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Design of Trisection Bases Band Pass Filter For 5G and 6G Communications

P. Sai Kusuma[1], B. Bhavya[2], B. Sathwika[3], K. Deepthi[4], B. Chinna[5], B. Karthik Naik[6]
[1]Assistant Professor, Electronics and Communication Engineering, SV College of Engineering (SVCE), Tirupati, A.P. India
[2,3,4,5,6] UG Scholar, Electronics and Communication Engineering, SV College of Engineering (SVCE), Tirupati, A.P. India

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ABSTRACT

The demand for high-performance filters in the realm of 5G and 6G communications has spurred innovation in bandpass filter (BPF) design. This study proposes a novel approach utilizing a trisection-based BPF, aiming to enhance performance and meet the stringent requirements of modern wireless systems. The designed filter, simulated using High Frequency Structure Simulator (HFSS) software, incorporates concentric ring resonators, strategically arranged to achieve resonance at desired frequencies. Central to the design is the integration of PIN diodes, semiconductor devices offering variable resistance at radio frequencies, simplifying circuitry for ON/OFF operations. The HFSS simulation incorporates the diode's behavior, enabling comprehensive analysis under both diode ON and OFF conditions. The proposed BPF exhibits excellent performance, surpassing existing designs in filter response. The final layout showcases three distinct frequency bands: 2.8-3.35 GHz, 5-5.6 GHz, and 7.52-7.94 GHz, catering to the diverse requirements of 5G communication. Concentric ring resonators, coupled with PIN diode integration, offer versatility and reliability crucial for next-generation communication systems. This research underscores the significance of innovative filter designs in advancing the capabilities of 5G and beyond, facilitating efficient spectrum utilization and seamless connectivity in the era of wireless communication evolution..

Keywords: Trisection Bandpass Filter,5G and 6G Communications, PIN Diode, RF Circuits

I. INTRODUCTION

The In the ever-evolving landscape of modern microwave communication systems, the management of Radio Frequency (RF) interference stands as a pivotal challenge. With the advent of technologies like 5G and the promising horizons of 6G communications looming, the demand for robust interference suppression mechanisms becomes increasingly pronounced. Among these mechanisms, Band Pass Filters (BPFs) emerge as crucial components, tasked with the selective allowance of desired frequencies while attenuating unwanted noise signals.

Traditionally, Planar BPFs have served as stalwart guardians against RF interference in wireless systems. However, as we march towards the frontiers of 5G and beyond, characterized by a diverse spectrum ranging from low-band to millimeter waves, the efficacy of conventional filters faces new tests. To meet the demands of these upcoming generations, there arises an imperative for novel designs capable of addressing the unique challenges posed by their frequency bands.

In response to this call for innovation, various approaches and structures have been explored, including stepped impedance resonators, ring resonators, parallel-coupled lines, and stub impedance resonators. While these designs have contributed significantly to the advancement of RF filtering, the quest for further improvement persists.

One crucial aspect deserving attention is the enhancement of both size and bandwidth. A broader bandwidth not only accommodates a greater diversity of applications but also facilitates the seamless integration of a higher number of users within the allocated spectrum. It is in this pursuit of improved performance that we introduce a novel design paradigm: the Trisection Band Pass Filter.

By harnessing the capabilities of High Frequency Structure Simulator (HFSS), our proposed Trisection BPF aims to push the boundaries of bandwidth enhancement. Through meticulous design and simulation, we endeavor to optimize the filter's performance parameters, thereby enabling it to efficiently cater to the stringent requirements of next-generation communication systems.

In this paper, we present the conceptual framework, design methodology, and simulation results of our Trisection BPF. By combining theoretical insights with practical implementation, we demonstrate the potential of our design to revolutionize RF filtering in the era of 5G and beyond. Our endeavor not only seeks to overcome existing limitations but also paves the way for a future where seamless, interference-free communication is the norm.

In summary, the proposed Trisection BPF stands as a testament to our commitment to innovation in the realm of RF filtering. Through its development, we aspire to contribute to the realization of efficient, reliable, and high-performance communication systems that empower the seamless exchange of data in the era of 5G and beyond.

