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COMPACT DUAL-MODE FILTER USING MEANDER SHORTED STUB LOADED RESONATORS

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Abstract—To reduce the size and improve the performance, a 4th-order miniaturized dual-mode microstrip bandpass filter (BPF) is developed. A meander shorted stub loaded resonator is used, and much compact size is obtained. Theoretical model is set up, and the odd and even modes of the BPF are analyzed based on a symmetrical structure. Full wave simulation validates the design method. To verify the design, a fabricated BPF sample has been tested. Experiment result demonstrates that the designed BPF has wider stopband and better selectivity. Its fractional bandwidth and a center frequency are available.

1. INTRODUCTION

In modern wireless communication systems, smaller size and better performance of devices are much required. Especially, multiple frequencies operation for the system has drawn attention. A bandpass filter (BPF) plays an important role in the communication devices. It can be designed as a multiple mode circuit. A dual-mode resonator can be employed as a doubly tuned circuit. Therefore, a dual-mode BPF can be designed by using this resonator [1], and the number of resonators can be reduced by half for those prescribed filters, resulting in a circuit with more compact structure in size. To the best of our knowledge, a dual-mode microstrip resonator was firstly developed by Wolff [2]. After that, some different geometric structures of dual-mode patch and loop resonators were developed by other researchers [3–8]. To design this circuit efficiently, a small perturbation method is introduced to the analysis of resonator. If a perturbation element is added into the resonator, a coupling between two modes of the

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resonator is determined by the size of element. Recently, a dual-mode open-loop resonator with a loaded element has been used for miniaturization of the dual-mode microstrip filters [9]. With loaded element inside the dual-mode open loop, the resonant frequency of loop resonator can be changed, but the size of profile of the loop resonator is not changed. Compared to the dual-mode patch, if a loaded element is added to the patch, the resonant frequency is changed, and the size of the profile of patch must be changed, therefore, the whole size of the patch is increased. According to Hong and Lancaster [7], the size of an open-loop resonator is approximate to one-quarter of the close-loop resonator. Clearly, the size reduction is significant. However, the present dual-mode filter configurations still occupy a large area. They are not quite suitable for the requirement of wireless communication system where size is a very important issue. Therefore, we have to find a new circuit with better performance and much smaller size than before.

In this paper, a meander shorted stub loaded resonator (SSLR) is designed to realize a miniaturized dual-mode BPF. The SSLR structures have been improved. Properties of the proposed resonator are analyzed theoretically and confirmed by full-wave simulation. A 4th-order dual-mode BPF has been designed based on the proposed structure, which is much more compact than the conventional dual-mode filters [10, 11]. The fabricated sample has been tested. Experiment result shows very good agreement with simulation.

2. DUAL-MODE RESONATOR IMPROVEMENT

The basic structure of a SSLR consists of a conventional microstrip half wavelength resonator and a shorted stub as shown in Fig. 1(a), where Y_1 and Y_2 denote the characteristic admittances, and L_1 and L_2 indicate lengths of the microstrip line and shorted stub, respectively. The shorted stub is shunted at midpoint of the microstrip line. Since the SSLR is a symmetrical structure, odd and even mode analysis can

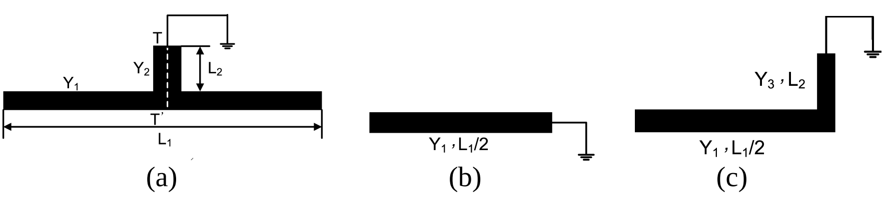


Figure 1. (a) Basic structure of the SSLR, (b) odd-mode equivalent circuit, and (c) even-mode equivalent circuit.

be adopted to characterize it.

For the odd mode excitation, the symmetry plane will be short circuited, whose equivalent circuit is given in Fig. 1(b). The resulting input admittance for odd mode can be expressed as

$$Y_{in,odd} = \frac{Y_1}{j\tan(\beta L_1/2)} \tag{1}$$

where β is propagation constant of the mode. From the resonance condition $Y_{in,odd} = 0$, the resonant frequencies can be deduced as

$$f_{odd} = \frac{(2n-1)c}{2L_1\sqrt{\varepsilon_{reff}}} \tag{2}$$

where $n = 1, 2, 3\ldots$, c is the speed of the light in free space, and ε_{reff} denotes the effective dielectric constant of the microstrip line. It can be observed that the odd-mode resonant frequencies are not influenced by the shorted stub.

