

# SwitchMate

A practical guide to Switching for Automated Test Systems





# SwitchMate

This book provides a description of switching via electronic relays.

It provides an overview for those new to switching and a useful source of reference material for the more experienced.

This is a living document that Pickering Interfaces will continue to develop in support of switching standards and their future evolution. We welcome any feedback from users on subjects they would like to be included in future issues.

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# 1

## INTRODUCTION

The goal of this document – SwitchMate – is simple: to give your test engineers the knowledge to make proper selections and to know what questions to ask of your switching vendors. One book will not answer all your questions, but it is a good place to start.

With a 50-year history of manufacturing instrument-grade Reed Relays and high performance Switching Systems, Pickering Interfaces has a significant body of experience in signal switching for test. Sharing this expertise, then, is the driver behind SwitchMate, a document designed to take you through all of the tough choices you need to make when selecting and integrating a switching system. From relay types, to system configurations, cables and connectors to platform types, and URLs to help you research your selections, at Pickering Interfaces we hope SwitchMate will prove to be an important asset in your test engineering library.

It is important to note that SwitchMate is not about Pickering Interfaces products. True, there are photos of Pickering Interfaces products used as examples throughout SwitchMate, however our goals are to present switching from all possible perspectives – platforms, configurations, cabling and so on. The questions raised apply to any switching vendor, including companies that build their own switching systems.

Pickering Interfaces would like to thank its colleagues at Pickering Electronics and Pickering Connect for their valuable expertise and input. Also deserving of recognition are two partners, MAC Panel and Virginia Panel Corporation, who helped immensely with the section on Mass Interconnect systems. I also want to thank NI for allowing me to add their CompactRIO® switching and United Electronic Industries for permission to refer to their Cube™ and RACKtangle™ switching in Section 4. In addition, RfCafe.com and Wikipedia are to be commended for excellent information on coaxial cables.

A word of caution before you move on. Too often customers have indicated they feel switching is the LAST portion of their test integration strategy. Switching is so simple, maybe boring... how can you go wrong there? At Pickering Interfaces, experience has shown there can be troubles down the road if switching is not considered in the early phases of test system design. Switching selection affects the accuracy, repeatability, speed, and even the safety of your test system.

Finally, if you feel the recommendations in SwitchMate are incorrect or incomplete, please contact us. Even after 50 years, we still have things to learn!

*Bob Stasonis – Technical Product Specialist (bob.stasonis@pickeringtest.com)*

# Introduction

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# 2

## WHY IS SWITCHING IMPORTANT?

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## Why is Switching Important?

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## Introduction

Signal switching can, in many instances, be the “heart” of your test system. By that we mean that signal switching connects instruments to the DUT (Device Under Test) and vice versa. Without that flow of “blood” (information) between the test system and the DUT, there is no operating test system. Quality problems cannot be diagnosed or perhaps will be incorrectly diagnosed. Poor switching choices affect accuracy, repeatability, and even system up time. The fact that you are reading this book implies you recognize the importance and want to learn more.



**Fig. 2.1 - Switching Hardware**

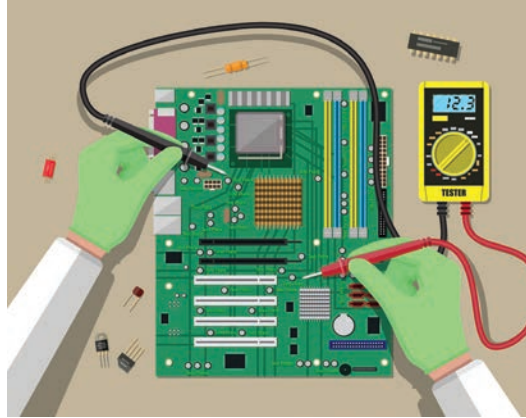
In developing a better understanding of signal switching in test, you need to know the types of switching configurations available, how relay types selected can influence your test strategy, and how the connectivity of the instruments and switching can be crucial. Once you have this knowledge there are questions to ask of your selected switching vendor.

Finally, it is important to understand that one test platform does not fit all switching applications. The various platforms to be discussed – PXI, PXIe, LXI, and USB – all have specific advantages in various applications.

To begin, it is important to understand why switching is necessary or, as it is also called, “Signal Management.” It is probably not a stretch to suggest most of you know that testing is a cost center: No additional benefit to increase the bottom line, or so many managers believe. But without testing, quality may suffer, especially in early production runs. Today’s zero defect culture demands constant vigilance in ensuring production quality – detecting and quarantining failures requires strong testing culture, and it’s not only for aerospace – driving FIT (Failures In Test) rates to zero is just today’s 6 Sigma culture. Nothing hurts a company’s reputation more than a purchased product out of the box that does not work. And if this product is safety related – say, anti-lock brakes – failure can be very expensive! So clearly, planning and implementing a comprehensive test program strategy is of the utmost importance. And in virtually all applications, your test system will require switching. So, let’s delve into the hows and whys of Signal Switching.

## Why is Switching Important?

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**Fig. 2.2 - Manual Test Measurement**

There are multiple reasons why you need to implement Signal Switching. The first and most obvious reason is to share resources. Generally speaking, you do not make just one voltage measurement or one waveform measurement in a test program. There are multiple measurements to be made to ensure that a DUT is fully operational. And if you do not share one Digital Multimeter (DMM) or digitizer using switching, the solution is to have an operator move a probe around the DUT. This can be time consuming and error prone. Of course, you can have multiple DMMs in your test system, but that can be costly and make the test system overly large.

If you are testing multiple DUTs, switching is even more important. We have seen complex switching systems used to create an asynchronous test strategy, where the operator can replace a DUT in the test fixture while other DUTs are still being tested. This allows the test system to be more efficient, lowering the cost of test and potentially reducing the number of test systems needed.

For portable applications, switching can shrink a test system footprint by more tightly integrating instruments. The sharing mentioned earlier allows the test system to potentially have fewer instruments.

When dealing with HALT/HASS Applications – HALT is Highly Accelerated Life Testing and HASS is Highly Accelerated Stress Screening – switching is usually required to access multiple DUTs in an environmental chamber. Because these tests can take weeks and months, Solid State switches may be used because they practically never wear out.

Finally, let's consider Hardware in the Loop Systems (HILS). HILS testing often involves both soft and hard failures. Soft failures may be something like bad serial data or errors in firmware. Switching is used to inject hard faults like shorted pins or connection to Voltage at the Common Connector (VCC) or Ground (GND) and monitor responses.

As you read the following sections, try to apply the recommendations to your DUT and/or the family of products you typically test. It is likely that not every recommendation will suit your requirements, although that could change in the future.

# 3

## SWITCHING BASICS

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As mentioned in the previous section, a thorough understanding of your DUT will help select the switch type needed. If your engineering department has released either a Theory of Operation or an actual test strategy, then these SwitchMate guidelines can be applied to your tester configuration.

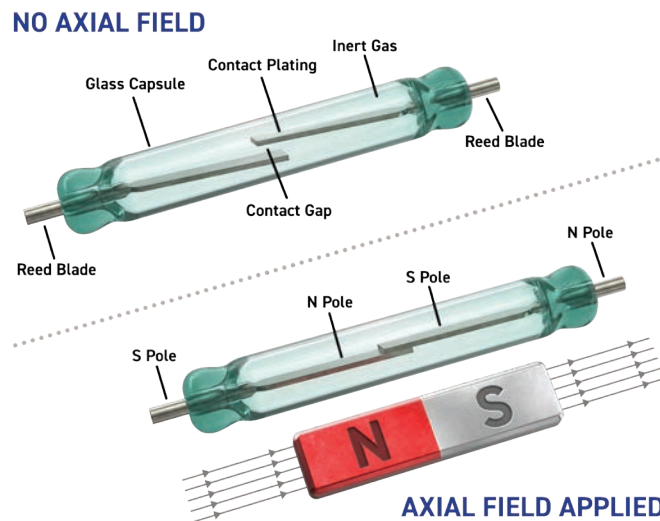
## Relay Technology

Because there is no one relay that will operate from millivolts to 1,000 volts at a frequency range of DC to 18 GHz, there are many choices in switching. This next section will examine the relay types used by all Switching System manufacturers. SwitchMate will highlight areas where each relay type excels and where it may not be applicable.

### Reed Relays

Reed Relays are deceptively simple devices in principle. The Reed Relay switch has two shaped metal blades made of a ferromagnetic material (roughly 50:50 nickel/iron) and a glass envelope that serves to both hold the metal blades in place and to provide a hermetic seal that prevents any contaminants entering the critical contact areas inside the glass envelope. Most, but not all, Reed Relay switches have open contacts in their normal state.

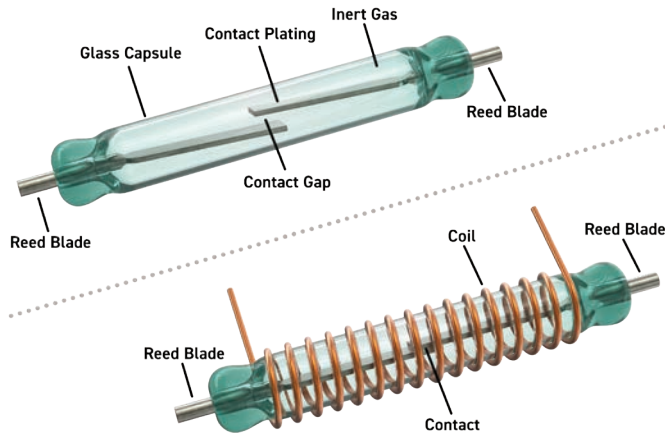
If a magnetic field is applied along the axis of the reed blades, the field is intensified in the reed blades because of their ferromagnetic nature, the open contacts of the reed blades are attracted to each other and the blades deflect to close the gap. With enough applied field the blades make contact and an electrical connection is made.



**Fig. 3.1 - Reed Switch Generating the Magnetic Field**

A magnetic field needs to be created that is capable of closing the Reed Relay switch contacts. Reed switches can be used with permanent magnets (for example to detect doors closing) but for many Reed Relays the field is generated by a coil which can have a current passed through in response to a control signal. The coil surrounds the reed switch and generates the axial magnetic field needed to close the reed contacts.

# Switching Basics



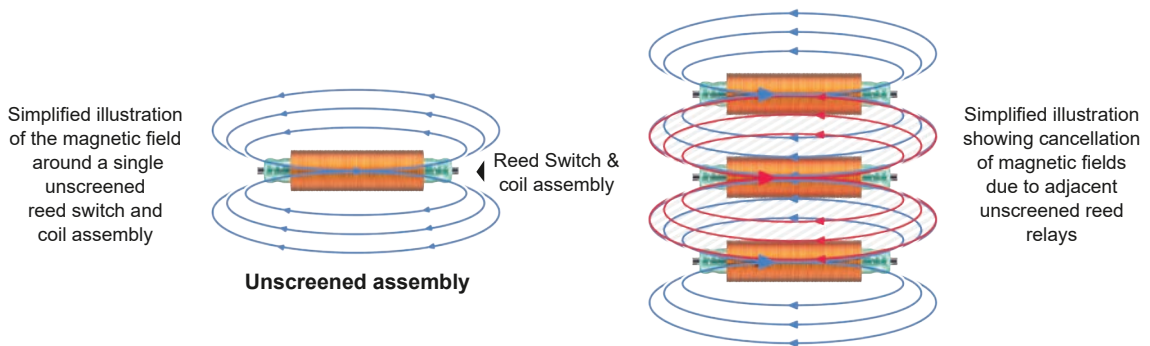
**Fig. 3.2 - Generating a Magnetic Field**

Different reed switches require different levels of magnetic field to close the contact, and this is usually quoted in terms of the ampere turns (AT) – simply the product of the current flowing in the coil multiplied by the number of turns. Again, this creates a great deal of variation in the Reed Relay characteristics. Stiffer reed switches for higher power levels or high voltage switches with larger contact gaps, usually require higher AT numbers to operate, so the coils require more power.

## Protection Against Magnetic Fields

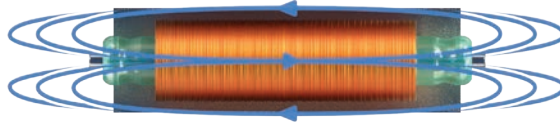
The fact that Reed Relays are magnetically operated causes a potential problem for users when they are assembled in dense patterns on PCB's.

The magnetic field required to close the reed blades flows through the nickel iron reed blades and returns by field lines which are outside the Reed Relay body. If several relays are placed close together the external field lines can be drawn by the neighboring reed blades and either reinforce or partially cancel the field in the reed, changing the current needed to close or open the contact. This can in some circumstances cause enough effect that the relay may either fail to close or open depending on the magnetic polarity. Some manufacturers suggest arranging the relays in different polarity patterns to mitigate the worst effect of the interaction, but this can become a complex compromise in dense arrays of relays where there are many near neighbors.



**Fig. 3.3 - Magnetic Interaction**

A much more sensible approach is to include a magnetic shield in the reed relay package, an approach used by Pickering Electronics for many years. The user is then free to use a layout pattern that best suits the application.



**Fig. 3.4 - Magnetic Shielding**

### Materials and Mechanical Life

The most reliable configuration for a Reed Relay is a Single Pole Single Throw (SPST) arrangement (Form A). Single Pole Double Throw (SPDT) switches (Form C) can be made but the difficulty in making them and the mechanical tolerance results in a product that generally has a lower life than SPST parts. If lifetime is important it can be better to use two SPST relays and drive the coils to synthesize a SPDT switch.

The mechanical life of a Reed Relay is still very long, typically more than  $10^9$  for Reed Relays manufactured by Pickering Electronics for use in low current and medium current applications. The reed switch features a hermetic seal and precise metal contact materials in the contact areas. The magnetic field acts directly on the contact and there are few moving parts.

The hermetic seal also makes Reed Relays a good choice in hazardous environments since sparking does not create a safety problem. The only moving part in the reed switch is the deflection of the blades, there are no pivot points or materials trying to slide past each other. The contact area is enclosed in a hermetically sealed envelope with either inert gasses, or in the case of high voltage switches, a vacuum so the switch area is sealed against external contamination. This gives the reed switch an exceptionally long mechanical life.

The materials used for the precious metal contact areas inside the glass envelope have a significant impact on the Reed Relay switch (and therefore the relay) characteristics. Some materials have excellent contact resistance stability; others resist the mechanical erosion that occurs during hot switch events. Commonly used materials are ruthenium, rhodium and iridium – all of which are in the relatively rare platinum precious metal group. Tungsten is often used for high power or high voltage Reed Relays because of its high melting point. The material for the contact is chosen to best suit the target performance - bearing in mind the material chosen can also have a significant impact on manufacturing cost.

Reed Relays are supplied graded according to their cost and performance. Lower quality commercial switches use Rhodium contacts that are less suited to switching low-level signals because of the build-up of polymer films in the contact area of the reed.

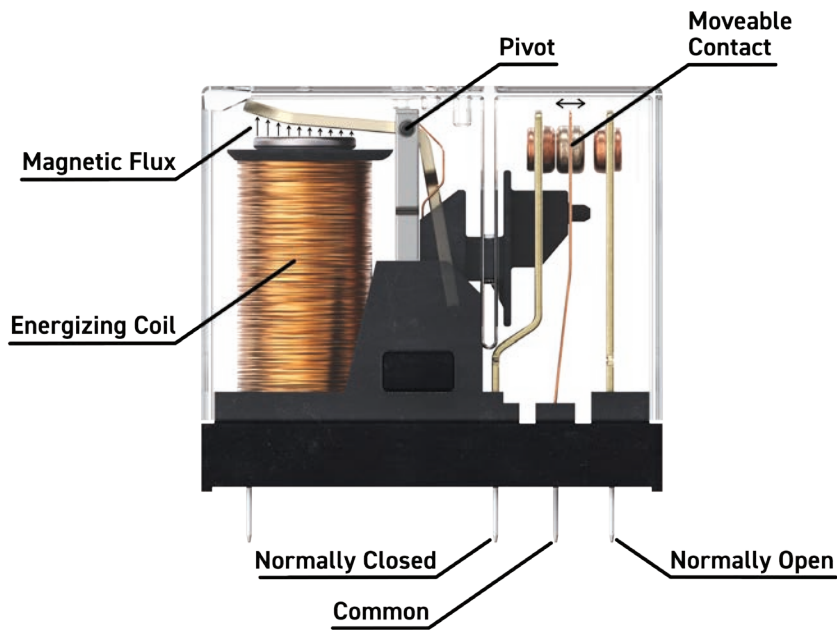
Instrument grade Reed Relays, used on all Pickering Interfaces Reed Relay modules unless otherwise stated, use sputtered ruthenium contacts that are suited for both low-level and high-level switching. The contact areas do not exhibit the same film problems that Rhodium Reed Relays have (or the more severe problems of electro-magnetic relays). If the application is expected to include low-level switching where repeatable contact resistance is required, then instrument grade ruthenium reeds should be specified.

For further information please refer to the Pickering 'Reed RelayMate' book.

# Switching Basics

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## Electro-Mechanical Relays



**Fig. 3.5 - Electro-Mechanical Relay**

Electro-Mechanical Relays (EMRs) are widely used in industry for switching functions and can often be the lowest cost relay solution available to users. EMRs are comprised of an actuator or armature moved by a magnetic field, the actuator in turn moving the position of a contact to make or break a connection. The magnetic coil is physically separated from the contacts being moved to operate the circuit. These are the most common form of relays available and can be used for a large range of switching functions, including high power applications.

Most relays of this type are not hermetically sealed, and this can make them unsuitable for applications where they are required to switch low level signals over long periods. Also, applications where there are flammable vapors – such as testing an aircraft on the flightline – may not be a good choice for EMRs because of their open frame construction. Contamination from the packaging process and plastic out-gassing can result in partially insulating films appearing in the contact areas, leading to increased contact resistance even if the contacts are designed with a wiping action. At higher currents and voltages these problems do not occur because the switching action cleans the contact and breaks down the films.

Some switches may include a specification for low level switching contact resistance that is worse than when switching high-level signals. For switching low-level DC signals hermetically sealed switches, such as Reed Relays, should be used.

EMRs are designed to have a wiping action when the contacts close, which helps to break small welds and self-clean their contacts. This does lead to higher contact ratings but may also increase wear on the contact plating.



EMRs can have much higher ratings and a lower contact resistance than Reed Relays because they use larger contacts, Reed Relays are usually limited to carry currents of up to 2 or 3 Amps. Because of their larger contacts, EMRs can also often better sustain current surges.

There are some notable differences between Reed Relays and EMRs which users should be aware of:

- Reed Relays generally exhibit much faster operation (typically between a factor of 5 and 10) than EMRs. The speed differences arise because the moving parts are simpler and lighter compared to EMRs.
- Reed Relays have hermetically sealed contacts which lead to more consistent switching characteristics at low signal levels and higher insulation values in the open condition. EMRs are often enclosed in plastic packages which provide a certain amount of protection, but over time the contacts are exposed to external pollutants, emissions from the plastic body, and oxygen and sulphur ingress.
- Reed Relays have longer mechanical life (under light load conditions) than EMRs, typically on the order of between a factor of 10 and 100. The difference is due to the lack of moving parts in Reed Relays compared to EMRs.
- Reed Relays require less power to operate the contacts than EMRs. The higher power requirements limit the number of simultaneously relay closures on a module. This may not be an issue for your application, but check the relay closure specification before you purchase to be certain that it meets your needs.

Reed Relays and EMRs both behave as excellent switches. The use of high-volume manufacturing methods often makes EMRs lower cost than Reed Relays, but within the achievable ratings of Reed Relays, the Reed Relay has much better performance and longer life.

### **Mercury Wetted Relay**

This is a type of Reed Relay with a film of liquid mercury retained by surface tension in the contact area to provide the electrical contact. These switches, which typically need a specific mechanical orientation to operate correctly, can have a long mechanical and electrical life. In the diagram here, you can see a Change-Over (Form C) mercury wetted reed switch. The mercury pool is at the bottom of the switch and to operate properly, it must be tipped vertical. The contact points are at the top. A non-ferrous spacer is mounted on the normally closed contact. Without this it would not deflect to the normally open contact in the presence of the magnetic field.

As to the way the mercury moves, the fixed blade that you see in the drawing forms a pump. When the moving blade moves, it squeezes the mercury which then moves up the roughened surface of the blade by capillary action to the contact.

But the presence of mercury in a relay causes environmental and health concerns. Their use is strongly discouraged where alternatives are available, and in many countries, they are banned by environmental legislation.

# Switching Basics

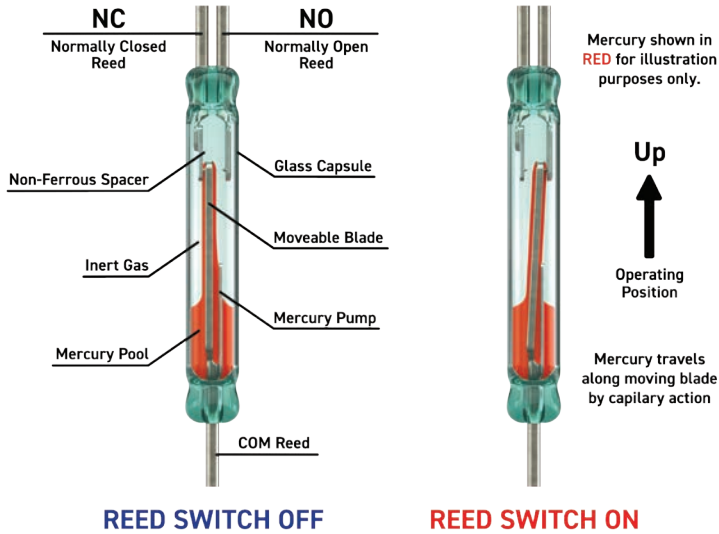


Fig. 3.6 - Miniature Mercury-Wetted Reed Switch (SPDT)

## Edgeline Relays

Edgeline Relays are used in high frequency and microwave switches where a good 50 ohm impedance is required to work at very high frequencies. The 50 ohm transmission line is formed between the edge of a moving contact ribbon and the RF ground plane or metal wall. By tightly controlling the gap between the edge of the ribbon and the wall, a good 50 ohm impedance can be maintained regardless of the position of the ribbon. The gap involved is typically very small and requires precision in the design and manufacture of the part.

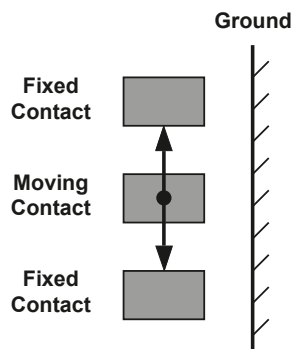
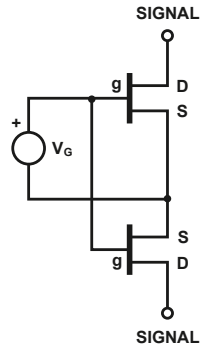


Fig. 3.7 - Edgeline Structure of an EMR for RF Switching

## Solid State Relays



**Fig. 3.8** - Solid State Relay using Two N Channel MOSFETs with an Isolated Gate Drive

Solid State Relay refers to a class of switches based on semiconductor devices. There are a large variety of these switches available. Some, such as PIN diodes, are designed for RF applications but the most commonly found solid-state devices that compete with Reed Relays are based on FET switches. A solid-state FET switch uses two MOSFETs in series and an isolated gate driver to turn the relay on or off. Some key differences compared to a Reed Relay include:

- All Solid State Relays have a leakage current specification, consequently they do not have as high an insulation resistance as EMRs and Reed Relays. The leakage current is also non-linear. The on resistance can also be non-linear, varying with load current.
- There is a compromise between capacitance and path resistance, relays with low path resistance have a large capacitive load (sometimes measured in nF for high capacity switches) which restricts bandwidth and introduces capacitive loading. As the capacitive load is decreased the FET size has to decrease and the path resistance increases. The capacitance of a solid-state FET switch is considerably higher than a Reed Relay.
- Reed Relays are naturally isolated by the coil from the signal path as the coil is wound around the reed switch. Solid state relays have an isolated drive incorporated into the relay.
- Solid State Relays can operate faster and more frequently than Reed Relays.
- Solid State Relays can have much higher power ratings.
- In general Reed Relays behave much more like perfect switches than Solid State Relays because they use mechanical contacts.

