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A Novel Filtering Antenna Using Dual-Mode Resonator

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Abstract—In this paper, a filtering antenna using a dual-mode resonator is presented. The rectangular patch performs not only as a radiator, but also as the last resonator of the bandpass filter. The dual-mode resonator works together with the patch antenna to form a third order bandpass filter with Chebyshev responses. The filtering antenna exhibits good performance, such as skirt selectivity, flat gain within the passband, and high out-of-band suppression.

1. INTRODUCTION

Both antennas and filters are key components in a passive circuit. Usually, filters are designed just behind the antenna for selecting signals within the operating band and rejecting the spurious. With the development of wireless communication, a growing need for high-performance and portable terminal equipment prompts the miniaturization and integration of antennas and filters.

Several efforts have been made to integrate filters with antennas [1–9]. The direct method is to design the antenna and filter separately and then integrate together by adding a matching circuit. However, such design methods dramatically enlarge the circuit size [1–3]. In [4–6], a filtering antenna is built by replacing the filter with a new structure embedded in the antenna. Nevertheless, this design method includes so many structure parameters and so much optimization process, which are complicated and time consuming. Recently, filtering antennas, designed following the synthesis process of bandpass filter (BPF), have been presented in [7–9]. In those designs, the last resonator and the load impedance of BPF were substituted by the patch antenna.

In this letter, a compact 3rd-order filtering antenna composed of a dual-mode resonator and a rectangular patch antenna is presented. The patch antenna and dual-mode resonator work together as a 3rd-order BPF with Chebyshev responses. The proposed structure exhibits good performance verified by the measured results, including skirt selectivity, flat in-band gain, etc.

2. DESIGN PRINCIPLE OF THE FILTERING ANTENNA

2.1. Design of Bandpass Filter

The design procedure starts from the 3rd-order Chebyshev BPF prototype. The first step is to determine the filter parameters, such as central frequency, bandwidth, and ripple level. A 3rd-order BPF is designed to have a fractional bandwidth of 2.33% with respect to the central frequency $f_0 = 2.0\,\text{GHz}$. A 3rd-order Chebychev low-pass prototype with ripple of 0.1 dB is chosen, and the element of the low-pass prototype is given as follow: $g_0 = g_4 = 1.0$, $g_1 = g_3 = 1.0316$, $g_2 = 1.1474$ [10]. Through the prototype parameters, the design parameters can be calculated by:

$$Q_{e1} = \frac{g_0 g_1}{\text{FBW}}, \quad Q_{e3} = \frac{g_3 g_4}{\text{FBW}} \tag{1}$$

$$M_{1,2} = \frac{\text{FBW}}{\sqrt{g_1 g_2}}, \quad M_{2,3} = \frac{\text{FBW}}{\sqrt{g_2 g_3}} \tag{2}$$

