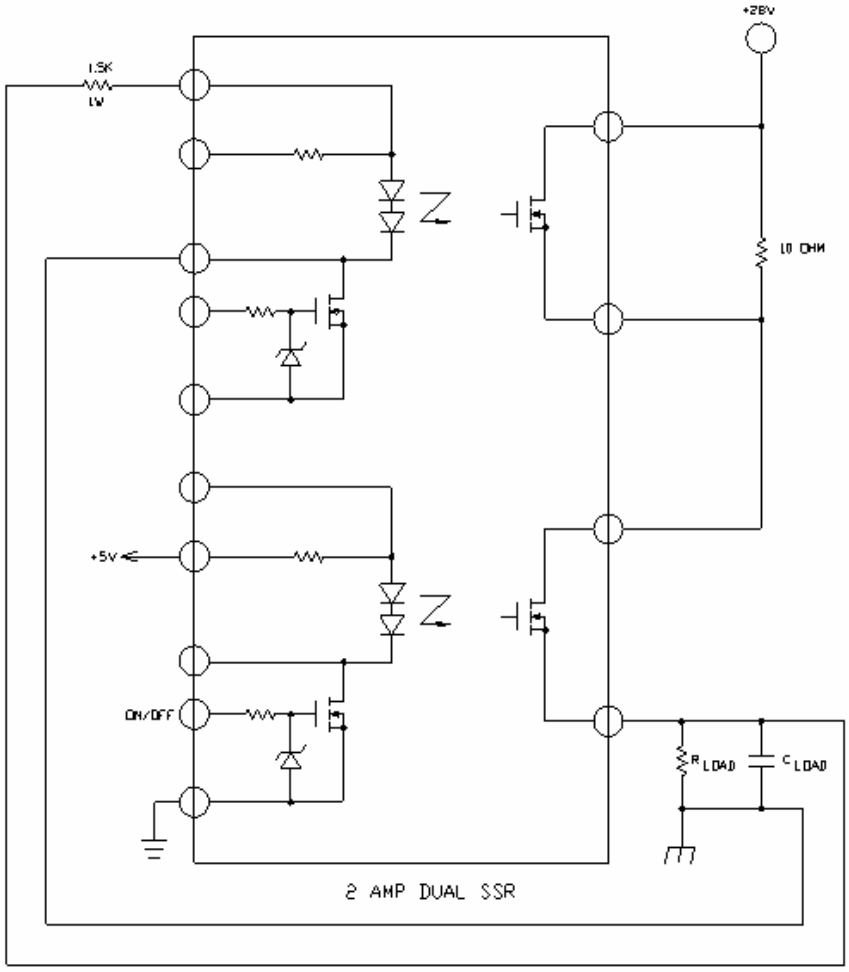


Figure 10.- Automatic bypassing of a current limiting resistor

In yet other applications, a faster turn-on is either desired, or required because of the presence of turn-on transients. Under these conditions, the following guidelines should be followed.

1. Start with an SSR from the “fast” series, not one from the “controlled” series.
2. Use an external resistor to parallel the internal R_{limit} so that the nominal LED current is 2x to 3x nominal, but no more than the maximum allowed per the applicable device data sheet. See Figure 11 and the following discussion.
3. Use an external R_s and C_s to increase the peak current at turn-on to 100 mA (or as much as the specification allows). R_s sets the peak current, while C_s sets the pulse width, usually 1 ms. Figure 11 and the following discussion show how to connect these components.
4. Tailoring the MOSFET used in the output can lead to a more robust design. Contact the SSR product line manager for further information.

