# A Compact Via-less Ultra-Wideband Microstrip Filter by Utilizing Open-Circuit Quarter Wavelength Stubs

Muhammad Yasir Wadood, Fatemeh Babaeian



***Abstract*****—**By developing ultra-wideband (UWB) systems, there is a high demand for UWB filters with low insertion loss, wide bandwidth, and having a planar structure which is compatible with other components of the UWB system. A microstrip interdigital filter is a great option for designing UWB filters. However, the presence of via holes in this structure creates difficulties in the fabrication procedure of the filter. Especially in the higher frequency band, any misalignment of the drilled via hole with the Microstrip stubs causes large errors in the measurement results compared to the desired results. Moreover, in this case (high-frequency designs), the line width of the stubs are very narrow, so highly precise small via holes are required to be implemented, which increases the cost of fabrication significantly. Also, in this case, there is a risk of having fabrication errors. To combat this issue, in this paper, a via-less UWB microstrip filter is proposed which is designed based on a modification of a conventional inter-digital bandpass filter. The novel approaches in this filter design are 1) replacement of each via hole with a quarter-wavelength open circuit stub to avoid the complexity of manufacturing, 2) using a bend structure to reduce the unwanted coupling effects and 3) minimising the size. Using the proposed structure, a UWB filter operating in the frequency band of 3.9-6.6 GHz (1-dB bandwidth) is designed and fabricated. The promising results of the simulation and measurement are presented in this paper. The selected substrate for these designs was Rogers RO4003 with a thickness of 20 mils. This is a common substrate in most of the industrial projects. The compact size of the proposed filter is highly beneficial for applications which require a very miniature size of hardware.

***Keywords*****—**Band-pass filters, inter-digital filter, microstrip, via-less.

## I. Introduction

RECENTLY, UWB systems have been developed significantly with a high demand for developing UWB circuits. The federal communication commission (FCC) allocated an unlicensed bandwidth (3.1 to 10.6 GHz) [1] for indoor communication. UWB systems have interesting features such as high data rates and low transmit power. In many applications such as chipless RFID systems [12], there is a requirement of having different hardware components with UWB properties. One of the essential components for these systems is a UWB bandpass filter [2]. Bandpass filters are required to pass the desired signals and suppress the unwanted out of band signals. However, designing bandpass filters with wide bandwidth is a challenge. Many pieces of research [3]-[11] have been conducted on UWB bandpass filter, and different designs have been proposed

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One approach for UWB bandpass filter design is cascading a low pass filter with a high pass filter [3]-[6]. Using this technique on UWB filter with a composite structure was designed with the frequency bandwidth of 10 GHz using a substrate with a dielectric constant 2.2 and a thickness of 0.508 mm in [3]. The advantage of the composite structure was mixing the low pass and high pass filter to reduce the size. The drawback of this structure was the presence of vertical interconnect access (via) holes which was a barrier for mass production.

A UWB bandpass filter using a left-handed metal material was proposed in [7], in which two split ring resonators were etched at the ground plane of the structure. Their design provided an operation bandwidth of 3.67 to 10.42 GHz, though it had a drawback of having a two-layer design which is not an interest in some of the industrial applications. In [8], an UWB bandpass filter consisting of two short-circuited stubs combined with two stages of stepped impedance resonators (SIRs) was proposed. However, the filter did not have an acceptable upper out of band rejection besides the presence of via holes in the design.

Another approach for UWB bandpass filter was interdigital coupled line bandpass filters [9], [10]. The performance of the interdigital bandpass filter structure was promising with fair rejections in upper and lower stop bands. The other benefit of that structure was having a low insertion loss in the pass band. However, since the interdigital structure contains via holes, it creates a significant challenge in manufacturing via holes [11] in practice. This problem is more significant when the width of the resonator is very narrow; it usually happens at high-frequency designs.

To combat the mentioned issues and to have the advantages of an interdigital filter, a via-less UWB filter is proposed in this paper. The proposed via-less structure was designed with inspiration from an interdigital filter. The main innovation for this design is to replace the via holes in a conventional interdigital structure with quarter wavelength open circuit stub. In addition, miniaturisation techniques were used to reduce the size. The proposed filter with compact structure has reduced the cost and size (5*18 mm), and increased manufacturing accuracy due to the absence of via holes.

This paper is organized as follows: Section II presents the theory of filter design, followed by Section III with design procedure. The results of simulation and measurement are demonstrated in Section IV. And the last section is the conclusions.

