LETTER

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Design approach for bandpass filter using triple-mode stripline resonator

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Abstract: This letter presents a design approach for a bandpass filter (BPF) using a novel triple-mode stripline resonator. We clarify the external Q factor with respect to the cutout size of the center conductor and feed-line position, to establish the design approach. It is found that external Q factors of each mode is handled respectively. From those results, a triple-mode BPF is designed and fabricated. The experimental results agree with the simulation results and accordingly it is confirmed that a design approach was established.

Keywords: triple mode, stripline resonator, BPF, external Q factor

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

References

[1] S. Wong, *et al.*: "Triple-mode dielectric resonator diplexer for base-station applications," IEEE Trans. Microw. Theory Techn. **63** (2015) 3947 (DOI: 10.1109/TMTT.2015.2488658).

[2] S. Bastioli, *et al.*: "A novel class of compact dual-mode rectangular waveguide filters using square ridge resonators," EuMC Tech. Dig. (2008) 626 (DOI: 10.1109/EUMC.2008.4751530).

[3] S. Amari: "On the theory and modeling of dual-mode cavity microwave bandpass filters," IEEE Microw. Symp. Dig. (2012) 1 (DOI: 10.1109/MWSYM.2012.6259600).

[4] M. Tamura: "Basic study on bandpass filters using hybridmode resonator (in Japanese)," IEICE Tech. Rep. **115** (2015) 227.

[5] M. Tamura and K. Ichinose: Japan Patent Appl. 021648 (2015).

[6] J.-S. Hong and M. J. Lancaster: *Microstrip Filters for RF/Microwave Applications* (John Wiley & Sons, New York, 2011) 2nd ed.

[7] J. A. Curtis and S. J. Fiedziuszko: "Miniature dual mode microstrip filters," IEEE Microw. Symp. Dig. (1991) 443 (DOI: 10.1109/MWSYM.1991.147031).

[8] P. Rezaee, *et al.*: "External Q computation by fuzzy inference method; Application to microstrip filter design," ICMMT Tech. Dig. (2008) 971 (DOI: 10.1109/ICMMT.2008.4540570).

[9] R. J. Cameron: "Advanced coupling matrix synthesis techniques for microwave filters," IEEE Trans. Microw. Theory Techn. **51** (2003) 1 (DOI: 10.1109/TMTT.2002.806937).

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[10] G. Macchiarella and S. Tamiazzo: "Design techniques for dual-passband filters," IEEE Trans. Microw. Theory Techn. **53** (2005) 3265 (DOI: 10.1109/TMTT.2005.855749).

1 Introduction

As one of the key techniques used to develop small-cell base stations in next generation mobile communications, miniaturized BPFs for a base station are reported [1]. In [1], a multi-mode resonator, utilizing cylindrical cavities, is used for miniaturization. A multi-mode resonator achieves size reduction and weight saving, because it has distinctive multi-resonances using only a single resonator [2, 3]. The reported resonator in [1] has the disadvantage of low-profile due to its height being determined by the resonant wavelength of the hybrid degeneration (HE) mode. The authors proposed the novel triple-mode stripline resonator in Fig. 1 to fulfill the need for a low-profile BPF [4, 5]. The proposed resonator consists of dielectric substrates and via holes, with construction of the proposed resonator of the cavity structure being relatively easy [4]. However, the design approach of the BPF using the proposed resonator isn't clarified. In order to design the BPF, it is necessary to elucidate on the external Q factor [6]. Elucidation of the external Q factor for the proposed resonator has not yet been undertaken.

In this letter, the design approach for the BPF with our resonator is discussed based on the analysis of the external Q factor. Firstly, the relation between the external Q factor of three resonant modes and the cutout size of the center conductor is clarified. Secondly, the relationship between the external Q factor and the tapping position of feed line is elucidated. Finally, the BPF designed based on those results is fabricated. The measured results are in good agreement with the simulated ones.