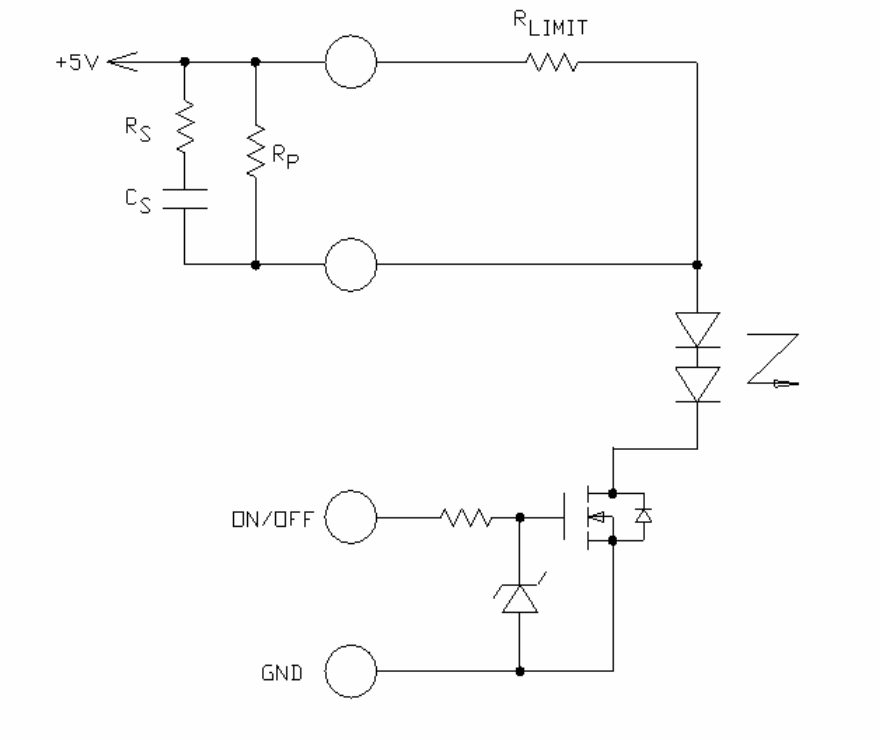


Figure 11.- Turn-on Speed-Up Circuit

The values of the components in figure 11 are calculated as follows. The RDHA702FT10A2FK

datasheet states that the internal LED diode drop is a nominal 2.6 Volts at a 10 mA drive current. The R_{limit} resistor sets this current, and is therefore equal to (5-2.6) V/10 mA, which is 240 Ohms. The data sheet also states that the maximum allowed LED DC current is 40 mA. In order to add an additional drive current of 30 mA, R_p calculates to be 2.4 V/30 mA, which is 80 Ohms.

The maximum peak LED current allowed per the datasheet is 100 mA for 1 ms. In order to add an additional peak current of 60 mA (so that the peak of 60 plus the DC current of 40 equals the maximum of 100 mA), R_s calculates to be 2.4 V/60 mA, which is 40 Ohms. C_s must set this 60 mA peak to have a time constant of no more than 1 ms. Since C_s sees basically just R_s, C_s calculates to be 1 ms/40 Ohms, which is 25 uF.

At these higher currents, the LED Voltage drop will be higher than the 2.6 Volts used in the above calculations. This means the DC and AC currents will not quite hit their mark, but it is not worth a recalculation. It is best to leave the values as-is since it will lead to a slightly more conservative design as far as pushing the LED currents to their maximum limits go.

Single Shot High Current Pulse Generator

Figure 12 depicts one way to generate a medium accuracy power pulse using known radiation hardened components. Use is made of the hysteresis built in to the inputs of the RIC7113 IC, as well as the inverting nature of the shutdown function. At a logic supply of 5 Volts, the input “high” threshold is about 3.2 Volts. After bringing the trigger pin high, the RIC7113 output goes high, which turns on the SSR. Trigger must remain high for the circuit to time out. It takes about 100 ms for the ~200K Ohm timing resistor (300 K in parallel with 600 K) to charge the 1 uF capacitor up to the 3.2 Volt threshold, turning the RIC off, which turns the SSR off. The circuit remains in the off state until the trigger pin is brought low and then high again (because of the RIC7113’s internal edge triggered reset circuitry).

Applicable formulas are as follows.

-R_t equivalent is equal to R_{t1} in parallel with R_{t2}.
-R_d softens the capacitor discharge surge.
-The 10K/10K divider reduces the SSR input voltage so its 10 V limit is not exceeded.
-The timing formula is as follows. $3.2=5e^{-t/RteqCt}$

