ULTRA-COMPACT MEANDERED MICROSTRIP BAND STOP FILTER AT 3.611 GHz FOR RF AND IOT APPLICATIONS

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Abstract: This research paper presents, a compact microstrip bandstop filter with a meandered-line resonator architecture is designed, simulated, and analyzed. The filter provides an affordable platform for RF and microwave applications when used on a FR-4 substrate, which has a relative dielectric constant of 4.4 and a thickness of 1.6 mm. The suggested filter exhibits a steep notch with a high stopband attenuation of -31.625 dB, targeting a center frequency of 3.611 GHz. Significant size reduction is made possible by the meandering structure, which results in an overall footprint of just 8.2 × 3.24 mm². The efficiency of the filter is confirmed by the simulation results, especially the S-parameters, which demonstrate negligible insertion loss in the passband and significant signal rejection in the stopband. These findings show negligible distortion throughout the operating band and outstanding frequency selectivity.

The compact size and simple planar design make the filter highly suitable for integration into modern wireless communication systems, including portable and embedded devices where space is a key constraint. The proposed structure offers a promising solution for applications requiring efficient interference suppression and compact form factors.

Keywords*: *Band-stop filter, return loss, insertion loss, Interdigital, Stubline, Spurline, Electromagnetic band gap (EBG).

INTRODUCTION:

Filters are essential components in communication and electronic systems used for frequency selectivity and signal processing. Their primary purpose is to allow desired frequencies to pass through while attenuating or rejecting unwanted frequencies. This capability is crucial for reducing cost and improving system performance in various applications like automotive radar and broadband wireless communication.

For adaptive signal pre-selection in contemporary wireless systems like 5G, reflectionless bandpass filters are essential. These filters protect connected active components by internally absorbing stopband energy, as opposed to reflecting undesired signals like traditional filters do. They guarantee nearly flawless input-reflectionless behavior thanks to their configurable complementary-duplexer architecture. Multiband responses and tunable selectivity are made possible by designs that range from first-order to higher-order combinations. Notwithstanding slight variations brought on by component constraints, workable prototypes utilizing lumped and microstrip technology have shown tunable performance.[1]

Numerous filter kinds and design methodologies are present. Reflective adaptive radio frequency filters, or absorptive filters, are a major area of interest. Reflectionless filters release the energy of the signal within the filter itself, as opposed to traditional filters that reflect it back to the source through its stopband or stopbands. This avoids reactive input impedance at stopband frequencies, which might harm active components that are coupled, such as mixers and amplifiers. Additionally, these filters may be tunable or frequency-reconfigurable, which allows for the adjustment of their frequency properties.[1]

There are various kinds of filters, such as bandstop filters (BSFs), which reject a certain range of frequencies, and bandpass filters (BPFs), which pass a particular range of frequencies. Modern microwave applications are becoming more and more dependent on compact designs. One specific type discussed is the interdigital band-pass filter, which uses arrays of resonator line elements. These filters are known for being very compact, having relatively noncritical manufacturing tolerances, and possessing strong stop bands. Interdigital filters can be designed with either short-circuited or open-circuited terminating lines, which are more practical for narrow/moderate or moderate/wide bandwidths, respectively.

The efficient bandpass filtering capabilities of interdigital filter structures, which were initially employed as slow-wave structures, are now acknowledged. They are made up of ground planes connected by parallel quarter-wavelength resonators that are coupled by fringing fields. There are two primary varieties: open-circuited lines for larger bandwidths and short-circuited lines for narrow to moderate bandwidths. These filters provide robust stopbands with spurious-free performance, are small, and can withstand manufacturing variances. Exact synthesis techniques improve performance optimization and design flexibility in a range of combinations.[2]. A microstrip interdigital bandpass filter, usually in TEM-mode, employs parallel quarter-wavelength resonators between ground planes. Fringing fields between neighbouring lines are how coupling happens. Current designs combine meandering electromagnetic band gap (EBG) slots etched in the ground plane with interdigital linked lines. Left-handed metamaterial features are made possible by the structure's formation of shunt inductance via grounded fingers employing via holes and series capacitance through the interdigital capacitor. [3-4] Another important class is tunable or reconfigurable filters, which allow for dynamic control over their frequency characteristics. Fully adaptive multiband bandstop filters can provide independent control of their stopbands' center frequency and bandwidth. This is particularly useful in broadband systems to mitigate undesired out-of-system interferers whose frequencies may change. [5]

