Design of a via-less, compact CPW-fed ZOR Antenna for WLAN Applications

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***Abstract*—A single layer, low profile, compact metamaterial zeroth-order resonator (ZOR) antenna has been proposed in this paper. A composite right/left-handed (CRLH) transmission line structure that is comprised of a single unit cell makes up the complete antenna. The design complexity of the proposed antenna is very low, since it does not involve any vias. A symmetric co-planar waveguide (CPW) structure is chosen to have design flexibility and to satisfy the design constraints. The main aim of incorporating the left handed behaviour into the design is to achieve compactness. The resonant frequency of zeroth-order mode is around 5.8GHz. A prototype of the proposed antenna has been fabricated and it has the dimensions of 0.348λo × 0.309λo × 0.033λo. The simulated peak gain of the antenna is found to be 0.65dBi. A significant amount of size reduction is observed in the patch area of proposed structure when compared to a regular patch antenna operating at the same frequency. The metamaterial behaviour has been verified with the help of dispersion diagram and vector electric field plot. Simulation is done so as to plot the reflection coefficient of the presented CPW ZOR antenna and it is also observed on the vector network analyzer (VNA). Simulation results show that the proposed ZOR antenna achieves -10dB impedance bandwidth of 7.76% and has a radiation efficiency of about 81.27% at the ZOR mode.**

I. INTRODUCTION

Russian physicist Viktor Veselago was the first to draw speculations on the existence of materials with simultaneous negative values of permittivity and permeability for which the electric field, magnetic field and the phase constant vectors will form a left-handed triad when electromagnetic waves are made to pass through them [1]. These were called left handed (LH) materials. In recent times many researchers have started exploring the world of metamaterials and they have been successful too. Metamaterials have been used extensively in the modeling of antennas, microwave filters, couplers and other such similar devices [2], [3], [4] and [5].

The property of negative refraction is one of the unique features of a metamaterial (anti-parallel group and phase velocity). One of the main reasons for using metamaterials in the design process of various structures is its ability to offer design compactness. However the main drawbacks while using such structures are narrow operational bandwidths and lower radiation efficiencies. Many a time these become serious issues in the world of wireless communication systems. So designers need to concentrate on increasing the operational bandwidth and gain while reducing the dimensions of the antenna. The operational bandwidth of an antenna essentially depends on the quality factor (Q) and impedance matching. Q value is determined by the reactive and resistive elements that make up the composite right/left handed (CRLH) transmission line structure. Larger the Q value, smaller is the operational bandwidth. Usage of substrates that have high dielectric constants and meander line inductors must be avoided as they result in high Q - factor. One of the methods to increase the operational bandwidth has been presented in [6]. The radiation efficiency of such structures is reduced because the rate of reduction of the radiation resistance is much higher than that of the ohmic resistance. One way of increasing the radiation efficiency is to reduce the ohmic losses and a method which uses this technique is mentioned in [7]. Reference [8] proposes a technique that provides a simultaneous increase in the bandwidth and radiation efficiency.

The concept of zeroth-order resonance (ZOR) has been employed in the proposed antenna. In the ZOR antenna, at the resonant frequency (ω_r, which is essentially a nonzero value) the propagation constant (β) vanishes. Mathematically, the wavelength goes to infinity. In contrast to the conventional transmission line structures, ZOR structures have unique properties that their resonant frequencies are independent of their physical size rather they depend on the modeled circuit parameters of the structures [9]. So it is possible to decrease the antenna size and still have good gain.

In the antenna design process, CPW feeding technique is used so that the circuitry can be built on a single plane and this makes the fabrication process simpler. Also a high degree of freedom in the design is obtained. To verify the ZOR characteristics, we have plotted the vectored electric field plot. Commercially available tool high frequency structure simulator (HFSS) has been used to perform the full wave simulation of the presented antenna. In the end, the simulated outcomes have been compared with the experimental results.

