COMPACT DUAL-BAND NARROWBAND BPF WITH STUB-LOADED INTERDIGITAL HAIRPIN RESONATOR FOR INTEGRATED WIMAX/WLAN SYSTEMS

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ABSTRACT:

This paper introduces a novel design for a Compact Planar Dual Narrow Band Pass Filter (BPF), employing a stub-loaded interdigital structure (IDS) situated between two hairpin resonators. The integration of the IDS with the hairpin structures effectively divides the passband into two distinct frequency bands, enhancing selectivity and performance. Fabricated on an FR-4 substrate with a thickness of 1.6 mm and a relative dielectric constant of 4.5, the filter operates at a center frequency of

4.8 GHz. It exhibits a fractional bandwidth of 18.18% and maintains a low insertion loss of 0.889 dB. The proposed structure is designed and simulated using Keysight Advanced Design System (ADS).

Keywords: Narrow Band Filter, Bandwidth, Return Loss, Hairpin-like Structure.

INTRODUCTION

Dual-band microstrip bandpass filters (BPFs) are essential components in Present Scenario wireless communication systems, especially with the growing use of technologies like WLAN and WiMAX [1]. As dual-band functionality becomes more important, researchers have proposed a wide range of design approaches [2–9]. A basic method to achieve dual-band filtering is to use two separate filters, each tuned to a different frequency. However, this tends to result in a bulky overall design. To reduce size, some designs use two compact resonators [2]. Another size-saving technique involves using admittance inverters with open- and short-circuited stubs [3]. While this approach helps make the filter more compact, it increases the design's complexity and cost due to the need for vias— metallic holes through the circuit board. Stepped impedance resonators (SIRs) are another popular solution. They allow for smaller filters while also reducing unwanted harmonic frequencies [4–5]. Researchers have also explored various types of resonators for dual-band filtering [6–10]. For instance, one design makes use of a short-circuited quarter-wavelength stub resonator [11], but it also faces manufacturing challenges because it requires vias. A novel design of single-band narrowband pass filter is discussed [12].

Dual-band microstrip bandpass filters (BPFs) are important in modern wireless systems like Wi-Fi (WLAN) and WiMAX. Many designs have been developed to meet the need for filters that works two different frequencies.
A basic method to make a dual-band filter is by using two separate filters, but this takes up a lot of space. To save space, smaller designs use special structures like compact resonators or admittance inverters with open and shorted stubs. These designs reduce size but can be harder and more expensive to build because they often need vias (tiny holes in the circuit).

Another smart approach is using stepped impedance resonators (SIRs), which help keep the filter small and avoid unwanted signals. Other types of resonators are also used, but many of them still face issues during manufacturing due to the need for vias.

I. **Design and Development of Proposed Filter**

In this work the dual pass band response is achieved by dividing a pass band into two parts. Thebandpassisachievedbycascadinghighpassandlowpassfilterstructuresanditisdivided into two parts by creating a transmission zero with in it. The structure of the proposed dual band micro strip BPF is shown in figure -1. It consists of three well known structures such as:
(a) Inter digital structure (IDS)- in center which shows high pass filter nature.
(b) Hair pin line- on left and right hand part of the structures act as low pass filter.
(c) Stub loaded on the finger of IDS- creates transmission zero.
(d) Triangular Structure-improve efficiency.

In the proposed configuration, the interdigital structure (IDS) is centrally embedded between two hairpin resonators to form the main passband characteristics of the filter. To enhance frequency selectivity, a stub is loaded on to one of the IDS fingers, which introduces a transmission zero with in the pass band. This strategically placed transmission zero effectively segments the pass band into two separate frequency ranges, thereby enabling dual-band operation. The first passband supports the 2.4GHz, 2.5GHz, and 3.5GHz bands, while the second pass band is centered at 5.8GHz, addressing key requirements for WLAN and WiMAX systems.

