ORIGINAL RESEARCH PAPER
Pages: 261-271

A Simple UWB Microstrip Band-Pass Filter with an Ultra-Wide Stopband Using Parallel Coupled lines and Hairpin Resonators

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DOI:10.22070/JCE.2023.17355.1236

Abstract- In this paper a simple ultra-wide band (UWB) microstrip band pass filter (BPF) with an ultra-wide stopband using novel dual hairpin resonators and parallel-coupled lines is proposed. The proposed filter has a wide pass band of 3.1 to 10.2 GHz with only 0.1 dB insertion loss. This wide pass band of 7.1 GHz, shows 106.7% fractional band width (FBW). The proposed BPF not only correctly operates at the ultra-wide pass band, but also provides an ultra-wide stopband from 12.8 to 28.2 GHz with more than 20 dB attenuation level. The proposed BPF has a very simple structure, which consists of four novel hairpin resonators and simple parallel-coupled lines. The proposed BPF has a compact size, which the overall circuit size of the device is only 11.7 mm × 7.2 mm (0.35 λ × 0.22 λ), where λ, is calculated at the center frequency of 6.65 GHz. The proposed device is simulated, fabricated and tested. The measured results confirm the correct performance of the proposed BPF.

Index Terms- Band pass filter (BPF), coupled lines, fractional bandwidth (FBW), ultra-wide band (UWB).

I. INTRODUCTION

Ultra Wideband (UWB) band pass filters (BPFs), have been widely used in the modern communication circuits and systems [1]. The standard frequency band of 3.1-10.6 GHz, was released by the Federal Communication Commission (FCC) for Ultra-wide band frequencies in 2002 [2], which in the past decade, several methods have been reported to design filters with ultra-wide pass band. Stepped impedance lines and multi-mode resonators have been widely used to create wideband filters in [3-7]. Also, parallel coupled lines technique is another common method to design UWB filters [8-11].

Recently, devices with filtering response have been considered, in which only operating frequencies

Manuscript received 15-March-2021 and revised 11-May-2021,
Accepted on 13- June-2021

P-ISSN: 2322-4088
E-ISSN:2322-3936

are passed and others bands are rejected. BPFs can be easily used in dividers [12,13], couplers [14], amplifiers [15,16] and diplexers [17] to shape the device with filtering responses. Defected ground structures (DGS) [18-20] and EBG [21-23] cells are other common methods to create wide-band BPFs. With these methods wide band responses are achieved but the fabrication processes are complicated and need extra process.

All of these mentioned filters have high insertion loss in the pass band, which is undesirable. Moreover, in most of these filters the provided stop bandwidths are not so wide. But, in the proposed filter, low insertion loss in pass band and ultra-wide stopband using parallel coupled lines and hairpin resonators are obtained.

II. DESIGN OF THE PROPOSED DUAL HAIRPIN RESONATOR

The proposed BPF consists of simple parallel coupled lines, which loaded by two dual hairpin resonators at both sides. These resonators provide transmission zeros at high frequencies, which resulted in wide stopband.

The structure of applied single hairpin and dual hairpin resonators are depicted in Fig1. The resonators are designed using 5880 substrate with εr = 2.2 and thickness of 20 mil. All dimensions are given in the millimeter unit.

The structure of the single hairpin and dual hairpin resonators are shown in Figs. 1(a) and (b), whereas the frequency response of the single hairpin and dual hairpin resonators are shown in Figs. 1(c) and (d). The single resonator creates a transmission zero (TZ) near 20 GHz, while the proposed dual hairpin resonator creates two transmission zeros (TZ1 and TZ2) at 16 and 22GHz, which resulted in wide stop bandwidth.

