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Tunable Microstrip Bandpass Filters Based on Planar Split Ring Resonators

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ABSTRACT

A tunable bandpass microstrip filter based on varactor loaded Split Ring Resonators (SRRs) is presented. The filter is designed such a way that it has one transmission zero at the right hand side of the passband. Silicon tuning diode, of which capacitance is controlled by DC bias voltage, is used as the varactor element and it is placed between two concentric split rings of SRR to tune SRR's resonance frequency. Single module of the tuning filter is designed and simulated using Momentum 2006C software. The size of the SRR is chosen to have passband located at 2.8 GHz. And, it is fabricated on Rogers RO4003 high frequency laminate.

INTRODUCTION

Filters used in current satellite communication systems employ waveguide, dielectric or cavity resonators [1]. This results in bulky circuitry, which is also complex and costly. Furthermore, current systems use multiple filters for each communication bandwidth which further increase the volume of the satellite front-ends. Miniaturized microstrip tunable filters, on the other hand, are promising alternatives due to their small size, extended functionality, easy integration, and robustness.

Microstrip tunable filters have being implemented using various techniques such as radio frequency micro-electromechanical system switches (RF-MEMS), ferromagnetic materials, or varactors. The mechanically tunable filter designed using MEMS have low insertion loss but their tuning speed is slow [2]. The ferromagnetic tunable filters are achieved magnetically altering the property of yttrium-iron-garnet element [3]. The methods explained above are difficult to fabricate and hard to miniaturize. Microstrip tunable filters using varactors, however, are easy to fabricate, robust and cost friendly.

SRRs have high Q factors and have small electrical sizes at the resonance [4]. These resonators have been used in the design of compact microwave filters [5]. A varactor loaded band-reject tunable filter is designed with SRRs [6], but the design of tunable bandpass filters using these resonators has not been investigated yet. In this paper, we present a compact tunable bandpass filter solution by using SRRs and silicon tuning diodes.

DESIGN METHODOLOGY

The design of varactors loaded SRR based tunable filter is similar to varactor loaded microstrip line ring resonator based design proposed by Makimoto [7].In both work, the resonators are loaded with varactors to tune the resonant frequency. In this our design, SRRs are employed instead of ring resonators for size reduction. The basic building block of the tunable filter is studied first, and the higher order tunable filter is then obtained by cascading the basic tuning block.

Basic Tuning Filter Block

The layout of the varactor loaded tunable filter cell is shown in Fig. 1. The tuning diode BB833, manufactured by Infenion Technology, is connected between concentric rings of split ring resonator as varactor. The reason of choosing these tuning silicon diodes is due to their high capacitance ratio. By changing the bias voltage from 0 V to 25 V, junction capacitance can be tuned from 9.75 pF until 0.75 pF. The tuning diode changes junction capacitance with respect to DC biasing voltage applied between its ports. The resonant frequency of split ring resonator depends on the capacitance between inner and outer concentric ring conductors and the equivalent inductance of outer concentric split ring.

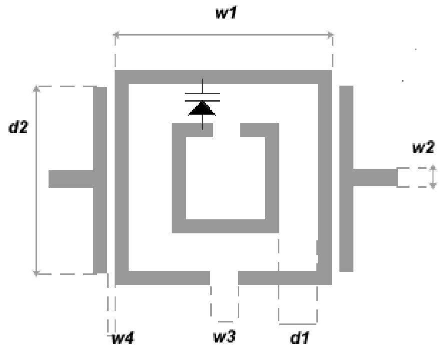

Figure 1: Schematic of varactor loaded SRR tuning block. Metal regions are depicted in gray. w1=10, w2=2.9, w3=1, w4=0.5, w5=8, d1=1.5, d2=8. All the dimensions are in mm

The equivalent lumped circuit model of the tunable filter block is shown in Fig 2. The resonant frequency of the resonator is calculated from

$$f_0 = \frac{1}{2\pi\sqrt{(C_g + C_s + C_d)L_s}} \, , \qquad (1)$$

where L_s is the equivalent inductance of outer concentric split ring and C_g is the equivalent gap capacitance between feed-line and SRR. C_s and C_d represents the equivalent capacitance between the concentric rings of SRR and the junction capacitance of the tuning diode respectively . By changing the bias voltage of the diode the passband of the filter can be tuned. A higher junction capacitance results in a lower passband. The tuning ratio of the filter depends on the ratio between diode junction capacitance (C_d) and the sum of C_s and C_g.

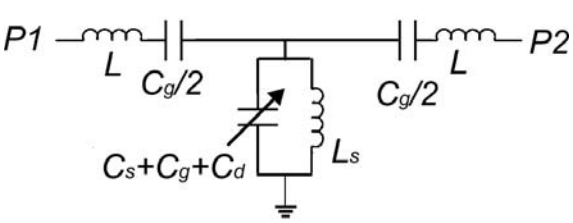

Figure 2: Equivalent lumped element circuit model for single tuning block.

The tunable filter module with a passband located at 2.8 GHz is designed using Agilent Momentum. Rogers RO4003 high frequency laminates (dielectric constant is 3.38 and substrate thickness 1.27 mm) is chosen as substrate. The width of the feed-line is set to 2.9 mm in order to have 50 ohm input impedance. The varactor loaded SRR is simulated for various C_d capacitance values. The simulated results are shown in Fig. 3.

