L AND S BAND TUNABLE FILTERS PROVIDE DRAMATIC IMPROVEMENTS IN TELEMETRY SYSTEMS

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ABSTRACT

Meeting the filtering requirements for telemetry transmitters and receivers can be challenging. Telemetry systems use filters to eliminate unwanted spurious or mixing products. The use of tunable microwave filters for both L and S Band can improve filter selectivity and provide low insertion losses in the filter passband. Along with meeting specifications, these microwave filters with the ability to tune an octave, reduce size and cost by the reduction of multiple, fixed-frequency filters. As size, weight and power are often a concern with aeronautical telemetry systems, this paper will demonstrate that microstrip tunable filters can be small in size and use minimal power.

Telemetry transmitters are subject to difficult spurious emission and interference specifications and require selective filters to eliminate spurious signals before the final amplification. Telemetry receivers on the other hand are subject to intense Image and Local Oscillator (LO) rejection requirements and demand low insertion loss for front-end filtering. Low insertion loss filtering before the Low Noise Amplifier (LNA) circuit limits degradation to the system noise figure (NF). By using different filter topologies and state-of-the-art, high-Q varactor diodes, tunable microwave filters can be optimized for two different functions. The two functions emphasize either low insertion loss or selectivity. An important design consideration with tunable filters, when compared to typical fixed frequency filters, is the degraded intermodulation performance. This is largely due to the non-linear behavior of the varactor diodes.

This paper describes the benefits and limitations of microwave tunable filter architectures suitable for both aeronautical telemetry transmitters and telemetry receivers. Information on the computer modeling of varactor diodes will be covered as a critical part of the design. Potential design considerations for microwave tunable filters will also be covered. Through the use of simulation software and filter prototypes, this paper presents dramatically improved filter performance applicable to telemetry transmitters and receivers.

KEYWORDS

Tunable, L Band, S Band, microstrip filter, varactor

INTRODUCTION

Technical advancements in telemetry require higher performance in smaller packages. This constraint has encouraged filter designers to explore the viability of tunable filters at L Band and S Band for aeronautical telemetry applications.

The use of tunable microwave filters for L and S band provides many benefits for telemetry transmitters and receivers operating under the challenging physical and electrical requirements inherent in telemetry applications. This paper indicates notable improvement is achieved by the careful design and implementation of microwave tunable filters.

FILTERS FOR TELEMETRY APPLICATIONS

Filters are used extensively in the design of aeronautical telemetry transmitters and receivers. The electrical and physical characteristics of the filter are driven by the specific functionality required. At the most basic levels of understanding, filters are desired to completely attenuate unwanted signals while passing wanted signals completely unchanged. Ideally, all filters would have zero insertion loss and infinite selectivity.

As ideal filters are not readily available, and because the two principle filter characteristics of insertion loss and selectivity are naturally conflicting, filters often favor one characteristic over the other. The design of tunable microwave filters provides some interesting options regarding insertion loss and selectivity, particularly when compared to fixed frequency filters. The advantages to tunable microwave filters are clearly evident in telemetry systems that support many channels over a wide frequency band, such as the IRIG-106 defined L and S bands.

The tunable filters discussed in this paper are limited to relatively broadband filter applications such as those addressing spurious emissions and not for close-in spectral mask requirements. Both low insertion loss and high selectivity tunable filters are presented.

L AND S BAND TUNABLE FILTERS

L and S telemetry bands, from 1400 MHz to 2400 MHz, cover a frequency range where filter design using lumped element components starts to become impractical. At the higher frequencies of L and S band, the parasitic capacitance and inductance of lumped element components becomes significant. An attractive alternative is filter design using distributed elements, utilizing common microwave design techniques such as microstrip and stripline. Distributed element filter design develops inductance and capacitance through the physical shape of a signal trace and its orientation to a close proximity ground. Tunable microwave filter designs employing both lumped elements and distributed elements are presented.

Figure 1 plainly shows the different physical structures for microstrip and stripline, which are readily utilized in modern printed circuit boards (PCB). Stripline requires a multilayered PCB while microstrip needs only a double-sided PCB. Tunable microwave filters using microstrip and stripline techniques are very rugged and well suited for the severe operational environments of aeronautical telemetry systems.

