Voltage Multipliers, Inc.

Application Note AN-0100
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Using a VMI Opto-coupler in Conjunction with High Voltage Relays

Background

This application is for use in a scanning electron microscope, which has different operating modes. In one mode, a large negative voltage (nominally –10kV) must be applied to an electrode. In the other mode, a small voltage must be applied, but with a high current capability. In both cases, the voltage must be very precise and low-noise. But the concept can be applied to any configuration where a relay is used to switch between sources that involve high voltage.

The circuit in Figure 1 shows a pair of SPST high voltage relays used to switch between one of two sources and an output load represented by R1 and C1.

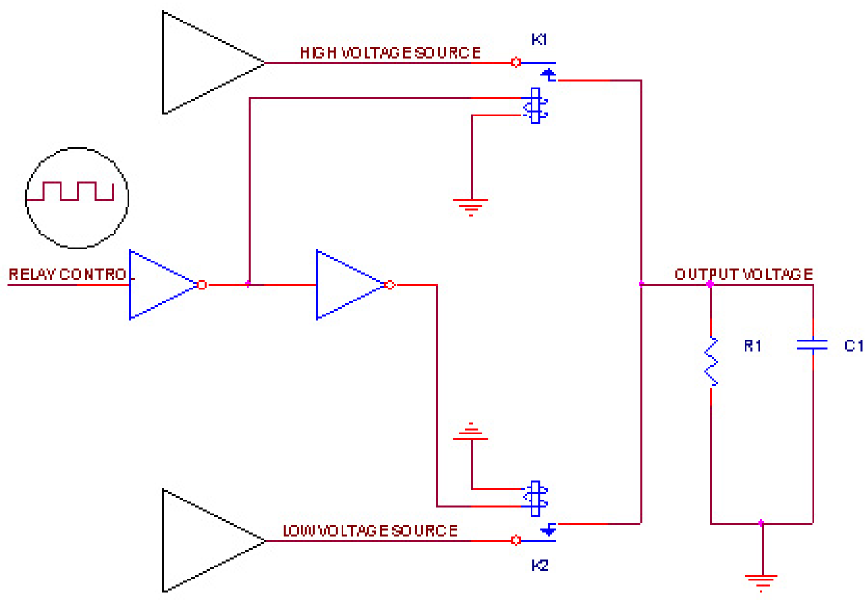

Figure 1: Switching using relays only

The relays used are special-purpose high-voltage relays, designed to hold off at least 20 kV, and with mechanical switching lifetime in the millions of cycles.

Although adequate for switching low voltages, this circuit is unreliable for high voltages because relays are “hot switched” i.e. contacts are opened and closed with voltage across them, and with current flowing through them. This leads to arcing between relay contacts during switching, greatly degrading them. Under these conditions the relays can fail after only a small number of cycles. In our configuration, failure occurred after about 100 cycles.

The switching current can be reduced by adding series resistors, which limit the inrush current during switching, and which are then shorted out (using another high voltage relay) after switching is complete. This prolongs the life of the relays by reducing the current during switching. This can prolong the relay lifetime to some tens of thousands of cycles. However, as the relays are still switched with voltage across them, they do still fail after time.

In order to achieve the performance and reliability required, the design discussed below uses a combination of high voltage relays and high voltage optocoupler solid-state relays.

Optocoupler Solid State Relays

The VMI (Voltage Multipliers, Inc.) OC-250 solid state relay consists of a stack of reverse-biased photodiodes that can withstand very high (absolute maximum 25kV) reverse bias, in a package that includes a set of light-emitting diodes (LEDs).

The diagram in Figure 2 below shows the circuit symbol for the OC-250.

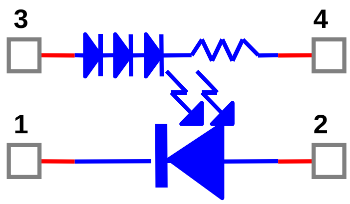

Figure 2: Representation of OC250 optocoupler solid state relay.

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In normal operation, the OC-250 is connected up with the more positive high-voltage potential connected to pin 1, and the more negative to pin 2. With no current through the LEDs, the typical dark-current reverse leakage from pin 1 to pin 2 is 250 nA.

When a current is passed through the LEDs, pin 3 to pin 4, the photodiode stack is illuminated and a photocurrent is produced. At an absolute maximum LED current of 100 mA, the typical reverse photocurrent is 100 uA. When fully illuminated, the photodiode also generates a photovoltaic potential of about 14-16 V.

Two OC-250s can be connected in series to make a high-voltage switch, as in Figure 3 below. With ISO1 switched on and ISO2 switched off, the output voltage will be at approximately V_{HV}.

