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Varactor-Tuned Dual-Mode Bandpass Filter With Nonuniform Q Distribution

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***Abstract*— This letter demonstrates an electronically reconfigurable microstrip dual-mode filter with nonuniform Q lossy technique. Varactors are used for continuous tuning of the bandwidth and center frequency. By deploying nonuniform Q distribution on the dual-mode open-loop filter, passband flatness is improved by loading resistors on the even–odd symmetrical plane of resonators. Coupling matrix is used to describe the tunable lossy filter. Design of this type of four-pole tunable lossy filter is presented and validated experimentally.**

***Index Terms*— Dual-mode resonators, microstrip filters, nonuniform Q-factor, reconfigurable filters.**

I. INTRODUCTION

MODERN microwave systems working flexible among multibands become more attractive. Electronically reconfigurable microwave filters play an important role in such RF systems [1]–[4]. Planar filter reconfiguration has been widely deployed by varying the electrical length and inner coupling between resonators in continuous or discrete steps with varactors or pin diodes [1], [2]. Nondegenerate dual-mode filters are attractive because of their interesting coupling topology and compact doubly tuned resonant circuit [3].

It is a challenge designing a tunable microstrip filter with a high Q factor and small size. Both microstrip and varactors have very limited Q factor resulting in high insertion loss variation across the passband with a typical rounding-edge effect [5]. With the raise of stringent demand for filter performance, filter with serious rounding-edge effect obstructs the development of microwave systems. In order to enhance the filter performance, several techniques have been introduced [5]–[8], which can flatten the passband for a desired application, though at the expense of insertion and/or return loss. Few efforts have been put on the tunable filter with lossy techniques [9]. Since passband flatness can be only achieved by a lossy technique with a particular Q distribution, the challenge of such type of filter is achieved by desired lossy distributions during the tuning.

In this letter, we present a new type of electronically tunable microstrip dual-mode filter with nonuniform Q technique. A flat passband is achieved by using resistive loading in proper positions of a non-degenerate dual-mode resonator. Bandwidth and center frequency are then tuned by using the varactors.

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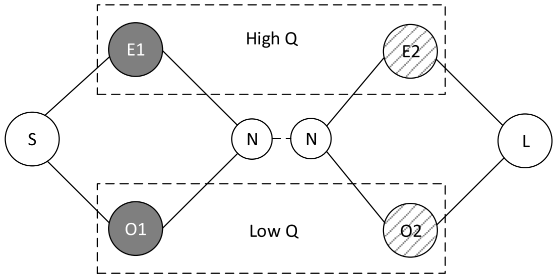


Fig. 1. Topology of a four-pole nondegenerate dual-mode lossy filter with nonresonating nodes.

II. ANALYSIS AND DESIGN

A nondegenerate dual-mode filter with transversal topology has advantage on nonuniform Q distribution with small size. The topology of the proposed filter is shown in Fig. 1. Nodes E1 and O1 represent the even and odd modes of the first non-degenerate dual-mode resonator, while E2 and O2 are the even and odd modes of the second dual-mode resonator. The even and odd modes, which operate at different frequencies and do not couple with each other, compose two separate coupling paths in a transversal topology. The nonresonating nodes are applied to get an easy control of coupling without affecting the nonuniform Q distribution.

The proposed four-pole tunable dual-mode lossy filter with a fractional bandwidth (FBW) of 10% centered at 1.6 GHz can be modeled by the coupling matrix of (1), as shown at the bottom of the next page, composed of two transversal networks in series with two nonresonating nodes. Each transversal network represents one dual-mode resonator. The dissipative loss in the filter has been included in the coupling matrix as $j\delta_0$ in diagonal manner. The value of $j\delta_{11}$ and $j\delta_{33}$ represents the added resistive loss for the low-Q resonators. The variable elements $\Delta m_{ij}(i, j = 1, 2, \ldots)$ denote the coupling variation and resonating frequency variation fulfilled by the varactors. Bandwidth reconfiguration is achieved by separating the four-node resonating frequency by Δm_{ii} with corresponding coupling variation $\Delta m_{ij}(i \neq j)$, and frequency response of a coupling matrix is calculated [10]. For a filter having an intrinsic unloaded $Q = 100$, Fig. 2 shows the matrix frequency response of bandwidth variation from 10% to 20% at 1.6 GHz, whereas the 10% FBW state has a nonuniform Q distribution of 33, 100, 25, and 100 for flat passband. The passband keeps a good flatness during the bandwidth tuning when the dispersive loss remains the same.

