Compact Dual-band Parallel Coupled T-shaped SIR Filter for WLAN Applications

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Abstract

In this article, a new compact dual-band bandpass filter was introduced. The filter utilized two operating bands centered at 2.45 GHz and 5 GHz widely used for wireless local area network applications. The filter consists of T-shaped sections of step impedance resonator. The structure is an even symmetrical around electrical or magnetic wall, so the operation mechanism of the filter can be analyzed by an even- and odd-mode transmission line theory. The resonator structure is parallel coupled to a pair of 50 Ω input/output ports. Proper feeding and coupling structures can realize at least two transmission zeros around each of the operating band. To enhance the spurs rejection in the out of the band response of the filter, additive transmission zero at 10 GHz was created by adding stub of quarter guided wavelength at a selected distant from the output port edge. The filter is designed and optimized using the full wave Electromagnetic simulator. The center frequency of the designed bands can be easily refined by the filter dimensions. The overall dimension of the filter is $0.3\lambda_g \times 0.48\lambda_g$ (where λ_g is the guided wavelength at the frequency of 2.45 GHz) corresponding to 14.3 mm x 22 mm.

Keywords: SIR resonator, microstrip bandpass filter, WLAN applications, dual-band filter

1. Introduction

Growing expansion of modern wireless communication systems motivates the researchers to concentrate their research topic on compact multi-band operation. Bandpass filters are essential circuit's of microwave structures. Recent trends are towards compact size and high performance resonator structures of printed planar microwave filters.

Stepped impedance resonators (SIR) are one way to dramatically reduce size and miniaturization of microstrip bandpass filters [1]. Sophisticated versions of SIR's have been applied to filter design looking for multi-band, compactness and wide upper stopband behavior [2,3]. Serious and essential work in the design of SIR filters are presented by Makimoto and Yamashita in 1980 [4]. Design formulas for band pass filters using parallel coupled stripline stepped impedance resonators (SIR) are derived. Their formulas take into accounts the arbitrary coupling length as well as quarter wavelength coupling.

A magnetically coupled bandpass filter using two pairs stepped impedance hairpin resonators and magnetically coupling is described in [5]. The result of the filter demonstrates compact size, a very low insertion and spurious response can be suppressed effectively. A compact microstrip cross-coupled bandpass filters realized by miniaturized stepped impedance resonators (SIR's) are proposed by [6]. The proposed cross-coupled filter not only has a compact size but also has high-selectivity and a very wide stopband response.

In [7], a periodic stepped-impedance ring resonator (PSIRR) is proposed to design dual-mode bandpass filters with a miniaturized area and desirable upper stopband characteristics. Microstrip triple band tri-section bandpass filter using stepped impedance resonators (SIRs) is designed, simulated, built for the first time using hair pin structure [8]. It is shown that the coupling effect between SIRs can be used as a knob to obtain better performing bandpass filter for the desired frequency band.

A compact dual-band SIR based bandpass filter using a multimode resonator (MMR) is proposed. The MMR is composed of two pairs of short-ended coupled-lines, two pairs of open-ended coupled lines and four connecting transmission lines [9]. The design is resulting in controllable dual bands and wide upper-stopband suppression. In [10], a multiband band-pass

filter based on the resonant characteristics of step-impedance and inter-digital capacitor resonators was proposed. This design leads to compact size and good filter performance.

In [11] a bandpass filter was designed using U shape resonator as hairpin resonator. The bandpass filter has the center frequency of 400 MHz. In this frequency, filter acquires quite a long resonator line, so the compact filter is nedded. In order to reduce the dimension of filter, the filter only two U shape resonators that arranged series with couple feed line were used. Besides that, the model used via ground holes designed in both of the line resonator and the substrate with higher dielectric constant was used.

Stepped impedance resonators (SIR), in addition to being compact, also are used for harmonics suppressions. In [12], T-Shaped SIR was used for harmonics suppression and their applications for diplexer. In [13], a broadband microstrip bandpass filter with compact size, sharp skirt and wide upperstopband performance was proposed using the triple-mode resonator loaded with two folded stepped-impedance open and short-circuited stub. The resonator can generate one odd mode and two even modes in the desired passband.

This study synthesizes dual-band bandpass filter based on single T-shaped SIR with controllable center frequencies used for wireless local area network (WLAN) applications. Compactness has been achieved by using single SIR to excite dual-band in the resonator. So, the total length of the resonators has been reduced.

