Application Guide

Wafer Acceptance Testing:
Leveraging Low Leakage Switching with Switched Guard Technology

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Introduction

Pickering has recently introduced a new range of switching products featuring a switching methodology based on two-pole, switched-guard designs which can be used in a driven-guard measurement system to enable a high number of very low-level current measurements to be automatically made, quickly and accurately. The new switched guard designs have isolation resistances of >1 teraohm (1TΩ = 10^{12} Ω), with leakage currents in the femtoamp (1fA = 10^{-15} A) region.

We have developed and refined these products in close collaboration with a leading semiconductor company for use in their Wafer Acceptance Test systems. These are high-speed parametric testers used by semiconductor manufacturing companies for process control monitoring and yield improvement.

Wafer Acceptance Test (WAT)

Designing and controlling manufacturing processes to maximize integrated circuit yield is critical to semiconductor manufacturers, who can lose $millions in earnings for each percentage point of yield loss. Wafer Acceptance Testing, or WAT, is a test strategy that examines the consistency of the semiconductor manufacturing process. By performing a series of relatively simple tests on wafers at both the process development and production test stages, wafer fab engineers can quickly generate statistical data to help them improve yields.

The manufacturer uses a WAT system during in-line and end-of-line tests in conjunction with an automatic prober to make electrical parametric tests on hundreds of special structures added to the wafer between layers of metal and dielectric. These test structures, which typically include resistors, capacitors, diodes and transistors, are stand-ins for actual devices and are specifically designed to allow fast test data collection to verify the performance of the production processes. Depending on the maturity of the product, the structures are sometimes located around the die itself and sometimes in the scribe line – the area between the dies. Chip manufacturers can quickly collect device performance data from these tests and make positive process adjustments depending on the feedback.

Figure 1 - A manufactured wafer prior to Wafer Acceptance Testing

WAT systems require a range of instrumentation to make the required current versus voltage (IV) and capacitance versus voltage (CV) measurements, typically including various Source/Measure Units (SMUs), precision digital voltmeters, pulse generators and capacitance meters, all connected via a suitable switch matrix to the appropriate test points on the wafer.

The parametric measurement set routinely includes current measurements in the sub-picoamp range, for example, when testing the off-state leakage of high impedance devices or dielectric characteristics. These measurements require the isolation between the complete test system channels, including the switch matrix and interconnections, to be $>10^{12}\,\Omega$ to minimize any leakage current noise (resulting from voltage drops across insulators in the test connections) from adversely impacting the very low current measurements. A "Driven Guard" measurement technique is usually required to achieve this extremely high level of isolation.

Driven Guard Measurement

In an ordinary coaxial cable connecting test instrumentation to a Device Under Test (DUT), when the conductor is at a certain potential, and the outer shield is grounded, a small leakage current, typically in the nanoamp region, can pass through the insulation between the main probe conductor and the cable's outer electromagnetic shield. Although this may not affect current measurements in the milliamp or even microamp range, leakage of this magnitude will significantly impact current measurements in the picoamp or femtoamp ranges.

A Driven Guard minimizes these leakage currents by surrounding the current-carrying conductor from the high impedance terminal, where low current measurements are made (also called the Force) with a guard conductor connected to a low impedance terminal driven at the same potential as the force via a voltage follower, or buffer, as shown in Figure 2. Since there is ideally no potential difference between the force and the guard, no leakage current will flow through the insulation between the two. In practice, the buffer cannot track the force voltage exactly, and the leakage current passing through the dielectric layer is typically in the femtoamp range.

