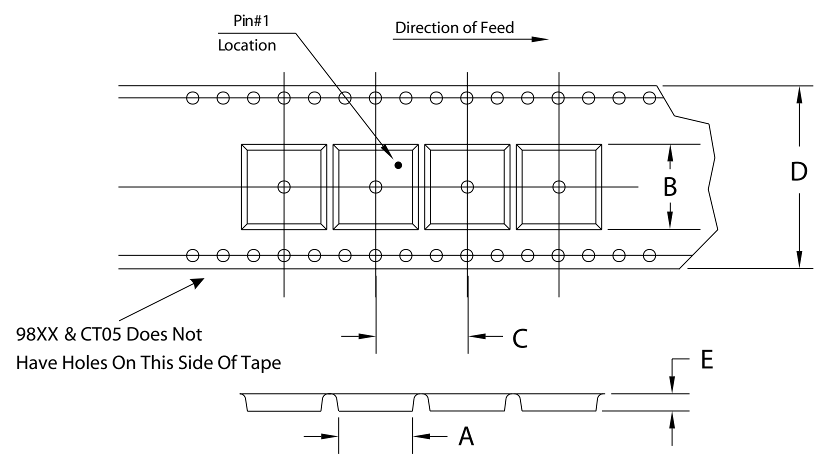
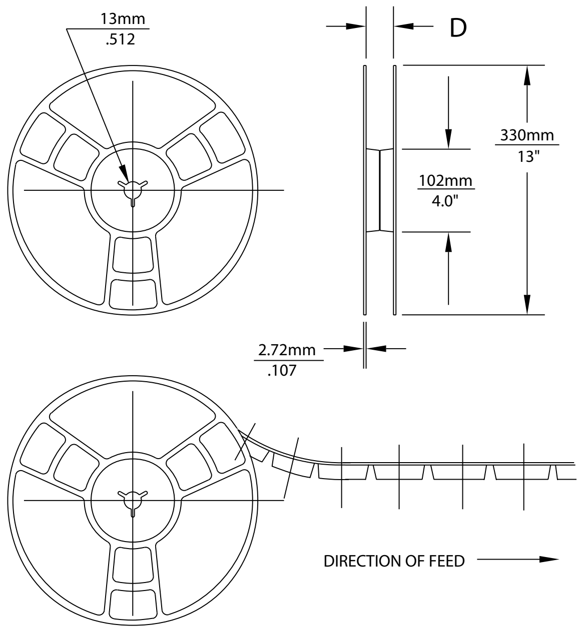
REED RELAYS

Technical & Applications Information

REED RELAY PACKAGING

Relay packaging consists of antistatic tubes or trays depending upon relay model. Several Coto surface mount reed relays are available in Tape & Reel packaging. Listed below are the dimensions by Coto series and lead style. If you would like tape & reel packaging on a Coto relay that is not listed or specific information on bulk packaging, please consult the factory or your local Coto representative.





REED RELAY TAPE & REEL PACKAGING

Series	A	B	C	D	E	Std. Qty/Reel
9200 Gull	6.35	24.64	12.00	44.00	5.97	1K
9200 “J”	6.35	21.59	12.00	32.00	7.37	1K
9290 Gull	4.72	20.83	12.00	32.00	5.08	1K
9290 “J”	4.76	18.54	12.00	32.00	5.33	1K
9300 “J”	6.22	21.34	12.00	32.00	7.75	1K
9400 Gull	6.17	22.48	12.00	32.00	6.76	1K
9400 “J”	6.10	15.75	12.00	32.00	6.48	1K
9814 “A”, Gull	4.83	13.59	12.00	24.00	5.33	1K
9814 “J”	4.83	11.18	12.00	24.00	5.46	1K
9852 “A”, Gull	5.08	13.20	12.00	24.00	5.84	1K
9852 “J”	5.08	11.17	12.00	24.00	5.84	1K
990X “J”	5.20	8.50	8.00	24.00	4.19	1K

(Dimensions in Millimeters)

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REED RELAY PAD LAYOUTS

Model	Lead Type	Fig. #	Dim. A	Dim. B	Dim. C	Dim. D	Dim. E	Dim. F	Dim. G	Dim. H	Dim. I
8L61	"J"	4	.400/10.16	.200/5.08	.100/2.54	.040/1.01	.100/2.54	.640/16.25	.400/10.16	N/A	N/A
9201	Gull	3	.980/24.89	.820/20.82	.080/2.03	.030/0.76	.150/3.81	.180/4.57	N/A	N/A	N/A
9201	"J"	3	.800/20.32	.600/15.24	.100/2.54	.030/0.76	.150/3.81	.180/4.57	N/A	N/A	N/A
9202	Gull	2	.980/24.89	.820/20.82	.080/2.03	.030/0.76	.075/1.90	.180/4.57	N/A	N/A	N/A
9202	"J"	2	.800/20.32	.600/15.24	.100/2.54	.030/0.76	.075/1.90	.180/4.57	N/A	N/A	N/A
9290	Gull	2	.850/21.59	.650/16.51	.100/2.54	.035/0.89	.050/1.27	.100/2.54	N/A	N/A	N/A
9290	"J"	2	.700/17.78	.500/12.70	.100/2.54	.035/0.89	.050/1.27	.135/3.42	N/A	N/A	N/A
9301	Gull	3	1.02/25.90	.780/19.81	.120/3.04	.035/0.89	.100/2.54	.135/3.42	N/A	N/A	N/A
9301	"J"	3	.800 20.32	.600/15.24	.100/2.54	.035/0.89	.100/2.54	.135/3.42	N/A	N/A	N/A
9401	Gull	3	.820/20.82	.580/14.73	.120/3.04	.030/0.76	.150/3.81	.180/4.57	N/A	N/A	N/A
9401	"J"	3	.600/15.24	.400/10.16	.100/2.54	.030/0.76	.150/3.81	.180/4.57	N/A	N/A	N/A
9402	Gull	2	.820/20.82	.580/14.73	.120/3.04	.030/0.76	.075/1.90	.180/4.57	N/A	N/A	N/A
9402	"J"	2	.600/15.24	.400/10.16	.100/2.54	.030/0.76	.075/1.90	.180/4.57	N/A	N/A	N/A
9814	Axial	1	.490/12.44	.394/10.00	.048/1.21	.025/0.63	.040/1.01	.150/3.81	N/A	.205/5.20	.380/9.65
9814	Gull	1	.560/14.22	.400/10.16	.080/2.03	.030/0.76	.040/1.01	.150/3.81	N/A	N/A	N/A
9814	"J"	1	.490/12.44	.240/6.09	.125/3.17	.030/0.76	.040/1.01	.150/3.81	N/A	N/A	N/A
9852	Axial	1	.490/12.44	.394/10.00	.048/1.21	.025/0.63	.040/1.01	.150/3.81	N/A	.205/5.20	.380/9.65
9852	Gull	1	.560/14.22	.400/10.16	.080/2.03	.030/0.76	.040/1.01	.150/3.81	N/A	N/A	N/A
9852	"J"	1	.490/12.44	.240/6.09	.125/3.17	.030/0.76	.040/1.01	.150/3.81	N/A	N/A	N/A
9901	Axial	3	.455/11.55	.337/8.56	.059/1.50	.028/0.71	.080/2.03	.108/2.73	N/A	.227/5.77	.306/7.76
9901	Gull	3	.455/11.55	.305/7.75	.075/1.90	.028/0.71	.080/2.03	.108/2.73	N/A	N/A	N/A
9901	"J"	3	.331/8.40	.213/5.40	.059/1.50	.028/0.71	.080/2.03	.108/2.73	N/A	N/A	N/A
9903	Axial	1	.455/11.55	.337/8.56	.059/1.50	.028/0.71	.040/1.02	.148/3.75	N/A	.227/5.77	.306/7.76
9903	Gull	1	.455/11.55	.305/7.75	.075/1.90	.028/0.71	.040/1.02	.148/3.75	N/A	N/A	N/A
9903	"J"	1	.331/8.40	.213/5.40	.059/1.50	.028/0.71	.040/1.02	.148/3.75	N/A	N/A	N/A

(Dimensions in Inches/Millimeters)

FIGURE 1

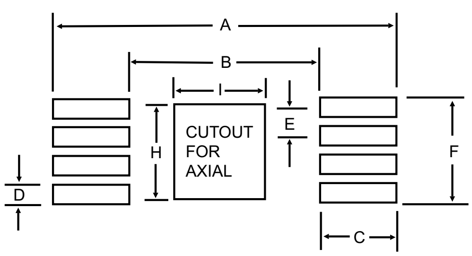


FIGURE 2

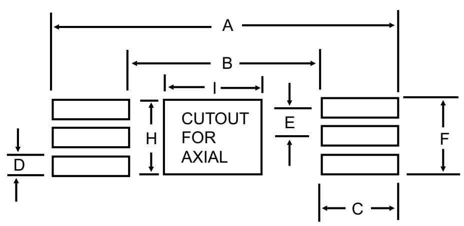


FIGURE 3

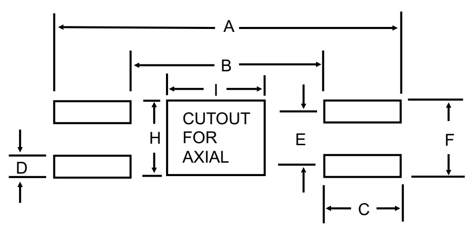
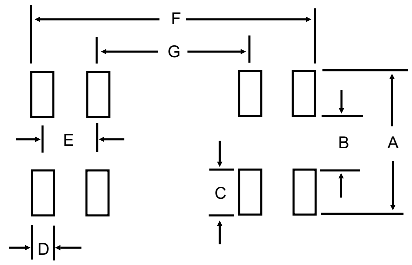


FIGURE 4



GLOSSARY OF TERMS

This Glossary of Terms was compiled from NARM Standard RS-436, MIL STD 202, and MIL STD R5757. They have been modified to pertain to Coto Reed Relays. The use of bold text within a definition indicates that a term is cross-referenced elsewhere in the glossary.

ACTUATE TIME: The time measured from coil energization to the stable contact closure (Form-A) or stable contact opening (Form-B) of the contact under test. (See also: **Operate Time**)

AMPERE-TURNS (AT): The product of the number of turns in an electromagnetic coil winding and the current in amperes passing through the winding. Used to quantify reed switch operate and release sensitivities.

BANDWIDTH: The frequency at which the RF power insertion loss of a relay = 50%, or 3dB

BIAS, MAGNETIC: A steady magnetic field applied to the magnetic circuit of a switch to aid or impede its operation in relation to the coil's magnetic field.

BOUNCE, CONTACT: Intermittent and undesired opening of closed contacts or closing of opened contacts usually occurring during operate or release transition.

BREAKDOWN VOLTAGE: The breakdown voltage is the maximum voltage that can be applied across the open switch contacts before electrical breakdown occurs. It is primarily dependent on the gap between the reed switch contacts and the type of gas fill used. High AT switches within a given switch family have larger gaps and higher breakdown voltage. It is also affected by the shape of the contacts, since pitting or whiskering of the contact surfaces can develop regions of high electric field gradient that promote electron emission and avalanche breakdown. Since such pitting can be asymmetric, breakdown voltage tests should be performed with forward and reverse polarity. When testing bare switches, ambient light can affect the point of avalanche and should be controlled or eliminated for consistent testing. Breakdown voltage measurements can be used to detect reed switch capsule damage. See **Paschen Test**.

CARRY CURRENT: The maximum continuous current that can be carried by a closed relay without exceeding its rating.

COAXIAL SHIELD: Copper alloy material that is terminated to two pins within the relay on each side of the switch. Used to simulate the outer conductor of a coaxial cable for high frequency transmission.

COIL: An assembly consisting of one or more turns of wire around a common form. In reed relays, current applied to this winding generates a magnetic field which operates the reed switch.

COIL AT: The coil ampere turns (AT) is the product of the current flowing through the coil (and therefore directly related to coil power), and the number of turns. The coil AT exceeds the switch AT by an appropriate design margin, to ensure reliable switch closure and adequate switch **overdrive**. Sometimes abbreviated as NI, where N = number of turns and I = coil current.

COIL POWER: The product, in watts, of the relay's nominal voltage and current drawn at that voltage. Most Coto relays have coil powers in the 20 –100 mW range.

COLD SWITCHING: A circuit design that ensures the relay contacts are fully closed before the switched load is applied. Must take into account **bounce, operate** and **release time**. If technically feasible, cold switching is the best method for maximizing contact life at higher loads.

CONTACT RESISTANCE, DYNAMIC: Variation in contact resistance during the period in which contacts are in motion after closing.

CONTACT RESISTANCE, STATIC: The DC resistance of closed contacts as measured at their associated contact terminals. Measurement is made after stable contact closure is achieved.

CONTACT: The ferromagnetic blades of a reed switch, usually plated with Rhodium, Ruthenium or Tungsten material.

CROSSTALK (CROSSTALK COUPLING): When applied to multichannel relays, the ratio, expressed in dB, of the signal power being emitted from a relay output contact to the power being applied to an adjacent input channel, at a specified frequency.

DIELECTRIC STRENGTH: When applied to the dielectric strength across open switch contacts, this term is synonymous with **breakdown voltage**.

DUTY CYCLE: The ratio of energized to de-energized time.

ELECTROSTATIC SHIELD: Copper alloy material terminated to one pin within the reed relay. Used to minimize coupling of electrostatic noise between the coil and contacts.

FORM-A: Contact configuration which has one Single Pole-Single Throw normally open (SPST n.o.) contact.

FORM-B: Contact configuration which has one Single Pole-Single Throw normally closed (SPST n.c.) contact.

FORM-C: Contact configuration which has one Single Pole-Double Throw (SPDT) contact. (One common point connected to

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one normally open and one normally closed contact.) Sometimes referred to as a Transfer Contact.

HARD FAILURE: Highly repeatable permanent failure of the contact or relay.

HERMETIC SEAL: An enclosure that is sealed by fusion to ensure a low rate of gas leakage. In a reed switch, a glass-to-metal seal is employed.

HOT SWITCHING: A circuit design that applies the switched load to the switch contacts during the period while they are opened and closed.

HYSTERESIS: When applied to reed relays, the difference between the electrical power required to initially close the relay and the power required to just maintain it in a closed state. (Usually expressed in terms of the relay's **pull-in voltage** and **drop-out voltage**) Some degree of hysteresis is desirable to prevent chatter, and is also an indicator of adequate switch contact force, due to snap action.

IMPEDANCE (Z): The combined DC resistance and AC reactance of a relay, at a specified frequency.

Impedance(Z) = R + jX

Where R = DC resistance and
$X = (2\pi fL - 1/(2\pi fC))$, f = frequency

Coto Technology's RF relays are designed to have a broadband impedance as close as possible to 50 ohms.

Technical Note: Because of the small residual capacitance across the open contacts of a reed relay, the impedance decreases at higher frequencies, resulting in lower ***isolation*** *(q.v.) at higher frequencies. Conversely, increasing inductive reactance at higher frequencies causes the impedance of a closed relay to rise, increasing the* ***insertion loss*** *(q.v.) at higher frequencies.*

IMPEDANCE DISCONTINUITY: A deviation from the nominal RF impedance of 50 ohms at a point inside the relay. Impedance discontinuities cause signal absorption and reflectance problems resulting in higher signal losses. They are minimized by designing the relay to have ideal **transmission line** characteristics.

INSERTION LOSS: Ratio of the power delivered to the input port of a relay with closed contacts, at a specific frequency, compared to the power emitted from the corresponding output port. Calculated from the polar magnitude of the $S_{1,2}$ parameters (Q.V., Reed Relay RF Parameter Measurement section.)

Technical Note: Insertion Loss, Isolation and Return Loss (q.v) are often expressed with the sign reversed; for example, the frequency at which 50% power loss occurs may be quoted as the "-3dB" point. Since relays are passive and always produce net losses, this does not normally cause confusion.

INRUSH CURRENT: Generally, the current waveform immediately after a load is connected to a source. Inrush current can form a surge flowing through a relay switching a low impedance source load - typically a highly reactive circuit, or one with a non-linear load characteristic such as a tungsten lamp load. Such abusive load surges are sometimes encountered when reed relays are inadvertently connected to test loads containing capacitors, or to long transmission lines with appreciable amounts of stored capacitive energy. Excessive inrush currents can cause switch contact welding or premature contact failure.

INSULATION RESISTANCE: The DC resistance between two specified test points. At higher operating temperatures, insulation resistance may be lower than stated values.

ISOLATION: The ratio of the power delivered to the output port of a relay, with open contacts, at a specific frequency, compared to the power emitted from the corresponding output port. Calculated from the polar magnitude of the $S_{1,2}$ parameters.

LATCHING RELAY: A bi-stable relay, typically with two coils, which requires a voltage pulse to change state. When pulse is removed from the coil, the relay stays in the state in which it was last set.

LIFE EXPECTANCY: The average number of cycles that a relay will achieve under specified load conditions before the contacts fail due to sticking, missing or excessive contact resistance. Expressed as Mean Cycles Before failure (MCBF). See *Reliability Testing* section for a detailed discussion on how Coto Technology uses reliability testing and Weibull failure analysis to predict relay life. Life expectancy depends on many factors, including type of switch, contact, contact plating materials, the switch AT, % **overdrive**, steady state and **inrush current**, and load voltage.

LOW THERMAL EMF RELAY: A relay designed specifically for switching low voltage level signals such as thermocouples. These types of relays use a thermally compensating ceramic chip to minimize the thermal offset voltage generated by the relay's self heating.

MAGNETIC INTERACTION: The tendency of a relay to be influenced by the magnetic field from an adjacent, energized relay. This influence can result in depression or elevation of the **pull-in** and **drop out voltage** of the affected relay, possibly causing them to fall outside their specification. Magnetic interaction can be minimized by alternating the polarity of adjacent relay coils, by magnetic shielding, or by placing two relays at right angles to each other. See *Magnetic Interaction Section* for more details.

MAGNETIC SHIELD: A ferromagnetic material used to minimize magnetic coupling between the relay and external magnetic fields.

