FUNDAMENTALS OF BUILDING A TEST SYSTEM

Switching and Multiplexing

CONTENTS

Introduction

Many automated test applications require routing signals to a variety of instruments and devices under test (DUTs). Often the best way to address these applications is to implement a network of switches that facilitate this signal routing between the instrumentation and the DUTs. Switching not only handles this signal routing, but it is also a low-cost way to increase the channel count of expensive instrumentation while increasing the flexibility and repeatability of your measurements.

When adding switching to an automated test system, you have three main options: design and build a custom switching network in-house, use a stand-alone box controlled via GPIB or Ethernet, or use a modular platform with one or more instruments such as a digital multimeter (DMM). Switching is almost exclusively used alongside other instruments, so tight integration with those instruments is often a necessity. An off-the-shelf, modular approach can meet these integration challenges inherent in most common test systems. This guide will outline best practices for integrated switching and multiplexing into your test system.

Switching Architectures

Switching can be a cost-effective and efficient option for expanding the channel count of your instrumentation, but it is not always the best option. There are four main types of switching architectures:

1. No Switching
2. Switching in Test Rack Only
3. Switching in Test Fixture Only
4. Switching in Test Rack and Test Fixture

The following table outlines the strengths and weaknesses of all four switching architectures.

Below ○ Average ◒ Above ●

	Flexibility	Throughput	Cost	Low-Level Measurements (mV, μA, mΩ)
No Switching	○	●	○	●
Switching in Test Rack	●	◒	●	○
Switching in Test Fixture	○	◒	◒	◒
Switching in Test Rack and Fixture	●	◒	◒	◒

Table 1. Pros and Cons of Various Switching Architectures

No Switching

In the first architecture, no switches are used to route signals between the devices under test (DUTs) and the instruments in the test system. Such systems typically have a single instrument channel dedicated to every test point.

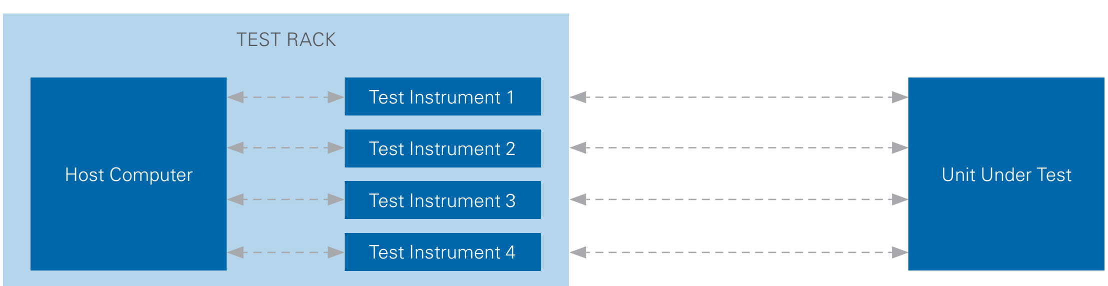


Figure 1. A test system without switching has a direct connection from each instrument to the unit under test.

Advantages of Not Switching

Cables and switches can often degrade the integrity of your signal. By not using switches, you can provide your signal with a more direct path to the measurement instrument and thus improve your measurement accuracy. In addition to improved measurement accuracy, you can achieve faster test speeds. By having a dedicated instrument for each test point, you can make parallel measurements rather than sequential measurements, and thus increase test throughput.

Disadvantages of Not Switching

Having a dedicated instrument for each test point can prove to be extremely costly. Another disadvantage is expandability. You can easily run out of space in your test rack if you build a test system without switching. This can cause you to completely redesign your test system, which can result in additional costs for hardware changes, software updates, and revalidation. For instance, suppose you have a test system that tests 20 resistance temperature detector (RTD) sensors in parallel using 20 PXIe-4081 digital multimeters (DMMs). Now assume your system needs to expand to test 40 RTD sensors. To do so, you need to add 20 more DMMs, which require 20 more PXI slots. Alternatively, you can use a single PXIe-4081 7½-digit DMM along with a switch to test all 40 RTD sensors sequentially, which requires as little as two PXI slots.

When to Build a Test System Without Switching

Building a test system without any switching is usually recommended if you are making either extremely sensitive measurements that would get distorted with the addition of cables and switches or if you need to keep test time to a minimum. For instance, some semiconductor test applications have a single parametric measurement unit or source measure unit dedicated to every pin on a chip, because semiconductors are a high-volume business and test costs often make up a significant portion of the total manufacturing cost of a chip. You can significantly reduce test costs by minimizing test time through parallel measurements with dedicated instrument channels. Additionally, in the semiconductor industry, testers are often built for specific chipsets or chipset families, so they are not usually expanded over their lifetimes.

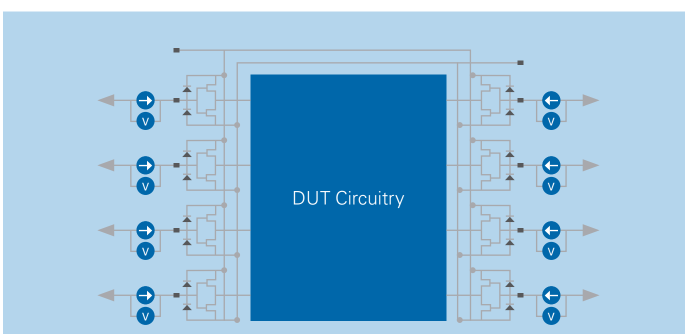


Figure 2. Some semiconductor applications use dedicated instruments to test each pin on a given chip in parallel.

Switching in Test Rack Only

The second switching architecture uses only commercial off-the-shelf (COTS) switches to route signals between measurement instruments and DUTs. Switching in the test rack provides a way to use existing switch products and offers the easiest path to expansion. It is important to choose a COTS switching platform that can offer a broad range of functionality and easy expansion options. Not doing so can result in higher expenditures because of test system redesign over the life of a tester.

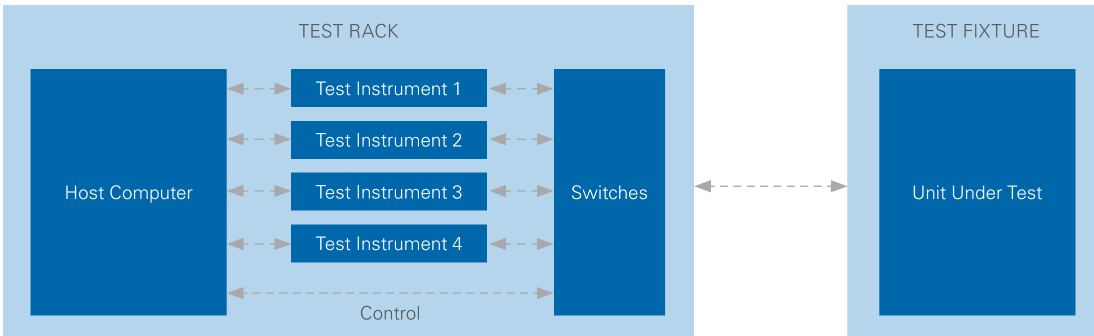


Figure 3. Some test systems integrate switching within the test rack for ease of expansion.

The PXI platform, for instance, offers more than 600 different types of switch modules that can route signals as high as 600 V, 40 A, and 40 GHz. NI alone makes 100 different PXI switch modules that you can configure in more than 200 different switch topologies.

Advantages of Switching in Your Test Rack

By using a COTS switching solution, you can save considerably on development time, including printed circuit board (PCB) design and driver development. Additionally, COTS switching improves test system scalability because you can now add more switching by purchasing additional modules from a switch vendor rather than redesign your entire test fixture.