## II. Theory

Selecting a suitable structure for designing a bandpass filter depends on the required specification. Centre frequency, fractional bandwidth and out of band rejection are the standard specifications of a bandpass filter. The order of the filter can be selected based on a tradeoff between required out of band rejection and the insertion loss. An increase in the order of filter improves the quality factor of the filter which leads to having a sharper transition between the passbands to stop band; as a result, higher out of band rejection can be achieved. However, having a higher number of resonators can increase the attenuation level in the filter. Size limitation is another factor in filter design which needs attention. An interdigital filter is a prevalent structure for bandpass filters due to its low insertion loss level and its high out of band rejection.

An interdigital filter consists of multiple parallel quarter-wavelength stubs which are shorted at one end. There are two techniques for excitation of the filter: 1) the signal can be coupled to the first and last stubs, and 2) a tapping point can be used with a connection to the first and last resonators.

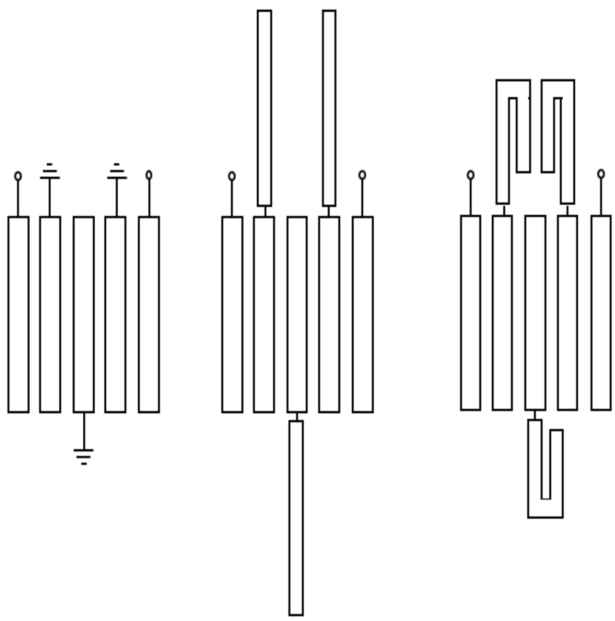
In an interdigital filter, there is no physical connection between adjacent resonators. With the excitation at the first port of filter, the electromagnetic field reaches the last resonator through coupling between adjacent resonators. Each resonator resonances at a specific frequency point in the operating bandwidth of the filter. The resonance frequency depends on the length of resonators. There is a gap between each adjacent resonator. The gap size can be tuned to achieve the desired bandwidth. Narrower gap size can increase the bandwidth of the filter. However, there is a limitation of the gap size due to fabrication accuracy.

A conventional interdigital bandpass filter is demonstrated in Fig. 1 (a). This filter contains five resonators with three short circuits at the end of alternative resonators. The implementation of a short circuit in a Microstrip filter is based on a vertical interconnect access (via) hole. In a via hole the top layer resonator is connected physically to the ground at the bottom layer of the substrate. The manufacturing of a via hole requires accurate drilling. The next step to create the connection is to fill the hole with a conductive material. There is a significant challenge to manufacture the via hole in radio frequency designs, as compared to low frequency or DC circuits. Consequently, this challenge exists in manufacturing a conventional UWB interdigital filter. This problem is more critical when the line width of stubs is too narrow. The size of via hole and its position is very vital in high-frequency design. The displacement of the position of via hole can create a frequency shift in the frequency response and mismatch in return loss. Having very precise via holes requires advanced technologies which are costly. Therefore, it is preferred to avoid having via holes in high-frequency filter designs.

## III. Design Procedure

In order to have the advantages of an interdigital filter and prevent the challenges in the fabrication of a via hole, a via-less structure for UWB bandpass filter is proposed. The design procedure consists of four steps.

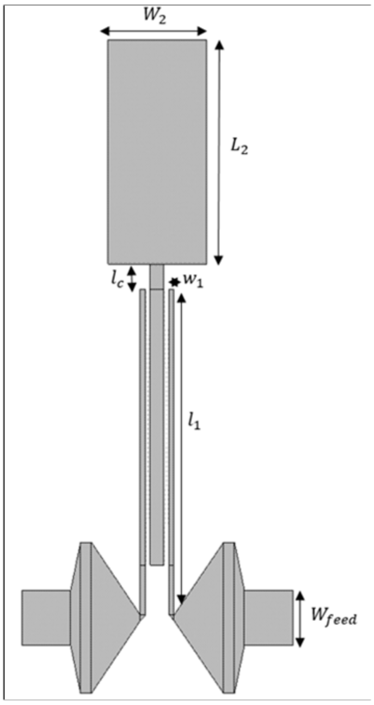
The first step is to design a UWB filter using an interdigital structure (Fig. 1 (a)). This step may include mathematical calculation and optimisation to meet the specifications of the filter. The second stage is to design the open circuit stubs which are a replacement of the via holes. This stage is shown in Fig. 2 (b). One challenge at this stage is to fit all the stubs in a limited spacing. So at the third stage, folding and meandering approaches can be used to reduce the occupied area by the resonators and stubs (Fig. 1 (c)). The shape of compressed resonators depends on the order of the filter and the provided space for the filter. The fourth stage is enhancing the return loss of the filter. Due to the unwanted coupling between open circuit stubs which may be arranged with a very close margin, the return loss may be affected. This effect can be minimised by using two tapered matching circuits at both input and output ports. And finally to achieve the best results the parametric designed filters need to be optimised.



