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A Novel Low-Cost Microstrip Bandpass Filter for Ultra-Wideband RF Applications

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Abstract- **A novel wideband bandpass filter (WBPF) using planar technology with compact size and sharp cutoff frequency is proposed. The presented microstrip filter consists of a three parallel coupled lines (TPCL) with a radial open stub. To validate the designed filter in term of compactness, insertion loss, return loss, and transmission zeros, a high meshing density is applied in two electromagnetic solvers Advanced Design System (ADS) and CST-Microwave Studio. The proposed filter is fabricated on an FR4 substrate with a relative dielectric constant of 4.4 and 1.58mm of substrate thickness and fed by a two 50Ω microstrip lines. Further, the filter is measured which exhibits a return and insertion losses of 20dB and 0.49dB, respectively, with a center frequency around 3.5 GHz and an operating bandwidth (2.1 GHz to 5.22 GHz) of about 85 %. Good agreement between the simulated and measured results demonstrates the proposed filter design. The overall circuit size of the filter was taken to be 23.24 X 40 mm^2.**

Index Terms- **Bandpass filter, Microstrip structure, Three parallel coupled lines (TPCL), Radial open stub, Wideband Applications.**

I. INTRODUCTION

In recent years, the ultra-wideband technology has become quite interesting in wireless communication system. As we know, wideband and ultra-wideband bandpass filters with a fractional bandwidth (FBW) more than 20% are required by the next generation wireless systems because of high data rate communication [1]. One of the major components for an ultra-wideband communication system is ultra-wideband (UWB) bandpass filter which is used to separate or combine different frequencies [2-3]. The fractional bandwidth of such BPFs usually exceeds 100% (3.1–10.6 GHz). Then to design a BPF with wide band, compact size, low insertion loss and wideband rejection either becomes a challenging task.

The design of wideband microwave filters has been a huge challenge over the last few years. Thus, several compact filter realizations exhibiting an extremely large pass band have been proposed in the literature using different technologies, such as microstrip and waveguide. For example, many approaches for microstrip filters have been investigated and commonly applied to circuit designs. Numerous researchers have proposed various configurations for WBPF designs with good wideband responses, among them: Methods using multi-mode resonators (MMRs) [4-6], multiple notch-band [7-8], stepped-impedance multiple-mode resonator [9-10], Ring resonators[11-13], multiple coupled transmission lines with defected ground [14-18], metamaterial [19], quasi-lumped element [20], and composite low pass-high pass filter or bandpass-bandstop filter [21-22]… etc.

However, these filters have not shown good return loss, low insertion loss in their pass band and the sharp out-of-band rejection. Due to the

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trend toward broader bandwidth and better selectivity, filters with a wide stop band in a linear wideband system are promising and remain as challenges.

Wideband is referred as a wide operating range of frequencies in microwave engineering, and its relevant technique was initially developed and applied for military communication in the past few decades. Since 2002, unlicensed usage of ultra-wideband (UWB) spectrum has been progressively released globally for short range wireless communications. It stimulates much interest in the exploration of various wideband or UWB techniques for civil applications [1].

In this paper, a wideband bandpass filter that consists of a three parallel coupled lines (TPCL) was developed. The middle line is connected to a radial open stub as shown in Fig.1. The wideband bandpass filter has an operating center frequency of 3.5GHz, with 85.1 % fractional bandwidth providing an attenuation of 30dB in the stop-band. The size of this filter is reduced due to the use of the simple TPCL and radial open stub while an excellent performance was achieved. The BPF is fabricated on an FR4 substrate with a relative dielectric parameter of 4.4, a thickness of 1.58 mm and loss tangent of 0.025. The simulation results are in line with the measured one.

