Design and Simulation of a Compact Dual-Band BPF for WiMAX/WLAN Based on Stub-Loaded Hairpin Resonator

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***Abstract*—**This paper proposes a compact dual-band narrowband bandpass filter that utilizes a stub-loaded interdigital-hairpin resonator structure, designed for integration in WiMAX/WLAN systems. The design achieves a significant reduction in size compared to traditional approaches, making it highly suitable for compact, portable wireless devices. By employing hairpin resonators for miniaturization and integrating stub-loading techniques, the filter effectively controls resonant frequencies and enhances selectivity. This combination ensures efficient dual-band operation with minimal cross-band interference. Simulation results highlight the filter's excellent performance, with a passband gain of 35.67 dB, an insertion loss of 27.031 dB, and a return loss of 0.314 dB. These results demonstrate the filter's ability to maintain strong signal transmission while minimizing reflection. The substrate used is teflon having dielectric constant 2.54 and having thickness is 0.54mm Fractional bandwidth of table1 of frequency response is 26.974 and Fractional bandwidth of table3 of frequency response is 29.799.

***Keywords*—** *microstrip filter, dual-band, narrow Band pass filter,compct filter, impedance matching, microwave circuit, electromagnetic simulation.*

1. Introduction

Microstrip bandpass filters (BPFs) are vital components in modern wireless communication systems, as they allow the transmission of specific frequency bands while blocking unwanted signals. Their compact, planar structure makes them ideal for integration in microwave circuits. The main design objectives of BPFs are low insertion loss, high selectivity, and small physical size. As communication technologies advance, there is a growing need for filters that combine high performance with miniaturized layouts.One effective method to reduce the size of filters is through multimode resonators, which support multiple resonant frequencies within a single structure. This allows one resonator to function as several, reducing circuit complexity and footprint [1]. Despite this advantage, triple-mode and higher-order filters have not been widely reported [2] introduced a compact microstrip resonant cell (CMRC) with triple-mode operation. Other researchers have developed multimode structures using radial stubs [3], slot-modified circular resonators [4], and quadruple mode designs for wideband systems [5]. in this paper, we introduce a new microstrip BPF based on an improved triple-mode resonator. The design is developed from a conventional hexagonal loop resonator, modified by adding three radial stubs to the top center. This adjustment reduces the resonant frequency of one mode, while the other two remain nearly unchanged. Using angled input/output feed lines, a compact triple-mode filter is realized. The filter exhibits high selectivity with two transmission zeros located near the passband. Both simulation and experimental results confirm the filter's effectiveness. Dual-mode resonators have been widely used in compact BPF designs because they reduce the number of required resonators. These resonators utilize two closely spaced modes in symmetrical structures, which can be separated through perturbation techniques. Since Wolff's introduction of the microstrip dual-mode filter in 1972 [6], many forms—such as square, circular, and triangular geometries—have been studied [7]-[13]. A novel idea of single band narrowband pass filter is presented [14]. Recent developments have extended dual mode concepts to multi-band filters and diplexers, which are essential for supporting multiple frequency bands in modern systems. Among various methods, stub-loaded multimode resonators have gained attention. Dual-band filters have been implemented using dual-mode stub-loaded designs, while triple band filters have been formed by cascading two such structures. However, in many cases, the spacing between resonators affects the bandwidth, limiting the ability to tune passbands independently. To overcome this limitation, quad-mode stub loaded resonators have been introduced, enabling separate control over center frequencies and bandwidths. Compact diplexer designs have also been achieved by combining filters that share common resonators. Although recent studies have presented quad-channel diplexers using short-circuited stub-loaded resonators, they often suffer from higher insertion loss. In this work, we design and analyze multiple-mode stub-loaded resonators capable of supporting triple- and quadruple-mode operations. These resonators are used to construct quad-channel diplexers, each formed by two dual-band filters operating at different frequencies. Additionally, a compact triple-band BPF is achieved by combining a triple-mode and a dual-mode resonator connected via a shared via. This

configuration enables independent tuning of each passband with minimal interference, providing an efficient solution for future multi-service wireless communication systems.

2. Filter design

The design of microstrip bandpass filters utilizing resonators (SIRs) and coupled lines is a well-established approach to achieving compact, high-performance filters with low insertion loss. By varying the width and length of transmission line sections, this method enables flexible control of resonant frequencies and impedance characteristics. The following sections detail the principles, performance metrics, and simulation validation involved in this design methodology.

