



AENSI Journals

Australian Journal of Basic and Applied Sciences

Journal home page: www.ajbasweb.com



Investigation of Tri-Band Bandpass Filter Using Impedance and Admittance Inverters

¹M. Sathia Bhama and ²K. Annaram

¹Department of Electronics and Communication Engineering Kamaraj College of Engineering and Technology Virudhunagar, India

²Department of Electronics and Communication Engineering Kamaraj College of Engineering and Technology Virudhunagar, India

ARTICLE INFO

Article history:

Received 23 September 2013

Received in revised form 24

November 2013

Accepted 25 November 2013

Available online 6 December 2013

Key words:

Bandpass filter, microstrip, tri-band, filter, compact, step-impedance resonator

ABSTRACT

A novel Tri-band bandpass filter (BPF) based on impedance and admittance inverters is presented in this paper. Based on the impedance and admittance inverters analysis, the tri-band BPFs first three resonance frequencies can be conveniently controlled. Benefiting from this feature, the impedance and admittance inverters can be utilized to implement a tri-band BPF. To demonstrate the proposed concept, a tri-band BPF using an impedance and admittance inverters are implemented. The experimented results verify the theoretical predictions and simulations at 1.8GHz, 2.45GHz and 5.8GHz respectively.

© 2013 AENSI Publisher All rights reserved.

To Cite This Article: M. Sathia Bhama and K. Annaram, Investigation of Tri-Band Bandpass Filter Using Impedance and Admittance Inverters. *Aust. J. Basic & Appl. Sci.*, 7(12): 320-327, 2013

INTRODUCTION

Microwave filter plays an important role in modern wireless and mobile communication systems. Planar filters are particularly popular structures because they can be fabricated using printed circuit technology and are suitable for commercial applications due to their compact size and low cost integration. Therefore, many applications to planar filter such as single-band and multi-band bandpass filters have been used in microwave communication systems due to their high performance and simple synthesis procedures. Multi-band multi-standard wireless communication systems have been gaining much attention in recent years. These systems prefer multi-band transceivers to several single-band ones. To meet the increasing communication requirements, many wireless communication systems have been developed and widely used in our day today life, such as GSM (1800/1900), WCDMA, WLAN and WiMAX. To incorporate two or more desired communication bands in a single unit and to filter unwanted frequencies, filters with a multi-band response have attracted more and more interest in modern microwave systems. So far, multi-band BPFs have been investigated aggressively to satisfy the newly developed multi-service system and the commercial products. Particularly in tri-band transceivers, tri-band BPFs are important building block and thus heavily demanded. In filter design now-a-days, the leading technique is to use multi-band and multi-mode resonance structures. Multi-mode ring resonators, step-impedance resonators (SIRs) and stub-loaded resonators (SLRs) are popular for the design of multi-band BPFs (Chen.C.F *et al.*, 2006; Chen.B.J *et al.*, 2009; Chen. F.C *et al.*, 2009; Luo. S *et al.*, 2011). Conventionally tri-band BPFs can be realized by utilizing three sets of resonators with a common feed circuit. However, the overall size is large due to the large number of resonators. To reduce the circuit size, the number of resonator sets can be reduced from three to two (Chen.B.J *et al.*, 2009; Di.H *et al.*, 2010; Hsu. C.I.G., *et al.*, 2008; Lai.X, Liang., *et al.*, 2008). One set of resonators operate at two frequencies and the other at one frequency. Hence, three pass bands can be obtained by using two sets of resonators. Furthermore, a tri-band filter can be designed by using only one set of resonators. Another method to design tri-band filter is to use transmission zeros to split a single passband to three pass bands. The transmission zeros can be generated by stubs or cross coupling. For close spaced triple pass bands, it is feasible to split a single passband into three passband by introducing transmission zeros between the adjacent pass bands. This method, however, is not applicable in the case of wide spaced pass bands (Chen.W.Y. *et al.*, 2007; Matthaei.G.L., *et al.*; Ren.L.Y, 2010). Besides, there were some other methods, such as band-splitting technique, frequency transformation, and so on (Chang, C.Y *et al.*, 1991; Mokhtarri. M, *et al.*, 2006). In the above approaches, there are three major problems remained to be solved, namely compact size, difficult to fabricate and independent control of passband frequencies and bandwidths. In this paper, Tri-band BPF is realized by using impedance and admittance inverters, which are arranged in a compact structure. The coupling coefficient and bandwidth of each band are extracted and the design guidelines are given, clearly indicating that the characteristics, including band