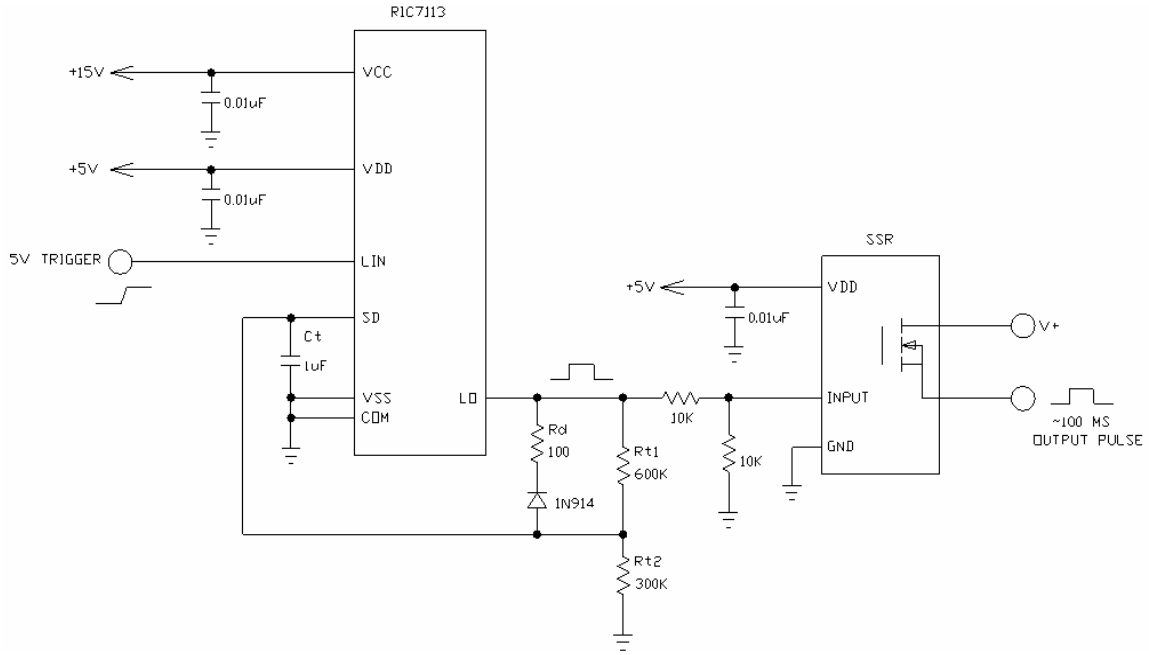
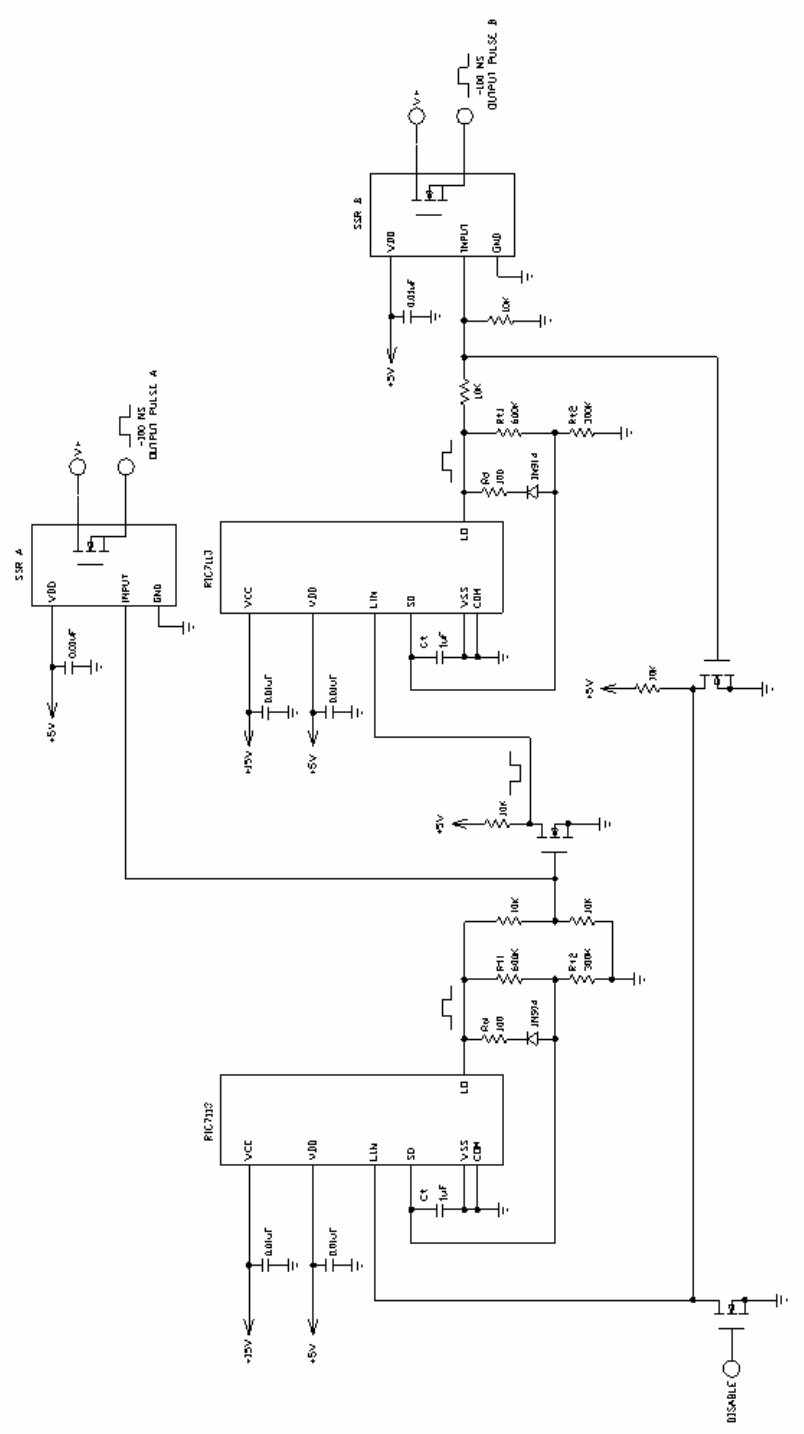