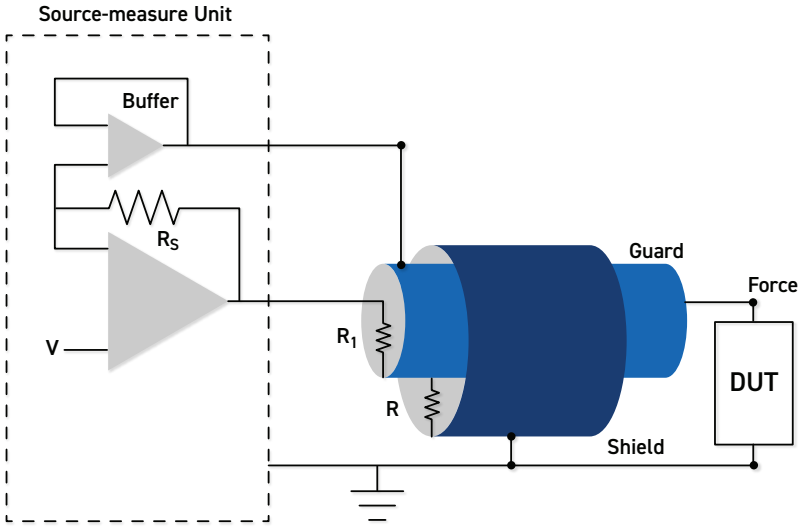


Figure 2 - Driven Guard measurement configuration using Triaxial cabling

Given that the guard is at the same potential as the force terminal, coaxial connector insulators or special triaxial cabling (usually shortened to "triax") are required for user safety. The triax cable assembly features a grounded outer EMI-shielding conductor separated from the guard by an additional insulating layer. Although a small current can flow between the guard and the outer shield, this is supplied by the buffer circuitry and, hence, has no effect on the measured current.

When a triax cable needs to be connected to coaxial terminals at an instrument or switch, special triax-to-coax adapters should be used to ensure both safety and accuracy.

Measurement Settling Time

Low current measurements require longer settling times due to the capacitive effects of cable insulation. This is especially critical if the test schedule requires the applied voltage to be swept, as this parasitic capacitance will draw a charging current in proportion to its magnitude and the rate of change of applied voltage (Ic = C dV/dt).

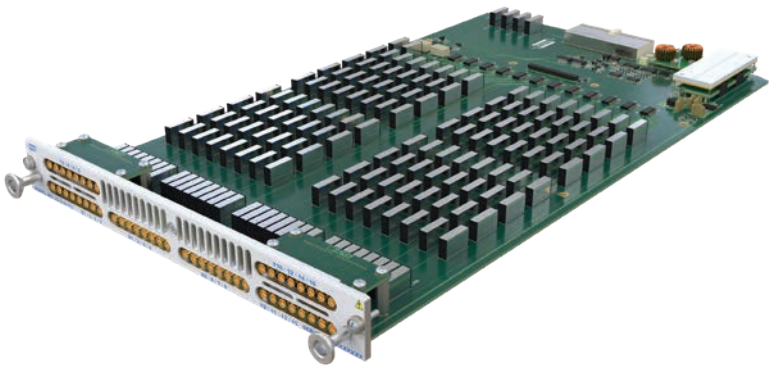
Slowing the sweep rate to reduce this charging current will increase the overall test cycle time, which is not desirable for process control monitoring applications, where testing needs to be completed and the results analyzed quickly to be able to optimize manufacturing processes and minimize product waste. With a driven guard, provided the buffer's response is fast compared to the sweep rate, the voltage between the force and guard remains constant, eliminating the charging current and minimizing measurement settling time.

65-290 LXI Modular Switched Guard Matrix

The 65-290 is a modular matrix platform that provides a switched guard reed relay matrix solution with up to $10^{12}\,\Omega$ channel to channel and channel to ground isolation (measured with a driven guard, 10 V drive, 21 °C ambient and 40 % Relative Humidity). Matrices are created by populating our standard scalable 2U LXI switching chassis (model 65-200-002) with either our 16x16 (model 65-290-001) or 8x16 (model 65-290-002) switched guard plug-in matrix modules – the plug-ins may be mixed in the same chassis for maximum application flexibility and cost-effectiveness.

