Reed Relays for Automated Test Equipment Applications

Automated Test Equipment (ATE) is used worldwide for testing semiconductor chips, assembled printed circuit boards, electronic equipment such as cell phones, cable assemblies and so on. Huge numbers of multi-channel test signals – digital and analog – may need to be sent to or received from pins on a Device Under Test (DUT), under program control from the ATE, and that's where relays are required, sometimes thousands of them.

Reed relays manufactured by Coto Technology (and available locally from Chendu China distributor, MagiChips Technology, Ltd.) have been the relay of choice for many of the world's ATE manufacturers for many years because they are small, they are fast, they are reliable, and they have electrical characteristics that exactly suit ATE needs – extremely high OFF resistance, and very low ON resistance. When OFF, their resistance may be a million megohms or more. When ON, their resistance may be under 100 mΩ.

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1 Introduction

Automated Test Equipment (ATE) requires relays for switching– lots of them. ATE is used worldwide for testing semiconductor chips, assembled printed circuit boards, electronic equipment such as cell phones, cable assemblies, etc. Huge numbers of multi-channel test signals – digital and analog – may need to be sent to or received from pins on a Device Under Test (DUT), under program control from the ATE, and that's where relays are required, sometimes thousands of them.

Electronics are getting smaller and faster, meaning test signals are running at frequencies not formerly encountered. And device pin-counts are increasing exponentially, meaning that the test cards (often called load boards) sending and receiving signals to/from the DUT's are getting more and more crowded. So to be useful, relays have to be small, and they have to transmit high frequency signals in the GHz range with minimal losses or distortion. Maybe above all, they have to be reliable, since an ATE system with thousands of relays may be put out of action if only one relay fails. ATE often runs 24/7, and with running costs of over $3/min, any down time is undesirable and expensive.

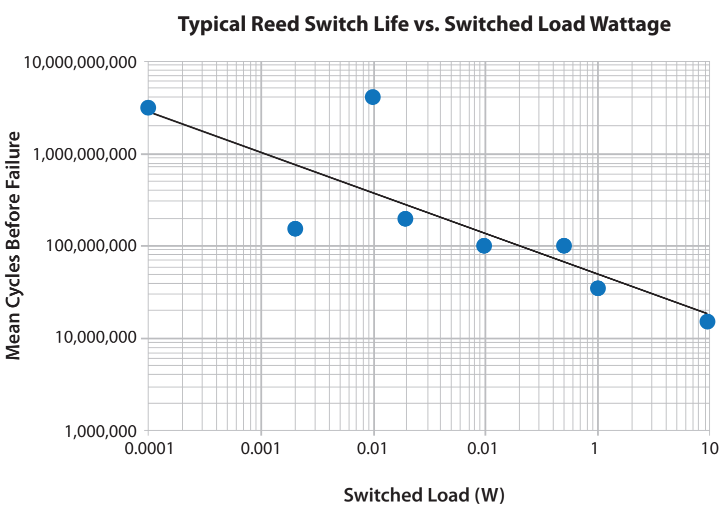

Figure 1: Reed contact life vs. switched wattage

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2 Reed Relay Reliability

Let's first address the issue of reed relay reliability. Sometimes reed relays get unfairly labeled for limited reliability, particularly from manufacturers of competitive technologies, because they are electromechanical rather than solid state. (They can be classified as electromechanical because they have two springy electrically-conducting nickel iron blades in a sealed glass tube that are attracted together and touch in a magnetic field, completing an electrical circuit.) But in fact, such a reed switch may have a life exceeding one billion cycles depending on the wattage level of a hot-switched load before the contacts reach unacceptably high resistance (called an open fault, resistance ≥ 2Ω) or stuck together (short fault, contacts stuck closed for more than 0.5s). Is a billion cycle life sufficient for ATE applications? Here's an illustration. Consider an ATE that runs 24/7 and has a 5 year projected life. Say it runs a typical ten tests per minute with 4 relay closures per test. That totals 103 million relay closures during the service life of the ATE. Notice that we said "depending on load". A relay hot switching 1V and 10mA may exceed one billion cycle life, where heavier currents or higher voltages may degrade the life. Figure 1 shows some trend data for reed switch contact life vs. switched load.

