Compact Half-Mode Triple-Band Bandpass Filter by using Stepped Impedance Resonators with Grounding Via Holes

Ceyhun Karpuz
Department of Electrical and Electronics Engineering
Pamukkale University
Denizli, Türkiye
ckarpuz@pau.edu.tr

Pınar Öztürk Özdemir
Air Force Academy
National Defence University
İstanbul, Türkiye
oozdemir33@hho.msu.edu.tr

Hasan Hüseyin Balık
Faculty of Electrical Electronics & Computer Engineering
Yildiz Technical University
İstanbul, Türkiye
hasanbalik@gmail.com

Alperen Cengiz
Department of Electrical and Electronics Engineering
Pamukkale University
Denizli, Türkiye
cengizalper118@gmail.com

Adnan Görür
Department of Electrical and Electronics Engineering
Nigde Omer Halisdemir University
Niğde, Türkiye
adnangorur@hotmail.com

2023 IEEE Radio and Wireless Symposium (RWS) | 978-1-6654-9344-4/23/$31.00 ©2023 IEEE | DOI: 10.1109/RWS55624.2023.10046318

***Abstract*— This letter presents a half-mode triple-band bandpass filter based on folded stepped impedance resonator stub. Also, an interdigital structure with lumped capacitance is added to the circuit to obtain a compact-size filter while maintaining the filtering characteristics. The utilization of the lumped capacitor at the middle point of the interdigital structure contributes to the shift down of the higher modes. Thus, an extra passband generates at the operating frequency range. Also, more reduced size is achieved by using a half-mode circuit.**

Keywords*— *triple-band, stepped impedance resonator, half-mode, bandpass filter.

I. Introduction

Multiband filters are among the attractive circuit components due to the increasing demand for capacity in the multi-standard communication system. Triple-band filter is indispensable and an essential building block in multi-band systems. There are many approaches for designing triple-band filters in the literature [1-3]. In [1], a triple notch-bands ultra-wideband band-pass filter based on an E-shaped resonator and open-load stubs is presented. The eventual circuit occupies quite a large area since the E-shaped resonator is coupled to the filter with open-load stubs to achieve a triple-notch bandpass filter. A tri-band bandpass filter [2] is realized by stepped impedance resonators and uniform impedance resonators. The proposed configuration has a large total surface area and poor performance in terms of insertion losses.

In this paper, a half-mode triple-band bandpass filter is presented. The proposed half-mode circuit is accomplished by cutting the conventional filter circuit along the symmetrical plane, which can be considered an equivalent magnetic wall. In this case, the half-mode configuration exhibits the same field

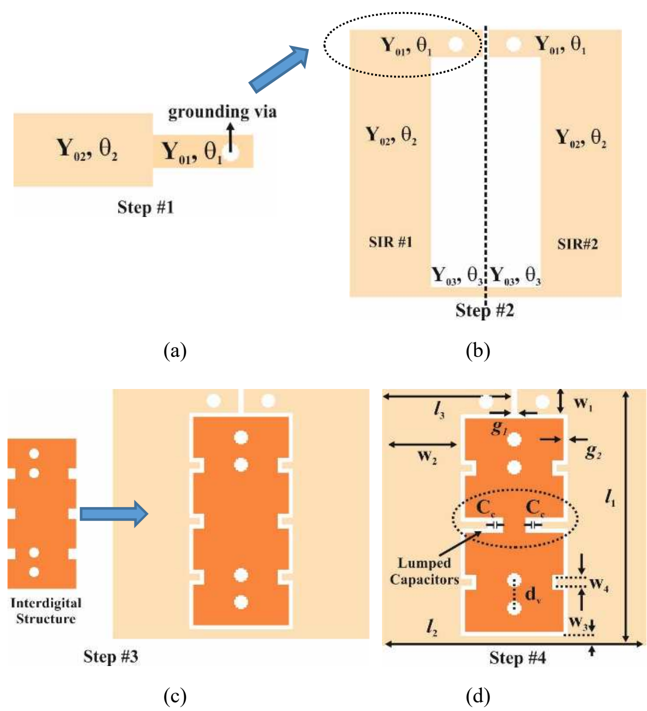


Fig. 1. Design steps and layout of the a) short circuited SIR b) dual-band SIR bandpass filter c) dual-band interdigital loaded SIR bandpass filter d) triple-band interdigital loaded SIR bandpass filter.