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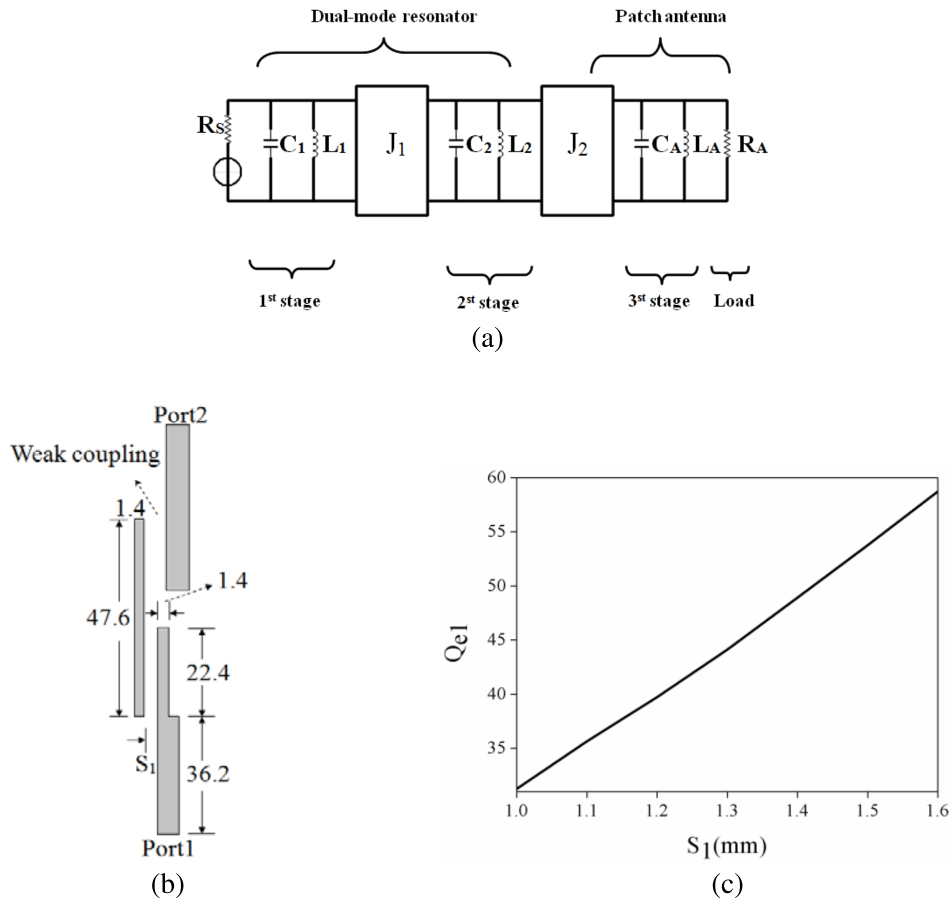


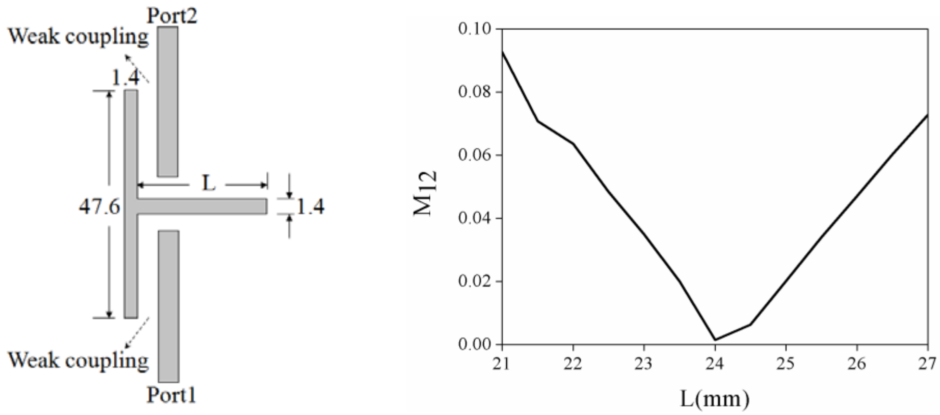
Figure 1. (a) Equivalent circuit of the proposed antenna; (b) The arrangement for the extraction of the input/output external quality factor (unit: mm); (c) The curve of the external quality factor Q_{e1} with respect to gap S_1.

where Q_{e1} and Q_{e3} are the input/output external quality factor; FBW is the fractional bandwidth of the BPF; $M_{1,2}$ and $M_{2,3}$ are the coupling coefficient between the adjacent resonators. In our design, the coupling coefficient and external quality factor are calculated to be $Q_{e1} = Q_{e3} = 44.3$ and $M_{1,2} = M_{2,3} = 0.0197$, respectively. The corresponding bandpass equivalent circuit is demonstrated in Figure 1(a), and the element values are given as follow: $L_1 = L_A = 2.46\,\mathrm{nH}$, $C_1 = C_A = 2.426\,\mathrm{pF}$, $C_2 = 4.855\,\mathrm{pF}$, $L_2 = 1.23\,\mathrm{nH}$, $R_A = R_S = 50\,\Omega$, $J_1 = J_2 = 3.77\,\mathrm{mS}$.

The full-wave electromagnetic simulator was utilized to extract the desired quality factor and coupling coefficient. The circuit is built on the substrate with dielectric constant of 2.94 and thickness of 1.27 mm. An arrangement for the extraction of input/output external quality factor Q_{e1} is shown in Figure 1(b).

