COMPACT DESIGN OF ULTRA-WIDEBAND BANDPASS FILTERS WITH STEP IMPEDANCE HAIRPIN-LOADED INTERDIGITAL STRUCTURE

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Abstract: This paper depicts a new structure of ultra-wide band bandpass filter by cascading an Inter Digital Structure and a hairpin line structure. The size of filter is further reduced from what it is in previous researches and ease of fabrication is achieved. As vias and defective ground structures are absent in the proposed structure, as a result the fabrication of filter is further simplified and a cost-effective method is obtained for its fabrication. The centre frequency of passband is 3.24 GHz with fractional bandwidth of 93.89%, an impressive return loss of -60dB. The s-parameter performance characteristics also includes good rejection performance. The proposed structure is designed and simulated using Keysight Advanced Design System (ADS). The proposed filter is designed on FR4 with dielectric constant 4.4 and thickness 1.6 mm.

Keywords: Ultra-Wide Band Filter, Return Loss, Harpin line structure

INTRODUCTION

Bandpass filters (BPFs) are essential components in wireless communication systems, designed to transmit desired signals while filtering out unwanted ones.[1][2].

Dual-band microstrip bandpass filters (BPFs) are advancing swiftly to meet the growing demand for innovative solutions in modern wireless communication systems [1]. Researchers have explored various techniques for designing dual-band BPFs [2–9]. A simple method involves connecting two bandpass filters with different passbands in parallel, though this increases the overall size. Alternatively, compact resonators can be used to achieve dual passbands [2]. Another approach for designing dual-band BPFs involves using dual-band J-inverters connected to open or shorted stubs [3]. However, shorted stubs require vias, leading to higher manufacturing costs. Stepped impedance resonators (SIRs) offer a practical alternative by generating dual bands through harmonic control [4–5]. Additionally, multimode resonators utilizing both fundamental and higher-order modes have been implemented in several dual-band BPF designs [6–9]. A novel multimode resonator introduced in [10] enables the creation of dual-wideband BPFs, with adjustable center frequencies and bandwidths for each passband by modifying parameter dimensions. This design also incorporates transversal signal interference and a double-finger feed structure, resulting in four transmission zeros. In [11], second-order dual-band BPFs were developed using modified $\lambda/4$ stub-loaded resonators, either open- or short-circuited. Most dual-band BPF designs include vias or defective ground structures to enhance passband performance or reduce size [12-13]. This work proposes a compact dual-band BPF with a wide stopband and superior passband characteristics, designed to support WLAN/WiMAX communication standards at 2.4 GHz, 2.5 GHz, 3.5 GHz, and 5.8 GHz.

- **Innovative Design for the Proposed Filter Structure:** Design Architecture of the Suggested Ultra-wide Bandpass Filter (UWBPF) is shown in Figure 1. The filter design consists of two main elements:

(a) A central Interdigital Structure (IDS) that enables dual passbands, though with a relatively weak stopband.
(b) A hairpin line placed at the upper and lower sections, which functions as a low-pass filter and structure also consist open rectangular stubs on top and bottom to improve overall performance of the UWBPF.

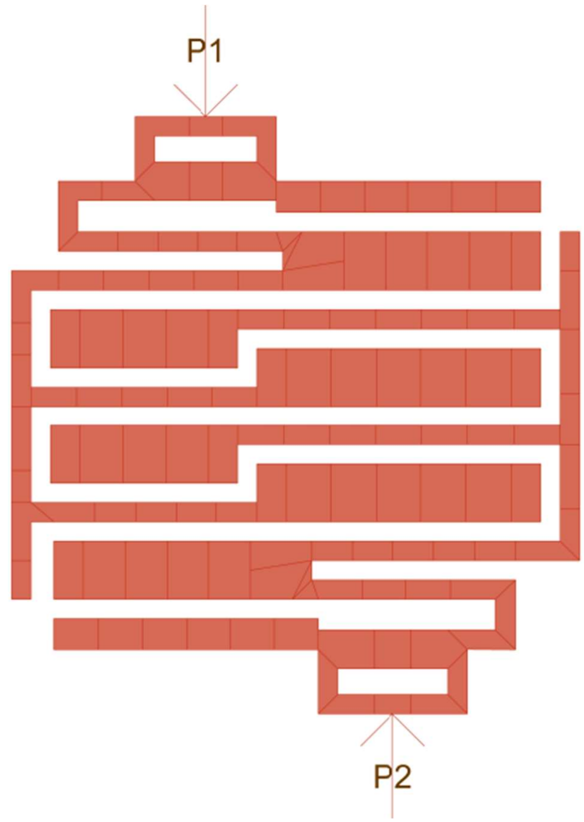

Figure 1: Structure of Proposed Filter

- While the Interdigital Structure exhibits dual passband capabilities, its stopband performance at higher frequencies is limited. To address this, a hairpin line structure is integrated with the Interdigital Structure. The dimensions of both elements are meticulously designed to achieve a first passband spanning 1.814 GHz to 4.977 GHz and a stopband is achieved at frequency 5.509 GHz. This forms the basis of the proposed UBPF structure.

