Design and Analysis of Small Planar Antenna Based on CRLH Metamaterial for WSN Application

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Abstract. In this paper a small antenna is proposed for wireless sensor network applications in the frequency band of 5 GHz to 15 GHz. Wireless Sensor Networks (WSN) is having significant attention due to their numerous features nowadays. The most important component in sensor is its TX/RX antenna. In this design a new efficient CRLH based DNG metamaterial antenna is proposed. The design of the unit cell of these antennas is based on the composite right/left-handed (CRLH) transmission line model. Antenna1 used two patches and obtained results are compared with antenna2 with four patch. In this paper, we introduce a new method of design of CRLH metamaterial antennas to tackle the above problem using CRLH mushroom structure. The results of antenna2 show improvements over antenna1 in gain and bandwidth. By employing CRLH geometry, an overall size reduction of 65% was achieved compared to the conventional rectangular patch antenna. The proposed antenna can be easily built in a miniaturized wireless sensor network (WSN). RogersRT/Duroid 5880 is taken as substrate with thickness 1.572 mm and relative permittivity 2.2. The bandwidth of this antenna less than 10 dB is 700 MHz and the percentage of the bandwidth is 6.1%. The antenna characteristics, such as return loss and VSWR achieved by the proposed structure are plotted.

Keywords: Return loss, WSN, VSWR, CRLH, Bandwidth.

1 Introduction

Metamaterial structures were first introduced by Veselago in 1968 [1]. Later on, the realization of such material was done by [2–4], where periodic array of wires with specific radios and spacing is used to produce negative permittivity [2] or capacitive loaded stripes can also be used to produce the same effect [4], whereas the negative permeability was induced using the split ring resonators [3]. These metamaterials have many interesting properties, one of these that the double negative metamaterials are able to match the intrinsic capacitance (reactance) of an electrically small antenna. This property was used in [5] toward producing an efficient electrically small wire antenna.

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One of the other metamaterial realizations was presented using transmission line (TL) theory based on the equivalent circuits of the right-handed and left-handed propagation in the unit cell of the TL [8–11]. This model is called composite right/left-handed (CRLH) met materials. The CRLH-TL can be realized using the mushroom structure [9] which was originally introduced by Seivenpiper [12] to produce high impedance surfaces. Park [13] emphasize on using the CRLH antenna structures at the zeroth-order resonance.

The Wireless Sensor Network (WSN) is a flexible and scalable paradigm that is drawing increasing attention due to its potential utilization in many civilian and military domains effect [4], A WSN utilizes a significant number of sensor motes and automatically builds a network topology. People staying at the coverage of the network can receive the signals sent by the sensors in time and thus swiftly arrived at the venue. Based on this requirement, in this paper our aim is to develop a novel small antenna that is compatible with the WSN. The novel antenna should have a compact size, low profile, low power, low cost, easy fabrication, and sufficient transmission range. They are suitable to develop a miniature WSN, combine individual wireless sensors, and become an information network for universal transmission of information.

2 CRLH Transmission Line Model

The equivalent electrical circuit models of a purely RH (PRH), purely LH (PLH), and CRLH lossless Transmission Line are shown in Figure 1(a), (b), and (c), respectively. Transmission Line theory has long been a powerful analysis and design tool for conventional RH materials. By modeling a CRLH metamaterial as an equivalent TL, TL theory can be used to analyze and design 1-D, 2-D, or even 3-D CRLH metamaterials. In this section the TL approach of CRLH metamaterials has developed. First, the CRLH metamaterial will be represented by an equivalent electrical homogeneous CRLH TL to gain immediate insight into its fundamental characteristics. Then, an LC network implementation of the TL will be developed, since homogeneous CRLH structures do not appear to exist in nature. The LC network pro-vides a realistic description of the CRLH metamaterial. Finally, physical realizations of the LC network will be discussed. For simplicity, only the lossless TL will be examined. This circuit model shows that the structure is a CRLH material, as explained in [14]. The unit cell consists of a ground plane, substrate, and patch on the top of the substrate. The via connects the patch and the ground plane, and there is a gap between the adjacent patches in the whole structure. The study of the TL model of his structure is vital to know the effect of the inductances and capacitances on the guided and radiating waves.