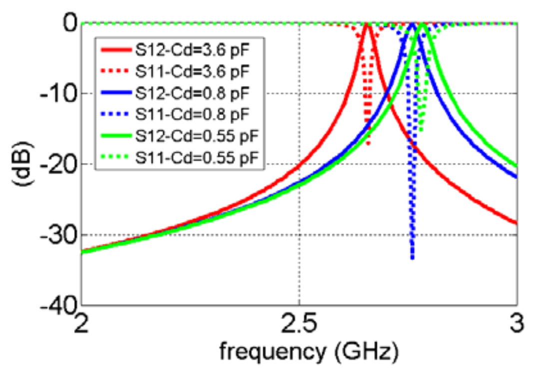

Figure 3: S11 (reflection) and S12 (transmission) of single tuning block for various C_d

The module is fabricated with LPKF circuit board milling machine and shown in Fig. 4. DC bias voltage is applied between the ports of the tuning diode by probes of voltage supply.

Figure 4: Fabricated basic tuning block.

The measured transmission parameters (S12) of the tunable single block using Vector Network Analyzer (VNA) is shown in Figure 5. The DC biasing voltage of the diode is varied from 0 V up to 20 V which corresponds to 9.8 pF to 0.75 pF. In this case, the tuning range of the filter is approximately 5 percent. The tuning range of the filter depends on the capacitance variation of the tuning diode and the intrinsic capacitance of SRR's outer ring.

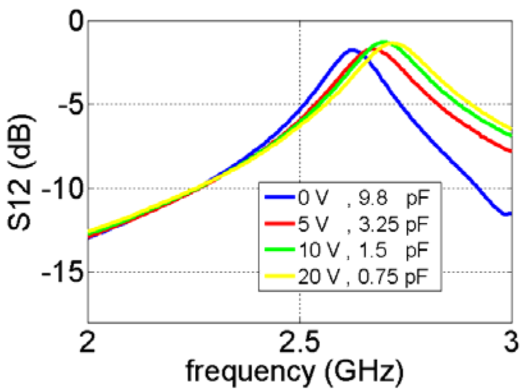

Figure 5: Measured S12 of single tuning block for various biasing voltages

Multi-stage Filter Implementation

In order to have more selective filter response, the order of the filter needs to be increased. The design methods proposed by Hong and Lancaster [8] are used for higher order filter implementation. The schematic of a third order filter bandpass filter with transmission zero located at the right side of the passband is shown in the figure 6. The feed-line is directly connected to the corners of the resonators R1 and R3. The resonator R2 is excited with electric field created by R2. By making the distance between the resonators is equal to each other, the coupling coefficients between R1 and R2; and between R3 and R2 are set equal to each other for simplification.

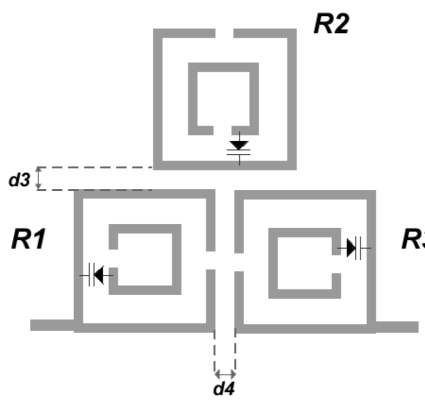

Figure 6: Schematic of the third order bandpass filter with single transmission zero located on the right side of passband.

The behavior of the 3rd order filter is simulated using Momentum for various capacitances (Figure 7). The resonant frequency of SRR is determined by the size of the SRR and the dielectric property of the substrate. A SRR with a smaller size or lower substrate dielectric constant has a higher resonant frequency.

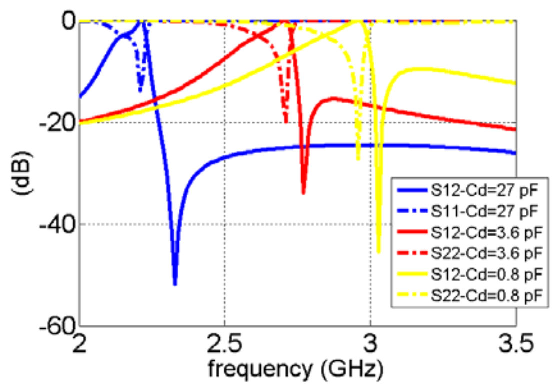

Figure 7: Simulation results of third order tunable bandpass filter various varactor capacitances

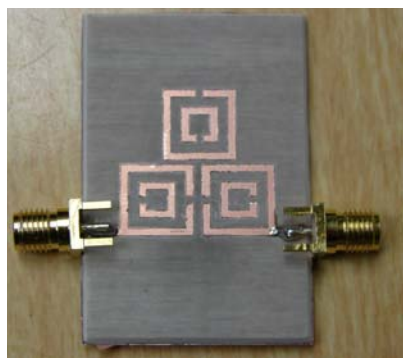

Figure 8: Fabricated third order tunable bandpass filter

CONCLUSION

A compact, robust and easy to integrate tunable filter using varactor loaded split ring resonators is presented. The tuning filter is designed and fabricated for 2.8 GHz using Rogers RO4003 substrate. The bandwidth of the filter is very narrow i.e. about % 2 because SRRs have high quality factors. The behavior of the tunable filter is verified by ADS Momentum simulation. Basic tunable SRR module is fabricated and measured using VNA. The measured response of the filter agrees well with the simulated response.

References

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