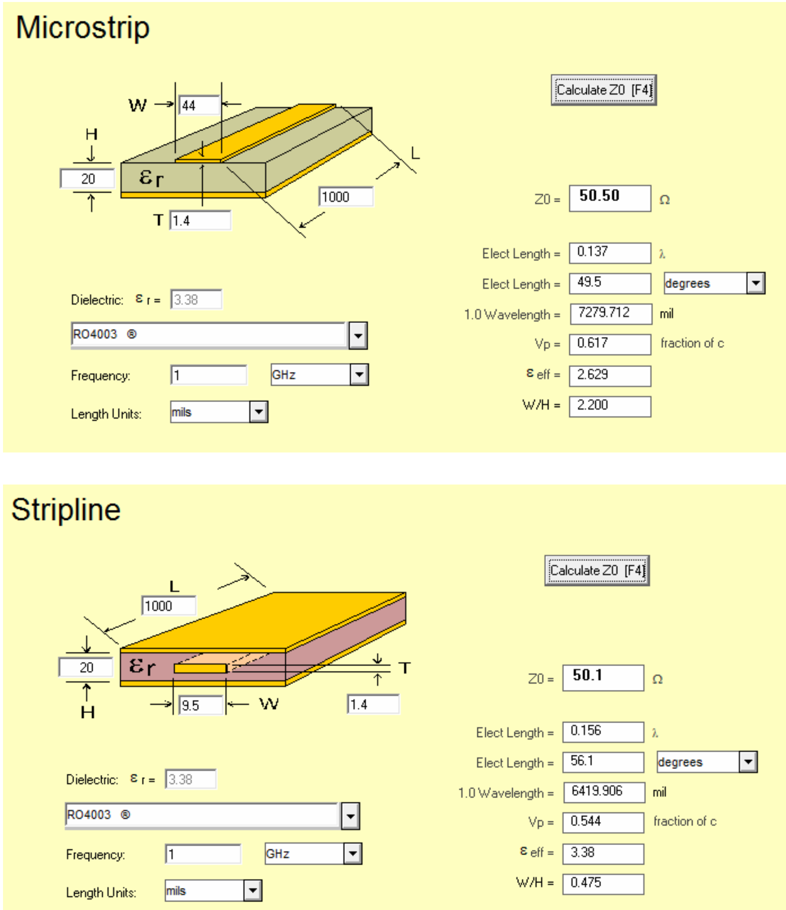


Figure 1: 50 ohm Trace for both Microstrip and Stripline (courtesy of AppCAD software, Agilent Technologies)

Benefits of Tunable Telemetry Filters

Some potential benefits of tunable microwave filters are:

- Selectivity – the bandwidth of the tuned filter can be optimized to pass the widest instantaneous signal; the filter passband does not need to be wide enough to cover all possible frequency channels for that particular telemetry band.

- Low insertion loss – a tunable filter can be optimized for low insertion loss yet still provide necessary filtering. Comparable performance from fixed frequency filters requires switching in multiple filters to provide low loss filtering over a telemetry band.

- Smaller size - fewer filter poles are needed to achieve the equivalent filtering rejection of undesired signals. This has particular appeal to system designs using frequency multiplication, where the frequency relationship between the unwanted multiplication products and the desired harmonic are completely predictable. This also permits the use of higher order frequency multiplication while simultaneously covering a broad frequency range, even to the point where several harmonics are within range of the tunable filter and only the desired is selected. The equivalent functionality using fixed frequency filters would require switching in different filters, at the cost of size.

Potential Concerns of Tunable Filters

As with most engineering designs, there are tradeoffs to consider when utilizing tunable filters for telemetry applications. Some of the potential limitations are:

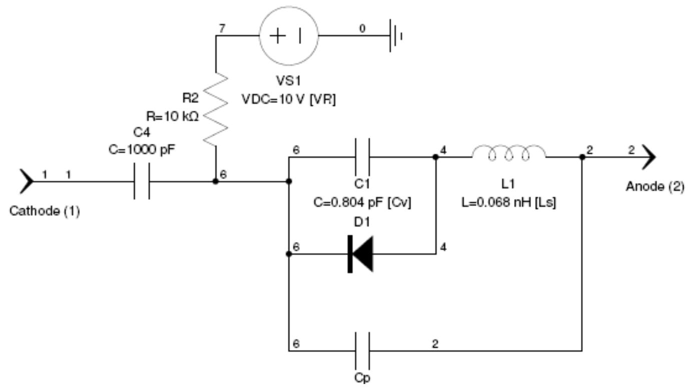
- Distortion – Tuning for tunable microwave filters is achieved almost exclusively through the use of varactor diodes. As varactor diodes are inherently non-linear devices, distortion increases as the Radio Frequency (RF) power level into the tunable filter increases. Distortion performance, which is formally specified as intermodulation requirements such as 1 dB compression point (P1dB) or Third-Order Intercept Point (IP3), can be lessened through proven design techniques.