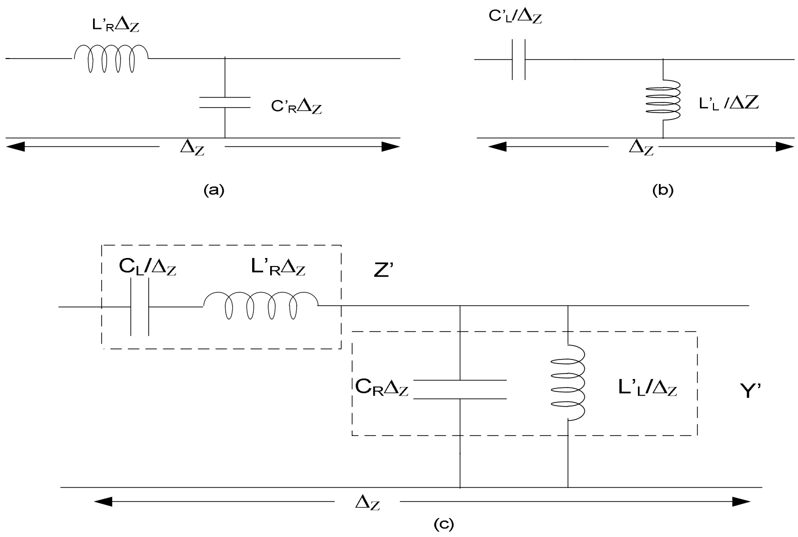

Fig. 1. Equivalent circuit model of (a) purely RH TL (b) Puruly LH TL (c) Purely CRLH TL

The propagation constant of a TL is given by $\gamma = \alpha + j\beta = \sqrt{Z'Y'}$, where Z' and Y' are, respectively, the per-unit length impedance and per-unit length admittance. In the particular case of the CRLH TL, Z' and Y' are defined as

$$Z' = j\omega L'_R - \frac{1}{\omega C'_L}$$

$$Y' = j\omega C'_R - \frac{1}{\omega L'_L} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

The advantages of using CRLH structures in the antenna design are that the resonances in the LH part of the dispersion diagram have lower resonant frequencies compared to the conventional antennas. This planar antenna has a zeroth-order resonant frequency that depends mainly on the values of the equivalent inductances and capacitances of the unit cell. Based on the open ended TL model of the CRLH, the zeroth-order resonance is given by

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$$f_o = \frac{1}{2\pi\sqrt{L_L C_R}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

and the bandwidth ratio at this resonance is proportional to $\sqrt{L_L/C_R}$.

3 Antenna Design with Two Patches

The geometry of the proposed CRLH based small antenna with two patches is shown in Fig. 2.

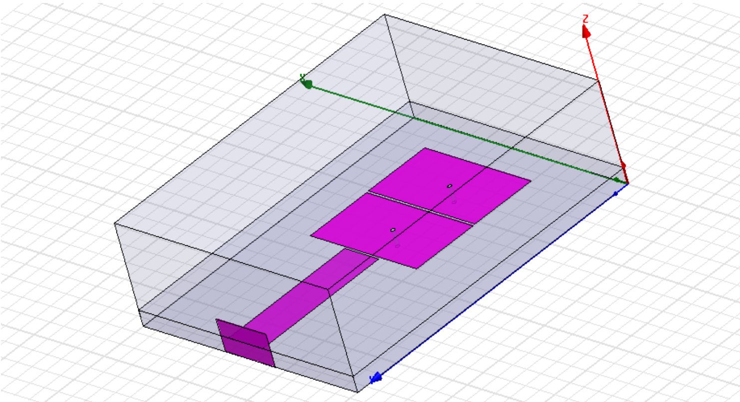

Fig. 2. CRLH metamaterial patch antenna1

The antenna is printed on a thin substrate with dielectric constant er=2.2 and dimensions of 30x35x1.575 mm3. Two patches are printed on the substrate; each

