# DESIGN OF ULTRA-WIDEBAND BANDPASS FILTER USING INTER-DIGITAL STRUCTURE WITH NOTCH

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**ABSTRACT:** An ultra-wideband (UWB) band pass filter is proposed in the paper. The filter is compact, small size and had planar structure. The suggested filter does not include any via and defective ground structure. The filter is designed using two inter-digital structures sandwiching concentric square ring resonator. The pass band starts from 5.11 GHz and ends at 13.63 GHz having insertion loss below 0.1 dB and maximum return loss of 39.58 dB at 6.75 GHz, with 3 dB fractional bandwidth of 90.92%. The notch in pass band is at 11.35 GHz having the maximum insertion loss of 14.80 dB and minimum return loss is below 2 dB, with 3 dB fractional bandwidth of 1.41%. The bandwidth shown by the pass band of proposed filter is 8.52 GHz which is in the range of UWB band pass filter. The proposed filter has been constructed and simulated in Keysight Advance Design System. The filter's rejection performance is good and the S-parameter characteristics provide high skirt selectivity over the pass band and notch. The frequency band and notch at 11.35 GHz are useful in existing communication systems such as cognitive radio systems, satellite communications and certain military applications for avoiding interference operating in the proposed frequency range.

**Keywords:** Inter-Digital Structure, Notch Band, Band-Pass Filter, Square Ring Resonator, Ultra-Wide Band**,** Rectangular Ring

## 1. INTRODUCTION

Using the unlicensed 3.1–10.6 GHz frequency spectrum, ultra-wideband (UWB) technology is a popular option for wireless transmission because of its advantages for short-range communication, low power consumption, high data rates and short broadcast periods [1]. In recent years, there has been significant research interest in developing high-performance and compact-sized UWB systems, as evidenced by the numerous publications in this area [2-9]. However, UWB technology has some its drawbacks caused by interference from other radio-based technologies such as WiMAX, Zigbee, Wi-Fi, Bluetooth and satellite communications which lies within the same frequency spectrum and can disrupt UWB signals. In modern wireless communication systems, there is a growing interest in band pass filters (BPF) that allow for the transmission of UWB frequencies while rejecting other bands that coexist within the same spectrum. In last few years several UWB BPF have been introduced and implemented. This is often accomplished using traditional methods, which need impedance-matching networks at the input and output stages and sometimes entail combining a high-pass and low-pass filter in a single structure that can be difficult to miniaturize.

To address these challenges, various UWB BPF designs have been proposed, including those that incorporate defected stub-loaded resonators [10], defective ground structures [11], multi-mode resonators [12,13], microstrip structures, stepped-impedance resonators and composite right/left-handed (CRLH) cells. For example, a UWB filter with a notch can be designed using a resonator that combines digital architecture with a defective ground structure. However, this approach requires high-precision manufacturing for tightly aligned coupled sections and may not be suitable for all designs. Although they can be prone to leakage and may have trouble obtaining broadband properties, defective ground structures can efficiently lower the size of the filter. Microstrip filters based on defective microstrip structures can help mitigate floor leakage, while UWB filters incorporating CRLH cells can reduce the size of the filters [14]. The finger length of the inter-digital structure on each side of the square ring resonator is adjusted to control the notch band in the proposed filter, while the port length remains constant. Two stepped impedance stubs and a ring resonator with multiple slot line resonators have been used to create a notch band in UWB BPF [15,16]. As shown in the Figure 1, the frequency at which the notch center may be moved is adjusted to the right by shortening of L5 both side of the resonator and to the left by lengthening both side of the resonator. Manipulation of the aggregation coefficient and frequency selection by varying the width of the feed line and inter-digital structure slot. It is possible to reduce the insertion and return losses by using rectangular rings at the port.