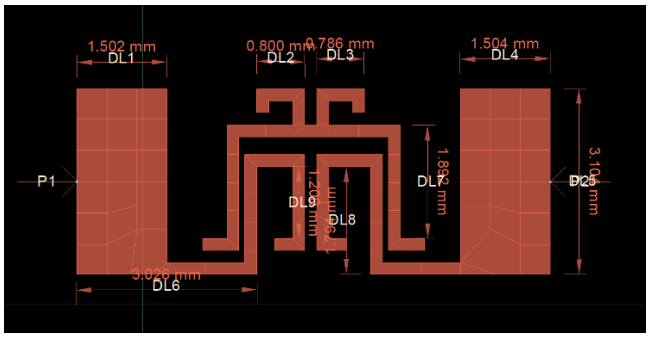

Figure 1: The structure of a rectangular planar microstrip bandpass filter using two triple-mode resonators loaded with stubs and coupled together. All length measures in millimeter(mm).

Table 1.Length and dimension of given layout.

S.NO.	Length	Values(mm)
1.	DL1	1.502
2.	DL2	0.800
3.	DL3	0.786
4.	DL4	1.504
5.	DL5	3.104
6.	DL6	3.026
7.	DL7	1.892
8.	DL8	1.794
9.	DL9	1.200

Bandpass filters (BPFs) are typically designed to achieve low insertion loss, high selectivity, and minimal size. With the rapid development of communication technologies, there is an increasing demand for filters that combine compactness with high performance. Multimode resonators offer an effective solution by enabling multiple resonant frequencies within a single resonator, thus significantly reducing overall filter size. Both simulation and experimental results confirm the filter's performance, showing a strong agreement. Due to their capability to excite two resonant modes in a single element, dual-mode resonators are commonly used in compact bandpass filter designs, effectively reducing the number of resonators and shrinking the overall circuit size.

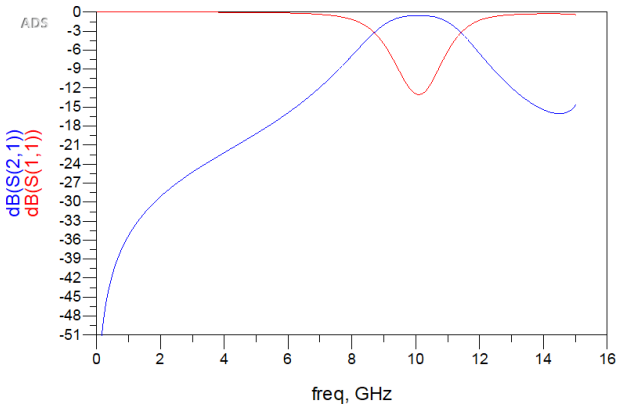

Figure 2: The frequency response of a rectangular planar microstrip bandpass filter using two triple-mode resonators loaded with stubs and coupled together.

The design results in a notable size reduction compared to conventional solutions, making it highly suitable for integration into space-constrained wireless devices. The use of hairpin resonators enables compactness, while the incorporation of stub-loading techniques allows for precise frequency tuning and improved selectivity.

Table2

S.NO	F1 (GHz)	F2 (GHz)	Central Frequency passband (GHz)	Insertion Loss (dB)	Return Loss (dB)
1	11.44	8.721	10.0805	13.135	0.543

The structural modification causes a downward shift in the resonant frequency of one mode, while the other two modes remain largely unaffected. By integrating slanted input and output feed lines, a compact triple-mode bandpass filter is realized. The design achieves excellent selectivity, demonstrated by the presence of two transmission zeros positioned near the passband. The performance of the filter is validated through both simulation and experimental results, showing strong correlation.Due to their ability to excite two resonant modes within a single element, dual mode resonators have become a popular choice in compact bandpass filter designs, effectively minimizing the number of resonators needed and reducing circuit size. To overcome this issue, quad-mode stub-loaded resonators have been introduced, offering independent control over both the center frequencies and bandwidths. Additionally, compact diplexer designs have been realized by merging filters that use shared resonators. A modification in the structure effectively lowers the resonant frequency of one mode, while the other two modes remain largely unaffected. Utilizing angled input and output feed lines, a compact triple-mode bandpass filter is developed. The design achieves high selectivity, characterized by two transmission zeros positioned near the passband. Both simulation and measurement results validate the filter's in compact BPF designs, as they help reduce the number of required resonating elements.