In communication systems, microstrip bandstop filters (BSFs) are essential for blocking undesirable signals, such as harmonics, while permitting the passage of required signals. They are preferred because they are inexpensive, lightweight, and simple to make. Although they usually have narrow stopbands, conventional designs employ quarter-wavelength shunt open-circuited resonators. Advanced structures like as frequency-selecting coupling structures (FSCS), defective ground planes, or photonic band gaps are employed to achieve broader stopbands. Performance and compactness are improved by reconfigurable multiband BSFs with tunable resonators and impedance inverters, which allow for flexible spectral control and integration with other RF components. [6-7] Microstrip bandstop filters (BSFs), which have the benefits of being inexpensive and simple to fabricate, are crucial for rejecting undesirable frequencies in microwave systems. Multiple stubs can increase size and loss, but traditional BSFs employ open-circuited stubs, each approximately a quarter-wavelength long, to form deep notches. Using an L-shaped slot in the microstrip line, spurline-based BSFs give a more compact option, but their bandwidth is usually only moderate. A spurline positioned between two open stubs is a more efficient design that incorporates both. This hybrid structure is appropriate for small, high-performance filtering applications because it adds an extra attenuation pole, which results in deeper rejection and a wider stopband without expanding the circuit footprint.[8]. Both stublines and spurlines can be used to produce compact, high-performance notch responses in a microstrip bandstop filter. Quarter-wavelength open-ended transmission lines coupled in a shunt, known as stublines, produce sharp notches at particular frequencies. The bandwidth and center frequency can be adjusted by adjusting the length and impedance ratios. Although they are by nature more compact, spurlines—which are created by embedding L-shaped slots in the microstrip line—also produce notches. Combining various structures, like sandwiching a spurline between two open stubs, broadens the stopband and improves rejection depth without making the circuit bigger. [8-9] A small RF component called a microstrip interdigital bandstop filter (BSF) is made to reduce signals in a particular frequency range while permitting others to flow through with little loss. These filters enable strong coupling through fringing fields by employing interdigital structures, which are parallel quarter-wavelength resonators with alternating open and short ends. They offer advantages such smaller size, easier manufacture, and robust stopband rejection when used in microstrip form. [6-8]

With their ability to reduce signals within a particular frequency range while permitting others to pass with little loss, microstrip bandstop filters are essential parts of radio frequency systems. They are crucial for reducing undesirable frequencies including spurious signals, harmonics, and out-of-band interference, which can impair performance in wireless communication, radar, and measurement systems. They are sometimes referred to as notch or band-rejection filters. Traditional large filter designs are no longer feasible due to the increasing need for small, power-efficient devices in contemporary wireless and Internet of Things applications. Microstrip bandstop filters are perfect for next-generation radio frequency systems because they provide a small, effective solution that allows for miniaturization without sacrificing performance.[9]

The Keysight Advanced Design System (ADS), 2021, is the simulation software utilized. It is employed for the modeling of physical layer components. S-parameters from the simulation results show how well the filter performs over a broad frequency range (0–20 GHz).

DESIGN METHODOLOGY:

- Targeting significant attenuation in the S-band region, the suggested microstrip bandstop filter (BSF) was designed with a stopband frequency of 3.611 GHz at its core. The filter was applied on a FR-4 substrate that had a standard copper cladding, a thickness of 1.6 mm, and a dielectric constant εr=4.4. Strategically connected to a central feedline, the filter topology consists of a mix of resonant stubs and meandering line structures. By extending the electrical length without taking up too much physical area, meandering lines provide a compact design.

  Key design steps include:

- **Initial Calculation**: Determining the quarter-wavelength (λ/4) at the center frequency using the effective dielectric constant and substrate height.

- **Coupled Line and Stub Optimization**: Using electromagnetic simulation tools to optimize the lengths and spacings (as shown in dimensions DL1–DL11) to maximize attenuation at the desired stopband while minimizing reflection and insertion loss in the passband.

- **Defected Ground Structure (DGS)**: Inclusion of etched patterns under the main transmission line to enhance stopband performance and suppress higher-order harmonics.
- **Parametric Sweep**: Tuning key dimensions (such as DL2, DL6, and DL9) to observe their effect on resonant frequency and rejection bandwidth.

