Design and Analysis of The Stub and Radial-Stub Loaded Resonator Band-Pass Filter with Cross-Shaped Coupled Feed-Lines for UWB Applications

B. Mohammadi [1], J. Nourinia [1], Ch. Ghobadi [1], and A. Valizade [2]

[1] Department of Electrical Engineering
Urmia University, Urmia, Iran
st_b.mohammadi@urmia.ac.ir, j.nourinia@urmia.ac.ir, ch.ghobadi@urmia.ac.ir,

[2] Young Researchers Club, Qaemshahr Branch
Islamic Azad University, Qaemshahr, Iran
a.valizade@sun.semnan.ac.ir

Abstract ─ In this paper, the procedure of attaining a compact microstrip ultra-wideband (UWB) band-pass filter (BPF) by the use of stub and radial stub loaded resonator and also cross-shaped coupled lines (CCLs) as feed-lines, is presented and discussed. Implementation of CCLs results in suppression of the unwanted pass-band harmonics while by loading the resonator, additional transmission zeros (TZs) are produced, which lead to improvement of the in-band performance of the BPF. Measurement results of the fabricated UWB BPF are in good agreement with simulation predictions and the presented BPF has a sharp roll-off and improved out-of-band performance in the frequency band of interest.

Index Terms ─ Band-pass filter, cross-shaped coupled lines, radial stub loaded resonator, stub loaded, and ultra-wideband applications.

I. INTRODUCTION

Since 2002 when the U.S. Federal Communications Committee (FCC) authorized the 3.1 GHz – 10.6 GHz frequency band for ultra-wideband indoor and hand-held wireless communications, tremendous efforts and researches have been carried out to develop UWB systems [1]. In UWB communication systems, designing a high performance band-pass filter with wide bandwidth, compact size, low insertion loss, and also wideband rejection is still a challenging task [2]. In order to design a wideband microstrip filter one of the common and easy to implement solutions is the use of cascaded parallel coupled sections. However, this structure suffers from spurious pass-band harmonics. In [2], defected ground structure (DGS) was used to eliminate the spurious responses. Also, to improve upper pass-band performance several other UWB filter structures based on multiple-mode resonators (MMRs) have been reported recently, which are fed by conventional quarter wavelength coupled lines and have low insertion loss, good selectivity and out-of-band rejection performance but suffer from larger circuit size and narrow upper stop-band [3-5].

In the design of UWB band-pass filters based on multiple-mode resonators, the first three resonant frequencies of the MMR should be placed in the UWB pass-band of interest almost equally. By varying the length of the center low-impedance line section or increasing the number of non-uniform sections in the MMR, UWB band-pass filters with more in-band transmission poles can be produced. On the other hand, the inevitable fourth or other higher-order resonant frequencies of the MMR may produce spurious and unwanted pass-bands at upper stop-band and degrade the performance of the resultant UWB filter. In order to overcome this intrinsic problem of the MMR-based filters, an interdigital coupled line with capacitive-ended loading and/or tapered strip

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shape can be implemented to the filter structure, and its first transmission zero is reallocated toward the full suppression of this fourth resonant frequency in the MMR [6]. In [7], it is shown that by the use of CCLs instead of conventional parallel coupled lines, not only the size of the microstrip filter is miniaturized but also by assigning the TZs toward the upper stop-band, the spurious harmonic pass-bands can be effectively suppressed.

This paper introduces a novel microstrip UWB BPF with improved in-band and out-of-band performances, which has sharp roll-off at both upper and lower cut-off frequencies. In the proposed structure, the sharp roll-off and high skirt selectivity is achieved by loading the resonator with a simple stub and a pair of radial stubs. These stubs produce additional TZs and resonances, which are controllable through their dimensions [5-8]. Also utilizing the radial stubs instead of the conventional stepped-stubs and forming radial stub loaded resonator (RSLR) reduces the vertical size of the filter [8].