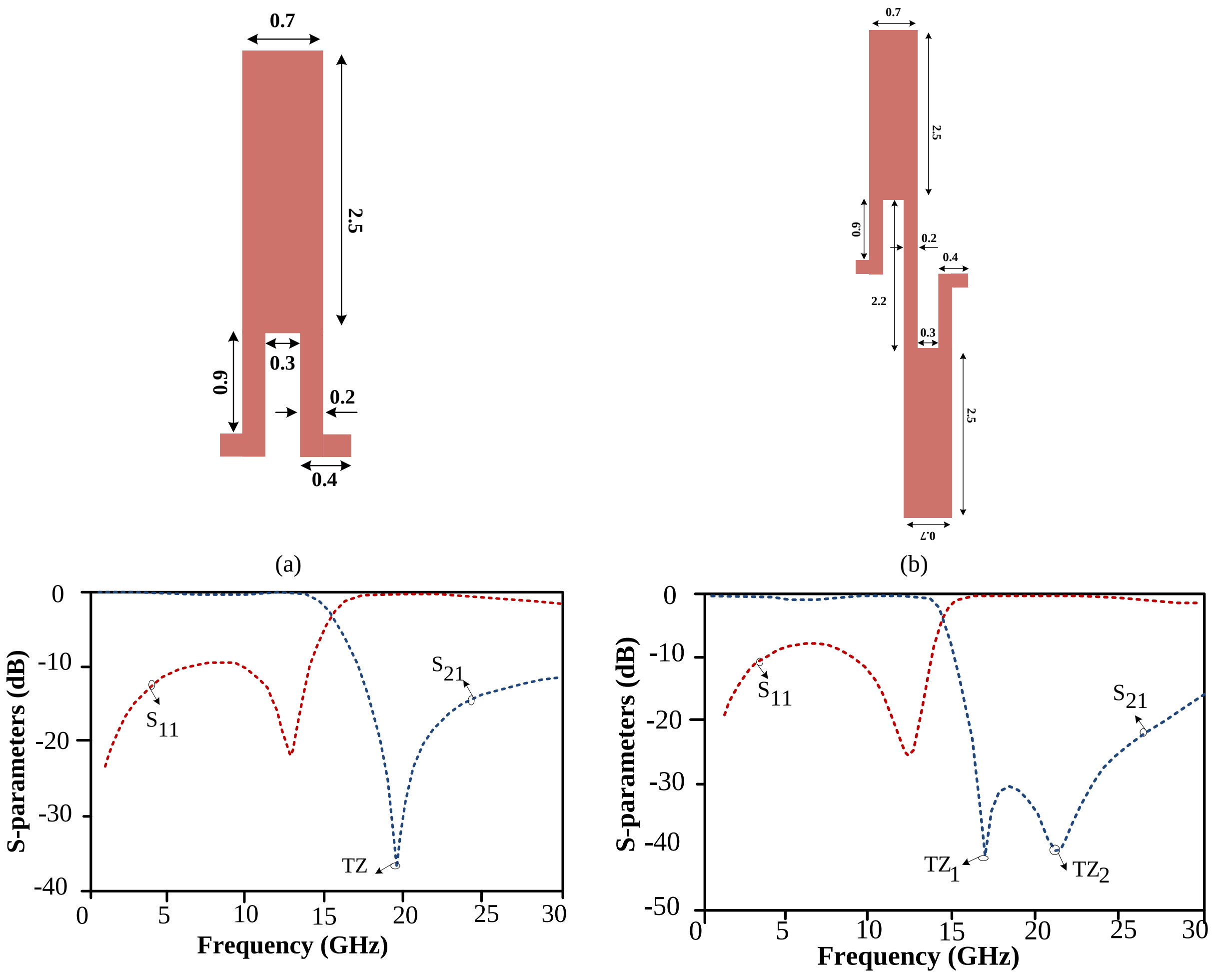
At first, a filter with two series resonant circuit, two inductors and a central capacitor is proposed, which can be realized as a single hairpin resonator as depicted in Fig. 2(a). To extract the transfer function of the proposed resonator circuit, the equivalent circuit is presented as shown in Fig. 2(b).

According to Fig. 2(b), the equivalent impedances of the circuit elements can be extracted as shown in Equations (1)-(3)

