Designing and Building the Perfect Switching Test System

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Introduction

Is this a familiar scenario: The switches in the test system are perfect. There are no signal losses or leakages. All signals are routed from point to point with no signal degradation.

And yet, the system isn't functioning properly. What happened? The following discussion will help diagnose some of the more common mistakes that are made when configuring switching into a test system, as well as offer some insight into proper design techniques to help avoid switching errors.

Common Sources of Errors

There are a number of common mistakes that designers makes when configuring a switching test system. Most are easy to spot and correct. Below are some that are the most easily recognizable and correctable.

Relay Open – In the ideal open relay or switch, the resistance between the contacts is infinite. In reality, there is always some finite resistance value that has to be taken into consideration. The key is to find the magnitude of the open resistance and to determine if it is going to affect the signal passing through the system. There are many different types of switches, and each of them has a specification for insulation/isolation resistance. Make sure that the specification is for contact-to-contact resistance in the open state. Refer to *Figure 1*.

In general, the higher the resistance in the open state the less effect on the signal. Most relays have open-state resistance specifications of between 1MΩ and 1GΩ, which is usually sufficient for most applications. For example, switching a power supply signal of 5V through a system has little to no effect due to the open-state resistance. This is because normally a power supply has a low internal impedance that the high switch impedance does not affect. ***Table 1*** provides examples of different types of relays with different magnitudes of insulation resistance.

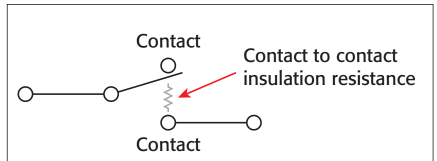

Figure 1. Contact to contact insulation resistance (Open)

Relay Closed – In the ideal closed relay or switch, there is no resistance between the contacts. Switches in the real world, however, have some resistance, however minute. Even superconductors have some resistance, albeit extremely small. Most contacts have resistance on the order of a few milliohms. Each relay type has different specifications for contact resistance. Most new relays have closed-contact resistance below 0.1Ω or 100mΩ. The resistance usually increases with use. Most relays have an end of life specification of about 2Ω. Depending on the relay type, this is after millions of cycles of use. Even at such high resistance, the relays can still function, although they may begin to have a greater impact on the signal passing through the switch. See ***Figure 2***.

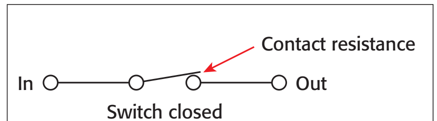

Figure 1. Contact resistance

Channel-to-Channel Isolation – Getting crosstalk and signal leakage from adjacent channels can be a tough problem to troubleshoot. It is easier to start out with

Relay Type	Isolation	Speed	Power	Life at Rated Load
Electromechanical	10^7–10^{10} Ω	20–100 ms	10–100 VA	10^7 cycles
Electromechanical (high frequency)	60–130 dB	20–100 ms	1–120 W	10^6–10^7 cycles (no load)
Contactor	10^6–10^9 Ω	100–250 ms	100–4 kVA	10^5 cycles
Dry Reed	10^9–10^{14} Ω	5–15 ms	10–50 VA	10^7 cycles
Mercury Wetted Reed	10^8–10^{12} Ω	5–10 ms	10–100 VA	10^{10} cycles
Solid State	10^6–10^9 Ω	10–20 ms	1–100 VA	10^{10}–10^{15} cycles

Table 1. Relay types, resistances, and life cycles

the proper design and specifications for the correct switching components than to spend precious time troubleshooting an elusive problem. Channel-to-channel isolation is a measure of the electrical isolation of any two adjacent switches. Normally on a switching or relay card, the channels are aligned in order to facilitate the proper voltage spacing and to accommodate the physical dimensions of the switches and other components, such as connectors. The PCB material and spacing could also allow a certain level of isolation between channels. The higher the isolation, the lower the chance of any cross-talk or leakage between channels.

