Stacking Our Solid State Relays for Higher Switching Voltages

INTRODUCTION

Vishay solid state relays (SSRs) are capable of high-voltage switching (presently up to 400 V) in packages as small as a 6 pin DIP. Higher switching voltages can be achieved when relays are wired in series (stacked). By adhering to the following recommendations, SSRs can easily be stacked to achieve switching capabilities into the thousands of volts range.

STACKING RELAYS

Electrical parameters that must be considered when stacking relays are on-resistance, load voltage, and load current. On-resistance of the stacked relay becomes the sum of the individual on-resistance of each relay. Likewise, total load voltage or standoff voltage becomes the sum of the individual load voltages. It is usually more prudent to choose relays with equivalent load voltages because the relays will equally block the applied voltage. Maximum load current becomes the lowest rated load current of the stacked relays. The primary design concern with stacked relays is maintaining load voltage during switching.
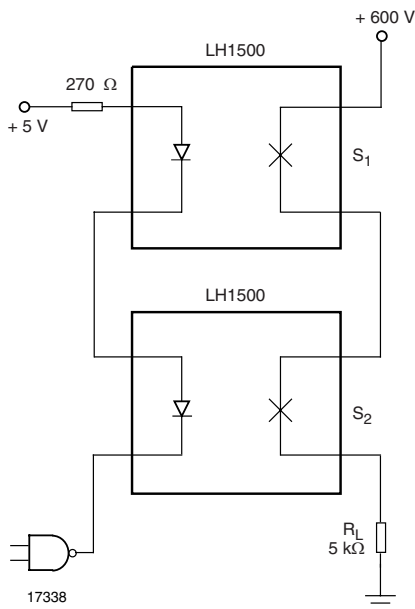

Fig. 1 - High-Side Driver

VOLTAGE SHARING

Figure 1 shows two LH1500 relays in a high-side driver configuration. The input LEDs are wired in series to obtain simultaneous control from the logic gate. The LH1500 relay has a rated load voltage of 350 V, and when two are stacked, they have the potential of switching 700 V.

Figure 2 (A) depicts a simple electrical model of the relays in the off-state condition. The 380 V zener diodes represent the avalanche breakdown value of the switches. Compared to the GΩ impedances of the off MOSFET switches, the voltage drop across R_L is insignificant, and each switch will equally stand-off 300 V. Figure 2 (B) shows a simple electrical model with both relays on. Each relay drops 2.4 V, and the remaining 595.2 V is passed on to the load.
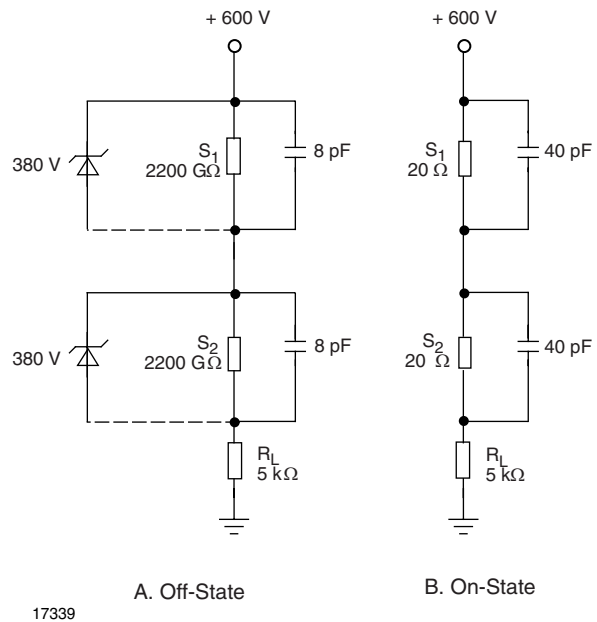

A. Off-State   B. On-State

Fig. 2 - Simple Output Model of High-Side Driver

SWITCHING

The stacked relay models in figure 3 will function properly if switches S_1 and S_2 turn on and off simultaneously; in actuality, this would be an optimum case. Even though Vishay SSRs exhibit a tight t_{on} and t_{off} distribution, individual SSRs and even the two poles of a DPST (2 form A) will still exhibit distinct t_{on}/t_{off} times that need to be considered. Differences in t_{on} and t_{off} and can be minimized (but not entirely eliminated) by increasing the LED drive current to 10 mA or 20 mA.

