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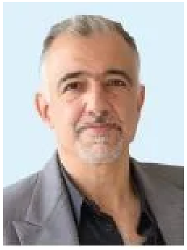

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Hepta-band bandpass filter based on folded cross-loaded stepped impedance resonator

T. Firmansyah✉, S. Praptodiyono, A.S. Pramudyo, C. Chairunissa and M. Alaydrus

A hepta-band bandpass filter (HB-BPF) based on folded cross-loaded stepped impedance resonator (SIR) was investigated. A cross-loaded SIR microstrip structure was arranged to produce several transmission zeros. In order to reduce the filter size, a folded cross-loaded SIR was proposed. The HB-BPF was designed on FR4 microstrip substrate with $\varepsilon_r = 4.4$, thickness $h = 0.8$ mm, and tan $\delta = 0.0265$. This HB-BPF achieves transmission coefficients of 0.15, 0.61, 0.45, 1.14, 1.57, 1.77, and 2.08 dB at 0.74, 1.49, 2.25, 3.19, 3.93, 4.68, and 5.50 GHz, respectively. The HB-BPF only occupies $0.1 \times 0.22\ \lambda g$, where λg is the guided wavelength at a first passband centre frequency. A good agreement between simulated and measured results validates the design method.

Introduction: In modern wireless communication systems, a multiband band-pass filter (MBPF) is an important and essential component. MBPF is a sub-system of a multiband radio frequency transceiver. An MBPF shall simultaneously operate at several frequencies with high performance [1]. There are some well-known methods frequently used for MBPFs design such as microstrip double-layered structure [2], stub-loaded resonators [3], penta mode resonator (PMR) [4], mixed electric and magnetic coupling [5], semi-lumped resonators [6], stepped impedance resonator (SIR) [7–9], and multiple coupling paths [10]. The authors in [2, 3] present effective methods to design MBPF with good performances by using microstrip double-layered structure [2] and stub-loaded resonators structure [3], however the fractional bandwidth (FBW) of this MBPF is not good. A PMR was proposed by [4], the result shows that the filter has a good performance MBPFs with a little poor result at the last frequency band. The MBPFs proposed by the authors in [5, 6] are still a fairly complex filter geometry with complicated designs and an MBPF with SIR [7] still achieves narrow bandwidth. Furthermore, the authors in [10] present efficient methods to design MBPF by using multiple coupling paths, however the FBW of this MBPF is low.

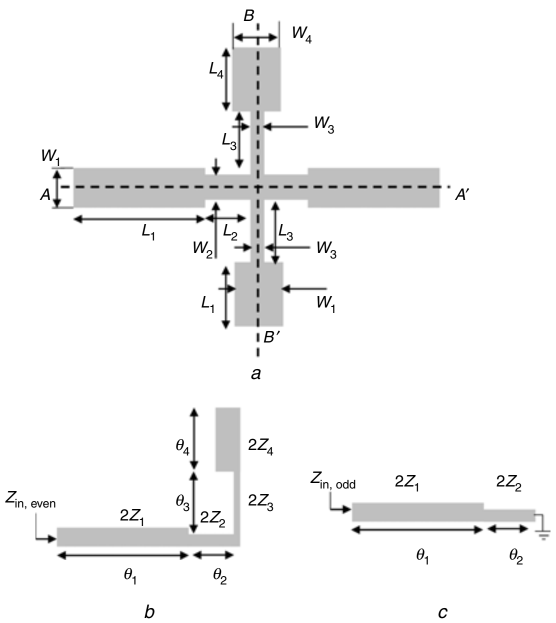


Fig. 1 *Structure of cross-loaded SIR; even-mode and odd-mode equivalent circuit*

a Structure of CL-SIR
b Even-mode equivalent circuit
c Odd-mode equivalent circuit

In this Letter, a cross-loaded SIR (CL-SIR) microstrip structure was proposed to produce hepta-band bandpass filter (HB-BPF). The CL-SIR is clearly distinct from the microstrip structure as used in [1–10]. The CL-SIR microstrip structure can significantly improve transmission coefficients, wider bandwidth, compact size, and ease of fabrication. A good agreement could be observed between the simulated and measured results, which demonstrated the validity of the design.