Corresponding Author: M. Sathia Bhama, Department of Electronics and Communication Engineering Kamaraj College of Engineering and Technology Virudhunagar, India

frequencies and bandwidths of each band of the proposed tri-band BPF filter can be controlled independently. To verify the proposed concept, a tri-band BPF with three passbands located at WLAN (2.45/5.8 GHz) and GSM (1800 MHz) is designed, simulated, fabricated and measured. The measured results agreed well with the simulated predictions.

2. Design of Tri-Band Bpf Using Series and Parallel Resonators:

In this section, a bandpass filter using a lumped element is designed to verify the series and parallel LC resonators application in Tri-BPFs. Figure 1 shows the structure of the equivalent circuit of the proposed filter using a series and parallel LC resonators.

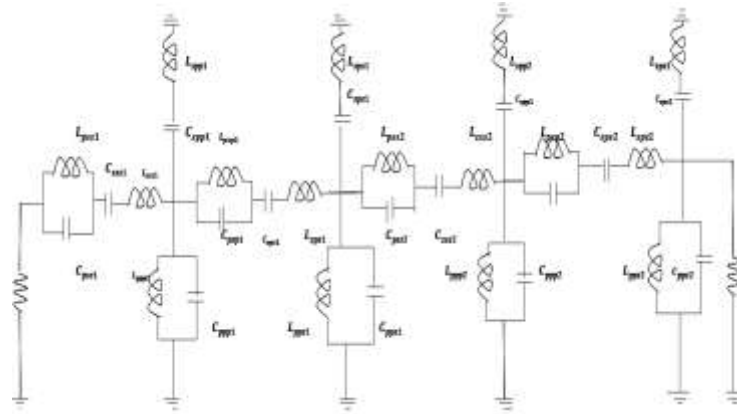


Fig. 1: Tri-band BPF using Series and Parallel resonators.

It consists of two sets of LC resonators. The series and parallel LC resonators are operating at the passband and stopband frequencies respectively. This filter has three pass bands and the passband specifications should be met simultaneously. The design procedure is as follows: The mapping function is given as:

$$L_{pssk} C_{pssk} = \frac{A_1 + A_2 + B_1 + B_2}{C_1 + C_2 + D_1 + D_2} = a, \quad k = 1, 2 \quad (1)$$

The value of A_i and B_i are given as:

$$A_i = \frac{1 - \frac{\omega_i^2}{\omega_{osss}^2}}{\omega_i} \quad (2)$$

$$B_i = \frac{1 - \frac{\omega_i^2}{\omega_{opss}^2}}{\omega_i} \quad (3)$$

$$C_i = \frac{\frac{\omega_i}{2}}{1 - \frac{\omega_i^2}{\omega_{ossp}^2}} \quad (4)$$

$$D_i = \frac{\frac{\omega_i}{2}}{1 - \frac{\omega_i^2}{\omega_{opsp}^2}} \quad (5), \quad i=1,2,3,4,5,6$$

