Asymmetrical coplanar waveguide zeroth-order resonant antenna with extended bandwidth

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Asymmetrical Coplanar Waveguide Zeroth-Order Resonant Antenna with Extended Bandwidth

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***Abstract*—This paper presents the design and analysis of a compact coplanar waveguide (CPW)-fed zeroth-order resonant (ZOR) antenna with extended bandwidth. Two new resonant frequencies are obtained by adding two stubs between the main patch and the CPW ground. With the combination of the ZOR frequency and the two new resonant frequencies, a wide bandwidth is achievable and increased up to 58.4%. The efficiency of the antenna is higher than 85% in the entire band from 3.7 GHz to 6.75 GHz. The proposed antenna has a compact size of 21mm×19mm and an omnidirectional radiation pattern, which is applicable in wireless applications at C-band.**

Keywords—bandwidth enhancement, high efficiency, zeroth-order resonant antenna (ZOR).

I. INTRODUCTION

Nowadays there are many efforts devoted to microstrip antennas with miniaturized size, wide bandwidth and high efficiency [1]. The planar metamaterials based on composite right/left-handed transmission line, as one of the novel antenna design approaches, have attracted much attention and been widely applied to antenna design [2-4]. They have unique properties in comparison with conventional nature materials, such as anti-parallel phase and group velocities, and a zero propagation constant [5]. One of the intriguing applications is the zeroth-order resonant (ZOR) antenna. Due to its zero-phase constant at a non-zero frequency, the resonator has an infinite wavelength and the size of the resonator is independent of the resonance frequency which provides the potential of miniaturization. Although the ZOR antennas offer the advantage of significant size reduction, the narrow bandwidth limits their application in modern wireless communication systems.

Recently, many researchers have attempted to solve the narrow bandwidth problem of ZOR antennas [6-9]. In [6], the antenna bandwidth increases to 6.8% with increasing shunt inductance and decreasing shunt capacitance. In [7], the idea of bisecting the antenna makes the antenna bandwidth increase to 6.1%. In [8-9], the bandwidth of the antenna is extended by merging the zeroth-order and first-positive-order resonant frequencies into one band.

In this paper, co-planar waveguide (CPW) feed is employed to simplify the fabrication process and facilitate the shunt elements easily integrated. First, a ZOR antenna is presented and its equivalent circuit is analyzed. In order to extend the bandwidth of the antenna, two asymmetrical stubs are added to connect the main patch with the CPW ground, which introduces two new resonant frequencies. With the combination of the two newly generated frequencies and the ZOR frequency, wide impedance bandwidth is achievable.

II. ANTENNA DESIGN AND METHOD

The schematic of the proposed antenna is shown in Fig.1. The CPW-fed line is used to match the antenna with the 50-Ω cable. Good impedance matching can be obtained by adjusting the size of the T-shaped feeding line and the gap to the ground. The main rectangular patch acts as the series inductance L_R. The series capacitance C_L can be found in the coupling between the main patch and the T-shaped feeding line, while the shunt capacitance C_R is provided by the coupling between the main patch and the CPW ground plane. The strip on the right of the main patch contributes to inductance Lg and the capacitive effect between the main patch and the right strip is modeled as Cg.

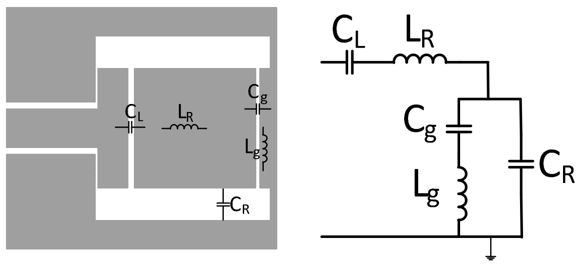

Fig.1. Equivalent circuit of the proposed antenna.

The series impedance and shunt admittance in Fig.1 can be obtained by [3]

$$Z = \frac{1}{j\omega C_L} + j\omega L_R \tag{1}$$

$$Y = j\omega C_R + \frac{j\omega C_g}{1-\omega^2 L_g C_g} \tag{2}$$

By applying periodic boundary conditions related to Bloch-Floquet theorem to the unit cell, the dispersion relation is determined to be

$$\beta(\omega) = \frac{1}{p}\cos^{-1}(1+\frac{ZY}{2}) \tag{3}$$

In case of an open ended zeroth-order resonator, its resonance occurs when

$$\beta_n = \frac{n\pi}{l}(n = 0, \pm1, ..., \pm(N-1)) \tag{4}$$

where l, n and N are the physical length of the resonator, mode number, and number of the unit-cells, respectively.