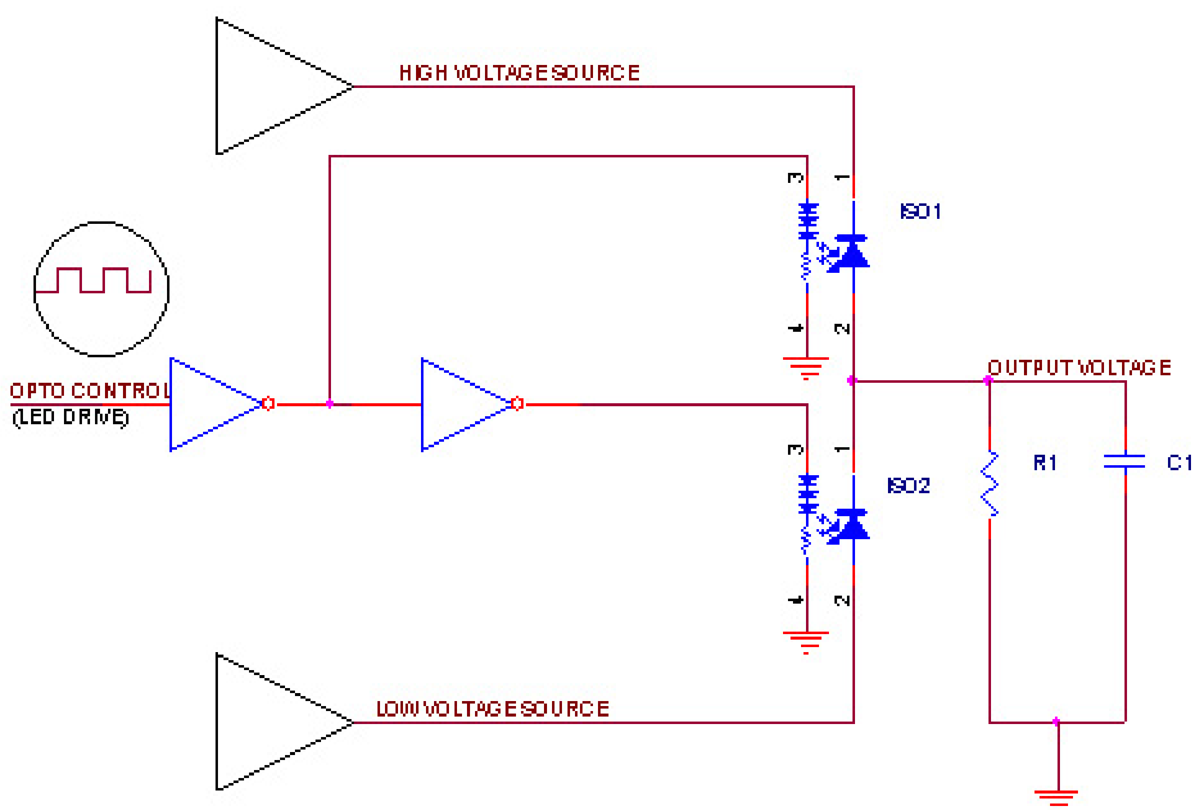

Figure 3: Switching using OC250 optocoupler solid state relays

When ISO1 switches off and ISO2 switches on, the capacitor will discharge through ISO2 with a current I_{IsoOn} of about 100 mA, plus the current through R1.

If the load capacitance is C1, then the discharge time will be somewhat less than ($[V_{LV} - V_{HV}]*C1)/ I_{IsoOn}$, due to the additional discharge current through R1. After discharge is complete the output voltage will be approximately equal to the low voltage source.

When ISO2 switches off and ISO1 switches on, the output voltage will ramp towards V_{HV} again. Because the 100 mA from ISO1 has to both charge up the capacitor C1 and provide the leakage current through R1, the time in this direction will be longer.

This scheme using the OC-250 devices has two major drawbacks:

- The OC-250 photodiodes exhibit a photovoltaic effect when illuminated, which will generate an offset voltage of 14-16 volts

- The OC-250 will only conduct up to 100 mA. This is insufficient to meet many requirements for which a relay is used

For these reasons, the OC-250 solid state relays cannot be used on their own. However, they can be used in conjunction with regular high voltage relays, in such a way that the two problems above are corrected, and the hot-switching reliability problems of the regular relays are eliminated.

Combined Opto- and Mechanical Relays

Figure 4 below shows a variation on the above switch, using OC-250s in conjunction with mechanical relays.

