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Common Challenges in Voltage Switching

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Designing an automated test system's switching demands an understanding of the signals to be switched and the test to be performed. For example, the most appropriate switch cards and techniques to use in applications that entail switching voltage signals will depend on the magnitude and impedance of the voltages involved.

Mid-Range Voltage Switching

Mid-range applications (1V to 200V) often involve switching a voltmeter or voltage source to multiple devices, such as testing batteries, electrochemical cells, circuit assemblies, thermocouples, etc. Switching multiple sources and switching multiple loads each have their own sets of associated problems.

Switching a Voltmeter to Multiple Sources in Series

Figure 1 illustrates switching a voltmeter to a series string of 30 voltage sources (VS). To avoid short-circuiting one or more of them, always open a given channel before closing a second one (break-before-make operation). Also, add fuses in series with each voltage source and avoid exceeding the card's common-mode rating. In this example, each source is 12V and the total voltage across the string is 360V. A channel-to-channel voltage rating and a common-mode voltage rating of at least 500V is desirable.

Switching a Voltage Source to Multiple Loads

Figure 2 shows a single voltage source connected to multiple loads. If two or more loads are connected to the source, the voltage at each load may be less than expected due to current flow through the common impedances (R), such as the test leads and trace resistance. As additional loads are connected, the total current will increase, thereby increasing the voltage drop across the common impedances (R).

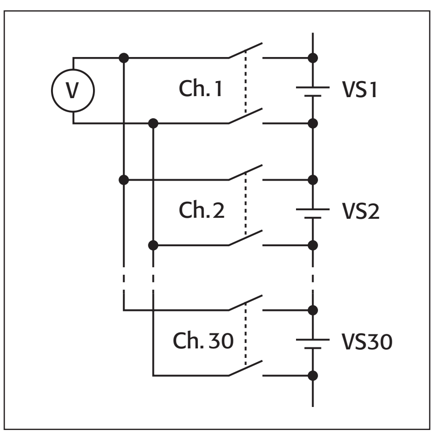

Figure 1. Switching a voltmeter to multiple sources in series.

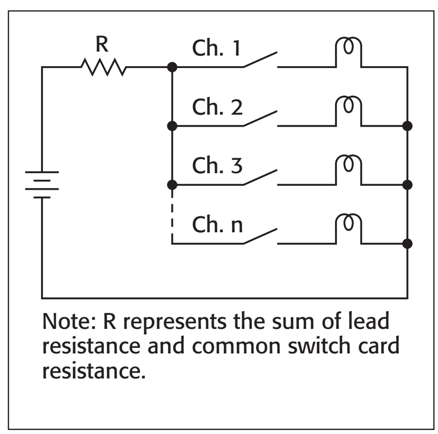

Figure 2. Switching a voltage source to multiple loads.

Switch Resistance

When switching a voltage source to multiple devices, it may become necessary to compensate for voltage drops due to switch resistance. In particular, if the devices have low resistance, the current flowing through the switches may cause a significant voltage drop. Remote sensing, in which external sense connections are made across the load, can help correct for any voltage drops in switches and wiring.

Low Voltage Switching

Special techniques can help prevent voltage errors when switching signals of millivolts or less. These errors may be due to thermoelectric offset voltage in the card and connecting cabling, switch film contamination, magnetic interference, or ground loops.

Thermoelectric Offset Voltage

A low voltage card's key specification is its contact potential or thermoelectric offset voltage. Thermoelectric voltage is the voltage generated by thermal differences at the junction of dissimilar metals, such as between the nickel-iron reed relays and the copper conductor to which they are connected. The temperature gradient is typically caused by the power dissipated by the energized coil. The offset voltage adds directly to the signal voltage and can be modeled as an unwanted voltage source in series with the intended signal. The offset voltage will cause an error in the applied stimulus to a device under test (DUT) or the value measured by the voltmeter.