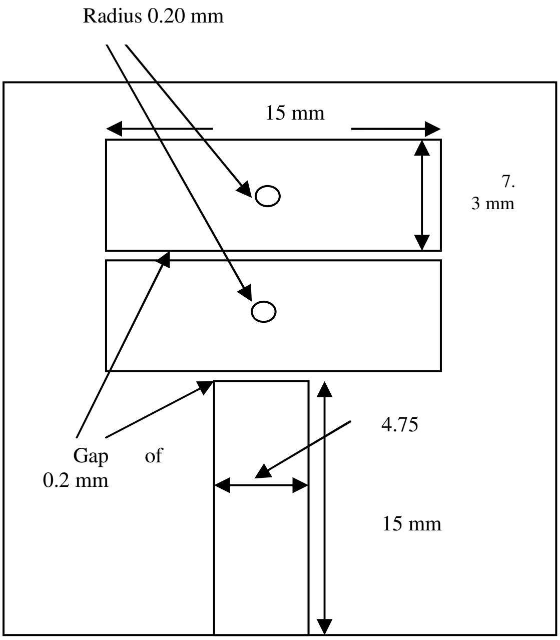

Fig. 3. Top view of CRLH antenna with two patches

patch has dimensions of 15x7.3 mm2 with a gap between the two patches of 0.2 mm. A micro strip line, of 4.75 mm width, is used to feed the first patch through a gap of 0.2 mm. A via with radius 0.2mm is used in each unit cell to introduce the shunt inductance L_L. The gap between the patches is used to introduce the series capacitance C_L. The antenna is simulated using HFSSv12 and the results plotted Figure 4 and 5. The results of the measurement agree well with the results of the simulation in the band 5–15 GHz.

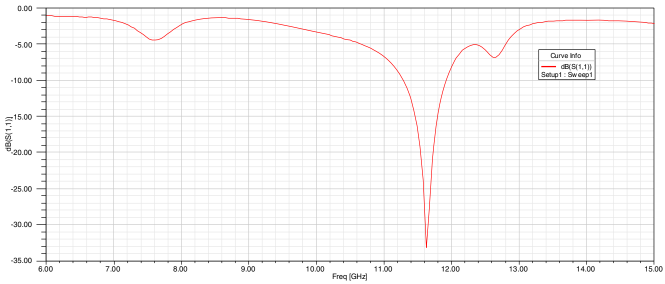

Fig. 4. Simulated Return loss (S11) plot for proposed antenna with two patches

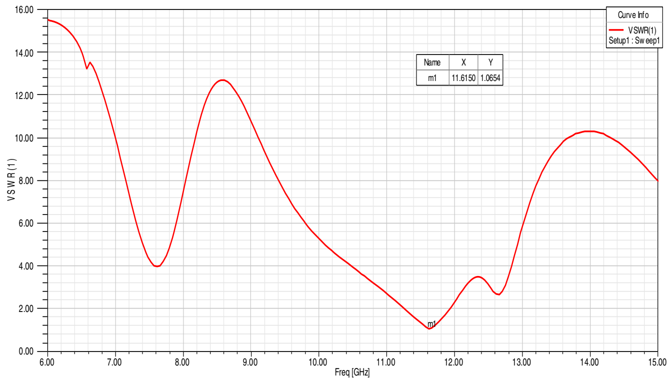

Fig. 5. Simulated VSWR plot for proposed antenna with two patches

4 Antenna Design with Four Patches

The geometry of the proposed CRLH based small antenna with four patches is shown in Fig. 5. The antenna is printed on a thin substrate with dielectric constant er = 2.2 and dimensions of 30x35x1.575 mm3. Four patches are printed on the substrate; each patch has dimensions of 15x5 mm2 with a gap between the two patches of 0.2 mm. A micro strip line, of 4.75 mm width, is used to feed the first patch through a gap of 0.2 mm. due to increase of patches over substrate the performance of antenna increases.