## PIN Diode

A PIN diode is a special type of diode made with a P type, Intrinsic type and N type semiconductor material. The structure results in diodes with a relatively long carrier lifetime. If PIN diodes are forward biased and used at frequencies well above the specifications, they behave as resistors, the resistance being dependent on the forward current. This allows them to be used as switches for some RF and microwave applications, but at lower frequencies they become non-linear and behave as conventional diodes.

# Switching Basics

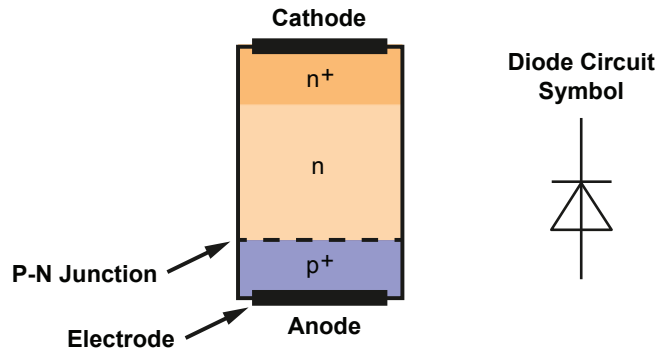


Fig. 3.9 - PIN Diode Structure

## Opto MOSFETS

Another type of Solid-State Relay is the Opto MOSFET (Optically Coupled MOSFET). In certain applications, they are popular replacements for reed relays. These devices are relatively slow in operation, but they feature very good voltage isolation because of the optical coupling. While the Opto MOSFET operation may seem similar to Photocouplers (Also known as an optocoupler or opto-isolator), it is important to note that Photocouplers only conduct DC in the output, while the Opto MOSFET conducts AC and DC signals. Generally, the operating speed of photocouplers is rated in microseconds, while that of Opto MOSFETs are rated in milliseconds.

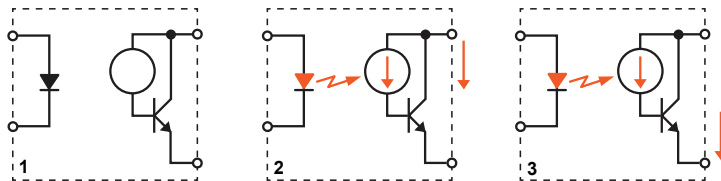


Fig. 3.10 - Photocoupler Operation Sequence

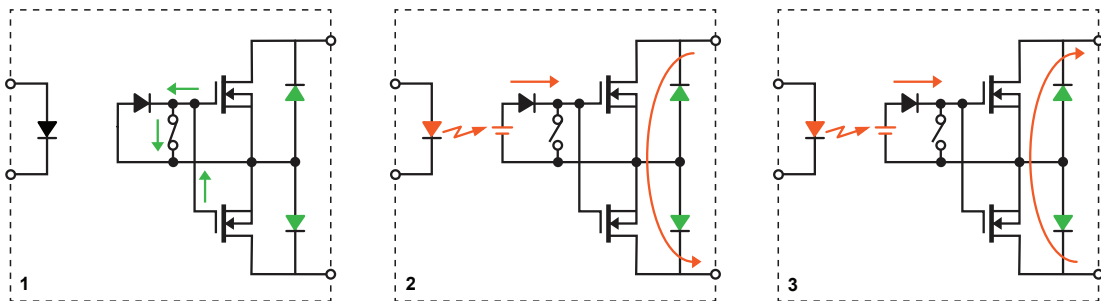


Fig. 3.11 - Opto-coupled MOSFET Operation Sequence (Make-type Contact)

In the drawing here, you see the difference between a standard Photocoupler and an Opto MOSFET. On the Photocoupler, when the LED is lit, the photodiode (Or a phototransistor) reacts and a current flows from the collector to the base, forward biasing the transistor which then passes current from the Collector through the

Emitter. In the case of the Opto MOSFET, when the LED is lit, the photovoltaic cells charge the gate capacitance to increase the gate-source voltage, turning on the MOSFETs in the case of a make-type contact.

## MEMs (Micro Electro-Mechanical Machines)

MEMs switches are fabricated on silicon substrates where a three-dimensional structure is micro-machined (using semiconductor processing techniques) to create a relay switch contact. The contact can then be deflected using either a magnetic field or an electrostatic field. For optical MEMs, mirrors are used in place of switch contacts.

Much has been written about the promise of MEMs switches, particularly for RF switching, but availability in commercially viable volumes at the time of this writing is very limited. The technology challenges involved have resulted in a number of vendors involved in MEMs failing and either ceasing to trade or closing down their programs. It should be noted that MEMs have had reasonable success in testing fiber optic based systems.

Like Reed Relays, MEMs can be fabricated so the switch part is hermetically sealed (either in a ceramic package or at a silicon level) which generally leads to consistent switching characteristics at low signal levels. However, MEMs switches have small contact areas and low operating forces which frequently leads to partial weld problems and very limited hot switch capacity.

The biggest advantage of MEMs relays – if they can be made reliable – is their low operating power and fast response. The receive/transmit switch of a mobile phone for example has long been a target for MEMs developers.

However, at their present stage of development, it seems unlikely MEMs will compete in the general market with Reed Relays because the developers tend to concentrate on high value niche opportunities and military applications.

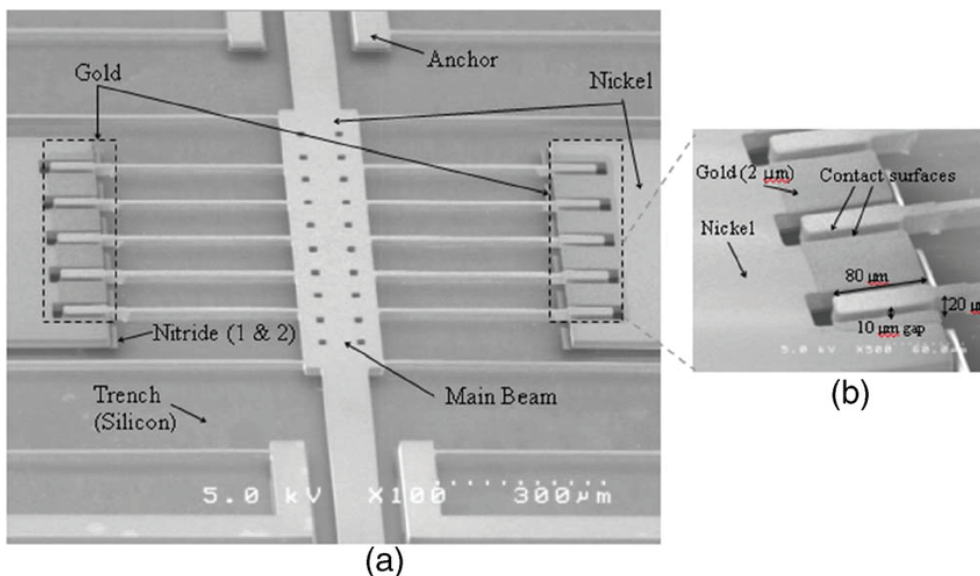


Fig. 3.12 - MEMs Relay Structure

# Switching Basics

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## Latching Relays

Latching Relays have two or more stable positions for the contacts when power is not applied. To change the state of a relay, a coil has a voltage transiently applied to it with a defined duration. Latching Relays can be used for applications where minimization of control power (coil current) is critical or where a power failure requires the switch to be left in the state it was set to until power is restored. The latter case needs careful design to avoid transient change instructions as the power fails. The latching mechanism usually relies on a magnet to provide the latching function.

Latching Relays are generally not used in modern software controlled test systems because the software may not have direct knowledge of the relay state, particularly at power on. Some latching relays can have extra contacts to provide a direct indication of the contact position.

## Safety Relay

Also known as a force guided contact relay, this type of relay is designed with two or more contact sets (poles) and the mechanical design is such that if one contact on one pole fails to change position because of a weld, the other contact on another pole cannot close the corresponding contact. The mechanical design usually relies on forces being applied to close to the contacts.

## Switch Types

### SPST (Single Pole Single Throw) (Can be 1 Form A or Form B)

Form A switches are open circuit with no power applied to the coil.

Form B switches are closed when no power is applied to the coil.

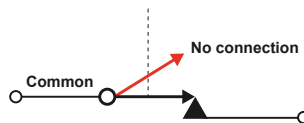


Fig. 3.13 - SPST Switch

### SPDT (Single Pole Double Throw) (1 Form C)

Form C switches have two possible outputs from input.

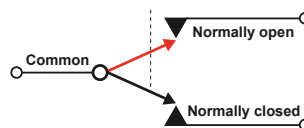


Fig. 3.14 - SPDT Switch

## DPST (Double Pole Single Throw) (Can be 2 Form A or Form B)

Two switches operated by the same control, each switch either being open circuit (no connection) or connected to an output.

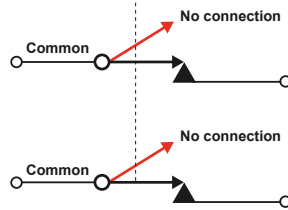


Fig. 3.15 - DPST Switch

## DPDT (Double Pole Double Throw) (2 Form C)

Two switches operated from the same control, each switch having an output connection for the normally open and normally closed contacts.

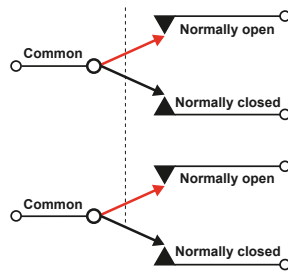


Fig. 3.16 - DPDT Switch

## Absorption Switches

A switch where the contacts that are not being used are terminated in 50 ohms. This avoids the presence of transmission lines that are not correctly terminated and the resonant structures they can generate. It requires the presence of other (embedded) switches that connect the load to the unused contacts but may not be shown on the equivalent circuit.

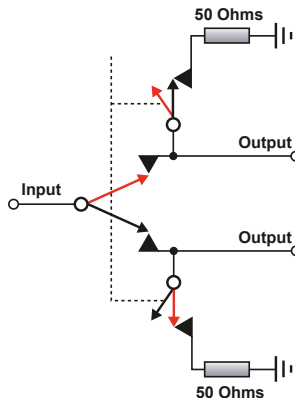


Fig. 3.17 - Absorption Switch





# 4

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# Platforms

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## Introduction

When an engineer is designing a functional test system, the goal is to design and integrate the best system in terms of measurement accuracy, throughput, and budget. Here is one key bit of advice: DO NOT attempt to build your system with just one platform type. This section defines “Platform “ as the mechanical/electrical standards PXI, PXIe, LXI, and USB.

It is important to note that keeping all instrumentation and switching on the same platform is not necessarily required. There are advantages to a hybrid solution, especially in the switching section of the test system. This section will present an overview of the three most popular platforms used for switching today, the advantages of each in various switching applications, and provide some basic questions to ask as you integrate any test system. Also discussed will be the pros and cons of DIY – Do It Yourself - or building a switching platform from scratch.

Of course, simply reading this won't make you an expert, but the information provided will arm you with enough knowledge to search for more details and ask the right questions.

## Which Platform is Best?

Now that the questions about relay and switch types are understood, you need to determine the best platform for the switching in your test system. Remember that, thanks to advances in software and test system architecture, many different platform types play well together, enabling you to select the best platform for your switching, power supplies, and instrumentation without regard to whether they will work together. So, choose the best platform based on performance, budget, and availability.

The first questions to ask regarding platform type depend on how you are structuring your test system and include:

- Switching Only? Is a chassis with just switching advantageous to your design?
- Interface to Test Controller – How do you anticipate connecting all the test elements? Is latency an issue for your test program?
- Voltage Isolation – If you are dealing with high voltage, do you need a level of isolation between the switching and the instrumentation?
- Remote/Distance Control – How close to the host Central Processing Unit (CPU) will the switching be located?
- Product Availability – Do you have vendors available that can support you with Commercial Off-The-Shelf (COTS) products? How long will they provide support?
- Vendor Support – Do you feel that your switching vendor of choice has the products and the support infrastructure to make you successful?
- Single Vendor Solution – Are you OK with dealing with a solution that is only available from one vendor?

# Platforms

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## PXI & PXIe

This section discusses the fundamental differences between the bus and mechanical architectures of PXI and PXI Express. The goal is to understand the differences and allow the reader to make the best chassis selection to support all of their PXI/PXIe requirements. For a deeper technical dive, please download or request a free copy of our PXI mate book at [pickeringtest.com/pximate](http://pickeringtest.com/pximate) or contact your local sales representative.



**Fig. 4.1 - PXI Chassis**

## PXI

PXI was introduced to the T&M market in 1997 (The hardware specification is PXI-1. This nomenclature can be used to describe a PXI module). The PXISA (PXI Systems Alliance) is the organization that manages, updates, and promotes the PXI and PXIe architectures and ensures interoperability of all PXI modules and chassis.

PXI is highly dependent on the Windows Architecture (Linux extensions are also available) and the PCI model of the late 90s. Testing extensions were added to the PXI Backplane to incorporate an internal clock for synchronization and a trigger bus.

Mechanically, PXI is based on the Compact PCI form/factor (cPCI). It is more rugged than standard PC plugins, and PXI chassis accept cPCI modules when necessary.

The PCI model has its good side and its bad side. In terms of switching in large applications requiring multiple PXI chassis, power sequencing is an issue. If you do not power these chassis in the correct order, the PC may not be able to enumerate the buses – this has the potential to lock up your PC or adversely affect the discovery process.

In the PXI platform, several companies are committed to PXI switching. At this time, Pickering Interfaces is the market leader, with more than a thousand choices. Other companies with switching include NI, Keysight and Marvin Test.

Because multiple companies are selling switching, there are regular new product introductions, giving you more choice. This breadth of choice means that new systems and upgrades are easily replicated with minimal effort.

Switching density has significantly progressed in recent years. It is now possible to get up to 528 cross-points on a PXI module that occupies just one chassis slot, potentially saving valuable slot count for other instruments.

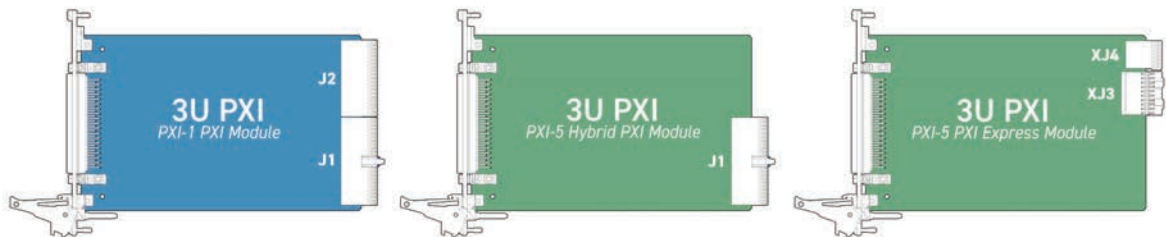
## PXI Express

As the demands on PC speed grew, the speed of the PCI bus increasingly became an issue. The concept of a multi-drop system based on a parallel bus structure was becoming ever harder to scale to escalating PC performance requirements. A breakthrough was made by introducing a fast serial interface, PCI Express (PCIe), which carries data on wire pairs usually referred to as PCIe lanes. A single lane of a Gen 3 PCIe backplane exhibits data speeds of up to 1.0 GT/Second, much faster than a PCI 32-bit interface. If greater speeds are required, lanes can be aggregated into higher data rate connections, with four lanes being popular. The serial connection is also point to point. A particular connection only carries traffic destined for the node connected at its end and has no un-terminated transmission line stubs to distort the high-speed waveforms. This serial interface system is inherently more scalable than a parallel bus system.

In 2005, the PXISA issued the PXI-5 PXI Express hardware and PXI-6 PXI Express software specifications that integrate PCIe technology into the PXI platform. The latest release for the hardware specification is Rev. 1.1 (May 2018), and the software specification is Rev. 1.4 (March 2020).

### Module and Backplane Differences

PXI and PXIe modules can be easily identified by their connectors. Here you see a standard PXI-1 module, a Hybrid PXI module, and a PXIe module. The PXI-5 Express module also has two connectors labeled XJ3 and XJ4. The PXI example here will only plug into a full PXI-1 slot.



**Fig. 4.2 - PXI and PXIe Modules**

In most cases, however, PXI vendors do not need the capabilities defined in the J2 connector and do not install it. In the PXI-5 specifications, this is called a “3U Hybrid Peripheral Slot Compatible PXI-1 Module”, which we will refer to as a PXI-5 Hybrid in this document. The PXI-5 Hybrid module can plug into a PXIe “Hybrid” slot in this configuration. Let’s look at an example backplane.

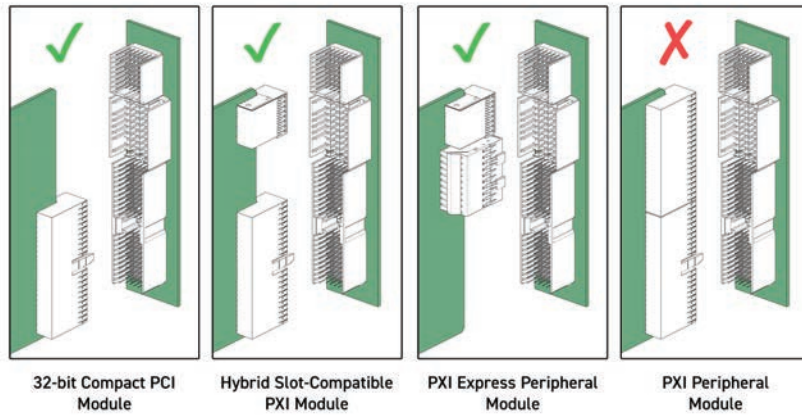


Fig. 4.3 - Fitting a Module to a PXIe Hybrid Slot

## PXIe Chassis - Configuration and Glyphs

In the image below, you can see a PXI hybrid chassis that supports all PXI-1 and PXIe types. You can see the original PXI-1 connectors J1 and J2 in slots 6, 7, & 8. Slot 3 is a PXIe only slot, and Slot 4 is a PXIe timing slot. As it has XJ3 and XJ4, slot 4 can support either a timing module or a PXIe peripheral. Finally, slot 5 is a hybrid slot supporting PXIe and PXI-5 hybrid modules. Note the color differences in the glyphs for each slot – PXI-1 is white with black numbers, and PXIe is black with white numbers. The timing slot (Slot 4) has a PXIe glyph surrounded by a square, noting that this slot supports either a timing module or a PXIe peripheral module.

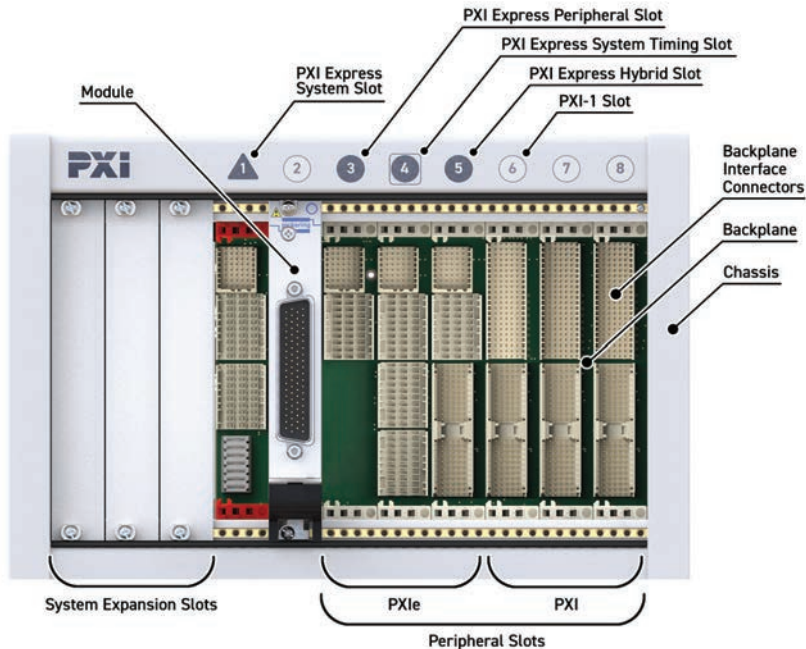


Fig. 4.4 - PXI Chassis Supporting PXI and PXIe Modules

## Chassis Selection

Armed with this knowledge, you can now select your chassis. The PXI-1 and PXIe chassis slot counts are the same, typically 8, 18, or 19. The important thing here is what module each slot supports. Some chassis are all PXI Express, limiting you to modules with only a PXIe interface, some mix in a few hybrid slots, and some are all hybrid slots. So, review your module requirements and their buss structure before making a chassis selection. That said, it's important to note that chassis with all hybrid slots offer the most flexibility in module selection. This becomes critical if a needed function is not available in a PXIe form factor; a hybrid slot will accept either a PXIe or PXI-5 module but not a PXI-1 module. Virtually all PXI Members manufacture chassis that have PXIe chassis models with hybrid slots. This should be one of the features that needs to be supported by your vendor of choice.

It should also be noted that since PXI Chassis vendors support hybrid slots, the PXI-5 Hybrid modules will be supported for the long run. So, there should be minimal concern in this instance. And should a PXI manufacturer decide to obsolete their PXI-1 modules, they are most likely to make a PXIe version, which would be software compliant with the PXI-1 module, thereby preserving your test programs investment.

## Bus Speed and Switching Speed

As stated at the beginning of this section, PXIe has much faster data transfer rates than regular PXI. This speed advantage that PXIe offers will exhibit little to no improvement in switching speeds when it comes to signal switching. This is because switching does not require much bandwidth compared to many instruments. Also, most of the execution time of a switch is limited by its mechanical nature. So, if you cannot find the switch configuration you need in PXIe, but it is available in PXI, you are still OK as long as you have an available hybrid slot in your chassis.

Pickering Interfaces duplicates many of its PXI modules in the PXI Express format. At present, we have over 200 models available in both PXI and PXIe configurations. This will increase over time but remember that the software is compatible between either configuration. So, your programming effort is protected if you start your development using PXI switching and it becomes available in PXIe.

## 6U PXI/PXIe

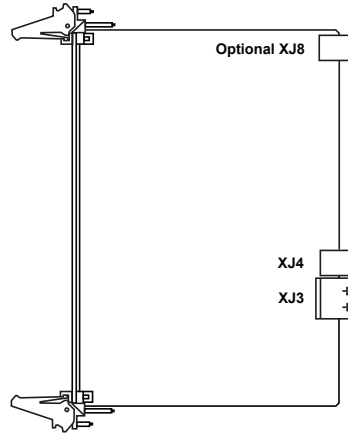
The PXI standard permits a chassis to be designed in 3U height, 6U height, or to have both 3U and 6U modules inserted in one chassis. 6U Modules are roughly twice as large as the 3U modules normally used in test systems. The larger size clearly has more room for switching and instrumentation. However, the 6U modules have the same 0.8-inch pitch of 3U PXI, so there are limitations to connectors.

6U PXI/PXIe has found favor in military branches around the world as well as defense contractors. One reason is that they can design in greater complexity because of the PCB's greater real estate. There are not as many PXISA members building 6U PXI. But as 6U chassis can accept 3U PXI (With a slot adapter for the greater height of the 6U in a pure 6U chassis and to keep the cooling air moving inside the chassis), a mix of 3U and 6U modules are used in a lot of applications. Looking at the chassis in Figure 4.7 (Courtesy of Marvin Test Systems), you can see one implementation which has a 3U and a 6U backplane. As noted above, the 3U modules can also plug into the 6U backplane as well.

The same rules for connectors for PXI-1, PXI-5, and PXI-5 hybrid modules apply. When selecting a 6U chassis, make sure the vendor of choice has the number of slot types you require for your application.



**Fig. 4.5** - Pickering 6U PXI Module  
45-542



**Fig. 4.6** - 6U PXIe Module



**Fig. 4.7** - 3U/6U PXI/PXIe Chassis  
(Courtesy of Marvin Test Solutions)



## LXI

Similar to PXI, LXI Ethernet has several switching vendors, making for a great many choices.

It should also be noted that both PXI and VXI switching platforms can also be LXI compliant, allowing switch modules to be sited in a separate chassis to the test instrumentation. The transformer coupling of Ethernet provides voltage isolation from the rest of the test system.



**Fig. 4.8 - LXI Microwave Multiplexer (2U)**

Generally, many LXI switching systems are ideal for solutions needing diverse and highly integrated switching. This includes large I/O counts and high power. The mechanical freedom of LXI switching allows for a wide variety of solutions that would not easily fit in other modular platforms.

LXI's Ethernet interface is simple to use and maintain. Localized intelligence provides freedom from the power sequencing issues previously mentioned. Built-in software drivers speed the initial starting and install process of a test system integration.