Several factors can affect a card's level of drift due to thermoelectric voltage, including the type of relays used (reed, solid-state, or electromechanical), the coil drive technique (latching or non-latching), and the material used for the contact plating (for example, nickel alloy or gold).

The power dissipated in the coil of the reed relay may cause the temperature to increase for several minutes after it is energized, so it is important to make low voltage measurements within a few seconds after contact closure. If many measurements are taken over several minutes after closure, a steadily increasing thermoelectric voltage will be added to the reading. Thermal time constants may range from seconds to hours. Even though solid-state relays have no coil dissipation, heat generated by internal IR drops can still produce thermoelectric drift. Latching relays use a pulse of current to actuate them, so they have very low thermoelectric drift.

The connections to the card represent another source of thermally generated voltages. Wherever possible, make connections to the card with untinned copper wire, and keep all leads at the same temperature. The offset voltage may be compensated for by using a short-circuited channel to establish a zero reference. However, this approach isn't ideal because the offset will change over time due to self-heating and ambient temperature changes.

When switching low voltages while making low resistance measurements, the thermoelectric offset voltages may be canceled by using offset compensation, which requires making two voltage measurements with two different values of current. To determine the resistance, the difference between the two resulting voltages is divided by the difference of the two test currents:

$$R = \frac{V_1 - V_2}{I_1 - I_2}$$

Switch Film Contamination

Over time, a contaminating film can form on the surface of a relay contact, increasing its resistance, which can make the switched voltages erratic when measuring or sourcing low voltage. Voltages >100mV are usually sufficient to clear this contamination. Using scanner cards with solid-state switches can help prevent this problem.

Magnetic Interference

A high rate of change in magnetic flux, such as that produced by a switching power supply or by switching a high current signal on and off, can induce a pulse of many microvolts in an adjacent low voltage circuit, causing significant error. Magnetic interference can be minimized by separating the noise source and the sensitive circuit as much as possible, by magnetic shielding, using shielded twisted pair cable and by reducing the enclosed area of the noise source and signal conductors.

Ground Loops

If a small potential difference exists between two ground points, some ground currents may flow through a sensitive part of the system. This might occur only when certain switches are closed, complicating diagnosis. Whenever possible, maintain a single system ground point. When this isn't possible, isolation techniques using optical coupling or balanced transformers can increase the effective resistance between the two points, reducing the common ground current to a negligible level.

High Voltage Switching

Applications like testing the insulation resistance of cables and printed circuit boards or high-pot testing often require switching high voltages. To avoid card damage, exercise caution when switching voltages of ~200V or higher by choosing a card rated for the desired voltage and power levels, such as the Keithley Model 3720 Dual 1×30 Multiplexer Card for the Model 3706 System Switch/Multimeter (***Figure 3***), and appropriately rated cables. Cold switching, if feasible, will extend relay life and permit increasing the allowable current.

Reactive loads can cause excessive current and voltage transients, so current surge limiting for capacitive loads and voltage clamping for inductive loads are required to prevent damage to the relays and external circuitry.

High Impedance Voltage Switching

High impedance voltage switching may be necessary in applications like monitoring electrochemical cells and measuring semiconductor resistivity. Switching and measuring voltage sources with high internal impedance is subject to errors like offset currents, stray leakage paths, and electrostatic interference. Shunt capacitance may increase the settling time.

When choosing a card to switch high impedance voltage, ensure the card has a low

Figure 3. Keithley Model 3706 System Switch/Multimeter.

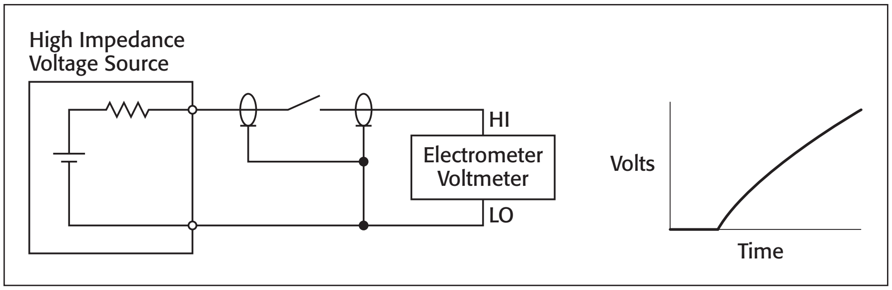

Figure 4a. Switching a high impedance voltage source to an electrometer.