What do we mean by the life of a relay? To evaluate life, Coto routinely takes 32 samples of production relays and repetitively cycles them to failure at different electrical loads. Even at high cycling rates, such tests may take weeks or months.

Weibull statistics are then used to calculate the mean cycles before failure (MCBF) for an individual relay. In addition, the Weibull distribution method produces an estimate, via the Weibull slope factor, of whether the relays under test will experience early failures after being put in service, a characteristic which is highly undesirable for a relay used in ATE. **Click HERE for more details on the statistical methodology**.

Failure rates for ATE systems containing many relays can also be calculated; for example, a system containing 2000 ATE grade relays having an individual MCBF of one billion cycles and a typical Weibull slope of 1.5 would experience a 1% system failure rate after about 300,000 system cycles. **(For more details on the statistical calculation, click HERE)** It is also possible to predict optimum preventive maintenance (PM) strategies for systems with multiple relays if their individual MCBF data is known. For example, for a PCB equipped with sixteen $3.00 relays having an MCBF of one billion cycles and unscheduled maintenance costing $500, the cheapest PM strategy is to replace ALL the relays after 88 million board cycles, whether or not any have failed. **Click HERE for more information on preventive maintenance.**

3 Factory Testing

The heart of any reed relay is the reed switch, and Coto life tests all types of switches used in its products to determine the MCBF under different electrical loads. Of course, such tests are destructive, so the best insurance for high reliability in shipped relays is to test all manufactured relays before they are shipped, and that's what Coto does. Depending on the relay's configuration, Coto applies from 9 to 12 different parametric tests to every shipped relay, including static and dynamic contact resistance measurements, operate and release voltage, operate and release times, insulation resistance and breakdown voltage.

4 Reed Relays for ATE Applications

What makes reed relays good for ATE applications? First, reliability, with switching lifetimes of 100 million cycles to over a billion cycles depending on the electrical load. Second, they behave almost like a perfect switch, with an ON/OFF resistance ratio around 10^{13}. Third, the ability to transmit high frequencies in the multi-GHz range, a vital attribute for modern high frequency ATE testing. Though other types of relays may outperform reed relays on some of these specific attributes, none provides reed relays' all-round performance, especially when cost of ownership is factored in.

Let's look at some of the reed relays Coto Technology provides to the ATE industry, from simple inexpensive 1-Form A (single pole, single throw) relays to ultra-high performance multichannel RF relays designed for switching in high speed SOC (System-On-Chip) and serial device testing.

5 1-Form A (Single Pole Single Throw, SPST)

1-Form A, SPST (single-pole, single throw) relays simply switch a channel on and off, though their very low ON-resistance allows them to be cascaded to provide an almost infinite array of different switching topologies. Examples are the Coto 9814 series relays, with RF bandwidths in the 5 to 6 GHz range depending on the lead design - axial for the maximum bandwidth, J-bend for intermediate bandwidth and gull wing for good RF performance coupled with easier rework capability. All these relays are designed for close to 50Ω RF impedance, and are provided with ferrous magnetic shells to minimize magnetic interaction in closely packed environments. The expected life is at least one billion cycles at a cold-switched or 1V 10 mA signal level load. (Cold switching means that no current flows through the contacts when the relay is activated.) Other relays in this category include the Coto 9900 series, which uses a smaller reed switch and is the smallest surface mount reed relays available. They have similar contact life, and with optional coaxial shields and the magnetic shield option they achieve bandwidths of 5.5 to 7.0 GHz depending on the lead style.