II. FILTER DESIGN AND ANALYSIS

As depicted in Fig.1, a miniaturized ultra-wideband bandpass filter will be designed based on the three parallel coupled lines (TPCL) and radial open stub. The basic element of this filter is a TPCL, and the advantages of this element include compact size, simple structure, and wide passband. Thus, this TPCL is suitable for compact wideband and UWB BPF design. The proposed design consists of a 3 - parallel coupled lines with a radial open stub as shown in Fig.1. The filter has two identical parallel lines with an electrical length of about a quarter wavelength at the desired center frequency (f_c) . The third line is centered between the two extreme lines with different length and width in which a radial stub is attached at its edge. The width of the middle line is Ws and Wi is the width of the extreme other lines. The lengths of the middle line, the left-hand and right-hand sides are ls and Li respectively. The feed lines used for this filter were designed to match a characteristic impedance of 50 ohms.

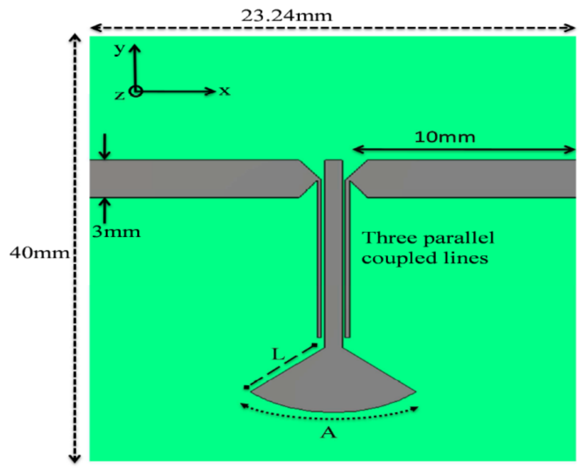

Fig.1. Geometry of the proposed bandpass filter

Fig.1 illustrates the geometry and configuration of the proposed filter, which is printed on the FR4 substrate with a: dielectric constant $\varepsilon_r = 4.4$, substrates thickness h=1.58mm, copper thickness of t = 35µm, and tangent loss tanδ = 0.025.

In order to obtain an enhanced fractional wideband of more than 60% at the center frequency of 3.5 GHz and to make the design work much simple, we have fixed the physical dimensions of the middle line to be *Ws=0.82mm*, *ls=14.85mm* and a gap spacing of *g=0.16mm* for optimization process.

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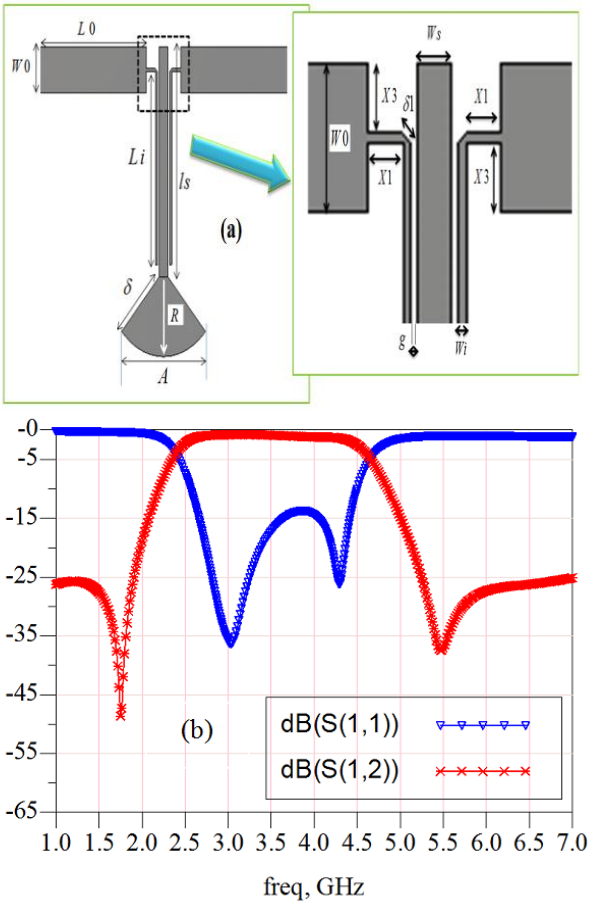

Fig.2. (a) Layout of the proposed UWB-BPF. (b) Frequency response of the simulated results. Associated dimensions: L0=10 mm, W0=2.98 mm, Li=12.5 mm, ls=14.85 mm, R=5 mm, A=90°, Wi=0.2 mm, g=0.16 mm, Ws=0.82 mm, X1=0.85 mm, X3=1.39 mm, δ1=0.82 mm, δ=5 mm.