Proposed cross-loaded SIR: The proposed resonator constructed by several SIR is shown in Fig. 1*a*, where (W_1, L_1) and (W_2, L_2) represent the widths and lengths of the SIR. The cross-loaded is connected to the centre of SIR, where (W_3, L_3), and (W_4, L_4) show the widths and length of the CL-SIR. Since the resonator is symmetrical to the *A*–*A*′ plane and *B*–*B*′ plane, the resonant frequencies for the even and odd excitation can be extracted from admittance condition $Y_{in} = 0$ or impedance condition $Z_{in} = \infty$ [11].

For the even excitation as shown in Fig. 1*b*, the resonance condition of the structure is found as follows:

$$\frac{Z_2}{4Z_3}\left(1 + \frac{Z_2}{Z_1}\tan\theta_1\tan\theta_3\right)\left(\frac{Z_2}{2Z_3}\tan\theta_3 + \frac{Z_2}{2Z_4}\tan\theta_4\right) + \left(\tan\theta_2 + \frac{Z_2}{Z_1}\tan\theta_1\right)\left(\frac{Z_2}{2Z_3} + \frac{Z_2}{2Z_4}\tan\theta_4\right) = 0 \quad (1)$$

Simultaneously, for the odd excitation, we obtained the following resonance condition:

$$\tan\theta_1 \tan\theta_2 = \frac{Z_1}{Z_2} \quad (2)$$

with the Z_n ($n = 1,2,3,4$) and θ_n ($n = 1,2,3,4$) denote the characteristic impedance and electrical length, respectively.

The dependency of the frequency ratios on the impedance ratio is given in Fig. 2*a*. The chart shows that by increasing the impedance ratio (Z_1/Z_2), the resonant frequencies will vary from fundamental frequency. Meanwhile, the f_2 and f_3 are more stable than f_4, f_5, f_6 and f_7. Fig. 2*b* shows the transmission coefficients with varied width W_3. It shows that the transmission coefficients in f_5, f_6 and f_7 fall dramatically, but still higher than −3 dB. Fig 2*c* illustrated the extraction of reflection coefficients with varied L_4. It shows that the variation of L_4 affected to reflection coefficients values and it also have effect on the frequency shift.

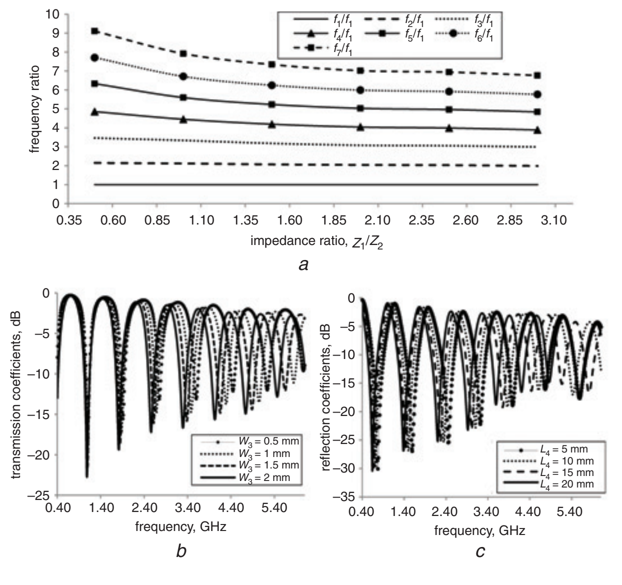
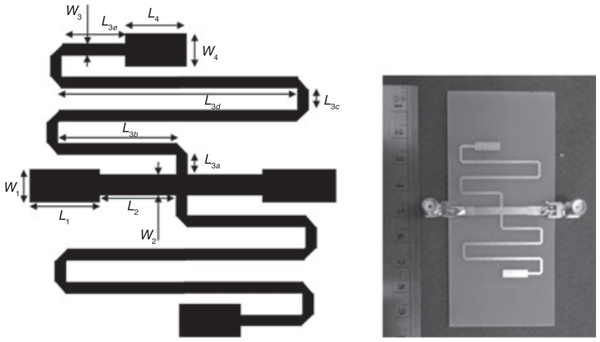


Fig. 2 *Frequency ratio, transmission coefficient, and reflection coefficient*

a Relationship between impedance ratio and normalised resonance
b Transmission coefficients characteristics with varied stub width W_3
c Reflection coefficient characteristics with varied stub length L_4

