3D Frequency Selective Rasorber Based on 2D Slotline Structures

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***Abstract*—In this paper, we briefly introduce the concept of 3D frequency selective rasorber (FSR) as well as its generalized equivalent circuit model. Based on this understanding, a new kind of 3D FSR based on stacked planar slotline structure is presented. As an example, a prototype 3D FSR is demonstrated to exhibit bandpass filtering response and good absorption performance at both sides of the passband, and it is then fabricated and measured. The measured results show that the minimum insertion loss in the transmission window is about 0.3 dB, and the absorption bandwidths are ranged from 1.6 to 2.3 GHz and from 3.6 to 4.6 GHz, respectively. To further verify the design concept, another design example with wider absorption bands is developed by introducing more lossy resonators.**

Keywords—*Frequency selective rasorber (FSR), bandpass, absorption, stacked slotline*

I. Introduction

In recent years, frequency selective rasorbers (FSRs) have found numerous applications due to their frequency filtering characteristics, which can not only transmit signals in their passband but also operate as an absorber outside the passband [1]. So far, most of the reported FSR designs [2-4] were realized by simply cascading a few lossy arrays of the Salisbury/Jaumann/CA absorbers and conventional 2D FSSs. Unfortunately, it is difficult for these cascaded designs to exhibit multiple and wide absorptions outside the passband, which is highly desirable in practical applications.

Recently, a new type of 3D FSS has attracted growing attention [5, 6]. These FSS designs can easily realize multiple resonators or propagation modes, thus exhibiting highly selective response by controlling the number of resonators or propagation modes. Then, by introducing lossy resonators to these 3D FSSs, the concept of 3D FSR is successfully developed in [7]. Based on this concept, 3D FSR can be designed to achieve a few superior performances, such as high selectivity and wide absorption band as reported in [8-10].

In this paper, the design concept of 3D FSR is described by virtue of a generalized equivalent circuit model firstly. After that, a design example is provided to verify the feasibility of our proposed concept. The unit cell of this structure, relying on the slotline structures, is composed of lossless and lossy resonators, thereby providing two transmission poles and two-sided absorptions outside the desired passband, respectively. A prototype of the 3D FSR example is then fabricated and measured, where good agreement is observed between the simulated and measured results. Furthermore, another example is designed to evidently demonstrate that the absorption bandwidths can be effectively broadened by introducing more lossy resonators while maintaining the core passband with high frequency-selective response.

II. Design Concept

Fig. 1(a) presents the filtering response of traditional bandpass FSS. It can be noticed that there exists strong reflection outside the transmission window, which may unavoidably give rise to a large RCS. Thus, it’s imperative to absorb the reflection wave in the rejection band to reduce the RCS. Accordingly, the concept of FSR is presented. Fig. 1(b) shows the S-parameter results of classical FSR, which indicates that this structure can realize the same filtering characteristic and absorb the reflection wave at both sides of the passband simultaneously.

Based on the above discussions, we propose a generalized equivalent circuit model for characterization of the proposed 3D FSR. As shown in Fig. 2(a), this circuit model contains a lossless resonator and lossy resonators in a unit cell. In this circuit model, the multiple resonators are connected with each other in series, leading to multiple propagation modes excited. Therefore, the lossless resonator connecting port 1 and port 2 can provide transmission poles at its resonant frequencies. Then, the lossy resonators in series connection with the lossless resonator can produce absorption characteristics. As shown in Fig. 2(b), the transmission poles at f_1 and f_2 are provided by the lossless resonator, while two lossy resonators can provide two perfect absorptions at f_{L1} and f_{U1}, respectively.

It must be mentioned that if one lossy resonator realize an absorption band at a lower frequency, its harmonics at higher frequencies are unavoidable. Employing this, we only need one lossless resonator and one lossy resonator to realize a FSR structure with two absorption bands. To do so, the first design example will be intensively described in the next section. Furthermore, it can be observed that wider absorption band can be achieved by introducing more lossy structures. Thus, the second example is given by introducing another lossy structure based on the first example to obtain wider absorption bands in the next section.