The size of the resonator is also demonstrated in Figure 1(b), while the length of the coupled section between Port1 and microstrip resonator is fixed at 22.4 mm. The curve of the extracted Q_{e1} varied with respect to gap S_1 is shown in Figure 1(c).

Similarly, the coupling coefficient of the dual-mode resonator can also be extracted, as shown in Figure 2(a). The coupling coefficient varied with respect to the length (L) of the open circuited stub is plotted in Figure 2(b). From Figure 2(b), the desired coupling coefficient M_{12} is readily satisfied when L is equal to 24.8 mm. Therefore, parameters S_1 and L can be determined as 1.3 mm and 248 mm, respectively.

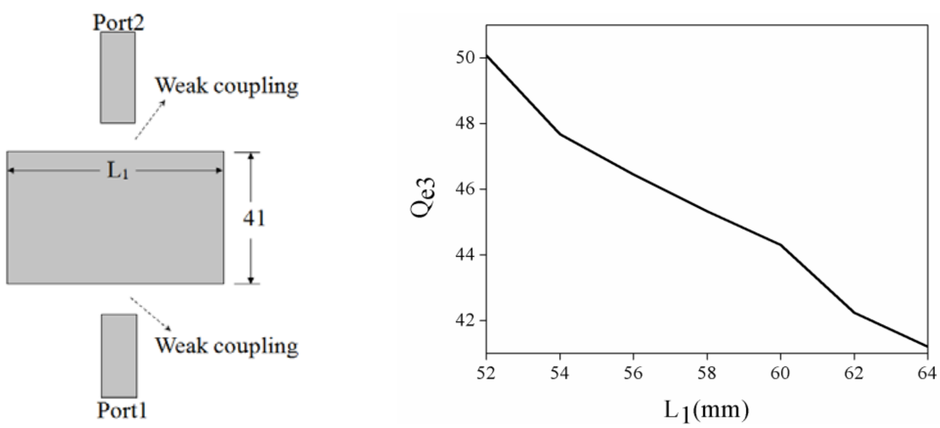


(a) (b)

Figure 2. (a) An arrangement for extracting the coupling coefficient M_{12} (unit: mm); (b) The curve of the extracting coupling coefficient M_{12}.

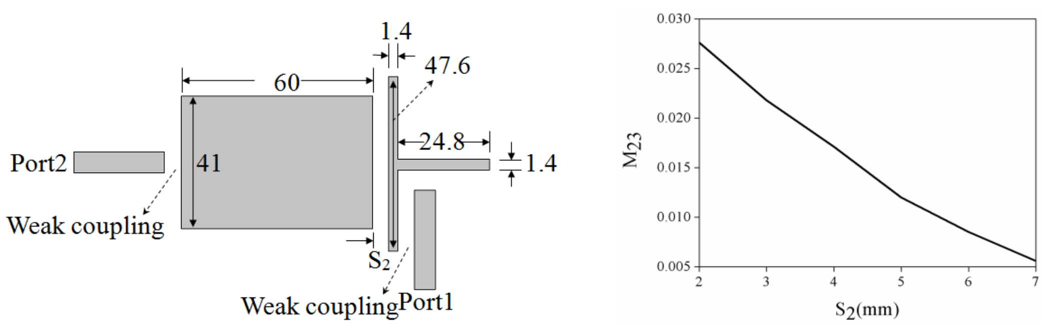
2.2. Design of Filtering Antenna

As shown in Figure 1(a), the patch antenna is designed to replace the resonator composed of L_A and C_A and the load resistance of BPF. In order to ensure the filter characteristics, it is necessary to make sure



(a) (b)

Figure 3. (a) An arrangement for extracting the quality factor Q_{e3} of the patch antenna (unit: mm); (b) The curve of the extracting external quality factor Q_{e3}.