In this study, the antenna is open-ended and there is only one unit cell. It indicates that the zeroth-order resonant frequency is only determined by the shunt part of the antenna and can be obtained when β=0. Therefore, the ZOR frequency of this antenna can be expressed as

$$\omega_{ZOR} = \sqrt{\frac{C_R + C_g}{C_R C_g L_g}} \tag{5}$$

The parameters of the antenna are given in the Fig. 2(a). The physical dimensions are (in millimeters): W1=19, W2=7.5, W3=3, W4=2.5, W5=9.2, L1=21, L2=6.8, L3=2.3, L4=0.8, L5=0.5, S=0.5, g1=0.5, g2=0.3. The ZOR antenna developed in this study is fabricated on Rogers 4350B substrate with a thickness of 0.762 mm, a dielectric constant of 3.66 and a dielectric loss of 0.0031. Fig. 2(b) is the simulated results of the antenna.

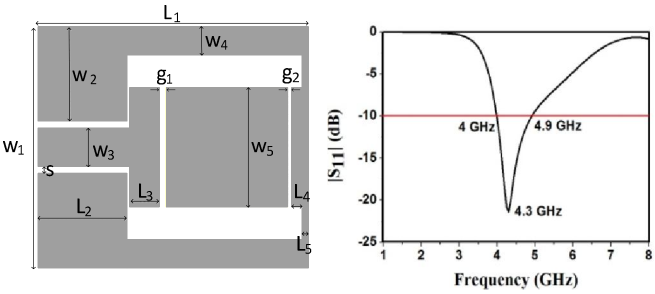

Fig. 2 (a) Dimensions. (b) Simulated return loss.

It is shown that the simulated zeroth-order resonant frequency is about 4.3 GHz. The simulated return loss bandwidth (-10 dB) is about 900 MHz (4 GHz-4.9GHz), which is approximately 10.1% fractional bandwidth at ZOR frequency 4.3 GHz.

III. ZOR ANTENNA WITH EXTENDED BANDWIDTH

In order to extend the bandwidth of the ZOR antenna, two asymmetrical stubs are added to the structure. One is at the bottom of the main patch and the other is on the top. The two stubs bridge the patch with the CPW ground, which introduces the shunt inductance L_{L1} and L_{L2}, as shown in Fig. 3.

The newly added parameters are (in millimeters): m=0.5, n=2.5, s1=0.5, s2=6.3. Other parameters are the same as the given parameters in Fig. 2. The equivalent circuit of the newly established structure is described in Fig.4.

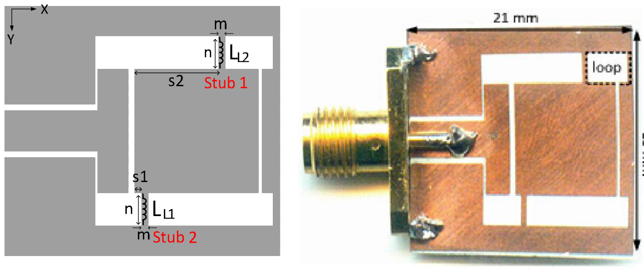

Fig. 3 (a) Geometry of the antenna. (b) Fabricated prototype of the antenna.

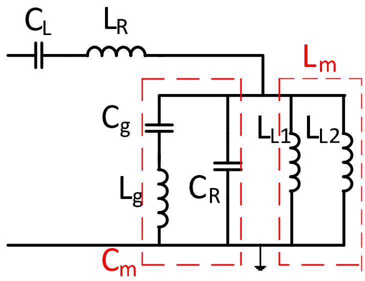

Fig. 4 The equivalent circuit of the proposed antenna.

The series impedance remains unchanged, and the shunt admittance of the structure is

$$Y = j\omega C_m + \frac{1}{j\omega L_m} \tag{6}$$

where

$$C_m = C_R + \frac{C_g}{1-\omega^2 L_g C_g}, \; L_m = \frac{L_1 L_2}{L_1 + L_2} \tag{7}$$

According to formula (3), when β=0, the ZOR frequency is

$$\omega_{ZOR} = \frac{1}{\sqrt{C_m L_m}} \tag{8}$$

It is shown that with the addition of the two stubs, the zeroth-order resonant frequency will be changed and depends on the shunt parameters L_m and C_m.