The 3-parallel coupled lines with radial open stub configuration is discussed in the above section. The simulated results of the filter presented in Fig.2(b) shows that the filter is centered at 3.5 GHz, with an insertion loss less than 0.88 dB from 2.6 to 4.5 GHz. In addition, two transmission zeros appear at 1.7 GHz and 5.4 GHz, with a rejection level more than 40dB. The main parameters of the proposed filter are studied and optimized. So, a parametric analysis of different variable of the filter will be carried out to obtain the optimized dimensions.

III. CONTROL OF THE FILTER CHARACTERISTICS

In order to make clear the effect of some parameters on the filter response, the initial parameters are fixed, and then one of them is varied while others remain constant.

A. Effect of the Radius Stub A

To describe the effect of the radial stub over the filter performances, we have maintained its length at L=5 mm and we have changed the angle (A). Fig.3 shows the variation response of return and insertion losses by varying (A) from 45° to100°. From the graphs, we can see clearly that the bandwidth decreases when the angle (A) is increased, however, a good matching input impedance around the center frequency is obtained when the (A) is increased.

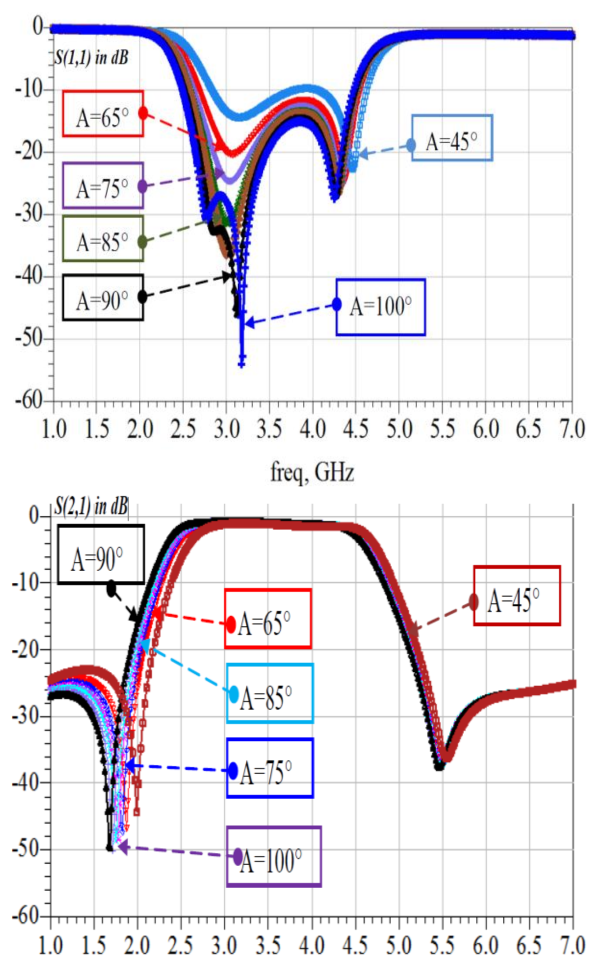

Fig.3. Effect of the radial stub angle (A) on S-parameter of the proposed filter

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B. Effect of the Radial Stub Length

Furthermore, the effect of the radial stub length over the filter performances is evaluated, this time, we have proceeded to the change of the stub length (L) by maintaining A=90 °. Fig.4 shows the variation of return on insertion losses, when L increase from 3 mm to 5.5 mm the return loss become more matched and centered at the desired frequency of 3.5 GHz, also the bandwidth is increased slightly at the lower frequencies.

