Bandwidth Tunable Optical Filter Based on the Quad-Mode Resonator

Zihan Zhang, Jikun Du, Jingwen Li
Dalian Jiaotong University, Dalian 116028, China.

Abstract: An innovative bandwidth tunable optical filter with controllable bandwidth, center frequency, and transmission zero is proposed in this paper. The proposed filter utilizes a quad-mode resonator to achieve a wideband filter centered at 2.42 GHz. By incorporating varactor diodes into the open branches of the resonator, the proposed filter's center frequency and bandwidth can be dynamically adjusted via the voltage applied to the diodes. This tunable filter exhibits low insertion loss of less than 2 dB, return loss exceeding 10 dB, and a relative bandwidth of up to 40%.
Keywords: Resonator Filters; Microstrip Filters; Varactor Diodes

1. Introduction

As wireless communication technology continues to rapidly develop and the number of network participants and services increases, the need for efficient utilization of spectrum resources has become increasingly crucial. This has resulted in a growing interest in the research of highly selective filters that possess continuously tunable center frequencies and bandwidths[1][2]. Combine topologies are a commonly used design approach for creating compact filters with wide stopbands. They are characterized by a simple structure consisting of multiple resonators that are arranged in parallel and electromagnetically coupled to each other[3]. There are some design methods for creating bandpass filters. The first method proposes a continuously tunable bandpass filter over a wide range of frequencies achieved by manipulating the electric and magnetic coupling between resonators[4]. The second method suggests several adaptations to the conventional combined filter, employing stepped impedance resonators to create filters with constant absolute bandwidth[5]. The final method proposes that tunability in these filters can be achieved by utilizing variable capacitors based on varactor diodes[6].

In this paper, based on a quad-mode resonator that is loaded with open-ended branches, the filter bandwidth is expanded by adjusting the length of the branch lines corresponding to the upper and lower cutoff frequencies. Furthermore, the implementation of varactor diodes on the three open branch lines of the filter yields a wideband filter with controllable bandwidth, center frequency, and transmission zero. The filter's unique structure contributes to its superior performance and potential for various applications.

2. Design of the Bandwidth Tunable Optical Filter

2.1 The Wideband Filter Configuration

The quad-mode resonator, depicted in Fig.1, consists of a T-shaped resonator loaded with open branches at the center and symmetrically loaded with open branch lines on the left and right sides, where the branch lines θ_2 and θ_4 are not equal.

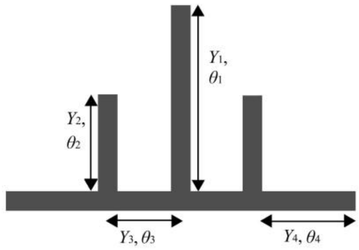


Fig.1 Quad-mode resonator structure

Fig.2 presents the overall design of a wideband filter that is based on the above quad-mode resonator. The filter is implemented on a Rogers RO4003 substrate with a dielectric constant of $\varepsilon r = 3.55$ and has a plate thickness of 0.8 mm, loss angle of 0.0027, and a copper foil thickness of 0.035 mm. The simulation results, displayed in Fig.3, demonstrate a relative bandwidth of 40%, a center frequency of 2.42 GHz, and a return loss of better than 10 dB. Additionally, the filter itself generates two transmission zeros located at 1.82 GHz and 3.10 GHz.

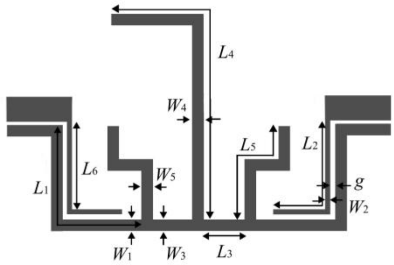


Fig.2 Geometry of the Wideband filter. (L_1=15.61 mm, L_2=13.8 mm, L_3=1.3 mm, L_4=27.5 mm， L_5=15 mm, W_1=0.5 mm, W_2=0.3 mm, W_3=W_4=W_5=0.5 mm, g=0.15 mm)

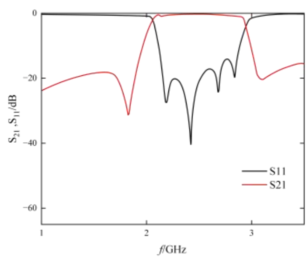


Fig.3 Simulation result of wideband filter

2.2 The Proposed Filter Configuration

A terminal grounding capacitor can be employed to substitute a section of the terminal open branch line, which has impedance characteristics of capacitance[7]. Fig.4(a) displays a schematic diagram of a section of the terminal open line, characterized by conductance Y and electrical length θ. Fig.4(b) illustrates a terminal grounding capacitor with capacitance value C.