If your testing requires switching remotely from a host PC, LXI and Ethernet assure control of your switching in the next room or around the world.

It should be noted that an LXI device that conforms to version 1.5 dated March 2017 (The latest specification) does not support any real time applications. This is because of the nature of Ethernet which is not deterministic. For real time applications, Pickering Interfaces recommends a pure PXI Solution.

## USB

This platform is being seen more frequently in test. USB is now as widely adopted as Ethernet in PCs. The latest specification, USB 3.0, is more robust than previous versions and much faster. The downside is that there are few choices in USB switching at this time, although it is anticipated that this will change in the coming years.



**Fig. 4.9 - 4-Slot LXI/USB Modular Chassis**

# Platforms

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Like LXI, USB can be used for remote data acquisition, although not as distant as LXI. We find that USB switching is seen as complementary to USB Data Acquisition in many applications.

In small benchtop applications, USB switching is simple to install and use.

The downside is that most USB switching platforms lack a locking connector, so the test engineer must address any strain relief needed.

## So How Do You Choose?

As we stated earlier, no one platform easily fits all applications.

**PXI** excels at:

- For compactness, PXI makes it easier to include switching and instrumentation in a single chassis.
- The high interface speed of PXI makes the instrumentation portion of your test system much more efficient.
- Because PXI is Windows-based, you normally deal with a single software environment.
- For compactness and portability, the PXI chassis can have the application controller and switching in a single chassis.
- Finally, PXI switching is best implemented with a diverse mix of different switching functions, mostly small to medium I/O count.

**LXI** also has its advantages:

- High Power, Current or Voltage Switching. This is because of the physically large relays and connectors that do not fit well in PXI.
- Microwave Switching, again because of the size of large microwave switches with coaxial interconnection.
- Switching Remote from the Controller. Ethernet control reaches a long way, across a building or around the world.
- LXI's local intelligence allows for simple recovery from power interruptions.
- There are standalone LXI chassis that can accept PXI switch modules for applications requiring a variety of switching types.
- If your company has made a corporate mandate to using LXI for all test applications, there are solutions to meet most switching needs.
- Finally, in very complex applications, the internal processor of an LXI device relieves host CPU overhead, which can reduce the test times.

**USB** is similar to LXI:

- Remote testing with USB is easily implemented. Also, the internal processor relieves host CPU overhead for very complex applications, much the same as LXI.
- Because USB is ubiquitous and has a very reasonable integration cost, low-cost test systems are easily implemented in USB. USB switching saves the limited slot count in the PC for

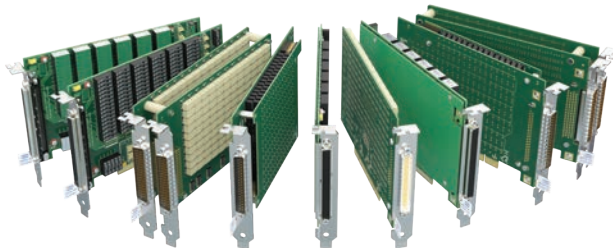
instrumentation for industrial PC applications. It can also move electrical switching noise outside of the PC, making it easier to make measurements.

## Other Platforms

Besides the platforms described in this section, there are other platforms in the market. At present they are less popular for switching but you may want to consider them.

### PCI:

Intel developed the Peripheral Computer Interconnect in the 1980s. Available in 32-bit or 64-bit configurations, with either a 32 MHz or 66 MHz clock, the maximum data rate is up to 533 Megabits per second. The PCI bus was superseded by the multi-Gigabit PCI Express. Because switching does not require this kind of bandwidth, it has remained available in Conventional PCI. This bus standard is no longer available on standard desktop PCs but remains popular on large industrial PCs. Pickering does still have a line of PCI switches and simulation modules available.



**Fig. 4.10 - A Range of PCI Cards**

### GPIB:

General Purpose Interface Bus, also known by the instrumentation standard number IEEE 488, has existed for more than 40 years and is still used today. The GPIB Standard is an 8-bit parallel communications standard. Maximum data rates are up to 8 Megabytes/second (IEEE 488.1), which is more than adequate for switching. But that data rate gets progressively slower when many instruments are connected to the bus. Several companies still manufacture GPIB based switching systems, but for the most part, they are older, potentially obsolete designs and tend to be expensive.



**Fig. 4.11 - GPIB Modular Chassis**

## Platforms

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### VXI:

VXI was the first modular standard defined in 1987 and became an IEEE standard in 1993. The military and defense industry embraced the standard, and it was used by every military prime contractor and all branches of the military in many countries around the world. Hundreds of CASS, IFTE, LANTIRN, and VIPER systems were deployed on bases, ships, and trucks.

But at the beginning of the 21st century, PXI was beginning to overtake VXI in its acceptance. There are still nine members of the VXIbus Consortium; however, there have been no new products listed on the VXIbus.org website in over four years. So, in general, VXI is not specified for new systems.

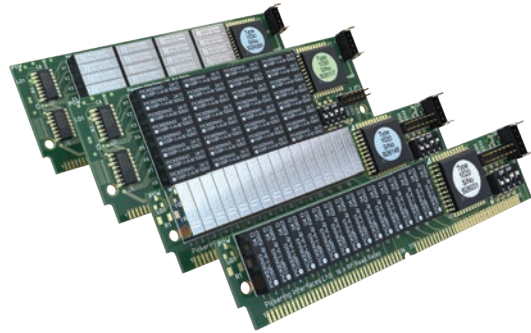


**Fig. 4.12 - VXI Modular Chassis**

Pickering Interfaces initiated a VXI to PXI migration program several years ago. You can find this information at [pickeringtest.com/vxitopxi](http://pickeringtest.com/vxitopxi).

### Proprietary Designs

Several companies are making switching in form factors unique to them. Because each product is only available from one company, unlike standards such as PXI and LXI, careful consideration should be made to ensure that they can address your switching needs. Examples of proprietary switch products include the SIMRC line from Pickering Interfaces small (16 relays maximum) PCBs designed to be installed in a test fixture and controlled serially. Other examples include the NI CompactRIO®, a rugged system that combines Ethernet control and local processing with modular, conditioned I/O modules and can control up to 64 relays in one chassis. Also, there are UEI's (United Electronic Industries) Cube™ and RACKtangle™ chassis. These products are Ethernet-controlled and support a wide variety of switching boards from UEI for general switching applications and the company's analog and digital I/O and avionics interfaces.



**Fig. 4.13 - SIMRC (Pickering Interfaces)**



**Fig. 4.14 - CompactRIO (NI)**



**Fig. 4.15 - CUBE (UEI)**

### DIY – Should You Build Your Own Switching System?

Back in the early days of functional test, most switching systems were built from scratch because few choices were available. So, test engineers needed to innovate. Fast forward to today and, even with the broad selection of COTS switching on the market, there are still some companies that build their own switching systems. This test strategy tends to be implemented in emerging countries with lower salaries than the rest of the world, but there are exceptions.

This is not to say that you should not design your switching. Instead, it should be pointed out where it can be cost-effective, and it is essential to make you aware of the potential challenges. In the end, your decision should be based on cost, complexity, and time to market.

- **KISS** (Keep It Simple Switching) If your switching requirements are extremely simple – e.g., a few SPST relays to simulate DUT switches, High Current Input Power only, etc. – there is little reason not to think about building up a set of relays on a simple PCB or breadboard. There are relay driver modules available in PXI and USB, making the job of controlling them from software relatively simple. If you must work with high input power, requiring a relatively large contactor, DIY is a good strategy because these types of switches do not fit well into a modular test format.
- **Applications** – There are times when your application is so unique that a COTS solution is just not good enough. So when looking at the specifications of the signals, you will assess that the switching exhibits acceptable insertion losses. Where the switching needs to be located, we recommend that you talk to as many different switching vendors as possible before making this choice.
- **Managing Your Costs** – It is often thought that internal labor is “free,” so your cost of switching development is lower than COTS solutions. If that is how your accounting folks see direct labor, then go ahead. But that is happening less often in modern industry environments. So be sure you keep these costs in mind.
- **Time To Market** – How long before your test system is to be implemented on the production floor? Unless you have a very large staff to throw at a project, switching system development can be as tedious as any new product design. As stated above, a straightforward switching development can be a no-brainer for internal development. But the more complex it is, the more time you need to allocate.
- **Protection Against Magnetic Fields** – If you are new to switching system design, the following information can be vital. The fact that relays are magnetically operated can cause a potential problem for users when they are assembled in dense patterns on PCBs, especially if you are designing with Reed Relays.

For example, the magnetic field required to close the Reed Relay blades flows through the nickel-iron reed blades and returns by field lines that are outside the Reed Relay body. If several relays are placed close together, the external field lines can be drawn by the neighboring reed blades and either reinforce or partially cancel the field in the reed, changing the current needed to close or open the contact. This can, in some circumstances, cause enough effect that the relay may either fail to close or open depending on the magnetic polarity. Some manufacturers suggest arranging the relays in different polarity patterns to mitigate the worst effect of the interaction, but this can become a complex compromise in dense arrays of relays where there are many near neighbors.

A much more sensible approach is to include a magnetic shield in the Reed Relay package, an approach used by Pickering Electronics for many years. The user is then free to use a layout pattern that best suits the application. The approach has the added benefit of improving the coil efficiency since it concentrates the magnetic field lines closer to the reed switch body, shortening the magnetic field length outside the reed blades and creating a larger field for a given number of ampere turns in the coil. Lower coil operating currents simplify coil driving and improve other parameters like thermoelectric EMF generation.

- **Support** – Once your test system is ready, where will it be deployed? If the answer is some other country, be prepared for support issues. All major COTS test instruments and switching manufacturers have field support staff to resolve most test system problems under warranty. In the case of a custom switch system, your company is responsible. So, for example, if your company designs a switching system in the US and is deployed to Malaysia, count on late-night phone calls and remote diagnostics.
- **Documentation** – Custom-designed switching too often has minimal documentation because most of the engineer's time was dedicated to the functional project. Besides, the engineer knows what he built and how it works! But explain that to an engineer overseas, especially if the designer has left the company.





# 5

## MIGRATING SWITCHING FROM LEGACY SYSTEMS

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# Migrating Switching from Legacy Systems

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## Introduction

There comes a time in the life cycle of a test system when it becomes obsolete. This may be because the product it was testing is no longer manufactured. More likely, the problem may be that the instruments or switching system became obsolete, so test engineering can no longer support the applications should a test system failure occur. This is a very pressing problem today, especially in the aerospace and defense industries. Aircraft and weapon systems are used for a very long time. For example, the US Air Force's B-52 was designed and built in the 1950's and yet those aircraft are still being used and upgraded. An ATE system in this segment of the market is expected to support applications for 15 years, 20 years, and even longer!

For the military and aerospace industries, many of the legacy systems are VXI-based. Developed in the 1980s, the aerospace and defense industries were early adopters of modular test platforms. One of the first successes was VXI and it has served these industries very well for more than 30 years. Now as VXI test systems become obsolete, test system developers look to PXI as the next generation modular platform for their industries.

In this section, we will focus on migrating VXI-based switching to a PXI platform. If you are migrating other platforms like GPIB, the thought process is similar.

## What Is VXI?

VME eXtensions for Instrumentation (VXI) is an open standard platform for automated test based on the modular VME computer bus. Introduced in 1987, this modular chassis-based architecture reduced the size and increased the performance of high-end test systems. VXI systems provided higher data transfer rates and real-time performance not possible with rack-and-stack systems, and were principally successful in the military and aerospace markets.



**Fig. 5.1 - VXI Chassis with Modules**

In the past, VXI was proven to be a popular architecture with the military, their prime contractors, and commercial ATE systems integrators. In 1999, according to Prime Data, the total yearly sales of VXI Modules and VXI-based Standard Systems were estimated at \$750 Million. Prime Data was forecasting a 16% growth in the VXI market in 2000, and continued growth through 2004.

# Migrating Switching from Legacy Systems

At that time, approximately 1200 VXI products were available from 80 test equipment vendors. Checking on vxibus.org, today only 9 companies still manufacture VXI modules. VXI is now more than 30 years old and many of the leading test and measurement companies are no longer supporting the standard.

VXI still has a strong offering in Data Acquisition. But in switching, there are only two switching vendors left and no new product introductions in years.

## What Are Your Options?

VXI defined three module sizes – B, C, and D. C-size modules were the most popular for ATE systems. The PXI specification primarily describes a 3U implementation. There is a 6U specification, but very few PXI Systems Alliance (PXISA) Members adopted it. Dimensions of C-size VXI compare to 3U PXI as follows:

	C-size VXI	3U PXI
Height	9.2 in	3.9 in
Depth	13.4 in	6.3 in



**Fig. 5.2 - VXI and PXI Size Differences**

Clearly, there is more real estate in a VXI module. Also, a single-slot VXI module has a width specification of 1.2 inches (also referred to as 6 HP) while a single slot 3U PXI module is only 0.8 inches wide (4 HP). So larger components will require a multiple slot PXI module.

It is obvious that you cannot pack the switching of a C-size VXI module into a PXI module without occupying more than one slot ... at least on the surface.

So, if I am going to migrate a test system from VXI to PXI, what do I need to know?

## Specifications

The first thing to do is analyze your present test system and the applications it is required to test. It is possible that the switching you have in VXI is overkill in terms of current, voltage, and even relay count. If so, when

# Migrating Switching from Legacy Systems

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specifying PXI modules, you might be able to select smaller, lower power modules which can save money on your test budget. But this cannot be assumed to work. So, the questions to ask are:

- What is the maximum voltage to be switched?
- Will the signals be hot or cold switched?
- What is the maximum current to be carried?
- How much power must be dissipated in each switching channel?
- What is the maximum frequency of any signal in the switching module?
- Will this PXI-based migration be required to test newer applications? If that is the case, you may need more switching than was available in the previous VXI-based system. So, you will either need to plan for more switching hardware or at least allocating additional slots in a PXI chassis for future expansion.
- What are the configuration sizes needed? By that, we mean the number of individual relays required, the channel count of the multiplexer, and the matrix size? Remember that your VXI system may have more switching channels than is necessary.

## Do Your Homework

Now that you have a clear understanding of what you need, you can research the PXI vendor offerings. Pickering Interfaces offer a cross reference table from their PXI offerings to match most of the popular VXI switch modules from the major manufacturers on their web site. It is likely that other PXI manufacturers offer cross references as well. Check with your vendor of choice.

## Mass Interconnect Versus Cable Connections to the DUT

Depending on the method of interfacing your test system to the DUT, migrating to a PXI-based switch system could be relatively easy. If your test system uses a Mass Interconnect (explained in Section 7), the migration is relatively simple. This is because all the connections to the DUT will be the same as before by interfacing to the Mass Interconnect. It is the other side of the Mass Interconnect that will change. All that is needed are small adapter cables or pull-throughs to go from the PXI switch to the Mass Interconnect.

If your test system uses cables to connect to the DUT, these will all have to be replaced or at least be rewired, because in almost every instance, the connectors on a PXI module will not be the same as those on the equivalent VXI module. Because VXI modules were much wider than PXI modules, the VXI vendors took advantage of the added space and used larger and often more robust connectors.

## Software

Fortunately, there was a push towards software standardization in the early 1990s. The VXI P&P (VXIplug&play Systems Alliance) was an organization whose members shared a common commitment to end-user success with open, multivendor VXI systems. The alliance accomplished major improvements in ease of use by endorsing and implementing common software standards and practices, beyond the scope of the VXIbus specifications. These standard frameworks gave end-users “plug & play” interoperability at both the hardware and system software level. The VXIplug&play Systems Alliance merged with the IVI

# Migrating Switching from Legacy Systems

(Interchangeable Virtual Instruments) Foundation in 2002. So, much of the software standards are still applicable. See Figure 5.3 (IVI System Architecture). It is worth noting that IVI drivers do not replace VISA, and typically use VISA as the I/O Library for the IVI driver to send commands.

If your VXI-based test programs were generated under the guidelines of the VXI P&P, specifically the VISA Layer, much of your code can be reused.

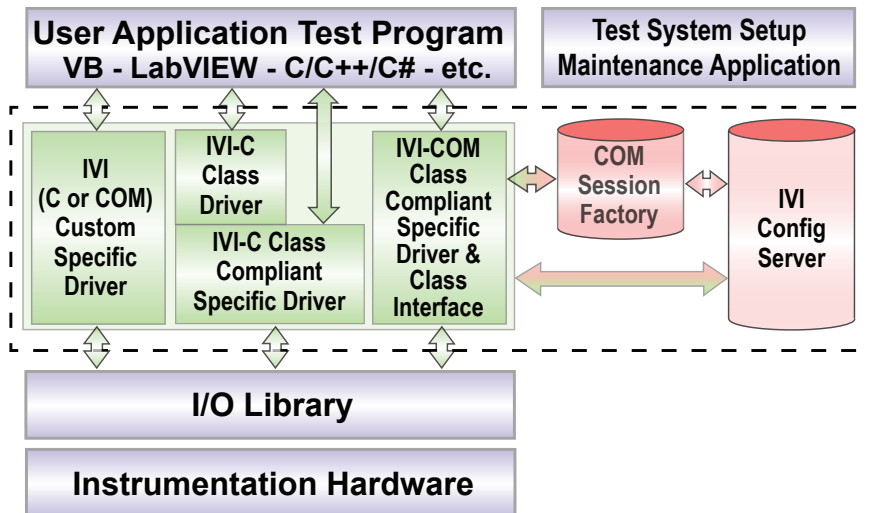


Fig. 5.3 - IVI System Architecture

IVI did not take off quickly in the early days. The reason was mostly competitive – If I write an IVI Driver for my customers, what is to stop them from replacing my product with a competitor's when the code will work for both vendors?

Another reason that slowed adoption was test speed. In 2002, PCs were not nearly as fast as today's models. Adding an extra layer of software could potentially slow things down because CPU resources were tasked with extra code.

That last reason is not as critical in today's test environment. But if you are migrating older test code, you will need to see if an IVI layer was incorporated into the test strategies.

# 6

## SWITCHING CONFIGURATIONS

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# Switching Configurations

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## Switching Configurations

### Cascade Switch

Cascade switches can be used to connect a single device to one of many others. Connection to one device ensures that all other connections are isolated. The disadvantage with this method is that the path length and the isolation specification vary with switch position resulting in variable insertion loss and screening depending on which path is in use.

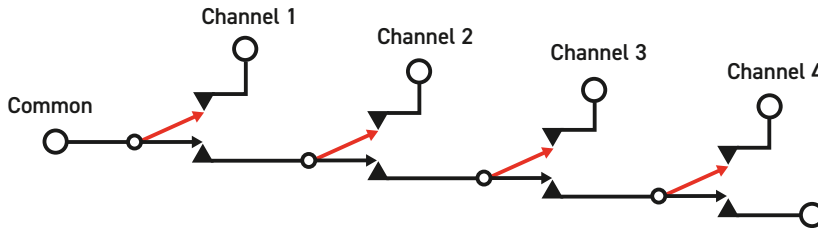


Fig. 6.1 - Cascade Switch

### Multiplexer

The word 'multiplexer', also known as a 'mux', as it relates to automated test is generally used to describe a switch that connects a common point, such as a Power Supply output or DMM input, to two or more test points usually referred to as channels. However, at least one test company calls this configuration a scanner. Multiplexers can be architected in many different ways (e.g, tree, bussed, cascaded, differential/controlled impedance, single-pole or multi-pole) but ultimately their value is in their ability to route a test instrument to multiple UUT points allows the test engineer to minimize the number of test instruments used in an ATE system. The multiplexer architecture will also determine whether or not multiple test points can be connected to the common line simultaneously, though the application requirements will dictate if that is a requirement. Finally, multiplexers have application usage across a broad range of electrical specifications, from low to high voltage and current, and DC - Light.

### Single Channel Multiplexer

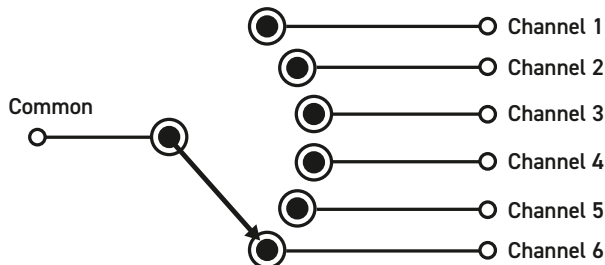


Fig. 6.2 - Single Channel Multiplexer

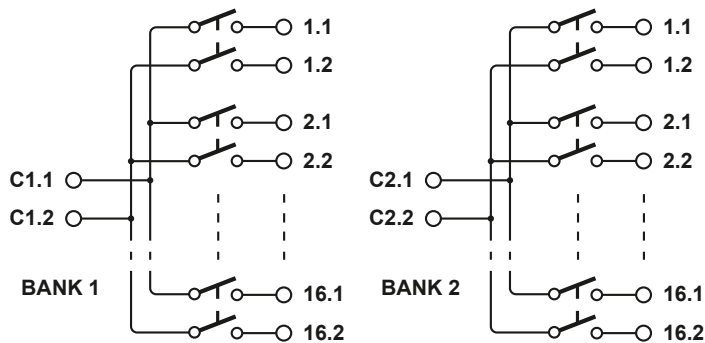
A single channel multiplexer allows one instrument to be connected to any of a selection of other instruments and/or DUT Test Points. Some definitions allow more than one connection, so one instrument could be connected to more than one output. In terms of RF systems, this is not a satisfactory arrangement, since it

# Switching Configurations

incorrectly terminates transmission lines. Relay switches are bidirectional, allowing input and output to be swapped.

## Multi-Pole Multiplexers

A multiplexer is defined as a certain number of channels, e.g., an 8 channel multiplexer. Channels may have multiple poles. This could be used to connect a 4-wire DMM to make multiple measurements in sequence. So, for example, if you had to make twenty-four four-wire measurements on a DUT using the same instrument, you would have to select a 4-pole, 24 channel multiplexer. COTS (Commercial Off The Shelf) multiplexers can have as many as 32 poles.



**Fig. 6.3 - Multi-Pole Multiplexer 40-635A-006**  
*Dual 16-Channel 2-Pole*

## MUXM

At the beginning of this section, it was noted that a multiplexer makes connections from the input to an output channel, one channel at a time. In the case of Pickering multiplexer modules, when you turn a second relay on, the first will switch off automatically in a “break before make” sequence via software, thus changing the channel connection.

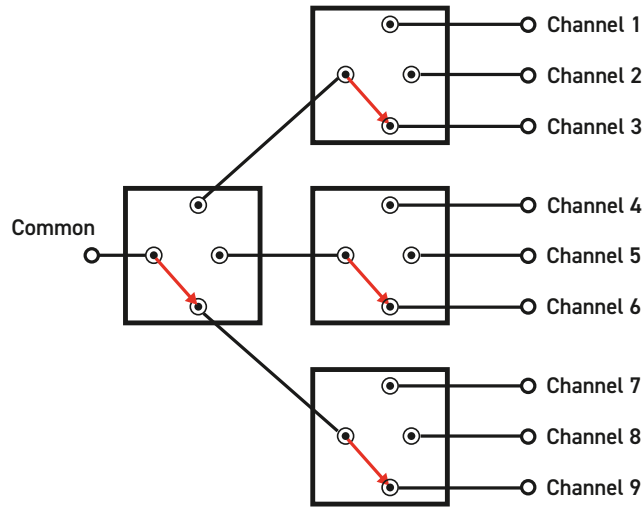
But Pickering has an option on many of its multiplexers called “MUXM” (It is noted on the datasheet as a “-M” option). MUXM means you can turn all the relays on one after the other and they will stay closed until turned off by a command in the test program.

So MUXM gives the test engineer more flexibility with switching the relays, but an extra command is required for switching relays off – there is no break before make sequence in MUXM mode. So if the test engineer is not careful in the MUXM mode, the program may short two or more signals together and generate a fault.

At least one test company calls this configuration a ‘multiplexer’. As you can see, there can be confusion on the form and function of this type of configuration. Be certain that you understand the operation of the multiplexer or scanner from your switching vendor of choice. By the way, Wikipedia’s definition of a multiplexer supports Pickering’s definition.

## Tree

Tree networks expand a switch system’s dimensions by connecting a series of switches in series. The simplest networks are based on SPDT switches which can be used to create larger multiplexers.