II. OPERATING PRINCIPLE AND ANTENNA DESIGN

A CRLH transmission line structure is used to realize the proposed antenna. A unit cell of the mentioned structure can be modeled as a lumped parameter circuit as shown in Fig. 1, whereas Fig. 2 shows the layout of the proposed antenna. The reported antenna in [10] serves as the motivation for the presented design. A simple, novel CPW feed ZOR antenna that comprises of a resonant ring for bandwidth enhancement has been proposed in there that is used as a reference for the proposed design. In [11], authors discuss the various feeding methods for a patch antenna that are classified into two distinct categories namely non-contacting and contacting. In the non-

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contacting technique, power is fed to the antenna through electromagnetic coupling mechanism (e.g. aperture coupling), whereas in the contacting feeding method, the excitation of the patch is done by connecting it directly to a co-axial cable or to a microstrip line. The circuit model exhibits both the right- and the left-handed properties. The property of right-handedness is exhibited by the series-arm inductance, L_R and the shunt-arm capacitance, C_R, whereas that of the left-handedness is exhibited by the series-arm capacitance, C_L and the shunt-arm inductance, L_L. Such unit cells do not occur in nature and need to be artificially engineered. The conventional transmission line structure model exhibits the properties of right-handedness only. The losses in the circuit are accounted for by a resistor, R and a conductor, G. The impedance of the series arm, Z and admittance of the shunt arm, Y are given by the expressions,

$$Z = R + j(\omega L_R - 1/\omega C_L) \quad (1)$$

$$Y = G + j(\omega C_R - 1/\omega L_L) \quad (2)$$

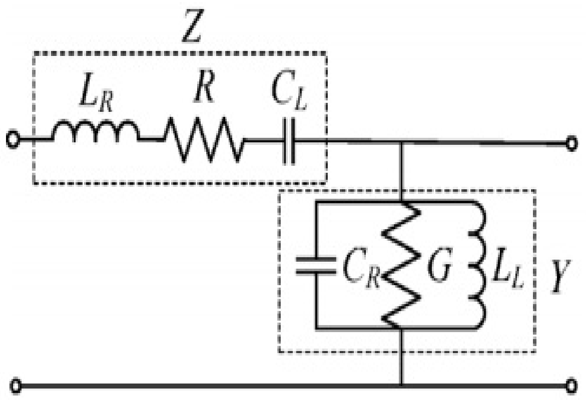


Fig. 1. Lumped equivalent circuit model of a CRLH TL unit cell [1].

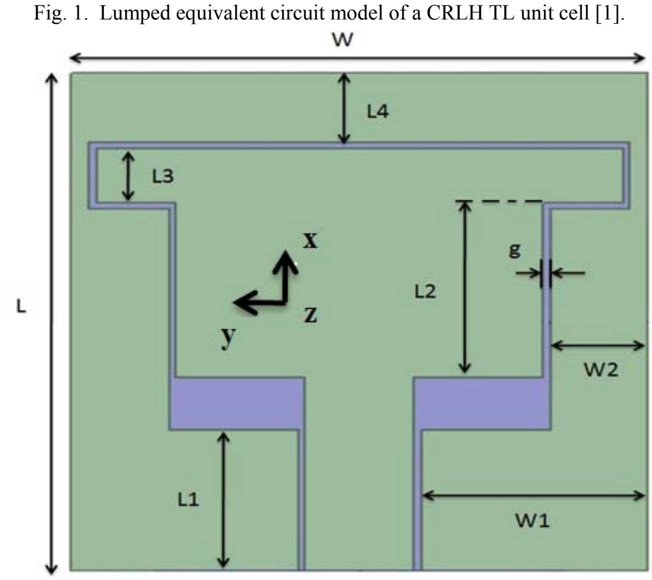


Fig. 2. Structure of the proposed ZOR antenna, where L = 18, W = 16, L1 = 5.1, L2 = 6.3, L3 = 2, L4 = 2.5, W1 = 6.3, W2 = 2.7, g = 0.2 (All dimensions are in mm).

The substrate used in the design of the antenna is FR4 epoxy that is 1.6mm thick and has a relative permittivity (ε_r) of 4.4 and the dielectric used has a loss tangent (tan δ) of 0.02. The feed line is 3mm wide. The radiating patch accounts for the right handed series-arm inductance, whereas the right handed shunt-arm capacitance and the left handed series-arm capacitance is accounted for by the divide (gap) between the patch and the ground. The value of left handed shunt-arm inductance can be controlled by varying the sizes of the patch and the ground and is modeled by shorting the ground terminals with each other. The equivalent lumped circuit parameter values are obtained by the method of Parameter Extraction (PE). The existence of ZOR mode can be verified by looking at the dispersion diagram that has been obtained by the Bloch Floquet analysis [12] and is shown in Fig. 3. The existence of right handed (RH) mode (prevails for frequencies greater than 5.83GHz) and left handed (LH) mode (prevails for frequencies less than 5.2GHz) can be verified by observing the dispersion diagram. The unit cell is an unbalanced one since the phase constant is zero in a frequency range and not at a single unique frequency.

