A Bandwidth Enhanced Elliptical Metamaterial Antenna

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Abstract— In this paper, an elliptical Zeroth Order Resonant (ZOR) antenna based on composite right/left handed (CRLH TL) is proposed. ZOR antennas suffer from a negative drawback of being narrow bandwidth. In this paper, an effort is made to circumvent this negative effect by implementing a coplanar waveguide (CPW) fed elliptical unit cells without vias. The bandwidth, gain and radiation efficiency of the proposed antenna is about 5%, 2.1054 dB and 65.937% respectively at 4.88 GHz ($n = 0$ mode). Simulated results are presented and discussed. The antenna consists of 2 elliptical unit cells flanked symmetrically on both sides by open ended spiral and anti-spiral inductors. The antenna was designed to operate from (4.715 to 4.945) GHz with a reflection coefficient of −24.2836 dB at the zeroth mode (4.88 GHz). The proposed elliptical ZOR antenna serves another purpose of being a very low profile one, exhibiting an omni-directional radiation pattern in H-plane (phi = 0 deg) and a dumb-bell shaped radiation pattern in E-plane (phi = 90 deg). Hence the proposed antenna is aptly suited for wireless applications (IEEE 802.11a standards). All simulations were carried out by using Ansoft HFSS.

1. INTRODUCTION

Low profile antennas with omni-directional radiation pattern are mostly suitable for modern day wireless communication systems. This requirement is met with the use of monopole and dipole antennas. However these devices being large couldn't meet the demands of compact, portable devices. Metamaterials comes into picture to solve this problem as metamaterials are popularly used to design low profile antennas and microwave devices [1, 2]. The composite right/left handed metamaterial transmission lines is an effective method to realize low profile,compact infinite wavelength zeroth order resonant antennas. But these ZOR antennas suffer from narrow bandwidth, low gain and low radiation efficiency [3, 4]. To circumvent all these negative effects a low profile elliptical ZOR antenna with symmetrically placed spiral and anti spiral inductors on both sides of each unit cell is designed and its performance studied.

In this paper, a low profile, extended bandwidth omni-directional antenna is designed with the foundation laid on CPW fed metamaterial CRLH TL concepts [5]. A high gain, monomode, single band antenna is achieved with 65.937% radiation efficiency. Simulated radiation pattern and 3D-gain using Ansoft HFSS are shown.

2. ZEROTH ORDER RESONANCE THEORY

ZOR phenomenon is based on infinite wave length with no dependence on its physical size at its zeroth order mode (fundamental mode). As shown below in Figure 1(a), a CRLH TL is composed of series capacitance C_L and inductance L_R as well as a shunt capacitance C_R and inductanceL_L.

The series and shunt resonant frequencies are given by

$$\omega_{se} = \frac{1}{\sqrt{L_R C_L}} \text{ rad/sec} \tag{1}$$

$$\omega_{sh} = \frac{1}{\sqrt{L_L C_R}} \text{ rad/sec} \tag{2}$$

By applying periodic boundary conditions (PBCs) related to the Bloch-Floquet theorem, the CRLH TL unit cell's dispersion relation is determined to be

$$\beta(\omega) = \frac{s(\omega)}{\Delta Z}\sqrt{\left[\omega^2 L_R C_R + \frac{1}{\omega^2 L_L C_L} - \frac{L_R C_L + L_L C_R}{L_L C_L}\right]} \tag{3}$$

where $s(\omega)$ and ΔZ are a sign function and the differential length, respectively.

For an unbalanced LC-CRLH TL, ω_{se} and ω_{sh} are unequal as shown in the dispersion diagram of Figure 1(b). At these resonant frequencies as $\beta = 0$, so an infinite wavelength can be supported and the resonance condition is independent of the size of the antenna (i.e.; the CRLH TL's length) while the shortest length of the conventional open ended resonator is one half of the wavelength. Thus, an antenna with a more compact size can be realized.