$$Z_1 = Z_5 = L_1 S \tag{1}$$

$$Z_3 = Z_4 = L_2 S + \frac{1}{C_2 S} \tag{2}$$

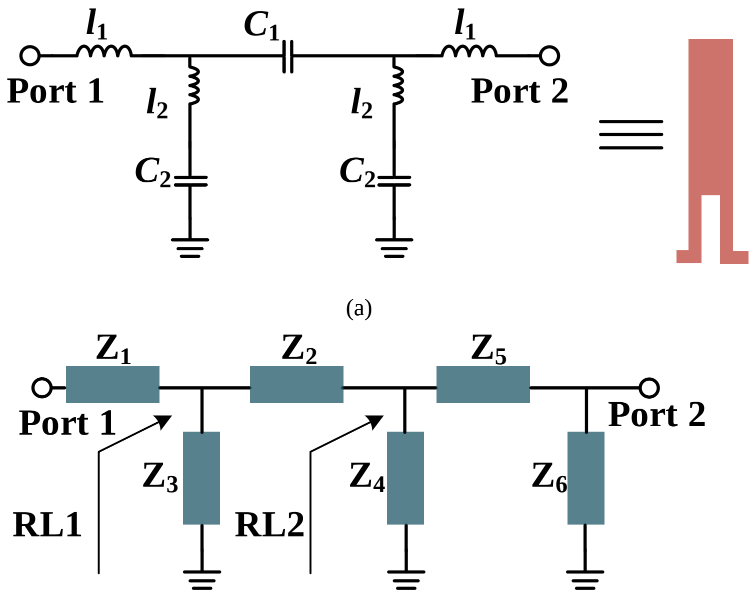
$$Z_2 = \frac{1}{C_1 S}, \quad Z_6 = R_L \tag{3}$$



(a) (b)

(c) (d)

Fig.1. The structure of the proposed (a) single hairpin and (b) dual hairpin resonators. The frequncy response of the (c) single hairpin and (d) dual hairpin resonators.



(a)

(b)

Fig. 2. Single hairpin resonator. (a) LC circuit of the resonator and (b) equivalent circuit used for analysis.

Also, the seen impedances of RL1 and RL2 can be written as shown in Equations (4) and (5).

$$RL_1 = Z_3 \parallel \left(Z_2 + RL_2\right) \tag{4}$$

$$RL_2 = Z_4 \parallel \left(Z_5 + Z_6\right) \tag{5}$$

According to equations (1)-(5), the transfer function of the proposed resonator circuit can be extracted as written in Equation (6).

$$H\left(S\right) = \frac{RL_1}{RL_1 + Z_1} \times \frac{RL_2}{RL_2 + Z_2} \times \frac{Z_6}{Z_6 + Z_5} \tag{6}$$

By substituting the values of Equations (1)-(5) in Equation (6), the transfer function formula can be written as shown in Equations (7). Also, the parameters of σ1, σ2, and σ3 are defined in Equations (8)-(10).

$$H\left(S\right) = \frac{R_L {\sigma_3}^2}{\left(L_1 S + \frac{\sigma_3\left(\frac{1}{C_1 S} + \sigma_2\right)}{\sigma_1}\right)\left(R_L + \frac{1}{C_2 S} + L_1 S + L_2 S\right)\sigma_1} \tag{7}$$

$$\sigma_1 = \frac{1}{C_1 S} + \frac{1}{C_2 S} + L_2 S + \sigma_2 \tag{8}$$

$$\sigma_2 = \frac{\sigma_3\left(R_L + L_1 S\right)}{R_L + \frac{1}{C_2 S} + L_1 S + L_2 S} \tag{9}$$

$$\sigma_3 = \frac{1}{C_2 S} + L_2 S \tag{10}$$

The analyses and circuit simulation responses of the proposed resonator circuit are shown in Fig. 3. Also, the response of the microstrip realization of the proposed single hairpin resonator is shown in Fig. 3 as layout EM simulation. As can be seen there is good agreement between analyses, circuit simulation, and layout simulation results.