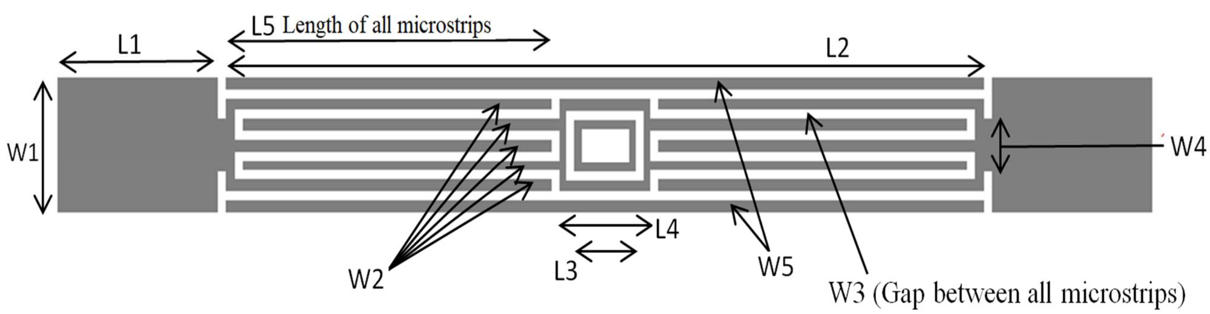


Figure 1. Configuration of the proposed UWB BPF

The remainder of the paper is written as follows: Section 2 provides a description of the Literature review. On the other hand, Section 3 suggests the assessment and implementation of the suggested UWB BPF. In Section 4, a comparative analysis is offered along with the parameters and simulation results of the implemented and simulated filter using Keysight Advance Design System. Finally, Section 5 contains the conclusions of the paper.

The literature review of the existing works reveals various designs and techniques for UWB BPF with and without notch bands.

The regulatory foundation for UWB systems, including UWB filters, was established in 2002 [1] by the Federal Communication Commission through its modification of Part 15 of the Commission's Rules. Hong and Shaman [2] proposed an optimal UWB microstrip filter comprised of a spiral resonator and a stepped-impedance resonator, which provides a wide pass band and high selectivity. Chen and Zhang [3] introduced filter comprises of a spiral and stepped-impedance resonator, which provides a wide pass band and high selectivity. The filter exhibits a fractional bandwidth of 128% and a minimum insertion loss of 0.5 dB. Wu et al. [4] revealed a UWB BPF having quintuple mode with a large pass band, a small size and a quick roll-off and super-wide upper stop band. Wang et al. [5] designed a UWB BPF with a novel structure and a super compact size. Although all these filters mentioned in [2-5] do not have a notch band while the proposed filter consists the notch band in pass band at 11.3 GHz. The notch has maximum insertion loss of 14.80 dB and minimum return loss is below 2 dB with the fractional bandwidth of notch of 1.41%. Luo et al [6] created a filter that is within the range of the UWB BPF by combining a hybrid microstrip and coplanar waveguide construction to create an ultra-narrow notched band. The detached-mode resonator is integrated λ/4 meander slot-line structure to utilize and obtain a notched band inside the UWB pass band, hence mitigating interferences like WLAN signals. In particular, at the notched center frequency of 5.80 GHz, the manufactured filter had a 10 dB notched fractional bandwidth of 2.06%. Mirzaee and Virdee [9] introduced a BPF for the UWB application that shows impressive selectivity. In order to address interfering signals in the UWB spectrum, this design combines notch band characteristics into the filter's pass band. A fractional bandwidth of 123% was obtained in the pass band of range (2.66–11.2 GHz) with a distinct notch band at 5.21 GHz. Song et al. [11] created a small BPF in the UWB range with two notch bands by utilizing faulty ground structures. The UWB notch band BPF's equivalent-circuit model has been established with the aid of transmission line theory. Rejection fractional bandwidths of around 2% at 10 dB are seen in the notched band with a center frequency of roughly 5.7 GHz.