The series branch element values of the lumped tri-band BPF can be calculated by using the following equations:

$$L_{pssk} = \frac{g_k Z_o}{\left(\frac{\omega_4}{1 - \frac{\omega_4^2}{\omega_{opss}^2}} - \frac{\omega_4^2}{\omega_{osss}^2} \right)} \quad (6)$$

$$C_{pssk} = \frac{1}{\omega_{opss}^2 L_{pssk}} \quad (7)$$

$$C_{sssk} = \frac{\alpha}{L_{pssk}} \quad (8)$$

$$L_{sssk} = \frac{1}{\omega_{osss}^2 C_{sssk}} \quad (9)$$

$$L_{pspk} = \frac{g_k Z_o}{\left(\frac{\omega_4}{1 - \frac{\omega_4^2}{\omega_{opsp}^2}} - \frac{\omega_4^2}{\omega_{ossp}^2} \right)} \quad (10)$$

$$C_{pspk} = \frac{1}{\omega_{opsp}^2 L_{pspk}} \quad (11)$$

$$C_{sspk} = \frac{\alpha}{L_{pspk}} \quad (12)$$

$$L_{sspk} = \frac{1}{\omega_{ossp}^2 C_{sspk}} \quad (13)$$

Table 1: Parameters of the series branch elements.

Series branch element values of the lumped tri-band BPF							
Inductor values (nH)				Capacitor values (pF)			
L_{pssk}	L_{pspk}	L_{sspk}	L_{sssk}	C_{pssk}	C_{pspk}	C_{sspk}	C_{sssk}
1.03	12.59	18.05	4.29	7.56	0.13	0.11	1.31
0.38	11.44	16.40	3.90	8.32	0.14	0.12	1.45

The shunt branch element values of the tri-band BPF can be calculated by using the following equations

Table 2: Parameters of the shunt branch elements.

Shunt branch element values of the lumped tri-band BPF							
Inductor values (nH)				Capacitor values (pF)			
L_{pppk}	L_{spsk}	L_{ppsk}	L_{sppk}	C_{spsk}	C_{pppk}	C_{sppk}	C_{ppsk}
3.2842	0.327	0.267	13.71	5.038	1.7194	0.411	7.2214
3.6154	0.365	0.294	15.09	4.577	1.5619	0.373	6.5613

$$L_{pppk} = \frac{\beta}{C_{sppk}} \quad (14)$$

$$C_{pppk} = \frac{1}{\omega_{oppp}^2 L_{pppk}} \quad (15)$$

$$C_{sppk} = \frac{g_k}{\left(\begin{array}{cc} 1 - \frac{\omega_4^2}{\omega_{oppp}^2} & \frac{\omega_4^2}{\omega_{oppp}^2} \\ \frac{\omega_4^2}{\omega_{ospp}^2} & \omega_4^\alpha \end{array} \right)} Z_0 \quad (16)$$

$$L_{sppk} = \frac{1}{\omega_{ospp}^2 C_{sppk}} \quad (17)$$

$$C_{spks} = \frac{g_k}{\left(\begin{array}{cc} 1 - \frac{\omega_4^2}{\omega_{opps}^2} & \frac{\omega_4^2}{\omega_{opps}^2} \\ \frac{\omega_4^2}{\omega_{osps}^2} & \omega_4^\alpha \end{array} \right)} Z_0 \quad (18)$$

$$L_{spks} = \frac{1}{\omega_{osps}^2 C_{spks}} \quad (19)$$

$$L_{ppsk} = \frac{\beta}{C_{spks}} \quad (20)$$

$$C_{ppsk} = \frac{1}{\omega_{opps}^2 L_{ppsk}} \quad (21)$$

Finally, the calculated values are slightly tuned to get desirable bandwidth of each passband as given in Table 1 and 2. The lumped element tri-band BPF is easy to design and tune. However, the lumped element devices are not suitable at the microwave frequency range.