Moreover, by implementing the CCLs instead of the conventional quarter wavelength parallel coupled lines, additional transmission zeros are added to the frequency response of the BPF, which are controllable by the dimensions of the CCLs. The out-of-band performance of the filter can be significantly improved by proper adjustment of the transmission zeros, which are produced by the CCLs toward the harmonic resonances of the multi-mode loaded resonator and eliminate the unwanted higher pass-bands. Also the size of the filter is reduced by the use of the CCLs [7]. In addition, in order to achieve tight coupling a defected ground structure (DGS) is used [9, 10]. The presented microstrip filter structure has a compact size and shows suitable performance in UWB frequency band.

II. FILTER DESIGN AND CONFIGURATION

The proposed microstrip UWB BPF with its design parameters is shown in Fig. 1. The filter substrate is Rogers (RO4003) with permittivity of 3.55, thickness of 0.8 mm, and loss tangent of 0.0027. The presented structure consists of a simple cross-shaped resonator, which is coupled with two cross-shaped meander interdigital lines, which are connected to the feed-lines. The feed-lines are connected to a 50 Ω SMA connectors for signal transmission, as shown in Fig. 1 (a). Then by loading the coupled resonator with a stub and a pair of radial stubs at its center, a stub loaded resonator (SLR) is formed, as shown in Fig. 1 (b). On the other side of the substrate, the ground plane with two symmetrical back-to-back T-shaped like defects at its center is placed, as shown in Fig. 1 (c). The defects on the ground plane perturb the current distribution and as a result the effective capacitance or inductance of the transmission lines is increased and is used here to achieve a tight coupling [8, 9].

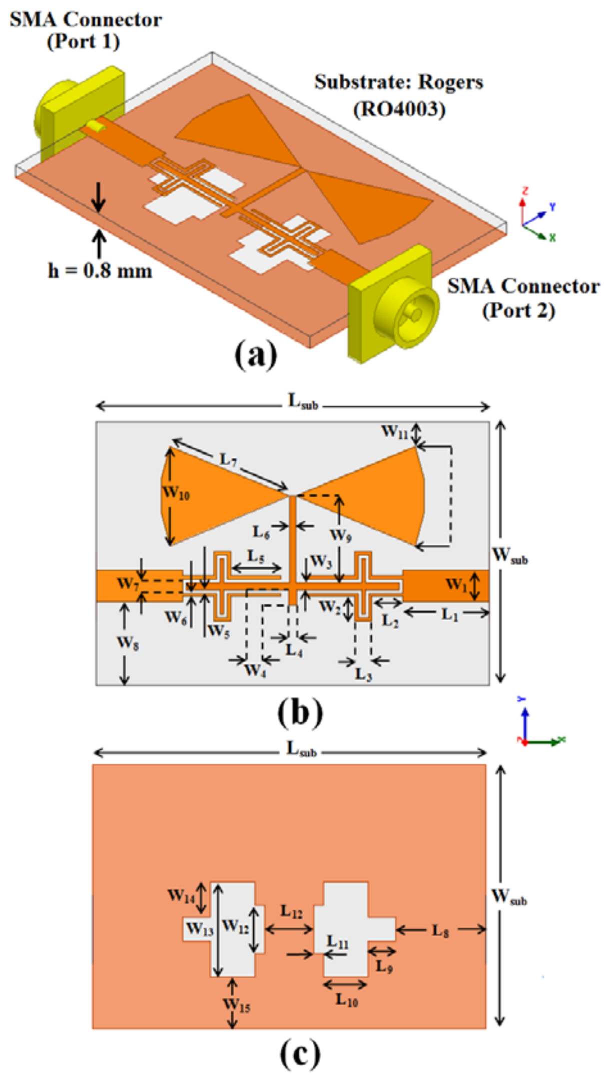

Fig. 1. Geometry and design parameters of the proposed UWB band-pass filter: (a) side view, (b) top view, and (c) bottom view.