Xu et al. [12] presented UWB BPF having a notch band that is miniature and uses an inter-digital linked feed line construction. The filter consists of a spiral resonator and an inter-digital coupled feed line structure, which provides a wide pass band and high selectivity. The notched band is achieved by introducing an inter-digital coupled feed-line structure with a notch frequency but it requires via holes and a complex structure. Gaurav and Chauhan [13] developed filter, a resonator in the shape of a rectangle is positioned between two inter-digital structures and a rectangular slot acts as a microstrip structure with a defect at the input and output ports. The insertion loss of the proposed filter is 21.5 dB in the notched band, which is centered at 7.9 GHz, and less than 0.7 dB in the pass band, which extends from 3.1 GHz to 10.8 GHz. Xie et al. [17] used coplanar waveguide technology to create the very effective UWB BPF. In order to obtain one transmission zero and four transmission poles, bow-tie cells are employed in filter design. Additionally, employed short-circuit stub of T- shaped to provide a deep attenuated trap frequency band, so blocking the 8.2 GHz-centered ITU 8.0 frequency band [17]. The introduced filter has a pass-band range of 3.7 GHz to 9.6 GHz with an insertion loss of less than 0.8 dB and a return loss of greater than 20 dB. Bohra et al. [18] created a small, single-notch wide band microstrip filter operating in the UWB frequency range by using an inter-digital linked open stub resonator and a shorted stub resonator. At the center frequency of 6.9 GHz, a fractional bandwidth of 104% . Applications like as UWB transceiver systems and radar systems are appropriate for this filter. Pan et al. [19] developed a flexible, highly selective coplanar waveguide BPF by employing bow-tie cells using inter-digital spoof surface Plasmon polaritons. The single-layer, high-selectivity design offers a 3-dB bandwidth of approximately 76.8% (2.28-5.12 GHz) in simulation, with $|S_{11}| < -15$ dB and -0.4 dB $> |S_{21}| > -1.1$ dB in the pass band. Measurements closely match simulations, confirming the filter's performance. Basit et al. [20] presented a new three-mode step impedance resonator for the purpose of designing an UWB filter in planar behavior that is miniature and has independently regulated notched bands at various frequencies. Fractional bandwidth of 127%, bandwidth of 2.7-12.1 GHz and four λ/4 short-circuited stubs make up the UWB filter. A bandpass microstrip filter based on polyester is proposed by Joshi et al. [21] for the NATO military frequency band of 4.35 to 4.60 GHz. The filter is constructed with self-adhesive copper tape and a polyester substrate using linked microstrip lines, stepped-impedance resonators, and split ring resonators. Joshi et al. [22] presented a wearable bandpass microstrip filter, which uses a stepped impedance resonator to create a tiny dual-band polyester construction. Wi-Fi, WLAN, and Wi-Max applications use the filter in the 3.74–7.42 GHz range, whereas ISM band applications use it in the 1.85-2.66 GHz area. This technology achieves fractional bandwidths of 34% and 81% while having low insertion loss and significant return loss.

Compared to the filters existed in the literature, the proposed filter provides a number of advantages.

- The filter is comprised of a planar structure without any via hole or defective ground structure and it is small, measuring 13.3 mm in length and with a 0.1 mm gap between the microstrip used to build the inter-digital structure.
- Two pass bands with low insertion loss and large return loss are present in the filter. The first pass band spans from 5.15 GHz to 11.20 GHz and has a return loss of 39.58 dB and an insertion loss of 0.19 dB, whereas the second pass band spans from 11.48 GHz to 13.63 GHz and has a return loss of 33.38 dB and an insertion loss of 0.414 dB.
- A characteristic that sets proposed filter apart from others on the market is its notch at 11.35 GHz with a fraction bandwidth of 1.41% in the pass band for satellite communication.

## 2. IMPLEMENTATION AND ANALYSIS OF ENHANCED UWB BPF

The proposed filter, as seen in Figure 1, has resonator in the shape of rectangle with two inter-digital structures situated between open stub-finger lines. The inter-digital structure of the filter is formed by connected finger lines, which may be viewed as an analogous circuit with a capacitor and an inductor, as shown in Figures 2(a) and 2(b).

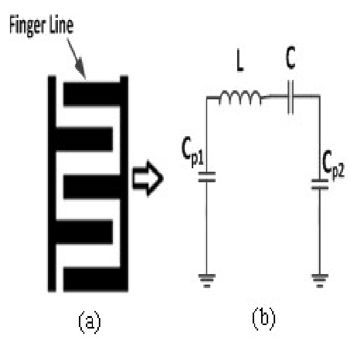


Figure 2. Inter-digital organization (a) Diagram (b) Comparable circuit design

An inductive effect is produced by the finger's length (L), whereas a capacitive effect is produced by the space between the fingers (C). Initially the analytical, modeling of the filter is done on the basis of the required inductor i.e 14.21 nH and capacitor i.e 0.508 pF value in the inter-digital structure for UWB band-pass response. It can be calculated using,

$$C = \frac{A \cdot \epsilon 0 \cdot \epsilon r}{d} \quad \& \quad L \approx \frac{A \cdot \mu 0}{d}$$