(a) (b)

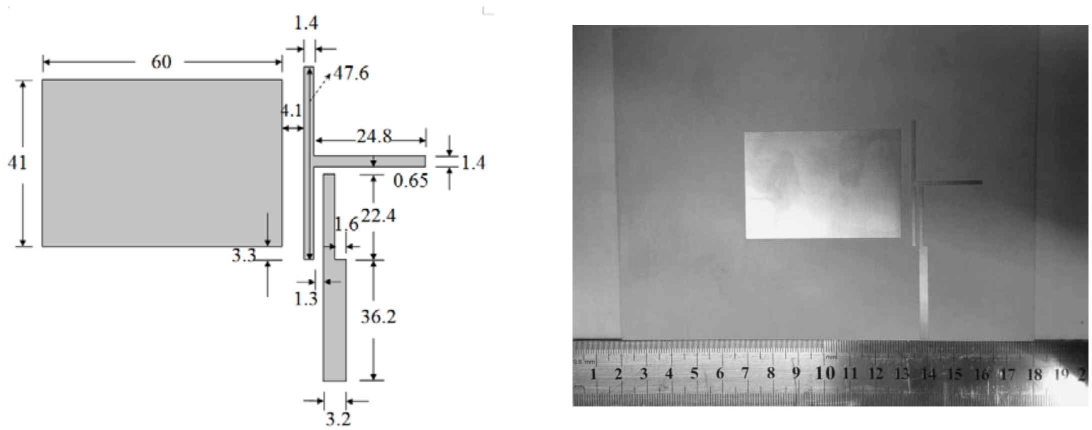
Figure 4. (a) An arrangement for extracting the coupling coefficient M_{23} (unit: mm); (b) Extracted curve of the coupling coefficient M_{23}.

the quality factor of patch antenna to be equal to the external quality factor Q_{e3} as desired Figure 3(a) shows how to extract the quality factor Q_{e3} of the patch. From Figure 3(b), Q_{e3} achieves 44.3 when L_1 is equal to 60.0 mm.

The coupling between the resonator and the patch antenna can be extracted according to the arrangement of Figure 4(a). The coupling strength is controlled by gap S_2 between the patch antenna and the dual-mode resonator. Figure 4(b) shows the curve of extracted M_{23} against gap S_2 based on Equation (4). From the curve, the required M_{23} is achieved when S_2 is equal to 4.1 mm.

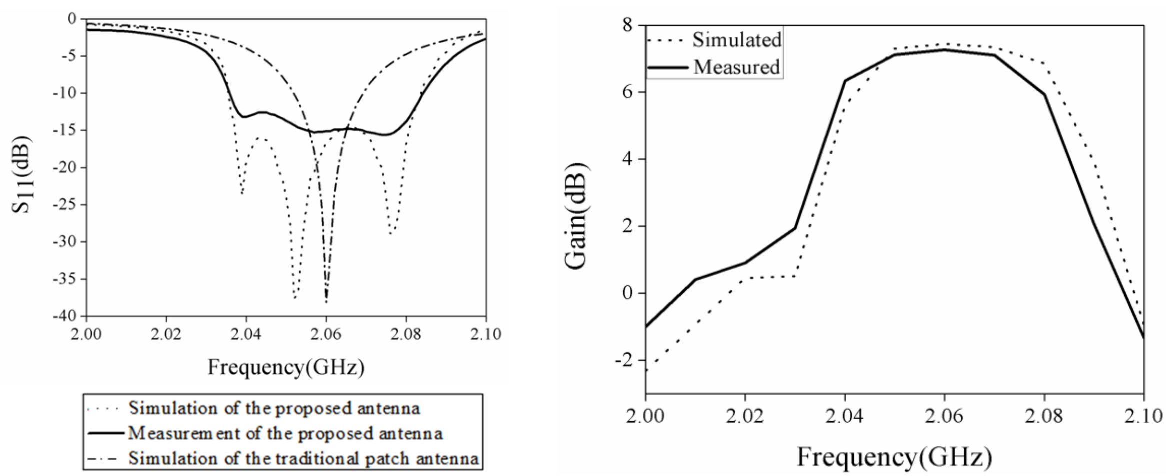
3. SIMULATED AND MEASURED RESULTS

The simulation was taken by the commercial full-wave electromagnetic simulator Zeland IE3D. The filtering antenna is etched on a substrate Roger 6002 with dielectric constant $\varepsilon_r = 2.94$ and thickness $h = 1.27$ mm. The optimized layout is illustrated in Figure 5(a), and a photograph of the fabricated antenna is shown in Figure 5(b). The simulated and measured results of the filtering antenna are shown in Figure 6. As can been seen from Figure 6(a), the measured S_{11} is below -10 dB from 2.036 GHz to 2.084 GHz, which indicates that the fractional bandwidth is 2.33% with central frequency of 2.06 GHz.



