A Cascaded Quadruplet (CQ) Bandpass Filter Using a Mushroom Resonator with an Asymmetrically Positioned Via-hole

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Abstract

A new cascaded quadruplet (CQ) bandpass filter is proposed for size reduction using a mushroom-based metamaterial resonator which has an asymmetrically positioned via-hole. The proposed resonator has a zeroth-order resonant mode which is decreased as increasing the distance between a centre point of a mushroom patch and via-hole. Total size reduction rate of the resonator is about 38.8 % comparing with that of the conventional mushroom type resonator with a centre positioned via-hole. Using the compact mushroom resonator, the CQ bandpass filter is implemented and experimented. Details of not only the proposed resonator but also the CQ bandpass filter are presented in this paper.

Keywords : Cascaded quadruplet filter, bandpass filter, asymmetric mushroom resonator

1. Introduction

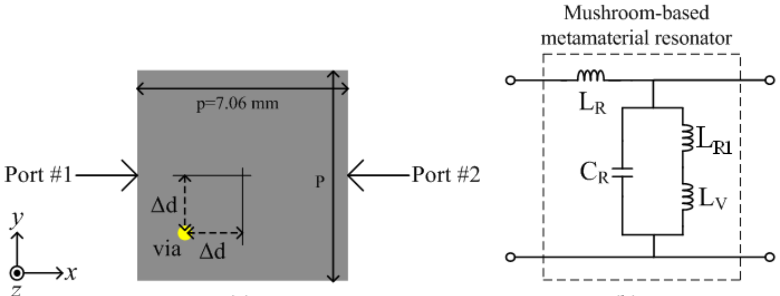
In recent, several bandpass filters with a sharp skirt characteristic, which are based on a metamaterial structure, have been widely investigated [1]-[2]. However, these filters are large size because they are based on a transmission line concept. In this paper, a bandpass filter based on a zeroth-order resonance of a metamaterial structure is proposed for size reduction. A mushroom-based resonator with an asymmetrically positioned via-hole is designed for achieving more size reduction that has a lower zeroth-order resonant mode comparing with that of the conventional mushroom resonator.

In general, a cascaded quadruplet (CQ) bandpass filter has been widely used in modern wireless communication systems, because it is a key component to meet a sharp spectral mask [3]. Therefore, the CQ bandpass filter employing the proposed mushroom-based metamaterial resonator is implemented and experimented to verify the usefulness of the resonator in this paper.

2. Design of The Proposed Filter

2.1 Unit-Cell Design

Figs. 1(a) and (b) show the schematic and equivalent circuit of the proposed mushroom-based metamaterial resonator with an asymmetrically positioned via-hole, respectively.



(a) (b)

Figure 1: Metamaterial unit-cell with an asymmetrically positioned via-hole.
(a) Schematic. (b) Equivalent circuit of the unit-cell.

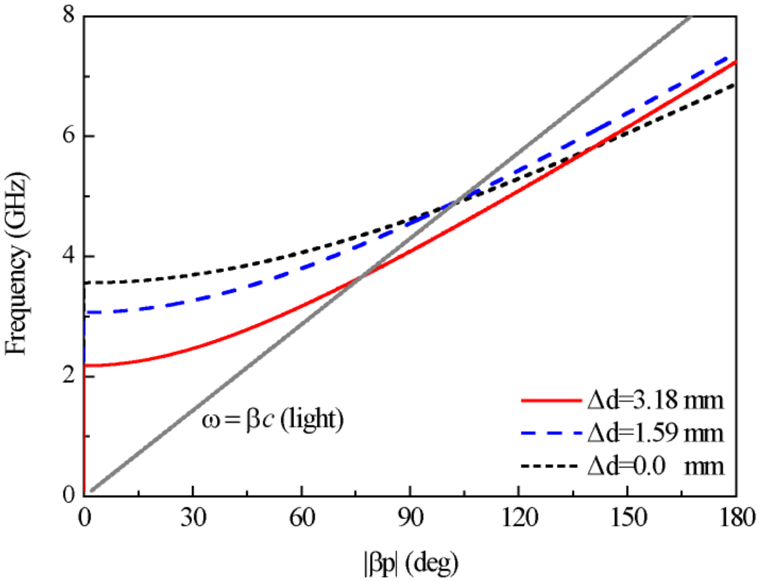


Figure 2: Dispersion diagram of the proposed unit-cell with the different Δd.