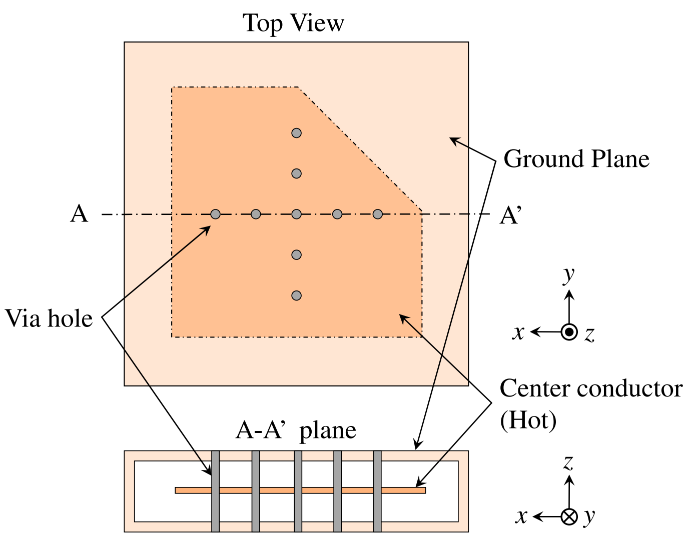

Fig. 1. The triple-mode stripline resonator.

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2 Analysis of external Q factor

Our proposed resonator has three resonance modes, which are TM_{10}, TM_{01}, and quasi-Lumped Component (LC) resonance modes. One corner of the center conductor is cut out, as shown in Fig. 2, due to the coupling between TM_{10} and TM_{01} [7]. The size of center conductor is 40×40 mm, the length of feed lines is 5 mm, the diameter of the via holes is 0.8 mm, and the distance between them is 4 mm. The center conductor is sandwiched between two pieces of dielectric substrate with a $\varepsilon_r = 3.4$, thickness = 0.75 mm, and $\tan\delta = 0.0015$. The feed line is tapped into the edge of center conductor symmetrically, as illustrated in Fig. 2. Fig. 3 shows the simulated external Q factor with respect to the different cutout distance from 0 to 20 mm, in the three cases, which are with 13, 17, and 21 via holes. The simulation was performed using CST Microwave Studio. When the cutout distance is 0 mm, TM_{01} mode has the highest external Q factor for the three cases. The LC resonance and TM_{01} mode ones have an almost constant value in the order of 10^2. By increasing the cutout distance, the external Q factor of TM_{01} mode gradually decreases and is close to the order of 10^2. This is caused by the admittance of the TM_{01} mode which becomes small according to the cutout distance. Therefore, the cutout distance is determined as half the length of the center conductor.

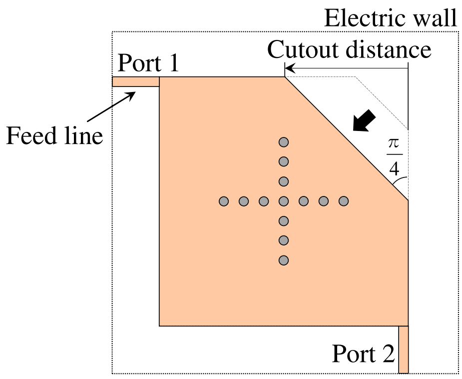

Fig. 2. Configuration of cutout distance of the proposed resonator.

A method for adjusting the external Q factor in TM mode resonator by changing the tapping position of the feed line is reported [8]. We investigate on the variation of the external Q factor depending on the tapping position p as depicted in Fig. 4(a). Fig. 4(b) shows simulated external Q factor against tapping position p from 0 to 20 mm, when the cutout distance is 20 mm. When the feed lines are close to $p = 0$, external Q factors of TM_{10} and TM_{01} modes gradually increase. LC resonance mode has a minimum external Q factor at $p = 10$ and increases at both ends. From these results, the relationships of the external Q factor of each mode with the cutout distance and tapping position are clarified.