Furthermore, each switch vendor provides solutions with their own unique advantages. NI switches, for example, have an onboard EEPROM that keeps track of the number of instances each relay on the module is activated and other features to monitor relay health, such as functional and resistive relay tests. With these features, you can predict when a specific relay will reach the end of its mechanical lifetime, and thus conduct predictive maintenance. These features are especially useful when maintaining high-channel-count switch systems that can be extremely difficult to debug manually, or on a manufacturing production floor where unexpected downtime can cause significant and costly delays.

You can also use NI switch modules to increase the throughput of your test application by downloading a list of switch connections to memory onboard the switch modules and cycling through the list using bidirectional triggering between the switch and any instrumentation, without interruption from the host processor.

Disadvantages of Switching in Your Test Rack

Using switches can often slow down your test process because it requires you to take measurements from your test points on any given DUT sequentially rather than in parallel, as discussed previously. Placing all of the switching within the test rack also increases the total amount of cabling. In addition to using cables between your switches and measurement instruments, you also need cables between DUTs and the switch. This can cause error in sensitive measurements, such as leakage current or low-resistance measurements.

Switching in Test Fixture Only

The third switching architecture uses switches in the test fixture only. In this case, signals from the measurement instrument are switched to various test points on the DUT using individual relays placed on a PCB near the fixture or in the fixture itself. If you are using this architecture, you need a relay driver in your test station to control the individual relays from your test program. A good example of a COTS relay driver is the PXI-2567, which is a 64-channel relay driver module that allows you to use the NI-SWITCH driver to control the external relays using a standard API, removing the need for custom programming. Alternatively, you can design an external circuit to drive your relays, but this requires additional design work.

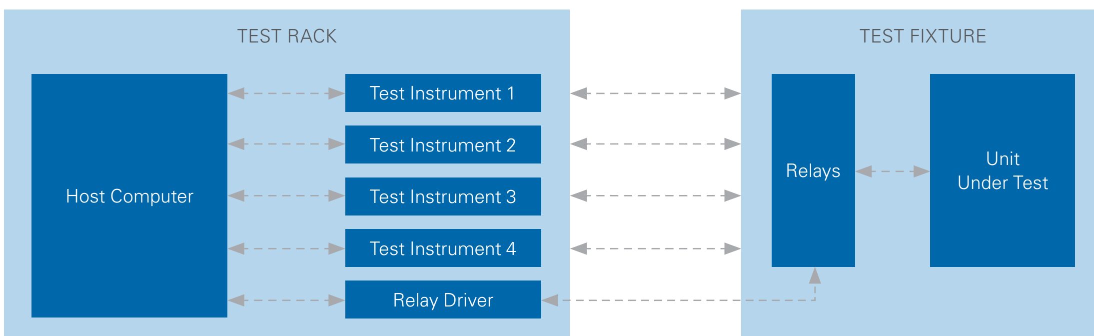


Figure 4. Test systems with switches in the test fixture require a relay driver.

Advantages of Switching in Your Test Fixture

As mentioned before, switching helps reduce test cost, regardless of location. Additionally, building switches into your test fixture eliminates the need for cables between your DUTs and the switches themselves. Reduction in cabling also helps decrease measurement error.

Disadvantages of Switching in Your Test Fixture

As discussed previously, using switches can often slow down your test process. Additionally, building custom switching into the test fixture requires PCB design experience, so this may not be an option for everyone. Switching within your test fixture also poses problems with the ability to scale your test system to accommodate more test points.

Another disadvantage of this option is the cost associated with designing a custom board for specific safety and compliance standards. If you are testing a high-voltage device, you likely need to build a switching fixture that adheres to various regulations such as UL, CE, and VDE. It can be challenging to design a PCB filled with relays that complies with the creepage and clearance requirements of those various standards. In such cases, using COTS switches can help reduce costs. Many COTS vendors certify their modules to comply with a wide range of safety standards. For instance, all NI switch modules that have a voltage rating greater than 60 V_{DC} or 30 V_{AC} and 42.2 V_{pk} are considered high-voltage devices and therefore built to adhere to the following safety standards.

Figure 5. NI switch modules meet a wide range of safety and compliance standards.

Switching in Test Fixture and Test Rack

The last switching architecture includes switches in the test station as well as the test fixture. Using this paradigm, you can take advantage of the benefits of both COTS switching solutions and simultaneously minimize errors in specific, sensitive measurements by placing switches closer to the DUTs and in the test fixture. By using the PXI-2567 relay driver along with other PXI-based switches, you can program your whole switch system, including both test rack COTS switches and custom relays in the test fixture, using a standard, well-supported driver API.

Advantages of Switching in Your Test Fixture and Test Rack

By placing COTS switches in your test rack and relays in your test fixture, you can build a switching system that scales easily and adds minimum errors into your critical or low-level measurements. Using this architecture, you can place those switches being used to route sensitive signals in the test fixture and all of the remaining switches in the test rack. In addition to scalability, using COTS switches helps you take advantage of vendor-specific features, such as the relay count tracking and hardware triggering features in NI PXI switch modules.

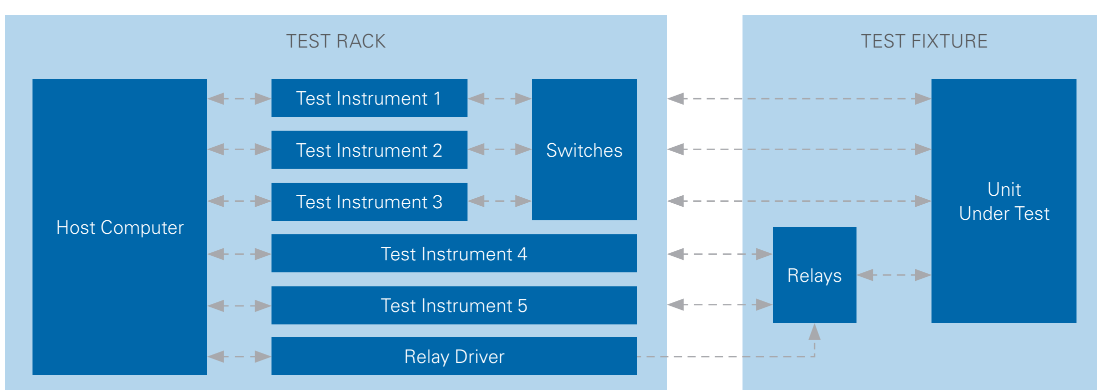


Figure 6. Test systems with switches in the test rack and test fixture provide great flexibility, but require additional design work.

Disadvantages of Switching in Your Test Fixture and Test Rack
Using switches can often slow down your test process because it requires you to take measurements from your test points sequentially rather than in parallel. Building custom switching into your test fixture can also be time-consuming and require a considerable amount of PCB design expertise, especially for high-voltage or high-frequency signals.

How to Select the Best Switch for Your Application

In addition to switch location, you want to compare the various switch topologies and relay types to ensure your switching subsystem meets your signal requirements and test goals. For automated test applications, the term switch is often used to describe a COTS device that uses relays to switch signals between multiple DUTs and instruments. Switches organize relays in various ways to create different switch topologies, such as general-purpose relays, multiplexers, and matrices. Different relay types have various trade-offs, including size, signal rating, and life expectancy. This section describes common switching topologies, popular relay types, key switching specifications, and general tips and tricks for switching in an automated test system.

Common Switch Topologies

After you have decided that switching is ideal for your application, the next step is to select the best switching topology, or way of organizing the relays to build a larger switch network. Most switch vendors categorize their switches into three main categories: general-purpose relays, multiplexers, and matrices. Some switches, such as PXIe-2524, are capable of multiple topologies, which gives you the ability to configure the topology in software. You can choose among five different topologies to meet changing requirements. When considering topologies, it is important to think about the total number of connections required, the maximum number of simultaneous connections, and the need to scale for future changes to the test system.

General-Purpose Relays
A general-purpose switch consists of multiple independent relays meant to be used independent of each other. A general-purpose relay is a great option when you simply want to make/break a connection within a circuit or switch between two possible inputs or outputs. Individual relays are often classified by their number of poles and number of throws. The pole of a relay is the terminal common to every path, and each position that a pole can connect to is called a throw.