In the resonator, a via-hole is positioned at the distance Δd from a centre point of a mushroom patch. The L_R, L_v, and C_R mean a series inductance of a microstrip patch, shunt inductance of a via structure, and shunt capacitance between a patch and ground plane, respectively. The inductance L_{R1} indicates the additional shunt inductance that is produced from its asymmetrical position.

As shown in Fig. 1(b), the zeroth-order resonant mode frequency of the proposed resonator can be determined by a shunt L-C tank, which can be calculated by

$$f_0 = \frac{1}{2\pi\sqrt{C_R \cdot (L_{R1} + L_V)}}. \tag{1}$$

where

$$C_R = \varepsilon_0 \varepsilon_r \cdot \frac{S}{h} \tag{2}$$

where $h = 0.635$ mm, S=49.84 mm^2, ε_r =10.2, and $\varepsilon_0 = 8.854\times10^{-12}$ F/m. The inductance L_{R1} and L_V can be found by a curve fitting method.

Fig. 2 illustrates the dispersion diagram of the proposed unit-cell. When Δd = 0, the resonator is the same with the conventional mushroom type resonator with a centre positioned via-hole. In case of Δd = 0, a zeroth-order resonant frequency is 3.56 GHz. As increasing Δd, the zeroth-order mode of the proposed resonator is moved to 2.18 GHz as shown in Fig. 2.

2.2 Design of a Cascaded Quadruplet (CQ) Bandpass Filter

The CQ bandpass filter using the unit-cell mentioned in sec. 2.1 is designed in this section. The desired fractional bandwidth (FBW) and the centre frequency are 0.08 and 2.05 GHz, respectively. The normalized input and output resistances are 1.0757. In a complex *s*-plane, the desired poles are S_p=±j0.940, ±j0.405 and zeros are S_z=±j1.90. The design coupling matrix for CQ configuration is as follows

$$[m_{ij}] = \begin{bmatrix} 0 & 0.8775 & 0 & -0.2035 \\ 0.8775 & 0 & 0.7894 & 0 \\ 0 & 0.7894 & 0 & 0.8775 \\ -0.2035 & 0 & 0.8775 & 0 \end{bmatrix} \tag{3}$$

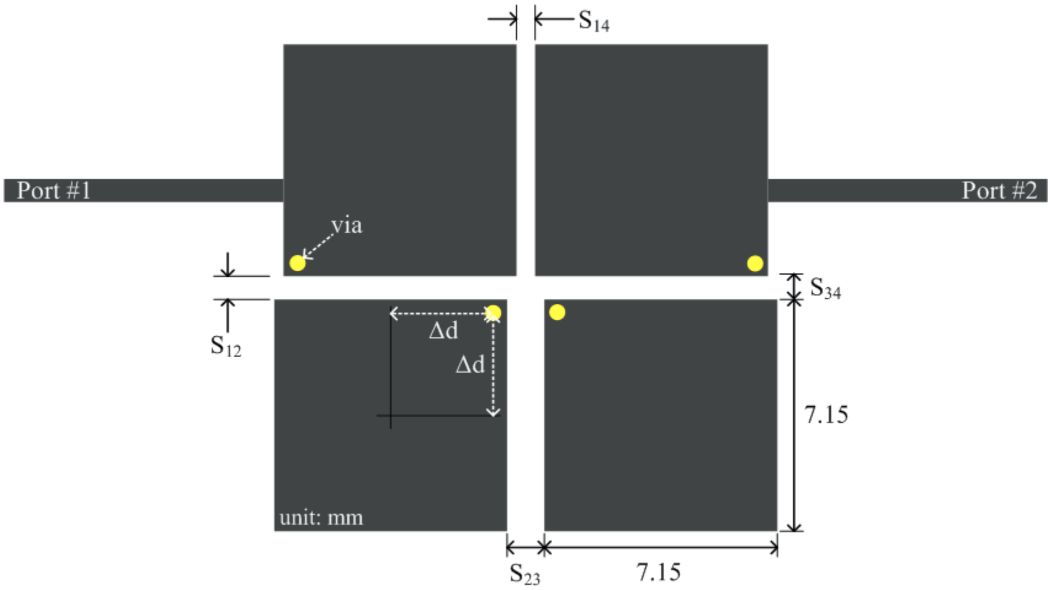


Figure 3: Schematic of the proposed CQ bandpass filter.