GLOSSARY OF TERMS

MERCURY WETTED CONTACT: A form of reed switch in which the reeds and contacts are wetted by a film of Mercury obtained by a capillary action from a Mercury pool encapsulated within the reed switch. The switch in this type of relay must be mounted vertically to ensure proper operation.

MISSING (CONTACTS): A reed switch failure mechanism, whereby an open contact fails to close by a specified time after relay energization or closes with a high resistance that is above a set test level (the manufacturer's recommended coil voltage that provides reliable operation) during a life test.

NOMINAL VOLTAGE: The normal operating voltage of the relay.

OPERATE TIME: The time value measured from the energization of the coil to the first contact closure (Form-A) or the first contact open (Form-B). [See also: **ACTUATE TIME.**]

OPERATE VOLTAGE: The coil voltage measured at which a contact changes state from its un-energized state.

OVERDRIVE: The fraction or percentage by which the voltage applied to the coil of relay exceeds its **pull-in voltage**. An overdrive of at least 25% ensures adequate closed contact force, and well-controlled bounce times, which result in optimum contact life. Coto Technology's relays are typically designed for a minimum of 33% overdrive. (For example, a relay with a nominal coil voltage of 5V will pull-in at no greater than 3.75V)

Technical Note: The circuit designer intending to use reed relays should ensure that, if possible, the overdrive applied to the relay does not drop below 25% under field conditions. Issues such as power supply droop and voltage drops across relay drivers can cause a nominally acceptable power supply voltage to drop to a level where adequate overdrive is not maintained. Higher operation temperature reduces coil overdrive by .4% / degree C.

PASCHEN TEST: Coto Technology uses this test to detect reed switch capsule damage. In the case of a cracked switch capsule or damaged switch seal, atmospheric oxygen can leak into the switch and eventually oxidize the switch contacts, causing increased contact resistance and possible contact failure. The presence of oxygen causes the breakdown avalanche voltage to increase, due to the ability of the electronegative oxygen to scavenge free electrons. The Paschen test observes the variation and magnitude of the breakdown voltage as a switch is opened, and the recorded waveform is used to diagnose the presence of oxygen.

RELEASE TIME: The time value measured from coil de-energization to the time of the contact opening (Form-A) or first contact closure (Form-B).

RELEASE VOLTAGE: The coil voltage measured at which the contact returns to its de-energized state.

RETURN LOSS: The ratio of the power reflected from a relay to that incident on the relay, at a specified frequency. If V_i = incident voltage, and V_r = reflected voltage, then return loss can be expressed in decibel format as:

$$\text{Return Loss (dB)} = -20 \log10(V_r/V_i)$$

Return loss plots shown in this catalog were measured with the relay closed, and terminated with a 50 ohm impedance.

SIGNAL RISE TIME: The rise time of a relay is the time required for its output signal to rise from 10% to 90% of its final value, when the input is changed abruptly by a step function signal. Can be estimated from the f_{-3dB} **bandwidth**, using the expression

$$T_r = 0.35/f_{-3dB}$$

where T_r = 10%-90% rise time (sec) and
f_{-3dB} = bandwidth (Hz)

Note: See Section on **RF Parameter Measurement** *for details on how Coto measures rise time.*

SHIELD, COAXIAL: A conductive metallic sheath surrounding the relay's reed switch, appropriately connected to external pins by multiple internal connections, and designed to preserve a 50 ohm impedance environment within the relay. Used in relays designed for high frequency service, to minimize **impedance discontinuities**.

SHIELD, ELECTROSTATIC: A conductive metallic sheath surrounding the relay's reed switch, connected to at least one external relay pin, and designed to minimize capacitive coupling between the switch and other relay components, thus reducing high frequency noise pickup. Similar to a **coaxial shield**, but not necessarily designed to maintain a 50 ohm RF impedance environment.

SHIELD, MAGNETIC: An optional plate or shell constructed of magnetically permeable material such as nickel-iron or mu-metal, fitted external to the relay's coil. Its function is to reduce the effects of **magnetic interaction** between adjacent relays, and to improve the efficiency of the relay coil. A magnetic shell also reduces the influence of external magnetic fields, which is useful in security applications. Magnetic shields can be fitted externally, or may be buried inside the relay housing.

SOFT FAILURE: Intermittent, self-recovering failure.

STICKING (CONTACTS): A reed switch failure mechanism, whereby a closed contact fails to open by a specified time after relay de-energization. Can be subclassified as hard or soft failures.

SWITCH AT: The ampere turns required to close a reed switch (pull-in AT) using a specified coil type. AT depends on the geometry, lead length, and stiffness of the reed blades and increases when

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the reed switch leads are cropped. This must be taken into account when specifying a switch for a particular application.

SWITCHING CURRENT: The maximum current that can be **hot-switched** by a relay at a specified voltage without exceeding its rating.

SWITCHING VOLTAGE: The maximum voltage that can be **hot-switched** by a relay at a specified current without exceeding its rating. Generally lower than **breakdown voltage**, since it has to allow for any possible arcing at the time of contact breaking.

TIME DOMAIN REFLECTOMETRY (TDR): An alternative to **return loss** for measuring the degree of impedance mismatch of a relay at a specific frequency. TDR data can be computed from return loss data using Fourier Transform techniques, or measured directly with specialized TDR equipment.

TRANSMISSION LINE: In relay terms: an interruptable wave-guide consisting of two or more conductors, designed to have a well-controlled characteristic RF impedance and to efficiently transmit RF power from source to load with minimum losses, or to block RF energy with minimum leakage. Structures useful within RF relays include microstrips, coplanar waveguides and coaxial transmission line elements.

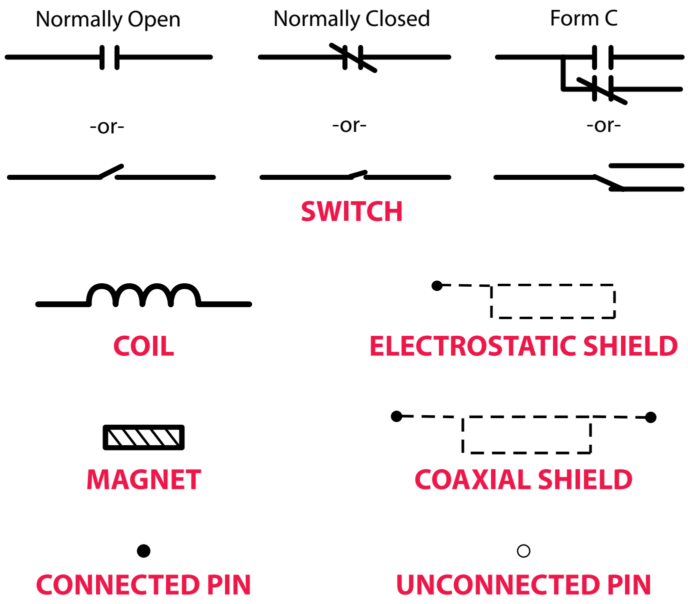
VSWR (VOLTAGE STANDING WAVE RATIO): The ratio of the maximum RF voltage in a relay to the minimum voltage at a specified frequency, and calculated from $(1+\rho)/(1-\rho)$, where ρ= the voltage reflected back from a closed relay terminated at its output with a standard reference impedance, normally 50 ohms. A VSWR of 1 indicates a perfect impedance match and zero reflection losses at a specific frequency. VSWR is normally computed from S_{11} parameter data via the reflectance coefficient.

AGENCY APPROVALS

Coto's Reed Relays and Switches are designed with the highest level of quality and reliability in mind. In addition, each individual relay is 100% tested to ensure compliance with specified limits. Because of our commitment to quality and reliability, many models have been recognized by international safety organizations such as Underwriters Laboratories (UL) and Canadian Standards Association (CSA). Reed Relays are recognized in UL file #E-67117 and CSA File #028537.

For other approval or compliance information, please contact the factory.

SYMBOLS USED IN REED RELAY SCHEMATICS



APPLICATIONS OVERVIEW & SAMPLE AND PRODUCTION TESTING

Applications Overview

Reed relays serve in many different applications requiring low and stable contact resistance, low capacitance, high insulation resistance, long life and small size. These include automatic test equipment and instrumentation. Reed relays can be fitted with coaxial shielding for high frequency applications. They also are available with very low thermal voltage for use in data acquisition equipment and process control. They are available with very high isolation voltages typically required for medical applications. Also, their low cost and versatility makes them suitable for many security and general purpose applications.

Sample and Production Testing:

A key aspect of the continuous improvement process for reed relays is the ability to accurately and efficiently test the relay while maintaining a statistical database for performance analysis. Coto has its own custom engineered test system which is used to conduct parametric tests on 100% of the manufactured product. This computer-controlled tester is called the System 320. It is capable of testing and storing data for the following parameters:

- Coil Resistance
- Static Contact Resistance
- Dynamic Contact Resistance
- Contact Resistance Stability
- Insulation Resistance
- Operate Voltage
- Release Voltage
- Operate/Release Ratio
- Operate Time (to first closure)
- Actuate Time (including bounce)
- Release Time
- Breakdown Voltage
- Diode Verification (if applicable)
- Overdrive (Form B)
- Kelvin Verification (Relay to Test Fixture)

Coto guarantees the catalog specifications of all its products using the System 320. If an application requires that particular specification(s) must be more tightly controlled, Coto will guarantee these specifications are attained on custom products using the System 320.

Performance data from every lot of relays is automatically organized into pareto chart and histogram format and saved to a central file server. See examples Figures 1-3.

This data is routinely used to review, control and continuously improve relay quality levels.

Figure 1: Pareto Chart

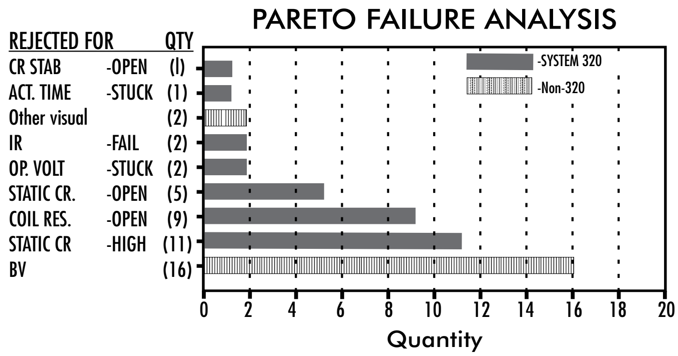
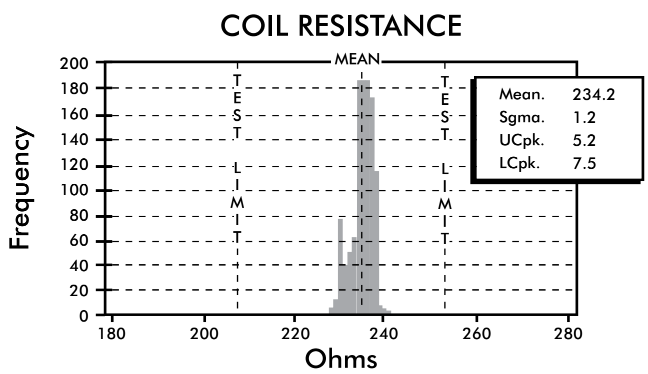
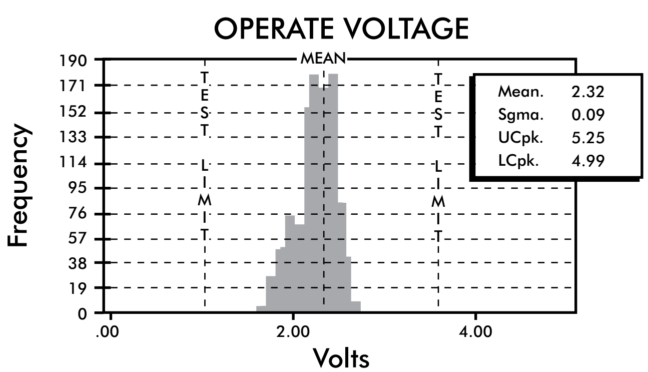


Figure 2: Histograms





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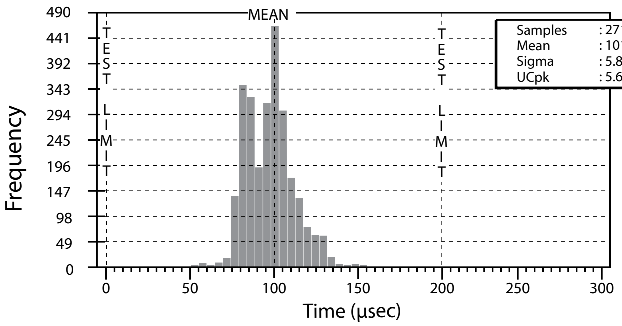
CONTACT RESISTANCE AND DYNAMICS

Reed relays offer several advantages over electromechanical relays, one of which is switching speed. The fastest switching reed relays have a typical actuate time of 100 microseconds as shown in Figure 3 below. Release time is approximately 50 microseconds. Actuate time is defined as the period from coil energization until the contact is closed and has stopped bouncing.

Figure 3: Relay Actuate Time



After the contacts have stopped bouncing, they continue to vibrate while in contact with one another for a period of about 1 millisecond. This vibration creates a wiping action and variable contact pressure. Close examination of the contact resistance during this period has proven to provide extremely valuable data on the overall quality of the reed relay. Coto has developed the Dynamic Contact Resistance (DCR) test to evaluate finished relays and discern the cleanliness of the contacts, the integrity of the hermetic seals on the switch, the presence of internal stresses, and the soundness of internal connections. The maximum dynamic contact resistance value and the peak-to-peak variation are measured and compared against specified normal limits. Empirical and actual DCR traces are shown in Figures 4 and 5:

Static Contact Resistance (SCR) is the resistance across the contact terminals of the relay after it has been closed for a sufficient period of time to allow for complete settling. For most reed relays, a few milliseconds is more than adequate, but the relay industry uses 50 milliseconds to define the measurement.

Another contact resistance measurement that has provided great insight into the overall quality of the relay is Contact Resistance Stability (CRS). CRS measures the repeatability of successive static contact resistance measurements. Coto typically uses 20 closures and subtracts the lowest contact resistance reading from the highest. This is compared against engineering specifications.

Figure 4: Dynamic Contact Resistance

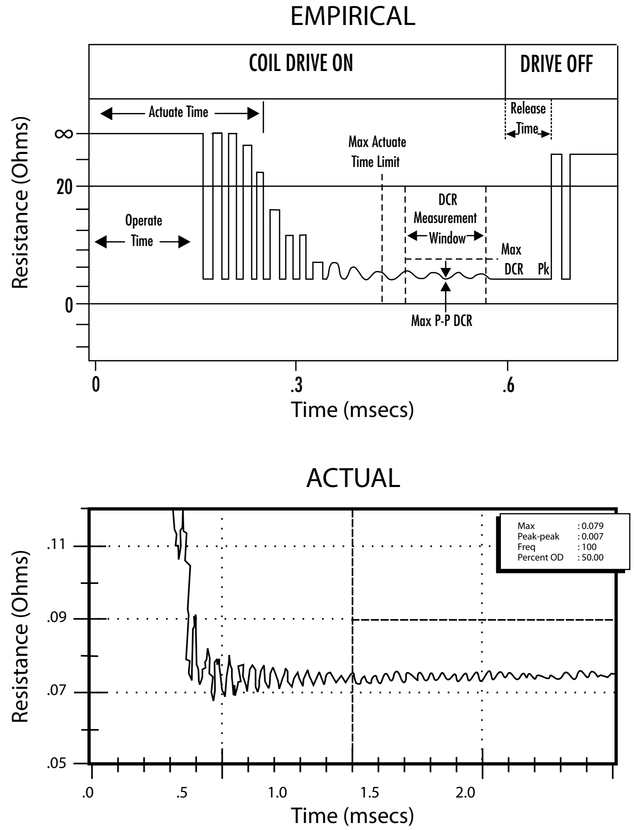
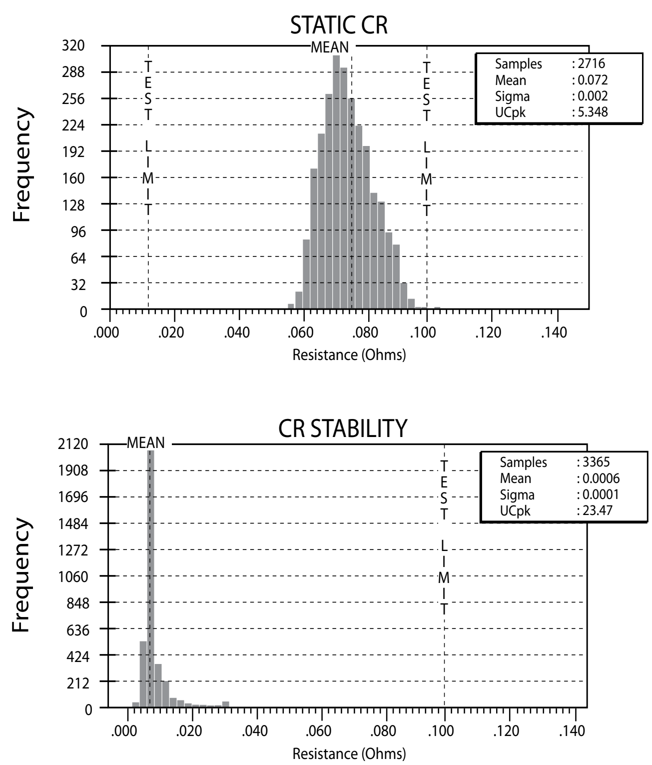
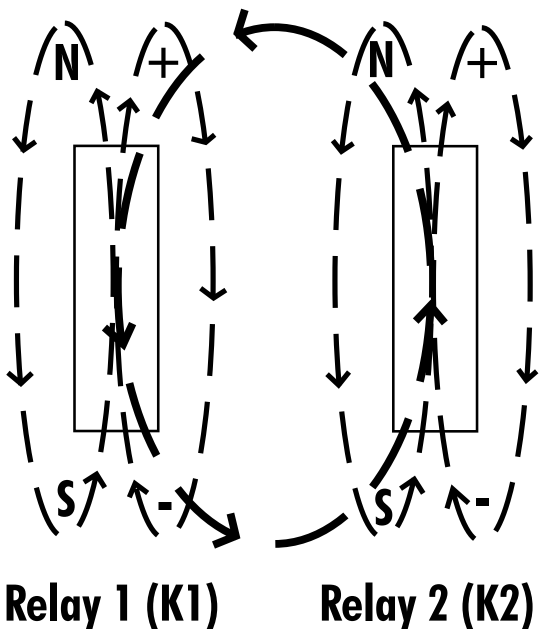


Figure 5: Static Contact Resistance and Stability



MAGNETIC INTERACTION

Reed relays are subject to external magnetic effects which may change performance characteristics. Such magnetic sources include the earth's magnetic field (equivalent to approximately 0.5 AT and generally negligible), electric motors, transformers etc. One common source of an external magnetic field acting on a relay is another relay operating in close proximity. The potential for magnetic coupling should be taken into account when designing circuits with densely packed single- or multi-channel relays.