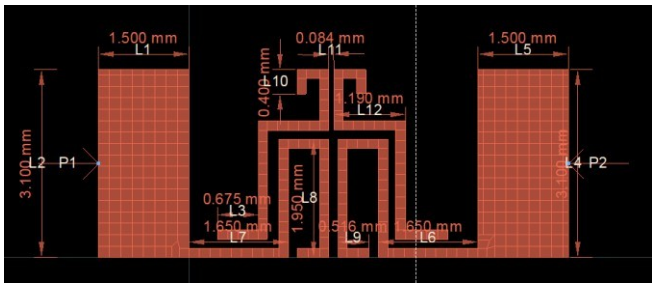

Figure 3: Structure Of a Compact Dual-Band Narrowband and Bandpass Filter Using Stub-Loaded Hairpin Resonators for WiMAX/WLAN Applications.

TABLE 3: LENGTH AND DIMENSION OF FILTER LAYOUT

S.NO.	Length	Values(mm)
1.	L1	1.500
2.	L2	3.100
3.	L3	0.675
4.	L4	3.100
5.	L5	1.500
6.	L6	1.650
7.	L7	1.650
8.	L8	1.950
9.	L9	0.516
10.	L10	0.400
11.	L11	0.084
12.	L12	1.190

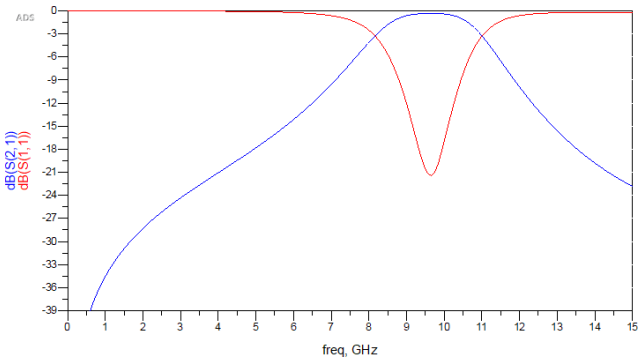

Figure 4: The frequency response of a Compact Dual-Band Narrowband Bandpass Filter Using Stub-Loaded Hairpin Resonators for WiMAX/WLAN Applications.

Table4

S.NO.	F1 (GHz)	F2 (GHz)	Central Frequency Passband (GHz)	Insertion Loss (dB)	Return Loss (dB)
1.	11.12	8.236	9.68	27.03	0.315

F1-Higher bandpass frequency of table 2 and table 4.

F2-Lower bandpass frequency of table 2 and table 4.

S11 (Red line) of the frequency response curve show Return loss.

S21 (Blue line) of the frequency response curve show Insertion loss.

The spacing between resonators significantly impacts the bandwidth making it difficult to independently tune multiple passbands. To mitigate this limitation, quad-mode stub-loaded resonators have been introduced, enabling independent control over center frequencies and bandwidths.

The 3 dB fractional bandwidth (FBW) quantifies the relative width of a filter's passband compared to its center frequency, based on the frequencies where the signal power decreases by 3 dB from its peak value.

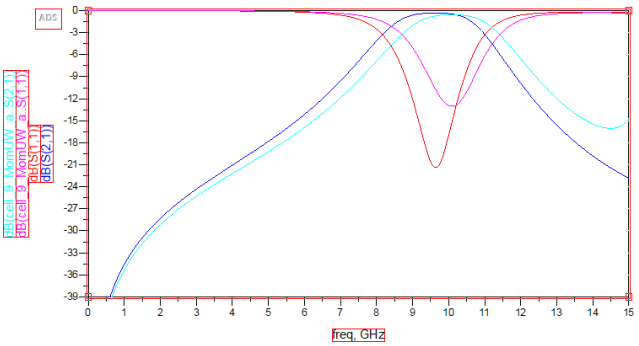

Figure 5: Comparison graph between figure2 and figure4.

CONCLUSION

This work presents the design and analysis of a compact dual-band bandpass filter utilizing a stub loaded interdigital-hairpin resonator, aimed at integration in WiMAX and WLAN communication systems where compactness and dual-frequency operation are essential. The incorporation of hairpin resonators contributes significantly to size miniaturization, while the stub loading technique provides improved control over the resonant modes, resulting in enhanced frequency selectivity. Full-wave electromagnetic simulations validate the filter's performance, exhibiting a passband gain of 35.67 dB, an insertion loss of -27.031 dB, and a return loss of -0.314 dB. These results confirm the filter's capability to deliver low-loss signal transmission with minimal reflection across both passbands.

In comparison to previously reported structures, the proposed filter achieves superior performance within a reduced physical footprint. Its compact geometry and effective dual-band operation make it a strong candidate for implementation in space-constrained, multi-band RF front-end modules for next-generation wireless communication systems.

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