A NEW GENERATION OF RF SWITCHING MATRIX FOR SPACE APPLICATIONS

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ABSTRACT

Teledyne is the original inventor of the TO-5 electromechanical relay. The high reliability, magnetic latching version of the TO-5 electromechanical relay (Teledyne 422 series) has been in space and satellite applications for over thirty years. Thirty years ago Teledyne also developed, and began manufacturing, high reliability connectorized coaxial switches for space and satellite applications. Approximately fifteen years ago Teledyne introduced a new generation of small outline radio frequency (RF) relays for use in applications from dc to 6 GHz. In recent years Teledyne has developed a new RF switch matrix product line using coaxial switches and small outline electromechanical relays with embedded electronics to provide remote control. Combining the technical expertise and experience in these areas Teledyne is developing RF relay matrices for space applications using small outline RF relays. The RF relay matrix can be used to replace the functions of a single coaxial transfer switch (also known as a C-Switch), T-Switch, or groups thereof. The primary advantage of the RF relay matrix is reduced mass and size when compared against traditional coaxial switches or other coaxial switch matrix schemes.

INTRODUCTION

The purpose of this paper is to explore the use of small outline electromechanical relays to build multi-path switching structures that can replace traditional coaxial switches in high reliability applications. Coaxial switches provide extremely wide bandwidth with excellent insertion loss performance but are heavy, large, and require additional coaxial cables for interconnections. In applications where weight is at a premium, especially in space based communication systems, matrices of small electromechanical switches, such at the TO-5 form factor relay, are a fraction of the weight of coaxial switches and can simplify interconnection by using printed circuit board (PCB) transmission lines for interconnections and redundant paths. While the bandwidth of small electromechanical relays is much smaller than coaxial switches, most communication systems are narrow band in nature and can realize the savings in weight, cost, and footprint size while still meeting radio frequency (RF) performance requirements.

For this study two different switching architectures were laid out on high performance RF laminate PCB: a four port transfer switch and a four port t-switch. These two switches, along with the simple single-pole double-throw (SPDT) configuration, represent that majority of coaxial switches used in space borne applications.

TEST SWITCH ARCHITECTURE AND COMPARISON BETWEEN COAXIAL SWITCHES

A transfer switch consists of four ports arranged to connect in two distinct states: port 1 to port 2 and port 3 to port 4 concurrently or port 1 to port 3 and port 2 to port 4 concurrently. Fig. 1 outlines a traditional transfer switch and Fig. 2 details the same switching scheme implemented as two double-pole double-throw (DPDT) relays.

A t-switch also consists of four ports, but is arranged to connect in three states. This allows the same two states as the transfer switch with the addition of a third state where port 1 to port 4 and port 2 to port 3 are connected concurrently. Fig. 3 outlines the traditional t-switch and Fig.4 is same switching architecture implemented as four DPDT relays.