distribution as the main structure. Therefore, half-mode filter circuits can be used instead of the conventional filter circuit to reduce size. The proposed filter consists of two short-circuited SIR stubs and a connecting line between the I/O ports. Adding an interdigital structure to the circuit achieves triple-band performance. Furthermore, it provides miniaturization by the slow wave effect.

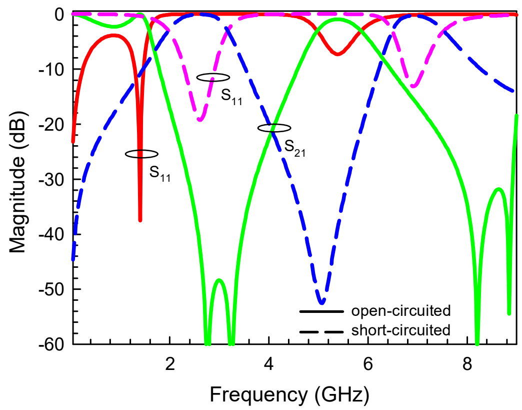


Fig. 2. The effect of the grounding vias on the folded SIR structure.

II. Filter Design Methodology

A. Stepped Impedance Resonator Analysis

The first step of the design is the short-circuited stub loaded stepped impedance resonator (SIR) analysis. The SIR is composed by combining the short-circuited low admittance (Y_{01}) line having an electrical length of θ_1 and a high admittance (Y_{02}) line with an electrical length of θ_2, as illustrated in Fig. 1(a). The input admittance of the SIR can be expressed as,

$$Y_{in} = Y_{02}\frac{Y_{01} - Y_{02}\tan(\theta_1)\tan(\theta_2)}{jY_{02}\tan(\theta_1) + jY_{01}\tan(\theta_2)}. \quad (1)$$

From the resonance condition (Im(Yin=0)), the admittance ratio can be extracted as in (2).

$$K = \frac{Y_{01}}{Y_{02}} = \tan(\theta_1)\tan(\theta_2) \quad (\text{at } f = f_0). \quad (2)$$

It can be seen from (2) that the passband location is controlled by the geometrical parameters of the SIR [3].

B. Design of the Dual-Band Bandpass Filter

The layout of the dual-band bandpass filter using the stepped impedance resonator with short-circuited stub is given in Fig. 1(b). The proposed dual-band structure is designed by using two SIRs connected by a transmission line between the I/O ports. The SIRs are folded to obtain size reduction. As can be seen from Fig. 1(b), the folded SIRs are terminated as a short circuit to achieve the dual-band characteristic. To demonstrate the effect of the grounding vias, the two folded SIR structures with a short and open-circuited stub are simulated by a full wave electromagnetic simulator [4]. Fig. 2 shows the effect of the grounding vias on the folded SIRs. The utilization of the grounding vias provides dual-band characteristic while also causing the shift to the higher resonance frequencies.

All parameters (Y_{01}, Y_{02}, Y_{03} and θ_1, θ_2, θ_3) that determine the K admittance ratio is very effective in determining the fundamental resonance frequencies. The simulated frequency responses versus different characteristic admittances (Y_{02}) are investigated in Fig. 3 to exhibit the relations between the resonance frequency and the admittance ratio. It is well known that the characteristic admittance of the line decreases if the width of the related line reduces since the capacitance per unit length decreases. Therefore, the change of the Y_{02} characteristic admittance is given depending on the different w_2 values in Fig. 3. Only one parameter (w_2) is changed while the other parameters are kept fixed to simplify the comparison. Also, both bandwidths can be controlled from left side of the passband as shown in Fig. 3. It should be noted that the bandwidth of the second passband rapidly changes.