Experiment and results discussion: The HB-BPF was designed on FR4 microstrip substrate with the relative permittivity $\varepsilon_r = 4.4$, a thickness $h = 0.8$ mm, and a loss tangent tan $\delta = 0.0265$. The HB-BPF was simulated by using momentum simulation advanced system design, whereby a RS-ZVA vector network analyser was used to test the fabricated prototype of HB-BPF. The layout and the prototype photograph are shown in Figs. 3*a* and *b*, respectively. The dimensions are given as follows (all in millimetres): $L_1 = 10$, $L_2 = 10$, $L_{3a} = 5.0$, $L_{3b} = 15$, $L_{3c} = 30$, $L_{3d} = 5.0$, $L_{3e} = 5.0$, $L_4 = 10$, $W_1 = 3.5$, $W_2 = 3.0$, $W_3 = 1.0$, and $W_4 = 3.0$. The HB-BPF only occupies $0.1 \times 0.22\ \lambda g$, where λg is the guided wavelength at a first passband centre frequency.



a b

Fig. 3 *Layout and photograph HB-BPF*

a Layout
b Photograph

Fig. 4 shows the simulated and measured transmission and reflection coefficients of the HB-BPF in a wideband response view. The measured group delays of all pass bands <5 ns are also depicted in Fig. 4. Table 1 gives the performance comparison of the multiband BPF with some previous works, from which it can be deduced that the presented study has great merits of transmission coefficient, wide bandwidth, compact size, and ease of fabrication.

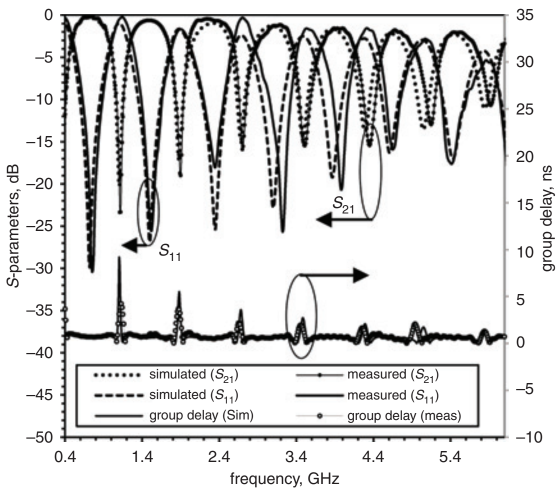


Fig. 4 *Simulated and measured results*

Table 1: Comparison with some previous multi-band BPFs

Refs.	Pass bands	Frequency, GHz	Transmission coefficients, dB	Size λ_0^2	– 3 dB FBW (%)
[4]	5	0.63/1.2/1.8/2.49/3.46	0.43/0.86/1.10/1.98/2.55	0.02	28.5/10/13.6/4.8/4.2
[5]	5	2.1/3.0/4.0/4.7/7.2	0.98/1.76 1.22/1.77/2.39	0.01	13.7/5.6/10.5/5.1/2.9
[6]	6	0.8/1.2/1.4/1.8/2.2/2.5	2.9/2.34/2.59/2.24/2.67/2.64	0.01	2.3/2.9/3.3/3.2/2.0/2.0
[7]	6	0.9/1.2/1.4/1.7/2.0/2.4	2.3/2.0/2.3/2.7/2.2/2.0	0.01	1.5/1.3/1.4/1.3/1.5/1.4
[10]	7	1.05/1.3/1.5/1.8/2.05/2.35/2.85	1.05/1.3/1.5/1.8/2.05/2.35/2.85	0.027	8/4/5/7.5/4.5/5.5/6.5
This work	7	0.74/1.49/2.25/3.19/3.93/4.68/5.50	0.15/0.61/0.45/1.14/1.57/1.77/2.08	0.022	67.5/32.2/25.3/12.8/9.16/6.19/6.00

Conclusion: A HB-BPF based on folded cross-loaded SIR was investigated, which has a good transmission coefficient, wide bandwidth, compact size, and ease of fabrication. The HB-BPF only occupies $0.1\ \lambda g \times 0.22\ \lambda g$, where λg is the guided wavelength at a lower passband centre frequency. A good agreement between simulated and measured results validates the design method.

Acknowledgments: The work was supported by the Ministry of Research, Technology and Higher Education, Indonesian Government in terms of Penelitian Kerjasama Perguruan Tinggi (grant no. 267/UN43.9/PL/K/2016).

Submitted: *27 March 2017* E-first: *12 July 2017*
doi: 10.1049/el.2017.1121

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