A single-pole single-throw (SPST) relay is similar to a standard light switch with on and off states. An SPST relay comes in two forms: Form A and Form B. Form A SPST relays are normally open until the relay is activated, which causes the relay contacts to touch, completing the circuit. Alternatively, a Form B SPST is normally closed until the relay is activated, which causes the relay contacts to break their connections, opening the circuit.

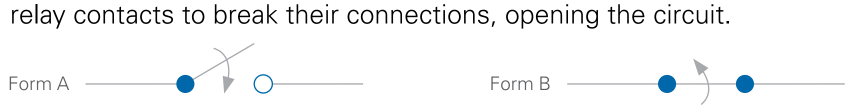


Figure 7. SPST relays come in two forms: normally open (Form A) and normally closed (Form B).

A single-pole double-throw (SPDT) relay has a single pole, or common connection, that can alternate between one normally open contact and one normally closed contact. Every SPDT is categorized as either a Form C or Form D relay. When a Form C SPDT activates, the normally closed signal path is opened before the relay connects to the normally open contact. This SPDT relay operation is described as "break before make," or BBM. Alternatively, actuating a Form D relay connects the normally open signal path before the normally closed signal path is opened. This SPDT relay operation is called "make before break," or MBB.

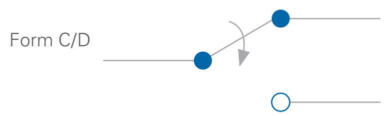


Figure 8. SPDT relays share one common pole between two possible throws, or connections.

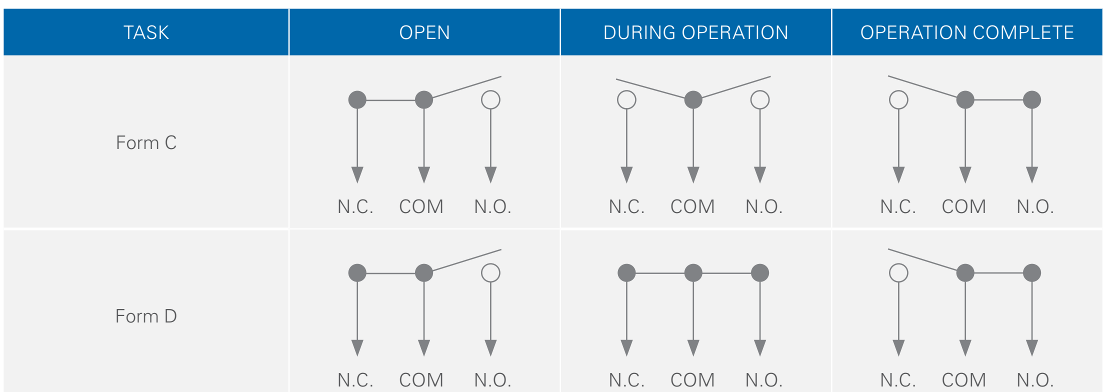


Figure 9. SPDT relays also come in two forms: Form C and Form D.

A double-pole single-throw (DPST) relay is when two Form A SPST relays are actuated simultaneously, usually with the same coil and packaged together. A DPST is ideal when two signal paths need to be opened or closed simultaneously. You can build a DPST from two independently controlled Form A SPST relays, but there might be some time difference between actuating the two relays.

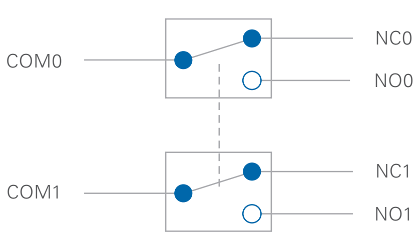


Figure 10. DPST relays offer simultaneous control of two Form A SPST relays.

Multiplexers

A multiplexer, or mux, is a way of organizing relays that gives you the ability to connect one input to multiple outputs, or one output to multiple inputs. Multiplexers provide an efficient way to connect multiple DUTs to a single instrument. However, this switching architecture requires more upfront knowledge of which DUT connections need access to your various instruments.

Multiplexers are sometimes built using multiple Form A SPST relays with the ends connected together. This method of building a multiplexer is simple and efficient, but its drawback is that the unused signal paths can cause AC signal reflections that degrade the bandwidth rating of the switch.

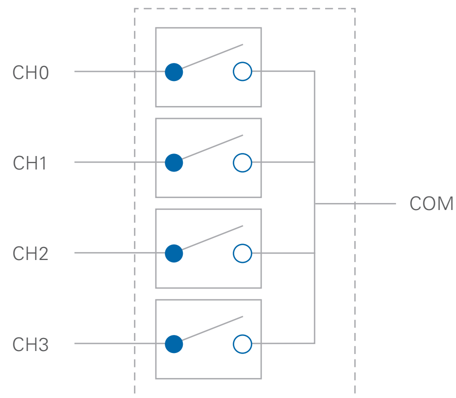


Figure 11. 4 x 1 Multiplexer Built from Multiple Form A SPST Relays Tied Together

Alternatively, multiplexers are sometimes built using cascaded levels of Form C SPDT relays to ensure the signal integrity of AC signals. This type of multiplexer often requires more PCB space, but it reduces any stubs or extra unterminated signal paths that might degrade the bandwidth of the switch.

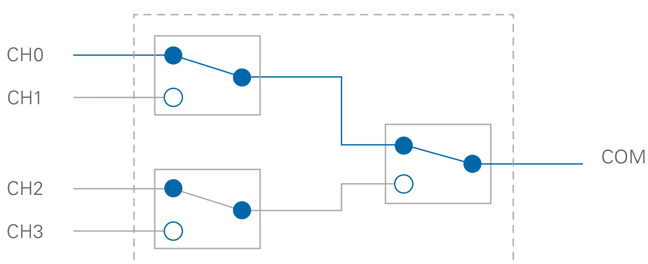


Figure 12. 4 x 1 Multiplexer Built From Cascaded Levels of Form C SPDT Relays

Matrices

A matrix is the most flexible switching configuration. Unlike a multiplexer, a matrix can connect multiple signal paths at the same time. A matrix has columns and rows with a relay at each intersection, which gives you the ability to connect column-to-column, column-to-row, and row-to-row signal paths. With the flexibility of matrices, you can connect all switch channels to each other through various signal paths that do not need to be predetermined. It is recommended that you plan your switch routes during the hardware planning phase, but matrices give you the flexibility to make changes to the switch routes as test requirements change.

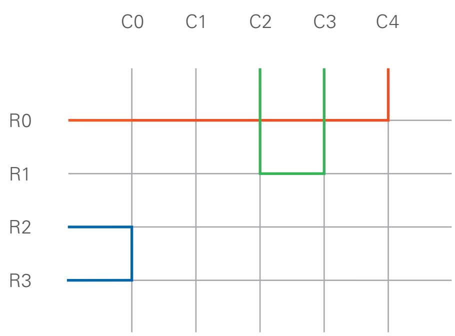


Figure 13. Matrices allow for maximum flexibility when routing signals.

Matrix size is often described as M rows by N columns (M x N) configurations. Some common configurations are 4 x 64, 8 x 32, and 16 x 16. However, in most cases, there is nothing special about rows or columns. A switch matrix can be transposed if it is easier for you to think in terms of more rows than columns, such as a 64 x 4 matrix instead of a 4 x 64 matrix.

Other Topologies

General-purpose, matrix, and multiplexer switches make up the vast majority of switches, but there are other specialized switching topologies such as a sparse matrix or a fault insertion unit (FIU).

A sparse matrix is a hybrid combination, somewhere between a matrix and a multiplexer, generally used for RF applications. By connecting the COMs of two multiplexers, you can create a pseudo-matrix with numerous rows and columns, but only one possible signal path can be connected at any given time. Multiplexers typically offer more channel density than a matrix does, because a matrix requires at least one relay per row-column intersection. Therefore, a sparse matrix typically offers more channel density in a given space, but is limited by a single signal path between the rows and columns. Sparse matrices are also useful for AC applications where signal bandwidth might be compromised by the stubs created by the unterminated rows and columns of a traditional matrix.

