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Switch Systems for Aerospace and Defense Testing

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A switching system can be as simple as the Keithley Model 7999-4 SPDT Microwave switch (a) or as large as one based on the Model 7002 ten-slot mainframe (b).

Testing for state-of-the-art systems requires choosing the appropriate switching systems and applying them correctly.

DEFENSE and aerospace electronic systems cover an enormous range, from active devices, such as radio frequency integrated circuits (RFICs) and microwave monolithic integrated circuits (MMICs), to remote sensing devices, to complete space communication systems. All of these require extensive testing at all stages of development and production with testing requirements that cover an equally broad range: DC measurements from femtoamperes to amperes, and from nanovolts to kilovolts, and RF/microwave measurements from a few MHz to beyond 40GHz.

Despite this variety, tests in all these areas share one important characteristic: Automation can make them faster and more repeatable and help to reduce operator error. An essential part of automated testing is a switching system, which routes signals between measurement instruments and the device under test (DUT). Multiple tests with different instruments can be run on the same DUT or multiple instruments can test multiple DUTs. For example, in ***Figure 1*** a switching system makes it possible to test a large number of tactical radios undergoing burn-in in an environmental chamber. This article will briefly discuss several important aspects of configuring a switch system.

Configuration of a switch system

Switch systems can be simple or elaborate. For example, a single-pole, double-throw (SPDT) switch can be used to route signals to two different DUTs, as shown in ***Figure 2a***. It can be expanded further into a "multiplexer" configuration, so that a single instrument can be routed to many different

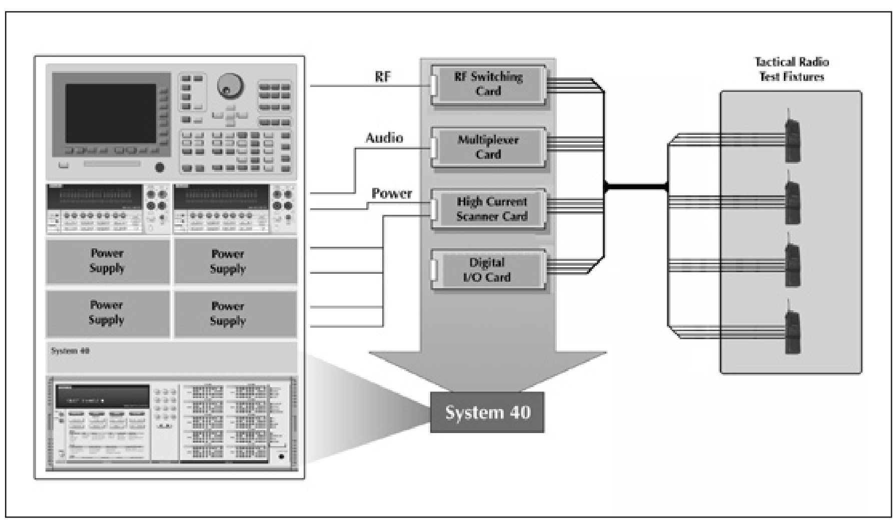

Figure 1: In a typical lifetime test, the DUT (here a handheld tactical radio) can be stressed at an elevated level for a specified period, then its electrical characteristics can be measured.

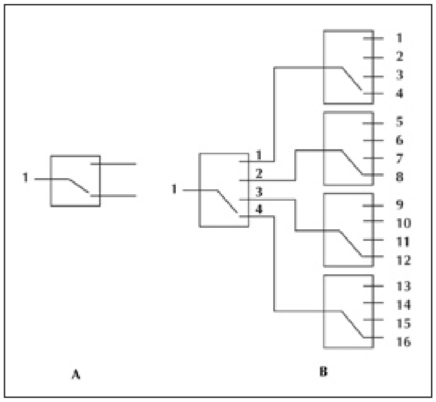

Figure 2: (a) A single-pole, double-throw (SPDT) switch can be used to route signals to two different DUTs. (b) This can be expanded into a "multiplexer" configuration, so that a single instrument can be routed to many different DUTs, as in this 1x16 multiplexer. Both of these use a "blocking" arrangement, in which only one signal path is active at any given time.

