Super Wide Band Tunable Microstrip BPF Using Stub Loaded MMR

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Abstract **─** A simpler structure of super wide band (SWB) tunable microstrip band pass filter (BPF) using stub loaded multimode resonator (MMR) is presented here. The MMR is formed by loading a single open-ended shunt stub at the center with a simple stepped impedance resonator. By incorporating this MMR with two interdigital parallel coupled feed lines, a novel SWB tunable BPF is formed. The BPF is fabricated using FR-4 substrate of 1.6 mm thickness with dielectric constant of 4.4 and simulated using high frequency structure simulator (HFSS) software. The simulated and measured results are in good agreement with each other, with a wide fractional bandwidth (FBW) of 179%. The measured insertion loss is less than -0.9 dB throughout the pass band of 3.1 GHz-15.4 GHz with the return loss higher than 11.5 dB. The group delay of the filter is relatively constant and less than 0.3 ns over the desired pass band.

Index Terms **─** Band Pass Filter (BPF), Multimode Resonator (MMR), Super Wide Band (SWB), Ultra Wide Band (UWB).

I. INTRODUCTION

Since 2002, the ultra-wideband (UWB) system was approved for civilian-use, by the US Federal Communications Commission (FCC) for both academic and industrial fields [1]. It provides high data rate transmission, low power assumption and low cost for the wireless communication system. Filter is an essential component in the UWB communication system. The challenge to design an UWB BPF is that the fractional bandwidth must exceed 110%. The parallel-coupled microstrip lines are one of the most commonly used RF/microwave circuits due to their design simplicity, planar structure, and relatively wide bandwidth [2]. Multiple coupled transmission line structure implementations have been increased to develop multiple-mode resonator (MMR) filters with wideband passband [3-9]. An UWB passband with five transmission poles was achieved by forming MMR and introducing quarter-wavelength parallel coupled lines in the input and output ports [10]. An improved microstrip line UWB BPF is proposed, designed, and implemented based on the stub-loaded MMR [11]. An equivalent circuit was used to derive filtering transfer function and the mathematical formulation was used to calculate characteristic impedance of filter [12]. Wideband BPF with high passband selectivity and deep stopband rejection performances, have been proposed based on various structures, e.g., ring resonators with open stubs [13], stub-loaded multimode resonators (MMRs) [14], harmonic-suppressed dual-transmission lines [15]. A highly selective triple band notch UWB (3.3 GHz-10.7 GHz) filter was presented where the UWB pass band characteristics were achieved by two coupled multi-mode resonators [16].

In this paper, a simpler structure of SWB tunable microstrip BPF is developed to cover the frequency range from 3.1 GHz-15.4 GHz. Therefore, the designed filter has a wide band passband to cover C-band (4 GHz-8 GHz), X-band (8 GHz-12 GHz), and some part of Ku-band (12 GHz-18 GHz) frequency range. This feature can also be used for the Cable Television Relay Service (CARS) stations with frequency range from 12.7 GHz-13.20 GHz. The CARS stations are point-to-point or point-to-multipoint microwave systems used by cable and other multichannel video programming distributor (MVPD) operators. The proposed filter is designed based on MMR, which is constructed by properly loading a stepped-impedance resonator with a single open-ended stub at the center. This SWB BPF with excellent passband selectivity is designed, analyzed and fabricated with FBW of 179%, insertion loss is less than -0.9 dB, return loss higher than 11.5 dB and group delay is relatively constant and less than 0.3 ns at the pass band.

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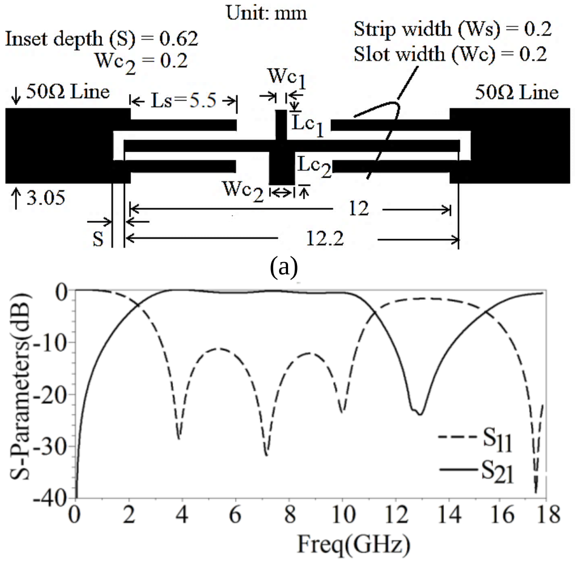
II. UWB FILTER DESIGN AND ANALYSIS