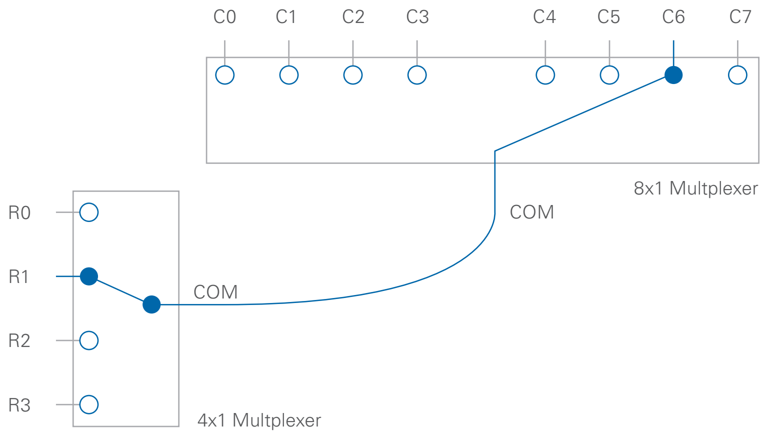


Figure 14. A sparse matrix is created by connecting the COMs of two or more multiplexers, and is commonly used for switching RF signals.

Another specialized switching architecture is the FIU, which is commonly used in hardware-in-the-loop (HIL) test systems. Hardware fault insertion, also known as fault injection, is a critical consideration in test systems that are responsible for the reliability of embedded control units, where it is imperative to have both a known and acceptable response to fault conditions. To accomplish this, FIUs are inserted between the I/O interfaces of a test system and the ECU so the test system can switch between normal operation and fault conditions, such as a short to power, short to ground, pin-to-pin shorts, or open circuit. For more information on FIUs, read the Using Fault Insertion Units (FIUs) for Electronic Testing white paper.

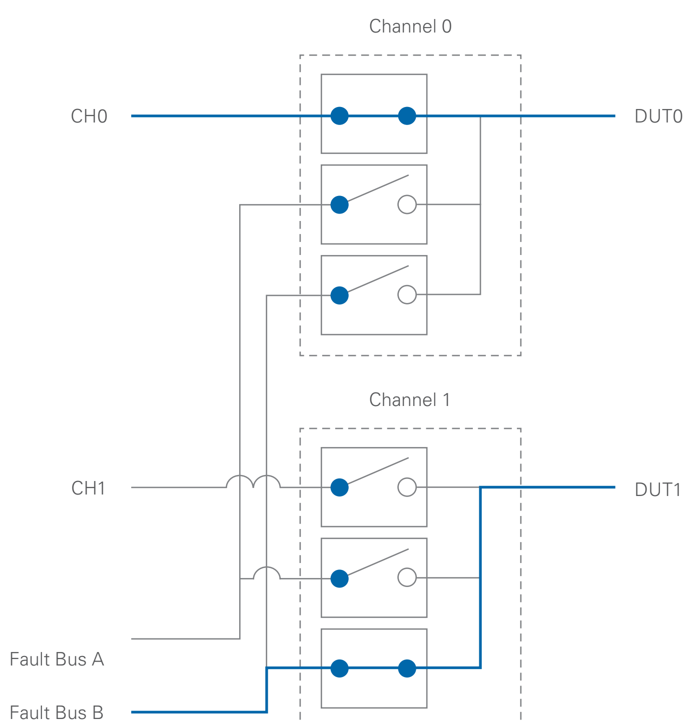


Figure 15. FIUs allow for automated fault condition testing, commonly used to test the reliability of embdded systems, such as automotive ECUs.

Relay Types

A relay is a remotely controlled device that makes or breaks a connection in an electric circuit. There are various types of relays, but four of the more popular relay types are electromechanical relays, reed relays, solid state relays, and field effect transistor (FET) relays. Each relay type has trade-offs that can impact the performance, cost, life expectancy, and density of a switch system, which is why it is important to select the best relay type to fit the needs of your application.

Note that the specs for an individual relay and a finished switch product differ in most situations. Relay specs, such as bandwidth, power rating, and contact resistance, refer only to the individual relay and do not include the PCB routes that connect the relays into a switch topology or the connector that provides the user with an interface to the switch topology. For example, a single relay may be rated for 0.05 Ω contact resistance and 300 V, but the finished switch product may have a larger path resistance (for example, 1 Ω), including multiple relays and PCB traces, and may not have the PCB creepage and clearance necessary to safely spec the switch product at 300 V.

Electromechanical Relays

An electromechanical relay (EMR), or armature relay, uses current flowing through an inductor coil to induce a magnetic field that moves the armature to the open or closed position, which completes the circuit by causing two contacts to touch. There are various types of EMRs, such as latching and nonlatching, that have small differences in operation. A nonlatching EMR uses a single coil and returns to its default position after the current stops flowing. Alternatively, a latching EMR remains in the position that it was switched to, even when the current stops flowing. Some latching EMRs use one coil and reverse the flow of current to reverse the direction of the magnetic field to push or pull the armature into the desired position. Other latching EMRs use a coil on either side of the armature to push the armature open or closed.

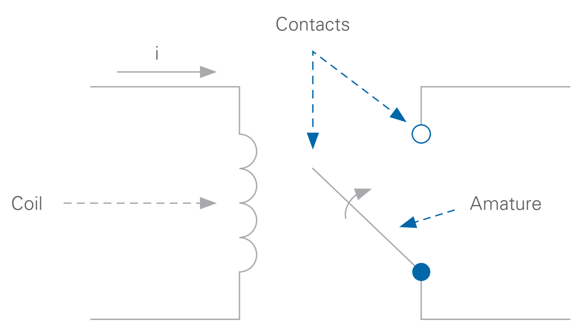


Figure 16. A single-coil electromechanical relay uses a magnetic field to open and close a mechanical switch.

EMRs support a wide range of signal characteristics, from low voltage/current to high voltage/current and DC to GHz frequencies. Also, EMRs have low contact resistance, typically much less than 1 Ω, and can handle unexpected surge currents and high power, up to 300 W. For these reasons, you can almost always find an EMR that fits the signal characteristics a test system requires. However, EMRs take up a lot of PCB space, are slow compared to other options (150 cycles/s), and have shorter life cycles because of their moving parts (up to 10ˆ6 cycles).

Because of these trade-offs, EMRs are a great choice when you need a durable relay rated for high power, high current, or high bandwidth, but you are not as concerned with relay speed and are willing to replace the relay as it degrades over time.

Reed Relays

Reed relays also use current flowing through an inductor to create a magnetic field used to connect physical contacts. However, reed relays can have much smaller and lighter contacts than EMRs. Reed relays use a coil wrapped around two overlapping ferromagnetic blades (called reeds) hermetically sealed within a glass or ceramic capsule filled with an inert gas. When the coil is energized, the two reeds are drawn together causing their contacts to complete a signal path through the relay. The spring force of the reeds causes the contacts to separate when the current ceases to flow through the coil.

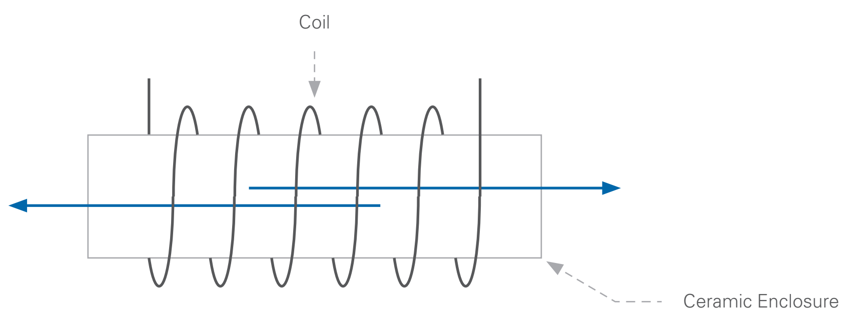


Figure 17. The spring force of the reeds causes the contacts to separate when the current ceases to flow through the coil.