In order to guarantee compactness and efficient suppression at the center frequency of 3.611 GHz, the suggested microstrip bandstop filter has been carefully sized. The overall arrangement is ideal for applications with limited space because it is roughly 4.3 mm in length (DL1) and 3.24 mm in height (DL10). The output line is 1.7 mm long (DL2) and 1.066 mm wide (DL3) close to the center coupling zone, and the input and output feedlines are symmetrically positioned. The 2.1 mm (DL7) and 1.2 mm (DL6) segments of the meandering resonator portions on the right side are intended to offer compact electrical channels that enable resonance. Furthermore, the horizontal line that extends from the right into the central junction is 2.0 mm (DL5).

Stubs with a fine width of 0.150 mm (DL9), suited for narrowband resonance, are connected to a vertical segment of width 1.015 mm (DL4) on the upper portion of the structure. To preserve symmetrical resonance properties, the lower portion is given a similar stub dimension of 0.150 mm (DL11). The vertical extension at the lower left is 0.200 mm (DL8). To improve the filter's selectivity and stopband performance while preserving the least amount of signal degradation in the passband, these exact geometrical dimensions were tuned using electromagnetic simulation tools.

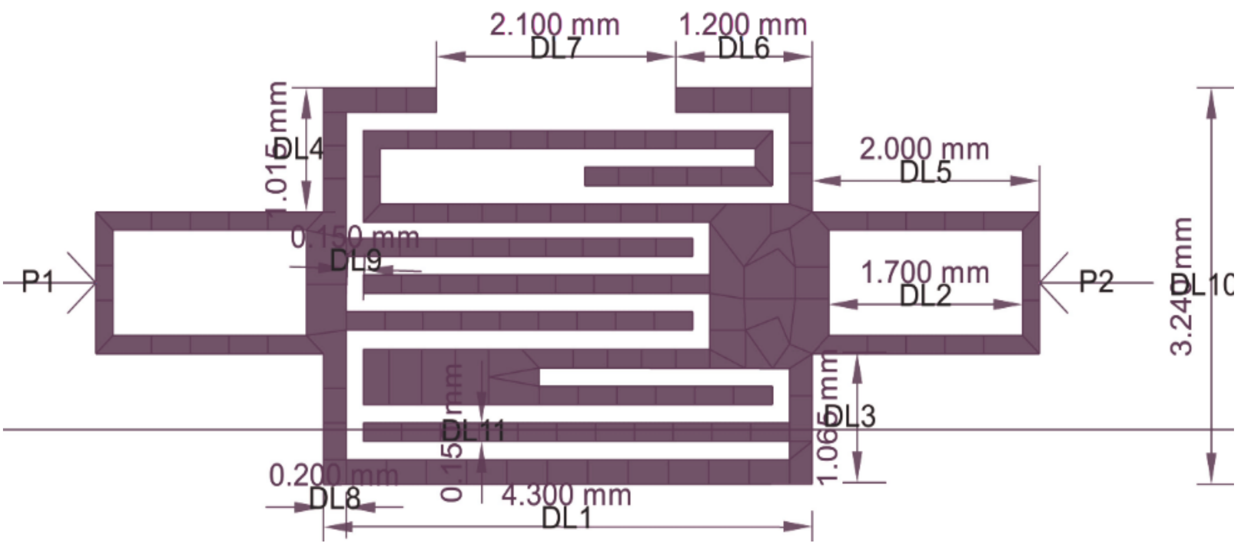

Figure 1: Configuration of the Inter-digital filter design.

The input and output ports are designated P1 and P2, respectively. The structure or coupling window of the central junction seems to be inspired by DGS. In terms of meandering and stubs, the structure is symmetrical along the horizontal axis.

Proposed Design Structure

In order to achieve sharp signal rejection at 3.611 GHz, the suggested bandstop filter comprises an open stub and a spurline resonator on a FR-4 substrate ($\varepsilon r = 4.4$, thickness = 1.6 mm). Strong notch performance is achieved by the spurline efficiently blocking particular frequencies and the open stub introducing a high-impedance route. The filter's small 4.3 mm x 3.24 mm footprint makes it ideal for incorporation in RF systems with limited space. It is perfect for wireless communication applications because of its straightforward, affordable structure and efficient stopband properties.