In this study we started with a simple cross-shaped resonator. This simple resonator generates two resonances within the UWB frequency spectrum but it suffers from the presence of spurious responses, which are generated at multiples of the center frequency [2]. Then in order to eliminate the spurious harmonic pass-bands and improve the out of band performance of the filter, cross-shaped coupled lines were added to the design. The main advantage of these cross-shaped coupled lines is that they produce additional TZs, which are controllable by the dimension of the cross-shaped coupled lines. By adjusting the dimensions of the cross-shaped coupled lines and placing the first two upper stop-band TZs at the harmonic resonances of the multiple-mode resonator the unwanted pass-band is effectively rejected [7]. At the next step of the design procedure, the coupled resonator was loaded by a simple and a pair of radial stub, and thereby a stub loaded resonator (SLR) is formed. Through adding these stubs to the filter structure, additional resonances and TZs were introduced to the frequency response of the proposed BPF, which are controllable by the dimensions of the stubs. Assigning the TZs toward the cut-off frequencies and assigning the resonances toward the UWB frequency band leads to desired high skirt selectivity and improved in-band performance, respectively.

III. RESULTS AND DISCUSSIONS

The proposed UWB BPF with its final and modified design parameters was designed, fabricated, and tested and in this section its simulation and measurement results are presented and discussed. Ansoft simulation software high frequency structure simulator (HFSS) was used for simulation studies [10]. Figure 2 shows different structures, which were investigated in simulation studies and the insertion loss characteristics for the slotted ground plane filter with simple cross-shaped resonator (Fig. 2 (a)), with CCLs (Fig. 2 (b)), with CCLs and simple stub (Fig. 2 (c)), with CCLs and a pair of radial stubs (Fig. 2 (d)), and the proposed filter structure are compared in Fig. 3.

As it can be observed in Fig. 3, the simple cross-shaped resonator is a double mode resonator and generates two resonances within the UWB frequency band and has some unwanted resonances at the upper stop-band. To overcome this problem, as shown in Fig. 2 (b), cross-shaped coupled lines were added to the filter structure and by suppressing the spurious responses by two CCLs at both input and output ports, the stop-band is extended to near than 25 GHz with a rejection level of more than 20 dB, but still the frequency response of the filter is not completely tuned for UWB performance. Therefore, a simple stub and a pair of radial stubs are added to the filter structure and the proposed UWB BPF is formed. The effect of each one of these stubs on the frequency response of the filter is shown separately in Fig. 3. As it can be seen in this figure, the simple stub can improve the upper frequency band while the radial stubs have effect on both upper and lower frequency bands. By adjusting these stubs and assigning their TZs to harmonic resonances and upper/lower cut-off frequencies, an UWB BPF with improved out-of-band performance, sharp roll-off, and high skirt selectivity is designed.

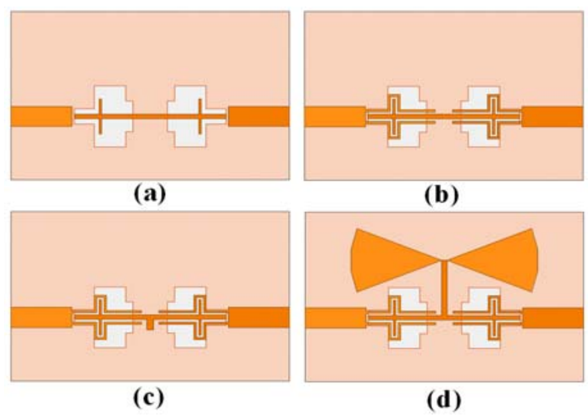

Fig. 2. Slotted ground plane filter with (a) simple cross-shaped resonator, (b) CCLs, (c) CCLs and simple stub, and (d) CCLs and a pair of radial stubs.