DUTs. ***Figure 2b*** shows a 1×16 multiplexer; like the SPDT switch, it's a so-called "blocking" arrangement in which only one signal path is active at any given time. A switch system can also connect multiple instruments to multiple DUTs in a "matrix", like the 4×4 blocking matrix in ***Figure 3***. It is also possible to close multiple paths if needed (to apply continuous bias voltage to a number of DUTs, for example), although this is practical only in DC testing—impedance considerations preclude it in RF testing.

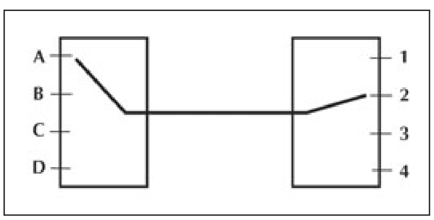

Figure 3: A blocking matrix, like this 4X4 arrangement, can switch only one signal to only one DUT at any time.

In order to switch any signal to any DUT at any time, a "nonblocking" matrix, like the 4×4 shown in ***Figure 4***, can be used. While this configuration has the highest flexibility, it increases the cost of the switching system by a considerable amount.

Signal conditioning

Many tests require more components than just switches. For example, testing receiving equipment involves switching gain and attenuation in and out to simulate varying receiving ranges and multipath effects. This means adding both active components, like amplifiers, and passive components, like attenuators, splitters/combiners, circulators, and directional couplers, to the test setup (***Figure 5***). Rather than connecting these components externally with a patchwork of cables, it's often preferable to include them within the chassis of the switching system. Not only is this a more orderly arrangement, it will give more consistent and repeatable results than an ad hoc setup.

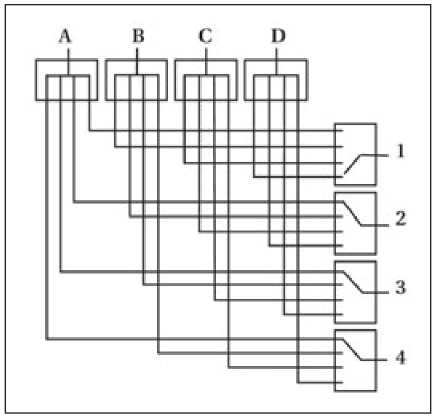

Figure 4: A nonblocking matrix makes it possible to switch any signal to any DUT at any time. While this configuration has the highest flexibility, it's also the most expensive.

Electrical specifications for RF and microwave switching systems

Bandwidth—Most switch system users would like to have as wide and as flat a bandwidth switch as possible. However, if the equipment to be tested involves no frequencies higher than 18GHz, it's a waste of money to use a 40GHz switch. It's also important to remember that as bandwidth increases, the selection of connectors and cables becomes more important.

Insertion Loss—Any component added to the signal path will cause some degree of loss. This loss is especially severe at higher or resonant frequencies. When signal level is low or noise is high, insertion loss is particularly important.

Voltage Standing Wave Ratio (VSWR)—Any mismatched impedances in the signal path (***Figure 6***) will increase VSWR. For optimal signal transfer, everything in the signal path—the source, the switch, the DUT, and any terminations used—should have the same impedance. Impedance "lumps" in the signal path can produce frequency-dependent signal strength variations, and by presenting complex loads they may degrade the stability of some DUTs. In high power systems, high VSWR can even lead to equipment damage.

