Solid State Relay, ASSR Series
Input Control Drive and Various Loads

Application Note 5302

Introduction

A Solid State Relay (SSR) is a solid state replacement of the electromechanical relays (EMR), and has been used for general purpose switching of signals and AC/DC loads. A SSR provides both switching and galvanic isolation functions without any mechanical movement during its operation. A SSR consists of the light emitting diode (LED), photodiode array, MOSFET drivers and the high-voltage MOSFETs. The LED on the input control side converts the electrical input signal into the optical signal. On the output side, the optical signal is converted back to the electrical signal that supplies the power to switch the MOSFETs. The purpose of this application note is to describe the input control drive circuits for the LED, the various loads of the SSR and the surge characteristics of Avago Technologies' new SSR product family, the ASSR series.

Input Control Drive Circuits

Operation of the ASSR Series requires at least 3 mA of input current. Higher input current drive results in faster switching time of the ASSR, though the turn-off time, T_{OFF}, does not reduce as much as turn-on time, T_{ON}; T_{OFF} is usually much shorter than T_{ON}. A simple circuit for obtaining the desired input forward current, I_F, and input OFF voltage, $V_{F(OFF)}$, is shown in Figure 1.

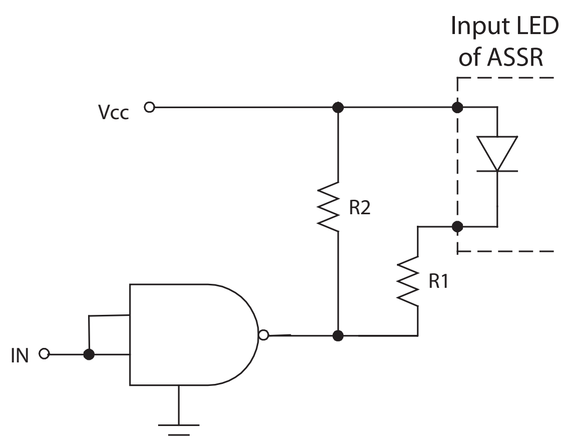


Figure 1. Logic-Driven Control Circuit.

The logic series used can be almost anything; any device from the TTL logic family, open-collector or totem pole, will work in the arrangement shown. The same is true for CMOS, provided only that the current-sinking capability is adequate. Current limiting resistor R_1 sets I_F, and it can be calculated by

$$R_1 = (V_{CC} - V_{OL} - V_F) / I_F$$

where VOL is the low level output voltage of the gate, and V_F is the forward voltage of the LED. V_{CC} is the supply

The purpose of resistor R_2 is to bypass logic-high leakage current with sufficiently small voltage drop to ensure a $V_{F(OFF)}$ less than 0.8 V. With open-collector TTL outputs, R_2 is always required. And it should meet

$$R_2 < V_{F(OFF)} / I_{OH}$$

where IOH is the high level output current.

R_2 is not required if the logic output has an internal pull-up circuit that is able to satisfy the $V_{F(OFF)}$ requirement of the ASSR.

The circuit in Figure 1 is basically a series-drive type because the active current is switched by a device in series with the LED. This type of drive circuit has a great deal of flexibility in achieving other design objectives. It can be used with TTL having either an active pull-up (totem-pole) output or open-collector output.

If an open collector TTL is available for driving the input control, a simpler alternative is the shunt-driven circuit as shown in Figure 2.

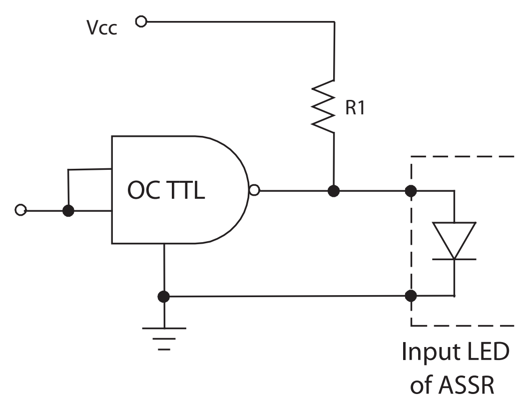


Figure 2. Shunt-Driven Control Circuit

It requires only a single resistor, R_1, and the logic-low voltage does not influence the I_F. The LED is switched off by directing current away from it with the shunt output transistor within the gate. When the output of the logic gate goes low, current is shunted away from the LED, and the ASSR turns off. Thus, the $V_{F(OFF)}$ requirement is inherently satisfied by the logic-low voltage. When the logic-gate output goes high, I_F is limited by the current limiting resistor R_1, which is calculated by

$$R_1 = (V_{CC} - V_F) / I_F$$

For the open collector gates, this configuration eliminates the extra pull-up resistor, R_2, required by the series-drive type shown in Figure 1.