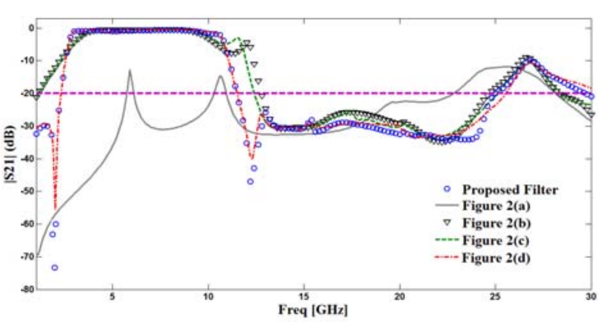

Fig. 3. Frequency responses of various filter structures shown in Fig. 2 and the proposed UWB BPF filter.

In order to modify the design parameters of the proposed filter, a parametric study was performed. The final values of the design parameters are listed in Table I. As examples of the aforementioned parametric study, the effect of two design parameters are presented and discussed here. Figure 4 shows the effect of the finger length of the CCLs (L_2 in Fig. 1) on the frequency responses of the proposed filter for different cases in Table II and compares it with the conventional parallel coupled lines. It is found that by changing the finger length, the TZs can be adjusted toward unwanted pass-bands properly. Figure 5 shows the effect of various radial stubs dimension on the return loss characteristic of the proposed UWB BPF for the cases listed in Table III. As it can be observed from this figure, the in-band performance of the filter is significantly affected by the dimensions of the radial stubs.

Table I: The final dimensions of the designed BPF.

Param.	mm	Param.	mm	Param.	mm
W_{sub}	15.25	W_{10}	5.74	L_4	0.5
W_1	1.8	W_{11}	1.43	L_5	2.9
W_2	1.4	W_{12}	2.8	L_6	0.4
W_3	0.4	W_{13}	5.5	L_7	7.5
W_4	0.9	W_{14}	2.05	L_8	5.2
W_5	0.2	W_{15}	1	L_9	1.6
W_6	0.2	L_{sub}	22.8	L_{10}	2.6
W_7	0.8	L_1	5	L_{11}	0.6
W_8	4.84	L_2	1.8	L_{12}	2.8
W_9	5	L_3	1	h	0.8

Table II: Three various cases for the finger length of CCLs.

Case	L_1(mm)
1	1.4
2	1.6
3	1.8

Another filter structure, which was compared with the presented BPF in simulation studies is shown in Fig. 6 and its frequency responses are compared with the proposed filter in Fig. 7. In this structure a smaller pair of radial stubs is used instead of the simple stub. As it is observed in Fig. 7 the frequency response of the compared filter is almost the same as the presented filter except that the presented filter has a more uniform and extended out-of-band performance but upper cut-off frequency roll-off is sharper for the compared structure.

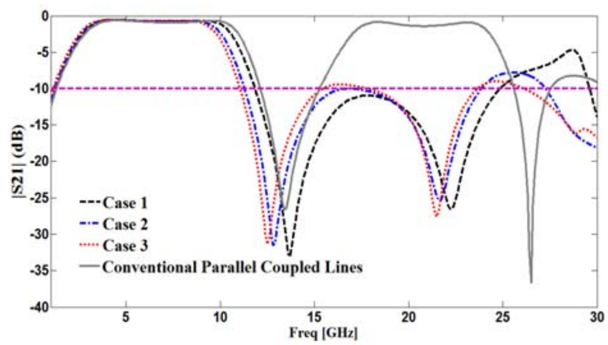

Fig. 4. Frequency responses for various radial stubs dimension listed in Table III.

Table III: Four various cases for the dimensions of the radial stubs.