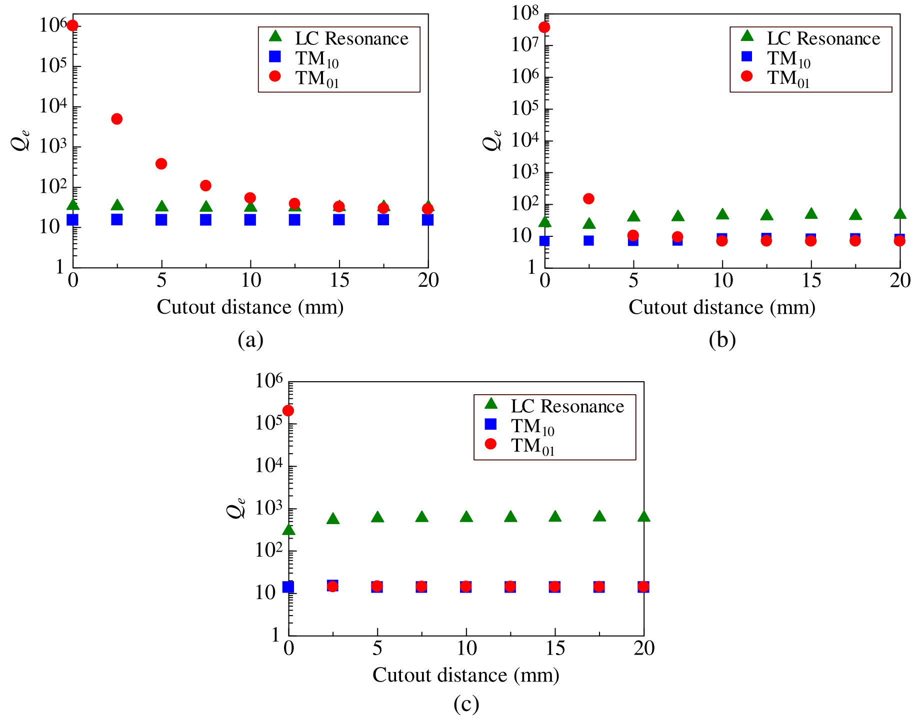

Fig. 3. Simulated external Q factor of each mode with respect to different cutout distance. (a) loaded 13 via holes. (b) loaded 17 via holes. (c) loaded 21 via holes.

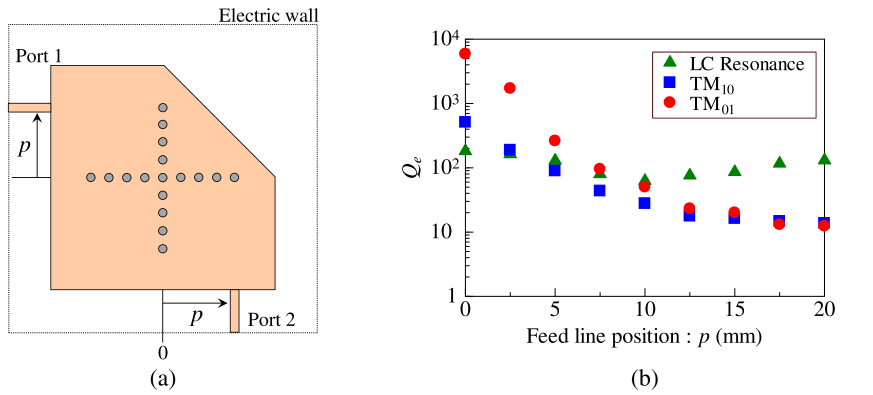

Fig. 4. (a) Schematic of tapping position. (b) Simulated external Q factor against feed line position.

3 Filter design and measurement

Design specifications of the filter are LTE Band7-Downlink (2.62–2.69 GHz) that is regulated by 3GPP. Return loss is 20 dB and transmission zeros are located at 3.3 and 4.0 GHz. TM_{01} mode excited in the proposed resonator is one wavelength mode on a diagonal connecting the feed line. Hence, the resonant frequency of TM_{01} mode is determined by the side length of the center conductor L

$$f_{TM_{01}} = \frac{c}{L\sqrt{2\varepsilon_r}} \tag{1}$$

where c is the velocity of light and ε_r is the relative dielectric constant. The number of via holes and the distance between them determines the bandwidth of the filter

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[4, 5]. Since the center frequency is 2.655 GHz and the bandwidth is 70 MHz, the number of via holes is 17 and the distance is 4.4 mm. The coupling scheme of the proposed triple-mode filter is shown in Fig. 5(a). The normalized coupling matrix can be obtained [9].

$$[M] = \begin{bmatrix} 0 & 0.570 & -0.765 & 0.513 & 0 \\ 0.570 & 1.475 & 0 & 0 & 0.570 \\ -0.765 & 0 & -0.101 & 0 & 0.765 \\ 0.513 & 0 & 0 & -1.438 & 0.513 \\ 0 & 0.570 & 0.765 & 0.513 & 0 \end{bmatrix} \tag{2}$$

From coupling matrix $[M]$, theoretical external Q factor can be evaluated by Eq. (3) [10]

$$Q_{en} = \frac{1}{FBW \cdot M_{Sn}^2} \quad (n = 1, 2, 3) \tag{3}$$

where FBW is fractional bandwidth. Using Eq. (3), external Q factors, Q_{e1}, Q_{e2}, and Q_{e3} of each mode are 116.7, 64.8, and 144.1, respectively.