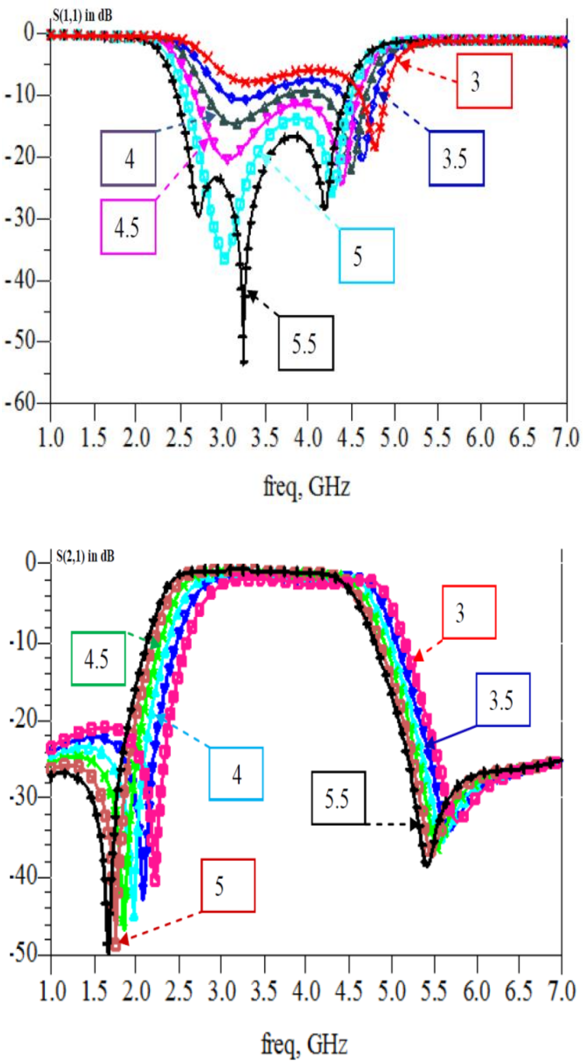

Fig.4. The effect of L (length of the radial stub) on S-parameter of the proposed filter

By taking the values founded by the yield analysis carried out previously, we found that promised dimensions that provide good performances are A=90 ° and L=5 mm. As a next step for enhancing the matching input impedance in both ports, we have added a short section with triangular shape as shown in Fig. 5(a).

Maintaining the same dimensions found previously, we have added a short section with triangular shape to improve the impedance matching as shown in Fig.5(a). The filter configuration is simulated with high meshing density and the physical parameters are derived after several optimization processes.

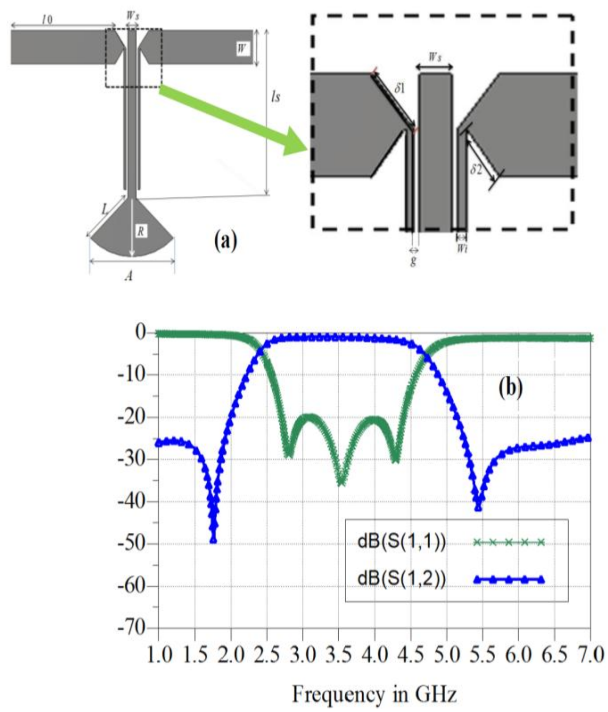

Fig.5. (a) Layout of the proposed bandpass filter. (b) Simulated S-parameters results