Fig. 3 illustrates a conceptual lossy nondegenerate dual-mode resonator. The microstrip open-loop resonator has a perturbation at the middle as shown in Fig. 3(a). Symmetrical analysis can be applied to even/odd mode. When an electrical wall is presented on the symmetrical plane, the middle of the resonator virtually connects to the ground as shown

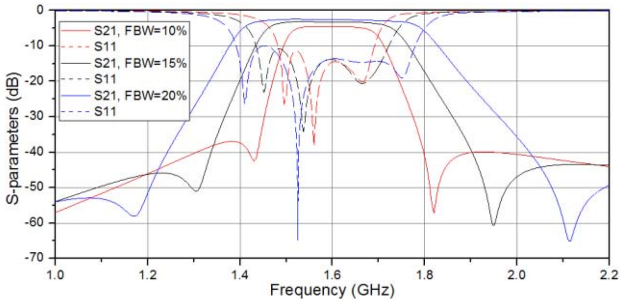
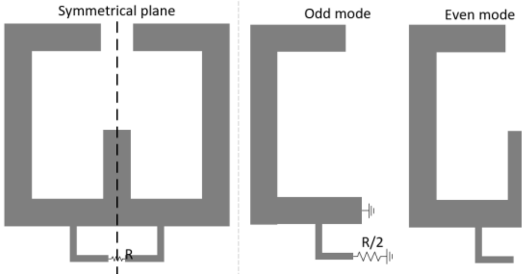


Fig. 2. Reconfigurable bandwidth characteristics of the proposed filter.



(a) (b) (c)

Fig. 3. (a) Layout of the conceptual microstrip resonator with a loading resistor. (b) Odd-mode equivalent circuit. (c) Even-mode equivalent circuit.

in Fig. 3(b). Therefore, the symmetrically loaded resistor is terminated to the ground by half of the resistance, consequently, introducing desired additional loss to the odd modes. If a magnetic wall is instead presented on the symmetrical plane, the resistor is opened out as shown in Fig. 3(c). Thus, the Q-factor of even modes remains the same. Since the electrical potential at an open end of the resonator is maximum with respect to the ground, the odd-mode Q-factor is more sensitive to the resistive loading near the open end. In addition, the odd-mode resonating frequency is more sensitive to any parasitic capacitance at the resonator open end as well. Considering the frequency shifting caused by the parasitic capacitance of the surface-mounting resistor and the tolerance of the resistance, the loading position is then chosen experimentally to release the component tolerances and to leave a space for the dc biasing circuit.

The designed layout of the proposed filter with a dc bias circuit is shown in Fig. 4. The tunability of bandwidth is provided by loading varactors C_a and C_b between the resonators to vary the coupling. Center-frequency tuning is introduced by the varactors C_{o1}, C_{o2}, C_{e1}, and C_{e2}. Note that C_{o1} and C_{o2} have effect not only on the odd-mode resonating frequency but also on the even-mode resonating frequency. The varactors C_{e1} and C_{e2} are used to adjust the even-mode resonating frequency only. A dc biasing voltage of 6 v can be found, as shown in Fig. 4, for controlling the varactors; 47-pF capacitors and 10-kΩ resistors are used for the dc block and the RF choke.

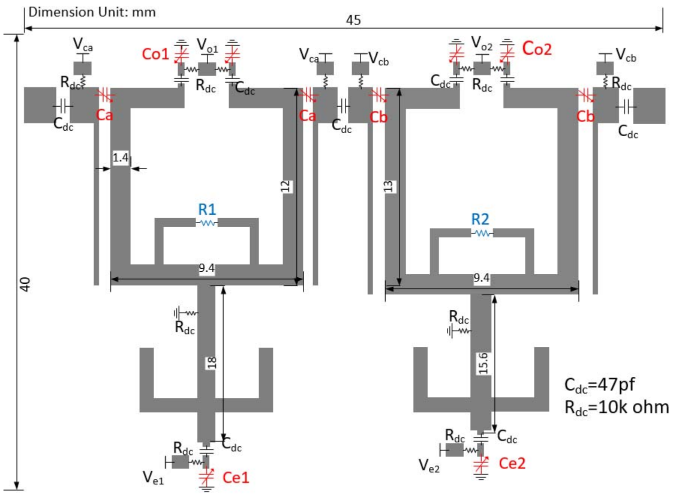


Fig. 4. Proposed microstrip filter design layout with dc biasing circuit, tunable varactor (red), and resistive loading (blue).