The organization of this document is as follows. In Section 2 (**Literature survey**), shown, In Section 3 (**Proposed method**), presented. In Section 4 discussed Simulation Results and Discussed in Section 5(**Conclusion**).

II. LITERATURE SURVEY

Yasir I. A. Al-Yasir et al. (2019): This study focuses on the design, simulation, and implementation of a very compact dual-band microstrip bandpass filter tailored for 4G and 5G applications. The work addresses the demand for compact yet efficient filters suitable for modern wireless communication systems.[1]

Shreyasi Srivastava et al. (2014): This paper presents the design, simulation, and fabrication of a microstrip bandpass filter. It contributes to the understanding of microstrip filter design methodologies and practical implementation techniques.[2]

Ambati N et al. (2021): The study explores the parametric analysis of a defected ground structure-based hairpin bandpass filter for VSAT System on Chip (SoC) applications. It delves into the performance analysis of a specific filter configuration, targeting a particular application domain.[3]

Gomez-Garcia R et al. (2019): This work investigates quasi-elliptic multi-band filters with center-frequency and bandwidth tenability. The research explores advanced filter architectures capable of accommodating multiple frequency bands with tunable parameters.[4]

J. Chen et al. (2018): The study presents a W-band dual-band waveguide bandpass filter employing dual-mode cavities. It contributes to the design and implementation of high-frequency filters for specialized applications requiring precise frequency control.[5]

Arain S et al. (2018): This paper introduces a reconfigurable bandwidth bandpass filter with enhanced out-of-band rejection using it-section loaded ring resonators. The research focuses on enhancing filter performance through innovative resonator configurations.[6]

Ghaderi A et al. (2017): The study presents the design of a compact microstrip tunable dual-bandpass filter, addressing the need for tunable filters in modern communication systems. It contributes to the development of compact and adaptable filter designs.[7]

Cheng T, Tam K (2017): This work proposes a wideband bandpass filter with reconfigurable bandwidth based on a cross-shaped resonator. It explores novel resonator geometries to achieve wideband operation with tunable bandwidth.[8]

T. Cheng et al. (2015): The study presents the design of a wideband bandpass filter with reconfigurable bandwidth using a cross-shaped resonator. It contributes to the development of reconfigurable filter architectures suitable for diverse applications.[9]

R. Gómez-García and A. C. Guyette (2015): This paper discusses reconfigurable multi-band microwave filters, focusing on the design and implementation of filters capable of operating across multiple frequency bands with adjustable parameters.[10]

These studies collectively contribute to the advancement of bandpass filter design methodologies and technologies, addressing the evolving requirements of modern wireless communication systems, including those for 5G and beyond.

III.PROPOSED METHOD

The designed bandpass filter has a good performance compared with the others with respect to the filter response. The designed filter is simulated by using HFSS Software. The design composed of concentric ring resonator. Concentric ring resonators are geometric structures consisting of ring-shaped loops arranged concentrically. It is designed to achieve resonance for the filter at the required frequency. A PIN diode comprises three layers: P-type, intrinsic, and N-type, hence its acronym "PIN."

A. Design of Bandpass Filter Using Pin Diode

Pin diodes show changing resistance at radio frequencies (RF), making circuit design simpler for ON/OFF operations. In both states, package inductance (L) remains. When ON, low Rs leads to insertion loss, while the OFF state involves a combination of parallel Rp and Cp.

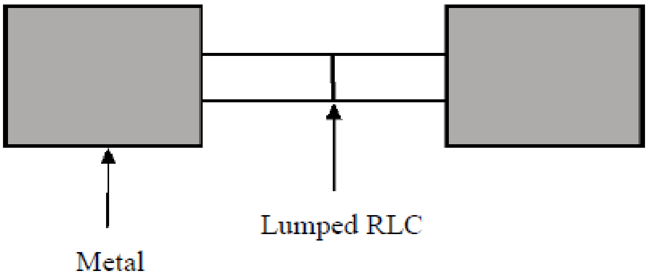


Figure 1: BPF using PIN Diode

In HFSS, the diode is represented by two series lumped RLC boundary conditions, indicating inductance (L), series resistance (Rs) for ON state, or parallel resistance (Rp) and capacitance (Cp) for OFF state. We used the pin diode, providing 0.6 nH of inductance and 244 Ω of resistance in the ON state. In the OFF state, they have 20 Ω of resistance and 0.011 pF of capacitance. Pin diodes are crucial components in a range of electronic systems, especially in RF and microwave circuits, where rapid switching speeds and high-frequency performance are vital. They enhance reliability for frequency-band reconfiguration..