3. DESIGN METHODOLOGY

The proposed elliptical antenna implemented on a Rogers RT/Duroid 5880 substrate ($\varepsilon_r = 2.2$) with a size of $32\,\text{mm} \times 30\,\text{mm} \times 1.6\,\text{mm}$ is presented. The antenna exhibits a high gain and antenna efficiency of about 2.1054 dB and 65.937% respectively at the zeroth mode of 4.88 GHz. The reflection coefficient achieved at this mode is about 24.2836 dB with a bandwidth of 5%.The antenna gives rise to an omni-directional radiation pattern in H-plane (phi = 0 deg) and a dumb-bell shaped radiation pattern in E-plane (phi = 90 deg). The ZOR antenna consists of 2 elliptical unit cells each of size ($6\,\text{mm} \times 7.8\,\text{mm}$) with coplanar waveguide feeding. Each unit cell is flanked symmetrically on both sides by a combination of short ended spiral and anti-spiral inductors. As the whole CRLH TL structure is excited by open circuiting, shunt resonance ω_{sh} initiates, with energy being stored in the shunt elements.

Therefore, in the open-ended CRLH resonator case, the fractional bandwidth is given by

$$B.W. = G\sqrt{\frac{L_L}{C_R}} \tag{4}$$

As bandwidth is directly proportional to the length of these spiral stub inductors (L_L) and inversely proportional to the overall area of the substrate (C_R). So by adopting this methodology of elliptical unit cells with spiral inductors, an extended bandwidth with high gain and radiation efficiency is achieved. As the spiral inductors are shorted at their ends to the CPW grounds so no vias are needed which simplifies the realization of this antenna.

4. ANTENNA DESIGN

The geometrical model of the proposed compact monomode, single-band ZOR antenna is shown in Figure 1 with two elliptical unit cells. The unit cells or the radiating patch is separated by a small gap of 0.2 mm. This gap provides the series LH capacitance C_L, while, the magnetic flux produced by the current flow along the radiating patch provides the parasitic series RH inductance L_R The short ended spiral inductors of width 0.4 mm introduce the LH inductance L_L. The gap between the spiral inductor strips is also equal to 0.4 mm. Figure 2 and Figure 3 shows the simulated reflection coefficients of −24.2836 dB and 3D-gain of 2.1054 dB at the zeroth mode respectively. Figure 4 shows the E-radiation pattern at x-y plane and H-radiation pattern at x-z plane at $n = 0$ mode. A dumb-bell shaped E-radiation pattern and an omni-directional based H-radiation pattern is obtained. Figure 5 shows that the VSWR of the antenna at $n = 0$ mode (freq = 4.88 GHz) is about 1.13 which is acceptable.

5. SIMULATION RESULTS

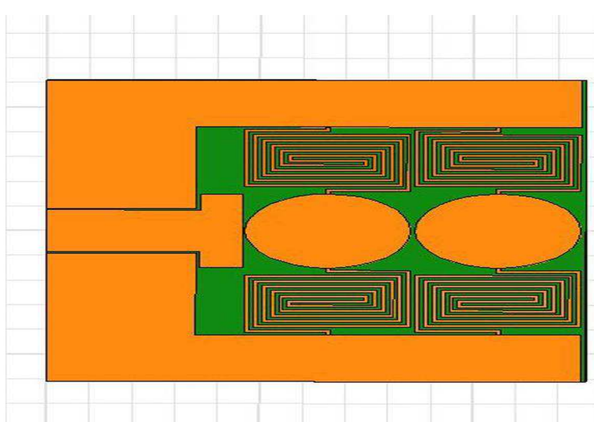

Figure 1: Geometrical model of the proposed single-band, monomode ZOR antenna (with two unit cells).

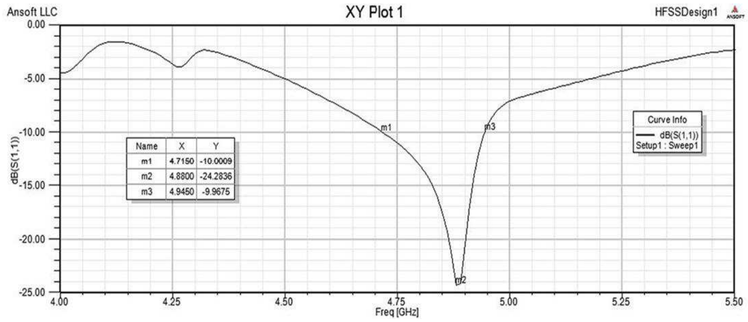

Figure 2: Simulated reflection coefficients of the proposed ZOR antenna.