The plug-ins provide access to the external driven guard X and Y connections via micro-miniature coaxial (MMCX) connectors with insulated connector covers. Different sized matrices are formed by interconnecting the plug-ins via front panel MMCX loop-thru connectors for expansion in both the X and Y axes as required. The loop-thrus can also be used to expand the matrix to additional chassis for very large switching applications. Each chassis supports up to six plug-in modules, which are loaded into the front of the chassis for ease of access. Users can specify the number of plug-in modules they initially require and can field upgrade the chassis to extend the matrix at a later date.

65-290-002 Plug-in



Each 65-290-002 plug-in is an 8x16 matrix module with all switched paths consisting of a signal and a guard connection. The matrix consists of two 8x8 matrices with isolation switches on both X and Y connections, as shown in Fig.3. The two sets of Y signals are routed to 16 front-panel MMCX connectors. The X signals are linked between the two matrix halves via isolation switches and routed to eight MMCX connectors. Dividing the matrix in this way reduces stub lengths and improves bandwidth and crosstalk performance. The X and Y buses also have loop-thru capability via a further set of MMCX connectors, allowing easy matrix expansion to other plug-ins via standard external cables to a maximum size for a chassis containing six 8x16 modules of either 16x48 for Y-axis looping or 96x8 for X-axis looping.

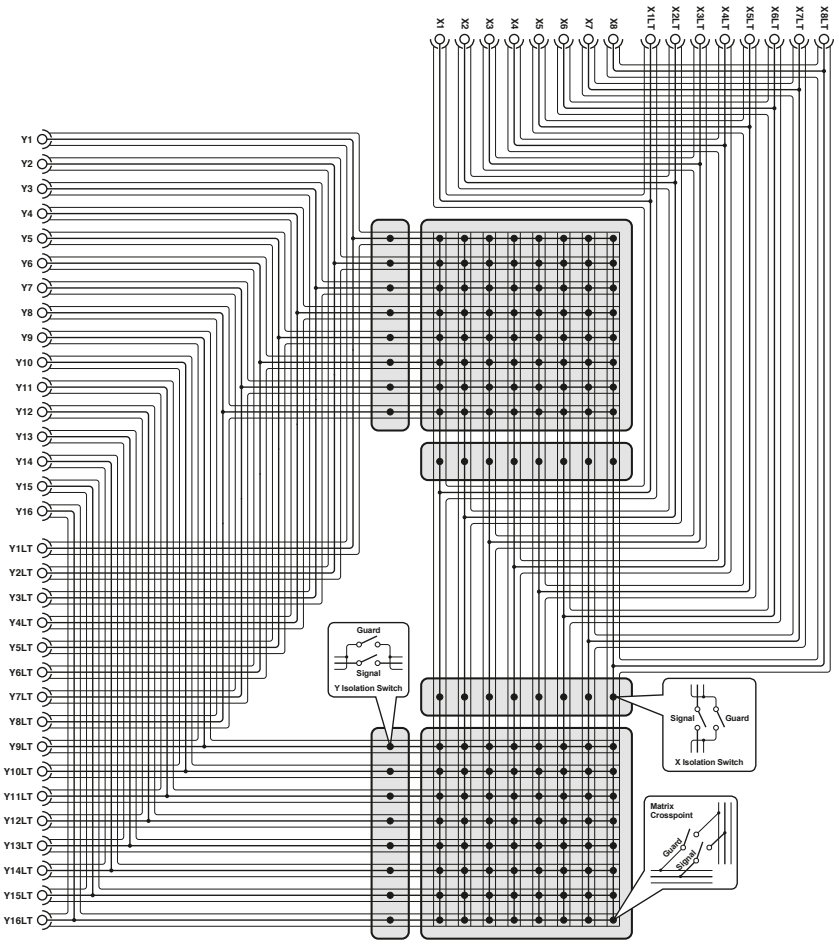


Figure 3 - Schematic diagram of the 65-290-002 plug-in

An example application diagram for the 65-290 configured as a single 48x16 switched guard matrix using Y-axis external loop-thru cables to interconnect six plug-ins is shown in Figure 4 below.

