A Compact Zeroth-Order Resonant Antenna on Vialess CPW Single Layer

Taehee Jang and Sungjoon Lim

In this letter, a novel zeroth-order resonant (ZOR) antenna on vialess co-planar waveguide (CPW) is proposed. It is based on a composite right/left-handed CPW transmission line. To achieve a compact size, this antenna utilizes the ZOR condition, and its reactive parameters determine the resonant frequency. Each unit cell is composed of a metallic top patch and meander lines. Since it is realized on the CPW single layer, the proposed antenna has the benefits of being a compact size and easy to fabricate. The bandwidth of 6.8% and efficiency of 62% are experimentally achieved. Its bandwidth is enhanced compared with other ZOR antennas.

Keywords: Metamaterials, composite right/left-handed transmission line, zeroth-order resonant (ZOR) antenna, co-planar waveguide (CPW).

I. Introduction

Recently, the composite right/left-handed (CRLH) transmission line (TL), which can realize left-handed (LH) metamaterial properties, has received considerable attention [1]. Generally, the CRLH TL consists of a series capacitance (C_L) and inductance (L_R) as well as a shunt capacitance (C_R) and inductance (L_L). Due to the LH property of the CRLH TL, it has features such as anti-parallel phase and group velocities and a zero-propagation constant. Particularly, the zero-propagation constant property is used to design zeroth-order resonant (ZOR) antennas [2], [3]. Therefore, the LH metamaterial properties of the CRLH TL make it a good candidate in the realization of small antennas. Because of the zero-propagation constant of the TL, the antenna has an infinite wavelength, and the resonant frequency is independent of the size of the antenna. Thus, a ZOR antenna can be more compact than a conventional half-wavelength resonant antenna. In spite of the benefit afforded by size reduction, its narrow bandwidth limits its wireless applications [2], [3].

In order to enhance the bandwidth of a ZOR antenna, a metamaterial ring antenna has been presented using two metamaterial unit cells and implemented on a multilayer structure in which a thick substrate with low permittivity was additionally employed [4]. Although this antenna provides a wider bandwidth, it is difficult to fabricate and requires a quarter-wave sleeve balun and holding brackets. The ZOR antenna presented in [5] uses a strip matching ground to achieve broader impedance matching. However, it is also built on multiple substrates, where a thin substrate with high permittivity is stacked on a thick substrate with low permittivity. Therefore, both of the above antennas require multisubstrates.

In this letter, we present a bandwidth-enhanced metamaterial resonant antenna using co-planar waveguide (CPW) technology. The proposed antenna has the benefits of having a simple design and fabrication process compared with the previously proposed broad metamaterial resonant antennas. In addition, the enhancement of the bandwidth is achieved by the design parameters rather than the material properties. The design principle is studied with the equivalent circuit parameters and demonstrated with both numerical and experimental results.

II. Antenna Design

1. Principle of ZOR Antenna

The resonance condition of an open-ended resonator with

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CRLH TL [3] is given as

$$\beta_n = \frac{n\pi}{l}(0, \pm 1, \cdots, \pm (N-1)), \quad (1)$$

where l is the physical length of the resonator, n is the mode number, and N is the number of unit cells. In the zeroth-order state, the wavelength becomes infinite, and the resonant frequency of the zeroth-order mode becomes independent of the size of the antenna. Thus, the size of the antenna can be compact. In the case of open boundary conditions, the infinite wavelength resonance depends on the shunt parameters of the unit cell, L_L and C_R, and the resonant frequency is given by

$$\omega_{sh} = \frac{1}{\sqrt{L_L C_R}}, \quad (2)$$

where ω_{sh} is the shunt resonant frequency.