Design and Analysis of Dual Bandpass Filter

Introducing the innovative pseudo-interdigital arrangement, Inter-digital structure's significance in ultra-wide Filter. The Fingers of the structure generate effect of inductor, L, and gaps between fingers generate effect of capacitor, C. In the equivalent circuit, Capacitor-Cp (1), and Capacitor Cp (2), originating from the Filter Dielectric, are distinctly featuring Filter as shown in fig 2(a). However, the interplay between the various capacitors and inductors introduces ripples within the passband of the frequency responses. The hairpin structure serves as a low-pass filter, where the spacing between the hairpin lines induces a capacitive effect, and the length of the hairpin lines contributes to an inductive effect as shown in fig 2(b).

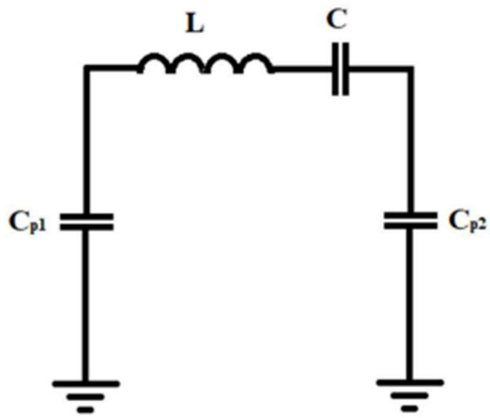

Figure 2(a): Equivalent Circuit of IDS

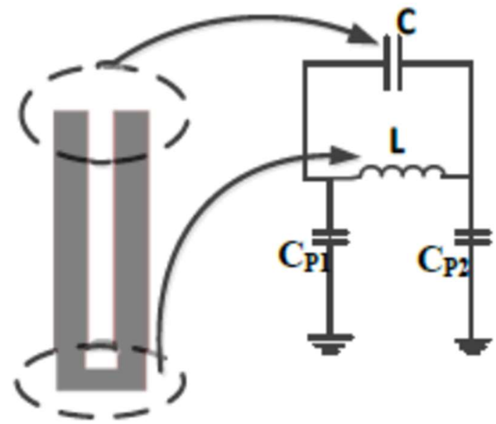

Figure 2(b): Hairpin Structure

When input and output ports are applied to the fingers of the Interdigital Structure, the frequency response exhibits dual passbands; however, the stopband performance is inadequate, as illustrated in Figure 3.

Figure 4: IDS with input and output at the finger

The Keysight Advanced Design System (ADS) is utilized to optimize the IDS and hairpin structure dimensions in the suggested filter in order to attain pass band frequencies of 2.4GHz, 2.5GHz, 3.5GHz, and 5.8GHz. By altering the IDS finger length, Lf, and hairpin length, the suggested filter's pass band frequency range can be changed. Changes in S21 in the higher band and a greater cutoff frequency in the lower band are observed when the finger length, Lf, of IDS is adjusted from 4.8 to 5.6mm in previous analysis and research.

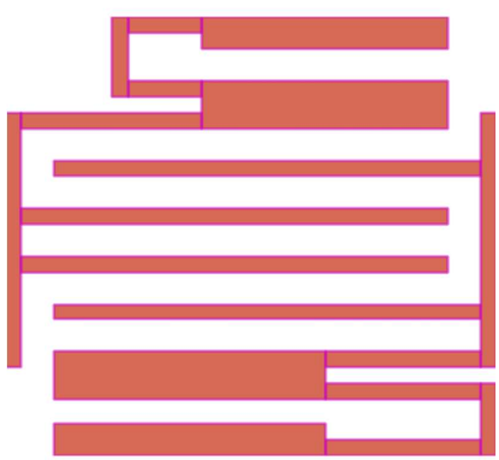

Figure 5: Equivalent Associated UBPF Design

Associated Parameter of fig 1 and fig 4 are Lf = 5.2 , W1 =0.4, G1 = 0.2 (dimensions are in millimeters).