Where, $\epsilon_r$ is the relative permittivity (dielectric constant) of the material between the fingers i.e 2.17, $\epsilon_0$ is the permittivity of free space ($8.854\times10^{-12}$ F/m), A is the area of overlap between the fingers i.e 26.855 $mm^2$, d is the distance between the fingers i.e 0.1 mm, $\mu_0$ is the permeability of free space ($4\pi\times10^{-7}$ H/m). Finally, to achieve miniaturization and compactness of the final structure, a parametric analysis and optimization is done using electromagnetic simulation software. Additionally, because of the presence of dielectric material of the proposed filter some capacitance is introduced which is $C_{P1}$ and $C_{P2}$. Its behavior is comparable to a band pass filter with its harmonics, as shown by the inter-digital structure's analogous circuit and frequency response. This suggests that the inter-digital structure can effectively filter specific frequency ranges, making it a valuable component in the proposed filter design.

The notch frequency of the proposed filter is determined by the first higher cut-off frequency of the inter-digital structure. In the meanwhile, the suggested filter's second cut-off frequency is determined using the inter-digital structure's second higher cut-off frequency. As seen in Figure 3(a), this structure's frequency response may be changed by adjusting the measurement of both inter-digital linked lines L1 and L2. The structure's notch band swings towards lower frequencies as L1 length is extended while holding L2 constant and the second cut-off frequency somewhat drops along with it. But as Figure 3(b) shows, there is no change in the lower cut-off frequency. As seen in Figure 3(c), a similar drop in the second cut-off frequency occurs when L2 length is increased but L1 remains unchanged. This decrease does not impact the lower cut-off frequency or notch band [13]. These adjustments enable precise control over the frequency response of the proposed filter, making it highly versatile for various applications [23].