A. Design of MMR and allocating UWB passband

Figure 1 (a) illustrates the schematic of designed UWB microstrip filter. The MMR is constructed with two sections of three coupled lines separated by a stub-loaded resonator. The stub-loaded resonator is formed by attaching one open-circuited stub with two high-impedance microstrip lines at its center. The first three resonant modes of the MMR can be evenly allocated within the 3 GHz-10.8 GHz passband with FBW of 113% by properly adjusting the length and width of the stub as shown in Fig. 1 (b). Two interdigital coupled line (ICL) sections are placed at two sides of the resonator to provide tight coupling with 50 Ω microstrip feed lines. These coupled line sections also provide the desired coupling for the passband. The length of the coupled lines is quarter wavelength ($\lambda_g/4$) at the center frequency. The effects of varying coupled line lengths of the filter structure are analyzed on parameter basis. The capacitively coupled gap and the quarter wavelength open stubs are adopted to generate transmission zeros at the edges of the desired passband to improve the selectivity of the parallel coupled BPF.



(a)

(b)

Fig. 1. (a) Schematic diagram, and (b) simulated S parameters performance of UWB BPF.

B. Equivalent transmission line network of the UWB BPF

Figure 2 gives an equivalent transmission line network of Fig. 1 (a), in which the pair of stubs can be perceived as an equivalent frequency dependent capacitance $C_s(\omega)$. The ICL section is characterized as a J-inverter susceptance (*J*) and two electrical lengths ($\theta/2$), which represents the series capacitive coupling and equivalent phase shifts respectively [17]. On the other hand, the central line can be perceived as an additional phase factor ($\phi/2$), so that the total electrical length φ should be made up of three separate parts, i.e. $\Phi = \theta/2+ \phi/2+ \theta/2$. For a symmetric two port network,

$$\bar{J} = \frac{\tan(\theta/2)+\bar{B}_{11}}{\bar{B}_{11}\tan(\theta/2)}, \tag{1}$$

$$\theta = -\tan^{-1}\left\{\frac{2\bar{B}_1}{1-\bar{B}_{11}^2+\bar{B}_{12}^2}\right\}, \tag{2}$$

where $\bar{J} = J/Y_0, \bar{B}_{11} = B_{11}/Y_0 = B_{22}/Y_0, \bar{B}_{12} = B_{12}/Y_0 = B_{21}/Y_0$ and Y_0 is the characteristic admittance of the microstrip line. On the basis of transmission line theorem, the normalized input admittance ($\bar{Y}_{in} = Y_{in}/Y_0$) at one termination (#1), looking into opposite termination (#1'), can be easily deducted and expressed as a function of $\bar{J}$ and Φ such that,

$$\bar{Y}_{in} = \frac{\bar{J}^2\left(1+j\bar{J}^2\tan\Phi\right)}{\bar{J}^2 + j\tan\Phi}. \tag{3}$$

Accordingly, the reflection coefficient (S_{11}) at #1 can be expressed as:

$$S_{11} = \frac{j\left(1-\bar{J}^4\right)\tan(\Phi)}{2\bar{J}^2 + j\left(1+\bar{J}^4\right)\tan(\Phi)}. \tag{4}$$

The stub-loaded resonator section of the circuit is responsible for the stopbands at two edges of the UWB bandpass filter.

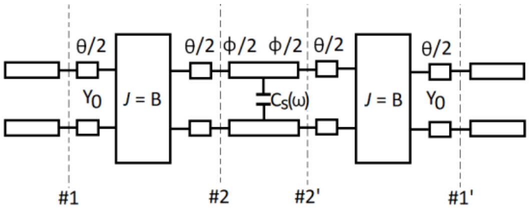


Fig. 2. Equivalent transmission line network of the proposed UWB BPF.