For the even mode excitation, the symmetry plane will be open-ended, whose equivalent circuit is shown in Fig. 1(c). The input admittance for even-mode can be approximately expressed as

$$Y_{in,even} = jY_1\frac{-Y_3 + Y_1\tan(\beta L_1/2)\tan(\beta L_2)}{Y_3\tan(\beta L_1/2) + Y_1\tan(\beta L_2)}, \tag{3}$$

the resonant frequencies can be derived, then we have

$$-Y_3 + Y_1\tan(\beta L_1/2)\tan(\beta L_2) = 0. \tag{4}$$

For a convenient compact structure, $Y_3 = Y_1$ has been chosen. The even mode resonant frequencies can be obtained from (4), and we have

$$f_{even} = \frac{(2n-1)c}{(2L_1 + 4L_2)\sqrt{\varepsilon_{reff}}}. \tag{5}$$

From Equations (2) and (5), it can be concluded that when $L_2 = 0$, the odd- and even-modes exhibit the same frequencies, and the resonator has a single-mode in this case. If $L_2 > 0$, the odd- and even-modes are split, which illustrates the dual-mode formed.

To make the size of circuit much smaller with lower frequency operation, a meander SSLR is adopted based on the structure above. By folding the half wavelength line, the SSLR is modified, as shown in Fig. 2 and formed with a meander open-loop. Odd-mode and even-mode effective circuits for the structure can also be picked-up from the figure. The two modes have been depicted in Figs. 1(b) and (c). Briefly, the whole structure of the meander SSLR is analyzed by using the commercially available circuit simulator, such as computer aided design software High Frequency Structure Simulator (ANSYS

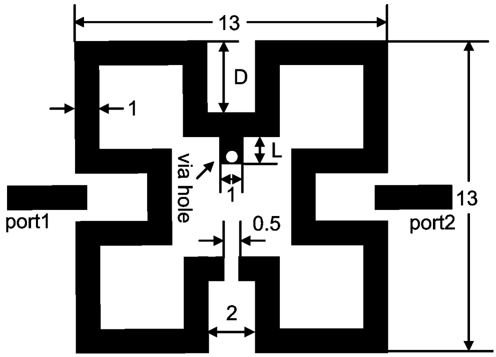


Figure 2. Layout of the meander SSLR with dimensions in millimeter.

HFSS) [12]. The model of the proposed meander SSLR is discussed as follows.

A layout of the meander SSLR is depicted in Fig. 2, which is placed on a Taconic RF60 dielectric substrate with a relative effective dielectric constant $\varepsilon_r = 6.15$, loss tangent 0.0028, and thickness 0.64 mm. The D is the length of dents of the meander SSLR, and an added shorted stub, L is tapped from inside onto the meander open-loop. When the L is changed, the resonant characteristic is also changed. To obtain the response of resonant frequency for the odd- and even-modes, the HFSS software has been used. To excite the resonator, two ports are weakly coupled to it. Simulated results are given in Fig. 3(a) when $D = 2$ mm. From the figure, L varies from 0.5 to 2.5 mm, the resonant frequency of the even-mode decreases from 1.06 to 0.94 GHz, while the odd-mode is almost unchanged. From the discussion of Equations (2)–(5), we find resonant frequency of the even-mode is affected when L is changed, but that of the odd-mode is unaffected.

In order to check the folded SSLR with the reduction of circuit size, we change the size of D while $L = 0.5$ mm, with other dimensions unchanged. The simulated results are given in Fig. 3(b). From the figure, it is found that D increases from 0.0 to 3.0 mm, the even and odd mode resonant frequencies decrease from 1.43 to 1.06 GHz and from 1.52 to 1.11 GHz, respectively. Therefore, with meander SSLR, the lower frequency can be obtained. The size reduction of the modified SSLR structure has been implemented.

