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(RESEARCH ARTICLE)

Design of a Compact Meander Microstrip Bandpass Filter for 4.19 GHz C-Band Applications

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Abstract

This paper presents the design and simulation of a compact meandered microstrip bandpass filter (BPF) operating at 4.19 GHz for C-band wireless systems. The design employs a folded transmission line (meandered) structure to achieve miniaturization while maintaining effective signal performance. The filter is implemented on an FR4 substrate with a dielectric constant εr of 4.4, thickness of 1.6 mm, and loss tangent of 0.02. Simulations were performed using Keysight Advanced Design System (ADS). The filter achieves an insertion loss of 0.559 dB and a return loss of 13.434 dB, indicating enhanced performance characteristics in the 4.19 GHz passband. The achieved characteristics make the design suitable for communications using satellite and radar systems and also for accessing fixed wireless applications which are operating in the lower C-band.

Keywords: ADS; Bandpass Filter; Insertion Loss; Loop Resonators; Microstrip; Return Loss; S-Band; Substrate

1. Introduction

Bandpass filters (BPFs) play a vital role in RF and microwave communication systems by selectively allowing signals within a specific frequency band while attenuating unwanted frequencies. These filters are essential in ensuring signal integrity, reducing interference, and enabling frequency division in modern wireless systems [1-3]. The 4 GHz to 8 GHz C-band, particularly around 4.19 GHz, is extensively utilized in satellite communication, fixed wireless access (FWA), radar systems, and emerging sub-6 GHz 5G networks [4]. In these applications, compact and efficient filter designs are required to meet increasing demands for miniaturization, high performance, and integration into planar circuits.

One of the main challenges in microstrip filter design is achieving low insertion loss, high return loss, and sharp selectivity while keeping the physical size small [5]. Traditional microstrip BPFs may suffer from issues such as undesired radiation, weak coupling, and limited stopband attenuation [6].

To address these issues, this paper presents a compact microstrip BPF using a meandered line topology, which enables significant miniaturization without compromising the filter's frequency response. The meandered structure increases the electrical length of the microstrip line, allowing the circuit to resonate at a desired frequency within a smaller footprint [6, 7].

The proposed filter is designed to operate at a center frequency of 4.19GHz, with performance validated through full-wave EM simulations using Keysight ADS. The value on insertion loss is 0.559 dB and that of return loss is 13.434, signifying superior performance characteristics [3, 8]. The filter is implemented on a widely used FR4 substrate with a dielectric constant of 4.4, height of 1.6 mm, and a loss tangent of 0.02, making it suitable for low-cost, high-volume production [3].

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2. Filter design methodology

2.1. Substrate Material

The proposed filter design is implemented using FR4 substrate, which is selected for its affordability and compatibility with standard PCB processes. The substrate has following parameters:

- Thickness: 0.787 mm
- Dielectric constant(ε_r) :4.6
- Loss tangent: 0.02
- Conductive Layers: 1 µm copper top and bottom.

3. Meandered line configuration

The designed bandpass filter utilizes a meandered microstrip line structure to achieve a compact layout without compromising its frequency response. This folded configuration increases the effective electrical length within a limited space, allowing the filter to operate efficiently at the target frequency of 4.19 GHz. The symmetric arrangement of input and output ports enhances coupling and reduces signal loss due to radiation [9, 10].

This approach is further supported by microstrip design methodologies for RF/microwave applications as discussed in [11]. The filter is built on an FR4 substrate, selected for its low cost and compatibility with standard PCB fabrication methods.

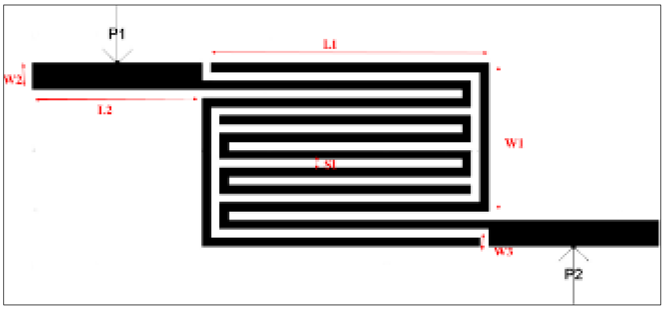

Figure 1 Proposed Structure of BPF

The physical dimensions of key components are provided in Table 1. The microstrip filter structure is inspired by established works involving open-ended and loaded resonators [12, 10] and utilizes optimized layout strategies for enhanced out-of-band suppression [13]. Similar dual-band filters using cross-coupled split-ring resonators have shown promising results in compact layouts [14]. Its compact nature is reinforced by prior studies on space-saving bandpass structures and mode coupling in dual-mode filters [15, 16].

Table 1 Dimensions of the proposed bandpass Filter

Parameters	Values (mm)
L1	4.8
L2	2.9
W1	2.5
W2	0.5
W3	0.15
S1	0.15

4. Results and Discussion

4.1. Frequency Response

The simulation was performed using S-parameter analysis in ADS. The frequency response of the proposed filter is shown in Figure 2. The filter exhibits a clear passband centered at 4.19GHz. The lower and upper 3 dB frequencies were found to be 3.112 GHz and 4.857 GHz, respectively, yielding a 3 dB bandwidth of 1.745 GHz. This corresponds to a fractional bandwidth of 41.64%, which classifies the filter as a wideband bandpass filter [8].