(a) (b)

Figure 5. (a) The layout of proposed filtering antenna (unite: mm); (b) The photograph of the fabricated antenna.



(a) (b)

Figure 6. The simulated and measured performance of the proposed filtering antenna: (a) S_{11}; (b) Gain.

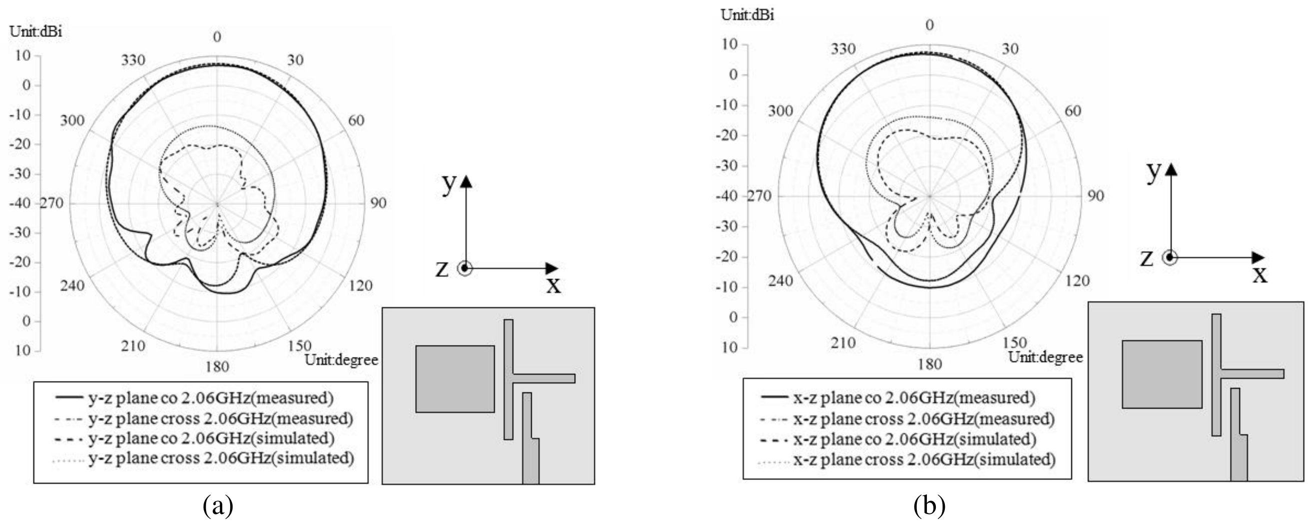


Figure 7. The simulated and measured radiation patterns: (a) y-z plane; (b) x-z plane.

The measured reflection zeros are not clear, which might be caused by the fabrication tolerance. As seen from Figure 6(a), the bandwidth of the proposed antenna is about three times wider than that of the traditional rectangular patch antenna. The measured gain varies within 1.0 dB over the passband with the maximum gain of 7.27 dBi, as shown in Figure 6(b). Meanwhile, the measured y-z and x-z plane radiation patterns at 2.06 GHz are drawn in Figures 7(a) and (b), respectively.

4. CONCLUSION

A novel filtering antenna composed of a dual-mode resonator and a rectangular patch radiator is proposed. The design process is based on filter synthesis method of 3rd-order Chebyshev BPF. The antenna work not only as a radiating element, but also as the resonator composed of L_A and C_A and load of the BPF. The measured results of the proposed structure agree well with the simulated ones, which indicates its good performance, including flat gain response within the passband, etc.

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