A. Design of BPF using HFSS

The final layout of the trisection based band pass filter for 5G Communication using HFSS Software is shown in Fig 2 and Fig 3. The range of Band1 is 2.8-3.35 GHz, Band2 is 5-5.6GHz and range of Band3 is 7.52-7.94 GHz. This Figure represents the proposed bandpass filter at diode ON and diode OFF conditions.

Concentric ring loop resonators are geometric constructs utilized in RF and microwave engineering. They comprise multiple ring-shaped loops arranged concentrically, sharing a common center. These resonators are designed to exhibit resonance at specific frequencies, making them useful components in microwave and RF (radio frequency) circuits. Concentric ring loop resonators are frequently utilized in RF filters, oscillators, and other microwave components due to their capacity to selectively amplify or filter signals within a narrow frequency band. They are commonly integrated into telecommunications, radar systems, and wireless communication devices.

A pin diode is a type of semiconductor device consisting of a P-type layer, an intrinsic (undoped) layer, and an N-type layer. In electronic circuits, the pin diode serves as a variable resistor or switch. Its unique structure enables it to manage high power levels and operate effectively at high frequencies. When the diode is in the ON state as shown in Fig 4.3, the forward-biased pin diode creates a continuous path from port 1 to port 2, functioning as a short circuit and that's the reason for disappearance of pin diode in diode ON condition. Activation of the stepped loop structure alongside the pin diode being turned on enables the transmission of a range of frequencies.

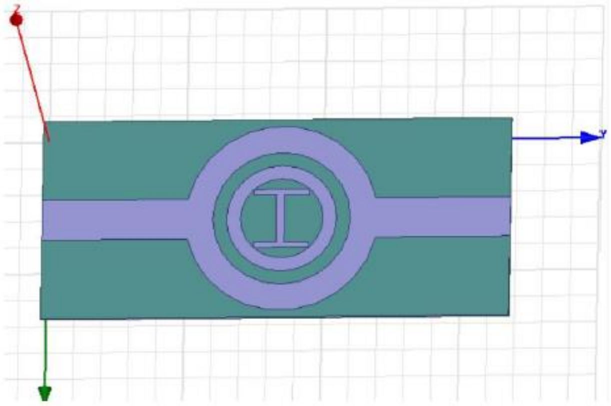


Figure 2: Trisection BPF at diode ON condition

In the OFF state as illustrated in Fig 4.4, the diode does not establish a continuous path, functioning instead as an open circuit, thus rejecting all frequencies. When the stepped loop is open-circuited (diode OFF), it reflects signals of other frequencies. Consequently, the filter functions as a narrowband frequency filter. In the OFF condition, the pin diode becomes visible.