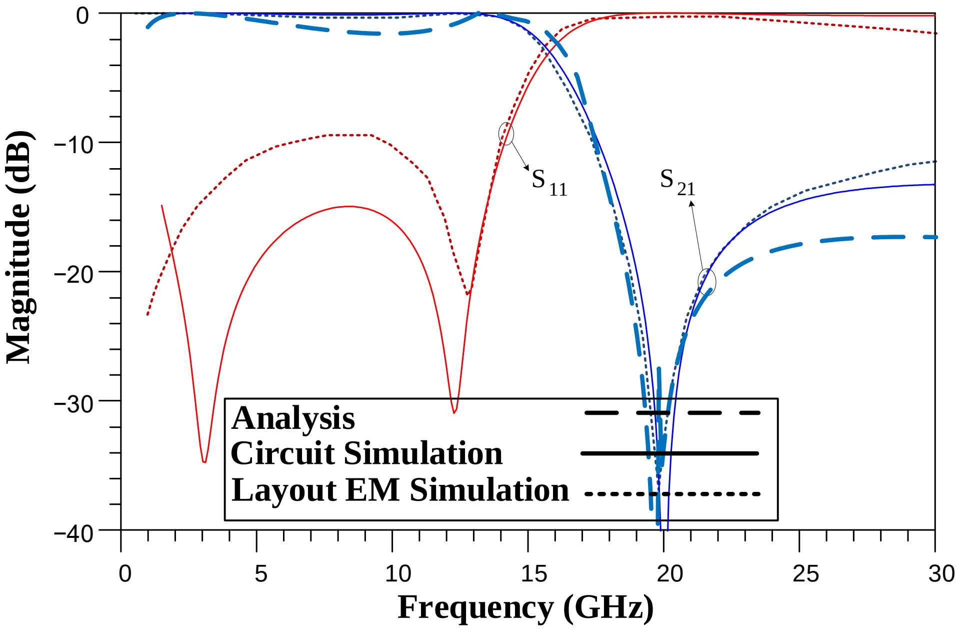


Fig. 3. The analyses, circuit simulation, and layout simulation results of the proposed single hairpin resonator.

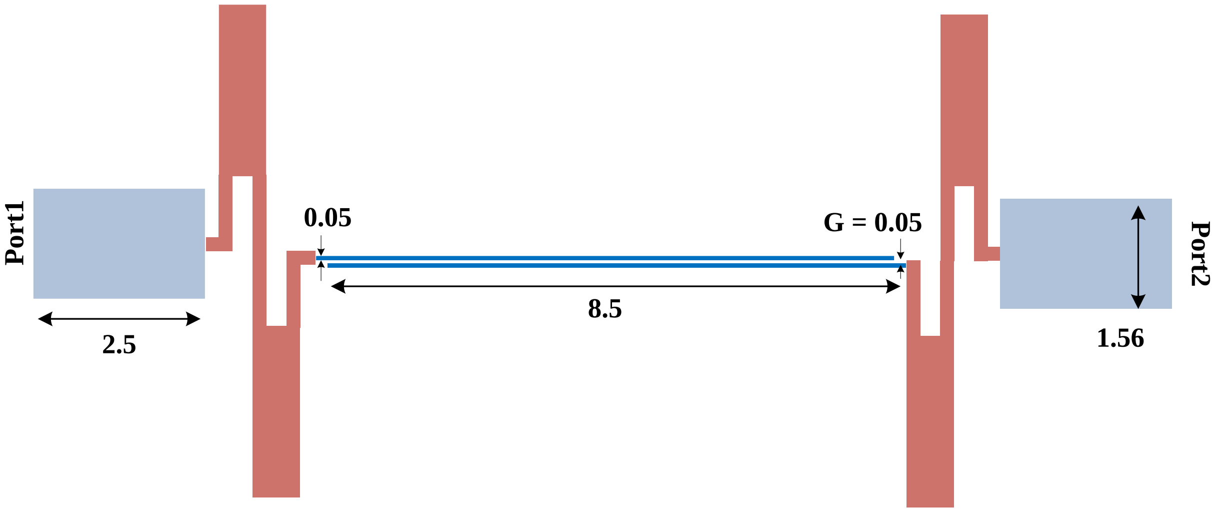


Fig. 4. Structure of the proposed BPF. All dimensions are written in millimeter.

III. DESIGN OF THE PROPOSED ULTRA-WIDE BAND BPF

The structure of the proposed UWB band pass filter is depicted in Fig. 4. The proposed BPF is consisting of parallel-coupled lines and four hairpin resonators. The designed BPF was simulated and fabricated on 5880 substrate with εr = 2.2 and thickness of 20 mil. The proposed BPF has a compact size and the overall circuit size of the device is only 11.7 mm × 7.2 mm (0.35 λ × 0.22 λ), where λ, is calculated at the center frequency of 6.65 GHz.