According to the above analysis, the proposed UWB bandpass filter is designed, simulated, and optimized using electromagnetic simulation tools integrated into ADS. The final dimensions of the UWB filter optimized by ADS are as follows:

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L0=10 mm, W0=2.98 mm, Li=12.5 mm, ls=14.85 mm, A=90°, Wi=0.2 mm, g=0.16 mm, Ws=0.82 mm, X1=0.85 mm, X3=1.39 mm, δ1=1.9 mm, δ2=1.625 mm, L=5 mm.

All dimensions were adjusted by optimization processes to obtain the desired performances. The characteristics of the filter are obtained using momentum solver integrated into ADS. Then the simulated S-parameter characteristics are shown in Fig.5(b). As it can be seen from the filter response that the proposed design accomplish the exhibiting performances, a return loss less than 20 dB between 2.75 and 4.45 GHz, the stop-band is from 4.5 GHz to 7 GHz with attenuation level of 25 dB to 50 dB and a fractional bandwidth at 10 dB is about 85.1 %. In addition, the developed UWB-BPF design has a compact structure with an overall size of 23.24 x 40 mm^2. Moreover, for a good analysis, we have evaluated the filter performances under other electromagnetic simulator using CST Microwave Studio software. A comparison of the two simulation results has been obtained. The filter not only exhibits a wide upper reject-band but also creates two transmissions zeros near the pass-band which help to improve selectivity without the use of a high order and large-size circuit.

In order to understand the reason behind the transmission at different values of frequency, the current density distribution on the filter metallization has been calculated using momentum software integrated into advanced design system (ADS) simulator. Fig.6 shows this distribution.

IV. Experimental Results & Discussion

The proposed ultra-wideband bandpass filter with 3-parallel coupled lines and a radial open stub has been designed, simulated and optimized, then fabricated and measured. The total area of the designed filter is 23.24 x 40 mm^2.

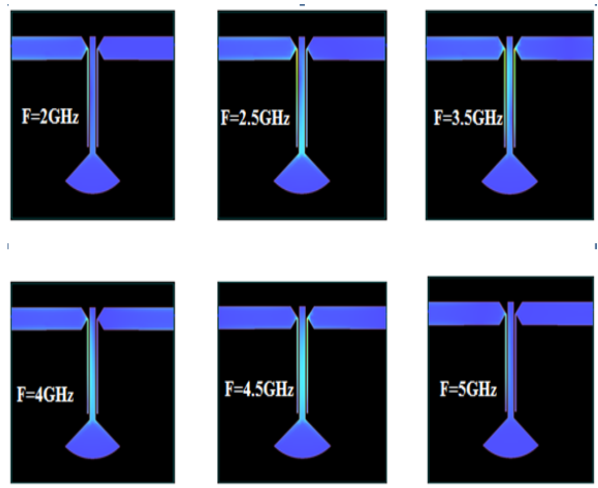

Fig.6. Current density distribution at different frequencies values on the filter surface

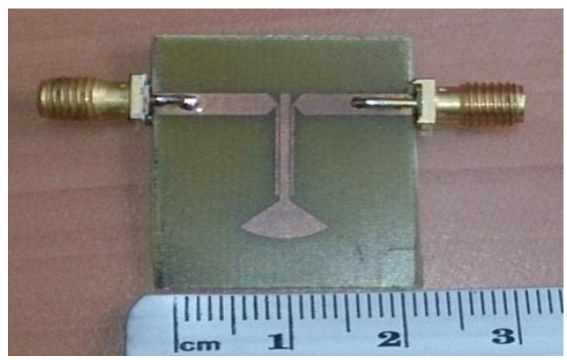

Fig.7. Photograph of the fabricated UWB Bandpass Filter

Finally, the performance was measured using the MS2028C Anritsu VNA (Master Vector Network Analyzer) in microwave laboratory, and the measurements are in good agreement with simulation which validate this filter for UWB and modern microwave communication.