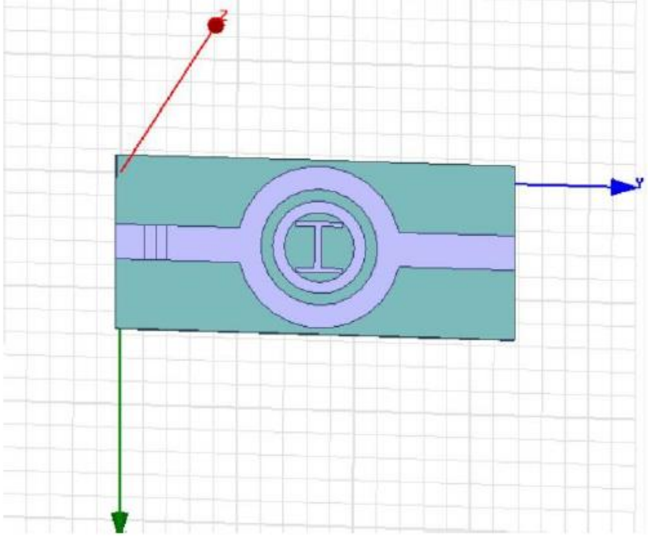


Figure 3: Trisection BPF at diode OFF condition

IV. SIMULATION RESULTS

A. Diode Off Condition

1. Return Loss

The return loss represents the amount of power reflected back from the filter due to impedance mismatches. When the diode is off, the return loss indicates the filter's ability to suppress reflected signals across the desired frequency band. A higher return loss value suggests better impedance matching and reduced signal reflection. Shown in figure 4.

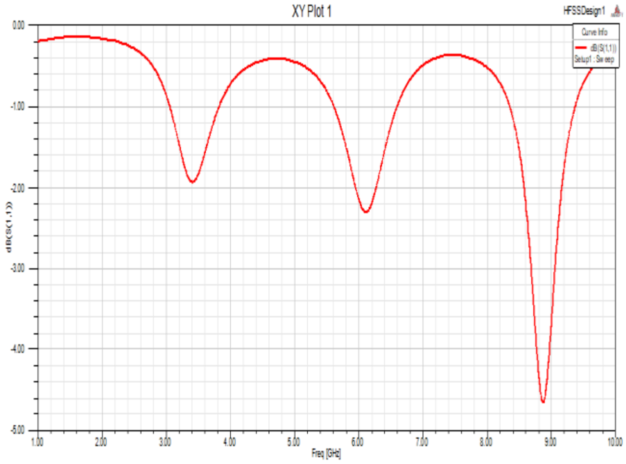


Figure 4: Return loss when diode off condition

2. Insertion Loss

Insertion loss refers to the reduction in signal power as it passes through the filter. In the diode off condition, this figure illustrates the filter's attenuation characteristics within the passband. Lower insertion loss values indicate less signal attenuation and better filter efficiency. Shown in figure 5.

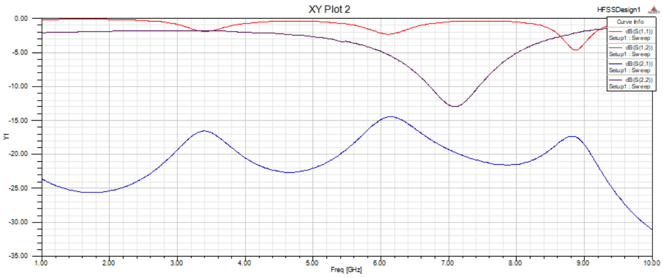


Figure 5: Insertion loss when diode off condition

3. Group Delay

Group delay measures the time delay experienced by different frequency components of a signal as they pass through the filter. In the diode off condition, this figure shows how consistent the delay is across the filter's passband. A flat group delay curve indicates minimal distortion and phase variation, ensuring the fidelity of the filtered signal. Shown in figure 6.

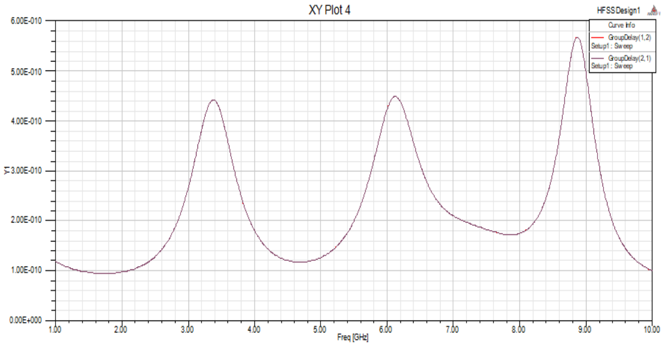
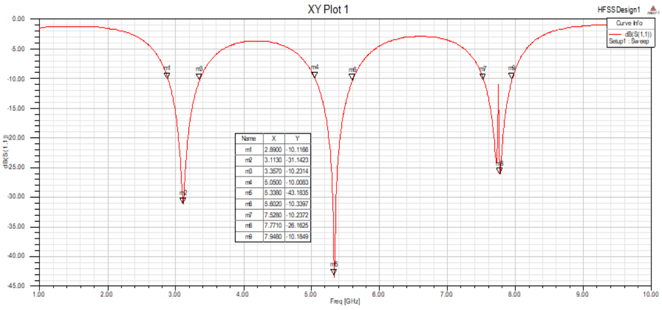