3. Design of Tri-Band BPF Using Impedance and Admittance Inverters:

This section presents the design methodology of impedance and admittance inverters, which form the basis of design for many different types of multi-band BPFs. As we discussed, BPF prototypes require shunt elements consisting of parallel LC resonators and series elements consisting of series LC resonators. Such an arrangement is very difficult to implement using transmission line sections, for which it is preferable to have either all shunt, or all series elements. While the Kuroda's identities are useful for transforming capacitors or inductors to either series or shunt transmission line stubs, they are not useful for transforming LC resonators. For this purpose, impedance (K) and admittance (J) inverters can be used. Such techniques are especially useful for BPF having narrow bandwidths. The conceptual design of impedance and admittance inverters is illustrated in figure 2. An impedance inverter converts load impedance to its inverse, while an admittance inverter converts load admittance to its inverse:

$$Z_{in} = \frac{K^2}{Z_L} \quad (22)$$

$$Y_{in} = \frac{J^2}{Y_L} \quad (23)$$

where K is the impedance inverter constant and J is the admittance inverter constant. The utility of impedance and admittance inverter can be used to transform between series-connected and shunt-connected elements. Thus, a series LC resonator can be transformed to a parallel LC resonator, or vice versa. The proposed BPF is designed by using T network (K inverter), or a π network (J inverter) (Luo.S., *et al.*, 2011).

$$C_{a1} = J_{01}^2 L_{ss1}, L_{a1} = \frac{C_{ss1}}{J_{01}^2} \quad (24)$$

$$L_{b1} = \frac{C_{ps1}}{J_{01}^2}, C_{b1} = J_{01}^2 L_{ps1} \quad (25)$$

$$C_{ai} = \frac{J_{01}^2 \dots J_{l+2,l+3}^2}{J_{12}^2 \dots J_{m+3}^2} L_{ssi}, L_{ai} = \frac{J_{12}^2 \dots J_{m+2,m+3}^2}{J_{01}^2 \dots J_{l+2,l+3}^2} C_{ssi} \quad (26)$$

$$L_{bi} = \frac{J_{12}^2 \dots J_{m+2,m+3}^2}{J_{12}^2 \dots J_{l+2,l+3}^2} C_{psi}, C_{bi} = \frac{J_{01}^2 \dots J_{l+2,l+3}^2}{J_{12}^2 \dots J_{m+2,m+3}^2} L_{psi} \quad (27)$$

The values of l and m are given as,

$$l = 0, 1, \dots, \frac{i-3}{2}, m = 1, 2, \dots, \frac{i-3}{2} @ i = 1$$

$$C_{ai} = \frac{J_{12}^2 \dots J_{l+2,l+3}^2}{J_{01}^2 \dots J_{l+1,l+2}^2} C_{ppi}, L_{ai} = \frac{J_{01}^2 \dots J_{l+1,l+2}^2}{J_{12}^2 \dots J_{l+2,l+3}^2} L_{ppi} \quad (28)$$

$$C_{bi} = \frac{J_{12}^2 \dots J_{l+2,l+3}^2}{J_{01}^2 \dots J_{l+1,l+2}^2} L_{spi}, L_{bi} = \frac{J_{01}^2 \dots J_{l+1,l+2}^2}{J_{12}^2 \dots J_{l+2,l+3}^2} L_{spi} \quad (29)$$

The values of l is given as,

$$l = 1, 2, \dots, \frac{i-2}{2} @ i = 2$$

For even values of i , the circuit elements of figure 2 calculated as:

$$J_{xi} = \sqrt{\frac{c_{ai}}{L_{xi}}} = \sqrt{\frac{c_{xi}}{L_{ai}}}; i = 1, 2, \dots, n \quad (30)$$

The impedance value can be calculated by using the following equation:

$$Z_o = \frac{1}{J_{01}} \quad (31)$$

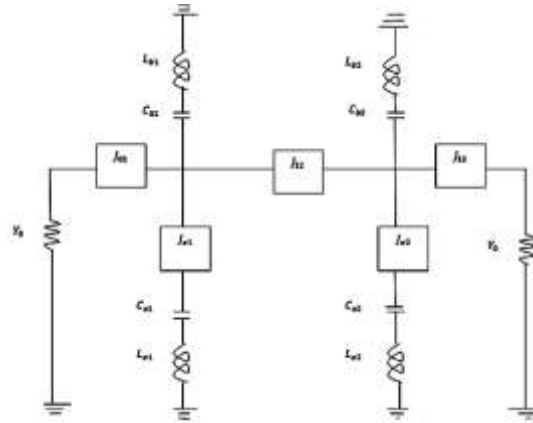


Fig. 2: J-inverters and series LC inverters.