To analyze this section, odd and even mode methods are implemented along this AA' line as shown in the following Figs. 3 (a-e). This AA' line subdivided the above section into two symmetric portions. For odd and even mode analysis, equivalent circuits are shown in Figs. 3 (b) and 3 (c) respectively. The input impedance expressions for odd mode and two even modes are given by equation (5) to equation (7):

$$Z_{in,odd} = jZ_1\tan\theta_1, \tag{5}$$

$$Z_{in,even1} = jZ_1\frac{\left(Z_1\tan\theta_1 - Z_2\cot\theta_2\right)}{Z_1 + Z_2\tan\theta_1\cot\theta_2}, \tag{6}$$

$$Z_{in,even2} = jZ_1\frac{\left(Z_1\tan\theta_1 - Z_3\cot\theta_3\right)}{Z_1 + Z_3\tan\theta_1\cot\theta_3}. \tag{7}$$

For the resonance condition, to achieve stopbands at the two UWB response,

$$Z_{in,even1} = Z_{in,even2} = 0, \tag{8}$$

and,

$$Z_{in,odd} = \infty. \tag{9}$$

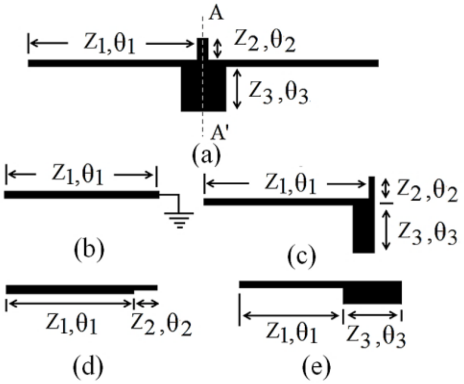


Fig. 3. (a) Circuit layout for, (b) odd, and (c) even mode analysis; (d) & (e) decomposed parts of even mode.

III. MODIFIED UWB FILTER DESIGN AND ALLOCATING SWB PASSBAND

A. Modified design of MMR and allocating SWB passband

The proposed structure is modified according to the consideration of inset feed and infinite ground plane. The simulated S parameters performance of SWB BPF is shown in Fig. 4.

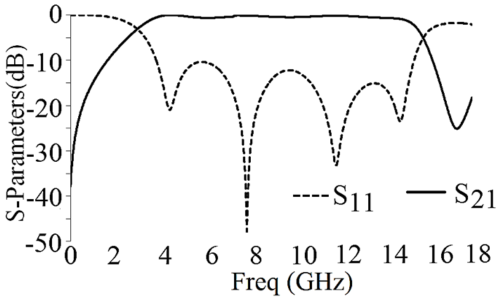


Fig. 4. Simulated S parameters performance of proposed SWB BPF.

The first four resonant modes of the MMR can be evenly allocated within 3.1 GHz-15.4 GHz passband by decreasing the coupling line lengths and stub width, where $S_{11} < -11.5$ dB and thus SWB passband is achieved. The slot width between the parallel coupled strip lines and strip width are defined by W_c and W_s respectively. The Inset depth is taken as S, length of coupled lines is defined by L_s, and the width and length of the open-ended stub are described by W_{c1}, W_{c2}, L_{c1}, and L_{c2} respectively. From this comparison the optimized dimensions of the wideband BPF are fabricated and the final design dimensions are: $L_s = 4$ mm, $L_{c1} = 0.25$ mm, $W_{c1} = 0.2$mm, $W_{c2} = L_{c2} = 0.76$ mm, $W_s = W_c = 0.2$ mm, and S = 0.62 mm as labeled in Fig. 1 (a). The overall length of this filter is approximately equal to one full wavelength at 6.85 GHz, which is much smaller than those reported in literatures. Finally, the bandwidth is increased with FBW of 179%. Increase of the slot width (W_c) reduces the bandwidth of the desired passband and vice versa. So, the pass band is controlled by the slot width. The performance of the BPF is improved by changing the coupling strip line lengths and stub width, to cover the SWB frequency range from UWB passband.