- Control of Tuning – a method is required to control the tuning of the filter. This may not be inconsequential, especially for systems without digital control circuitry already in the system. Typical tuning control is a voltage bias applied across a varactor diode. The precision of the tuning bias required is highly dependent on the narrowness of the tuned filter.

Varactor Modeling

A crucial component of the tunable microwave filters is the tuning element. The tuning element is usually a varactor diode. All tunable filter designs considered here use varactor diodes as the tuning element. A varactor diode has a variable capacitance that is inversely proportional to the voltage applied across the diode. An applied bias voltage causes the depletion region to change, which alters the capacitance. Varactor diodes operate in a reverse biased configuration so little or no current flows through the component; hence the varactor diode uses minimal additional power.

A spice model of a varactor diode is shown in Figure 2, along with the equations defining the relationship between capacitance and applied voltage.



$L_s = 0.068$
$M = .46$
$VR = 22$
$C_p = 0.15$
$X = (1+ (VR/.6))$ ^M
$C_v = (2.45/X) + C_p$

Figure 2: Spice Model for Varactor Diode

Symbol definitions:
- L_s = the specific series inductance (manufacturer supplied)
- M = constant also provided by the manufacturer
- VR = the voltage applied from the cathode to the anode
- C_p = package capacitance
- X = value for interim calculation
- C_v = total resulting capacitance

Capacitance versus bias voltage was plotted for a simulated varactor mathematically modeled by the equations and constants of Figure 2. The resulting plot is shown in Figure 3. Note the very non-linear shape of the curve. Further, witness the reduced change in capacitance with higher voltage, which is ultimately limited by the parasitic capacitance of the diode package. In this simulation, the capacitance approaches but does not reach 0.5 pF at the highest bias voltages.

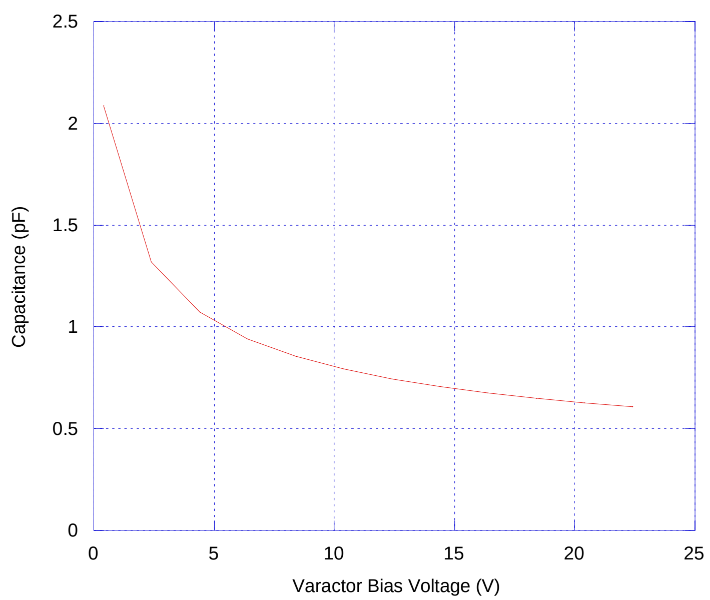


Figure 3: Capacitance vs Bias Voltage of Varactor Diode Model

A design concern for tunable microwave filters is the distortion which occurs. As mentioned previously, this distortion is the result of the non-linear characteristics of the varactor diode. A proven technique for reducing this effect is to place varactor diodes in series and effectively distribute the RF voltage swings across two diodes. Since each diode experiences only one-half the RF swing, distortion effects now occur at higher RF input levels. A common practice is to use four varactor diodes in a series/parallel configuration, as shown in Figure 4. The resulting total capacitance is equal to one varactor but with better distortion performance. The IP3 of a filter was measured with only one varactor for each tuning element and then with a circuit similar to Figure 4 replacing the single varactor. The IP3 improved from +4.7 dBm to +11.6 dBm.