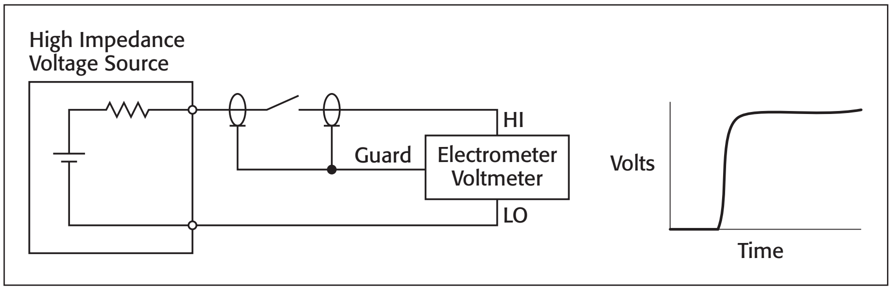

Figure 4b. Using a driven guard to neutralize shunt capacitance.

Figure 5. Keithley Model 7001 Switch Mainframe.

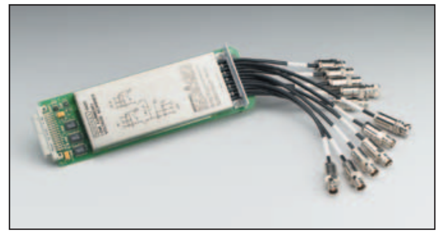

Figure 6. Switch card for the Keithley Model 6517B Electrometer/High Resistance Meter.

offset current. Any offset current flowing through a high impedance device will cause an unwanted voltage to appear across the device, adding to the voltage measurement.

High impedance circuitry is susceptible to electrostatic interference, so both the DUT and the connecting cables should be well shielded to prevent noise pickup.

Leakage paths in the instrument, switch cards, cables, and fixtures can cause errors by reducing the measured voltage. Choose a card with high isolation resistance, use guarding wherever possible, and select insulators with the highest possible insulation resistance.

Response time is another concern when switching high impedance voltage signals. Excessive response time may be caused by shunt capacitance in both the switch and the associated cables. In some cases, the shunt capacitance can be largely neutralized by using a driven guard, which will keep the cable's shield at nearly the same potential as its center conductor (or high impedance lead). ***Figure 4a*** shows a high impedance voltage connected through a switch to an electrometer voltmeter. Note the slow response to a step function. To guard the signal, make a connection between the guard output (unity gain or preamp output) of the electrometer and the shield of the card, as shown in ***Figure 4b***. Some electrometers, such as Keithley's Model 6517B, can make this connection internally by enabling the internal guard connection. Enabling the guard effectively reduces the cable and switch capacitance, thereby improving the electrometer's response time.

A card with triax connections is necessary to ensure safety if the guard voltage could exceed 30VDC. Cards appropriate for high impedance voltage switching include Keithley's Model 7158 for the Series 7000 switch mainframes (***Figure 5***) and Model 6522 for the Model 6517B Electrometer (***Figure 6***).

Conclusion

To learn more about voltage switching in automated test systems, download a free copy of Keithley's *Switching Handbook* at http://www.keithley.com/knowlegecenter.

About the Author

Dale Cigoy is a Senior Application Engineer at Keithley Instruments in Cleveland, OH. With 25 years of experience in instrument applications, his major responsibility is helping customers with electrical measurements that include Keithley equipment. Prior to this he wrote technical instruction manuals for Keithley products. Cigoy joined Keithley in 1976 after earning a Bachelor of Science degree in Electronic Technology from Capitol College in Laurel, MD.

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