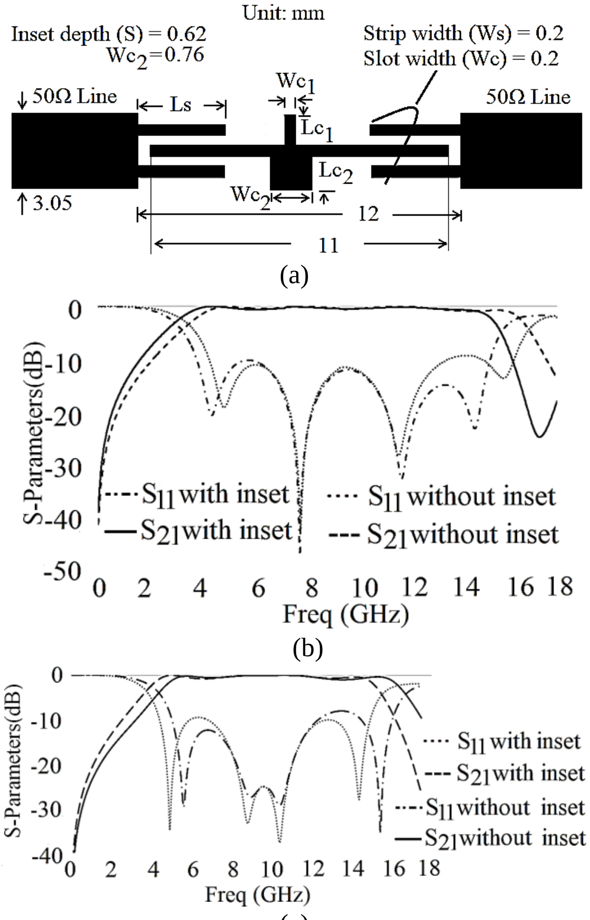


Fig. 5. (a) Schematic diagram of modified SWB BPF, (b) simulated S-parameters performance, with and without inset feed of SWB BPF for infinite ground, and (c) finite ground.

B. Effect of infinite and finite ground plane with inset and without inset feed line

Here the frequency re-configurability can be achieved with a change in the induced current distribution by varying the size of the ground plane and inset feed. Better impedance matching is achieved by giving the inset feed. The schematic diagram of modified SWB microstrip BPF is shown in Fig. 5 (a). In this design no inset feeding is provided, and the ground plane is finite. It is seen that the lower frequency and higher frequency shifted from 3.1 GHz to 5.4 GHz and 15.4 GHz to 15.8 GHz respectively due to the finite plane and without inset feeding. So, the size of ground plane has a significant effect on the frequency shifting.

Figures 5 (b-c) show the simulated S parameters performance, with and without inset feed of proposed and modified SWB BPF for infinite and finite ground respectively. The performance comparison of SWB and modified SWB BPF is shown in Table 1.

Table 1: Performance comparison of SWB and modified SWB BPF

Figure No.	**Ground Plane**	**Feeding**	**Bandwidth (GHz)**
Fig. 5 (b)	Infinite	Without Inset	3.6-15.8
		With Inset	3.1-15.4
Fig. 5 (c)	Finite	Without Inset	5.4-15.8
		With Inset	4.3-15.4

Figure 6 shows the comparison of ground plane size with inset feed. And it confirms that the infinite ground plane with inset feed give the best results. The current density of the proposed filter at the center frequency of 6.85 GHz of the pass band is shown in Fig. 7.

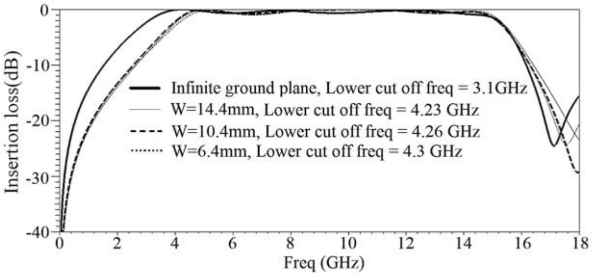


Fig. 6. S_{21} performance for different widths of ground plane with inset feed.

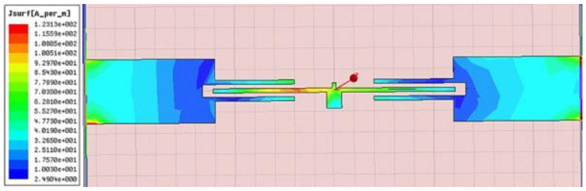


Fig. 7. Current density of the proposed SWB BPF.

Here the stub loaded resonator with high impedance line resonates with a much higher density at the center frequency.

IV. FABRICATION AND MEASUREMENTS

A prototype of the proposed SWB microstrip BPF with MMR is fabricated as shown in Fig. 8. It is also measured by vector network analyzer (VNA). The fabricated filter occupies a small size of 12.2 mm × 1.01 mm which amounts to 0.279 $\lambda_0 \times 0.023\ \lambda_0$, where λ_0 is the free-space wavelength of the operating frequency. For the measurement, a 6.4 mm long 50 Ω microstrip feed line is added at both input and output. The simulated and measured results are in good agreement with each other over the wide frequency range of 500 MHz-18 GHz. In the measurement, the lower and higher cut-off frequencies of the SWB pass band are equal to 3.1 GHz and 15.4 GHz respectively, as observed in Fig. 9. This indicates that the relevant fractional bandwidth about 179% is achieved. The measured insertion loss is found as -0.9 dB at the centre frequency of 6.85 GHz. The return loss in simulation and measurement are both higher than -11 dB with four transmission poles over the passband.