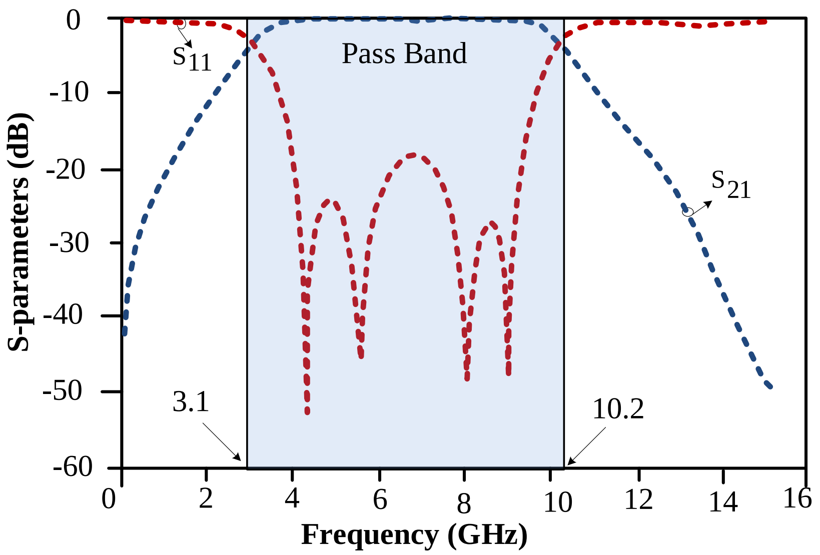


Fig. 5. In-band frequency response of the proposed BPF with 106.7% FBW.

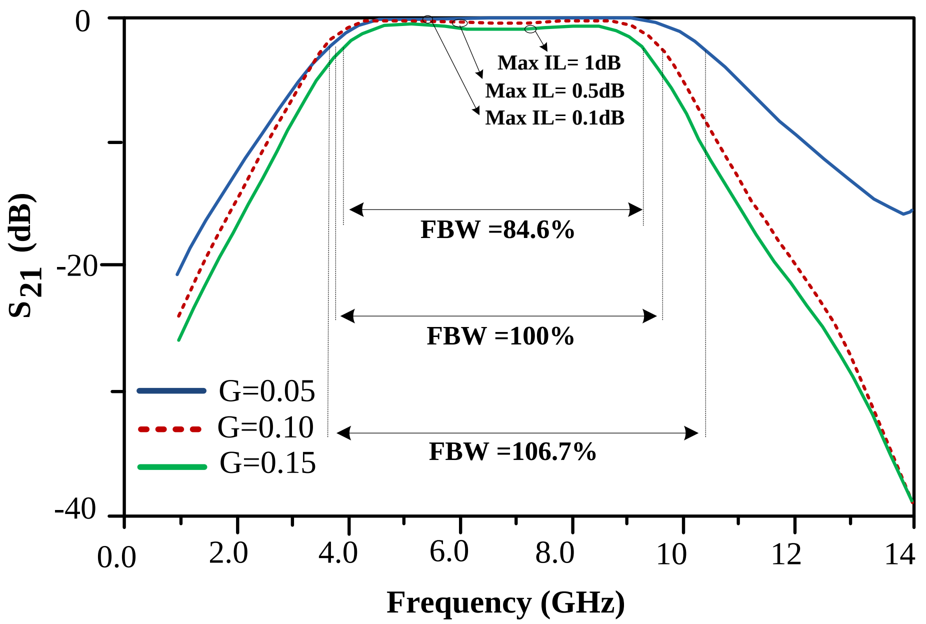


Fig. 6. The effect of the different values of coupling gap (G) parameter in the frequency response of the proposed UWB BPF.

The in-band frequency response of the proposed UWB filter is depicted in Fig. 5. The results show that the proposed band pass filter has an ultra-wide pass band from 3.1 GHz to 10.2 GHz with bandwidth of 7.1 GHz and center frequency of 6.65GHz, which shows 106.7% fractional band width (FBW).

The proposed BPF has a desirable response in the pass band, where the insertion loss (IL) is less than 0.1 dB and return loss is more than 18 dB in the whole operating bandwidth.

The effects of the different values for coupling gap (G) parameter in the frequency response of the proposed UWB BPF is depicted in Fig. 6. In this figure, three different values of coupling gap (G) are investigated. The results show that in case 1, with G=0.15 mm, the pass band is between 3.9 to 9.1