An extreme case of t_{on} or t_{off} mismatch would be where S1 actually turns on before S2 (figure 3). If this occurs, the full 600 V of the power source is applied directly across S2 driving it into avalanche breakdown.

In this instance, an avalanche current of 120 mA could flow, possibly destroying the switch if applied for any lengthy duration. In practice, the delta of turn-on and turn-off times will fall somewhere between the optimum and extreme cases, mandating some form of external conditioning.
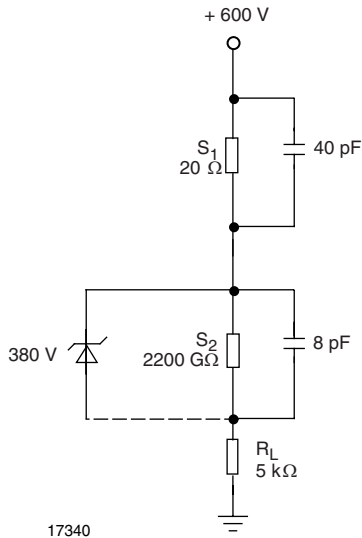

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Fig. 3 - Simple Output Model of High-Side Driver
with Mismatched t_{ON}

RC SNUBBER

One way to keep SSRs from avalanching during switching is to place a simple RC snubber across each switch output (figure 4). The RC snubber network will provide dynamic voltage sharing during switching.
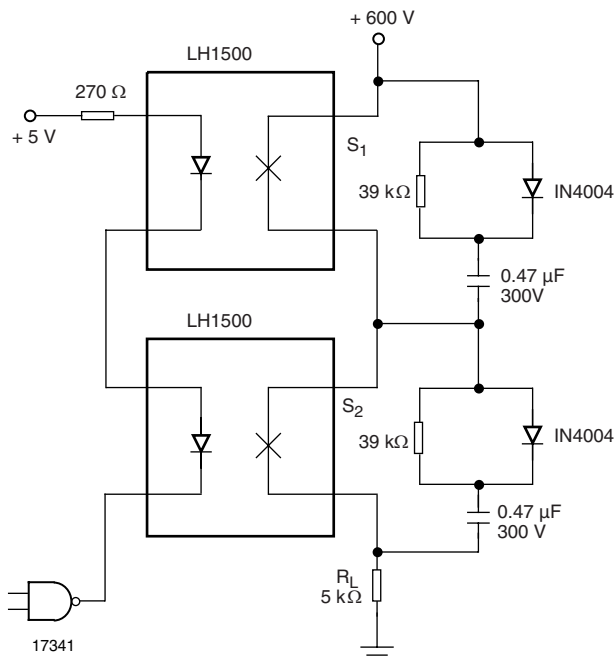

Fig. 4 - High-Side Driver with RC Snubber

During relay turn-off, a charging path is set up from the power source through the two diodes and capacitors and returning through the load. The minimum RC snubber capacitance is governed by the equation:

$$C_{(min.)} = I_L tf / 2V_L \qquad (1)$$

where I_L is the load current determined by the power source and the load, t_f is the time it takes for the load voltage to drop from power source potential to ground (assumes the fall times for both relays are nearly equivalent), and V_L is the load voltage of one relay (assumes two relays with equal load voltage rating). If the fall times are not equivalent, another factor should be added to the equation:

$$C_{(min.)} = I_L tf + 2I_L \Delta t_{OFF} / 2V_L \qquad (2)$$

This equation assumes that one relay turns off before the other, thus allowing twice the charging current to that relay's snubber capacitor until the other relay turns off.

During relay turn-on, the capacitor discharges through the relay and the snubber resistor. The load voltage pulse shape can be manipulated by the snubber resistor value.

A snubber solution is tailored for specific switching conditions, and capacitor values can be selected to operate SSRs up to their maximum load voltage rating. In the event of a high-voltage transient from another source, the SSRs would still be in jeopardy of avalanche breakdown. Also note that the load will be subjected to positive transients that feed through the snubber network capacitance. Component sizing is also a consideration; with the relatively slow switching speeds of the SSR, snubber capacitance values become fairly large. These high values coupled with a high working voltage equate to a rather substantial capacitor.