Fig.7 shows a photograph of the achieved and fabricated filter which is fabricated on FR4 substrate.

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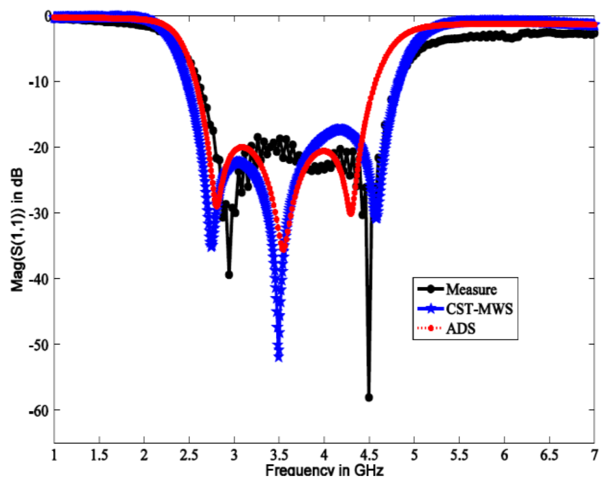

Fig.8. (a) Measured and simulated return loss of the designed microstrip filter

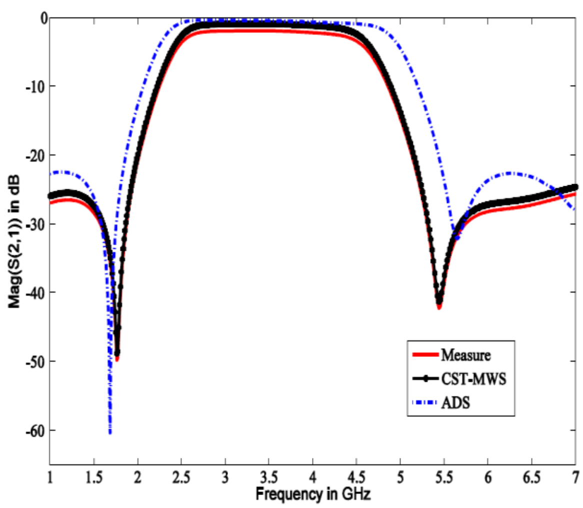

Fig.8. (b) Measured and simulated insertion loss of designed wideband bandpass filter

Fig.8(a), (b) and 9 present the S-parameters and group delay of the wideband bandpass filter. It can be seen that these simulated results founded by the two electromagnetic solvers are in agreement. As it can be observed from Fig.8, the lower and higher edge frequencies of the pass band are equal to 2.18 GHz and 4.89 GHz in CST-MWS with their counterpart frequencies of 2.22 GHz and 4.87 GHz in the ADS simulation. Furthermore, the filter has achieved the return loss more than 20 dB from 2.56 GHz to 4.56 GHz. The 0.49 dB insertion loss bandwidth is about 3.5 GHz.

The simulated and the measured scattering parameters are described in Fig.8(a) and (b), with good agreement. Referring to Fig.8, the fabricated BPF has a band pass from 2.2 to 4.65 GHz. The corresponding input/output return loss of 20 dB is reached for the operating frequency band. Besides, the stopband attenuation of more than 25 dB appears from 5 GHz to 7.0 GHz. In fact, the fabrication tolerances, as well as the SMA connectors and the calibration errors, may have led to the small discrepancies between the simulated and the measured results. The group delay varies from 0.32 to 0.55 ns. In other words, the maximum variation in group delay achieves 0.23 ns, indicating a good linearity of the developed UWB BPF as well.