The proposed concept introduces the flexibility in choice of J-inverter values and allows the designer more freedom in the design and realization of the proposed tri- band BPF.

4. Design and Fabrication:

For demonstration purpose, a tri-band BPF is implemented operating at 1.8GHz, 2.45GHz, and 5.85GHz, respectively. Figure 3 shows the geometry of the proposed tri-band microstrip BPF. The design parameters are calculated by using the microstrip line synthesis formula. The layout of the proposed design is shown in figure 3. By using the synthesize parameters the proposed BPF is simulated in Agilent ADS software. Following the design process, the dimensions are determined as tabulated in Table 3. The experimental filter is fabricated on a substrate with a relative dielectric constant of 4.6 with thickness of 1.6 mm. The overall size of this tri-band BPF is 4 X 3.3 cm². The photograph of the fabricated prototype is shown in figure 4.

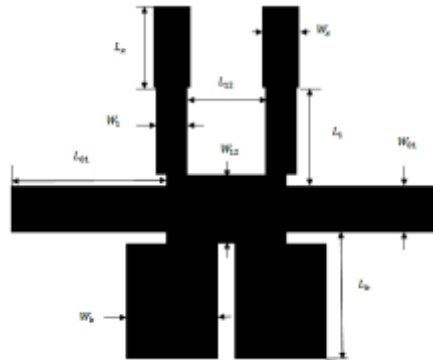


Fig. 3: Layout of the Tri-band BPF.

Table 3: Dimension of the proposed tri-band BPF.

Admittance Inverter values	Impedance (Ω)	Length (mm)	Width (mm)
$J_{01} = 0.025$	$Z_{01} = 40$	$L_{01} = 13.41$	$W_{01} = 4.25$
$J_{12} = 0.033$	$Z_{12} = 30.30$	$L_{12} = 13.1$	$W_{12} = 6.4$
$J_1 = 0.058$	$Z_1 = 49.99$	$L_1 = 2.96$	$W_1 = 2.96$
Inductor(nH) and Capacitor values (pF)	Impedance(Ω)	Length(mm)	Width(mm)
$L_b = 0.34224$ $C_b = 4.819$	$Z_b = 24.43$	$L_b = 12.91$	$W_b = 8.53$
$L_x = 2.0026$ $C_x = 0.9771$	$Z_x = 45.27$	$L_x = 13.56$	$W_x = 3.49$

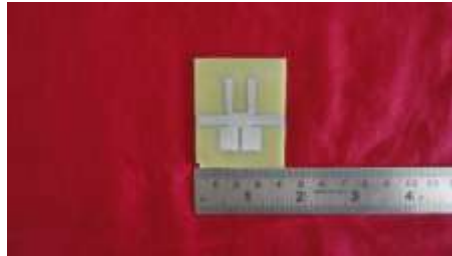


Fig. 4: Fabricated prototype of the proposed BPF.

RESULTS AND DISCUSSION

The S parameter measurement of the fabricated prototype model has been carried out using Agilent N5230A PNA series vector network analyzer. The measured results are agreed well with the simulated results. The return loss and insertion losses are measured as shown in figure 5 and 6 for the three passbands centered at f_1 , f_2 and f_3 . The proposed design has minimum insertion loss at the desired frequency ranges.

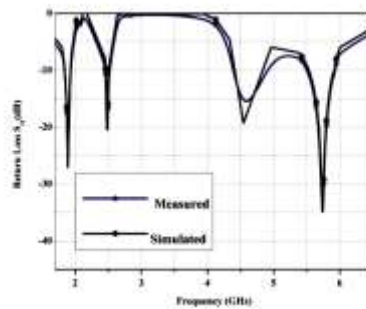


Fig. 5: Return loss(S_{11}).