Typical values of channel-to-channel isolation are up to 10GΩ with capacitance of less than 100pF. Still, contact-to-contact resistance must be taken into consideration when designing any switch system. For example, in high-frequency applications, the capacitance becomes an important consideration. Usually with high frequency applications, the isolation is stated in dB. For instance, 60dB would be an isolation of 1000 to 1 from channel to channel, meaning that 1V on one channel could bleed over and become 1mV on an adjacent channel. The higher the isolation, the better the integrity of the signal passing through the system. Refer to ***Figure 3.***

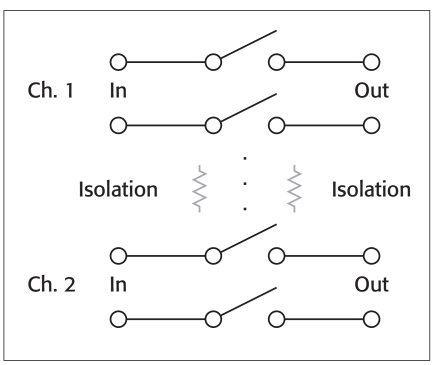

Figure 3. Channel to channel isolation

Relay Settling Time – The settling time is the time it takes for the relay contacts to stop bouncing and make a solid reliable connection. Settling time varies from relay to relay with typical times in the millisecond range. Sometimes relay switching cards have a built-in delay to avoid this phenomenon, while some switching equipment may even have a user programmable delay time.

Some signals take longer to settle, which means that relay contact bounce as well as signal type must be taken into account. If the signal is of extremely high impedance (e.g. very low current), then it may require several seconds or even minutes to settle. The settle time is directly related to the small current charging the cable or stray capacitance in the circuit. The higher the impedance the lower the current and the more time it takes to settle out.

When a relay opens or closes, there is a charge transfer on the order of picoCoulombs that causes a current pulse in the circuit. This charge transfer is due to the mechanical release or closure of the contacts, the contact-to-contact capacitance, and the stray capacitance between signal and relay drive lines. Does the second part of the paragraph relate to the first part? I think they need to be two paragraphs.

Making sure the relay is completely closed and the contacts settled can help ensure the signal will pass with minimal degradation and without added noise that could generate false readings. Some instruments have displays that depict when the relay is closed. However, some relays take several milliseconds to close as the switch bounce settles. This must be taken into account. Look at the relay specifications for typical relay settle times.

Effect of Switching and Associated Cabling on Signal Quality – Each type of signal has some unique unwanted characteristic that can be reduced or eliminated by choosing the appropriate cabling. Not using the appropriate cabling for switching signals could degrade signal quality. In a high-frequency switch system, using a 75Ω coax cable in a 50Ω characteristic impedance system would cause signal reflections and a poor VSWR (Voltage Standing Wave Ratio). Also, using a coax cable in a high magnetic field would help reduce the magnetic field effect, but using shielded twisted-pair cable would be much better. **Table 2** gives some examples of signals and appropriate cables.

Switch Element Lifecycle Implications of Hot vs. Cold Switching and Scanning Rate Strategies – Cold switching is defined as opening and closing the switch when no current is flowing. Using cold switching lengthens the contact life of the switch. The carry current is the maximum current the switch can tolerate once the contacts have been closed and is limited by the cross-sectional area of the path through the switch contacts. Does carry current relate to cold switching? These seem like to different thoughts.

Hot switching is defined as opening and closing the switch when current is flowing or when the signal to be switched is applied. How can current flow when the switch is open? Maybe we need to say "when current is available such as when a power source is on. Depending on the switch specifications and the signal passing through, contact life is usually reduced when using hot switching. Switched current is the maximum current that can be handled reliably while opening and closing contacts. Contact material and plating are the primary factors that determine this specification, which is used to determine the life of the switch. If the switched current is too high, the resulting temperature increase and contact arcing will degrade the relay and shorten contact life. In extreme instances the contacts may weld together. Here, I can see how switching current relates to hot switching. But, is isn't clear how carry current relates to cold switching.

The rate of the repetitive open and close cycles of the switch also has an affect on the life of the switch. If the switch being used cycles ten times a second for 24 hours a day seven days a week, then it will reach end of life fairly quickly. For example, if a relay life specification is 100,000,000 cycles, which is typical, then at this rate it would reach end of life in about four months. Ten times in a second is a medium to slow speed for some

Signal Type	Unique Parameter	Cable Type
High frequency	Impedance match	e.g. 50Ω to 50Ω
Magnetic field	Magnetic flux	Shielded twisted pair
Low current	Triboelectric effect	Low noise cable (graphite on shield braid)
Low current	Leakage currents	Low noise coax or triax with driven guard
Low voltage	Thermal effect	Copper wires
Electrostatic field	Noise	Shielded cable (coax or triax)

Table 2. Signal types and appropriate cables

test systems. Some systems require higher speed and some slower speeds depending on the requirements. So take care when specifying a switch in the test system. Be aware of the switching rate of the system and the life cycle specifications of the relay along with the signals being switched for maximum performance and life of the switches.