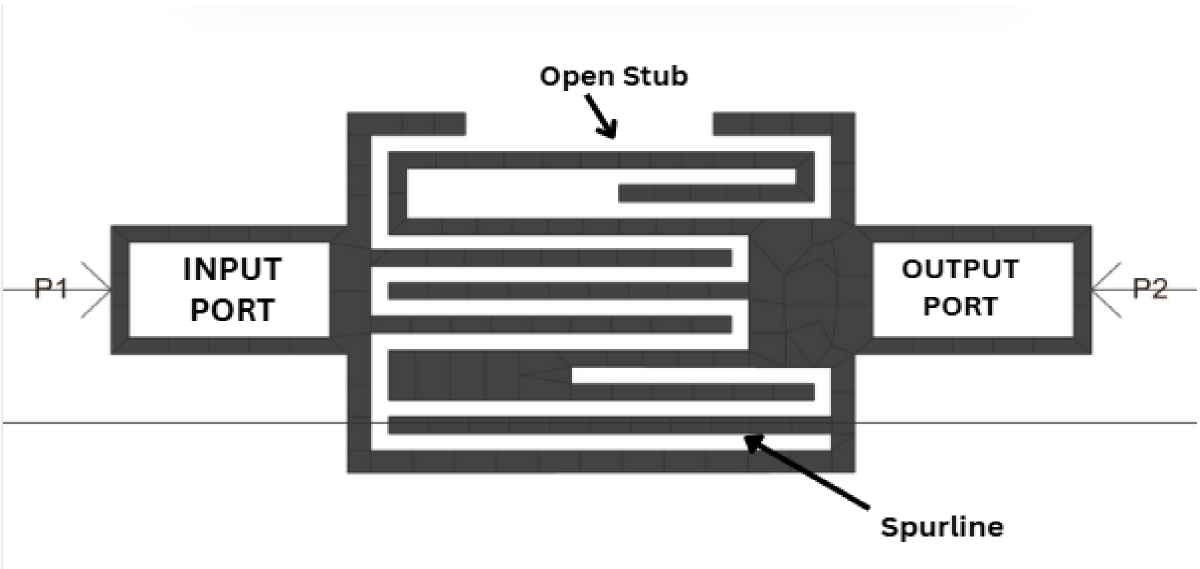

Figure 2: Proposed Filter Design.

RESULT AND DISCUSSION:

The performance of the proposed microstrip bandstop filter was analyzed using S-parameter simulations, covering a frequency range from 0 to 20 GHz. The key performance metrics include insertion loss (S21), return loss (S11), and the identification of resonance points that characterize the stopband and passband behaviour of the filter.

1. Stopband Performance:

The simulation results confirm that the filter exhibits a sharp and deep notch at 3.611 GHz, which is the desired stopband center frequency. At this point, the insertion loss S21 reaches -31.625 dB, indicating excellent signal suppression. The return loss S11 is approximately -0.297 dB, signifying that the signal is mostly absorbed or blocked rather than reflected, which is expected in a well-designed bandstop filter.

2. Additional Resonances:

Besides the main stopband, two other resonant behaviors were observed in the frequency response:

A minor reflection occurs at 2.552 GHz, where S11 is -3.183 dB, which may result from weak coupling or structural discontinuity. Another suppression region appears at 4.349 GHz, where S21 drops to -3.4 dB. This could indicate a higher-order mode or parasitic resonance, which may be influenced by the stub lengths or layout symmetry.

3.Passband Characteristics:

Across most of the spectrum (outside the stopband), the insertion loss remains relatively low, suggesting high transmission efficiency in the passbands. This highlights the filter's suitability for applications requiring minimal loss outside the rejection band. The layout also avoids spurious harmonic suppression peaks, indicating stable performance up to 20 GHz.

4. Summary of Key Simulation Results:

Marker	Frequency (GHz)	S-Parameter	Value (dB)	Interpretation
m2	3.611	S (2,1)	-31.625	Main stopband frequency (strong rejection)
m1	3.576	S (1,1)	-0.297	Return loss near stopband center
m3	2.552	S (1,1)	-3.183	Minor reflection (possibly parasitic)
m4	4.349	S (2,1)	-3.400	Secondary suppression (higher-order mode)

5. Compactness and Integration Potential:

The total physical size of the filter, approximately 4.3 mm × 3.24 mm, demonstrates enhanced miniaturization without sacrificing performance. This makes the filter highly suitable for portable RF front-end modules, wireless transceivers, and interference mitigation in compact circuits.