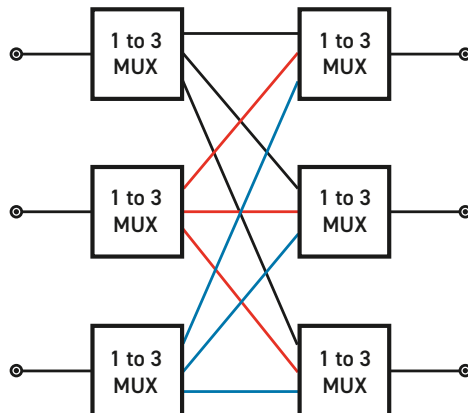


**Fig. 6.4 - Tree Switching Network using SP3T Switches to Create a 1 to 9 Channel Multiplexer**

A tree switching network can also expand the capacity of the multiplexer at the expense of more switches and greater insertion loss. In tree networks each of the paths has the same number of switches, and to a first approximation, insertion loss will be the same for each input to output route.

## Matrix

A matrix switch allows several devices to be connected to a number of test points on the DUT. For RF applications only one device should be connected to any one output, unless the switch includes power dividers.

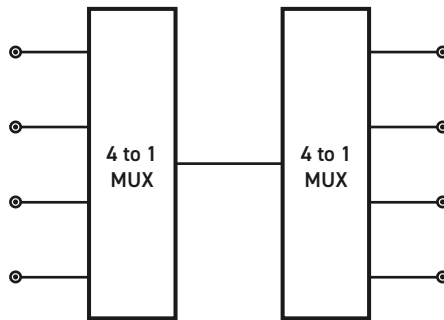


**Fig. 6.5 - A 3x3 Matrix Switch Constructed from 3-Way Multiplexers**

Some types of matrix switches are configured as a blocking switch in order to reduce complexity. The example below shows a matrix where only one device at the input can be connected to one device at the output. All other inputs and outputs are disabled. Some manufacturers also refer to a blocking matrix as a “sparse” matrix.

# Switching Configurations

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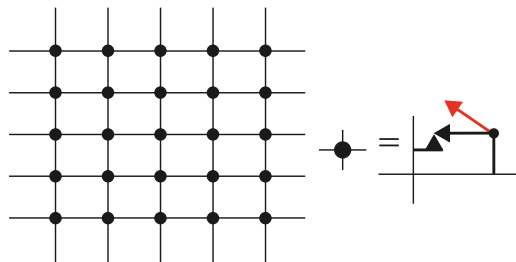


**Fig. 6.6 - A Blocking 4x4 Matrix allowing only One Connected Path**

Matrix switches with no blocking limitations become very complicated, the number of switches tending to increase geometrically with the number of connections allowed. For applications where the blocked paths are not required, or an alternate method can be adopted to circumvent them, the simpler matrix may offer better performance and lower cost because of the lower switch numbers. The blocking matrix will, however, impose restrictions on future test applications.

## Crosspoint Matrix

Crosspoint switches are arranged in rows and columns. A switch located wherever a Crosspoint occurs allows the row and column to be connected, hence the name. There is no limit to the number of connections a particular row or column has, but if more than one connection is made the load on the signal source increases.

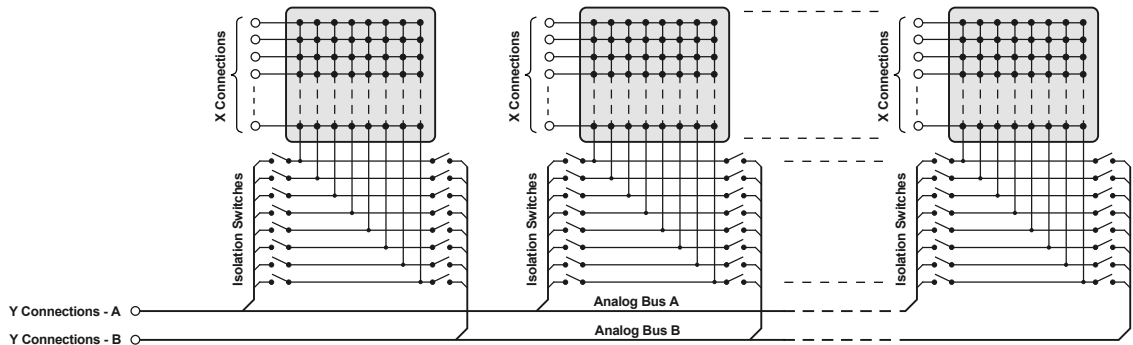


**Fig. 6.7 - Crosspoint Switch**

Crosspoint switches are also often described as (or are part of) matrix switches, especially in applications where rows and columns are intended to have only one connection point.

## Analog Buses

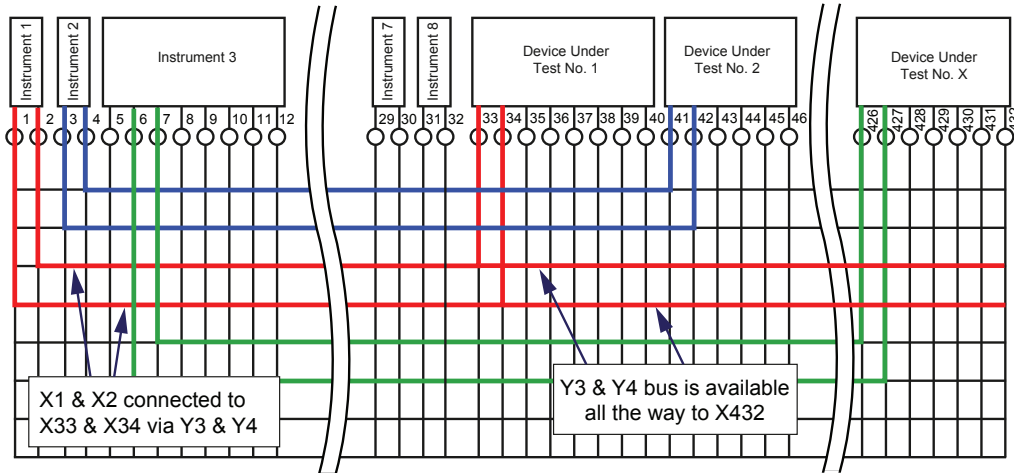
Typically, the Y-axis rows are considered a single analog bus. In this instance the Y-axis rows connect to all X-axis columns. In some designs, the test engineer is able to create multiple matrices programmatically by "separating" the matrix into one or more smaller matrices. In this configuration, relays are added in the Y-axis such that multiple Y-axis buses may be connected, each one accessing a section of the matrix's cross points. The advantage is that the matrix is more flexible in that it can be configured in several different ways as may be needed by the test program for as particular DUT. It may also reduce the number of slots required for a test system by eliminating the need for a second matrix. In the example here, you see a switching system that may be flexibly configured into one or two separate matrices.



**Fig. 6.8 - Dual Bus Matrices**

## Stub Length

One of the downsides of a matrix becomes evident as signal frequencies go higher. Crosspoint matrices always have interconnections across the whole X and Y axes, and at high frequencies these can act as unterminated transmission lines, or “stubs”. These can create resonant structures and limit the bandwidth of the switch. The available bandwidth is also dependent on the number of crosspoint switches closed.



**Fig. 6.9 - Stub Example**

In this example, an Instrument is connected to a device under test via the Y3 and Y4 row. The problem is that the Y axis rows are quite long in this application, spanning 432 X columns. X2 is connected to X33 via the interconnecting row Y3, but this row extends to an additional 399 X columns. This portion of the row acts like an antenna and can seriously degrade the signal and induce cross talk. The matrix manufacturers will normally refer to the max frequency that a matrix can support with minimal stub length issues.

Several matrix manufacturers use “Isolation Relays” that will disconnect the excess stub length when necessary, thus improving performance. Look for this feature if higher frequencies need to be considered.

# Switching Configurations

## Two Pole Matrices

When a signal needs to be measured with a shielded connection (controlled differential line impedance), two pole matrices are recommended. For this configuration, DPST relays are used instead of SPST relays. A second example is when you are switching a voltage source and are using remote sense to ensure regulation at the DUT is being sensed - the two-pole arrangement ensures that the sense connection follows the power connection.

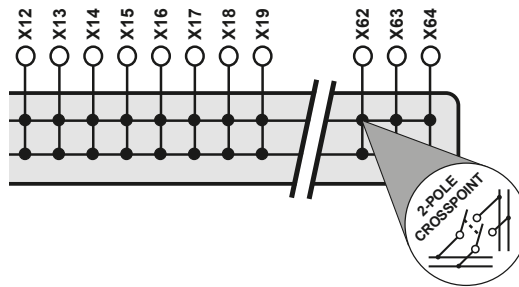


Fig. 6.10 - A Matrix 2-Pole Crosspoint

The other way to implement a two-pole matrix is to order a matrix with double the number of Y-Axis rows that are needed and program two rows simultaneously. This is a much more expensive implementation because you will be effectively doubling the number of relays needed for a test. It can also increase the number of slots required in a modular platform.

## Testing With A Crosspoint Matrix

A crosspoint matrix allows a set of connections on one axis (Y) to be connected to another set of connections on another axis (X) through the use of a crosspoint switch. It can be an extremely useful type of switching network since in principle any point on the Y axis can be connected to any point on the X axis.

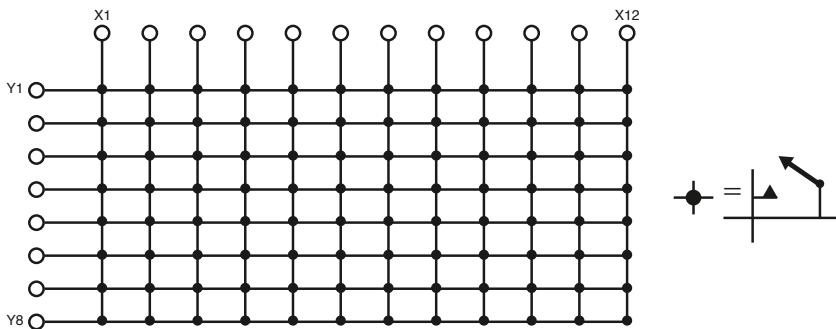
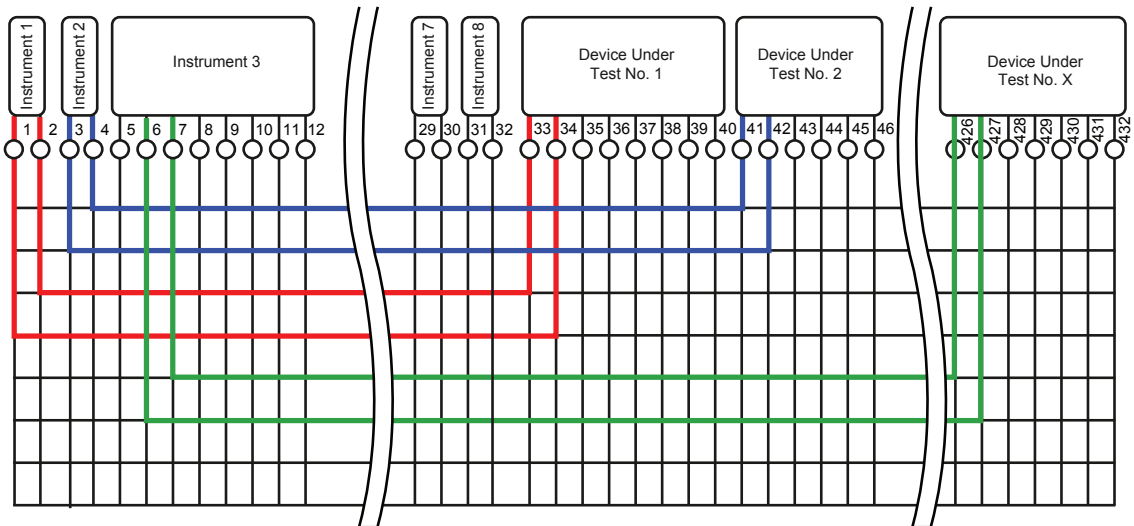


Fig. 6.11 - Crosspoint Matrix

If a test system is using a matrix to connect test equipment on the Y axis to the device under test on the X axis, the resulting system can require a very large number of relays. The large size of the matrix limits the bandwidth of the test system because of the high loading factors and significantly increases the cost of the switch system. For example, if the test equipment requires 32 access points and the device under test uses 400 access points, the crosspoint matrix will require 12,800 relays.

In practice many of the relays may never be used, and there is a more practical way of configuring the matrix.



**Fig. 6.12 - More Efficient Testing using Only X-Axis Connections**

Taking the above example, if the test equipment and the device under test are arranged on just one axis (X) of the crosspoint matrix the X axis requires 432 access points. The Y axis is now used to simply connect two points on the X axis together by closing the relays at both crosspoint positions.

The number of Y axes required is now controlled by the maximum number of simultaneous connections necessary to connect the test equipment to the device under test. In many cases just 4 or 8 Y axes will enable the user to perform all required tests. The crosspoint matrix complexity is dramatically reduced since it now only requires a 432 by 8 matrix requiring 3,456 relays.

Because the size of the matrix is reduced the cost is reduced, and the bandwidth is likely to be higher. It will offer a more compact and flexible test solution with greater chances of module re-use in future applications.

The disadvantage is that each connection requires two relays in series rather than just one for more conventional methods. The additional relay marginally increases the resistance between the paths, but the increase is relatively small compared to other factors.

The Pickering Interfaces BRIC range of matrix switches are designed for this type of application.

## Power Limitations of a Matrix

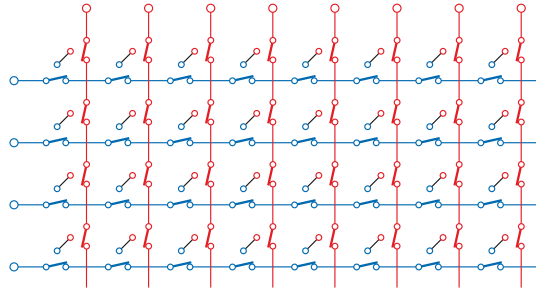
As mentioned earlier, a crosspoint matrix can have literally thousands of relays in its configuration. Whenever a relay is closed it will draw power as long as it is closed. If you close many relays in a test sequence, you can possibly reach a scenario where you are trying to draw more power than the system was designed to supply. That is why many large matrices have a relay closure limit in the driver. So, when you are purchasing a large matrix, this specification could be important if your test code requires a large number of simultaneous relay closures.

# Switching Configurations

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## “Stubless” Matrices

Crosspoint matrices are normally created from arrays of SPST relays arranged as a simple grid. Stubless Matrices are created from Tree Multiplexers to provide solutions for matrices requiring very high RF or microwave bandwidths. In creating these matrices, they also restrict the connectivity that can be provided. Implementation of Tree Matrixes can be complicated by the difficult routing that they impose on PCB designs because there are large numbers of crossing tracks, or by the number of coaxial connections required.



**Fig. 6.13 - A Stubless Matrix**

## Maintenance of Switching Systems

Switching systems are often placed in vulnerable positions in a test system. They are often required to be operated many times during a test and hot switching of the loads may be unavoidable. In addition, faults in the device under test may cause unexpected switching conditions to occur (voltage or current) that limit the relay life. During test system creation software errors or wiring problems may result in fault conditions that exceed the switch ratings. Combined with a finite mechanical life it is apparent that switching must be integrated with the expectation that relays may fail, and that in turn means the test system has to be maintainable.

If a failure does occur, the application often requires the failure to be fixed quickly because down time in the system costs money. It is essential, then, that the system is designed to allow repair to be carried out at, or close, to the point of use.

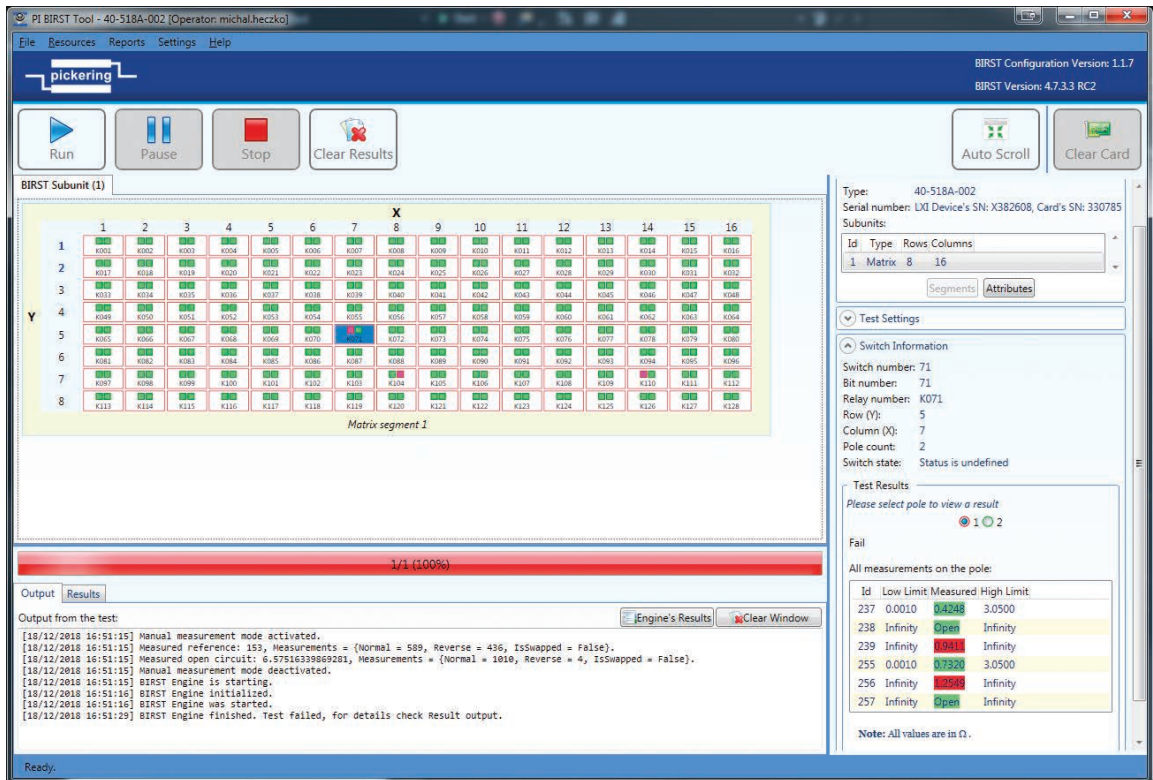
There are a number of considerations that need to be checked:

- Does the manual identify the relay types used?
- Does the supplier provide a fast way of obtaining replacements?
- Does the product have spare relays installed that can be used to replace defective ones (remember to replace the spares though!)
- Does the manual provide a cross check from the functional position of a relay to its physical position in the product?
- For complex products where fault diagnosis may be complicated, is there a tool to help locate the defective relay?
- Having identified the defective relay can it be extracted and replaced without the use of complex tools or having to send it back to the supplier?



Pickering Interfaces takes all these aspects into account when designing modules. The manual does provide all the information that is needed and offers to supply replacement relays from its own stocks if the relay is hard to obtain or on long delivery. Where feasible, modules do have spare relays fitted.

Pickering Interfaces also incorporates BIRST (Built In Relay Self Test) into many of its larger complex matrices. The BIRST diagnostic test tool provides a quick and simple way of finding relay failures on some Pickering Interfaces LXI and PXI switch matrices. To conduct a test, the user simply disconnects the switching module from the DUT (Device Under Test) and test instrumentation and runs the supplied application program. No supporting test equipment is needed; the test runs automatically and identifies any defective or suspect relays within the module.



**Fig. 6.14 - A Typical BIRST Soft Front Panel**

For other switching modules (including PCI switch modules), there is eBIRST (external BIRST). The eBIRST toolset consists of three different tools that support 200-pin LFH, 78-pin D-type and 50-pin D-type connectors and a set of adaptors that allow connection to other connector types. A supplied application program controls the eBIRST tools via a USB2 port that also provides the tool power and controls the switching system using a Test Definition File to define the test sequence. These tools work by measuring the path resistance at the switching system external connectors using four-wire measurements, quickly establishing whether the path is good, has increased resistance, or has failed.

## Switching Configurations

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It should also be noted that the relay packaging used is particularly important. Systems based on the use of leaded relays or relays adapted for surface mount using folded leads are relatively easy to remove without special tooling. Packages based on styles similar to ball grid arrays (BGA) however can cause serious service problems, particularly when they are densely packed. The inaccessibility of the solder joints requires specialist tools to remove the devices, and the tools tend to stress the adjacent components while the operation is being carried out – risking additional failures.

Pickering Interfaces does not recommend the use of BGA-style packages for this reason, and does not use them on any of its switching modules.

# 7

## CABLES, CONNECTORS, AND MASS INTERCONNECT

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## Introduction

The best switch module is rendered virtually useless unless the cabling and the connector types are right. Too small a wire gauge and you can get serious voltage drops, a long cable may have a fair amount of capacitance which can damage your switching when discharging the energy in the cable, poor connectors may wear out too soon creating intermittent problems, and many other scenarios. Many of these issues are addressed by the test companies that support switching in test, but there are times when management chooses to build the cables in house or use a third party. In either scenario, if the persons involved do not understand test requirements, there could be trouble down the road.

This section will focus mainly on cables and harnesses for low power applications, although the concepts apply to all cabling situations. Finally, this section will look at Mass Interconnects and how and where they are best implemented.

## Commercial Solutions

If you have chosen to purchase a COTS (Commercial Off the Shelf) switching system, chances are that your vendor of choice already has solutions that are matched to the specifications of the module.

Figure 7.1 shows a standard set of specifications for a particular cable sold by Pickering Interfaces. Cables for test are usually sold by length and terminations – one end of course connects to the switch module and the other end may be unterminated or may feature various connector types. As mentioned earlier, the cables are designed to support certain switch modules, so their voltage and current rating are either equal or better than the actual switch module. In all cases, adhering to the specifications of the switch module is best practice.

Technical Specification

<b>Connector Type (End A):</b>	50-Pin D-Subminiature
Gender	Female
Securing Method	4-40 UNC screwlocks, male
<b>Connector Type (End B):</b>	50-Pin D-Subminiature
Gender	Male
Securing Method	4-40 UNC screwlocks, male
<b>Cable Assembly Rating:</b>	
Maximum Current	5A
Maximum Voltage	250VAC/400VDC
Insulation Resistance	1000MOhm
<b>Connectors:</b>	
Contact Material	Gold plated copper alloy
Contact Resistance	<20mOhm
Cable Exit	45° (See Order Codes)
Overall Size (Approx)	H68 x W18.5 x D55mm
<b>Cable Type:</b>	Individual wires, screened & sleeved
Conductor: Material	Copper
Strands	19/0.18 (0.41mm <sup>2</sup> , 21AWG)
Resistance	0.041Ω/m
Insulation	PFA
Outer Sleeve	Polyester
Screened Construction	Yes
Additional Braided Sleeve	Yes
Cable O/D	12mm
Minimum Bend Radius	25mm
Door Closure Allowance	55mm (see diagram)
<b>Notes:</b>	
Other cable lengths can be supplied.	

Fig. 7.1 - A Typical Pickering Technical Specification

# Cables and Connectors

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## Understanding Cable Assembly Ratings

The data sheets for these accessories contain information on the cable assembly construction, detailing the materials used and parameters like wire gauge. This in turn defines parameters like capacitance and resistance per meter of cable.

What is less obvious is how this impacts the performance of a cable assembly under load. For example how many wires can carry full rated current at the same time without an excessive temperature rise in the cable? This section explains briefly how Pickering Interfaces does tests on cable assemblies and explains the specification results placed on the data sheet. Other vendors likely use similar methods, but you should ask your vendor of choice. These guidelines will apply if you build your own cables as well. For these measurements, the cable assembly is terminated on both ends – has mating connectors fitted – but the same results apply for cable assemblies where one end is not terminated.

## How We Test

To test a cable assembly, Pickering Interfaces constructs a sample cable, typically 1 meter long, which has embedded thermocouples in the cable to measure various temperatures. For a cable assembly these might include the following:

**Measurement of the connector shell temperature** – This parameter is useful because some users might only load the assembly to a point where a user can reasonably expect to handle the connector under load without a burn risk. Other users may consider the connector should not be handled during use so higher loads can be applied. The temperature inside the connector shell may also be measured.

**Measurement of the connector pin temperature** – This measurement can indicate if the load conditions might create problems in the mating connector. Unfortunately, manufacturers do not always provide extensive information on this parameter.

**Measurement of the surface temperature of the cable** – The maximum working temperature of the materials used on the outside of the cable assembly might limit how much load current is allowed in the cable assembly.