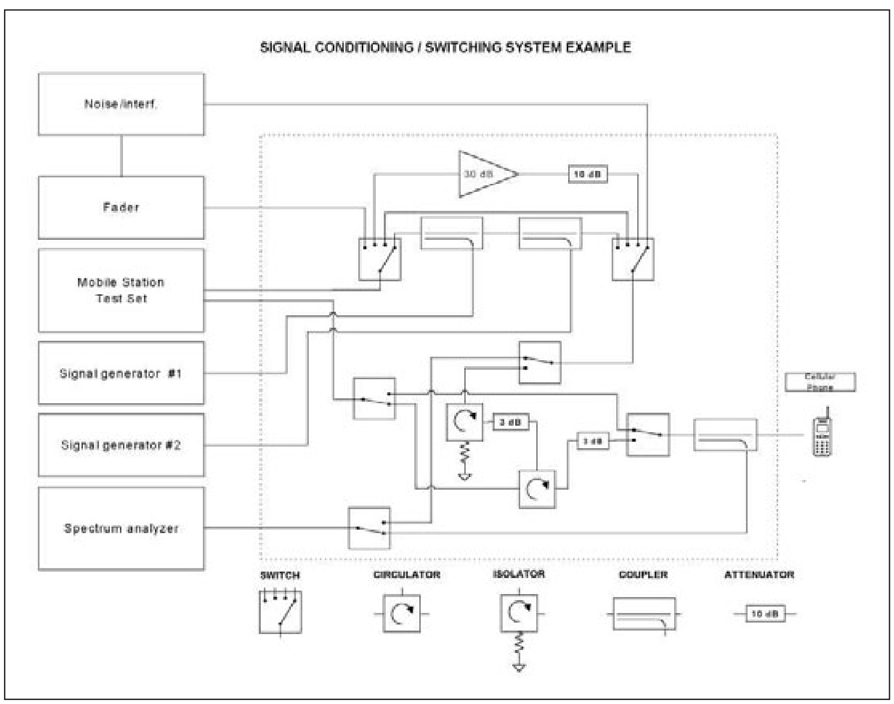

Figure 5: It's often preferable to include active components like amplifiers, and passive components, like attenuators, splitters/combiners, circulators, and directional couplers, within the chassis of the switching system, rather than connecting these components externally with a patchwork of cables.

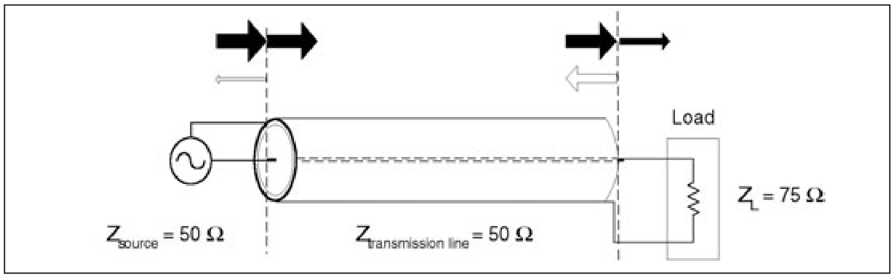

Figure 6: The impedance mismatch between the load and the cable result in a VSWR of 1.50:1, or a return loss of 14 dB. For 50W forward power, 2W of power is reflected back to the source.

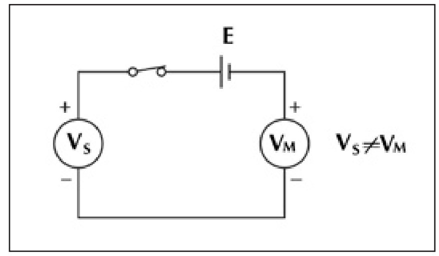

Figure 7: Temperature differences among the different parts of the signal path can introduce voltages through the Seebeck effect.

Power Handling Capacity—When testing RF power equipment, it's important to keep in mind the maximum power-handling rating of the switch—and to remember that high VSWR can significantly degrade it.

Path Isolation—At higher frequencies, signals traveling on different paths can interfere with each other due to capacitive coupling between the paths or through electromagnetic radiation. Sometimes referred to as "crosstalk", it's especially severe when signal paths are not properly shielded or decoupled from each other. Crosstalk is particularly problematic when a weak signal is physically adjacent to a very strong signal.

Phase Distortion—As a test system expands in size, signals from the same source may travel to the DUT via different paths of different lengths and different propagation delays. In digital testing where differential signal testing is key, the resulting phase shift may cause errors.