The switching time is influenced by the level of input forward current, I_F. As it increases, T_{ON} becomes shorter. It may not be desirable to operate with a high I_F as it would increase the output offset voltage, $V_{(OS)}$, due to heat transferred from the LED control to the MOSFETs at the output. Consequently, when the ASSR is used in measuring instruments, a high $V_{(OS)}$ would inevitably give an error in measurement. A high I_F also increases the input power consumption and accelerates LED's light output power (LOP) degradation. It is cautioned that the input power should not exceed the input power dissipation value, PIN, as stated in the absolute maximum ratings in the datasheet. The LOP degradation is a function of temperature, time, and I_F. In general, LOP degradation occurs up to about 1000 hours, at which point the degradation stabilizes.

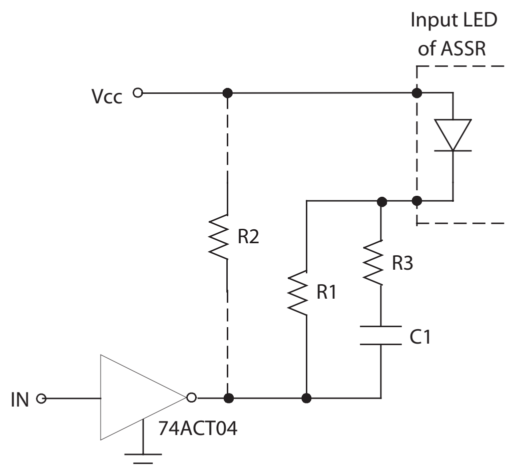


Figure 3. Recommended Peaking Control Circuit

In situations requiring fast T_{ON} but low $V_{(OS)}$, a peaking circuit, consisting of resistor R_3 and capacitor C_1, shown in figure 3 can be considered. When the logic output is high, R_2 ensures that the current through the LED is so small that C_1 is completely discharged. When the logic output goes low, a surge of current flows through both R_1 and R_3 until C_1 is charged to the voltage across R_1. For the ASSR Series, C_1 is recommended to be 10 µF .

Table 1. Typical Peaked Turn-on Time with C1 = 10µF

R3 (Ω)	Icc(mA)	Ton (ms)
-	10	0.15
680	11	0.10
330	11	0.08
33	12	0.015

Table 1 illustrates the influence of the peaking circuit on the T_{ON} of the ASSR-3220 (250 V, 0.2 A, 10 Ω) where T_{ON} includes the propagation delay time. Thus the peaking circuit permits fast T_{ON} as well as low I_F. Switching on the output MOSFETs requires charging the gate capacitances in the MOSFET driver circuit. This charge is the time-integrated photocurrent from the photodiode array and translates into a certain amount of current that must pass through the LED. The corresponding amount of LED charge is set by the value of the peaking capacitor, C_1, and the voltage across R_1. For this reason, it is not necessary to change the value of C_1 when other values of peak current are desired; it is necessary only to change the value of R_3 and make sure that the logic output is capable of sinking the higher current.