**Measurement of the cable copper temperature** – The copper that carries the current heats up and is insulated from the ambient temperature by other wires and the insulation materials that are used, so it reaches higher temperatures than just a free air wire. The insulation materials immediately in contact with the copper will have a temperature which is the same (almost) as the copper and so this copper temperature might impose a load limit on the cable assembly because much depends on the materials used for the wire insulation.

Having created the sample cable assembly, Pickering Interfaces then performs a set of load tests and records the temperatures. In addition to recording the stabilized temperature Pickering Interfaces also records how the numbers change with time to gain an estimate of the thermal time constant. Because currents flowing in a test system vary with time, thermal inertia permits cables to carry higher loads as long as the duration of the load is less than the thermal time constant and the high load condition is followed by a lower load condition so the temperatures can start falling again.

Temperature rise of a connector accessory generally produces two different specification ratings for the maximum load, the higher load is where only the specification of the materials is considered, the lower load rating is where the user has to consider surface temperatures which might be a burn hazard to the user. User temperature limits are defined according to materials in EN61010 (a series of technical standards

for the safety and essential performance of medical electrical equipment, published by the International Electrotechnical Commission). In some applications, the connector accessory is not accessible to a user (for example behind a closed cabinet door), so it is the materials which establish the limit. The ambient temperature is also a factor, as the ambient temperature rises then the temperature rise permitted to reach the maximum temperature (whether material ratings or burn hazard) becomes lower.

### Key Specification Values

**Current Rating** – This is typically for a single wire and is limited by the connector rating. As more wires are loaded with current, temperatures rise and at some stage a maximum load current must be imposed.

**Voltage Rating** – This is limited by the connector used and the construction of the cable including insulation materials and clearance distances.

**Temperature Rating** – The data sheet will include information about the recommended maximum working temperature for various parts of the cable assembly. For cables based on the high temperature material Perfluoroalkoxy (PFA), the copper should not get to more than 260°C, and cables using polyester outer materials should limit to a surface temperature of 100°C. How this translates into a load rating however is complicated because of the varying conditions that users might have, including the ambient operating temperature of the cable assembly.

For a cable, the power dissipated is primarily dependent on the square of each of the load currents in each wire added together (the power is obtained then by multiplying by the resistance). To avoid having to detail the resistance part of the equation, we simply express the rise in temperature for the key parts (typically the connector shell and the surface temperature of the cable) for a unit sum of the square current in the wires.

**Thermal Time Constant** – The key parts of the cable assembly will include a thermal time constant that can be used to estimate the ability of a cable to withstand a short term higher load than the static conditions would suggest.

### What Limits The Maximum Load?

There are two primary issues that can impact the maximum current specification.

The first issue is that the EN61010 specification contains specifications on the maximum surface temperature that a component can reach when accessible to a user. In the case of a cable assembly this will typically be the connector shell and the cable surface. The actual temperature limit is not determined by the material capability but rather by the probability of user harm (burns) created. For that reason, metal surfaces have a lower temperature than plastic because they are better conductors and more likely to transfer heat quickly on contact, thus causing a burn.

However, in a test system the cables may not be accessible to the user, for example, if the system is behind a door in a rack. In such cases the ratings can be limited by the materials used and could be higher than those imposed by EN61010. For that reason some assemblies may allow higher load ratings than would be imposed by concerns about surface temperatures.

In some cases, the materials may limit ratings before EN61010 limits are reached, particularly true for lower cost cable assemblies where, for example, PVC may be used.

# Cables and Connectors

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## Deriving A Load Condition Maximum

The load will be limited by the first parameter to reach an operating limit, so if the user has a concern about the total load current in a cable assembly each limiting factor must be checked.

Suppose the user has a cable rated at 5A and with 50 wires. Its maximum surface temperature is 100°C and the ambient is 25°C, so the cable can have a maximum rise of 75°C. The data sheet indicates that the temperature rise under load increases by 0.08°C per square of current (Amps). Simple arithmetic then suggests the maximum square load current should be 937 Amps. A wire carrying 5A has a square load current of 25, so 37 wires could be carrying 5A and the temperature will rise to a little less than 100°C. If the use had an operating temperature which is higher, then the maximum load would be more restricted. If all wires were carrying the same current (an unlikely scenario) then the square of the current in each of the 50 wires should be 18.7, or 4.3A.

The user may want to limit operating temperatures for other reasons. Keep in mind that if the cables are in a confined area, then the ambient temperature will rise. Having forced air blowing across the cables will help keep the ambient temperature under control, but it is unlikely to have a big impact on the temperature rise per square of current of the cable itself without a significant user effort.

Users may also be concerned about connector shell temperatures. As this rises, a user handling the shell under high loads may risk a skin burn, so the same methodology should be applied to the connector shell if this is a risk. If for example the user wants the shell restricted to a 35°C rise and the shell has a 0.044°C rise per square of the current, then in the above example the sum of the squares of the current needs to be limited to 795A.

## Short Term Overloads

The thermal inertia of the cable assembly means that a cable can be more highly loaded for short time intervals provided the average remains within limits and the time that this occurs is less than the thermal time constant of the critical parts of the assembly. If, for example, the thermal time constant is 5 minutes, then loading a 50 wire 5A assembly for one minute followed by no load for one minute is likely to be a safe operating condition for many applications because the sum of the squares is 1250A, the duty cycle is 50% so the average is 625A and the time constant is significantly less than the thermal time constant for the key parts.

## The DIY (Do It Yourself) Route

There are always times when you need custom cables – different connector types, special cable sheathing, nomenclature, and so on. In these instances, you can hire a subcontractor who specializes in cabling or assign some of your technicians to create the cable assemblies.

In either case, the people building your cable should be aware of the application being assembled. What is the DUT performance specification, and the environment the device will be tested in? For example, if you are doing testing in an environmental chamber and temperatures in the chamber are in the area of 150°C, your basic polyester insulation might just melt inside that chamber. So make sure you provide all necessary details.

As one option, Pickering has an online custom cable tool ([pickeringtest.com/cdt](http://pickeringtest.com/cdt)). You can create a datasheet of your own using the tool which will have all of the electrical and environmental parameters listed. Pickering can quote for the cable, or you are free to take the datasheet to your cabling vendor to have them build it.



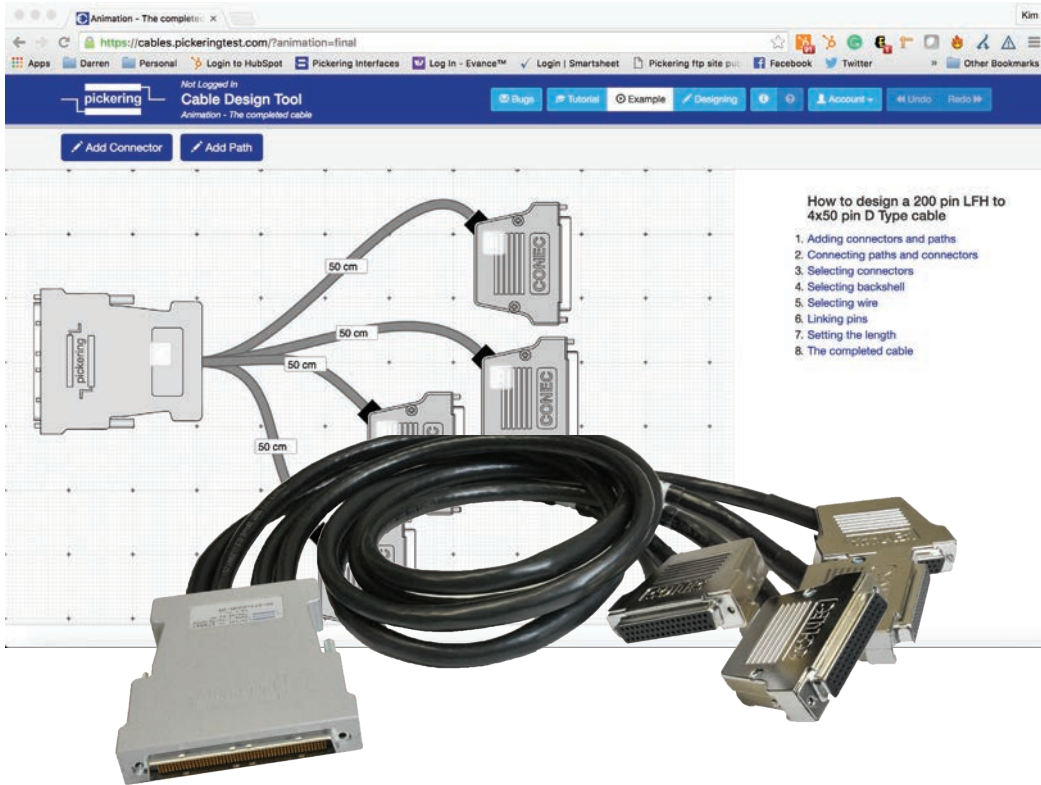


Fig. 7.2 - Pickering's Cable Design Tool

## Common Mistakes When Designing/Building Cables:

- **Wrong gauge of wire for the application** – too thin and cables get hot and eventually fail; too thick and cables become difficult to make and therefore more expensive, the bend radius may be reduced, and there is added stress on the locking systems due to the increased cable weight.
- **Wrong insulation material for your application**; for example, PVC gives off toxic fumes when burning, therefore it is not usable in Aircraft or enclosed spaces where there are people. Polytetrafluoroethylene (PTFE) and PFA (Teflon) are good where PVC can't be used, and typically have thinner insulation (useful in "tight" designs). But in most cases, they are far more expensive.
- **Connectors and Backshells** – Wire size and insulation thickness play into a balancing issue when trying to insert hundreds of wires into a small connector backshell. Selecting the correct gauge of wire can go a long way to resolving this and making the finished custom cable assembly more affordable.

# Cables and Connectors

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## Wire Types:

- **Copper** is the best (affordable) conductor of electricity and is the most common material for wire.
- **Tinned Copper** – Tinning copper wire stops the surface from tarnishing (green copper oxide), it also makes the wire ends easier to solder. The downside is that at high frequencies (due to the skin effect) the signal favors the outer skin of the conductor. If this is tin, then it has worse conductive abilities.
- **Silver-Plated Copper** – Silver plating overcomes the disadvantage of tinned wire (at high frequencies), and also reduces contact resistance. However, it may increase your costs.
- **Gold-Plated Copper** – Usually used on connectors, the gold reduces contact resistance and is more conductive than copper, again at an increase in cost.
- **Use of Steel and Aluminum with Copper** – Sometimes used in long runs of low power/high frequency cable to reduce cost. A good example is the cheaper grade of Cat 5/6 network cable. The high frequency of gigabit ethernet signals causes the signals to travel on the outer edges of the wire (skin effect). The steel or aluminum core is used as a lower cost filler material. Steel also adds strength to the wire.

## Wire Construction:

- **Solid Wire:** Cheaper to produce, but less flexible than stranded wire. It is more suited to static (non-flexing) applications; Higher current carrying ability compared to the same size stranded wire; More corrosion resistant (less surface area); Less skin effect at high frequencies (less surface area).



**Fig. 7.3 - Solid Wire**

- **Stranded Wire:** More Flexible (the higher number of strands = more flexibility); Slightly lower current handling (higher resistance) for the same amount of copper; More expensive; More susceptible to corrosion.



**Fig. 7.4 - Stranded Wire**

- **Sizing (AWG/Metric):** Wire sizes are derived from the American Wire Gauge standard (AWG) and are ranked from 0000 to 40. Remember the smaller the number, the larger the wire size. AWG ratings are more popular in the U.S. Originally designed for solid wire, it does not usually express stranding info, although occasionally stranding is shown in the form of AWG overall size/number of strands/AWG size of strand; so for example, AWG 22/7/30 indicates a wire made of 7 strands of AWG 30 wire to make a wire equivalent to AWG 22. – In the Metric world, wire is rated as the diameter in mm (millimeter) and/or no strands/diameter of strands in mm.

### RF/Microwave Cabling

Selecting the correct RF Cabling is another matter. The coaxial (also called “coax” for short) cable selected can affect insertion loss, distort the signal because of the added capacitance, and limit the power to be handled. According to the RF Café (rfcafe.com), if you choose the correct cable for your application, there should be minimal surprises. However, you should not make a bend of smaller than the recommended radius, expose the cable to excess temperatures, vibration, mechanical stress, or chemicals. Be certain to attach the coaxial cable into properly designed connectors, paying careful attention to insulation and dielectric strip lengths, solder temperatures and dwell times, and shielding preparation. This same web site has a specifications chart of the most popular coaxial cable types.

Questions to ask when designing an RF Cable “channel” (a signal path from the instrument to the DUT and a return path) for a given stimulus and/or measurement:

- **Insertion Loss** – The switching and the entire path of the channel must be considered. The coax wire type, cable length and the number of connectors involved, as well as the insertion loss of the switching module all contribute to the quality of the channel. When using a Mass Interconnect, you automatically add three more insertion losses – the connector from the instrument cable, the Mass Interconnect’s interface, and the connector from the DUT cable to the Mass Interconnect.
- **Performance** – Will coax with a simple braid shield be adequate or do you need to invest in more than two shield layers, such as double shielding or even “quad-shield”, which uses four alternating layers of foil and braid? The best performance will be a “semi-rigid” coax. As the name implies, the cable is not as flexible as most coax types. With a solid copper outer shield, semi-rigid cable must be carefully bent so as not to kink the shield, resulting in signal losses.
- **Connector Types** – The instruments you choose will have a particular connector type to interface to the DUT. These connectors will usually fit to a limited number of coax types. So, selecting the coax must be tempered with the required connector.
- **Impedance** – To get a clean, repeatable signal, the signal path must match the impedance of the DUT as well as the instruments used. Coax cables are available with impedances ranging from 50  $\Omega$  to 125  $\Omega$ , so beware of this specification as well.

### Mass Interconnect

In any discussion on cabling, “Mass Interconnect” needs to be considered. This is a mechanical interface that simplifies connection between the power supplies, instruments and switching to the DUT in a test environment. In the illustration here, a test receiver is connected to the front of the modular instrumentation, in this case, a PXI chassis. This receiver is connected to the switching and instrumentation. An Interface Test Adapter (ITA) has a series of mating connectors that plug onto the Mass Interconnect. These connectors are wired either to a series of connectors that mate to the DUT or to a connector where a DUT PCB is inserted for testing. An enclosure is installed to protect the wiring and connectors.

## Cables and Connectors

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**Fig. 7.5 - Cabled Mass Interconnect (VPC)**

The illustration below shows a test fixture with a PCB plugged into the enclosure.



**Fig. 7.6 - Mass Interconnect Connection for PCB Test (MAC Panel)**

The Mass Interconnect is clearly an additional piece of hardware to order, assemble, and integrate, so there will be added costs. To justify the expense, there are questions to be asked and considered, plus several design considerations:

1. **What is the overall DUT volume versus DUT type mix?** If your test system will be testing many different DUT types, which may require many ITA changes, a Mass Interconnect will make a lot of sense.

If you choose to cable directly to the modular chassis or discrete instrumentation, keep in mind that most connectors on the front of these devices are usually rated for perhaps fifty insertions or even less. So, if you are constantly changing test fixtures, you will wear these connectors out very quickly. Mass Interconnect systems are typically tested to 10,000 insertions or even more. Of course, if you are testing only one or two DUTs and ITA changes are usually not necessary, you probably don't need to use a Mass Interconnect.

2. **How much down time can you justify for your test system in a day?** In a high-volume test strategy, ITA changeover times will be shorter with a Mass Interconnect approach. Also, the possibility of connecting the cables to the wrong mating connectors is eliminated or reduced.
3. **What are your accuracy requirements?** Mostly due to the robustness of the connections to the ITA, a Mass Interconnect will help ensure repeatability when changing over ITAs. At higher frequencies, signal fidelity may be improved over using loose cables to connect the ITA because the wiring is shorter and rigid in terms of its placement in the ITA and Mass Interconnect.  
  
If you plan to replicate the test system multiple times, a Mass Interconnect helps to guarantee repeatability across all systems.
4. **Is ruggedness a requirement?** Mass Interconnects are very robust and may make sense if your tester will be in an environment where damage to the test system is possible.
5. **Will a self-test fixture be required for the system?** A Mass Interconnect will make the use of a self-test fixture easier and more repeatable.
6. **Are you migrating an older test system (e.g., VXI-based) to a new test platform such as USB or PXI?** If your present test system already has a Mass Interconnect, then the migration is made easier because you can reuse the ITAs. The Mass Interconnect just needs to be cabled in such a way that the test resources are connected to the same connector pinmap as the previous design.

### Making Your Choices

If you have concluded that you need Mass Interconnect, you need to select a vendor. There are two major players in the market – MAC Panel and Virginia Panel (VPC). There are several other smaller players. Pickering Interfaces is not making any recommendations. Your choice should be based on available product, level of support needed, and your test budget. All of these companies can support you in terms of configurations, technical consultation, and customization as required. For ITA selection, the provider of your Mass Interconnection can help. In addition, many systems integrators and test fixture designers/manufacturers are located in many cities around the world.

Connector types have very well-defined specifications and they should be observed. Connectors are rated for max voltage, current, power, and frequency. A connector rated at 100 Volts and 10 Amps is not necessarily a 1,000-Watt connector – It maybe be up to 100 volts or up to 10 Amps and not both. Be sure you understand your needs before specifying connectors.

Before you make the vendor selection, be certain that you have determined the test system hardware required for all DUTs to be tested (this helps to determine how large the receiver needs to be), specifications and accuracy to be tested and DUT dimensions. If the DUT is a PCB, then CAD files will be critical for PCB placement.

With the above information, your vendor(s) can help select the size of the receiver and ITAs and configure the proper pinouts, receiver connectors, and the wiring required.

## Cables and Connectors

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### To Wire Or Not To Wire?

This question brings up one more decision: how to best connect the modular instruments and switches to the Mass Interconnect. The connections from the instruments in a modular chassis can be made using cables or a PCB (discrete instruments and power supplies are likely to be cabled). Each has its advantages because modular instruments are pushing the bounds of performance and I/O density, and close consideration needs to be given to system connectivity. Similar to other choices we have discussed, it really depends on your application.



**Fig. 7.7 - Mass Interconnect (VPC)**

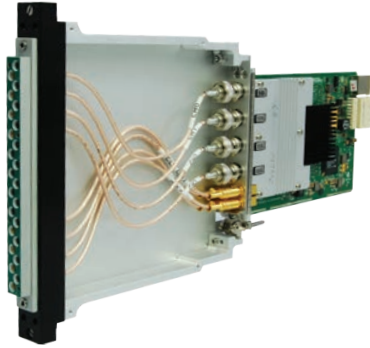
The simplest and lowest cost configuration when building a single test system is cabling from the instruments and switching to connectors in the Mass Interconnect. As you can see in this illustration of a PXI application, the cables are long enough to simplify troubleshooting. The downside really is application specific. The higher the frequency of the signals, there is a possibility that the signal fidelity can be compromised between the DUT and the measuring instruments, so careful cable choices and even placement must be taken into consideration. If you are replicating this test system many times, placement of the cables is also important for accuracy and repeatability.

The two most common types of interconnection are the traditional cabled method or a “pull-through” style interface that typically uses PCB or flex-circuit connections. Each method has advantages and disadvantages depending on the application priorities of the ATE.

Both interface styles offer a simple modular approach to interconnection – both Mass Interconnect vendors offer online configuration tools to define the interface. In some system configurations the cabled interface method can reduce the size of interface required by connecting multiple instruments to a connection module, thus reducing the overall quantity of Mass Interconnect modules required.

In the case of a cabled system the cables should be long enough (typically 0.5m) to simplify troubleshooting. For DC or low frequency applications, this approach is very low cost and easy to troubleshoot. But the higher the frequency or speed of the signals, the poorer the signal fidelity will likely be seen at the DUT and the

measuring instruments. Signal noise and losses become a concern. If you are replicating a test system design multiple times, placement and routing of the cables is important to achieve accuracy and repeatability.



**Fig. 7.8 - "Pull-through" Adapter (MAC Panel)**

Another possibility that will shorten the cable lengths and potentially improve signal fidelity and repeatability is to use what is called a "pull-through" adapter. This is an aluminum case that bolts onto the instrument and features a connector that becomes part of the Mass Interconnect. Some of the advantages include:

- As the Instrument/switch module is bolted to the pull-through, it is easier to remove an instrument or switch module from a modular chassis for calibration, upgrade, or maintenance because the module and pull-through come out together.
- Shorter wire length – the average is about 150 mm.
- Inherent shielding of signals within the pull-through.
- Simplified design, potentially lowering cost.
- Although it is not recommended, multiple instruments and power supplies can share a connector on the Mass Interconnect.

If the pull-through is your choice for your next test system, you need to decide if wiring or a rigid or flex PCB is installed in the pull-through. Again, advantages and disadvantages to each.

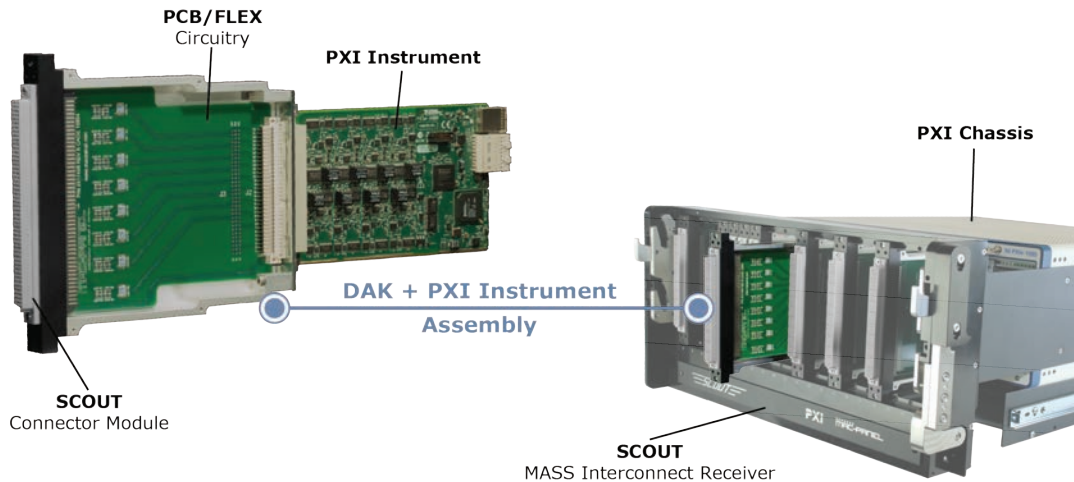
### 1. Hard-Wired Pull-Through:

- Advantage – Hard wiring the pull-through is the simplest and lowest cost of a one-off test system design. If multiple test systems are planned, once you factor out the cost of designing and manufacturing a PCB, repeat systems may come together faster because the wiring labor is greatly reduced.
- Advantage – Changes in the pull-through wiring are easily managed. They are also the most flexible.
- Disadvantage – Possible repeatability issues between testers at higher frequencies.

## Cables and Connectors

### 2. PCB-Based Pull-Through:

- Advantage – Clean design, repeatable. Every test system will exhibit the same performance.
- Advantage – Signal fidelity can be optimized.
- Disadvantage – If changes are needed farther down in the life of the test system, a new PCB must be designed and manufactured.



**Fig. 7.9 - A PCB-Based Pull-Through (MAC Panel)**

### Consider The Test Fixture

A similar consideration is required regarding the test fixture design. Often the simplest way to connect a fixture to the DUT is to use cables. This has been the traditional method for many years. However, it is generally considered that fewer cables offer enhanced and more stable signal performance at the DUT. Modern fixturing techniques have made connecting to the DUT via a PCB a viable consideration. Using a PCB-style fixture is particularly beneficial when building fixtures with critical performance requirements or if multiple fixtures of the same design are required. The choice comes down to a balance of cost and performance; if performance is critical then perhaps a PCB fixture should be considered. If only building a single fixture, the wired option is often a lower cost option, but when multiple identical fixtures are required then the PCB connection would significantly reduce the cost of each fixture.

As noted in the beginning of this section, Pickering Interfaces is not making any recommendations as to vendor or types of Mass Interconnect. Each application may call for different designs. That is between you and your Mass Interconnect vendor.



# 8

## RF SWITCHING - THE SUM OF THE WHOLE

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## Introduction

Sometimes called a “Black Art”, RF and especially microwave switching can be a challenge. Very often, many test systems have been marginalized because the test engineer did not consider all the components of their test system: instruments, switching, cabling, Mass Interconnect, fixture design, and so on. Each component has its own set of characteristics. Because we are talking about RF and microwave components, effects like insertion loss, VSWR, bandwidth, etc. need to be considered as well.