Fig. 3 shows the schematic of the proposed bandpass filter which is fabricated on the substrate with a dielectric constant of 10.2 and a thickness of 0.635 mm. The parameters of S_{12} (or S_{34}), S_{23}, and S_{14}, which can be determined by each coupling coefficient, are 0.474, 0.862, and 0.464 mm, respectively. And, the distance Δd and the radius of a via-hole are 3.18 mm and r = 0.2 mm, respectively.

3. Implementation and Experimental Results

Fig. 4 plots the measured and simulated frequency responses of the designed filter shown in Fig. 3. The measured S-parameters and group delays are in good agreement with the simulated ones. The measured centre frequency is 2.02 GHz and 3-dB FBW is about 0.079 at the centre frequency (1.94 GHz ~ 2.10 GHz). The insertion and return losses at the centre frequency of 2.02 GHz are 1.71 and 12.80 dB. The variation of the measured group delay is less than 4.4 ns.

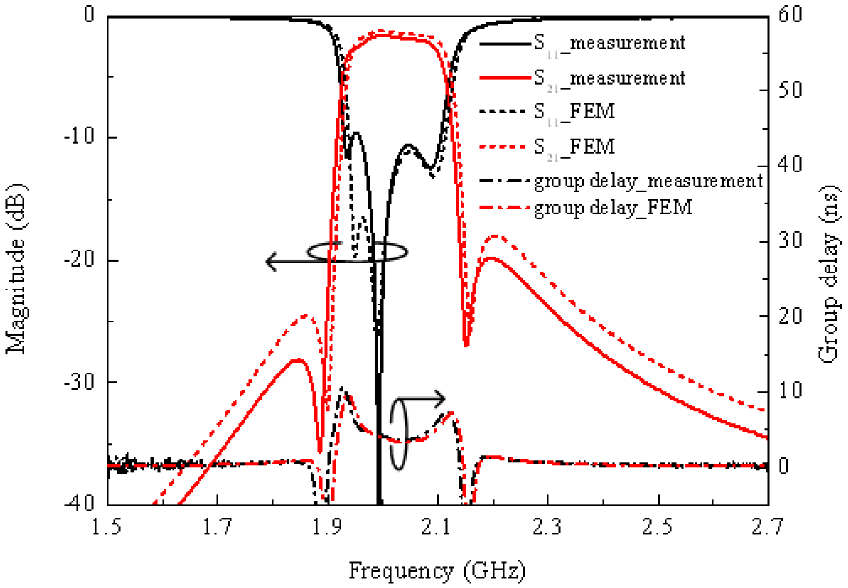


Figure 4: Measured results of the proposed CQ bandpass filter.

4. Conclusion

In this paper, the mushroom-based metamaterial resonator with an asymmetrically positioned via-hole is proposed for size reduction comparing to the conventional metamaterial resonator with a centred via-hole. A zeroth-order resonance mode is moved from 3.56 GHz to 2.18 GHz. The total size reduction rate of the proposed resonator is 38.8 %. For verifying the usefulness of the resonator, the CQ bandpass filter with compactness and sharp skirt is implemented by using the proposed mushroom resonator. The size (area) reduction rate of the proposed filter is about 16.7 % comparing with the conventional open-loop CQ bandpass filter (the conventional CQ model: 16.455 mm × 16.12 mm, the proposed model: 14.963 mm × 14.774 mm). The proposed simple technique for size reduction and the designed bandpass filter will be very useful in many RF systems and applications which require a compactness property.

References

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