2. Analysis of T-Shaped SIR Resonator

The T-shaped SIR resonator is shown in Figure 1. As the structure of the resonator is symmetrical along the electrical or magnetic wall, then even-odd method can be used for simplifying the analysis of the equivalent circuit as shown in Figure 2. Here, θ_1 and θ_2 are electrical lengths of the two sections, and Y_1 and Y_2 are the characteristic admittances corresponding to the sections impedances Z_1 and Z_2 respectively. As depicted in Figure 1, the resonant modes of the designed SIR can be modeled and evaluated by the transmission line theory. The input admittance can be determined by [14]:
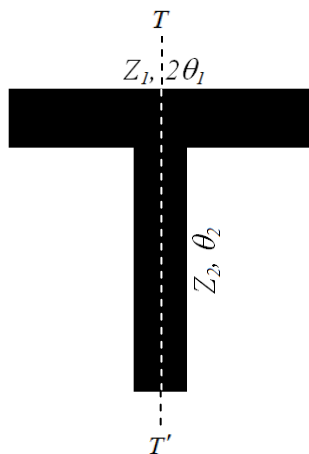

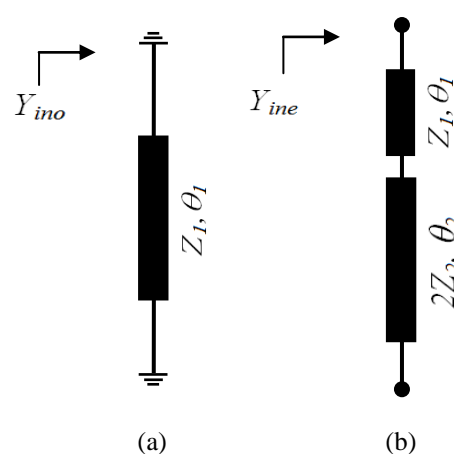Figure 1. Configuration of T-shaped SIR resonator

Figure 2. Equivalent Circuits for Analysis (a) Odd Mode (b) Even Mode

$$Y_{in} = -jY_2 \frac{Y_1 - Y_2 \tan\theta_1 \tan\theta_2}{Y_2 \tan\theta_1 + Y_1 \tan\theta_2} \tag{1}$$

When Y_{ino} enforced to zero, then the odd mode analysis of Figure 2(a) gives:

$$\tan\theta_1 = 0 \tag{2}$$

Similarly when $Y_{ine} = 0$, the even mode analysis of Figure 2(b) leads to:

$$R_z - \tan\theta_1 \tan\theta_2 = 0 \qquad (3)$$

Where $R_z = \dfrac{Z_2}{Z_1}$ defined the impedance ratio of the two sections. By equating Y_{ino} and Y_{ine} in (2) and (3), the transmission zeros of the circuit in Figure 1 can be calculated according to:

$$R_z - \tan\theta_1(\tan\theta_2 + 1) \qquad (4)$$

It seems clearly that the locations of transmission zeros depend on the transmission line impedances (Z_1 and Z_2), the electrical lengths (θ_1 and θ_2). By proper selection of these parameters, transmission zeros can be found and located as they are the roots of (4). This may be simply achieved using full wave Electromagnetic Simulators.

3. Design of Dual-Band Band Pass Filter Using T-Shaped SIR Resonator

The proposed filter configuration is shown in Figure 3. The filter consists of single T-shaped resonator parallel coupled to 50 Ω feeding ports. The filter is designed and optimized using the full wave Electromagnetic Simulator.
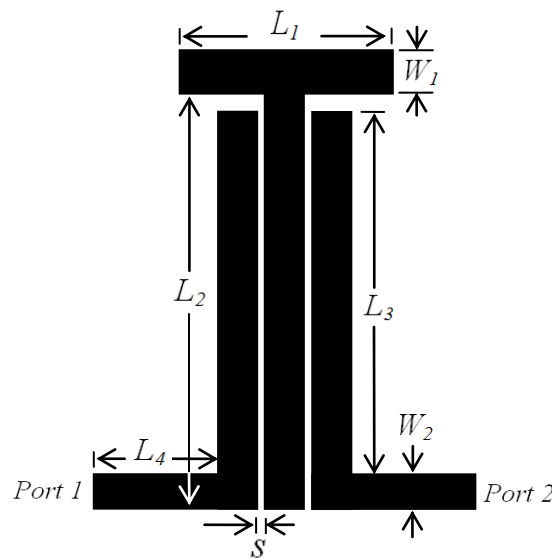