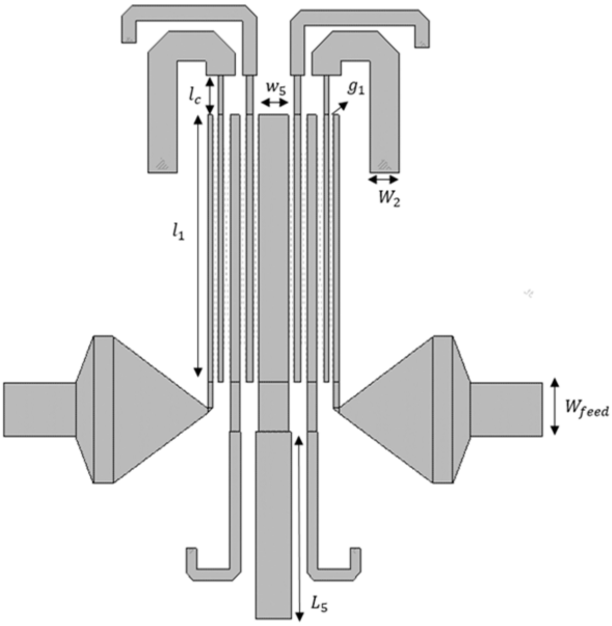
(a) (b) (c)

Fig. 1 (a) Conventional interdigital filter, (b) Stage one of the modifications with quarter wavelength open circuit stub, and (c) the modified filter with a compact size

The geometry of a second-order and eighth-order bandpass filters are demonstrated in Figs. 2 (a) and (b) as two examples of designed filters using the proposed structures. The second-order filter consists of three main resonators while the eighth-order contains nine resonators. The excitation of this filter was through the coupling stubs. The selected substrate was RO-4003 with a dielectric constant of 3.38 and a thickness of 20 mils. The operating bandwidth of these filters was 5.8-10 GHz. As it was expected, the out of band of the eighth-order filter is 15 dB higher than this parameter for the second-order filter.



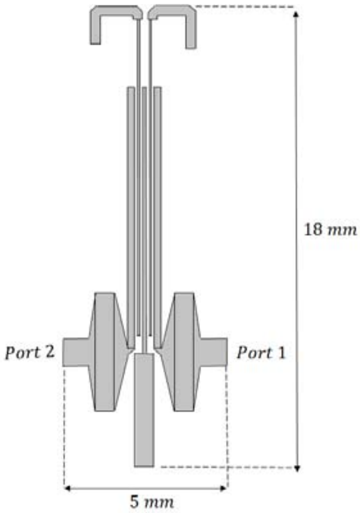

(a)



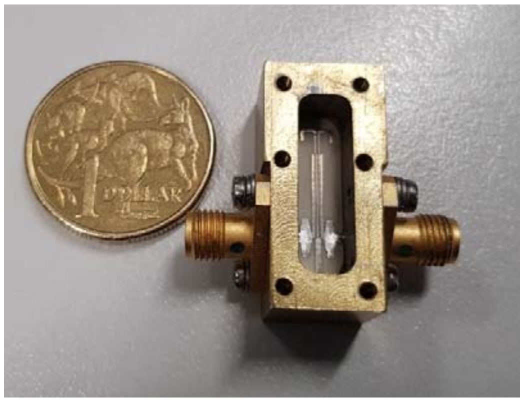

(b)

Fig. 2 Geometry of (a) second-order, (b) eighth-order filter

In Fig. 2, $l_i$ and $L_i$ show the length of the main resonator and the length of the open circuit stub of the i[th] resonator respectively. As it can be seen, there is a connection between the resonator and the open circuit stub with a length of $l_c$ and the same width as each main resonator. The summation of the length of each the open circuit stub and the connection stub is equal to the length resonator. The length each resonator is equal to a quarter wavelength. Also, $w_i$ is the width of the ith resonator while $W_i$ is the width of the open circuit stub connected to the ith resonator. The width of each open circuit was tuned with a different width size to operate as a short circuit at each resonance frequency. Increasing the width of open circuit stub caused a reduction of the length in the optimization process. There is a gap between each adjacent resonator with is indicated with $g_i$. Since this is a symmetric structure, each description for the first and last resonators has the same value. The port lines have a line width of $W_{feed}$ and an adjustable feedline length.