The key factor here is all of these parameters can be additive. So, if you have a switch with 1 dB of loss going through a three-meter cable that has a loss of about 0.1 dB per meter, then a connector with 0.2 dB loss and into another cable, you soon have almost 2 dB of insertion loss! Note this may be OK if you plan for the loss and calibrate it out, but depending on the test specifications, it may be unacceptable.

Your test strategy is driven by many factors – the test specification from engineering, accuracy expected, your test budget, time to market ... the list goes on.

Remember, proper switching system design is essential, so it's important to make the right choices if you want your automated test system to be successful. Your decisions may be limited by issues such as available hardware, time to market, and the ever-present budget limitations. So, if forced to make compromises, keep in mind in an RF test, the accuracy is the sum of all components in the measurement/stimulus chain – this includes instruments, switching, connectors, cable, and any Mass Interconnect. It's impossible to tell you everything to consider in only a few pages, but hopefully, this information will provide you with enough knowledge to do it right the first time.

## What Are We testing?

Before designing a functional test system, it is best to understand the DUT and the parameters that need to be tested. Some of the questions to ask include:

- What is the frequency range of the signals I'm going to be switching?
- How much power will the switching system have to handle?
- Are there existing connectors and cabling to which the switching system must connect?
- What kind of cabling and connectors does the device under test use?
- How fast must the switching system switch?
- How am I going to control the switching system?
- What parameters need to be sourced and measured?
- What kind of accuracies are in Engineering's test plan?

The answers to these questions will help to determine which switching modules you'll choose for your system, what type of relays will be on those switching modules, and how you connect to your DUT.

# RF Switching

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## Switching Types

After you've determined the driving points of your application, you'll next want to decide whether you want to use switching modules with electromechanical relays or solid-state relays. Several vendors provide modular solutions. The table below summarizes the advantages and disadvantages of each type.

Relay Type	Advantages	Disadvantages
Electromechanical	<ul style="list-style-type: none"><li>• Lower insertion loss, Better isolation</li><li>• Wider frequency range (DC – 65GHz)</li><li>• Higher power handling</li></ul>	<ul style="list-style-type: none"><li>• Slower switching speed (ms vs. <math>\mu</math>s)</li><li>• Larger than solid-state switching systems</li><li>• Limited life</li></ul>
Solid-State	<ul style="list-style-type: none"><li>• Faster switching speed (up to 1,000 times faster)</li><li>• Smaller than electromechanical relays</li><li>• Better reliability, virtually forever</li></ul>	<ul style="list-style-type: none"><li>• Higher insertion loss</li><li>• Narrower frequency range (10MHz – 8GHz)</li></ul>

Solid-state relays are switches fabricated from either CMOS or GASFET technology and have very fast switching speeds and longer service life compared to electromechanical relays. The reason for this is that they have no moving parts. Switching systems that use solid-state relays also feature very high insertion losses when compared to systems that use electromechanical relays. This may or may not be an issue in your application, and in many applications, this higher insertion loss may be calibrated out because the loss tends to be very repeatable.

Isolation specifications may also be lower than electromechanical switches. The very nature of solid-state relays is that they are very small, have very small gaps and hence struggle on isolation. The switching system designer can use multiple switches to achieve good isolation, but then the switching system loses out even more on the insertion loss.

The lifetime (the number of switch operations they will endure under light load conditions) of electromechanical relays is more limited, peaking out at 20 million operations or less. In the case of solid state switching, lifetime operations are virtually infinite when operated within their specifications.

Solid-state relays do have some disadvantages. For example, they cannot handle as much RF power as their mechanical counterparts. Switches using solid-state relays are well-suited for applications with signal levels up +20dBm, which is more than enough for most applications. At +20dBm, IP3 (a parameter that gauges linearity in radio frequency (RF) functions and components.) products are typically less than 80dBc. Solid-state relays can be used for signals with higher power levels, but other performance characteristics, such as intermodulation, might become an issue. Some electromechanical relays, on the other hand, can switch hundreds of watts.

Another disadvantage is that solid-state relays do not handle low-frequency or DC signals very well at all. At lower frequencies (typically around 1MHz to 10MHz), solid-state relay manufacturers de-rate their specifications. As a result, RF switching systems that use solid-state relays are generally not usable below

10MHz. To avoid potential damage to the solid-state relays by the accidental application of DC signals (from amplifiers for example), you should make sure that the switches are AC-coupled.

RF switches using solid-state relays can also exhibit some non-linearity. If this is important in your application, be sure to check the third order intercept specification. Pickering's 40-880 series, for example, have a typical third order intercept level of greater than +60dBm.

RF switching systems come with a variety of RF connectors. Following is a summary of the many different types available.

### Connectors

#### SMB

This small connector can be used at frequencies up to 4GHz, and is available in 50 $\Omega$  and 75 $\Omega$  versions. Its small size makes the SMB connector a good choice for use on PXI modules capable of switching 3GHz signals because you can fit many of them on the front panel of the module. Because the connectors snap on, you don't need a wrench to tighten the connector, and because it is a very commonly-used connector, cable assemblies can be purchased from distributors.



**Fig. 8.1 - SMB Plug (Female Basket)**

One disadvantage of its small size is that it can only be used with relatively thin coaxial cables. This could increase losses at higher operating frequencies when compared to connectors that can accommodate larger coaxial cables.

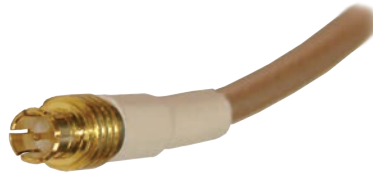
Another disadvantage is that SMB connector gender is sometimes confusing. Generally, the inner contact of a connector determines its gender, with the male contact being referenced as the plug. In the case of SMB connectors, however, the male inner contact is the socket. This can confuse users when ordering parts to interface to RF switching systems.

#### MCX

MCX connectors have several advantages over SMB connectors. They offer better RF performance (up to 6GHz), and are smaller than SMB connectors. Like the SMB connector, they snap together, meaning that you do not need a wrench to tighten them down. Although not as common as SMB connectors, they are a superior option and cable assemblies are widely available from many cable assembly manufacturers. They are available in both 50 $\Omega$  and 75 $\Omega$  versions.

## RF Switching

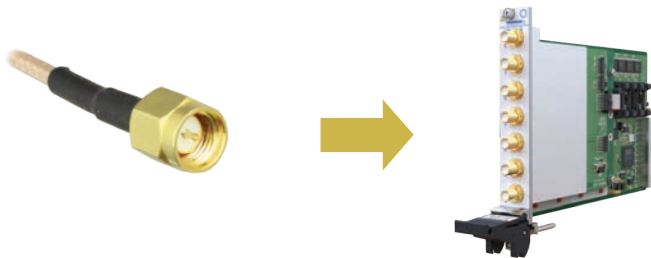
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**Fig. 8.2 - 75Ω MCX Plug (Male)**

### SMA

SMA connectors are suitable for use up to 18GHz or even higher and mate well with semi-rigid and larger cables, ensuring systems that use this connector have high performance and low loss. They are, though, bigger than SMB and MCX connectors and you must use a wrench to tighten the connector nut. Another disadvantage is that they are only available with an impedance of 50Ω.



**Fig. 8.3 - SMA Plug (Male) Mating to a Pickering 40-881 6GHz Multiplexer**

There are various sizes and bandwidth of SMA type connectors. The SMA connector is typically rated from DC to 18 GHz, though some proprietary versions are rated to 26.5 GHz. For performance above this, other SMA-like connectors are used. These include the 3.5 mm connector, rated to 34 GHz, and the 2.92 mm (also known as 2.9 mm, K type, or SMK), good up to 40 GHz and others. These connectors keep the same outside thread as the SMA, so they can potentially be cross-mated, but the precision center connector can be easily damaged when mating with certain SMA connectors.

The list below notes the SMA and SMA-like connector types and their bandwidth;

- 3.5mm (to 34GHz)
- 2.92mm (to 40GHz)
- 2.4mm (to 50GHz)
- 1.85mm (to 70GHz)
- 1.0mm (to 110GHz)

Note that I mentioned SMA-like. Strictly speaking, some of these are not true SMA connectors, even if we and many switching vendors do refer to them in our documentation as SMA 2.92, SMA 2.4 etc. At Pickering, we do not see 3.5mm in use though they are sometimes requested, and currently we only go up to 1.85mm for 67GHz switching. So clearly, it is important to match your cable connector to the proper type of mating connector.

## QMA

QMA connectors were specifically developed for telecommunications systems, small cellular systems, and Wi-Fi applications, where high-performance, tool-free connections must be made. They are similar to SMA connectors, but they have a snap lock interface. The connector snaps on and then cannot be released until the barrel is pulled back. Accidental loosening or disconnection of a mating cable is almost impossible. QMA connectors are usable up to 18GHz, but work best at 6GHz and below. They are only available in 50Ω versions.



**Fig. 8.4 - QMA Connector (Male)**

## Type N

Type N connectors are popular on bench instruments because the connectors are large and robust, allowing them to be installed on large, low-loss cables. They are available in both 50Ω and 75Ω versions. They are, however, generally considered to be too large for successful deployment in PXI/PXIe RF switching systems.



**Fig. 8.5 - Type N Connector (Male)**

## Type F

Type F connectors are the preferred connector for broadcast applications. Although they are often specified as being usable up to 2GHz, that's really pushing it. To be safe, you should only use them up to 1GHz. One of the reasons for this is that many Type F connector designs have very poor transmission line impedance characteristics. Although the nominal impedance is 75Ω, it's not uncommon to find connectors with a characteristic impedance of 50Ω. This leads to significant signal degradation as a result of high Voltage Standing Wave Ratio (VSWR). F-type connectors should only be used when there is no other option.



**Fig. 8.6 - Type F Connector (Male)**

# RF Switching

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## Multipole RF Connector

This type of connector is manufactured by Positronics, Souriau and others. A connector block accepts a number of coaxial connections using proprietary connectors. The connectors pack a relatively large number of connections in a small amount of front panel space so it is a solution used where a dense interconnect is required. It also allows the quick connection of multiple coaxial connections. The connectors used are very small and use crimp-style terminations. The construction severely limits the bandwidth of connection. For example, we recommend not using these connectors for signals with a frequency greater than 500MHz. Above that frequency, the VSWR can be greater than 1.5 and significant signal degradation can occur.



**Fig. 8.7 - Multipole RF Connector**

## RF Termination

Terminating the ports of an RF switch is advantageous in some applications. Although RF switches with terminated inputs and outputs cost more than non-terminated switches, terminated outputs improve system performance by reducing the amount of signal that leaks to other connections (crosstalk and isolation). Where there is some leakage, the RF switch characteristics will be more consistent. There will be no resonant dips and rises as the connection length goes through quarter wave rotations which cause signals to add or subtract.

If the impedance of the source driving a port is not well matched to the port's input impedance, i.e. has a relatively high VSWR, a non-terminated switch port can reflect high voltage levels. In addition to creating high voltages at the switch, the reflections can also stress the RF source. It is usual for transmitter sources to have a poor output VSWR in order to minimize power loss in the driving amplifier (if it was a perfect  $50\Omega$ , then half the power would be lost in the output impedance), so this tends to be a particular concern for systems with power amplifiers.

A disadvantage of using switches with built-in terminations is that the termination limits the RF power that the switch can handle. With no termination in the module the RF thermal load is limited to that caused by insertion loss through the RF paths, whereas for terminated switches it tends to be the termination that limits the load.



## Crosstalk and Isolation

The impact of crosstalk and isolation on RF switching systems can vary widely depending on the application. In some applications, it barely matters at all. For example, if you are sequentially testing a bank of phones, and only one phone is enabled at a time, crosstalk and isolation are not significant issues because the phones not being tested are not generating signals. Another example of an application that does not require a high level of isolation is when the products under test use different frequencies or different time slots to transmit, and the measuring device is either frequency-selective or time-selective.

In other applications, though, the RF switch might be asked to handle a variety of signals, and it's important to keep crosstalk to a minimum. For example, if you are multiplexing four signals with similar frequencies and levels, the selected channel will see interfering signals from the other three channels. Assuming these signals are not correlated (usually the case), the signals will add on a power (root mean square) basis. Two interfering signals of equal strength from two ports with the same amount of crosstalk will raise the interference by 3dB compared to a single interferer. For large multiplexers (or matrices) this can significantly raise the interfering signal levels and so require higher isolation between channels.

Applications where the signal levels on different ports of an RF switch have widely varying signal levels can also require that you use a switch with low crosstalk between channels. For example, if one signal (the interferer) is at +13dBm and the victim channel is at -17dBm, then the interferer is 30dB above the victim channel level, and the application may demand that the isolation between those two channels be at least 30dB.

As with any engineering project, you have to make trade-offs between cost and performance. If your application requires higher isolation and lower crosstalk, then you will have to select less dense switching solutions or more expensive RF switches with a high level of screening.

When designing an RF switching system, there are some things that you can do to minimize crosstalk and enhance isolation. For example, choosing an appropriate signal level can reduce the crosstalk between channels by ensuring that interfering signals fall below the noise floor of the receiving device. Another thing that you can do is to design in a power control mechanism that reduces the signal levels on the paths not selected for measurement.

When designing your RF switching system, keep in mind that crosstalk and isolation are measured in impedance-controlled conditions, usually 50Ω. For many switching systems, especially systems switching low frequency signals, the main cause of crosstalk is capacitive coupling between tracks or relay contacts. If the source and load impedances are significantly higher than 50Ω, the crosstalk between channels is likely to be worse than specified. As a rough guide, you might expect the crosstalk to be roughly 6dB worse for every doubling of the impedance. For example, if the source and load impedance was 600Ω instead of 50Ω, the crosstalk between channels will be approximately 20dB worse than if the source and load impedances were 50Ω.

Also, keep in mind that crosstalk and isolation are measured at the module connectors. That being the case, cables and connectors can also degrade crosstalk performance.

Finally, you need to consider which platform to use for your RF switching system. All systems have advantages and disadvantages. PXI systems, for example, tend to be physically smaller than LXI systems. They are a good choice for systems that use relatively diverse and compact switching and compact instrumentation from multiple vendors.

## RF Switching

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The LXI platform, on the other hand, may be the better choice for systems that need large switching architectures, the highest parametric performance, or control at a distance. Testing cable runs in an airframe, for example, might require you to locate instrumentation, and the RF switching system to support it, at one end of a very long cable. This is easily accomplished with LXI instrumentation.

Keep in mind that your system needn't be entirely PXI or entirely LXI, but rather a hybrid of both. Modern test software allows you to integrate both, giving you the flexibility to choose the instrumentation and switching modules that best suit your application.

# 9

## FAULT INSERTION SWITCHING

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# Fault Insertion Switching

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## New Automated Test Strategies

Several substantial changes in electronic technology over the last twenty years or so have brought about new strategies for automated test. First is the increasing use of electronics to provide active safety in transportation vehicles. Another, that is more pervasive, is the increased amount of software being embedded in individual ECUs (Electronic Control Units). Let's examine the reasons why these enhancements are bringing about change.

In the case of active safety, there is a wide range of standard features and options that make your car or truck safer to drive. ABS (Antilock Braking System) and Air Bags initially come to mind. But there are so many other options today – for example, there is BLIS® (BLindspot Information System) which warns the driver when accidentally pulling into a lane where a vehicle is already in your planned path, Adaptive Cruise Control, which uses RADAR and LIDAR to scan the road ahead and keep your vehicle from getting too close to the vehicle in front of you, and even Rollover protection, which will stiffen the suspension and take control of braking and steering to keep your vehicle from turning over in a crash. These are just a few examples.

Of course, all this safety is desirable for peace of mind while driving, but what happens if it fails or acts incorrectly? People can be injured or killed and of course there will likely be lawsuits. Obviously, none of these outcomes are desirable and so these active safety devices require much more stringent testing than non-safety related electronic products.

Now let's talk embedded software. To make ECUs smarter, smaller, and more autonomous, Microprocessors and FPGAs (Field Programmable Gate Arrays) are implemented. These devices have an extensive amount of computer code that is designed to make the ECU more intelligent and autonomous, as mentioned above. And as more lines of code are implemented, the more chances there are for software bugs. So simple Go/No-Go testing will not suffice. You need something like Go/No-Go/Fail Safe testing for not only standard operating conditions, but also to see how the ECU reacts in marginal or bad conditions. The most obvious example would be a FADEC (Full Authority Digital Electronic Control). This device controls the fuel injection on a turbo-prop or a jet engine. Now if you are cruising along at 20,000 feet and a sensor for the FADEC fails, the pilot can't just pull over to the side of the road and call the Auto Club. The engine must do the best it can to keep functioning and get the plane and its pilot and passengers on the ground safely.

This same example can be applied to many devices, ranging from a locomotive to a missile – they basically must not fail. So new test strategies for DUTs need to be created.

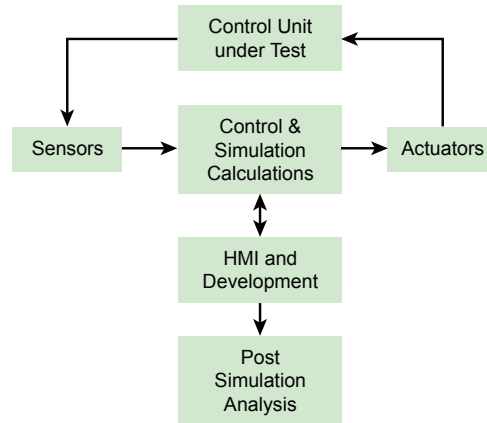
## Hardware in the Loop Simulation (HILS)

Following the above, the concept of HILS (Hardware In the Loop Simulation) was created. Wikipedia defines HILS as *“a technique that is used in the development and test of complex real-time embedded systems. HIL simulation provides an effective platform by adding the complexity of the plant (also thought of as the end system that the DUT is a part of) under control to the test platform. The complexity of the plant under control is included in test and development by adding a mathematical representation of all related dynamic systems. These mathematical representations are referred to as the “plant simulation”. The embedded system to be tested interacts with this “plant simulation.”*

As noted here, HILS has a mathematical representation of the systems related to the DUT. In the case of Automated test, instrumentation and other hardware are used to simulate other devices in the system that the DUT is designed to work in and test code is written to implement this simulation. What cannot be simulated

## Fault Insertion Switching

so easily is the electrical faults that may occur. How will a DUT react when two of its connections are shorted together? Then there are also open circuit, short to VCC or ground, and high impedance connections to consider. All these faults need to be simulated and the resulting DUT response measured.



**Fig. 9.1 - Hardware in the Loop Simulation**



**Fig. 9.2 - A Patch Panel**

There are several ways to create these faults, the simplest being a patch panel. This is basically a grid of electrical connections arranged in an X and Y configuration. Patch cables are used to connect one electrical connection – this could be an instrument, load, or other part of a test system – to some electrical point on the DUT. Patch panels have been used for decades because they are reasonably low cost and flexible. The downside is that patch panels are essentially manually operated and therefore very slow. They are prone to error (especially in a very large patch panels) and possible repeatability issues. For faster more repeatable tests, programmable fault-insertion switches are routinely used in modern HILS systems.

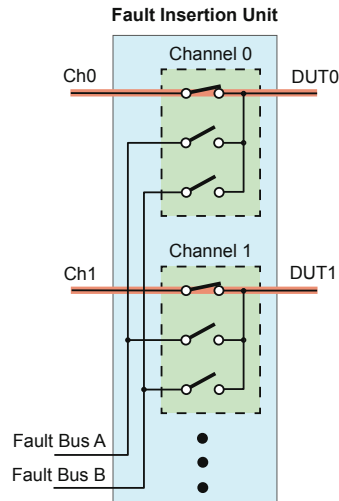
Now that we have established why HILS is necessary and that all common electrical faults must be simulated to check their effect on DUT operation, let us look at the functions of a switch module called the FIU (Fault Insertion Unit).

## Fault Insertion Unit (FIU)

### Typical Faults Injected

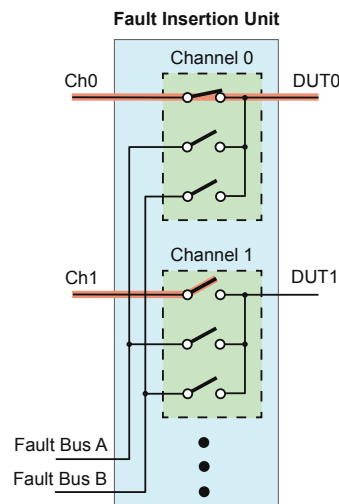
There are several distinct fault types available in commercially available Fault Insertion modules which emulate the actions that an operator would take using a patch panel. Let's look at each individually.

- **Normal Mode** – No faults are inserted. As seen here, the instrumentation is directly connected to the DUT. A normal Go/No-Go test is run in this mode.



**Fig. 9.3 - FI Normal Mode**

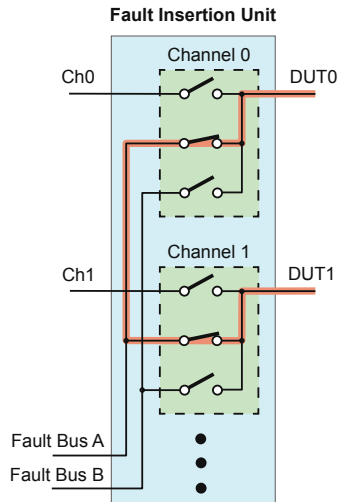
- **Open Connection** – in this scenario, one or more connections from the ATE system to the DUT are opened simulating a broken wire or wires. A test would be run to see how the DUT reacts to this external fault.



**Fig. 9.4 - FI Open Connection**

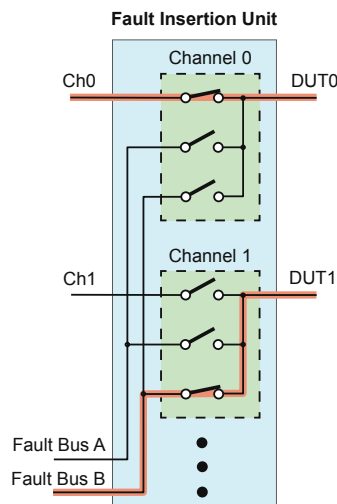
## Fault Insertion Switching

- **Shorted Connection to one or more signals on the DUT** – In this instance, relays are set up to disconnect two or more pins from the ATE system and then connect these pins to each other. A test would be run to see how the DUT reacts to this external fault.



**Fig. 9.5 - FI Shorted Connection**

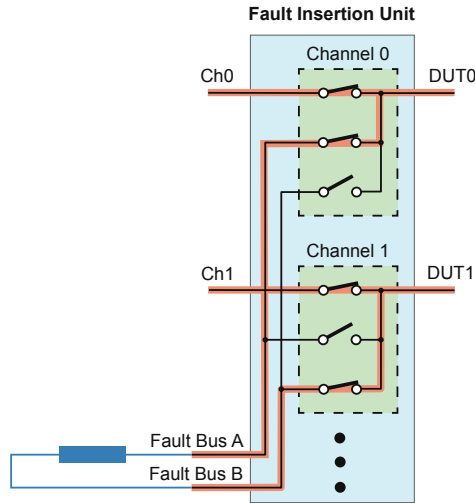
- **Shorted to VCC or Gnd.** – Here we see the use of a “Fault Bus”, which is a connection that can be used to bring faulty signals into the DUT during test. Here the Fault Bus B is connected to VCC. The ATE system disconnects one or more DUT pins from the instrumentation and the fault bus is connected to the DUT pin(s). A test would be run to see how the DUT reacts to this external fault.



**Fig. 9.6 - FI Shorted to VCC or Gnd**



- **Fault Injection** – This is a condition similar to the Short to VCC or Ground where a faulty signal is injected into a circuit. Examples include an incorrect sensor level, resistive fault (seen here where a resistor is connected across two fault buses and then injected into the DUT), and faulty serial data or other corrupt information.



**Fig. 9.7 - FI Fault Injection**

## Fault Insertion Unit (FIU) Types

FIU modules use similar hardware to regular switch modules – Reed Relays, EMRs, and Solid-State devices. This means that the same parameters and questions you use to select regular switching modules apply to FIU selection. Once you have decided on relay types for voltage and current, the key parameters required to select the right FIU modules are as follows:

- How many channels? Of all the I/O connections on the DUT, how many will have to be tested using Fault Injection?
- Pin Shorting – Will it only be necessary to short adjacent pins together or do you need to simulate a cable short which could be any pin to any pin?
- Number of Simultaneous Relay Closures – We have worked with customers who needed all but one connection on the DUT to be connected to all other pins on the DUT. This can be an issue with some FIU designs as they have a limited number of simultaneous closures. This specification should be stated in the module's datasheet. If not, ask your vendor of choice for the information.
- How many external faults will be required? If the program requires external injection of faults, the number of fault buses is important. Typically, a FIU module will have anywhere from two to eight fault buses.