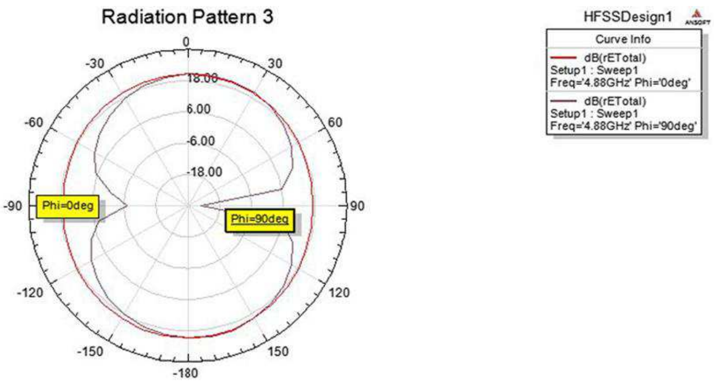

Figure 3: Simulated radiation pattern at $n = 0$ mode (freq $= 4.88$ GHz) [Phi $= 0$ deg (x-z plane) and Phi $= 90$ deg (y-z plane)].

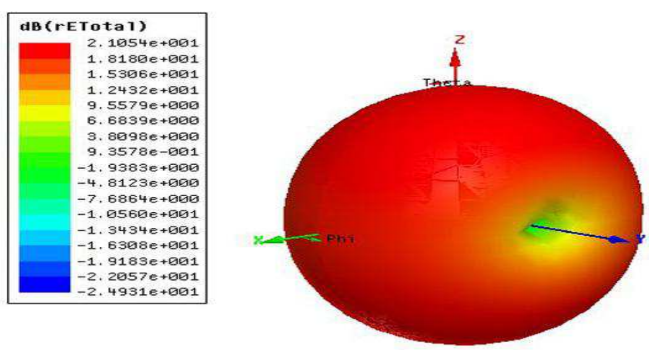

Figure 4: 3D-Gain of the proposed antenna at $n = 0$ mode (freq $= 4.88$ GHz).

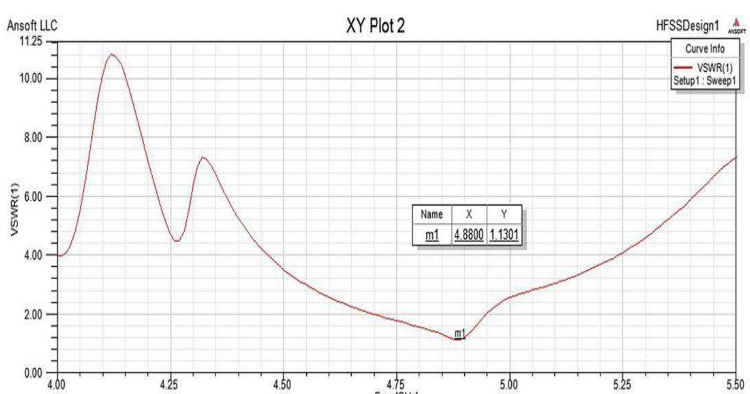

Figure 5: VSWR of the proposed antenna at $n = 0$ mode (freq $= 4.88$ GHz).

6. CONCLUSION

A new compact metamaterial based elliptical antenna built on a Rogers RT/duroid 5880 substrate is designed and presented. It radiates omni-directional waves in the horizontal plane. It is miniaturized by increasing the LH inductor by using a combination of spiral and anti-spiral stub inductors. This antenna, which exhibits a size of 0.158_0 × 0.07_0, shows a simulated gain of 2.1054 dB and a fractional bandwidth of 5%. with an antenna efficiency of 65.937%. Besides, the antenna gain of 2.11 dB and the efficiency of 65.937% were achieved.

ACKNOWLEDGMENT

The authors would like to thank Prof. D. R. Poddar, Jadavpur University, Kolkata, India for providing simulation facilities at his laboratory to carry out this work.

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