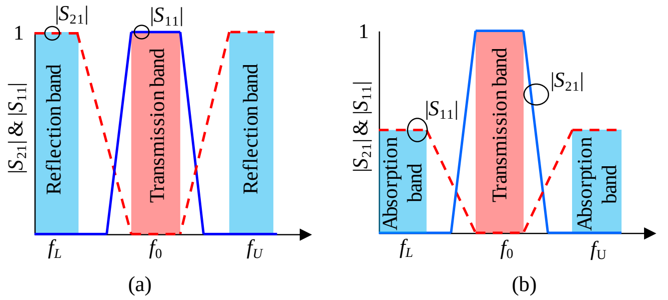


Fig. 1. Ideal frequency responses of transmission and reflection coefficients of (a) an FSS and (b) an FSR.

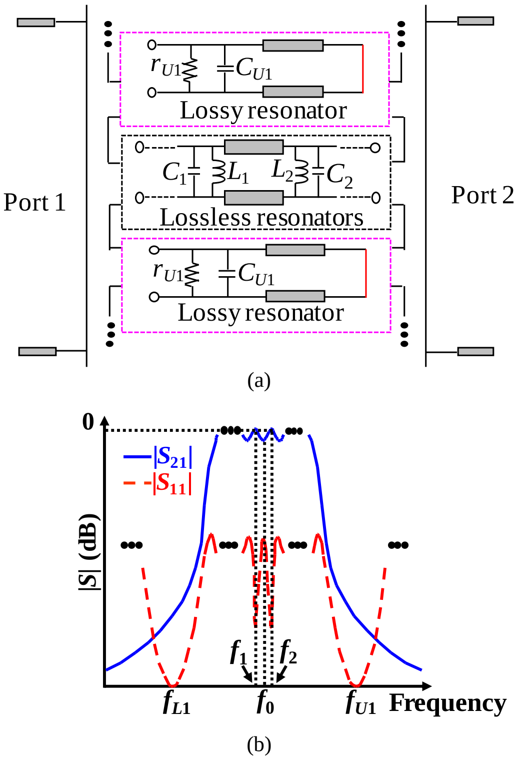


Fig. 2. Generalized equivalent circuit model of 3D FSR and its corresponding filtering response. (a) Equivalent circuit model and (b) frequency response.

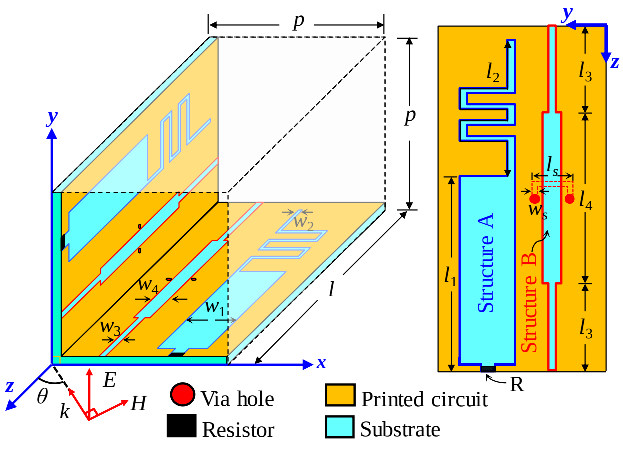


Fig. 3. (a) Perspective view of a unit cell and (b) top-layer of the PCB in a unit cell.