Figure 12.- Rad-Hard Single Shot High Current Pulse Generator

Sequencing High Current Pulse Generator

Figure 13 depicts one way to generate medium accuracy sequenced power pulses using known radiation hardened components. This design is similar to that shown above, except for the inclusion of additional stages in a “ring” format to create the sequencing.


SSR B
SSR A
IRIC7113
IRIC7112
INPUT1
VDD
GND
VCC
LIN
SD
VSS
COM
LO
Ct
1uF
0.01uF
10K
+5V
+15V
DISABLE

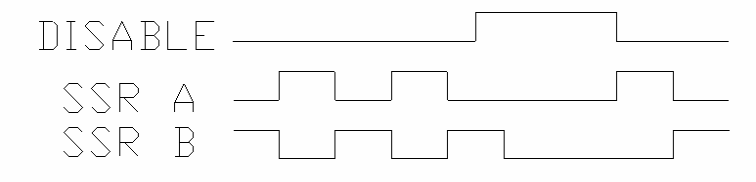


Figure 13- Rad-Hard High Current Sequenced Pulse Generator

Design for Survivability in a Radiation Environment

Radiation hardened MOSFETs are used throughout this product line. They are easily capable of sustaining exposure to >100 Krad(Si) TID, and to an SEE of 37 MeV/(mg/cm^2) or higher.

The PVI are also characterized to these same levels. Some degradation does occur to the PVI as they are exposed to radiation. Ways to minimize any negative effects on SSR performance are as follows.

1. Run an LED current of at least 10 mA, and preferably higher. The higher the LED current, the more degradation can be withstood.
2. Choose a PVI with two LEDs. Again, this yields more room for degradation.
3. If possible, choose a slower PVI. This may seem to be in conflict with advice given above, but the slower devices are simpler, and thus more immune to radiation.

Radiation Effects

1. External to the SSR
    a. All of our SSRs employ a Rad-Hard MOSFET output device. The particular part used is listed on the SSR data sheet. The radiation effects on MOSFET parameters that are “external” to the SSR, i.e. Drain-to-Source specifications, can be found in the MOSFET data sheet. Listed will be maximum changes in such areas as break-down Voltage, output leakage current, etc.
    b. For the most part, none of the SSR input parameters are radiation sensitive. Input current in the “on” state may increase a bit due to an increase in gate-to-source leakage in the input buffer FET.

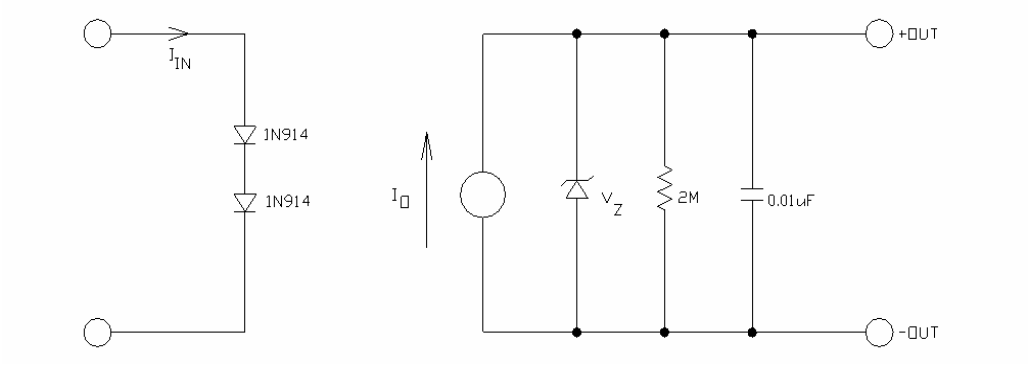
2. Internal to the SSR
    a. As radiation exposure progresses, the MOSFET gate to source Voltage may change a bit. This will affect SSR switching time to a very small degree, as this shift is small in a Rad-Hard MOSFET.
    b. MOSFET gate-to-source leakage current will also increase, causing a slight increase in switching times. The opto output current must now divide between charging the gate and supplying this leakage, causing a small increase in delay time.
    c. With continued exposure, the opto will also be affected. The LED(s) will put out less light, and the photovoltaic array will become less efficient. Both of these effects will work to reduce the current available from the opto-coupler, thus increasing the SSR switching times. However, we are conservative in our designs, and have tested these devices to insure that they will still be functional after exposure to the radiation limits as stated on the individual data sheets.