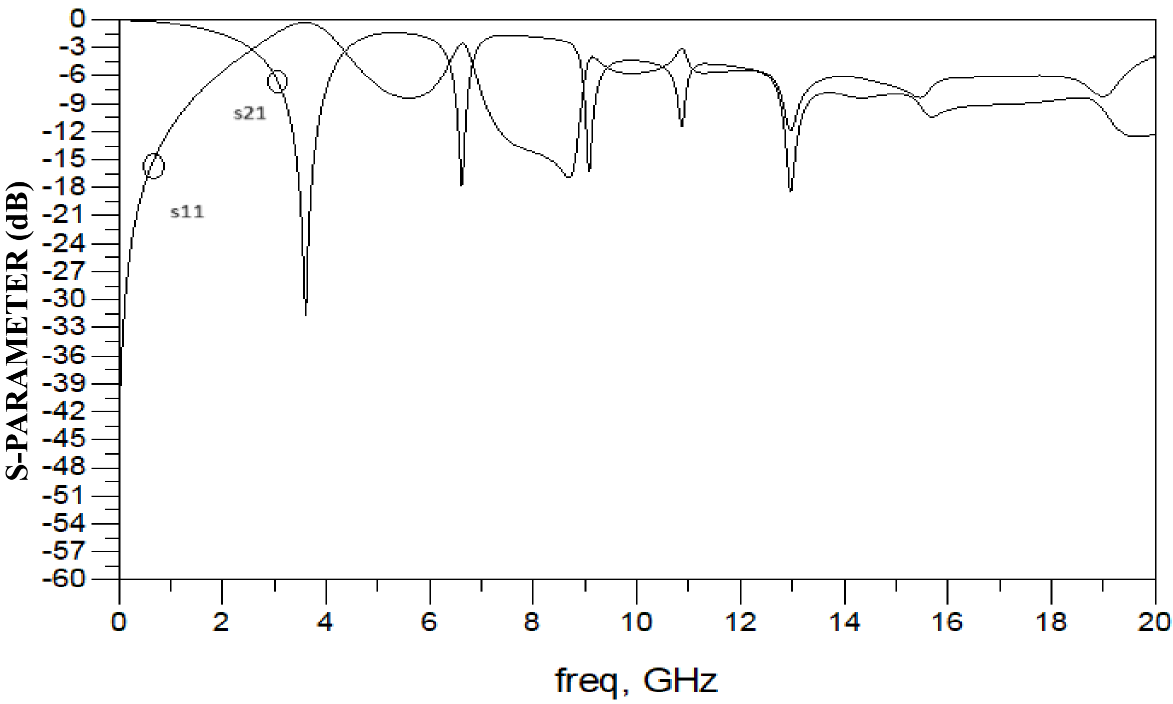

Figure 3. Frequency Response of the Band-stop filter at 3.611 GHz

CONCLUSION:

A tiny microstrip bandstop filter (BSF) with a 3.611 GHz center was built, simulated, and examined in this work using Keysight ADS. Outside the stopband, the filter exhibits good performance in reducing undesirable frequencies with little insertion loss. Strong rejection characteristics were confirmed by achieving a deep notch at the center frequency with an insertion loss of –31.625 dB. The design's ability to reduce signal reflection is further supported by the return loss value of -0.297 dB at this frequency.

The filter's design makes use of compact stubs and meandering lines on a FR-4 substrate, creating a very small structure with overall measurements of about 4.3 mm × 3.24 mm. The filter retains substantial attenuation at the target frequency, great selectivity, and steady performance in spite of its small limitations up to 20 GHz. Additional suppression capabilities and multi-mode behavior are suggested by minor resonances detected at 2.552 GHz and 4.349 GHz, which may be useful in wideband or harmonic control settings.

Advantages:

1.Compact Size: Takes up very little PCB space, making it perfect for incorporation into compact electronics.

2. High Stopband Rejection: Effectively reduces the target frequency (~3.611 GHz) by more than 31 dB.

3.Minimal signal deterioration outside the stopband is ensured by low insertion loss in the passband.
4. Economical Production: Developed on a typical FR-4 substrate with straightforward shapes.
5. Good Return Loss Performance: Verifies low reflections and appropriate impedance matching.
6. Multi-Resonant Behavior: Promotes wider interference mitigation and suppresses harmonics.

Applications:

The suggested bandstop filter works well with a number of contemporary RF applications and communication systems, including:
Wireless communication systems, including 5G sub-6 GHz, LTE, and Wi-Fi
1. RF Front-End Interference Rejection
2. Security of Radar and Satellite Receivers
3.Software Defined Radios with Band-Selective Filtering (SDR)
4. Small Modules for Wearables and IoT Devices
5. Filtering Dense Mixed-Signal Circuits with EMI/EMC

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