Because reed relays can be smaller, you can fit more within a smaller footprint and they can switch faster than EMRs, up to 2,000 cycles/s. Also, their limited moving mechanical parts and isolated environment provide longer mechanical lifetimes, up to 10ˆ9 cycles.

However, because of their smaller contact size, reed relays cannot handle as much power and are more susceptible to damage from self-heating or arcing, which can melt small sections of the reeds. If the two reeds are still connected when the molten section solidifies, the contacts may weld together. In this situation, the relay remains shut, or breaks one of the reeds if the spring force is enough to pull the two reeds apart. To protect against damage, monitor signals for large inrush currents that might be caused by hot-switching a capacitive load and use inline protection resistors to reduce the level and duration of the current spike. For more information on protecting reed relays, read the Reed Relay Protection white paper. The small size and high speed of reed relays make them a great choice for many applications. Reed relays are more often found on matrix and multiplexer modules rather than general-purpose switch modules. A good place to start is the PXI-2530B, which is a COTS switch that you can configure as 13 unique matrix or multiplexer topologies by swapping various front-mount terminal blocks.

Solid State Relays

Solid state relays (SSRs) are electronic relays that consist of a sensor that responds to an input, a solid-state electronic switching device that switches power to the load circuitry, and a coupling mechanism to enable the control signal to activate without mechanical parts. They are often constructed using a photosensitive metal-oxide semiconductor, field-effect transistor (MOSFET) device with an LED to actuate the device.

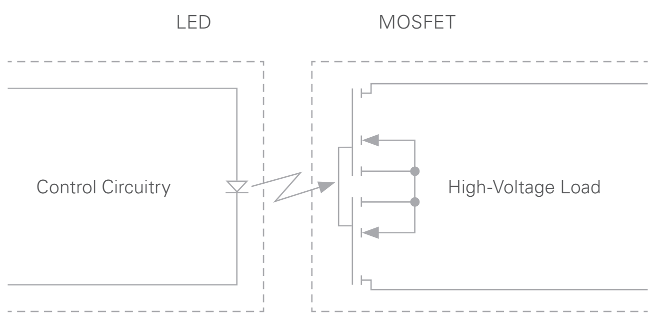


Figure 18. SSRs use photo-sensitive MOSFETs with an LED to actuate the device.

SSRs are slightly faster than EMRs, up to 300 cycles/s, because their switching time is dependent on the time required to power the LED on and off. Because there are no mechanical parts, SSRs are less susceptible to physical vibrations that could damage the relay, which provides an unlimited mechanical lifetime.

However, SSRs have their downsides. First, they are not as robust as EMRs and are easily damaged if used with signal levels outside of their rating. Second, they are expensive and generate more heat than alternatives. Finally, SSRs can have large path resistances, anywhere from less than 1 Ω to 100 Ω or more, because the connection is made through a transistor instead of a physical metal connection. Most modern SSRs have improved path resistance to make this less impactful.

Unlimited mechanical lifetime of SSRs make them an excellent choice when you have small-to-moderate signal levels and you need a relay that can last through many relay cycles. An example COTS SSR switch is the PXI-2533, which is a 4 x 64 matrix rated for 55 W of switching power and offers unlimited mechanical lifetime.

FET Relays

Similar to SSRs, FET relays are not mechanical devices and use transistors to route signals. Unlike SSRs, the control circuitry drives the gates of the transistors directly instead of driving an LED.

Directly driving the transistor gate allows for much faster switching speeds than any other type of relay mentioned, up to 60,000 cycles/s. Also, the lack of mechanical parts make FET relays much smaller and less susceptible to shock and vibration issues than electromechanical or reed relays, which affords FET relays an unlimited operational lifetime. However, FET relays have a much higher path resistance than any other relay option, typically in the 8 Ω to 15 Ω range, and they lack physical isolation and thus may be used with only low-level signals.

FET relays are an excellent choice for low-level signals and applications that require fast relay operation or unlimited mechanical life. An example of a COTS FET switch is the PXI-2535, which is a 4 x 136 matrix that can perform relay operations in less than 16 µs.

Below ○ Average ◒ Above ●

Capability	Armature	Reed	FET	SSR
High Power	●	◒	○	◒
High Speed	○	◒	●	◒
Small Package Size	◒	●	●	●
Low Path Resistance	●	◒	○	◒
Low Voltage Offset	◒	○	◒	●
Extended Lifetime	○	◒	●	●

Table 2. Comparison of Relay Options

Switch Expansion

If you build your own switching topology, then you can create a matrix or multiplexer to meet the exact dimensions of your application. However, many customers use COTS switches to reduce development effort and most COTS switches have fixed dimensions. Therefore, it is important to know how to combine multiple matrices or multiplexers to create a larger matrix or multiplexer.

Multiplexer Expansion

The easiest way to expand the channel count of a multiplexer is to directly tie the COMs of multiple multiplexers together. With this approach, there is some risk of shorting input channels together and possibly damaging your hardware. Therefore, you need to ensure that only one of the channels is connected to a COM at any given time. Some switching software, such as Switch Executive, gives you the ability to define software exclusions that prevent multiple input paths from being connected to a COM at any given time. Another downside to this approach is that the unused and unterminated routes result in stubs, which adds capacitance and degrades high-frequency performance.

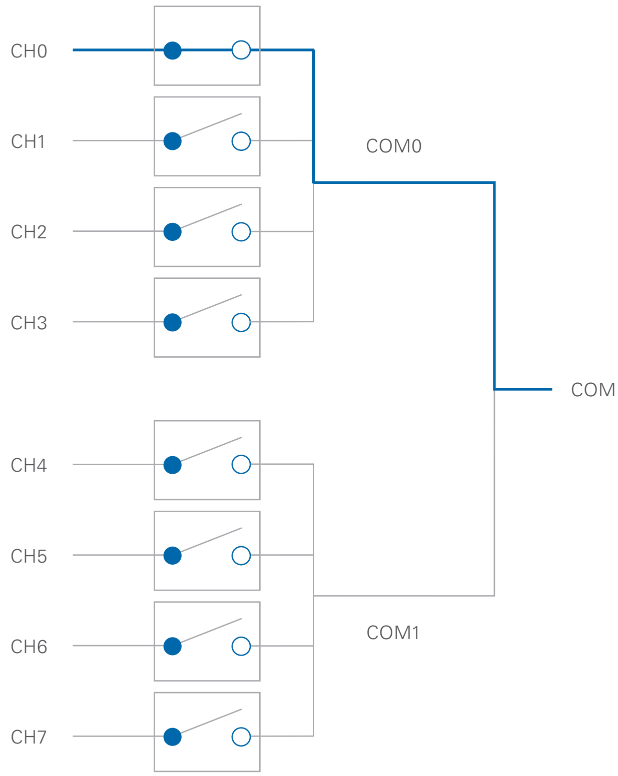


Figure 19. An 8 x 1 multiplexer is created by tying together the COMs of two 4 x 1 multiplexers.

Another approach is to connect the COMs of multiple multiplexers through an additional multiplexer, which inherently allows only one channel path to a COM but requires more multiplexers. However, this approach still results in PCB trace stubs that can degrade bandwidth performance.