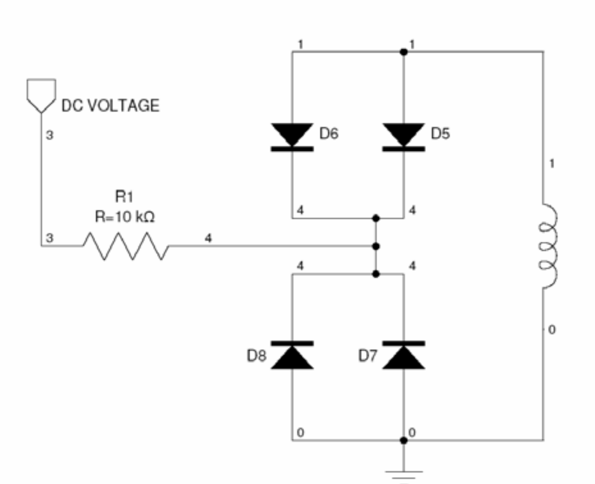


Figure 4: Using Varactor Diodes in Series and Parallel Configuration for Distortion Reduction

Design Considerations for L and S Band Tunable Filters

A tunable microwave filter was designed and simulated using Genesys software from Eagleware. The bias on the varactor diode was stepped and the response plotted. This three-pole filter was synthesized as a tapped-combline filter with varactor diodes added to adjust the electrical length of the resonant structures. The layout and the swept filter response are shown in Figure 5. The simulated filter response shows good insertion loss performance from 1.9 GHz to 2.5 GHz.

The prototype board for this tunable filter design was measured. Figure 6 shows several filter responses as the varactor bias was adjusted. The measured insertion loss did not equal the simulation but the tuning range did match the simulation. The most likely explanation for insertion loss differences is that a more sophisticated model of the varactor quality factor (Q) is needed; a model that reflects the change in Q versus frequency and tuning bias.

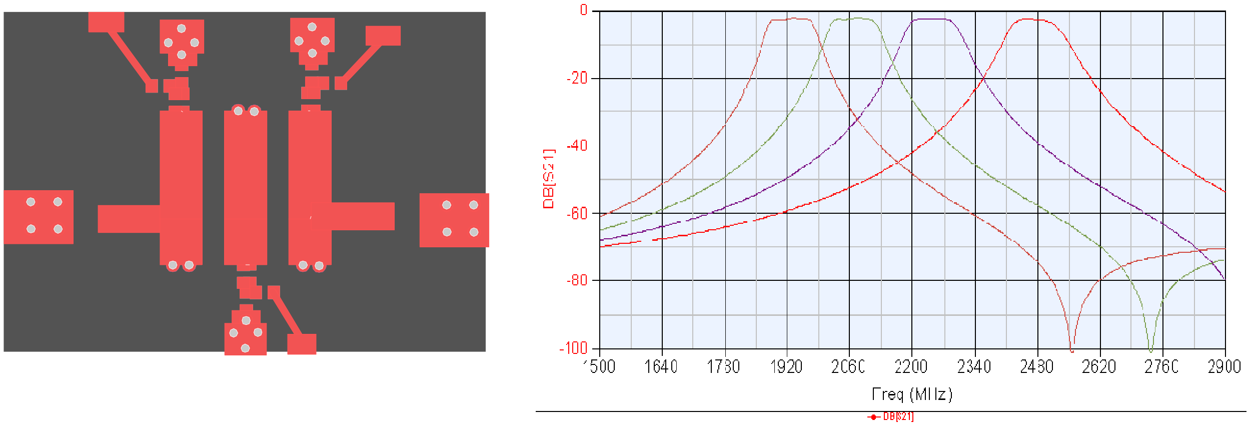


Figure 5: Microstrip Tunable Filter Layout and Simulation Covering 1.9 GHz to 2.5 GHz