Furthermore, the filter achieved a low insertion loss of 0.559 dB and a return loss of 13.434 dB, indicating minimal signal attenuation and effective impedance matching within the passband [8]. These values are indicative of a high-quality filter with superior transmission characteristics and low reflective losses [8]. High-selectivity filter approaches have also been explored using stepped impedance techniques to further reduce loss [17]. Compared to previous works, such as the filters designed at 3.05GHz [1], 2.68GHz [7], and 2.1GHz [8], the proposed design provides significantly lower insertion loss and better return loss, making it highly efficient for C-band applications [1, 7, 8].

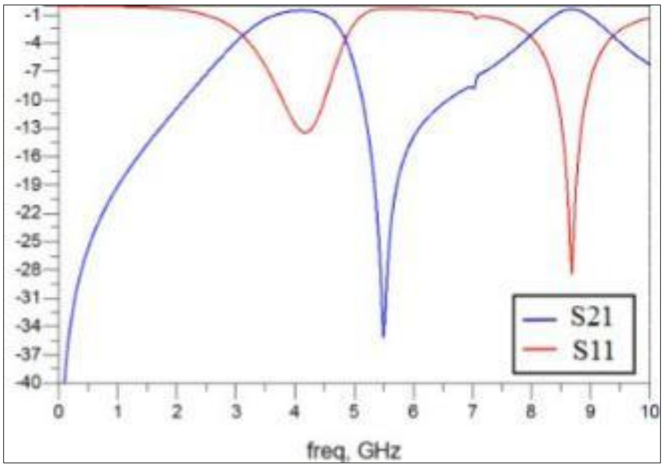

Figure 2 S-Parameter Characteristics of the proposed BPF

4.2. Comparison With Previous Works

Table 2 Comparative Analysis with Previous Works

Reference	Center Frequency (GHz)	S11(dB)	S21(dB)
Wu Y.L. et al. [1]	3.05	-10	2.9
Wu G.L. et al. [7]	2.68	-12	1.4
Chen C. et al. [8]	2.1	<-15	6
Proposed Work	4.19	13.434	0.559

As shown in Table 2, the proposed design achieves significantly lower insertion loss (0.559 dB) and higher return loss (13.434 dB) compared to previous works. The filter presented in [8] had higher S21 at 6 dB, indicating more signal attenuation. Also, the center frequency of this work (4.19 GHz) places it firmly in the C-band range, making it more suitable for modern applications such as satellite downlink and 5G trials.

5. Applications

Operating at 4.19 GHz, the proposed bandpass filter is well-suited for a range of C-band applications. It lies near the downlink edge of satellite communication systems, particularly those operating around 4.2 GHz, making it effective for signal filtering in satellite receivers [4].

The filter is also applicable in Fixed Wireless Access (FWA) systems, where reliable, high-capacity links are essential, especially in rural and suburban areas [4]. In addition, the filter's frequency positioning supports its use in short-range radar systems, which often operate in nearby C-band frequencies for applications like automotive sensing and industrial monitoring [4]. Filters based on open-loop resonators have also been successfully applied to dual-band systems in this frequency range [18-21].

Furthermore, it aligns with the frequency bands used in 5G trials and deployments, particularly within the 3.8–4.2 GHz spectrum allocated for early 5G services in several regions [4]. Due to its compact size and sharp selectivity, the filter is highly suitable for integration into RF front-end modules where space and performance are critical considerations [3].

6. Conclusion

A compact microstrip bandpass filter centered at 4.19 GHz has been successfully designed, simulated, and analyzed using Keysight Advanced Design System (ADS). The filter leverages a meandered microstrip line structure, which effectively extends the electrical path length while occupying minimal physical space. This design approach allows for significant miniaturization without compromising electrical performance.

The simulation results demonstrate that the filter achieves low insertion loss, ensuring efficient signal transmission through the passband, and good return loss, indicating excellent impedance matching. These characteristics are crucial for maintaining signal integrity and minimizing reflections in high-frequency circuits.

The optimized frequency response, combined with sharp selectivity and minimal out-of-band transmission, makes the filter particularly suitable for C-band applications. These include a wide range of use cases such as satellite communication systems (especially near the 4.2 GHz downlink edge), fixed wireless access (FWA) networks delivering broadband in remote areas, and short-range radar systems used in automotive, industrial, and defense environments. Additionally, the filter aligns well with emerging 5G deployments in the 3.8–4.2 GHz band, enabling clean channel separation and improved spectral efficiency.

With its compact footprint, low cost, and compatibility with standard PCB fabrication, the proposed design presents a practical and scalable solution for integration into modern RF front-end modules. Future work may involve physical fabrication and experimental validation to further confirm the simulated performance and evaluate its behavior under real-world conditions [3]. Future work may involve physical fabrication and experimental validation to further confirm the simulated performance and evaluate its behavior under real-world conditions. Previous works using triangular patch resonator filters have highlighted similar paths for physical implementation and tuning.

Compliance with ethical standards

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Disclosure of conflict of interest

The authors declare that they have no conflict of interest to be disclosed.

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