# Fault Insertion Switching

## Fault Insertion Unit (FIU) Configurations

There are two different styles of FIU modules. There may be variations within these styles, but they generally do the same thing. The main differences have to do with the number of channels, number of fault buses, and complexity of the switching portion.

### Straight-through Fault Insertion Modules

This is the most popular type of Fault Insertion module. The “Straight-through” reference explains that the module is designed to go in series with the DUT connections and the ATE instruments, power supplies, switching, etc. As you can see in the diagram here, the relays between the “M” connections and the “U” connections are normally closed – opening these relays simulates an open connection. Other relays connected to these channels are used to short other pins together or insert bad signals via the fault buses. The example here has 74 channels. Depending on the voltage and current in the test, this channel count will vary depending on the size of the relays and available Fault Insertion Module Real Estate.

As you can see here, there are 8 fault buses available to the test programmer. An optional “Monitor” connection is used to connect instrumentation to the fault buses to see how the signal is being presented to the DUT.

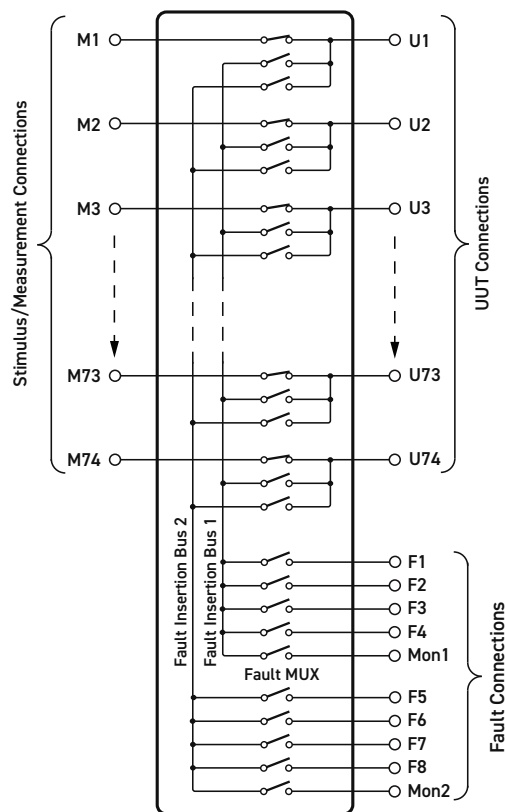


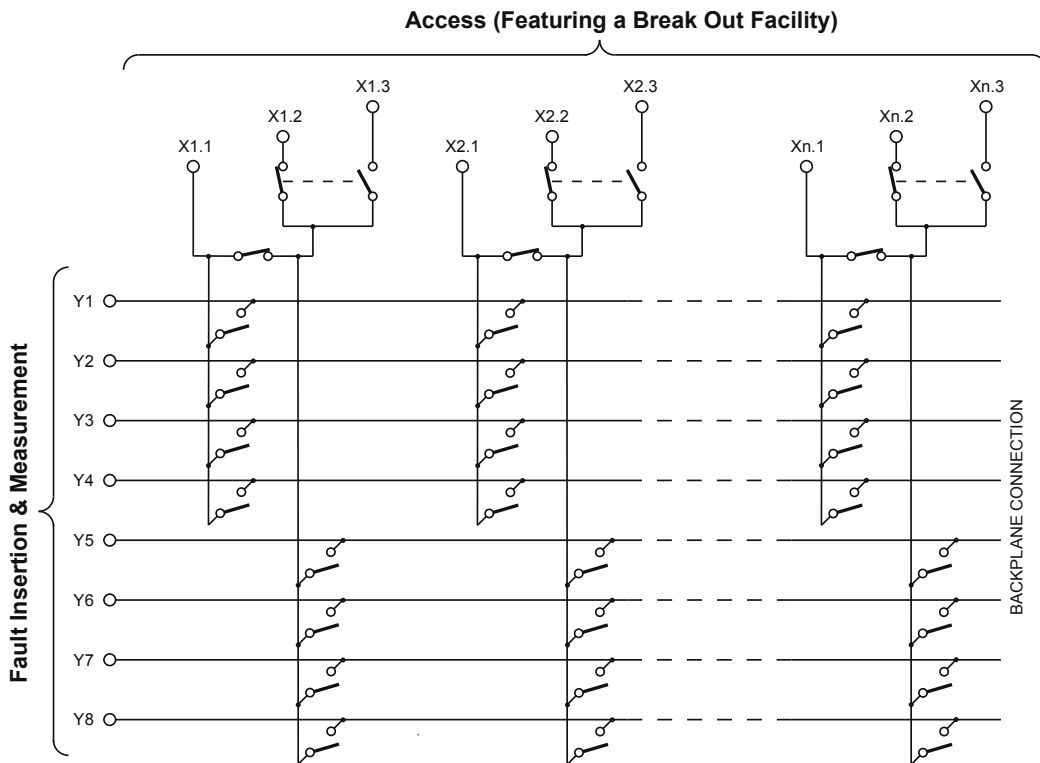
Fig. 9.8 - Straight-Through Fault Insertion Schematic

## FIBO (Fault Insertion Break Out) Matrices

As referred to in Section 6, cross-point matrices are the most flexible switching system you can implement. With the right configuration, you can route virtually any test resource to any test point on the DUT. Also, because of its flexibility, it is easy to reconfigure for new DUTs with minimal wiring changes.

In Fault Insertion testing, a Matrix can easily create shorts between two or more test points as well as open the connection. To further improve the matrices' fault injection capability, a few extra relays are all that is needed.

In this schematic, you see how a FIBO Matrix is created. Across the X Axis, a fault bus is added. For example, X1 has three added relays – X1.1, X1.2, and X1.3 – all three of these relays can be used to inject a resistive load, faulty serial buses, and a number of other faults. In this particular design, you can see an additional relay between X1.1 and half of the X1 bus. Using these relays, it is possible to split the matrix into two matrices for even greater flexibility.

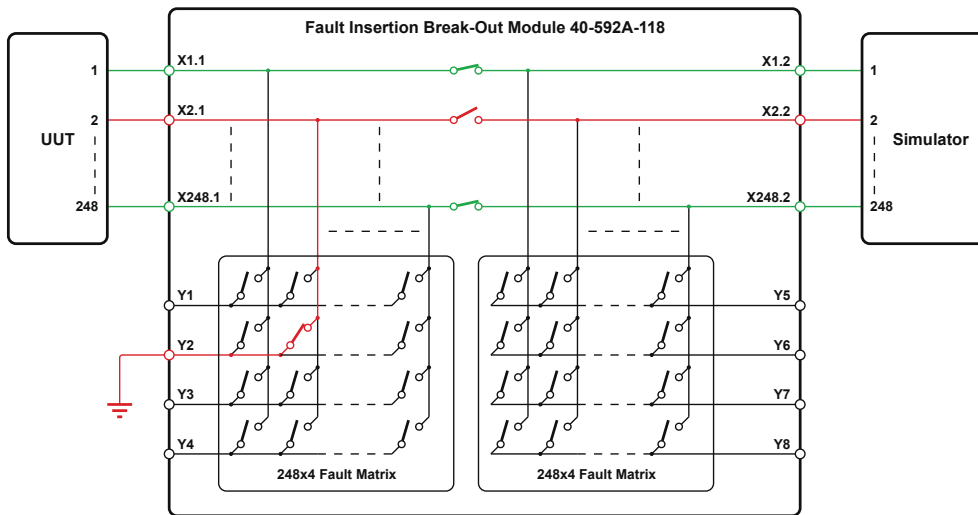


**Fig. 9.9 - FIBO Schematic**

# Fault Insertion Switching

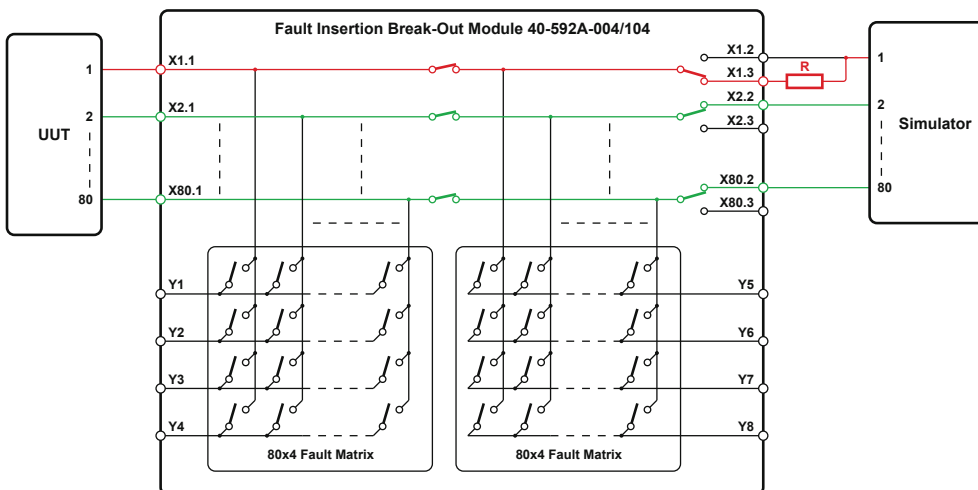
## Sample FIBO Applications

As stated earlier, a FIBO Matrix can perform similar to Straight-Through FIU modules – the big difference is the flexibility of injecting faults on virtually any test point. Here is an example of a test made easier using a FIBO Matrix configuration. A short is applied to a signal connection of the DUT on Breakout 2 by applying a ground to Y2. The same can also be done on the other side of the Through connection.



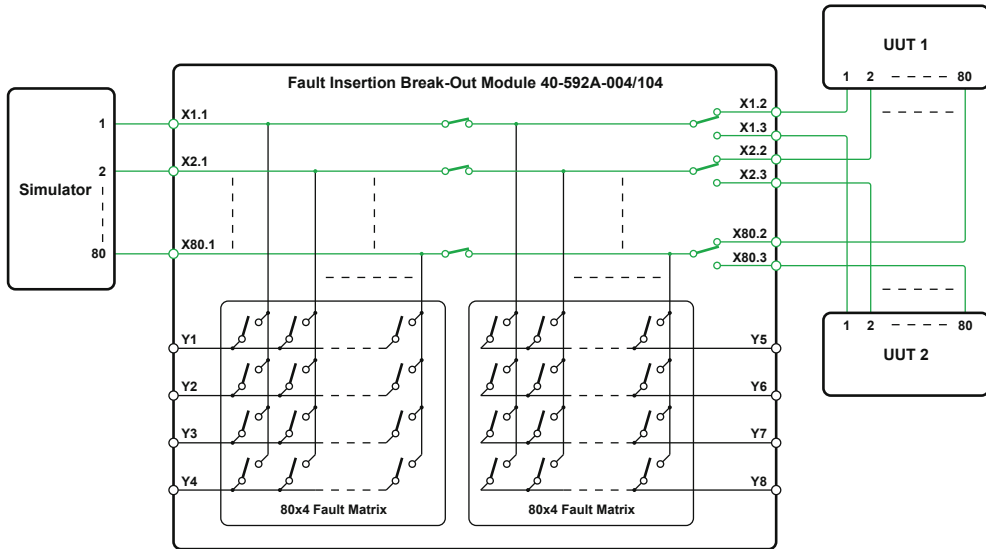
**Fig. 9.10 - Fault Insertion Example: Signal Short to Ground using Y2 with Breakout 2 Connection Open**

In this instance, a series resistor is inserted on a signal line using the breakout connections 1.2 (Normal signal) and 1.3 (Resistive voltage drop):



**Fig. 9.11 - Fault Insertion Example: Adding Series Resistance into Break-Out using 1.3**

In this example, the ATE system can compare the performance of two different UUTs. Alternatively, one UUT can be connected and start testing while a second UUT is being mounted in the system ready for test, allowing for a more efficient test strategy because the DUT load/unload time can be eliminated.



**Fig. 9.12 - Fault Insertion Example: Routing Signals to Two UUTs for Comparison**

# Fault Insertion Switching

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# 10

## HIGH VOLTAGE SWITCHING

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Relay Types.....	10.3
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Things to Watch For .....	10.5
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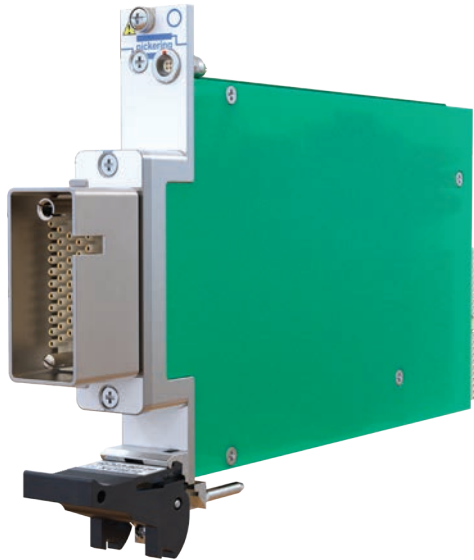
# High Voltage Switching

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## High Voltage Switching

Designers in fields as diverse as semiconductor manufacturing, gas analysis for mining applications, electrosurgical, defibrillators, lightning strike simulation, solar energy and EVs are all looking for switching modules with a higher stand-off and switching voltage characteristics. However, one size rarely fits all, and there are some essential considerations that users should be aware of when specifying a switching module for high voltage use. This section will look at configurations, specs, cabling issues, and some safety features.



**Fig. 10.1 - High Voltage PXI Module**

The configurations of switching modules are much the same as switching for lower voltage applications. There are uncommitted switches, fault insertion, multiplexers, and matrices. And there are reed relay solutions as well as EMRs. The most apparent difference is switching density. Because of voltage standoff issues, relays are spaced much farther apart. So, for example, a single-slot PXI module switching up to 9 kV may have a maximum of 14 relays fitted. These can be uncommitted or configured as, for example, a 1 by 12 multiplexer or a 4 by 3 matrix via external wiring. Other form factors with more real estate may have a larger relay count and other configurations. Expanding a switch design to use multiple slots can, of course, expand the configurations. But when you consider that a single-slot PXI module can hold up to 528 low voltage relays, the limitation becomes very clear. Other modular formats such as LXI can give your test system more real estate to work with, but the density will still be less when compared to low voltage applications.

## Relay Types

Reed relays tend to be a good fit for high voltage applications. Reed relays feature a hermetically sealed switch, and the contacts operate in a vacuum or an inert gas. Therefore, the tracking distance can be much less than for devices like EMR relays that operate in free air. In the nanoampere region, leakage currents are low for reed relays, with isolation resistance of up to  $10^{15} \Omega$ .

# High Voltage Switching

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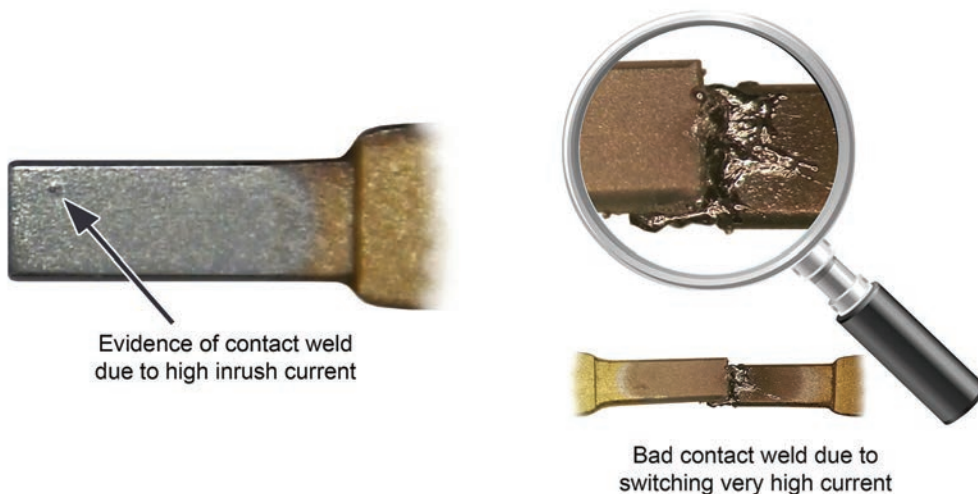


**Fig. 10.2 - Examples of High Voltage Reed Relays**  
(Courtesy of Pickering Electronics)

With electromechanical relays (EMR), the contacts are open to the environment. This can be an issue with contact contamination and operating EMRs in a hazardous situation, such as testing on a flight line when jet fuel fumes are likely present. Solid-state relays (SSR) suffer from high leakage currents and susceptibility to high voltage spikes, which become more problematic at higher voltages.

## Hot or Cold Switching

Reed Relays generally have a higher Carry Current (Cold Switching) rating than their 'Hot' Switching Current rating. Looking at Figure 10.3, it is usually during hot switching that contact damage occurs, caused by the resulting arc across the contacts as they open or close. A severe current overload will quickly melt the contact area causing the two surfaces to fuse, creating a hard weld as soon as the contact closes. Less severe current inrushes will cause a milder weld or gradually build up a 'pip' on one contact and erode a 'crater' on the other contact according to the direction of current flow.



**Fig. 10.3 - Damaged Relay Contacts due to Excessive Hot Switching or Exceeding Relay Specifications**

## Specifications

Like the selection of any other switching system, your Engineering test specification will dictate the switching system. So careful analysis of the datasheets of your switching system of choice is essential to study before making a purchase.

Specifications to pay close attention to include:

- Voltage - Usually, a reed relay will be rated at DC voltage. If a device is rated at 3000 V for AC peak voltage, the RMS value will be  $3000 / \sqrt{2}$ .
- Peak Voltage - This is usually the same number as the DC operating specification. However, compared to the maximum DC voltage specification, it is generally recommended that the AC source be fully isolated from the mains AC supply.
- Hot Switching Limits - When hot switching, it is vital to ensure that the product of the voltage and current to be switched does not exceed the overall switching power rating of the relay. For example, consider a relay with a maximum switching power rating of 50 W and 0.25 A. If the application requires the relay to switch at 5000 V, the maximum current will be limited to 10 mA and not 0.25 A, as that would necessitate a power rating of 1,250 W. Hot switching, of course, will shorten relay life and reduce voltage stand-off as arcing occurs once the plating degrades.

## Things to watch for

Besides voltage and current specifications, conditions surrounding the test system design or characteristics of the DUT require the test system designer to consider certain features that may need to be implemented for the safety or reliability of the test system. Here are a few considerations:

### Capacitive Inrush Currents

High voltage relays fail because the reactance (capacitance or inductance) in the circuit has not been adequately considered. See Figure 10.4.

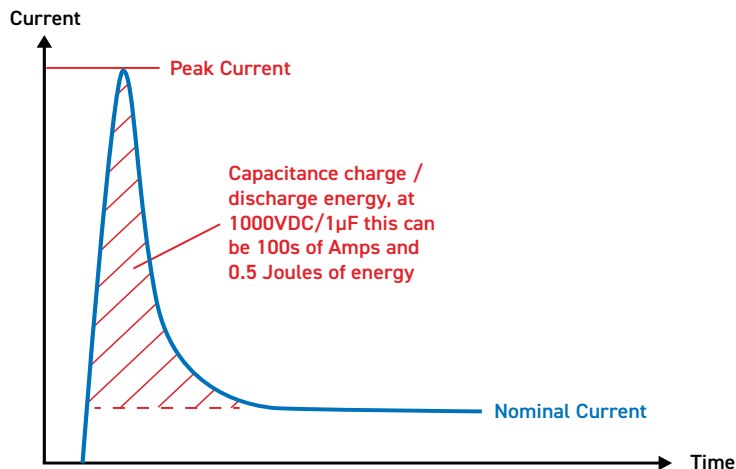


Fig. 10.4 - Capacitive Inrush Currents

# High Voltage Switching

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Any capacitance in a high voltage circuit can be charged or discharged by the closing switch - if there is no load to limit the inrush, the current can be 100s of Amps. This energy can cause significant damage to the relay contacts. Therefore, either the nature of the capacitance in the circuit needs to be considered, or protection must be included. This protection could be additional relays large enough to discharge the cable before testing.

## Allow A Safety Margin

Manufacturers rate devices at a voltage level, but – especially above 10 kVDC for switching or 15 kVDC for isolation – it is inadvisable to push any switch module to the absolute maximum limit specified. When the part is new, it should perform according to the datasheet, but throughout its life, arcing will occur, especially when hot switching is employed. Metal transference will take place between the contacts. This can cause a build-up on one contact, reducing the contact gap and hence the voltage stand-off.

By allowing a margin of at least 10%, the relay can be expected to perform reliably throughout its life.

## Safety Interlock

As there can be potentially dangerous voltages present on switch connectors, whether the test system is actively running a test program or even at the end of a test program because of residual capacitance, a safety interlock is implemented on many manufacturers' switching systems, which will open all relays should an event selected by the test engineer occurs (example, activating the mass interconnect interlock when the test fixture is released) to protect the operator. This interface signal should be able to be daisy-chained to all high voltage switching modules. The signal can also be used to disable the high voltage source.

## RFI Suppression

In some cases, effective RFI suppression integrated into the switch module or as part of the test system can extend relay contact life in hot switching applications and control surges caused by high voltage transients in cold switching applications. RFI suppression also ensures a module's safe operation when connected to a high voltage source via cable assemblies that might otherwise generate additional transients or RFI problems. However, suppression components can result in reduced bandwidth and a slightly higher path resistance than standard designs.

## Corona Discharge

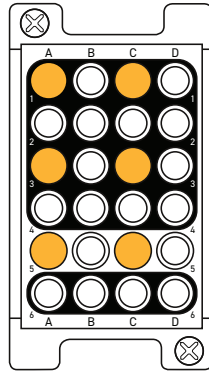
Wikipedia states that a corona discharge is "an electrical discharge caused by the ionization of a fluid such as air surrounding a conductor carrying a high voltage." This discharge can be visual (seen as a bluish glow) and aural in some situations. The discharge can create corrosive gasses that can damage connections and be hazardous to the test system operator. Depending on the application, Corona discharge can occur in voltage ranges from as little as 2 kV to 6 kV. While this is primarily prevalent in high voltage transmission lines, small corona discharges during test are possible. The possibility of corona discharge can be minimized by using the correct insulation – consult your cable vendor for the most suitable wire to use in your high voltage application.

## Cables and Connectors

Selecting the correct wire insulation is essential for high voltage applications. For example, standard PVC (polyvinyl chloride), a common insulation, is only rated to 1,000 volts. IEWC Global solutions ([iewc.com](http://iewc.com))

recommends Polyethylene for cables up to 9 kV. Polyethylene is a very good insulation as it offers a low and stable dielectric constant overall frequencies and a very high insulation resistance.

Connector types are equally important. The key limitations are pin spacing in the connector and the dielectric used to hold the pins in place. Connector specifications to consider are the rated voltage and current, the withstand voltage (similar to the cold switch rating of Pickering's switch modules), breakdown voltage, and the insulation resistance. Of course, the higher, the better is suitable for the latter.



**Fig. 10.5 - High Voltage Connector with Checkerboarding Pinouts**  
(Coutesy of VPC)

As the dielectric is one of the key contributors to isolation, if you have very few high voltage signals to connect, you may want to “Checkerboard” your pin connections. In this example of a 24-pin high voltage connector (Figure 10.5), you can see that no signal is directly adjacent to another. As the space between signals is doubled, the isolation spec of the connector is significantly increased. As only 25% of the pins are used, it is a limitation in some applications.

Mass Interconnect systems from companies like MacPanel and Virginia Panel have connectors rated for an operating voltage of up to 1.5 kV DC (1.25 kV AC) and a withstand voltage of up to 4.5 kV DC (3.75 kV AC). (Consult your mass Interconnect vendor of choice before making a selection). So, a separate connector for the HV connections is necessary for applications above these voltages. This brings up a point – if you are using a mass interconnect in your test system and need to use a separate connector for your HV connections, pay close attention to the number of mating cycles the connectors are rated to. Many high voltage connectors are rated to just over 100 mating cycles, unlike mass interconnects, which are rated for thousands of mating cycles. A connector like this will necessitate added maintenance as frequent replacement may be necessary.