(a)Terminal open stub (b)Terminal ground capacitance

Fig.4 Open stub and terminal ground capacitance

Based on this feature, a bandwidth tunable optical filter is designed by incorporating varactor diodes on the open branches L_4 and L_5, as depicted in Fig.5.

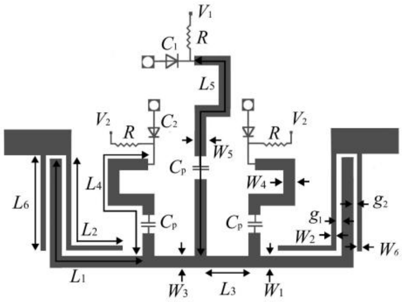


Fig.5 Geometry of the bandwidth tunable optical filter (L_1=16.25 mm, L_2=12 mm, L_3=0.5 mm，L_4=4.85 mm, L_5=11.25 mm, L_6=8 mm, W_1=0.5 mm, W_2=0.3 mm, W_3=W_4=W_5=0.5 mm, W_6=0.3 mm, g_1=g_2=0.15 mm)

2.3 Design Guidelines

In the above theory and analysis process, the design of the proposed filter is mainly divided into the following steps.

1） Design a resonator with four resonant modes.

2） Add open branches to the resonator to obtain the ideal wideband filter by bending and changing the distance between these branches.

3） Add varactor diodes and apply the appropriate voltage.

4） Optimize the relevant parameters to improve the performance

3. Results

3.1 Voltage V_1 is fixed while voltage V_2 regulates the upper sideband and the right transmission zero

The results of the simulation, depicted in Fig.6, demonstrate the effect of gradually increasing voltage V_2 from 6 V to 14 V while voltage V_1 is held constant at 7 V. As voltage V_2 increases, the upper sideband of the passband widens towards the right and the passband bandwidth increases from 651 MHz to 1129 MHz. The return loss S_{11} in the passband remains below 10 dB during the tuning process, and the right side transmission zero point shifts from 3.18 GHz to 3.66 GHz at the high-frequency end. It can be inferred that voltage V_2 has the ability to control the upper sideband of the passband and the transmission zeros on the right side, leading to an expansion of the bandwidth in that direction.

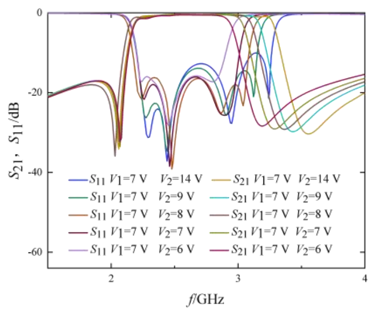


Fig.6 Bandwidth varies with V_2

3.2 Voltage V2 is fixed while voltage V1 regulates the lower sideband and the left transmission zero.

The decrease in voltage V_1 from 15V to 6V, while voltage V_2 is fixed at 10V, results in a change in the S_{21} and S_{11} curves as depicted in Fig.7. As voltage V_1 decreases, the lower sideband of the passband expands towards the left, leading to an increase in the passband bandwidth from 764 MHz to 1099MHz. Additionally, the S_{11} value remains above 10 dB, and the transmission zero point on the left side shifts from 3.17 GHz to 3.55 GHz towards the right. It can be inferred that voltage V_1 has the ability to regulate the lower sideband of the control passband and the transmission zeros on the left side, leading to a widening of the bandwidth towards the left.