Design and Analysis of Ultra-Wide Band Pass Filter

The passband frequencies of 2.4 GHz, 2.5 GHz, 3.5 GHz, and 5.8 GHz in the proposed filter were achieved by optimizing the dimensions of the interdigital structure (IDS) and hairpin resonator using ADS software. Adjustments to the IDS finger length (Lf) which is divided into two parts L4 and L6 and other part of IDS finger divided into two different length which is L5 and Lf from the previous design to make it compact and filter provide good performance and hairpin length enable tuning of the filter's frequency range and also the open loop rectangular present and top and bottom improves the overall insertion loss and Return loss. Analysis, as depicted in Fig 4, shows that varying the IDS finger length in two length range first range is 1.45mm to 1.75mm and the second range is 2.2mm to 2.5mm impacts the upper cutoff frequency of the lower band and the higher band frequencies.

In the design of proposed filter IDS, Hairpin and open and closed rectangular loop structures are used to improve the overall performance of the filter. To achieve required band with good performance the dimensions of the proposed filter are given in table-1. Filter is designed on FR4 with dielectric constant of 4.4 and of thickness 1.6mm.

TABLE 1: DIMENSIONS OF PROPOSED FILTER

S.NO	PARAMETERS	VALUES (mm)
1.	L1	1.4
2.	L2	1.53
3.	L3	2.05
4.	L4	1.45
5.	L5	2.2
6.	L6	2.5
7.	Lf	1.75
8.	W1	0.45
9.	W2	0.25
10.	W3	0.45
11.	W4	0.15
12.	G1	0.15

The filter's first band, which covers 1.814GHz to 4.977GHz with a good insertion loss of less than 0.4dB and passband is wide with return loss of 60db, includes WiMax/WLAN frequencies including 2.4GHz, 2.5GHz, and 3.5GHz.

The filter's second pass band, which has an insertion loss of 0.18 dB, includes 5.8GHz. The stop band is wide, with an insertion loss exceeding 10 dB. The recommended filter is 6.4×5.4 mm^2. The centre frequency of passband is 3.24 GHz with fractional bandwidth of 93.89%, an impressive return loss of -60dB. The s-parameter performance characteristics also includes good rejection performance.

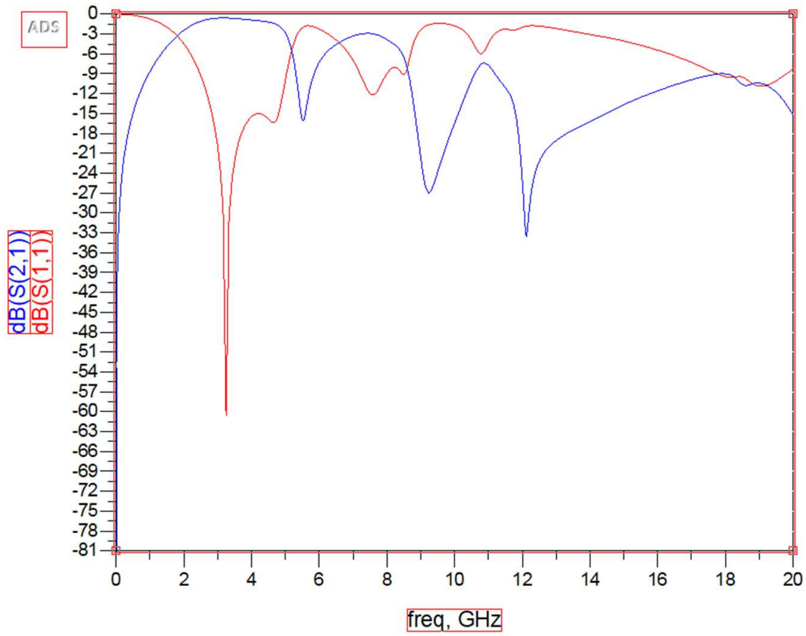

Figure 2: Frequency Response of Proposed Filter

The proposed filter is smaller, has a larger stop band, and has a better pass band response when compared to previous works [6-13].

CONCLUSION

This paper presents two advanced designs for bandpass filters (BPFs). The first is an ultra-wideband BPF that combines an interdigital structure (IDS) with a hairpin line configuration with step impedance in the middle of structure. It offers a compact form factor, simplified fabrication by avoiding vias and defected ground structures, a center frequency of 3.24 GHz, a fractional bandwidth of 93.98%, and a return loss of -60 dB. The design exhibits excellent rejection characteristics and shows strong alignment between simulation and measurement results on an FR4 substrate. The second design is a dual-band BPF tailored for Wi-Max and WLAN standards, operating at 2.4 GHz, 2.5 GHz, 3.5 GHz, and 5.8 GHz. It features a compact footprint of 4.401×4.648 mm² at a center frequency of 2.88 GHz, low insertion loss (<0.5 dB), high stopband attenuation (>10 dB), and minimal group delay. Both designs offer simplified fabrication, cost-effectiveness, and superior performance compared to previous designs.

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