A Fourth Order Tunable Capacitor Coupled Microstrip Resonator Band Pass Filter

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***Abstract* — This paper presents a simple and efficient tunable microstrip band pass filter based on the reflected group delay method. The effect of varactor location on the filter performance is investigated in details to guide the filter design. The measured results are consistent with both analytical and simulation results.**

***Index Terms* — Band pass filter, microstrip filter, reflected group delay, tunable filter.**

I. INTRODUCTION

Low loss tunable band pass filters (BPF) are essential for modern multiband and wideband systems. Efficient and convenient synthesizing method is important for designers to have design insights. One of the efficient filter design methods is to use the reflected group delay information. This method was first proposed by J. B. Ness in 1998[1]. Ref. [2] presents a design procedure by using this method to design a cross-coupling microstrip BPF. A maximum of three parameters are optimized at any step, which alleviates the tuning efforts. However, the filter is not tunable. To achieve tunability, this paper presents a tunable BPF using the reflected group delay method, and investigates the effect of varactor locations on the filter performance.

II. BAND PASS FILTER DESIGN WITH REFLECTED GROUP DELAY METHOD

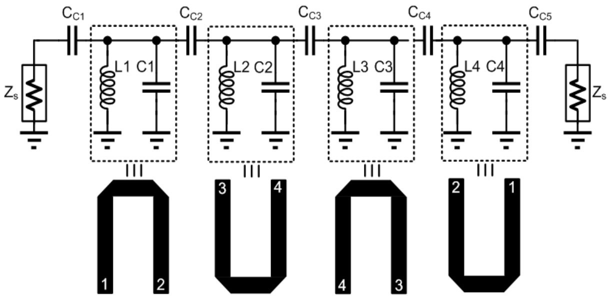


Fig. 1. Lumped model of a fourth order bandpass filter

The capacitor coupled microstrip resonator based BPF, designed with the reflected group delay method [1], is shown in Fig. 1, which is modelled with lumped circuit components. The lumped circuit component model is used to derive the desired filer response and reflected group delay information. When converting to distributed MMIC design, the filter component size, such as the resonator length, coupling capacitor values, are optimized based on the desired filer response and reflected group delay information from the lumped model. Compared with other filter design methods, the reflected group delay method saves tuning efforts and is easier to adopt in both MMIC and RFIC designs. However, frequency tuning methods are not provided, which is the focus of this work.

III. TUNING METHOD ANALYSIS

Frequency tunability is important for filters to realize reconfigurability for multi-band and software-defined ratio applications and enhance yield and reliability to cover PVT variations. Adding varactors is a well-known method for frequency tunability [3]. However, the location of varactors determines the filter performance. For example, in Fig. 1, the varactors added far from the generator (position 2&4) has much better performance than added near the generator (position 1&3). Section III. B will explain why the varactors position determines the filter performance.

A. Tunable Filter Simulation Result Comparison

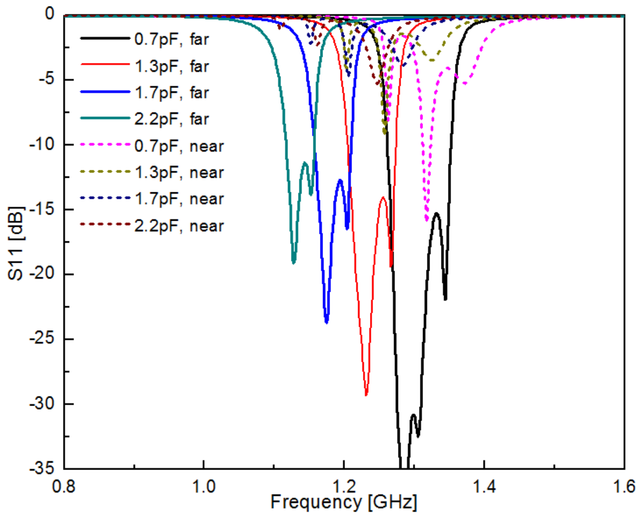


Fig. 2. S11 comparison with different varactor positions

Fig. 2 shows the simulated S11 from EM tool HFSS for both varactor positions: far from the generator represented by the solid lines and near the generator represented by the dash lines. In addition, different varactor control voltage is also applied to validate the frequency tunability. Fig. 2 shows that when the varactor is added on the terminal far from the generator, the S11 is continuously below -10 dB. However, when moving the varactor to the terminals near the generator, the S11 becomes much poorer, typically worse than -5 dB. The lower the band, the poorer the S11 is. This is because of a larger varactor value in the lower band, which deteriorates S11 more severely.