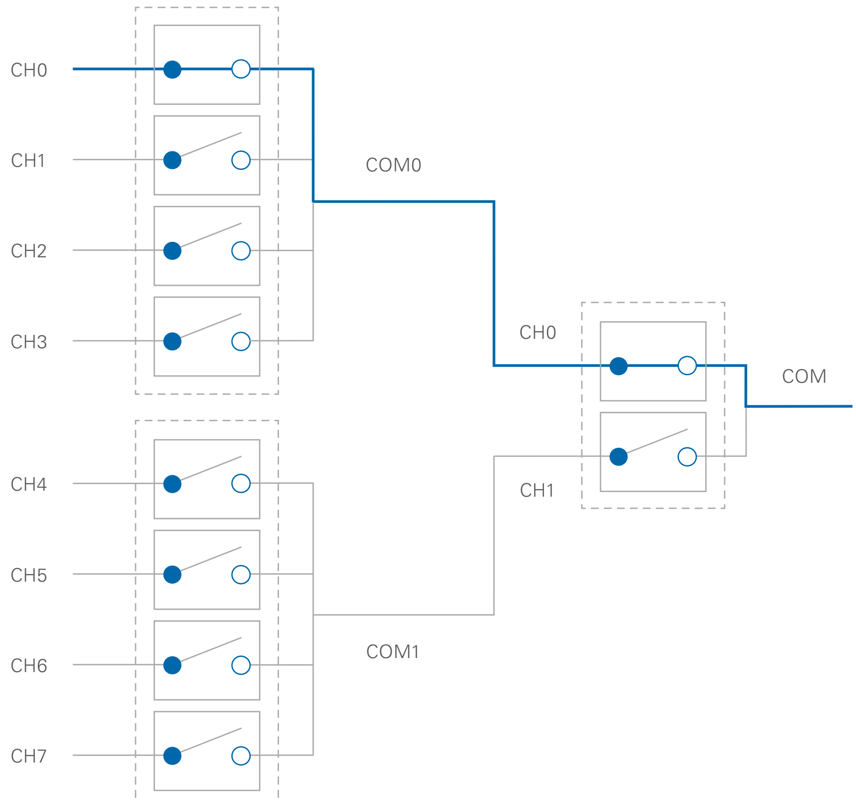


Figure 20. An 8 x 1 multiplexer is created by switching the individual COMs of two 4 x 1 multiplexers through an additional multiplexer.

For high-frequency applications, you should use Form C SPDT relays to create a large multiplexer. This option ensures there are no stubs along the active signal path, which helps increase the bandwidth of the switch.

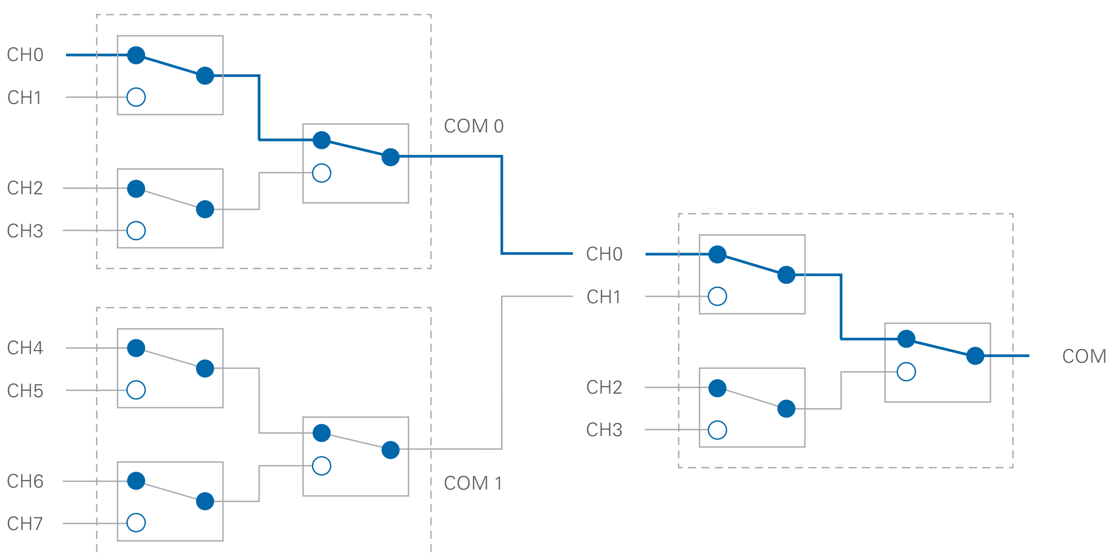


Figure 21. An 8 x 1 multiplexer is created by cascading three 4 x 1 multiplexers with Form C SPDT relays.

Matrix Expansion
Switch matrices can also serve as building blocks for creating larger configurations that are well beyond the size of a single COTS matrix switch. There are two ways to expand matrices. Column expansion is the process of connecting each row between two or more matrix modules, effectively doubling the number of columns within the expanded matrix. Alternatively, row expansion is the process of connecting each column of two or more matrix modules, doubling the number of rows within the expanded matrix.

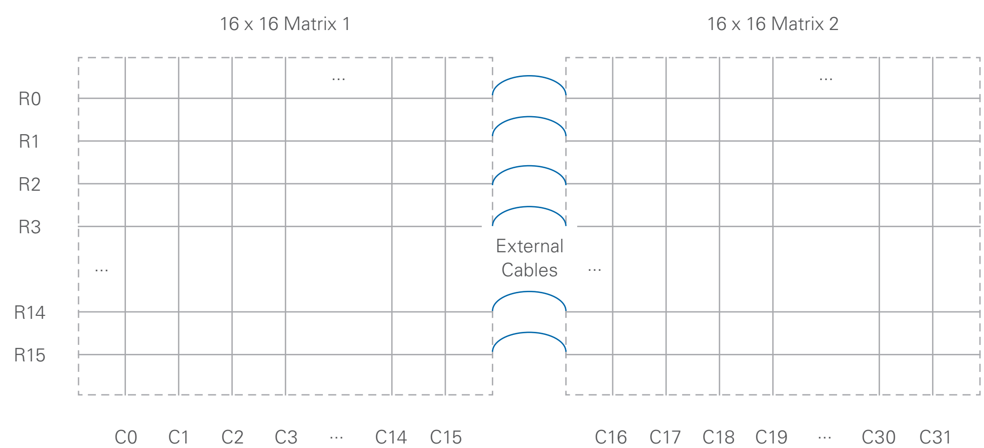


Figure 22. 16 x 32 Matrix Created by Column Expansion

For easy matrix expansion, some COTS matrix switches, such as the PXIe-2532B, offer specialized cables to combine matrices by easily connecting rows of multiple switch modules. However, all matrices are expandable, even if there are no prebuilt accessories to do so. To expand a matrix manually, you can use external wires to connect the rows or columns of individual matrices. For more information on matrix expansion, including examples and frequently asked questions, read the Matrix Expansion Guide for PXI Switch Modules.

Key Switching Specifications
In addition to relay type and switch topology, it is important to ensure that your switching subsystem maintains the signal integrity of the connected signals. Most switches fall into two categories based on signal types: low-frequency/DC and RF.

Low-Frequency/DC Switching Specifications
Switches typically advertise voltage and current ratings, but you should also pay attention to the maximum switching power specification, which refers to the upper limit of power that the contacts can switch. For example, a 150 V, 2 A switch may be limited to 60 W switching power and should not be used with 150 V at 2 A (300 W). Therefore, it is important to consider the maximum power of your signals in addition to your maximum voltage and current levels.

Signal frequency is also a tricky topic when dealing with switches. Many times, a signal is described with its fundamental frequency, which is fine for a simple sine wave. However, if you plan to switch square-shaped signals, or signals with sharp edges, then it is important to remember that a square wave has harmonic frequencies well above the fundamental frequency, which help shape the sharp edges. If you plan on switching a square wave, choose a switch rated for seven to 10 times the fundamental frequency of your signal. For example, if you were to route a 10 MHz square wave through a switch rated for 10 MHz, the output would look closer to a sine wave than a square wave.

For more information on switch bandwidth, read the Selecting Switch Bandwidth white paper.

