

A fully tunable filter with wide range notch frequency tuning and bandwidth switchable

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Abstract A compact wideband fully tunable filter is designed based on a quarter-mode integrated waveguide resonator. With only two varactor diodes at the port gap, the notch frequency can be tuned continuously in the entire passband range, and the interference signal in the band can be flexibly suppressed. In addition, by controlling the on and off of two PIN diodes, switching between the two bandwidths of 1.7 GHz and 3.3 GHz is achieved without affecting the notch frequency tuning in the bandwidth. The notch frequency tuning range is 4 GHz to 6.4 GHz. The insertion loss at the notch frequency is $-15 \, dB$ to $-30 \, dB$, which is sufficient to eliminate in-band noise.

Keywords: fully tunable, wideband, notch frequency

Classification: Microwave and millimeter-wave devices, circuits, and modules

1. Introduction

With the rapid development of wireless communication and the birth of 5G technology, broadband system has gradually become a hot research topic due to its high confidentiality, strong multipath resistance and low radiation [1, 2, 3, 4, 5, 6]. In broadband communication, noise is inevitably present, which interferes with the quality of communication. Therefore, the notch filter is designed to suppress in-band interference signals [7, 8, 9, 10, 11, 12, 13]. However, most of these designs are relatively complicated and lacks dynamic tuning factors, and the noise interference in the broadband cannot be flexibly eliminated.

This paper designs a wideband fully tunable notch filter. The notch frequency can be tuned in the entire passband, which greatly improves the anti-interference ability of the filter. Bandwidth can be switched between two modes by the PIN diodes, which enhances the adaptive performance of the filter.

2. Design of the fully tunable filter

2.1 Structure of the filter

This paper uses the single-layer quarter mode integrated waveguide technology [14], and achieves a broadband filter by plating a metal layer on the upper surface. SIW has the advantages of high quality factor, small size and

DOI: 10.1587/elex.16.20190599 Received September 24, 2019 Accepted September 30, 2019 Publicized October 29, 2019 Copyedited November 25, 2019 easy integration [15, 16, 17, 18, 19, 20, 21, 22, 23]. The layout and structure of the filter are shown in Fig. 1 and Fig. 2. The filter consists of two layers of metal and one layer of dielectric. The via holes are sequentially arranged along the inclined sides of the metal layer, and the boundary on both sides is formed by two equivalent cuts of the full-mode substrate integrated waveguide resonator. The diameter of the metalized through holes is 0.6 mm, and the spacing between adjacent holes is 0.75 mm. The remaining parameters are L1 = 17.5 mm, L2 = 4.5 mm, L3 = 15.5 mm, L4 = 2.8 mm, La = 1.4 mm, Lb = 2.4 mm, Gl = 1.5 mm, Gf = 1.4 mm.



Fig. 1. Layout of the proposed tunable filter with two varactors and two capacitors.



Fig. 2. Layout of the proposed tunable filter with two varactors and two capacitors.

2.2 Analysis of tunable performance

The notch filter is a special band-rejection filter that eliminates the noise interference of broadband energy by generating a very narrow resistance band [24, 25, 26]. In order to introduce an tunable notch into the wideband, two varactors C1 are loaded on the surface of the gap G1 at the two ports to be used as equivalent capacitance. By applying a bias voltage across the capacitor, a specific capacitance can be formed at the gap to produce a high impedance that suppresses the frequency noise. Thus, a narrow stop band, the notch frequency, is formed on the

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frequency response. It can be known from (1) that by increasing the capacitance of the varactor C1, the notch frequency ω_{notch} can be changed from large to small, and L_{eq} is the equivalent inductance of QMSIW resonator.

$$\omega_{notch} = 2\pi f_{notch} = \frac{1}{\sqrt{L_{eq}C1}} \tag{1}$$

When C1 = 1.3 pF, the notch frequency is 4.5 GHz and S11 and S21 are in good performance, as shown in Fig. 3. What's more, when the varactors C1 are in the range of 0.6 pF to 1.68 pF, the notch frequency can be varied from 4 GHz to 6.3 GHz continuously. At the same time, the Q value of the filter does not vary greatly with the varactor, and the unload Q remains around 313–315.



Fig. 3. (a) S-parameter at C1 = 1.3 pF (b) Curve of Q_u and notch frequency when C1 changes from 0.65 pF to 1.68 pF.

In order to achieve bandwidth tuning, we use two PIN diodes to mount on the top metal surface. One end of the PIN diodes is connected to the protruding square at the edge of the top metal layer, and the other end is connected to the underlying metal layer through a metal via. When the PIN diodes are disconnected, the filter is in the normal bandwidth of 3.6 GHz–6.9 GHz. When the PIN diodes are connected, the upper metal is connected to the underlying metal through the PIN diode, causing a change in the electric field as shown in Fig. 4(a) and the bandwidth is reduced to 4.5 GHz–6.2 GHz. Taking C1 = 1.3 pF as example, the bandwidth is shown in Fig. 4(b).



Fig. 4. (a) Electric field changes with PIN diodes on (b) Bandwidth changes with PIN diodes on and off

3. Simulated and measured results

The fabricated filter is shown in the Fig. 5. The dielectric material of the filter is Rogers RO3010 ($\varepsilon_r = 10.2$), and the thickness is 1 mm. The type of two varactors at port gap is SMV2020-079LF. The measured results of the filter agree well with the simulation results, as shown in Fig. 6.



Fig. 5. Fabricated fully tunable filter



Fig. 6. Simulated (a) and measured (b) of the filter

In order to better demonstrate the performance of the filter, Table I lists the notch frequency tunable filters in recent years. Besides the wider tuning range, this filter has smaller size and fewer tuning components, which simplifies the circuit soldering process and reduces losses.

Table I. Parameters comparison

Ref	Notch frequency (GHz)	Bandwidth (GHz)/FWB	Size (mm)	Insertion Loss of Notch (dB)	Number of tuning elements
[27]	No/5.1	5.92 (86%)	no	24	1
[28]	0.475–0.485	0.017–0.018 (3.2%–4.5%)	95 × 40	20-22	20
[29]	1.2-1.9/2.5-3.3	0.31/0.72 (16%–26%)	25 × 39	24-36/21-30	6
[30]	0.98–2.02	0.09–1.44 (6%–115%)	70 × 94	13–31	6
This	4-6.4	1.7/3.3 (32%–62%)	36.6 × 36.6	16–30	4

4. Conclusion

In this paper, a compact wide-band fully tunable filter is designed. The proposed filter has the advantages of simple structure and compactness, and notch frequency can be tuned in the full passband only by two varactor diodes. The measured results agree well with the simulation results. Compared with the previous notch tunable filter, this filter has a wider tuning range and a flexible switching mode, which can dynamically suppress noise in wide bandwidth.

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