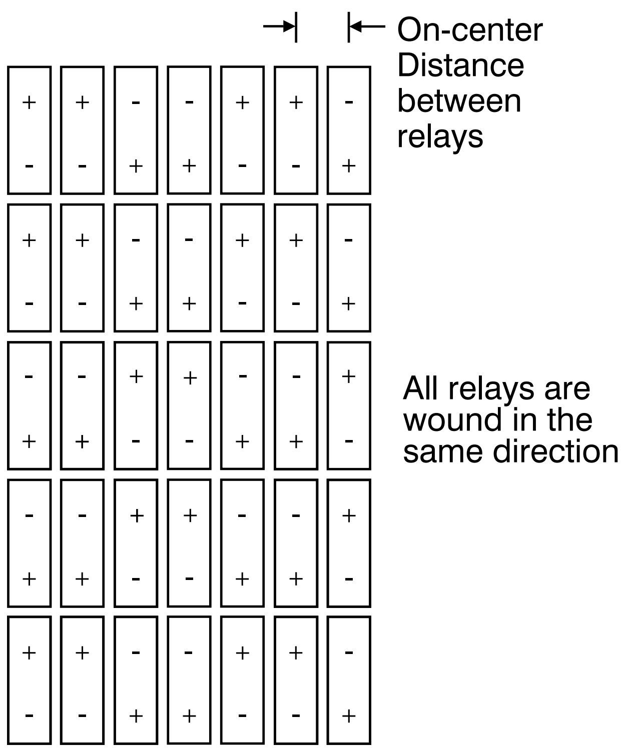


An example of magnetic interaction is shown in Figure 6. Here, two relays K1 and K2 are mounted adjacently, with identical coil polarities. With K2 "off", relay K1 requires a certain voltage to operate. When K2 is activated, the magnetic fields appear as shown. Since the magnetic fields oppose, the effective magnetic flux within K1 is reduced, requiring a proportional increase in coil voltage to compensate and operate the reed switch. For closely packed relays without magnetic shields, a 10 to 20% increase in operate voltage is typical, possibly driving the relays above their specified limits. The converse effect occurs if K1 and K2 are polarized in opposite directions; in this case, the operate voltage for K1 will be reduced by a similar percentage, though this situation is rarely as problematic.

There are several ways to reduce magnetic interaction between relays.

- Specify relays that incorporate an internal or external magnetic shield.
- Apply an external magnetic shield to the area where the relays are mounted. A sheet of Mu-metal or other high magnetic permeability ferrous alloy between 2 and 5 mils thick is effective.
- Provide increased on-center spacing between relays. Each doubling of this distance reduces the interaction effect by a factor of approximately four.
- Avoid simultaneous operation of adjacent relays.
- Provide alternating coil polarities for relays used in a matrix (including independently addressable multi-channel relays such as the Coto B-40) A typical matrix section is shown in Figure 7. Orienting the coil polarities as shown minimizes the mutual magnetic interaction between the relays, provided that the coils are wound in a consistent direction. All Coto reed relays are manufactured using automatic winding equipment that guarantees consistent wind direction.

Figure 7: Reed Relays Used in a Matrix



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Environmental Temperature Effects

The copper wire used to wind reed relay coils increases its resistance by 0.4% for every 1°C rise in temperature. Reed relays are current-sensitive devices: their operate and release levels are based on the current input to the coil. If a voltage source is used to drive the relays, an increase in coil resistance causes less current to flow through the coil. The voltage must be increased to compensate and maintain current flow. From a voltage perspective, the relay has become less sensitive. Industry standards define that relays are typically specified at 25°C ambient, unless otherwise specifically defined in advance by the user. If the relay will be used under higher ambient conditions or near external sources of heat, this must be carefully considered. Sometimes standard relay designs have to be customized to accommodate high ambient temperature conditions.

Consider for example that a standard relay nominally rated at 5 VDC may have a 3.8 VDC maximum operate value at 25°C as allowed by the specifications. If the relay is to be used in a 75°C environment however, the 50 degree temperature rise increases the operate voltage by 50 x .4%, or 20%. Thus the relay will be observed to operate at 3.8 VDC + (3.8 VDC x 20%), or 4.56VDC. If there is more than a 0.5 VDC drop in supply voltage due to a device driver or sagging power supply, the relay may not operate. If there is sufficient voltage to drive the relay, it should be noted that there will be increases in operate and release timing to approximately the same 20% .

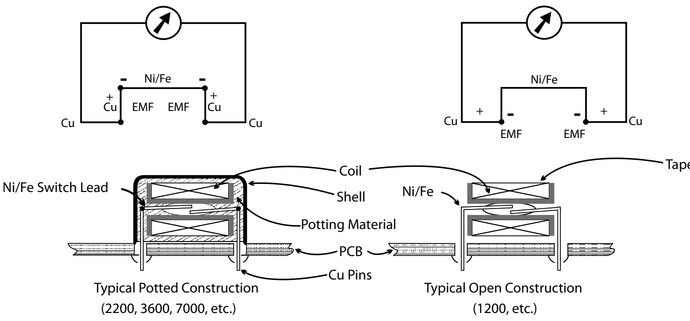
Thermal Offset Voltage

The leads on reed switches are made of various types of nickel-iron alloys. These alloys are selected by the switch manufacturer based on their specific ferromagnetic properties. These alloys in general have less-than-desirable electrical properties from a conduction standpoint. At some point in the electrical circuit, either inside the relay or on the printed circuit board, it is necessary to make a transition from the nickel-iron to a copper (or copper alloy) conductor.

This transition results in two dissimilar metals coming into contact. When this occurs, a voltage develops which depends on the particular metals and the temperature of the junction. This voltage is called the thermoelectric voltage or thermal electromotive force (EMF). Unfortunately, nickel, iron and copper are among the most active metals with regard to voltage generation and is why they are used in most of the ANSI-standard thermocouples. Although this voltage is very small, there are some applications (like digital voltmeters or thermocouple scanners) where it must be considered and managed. Figure 8 shows a reed switch terminated to copper pins inside a relay and another case where the termination occurs at the printed circuit board.

Note the resulting thermal voltages and their polarities. The polarities are such that if the magnitude of the developed voltages is the same, they will cancel each other out so as not to add or subtract from the signal being carried by the switch. For the magnitude of the two voltages to be equal, however, the two junctions must be at the same temperature.

Figure 8: Thermocouple Junctions



Considering the case where the transition occurs on the PCB, it is the user's responsibility to assure controlled conditions in the termination area if the thermal voltage is to be managed. Non-uniform air currents, for example, can produce thermal effects on the order of 20 to 40 microvolts or even higher.

In the case where the termination occurs within the relay, there are several factors to consider. In general, Coto does nothing in the relay to deal with thermoelectric effects. The relays are usually potted or molded in epoxy which is a poor thermal conductor and a large thermal mass relative to the junctions. When the relay is off, the junctions are likely to be at the same temperature. The relay is turned on by applying power to the coil. This power produces the required magnetic field but also an undesirable byproduct: heat. he amount of heat depends on the electrical design of the coil and the length of time the coil remains energized. The effect that this heat has on thermoelectric voltage generation depends on the symmetry of the relay from a thermal perspective. Figure 9 shows a recorder trace of the net thermal EMF from a typical reed relay.

Some applications are so critical that Coto had to develop technology to reduce thermal EMF below otherwise normal levels. This "Low Thermal" technology is used in the 3500- and 3600-series reed relays. These series of relays are 100% tested for thermal EMF and guaranteed to not exceed a specific value. The 3501 and 3540 are single-pole relays compensated to provide low thermal offset voltage. They are tested using the circuit in shown below in Figure 10.

Two-pole low-thermal relays are differentially compensated. The thermal performance is guaranteed only when the two poles are connected in series with the load or input signal. They are tested using the circuit model shown in Figure 11.

ENVIRONMENTAL TEMPERATURE EFFECTS

The 3650 and 3660 relays are three-pole low-thermal relays, but only two of the poles are thermally compensated. They are compensated for differential application. The third pole is uncompensated. It is provided for use as a guard or ground switch.

Figure 9: Thermal EMF

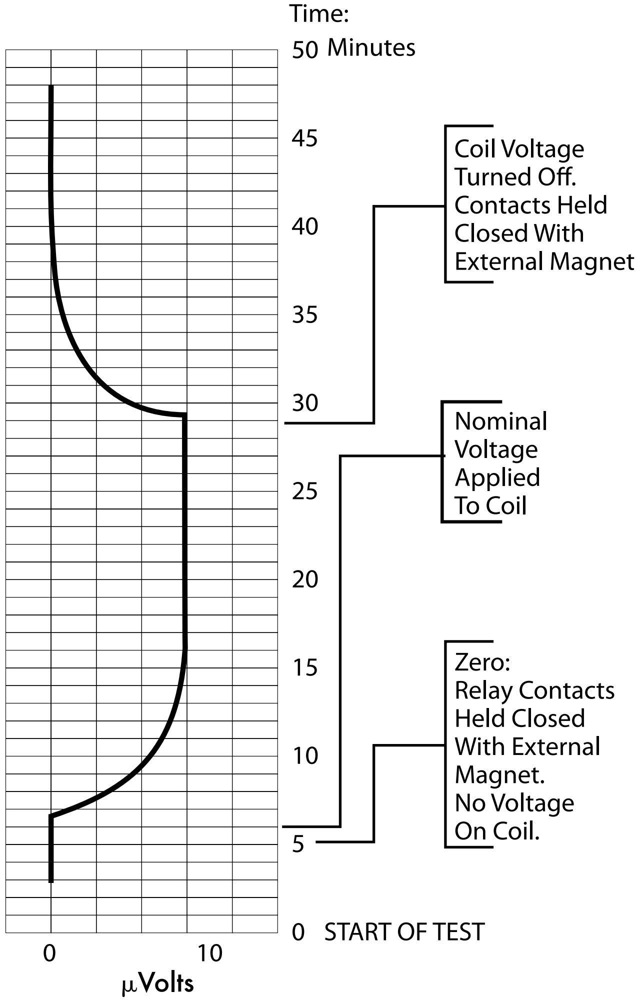


Figure 10: Test Circuit for Individual Compensation

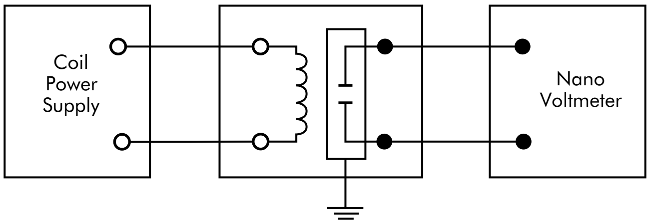
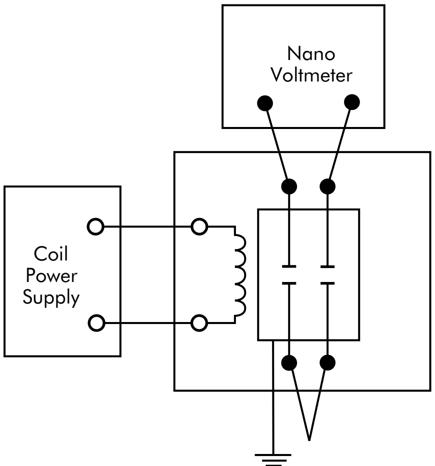


Figure 11: Test Circuit for Differentially Compensated Relays



REED RELAY RF PARAMETER MEASUREMENTS

Insertion and other losses

In the past, the typical parameters used to quantify the RF performance of reed relays have been Insertion Loss, Isolation, and Return Loss (sometimes called Reflection Loss). These are frequency-related vector quantities describing the relative amount of RF power entering the relay and either being transmitted to the output or being reflected back to the source. For example, with the relay's reed switch closed and 50% power being transmitted through the relay at a particular frequency, the insertion loss would be 0.5. This is more conveniently expressed in decibels – in this case the insertion loss would be $10\log_{10}(0.5)$ = -3dB. The frequency at which –3dB rolloff occurs is a convenient scalar (single valued) quantity for describing insertion loss performance.

Isolation

Similarly, the RF isolation of the reed relay can be determined by injecting an RF signal of known power amplitude with the reed switch open (coil unactivated). Sweeping the RF frequency and plotting the amount of RF energy exiting the relay allows the isolation curve to plotted. Again, plotting on a dB scale is most convenient because of the very wide range between input and output power amplitudes. At lower frequencies, the isolation may be –40dB or greater, indicating that less than 0.01% of the incident power is leaking through the relay. The isolation decreases at higher frequencies, because of capacitive leakage across the reed switch contacts.

Return Loss

Finally, return loss represents the amount of RF power being reflected back to the source with the reed switch closed, and the output terminated with a standard impedance, normally 50 ohms. If the relay was closely matched to 50 ohms at all frequencies, the reflected energy would be a very small fraction of the incident energy from low to high frequencies. In practice, return loss gradually increases (more power is reflected) as frequency increases. High return loss (low reflected energy) is desirable for high speed pulse transmission, since there is less risk of echoing signal collisions that can cause binary data corruption and increased bit error rates. Return loss is calculated from the reflection coefficient (ρ), which is the ratio of the magnitude of signal power being reflected from a closed relay to the power input, at a specified frequency.

$$\text{Return Loss (dB)} = -20 \log \rho$$

Thus, characterization of the RF performance of a reed relay involves injecting a swept frequency RF signal of known power and measuring the amount of RF energy transmitted through, or reflected back from the device under test (DUT). These measurements can be conveniently made using a Vector Network Analyzer (VNA). These test instruments comprise a unified RF sweep frequency generator and quantitative receiver/detector. In the case of a Form "A" relay, the device is treated as a network with one input and one output port, and the amount of RF energy entering and being reflected from each port is recorded as a function of frequency. Thus a complete characterization of a Form "A" relay comprises four data vectors, designated as follows:

- S_{11} power reflected from input port
- S_{12} power transmitted to input port from output port
- S_{21} power transmitted to output port from input port
- S_{22} power reflected from output port

Since a relay can be open or closed, there are 8 possible data vectors to determine. And since both magnitude and phase are involved, two data points need to be determined, a real quantity measuring magnitude and an imaginary quantity representing phase. Thus, 200-point frequency step characterization of a Form "A" relay would comprise 200 * 2 * 8 = 3200 data points.

In practice, these measurements can be simplified. First, Form "A" reed relays are mechanically and electrically symmetrical devices, so that an RF signal can be injected in either switch connection with the same (or at least very similar) results. This means that only S_{11} and S_{21} need to be recorded. Second, the measurements yielding insertion loss, isolation and return loss are simply S_{21} (switch closed), S_{21} (switch open) and S_{11} (switch closed) respectively. S_{11} with the switch open is not a particularly useful measurement, and is not included in the plots shown below. Third, for graphical representation, the magnitude and phase information at each frequency can be simply combined by computing the vector length of the magnitude and phase components from their root sum-of-squares. This simplification converts the measured S-parameters to the more familiar representation of insertion loss, isolation and return loss.

For further information on S-parameter measurements, consult the following references, available from Agilent (www.agilent.com).

Agilent Technologies Application Note 95-1, "S-Parameter Techniques for Faster, More Accurate Network Design."

Agilent Technologies Application Note 1287-9, : "In-Fixture Measurements Using Vector Network Analyzers"

Agilent Technologies, "Network Analyzer Basics", in "1997 Back to Basics Seminar."

Circuit simulation using S-Parameter data

Note that the complex magnitude and phase information for each S-parameter at each frequency has to be preserved if the S-parameters are to be used for modeling the relay's performance in an electric circuit. Most SPICE-type circuit simulation programs or Smith Chart graphics programs allow S-parameter data to be imported, allowing

REED RELAY RF PARAMETER MEASUREMENTS

the component's electrical performance to be modeled as a "black box." On request, Coto Technology can provide the full S-parameter data for any of the relays listed below in electronic format.

Voltage Standing Wave Ratio (VSWR)

VSWR is a measurement of how much incident signal power is reflected back to the source, when an RF signal is injected into a closed relay terminated with a 50 ohm impedance. It represents the ratio of the maximum amplitude of the reflected signal envelope amplitude divided by the minimum, at a specified frequency. A VSWR of 1 indicates a perfect match between the source, relay and output load impedance, and is never achievable in practice. VSWR is conveniently calculated from the S11 parameter data using the following transformation:

$$VSWR = (1+\rho)/(1-\rho)$$

Where $\rho = alog_{10}(-R_{dB}/20)$
and R_{dB} = return loss at a specific frequency.

Note that network analyzers treat S_{11} reflection data as negative-signed, so that the sign needs to be changed before this transformation is applied.

VSWR plots are a simple transformation of reflection data plots, they are not shown below. VSWR at any particular frequency can be converted from y-axis Return Loss using the following table:

Return Loss (dB)	VSWR
-50	1.01
-40	1.02
-30	1.07
-20	1.22
-10	1.93
-3	5.85

Rise Time

The rise time of a reed relay is the time required for its output signal to rise from 10% to 90% of its final value, when the input is changed abruptly by a step function signal. The relay can be approximated by a simple first-order low-pass filter. The rise time is approximately:

$$T_r = RC * \ln(90\%/10\%) = 2.2RC.$$

Substituting into the equation for the 50% roll-off frequency $f_{-3dB} = 1/(2\pi RC)$ yields the relationship:

$$T_r = 0.35/ f_{-3dB}$$

Thus the relay's rise time can be simply estimated from the S_{21} insertion loss curve, by dividing the –3dB rolloff frequency into 0.35. For example, the B41 ball grid relay has f_{-3dB} = 8.0 GHz, from which the rise time can be estimated as 45 pS.