Other types of specialized 1-Form A relays include Coto's 9104 model, capable of switching up to 1000V and standing off 4000V. This relay is ideal for ATE applications such as cable dielectric testing. And, at the other end of the switched voltage spectrum, Coto's 3500 and 3600 series relays are specially designed to reduce the thermal EMF's generated between dissimilar metal junctions to sub-microvolt levels, making them indispensable for equipment designed for measuring minute voltages, such as scanners, multiplexers and digital voltmeters.

6 1-Form C (Single Pole Double Throw, SPDT)

Loadboards designed for testing high-pin-count semiconductor devices often have severe space constraints, since PCB traces carrying RF frequency signals must be kept as short as possible to minimize transmission line losses. In addition, double-sided PCB mounting is often needed to maximize loadboard component packing density. So 1-Form C, SPDT (single pole, double throw) relays are highly desirable if they retain the same form factor as their Form A counterparts, especially as a very common application in ATE is switching different signal sources onto a single DUT pin. Perhaps the most common type of this application is switching between parametric measurements of characteristics such as current, voltage and resistance at a DUT pin (which are essentially low frequency measurements), and high speed signal sources such as serial pulse trains that can have multi-GHz bandwidths.

A Form C relay that suits this application must have good RF bandwidth so as not to distort the high frequency signals, and low ON-resistance to avoid biasing the low frequency parametric measurements. The **Coto 9852 1-Form C relay** was designed for this purpose. It contains a Form C reed switch that routes an incoming signal to either of two contacts depending on whether the relay's coil is activated or not. Break-before-make is guaranteed. Both the normally open (NO) and normally closed (NC) relay channels have bandwidths of approximately four GHz.

Bear in mind that the contact forces in a Form C reed switch are somewhat lower than those of a Form A switch, so the Form C contact life is somewhat lower. For example, the MCBF at a 1V 10 mA signal-level load is 200 million for the model 9852 1-Form C NO contact, and 100 million for the NC contact. To guide customers, Coto has developed a list of ways to optimize the performance of the 9852 relay and achieve maximum life. Refer to **"Best Practices for Applying Coto Technology's 9852 Form C Reed Relay"** for further information.

An alternative to a true Form C relay such as the 9852 is a pseudo-Form C design. A model of particular interest in ATE is the **2970 Reed Relay series**, aimed at high temperature testing (for example automobile under-the-hood semiconductor testing) up to 125ºC. The 2970 contains two reed switches, with one being biased shut (that is, normally closed) by a small permanent magnet. The reed switches are surrounded by a common coil which, when activated with the correct polarity, cancels the field from the magnet and forces the NO switch to close, and allows the NC switch to open. The result is Form C functionality. Note that break-before-make cannot be guaranteed for this type of relay.

7 RF Relays

Reed relays designed to handle very high frequency signals with more than 5 GHz bandwidth require specialized design and testing. Design usually involves computer simulation with finite element analysis software, solving Maxwell's equations to optimize the RF impedance for 50Ω transmission at the signal entry and exit ports and through the body of the relay. Testing such relays involves not just the usual life testing at different loads and low-frequency parametric testing for contact resistance and switch timing etc., but also advanced RF testing. Generally the RF performance of reed relays is characterized by the relay's scattering parameters (S-parameters) using a Vector Network Analyzer (VNA). In turn, the S-parameter data can generate plots of the relay's insertion loss, return loss and isolation at different frequencies. Additionally, eye diagrams can be

