# RF Characteristics of Electromechanical Relays

## RF Measurements of E-M Relays

Electromechanical relays can be built with high frequency RF characteristics that allow them to pass and switch signals in the 7G Hz range and beyond with the proper packaging. Two key RF parameters are the insertion loss and return loss. These parameters measure how much of the RF power passes through the relay when the contacts are closed and how much is reflected back to the source. RF relays are built with a specific characteristic impedance to match the application, and an impedance of 50 Ohms is typical.

Insertion loss is a measure of the power being transmitted through the relay. This parameter is typically measured in dB and is calculated as follows.

$$IL(dB) = -10\log\left(\frac{Pout}{Pin}\right)$$

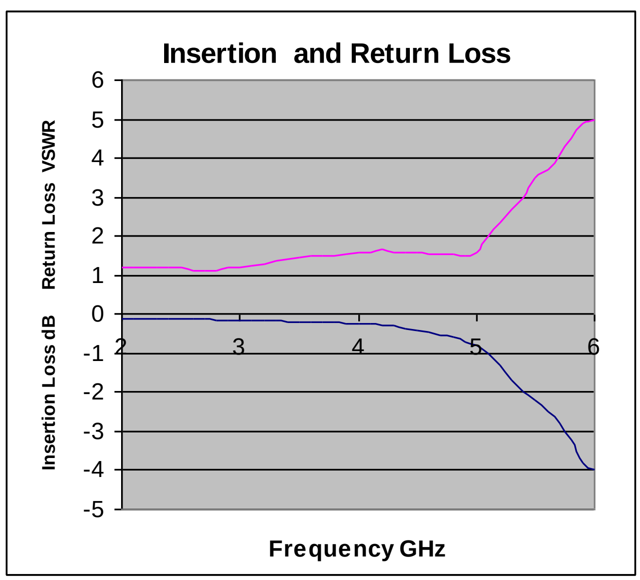
A point of particular interest is the -3 dB point, which is the frequency where only 50% of the power is being transmitted through the relay. This point usually defines the maximum usable application frequency range for the relay.

Return loss is the amount of power being reflected back to the source. For an ideal relay, if the characteristic impedance was matched to the transmission line and the output was terminated to this impedance, the reflected power would be very small across the frequency range. The return loss can be specified by the Voltage Standing Wave Ratio (VSWR). The VSWR is the measurement of the portion of the incoming signal that is reflected back to the source. The relationship between the return loss expressed as VSWR or dB is reflected by the following equation.

$$RL(dB) = -20\log\left(\frac{VSWR-1}{VSWR+1}\right)$$

For an ideal network, the VSWR would be close to 1 and the return loss in dB would be as high as possible (> 20 dB). Figure 1 shows an insertion and return loss diagram for a microminiature RF reed relay mounted in a gullwing SMD package. The insertion loss is shown on the lower plot line and is represented in dBs. It can be seen that for this particular example the –3 dB roll-off frequency is approximately 5.7G Hz. The return loss is represented by the top line and is shown as VSWR.

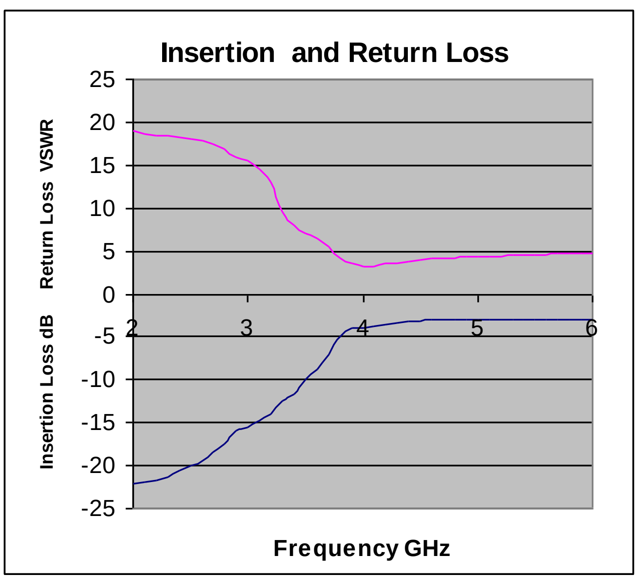
**Figure 1: Insertion and Return Loss Plot**



Another measure of the RF performance of a relay is its isolation. This is measured with the relay contacts open. At low frequencies, none of the incoming signal would pass through the relay and the isolation would be high (>20 dB). However, at higher frequencies, a portion of the incoming signal would pass through due to the capacitance across the open contacts. Typically, armature relays can be built with better isolation at high frequencies, since the contacts can be built with wider spacing than reed relays and the resulting lower capacitance.