Reliability and Repeatability—An electromechanical switch relay should provide a lifetime of at least one million closures; some electromechanical relays offer rated lifetimes of five million closures or more. Repeatability is the measure of the changes in the insertion loss or phase change from repeated use of the switch system. In RF measurement, it's not easy to eliminate the effects from the cycle-to-cycle change in the switch relay closure.

DC switching

Considerations in the design of a DC switching system vary with the levels of signals to be switched. Low-level switching considerations are about accuracy, much of it having to do with offset voltages or currents. High-level switching considerations are mostly about preventing damage to equipment or hazards to personnel. We will look at low-level switching first.

Low voltage switching

When switching DC signals ranging from millivolts down to nanovolts, there are many potential sources of error.

Thermoelectric (contact) potentials—Temperature differences among the different parts of the signal path can introduce voltages through the Seebeck effect (***Figure** 7*). Methods for minimizing this problem include careful selection of materials, control of temperature differentials, and use of 2-pole differential switching (***Figure 8***). As shown in ***Figure 9***, any potential difference due to the junction of wires to switch in the hot side of the circuit will be cancelled by an equivalent contact potential in the return side. Contact potentials among switching cards can vary from less than 500nV to more than 100 microvolts, so be sure to choose one that matches your needs.

Switch film contamination—Over time, a contaminating film can form on the surface of a relay contact, increasing its contact resistance and introducing erratic errors when working with low voltages. This problem is most troublesome with voltages less than 100mV; it may be necessary to use solid-state switching to eliminate it. If it is not practical to keep the switched voltage above this level, it may be possible to keep the contacts clean by periodically switching a voltage in excess of 100mV.

Magnetic interference—The act of switching a large current (generally one measured in amps) in one circuit can induce noise pulses in nearby circuits. This effect can be minimized by physical separation, by magnetic shielding, and by the use of twisted pair conductors (if frequencies of interest are below a few hundred kHz). Note that circuits containing reactive loads can experience current surges and spikes sufficient to cause interference, even if the steady-state current is fairly small.

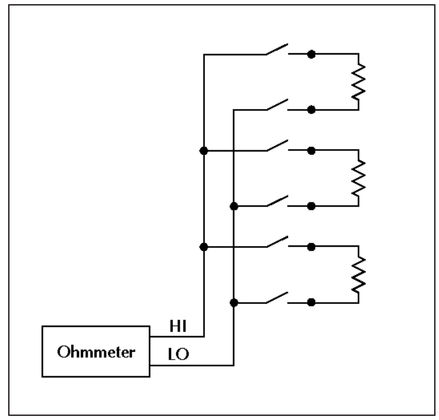

Figure 8: Two-pole differential switching can help to reduce the effects of thermoelectric potentials.

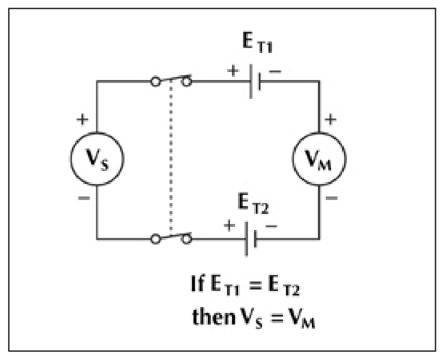

Figure 9: With 2-pole differential switching any potential difference due to the junction of wires to switch in the hot side of the circuit will be cancelled by an equivalent contact potential in the return side.

Ground loops—Ground loops can easily occur in a complex test system. If a small potential difference exists between two ground points, some ground currents may flow through a sensitive part of the system. This may occur only when certain switches are closed, so it can be very difficult to diagnose. When possible, try to maintain a single system ground point. When this is not possible, isolation techniques using optical coupling or balanced transformers may help.