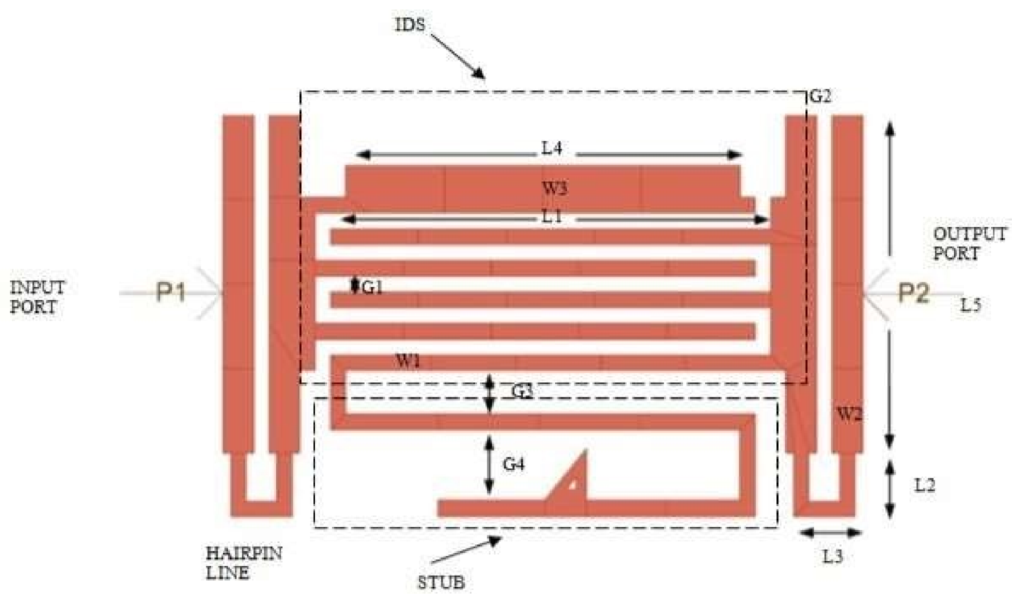

Fig.1: Proposed Structure of Dual Band NBPF

Design and Analysis of Dual Band Pass Filter

An interdigital structure is made of several parallel microstrip lines, called fingers, placed close to each other. The gap between fingers generates capacitive effect

- **The length of each finger acts like an inductor (it creates inductance).**

- **The small gaps between the fingers act like capacitors (they create capacitance).**

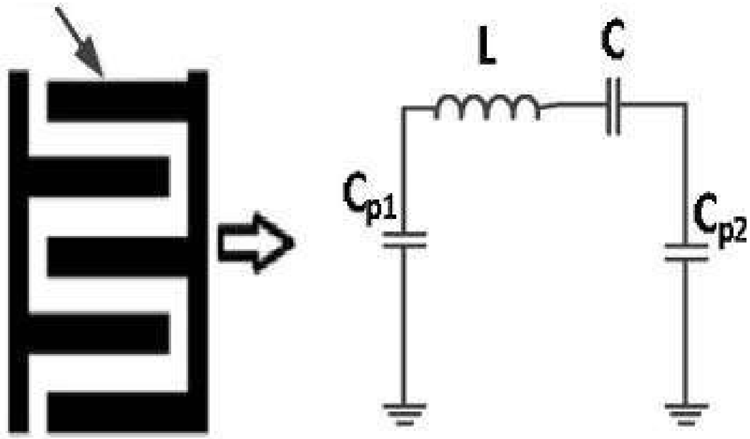

Fig2: Equivalent Circuit of IDS Structure

Together, these inductive and capacitive effects make the structure useful in designing filters and resonatorsinRFandmicrowavecircuits.TheequivalentcircuitoftheInterdigitalStructure(IDS) is illustrated in Figure 2(a). In this model:

- The inductive behavior of the fingers is represented by L,
- While the capacitive effect of the gaps between fingers is shown by C.
- Additionally, the dielectric substrate use dimensions constructing the IDS contributes extra capacitance, denoted as Cp1 and Cp2.

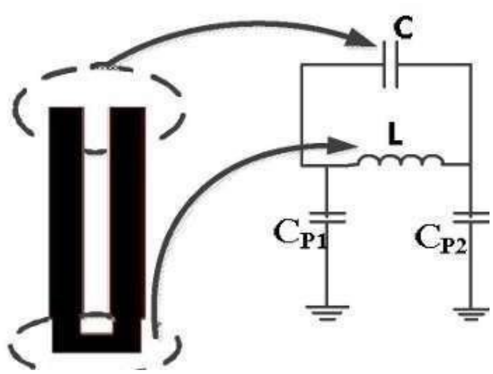

Fig: 2(a) Hair Pin Structure

Similarly, a hairpin line structure is essentially a microstrip line bent into a U-shape.