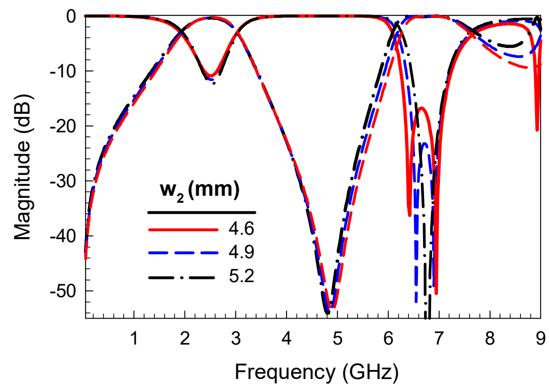


Fig. 3. Simulated frequency responses versus the characteristic admittances (Y_{02}) depending on the w_2 variation.

The distance between the grounding vias which are placed on the interdigital structure affects only the second passband, as can be seen in Fig. 4. It means that the second passband can be controlled independently.

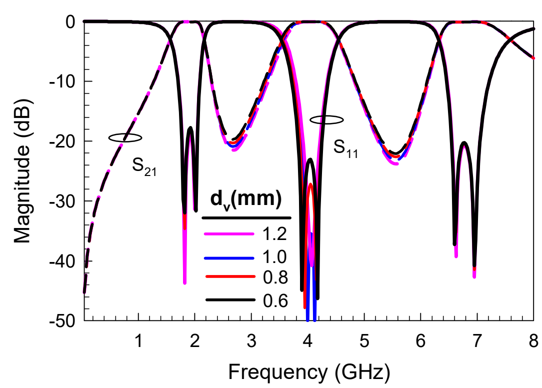


Fig. 4. Simulated frequency responses versus the distance between grounding vias on the interdigital structure (d_v).

C. Design of the Triple-Band Bandpass Filter

The proposed triple-band filter circuit consists of two short-circuited SIRs stubs connected to each other with a transmission line, an interdigital structure with grounding vias, and the lumped capacitors connecting the interdigital structure and the resonator. To further explain the steps of the design, the simulated results of the development stages depending on Fig. 1 are given in Fig.5. It should be noted that the filtering characteristic is preserved in the operating frequency range when passing from Step #2 to Step #3. To summarize, two passbands are obtained through the vias added on the folded SIRs configurated depending on the admittance ratio in the design. The interdigital loading contributes to the shift down of the higher modes since it increases the capacitive effect of the resonator using the slow wave effect. It can be observed from Fig.5 that these modes are arranged as the second passband by adjusting the value of the attached lumped capacitors between the resonator and the interdigital structure.

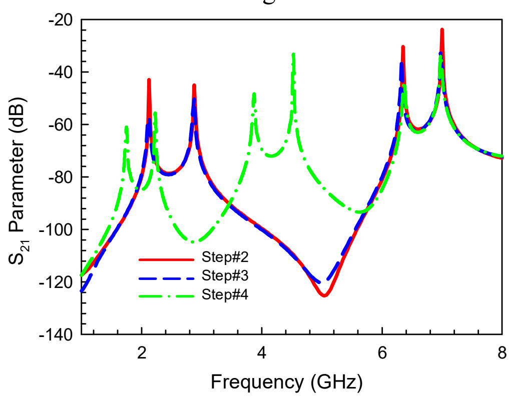
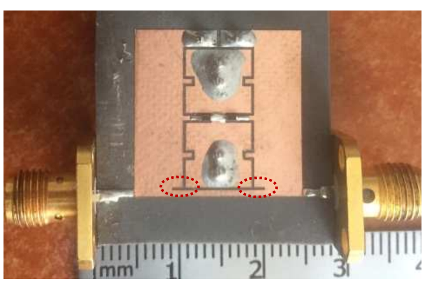