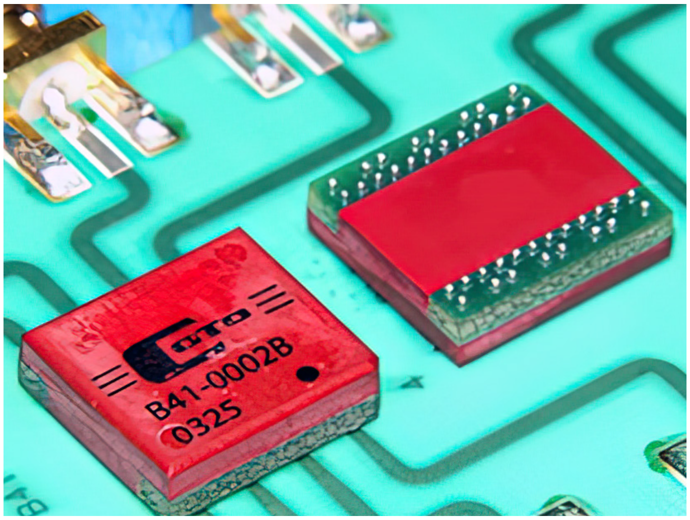


Figure 2: B41 4-channel RF relay showing ball grid array

simulated to predict the relay's ability to carry high speed digital pulse streams with acceptable fidelity.

The types of relays previously discussed use pins or leads for through-hole or SMD mounting. Those types of connections create inductive reactance at every bend, presenting an electrical resistance that increases with frequency and inevitably limits the relay's bandwidth. The 4-channel SPST B41 (Figure 2) does away with leads altogether, instead using internal waveguides connecting through a ball-grid array (BGA) to 50Ω transmission lines on a PCB. This maintenance of a 50Ω environment without significant impedance discontinuities greatly improves the system bandwidth. **Click on this link to see the datasheet for the B41 relay.** For further general reading on relay leadforms, read **"Leadform Follows Function in RF Relay Design."**

Figure 3 compares the bandwidth of the 9814 relay with its various leadforms with that of the B41. The improvement with the B41's design is obvious. Figure 4 shows an eye diagram for the B41 transmitting a 15 Gbps Compliant Jitter Tolerance Pattern (CJTPAT) pseudo-random bit stream (PRBS), equivalent to a signal frequency of 10 GHz. The openness of the eye is obvious. Figure 5 shows a 9852 eye for the NC contact at 5 Gbps. The NO contact eye is very similar

8 ATE Applications

IC Device Testing – three examples of reed relay use

Pin electronics switching

The heart of the pin electronics in an IC device tester is the pin driver. This device must produce highly repeatable, low-jitter pulses with precisely set amplitude and slew rate for the DUT. The pin-driver timing is set digitally; its amplitude is determined by analog control voltages. In Figure 6 the Parametric Measurement Unit (PMU) attaches to the interconnect downstream of channel A of the pseudo-Form C relay, which can be ½ of a B41. This is important because opening switch A isolates the Driver Comparator Load (DCL) which has a leaky output stage that would corrupt the PMU measurements. A chip ferrite [f] acting as a low-pass filter placed close to the relay