- The gap between the two folded arms introduces a capacitive effect,
- And the length of the line results in an inductive effect.
- The dielectric material underneath the hairpin line also introduces parasitic capacitance are represented by Cp_1 and Cp_2 in the circuit

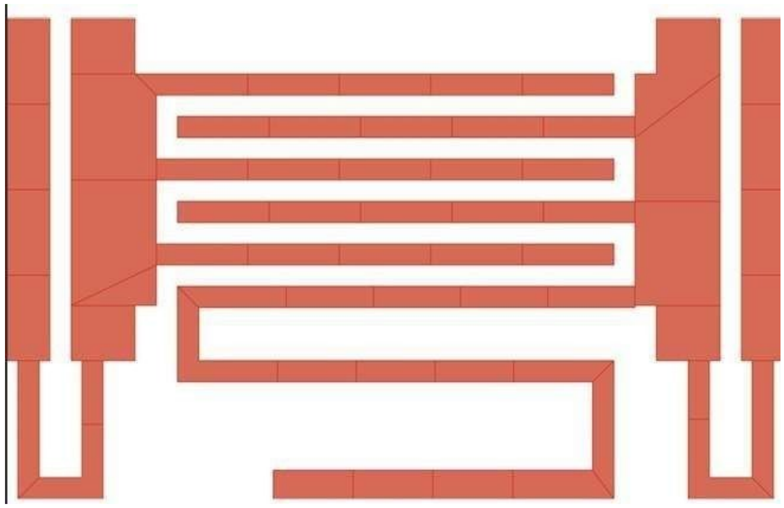

Fig-2: IDS and Hairpin Structure with stub load

In this work, a compact and efficient IDS and Hairpin structure with stub load has been presented and analyzed for microwave frequency applications. The integration of interdigital capacitive elements and hairpin resonators enables effective miniaturization while maintaining desirable bandpass filtering characteristics. The inclusion of stub loads further enhances the impedance matching and frequency selectivity. This structure proves to be a promising candidate for use in modern RF and microwave circuits, especially where size and performance are critical constraints.

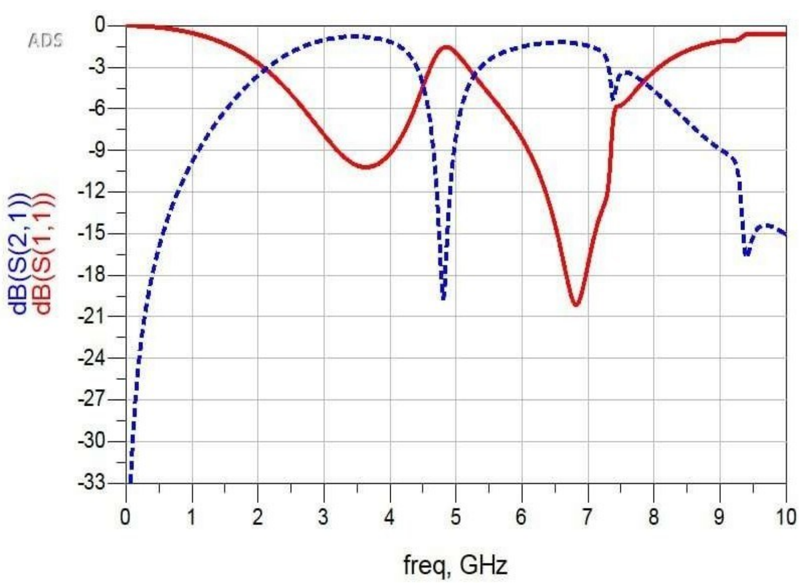

Fig-3: Frequency response of IDS and Hairpin Structure with stub load

The IDS finger structure operates as a high-pass filter, whereas the hair pin structure serves as a low- pass filter. When combined, they effectively form a bandpass filter. However, the addition of a triangular resonator alters the filter’s characteristics, transforming it into a narrowband bandpass filter. This effect becomes more significant as the stub loading increases, allowing for enhanced control over the filter's bandwidth.