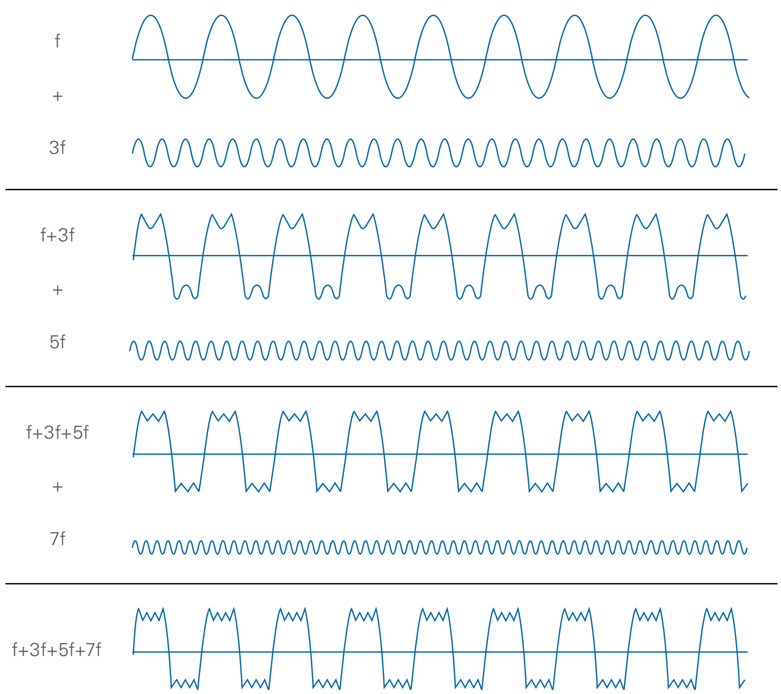


Figure 23. Square-shaped signals have harmonic frequencies well above the fundamental frequency.

Switch path resistance, thermal EMF, and offset voltage can affect low-level signal measurements, such as DMM resistance measurements. Therefore, you should select a switch that minimizes the effect on your measurements and design a measurement technique to compensate for these sources of error. For more information on how to reduce errors when switching low-level signals, see one of the following white papers:

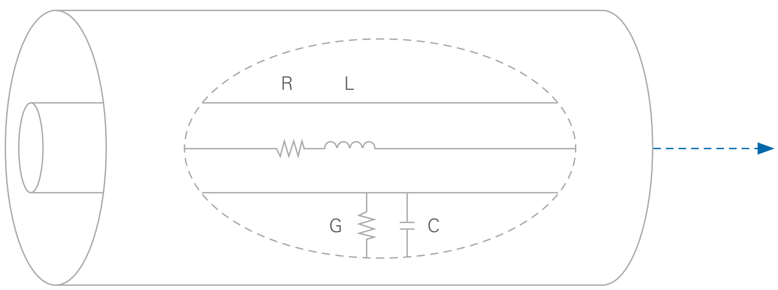
Part I: How to Reduce Errors When Switching Low-Voltage Signals

Part II: How to Reduce Errors When Switching Low-Current Signals

Part III: How to Reduce Errors When Switching Low-Resistance Signals

RF Switching Specifications
A switch that is rated for more than 10 MHz or 20 MHz is often called an RF switch. RF switches typically have lower channel density to preserve signal integrity, so RF switches should be reserved for signal paths that require the increased bandwidth. However, topology and bandwidth do not provide you with enough information to select an RF switch.

All RF switches have a rated characteristic impedance, which is a transmission line parameter that determines how propagating signals are transmitted or reflected in the signal path. Component manufacturers specifically design their equipment to have a characteristic impedance of either 50 Ω or 75 Ω, because all components in an RF system have to be impedance matched to minimize signal losses and reflections. 50 Ω RF systems make up the bulk of the RF market and include most communications systems. 75 Ω RF systems are smaller in number and are prevalent mainly in video RF systems. It is crucial you ensure parts such as cables and connectors in addition to other instruments that may reside in the test system are all impedance matched.



$$Z_o = \sqrt{\frac{R + j\infty L}{G + j\infty C}}$$

Figure 24. Characteristic Impedance of a Transmission Line

In addition to bandwidth and characteristic impedance, there are other RF switching specs that directly affect your signal integrity, such as insertion loss, voltage standing wave ratio (VSWR), isolation, crosstalk, and RF power. Insertion loss is a measure of the power loss and signal attenuation that occurs as a result of passing the signal through the switch. VSWR is the ratio of reflected-to-transmitted waves, specifically the ratio of maximum (when reflected wave is in phase) to minimum (when reflected wave is out of phase) voltages in the "standing wave" pattern. Isolation is the magnitude of a signal that is coupled across an open circuit and crosstalk is the magnitude of a signal that is coupled between circuits, such as separate multiplexer banks.

An interesting thing about RF switches is that all of these specifications vary depending on the signal frequency. Therefore, when choosing an RF relay or switch, you should compare specs at the specific frequency of your signals. Otherwise, it is easy to misinterpret the performance of an RF switch.

For more information on RF switch selection, read the Understanding Key RF Switch Specifications white paper.

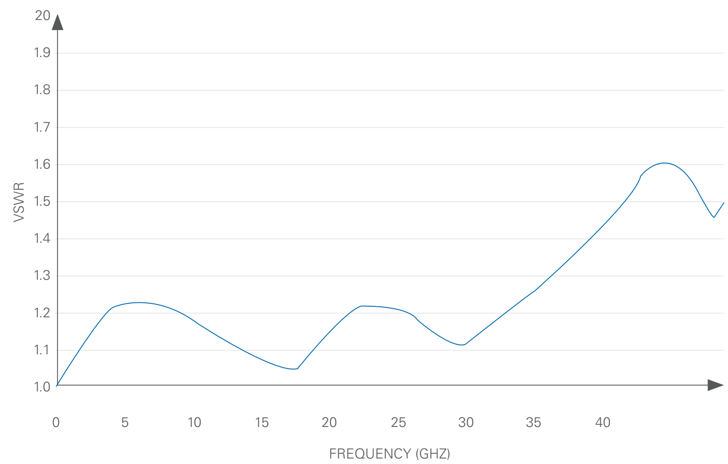


Figure 25. Many RF switch specifications vary with signal frequency.

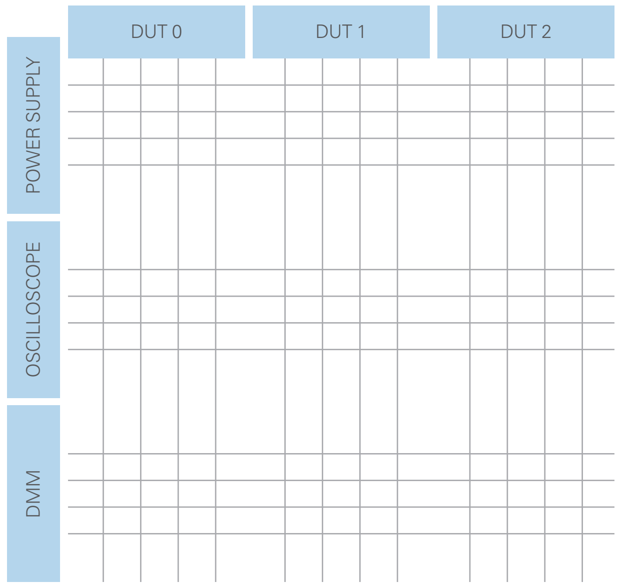
Switching Tips and Tricks

When planning the switching portion of an automated test system, a few general tips can help you build an efficient switching system that preserves signal integrity.