Provided the S_{21} data is correctly compensated for the contribution of signals losses from the test fixture, this method for measuring rise time is simpler than alternative pulse injection techniques that require deconvolution of the system response time.

The following table shows the f_{-3dB} insertion loss frequency and estimated rise time for the Coto Technology relays useful for high frequency service. These relays contain a coaxial RF shield to maintain the relay's RF impedance close to 50 ohms. With the exception of the 9852, all are Form "A" relays. The 9852 is Form "C", with both normally open (NO) and normally closed (NC) contacts. The bandwidth and rise times are listed for both 9852 contact types:

Effect of Lead Form on High Frequency Performance

Coto Technology reed relays are available with several lead form options. Surface mount (SMD) relays give better RF performance than those with through hole leads. SMD leadforms comprise gullwing, J-bend and axial forms. Each has its advantages and disadvantages, but the RF performance point of view, axial relays generally have the

Relay Type	Leadform	f_{-3dB} (GHz)	Rise Time (pS)
9002	Through-hole	1.6	220
9202	Gull	2.0	175
9202	J	2.0	175
9290	Gull	1.25	280
9290	J	3.0	117
9402	Gull	1.25	280
9402	J	1.25	280
9814	Gull	5.0	70
9814	J	5.8	60
9814	Axial	6.3	56
9852 NO	Gull	4.0	88
9852 NO	J	4.0	88
9852 NO	Axial	4.0	88
9852 NC	Gull	3.2	109
9852 NC	J	3.8	92
9852 NC	Axial	3.8	92
9903	J	6.2	56
B41	BGA	8.0	45

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best RF performance in terms of signal losses, followed by J-bend and gullwing in that order. The straight-through signal path of axial relays minimizes capacitive and inductive reactance in the leads and minimizes impedance discontinuities in the relay, resulting in the highest bandwidth. However, the axial leadform requires a cavity in the user's printed circuit board to receive the body of the relay. An advantage is the effective reduced height of the axial relay, where space is at a premium.

J-bend relays provide the next-best RF performance, and have the advantages of requiring slightly less area on the PCB. The gullwing form is the most common type of SMD relay – having the longest lead length between the connection to the PCB pad and the relay body results in slightly lower RF performance than the other lead types, but initial pick-and place soldering is simple, as is rework, resulting in a broad preference for this lead type unless RF performance is critical.

Newer Leadforms

Coto Technology has developed patented new types of leadless relays with greatly enhanced RF performance. These new relays do not have traditional exposed metal leads; instead, the connection to the user's circuit board is made with ball-grid-array (BGA) attachment, so that the devices are essentially leadless. In the new BGA relays, the signal path between the BGA signal input and output is designed as a an RF transmission line, with an RF impedance close to 50 ohms throughout the relay. This is achieved using a well-matched combination of coplanar waveguide and coaxial structures with very little impedance discontinuity through the relays.

Skin Effect in Reed Relays

It is well known that at high frequencies, RF signals tend to travel near the surface of conductors rather than through the bulk of the material. The skin effect is exaggerated in metals with high magnetic permeability, such as the nickel-iron alloy used for reed switch blades. In a reed switch, the same metal has to carry the switched current and also respond to a magnetic closure field. A perennial question is the influence of skin effect on degradation of high frequency reed relay performance. Does increasing AC resistance at higher frequencies due to skin effect losses significantly affect insertion loss, isolation and return loss? And are there better choices for switch blade materials, or conductive surface plating techniques to reduce the effect?

The answers are: "not significantly", and "possibly, but difficult to implement." Coto Technology has run tests to determine the significance of skin effect on high frequency relay performance. Relays were made up with dummy reed switches fabricated with copper wire and other experimental materials replacing the reed switch leads. Precautions were taken to ensure that these artificial switches closely simulated the impedance environment inside the actual reed relay. When these test parts were run in comparison to a standard reed relay, the difference in measured S-parameters were generally negligible.

There are several possible reasons for this; first the increase in AC resistance due to skin effect is only proportional to the square root of frequency, whereas the losses due to increasing reactance are directly proportional to L and inversely proportional to C, and tend to override the skin effect at higher frequencies. Furthermore, the blade materials used in Coto Technology reed switches have proprietary diffused surface layers made of metals more conductive than nickel-iron, which tend to increase the conductivity near the surface. Finally, the external lead surfaces are coated with tin or solder alloys for enhanced solderability; these also help to reduce skin effect losses. Note that plating the surfaces of reed switch blades with conductive metals is not practical (except outside the glass capsule), because of problems with reduced contact force and glass-to-metal seal integrity.

The conclusion is that skin effect is as well controlled as it can be, and is not a major contributor to high frequency performance degradation under practical application conditions.

Selecting reed relays for high frequency service

The circuit designer faced with developing high speed switching circuits has several choices, including reed relays, electromechanical relays (EMR's) specifically designed for high frequency service, solid state relays (SSR's), PIN diodes and micro-electromechanical systems (MEMS) relays. In many cases, Coto Technology reed relays are an excellent choice, particularly with respect to their unrivalled RC product. RC is a figure of merit expressed in pF•ohms – where R = closed contact resistance and C = open contact capacitance. The lower this figure, the better the high frequency performance. The best available SSR's currently have pF•ohm products equal to about 6, almost 75 times higher; in addition, the breakdown voltage at these pF•ohm levels is far lower than that of a reed switch. The turn-off time for SSR's is also far longer than the 50 microseconds needed by a reed relay to reach its typical 10^{12} ohm off resistance. Though the drive power required by the SSR is lower than that of the reed relay, this appears to be the only general advantage; the perception of lower reliability for reed relays compared to solid state devices is largely unjustified, due to continuous technological improvements. Most Coto reed relays now have demonstrated Mean Cycles Before Failure (MCBF) values of several hundred million to several billion closure cycles at typical signal switching levels.

PIN diodes are occasionally considered as an alternative to reed relays for HF switching. It is difficult to find any advantages in such a choice, for several reasons; PIN diodes require relatively complex drive circuitry compared to the simple logic circuitry that can drive

REED RELAY RF PARAMETER MEASUREMENTS

reed relays. PIN diodes typically have a lower frequency cut-on of about1 MHz. In contrast, a reed relay can switch from DC to its useful cut-off frequency. In addition, the high junction capacitance of PIN diodes results in lower RF isolation than a reed relay when the PIN diode is biased "open". When biased "closed", the higher on-resistance of the PIN diode can lead to Q-factor damping in the circuit to which it is connected. Furthermore, PIN diodes can exhibit significant non-linearity, leading to gain compression, harmonic distortion and intermodulation distortion. In contrast, reed relays are inherently linear switching devices.

Electromechanical relays (EMR's) have been developed with claimed bandwidths to about 6 GHz, and isolation of about –20dB at that frequency. This isolation is somewhat better than that of a reed relay, since the contacts can be designed with bigger spacing than can be achieved in a reed switch, resulting in lower capacitive leakage. However, this advantage must be weighed against the increased size and cost of EMR's compared to reed relays, and lower reliability. The EMR has a complex structure with more moving parts than the simple blade flexure involved in closing a reed switch, resulting in a much lower mechanical life. If higher isolation is required with a reed relay solution, two relays can be cascaded together with a combined reliability that is still higher than that of a typical EMR.

MEMS (MicroElectroMechanical Structure) devices have been developed into switches and relays using planar silicon structures with electrostatic closure, or ferrous metal structures with magnetic closure. They offer potential advantages in terms of small size and low-loss high frequency signal switching. So far though, none has demonstrated adequate contact reliability at the switching loads required for Automated Test Equipment (ATE) applications. There are various technical reasons for this limitation that may be overcome in the future. Coto Technology is monitoring these developments and may offer a microfabricated solution when reliability problems can be overcome.

Time Domain Reflectometry (TDR)

TDR measurements are an alternative method for displaying a relay's HF performance. They can be made be made by launching a high speed, rapid risetime pulse into a relay, and measuring the time and amplitude of the return signal. Provided the risetime of the pulse is sufficiently small, the return time can be related to the distance of an impedance discontinuity inside the relay, and the shape of the returned pulse can be used to identify whether the discontinuity is capacitive, inductive or a combination of both. Though specialized TDR equipment or oscilloscope plug-ins are available, most modern VNA's can provide TDR data by Fast Fourier Transformation (FFT) of the frequency domain reflection data. Since TDR plots do not present unique information, they are not shown in this catalog. Contact Coto Technology if you have a specific need for TDR information on any of the RF relays described in the catalog.

Relay RF Data Presentation

The data shown in the graphs following this section are derived from S-parameter measurements made using an HP 8719D Vector Network Analyzer and is presented as relative power using the transformation:

$dB_f = 20 \log (S_{Pij})$, i = 1 or 2, j = 1)

where S_{pij} = the S-parameter polar magnitude at a particular frequency, and dBf = signal power in decibel format.

Data points are shown over a frequency range from f = 0.05 to f = 8.0 GHz except for the B41 ball-grid array relay, which is plotted from 0.05 to 13 GHz.

Insertion loss is derived from S_{21} data with the reed switch closed. Isolation is derived from S_{21} data with the reed switch open. Return loss (sometimes called reflection loss) is derived from S_{11} data with the reed switch closed.

Each data point is plotted as the polar magnitude of the real and imaginary components of the complex S-parameters recorded at each frequency step. The original full S-parameter data sets are available in complex number format on request, in Microsoft Excel, CITIfile or Touchstone format. These data sets can be imported directly into most SPICE-type circuit simulation programs, or Smith Chart display programs.

S_{11} parameters for the return loss curves were measured with the relay's reed switch closed, and the output terminated by a 50 ohm impedance load. Calibration was performed using an RF test card having a reference microstrip trace, using one-port error correction. The intention is to provide the true frequency response of the relay while eliminating spurious responses from extraneous elements such as the RF test card's microstrip transmission lines or coaxial connectors.

S_{21} data were measured with the switch open, to provide data for the RF isolation curve, or with the switch closed to provide the insertion loss curve. The network analyzer was calibrated with a full two-port method.

Since the Coto reed relays are symmetrical two-port devices, the reverse S- parameters (S_{12} and S_{22}) are nominally identical to the forward coefficients (S_{11} and S_{21}) and are not presented here.

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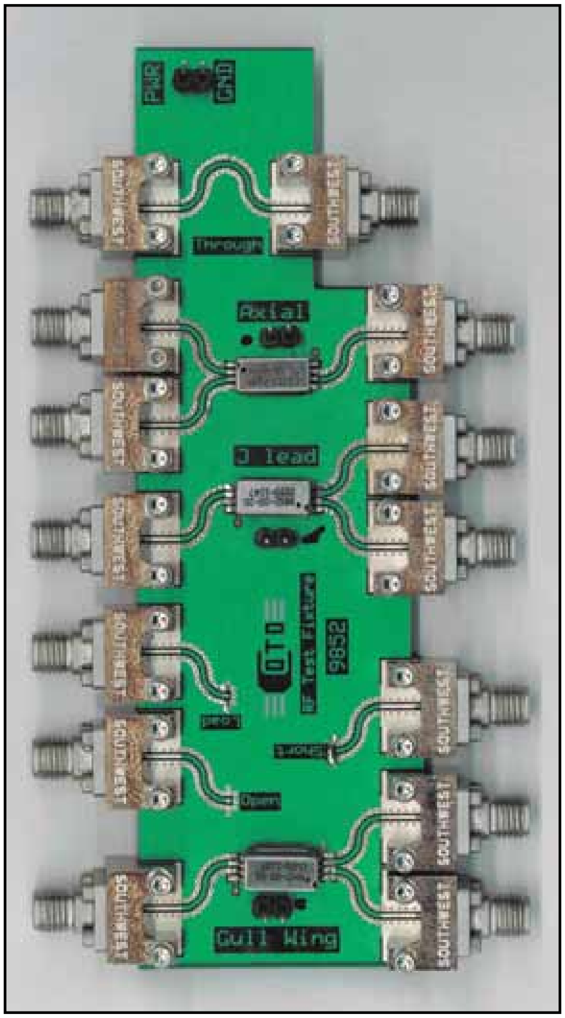
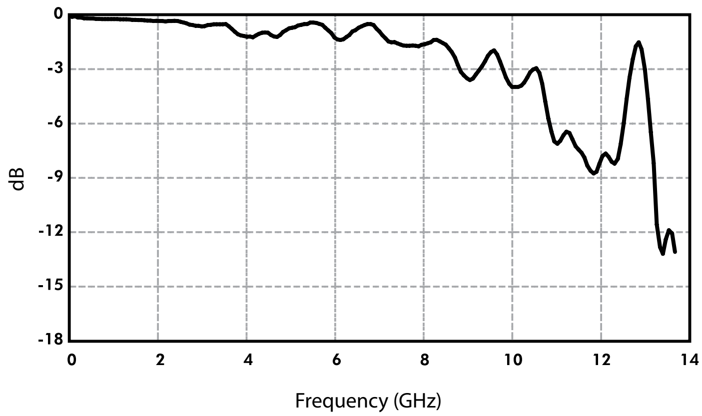
Typical RF Test Card

Showing 50 ohm microstrip line connection to relay contact pins, and reference compensation trace.

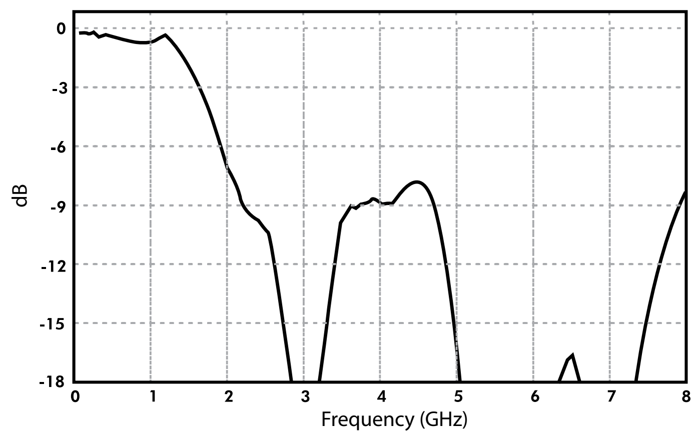


RF GRAPHS

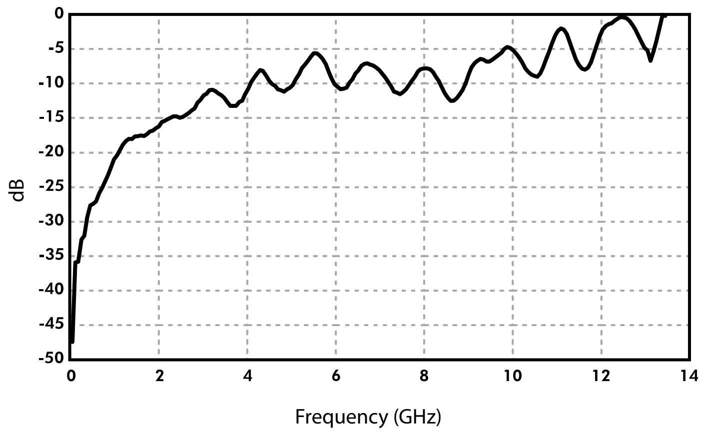
B41 Insertion Loss



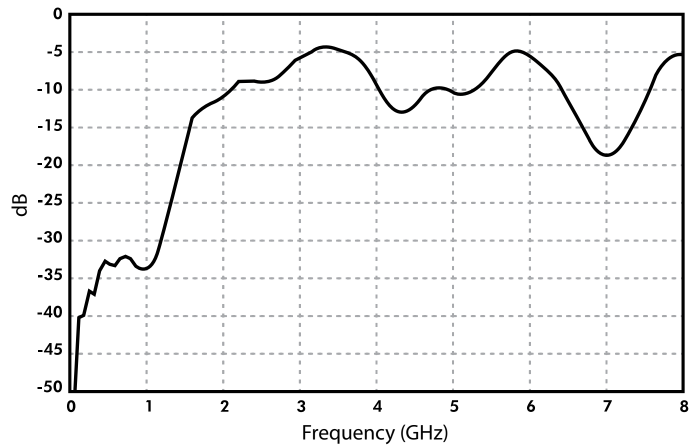
9002 Insertion Loss



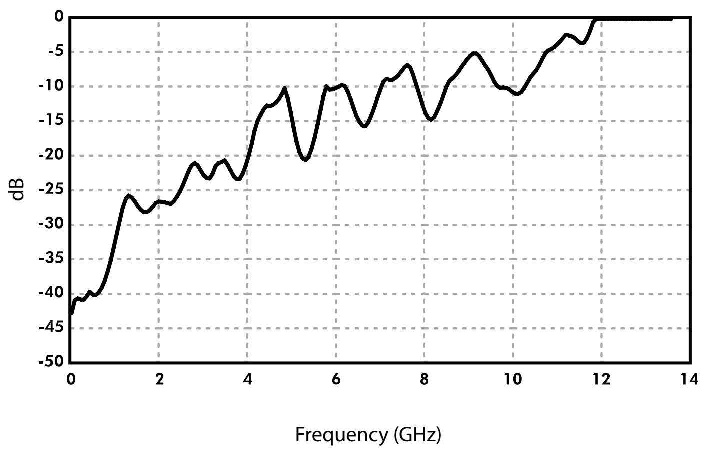
B41 Isolation



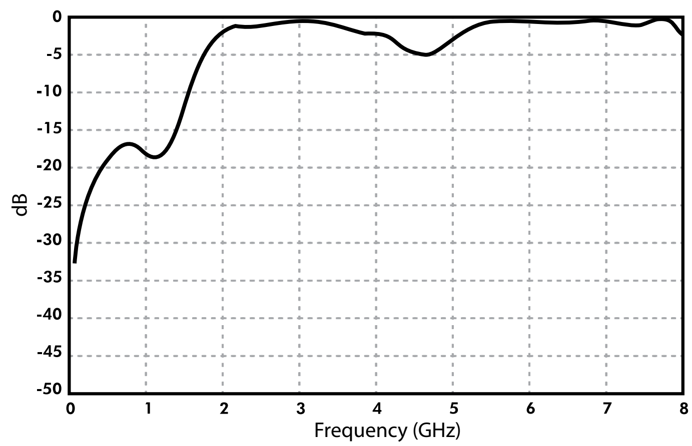
9002 Isolation



B41 Return Loss



9002 Return Loss



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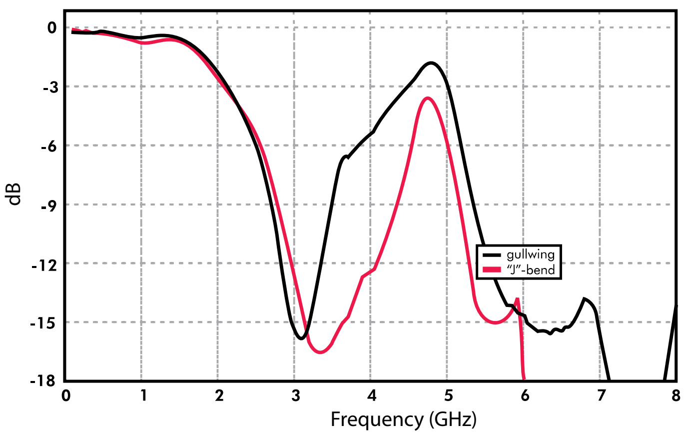
9202 Insertion Loss