Simulation Model

The SSR can be simulated by entering its individual parts as if they were elements of the overall schematic. Each data sheet calls out the IR part number of the main switching FET. Input buffer FETs are as follows.

- 5 Volt actuated SSR have an IRHG57110 input buffer transistor
- 3.3 Volt actuated SSR have an IRHLF770Z4 buffer transistor

Controlled switching devices have a single LED PVI, and its components are shown in figure 14. Fast switching devices have a dual LED PVI, and its components are shown in figure 15. Both of these are pre irradiation.



$I_o=I_{in}x(1.00x10^{-3}-0.0025x10^{-3}x(T-298 \text{ deg Kelvin}))$

$V_z=11.5-0.045x(T-298 \text{ deg K})$

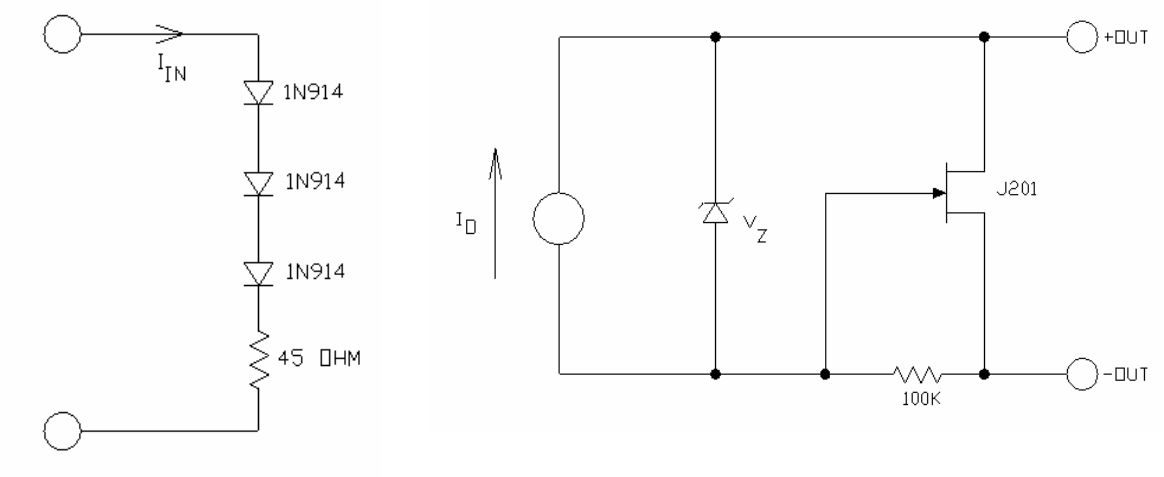
I is in Amps, V is in Volts, T is in degrees Kelvin

As a check, @ 25 deg C and I_{in}=10mA, I_o=10 uA, V_z=11.5 Volts

I_o falls off at the rate of 0.025 uA per degree of temperature increase.

V_z falls off at the rate of 45 mV per degree of temperature increase.

Figure 14.- Components for simulating the PVI in a controlled response SSR



$I_o=I_{in}x(4.9x10^{-3}-0.013x10^{-3}x(T-298\ deg\ Kelvin))$

$V_z=13-0.050x(T-298\ deg\ K)$

I is in Amps, V is in Volts, T is in degrees Kelvin

As a check, @25 deg C and I_{in}=10mA, I_o=49 uA, V_z=13 Volts

I_o falls off at the rate of 0.130 uA per degree of temperature increase.

V_z falls off at the rate of 50 mV per degree of temperature increase.

Figure 15.- Components for simulating the PVI in a fast response SSR