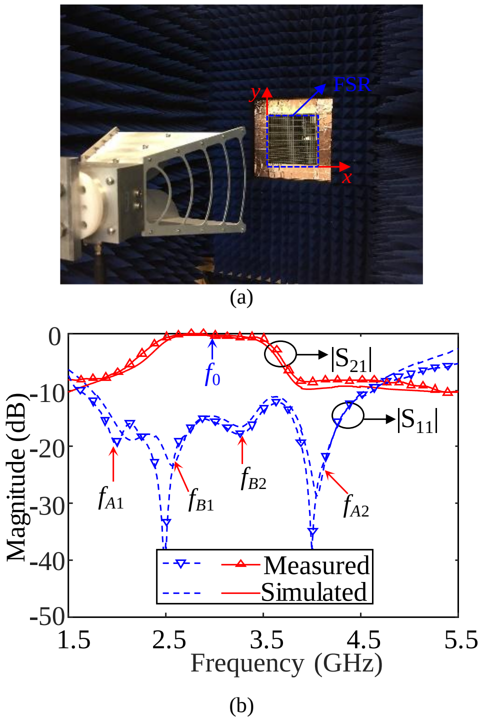


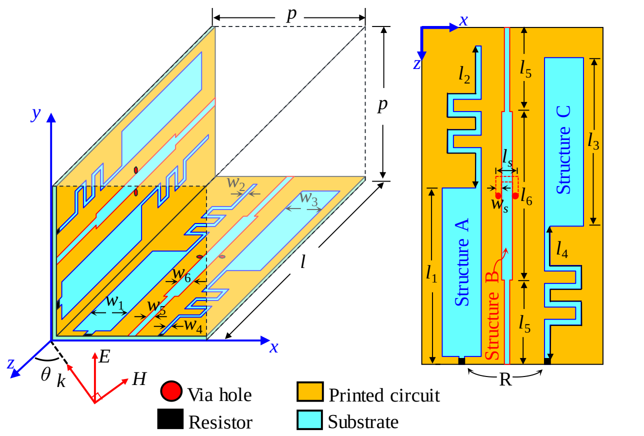
Fig. 4. (a) Photograph of the measurement setup, (b) comparison of S-parameters between measurement and simulation under normal incidence. (Physical dimensions (units: mm): l = 30, p = 10, l_1 = 17, l_2 = 21.05, l_3 = 7.5, l_4 = 15, w_1 = 3, w_2 = w_3 = 0.4, w_4 = 1, w_s = 0.3, l_s = 2.8; ε_r = 3.55, R = 400 Ω).

III. Design Examples

A. 3D FSR with Two Absorption Bands

As shown in Fig. 3(a), the perspective view of the first design example based on a unit cell is presented. As shown herein, the FSR in a unit cell is composed of two pieces of PCBs etched with planar slotline structures, which are vertically and horizontally cross-inserted together. The PCB pieces along the *y*- and *x*-axis are distinctively responsible for TE and TM polarization incidences, respectively. Fig. 3(b) illustrates the top layer of a single PCB piece in a unit cell. It can be observed that two separate slotline structures, denoted as structures A and B, are in parallel etched in the left and right regions of the top-layer, respectively. The structure A serves as a lossy resonator containing a short-circuited stepped-impedance slotline structure, which can provide two absorption bands at both sides of the desired passband. In addition, the structure B (lossless resonator) is an open-circuited stepped-impedance slotline structure with a U-shaped stripline, exhibiting bandpass characteristic with two transmission poles.

The scattering parameters of the fabricated FSR is measured by the free-space method in an anechoic chamber, as shown in Fig. 4(a). In addition, the comparison of S-parameter results between measurement and simulation under normal incidence is depicted in Fig. 4(b). It can be clearly seen that a passband with the center frequency at f_0 (3.0 GHz) is satisfactorily achieved with two in-band transmission poles at f_{B1} (2.6 GHz) and f_{B2} (3.3 GHz). Moreover, two absorption bands are realized at around f_{A1} (2.1 GHz) and f_{A2} (4.0 GHz). The bandwidths of the absorption bands ($|S_{21}| \leq$ -3 dB & $|S_{11}| \leq$



(a) (b)

Fig. 5. (a) Perspective view of a unit cell and (b) top-layer of the PCB in a unit cell.

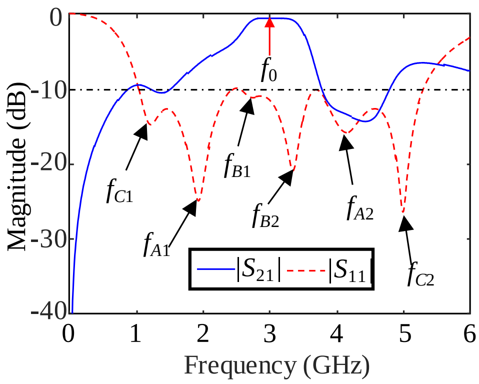


Fig. 6. Simulated S-parameter results. (Physical dimensions (units: *mm*): l = 30, p = 13, l_1 = 17, l_2 = 20.7, l_3 = 17.5, l_4 = 22.2, l_5 = 7.5, l_6 = 15, w_1 = 4, w_2 = 0.3, w_3 = 4, w_4 = w_5 = 0.3, w_6 = 0.6, w_s = 0.5, l_s = 1.6; ε_r = 3.55; R = 400 Ω).