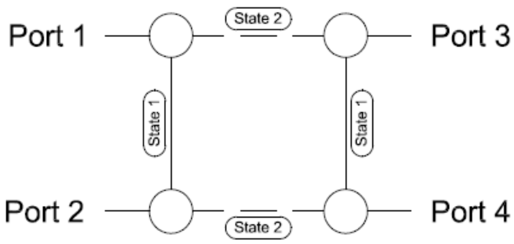

Fig. 1. Traditional Transfer Switch Architecture

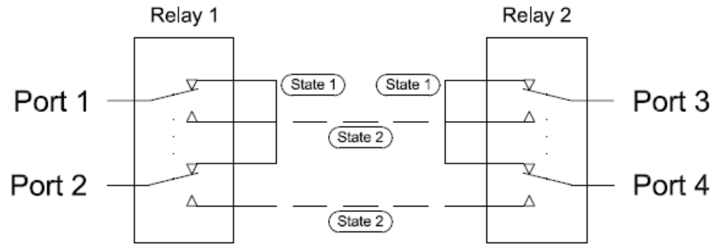

Fig. 2. Transfer Switch Implementation with Two DPDT Relays

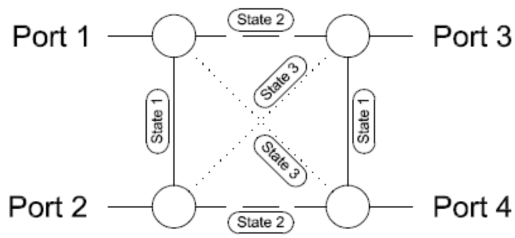

Fig. 3. Traditional T-Switch Architecture

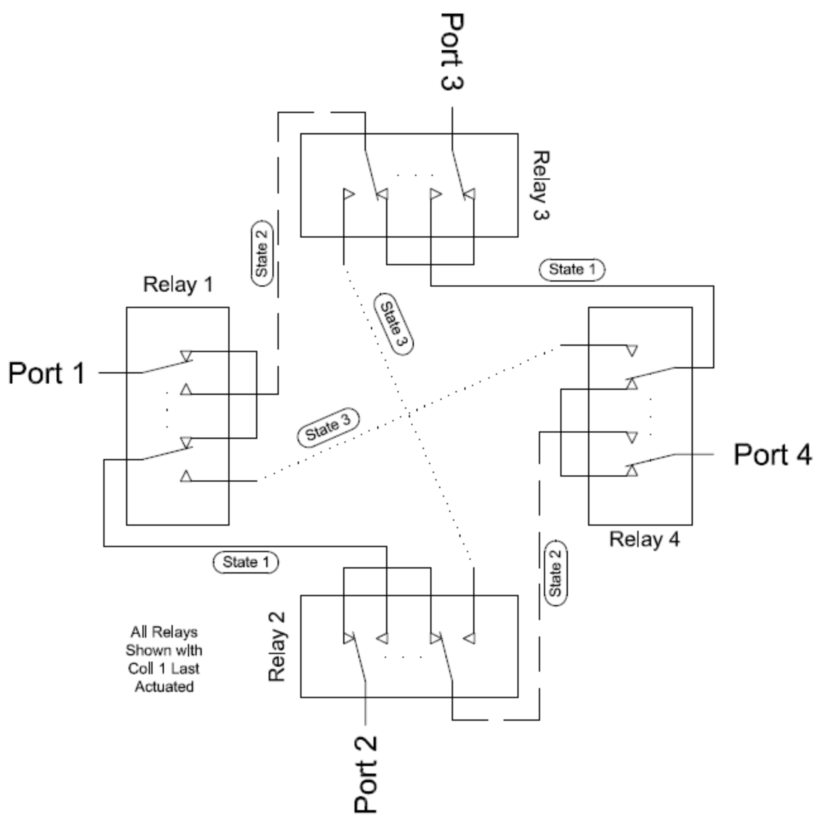

Fig. 4. T-Switch Implementation with Four DPDT Relays

The weight of a typical transfer switch is approximately 70 grams while the transfer switch structure used for this demonstration without the stainless steel connectors used for characterization is only 8.22 grams (46.78 grams with the weight of the connectors). The overall size of the transfer switch matrix is 4 cm long by 6 cm wide and less than 1.5 cm tall. The size of a typical coaxial transfer switch is 3.5 cm square and over 5 cm tall. Similarly, the weight of a typical t-switch is also approximately 70 grams while the t-switch matrix without the characterization connectors weighs only 13.32 grams (52.16 grams with connectors). The t-switch matrix is 7 cm square and less than 1.5 cm tall while a coaxial t-switch is approximately 4 cm in diameter and over 5 cm tall.

The power requirements for a typical coaxial switch are much larger than an electromechanical relay matrix. For a 28 V transfer switch the actuation current is 60 mA nominal. To drive both of the relays in the transfer switch matrix at 28V the total current would be 26 mA nominal. Typical operating current at 28 V for a coaxial t-switch is greater than 100 mA. For all four TO-5 relays used in the t-switch matrix, the current requirement would be 54 mA nominal. The latching time for these small outline relays is about half as long as the coaxial switches, allowing for a shorter duration pulse for much less total power draw.

SWITCH LAYOUT AND DESIGN CONCEPTS

For both of the circuits in this study, Teledyne Relays' RF342 was chosen for its RF performance, DPDT configuration, and latching actuation. A latching actuator consists of two separate coils and a permanent magnet that allows for a very short pulse of coil voltage to "latch" each relay in the required state, even when voltage is removed. These relays use less power than a coaxial type switch, which has a much larger moving armature mass, and therefore requires more actuation power.