Simulated Result of Proposed Filter

The effect of changing the stub length attached to the finger of the Interdigital Structure (IDS) has been studied, while keeping all other design values the same. This study looks at how these changes influence the transmission zero and the higher cutoff frequency. The results show that the lower cutoff frequency mostly depends on the length of the IDS finger, while the higher cutoff frequency is affected by the size of the hairpin line and the stub added to the finger.

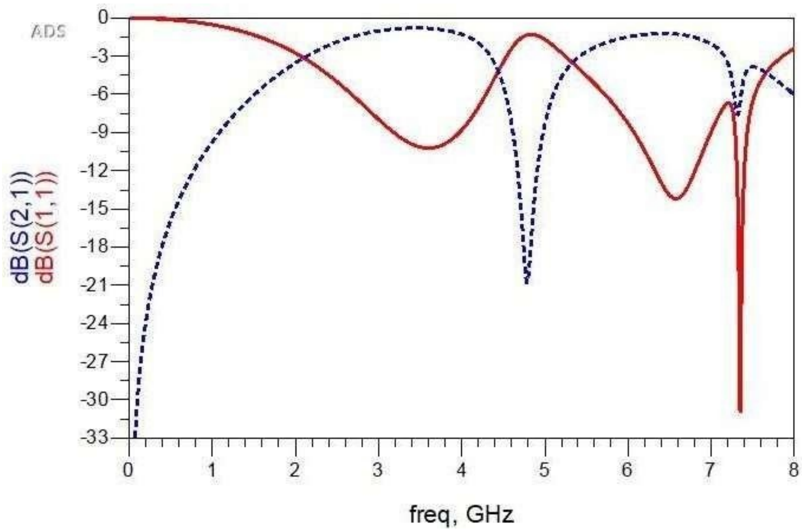

Fig-4: frequency response of purposed filter

Fig: To understand how the filter behaves, its dimensions were adjusted. As we add the triangular structure with dimension0.4mm, 0.48mm, as triangle is Scalene As seen in Figure, leads to changes in the higher frequency band and the size of L1 is 4.3mm, L2 reduces to 1.1mm to 0.61mm, L3 reduces from 0.8mm to 0.6mm which change the behavior of filter and size become more compact due to this affects the upper limit of the lower band.

The final design of the filter works well for both WiMAX and WLAN frequency ranges. The filter is made on an FR4 substrate with a dielectric constant of 4.4 and thickness of 1.6 mm, and its dimensions are listed in Table 1.

To achieve good performance across both WiMax and WLAN frequency bands, the proposed dual band filter is designed on an FR4 substrate featuring a dielectric constant of 4.5 and a thickness of 1.6mm. The specific dimensions of the filter are listed in Table 1.

Additionally, the filter features a broad stop band, further enhancing its overall effectiveness. Demonstrates a consistent and favorable behaviour across the frequency spectrum.
Theproposedfilter'sfirstpassbandefficientlycoversthe2.4GHz, 2.5GHz, and 3.5GHz frequencies, exhibiting an excellent result.

A note able feature of this design is the absence of vias or defected ground structures, which simplifies the fabrication process and lowers manufacturing costs. Compared to recent designs, the proposed filter not only achieves better performance but also occupies a smaller physical area.

TABLE-1: DIMENSIONS OF PROPOSED FILTER

SR.NO	PARAMETER	VALUES(MM)
1	L1	4.3
2	L2	0.61
3	L3	0.6
4	L4	3.85
5	L5	3.22
6	W1	0.15
7	W2	0.3
8	W3	0.3
9	G1	0.15
10	G2	0.15
11	G3	0.415
12	G4	0.666

CONCLUSION:

In this work, a compact planar dual-band bandpass filter (BPF) based on a stub-loaded interdigital structure integrated with hairpin resonators has been successfully designed and analyzed. The integration of the IDS and hairpin topology enables effective control over the filter's pass band characteristics, allowing for the formation of two distinct frequency bands. Fabricated on a low-cost FR-4 substrate, the proposed filter achieves a fractional bandwidth of 18.18% and demonstrates low insertion loss, making it a viable candidate for wireless communication systems operating around 4.8GHz. The design, simulated using Keysight ADS, confirms both compactness and high performance, proving its potential for future integration in space-constrained RF front-end modules.

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