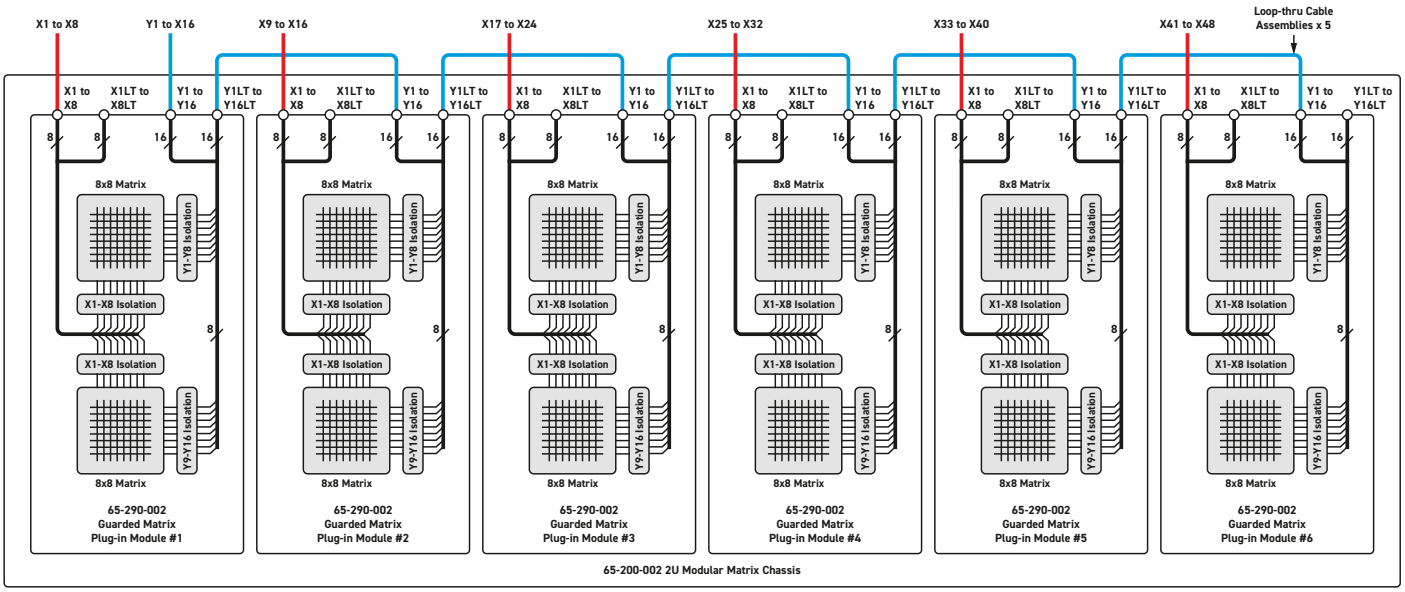
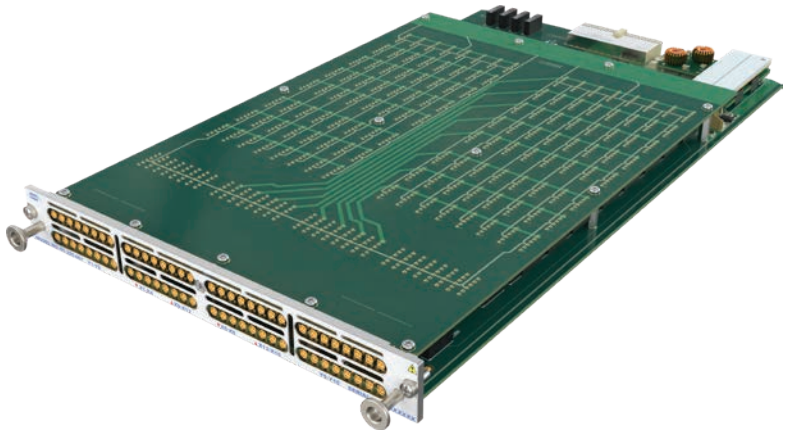