Both circuits were designed for a simple three layer PCB utilizing Rogers 4350B RF laminate material with 1 ounce copper for outer layers and 0.5 ounce copper for the inner layer. The top and bottom layers are both signal layers with the inner layer providing an RF ground plane for the grounded coplanar waveguide coaxial transmission line structure used.

For the purpose of this demonstration, the lead wires for relay coils are brought out to stubs of wire that allow for voltage application with a clip lead during bench testing. Fig. 5 and Fig. 6 are photographs of the transfer switch matrix and t-switch matrix, respectively. For production flight units an additional RF ground layer and an inner signal layer can be easily added to bring coil leads together into a multi-pin dc connector typical of current coaxial switches without impact to overall cost. Fig. 7 is a 3D model of a conceptual packaged including a micro subminiature D type connector. High performance SMA edge launch connectors are used to characterize the RF performance of these two demonstration models.

By pulsing the correct combination of relay coils, users can put the transfer switch matrix into one of its two states or the t-switch matrix into one of its three states. For the purpose of this evaluation 5 volt relays were used, but Teledyne Relays offers small outline electromechanical relays in various voltages to suit any bus power requirement. The connection truth tables are given for both designs in Fig. 8 and Fig. 9.

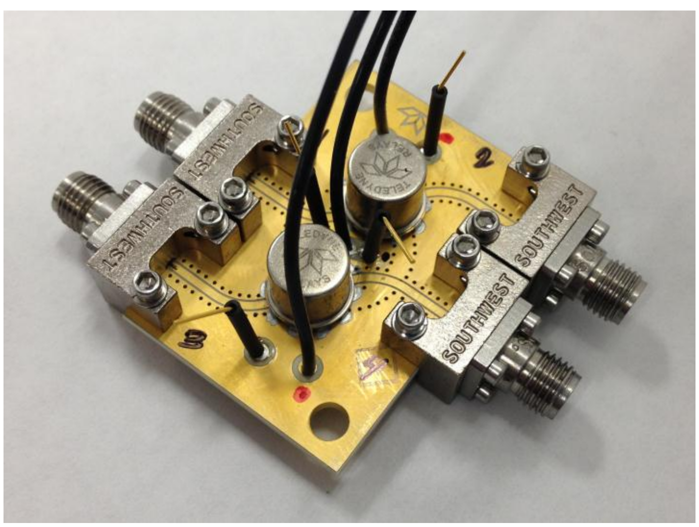

Fig. 5. Transfer Switch Relay Matrix Photograph

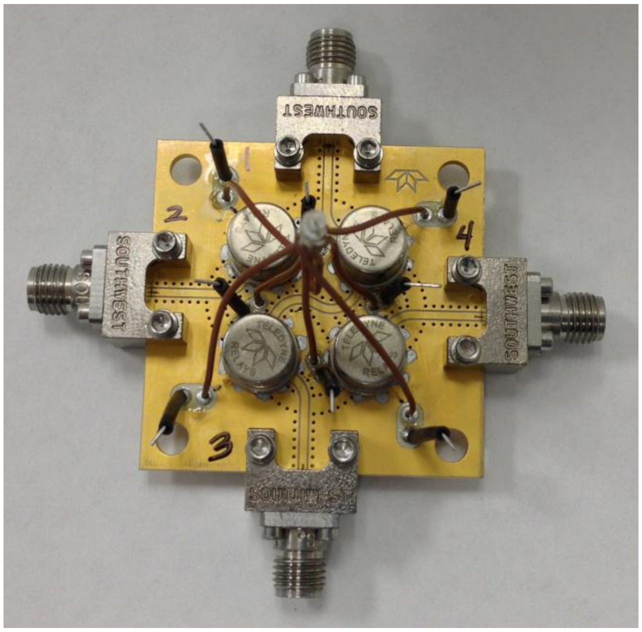

Fig. 6. T-Switch Relay Matrix Photograph

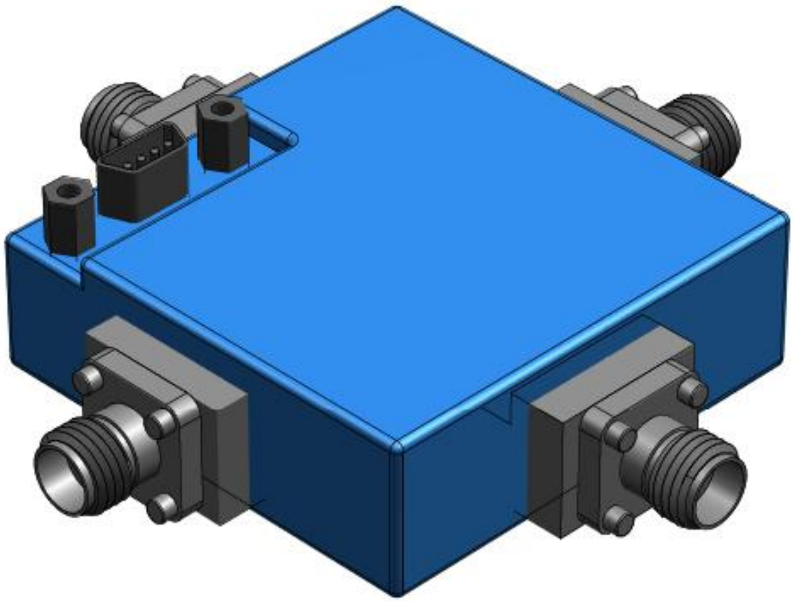

Fig. 7. Conceptual Drawing of Packaged Relay Matrix with D-Sub Connector

Fig. 8. Transfer Switch Matrix Connection Truth Table

	State 1	**State 2**
Relay 1	5 V on Coil A (Pin 4)	5 V on Coil B (Pin 9)
Relay 2	5 V on Coil A (Pin 4)	5 V on Coil B (Pin 9)