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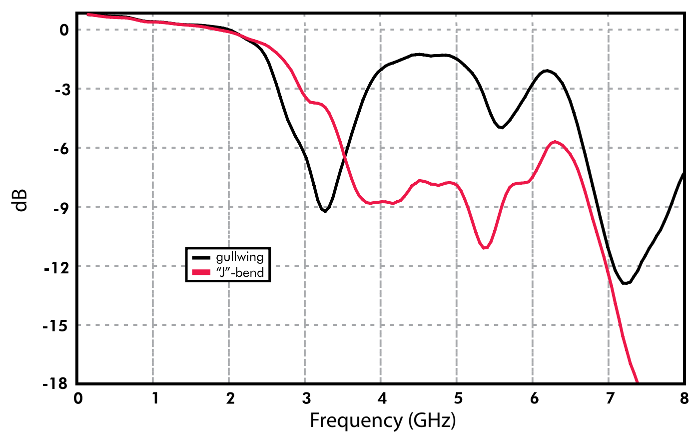
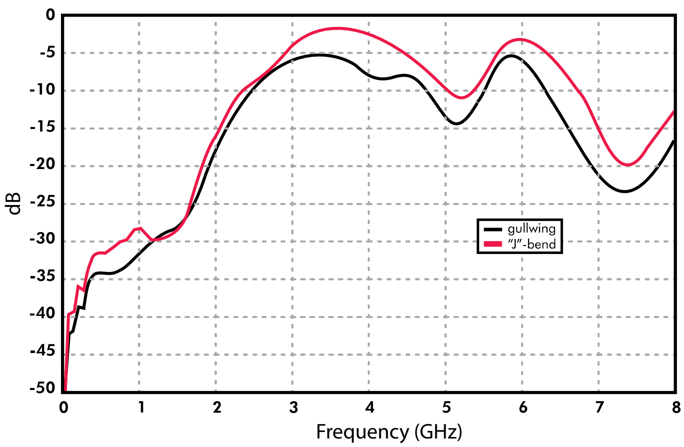


9202 Isolation



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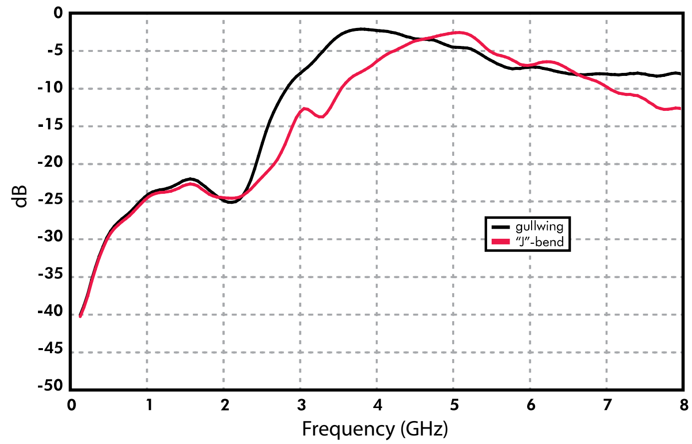

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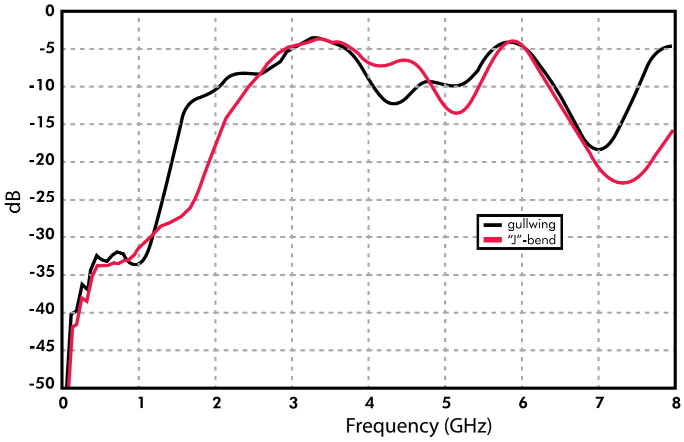
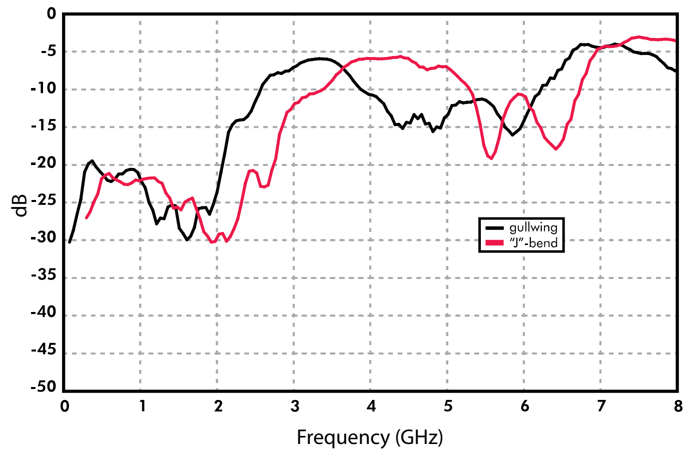
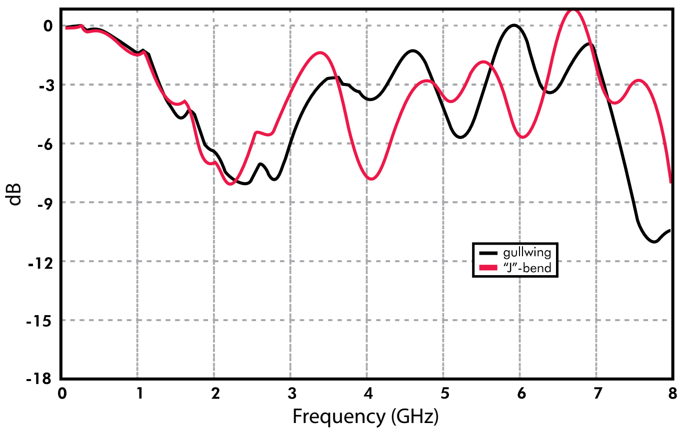


9290 Return Loss



RF GRAPHS

9402 Insertion Loss



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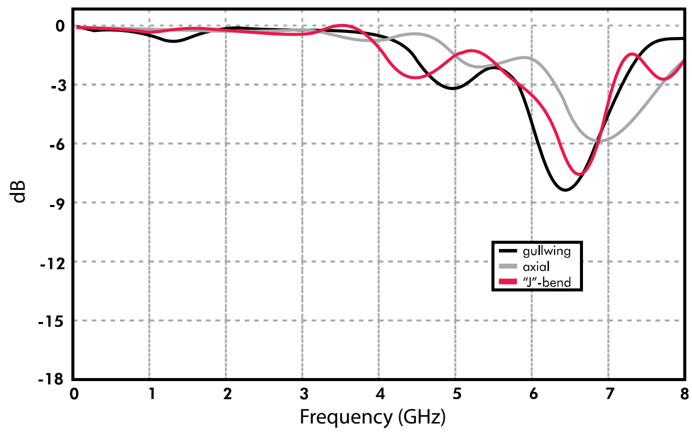

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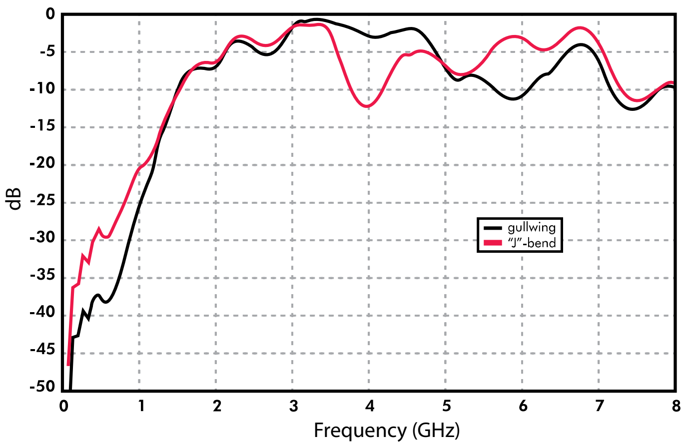

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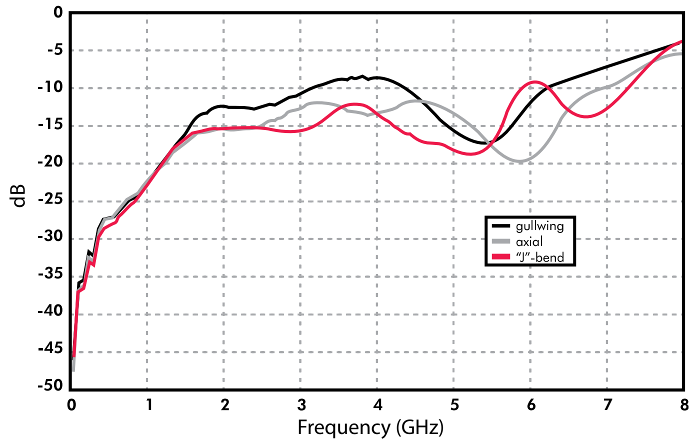

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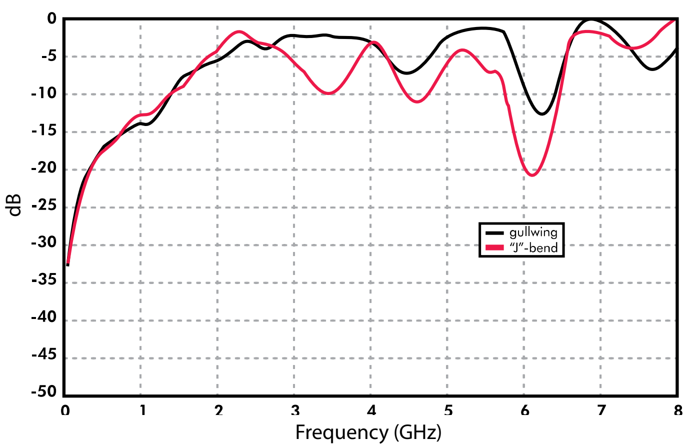

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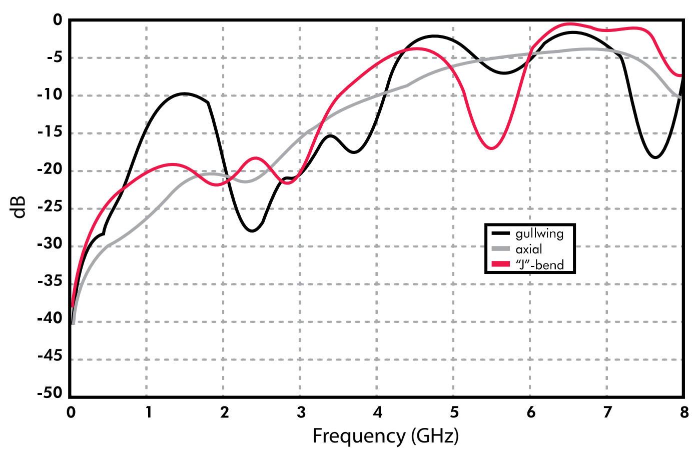

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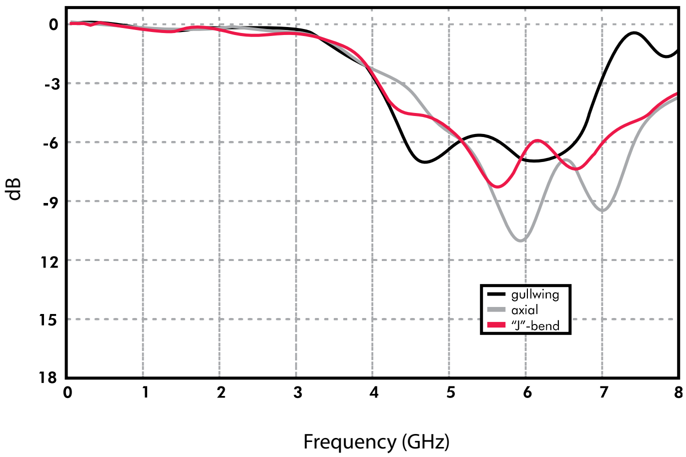
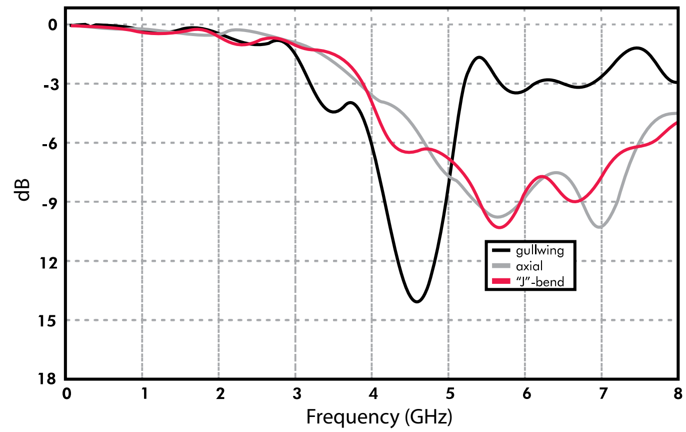
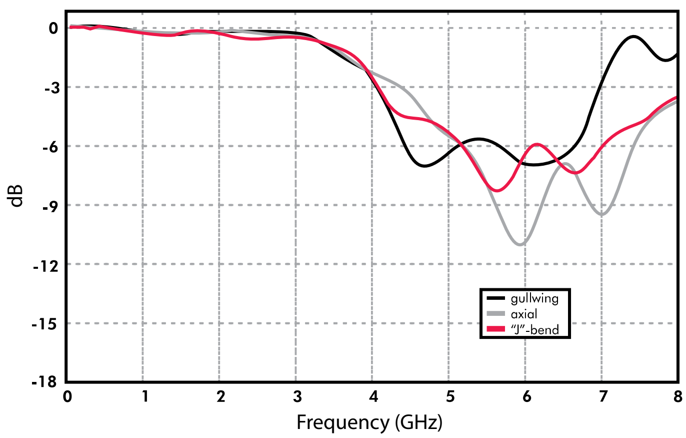
9852 Insertion Loss (NO)



9852 Insertion Loss (NC)



9852 Isolation (NO)



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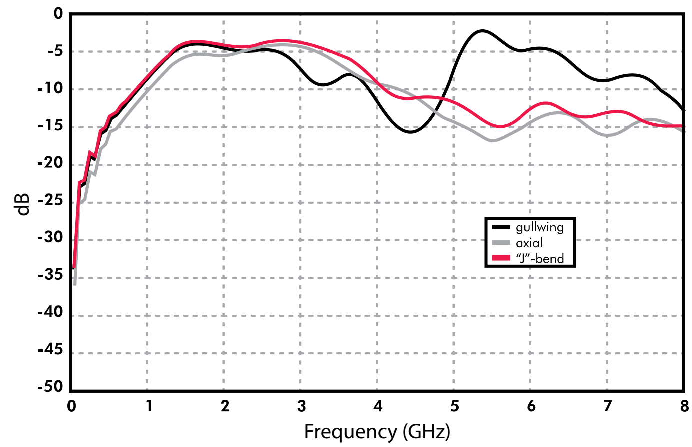

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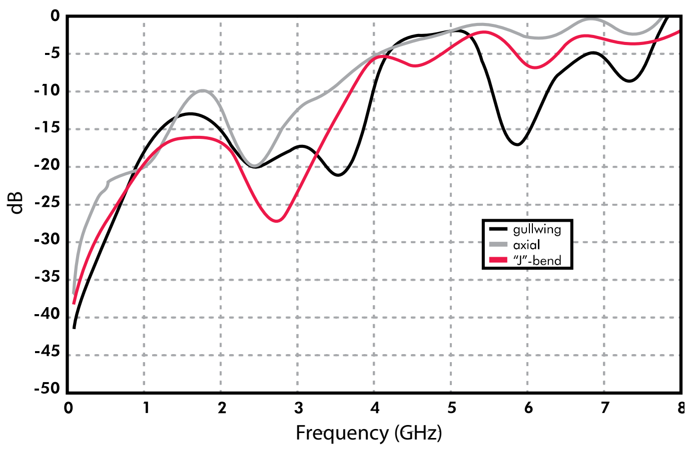