Low current switching

The main problems in switching currents of 1 microamp or less are offset currents, leakage currents, electrostatic interference, triboelectric currents, and electrochemical currents. They may be due to the scanner card itself, the connecting cables, or the test fixturing. Allowing sufficient settling time before making a measurement is also crucial when switching low current.

Offset Currents—Offset current is a spurious current generated by a switching card even though no signals are applied. It is especially significant when measuring low currents where the magnitude of the offset can be comparable to the current being measured. Offset current comes mostly from the finite coil-to-contact impedance of the relays, but it is also contributed to by triboelectric, piezoelectric, and electrochemical effects present on the card. Switching and scanner cards designed to minimize offset current are commercially available.

Leakage Currents—Leakage current is an error current that flows through insulators when a voltage is applied. It can be found on the switch card, in the connecting cables, and in the test fixture. Even high resistance paths between low current conductors and nearby voltage sources can generate significant leakage currents. Use a card with high isolation, guard the associated test fixtures and cables, select proper insulating materials, and clean the circuit boards to reduce these effects.

Electrostatic Interference—High impedance circuitry can pick up radiated noise, which makes shielding necessary. Relay contacts should be shielded from the coil to minimize induced noise from the relay power supply. The DUTs and interconnect cabling should also be shielded to prevent noise pickup. All shields should be connected to circuit LO.

Triboelectric Currents—Triboelectric currents are generated by charges created by friction between a conductor and an insulator, such as in a coaxial cable. This noise source can be reduced by using special low noise cable that has a conductive coating (such as graphite) and securing the interconnect cabling to minimize movement.

ElectrochemicalCurrents—Electrochemical currents are generated by galvanic battery action caused by contamination and humidity. Thorough cleansing of joints and surfaces to remove electrolytic residue, including PC etchants, body salts, and processing chemicals, will minimize the effect of these parasitic batteries.

Settling Time—When a relay opens or closes, there is a charge transfer (on the order of picocoulombs), which causes a current pulse in the circuit. This charge transfer is due to the mechanical release or closure of the contacts, the contact-to-coil capacitance, and the stray capacitance between signal and relay drive lines. After a relay is closed, it's important to allow sufficient settling time before taking a measurement. When currents are very low and impedances are very high, this time can be as long as several seconds.

High voltage switching

Some applications, such as testing insulation resistance of cables and printed circuit boards and high-pot testing, may require switching high voltages. Choose a switch card rated for the desired voltage and power levels. Be sure to use appropriately rated cables when switching high voltages.

Applying a high voltage to a circuit containing appreciable capacitance can create a current spike large enough to weld relay contacts. The usual solution is to put a resistor in series to limit the charging current, as shown in *Figure 10*. The resistor must be able to withstand the applied voltage; otherwise the high voltage may arc across the resistor, damaging the device under test and the switch card. All components must be rated for peak voltage and current. In addition, the resistor value should not be so large as to affect measurement accuracy.

When calculating the resistor value, consider the maximum load in VA. For example, if the maximum load is 10VA and 500V is switched, then the current must be limited to 20mA. The series resistance is then calculated as:

$$R = \frac{500V}{20mA} = 25k\Omega$$

While testing capacitors for leakage and insulation resistance is an obvious example of the situation in *Figure 10*, the capacitance in the circuit may not be a separate component but may be something as subtle as the capacitance of a shielded connecting cable. In this case, the series resistor should be placed as close to the relay as possible to limit the current when charging the cable capacitance.

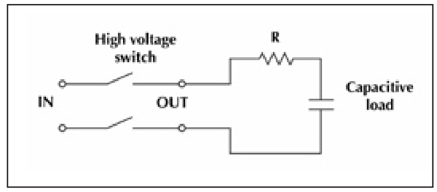

Figure 10: Limiting capacitor charging current with a series resistor.

High current switching

When designing a switching circuit for currents in excess of 1A, pay particular attention to the maximum current, maximum voltage, and VA specifications of the switch card. Also, it's important to choose a switch card with low contact resistance to avoid excessive heating that can cause contact failure by welding the contacts together. Contact heating is caused by I2R power dissipation.