The insertion and return loss are shown in figure 2 for a microminiature RF reed relay with open contacts. From the plot it can be seen that the insertion loss is high, approximately -22 dB at 2G Hz, but drops off to approximately –3 dB for frequencies over 4G Hz. This relay is passing half of the input power to the output for frequencies above 4G Hz. The return loss VSWR is also high at approximately 18 at 2G Hz, but drops to approximately 5 for frequencies over 4G Hz. This translates to about 3.5 dB, or again half of the power is being reflected back to the source and half is passing through the relay. The usable upper frequency for this relay would be approximately 3G Hz due to this isolation performance.

**Figure 2: Open Contact Insertion/Return Loss**




Another measurement of the relay's RF performance is the rise time for the output signal to rise from 10% to 90% of its final value. This time can be approximated by the following equation.

$$T_r = RC * \ln\left(\frac{90\%}{10\%}\right) = 2.2 * RC$$

The 3dB (50% power) roll-off frequency is defined by the following equation.

$$f_{-3dB} = \left(\frac{1}{2\pi RC}\right)$$

Now an equation, which ties the rise time to the 3 dB frequency, can be derived from the two preceding equations.

$$T_r = \left(\frac{0.35}{f_{-3dB}}\right)$$

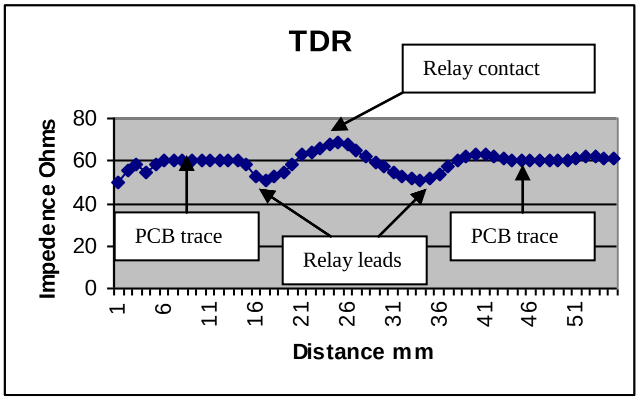
With this equation the rise time can be approximated from the insertion loss plot by dividing the –3 dB roll-off frequency into 0.35.

## Importance of Set Up and Packaging

For the higher RF frequency ranges (above 2G Hz to 3 G Hz) the package selected and the PCB environment are of significant importance. The key is to match the transmission line impedance from the application PCB through the relay package leads and through the relay contacts. Any discontinuities throughout this path would result in reflection of the incoming signal and losses to the output. The higher the frequency of operation the more important is the impedance match for the signal path. This path prefers to be in a straight line without sharp turns. Turns provide discontinuities that result in either peaks or valleys in the characteristic impedance throughout the signal path.

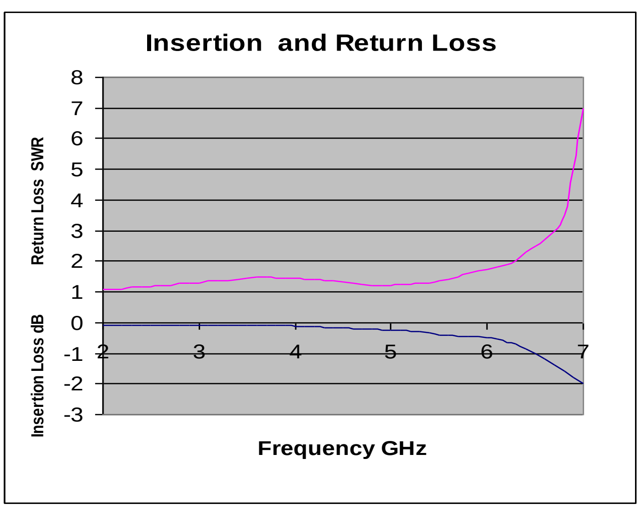
An important tool for analyzing the signal path is the Time Domain Reflectometer (TDR). This instrument sends a high frequency, fast rise time pulse into the RF system and measures the time and amplitude of the return signal. The TDR plot provides a representation of the impedance through the signal path. Figure 3 shows a TDR plot of one of the RF reed relays from this study. On this plot the impedance of the PCB trace is shown, along with the discontinuities through the relay lead and through the relay contacts. These discontinuities result in higher insertion losses and higher return losses. The ideal TDR plot would be a straight line at the desired characteristic impedance.