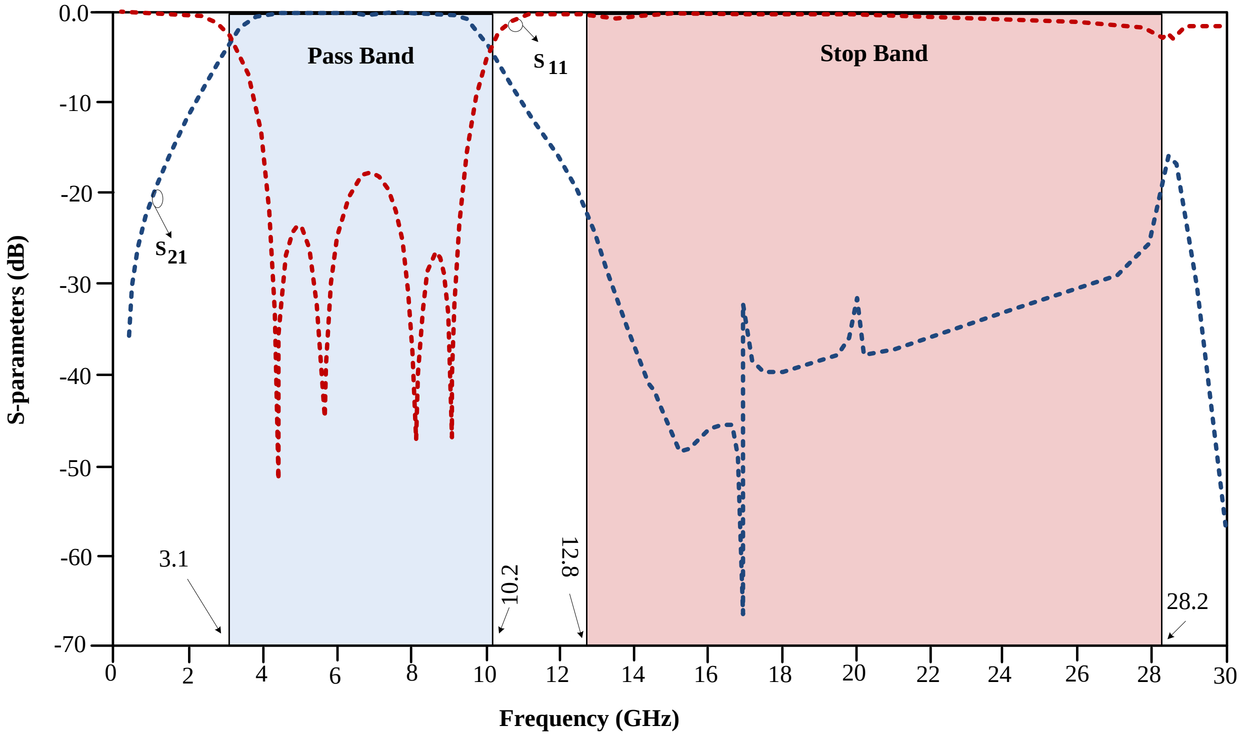


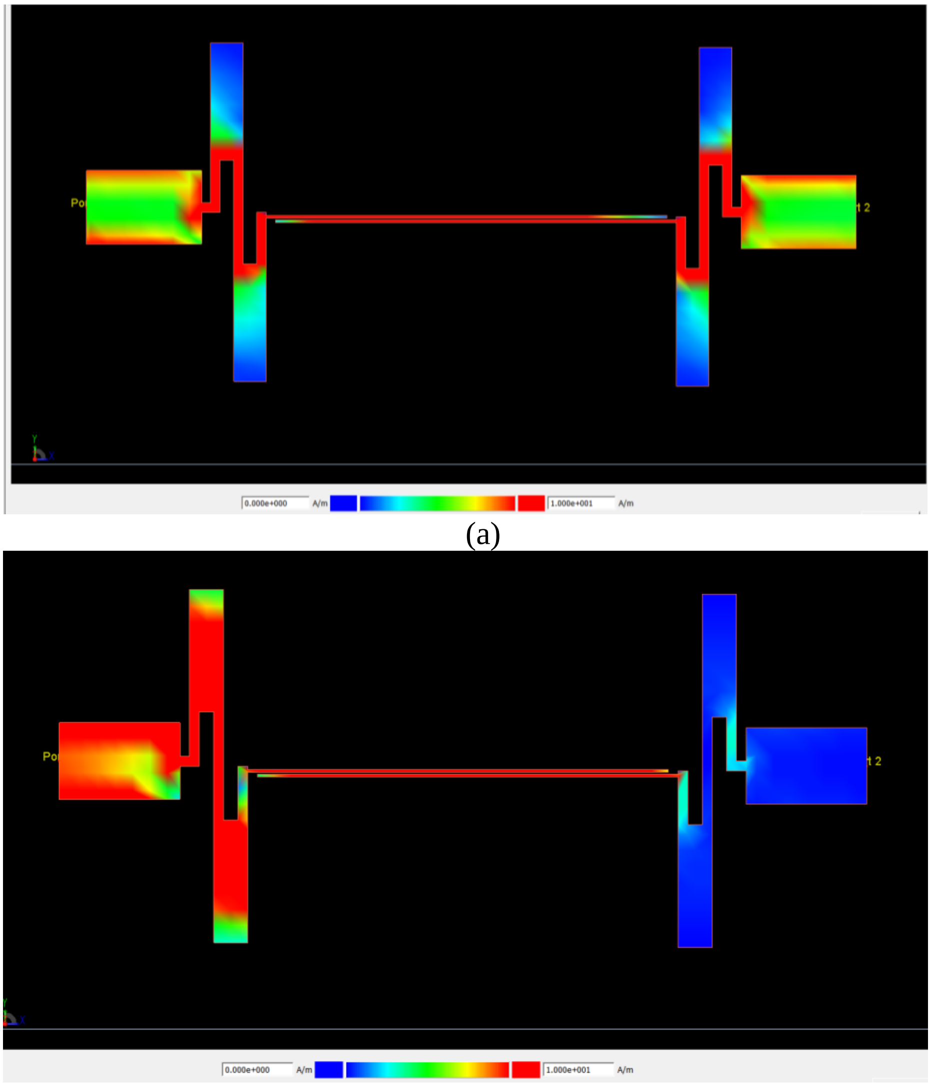
Fig. 7. The frequency response of the proposed BPF in a wide frequency range.