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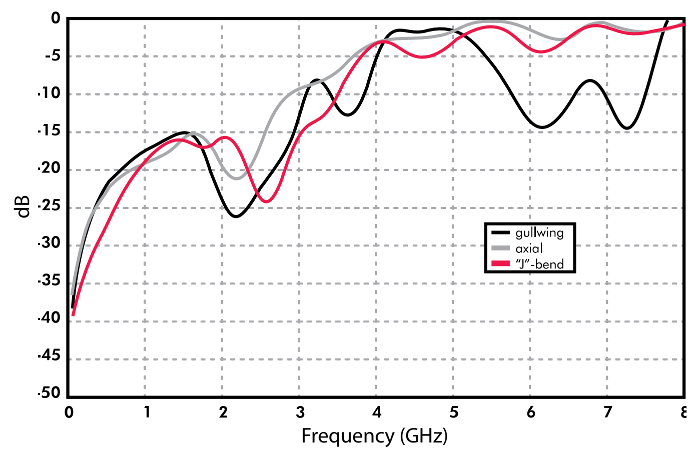
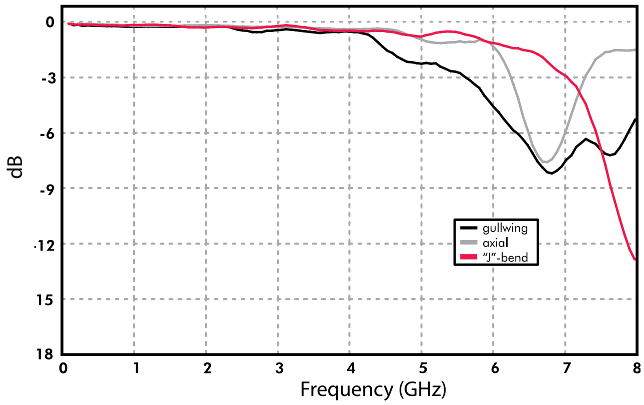
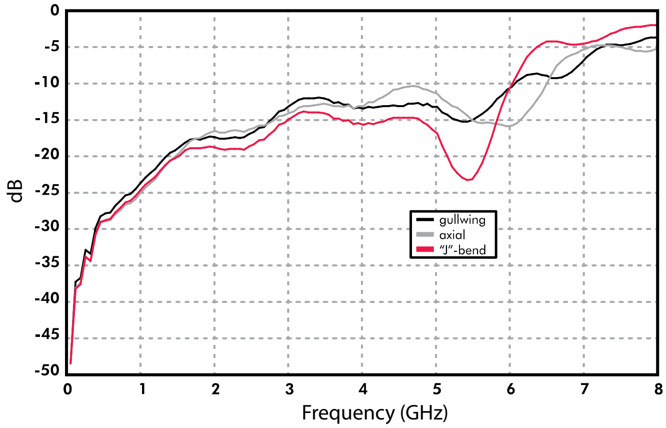


RF GRAPHS

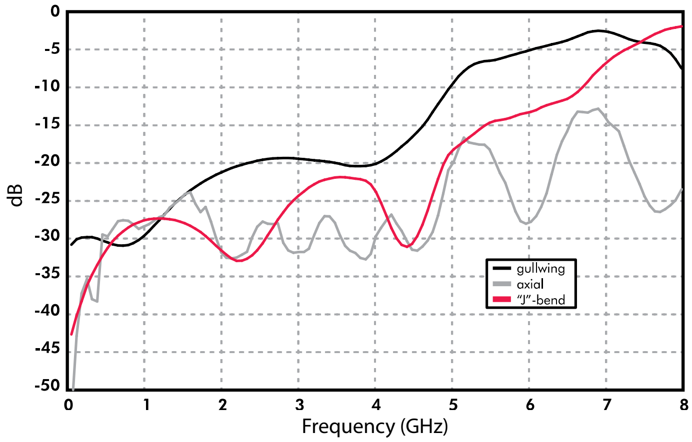
9903 Insertion Loss



9903 Isolation



9903 Return Loss



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RELIABILITY TESTING

In addition to the parametric testing performed on every switch and relay that leaves the Coto factories, we subject samples of all our products to rigorous life testing. Products are tested at various current and voltage loads, including inrush current profiles where necessary. We frequently tailor these loads to our customers' special technical requirements. The sample sizes and the number of test cycles are chosen to allow accurate assessment of MCBF (mean cycles before failure) and other reliability statistics – often involving sample sizes of 64 or 128 test parts and several billion test cycles over many weeks.

Coto Technology uses Weibull distribution analysis for predicting MCBF, expected life before 1% part failure, estimation of expected infant mortality and wearout characteristics, and other pertinent reliability data.

Weibull distribution

This distribution is widely described in reliability literature. The number of cycles to failure for a sample of relays or switches is fitted by least-squares techniques using the two-parameter Weibull distribution function F(t), where

$$F(t) = 1 - e^{-(t/\eta)^\wedge\beta}$$

Here, F(t) is the unreliability function, t = time or cycles to failure, η and β are the Weibull distribution parameters.

This equation can be linearized by plotting

$y = \log_e(\log_e(1/(1-F(t))))$ on the y-axis and
$x = \log_e(t)$ on the x-axis.

After linear regression of y on x, the slope of the regression line = β and the intercept = $\beta \log_e(\eta)$.

Given a set of cycles to failure for a particular sample of relays, F(t) values are calculated with Benard's approximation for median ranks:

$$F(t) = (j - 0.3) / (N + 0.4)$$

where j = the rank order number for the failure and N = total number of failures. Special precautions are taken to deal with censored data from parts that survive the test without failure.

The product's MCBF and its confidence limits are then calculated from the fitted Weibull parameters η and β. The Weibull slope parameter β is particularly useful, since its magnitude relates to the wearout characteristics of the product being tested. A value of $\beta < 1$ indicates "infant mortality" failures, that can potentially be reduced by manufacturing improvements, or screened out by burn-in testing. Values of $\beta > 1$ are more desirable, since they indicate a normal mechanism of wearout after a stable period of reliable operation.

The MCBF can also be expressed as a failure rate; one is simply the reciprocal of the other. Thus, a switch with an MCBF of 250 million cycles has an average failure rate of 4.0E-09 per cycle. This does not necessarily infer that a part has a constant failure rate throughout its life; for example, a part that shows wearout characteristics (large Weibull beta) will demonstrate an increasing failure rate as it nears the end of its service life.

What is a failure?

Reed relays eventually fail in one of three ways. They do not open when they should ("sticking"), they fail to close when they should ("missing"), or their static contact resistance gradually drifts up to an unacceptable level. At light loads, failure may not occur until several billion closure cycles have occurred. The first two listed mechanisms can be further subdivided into "soft" and "hard" failures. A soft failure is recorded when a switch is found to have missed or stuck a few milliseconds after coil activation or de-activation, but it is then found to have recovered from the problem when checked a short time later. If recovery from the initial soft failure has not occurred by the time the second check is made, the failure is classified as permanent or "hard".

Since even one soft failure can be problematic in critical applications such as ATE, Coto records failures for "expected life" estimation as the first, **soft failure** due to sticking, missing or excessive contact resistance. This is a deliberately conservative criterion. Comparison with the reliability data published by other relay manufacturers is difficult, because they may be less rigorous in their choice of failure criteria or less scrupulous in presenting statistical reliability data.

Typical Example of Life Data Analysis and Interpretation

The Weibull regression plots shown in Figure 12 were generated from a life test of 64 Coto ATE-grade relays compared to an equal number of commercially available competitive parts. The test was run at 200 Hz, using a 5V, 10 mA resistive load. It was continued until all 128 parts had failed at about one billion cycles and 55 days of continuous testing. The MCBF for each relay type can be approximately estimated from the intercept of each fitted reliability plot with the 50% unreliability ordinate, or more accurately determined by numerical methods beyond the scope of this catalog. Shown on the plot as a vertical dotted line projected onto the x-axis, the estimated MCBF for the competitive relay is 66 million cycles, compared to 450 million for the Coto relay. The dotted lines indicate the 90% confidence limits for each plot - since these do not overlap at any point, the parts clearly have significantly different reliability levels with a 90% confidence level. Another useful reliability statistic is the expected life before 1% failure; the plots show that estimated 1% life is between 1 and 4 million cycles for the competitive relay, compared to 30 to 70 million for the Coto relay. The explanation of this bigger reliability differential is the steeper slope of the Weibull plot for the Coto part, indicating a more pronounced wearout

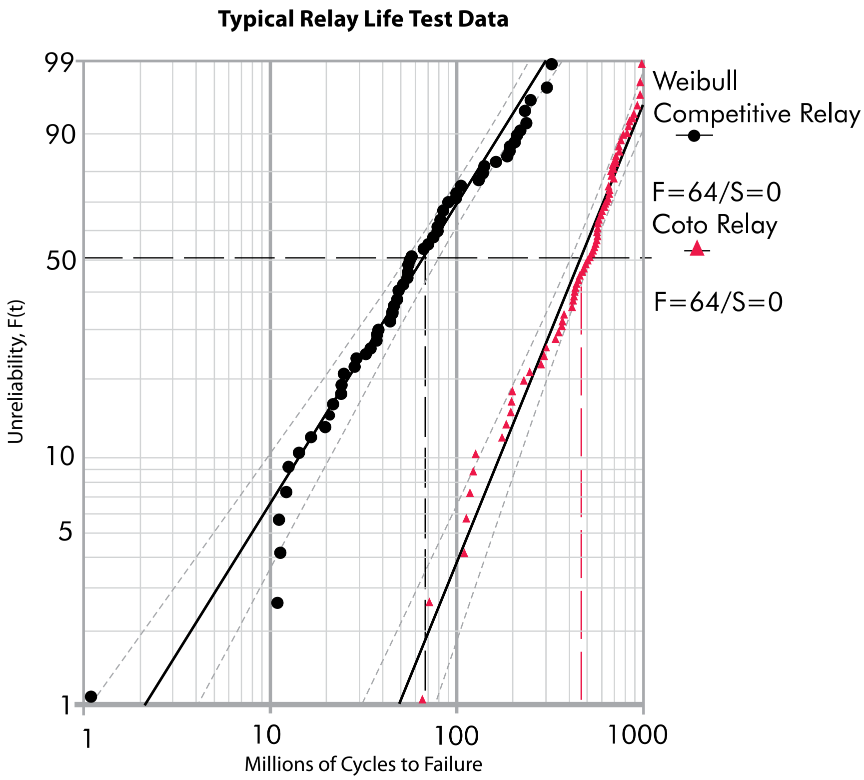
RELIABILITY TESTING

characteristic than the random failures exhibited by the competitor. Since the cost to locate, remove and replace a failed relay can greatly exceed the actual purchase price of the part, steeper Weibull slopes and higher MCBF's mean lower maintenance and replacement costs, and fewer expensive "infant mortality" failures.

Published life expectancy data

In the relay product specifications listed in this catalog, the term "Expected Life" is synonymous with MCBF or mean cycles before failure. Since the confidence limits associated with MCBF estimates are usually quite broad, the life estimates are rounded to an appropriate number of significant figures to avoid implied over-accuracy. Relay reliability data are only given for 1V, 10 mA or 1V 1 mA resistive loads. Switch life data is given at several different loads, depending on the application. Contact Coto Technology for life data at other loads. We have an extensive database of life test data, and may be able to predict reliability under other load conditions or set up a special life test meeting your requirements.

Figure 12: Weibull Regression Plots



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RELAY PROCESSING

Soldering Notes:

Through-hole relays

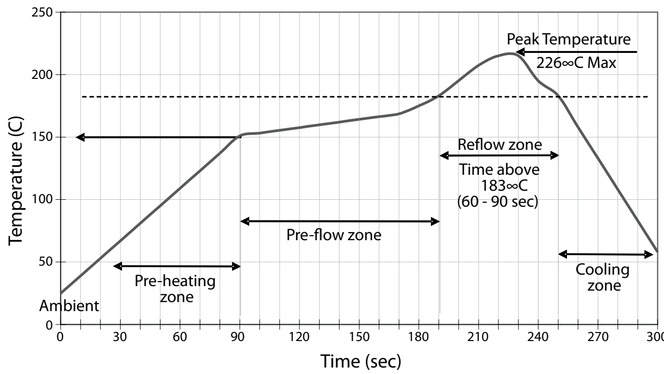
The attachment method is typically eutectic soldering.
RoHS requires solder with no elemental lead (Pb). SAC alloy (96.5Sn/3Ag/0.5Cu) is the most popular choice. Relays can be soldered by hand or by wave solder processing. Coto Technology recommends the maximum wave solder temperature (measured at the relay leads) as 270°C for 10 seconds. Temperature and time in excess of the recommended levels may result in damage to the relay. All of our through-hole relays will be compatible with either SAC alloy or eutectic soldering process.

Surface mount relays including
SAC Alloy BGA Relays (RoHS versions)

The most common method of attachment is by SMD processing – stencil/screen solder paste, then oven reflow. Due to board thickness, component density, and other circumstances that dictate the required reflow temperature, Coto Technology uses a higher temperature solder for all internal connections. We recommend that the max relay temperature during the solder reflow process does not exceed 260°C for one minute maximum. Temperature and time in excess of the recommended levels may result in damage to the relay.

Typical solder profiles are shown for conventional SnPb process using eutectic alloy and for the preferred method of SAC alloy (no Pb). Relay series converted to high temp process are both forward and backward process compatible for reflow purposes.

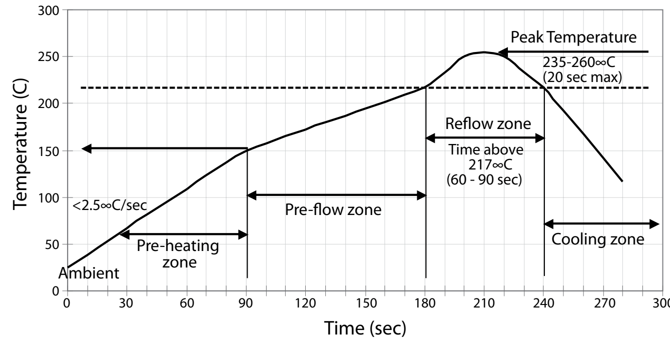
Recommended Reflow Profile
SnPb Eutectic Alloy



BGA Relays (non RoHS versions):

Ball Grid array devices currently use eutectic solder balls (Pb37/Sn63). Some designs incorporate non-melting balls (Pb90/Sn10) to eliminate excessive ball collapse during reflow. In either case, eutectic solder paste and reflow process should be used. These parts will not meet the higher temperature reflow processes because of materials considerations.

Recommended Reflow Profile
SAC Alloy



Post Soldering Cleaning:

Cleaning populated circuit boards for either through-hole or SMD process is performed to remove flux and or other residues that were used during the component attachment process. Leaving fluxes and other residues on the board surface and component pad/leads may reduce performance or life of the board if left in place. If fluxes or residues are left, the result maybe reduced insulation resistance due to the conductive properties of the flux/residues. In addition, some fluxes have corrosive characteristics that could interact with metalized surfaces of the circuit board and components.

The reed switches used in Coto Technology's relays have hermetically sealed glass capsules to protect the reed blade contacts in an inert environment. The switches are assembled into relay assemblies and then encapsulated by overmolding or potting techniques. Both of these encapsulation methods are effective in protecting the relay assembly. However, the relays are not truly hermetic components.

Coto relays are designed and manufactured to provide an adequate seal from external conditions. However, caution must be taken during the cleaning process not to expose the relays to conditions that will allow moisture to permeate into the package. Dwell time between reflow and cleaning, high pressure spraying, and time in cleaning solvent/aqueous solutions are cleaning process parameters to be careful of as they can contribute to moisture permeation. Board level bake out may be required after wash to remove moisture that has been introduced during cleaning operations.

Pick and Place

Coto Technology can provide molded relays in packaging that can support automated component placement. Tape and reel and component tubes are the most common packaging for this. As with all placement operations, component lead configuration and lead reliability are critical. Some of the critical lead characteristics that Coto Technology monitors on SMD products are:

RELAY PROCESSING

Lead Coplanarity
Coplanarity is the distance of any lead above the seating plane. This is measured at the relay lead tip. All leads must fall within a range of .004" relative to the component-seating plane unless otherwise specified.

Lead Pitch
Pitch is the distance between the centers of two adjacent leads. This is measured at the component body. Center to center lead position is specified as lead pitch ± tolerance (usually ±0.005").

Lead Skew/Sweep
Skew/sweep is the distance between the lead centerlines. This is measured at the lead tip. Lead centerlines must be within ±0.005" from nominal centerline and meet co-planarity requirements shown above.

Relay Removal
If failure analysis is required for a relay, care must be taken in order not to damage the relay during removal. Whether a solder vacuum, solder wick, hot gas removal station, wave removal station, or hot plate is used, the recommended maximum temperature and time cannot be exceeded. Temperature and time in excess of the recommended levels may result in internal damage to the relay, which will make failure analysis difficult or impossible.

All solder must be removed or in the liquid state before the relay is removed from the board. Failure to do so may result in stress to the relay and potential internal damage. Do not cut the relay leads to remove the relay as the leads are required for analysis and may cause internal damage if cut.

Relay Storage
Typically, relay parametric specifications are specified at 25°C and 40% RH. Reduced relay performance may result if storage or use environments significantly exceed these conditions. If high insulation resistance is required, Coto Technology recommends that relay storage, processing, and use environments are adequate to achieve the desired results. Relays should be stored in similar environmental conditions as other high reliability active and passive electronic components.

Proper storage of relays is also important to maintain solderability over an extended period of time. As with storage for electrical performance, relays should be stored similar environmental conditions as other high reliability active and passive electronic components. If stored properly, solderability should be maintained for at least the warranty period of the component.

Other Notes
Relays should be handled with care. Dropping or mishandling relays may result in damage that can contribute to a direct failure or, even worse, a latent field failure. If relays are dropped, Coto Technology recommends that they should be discarded.

Coto Technology does not recommend use of ultrasonic activated equipment with relays. The use of ultrasonic equipment may change the characteristics of the relay and can contribute to failure.

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TESTING REED SWITCHES AND RELAYS FOR RELIABILITY

A White Paper by Coto Technology

BACKGROUND

For many switching applications reed relays remain the best solution, particularly when small size, high electrical off-isolation, very low on-resistance and ability to withstand electrostatic discharge (ESD) are required features. Reed relays can also be the best answer to applications needing excellent radio-frequency performance, since their low electrical capacitance and tunable impedance enables devices capable of switching signals in the GHz range. However, reed relays are inevitably perceived as mechanical devices in an increasingly solid state world, and it is critically important to understand their reliability under field conditions. Knowing how many switching cycles they will last under different electrical load conditions is an important issue when deciding if a reed relay is the best application choice. A rigorous reliability testing program is therefore a vital tool for providing our customers with technical support, and also for continuously improving the quality of Coto's products.