Fig. 9. T-Switch Matrix Connection Truth Table

	State 1	**State 2**	**State 3**	**No Paths Connected**
Relay 1	5 V on Coil B (Pin 9)	5 V on Coil B (Pin 9)	5 V on Coil A (Pin 4)	5 V on Coil A (Pin 4)
Relay 2	5 V on Coil A (Pin 4)	5 V on Coil B (Pin 9)	5 V on Coil B (Pin 9)	5 V on Coil A (Pin 4)
Relay 3	5 V on Coil B (Pin 9)	5 V on Coil B (Pin 9)	5 V on Coil A (Pin 4)	5 V on Coil A (Pin 4)
Relay 4	5 V on Coil A (Pin 4)	5 V on Coil B (Pin 9)	5 V on Coil B (Pin 9)	5 V on Coil A (Pin 4)

RF TEST DATA

The RF measurements were made using an Agilent PNA Model N5230C calibrated using an Agilent eCal module from 50 MHz to 6 GHz. In all of the measurements made, the effects of the connectors and end launches are included to demonstrate the actual connector to connector performance that is achievable. Fig. 10 shows the Insertion Loss measurements of the transfer switch matrix and of the t-switch matrix. For the transfer switch matrix, it has monotonic loss up to 4.25 GHz with insertion loss less than 1 dB up to 3 GHz. For the t-switch matrix the signal paths with three sets of relay contacts in series are less than 1.4 dB of insertion loss up to 3 GHz. For the signal path which has four relay contacts in series, it is less than 1.8 dB loss to 3 GHz.

The VSWR performances of all signal paths for both transfer switch matrix and t-switch matrix are shown in Fig. 11. All paths have VSWR performance under 1.22:1 up to 3 GHz and exhibit good performance up to between 4 and 5 GHz. Isolation measurements of all transfer and t-switch matrix paths are shown in Fig. 12. All isolation measurements are greater than 40 dB up to 2 GHz and greater than 30 dB of isolation up to 3 GHz. The overall isolation performance up to 4 GHz to 5 GHz is greater than 20 dB of isolation.

The RF Power handling capabilities of the RF342 relays have been also been characterized by Teledyne Relays for hot switching and carry only loads. The RF power across the frequency range that the RF342 relays can withstand is charted in Fig. 13.