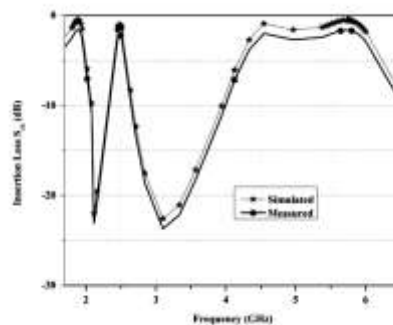


Fig. 6: Insertion loss(S_{12}).

Table 4: Performance comparison.

Filter	Frequency	S_{11} (dB)		S_{12} (dB)	
		Simulated	Measured	Simulated	Measured
Tri-band BPF	f_1	-27.84	-27.04	-0.475	-1.575
	f_2	-20.673	-19.87	-1.002	-2.10
	f_3	-13.59	-12.79	-0.763	-1.863

Conclusion:

This research work concludes, the bandwidth of the proposed design can be arbitrarily controllable by using J and K inverters. The proposed design uses the impedance and admittance inversion techniques which were applied for easy realization of the distributed transmission lines. The proposed method is flexible enough to enable the design of BPFs with three pass bands of significantly different bandwidths. In future this technique can be useful for the design and development of multi-band BPFs which can be used in multi-band communication systems.

REFERENCES

- Chang, C.Y. and T. Itoh, 1991. A modified parallel coupled filter structure that improves the upper stopband rejection and response symmetry, *IEEE Transaction on Microwave Theory and Techniques*, 39(2): 310-314.
- Chen, C.F., C.Y. Huang and R.B. Wu, 2006. Design of dual-band triple pass-band filters using alternately cascaded multiband resonators, 54: 3550-3558.
- Chen, B.J., T.M. Shen and R.B. Wu, 2009. Design of tri-band filters with improved band allocation, 57: 1790-1797.
- Chen, F.C. and Q.X. Chu, 2009. Design of compact tri band bandpass filters using assembled resonators, 57: 165-171.
- Chen, W.Y., S.J. Chang, M.H. Weng, Y.H. Su and H. Kuan, 2011. Simple method to design a tri-band bandpass filter Using asymmetric SIRs for GSM, WiMAX and WLAN applications, 53: 1573-1576.
- Chen, X.P., K. Wu and Z.L. Li, 2007. Dual band and triple band substrate integrated waveguide filters with Chebyshev and quasi Elliptic responses, 55: 2569-2578.
- Di, H., B. Wu and C.H. Liang, 2010. Synthesis of cross couple triple pass band filters based on frequency transformation, 20: 432-434.
- Hsu, C.I.G., C.H. Lee and Y.H. Hsieh, 2008. Tri-band bandpass filter with sharp passband skirts designed using tri-section SIRs, 18: 19-21.
- Lai, X., C.H. Liang, H. Di and B. Wu, 2010. Design of tri-band filter based on stub loaded resonator and DGS resonator, 20: 265-267.
- Lee, C.H., C.I.G. Hsu and H.K. Jhuang, 2006. Design of new tri-band microstrip BPF using combined quarter wavelength SIRs, 16: 594-596.
- Luo, S., Zhu and S. Sun, 2011. Compact dual-mode triple-band bandpass filters using three pairs of degenerate modes in a ring resonator, 59: 1222-1229.
- Matthaei, G.L., L. Young and E.M.T. Jones, 1964. *Microwave filters, impedance matching networks, and coupling structures*, McGraw- Hill Book Co., New York, NY.
- Mokhtarri, M., J. Borenemann, K. Rambabu and S. Amari, 2006. Coupling matrix design of dual and triple pass band filters, 54: 3940-3946.
- Ren, L.Y., 2010. Tri-band bandpass filters based on dual plane microstrip/DGS slot structure, 20: 429-431.
- Quendo, C., E. Rius, E. Manchec, Y. Clavet, B. Potelon, J.F. Favennec and F. Person, 2005. Planar tri-band filter based on dual behaviour resonator, 269-272.