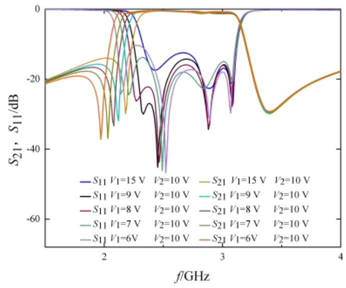
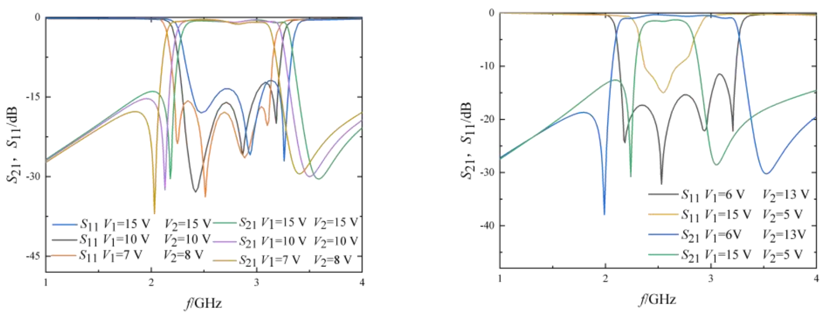


Fig.7 Bandwidth varies with V1

3.3 The simultaneous alteration of voltages V1 and V2 serves to regulate the center frequency.

Fig.8(a) illustrates the relationship between S_{21} and S_{11} and the simultaneous changes in voltages V_1 and V_2. The variation in the filter center frequency and passband bandwidth is observed as the values of V_1 and V_2 are altered. For instance, when V_1=15 V and V_2=15 V, the center frequency is 2.79 GHz and the bandwidth is 994 MHz, whereas, when V_1=10 V and V_2=10 V, the center frequency is 2.71 GHz and the bandwidth is 977 MHz . A further change in the values of V_1 and V_2 to V_1=7 V and V_2=8 V results in a center frequency of 2.62 GHz and a constant bandwidth of 989±10 MHz . This indicates that by adjusting the values of voltages V_1 and V_2, a wideband filter with an adjustable center frequency and a constant bandwidth can be achieved.

Fig.8(b) demonstrates the impact of voltages V_1 and V_2 on the passband bandwidth. For instance, when V_1=15 V and V_2=5 V, the minimum bandwidth is 431 MHz with a maximum interpolation loss of 1.53dB and a return loss S_{11} better than 15dB. On the other hand, when V_1=6 V and V_2=13 V, the widest bandwidth is 1119 MHz with a maximum interpolation loss of 1.16dB and a return loss S_{11} better than 11dB.



(a) Effect of V1 and V2 on the passband bandwidth (b) Effect of V_1 and V_2 on the center frequency

Fig.8 Effect of V_1 and V_2 on the frequency response

4. Conclusion

In this paper, an innovative bandwidth tunable optical filter with controllable bandwidth, center frequency, and transmission zero is proposed. The bandwidth, center frequency, and transmission zero can be controlled by adjusting the voltage of the varactor diodes, respectively. According to the simulation results, the measured insertion loss is less than 2 dB, the return loss exceeds 10 dB, and the relative bandwidth reaches 40%.

References

[1] Helaoui M, Boumaiza S and Ghannouchi FM, "Reconfigurable platform for software/hardware co-design of SDR base band pre-processing module", International Symposium on Antenna Technology and Applied Electromagnetics and Canadian Radio Sciences Conference, pp. 1-4, Jul. 2006.

[2] Chen R. and Hashemi H, "Reconfigurable SDR receiver with enhanced front-end frequency selectivity suitable for

intra-band and inter-band carrier aggregation", IEEE International Solid-State Circuits Conference (ISSCC), pp. 1-3, Feb. 2015.

[3] Wünsche R., Collmann R., Krondorf M and Forster J, "Microstrip Combline Bandpass Filter with Tuning Range Enhancement and Bandwidth Tunability Using Resonator Loaded Series Varactor and SLR," 2022 14th German Microwave Conference (GeMiC), Ulm, Germany, 2022, pp. 148-151.

[4] Lin F and Rais-Zadeh M, "Continuously Tunable 0. 55-1. 9-GHz Bandpass Filter With a Constant Bandwidth Using Switchable Varactor-Tuned Resonators[J]", IEEE Transactions on Microwave Theory and Techniques, vol. 65, no. 3, pp. 792-803, 2017.

[5] Kim BK and Yun SW, "Varactor-tuned combline bandpass filter using step-impedance microstrip lines", IEEE Transactions on Microwave Theory and Techniques, vol. 52, no. 4, pp. 1279-1283, 2004.

[6] Sanchez-Renedo M and Gomez-Garcia R, "Small-size planar tunable combline filter using decoupling walls", Electronics Letters, vol. 43, pp. 532-534, 02 2007.

[7] Zhu D, "Research on miniature multimode filter[D]". Nanjing: Nanjing University of Science and Technology, 2015.