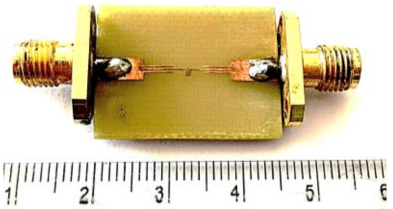


Fig. 8. The photograph of the fabricated SWB BPF.

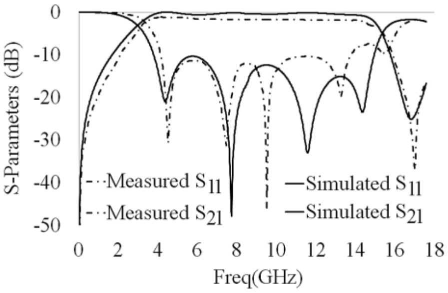


Fig. 9. The measured and simulated SWB BPF S parameters performance.

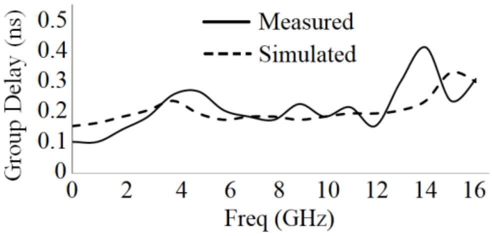


Fig. 10. Simulated and measured group delay of proposed SWB BPF.

The proposed SWB BPF group delay is obtained from the simulated as well as measured results as shown in Fig. 10. It is clear that the variations in the group delay are around 0.3 ns for the frequency band of 3.1 GHz-15.4 GHz.

V. PERFORMANCE SUMMARY OF SOME PUBLISHED WIDEBAND BPFs

The SWB filter here shows two transmission zeros at the lower and upper edges of the desired passband and four attenuation poles inside the passband which enhanced the performance of the filter. Taking λ_0 is the free-space wavelength of the operating frequency, the resonator size is compared. It can be easily found that the overall length of this proposed SWB BPF is smaller and simpler than the existing publications as shown in Table 2. At the center of 6.85 GHz, the insertion loss and return loss results are better as compared with some referred journals [5-11].

Table 2: Comparison with other topologies

Reference	Center Frequency (GHz)	FBW	$\lvert S_{21}\rvert dB$	$\lvert S_{11}\rvert dB$	Physical Dimension (mm)	Dielectric Constant/Height (mm)
[5]	6.85	119%	≤ 1.1	≥10	9.44 x 7.09	10.8/0.635
[6]	6.85	117%	≤ 2.0	≥7.0	22.3 x 13.64	2.55/0.8
[7]	6.85	117%	≤ 1.4	≥12.5	22.3 x 16.18	10.5/0.635
[8]	6.85	116%	≤ 1.4	≥11.0	31.92 x 15.3	2.55/0.8
[9]	6.85	120%	≤ 1.6	≥12.5	10.1 x 6.99	10.5/0.635
[10]	6.85	113%	≤0.55	≥10	15.65 x 1.049	10.8/1.27
[11]	6.85	114%	≤0.8	≥14.3	13.77 x 2.711	10.8/1.27
Proposed work	6.85	179%	≤0.9	≥11.5	12.2 x 1.01	4.4/1.6

VI. CONCLUSION

The MMR is constructed of two sections of three coupled lines separated by a stub-loaded resonator. The stub-loaded resonator is formed by attaching one open-circuited stub with two high-impedance microstrip lines at its center. The MMR structure is analyzed, and the corresponding transmission line equivalent model is given. The coupling space of the input/output interdigital coupled line sections are largely taken to realize a good SWB pass band performance. All the predicted parameters, i.e., insertion loss, return loss, group delay are experimentally verified. It can be seen that, a SWB passband can be achieved from a UWB BPF, by decreasing the coupled line length and width of stub. When the ground plane is finite, resonator length is decreasing and the structure is without inset feeding, this leads to shift of the overall passband frequency to higher value. By giving the inset feed, better impedance matching is achieved and the SWB passband is realized. So, the pass band is tuned by the size of resonator length, coupling line length, stub width, ground plane and inset feed. The SWB BPF is fabricated using FR-4 substrate. The filter is simulated using HFSS software and realized using photolithographic technique. The outcome of FBW about 179% of this smaller and simpler structure is the achievement of the design. Here the insertion loss ≤ -0.9 dB and the variations in the group delay are around 0.3 ns throughout the pass band of 3.1 GHz-15.4 GHz and has a wide -30 dB rejection in the upper stop band. The simulated results are in good agreement with the measured ones and a sharp selectivity is achieved.

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