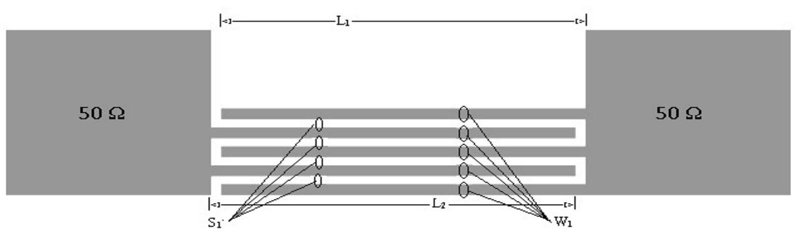


Figure 3(a). Configuration of coupling apparatus

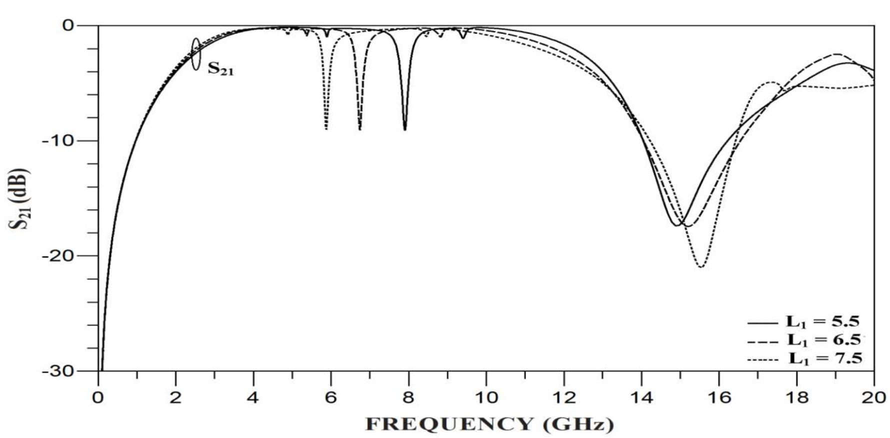


Figure 3 (b). L1 is changed while L2 remains unchanged

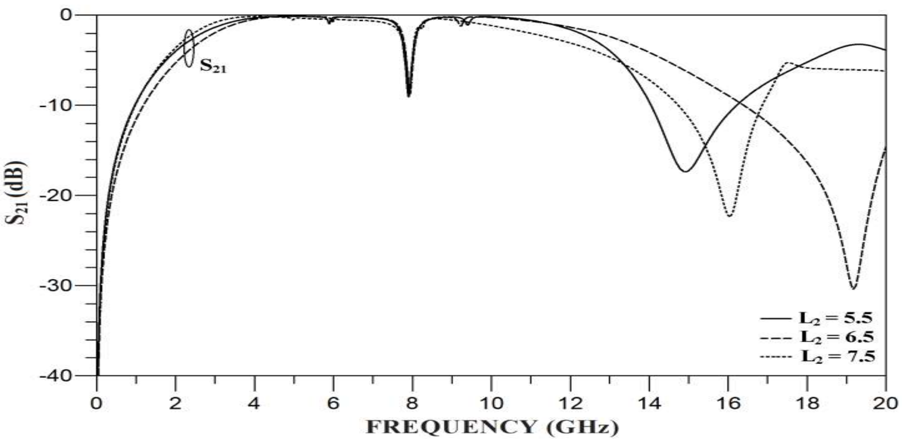


Figure 3 (c). L2 is changed while L1 remains unchanged

The proposed filter design has some limitations, such as insufficient attenuation and difficulty in adjusting the higher cut-off frequencies and lower cut-off frequencies without changing the notch band frequency [24]. To address these issues and to enhance the attenuation, open stub finger lines was included with the resonator in the shape of rectangle. A concentric rectangular ring resonator was also introduced between two inter-digital structures to control cut-off frequency of higher order and notch [25-30]. However, this combination did not meet the UWB frequency range requirements. An ineffective microstrip structure is fitted into a concentric rectangular slot, which allowed the inter-digital structures to be connected to the input and output port, This fixed the problem. Enhanced s-parameters are the outcome of this adjustment, which also enhanced the impedance matching between the filter and ports. Another advantage of the rectangular slot is that it allowed the cut-off frequencies to be altered without affecting the notch band frequency [31,32]. By varying the width and length of the rectangular slot, a small decrease of 0.35 GHz in the upper cut-off frequency and 0.15 GHz in the lower cut-off frequency was achieved.

The suggested filter's final optimal dimensions, which include the resonator's diameter and rectangular slots, achieved a pass band having values between 5.11 GHz and 13.63 GHz with a notch at 11.35 GHz. The miniaturization of the filter was achieved by optimizing the filter dimensions. The final s-parameter characteristics of the proposed filter is shown in Figure 4.

## 3. EXPERIMENTAL RESULTS AND DISCUSSION

As shown in the Figure 1, the proposed filter has the dimensions as follows: L1 = 2.8 mm, L2 = 13.1 mm, L3 (inner rectangular resonator length) = 0.8 mm, L4 (outer rectangular resonator length ) = 1.3 mm, L5 ( length of all microstrip) = 5.5 mm, W1 = 2.05 mm, W2 (microstrip width) = 0.2 mm and W3 ( gap between microstrip) = 0.1 mm, W4 = 0.8 mm , W5 = 0.225 mm, width of both rectangular resonator = 0.15 mm. 5.11 GHz is the lower cut-off frequency and 13.63 GHz is the higher cut-off frequency according to the suggested filter's simulated findings with the insertion loss of Less than 0.2 dB and maximum return loss of 39.58 dB. There is also 14.80 dB attenuation in notch at 11.35 GHz in the filter. 3dB rejection fractional bandwidth of the proposed filter is 90.92%. With a thickness of 0.508 mm and a relative dielectric constant of 2.17, the filter is applied on a single metallic substrate (Rogers RT/Duroid 5881).

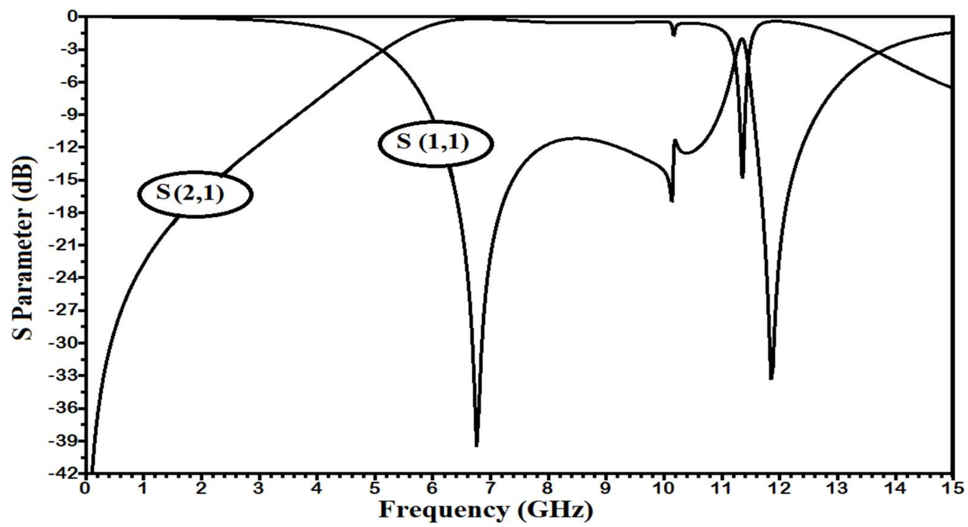


Figure 4. S-parameter simulation of the suggested UWB BPF

Table shows the performance comparison between proposed design and the previous designs.