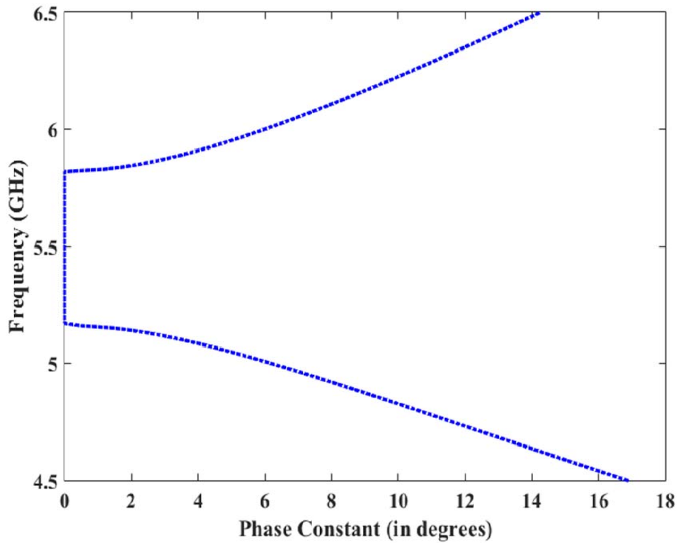


Fig. 3. Dispersion Plot (Extracted lumped parameters: L_L = 11.2 nH, L_R = 5.96 nH, C_L = 125.4 fF, C_R = 84.9 fF).

III. Simulation And Experimental Results

The simulated ZOR frequency is 5.8GHz while the experimentally measured ZOR frequency is around 5.72GHz. Similarly the simulated Impedance bandwidth, radiation efficiency and 3D Maximum Gain are 7.76%, 81.27% and 0.65dBi respectively. The experimentally measured Impedance bandwidth is 7.35% and it agrees well with the simulated result.

A plot that needs to be analyzed is the "Reflection coefficient" or the "S11" plot. It is shown in Fig. 4. The plot essentially compares the results obtained from the simulation and from the experimental analysis. Because of the fabrication tolerances and some undesired parasitic effects, there exists a small gap between the valley points of the two plots. However it can be observed from the curves in the plot that there isn't much difference in the fractional bandwidths.

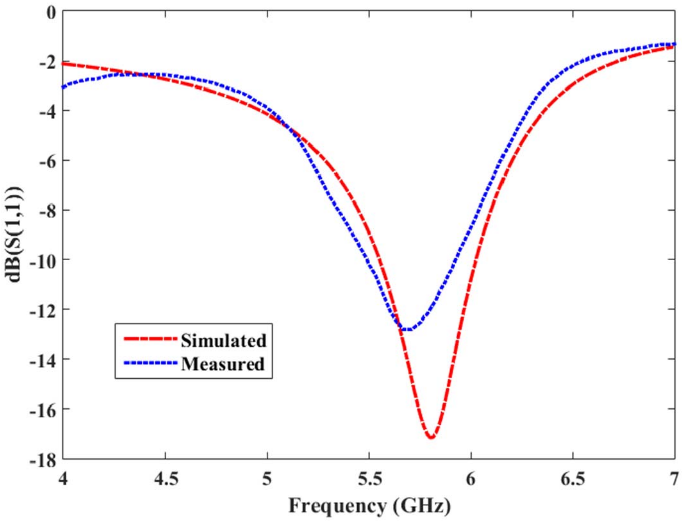


Fig. 4. Measured and simulated reflection coefficient of the proposed antenna.

The vector electric field plot at 5.8GHz is shown in Fig. 5. It can be inferred by observing the plot that the field lines are in phase, which is a characteristic of an antenna operating in ZOR mode.