What is reliability?

Reliability can be defined as the probability that a device or system will meet its product specification when called upon to do so. It can only be estimated, never determined exactly, and it can only be estimated by examining the failure rates of individual products taken from a representative sample. Obtaining these estimates requires the use of statistical analysis.

The reliability of a relay is best defined in terms of the number of cycles it can operate while meeting its specifications before it fails. Measures such as MTBF (mean time between failures) or MTTF (mean time to failure) are less useful, since the life of a relay is heavily dependent on how many switching cycles is has been subjected to, not simply how long it has been in service. The MCBF (mean cycles before failure) is a useful measure of reliability for relays, and that is one of the measures Coto Technology uses to estimate relay reliability.

However, estimating and publishing the MCBF for a relay does not show the full picture. How many samples were used to make the estimate? What were the electrical load conditions? What are the confidence limits for the MCBF? A more searching question from a relay user might be: "I don't have the luxury of running my relays until half of them fail so I can see how accurate your MCBF estimate was. How many cycles can I expect my relays to run until one in a thousand has failed, and what confidence do you have in this estimate?"

Properly designed and implemented, reliability testing can answer these kinds of questions, and many more. Is one type of relay significantly more reliable than another? Does this relay get more reliable as it gets older, or does it show wearout characteristics like people do? What failure rate can I expect for new relays just removed from the box? If a relay fails on a board that has 15 more, is it more cost effective to replace just the failed relay or all of them at the same time? Accurate estimates of reliability statistics allow those types of questions to be answered objectively rather than by the "seat of the pants."

What is a failure?

Reed switches or relays eventually fail in one of three ways. They do not open when they should (usually called "sticking"), they fail to close when they should ("missing"), or their static contact resistance gradually drifts up to an unacceptable level. At light loads, failure may not occur until several billion closure cycles have occurred. The first two listed mechanisms can be further subdivided into "soft" and "hard" failures. A soft failure is recorded when a switch is found to have missed or stuck a few milliseconds after coil activation or deactivation, but it is then found to have recovered from the problem when checked a short time (typically half a second) later. If recovery from the initial soft failure has not occurred by the time the second check is made, the failure is classified as permanent or "hard".

Miss and stick failures need to be defined in terms of the resistance recorded a certain time after causing the switch to close by activating the drive coil, or to open by de-activating the coil. A miss failure is called when the resistance is greater than a defined threshold when the switch is closed. Conversely, a stick failure occurs when the resistance is less than a defined threshold when the switch is opened. These threshold resistances and the measurement timing depend on the application. Coto typically uses one ohm for soft miss failures and half the contact load resistance for soft stick failures, measured one millisecond after drive coil activation and deactivation. These parameters are measured for each switch test cycle.

Since even one soft failure can be problematic in critical applications such as Automated Test Equipment (ATE), Coto records failures for "expected life" estimation as the **first, soft** failure due to sticking, missing or excessive contact resistance. This is a deliberately conservative criterion. Comparison with the reliability data published by other relay manufacturers is difficult, because they may have less stringent failure criteria or different ways of presenting statistical reliability data.

How can reliability be estimated?

The raw data for estimating the reliability of a reed relay is obtained by taking a representative set of samples and cycling them to failure, counting the number of cycles before they fail. Once this basic raw data has been obtained, it must be analyzed so that appropriate reliability statistics can be determined. The objective is to find a modeling function that closely fits the available data, and can used for interpolation or judicious extrapolation to find estimates of the MCBF and other reliability statistics.

Like many statistical estimates, the accuracy of the reliability prediction increases in proportion to the square of the number of samples; a reasonable and practical quantity of tested relays is 16 or 32 for routine testing. To get a reliability prediction, it is not necessary to test the relays until they all fail. The life test can be suspended after a certain proportion of relays have failed – generally the test should be run until at least 50% have failed. This type of data set is called "right-censored," and the information about the relays that survived after the test was suspended is useful and therefore not discarded. This can be understood intuitively; if 32 relays were tested to 100 million cycles and half survived, it's likely that the MCBF is at least 100 million. Estimating the MCBF from just the 16 failed relays would give a much lower estimate.

A widely accepted statistical distribution for modeling reliability data is the Weibull distribution.(1) Reference (2) is a useful guide to the application of Weibull analysis. Given a set of number of cycles to failure for a series of tested relays, the parameters of this distribution can be fitted to the failure data using least squares regression techniques. Generally (but not always) the predicted fit using the Weibull distribution is better than that obtained with other statistical distributions, leading to better estimates of reliability parameters. Two parameters are obtained - one is the Weibull scale parameter, from which the MCBF can easily be derived. This parameter is sometimes referred to by the Greek letter Eta (η) The second parameter is the Weibull slope, sometimes called the shape parameter or Weibull Beta (β). Once the Weibull regression parameters have been determined, the fitted equation can be used to predict parameters such as MCBF, expected life before 1% part failure, estimation of expected infant mortality and wearout characteristics, and other pertinent reliability data.

Though it might appear that running a 100 million cycle life test might take a very long time, accelerated life testing can be used. The rapid switching time of reed relays allows them to be cycled up to about 200Hz – thus, a 100 million cycle test would take 4.8 days to complete, and probably less if the test was suspended before all relays had failed.

Methods for deriving the Weibull parameters η and β are described in Appendix I. Subsequent estimation of the MCBF is also described.

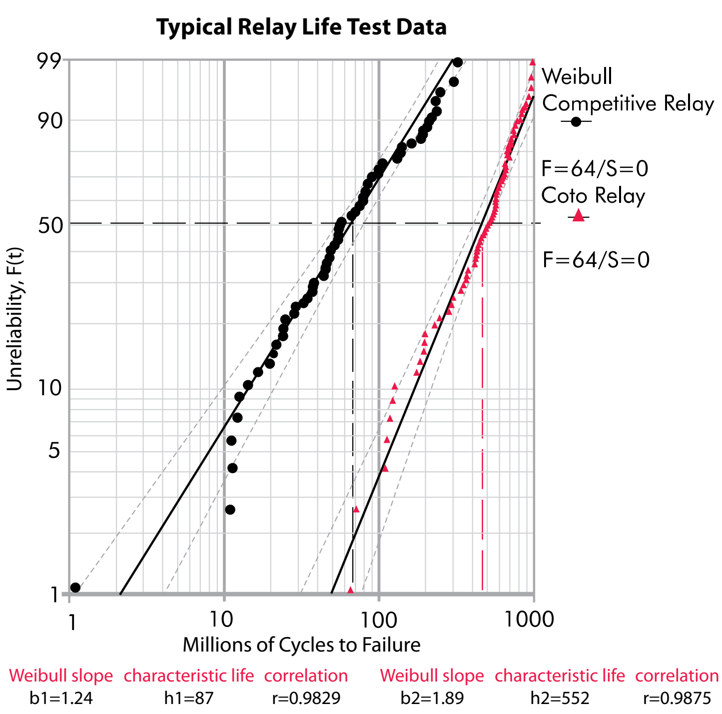
Relationship between reliability testing and parametric testing

Coto Technology runs up to twelve electrical tests on every relay and switch product that leave its factories. These non-destructive tests are referred to as "parametric" testing, since the measurement results are product parameters such as pull-in and drop-out voltage, static and dynamic contact resistance, opening and closure times etc. In contrast, reliability testing is generally destructive and takes a long time, and therefore can only be applied to representative samples of products. Products are tested at various current and voltage loads, including inrush current profiles where necessary. We frequently tailor these loads to our customers' special technical requirements. The sample sizes and the number of test cycles are chosen to allow an accurate assessment of MCBF and other reliability statistics – often involving sample sizes of 64 or 128 test parts and several billion test cycles over many weeks.

Typical example of life data analysis and interpretation

The Weibull regression plots shown In Figure 1 were generated from a life test of 64 Coto ATE-grade relays compared to an equal number of commercially available competitive parts. The test was run at 200 Hz, using a 5V, 10mA resistive load. It was continued until all 128 parts had failed at about one billion cycles and 55 days of continuous testing. The MCBF for each relay type can be approximately estimated from the intercept of each fitted reliability plot with the 50% unreliability ordinate, or more accurately determined by numerical methods described in Appendix I. The estimated MCBF for the competitive relay is 66 million cycles, compared to 450 million for the Coto relay. The dotted lines indicate the 90% confidence limits for each plot – since these do not overlap at any point, the parts clearly have significantly different reliability levels with a 90% confidence level. Another useful reliability statistic is the

Figure 1: Weibull Plots of Relay Life Test Data



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expected life before 1% failure; the plots show that estimated 1% life is between 1 and 4 million cycles for the competitive relay, compared to 30 to 70 million for the Coto relay. The explanation of this bigger reliability differential is the steeper slope of the Weibull plot for the Coto part, indicating a more pronounced wearout characteristic than the random failures exhibited by the competitor.

Since the cost to locate, remove and replace a failed relay can greatly exceed the actual purchase price of the part, steeper Weibull slopes and higher MCBF's mean lower maintenance and replacement costs, and fewer expensive "infant mortality" failures.

How not to lie with statistics – Publishing valid, useful life expectancy data

Misapplied statistics led to the English Prime Minister Benjamin Disraeli's famous quote: "There are three kinds of lies; lies, damned lies, and statistics." Certainly misapplied statistics can inadvertently lead to inflated estimates of reliability. Coto attempts to provide reliability data in an unbiased and accurate manner using industry-standard software tools.

In the Coto catalog, the "Expected Life" is synonymous with MCBF or mean cycles before failure. Since the confidence limits associated with MCBF estimates are usually quite broad, the life estimates are rounded to an appropriate number of significant figures to avoid implied over-accuracy. Relay reliability data are only given for 1V, 10mA or 1V, 1mA resistive loads. Switch life data is given at several different loads, depending on the application. Contact Coto Technology for life data at other loads. We have an extensive database of life test data, and may be able to predict reliability under other load conditions or set up a special life test meeting your requirements.

Demonstrating product reliability for a specific number of switching cycles

A different testing approach is possible if it is only necessary to estimate a relay's reliability after a certain number of switching cycles, rather than determining its MCBF. For example, let's assume we want to be able to say with 90% confidence that the reliability of a certain relay is at least 99% after 100 million cycles. In other words, we want reasonable assurance that less than 1% of relays will have failed by that number of cycles. It can be shown by re-arrangement of the Weibull equation that in this case, if 44 relays are put on test for 300 million cycles and they all survive, the 99% reliability requirement has been demonstrated with 90% confidence[1]. That test would take about 17 days at 200 Hz. Test time can be traded off against the number of tested relays; if the test was extended to 370 million cycles (22 days) and the number of test relays was reduced to 32, the required reliability would have been demonstrated if all 32 relays survived. This number of DUT's is convenient since it is the maximum number of relays a single Coto relay life test system can accommodate.

Failure rates and FIT rates

The MCBF can also be expressed as a failure rate; one is simply the reciprocal of the other. Thus, a relay with an MCBF of 250 million cycles has an average failure rate of 4.0E-09 failures per cycle. In other words, if the failure rate is constant, there's a chance of four in a billion that the relay will fail in any given switching cycle. However, relay failure rates are rarely constant; a mature product will have $\beta > 1$, and an increasing failure rate as it nears the end of its service life.

Since relay failure rates are usually very low, it is convenient to define a Failure-In-Time (FIT) rate as the number of failures that can be expected in one billion (10^9) cycles of operation. Note that FIT rates make the assumption that the failure rate is constant in time (i.e. Beta = 1). This is rarely the case, and the combination of Weibull η and β is a much more useful reliability metric.

THE RELIABILITY OF RELAY SYSTEMS

Estimating system reliability for equipment using multiple relays

Consider a system containing 2000 identical relays. The system fails if any one of the 2000 relays fails. There is no redundancy or backup in the system design. If the reliability of an individual relay is known, is it possible to estimate the most likely number of cycles before the system fails? The answer is yes, but the result may be surprising, especially for relays with low MCBF or shallow Beta slopes. This is a case where using an extremely high reliability relay is vital.

One approach to estimating the system reliability is to use Monte Carlo simulation. Referring to Appendix I, it can be seen that the unreliability of an individual relay is given by

$$F(t) = 1 - e^{-(t/\eta)^\beta} \qquad (1)$$

If t_r is the expected number of cycles to failure and η, β estimates are already available from life testing, random values of t_r can be generated from the expression

$$t_r = \eta\,(-\ln(RND))^{1/\beta} \qquad (2)$$

where RND is a random number uniformly distributed on the interval 0 - 1.

For a system with 2000 relays, computing t_r 2000 times and sorting to find the lowest value provides an estimate of when the system is

[1]An assumption of the Weibull Beta has to be made to use this testing method. In this example, a Beta value of 1.5 was assumed. Had the Beta value been higher, the number of tested relays would have been lower. For example, at Beta = 2, only 14 test relays would be needed.

most likely to fail (since we assume it fails when the first relay fails.) Repeating this simulation a large number of times allows a distribution of cycles to failure for multiple systems to be developed. The following table (Table 1) shows the results of such a simulation, for various values of η and β.

Number of System Cycles Before 1% of Systems Fail

ETA (Millions)	Beta				
	0.5	1	1.5	2	3.44
1000	0	4,335	295,883	2,299,897	31,781,920
500	0	2,717	232,301	1,171,054	14,759,612
250	0	1,117	70,223	620,461	6,868,718
100	0	619	28,872	225,721	2,578,993
50	0	253	19,092	98,634	1,435,337

Table 1. Estimated number of system cycles before 1% of systems fail, for various values of Weibull characteristic life (Eta) and shape parameter (Beta). Numbers are based on the simulation of one thousand systems, each containing 2000 relays, where one relay failure is assumed to cause a system failure.

A premium grade Coto reed relay can be expected to have a characteristic life of at least a billion cycles when switching low level electrical loads. It will also have a Weibull Beta between 1.5 and 4.0 It can be seen that for relays with a characteristic life of 1000 million (one billion) cycles, the estimated number of system cycles before 1% of systems fail is between about four thousand cycles for β =1.0, to almost 300 thousand cycles for β = 1.5 and over two million cycles for Beta = 2.0 Clearly, a small increase in β makes a very big difference to the expected system reliability. And since MCBF is highly correlated with the characteristic life η, the table also shows that specifying relay reliability based on MCBF alone is insufficient; it is important to specify both the MCBF (or characteristic life) AND the Weibull shape parameter β if meaningful estimates of system reliability are to be made.

Obviously not all systems are designed so that any one of a very large number of relays fail, the system goes down. Various strategies such as redundant design can reduce the potential problem. It's worth noting that redundancy based on parallel use of relays in critical locations may improve system reliability under some conditions. However, running relays in parallel in an attempt to increase load switching capacity is NOT a good strategy, since one relay always closes before the other, and the contacts of that relay bear the full switching load.

Simulating systems that have redundancy strategies or components (including relays) that have different levels of reliability is beyond the scope of this White Paper. Commercially available software such as BlockSim (from Reliasoft Inc.) is of great help in predicting the reliability of complex systems.

What Weibull Beta means

The astute reader may be wondering why a Beta value of 3.44 heads the last column of Table 1. It turns out that the Weibull distribution with Beta = 3.44 closely approximates the normal distribution with its familiar, symmetrical bell-shaped curve. The normal distribution can accurately model the failure rates of consumable items such as printer cartridges and incandescent light bulbs that wear out rapidly after a certain number of cycles. However, reed relays have more complex failure mechanisms than printer cartridges, and their Beta values are generally lower, in the range of 1.5 to 2. In other words, they exhibit wearout characteristics after a long period of stable life.

PREVENTIVE MAINTENANCE STRATEGIES

Is it best to replace relays individually when they fail, or replace them in groups on a preventive maintenance schedule whether they have failed or not? Reliability statistics allow an analytical approach to solving this problem, based on a concept called Cost Per Unit Time (CPUT) Minimization. This method takes into account both the costs of preventive maintenance (PM) and the cost of unplanned (unscheduled) maintenance, UM. It is widely accepted in the ATE industry that the cost of finding and repairing a failed relay in the field is between ten and one hundred times the cost of repairing it during line installation. Replacing a $5 relay when the failure is discovered during manufacturing test might cost $500 in the field. If that failed relay is mounted on a board with (say) 15 others, is it cost-effective to change all of them at the same time during a field repair, even though 15 out of 16 may have not failed? Perhaps surprisingly, the answer is often "yes".

In this example, let's set the PM cost as 16 relays * $5/relay = $80. Let us also assume that the cost of the UM to find and replace the one failed relay is $500. First, let's figure the reliability of the 16-unit board, regarding it as a system which is to be replaced when one or more individual relays fail. For a system that fails if one relay fails, it can be shown by manipulation of the Weibull distribution equation that the reliability after t cycles of a system containing n relays is:

$$R_s(t) = R_r(t)^n \qquad (3)$$

where $R_s(t)$ = system reliability at t cycles

$R_r(t)$ = individual relay reliability at t cycles

n = number of relays in system

The scale parameter (Eta) for the system can be determined from the scale parameter of the individual relays using the expression:

$$\eta_{system} = \frac{\eta_{relay}}{\sqrt[\beta]{n}} \qquad (4)$$

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From Equation (4), a 16-relay system using relays with a characteristic life (Eta) of 1000 million cycles and a Weibull Beta of 1.5 will have a characteristic life of 157 million cycles and a MCBF of 142 million cycles. The system Beta remains the same at 1.5.

Given these estimates for the Weibull parameters of the 16-relay system, we are almost ready to calculate the preventive maintenance period that minimizes the CPUT. To take an extreme example, let's first assume PM is performed every million system cycles and all the relays are replaced; in this case, the PM cost in that million cycles would be $80, plus an additional expectation for the small probability of an unscheduled failure costing $500. It turns out that CPUT would be $80.15 per million cycles. Clearly this would be an over-aggressive and uneconomical PM policy, though UM events would almost never occur. It would be equivalent to trading in a new Rolls-Royce when the ashtray was full. However, by calculating the CPUT for this example using increasing periods between PM, it can be shown that a distinct minimum CPUT of $2.89 occurs when the number of cycles between PM is set at 81 million In other words, this PM strategy costs $2.89 per million system cycles.