Figure 4 - 65-290 Configured as a 16x48 Switched Guard Matrix

65-290-001 Plug-in



The 65-290-001 plug-in is a 16x16 matrix module consisting of a 65-290-002 8x16 motherboard with a functionally identical 8x16 daughtercard fitted to it.

The 16 Y signals are routed from the motherboard to the two 8x8 matrices on the daughtercard, with the eight X signals from the daughtercard (X9 to X16) linked between these two matrix halves via isolation switches and routed to an additional eight MMCX connectors as shown in Figure 5. Both 16 X and 16 Y buses have loop-thru connections, allowing simple matrix expansion to a maximum size of 16x96 or 96x16 for Y or X-axis looping respectively in a chassis containing six 16x16 modules.

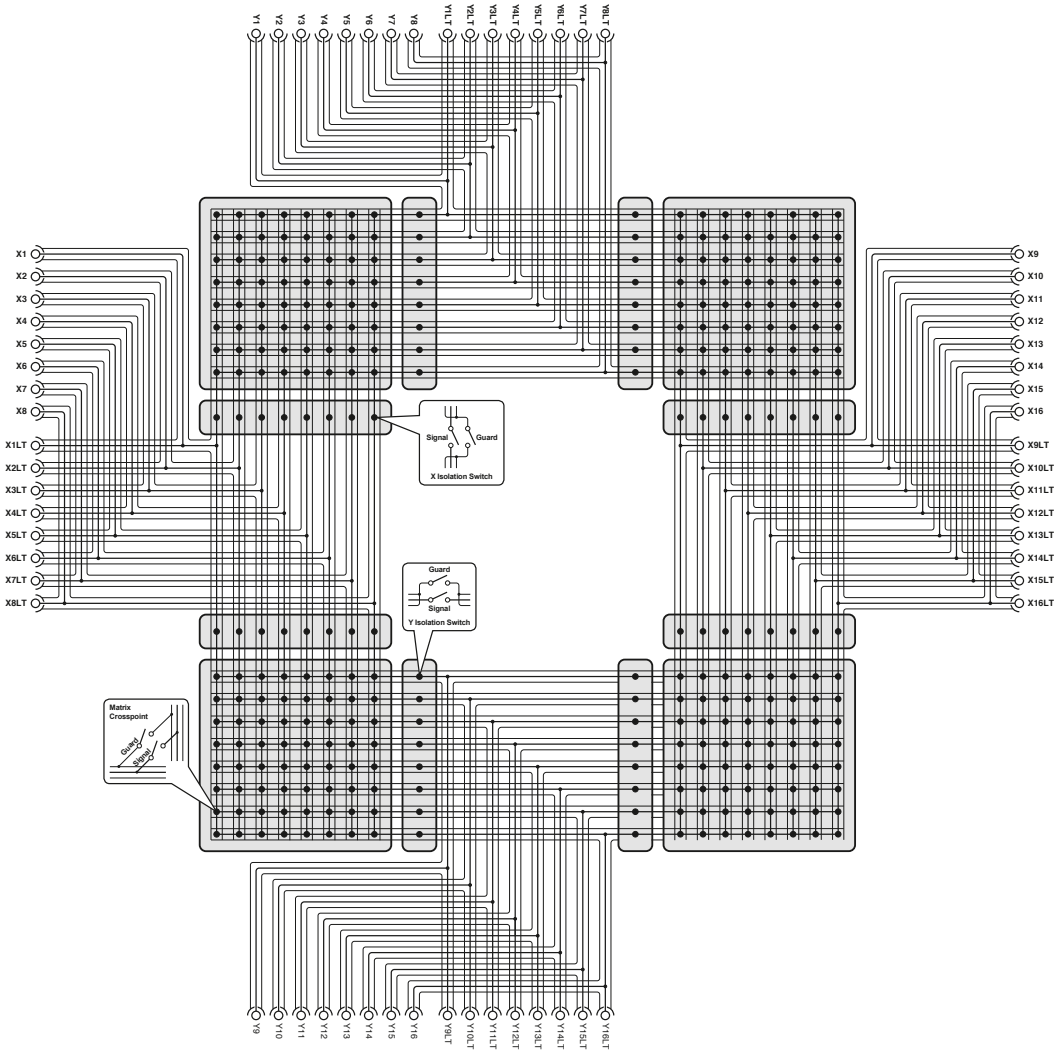


Figure 5 - Schematic diagram of the 65-290-001 plug-in

Relays and Software

The relays used on the plug-ins are custom reed relays from Pickering Electronics, our relay division, specially developed for these switched guard applications. They consist of a signal reed and a shielded guard reed, both operating simultaneously. They are enclosed in a specially designed Mu-metal shield and plastic enclosure to minimize leakage. Like all our reed relays, they exhibit precision low-level switching, high switch speed, high isolation and long life and are ideally suited to this switched guard application.