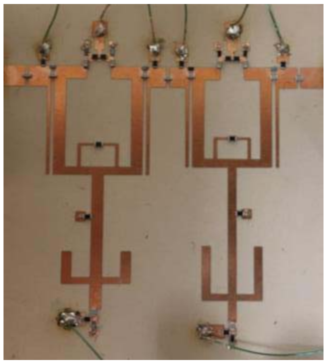


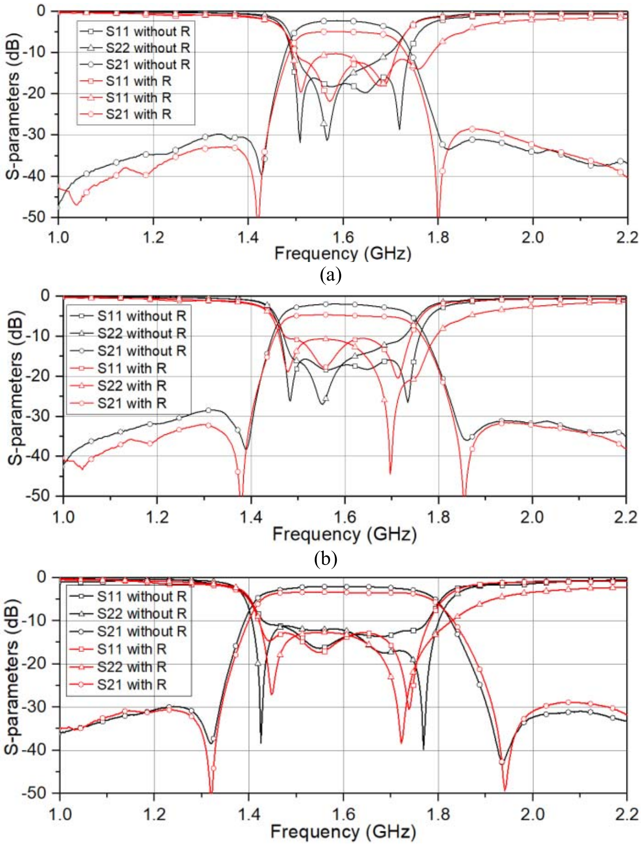
Fig. 5. Photograph of the fabricated four-pole tunable dual-mode filter with nonuniform Q distribution.

III. FABRICATION AND MEASUREMENT

A. Fabrications

A prototype filter, as shown in Fig. 5, is fabricated on RO3003 with a thickness of 1.02 mm and a dielectric constant of 3. The filter has a layout size of 40 mm × 45 mm. The variable capacitors are implemented by an MA46H120 varactor with a tuning range of 0.17–1 pF. The varactors are controlled by the dc biases ranging from 0 to 20 V. By using the full-wave EM simulation [11], the dielectric losses, losses in the metal, and Q-factor of varactors are considered. The loss introduced by the varactors is synthesized by an equivalent resistor in parallel as $R = Q_u/(\omega C)$ [10], where Q_u is the unloaded Q of varactors, ω is the frequency, and C is the capacitance of varactors. Panasonic chip resistors of 50 and 100 Ω are chosen on purpose for the desired nonuniform Q distribution. With different combinations of dc bias, bandwidth and center-frequency tuning are performed. The measurements have been obtained using a microwave network analyzer.

$$\begin{bmatrix}
0 & 0.8554+\Delta m_{s1} & 0.5805+\Delta m_{s1} & 0.01 & 0 & 0 & 0 & 0 \\
0.8554+\Delta m_{s1} & 0.9651+\Delta m_{11}-j\delta_0-j\delta_{11} & 0 & -0.8554+\Delta m_{s1} & 0 & 0 & 0 & 0 \\
0.5805+\Delta m_{s1} & 0 & -1.0159+\Delta m_{22}-j\delta_0 & 0.5805+\Delta m_{s1} & 0 & 0 & 0 & 0 \\
0.01 & -0.8554-\Delta m_{s1} & -0.5805+\Delta m_{s1} & 0 & 1.15 & 0 & 0 & 0 \\
0 & 0 & 0 & 1.15 & 0 & 0.7408+\Delta m_{21} & 0.46+\Delta m_{21} & 0.01 \\
0 & 0 & 0 & 0 & 0.7408+\Delta m_{21} & -0.6095+\Delta m_{33}-j\delta_0-j\delta_{33} & 0 & -0.7408-\Delta m_{21} \\
0 & 0 & 0 & 0 & 0.46+\Delta_{21} & 0 & 1.0667+\Delta m_{44}-j\delta_0 & 0.46+\Delta m_{21} \\
0 & 0 & 0 & 0 & 0.01 & -0.7408-\Delta m_{21} & 0.46+\Delta m_{21} & 0
\end{bmatrix} \quad (1)$$