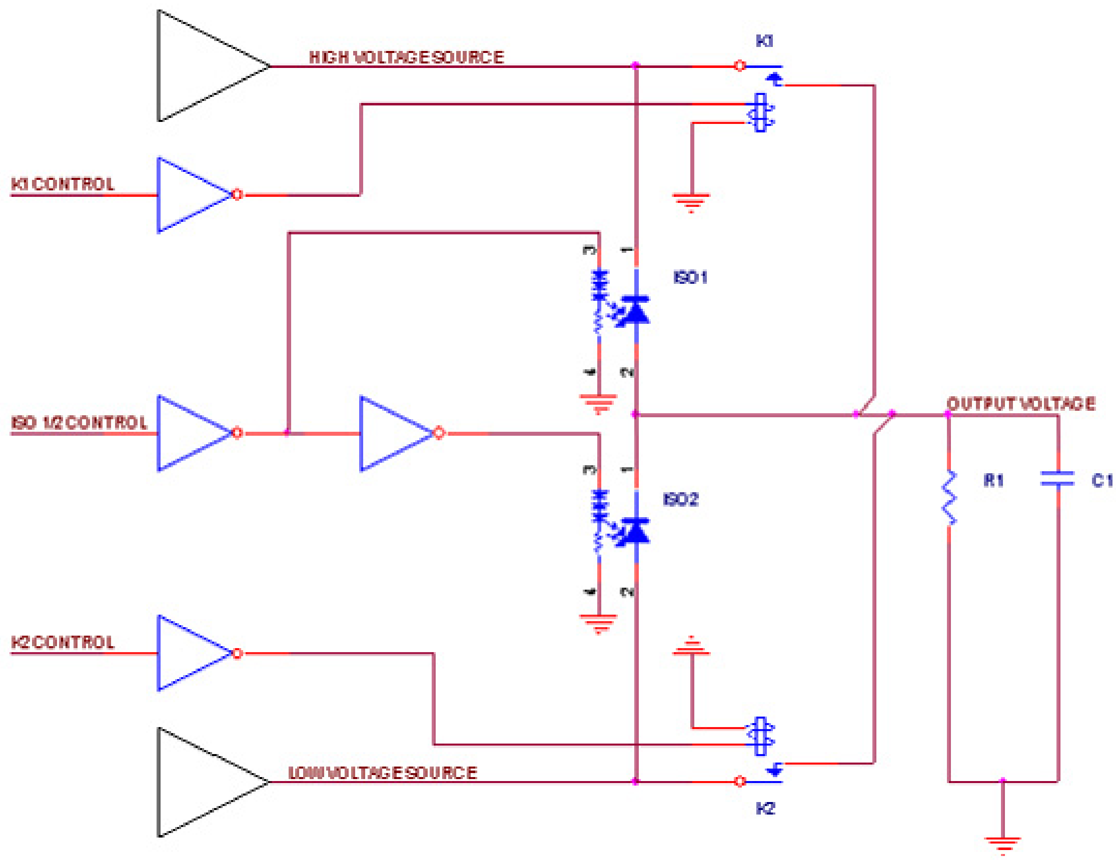

Figure 4: Switching using relays and opto-couplers

Here the sequence is:

From high voltage to low voltage:

Initial state: ISO1 on; ISO2 off; relay K1 closed; relay K2 open; output at HV.

1. Open K1. (At this point, no voltage across K1 contacts as ISO1 is on. So the relay is not hot-switched).

2. Toggle ISO1/2 control, to open ISO1, close ISO2.

3. Wait time T1 for C1 to discharge.

4. Close K2. (At this point, no voltage across K2 contacts as ISO2 is on. So this is not a hot-switch).

From low voltage to high voltage -

Initial state: ISO1 off; ISO2 on; relay K1 open; relay K2 closed; output at low voltage (stage bias)

1. Open K2. (At this point, no voltage across K2 contacts as ISO2 is on. So this is not a hot-switch).
2. Toggle ISO2/4 control, to open ISO2, close ISO1
3. Wait time T2 for C1 to charge
4. Close K1. (At this point, no voltage across K1 contacts as ISO1 is on. So not a hot-switch).

Note that this scheme addresses the individual problems with opto- relays and mechanical relays:

- The mechanical relays that switch between high voltages operate in SPST mode.

- The mechanical relays switch only with no voltage between contacts, i.e. they do not hot-switch. This greatly extends the lifetime of the relays.

- The mechanical relays are in parallel with the opto relays. They thus remove the photovoltaic offset.

- The mechanical relays are in parallel with the opto relays. They thus allow for a high current connection rather than the 100 mA limit of the OC250 devices.

Because of the time delays involved, the sequencing of the relays is critical. This is performed by simple state-machine logic, using a low-frequency clock to attain the time delays required. ❖

About the Authors