Figure 6: Group delay when diode off condition

B. Diode ON Condition

1. Return Loss

When the diode is switched on, the return loss graph demonstrates how well the filter maintains impedance matching and suppresses reflected signals across the passband. Any degradation in return loss compared to the diode off condition may indicate changes in the filter's impedance characteristics due to diode activation. shown in figure 7.



Name	X	Y
m1	2.8900	-10.1166
m2	3.1130	-31.1423
m3	3.3570	-10.2314
m4	5.0500	-10.0083
m5	5.3380	-43.1835
m6	5.6020	-10.3397
m7	7.5280	-10.2372
m8	7.7710	-26.1625
m9	7.9480	-10.1849

Figure 7: Return loss when diode ON condition

2. Insertion Loss

In the diode on condition, the insertion loss curve shows how much signal power is attenuated as it traverses the filter. Changes in insertion loss compared to the diode off condition may reveal alterations in the filter's transmission characteristics induced by diode activation, such as additional loss introduced by the diode .shown in figure 8.

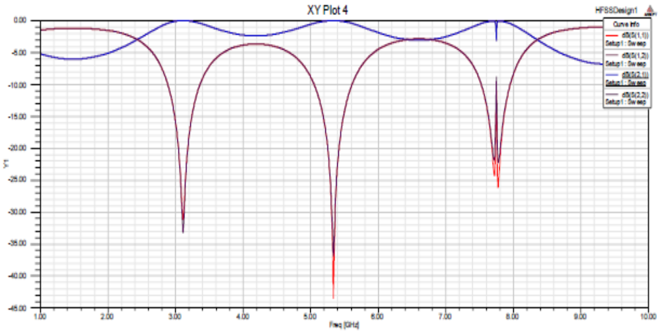


Figure 8: Insertion loss when diode ON condition

3. Group Delay

Group delay under the diode on condition illustrates any changes in the time delay experienced by different frequency components of the signal passing through the filter. Consistency in group delay across the passband indicates minimal distortion introduced by diode activation, ensuring the integrity of the filtered signal's phase relationships. Shown in figure 9.

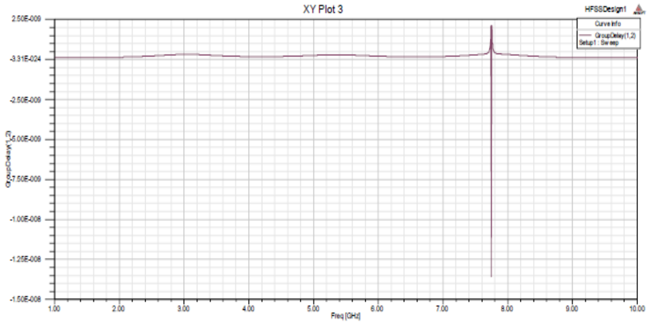


Figure 9: group delay when diode ON condition

By analyzing these simulation results under both diode off and diode on conditions, engineers can assess the performance and operational characteristics of the trisection bandpass filter, evaluating its suitability for specific communication applications, particularly in scenarios requiring dynamic control over filter behavior.

V. CONCLUSION

The proposed trisection-based bandpass filter, integrated with PIN diodes and simulated using HFSS software, presents a promising solution for the evolving landscape of 5G and 6G communications. Through comprehensive analysis and simulation, the filter demonstrates superior performance compared to existing designs, exhibiting excellent filter response and versatility across multiple frequency bands crucial for modern wireless systems.

VI. Future Scope

Future research and development can focus on several key areas to further enhance the capabilities and applicability of the proposed bandpass filter Continued optimization of the filter design parameters, including resonator geometry, diode characteristics, and layout configuration, can lead to further improvements in performance metrics such as insertion loss, return loss, and bandwidth..

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