### Important Specifications

Two different specifications are commonly cited in high voltage connectors – Typical Breakdown Voltage and Dielectric Withstanding Voltage (DWV). Breakdown voltage is relatively straightforward: applying this voltage will cause catastrophic failure in your connector, cabling... and possibly instruments and DUTs.

DWV sometimes referred to as the “Voltage Proof Test” or “Wet Dielectric Test”, is probably the most important specification you will want to know. A spokesperson for Virginia Panel states, “The DWV test

# High Voltage Switching

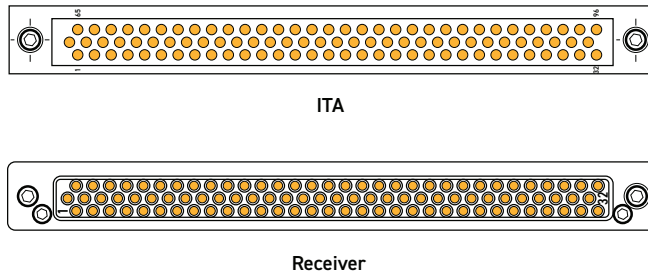
consists of applying a voltage higher than rated voltage for a specific time between mutually insulated portions of a connector or between insulated portions and ground. For purposes of standardization, the withstanding voltage is established as 75% of the minimum breakdown voltage of the connector, and it is suggested that the operating rated voltage of the connector be established as 1/3 of the withstanding voltage.”

“This serves to determine whether insulating materials and spacing in the component parts are adequate. When a connector is faulty in these respects, applying the test voltage will result in either disruptive discharge or deterioration. Disruptive discharge is evidenced by flashover (surface discharge), spark-over (air discharge), or breakdown (puncture discharge). When the DWV test is performed, the condition also has a current leakage requirement.”

### Specifications

Available contact positions	96
Typical Breakdown Voltage	2.7 kVDC 1.5 kVAC
Dielectric Withstanding Voltage (DWV)	1.5 kVDC 1.0 kVAC

### Contact Arrangement



**Fig. 10.6 - Sample High Voltage Connector and Specifications**  
(Coutesy of VPC)

In Figure 10.6, you see a Mass Interconnect connector pair with the specification mentioned above. It is important to note that the DWV and Breakdown voltage is lower for AC applications.

A spokesperson from MAC Panel also added that “the environment must always be included in High Voltage connector system design as the relative humidity, temperature, and composition of the gases around the contacts will affect the positive outcome of the test. All the figures we publish are assumed to be 50% humidity and in air. But when inert gasses are around, or the relative humidity is high, the test designer should talk to their partner’s application team.”

So, in summary, an excellent high voltage test system design is a combination of the application’s specifications, wire type, insulation, discharge and RFI suppression, environment and connector types.

# 11

## USEFUL INFORMATION

This section provides useful information sources for products, associated organizations and standards.

<b>PXISA</b> .....	11.3
The PXISA is responsible for the maintenance of the PXI standard and its promotion. This section explains its aims and membership.	
<b>AXIe Consortium</b> .....	11.3
The AXIe Consortium is responsible for the AXIe standard.	
<b>IVI Foundation</b> .....	11.3
The IVI Foundation promotes specifications for programming Test Instruments.	
<b>LXI Consortium</b> .....	11.3
The LXI Consortium is responsible for the creation and promotion of the LXI standard.	
<b>PICMG</b> .....	11.3
The PICMG is responsible for the cPCI standard, on which the PXI standard is based.	
<b>PCISIG</b> .....	11.4
The PCISIG supports the PCI standard.	
<b>USB</b> .....	11.4
The USB Implementors Forum is responsible for the Universal Serial Bus.	
<b>Useful Websites</b> .....	11.5
Some useful web sites to get more information about PXI and other systems.	
<b>Terminology</b> .....	11.5
A glossary of terms that you might come across.	

# Useful Information

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### PXISA



The PXI Systems Alliance is a not-for-profit organization run by companies involved in PXI products.

The organization is responsible for the production of the technical specifications for PXI and the promotion of the PXI concept in the market.

Membership of the PXISA is open to any company that is willing to promote the PXI standard.

### Other Organizations

#### AXIe Consortium



The AXIe Consortium is responsible for the development and promotion of the open AdvancedTCA Extensions for Instrumentation and Test (AXIe) standard.

#### IVI Foundation



The IVI Foundation promotes specifications for programming test instruments that simplify interchangeability, provide better performance, and reduce the cost of program development and maintenance.

#### LXI Consortium



The LXI Consortium is responsible for the creation and promotion of the LXI standard. It has a similar structure to the PXISA since it has different membership levels and working groups to create and maintain the specification.

#### PICMG



PICMG (PCI Industrial Computer Manufacturers Group) is a consortium of over 600 companies who collaboratively develop open specifications for high performance telecommunications and industrial computing applications, including the CompactPCI (cPCI) standard. CompactPCI products can be used in PXI Chassis and PXI products can be used in cPCI chassis with some limitations in each case.

## Useful Information

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- **Mission**

Founded in 1994, PICMG's original mission was to extend the PCI standard, as approved by the PCI Special Interest Group (PCISIG) for computer systems such as PCI/ISA, PCI/EISA and the PCI/3U or 6U Eurocard form factor known as CompactPCI. PICMG continues to develop important extensions and improvements to CompactPCI.

- **Purpose**

PICMG's purpose is to offer equipment vendors common specifications, thereby increasing availability and reducing costs and time to market. The PCI specifications provide a clear upgrade path for OEMs wishing to migrate to new designs.

All of the organizations listed are not for profit.

### PCISIG



The purpose of the PCI Special Interest Group (PCI-SIG) is to deliver a stable, straightforward and compatible standard for PCI devices.

The organization is important to PXI since the control interface is built on the PCI standard and uses common electrical devices to PCI cards, including the PCI Bridges incorporated into the PXI backplane.

### USB



The USB Implementors Forum (USB-IF) promotes the Universal Serial Bus and maintains the specifications and a compliance program. USB 1.1, 2.0 (High Speed), and 3.0 (Super Speed) devices are available. USBTMC is a software interface standard created to support test and measurement applications and is now controlled by the IIVI foundation.

## Useful Websites

AXIe Consortium	<a href="http://www.axiestandard.org">www.axiestandard.org</a>
Cable Design Tool	<a href="http://www.pickeringtest.com/cdt">www.pickeringtest.com/cdt</a>
IVI Foundation	<a href="http://www.ivifoundation.org">www.ivifoundation.org</a>
Keysight Impedance Measurement Handbook	<a href="http://literature.cdn.keysight.com/litweb/pdf/5950-3000.pdf">literature.cdn.keysight.com/litweb/pdf/5950-3000.pdf</a>
LXI Consortium	<a href="http://www.lxistandard.org">www.lxistandard.org</a>
MacPanel	<a href="http://www.macpanel.com">www.macpanel.com</a>
Pickering Interfaces	<a href="http://www.pickeringtest.com">www.pickeringtest.com</a>
PXI Systems Alliance	<a href="http://www.pxisa.org">www.pxisa.org</a>
Tektronix Keithley Switching Handbook	<a href="http://www.tek.com/document/handbook/switching-handbook">www.tek.com/document/handbook/switching-handbook</a>
Virginia Panel	<a href="http://www.vpc.com">www.vpc.com</a>
Wikipedia on Coax Cable	<a href="http://en.wikipedia.org/wiki/Coaxial_cable">en.wikipedia.org/wiki/Coaxial_cable</a>

## Terminology

3U, 6U	Refers to the height of the module, the 6U modules being approximately twice the height of 3U modules. 1U is 44.45mm (1.75 inches).
6 Sigma	Techniques and tools for process improvement.
API	Application Programming Interface
AT	Ampere Turns
AXIe	AdvancedTCA Extensions for Instrumentation and Test
BIRST	Built In Relay Self Test
CompactPCI (cPCI)	A ruggedized version of a PCI card conforming to PICMG 2.0 specification, providing superior mechanical performance and easier insertion & removal of cards.
COTS	Commercial Off-the-Shelf
CPU	Central Processing Unit
DUT	Device Under Test
eBIRST	External BIRST Tools
ECU	Electronic Control Unit
EMR	Electromechanical Relay
EN61010	Safety Standard for Medical Devices.
FET	Field Effect Transistor
FIBO	Fault Insertion Break Out
FIT	Failures in Test
FIU	Fault Insertion Unit
Form A	Single Pole, Single Throw, Normally Open Relay.
Form B	Single Pole, Single Throw, Normally Closed Relay.
Form C	Single Pole, Double Throw Relay.
GPIB	General Purpose Interface Bus, a standard used for interconnecting bench instruments using an 8 bit wide data system. Standard is defined by IEEE 488.

## Useful Information

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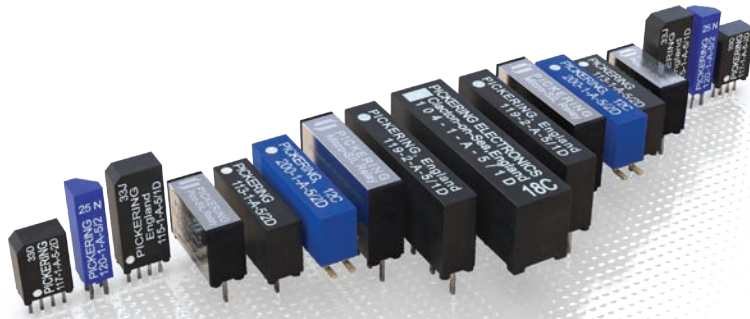
HALT	Highly Accelerated Life testing
HASS	Highly Accelerated Stress Screening
HILS	Hardware in the Loop Simulation
HP	Horizontal pitch (Unit of length)
ITA	Interface Test Adapter
IVI	Interchangeable Virtual Instrument
J1, J2, J3	Connectors on PXI modules that mate to the PXI chassis backplane connectors P1, P2 and P3. On 3U modules only connectors J1 & J2 are used.
Local Bus	Bus that can be used to connect adjacent PXI modules in a chassis without the use of PXI features. The Bus can be used for analog or digital signals and is module defined.
LXI	LAN eXtensions for Instrumentation.
Opto MOSFET	Optically Coupled MOSFET
PCI	Peripheral Component Interconnect, bus system commonly used in computers to provide additional functionality.
PCISIG	PCI Special Interest Group
PICMG	PCI Industrial Computer Manufacturers Group
PXI	PCI eXtensions for Instrumentation
PXIe	PXI Express
Star Trigger	Optional fast trigger system driven from Slot 2 in a PXI chassis that provides a low latency synchronized trigger to all Peripheral Modules.
Trigger Bus	A bus defined in the PXI standard that can be used to trigger events. The triggers can be conditioned by software.
USB	Universal Serial Bus
VISA	Virtual Instrument Software Architecture
VSWR	Voltage Standing Wave Ratio
VXI	VME Extensions for Instrumentation
P1	Backplane connector on a chassis carrying the 32-bit PCI bus.
P2	Backplane connector on the chassis carrying the 64-bit PCI bus and PXI specific features.
P3	Reserved connector whose use is undefined by the PXI standard and can be fitted to 6U Chassis.
P4	Connector used on 6U Chassis that allows 3U cards to be fitted in 6U Slots. It provides the same functions as P1.
P5	Connector used on 6U Chassis that allows 3U cards to be fitted in 6U slots. It provides the same functions as P2.
System Slot	Slots on the left-hand side of a PXI Chassis reserved for use by the system controller.

# 12 ABOUT PICKERING

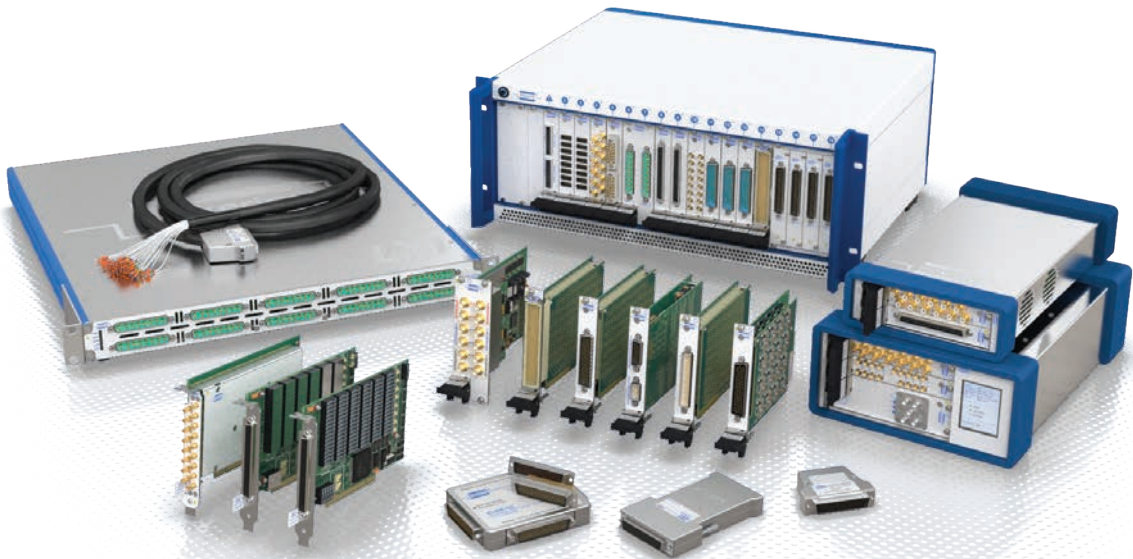
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Reed Relays.....	12.4
Modular Switching & Simulation .....	12.5
Cables and Connectors .....	12.8

## About Pickering

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**Reed Relays from Pickering Electronics**



**Modular Switching, Simulation and Connectivity from Pickering Interfaces and Pickering Connect**



### Introduction - Pickering Group

The Pickering Group of companies is comprised of: Pickering Electronics—our relay division; Pickering Interfaces—our switching and simulation division and Pickering Connect—our connection division. Together, we deliver high-quality switching and simulation products and a full range of standard and custom cable and connector solutions.

**Pickering Electronics** was established in 1968 to manufacture high-quality Reed Relays predominantly for use in Instrumentation and Test equipment. Pickering Relays are available in Surface Mount, Single-in-Line (SIL/ SIP) and Dual-in-Line (DIL/DIP), with the option of dry or mercury wetted switches. These small relays are sold in high volumes to large ATE and instrumentation companies worldwide.

**Pickering Interfaces** was formed in 1988 to design and manufacture modular signal switching and simulation for use in electronic test and verification and now offers the most extensive range of switching and simulation products in the industry for PXI, LXI and PCI applications. Our products are specified in test systems installed worldwide and have a reputation for providing excellent reliability and value. We serve many electronics industries, including automotive, aerospace & defense, energy, industrial, communications, medical and semiconductor.

**Pickering Connect** offers a comprehensive range of standard and custom connectivity solutions, specializing in custom cable and connectivity and can manufacture in quantities of one to many thousands. Established in 2004 our high-quality products are used throughout the world in many applications, including aerospace, automotive, medical and military.

Learn more at [pickering-group.com](http://pickering-group.com).

# About Pickering

## Reed Relays from Pickering Electronics - [pickeringrelay.com](http://pickeringrelay.com)

Our reed relays are manufactured using our patented **SoftCenter™** technology and utilize instrument grade reed switches, former-less coils and mu-metal magnetic screening to increase performance and reliability. We provide relays for the following applications:

- High Density
- High Voltage Switching
- RF & High-Speed Digital
- High Power Switching
- General Instrumentation
- Low Capacitance Switching
- Low Thermal EMF
- Data Acquisition

### What is **SoftCenter** Technology?

Pickering reed relays are encapsulated using a soft inner material to greatly reduce physical stresses on the glass/metal seal of the reed switch capsule. The very hard compounds used by most manufacturers can cause stresses that can damage seals or distort the reed switch and therefore degrading contact resistance stability and life expectation.

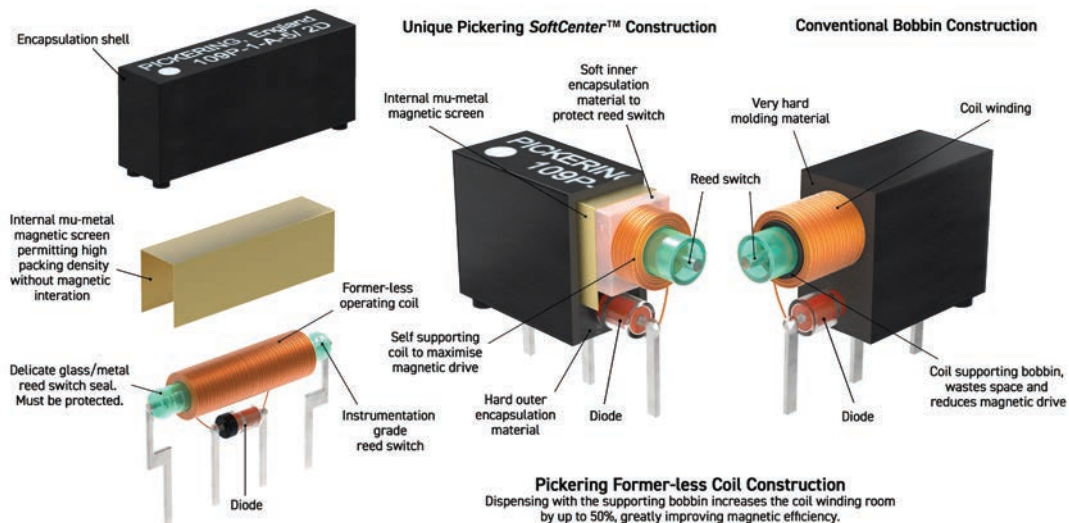
### Built-in, Mu-Metal Magnetic Screening

Reed switches are operated by the magnetic field from a coil. Without magnetic screening this field spreads outside the confines of the relay de-sensitizing other reed relays mounted alongside. Mu-metal has high permeability and low magnetic remanence, eliminating the effects of magnetic interaction.

### Former-less Coils

Relay operating coils are commonly wound on bobbins. Pickering relays are manufactured with self-supporting coils, avoiding the space required for these bobbins. In the case of smaller relays, this gives 50 percent more room for the coil winding, allowing the use of less sensitive reed switches to provide higher operating and restoring forces and allowing extremely high coil resistance figures.

## Typical Pickering Construction using Former-less Coils and our **SoftCenter™** technology



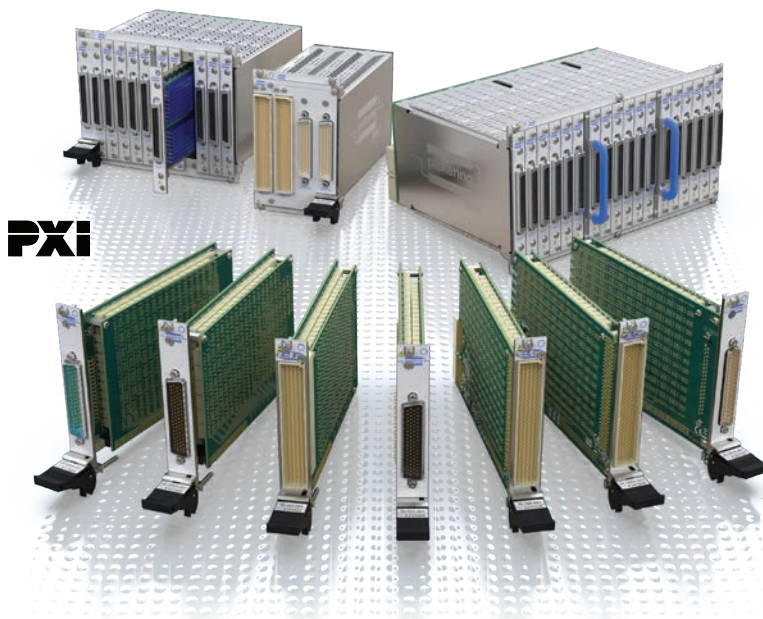


## Modular Switching & Simulation from Pickering Interfaces - [pickeringtest.com](http://pickeringtest.com)

We introduced our first modular switching system in 1988 and are now a leading manufacturer of PXI, PCI, LXI & USB switching & simulation products. With our deep portfolio of products, we assure you that we can optimize your test system switching and simulation to exactly fit your needs.

### PXI Switching

We first entered the PXI market in 1998 and are now offering over 1,000 PXI & PXIe switching modules. These modules range from the BRIC™ highest density switching matrices, RF/microwave up to 67 GHz and optical switching to fault insertion modules. All of our modules will plug into any PXI compliant chassis or a Hybrid slot in a PXIe chassis and may also be used in our Ethernet controlled LXI/USB chassis.



### PXI Simulation Solutions

Does your test strategy require simulating environmental sensors, including temperature, pressure, altitude, movement, PLC/instrument communications and strain gauges? We offer an extensive range of PXI & PXIe solutions for sensor simulation, including programmable resistors, strain gauge simulators, thermocouple simulators, LVDT, RVDT and resolver simulators, analog output/current loop simulators, and battery simulators.



# About Pickering

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## LXI Switching Solutions

We were early adopters of the LXI standard to provide a standardized interface for Ethernet (LAN) controlled instruments. We now offer a large range of LXI switching solutions, including low-frequency matrices, multiplexers, RF & microwave up to 67 GHz, optical systems, and turnkey microwave & optical switch and signal routing solutions.



## PXI & LXI Modular Chassis

Our PXI modules plug into any PXI compliant chassis or a Hybrid slot in a PXIe chassis, and our PXIe module into any compliant PXIe slot or Hybrid slot in a PXIe chassis. We offer both PXI & PXIe modular chassis, including 8, 14, 18 & 19-slot versions.

We also offer LXI & LXI/USB modular chassis—these chassis allow any of our extensive range of 3U PXI modules to be controlled in an LXI environment, enabling remote control over a gigabit Ethernet connection, or via a USB3 connection. These include 2, 4, 6, 7 & 18 slot versions.



### PCI Switching & Simulation

Our PCI switch & simulation cards are built using the same basic technology as our acclaimed PXI range utilizing the same software drivers, soft front panels and control electronics. The range includes matrices, multiplexers, fault insertion switching and programmable resistors.



### Comprehensive Software Solutions

Our commitment to delivering you high-quality products does not just extend to our switching and simulation products. Our in-house software team has created all of our application software packages and software drivers to help you simplify and expedite the development and deployment of your automated test systems. Our Switch Path Manager signal routing software simplifies signal routing through switching systems and speeds up the development of switching system software.

### Diagnostic Test Tools

Verification and diagnosis of complex switching operations in a test system have always been an issue. Our eBIRST diagnostic test tools provide you with a quick and straightforward way of finding relay failures within our PXI, PCI and LXI switch systems.

### Long-term Support

Many of you expect your test systems to last at least as long as the products being tested. We understand this need and pride ourselves that the design and manufacture of all our switching, simulation, software and connectivity products are done in-house. These capabilities enable us to provide guaranteed long-term support, typically 15 to 20 years, and low obsolescence.

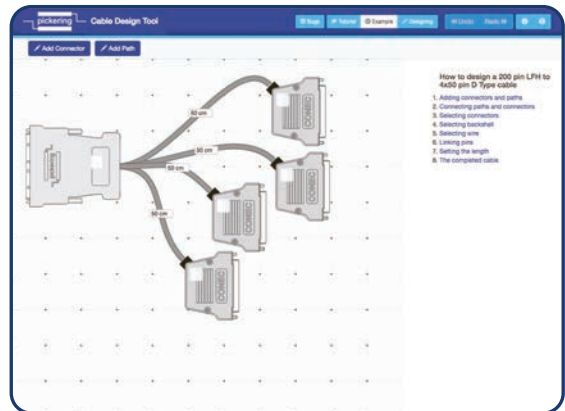
# About Pickering

## Cables & Connectors from Pickering Connect - [pickeringconnect.com](http://pickeringconnect.com)

We offer a comprehensive range of standard and custom connectivity solutions. We specialize in custom cable and connectivity and can manufacture in quantities of one to many thousands. Our cable engineering expertise, in-house PCB, 3D mechanical design, CNC and PCB component placement capabilities enable us to provide quick turn around on customized solutions to match all of your requirements.

Since 2004 we have nurtured a reputation for excellence, reliability and value. Our high-quality products are used throughout the world in many types of applications, including aerospace, automotive, medical and military.

We can also manufacture cable assemblies to special requirements. Try our unique, free Cable Design Tool to create custom cable assemblies. With this online tool, you can graphically design your cable assemblies using our built-in library of standard cable sets or create them from scratch. To learn more or to try the tool, go to [pickeringtest.com/cdt](http://pickeringtest.com/cdt).







## Direct Sales & Support Offices

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