Dual-Mode Bandpass Filter with Independently Tunable Center Frequency and Bandwidth

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***Abstract* — This paper presents a compact dual-mode tunable bandpass filter (BPF) with independently tunable center frequencies and bandwidths based on varactor loaded transmission line dual-mode resonator. The center frequency can be controlled by tuning the even-mode and odd-mode resonant frequencies of the dual-mode resonator. The bandwidth of passband can be tuned by fixing the odd-mode and changing the even-mode resonant frequency. To validate the proposed structure, two-pole microstrip tunable BPF is presented and experimentally verified.**

***Index Terms* — Controllable bandwidth, dual-mode resonator, tunable bandpass filter, varactor diodes.**

I. INTRODUCTION

For modern wireless communication systems, there is growing interest on designing of electrically tunable microwave filters [1]-[2]. To meet these requirements, various approaches have been applied to design tunable BPFs using different kinds of tuning devices such as micro-electromechanical systems (MEMS), p-i-n diodes, varactor diodes and so on [3]-[9].

The dual-mode resonators are attractive to design the compact BPFs as each dual-mode resonator can be used as a doubly tuned resonator circuit. Therefore, number of resonators required for the dual-mode BPF can be reduced by half, resulting the compact size of reconfigurable filters [10][11].

In comparison to the tunability of center frequency, there has been little effort made in tunability of center frequency and bandwidth simultaneously. In [12], Tang *et. al.* presented a reconfigurable combline filter with tunable center frequency and bandwidth by controlling electrical length of transmission line and inter-resonator coupling electronically which requires large number of biasing circuits and has huge size.

In this paper, a compact dual-mode tunable BPF is proposed. The proposed filter offers the tunable center frequency and bandwidths.

II. CHARACTERISTICS OF PROPOSED TUNABLE DUAL-MODE RESONATOR

Fig. 1(a) shows basic structure of proposed dual-mode resonator. It consists of transmission line and three varactor diodes.

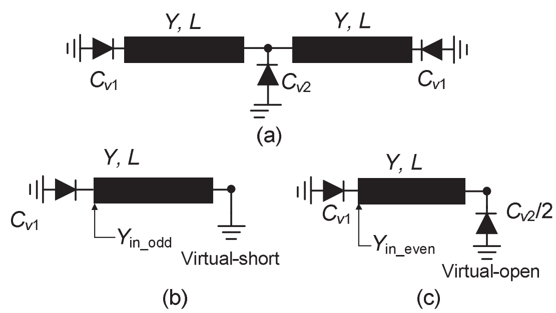

Fig. 1. Proposed dual-mode tunable resonator and their equivalent half circuits of under even and odd excitation: (a) basic structure of resonator, (b) odd-mode excitation, and (c) even mode excitation.

For the theoretical analysis, it is assumed to be a lossless transmission line with characteristic admittance *Y* and total physical length of 2*L.* Two varactor diodes are attached at the ends of transmission line and one varactor diode is placed at the center point of transmission line. For simplicity, the parasitic elements of varactor diodes are ignored. Since the structure is symmetrical, the even/odd-mode analysis method is applicable to obtain the resonant frequencies [9].

When the odd-mode excitation is applied to the proposed resonator as shown in Fig. 1(a), there is a voltage null along the symmetry plane. Under the odd-mode excitation, it can be represented by the half equivalent circuit as given in Fig. 1(b). The odd-mode input admittance is given as follows.

$$Y_{\text{in\_odd}} = j\left[\omega_{odd} C_{v1} - Y\cot\left(\beta L\right)\right] \tag{1}$$

Where C_{v1} and   are the capacitance of the varactor diode connected at the end of the line and the propagation constant of the transmission line, respectively. From the resonance condition of Im($Y_{\text{in-odd}}$)=0, the odd-mode resonant frequency can be determined as follows.

$$f_{odd} \times \tan\left(\frac{2\pi f_{odd} L}{v_p}\right) = \frac{Y}{2\pi C_{v1}} \tag{2}$$

Where v_p is the phase velocity. From (2), it is clear that the odd-mode resonant frequency fully depends on the capacitance C_{v1} of varactor diode connected at the ends of the transmission line. Therefore, the change of the bias voltage on both end varactor diodes will result in the change of odd-mode resonant frequency. Moreover, the

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odd-mode resonant frequency is not affected by the varactor diode connected at the center of the transmission line.