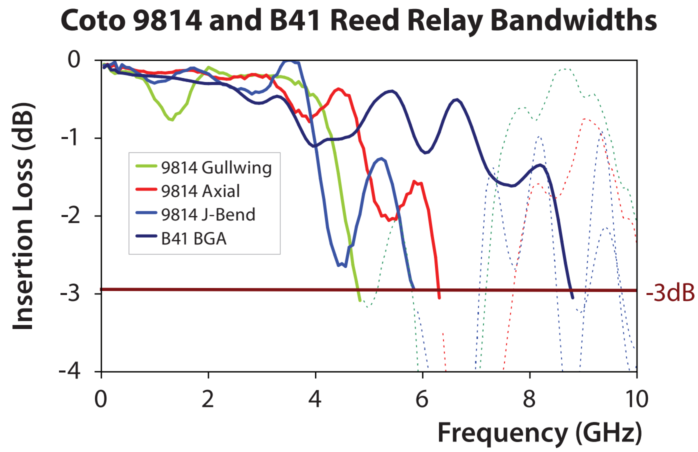


Figure 3: Comparison of Coto 9814 and B41 bandwidths

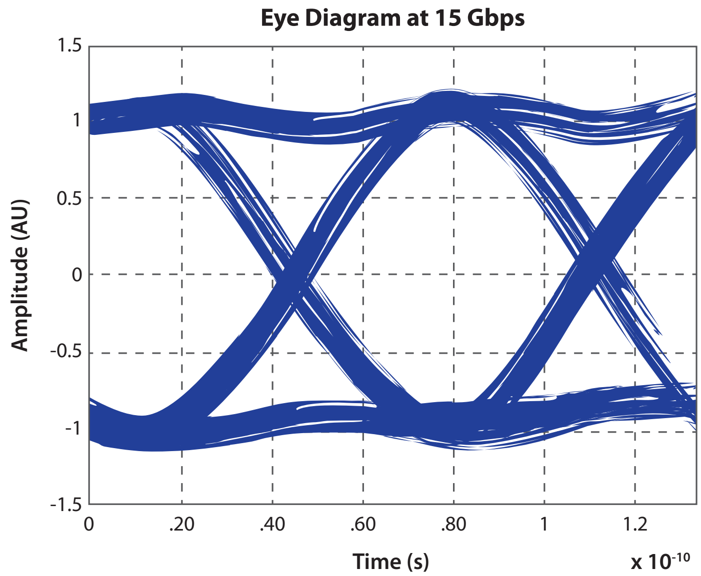


Figure 4: B41 relay eye diagram at 15 Gbps (~10 GHz), CJTPAT bit stream

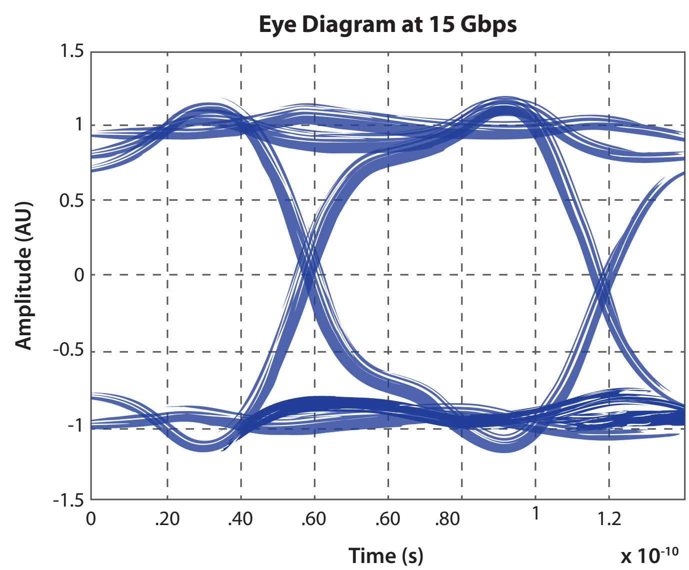


Figure 5: 9852 relay eye diagram at 5 Gbps (~3.3 GHz), CJTPAT bit stream

reduces the stub capacitance from the PMU line that would otherwise reduce the bandwidth on the DCL line. In this configuration the B41 provides a high frequency path between the DCL and the DUT. If differential signaling is employed, the full four channels of the B41 can be used to switch between the DCL and PMU on each differential channel.

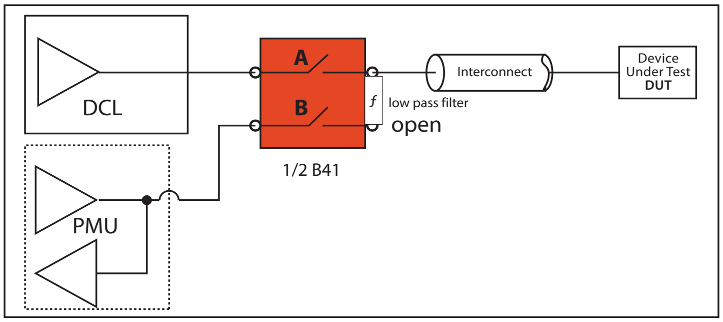


Figure 6: Simplified diagram of PMU/DCL switching circuitry

Loopback testing

Loopback testing (Figure 7) involves connecting the transmit line (TX) of a serial port back to its own receive line (RX). Using its on-chip BIST (Built in self-test) circuitry, the device is made to transmit a known pattern of serial data. Once the data is transmitted and received, the tester monitors lower-speed pins of the device, which have states that depend upon the correct operation of the TX and RX lines, to determine whether the test passes or fails. Form C or dual Form A relays are used to switch between the high speed loopback line and the lower speed BIST status pins of the DUT.