Design Tips to Avoid Switching Mistakes

Large RF Matrix is Required – Given the fast growth of the communications industry, a large amount of testing is being performed on the various components that comprise different communication systems. The components range from active components such as RFICs (Radio Frequency Integrated Circuits) to complete communication systems. The main components in an RF test system may include a DC bias source, DC measurement RF power meter, network analyzer, RF sources, and other instruments. Automating the test process and improving test efficiency demands integrating RF/Microwave and low-frequency switching systems into the test system. The RF matrix is one important part of a test system. Typically, an RF matrix type switch system is required when there are multiple pieces of test equipment to be routed to multiple devices. The number of devices to be tested and the number of pieces of test equipment required normally determine the size of the matrix. Initially, this looks like it could lead to a large matrix, but upon further review it may not need to be as large.

There are three types of RF matrices for RF switching. Examining them could lead to a smaller and more efficient matrix.

- *Non-Blocking Matrix* – This matrix allows simultaneous connections of multiple input/output single paths, up to the full number of matrix inputs. This is the most flexible and most expensive matrix. Although it is possible to close multiple paths, this is only practical in DC testing such as applying a continuous bias voltage to a number of DUTs. Impedance considerations preclude closing multiple paths in RF and microwave switching. Given that a switch system is positioned between the measurement instrument and the DUT, matching the impedance levels of all elements in the system is critical. For optimum signal transfer, the output impedance of the source should be equal to characteristic of the switch, cables and the DUT. Proper impedance matching will improve signal integrity. Refer to ***Figure 4***.
- *Blocking Matrix* – This matrix allows the connection of a single input to any single output. Therefore, only one signal path is active at any given time. This is somewhat restrictive, but working with RF and microwave signals, the paths must have impedance matching. Closing several paths at one time could cause reflections and therefore poor VSWRs. This results in loss of signal and power. So a blocking matrix may be restrictive but most of the time it is necessary for signal quality issues. Refer to ***Figure 5***.
- *Full or Partial Matrix* – This matrix allows simultaneous connection of an input to multiple outputs. Switch mainframes would include switching cards where the actual signal switching takes place. Switching cards are normally designed in 1×4 building blocks, meaning one card may have three or four 1×4 switches on them. These can be configured together to obtain a larger matrix, either more row or more columns or both. But the system would require a power divider at each input and a multiple position switch at the outputs. Again, impedance matching is important. The advantage of these configurations includes the absence of unterminated stubs, access to all channels, and similar path characteristics. Disadvantages include the need for extensive cabling and the use of many coaxial relays. See ***Figure 6***.

Using Solid-State Switches for Fast Switching Applications – Standard electromechanical relays can switch from one state to another in as little as a few milliseconds, which is fast enough for some applications. However, in production applications where test time carries a significant dollar value, this switching time may be too long. Solid-state relays (e.g. transistors, FETs) have a much faster switching time, generally below one millisecond. Going from a few milliseconds to a few hundred microseconds could shave off substantial test time and increase test throughput.

Another advantage of solid-state relays is their reliability. Solid-state relays have a switching life of almost 100 times that of electromechanical relays. This would be on the order of about 10 billion switch cycles instead of a good electromechanical relay's life of about 10 million cycles.

One disadvantage is the "on" resistance of solid-state relays, which is on the order of tens of ohms. Such a high resistance could lead to measurement inaccuracies in a two-wire resistance measurement. Trying to measure a few milliohms with upwards of 10Ω of resistance in the circuit from the "on" resistance would effectively bury the low-resistance measurement. One way around this is to use a so-called golden or standard channel. This is a channel with a short on the