For the even-mode excitation, there is no current flowing through the center of the transmission line. Under the even-mode condition, the proposed resonator can be represented by the equivalent half circuit shown in Fig. 1(c). The even-mode input admittance is given as follows.

$$Y_{\text{in\_even}} = j\left(\omega_{even}C_{v1} + Y\frac{\omega C_{v2}/2 + Y\tan(\beta L)}{Y - \omega\tan(\beta L)C_{v2}/2}\right) \quad (3)$$

Where C_{v2} is the capacitance of the varactor diode connected at the center of the transmission line. For the resonance condition, the even-mode resonant frequency can be determined as follows.

$$\left(f_{even} - \frac{Y^2}{2\pi^2 f_{even}C_{v1}C_{v2}}\right)\tan\left(\frac{2\pi f_{even}L}{v_p}\right) = \frac{Y(C_{v1}+C_{v2}/2)}{\pi C_{v1}C_{v2}} \quad (4)$$

From (4), it is observed that the even-mode resonant frequency depends on C_{v1} and C_{v2}. Thus, the change of the bias voltages applied to all of the varactor diodes will also results in the change of even-mode resonant frequencies. Moreover, when C_{v1} is fixed (odd-mode resonant frequency is fixed), the even-mode resonant frequency can tuned with the help of C_{v2} alone. These characteristics can be used to tune the bandwidth of proposed tunable filter.

In order to verify the above theoretical analysis, a full-wave electromagnetic (EM) simulation was carried out by using HFSS v12 of Ansoft. Two microstrip lines with characteristics impedance of 50 are utilized to feed the proposed resonator using loose coupling to investigate its resonant behavior. The used substrate is an RT/Duriod 5880 made by Rogers with a dielectric constant ($_r$) of 2.2 and thickness (h) of 31 mils. The total length of resonator ($2L$) is fixed at 28 mm.

Fig. 2 shows the simulated S_{21}-magnitude of weak coupling resonator circuit according to different capacitances combination of varactor diodes. As the capacitances are varied, the odd-mode and even-mode resonant frequencies are tuned simultaneously. This characteristic of the proposed resonator can be utilized to tune the center frequency of passband.

Fig. 3 shows the simulated S_{21}-magnitude of the resonator circuit in the case where the capacitances of the varactor diodes connected at the end of the transmission line are fixed. Under this condition, it is obvious that the odd-mode resonant frequency is fixed and the even-mode resonant frequency can be tuned by varying the capacitance of the varactor diode connected at the center of line. This characteristic of resonator can be used to tune the bandwidths of passband.

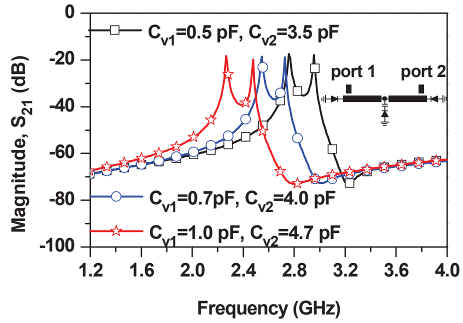

Fig. 2. Resonant frequencies according to the capacitance with tunable odd and even-mode resonant frequency.

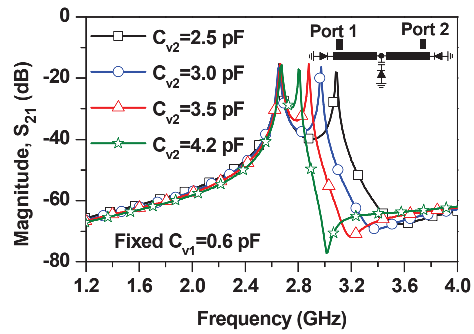

Fig. 3. Resonant frequencies according to the capacitance with fixed odd-mode and tunable even-mode resonant frequency.

III. Filter Implementation and Verification

To verify the analytical analysis of the proposed resonators, two-pole tunable BPF was designed, simulated and measured. Fig. 4 shows the configuration of the dual-mode microstrip tunable BPF. The two varactor diodes connected at the end of transmission line are SMV 1231-011LF and varactor diode connected at the center of transmission line is SMV 1233-079LF of Skyworks Solutions Inc. The dc block (C_{DC}) capacitor was attached at the center point of transmission line. In the EM simulation process, ideal capacitors were used. After the simulation, the physical parameters values of filter are determined as shown in Fig. 4.