B. Matching Analysis

To investigate the difference of these two scenarios, use one resonator as the example to exam the input impedance. Fig. 3. illustrates the configuration of three cases: original resonator without varactors, the tunable resonator with a varactor near the generator, and the tunable resonator with a varactor far from the generator. The input impedances of the three cases are $Z_{in,org}$, $Z_{in,near}$, $Z_{in,far}$ respectively, can be represented as equation (1)-(3).

The original resonator without varactors will form ideal matching when constructing the filter shown in Fig.1. Therefore, the closer the impedance to the original case, the better the matching will be for the complete filter. To give a quantitative comparison, using the designed filter

$$Z_{in,\mathrm{org}} = Z_o \frac{Z_f + jZ_o \tan\theta}{Z_o + jZ_f \tan\theta}, \quad Z_f = Z_S + \frac{1}{j\omega C_{c1}} \tag{1}$$

$$Z_{in,near} = Z_o \frac{Z_f + jZ_o \tan\theta' - \omega' C_{\mathrm{var}} \tan\theta' Z_o Z_S + j\dfrac{C_{\mathrm{var}}}{C}\tan\theta' Z_o}{Z_o + jZ_f \tan\theta' + j\omega' C_{\mathrm{var}} Z_f Z_o} \tag{2}$$

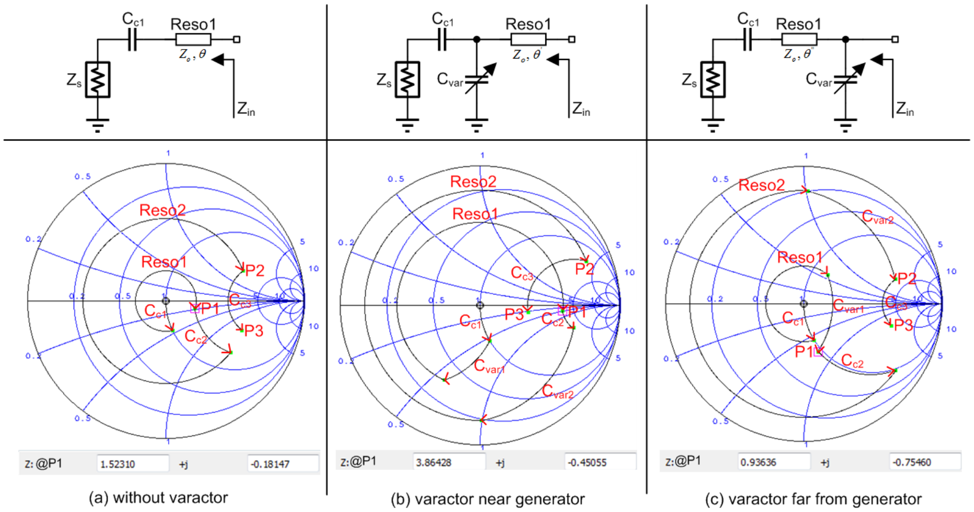
$$Z_{in,\mathrm{far}} = Z_o \frac{Z_f + jZ_o \tan\theta''}{Z_o + jZ_f \tan\theta'' + j\omega'' C_{\mathrm{var}} Z_f Z_o - \omega'' C_{\mathrm{var}} \tan\theta'' Z_o^2} \tag{3}$$

values with C_{c1}=4.73pF, C_{c2}=1.33pF, C_{c3}=0.6pF, and the electrical length of the resonator of 150 degree at 1.5GHz to derive these input impedances: $Z_{in,org}$=(1.52-j0.18)Z_O, $Z_{in,near}$=(3.85-j0.45)Z_O, and $Z_{in,far}$=(0.94-j0.74)Z_O. These points are annotated as the P1 in the corresponding Smith Charts. One point to mention is that the addition of the varactor increases the equivalent electrical length of the resonator which results in a lower resonant frequency, such as 1.24 GHz in this setting. Fig. 3.(b) shows that the impedance of the case with the varactor far from the generator is closer than that from the case with the varactor near the generator. Therefore the former setup has better matching.

To further visualize this comparison, Fig. 3(b) further adds the impedance contour for the 2nd resonator of Fig. 1. Due to the symmetrical feature, perfect matching of the filter performance in Fig.1 requires C_{c3} realizing impedance conjugate conversion. The closer C_{c3} realizing impedance conjugate conversion, the better the filter performance. Left Smith Chart is the original case without varactor, which realizes perfect impedance conjugate matching by C_{c3} from P2 to P3. Compare the points of P2 and P3 in the other two Smith Charts, the case with varactor far from the generator is closer to realize conjugate impedance matching, therefore has better performances.