| Ref. No. | Fractional bandwidth at 3dB (%) | Maximum Return Loss (dB) | Minimum Insertion loss (dB) | Relative Dielectric constant / Thickness of Dielectric (mm) | Size (λg × λg) | Notch Capability |
|---|---|---|---|---|---|---|
| [3] | 96 | 30 | < 2 | 2.2/0.508 | 0.87 × 0.35 | No |
| [6] | 113.5 | 11.6 | 0.9 | 2.2/0.508 | 0.30 × 0.17 | Yes |
| [7] | 102.8 | 8 | 1.33 | 6.15/0.635 | 1.05 × 0.51 | Yes |
| [8] | 125 | 10 | 1.1 | 2.2/0.127 | 0.27 × 0.22 | Yes |
| [9] | 123 | 12 | 0.94 | 3.38/0.81 | 0.94 × 0.14 | Yes |
| [10] | 122 | 10 | 1.5 | 2.55/0.8 | 0.75 × 0.48 | No |
| [11] | 118 | >20 | < 2 | 2.65/1.0 | 1.01 × 0.53 | Yes |
| [12] | 118 | 13 | 1 | 3.5/0.508 | 0.58 × 0.12 | Yes |
| [13] | 111 | 19.37 | 0.7 | 4.4/1.6 | 0.56 × 0.08 | Yes |
| [18] | 104 | >14 | < 0.5 | 3.5/0.50 | 0.29 × 0.18 | Yes |
| [19] | 76.8 | <15 | 0.8-1.4 | 2.65/0.5 | 0.92 × 2.92 | Yes |
| [20] | 127 | >15 | 0.1 | 2.20/1.6 | 0.07 × 0.02 | Yes |
| [23] | 110 | >25 | < 0.4 | 3.2/0.79 | 1.55 × 0.12 | No |
| Proposed Work | 90.92 | 39.58 | < 2 | 2.17/0.508 | 0.60 × 0.12 | Yes |

Table. Appraisal of the proposed design relative to prior designs

The proposed filter exhibits several distinguishing features compared to other designs. It achieves a maximum return loss of 39.58 dB, significantly higher than all the other referenced designs, indicating enhanced performance in terms of signal reflection and efficiency in minimizing power loss. Additionally, the proposed structure demonstrates substantial miniaturization with dimensions of 0.60 × 0.12 (λg × λg), representing one of the smallest sizes among the compared designs. This compactness is achieved without compromising performance, making it highly suitable for applications with critical space constraints. Furthermore, the proposed filter maintains notch capability, ensuring effective filtration of unwanted frequencies, similar to most other designs. These features underscore the value of our proposed filter in achieving high performance while maintaining a compact size, distinguishing it from other designs in the literature.

Rogers RT/Duroid 5881, a single metallic substrate with a relative dielectric constant of 2.17 and a thickness of 0.508 mm is used to build a physical structure based on the simulation result and parameters [33]. Though it requires many attempts and is fairly challenging to accomplish, the suggested filter with a 0.1 mm gap between the inter-digital microstrip may be successfully built and examined throughout a frequency range of 10 MHz to 20 GHz using an Agilent 5230A network analyzer.