The characteristics of the antenna were simulated by the full-wave electromagnetic simulator IE3D (Version 15.0) and measured by an Agilent N5230A network analyzer. Fig. 5 presents the simulated and measured return losses of the newly established antenna compared to the former antenna. As can be seen from the figure, with the addition of the two stubs, the ZOR frequency occurs at 4.5 GHz, and the extracted values for L_m and C_m are 6.46 nH and 0.194 pF, respectively. Besides the ZOR frequency, two new resonant frequencies are also brought in.

One is resonant at 3.85 GHz, which is mainly generated by the loop composed of the inner edge of the main patch, the stub 1 and CPW ground, as can be seen in Fig. 3(b). The loop acts as a one-quarter wavelength short-circuited transmission line resonator and the length is about 12.5 mm. Here, with f=3.85 GHz, c=3×10^8 m/s and ε_r=3.66, we can obtain that

$$\lambda_g = \frac{\lambda_0}{\sqrt{\varepsilon_{re}}} = \frac{c}{f\sqrt{\frac{1}{2}(\varepsilon_r + 1)}} = 51\,mm \tag{9}$$

A quarter of the guided wavelength is 12.75 mm, which is quite close to the loop length. Therefore, it indicates that the resonant frequency at 3.85 GHz is mainly attributed to the loop. However, it does not imply that we can constitute the loop with an arbitrary length and generate any desired resonant frequency. The position of the stub 1 will also interact with other resonant frequencies and thus it should be appropriately chosen.

The other resonant frequency at 6.5 GHz is contributed by the +1 mode of the antenna which is generated from stub 2. The location of stub 2 is different from stub 1 and this provides the capability of tuning the resonant frequency by changing the stub position. Bringing the three resonant frequencies closer by tuning the position of the stubs, wide bandwidth is achievable. The simulated return loss bandwidth (-10 dB) of the antenna is 3200 MHz (from 3.8 GHz to 7 GHz), and the measured bandwidth (-10 dB) is about 3050 MHz (from 3.7 GHz to 6.75 GHz), which corresponds to approximately 58.4% fractional bandwidth at 5.225 GHz.

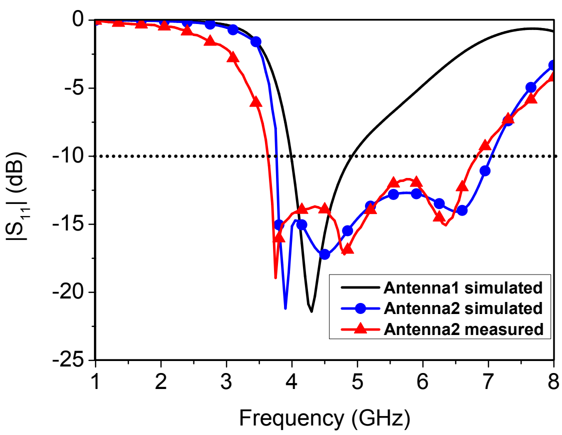

Fig. 5 Comparison of S_{11} between the two antennas.

As for the conventional ZOR antennas, the introduced gaps between the adjacent unit cells in periodic structure will reduce the efficiency of the antenna, because the electromagnetic fringing fields between the two microstrip open ends are not completely closured which leads to the dissipation of energy. However, the proposed structure successfully overcomes the degradation of the efficiency and improves it in the whole band. The simulated radiation efficiency and peak gain according to the operation band are presented in Fig.6. It is shown that the antenna efficiency is almost over 85% in the entire band.

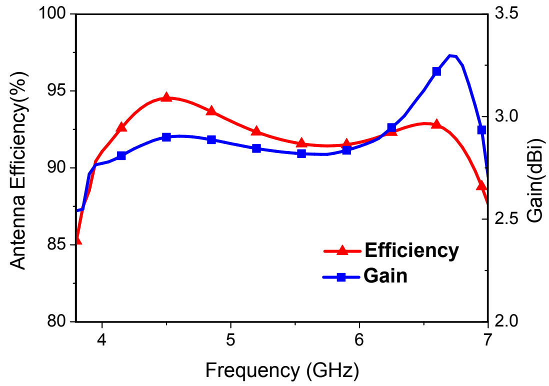

Fig. 6 Simulated gain and efficiency of the antenna

The simulated and measured patterns in *yz*-plane (*E*-plane) and *xz*-plane (*H*-plane) at 3.85 GHz, 4.5 GHz and 6.5 GHz are plotted in Fig. 7 respectively. The measured results agree well with the simulated results. The radiation patterns are approximately omnidirectional at all the three resonant frequencies in the *H*-plane and monopole-like in the *E*-plane.