2. Proposed Antenna Design and Analysis

A schematic of the bandwidth-enhanced ZOR metamaterial antenna is shown in Fig. 1. The proposed ZOR antenna is fabricated on a Rogers RT/Duroid 5880 with a dielectric constant of 2.2 and thickness of 1.6 mm. The antenna is composed of top metallic patches, shorted meander lines, a CPW ground plane, and a bottom ground plane. The proximity coupling is used as the feed network to achieve a good impedance matching to 50 Ω, and the meander lines are connected to the CPW grounds as the shorted stub. In order to obtain the desired ZOR frequency, the antenna's dimensions are determined from the extracted circuit parameters (unit: mm): L_1=2, L_2=7.8, L_3=17.8, W_1=3.4, W_2=6, W_3=9, g_1=0.1, g_2=g_3=0.2, l_1=0.2. The proposed ZOR antenna using CPW technology is realized by cascading the unit cell periodically. The resonant frequency of the proposed antenna is determined by the shorted meander line (L_L) and capacitance between the top patch and CPW ground (C_R). By changing the length of the meander line, the shunt inductance and resonant frequency can be easily modified. The bottom ground plane is placed under the top patch. Increasing the length of the bottom ground plane (W_3) increases the value of the C_R. The width of the bottom ground plane (L_3) is adjusted to achieve the impedance matching.

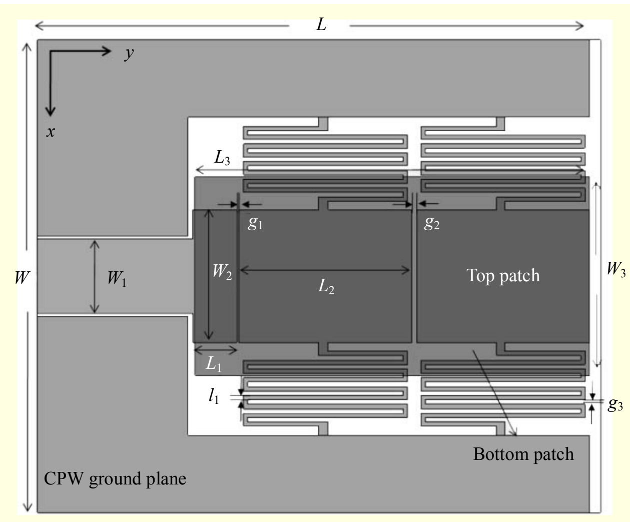

Fig. 1. Schematic of the proposed ZOR antenna. L_1=2, L_2=7.8, L_3=17.8, W_1=3.4, W_2=6, W_3=9, g_1=0.1, g_2=g_3=0.2, l_1=0.2 (unit: mm).

Since the CPW TL provides more design freedom for the reactive parameters, both a wider bandwidth and small size can be satisfied by using a proper design. When the impedance matching at the input terminal of the antenna is not considered, its fractional bandwidth is given by

$$BW = G \times \sqrt{\frac{L_L}{C_R}}, \quad (3)$$

where G is the shunt conductance of a lossy CRLH TL [1]. According to (3), in order to improve its bandwidth, the proposed antenna is designed to have a large L_L. Therefore, the meander lines are utilized so as to realize a short stub as well as to enlarge L_L easily. Because the top patch is situated far from the CPW ground, C_R is small. Therefore, from (3), the bandwidth of the antenna is increased because of the large L_L and small C_R.

The impedance matching network is an important factor to increase the bandwidth [5]. In order to match the impedance, a stub on top of the substrate and partial ground plate are introduced. Both the width and length of the stub play important roles in impedance matching. In addition, the length of the bottom ground (L_3) is exploited to obtain good impedance matching.

III. Simulation and Experimental Results

The fabricated prototype is shown in Fig. 2. This antenna is built with a CPW configuration and printed on the top and bottom of the substrate without vias. Thus, the proposed antenna has the features of easy fabrication and low profile configuration. The proposed antenna is designed to have its zeroth-order mode at 2.03 GHz by Ansoft High Frequency Structure Simulator (HFSS). The electrical size of the unit cell of the antenna is $0.097\lambda_0 \times 0.053\lambda_0$ at 2.03 GHz. The overall area of the antenna is approximately $0.145\lambda_0 \times 0.172\lambda_0 \times 0.011\lambda_0$ (21.4 mm × 25.4 mm × 1.6 mm). Figure 3 shows the simulated and measured return losses. The measured 10 dB bandwidth is 6.8%. Figure 4 shows the simulated and measured radiation patterns on the x-z and y-z planes at 2.03 GHz. The measured

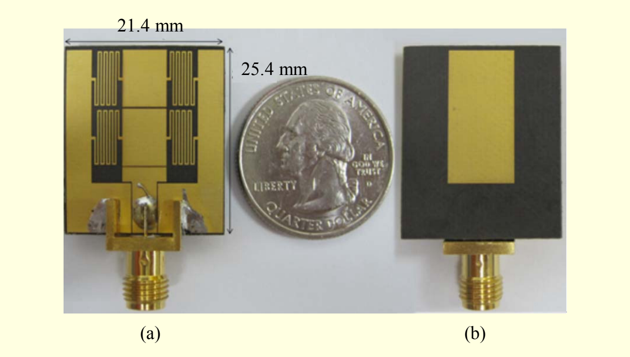

Fig. 2. Prototype of the proposed ZOR antenna: (a) top and (b) bottom.