(a)

(b)

(c)

Fig. 6. Experimental results of the proposed bandwidth tuning at 1.6 GHz. (a) FBW = 10%. (b) FBW = 15%. (c) FBW = 20%.

B. Measurements

The measured filter has a continuous bandwidth tunability from 10% to 20% with FBW at 1.6 GHz. Fig. 6(a)–(c) shows the filter tuning states 10%, 15%, and 20% with a comparison between responses before and after loading resistor. As expected, the nonuniform Q distribution by resistive loading is successfully improving passband flatness for all bandwidth states. The passband variation at 10% FBW state has been improved from 1.2 to 0.5 dB with at the expenses of 2.6-dB passband insertion loss (from 2.3 to 4.9 dB), as shown in Fig. 6(a). In Fig. 6(c), the improvement of passband variation at 20% FBW is from 1.2 to 0.7 dB with an insertion loss rising from 2.1 to 3.3 dB. The return loss within the passband of the tuned filter has been maintained less than 10 dB. An unsymmetrical return loss ($S_{11} \neq S_{22}$) is exhibited in the passband due to the asymmetric configuration of the filter. A good adjacent band attenuation is larger than 25 dB.

Furthermore, the filter also shows a good tunability on center frequency while the flat passband is preserved. As shown in Fig. 7, the filter response exhibits a tunability from 1.35 to 1.6 GHz with 10% FBW. The insertion loss variation attains 0.5 dB during center-frequency tuning with a constant insertion loss of 4.8 dB. Filter wideband responses with and without loading resistors are plotted in Fig. 8 with a center frequency of 1.6 GHz and a tuned fractional passband of 20%. A spurious resonating frequency can be found at 3.7 GHz, which is caused by the nonresonating nodes.

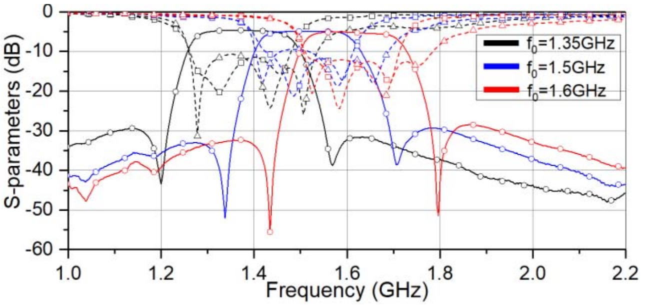


Fig. 7. Measurements of the proposed filter with loading resistor and center-frequency tuning.

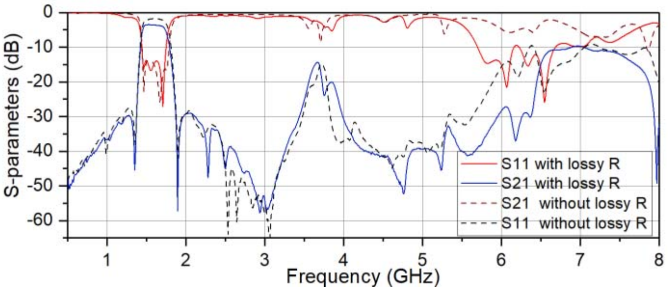


Fig. 8. Wideband response for the tunable filter with tuned 20% FBW.

IV. CONCLUSION

A new type of tunable lossy nondegenerate dual-mode microstrip bandpass filter is introduced with both bandwidth and center-frequency tuning. Varactors are used in continuous tuning of resonating frequency and coupling. The filter passband flatness can be enhanced in a simple way by loading resistors on the symmetrical plane of the resonator to reduce odd-mode Q. Measurement results have been demonstrated showing interesting characteristics.

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