GHz with maximum 1 dB insertion loss. The FBW in this case is 84.6%. In case 2, with G=0.1 mm, the pass band is between 3.5 to 9.75 GHz with maximum 0.5 dB insertion loss. The FBW in case 2 is 100%. In case 3, with G=0.05 mm, the pass band is between 3.1 to 10.2 GHz with maximum 0.1 dB insertion loss. The FBW in case 3 is 106.7%. According to the fabrication process limitations, the fabricated coupling gap (G) of 0.05 mm is chosen, which the proposed BPF has the best performance in this gap.

The frequency response of the proposed BPF in a wide frequency range is depicted in Fig. 7. The proposed BPF not only has obtained prefect results in the pass band, but also it provided an ultra-wide stopband from 12.8 to 28.2 GHz with more than 20 dB attenuation level.

The current distributions of the proposed BPF at center frequency of 6.65 GHz, which is located in the pass band, and also at 13.3 GHz, which is located in the stop band, are provided in Figs. 8(a) and (b), respectively, which show correct performance of the proposed BPF.

The proposed BPF has a prefect performance, in order to have a better comparison, the performance of the proposed filter and similar reported works are listed in Table.1. As results shown the proposed BPF has the smallest size, lowest insertion loss and provide the widest stop band, compared with the other works in this table. In addition, the other parameters of the proposed BPF are desirable.