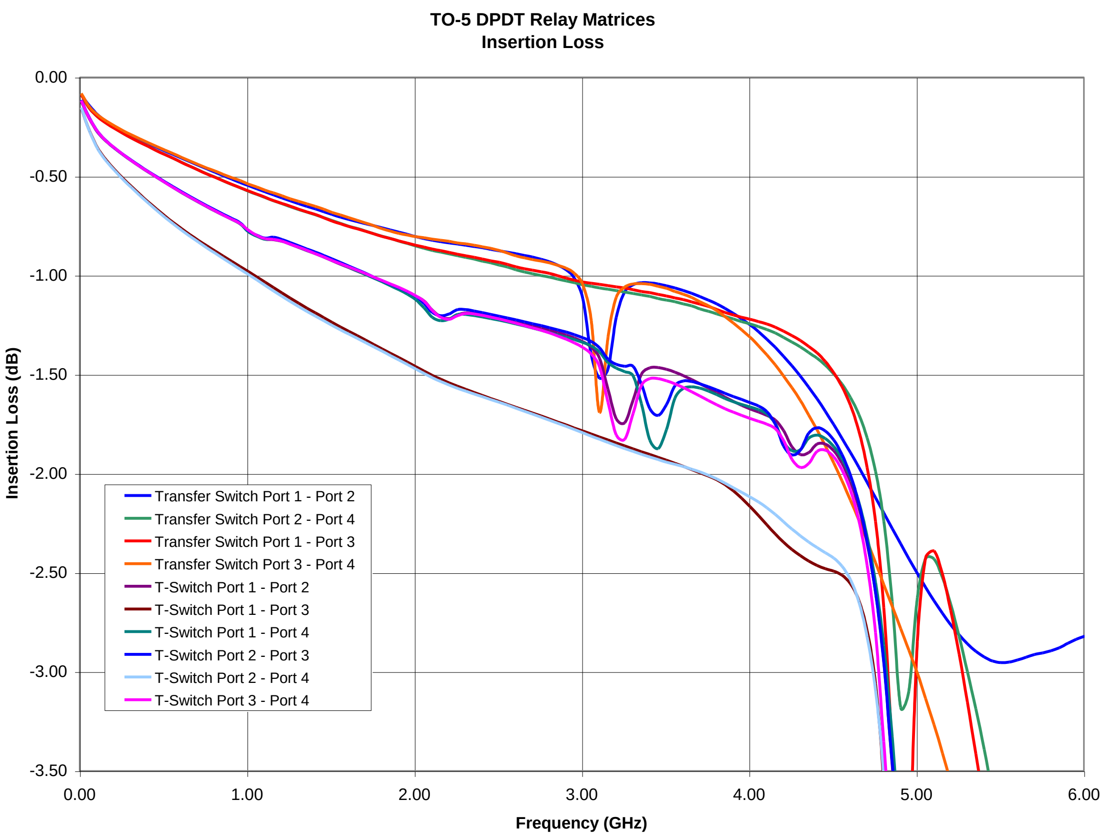

Fig. 10. Insertion Loss Measurements for Transfer and T-Switch Matrices

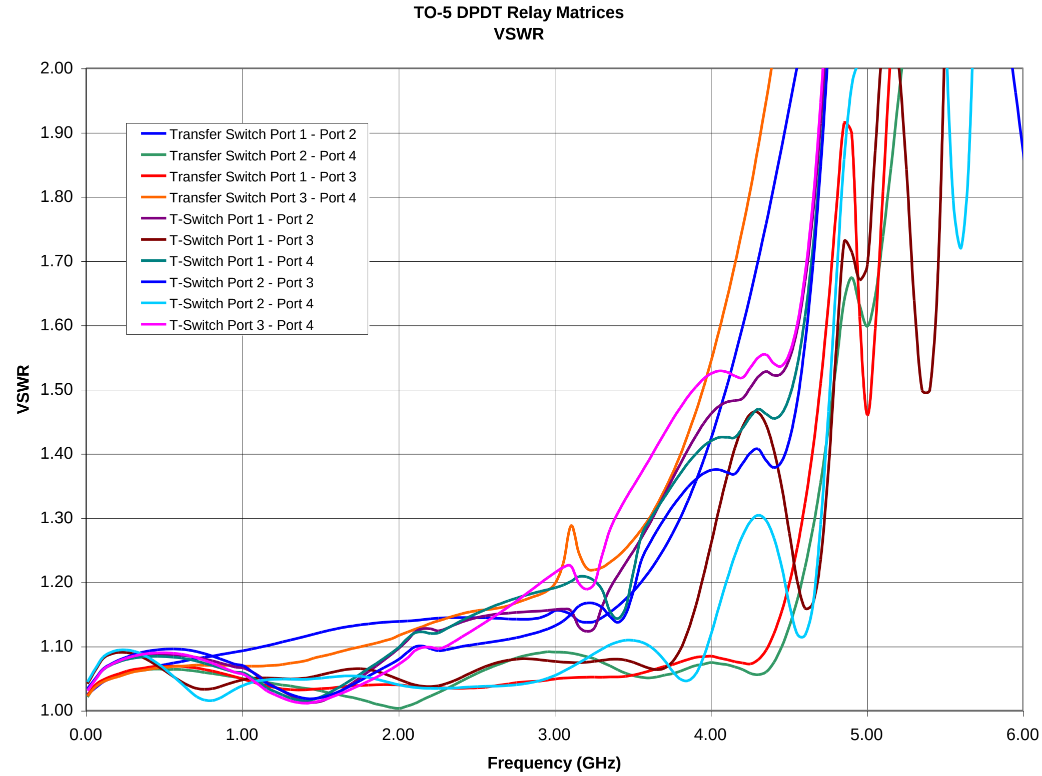

Fig. 11. VSWR Measurements for Transfer and T-Switch Matrices

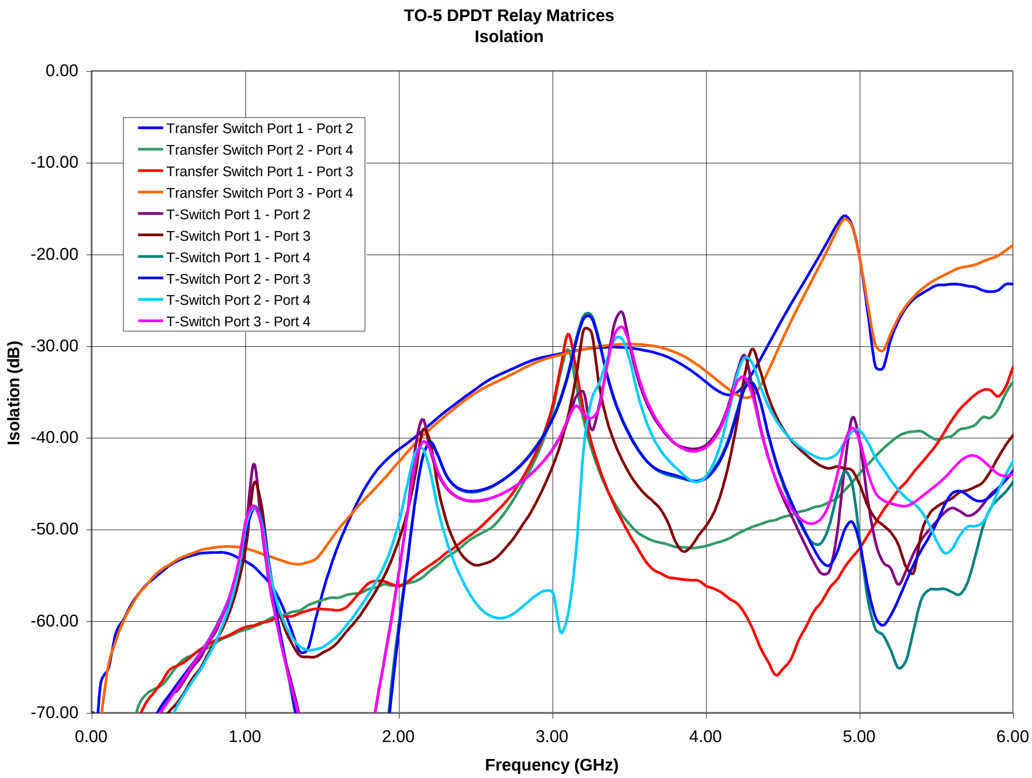

Fig. 12. Isolation Measurements for Transfer and T-Switch Matrices

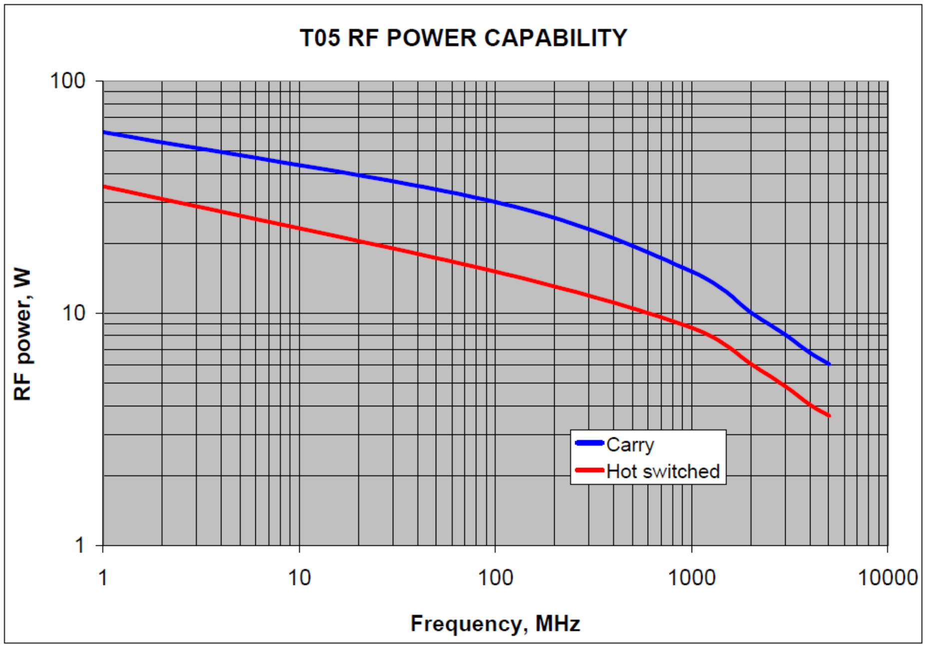

Fig. 13. RF Power Handling Capabilities of Teledyne Relays' RF342 Relay

IMPROVEMENT AND FUTURE WORK

The insertion loss notches recorded between 3 and 4 GHz for both matrices in Fig. 10 have been analyzed and attributed to the use of back to back contacts on the same relay. To realize the full potential of monotonic loss up to 4.5 GHz, a rearrangement of contacts is necessary to avoid reflections with a signal going through the same relay twice. This change will be incorporated into future switching matrices to avoid higher loss notches in the insertion loss performance.