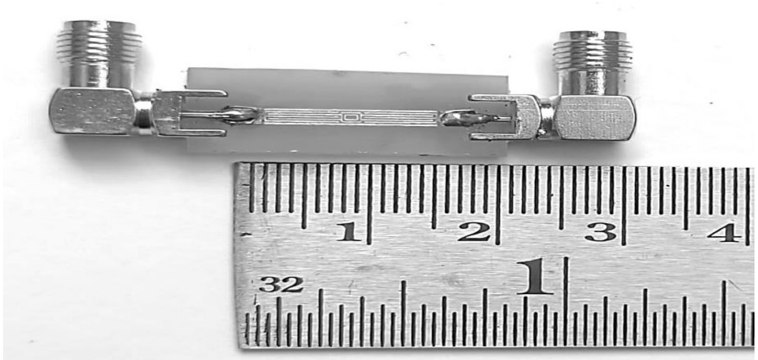


Figure 5 (a). Photograph of fabricated filter

The simulated and experimental results of the proposed filter are shown in Figures 5(a) and 5(b), where a good agreement is achieved. The simulated filter has a fractional bandwidth of 90.92% for the pass band and strong UWB band pass performance from 5.11 to 13.63 GHz. The observed findings indicate a bandwidth of 98.30% for the band pass between 4.80 GHz and 14.08 GHz. The simulated filter exhibits the emergence of a notched band at 11.35 GHz with an insertion loss of 14.80 dB and 3 dB notched fractional bandwidth of 1.41%, whereas the constructed filter achieves a notch band at 11.57 GHz with an insertion loss of 14.28 dB and 3 dB notched fractional bandwidth of 1.04%. For both the manufactured and simulated filters, the measured insertion loss is determined to be below 2dB, which is minimal. Additionally, compared to the published UWB BPF with a notched band, the suggested filter has the advantage of being smaller in size.

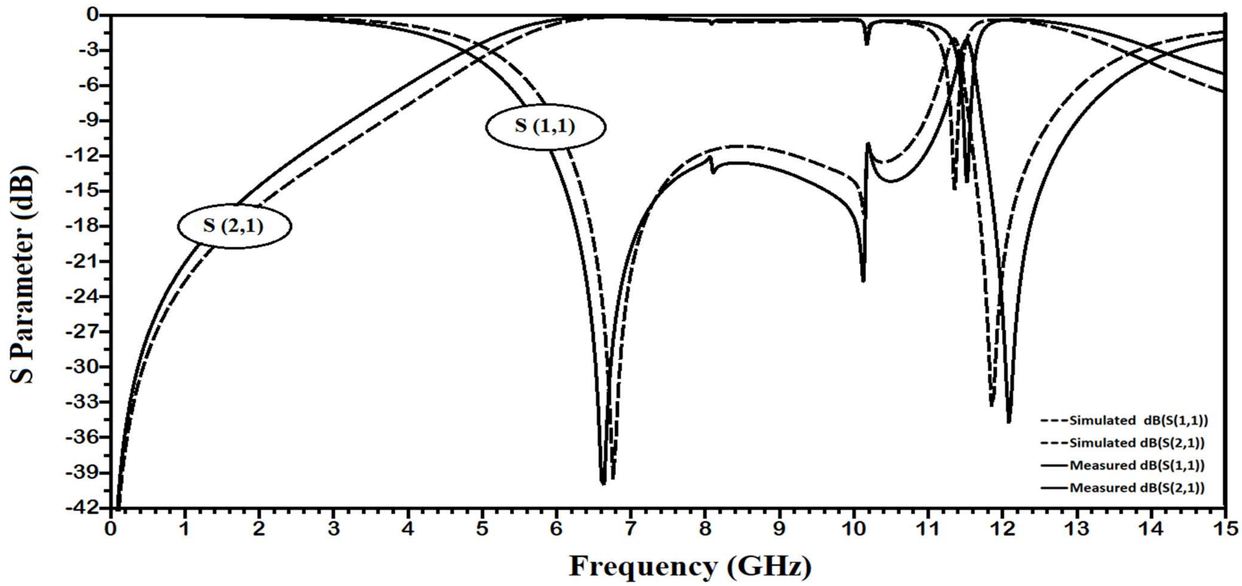


Figure 5 (b). Correspondence between measured and simulated S-parameter

## 4. CONCLUSION

This study presents the design and development process of a microstrip UWB BPF by using the resonator in rectangular shape sandwiched between two inter-digital structures. The proposed filter is compact in size with dimensions of 0.60 × 0.12 (λg × λg) and exhibits a 3 dB fractional bandwidth of 90.92%. It also features a low pass band insertion loss and a high notch band rejection level, as reported in the table. Additionally, shows how changing the length of the microstrip resonator alters the position of the notch. Potential uses of the suggested filter include the removal of satellite communication interference signals that are in the same frequency range as UWB. Experimental validation is performed to verify the efficacy of filter design and the findings are found to be in excellent agreement with simulation results.

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