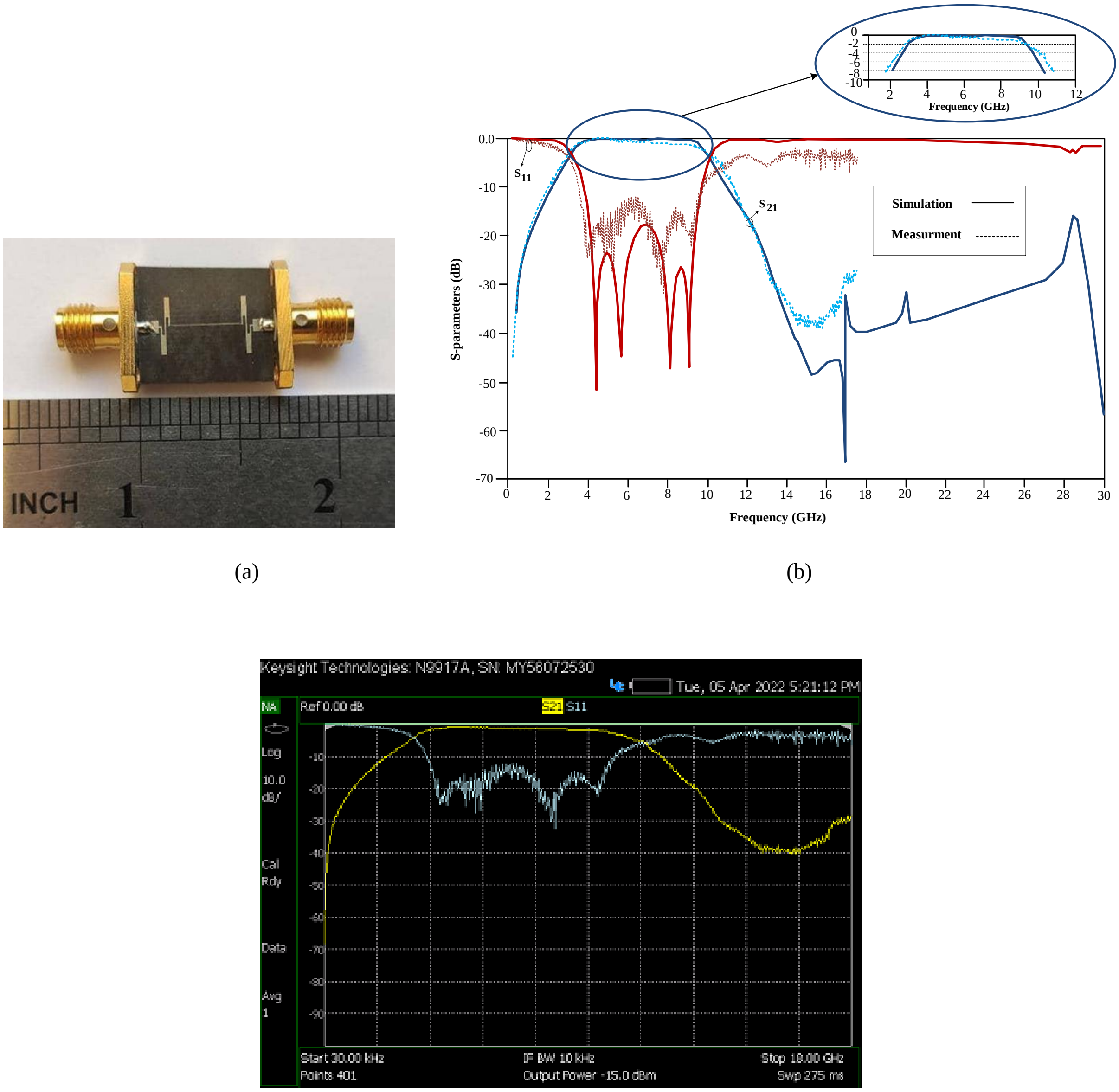
(a)

(b)

Fig. 8. The current distributions of the proposed BPF at (a) 6.65 GHz, located in the pass band, and (b) 13.3 GHz, located in the stop band.

Table1. performance summary of the proposed BPF compared with similar works.

Ref	Passband (GHz)	Center freq.(GHz)	IL (dB)	RL (dB)	FBW (%)	Size (mm×mm)	λ at center freq. (mm)	Size (λ×λ)	Upper Stopband (GHz)
[24]	3.5-10.5	7	1.3	14	100	27.7 × 1.08	16	1.7 × 0.06	16
[25]	4.1-8.65	6.375	1	19	71.3	-	18	-	12
[26]	3.8-10.5	7.15	1	15	93.7	20 × 50	30.8	0.65 × 1.6	16
[27]	3.5-10.5	7	0.5	17.2	100	11.9 × 8	26.2	0.45 × 0.3	16
[28]	3.1-10.6	6.85	0.5	18	109.4	18.6 × 13.5	26.8	0.69 × 0.5	16
This work	3.1-10.2	6.65	1	15	106.7	11.7 × 7.2	32.7	0.35 × 0.22	28.2



(a)

(b)

(c)

Fig. 9. (a) The photo of the fabricated device and (b) simulated and measured S-parameters and (c) network analyzer screen.

IV. CONCLUSION

In this paper, design and implementation of a simple UWB band pass filter with planar structure is presented. The proposed BPF has a simple structure, which consists of main coupled lines and four hairpin resonators, which provides ultra wide pass band from 3.1 to 10.2 GHz with very low insertion loss of 0.1 dB. The proposed BPF has a wide pass band with bandwidth of 7.1 GHz and center frequency of 6.65GHz, which shows 106.7% fractional band width (FBW). The designed BPF not only has prefect results in pass band, but also provides an ultra-wide stopband from 12.8 to 28.2 GHz with more than 20 dB attenuation level. The designed filter has a compact size, which the overall circuit size of the device is only 11.7 mm × 7.2 mm (0.35λ × 0.22λ).

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