Figure 3. Proposed filter configuration based on T-shaped SIR resonator

The substrate used in the design of the filter is Rogers RO3210 with relative dielectric constant of 10.8 and thickness of 1.27 mm. Based on the circuit analysis given in the previous section, a dual-band BPF shown in Figure 3 is constructed in the full-wave simulator SONNET. The related circuit parameters at the center frequency of 2.45 GHz are listed in Table 1.

Table 1. The Design Parameters

Parameter	Magnitude	Units
θ_1	24.3	degree
θ_2	51	degree
$Z1$	46.3	Ohm
$Z2$	66.85	Ohm

4. Simulation and Results

The structure of the filter is optimized using the Electromagnetic Simulator. The final dimensions in (mm) are: L_1=8.1, L_2=17, L_3=11.2, L_4=5.3, W_1=1.3, W_2=1.1, S=0.2. Figure 4 shows the simulated frequency response of the filter. Four transmission zeroes around the bands are clearly observed at 0.1, 1.1, 3.05, 5.75 and 7.95 GHz with a return loss of -38.12, -48.74, -38.92, 51.07 and -22.45 dB respectively. The response has two transmission bands at 2.45 and 5 GHz with return loss of -18.47 and -31.43 dB respectively. To enhance the out-of-the band rejection, transmission zeroes may be added in the frequency range from 5.7 GHz to 10 GHz. The transmission zero at 9.4 GHz was created by adding stub of quarter guided wavelength at the selected frequency and a width of 0.3 mm located at 1.4 mm from the outer edge of port 2. The effect of adding an extra zero to the frequency response of the filter is shown in Figure 5. The additive zero Tz6 reduce the effects of spurs in the region from 5.75 to 10 GHz.
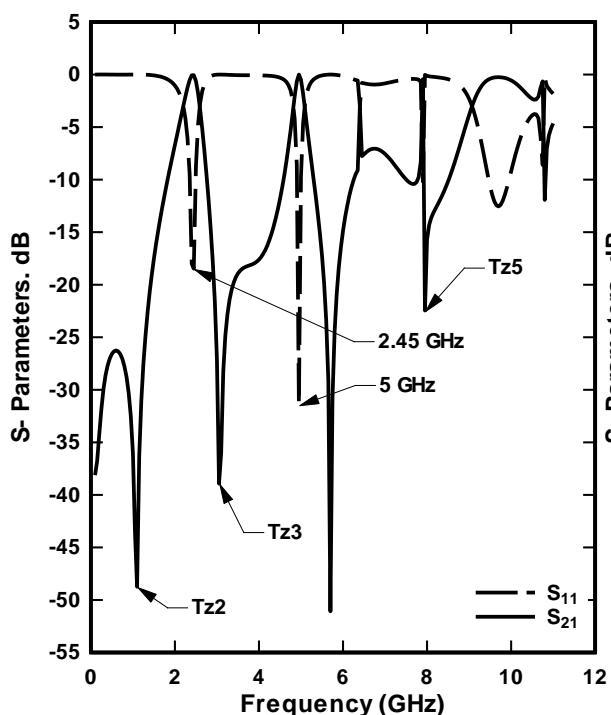

Figure 4. Frequency response of the filter: return loss (slotted) line and insertion loss (solid) line
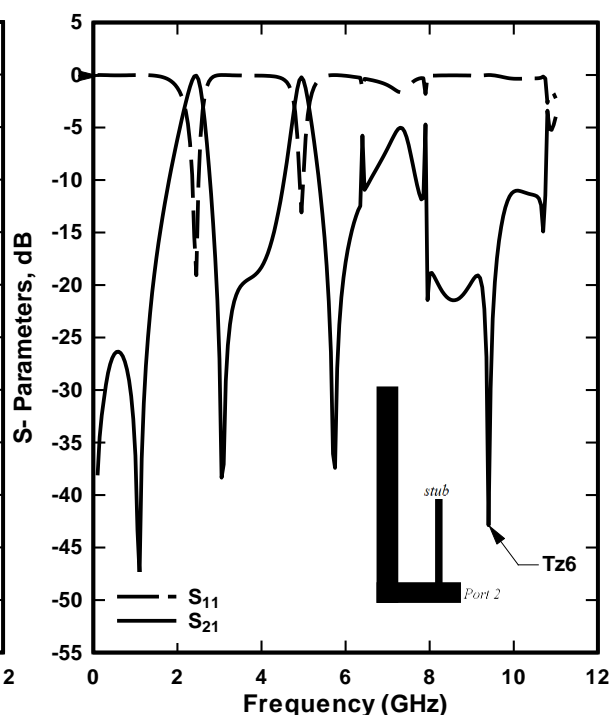
Figure 5. The effect of adding zero Tz6 on frequency response of the filter