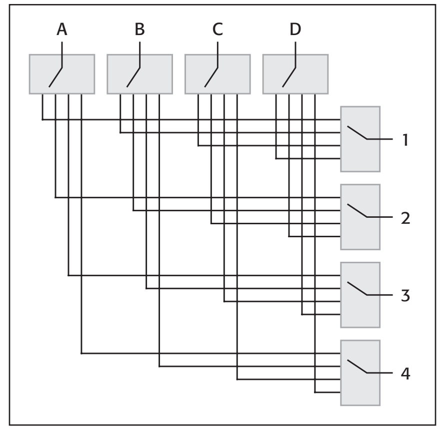

Figure 4. Non-blocking matrix

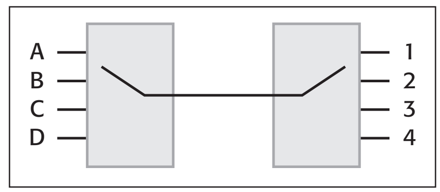

Figure 5. Blocking matrix

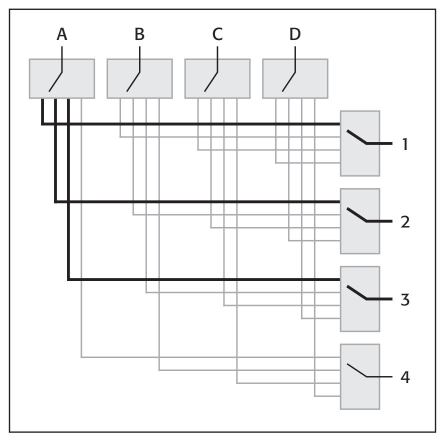

Figure 6. Full access matrix

device side. The channel is closed, the resistance measurement is made, and the measurement is subtracted from all other channels. Therefore, the "on" resistance is essentially zeroed out. The problem is that this holds for only the golden channel and would be slightly different on each channel. Using this method would depend on the magnitude of the resistance to be measured and the accuracy required.

Another method used to correct for this resistance is the four-wire measurement technique, which involves using two channels instead of one. One channel is used to source the current and one to sense the voltage. This is a standard method to measure low resistance. Using an electromechanical or reed relay would only have a contact resistance of tens of milli-ohms, which would be more advantageous to the low-resistance measurement using the two wire method.

Four Wire Switching for Low Resistance Applications – Applications such as contact resistance measurements and cable continuity testing typically involve switching low resistance. Low resistance switching (<100Ω) requires techniques that are normally not required for mid range or high resistances. As previously mentioned, using four wires for low-resistance applications is an accurate method. Using the four-wire technique eliminates both lead wire and switch contact resistance. This would involve two channels instead of one, where each channel is a two-pole channel.

Normally these two channels are paired in the four-wire or four-pole mode, which eliminates all the trace and test-lead resistance from the measurement. When measuring low resistance, this is the standard technique. A matrix is not required for low resistance switching applications, with only a multiplexer required for the switch portion. The multiplexer can use both the current source and voltage sense channels in a single four-pole switch. A matrix can connect all of the rows to all of the columns. While this is powerful for some applications, it is not required for the low-resistance application. Refer to ***Figure 7***.

Conclusion

Switching signals inherently cause some signal degradation to the test system. Some of the errors and common mistakes could be eliminated or minimized by using some techniques outlined in this article. It is in the test engineer's best interest to understand the signals and switches to be used in the system.

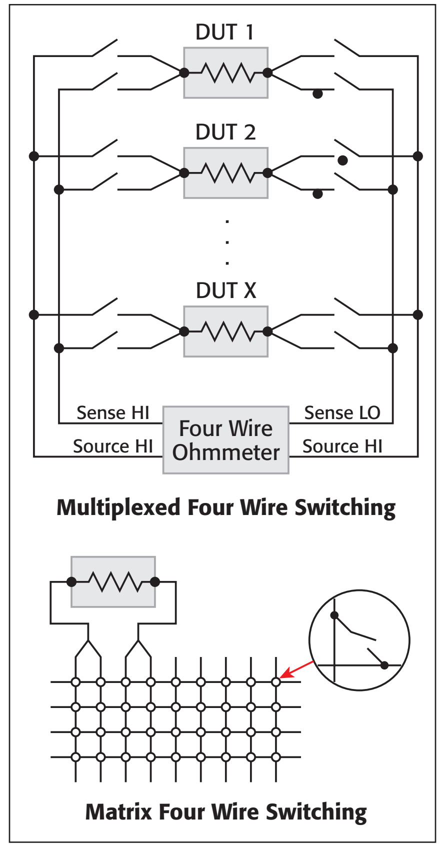

Figure 7. Four wire switching

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