**Figure 3: Example TDR Plot**




The relay package has a large impact upon the RF characteristics of the device. Surface Mount Device (SMD) packages offer better performance than through-hole packages. The leadless and axial packages offer the overall best performance and highest bandwidths. Figure 1 shows the insertion and return losses for a gullwing SMD relay. The performance of a similar device mounted in a leadless ceramic package is shown is figure 4.

**Figure 4: Leadless SMD Mounted Reed Relay**




The –3 dB roll-off points between the gullwing device shown in figure 1 and the SMD leadless device shown is figure 3 are approximately 7.5G Hz and 5.7G Hz. The rise times of the leadless SMD and the gullwing device are calculated at 47 picoseconds and 61 picoseconds respectively. This improved RF performance for the leadless device is generally due to the improved signal path through the relay.

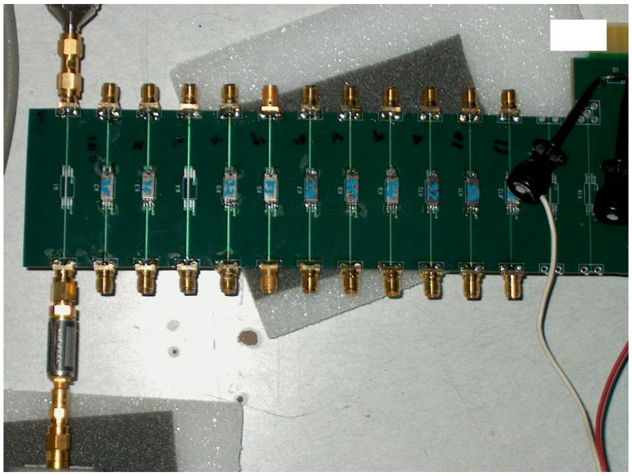
## Aging Effects on RF Performance

Normally, as relays are switched for many millions of cycles the contact resistance will start to degrade to a point of failure. For low-frequency applications, failures are typically defined as a point where the contact resistance has increased to some high resistance. For most small reed relays, the contact resistance is typically in the range of 50 milliohms for a new relay. A life-test failure is generally defined as the point when the contact resistance exceeds 1 Ohm.

An experiment was set up with 10 micro-miniature surface-mount gullwing reed relays mounted on a PCB. A picture of this PCB is shown in figure 5. The PCB had a ground plane with the trace width designed for 50-Ohm impedance. Side mount SMA connectors were used in order to keep the signal path a straight line from input to output. The relays and PCB were characterized using a TDR, and the insertion loss and return loss were measured before the relays were aged. The relays analyzed in this study all had characteristic impedances at the contacts of approximately 70 Ohms, not the ideal 50 Ohms as advertised.

To accelerate the aging, the relays switched a 10 Volt 10 mA resistive load for up to 300 million cycles. The insertion and return loss were measured at incremental points as the relays aged. A total of 4 relays failed during this life test, with contact resistances over 1 Ohm. The first failure occurred by 250M cycles, with a contact resistance of 1.6 Ohms. The remaining three failures occurred by 300M cycles, with contact resistance readings of 1.6 Ohms, 1.1 Ohms, and 1.9 Ohms. There were no appreciable changes in the TDR, the insertion loss, or the return loss measurements for any of the devices that failed the standard life test. All of the relays had almost identical RF readings before and after the life test.

**Figure 5: Test PCB**



## Conclusion and Recommendations

A range of RF relays is available, depending upon the application. An important aspect of the high frequency operation is the relay package and pin configuration. The highest speed operations can be achieved with surface mount packages that minimize the lead direction discontinuities. The J-lead and gullwing configurations are superior to the standard through hole. However, for the highest frequency operation, either leadless surface mount packages or axial lead packages offer the best performance since signal path discontinuities are minimized.

The ability of the relays in this study to effectively transmit the RF signals (from the insertion and return loss measurements) over the frequency range was not altered as the relays were aged. The contact resistance could increase by over an order of magnitude without altering the characteristic impedance of the relay or its insertion and return loss characteristics over the frequency spectrum. The implication of these results is that a RF relay should be capable of delivering a total number of life cycles equivalent to its mechanical performance for most low-level RF switching applications.

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