5. Conclusion

A T-shaped SIR resonator has been presented and analyzed for dual-band bandpass filter design. Even and odd modes of the resonator structure are allocated in the first and second passband using full wave Electromagnetic simulator. The results from circuit modeling and simulating a dual-band filter show the creation of five transmission zeros caused in a skirt shape response around each of the two bands. Clearing the out of the band region from spurs was achieved by addition of an extra zero in a selected location of the filter frequency response. The filter was compact size, simple shape and low profile with dual-band operation suitable for many wireless applications.

References

[1]   Chang K, Hsieh LH. Compact Elliptic Function Low Pass Filters Using Microstrip Stepped Impedance Hairpin Resonators. *IEEE Trans. on Microwave Theory and Techniques*. 2003; 50(1): 193–199.

[2] Emad SA. Design of Tri-Band Bandpass Filter Based on Quad-Sections SIR Resonator For Wireless Applications. *WSEAS Transactions on Communications*. 2013; 12(12): 641-650.

[3] Packiaraj D, Ramesh M, Kalghatgi AT. Design of a tri-section folded SIR filter. *IEEE Microwave and Wireless Comp.Lett.* 2006; 16: 317-319.

[4] Makimoto M, Yamashita S. Bandpass Filters Using Parallel Coupled Stripline Stepped Impedance Resonators. *IEEE Transactions on Microwave Theory and Techniques*. 1980; 28(12): 1413-1417.

[5] Weng MH, Chen WN, Wu HW. A Novel Magnetically Coupled Bandpass Filter Using Sir Hairpin Resonator. *Journal of Microwaves and Optoelectronics.* 2004; 3(4): 64-70.

[6] Chen CF, Huang TY, Wu RB. *Compact Microstrip Cross-Coupled Bandpass Filters Using Miniaturized Stepped Impedance Resonators*. Asia-Pacific Microwave Conference (APMC). Suzhou. China. 2005.

[7] Kuo JT, Tsai CY. Periodic Stepped-Impedance Ring Resonator (Psirr) Bandpass Filter With A Miniaturized Area and Desirable Upper Stopband Characteristics. *IEEE Transactions on Microwave Theory and Techniques*. 2006; 54(3): 1107-1112.

[8] Eroglu A, Smith R. *Triple Band Bandpass Filter Design and Implementation Using SIRs*. 26th Annual Review of Progress in Applied Computational Electromagnetics. Tampere. Finland. 2010.

[9] Zhu H, Emad SA, Abbosh AM. *Compact Dual-Band Bandpass Filter Using Multi-Mode Resonator of Short-Ended and Open-Ended Coupled Lines*. Asia-Pacific Microwave Conference (APMC). Nanjing. 2015; 2: 1-3.

[10] Meesomklin S, Chomtong P, Akkaraekthalin P. A Compact Multiband BPF Using Step- Impedance Resonators with Interdigital Capacitors. *RADIOENGINEERING*. 2016; 25(2): 258-267.

[11] Lerdwanittip R, et al. Bandpass Filters using T-Shaped Stepped Impedance Resonators for Wide Harmonic Suppression and their Application for a Diplexer. *Journal of Semicond. Tech. and Sci.* 2011; 11(1): 65–72.

[12] Wen C, Yongjiu Z, Zhouxiao J. Compact and Wide Upper-Stopband Triple-Mode Broadband Microstrip BPF. *TELKOMNIKA*. 2012; 10(2): 353-358.

[13] Makimoto M, Yamashita S. Microwave Resonators and Filters for Wireless Communications: Theory, design and Applications. Berlin: Springer. 2001.