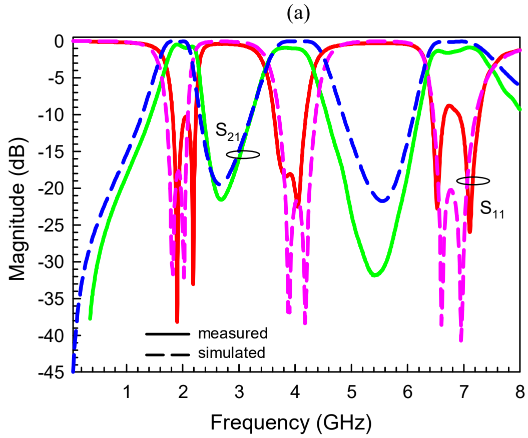
Fig. 5. Simulated results with a weak coupling for the development stages.

III. Experimental Study

To demonstrate the proposed approach, a triple-band bandpass filter has been designed and fabricated on an RT/Duroid 5880 substrate with a thickness of 0.51 mm and a relative dielectric constant of 2.2. A photograph of the fabricated filter is shown in Fig. 6(a).



(a)



(b)

Fig. 6. a) Photograph of the facricated half-mode triple-band bandpass filter circuit b) the comparison of the simulated and measured results.

The overall size of the designed filter is about $0.215\lambda_g$ x $0.175\lambda_g$. λ_g is the guided wavelength at the measured center frequency of the first passband. All physical dimensions of the filter are given in Table I. The diameter of the grounding vias is 1.0 mm. The capacitance of the lumped capacitor is taken as 2.0 pF. Measurement has been performed by a Vector Network Analyzer Keysight N5222A PNA. The comparison of the measured and simulated results is depicted in Fig. 6(b). According to the measured results, the center frequencies of the passbands are 2.07 GHz, 3.93 GHz, and 6.83 GHz with insertion losses of approximately -0.93 dB, -0.97 dB, and 1.42 dB, respectively. The gap, which is marked by the red dashed line in Fig. 6(a), is extended towards the resonator to adjust the return loss level at the center frequency of all passbands.

TABLE I. Dimension of the Fabricated Half-Mode Triple-Band Bandpass Filter

w_1	w_2	w_3	w_4	l_1	l_2	l_3	g_1	g_2	d_v
1.9	5.6	0.7	0.5	18.8	18.5	9.2	0.4	0.3	0.8

(All dimension in mm.)

IV. Conclusion

The half-mode triple-band bandpass filter configuration has been presented in this letter. The first and third passbands have been realized by connecting the two short-circuited stepped impedance resonators. Dual-band response is achieved by using grounding vias on the folded SIR stubs. It is possible to achieve the dual passband (first and third) using the same surface area without the need for an extra resonator circuit in this way. This property is quite critical for reducing the size of microwave components. In addition, the capacitance effect per unit length is increased through the capacitors placed between the interdigital structure and the resonator. Thus, an extra (second) passband has been obtained by moving the two higher modes to the operating frequency range. The half-mode triple-band filter design parameters have been described in detail by using a full-wave electromagnetic simulator. The configuration of the interdigital loaded SIR with lumped capacitors has been designed and performed to demonstrate its validity.

Acknowledgment

This work was supported by the Scientific and Technological Research Council of Turkey (TUBITAK) under Grant 120E101.

References

[1] X. Zheng, and T. Jiang, "A novel triple notch-bands UWB band-pass filter using E-shaped resonator and open-load stubs," IEEE 6th International Symposium on Microwave, Antenna, Propagation, and EMC Technologies (MAPE), pp. 570-573, 2015.

[2] S. Zhang and L. Zhu, "Compact Tri-Band Bandpass Filter Based on λ/4 Resonators With U-Folded Coupled-Line," IEEE Microwave and Wireless Components Letters, vol. 23, no. 5, pp. 258-260, May 2013.

[3] M. Makimoto and S. Yamashita, Microwave Resonators and Filters For Wireless Communication: Theory, Design, Application. New York: Springer, 2000, pp. 19-30.

[4] EM User's Manual, *Sonnet Software*, Inc, Liverpool, NY; 2008.