-10 dB) are ranged from 1.74 to 2.4 GHz and from 3.6 to 4.6 GHz, respectively. The above design example verifies that only one lossy resonator is needed to realize an FSR with two-sided absorption band, as can be demonstrated by this structure.

B. 3D FSR with Wider Absorption Bands

The perspective view of the modified FSR based on the first design example is shown in Fig. 5(a) to further broaden the absorption bands by introducing more lossy resonators in a unit cell. Thus, from the top layer views of this structure shown in Fig. 5(b), it can be seen that apart from lossy structure A and the lossless structure B, another lossy short-circuited slotline structure C is introduced. Fig. 6 shows the S-parameter results of this structure, indicating that two transmission poles can be achieved by structure B. Besides, by adjusting the slotline width-to-length ratios of these slotline structures, structure A can provide two absorptions at around f_{A1} (2.0 GHz) and f_{A2} (4.2 GHz), which is similar to the first example, and structure C produces absorptions at around f_{C1} (1.2 GHz) and f_{C2} (5.0 GHz). Thus, two absorption bands enventually appear at both sides of the desired passband. The absorption bandwidths ($|S_{21}| \leqslant$ -3 dB & $|S_{11}| \leqslant$ -10 dB) are ranged from 1.0 to 2.5 GHz and from 3.5 to 5.3 GHz, respectively. Thus far, it has been evidently confirmed that the absorption bandwidths can be effectively broadened by introducing more lossy resonators.

IV. CONCLLUSION

In this paper, the concept of 3D FSR is presented and further analyzed by means of a generalized equivalent circuit model. Based on this model, we propose two design examples using stacked 2D slotline structures with dual-polarized and dual-band absorption characteristics. Moreover, a prototype of the first design example is fabricated and measured, where good agreement is observed between simulated and measured results. In order to further show a few attractive advantages of 3D FSR, the second example with wider absorption band is described by introducing another lossy resonator.

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REFERENCES

[1] B. A. Munk, Metamaterials: critique and alternatives, Wiley, New York, 2009.

[2] Y. Han, W. Che, X. Xiu, W. Yang and C. Christopoulos, "Switchable low-profile broadband frequency-selective rasorber/absorber based on slot arrays," *IEEE Trans. Antenna Propag.*, vol. 65, no. 12, pp. 6998–7008, 2017.

[3] H. Huang and Z. Shen, "Absorptive frequency-selective transmission structure with square-loop hybrid resonator", *IEEE Antennas Wireless Propag. Lett.*, vol. 16, pp. 3212-3215, 2017.

[4] Q. Chen, D. Sang, M. Guo, and Y. Fu, "Frequency-selective rasorber with inter-absorption band transparent window and interdigital resonator," *IEEE Trans. Antenna Propag. (Early Access)*, 2018.

[5] B. Li and Z. Shen, "Three-dimensional bandpass frequency selective structures with multiple transmission zeros," *IEEE Trans. Microwave Theory Tech.*, vol. 61, no. 10, pp. 3678-3589, 2013.

[6] A. Al-Sheikh and Z. Shen, "Dual-band bandpass frequency-selective structures with arbitrary band ratios," *IEEE Trans. Antennas Propag.*, vol. 62, no. 11, pp. 5504-5512, Nov. 2014.

[7] Z. Shen, J. Wang and B. Li, "3-D frequency selective rasorber: concept, analysis, and design," *IEEE Trans. Microw. Theory Techn.*, vol. 64, pp. 3087-3096, 2016.

[8] A. A. Omar, Z. Shen and H. Huang, "Absorptive frequency-selective reflection and transmission structures," *IEEE Trans. Antennas Propag.*, vol. 65, pp. 6173-6178, 2017.

[9] Y. Yu and Z. Shen, "3D frequency selective rasorber with wide upper absorption band," *IEEE Trans. Antennas Propag.*, vol. 65, no. 8, pp. 4363-4367, Aug. 2017.

[10] Y. Zhang, B. Li, L. Zhu, Y. Tang, Y. Chang and Y. Bo, "Frequency selective rasorber with low insertion loss and dual-band absorptions using planar slotline structures", *IEEE Antennas Wireless Propag. Lett.*, vol. 17, no. 4, pp. 633-636, 2018.