IV. Conclusion

A compact and broadband ZOR resonant antenna with a combination of three resonant frequencies has been presented. The working band of the antenna is from 3.7 GHz to 6.75 GHz with a fractional bandwidth of 58.4%. Besides, the radiation efficiency is above 85% through the entire band. The proposed antenna has compact size, wide operating bandwidth and omnidirectional radiation pattern, which can be applied to wireless applications at C-band.

Acknowledgement

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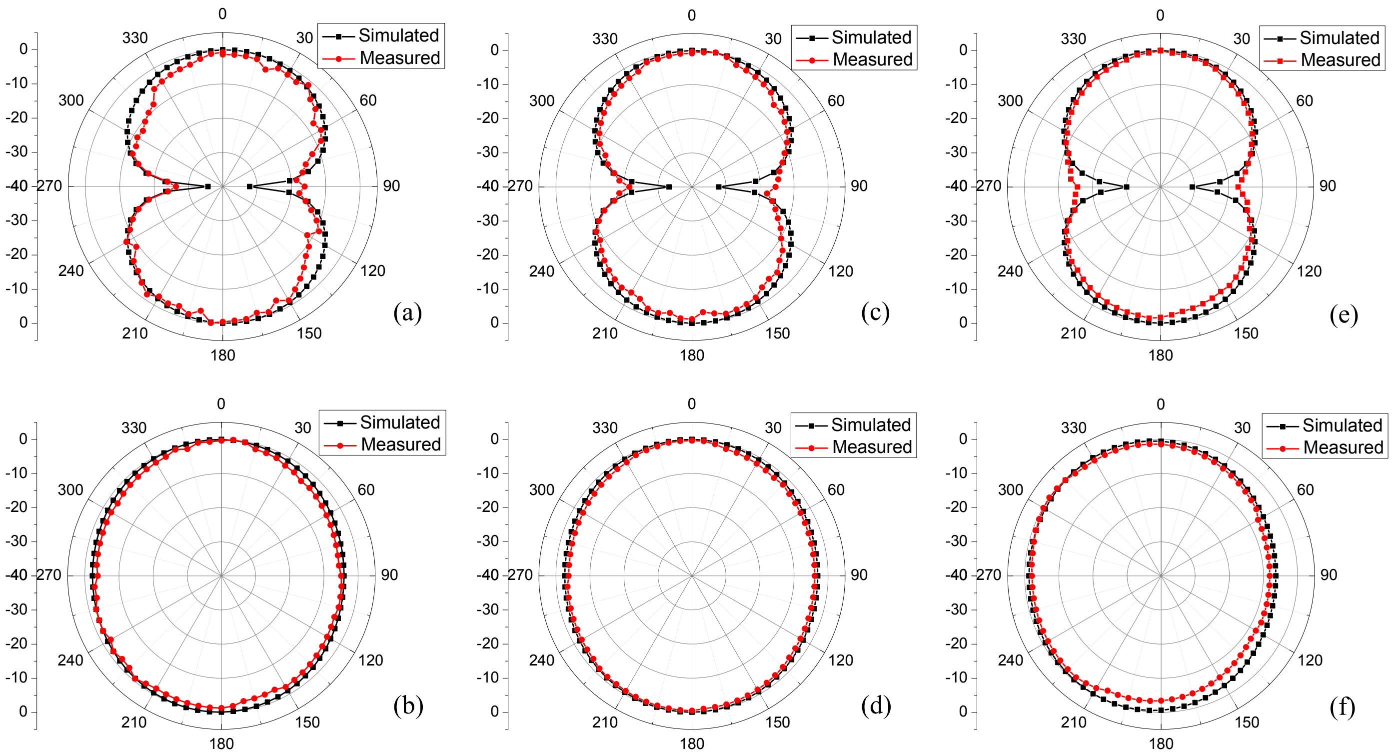

Fig. 7 Simulated and measured radiation patterns: (a) *yz*-plane at 3.85 GHz; (b) *xz*-plane at 3.85 GHz; (c) *yz*-plane at 4.5 GHz; (d) *xz*-plane at 4.5 GHz; (e) *yz*-plane at 6.5 GHz; (f) *xz*-plane at 6.5 GHz;

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