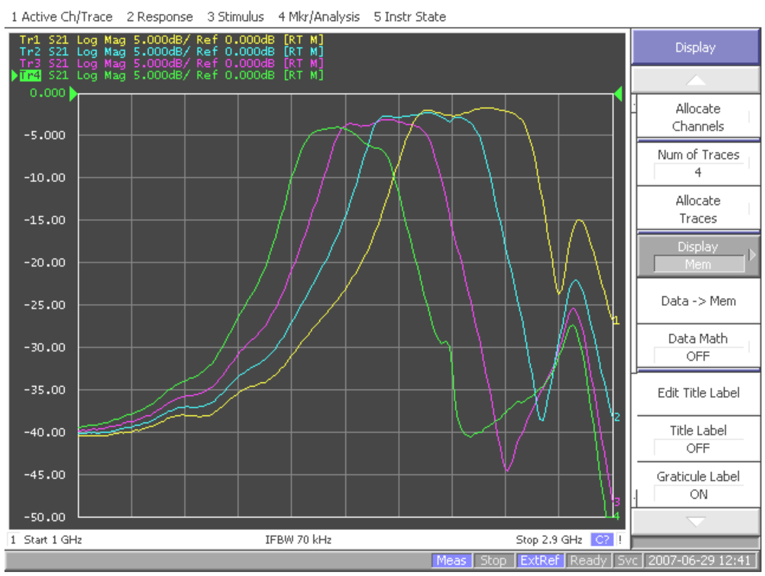


Figure 6: Measured Filter Response for 3 Pole Prototype Filter

A second, tunable microwave filter using lumped elements was designed, simulated and built. The layout and measured response is shown in Figure 7. Requiring less than a square inch of board area, this very compact filter design has impressive performance. This tunable filter design was optimized for selectivity with much less concern for insertion loss.

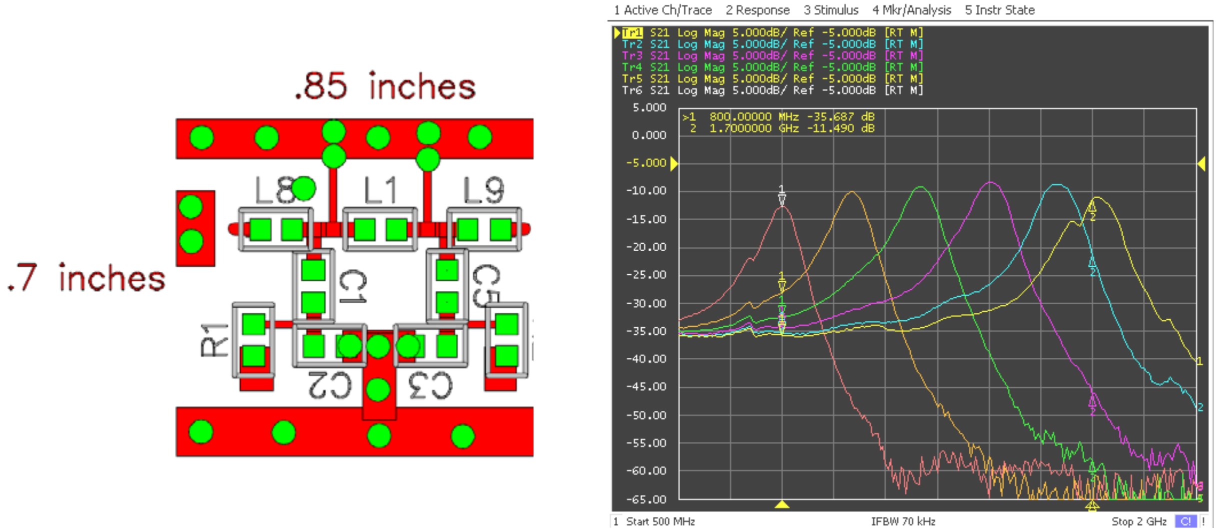


Figure 7: Layout and Measured Response of Lumped Element Tunable Filter Optimized for Selectivity

CONCLUSION

Benefits of L and S Band tunable filters include dramatically improved filtering performance, especially across broad frequency bands like L and S Band. Tunable microwave filters can save space by taking the place of multiple fixed frequency filters. A design concern for the tunable filters is distortion due to the varactor diodes, but proven techniques exist to lessen the effect.

The use of tunable microwave filters for L and S Band provides many benefits for telemetry transmitters and receivers operating under the challenging physical and electrical requirements inherent in telemetry applications.

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