High current switching can be used for either switching a power supply to multiple loads or for switching an ammeter to multiple sources. ***Figure 11*** is an example of switching a power supply to multiple loads using a multiplexer scanner card. In this example, the power supply will output 1A to each of four loads. This doesn't present a problem when only one channel is closed at a time. However, when all four channels are closed, the power supply will output 4A through the common path, which may not be able to tolerate this much current. Unfortunately, the maximum allowed current on the common is not usually specified for a switch card, but the limitation is usually a function of the trace width and connector ratings. One way to avoid this problem is to use a switch card with independent (isolated) relays and connect with wires rated to carry the total current.

When currents that exceed the card ratings must be switched, a general-purpose

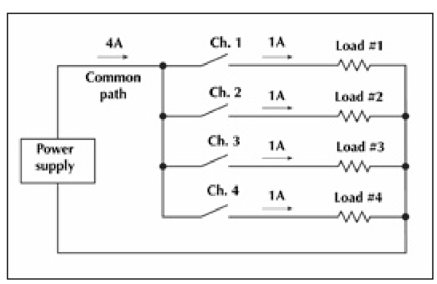

Figure 11: Switching a power supply to multiple loads.

switch card can be used to control external high current relays, contactors, or solid-state relays. Under no circumstances should unlimited power (direct from the power line) ever be connected directly to a switch card.

When switching high VA loads (power line to motors, pumps, etc.), solid-state relays (SSR) are often used. Available from many sources, these SSR modules can be controlled from TTL-level digital outputs from a board that plugs into a PC or from a scanner mainframe. Some SSR modules can switch up to 1kVA.

Concerns about switching transients with reactive loads also apply to high current switching. When voltage is first applied to an inductive load, the current will increase relatively slowly. However, when the switch is opened, a large inductive voltage spike, L(di/dt), will appear across the switch contacts and may damage the contacts. Any contact bounce that occurs on closure can also produce an inductive spike because the current is interrupted repeatedly. A voltage-clamping device across the inductive load is usually required. ***Figure 12*** shows two typical clamping circuits, one using a diode for clamping DC voltages and the other using back-to-back zener diodes for clamping AC voltages. For best results, the voltage-clamping device should be located near the load. Applications that involve switching inductive loads include testing motors, solenoids, and transformers.

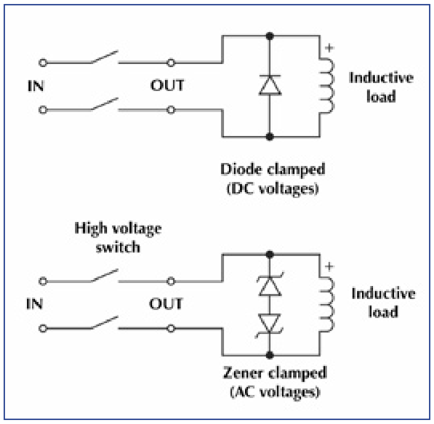

Figure 12: Clamping circuits can limit inductive voltage spikes.

Cold vs. hot switching

One way to prevent problems from switching high voltages and currents is to use so-called "cold switching". In cold switching, a switch is actuated with no applied voltage; no current will flow when the switch closes, and no current will be interrupted when the switch it opens. This increases the life expectancy of the switches (as much as 1000 times the number of cycles with hot switching) and eliminates arcing at the relay contacts and any RFI that it might cause.

Hot switching may be required when the time between power application and measurement must be closely controlled. For example, hot switching is typically used with digital logic because devices may change state if the power is interrupted even for a brief instant.

With relatively large relays, hot switching may be needed to ensure good contact closure. The connection may not be reliable without the "wetting" action of the current through the contacts.

Conclusion

When specifying a switch system, the first step is to consider the system configuration. In order to achieve an optimal, yet cost-effective system, system designers must weigh a variety of electrical and mechanical parameters. Understanding these parameters makes it possible to make informed tradeoffs between switch flexibility and system cost.

About the Authors

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