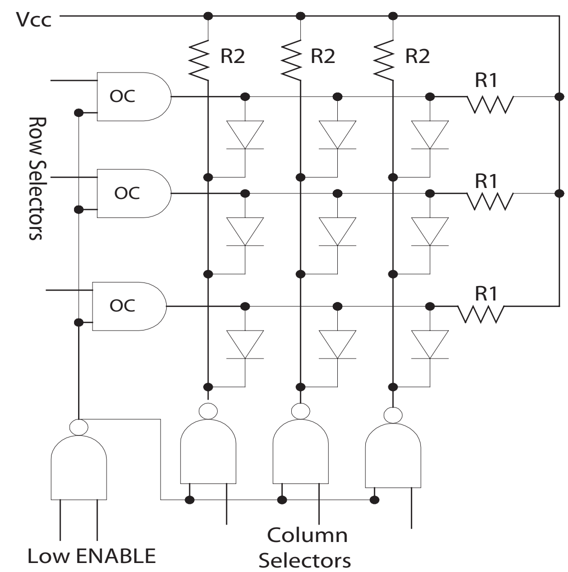
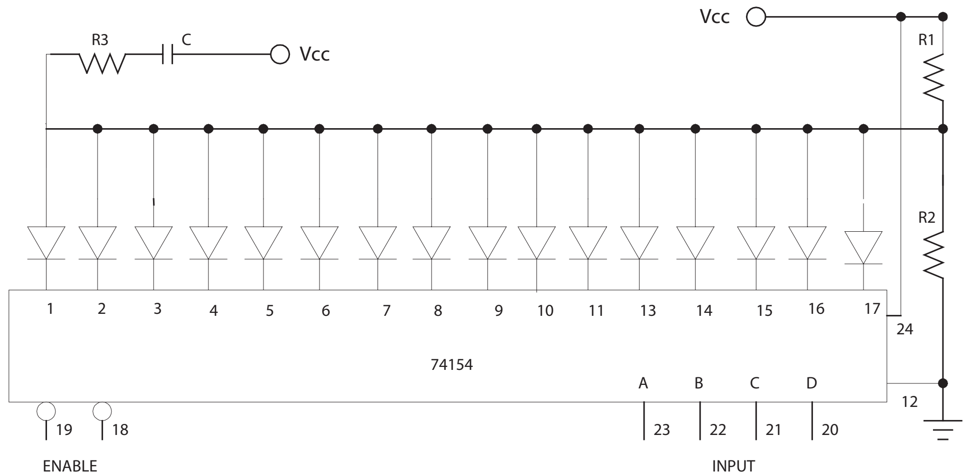


Figure 4. Matrix-Driven Control Circuit

Figure 4 shows a combination of series-shunt drive. The column drivers do the series switching and the row drivers operate in shunt mode. With the ENABLE input high, selection is made of the desired row and column (high true), but the selected LED remains OFF until the ENABLE goes low. This provision is necessary to ensure "break-before-make" operation of the output contacts. With turn-off time longer than turn-on time, there must be a "dead" time of 0.2 msec or more to prevent overlapping contact closure. The values of resistor R_1 and R_2 are selected as described for the circuits of figures 1 and 2, and, if desired, the peaking circuit consisting of R_3 and C_1 may be added in parallel with each R_1.

The matrix arrangement in Figure 4 is worth considering only if a very large number of switches are to be selectively operated. To make a selection from a smaller number of switches, a much simpler circuit is shown in Figure 5, where a decoder or de-multiplexer IC is used.



$$I_F = \frac{V_{CC} - V_F - V_{OL}}{R1} - \frac{V_F + V_{OL}}{R2}$$

$$V_{F,OFF} = \frac{R2}{R1 + R1} V_{CC} - V_{OH}$$

Figure 5. Control Circuit for 16-Channel Multiplexer

The values of the resistors R_1 and R_2 are not computed in the same way as for the circuits of Figures 1 and 2. Here the principle is to select a ratio R_1/R_2 such that the forward voltage across the LED, V_F, is less than 0.8 V when the 74154 decoder output is high, then establish this ratio with resistor values small enough to allow adequate I_F when the 74154 decoder output is low. Actual selection of resistor values is most easily done by first selecting R_1 with a large margin in the inequality to provide a wide range for selection of R_2 to fit within the two sided inequality. If peaking is desired on any or on all three of the anode bus lines, the peaking circuit may be added with no effect on the choice of R_1 and R_2 values. The peaking circuit may be connected either to V_{CC} or to ground. An important concern is operation of the ENABLE (Pin 18 and 19) inputs of the 74154 decoder. Both of these must be low to make the output (selected by the address) go low. It is recommended that at least one of the ENABLE inputs be made high for an interval of 0.2 ms or more, following address selection, to prevent overlapping contact closure. In Figure 5 (also in Figure 4) the length of time that any individual contact is held closed may depend on how fast the contact circuit can respond to the contact closure.

Various Loads

Depending on the type of load, the SSR may be required to withstand a substantial amount of surge current. A purely resistive load is the easiest type for the SSR to switch since it has no surge current requirement. Other typical loads and their related inrush versus steady state currents are shown in Table 2.

