

## HIGH SELECTIVITY DUAL-MODE BANDPASS FILTER WITH SOURCE-LOADED COUPLING

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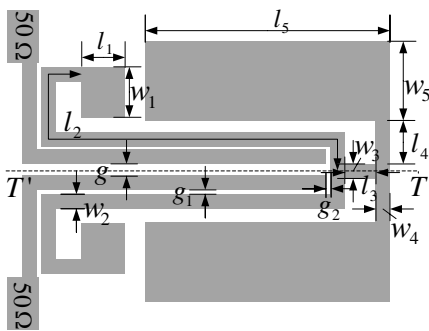
**Abstract**—In this letter, a novel high selectivity microstrip filter with source-loaded coupling is proposed using the dual-mode resonator. The resonator can generate one odd mode and one even mode in the desired band. The folded stepped-impedance open stub at the central plane can control the even mode resonant frequencies, whereas the odd mode ones are fixed. A transmission zero is created near the lower cut-off frequency due to the main path signal counteraction. Two additional transmission zeros attributed to source-loaded coupling are generated near the upper cut-off frequency and in the upper-stopband. A dual-mode filter prototype is simulated, fabricated and measured. The EM simulated and measured results are presented and excellent agreement is obtained.

### 1. INTRODUCTION

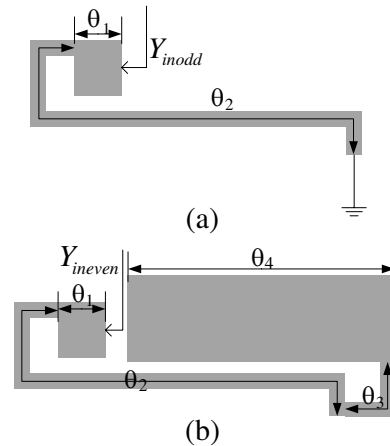
Compact, high performance microwave bandpass filters (BPFs) are highly desirable in wireless communications systems such as satellite and mobile communications systems [1]. In general, microstrip bandpass filters may be designed using single or dual-mode resonators [2]. The primary planar microstrip dual-mode filter was presented by Wolff [3], since then numerous researchers have proposed various dual-mode microstrip resonator configurations for wideband filter design [4–9]. Several types of dual-mode microstrip resonators with perturbation element have been investigated, including ring resonator [4], square-ring resonator [5], multi-arc resonators [6]. For the

aforementioned geometrically symmetrical resonators [4–6] once the modes are split by introducing a perturbation element in a resonator, there will be coupling between the two modes. Subsequently, the dual-mode resonators whose odd and even modes do not couple have been given in [7]. In order to improve the selectivity of the filter, recently, two triple-mode filters with high selectivity were presented in [8] and [9]. A filter using resonator-embedded dual-mode resonator has been given in [8]. Three transmission zeros are created to improve the selectivity and upper-stopband performances. In [9], two transmission zeros of the triple-mode filter can be obtained simultaneously near the cut-off frequencies, as two T-type open stubs are introduced into the half-wavelength stepped-impedance resonator (SIR). However, the structures are relatively complicated and the sizes are also very large.

In this letter, a novel high selectivity dual-mode filter with dual-mode resonator is proposed in Figure 1 using source-loaded coupling. The folded stepped-impedance open stub at the central plane can control the even mode resonant frequencies, whereas the odd mode ones are fixed. A transmission zero is created near the lower cut-off frequency due to the main path signal counteraction. Two additional transmission zeros attributed to source-loaded coupling are generated near the upper cut-off frequency and in the upper-stopband. Finally, one filter prototype is fabricated for experimental verification of the predicted results. The substrate used herein is RT/Duroid 5880 with a thickness of 0.508 mm, permittivity of 2.2 and loss tangent 0.0009.



**Figure 1.** Schematic of the dual-mode filter with source-loaded coupling.



**Figure 2.** (a) Odd mode equivalent circuit, and (b) even mode equivalent circuit.

## 2. PROPOSED DUAL-MODE RESONATOR

The dual-mode resonator in Figure 1 is formed by adding a folded stepped-impedance open stub with lengths  $(l_3, l_4, l_5)$  and widths  $(w_3, w_4, w_5)$  at the centre plane to the SIR denoted by lengths  $(l_1, l_2)$  and widths  $(w_1, w_2)$ . Since the resonator is symmetrical to  $T-T'$  plane, the odd-even-mode method is implemented [7]. Modal decomposition provides a deep insight to operation of the resonator. Figure 2 is the corresponding odd and even mode equivalent circuits assuming for  $w_3 = 2w_4 = 2w_2$ .  $\theta_1, \theta_2, \theta_3$  and  $\theta_4$  refer to the electrical lengths of the sections with lengths  $l_1, l_2, l_3 + l_4$  and  $l_5$  respectively.  $Y_1, Y_2$  and  $Y_3$  refer to characteristic admittances of the widths  $w_1, w_2$  and  $w_5$ . From the condition  $Y_{inodd} = 0$  and  $Y_{ineven} = 0$ , the resonant frequencies can be extracted [8]:

$$Y_2 - Y_1 \tan \theta_1 \tan \theta_2 = 0 \tag{1}$$

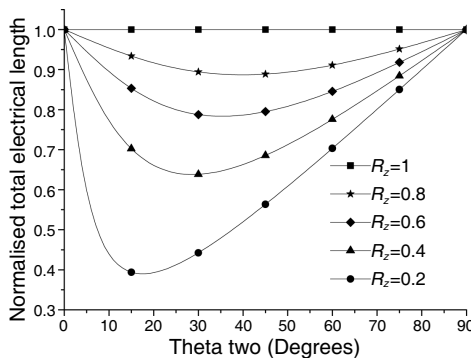
$$Y_2 Y_3 \tan \theta_4 + Y_2^2 \tan(\theta_2 + \theta_3) Y_1 Y_2 \tan \theta_1 - Y_1 Y_3 \tan \theta_1 \tan \theta_4 \tan(\theta_2 + \theta_3) = 0 \tag{2}$$

From the formula (1), the total electrical length  $\theta$  of the odd mode resonator is found to be the following:

$$\theta = \theta_1 + \theta_2 = \arctan \left( \frac{R_z}{\tan \theta_2} \right) + \theta_2 \tag{3}$$

where  $R_z$  is the impedance ratio  $Y_2/Y_1$ .

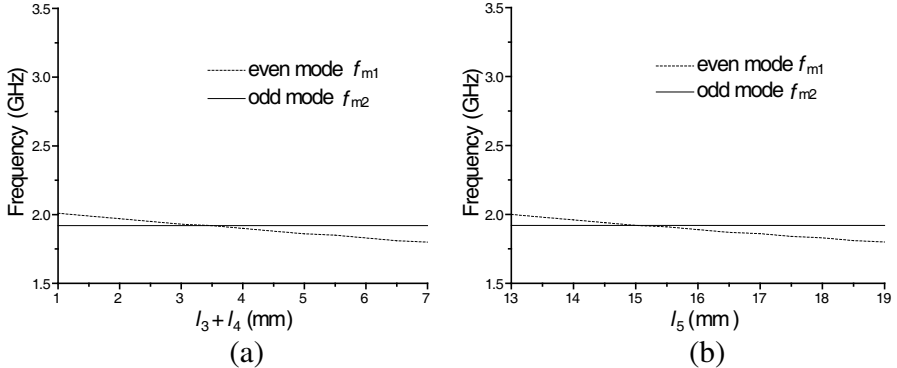
To illustrate size reduction, the variation of the normalized total electrical length  $\theta$  varied with  $\theta_2$  and different impedance ratios  $R_z$  is shown in Figure 3. It can be seen that the amount of size reduction is



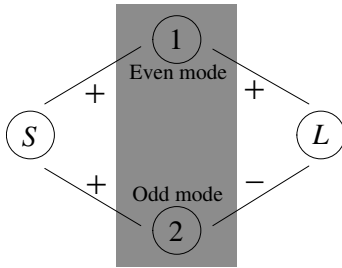
**Figure 3.** Normalized total electrical length  $\theta$  with varied  $\theta_2$  for different impedance ratios  $R_z$ .

a function of  $\theta_2$  and inversely proportional to the impedance ratio  $R_z$ . Compact size may be obtained by having an appropriate  $\theta_2$  and small impedance ratio  $R_z$ . Hence, the parameters of the odd mode resonator herein may be chose as:  $l_1 = 3$  mm,  $w_1 = 3.5$  mm,  $l_2 = 28.8$  mm,  $w_2 = 1$  mm.

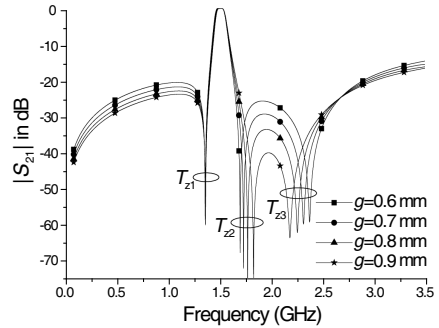
From the formulas (1) and (2), it can be found that the electrical length  $\theta_3$  and  $\theta_4$  only make an effect on the even mode resonant frequencies. The specific effects of the lengths  $l_3$ ,  $l_4$  and  $l_5$  are investigated and resonant-mode frequencies with fixed  $w_4 = 1$  mm,  $w_5 = 5.5$  mm and varied the lengths  $l_3 + l_4$  and  $l_5$  are interpreted in Figure 4. It can be seen that there are one odd mode and one even mode in the range of 0.1–3.5 GHz. As illustrated in Figures 4(a) and (b), the common characteristics can be found that as the  $l_3$ ,  $l_4$  and  $l_5$  increase, the even mode frequency  $f_{m1}$  moves towards the lower frequency, whereas the odd mode frequency  $f_{m2}$  remains stationary. Furthermore, the widths  $w_4$  and  $w_5$  have the same effects on the resonant-mode frequencies [13]. Thus, the resonant frequency  $f_{m1}$  and  $f_{m2}$  can be allocated within the desired passband by reasonably choosing the parameters of SIR and the folded stepped-impedance open stub, respectively.