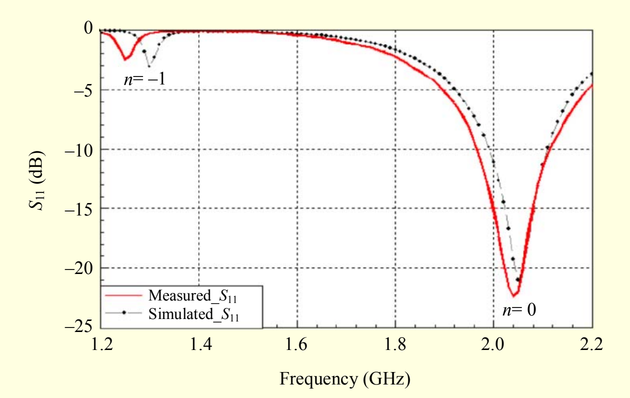

Fig. 3. Simulated and measured return losses of the proposed antenna.

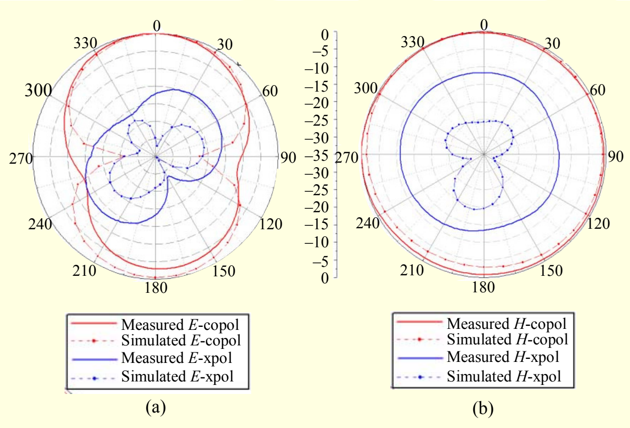

Fig. 4. Measured and simulated radiation patterns for (a) *E*-plane and (b) *H*-plane at 2.03 GHz.

and simulated co-polarization radiation patterns show good agreement and the measured cross-polarization levels are higher than the simulated ones. This is because of the fabrication errors in the fine meander lines and the measurement errors due to the small aperture size compared with the RF cable. Figures 5(a) and (b) show the electric field

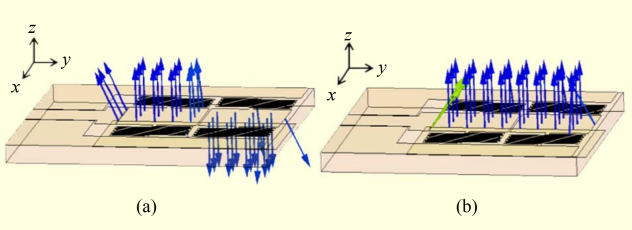

Fig. 5. Electric field distributions at (a) n=–1 mode and (b) n=0 mode.

distributions for the $n = –1$ and $n = 0$ modes, respectively. The distribution of the $n = –1$ mode shows the electric field, which is 180° out of phase. As shown in Fig. 5(b), the electric field distribution is in-phase at $n = 0$. The measured gain and radiation efficiency are 1.35 dBi and 62%, respectively. In addition, it can be easily designed and fabricated in a single layer without vias.

IV. Conclusion

A ZOR antenna on a vialess CPW single layer was proposed. The proposed antenna is realized with a CRLH structure. The zeroth-order resonance of the CRLH resonator enables a small antenna to be realized. In order to realize the compact size and enhance the bandwidth, the equivalent circuit parameters are modified in CPW-based antenna geometry. At 2.03 GHz, the bandwidth and efficiency are measured to be 6.8% and 62%, respectively. Additional benefits of compactness are provided by a via free and single layer process. Therefore, the proposed antenna may be useful in wireless communication applications.

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