Table 2. Typical SSR Loads

Load Type	Typical Inrush vs. Steady State Current	Inrush Duration (ms)
Small Solenoid	10-20X	70-100
Fractional Horsepower Motor	5-10X	200-500
Miniature Incandescent Lamp	20-15X	30-100
Capacitive Load	20-40X	10-40

The surge current requirement of the load should be within the peak surge current rating of the SSR. Therefore, an SSR that switches one of these types of loads should have current specifications that meet both the steady-state and surge current requirements. Compared to EMRs, SSRs are more tolerant of surge currents because they do not have contact bounce, which results in arcing with EMR contacts. The high-temperature arc could cause melting and eventual degradation of the EMR contact. For example, the ASSR-3220-002E (250 V, 0.2 A, 10 Ω, and 2 Form A in a DIP 8 package) has a single shot, peak output current rating of 1.8 A for a 100 ms single pulse width. For longer pulse widths, the single-shot, peak output current rating would decrease. Figure 6 shows the peak surge current as a function of the duration of the surge current. The results of an experiment performed on twenty units of the ASSR-3220. The graph shows the peak surge current that we were able to apply to the output of twenty typical ASSRs without any one of them failing. The duty cycle of the surge current is 10%, every unit is tested for 15 minutes with the repetitive current surge applied. Another 10 units of ASSR-3220 were tested for 15 minutes each with surge current pulses applied for 100 ms at 100 ms intervals (fifty percent duty cycle). Under these conditions, the maximum repetitive surge current to failure was 1.9 A for the ASSR-3220.

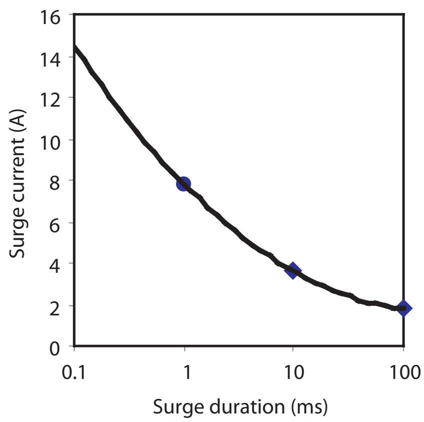


Figure 6. ASSR-3220 Peak Surge Current as a Function of the Surge Current Duration at 25°C

Figure 7 illustrates the use of SSRs in a lamp sequence control. Some areas that use SSRs to control lamp loads include process equipment, navigational devices, illuminated signs, and games. In aircraft applications, SSRs may control lamps for cabin lighting, instrumentation lighting, and status indicators. Ten units of the ASSR3220 were tested at room temperature under these conditions:

Input current, I_F=10 mA (1Hz), lamp bulb as load, and load voltage, V=230 VAC, 60 Hz. Each unit was tested for 1 million cycles. All units passed without catastrophic failure.

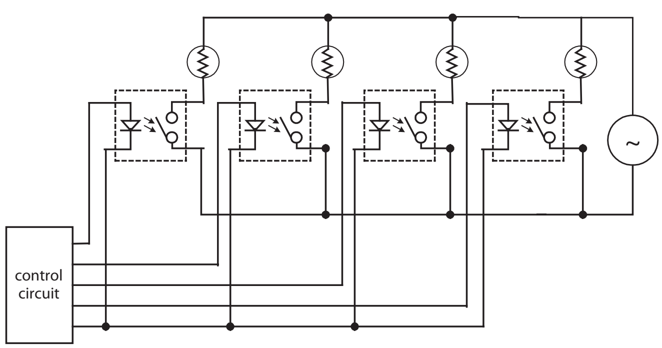


Figure 7. Lamp Control

Compared to EMRs, SSRs are especially useful in aircraft environments because they are immune to shock and vibration and are unaffected by electro-magnetic interference. Upon turn-on, the current through a lamp is very high initially because of the Tungsten filament's low resistance at room temperature. The current decreases as the filament heats up. Hence, the inrush current can be reduced by using a "keep alive" voltage across the filament to keep it warm but below the level of incandescence.

Similar to a lamp load, a capacitive load will cause a surge current to flow through the output MOSFETs of the SSR upon initial turn-on. This surge current will depend on the load capacitor value and the rate of rise of the load voltage. In addition, the frequency at which the SSR is switched will affect the output power dissipation.