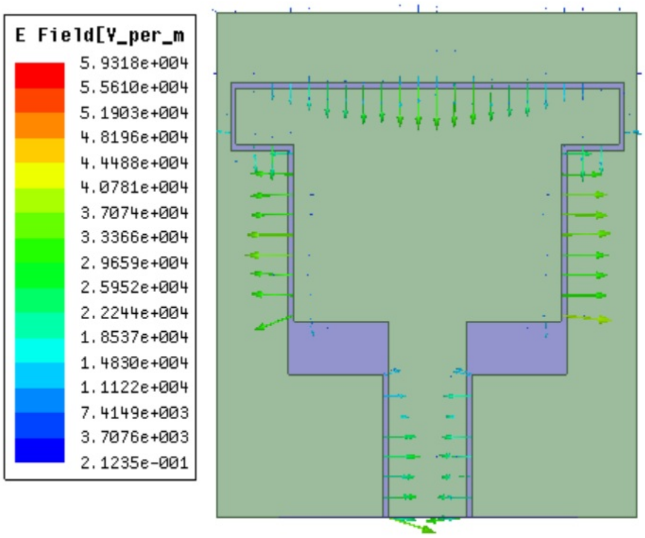
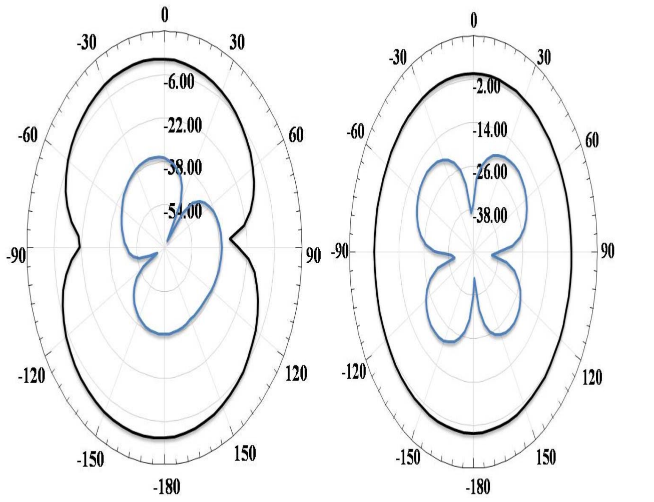


Fig. 5. Vectored electric field plot of the presented antenna at 5.8GHz.

Fig. 6. Fabricated prototype of the presented CPW-fed ZOR antenna.



(a) (b)

Fig. 7. Simulated radiation pattern of the presented antenna at its ZOR frequency. (a) xz plane, (b) yz plane. Black coloured line: co-polarization, Blue coloured line: cross polarization.

A snapshot of the fabricated prototype of the presented antenna is shown in Fig. 6, whereas the simulated radiation pattern of the proposed antenna in the xz and yz plane is shown in Fig. 7(a) and Fig. 7(b) respectively. From Fig. 6, it can be presumed that the xz plane has a dipole like radiation pattern and the yz plane has an isotropic like radiation pattern. The cross polarization levels in both the planes are minimal. Table I provides a comparison overview of a few parameters of the proposed antenna with that of some existing WLAN antennas.

TABLE I. COMPARISON OF THE PROPOSED ANTENNA WITH CONTEMPORARY WLAN ANTENNAS.

	Proposed Work	**[13]**	**[14]**
Operating Frequency (GHz)	5.8	5.8	5.8
Vias	Not present	Present	Not present
Gain (dBi)	0.65	6.1	5.17
Simulated Fractional bandwidth (%)	7.76	4.1	6.9
Efficiency (%)	81.27	-------	--------
Antenna dimensions (λ_o)	0.348 × 0.309 × 0.033	1.547 × 1.16 × 0.033	0.556 × 0.627 × 0.039
Dielectric used	FR4 epoxy ($\varepsilon_r = 4.4$)	Rogers 5880 ($\varepsilon_r = 2.2$)	RT-Duroid ($\varepsilon_r = 2.2$)

IV. CONCLUSION

The design of a CPW-based compact, low profile, simple and radiation efficient ZOR antenna based on CRLH-TL has been presented in this paper. The structure has been implemented on a low cost via-less FR4 board. At 5.8GHz, we obtain the ZOR mode. ZOR mode of operation of antenna reduces its size. The vector electric field plot of the antenna can be used to verify the existence of the ZOR mode. A reasonable gain and radiation efficiency level of the presented antenna is obtained at the ZOR mode. There ain't much difference between the simulation and experimentally measured results w.r.t various operational parameters of the proposed antenna. In the end, a comparative analysis between the proposed model and two other existing models has also been done.

V. ACKNOWLEDGMENT

We would like to express our gratitude to Dushyant Marathe, N. Anvesh Kumar and Paritosh Peshwe for the assistance that they provided in carrying out the proposed work.

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