(a)



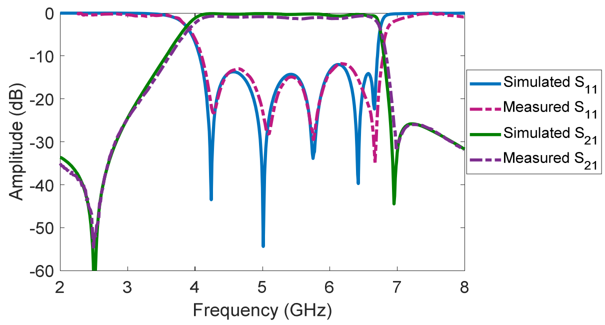
(b)

Fig. 3 (a) Fourth-order via less filter, and (b) fabricated prototype filter

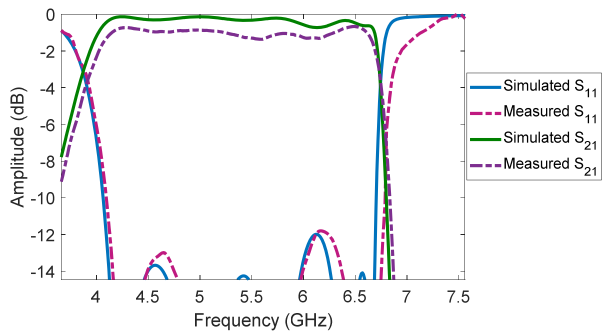
Initially, the coupling effect between adjacent resonators caused a mismatch in the result. To compensate this effect two tapered stubs were utilised at the tapping points to improve the return loss of the ports.

## IV. Results

Based on the proposed structure a fourth-order bandpass filter was designed using an RO-4003 substrate with a dielectric constant of 3.38 and a thickness of 20 mils. The simulation was conducted in ADS. A prototype of this filter was fabricated using a manual printing technique. Fig. 3 (a) shows the structure of the fourth-order filter. The physical values for the parameters of this filter are presented in Table I. In addition, Fig. 3 (b) demonstrates a photo of a fabricated prototype. A metal case was designed and fabricated to reduce EMC interference in the measurement. This filter consists of five parallel resonators with four gap sizes which produce four poles in the frequency response. The filter has a compact size. The total size of the board of the filter is less than $5\times 18\ mm$. The compact size of this filter is beneficial for the applications in which a small size of the circuit is mandatory.




(a)




(b)

Fig. 4 The simulated and measured S-parameters of the designed filter

TABLE I
PHYSICAL VALUES OF THE FILTER PARAMETERS IN MILLIMETERS

| Resonator order ($i$) | $l_i$ | $L_i$ | $w_i$ | $W_i$ | $g_i$ | $l_c$ |
|---|---|---|---|---|---|---|
| 1 | 10 | - | 0.5 | - | - | - |
| 2 | 10 | 4 | 0.2 | 0.6 | 0.1 | 3 |
| 3 | 10 | 4 | 0.3 | 1 | 0.15 | 1 |
| 4 | 10 | 4 | 0.2 | 0.6 | 0.15 | 3 |
| 5 | 10 | - | 0.5 | - | 0.1 | - |

The results of the simulation and measurements of this filter are depicted in Figs. 4 (a) and (b). As it can be seen, the simulation and measurement results agreed with an acceptable error. In the simulation result, the magnitude of insertion loss is below 0.53 dB, which reached to less than 1 dB in measurement. The return loss is lower than 12 dB in the passband frequencies in both simulation and measurement results. The 3-dB bandwidth is from 3.85 GHz to 6.8 GHz with 56.7% of fractional bandwidth. In addition, the variation of group delay in the passband is below 0.47 ns which makes it suitable for radio communication systems.

In the amplitude response of this filter, four resonances can be seen. It was expected to have four resonances as the filter is a fourth order one.

## V. CONCLUSION

In this paper, a compact via-less UWB microstrip bandpass filter structure has been proposed. The model is based on enhanced interdigital bandpass filter. In order to overcome fabrication limitation and difficulties in manufacturing via holes in microstrip filters, via has been replaced by short circuits quarter wavelength stubs. As a result, it simplifies the fabrication process and reduced the cost by avoiding the via holes in the filter design. Two microstrip UWB filters in 3.85-6.8 GHz and 5.8-10 GHz have been designed and fabricated on 20-mil Rogers RO4003 substrate. The result of the simulation and measurement of the filter with a lower frequency range were presented in this paper. The measured results were promising, and they well agreed with the simulation results. The outcome proved the improvement in fabrication accuracy with avoiding the via hole in the proposed filter.

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