IV. EXPERIMENTAL RESULTS

The microstrip band pass filter is realized on RO4003 with 60 mil thickness, as shown in Fig. 4. The dimensions are L_{c1}=200mil, L_{c2}=60mil, L_{c3}=40mil, W_{Roso1}=300mil, W_{Reso2}=300mil, L_{Reso1}=800mil, L_{Reso2}=1000mil. The space



(a) without varactor (b) varactor near generator (c) varactor far from generator

Fig. 3. Input impedance calculation circuit and Smith Chart with different varactor positions

between capacitor fingers is 10 mil, which is set by the mill machine resolution. The varactor is from Skyworks company SMV1405, which can be tuned from 0.63pF to 1.84pF with 30V-1V bias voltage.

The measured (solid lines) and simulated (dash lines) results of S21, S11and group delay are shown in Figs. 5-7 respectively. The center frequency (f_c) of BPF can be tuned continuously from 1.17GHz to 1.37GHz with 2.3 dB minimum insertion loss. The maximum insertion loss of 6.3 dB in the lowest band is due to the smallest quality factor of varactor with the largest capacitance. Contact resistance leads to extra insertion loss which is included in the simulation. The return loss is better than -8 dB. The deterioration of S11 is from inaccurate coupling capacitor value. The 3dB bandwidth increases from 37 MHz when f_c is 1.17GHz to 77 MHz when f_c is 1.37GHz. The decreasing bandwidth in the lower frequency band is properly due to frequency-insensitive resonator coupling coefficient variation.

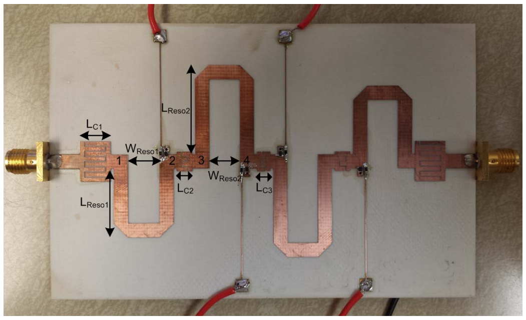


Fig. 4. Image of fabricated BPF board

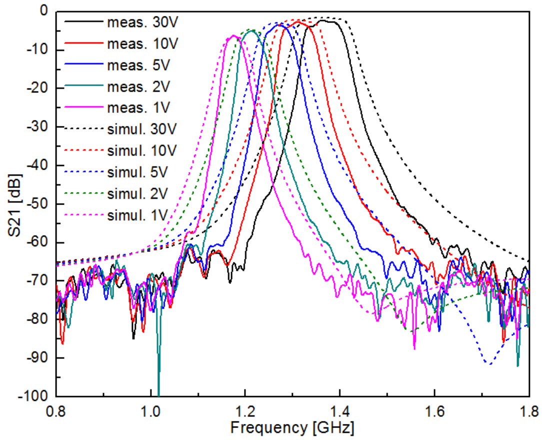


Fig. 5. Measured and simulated S21 with different bias

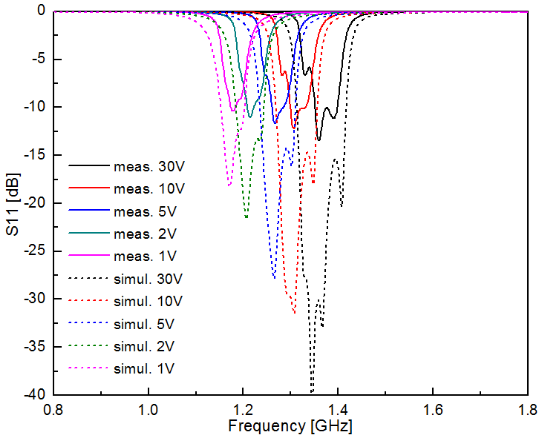


Fig. 6. Measured and simulated S11 with different bias

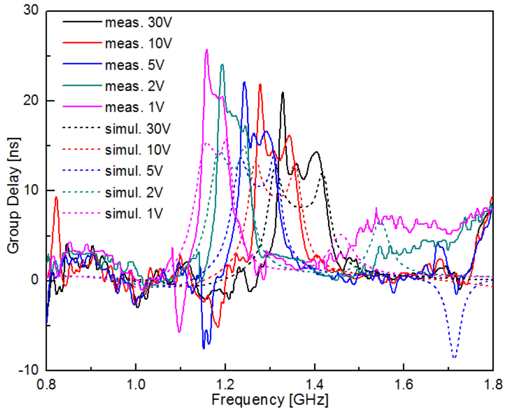


Fig. 7. Measured and simulated group delay with different bias

V. CONCLUSION

In this paper, a simple and efficient tunable microstrip band pass filter is designed with reflected group delay method. The effect of varactor location on the filter performance is investigated to guide the design. The measured results are consistent with analytical and simulation results.

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