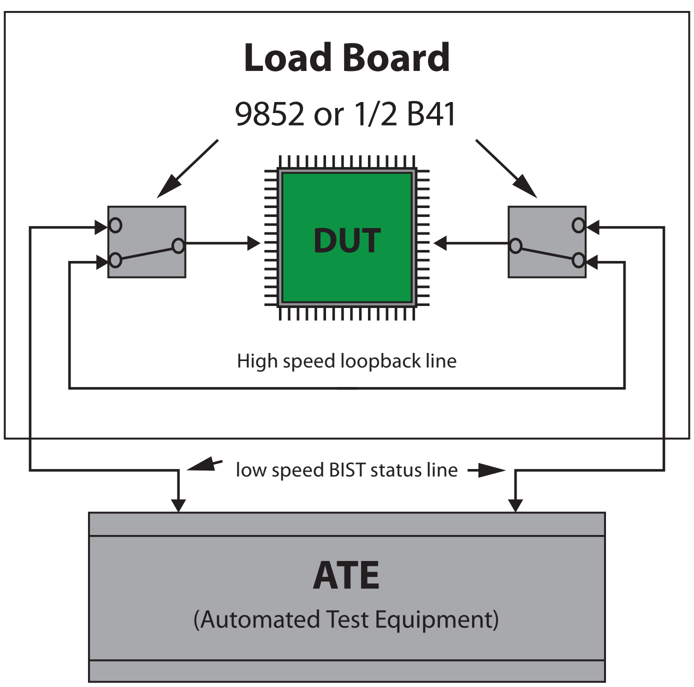


Figure 7: Simplified diagram of loopback testing

Receiver stress testing

Semiconductor stress tests verify that a device continues to perform acceptably when one or more external conditions approach their limits. Common stresses include high voltage, high temperature and higher-than-normal clock rates. Figure 8 shows a simplified example of receiver voltage stress testing. The low pass filter [f] mounted close to the B41 relay has very low impedance at low frequency and allows a varying DC bias to be applied to the Tx/Rx line, while its high impedance at high frequency reduces distortion of the high speed signal.