As Teledyne pushes advancements in its ultra-miniature electromechanical relays, plan is to leverage these new products to make higher bandwidth switch matrices that have much lower insertion loss and higher isolation than the current generation of small outline electromechanical RF relays. The next generation of Teledyne Relays' products has the potential of meeting RF performances up to 12 GHz, allowing these switch matrices to meet requirements of applications in the frequency range of the C band and X band.

CONCLUSION

Teledyne Relays' small outline electromechanical relay has been the workhorse of many high reliability and space-grade switching applications for the last forty years. Its hermetic design and high reliability make it a natural choice for the demanding requirements of space borne systems. As improvements have been made to the RF performance of these relays and advancements in circuit board capabilities have grown, it is now possible to realize more complex switching structures using board mounted TO-5 relays to replace coaxial switches in applications where size and weight are fundamental design constraints. Teledyne Relays has proven the feasibility or making such replacements using two different switching structures to duplicate the connection functions of a transfer switch and a more complex t-switch for applications in the frequency range up to S band and eventually reaching C band and X band.

The advantages of using an electromechanical switching matrix instead of coaxial switches are weight and space savings, longer cycle life, hermeticity, lower operating power, and the ability to put even more complex switching arrangements onto a single PCB. This approach will further decrease size and weight by eliminating connectors and cables and replacing them with PCB level transmission lines between interconnected and redundant signal paths. The drawbacks to this switching approach come from the RF performance as decreased bandwidth, increased insertion loss, decreased isolation between ports, and lower RF power handling capability.

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