Ten units of the ASSR-3220 were tested at room temperature under these conditions:

Input current, I_F=10 mA (1Hz), 100 µF capacitor as load, and load voltage V=230 VAC, 60 Hz. The capacitor is charged by the load voltage through a 1.25 kΩ series resistor. The ASSR is parallel with the capacitor to discharge it when the ASSR is on. Each unit was tested for 1million cycles. All units passed without catastrophic failures.

The ASSR-3220 can be used to drive fractional horsepower motors. A reversing control for a synchronous AC motor is shown in Figure 8. For motors that cycle on and off frequently, a SSR is often preferred over an EMR because it can handle surges better and does not produce EMI. A SSR might also be used to control small DC motor loads such as computer disk drives, VCD, DVD drives, various audio or video drives, household electronic appliances or automotives electronics. A SSR can also used to control the input coil of an EMR, which is an inductive load. Other inductive loads include small transformers, contactors, solenoid valves, etc. When a SSR drives an inductive loads, very high transient voltage can occur across the output of the SSR when it is turned off. The ASSR3220 can withstand a reasonable amount of inductive overload.

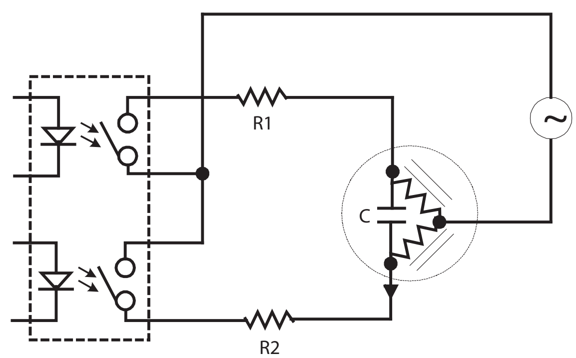


Figure 8. Motor Reversing Control

Ten units of the ASSR3220 were tested at room temperature under these conditions:

Input current, I_F=10 mA (1Hz), 8 mH inductor as load, load voltage V=230 VAC, 60 Hz, and load current is 0.2 A. Each unit was tested for 1million cycles. All passed without catastrophic failures.

Overvoltage Protection

In some applications, there is a possibility that the contacts may be exposed to destructively high voltages. For example, lightning can introduce high voltage surge into the telecommunication system. Over-voltage protection is always needed to protect an SSR. One such situation is partially illustrated in Figure 9, where the ASSR-3220 is being used to control the on/off-hook in a telephone set.

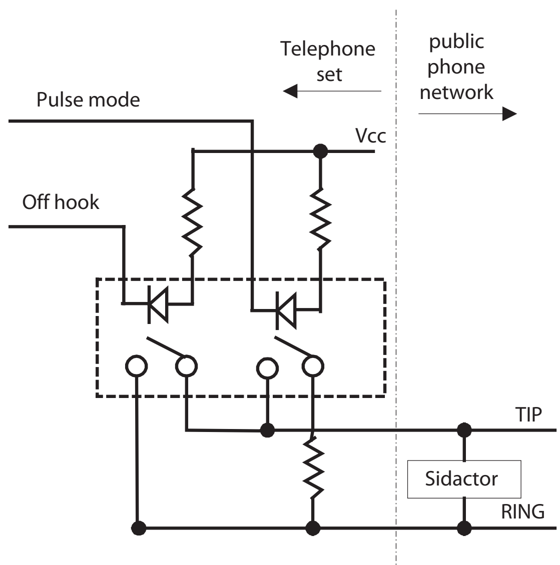


Figure 9. Protection Circuit for a Pulse Dialing Phone Set

When open, the contacts of the ASSR-3220 can withstand 250 V, positive or negative. Protection against damage due to exceeding 250 V is provided by the breakdown devices shown. These devices may be either General Semiconductor Sidactor, Trisil or MOV (Metal Oxide Varistors). They break down and conduct heavily when the voltage across them rises above a design level. As indicated by the symbol, the breakdown voltage is of either polarity, but single-polarity devices are also available. All of them fail "short" so protection does not fail even if operation does. The series resistors must be large enough to limit surge current to values specified for the protection devices. Selection of the breakdown voltage of the protection devices may depend on the particular situation.

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