Case	L_7(mm)
1	6
2	6.5
3	7
4	7.5

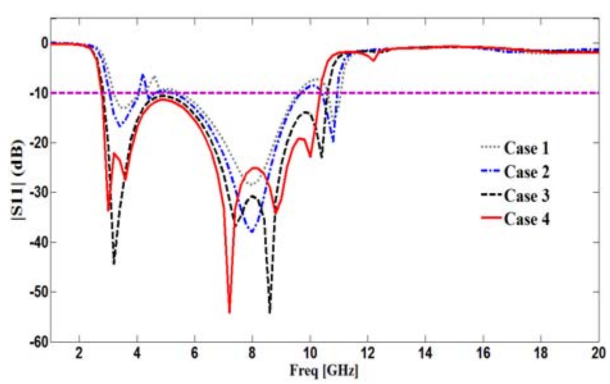

Fig. 5. Return loss characteristics for various radial stubs dimension listed in Table III.

Figure 8 shows the fabricated filter and its measured and simulated frequency responses are compared in Fig. 9. The measured results are in good agreement with the simulation data and the fabricated UWB BPF has a 3 dB pass-band, which covers the range of 2.62 GHz – 10.67 GHz with a fractional bandwidth of 117 %. The improved out-of-band performance of this filter has an attenuation level more than 20 dB for frequencies up to 20 GHz and even more. A comparison between the proposed filter and other reported UWB BPFs is presented in Table IV. The small size and good in/out-band performances of the proposed filter are its main advantages.

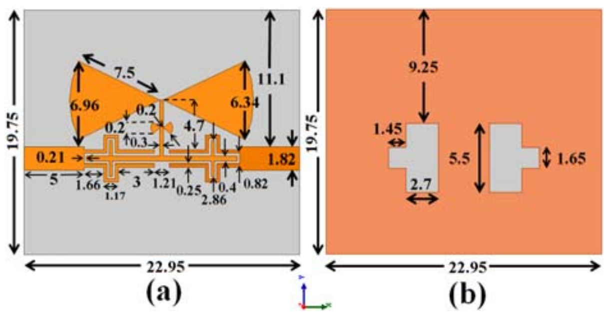

Fig. 6. Filter structure, which was used for comparison in simulation study.

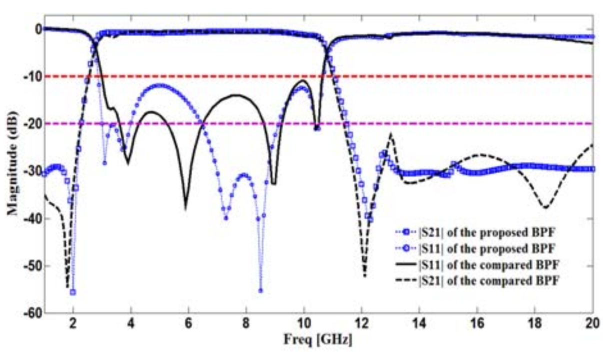

Fig. 7. Frequency responses of the filter structure shown in Fig. 6 in comparison with the proposed filter.

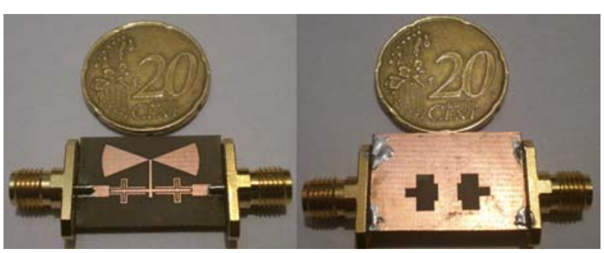

Fig. 8. The photograph of the fabricated UWB BPF.

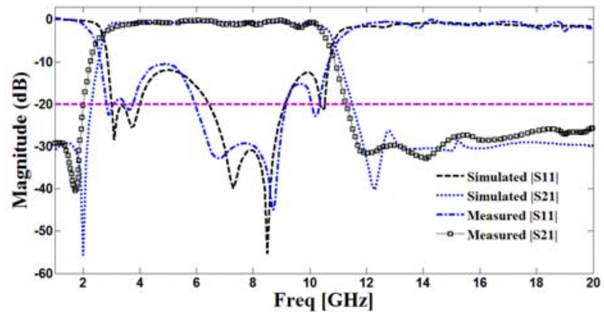

Fig. 9. Simulated and measured frequency responses of the proposed BPF.