As mentioned previously, maximizing the speed of test in semiconductor PCM applications is critical for timely feedback to production. The 65-290 features Pickering's standard scan-list sequencing and triggering functionality to maximize throughput when used with multiple instruments. In addition, to simplify the programming of this complex switching system, Pickering's Switch Path Manager automated signal routing application may be used to resolve the required multiple relay operations for each instrument to DUT connection down to a single endpoint-to-endpoint command such as CONNECT (SMU3_HI, DUT_37).

40/42-590 PXI/PXIe Switched Guard Matrix

For smaller low-current parametric test requirements, we have ported the switched guard technology to PXI and PXIe format modules. They include single-slot 16x4 switched guard matrix modules (model 40/42-590-101) and the smaller 8x4 (model 40/42-590-102) variants. They each provide a switched guard reed relay matrix solution with up to $10^{13}\,\Omega$ channel to channel and channel to ground isolation, which can be expanded in the X direction by utilizing front panel loop-thru connectors to externally interconnect adjacent modules' Y-buses together, as shown in Figure 6.

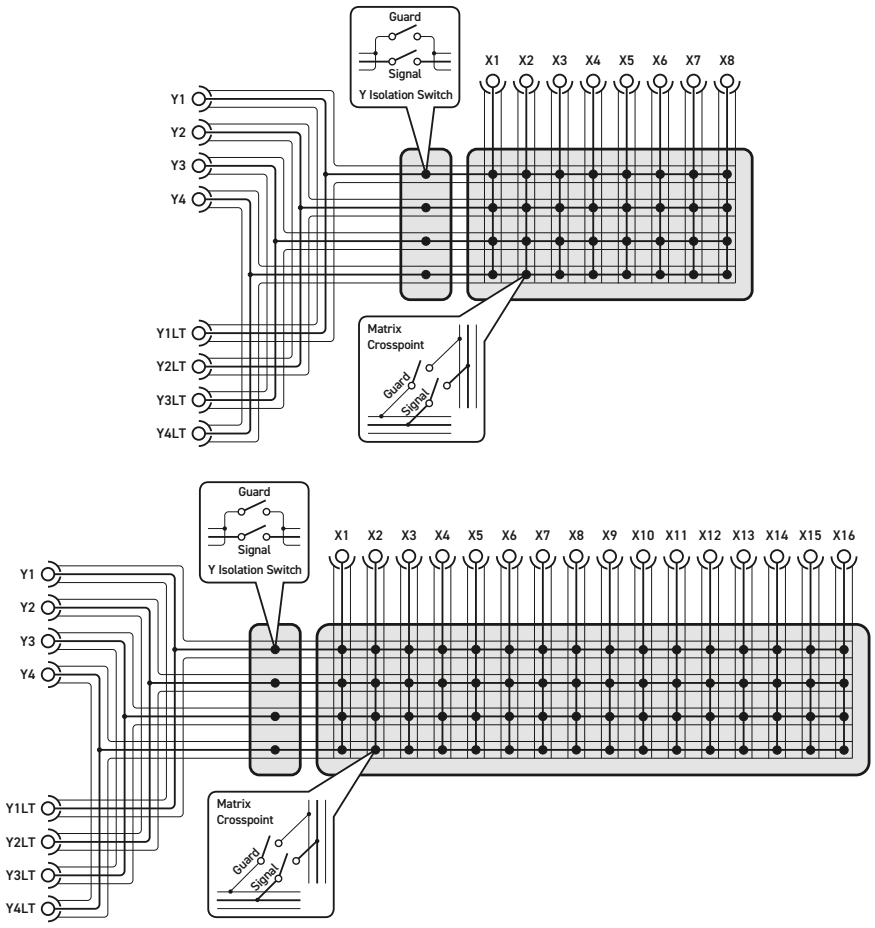
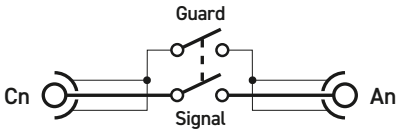