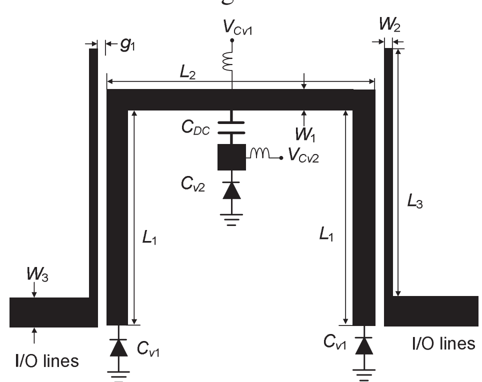

Fig. 4. Configuration of proposed tunable filter and physical dimensions: L_1=7.2, L_2= 10.4, L_3= 11, W_1=1, W_2= 0.4, W_3=2.4, C_{dc}= 5.2 pF. [Physical unit: mm].

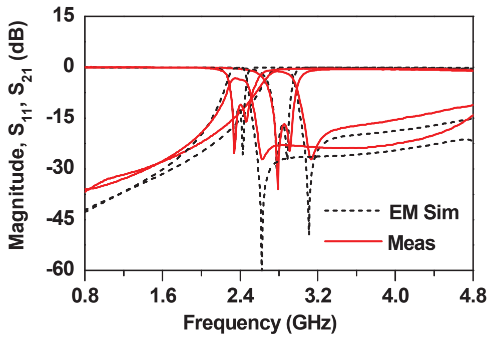

Fig. 5. Simulated and measured results for demonstration of tunability of center frequency of passbands characteristics. Bias voltage variation: V_{cv1}=4.5~15 V and V_{cv2}=3.85~15V.

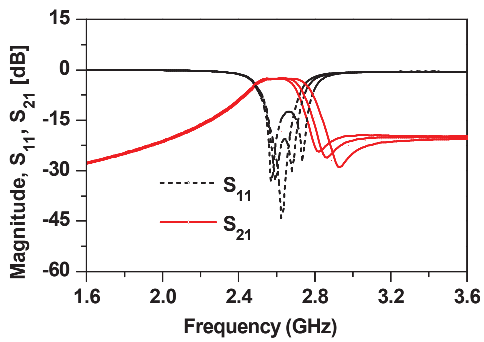

Fig. 6. Measured results for demonstration of controllable 3-dB bandwidth of passbands. Bias voltage conditions: V_{cv1} fixed at 7.6 V and V_{cv2}=3.85~15V.

Fig. 5 shows the simulation and measurement results of proposed dual-mode BPF according to the bias voltages. The measurement results agreed well with the simulation results. The measurement results show that center frequency of passband can be tuned from 2.36 to 2.85 GHz with almost constant fractional bandwidth. The return loss is better than 12 dB in the overall tuning range. The insertion loss varies from 1.45 to 3.52 dB as shown in Fig. 5. The measured insertion losses are some higher than simulation results because of the ideal capacitors used in the EM simulation.

Fig. 6 shows the measured results of proposed filter with the fixed center frequency at 2.65 GHz and tunable 3-dB bandwidth. In this case, the bias voltage of varactor diode connected at end of transmission line is fixed, which means the odd-mode resonant frequency is fixed. From experiment, it was found that the 3-dB bandwidth was controlled from 227-300 MHz (3-dB fractional bandwidth tunabiltiy: 8.56% to 11.3%) with the fixed at the center frequency 2.65 GHz by varying the bias voltage of varacator diode connected at the center of transmission line.

IV. Conclusion

In this paper, a compact dual-mode bandpass filter with independently tunable center frequency and bandwidth of passband is presented. The passband center frequency of proposed filter can be tuned by controlling the odd-mode and even-mode resonant frequencies as these two operating modes do not couple to each other. Similarly, the bandwidths of passband in the proposed filter can be tuned by fixed odd-mode resonant frequency and controlling the even-mode resonant frequency. In order to validate the theoretical analysis, two-pole tunable bandpass filter have been demonstrated with both simulation and experimental results. The measured results have good agreement with the simulations.

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