If it ain't broke, fix it

Now let's look at the expected maintenance costs if no PM is performed, and any individual relay is simply replaced when it fails. We know that the system MCBF is 142 million cycles, and we've estimated that the cost of unscheduled maintenance is $500 per event. The expected cost per million system cycles is therefore $500 / 142 = $3.52 per million cycles. In comparison, running the 81 million cycle PM strategy will save almost 25% in maintenance costs! Actually, the savings will be even higher, since every 81 million cycles a new system board with all-new relays is started, all of which have a period of stable life before they begin to wear out. On the other hand, when a UM replacement strategy is followed, a significant fraction of the un-replaced relays will be in the wear-out phase, and more likely to fail prematurely than the fresh relays replaced under the "replace them all" PM strategy.

Now consider a system board with 64 relays of the same type and cost. Assume that Weibull Beta is 2. The system characteristic life at Beta = 2 is 125 million cycles. Changing all the relays on a PM schedule costs $5 * 64 = $320. Assume the UM cost is $500 as before. In this case the optimum PM interval is 201 million cycles, with a CPUT of $4.42/million cycles. On the other hand, the CPUT for a UM strategy is $500/125 = $4.00/million cycles. In this case, it's less expensive just to repair individual relays when they fail. The Weibull Beta would need to be significantly higher before a PM strategy could show a cost benefit.

Effects of Weibull Beta on the PM strategy

Modest Beta values between 1.5 and 2.0 were used in the previous examples. The savings with a PM strategy can increase significantly for relays with a higher Beta. For the 16-relay system at a Beta of 2 for example, the minimum CPUT of $1.47/million cycles occurs for a PM interval of 112 million cycles. This represents a savings of ($1.47 - $3.52)/$3.52 = 58% over the UM ("fix 'em when they break") strategy. In this case, "if it ain't broke, don't fix it" is not a good idea. The CPUT is lower because the MCBF of the system is now about 250 million cycles, and the wearout curve is steeper, allowing a bigger interval between PM. This further illustrates the vital need for both the MCBF and the Weibull Beta to be reviewed when considering relay reliability. If a manufacturer does not publish both factors or make them available, a potential relay user should request them before selecting a product. A quality supplier will either have them on file, or be prepared to run a life test to demonstrate them.

Note that a PM strategy is not effective if the relay's Weibull Beta value is one or less. In this case failures are random or decreasing with time and there is no wearout characteristic. In this case the CPUT never shows a minimum, and there are no savings to be had by adopting a PM strategy. Fortunately, good quality relays never have Beta <= 1.

Preventive maintenance strategies – a summary

Sometimes, *"if it ain't broke, don't fix it"* is not a good strategy. For systems containing relatively small numbers of relays with Weibull Beta > 1, replacing ALL the relays on a preventative maintenance schedule can reduce costs compared to simply fixing individual relays when they fail. The breakeven point depends on the number of relays in the system, the Weibull Beta of the relays used, the estimated cost for relay replacement, and the estimated cost of fixing individual failed relays on an unscheduled basis. Coto is working on a comprehensive model that will allow relay users to carry out these calculations and devise an optimum PM strategy. The model will be the subject of a future White Paper.

A PRIORI PREDICTION OF RELAY RELIABILITY

The methods for predicting relay reliability that have been described so far are purely empirical, and rely on statistical estimates using representative samples of relays. But relays are relatively simple devices; is it possible to predict how long a relay will last in service, knowing how it is constructed and what electrical load it will be switching, based solely on the physics of the device? No-one has succeeded in doing this so far, despite the simplicity of a reed relay. As an example, consider the relationship between the life of a relay and the electrical load it switches. If an arc occurs on each switching cycle, one might expect that each arc might ablate a small amount of contact material from the contacts, until the contact eventually burns though and the switch fails. In fact, there is some evidence for this phenomenon occurring in reed relays switching relatively high voltages and currents, since the measured Weibull Beta values are usually high for this kind of load, approaching the 3.44 value typical of consumable items. Furthermore, testing at Coto has shown the MCBF of switches operating under high voltage, high current loads is roughly proportional to the thickness of the precious metal laid down on the contacts – supporting the consumable material model. However, extrapolation of life estimates to lower loads is very difficult. For example, the relationship between switch life and electrical load is not a simple monotonic function, even for switches in the same size class, with the same blade design, contact coating and amp-turn sensitivity. For example, the life of a reed relay switching a load of 5V, 10mA may be 100 times greater than the life at 12V 4mA, though the wattage switched is almost identical[2]. Such anomalies make prediction of life based on electrical load very difficult.

There is some evidence that parametric measurements made after a reed relay is manufactured can be used as predictors of relay life. For example, the amp-turn sensitivity of the reed switch is very strongly correlated with life – doubling the AT can triple the life, and tripling the AT can cause a twenty-times increase in life at certain loads. The reasons for these large improvements in life at higher AT are the larger switch gap, giving less probability of bridging, and the higher spring forces at higher AT, which tend to pull the switch blades apart when the coil current is released and the magnetic field decays. Pull-in to drop-our ratio is a related parameter; a high ratio indicates good "snap action", which also leads to enhanced contact life.

Other parametric measurements such as dynamic contact resistance (DCR, contact resistance measurements made while the relay contacts have just closed but are still vibrating) are predictors of ultimate relay reliability, but little has been published that establishes the degree of correlation. However Coto routinely measures the DCR of all relays it ships, since DCR is a valuable indicator of relay quality parameters such as contact cleanliness, hermetic seal integrity, the presence of internal stresses and the soundness of internal connections.

It has also been claimed that magnetostrictive twist measurements on new relays can predict eventual relay life. (3) Measurements of contact resistance are made close to the drop-out point, where interaction between the magnetic flux generated by the coil interacts with the flux generated by the contact load current. Proponents of this method claim that this interaction causes blade twisting, and that contact resistance measurements made in this manner are correlated with eventual contact failure. The relative value of this method compared to other dynamic measurement methods was subsequently disputed by Gusciora(4).

RELIABILITY AND REED CONTACT DESIGN

No subject in reed switch engineering is more controversial than switch contact design. What contact coating should be used? Ruthenium, rhodium, or iridium? Should it be electroplated or sputtered? What is the right coating thickness? How will the chosen coating handle inrush currents and other abusive loads? What layer structure should be used? Coto Technology has had many years experience in evaluating such issues. We are convinced that sputtered ruthenium coating is the best choice for most ATE applications. The hardness and high boiling point of ruthenium compared to other platinum group metals provides superb contact wear characteristics and resistance to sticking. Applying ruthenium by sputtering is a slower and more expensive process than the electrolytic plating commonly used by other reed switch manufacturers, but provides superior contact reliability by eliminating impurity inclusions.

These qualities have been demonstrated by controlled side-by-side testing of Coto reed switches against those manufactured by our competitors. A recent independent study supports these conclusions. Oshiyama et. al.(5) found that metal transfer under hot switching conditions was the principal cause of sticking failures, and that switches with ruthenium contacts were seven times less prone to this effect than switches having rhodium contacts.

RELAY TESTING SYSTEMS

Relay life testing systems have unique requirements, including the need to be more reliable than the devices they are testing. Because of the unique requirements of reed relay life testing systems, Coto Technology designed and built its first custom designed life tester in the 1980's and has since upgraded the system several times. Coto now has six testers, designated the Coto System 300, installed at its corporate HQ in Rhode Island USA, and at its production facility in Mexicali, Mexico. (Fig 2)

Fig 2. Coto Technology System 300 Relay Life Test System

Each system has 32 test channels capable of testing reed switches at loads that can be varied from 0.03V, 1mA (30 microwatts) to 60V, 1A (60 watts). Auxiliary driver modules allow loads up to 150V, 10A

[2]It is believed that the 12V load causes molten precious metal "whiskers" to form by electrostatic pulling forces. These eventually bridge the switch gap and cause sticking, since the 4mA current is too weak to burn away the whiskers. However at 5V, 10mA, the electrostatic forces are lower (causing less whiskering), and the higher current can burn away any whiskers that do form.

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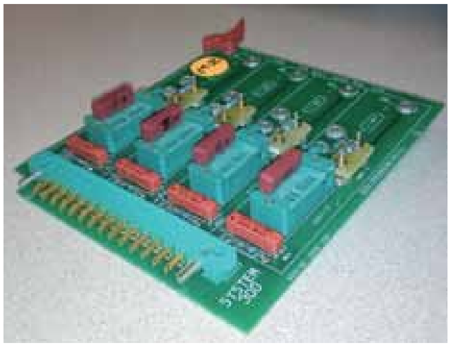
(1500 watts) or 1000V, 10mA (10 watts) to be used. Modular plug-in load cards enable resistive, capacitive, inductive or hybrid loads to be set up. (Fig 3)

The test cycle frequency is typically set at 200 Hz or an optional sweep over a 10 Hz to 255 Hz range. Soft sticks and misses are tested on every switching cycle – if either is detected, the system waits for 0.5s and checks if a failure is still present, and registers a hard stick or miss if it is. In addition, parametric measurements of contact resistance are made at programmed intervals; these can be plotted later for evaluation of contact resistance degradation during the completed life test.

Fig 3. System 300 Life Test System Load Card.



The recorded life data is exported in Microsoft Excel format for subsequent processing of the reliability statistics using a commercial reliability software program.

Coto also has specialized life test equipment that can test individual relays with HF loads over a 20KHz to 1 MHz frequency range, at loads up to 300V, 6A. Such relays are typically used in broadcasting and medical equipment. Coto's environmental test chamber also allows life tests to be run between -40 and +150 degrees C in either static or cyclic temperature modes.

GETTING THE HIGHEST RELIABILITY FROM YOUR REED RELAYS

You've decided on a reed relay solution for your next switching project, and selected what appears to be a suitable Coto product. The Applications Engineer at Coto has reviewed your proposed use and confirmed you have made the most appropriate choice. What can you do during the design-in process to ensure you get the maximum reliability? Here are a few tips.

1. Cold switch if possible
It's not always practical, but if you can design your system so the relays only switch when the current is off, the relay life will be greatly extended.

2. Avoid reactive loads
Reed relays are most reliable when switching resistive loads. Heavy inrush currents from capacitive circuits can cause premature contact failure or even contact welding, and inductive loads can cause excessive arcing on break. Contact Coto for technical advice if you expect to be switching a reactive load.

3. Maintain Overdrive
A relay with a nominal coil voltage of 5V will typically have a listed "must operate by" operate voltage of 3.8V. Try to ensure that the voltage applied to the coil is at least 25% higher, i.e. 4.75V. This overdrive of 25% will ensure that the relay contacts are firmly closed, enhancing the relay's life.

4. Magnetic interaction
If relays are to be stacked closely together on a PCB, ensure that they are oriented to minimize magnetic interaction that can increase the effective operate voltage of the relay, reducing the effective overdrive. Typically this means orienting the relays with opposing polarity. Consult the Coto catalog for optimum layout patterns.

5. Use a relay with a ferrous metal shell
Many Coto relays are offered with a ferrous metal shell that minimizes magnetic interaction and maintains maximum overdrive. Select a relay with a shell if possible.

6. Keep the operating temperature low
The coil resistance of a reed relay increases by 0.39% for every degree Celsius increase. Assuming you are using a constant voltage coil supply, a 50 degree C increase causes a 20% increase in coil resistance, and a corresponding 15% reduction in the power supplied to the coil. This reduces the overdrive, and could reduce the relay's life.

7. Maintain coil voltage after relay closure
Avoid using relay driver IC's that allow the coil voltage to be lowered after the relay closes to save power (or simply turn the programmed reduction off.). Most small reed relays don't have enough differential between pull-in and drop-out voltages to maintain adequate overdrive this way, and relay life may suffer.

8. Use an independent power supply for the relay coils
Relay coils are inductive, and may send potentially damaging spikes down power lines. It's good design practice to provide an independent PSU for the relay coils. Consider external diode inductive spike suppression for all relays that do not have built-in diodes.

9. Program an occasional exercise cycle (Form C relays)
Form C reed relays that are only activated occasionally spend a lot of time with the normally-closed contact shut. This can sometimes lead to contact sluggishness when the relay is first activated, or on

rare occasions the relay may remain stuck in the normally-closed position. Programming an occasional burst of relay operations can greatly alleviate this problem.

APPENDIX I

The Weibull Distribution and Methods For Calculating Its Parameters

This distribution is widely described in the reliability literature. The number of cycles to failure for a sample of relays or switches is fitted by least-squares techniques using the two-parameter Weibull distribution function F(t), where

$$F(t) = 1 - e^{-(t/\eta)^\wedge\beta} \qquad \text{(A1)}$$

Here, F(t) is the unreliability function, t = time or cycles to failure, η and β are the Weibull distribution parameters.

This equation can be linearized using the transformations:

$$y = \log_e(\log_e(1/(1-F(t)))) \qquad \text{(A2)}$$

$$x = \log_e(t) \qquad \text{(A3)}$$

After linear regression of x on y, the slope of the regression line = β and the intercept = β $\log_e(\eta)$.[1]

Given a set of cycles to failure for a particular sample of relays, F(t) values can be calculated with Benard's approximation for median ranks:

$$F(t) = (j - 0.3) / (N + 0.4) \qquad \text{(A4)}$$

where j = the rank order number for the failure and N = total number of failures. Special precautions are taken to deal with censored data from parts that survive the test without failure.

The product's MCBF and its confidence limits are then calculated from the fitted Weibull parameters η and β. The parameter η (eta) is the characteristic life, or life for 63.2% failure. The Weibull slope parameter β is particularly useful, since its magnitude relates to the wearout characteristics of the product being tested. A value of β < 1 indicates "infant mortality" failures, that can potentially be reduced by manufacturing improvements, or screened out by burn-in testing. Values of β > 1 are more desirable, since they indicate a normal mechanism of wearout after a stable period of reliable operation. Typical values of β for reed relays are usually in the range of 1.5 to 4.0

The regression equation described above can be fitted with general purpose spreadsheet software such as Microsoft Excel. However, treatment of data sets with censored data is not straightforward. Commercially available software packages such as Reliasoft Weibull++ (6) or Minitab (7) greatly simplify the calculations, and also have built in capability for calculating supplementary parameters such as confidence limits.

Fig. A1: Computation of the Gamma Function (From Abramowitz & Stegun, *Handbook of Mathematical Functions (8)*)

Series Expansion[2] for 1/r(z)	
6.1.34	$\frac{1}{\Gamma(z)} = \sum_{k=1}^{\infty} c_k z^k \qquad (\lvert z \rvert < \infty)$
k	***C_k***
1	1. 00000 00000 000000
2	0. 57721 56649 015329
3	−0. 65587 80715 202538
4	−0. 04200 26350 340952
5	0. 16653 86113 822915
6	−0. 04219 77345 555443
7	−0. 00962 19715 278770
8	0. 00721 89432 466630
9	−0. 00116 51675 918591
10	−0. 00021 52416 741149
11	0. 00012 80502 823882
12	−0. 00002 01348 547807
13	−0. 00000 12504 934821
14	0. 00000 11330 272320
15	−0. 00000 02056 338417
16	0. 00000 00061 160950
17	0. 00000 00050 020075
18	−0. 00000 00011 812746
19	0. 00000 00001 043427
20	0. 00000 00000 077823
21	−0. 00000 00000 036968
22	0. 00000 00000 005100
23	−0. 00000 00000 000206
24	−0. 00000 00000 000054
25	0. 00000 00000 000014
26	0. 00000 00000 000001

Figure A1: Computation of the gamma function (From Abramowitz and Stegun, Handbook of Mathematical Functions (8).

[1]Since the errors on time-to-failure are greater than those of the unreliability estimates, it is common practice to assign the log transform of time-to-failure as the dependent variable, and regress x on y rather than the more familiar y-on-x. Other methods such as Maximum Likelihood Estimation (MLE) can also be used to estimate the Weibull regression parameters. Details are covered in the Reliasoft Weibull++ software documentation (6) and the Minitab documentation (7)

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Calculation of MCBF from the Weibull Scale Parameter η and slope β

The MCBF can be calculated (Ref. 2, page 4) from the expression:

$$MCBF = \eta\Gamma(1 + 1/\beta) \qquad (A5)$$

Where $\Gamma(z)$ is the gamma function. This function is available in tables or can easily be calculated in a spreadsheet using the series expansion shown in Figure A1.[2] The Reliasoft Weibull++ software has a MCBF calculator that simplifies this operation.

REFERENCES:

(1) Weibull, W, *"A Statistical Distribution of Wide Applicability"*, J. Appl. Mech.18:293-297 (1951)

(2) Dodson, B, *Weibull Analysis*, Milwaukee WI: American Society for Quality, 1994 (ISBN 0-07389-295-X)

(3) Sutherland, E. F., *"Predicting Early Failure of Dry Reed Contacts"*, Proc. 25th Annual Relay Conference, Oklahoma State University, April 26/27, 1977

(4) Gusciora, R. H., *"A Statistical Study of Contact Attributes and Reed Relay Life,"* Proc. 27th Annual Relay Conference, Oklahoma State University, April 24/25, 1979

(5) Oshiyama, Y., M. Fukushima and F. Katada, *"Life Time Diagnosis of Reed Relays Operated Under Hot Conditions."* Proceedings of the 50th Int'l Relay Conference, Newport Beach, Ca., USA, April 14-17, 2003. pp 4/1 – 4/5

(6) Reliasoft Weibull++ Version 7 (Reliability Statistics Software). Tucson AZ: Reliasoft Corporation. www.reliasoft.com

(7) Minitab Version 15 for Microsoft Windows (Statistical Software). State College PA: Minitab Inc. www.minitab.com

(8) Abramowitz, Milton; Stegun, Irene A., eds. (1972), *Handbook of Mathematical Functions with Formulas, Graphs, and Mathematical Tables,* New York: Dover Publications, ISBN 978-0-486-61272-0

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DISCLAIMER

[2]The numerical method described by Dodson (Ref. 2 page 185) is incorrect. Instead, the series expansion shown in Abramowitz and Stegun (Fig. A1) may be used to estimate Γ.


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