The tapping position is determined to fit the theoretical external Q factors. The p is 7.5 mm from the method using Fig. 4(b). The dimensions of the designed filter are shown in Fig. 5(b). The photograph of the fabricated filter is given in Fig. 6. Performance is measured by a vector network analyzer. Fig. 7 shows the measured S-parameters of the fabricated filter. The measured results agree well with the simulation results, and two transmission zeros are generated as designed. Return loss is less than 12.1 dB, and insertion loss is 2.68 dB within the passband. A design approach is established from these results.

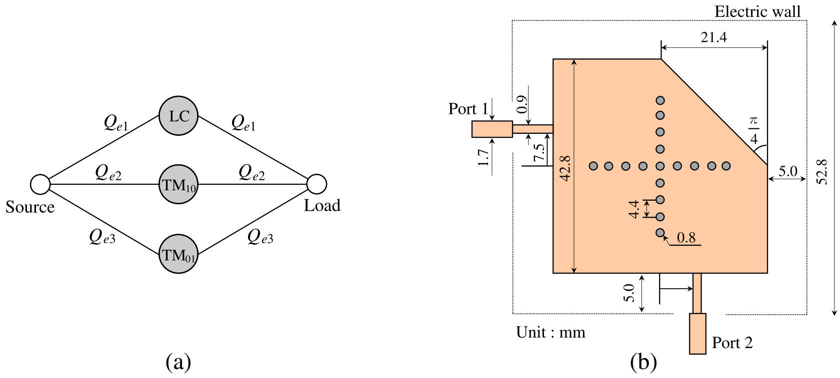

Fig. 5. (a) The coupling scheme of the proposed BPF. (b) Dimensional parameters of designed filter.

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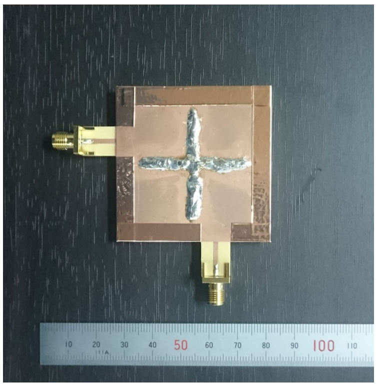

Fig. 6. Photograph of the fabricated filter.

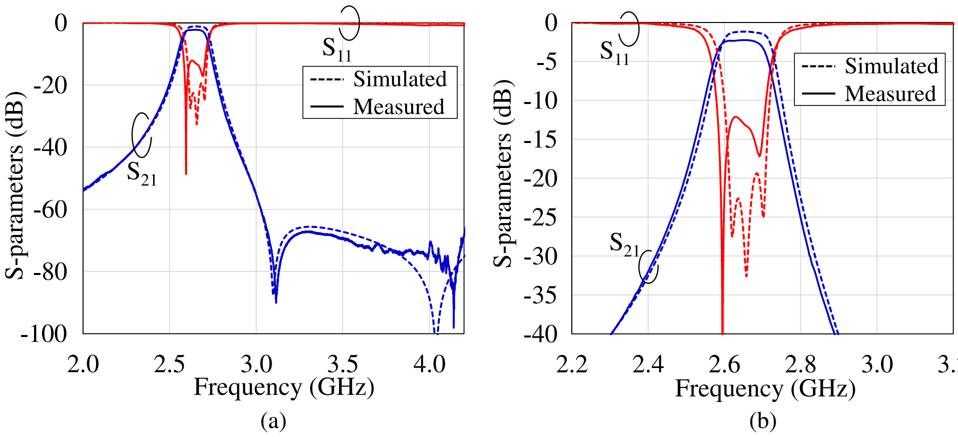

Fig. 7. Simulated and measured *S*-parameters of the proposed BPF. (a) Wideband response. (b) Narrowband response.

4 Conclusion

In this letter, a design approach for bandpass filter (BPF) using a novel triple-mode stripline resonator was discussed. It is found that the external Q factors of each mode can be controlled by the cutout distance. It is also clarified that the external Q factors of each mode can be handled by the tapping position. Using that result, a triple-mode BPF was designed and fabricated. It is confirmed that the proposed filter was demonstrated, and the measured results are in good agreement with the simulated ones. Consequently, a design approach was established.

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