VOLTAGE SUPPRESSION

Another method of preventing the SSRs from avalanching is to place a metal oxide varistor (MOV) across the outputs of the relay. A properly selected MOV suppression device will keep the relay from ever exceeding avalanche breakdown. MOV selection is very critical. The maximum standoff voltage of the stacked relay now becomes the sum of the MOV's maximum continuous voltage rating. If the MOV continuous rating is exceeded, the MOVs could conduct substantial current when the stacked relay is supposed to be off, creating an undesirable leaky operation and eventual MOV destruction. Also be sure that under worst-case conditions the SSR load voltage is not compromised.

Referring to figure 5, to achieve the original 600 V target, each MOV must be rated for 300 V DC continuous voltage or greater. A V230LA4 MOV (Harris Corp or equivalent) meets these qualifications. Its varistor voltage at 1 mA ranges from 324 V to 396 V. To use this MOV, the load voltage of the individual relays needs to increase to 400 V. Notice the LH1500 relays that were originally used with a 350 V load voltage rating have been replaced with the LH1535 relays that are rated at 400 V.
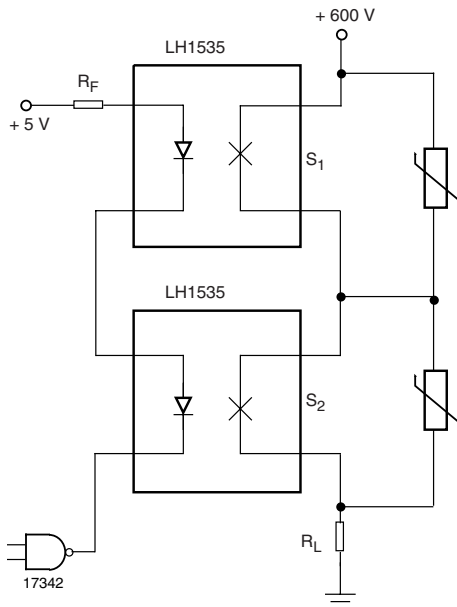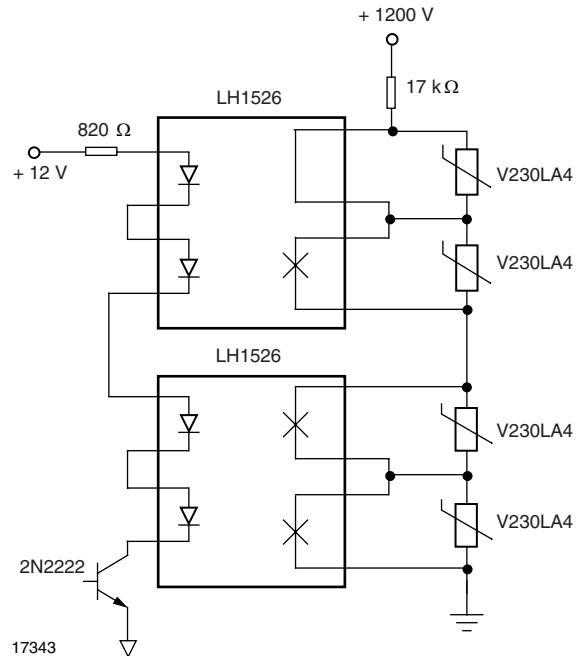
Fig. 5 - High-Side Driver with MOV Protection

To protect against high-current transients that could drive the MOV to even higher varistor clamp voltages, a third SSR may be required. In this case, perhaps a more attractive alternative would be to use a solid state suppression device. Solid state suppression devices exhibit lower clamp voltage ratio values than MOVs. The P3300AA61 *SIDACtor* from TECCOR Corp. has a break over voltage of 330 V. This part allows 300 V continuous voltage without exceeding the 350 V load voltage rating of the LH1500, even under high-surge current conditions.

Applying this information, it is very easy to see how a 1200 V relay can be constructed using two LH1526 400 V relays. By stacking the outputs of these two relays and using four V230LA4 MOVs (capable of DC operation up to 300 V) for dynamic voltage sharing and protection, we achieve a relay capable of switching 1200 V and 70 mA (see figure 6). Similarly, even higher voltage and current relays can be created by stacking the desired type and appropriate number of relays.

Fig. 6 - A 1200 V Low-Side Driver

REFERENCE:

Switching Very High Values of Blocking Voltage, Miro Glogolja and John Kerr, Vishay.