Figure 6 - Switching diagrams for 40/42-590 8x4 & 16x4 switched guard matrix modules

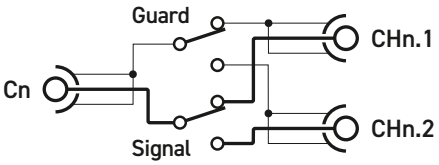
40-121 PXI Switched Guard Reed Relay Modules

Our third family of switched guard products is the 40-121 range, consisting of the following members:

- 40-121-001 26x SPST Switches
- 40-121-002 13x SPST Switches
- 40-121-011 16x 2:1 Multiplexers
- 40-121-012 8x 2:1 Multiplexers



Example SPST channel of 40-121-001



Example multiplexer channel of 40-121-011

Figure 7 - Switching diagrams for 40/42-121 switched guard relay modules

All are single-slot PXI modules designed to provide an isolation resistance in excess of $10^{13}\,\Omega$. Connection of the signal/guard coaxial cables is via easy-to use MS-M RF multiway connectors. The modules may be used to provide additional general-purpose switching functionality to switched guard systems, such as connecting or isolating additional instrumentation.

Summary

Pickering's switched guard PXI, PXIe and LXI switch products provide compact, cost-effective and high-performance switching solutions for semiconductor WAT and other low leakage test applications such as LCR testing. They are based on industry-standard platforms designed for scalability, longevity and ease of integration into a wide variety of test systems.

Technical Support

For Technical Support please contact Pickering Interfaces either by phone, the website or via e-mail.

Warranty

All products manufactured by Pickering Interfaces are warranted against defective materials and workmanship for a period of three years, excluding programmable power supplies, from the date of delivery to the original purchaser. Any product found to be defective within this period will, at the discretion of Pickering Interfaces be repaired or replaced.

Products serviced and repaired outside of the warranty period are warranted for ninety days.

Extended warranty and service are available. Please contact Pickering Interfaces by phone, the website or via e-mail.

Environmental Policy

Pickering Interfaces operates under an environmental management system similar to ISO 14001.

Pickering Interfaces strives to fulfil all relevant environmental laws and regulations and reduce wastes and releases to the environment. Pickering Interfaces aims to design and operate products in a way that protects the environment and the health and safety of its employees, customers and the public. Pickering Interfaces endeavours to develop and manufacture products that can be produced, distributed, used and recycled, or disposed of, in a safe and environmentally friendly manner.

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