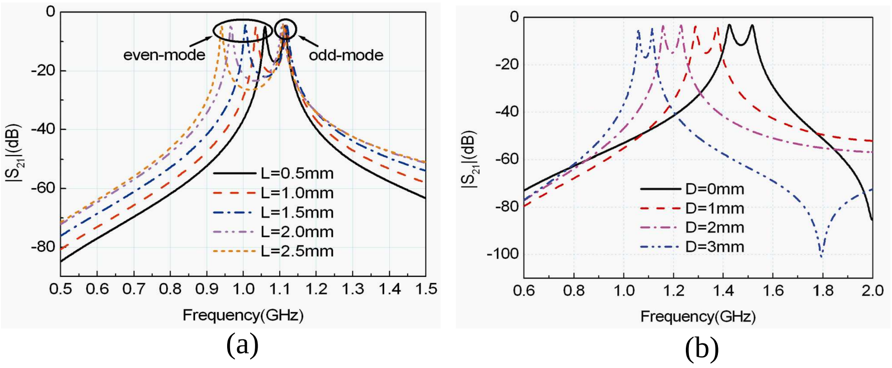


Figure 3. Frequency responses of the meander SSLR, (a) the L is changed while $D = 2\,\text{mm}$, and (b) the D is changed while $L = 0.5\,\text{mm}$.

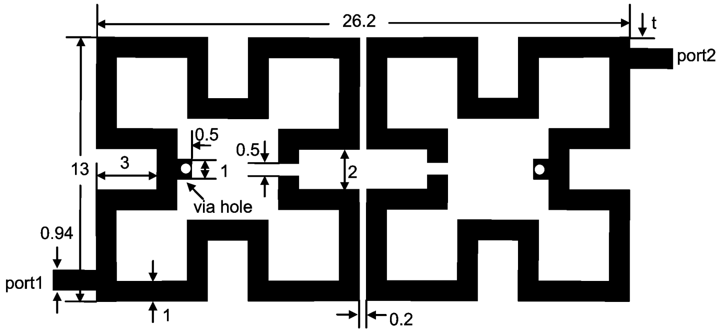
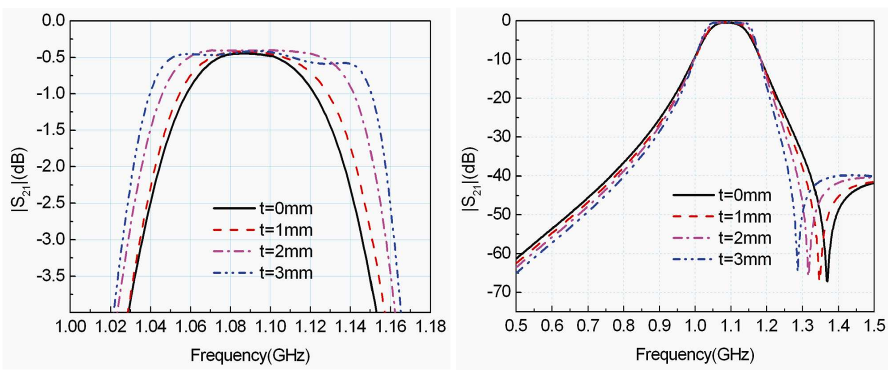


Figure 4. Layout of the miniaturized 4th-order BPF with dimensions in millimeter.

3. FILTER IMPLEMENTATION

To verify the usefulness of the proposed method, a microstrip BPF is designed. It must be mentioned that 1.09 GHz is an important military frequency. The configuration of the miniaturized 4th-order BPF is depicted in Fig. 4, which is operated at the center frequency of 1.09 GHz. This circuit consists of a pair of meander SSLRs and the electric coupling structure is chosen. Input and output ports are implemented based on $50\,\Omega$ taped-line structures. According to analysis of Equations (2) and (5), the dimensions of the proposed structure have been confirmed after we optimize the design process.

The design philosophy is validated by using simulation and fabrication for the practical application, and the same substrate is chosen as the basic material for both. In Fig. 4, the positions of input and output ports are checked first. t is a main parameter to be viewed. Transmission loss (S_{21}) between two ports is simulated. When t increases from 0.0 to 3.0 mm, as shown in Fig. 5(a), the fractional bandwidth increases from 0.10 to 0.14. Thus the proposed filter can be designed as a certain bandwidth by properly setting the tapped position. Meanwhile, the transmission zero moves from 1.37 to 1.29 GHz for the same increase of t. This result is shown in Fig. 5(b). There is a transmission zero allocated at a frequency close to the



(a) (b)

Figure 5. Simulated frequency response of the proposed filter in (a) passband and (b) wide band.

