An X-band waveguide bandpass filter with enhanced stopband using offset resonators

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Abstract This letter presents a narrowband third-order waveguide bandpass filter (BPF) with extended out-of-band response. The filter is composed of three offset resonators, and each resonator is constructed by shifting half of a rectangular resonator, featuring a very large distance between the first and second resonant frequencies. The BPF was designed with a center frequency (f0) of 9.5 GHz and a passband bandwidth of 100 MHz and was fabricated by using the Computer Numerical Control (CNC) milling process. The experiment results show that the BPF has an average insertion loss of 0.45 dB, a returns frequency of 9.5 GHz, and a 30-dB stopband suppression level up to 1.75 f0. The measured results agree well with the electromagnetic (EM) simulations.

key words: offset resonator; waveguide; enhanced stopband

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

1. Introduction

Waveguide bandpass filters (BPFs), featuring the merits of low insertion loss and high-power capacity, are widely used in modern wireless communication and radar systems [1, 2, 3, 4]. However, the spurious resonances deteriorate the filter’s stopband performance. To alleviate this, several approaches have been presented to improve the stopband performance in recent years [5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19]. For one possible approach, the spurious passband can be effectively suppressed by cascading the filter with a low-pass filter [5, 6, 7], however, this gives additional loss and size. Another approach was focusing on the magnetic field features of the higher-order modes, where the couplings of higher-order modes were designed so that these higher-order modes can be effectively reduced [8, 9, 10]. As the 3rd approach, slots can be added onto the resonators to radiate the undesired spurious resonances [11, 12, 13, 14, 15, 16, 17, 18, 19]. However, this may cause potential electromagnetic (EM) interference problems.

In this letter, we propose a new solution based on offset resonators. The filter designed based on the offset resonators achieves an enhanced stopband with a 30-dB suppression level up to 1.75 f0. The design and the results are shown in the following sections.

2. Design of resonator

The configuration of an offset resonator with weakly feed waveguide ports is shown in Fig. 1(a). The resonator is based on a rectangular resonator but reconstructed by shifting half of the resonator along the y-axis with a distance of h1. As shown in Fig. 1(b), by increasing the value of h1 from 0 mm to 6 mm, the first resonant frequency decreases, while the second resonant frequency is nearly unaffected. The first resonant mode of the resonator with l1 = 20.66 mm and h1 = 6 mm is resonant at 8.11 GHz. To further increase the first resonant frequency to the operating frequency of 9.5 GHz, we compressed the longitudinal size. The first resonant frequency of the resonator with l1 = 12.44 mm and h1 = 6 mm is 9.5 GHz, and the second resonant frequency is 18.2 GHz (1.92 times of the first). Hence, the second resonant frequency of the proposed offset resonator can be effectively extended far away from the first resonant frequency in comparison with a rectangular resonator (l1 = 20.66 mm and h1 = 0 mm).

Fig. 1. Design of offset resonator. (a) Configuration of offset resonator. (a) = 22.86, b = 10.16, and d0 = 3.5. (unit: mm.) (b) EM-simulated transmission coefficients.
Fig. 2. Design of offset resonator BPF. (a) Coupling topology. (b) Air-filled simulated internal structure. The dimensions are: \( a = 22.86 \), \( b = 10.16 \), \( d_0 = 10.7 \), \( d_1 = 6.28 \), \( a_1 = 22.13 \), \( a_2 = 23.94 \), \( l_0 = 8 \), \( d_{01} = 10.7 \), \( d_{12} = d_{23} = 6.28 \), \( a_1 = 22.13 \), \( a_2 = 23.94 \), \( l_1 = 6 \), \( h_1 = 6.1 \), \( t = 2 \), \( r_1 = 1.5 \). unit: mm.

Fig. 3. Extracted \( Q_e \) and \( \kappa_{12} = \kappa_{23} \). (a) Extracted \( Q_e \) versus \( d_{01} \). (b) Extracted \( \kappa_{12} = \kappa_{23} \) versus \( d_{12} = d_{23} \).

3. Design of filter

To validate the feasibility of the above resonator, a third-order waveguide filter was constructed. Fig. 2 shows the coupling topology and 3D structure of the proposed filter. The proposed BPF is fed by a standard WR-90 rectangular waveguide \((a \times b)\). The proposed BPF is designed with a Chebyshev response and has a center frequency of 9.5 GHz, a 100 MHz passband bandwidth (fractional bandwidth of 1.05%), and a passband return loss of 20 dB. Using the coupling matrix methodology [20], the external quality factor \( Q_e \) and coupling coefficients \( M_{ij} \) of the above design specifications are calculated as \( Q_e = 80.9001 \), \( \kappa_{12} = \kappa_{23} = 0.0109 \). The relations between the physical dimensions of the coupling irises and \( Q_e \) as well as \( \kappa_{ij} \) can be extracted by EM simulation [21, 22, 23, 24, 25, 26, 27], and are plotted in Fig. 3(a) and Fig. 3(b). Hence, the initial dimensions of the coupling irises can be determined from Fig. 3(a) and Fig. 3(b). The proposed BPF is simulated and optimized by utilizing EM simulation software CST Microwave Studio [28], and the finalized dimensions are given in the caption of Fig. 2(b).

4. Measurement and discussion

To verify the practical performance of the proposed BPF, the filter was fabricated by using a CNC milling process with aluminum alloy (AL6061). The fabricated prototype of the BPF is shown in Fig. 4. An Agilent Network Analyzer E8363B was used to test the S-Parameters of the proposed BPF. The simulated and measured frequency responses are compared in Fig. 5, exhibiting a good agreement. The experiment results show that the proposed BPF has an average passband insertion loss of 0.45 dB, a return loss of > 16 dB and a 30-dB stopband suppression up to 16.65 GHz (1.75 \( f_0 \)). A performance comparison between this filter and several prior works is tabulated in Table I.

Table I: Comparison with other BPFs

| Ref | Freq. (GHz) | IL (dB) | FBW (%) | SLL (dB) | Ratio |
|-----|-------------|---------|---------|----------|-------|
| 12  | 9.7         | -       | 10.3    | ≥ 30     | 1.5   |
| 14  | 12.1        | 0.5     | 1.49    | ≥ 30     | < 1.6 |
| 29  | 9.6         | 0.5     | 8.4     | ≥ 30     | < 1.6 |
| 30  | 11          | -       | 12.8    | ≥ 40     | < 1.8 |
| This work | 9.5     | 0.45    | 1.05    | ≥ 30     | 1.75  |

Freq.: Center frequency; IL: Insertion loss; FBW: Relative bandwidth; SSL: Stopband suppression level; Ratio: Ratio of the stopband suppression frequency to the center frequency.
5. Conclusion

An X-band third-order waveguide BPF with enhanced stopband based on offset resonators was presented in this letter. The design principles of the offset resonator and filter were presented. The proposed filter features the merits of simplicity in structure and miniaturization in longitudinal size. It can be a good potentiality for modern wireless communication systems.

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