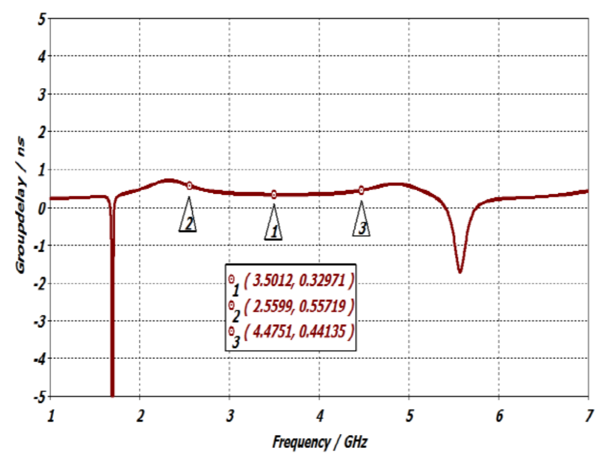

Fig.9. Group-Delay response of the designed filter

It is clearly seen that this structure inherently introduces two transmission zeros which help to improve selectivity without the use of a high order and large-size circuit design. The roll-off rate is given by $\zeta = \frac{\alpha_{max} - \alpha_{min}}{f_s - f_c}$ where α_{max} and α_{min} are the 20dB and 3dB attenuation points, respectively. f_c is the 3-dB cut-off frequency and f_s is the 20 dB stopband frequency.

Table 1: Simulations and measurements of the proposed filter

	Simulations	Measurements
Fc in GHz	3.5	3.49
FBW %	85.1	71.53
Return loss	20dB	20dB
Insertion loss	0.49dB	0.75dB
Roll-off rate	31.5dB/GHz	21.75 dB/GHz
Gr-Delay	0.32ns	0.35ns

Table 2: Comparison of this work with others

Ref.	fc,GHz	FBW %	Size	IL,dB	RL,dB
This work	3.5	85.1	(23.24x40)mm^2	0.49	20
[5]	3.2	80	---	0.5	25
[6]	6	72.6	(0.65×0.25)λ_g	---	---
[11]	4.65	62.2	---	1	14
[13]	1.5	93	(0.71 x 0.3)λ_g	0.75	11
[18]	4	61%	(0.5 x 0.255)λ_g	1.55	13.5
[14]	3.5	105%	---	0.9	9
[4]	4.25	54.1%	---	0.5	15
[9]	2.5	115.3%	(0.14 x 0.21)λ_g	0.32	15.15
[12]	5	75%	(22.6x8.2)mm^2	0.4	11.5
[13]	4.25	64%	(0.75 x 0.5) λ_g	0.9	17.5
[19]	6.75	>100%	---	<1	10

IL: Insertion loss over the whole pass-band.
RL: Return loss over the whole pass-band.
fc : The central frequency.
ε_r: Substrate relative dielectric constant.
h: Substrate thickness.
λg: The guided wavelength of the operating frequency at the center of the pass-band.

To further demonstrate the performance of the filter, Table 2 is provided for comparison of this work with other works which are all based on wide-band bandpass filter category. A comparison of the main performances of several UWB planar filters is listed.

V. CONCLUSION

In this paper, a compact structure of ultra-wideband-band pass filter (UWB-BPF) is proposed using only three parallel coupled lines with a radial open stub. Parametric analysis of different variable of the proposed filter was carried out to obtain the optimized dimensions. The filter was simulated with two simulators ADS & CST-Microwave Studio and the simulation results are in good agreement. The total dimensions of this UWB BPF are 23.24 by 40 mm^2. After the validation of this filter into simulation, we have conducted the fabrication of the microstrip wideband filter which was tested. The measurement results are in good agreement with simulated one which validate this filter for WiMAX and ultra-wideband RF applications.

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