**Figure 4.** (a) Resonant-mode frequencies with fixed  $w_4 = 1$  mm,  $w_5 = 5.5$  mm,  $l_5 = 17$  mm and varied  $l_3 + l_4$ . (b) Resonant-mode frequencies with fixed  $w_4 = 1$  mm,  $w_5 = 5.5$  mm,  $l_3 + l_4 = 5.1$  mm and varied  $l_5$ .



**Figure 5.** Coupling scheme of the proposed filter.



**Figure 6.** Simulated insertion losses with varied  $g$ .

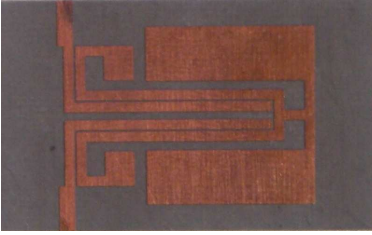
### 3. HIGH SELECTIVITY BPF WITH SOURCE-LOADED COUPLING

Based on the dual-mode resonator, the first two resonant modes  $f_{m1}$  and  $f_{m2}$  can be applied to make up of a bandpass filter, when the resonator is properly fed with increased coupling degree [10]. The parameters  $l_3 = 2.1$  mm,  $l_4 = 3$  mm and  $l_5 = 17$  mm are chose and two resonant frequencies  $f_{m1}$  and  $f_{m2}$  are 1.73 GHz and 1.80 GHz. The corresponding coupling scheme is shown in Figure 5. The coupling matrix can be expressed as:

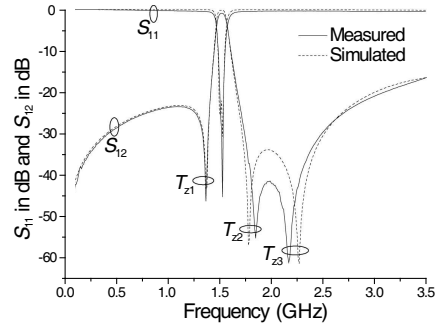
$$M = \begin{bmatrix} 0 & M_{S1} & M_{S2} & M_{SL} \\ M_{S1} & M_{11} & 0 & M_{1L} \\ M_{S2} & 0 & M_{22} & M_{2L} \\ M_{SL} & M_{1L} & M_{2L} & 0 \end{bmatrix} \quad (4)$$

As illustrated in [11], the transmission zero due to the main path signal counteraction can be shifted from one side of the passband to the other side by properly choosing the values of  $M_{s1}$  and  $M_{s2}$  as well as the signs of  $M_{11}$  and  $M_{22}$ . In this filter the even mode  $f_{m1}$  is lower than odd mode  $f_{m2}$ , so the transmission zero  $T_{z1}$  is created near the lower cut-off frequency due to the main path signal counteraction [9, 11].

Then the resonator is coupled to  $50 \Omega$  input/output capacitive coupling feeding lines under the tight coupling case with  $g_1 = 0.2$  mm. Under the length  $l_2$  unchanged, the insertion losses ( $|S_{21}|$  in dB) with varied  $g$  are simulated by HFSS and illustrated in Figure 6. Two additional transmission zeros  $T_{z2}$  and  $T_{z3}$  are created near the upper cut-off frequency and in the upper-stopband owing to source-loaded coupling [8, 12]. As  $g$  increases, the transmission zero  $T_{z2}$  is far from the upper cut-off frequency and  $T_{z3}$  moves towards the upper cut-off



**Figure 7.** Photograph of the implemented filter.



**Figure 8.** Simulated and measured frequency responses of the dual-mode filter.

frequency. Considering the out-band performances, we may choose the parameter  $g = 0.8$  mm.

After studying the characteristics of the dual-mode filter with source-loaded coupling, a novel high selectivity filter is fabricated on the RT/Duroid 5880 substrate through the standard PCB process and the fabricated filter photograph is shown in Figure 7. The filtering performance is measured by Agilent network analyzer N5230A. The simulated and measured frequency responses shown in Figure 8 are found in good agreement with each other. The measured  $-3$  dB passband is in the range of 1.48 to 1.57 GHz and its measured input return loss ( $|S_{11}|$  in dB) is less than  $-23.4$  dB. Three transmission zeros ( $Tz_1$ ,  $Tz_2$ ,  $Tz_3$ ) are located at 1.43 GHz, 1.88 GHz and 2.23 GHz resulting in sharp skirt, with an attenuation level of less than  $-47$  dB. The upper-stopband in experiment is extended up to 3.5 GHz with an insertion loss better than  $-18.2$  dB.

#### 4. CONCLUSION

In this letter, a novel high selectivity microstrip filter with source-loaded coupling is designed by using the dual-mode resonator. The folded stepped-impedance open stub can control the even mode resonant frequencies, whereas the odd mode ones are fixed. Due to the main path signal counteraction and source-loaded coupling, three transmission zeros are created near the cut-off frequencies and in the upper-stopband, leading to a high selectivity. A filter prototype is fabricated to demonstrate the predicted performances in experiment.

## ACKNOWLEDGMENT

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