Table IV: A comparison with reported UWB BPFs.

Ref	IL (dB)	RL (dB)	S.F.	ε_r/h (mm)	size ($\lambda_0 \times \lambda_0$)	f_c (GHz)
[3]	1.5	11	0.921	2.55/0.8	0.51×0.34	16.8
[4]	0.55	10	0.642	10.8/1.27	0.36×0.05	13.6
[5]	2	12.5	0.757	10.5/0.635	0.23×0.16	18
[6]	1.4	10	0.812	2.55/0.8	0.31×0.38	24
[7]	0.8	12	0.828	2.2/0.508	0.37×0.24	17
This Work	1	11	0.783	3.55/0.8	0.3×0.24	24

IL: insertion loss at the 6.85 GHz; RL: return loss over the whole pass-band; S.F.: selectivity factor of the pass-band (S.F. = $\Delta f_{3dB}/\Delta f_{30dB}$); Δf_{3dB}, Δf_{30dB}: 3 dB bandwidth and 30 dB bandwidth of the pass-band, respectively; ε_r: substrate relative dielectric constant; h: Substrate thickness; f_c: the upper stop-band frequency with 20 dB attenuation; λ_0 is the free space wavelength of the operating frequency at the center of the pass-band (6.85 GHz).

IV. CONCLUSION

A compact microstrip filter with sharp roll-off and improved out of band performance for UWB applications was presented and discussed. In the proposed structure cross-shaped coupled lines are used to improve the out-of-band performance of the filter while a sharp roll-off and high skirt selectivity is achieved by implementing a simple stub and a pair of radial stubs. Also by the use of this structure the overall size of the filter is reduced. The proposed filter is cheap, easy to fabricate, and a good candidate for UWB applications.

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Bahman Mohammadi was born in Divandareh, Iran 1989. He received the B.Sc. degree in Electrical Engineering from Tabriz University, Tabriz, Iran, in 2011, where he is currently working toward the M.Sc. degree in Electrical Engineering from Urmia University, Urmia, Iran. His research interests include electromagnetic computation and wideband passive microwave devices (couplers, filters, phase shifters, etc.).

Javad Nourinia received his B.Sc. in Electrical and Electronic Engineering from Shiraz University and M.Sc. degree in Electrical and Telecommunication Engineering from Iran University of Science and Technology, and Ph.D. degree in Electrical and Telecommunication from University of Science and Technology, Tehran Iran in 2000. From 2000 he was an Assistant Professor and now he is a Professor in the Department of Electrical Engineering of Urmia University, Urmia, Iran. His primary research interests are in antenna design, numerical methods in electromagnetic and microwave circuits.

Changiz Ghobadi was born on 1st of June, 1960 in Iran. He received his B.Sc. in Electrical Engineering-Electronics and M.Sc. degrees in Electrical Engineering-Telecommunication from Isfahan University of Technology, Isfahan, Iran and Ph.D. degree in Electrical-Telecommunication from University of Bath, Bath, UK in 1998. From 1998 he was an Aassistant Professor and now he is a Professor in the Department of Electrical Engineering of Urmia University, Urmia, Iran. His primary research interests are in antenna design, radar, and adaptive filters.

Arash Valizade was born in Tehran, Iran 1986. He received his B.Sc. in Electrical Engineering-Electronics from Azad University of Sabzevar, Iran, in 2008 and M.Sc. degrees in Electrical Engineering-Telecommunication from Urmia University, Urmia, Iran, in 2012, and he is currently a Ph.D. student at Semnan University, Semnan, Iran. His primary research interests are in numerical methods in electromagnetics, microstrip antenna design, microwave circuits, active integrated antenna, and reconfigurable structures.