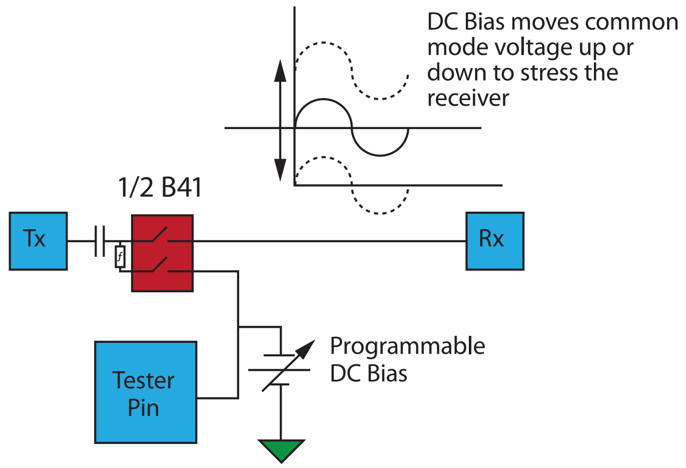


Figure 8: Simplified diagram of receiver voltage stress testing

Other common ATE applications

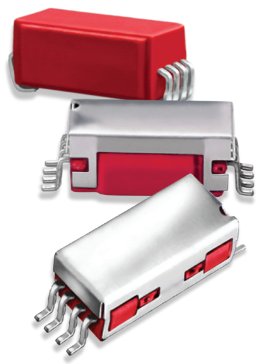
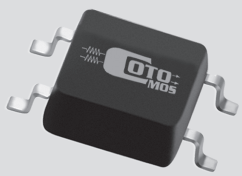
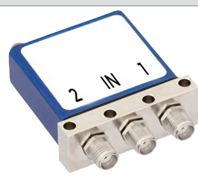
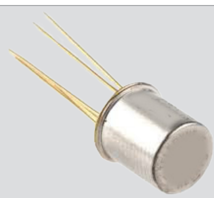
Other common ATE applications include cable testing **(click for more information)**, high temperature testing **(click for more information)**, and general switching needs for Flying Probe Testers.

9 Alternative ATE switching Technologies

Alternative switching technologies for ATE applications include Solid State Relays (SSR), usually optically isolated designs; electromechanical relays (EMR), coaxial relays, and microelectromechanical relays (MEMS). Table 1 lists some of the advantages and disadvantages of each type.

Table 1 is not intended to be quantitative or wholly comprehensive. However, it cites parameters published in manufacturers' data sheets that should be investigated before deciding which technology should be incorporated into a new ATE design.

Table 1: Alternative ATE switching Technologies

Type	Picture (not to scale)	Advantages	Disadvantages	Comments
Reed		• Sufficient to excellent life depending on electrical load • Good hot switching capability • Extremely high DC isolation • Very low ON resistance • High ESD resistance • Low height allows double-sided PCB • Inexpensive $$	• 3dB bandwidth limited to 8 GHz depending on type • RF isolation lower than electromechanical relays	• Very widely used in ATE • Stand up well to the abusive loads commonly found in ATE
Optically Isolated SSR		• Small size. • Low height • Solid state. • High reliability. • Fast operate and release times. • Inexpensive $	• High on resistance • High output capacitance • Poor RF isolation • Vulnerable to ESD	• Not suited for high speed ATE applications due to relatively high output capacitance, high ON resistance, and OFF state leakage • Sometimes used in ATE for lower speed apps such as memory test
Coaxial		• Very low RF insertion losses and high isolation • High power capability	• Very large • Very expensive $$$$ • Limited life	• Usage rare in ATE
Electro-mechanical (Hermetically sealed metal can)		• Some models have high RF bandwidth (DC – 18 GHz) • Good RF isolation • 2 Form-C (DPDT) available • Hermetically sealed to reduce contamination	• Large size • Expensive $$$ to $$$$ • Limited life (~ 10 million operations) • High power consumption	• Widely used in moderate to high speed ATE applications. • Dimensions too large for modern high-density load boards
Electro-Mechanical Signal Relay (Plastic encapsulated)		• Inexpensive $$ • Low return and insertion losses over 3GHz frequency range	• Large size, 20 *9 * 9 mm • Limited frequency range (3 GHz) • Limited life (100K to 300K depending on load) • Limited to 70oC operation • High power consumption • Not hermetically sealed	• Large size, low RF bandwidth, limited temperature range and very limited life make plastic encapsulated signal relays unsuitable for most ATE applications
MEMS (recent typical)		• Excellent RF performance reported by manufacturer • Very low insertion loss, high isolation • ON resistance 3Ω • Four channel SPST • Small footprint, low height	• Poor hot switching capability (400,000 cycle life at 30 dBm 1 W) • Very vulnerable to ESD (HBM = 100V) • DPDT not available • Variable ON resistance • Expensive $$$	• Despite 25 years work by many different developers, (including Coto Technology), has seen extremely limited adoption by ATE manufacturers

10 Conclusions

Reed relays are the technology of choice for many ATE switching applications because of their extremely high OFF resistance, very low ON resistance, hot switching capability, the ability to shrug off abusive loads, resistance to ESD damage, relatively low cost, availability, and proven reliability. Other switching technologies may surpass reed relays in certain specific areas such as RF isolation or minimum footprint, but reed relays from Coto Technology remain the dominant choice for ATE switching applications.