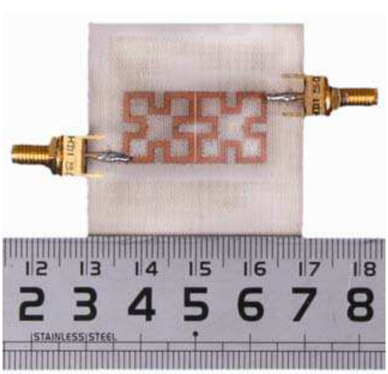


Figure 6. Photograph of the fabricated filter.

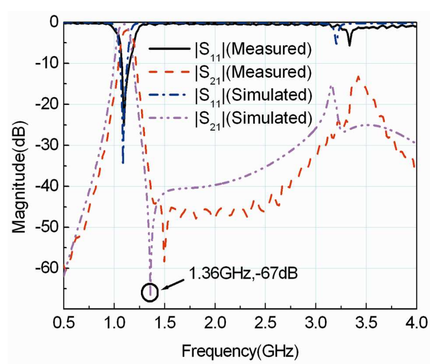


Figure 7. Measured and simulated frequency response of the proposed filter.

upper edge of the passband. Therefore, increasing the size of t, we can improve the selectivity of the proposed filter even more.

The fabricated BPF sample has been photographed in Fig. 6. The filter size amounts only to $13\times 26.2\,\mathrm{mm}^2$, equivalent to $0.0755\times 0.152\lambda_g^2$, where λ_g is the guided wavelength on the substrate at the center frequency. Hence, the proposed filter achieves relative size reduction of 68%, 88%, and 93% compared to the conventional dual-mode filters using open loop [9], meander loop [8], and square loop [7], respectively, whose operating frequencies are around the same bands.

The sample is measured in our laboratory using the AV3629 vector network analyzer. Results are depicted in Fig. 7. Simulation results are given in the same figure to compare with the experiment. Owing to a tolerance in the fabrication, the measured center frequency is 1.13 GHz, slightly larger than the simulated result 1.09 GHz. For the 3 dB power decrease, the measured fractional bandwidth is 0.11, approximately equal to the simulated result. For minimum insertion loss, measured result is 1.85 dB, larger than simulated 1.41 dB. The otiose loss is due to circuit loss including conductor and dielectric losses. It is sustainable within the real applications. The measured and simulated return losses at their center frequencies are better than 20 dB. The first spurious response is measured at 3.42 GHz, 3 times of the fundamental frequency. Thus, a wide stopband is achieved. Approvingly, there is a transmission zero allocated at 1.36 GHz as expected.

Simulated current distribution is carried out at the 1.36 GHz. Results are illustrated in Fig. 8. It is clear that one arm of the first dual-mode resonator resonates at this frequency, which presents a short circuit at the input, resulting in the transmission zero and observed in Fig. 7. Practically, measurement results show very good agreement with the simulation. The useful design method has been verified by this example.

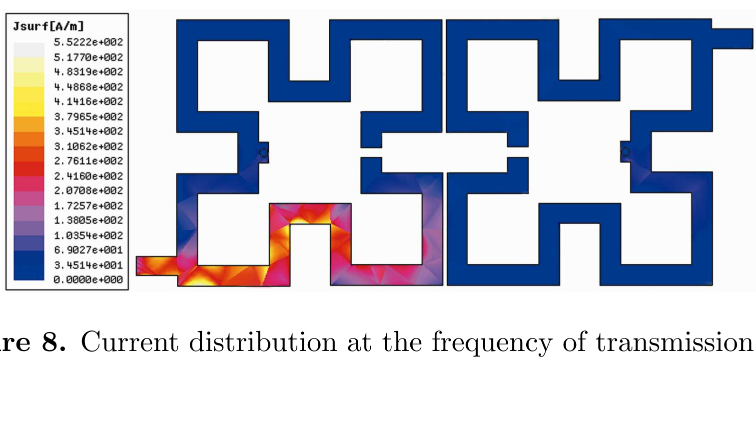


Figure 8. Current distribution at the frequency of transmission zero.

4. CONCLUSION

A much compact meander SSLR has been designed to build up a 4th-order dual-mode microstrip BPF. On the basis of odd and even mode analysis, it is found that when the length of the shorted stub of the SSLR is increased from 0, the two modes split. As a result, a dual-mode resonator is achieved from a single-mode resonator. The newly designed filter has wider stopband. Compared to conventional dual-mode filters in [7–9] operated around the same frequencies, the size reduction of proposed one is 93%, 88%, and 68%, respectively. The first spurious response is 3 times of the fundamental frequency. Meanwhile, the selectivity of the proposed filter is very high as there is a transmission zero allocated at a frequency close to the upper edge of the passband.

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