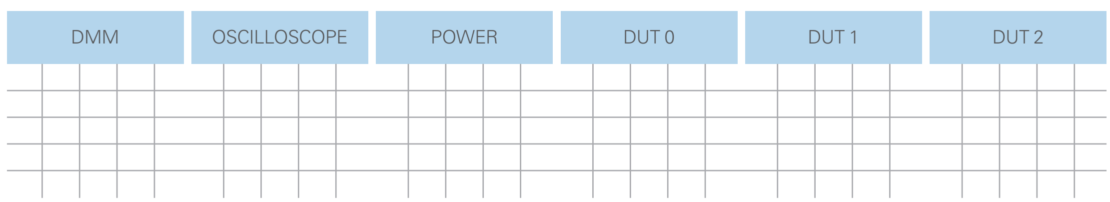
Total Test Points Versus Simultaneous Connections

When using a matrix, consider the maximum number of possible connections and the maximum number of simultaneous connections. If you simply focus on the total number of possible connections, then you often end up with entire rows dedicated to each I/O pin of each instrument. However, this approach can lead to unnecessarily large matrices. For example, if you have 22 instrument pins and 106 DUT test points, then you might suggest a 22 x 106 matrix (2,332 relays) with the 22 I/O pins connected to the rows and the 106 DUT test points connected to the columns.

However, if you only need to connect at most four instrument pins at any given time, then the 22 x 106 matrix is unnecessarily large and wasteful. Instead, you could consider placing the instruments on 22 additional columns and use the rows for routing between columns. In this case, you would reduce the matrix size to 4 x 128 (512 relays), nearly 20 percent of the original size. This can save you space and money without affecting the test time or quality.



2,332 CROSSPOINTS



512 CROSSPOINTS

Figure 26. Place instruments on columns and use rows for routing to conserve matrix space during sequential test execution, but keep instruments in rows for faster parallel test requirements.

N-Wire Switching

Many matrix or multiplexer switch modules can switch two or four signal paths within a given topology instead of the standard 1-wire switching mode. You can use 1-wire switching to route various signals to an instrument that might reference a single signal or ground when performing measurements.

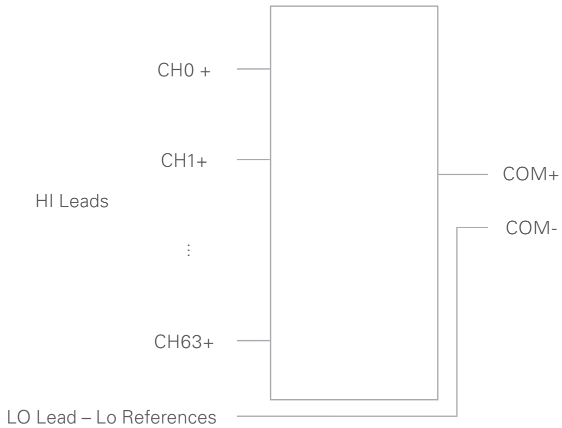


Figure 27. Single-ended multiplexers are great for measurements that reference a shared signal or ground.

Sometimes more than one signal needs to be switched at the same time. A 2-wire, or differential, switch provides two signal paths that you can control with one command. This provides an easy way to switch differential signals, which offers a great common-mode noise rejection. A 4-wire switch is typically reserved for 4-wire resistance measurements, which use two leads for excitation and another two leads to measure the voltage drop across the DUT.

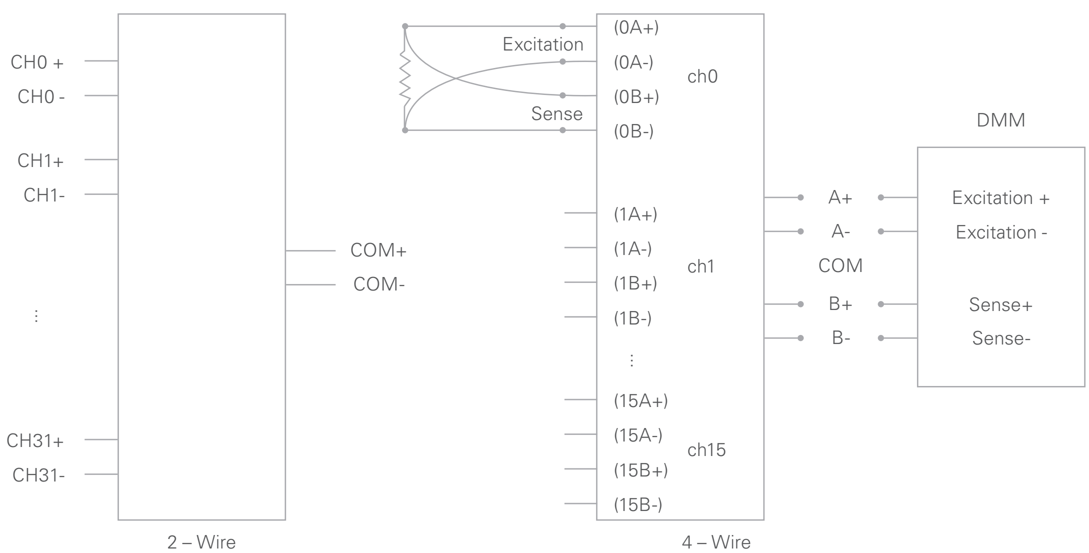


Figure 28. Switch multiple signal paths at the same time using 2-wire or 4-wire switching.

Switching Power

Many times, a test requirement plan includes maximum voltage and current levels, but instantaneous power is often overlooked. A switch or relay may be rated for 100 V and 2 A, but that doesn't necessarily mean it can handle 200 W. Many switches have maximum power ratings completely separate from their voltage and current ratings. For example, a common reed relay might be rated for 100 V and 500 mA, but it may have a maximum power rating of 10 W. Therefore, you should consider your maximum instantaneous power levels when selecting your switches.

Separate High-Level Signals From General or Low-Level Signals

Switches rated for high-power or high-frequency signals generally have lower density than switches for general-purpose signals. Therefore, you should isolate your high-power or high-frequency signals from your main switching system to preserve the channel density of the main switching system. If you try to build a single switch for all of your signals that is spec'd to handle your high-level signals, then it will likely end up large and expensive.

Compare RF Specs Based on Signal Frequency

When comparing RF switches, you should evaluate specifications based on signal frequency. Many RF specs, such as isolation, VSWR, insertion loss, and RF carry power, vary depending on the signal frequency. For an accurate comparison, look in the detailed switch specs to find the specs at the frequency of interest. Additionally, some switch vendors publish guaranteed and typical specs for each category, while others publish only typical specs that will appear to be much better than guaranteed specs.

Consider Hardware-Triggered Switches for Maximum Switching Speed

In many automated test scenarios, time is money. Many switches are controlled individually using software commands, with bus latency and software overhead added to each switching operation. Some switches offer hardware timing and triggering, which gives you the ability to load a list of switch connections to memory onboard the switch and use hardware triggers to advance through the list of connections. After each switching operation is complete, the switch can send out triggers to your instrumentation, starting the next measurement.

This operation is called switch handshaking and can eliminate the software overhead and bus latency associated with traditional software-triggered switches. Switch handshaking is especially important for faster relay types, such as FETs or SSRs, where the software overhead and bus latency make up a larger portion of each switching operation. An application using switch handshaking with reed relays might realize a 10X improvement in total switching time, while an FET switch might see a 100X improvement or more. The faster a relay, the more that switch handshaking can improve throughput.

Next Steps

NI Switch Products

Whether you are performing high-accuracy, low-speed measurements on a dozen test points or high-channel, high-frequency characterizations of integrated circuits, NI delivers a flexible, modular switching solution based on PXI to help you maximize equipment reuse, test throughput, and system scalability.

Learn more about NI PXI switch products

Switch Executive

Switch Executive is an intelligent switch management and routing application that accelerates development and simplifies maintenance of complex switch systems. The point-and-click graphical configuration, automatic routing capabilities, and intuitive channel aliases make it easy to design and document your test system.

Learn more about Switch Executive

NI Switch Health Center

To simplify relay maintenance and increase reliability in high-channel-count systems, the NI Switch Health Center verifies the condition of each relay by sending a test signal through every route in a switch. The health center alerts users if it determines a relay has failed, is stuck open, or is stuck closed, and reports changes in resistance to determine whether a relay is nearing the end of its usable life.

Learn more about the NI Switch Health Center