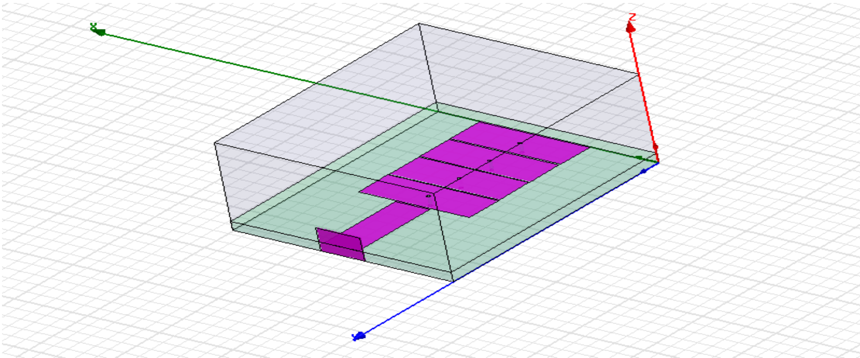

Fig. 6. CRLH metamaterial antenna with four patches

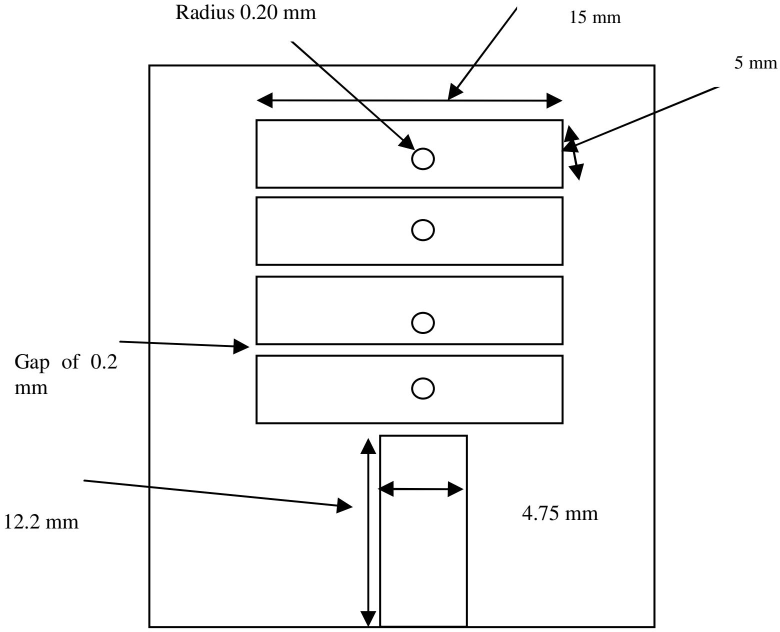

Fig. 7. Top view of CRLH antenna with four patches printed on thin substrate

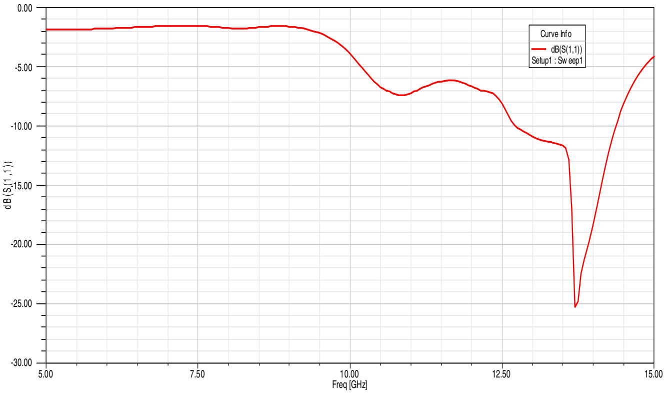

Fig. 8. Simulated Return loss (S11) plot for proposed antenna with four patches

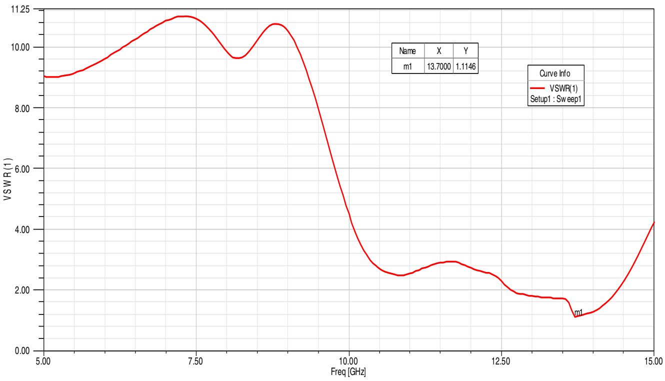

Fig. 9. Simulated VSWR plot for proposed antenna with four patches

5 Conclusions

The small size planner antenna designed for used in WSN is mainly intended to reduce power, achieve miniaturization, and achieve significant transmission distances. In this paper, we select the CRLH based double negative metamaterial for antenna miniaturization. We can shift the center frequency of the antennas by adjusting the gap between two CRLH unit and radius of via which is connected to ground and patch. Because of the advantage of the DNG Metamaterial it increases the bandwidth; moreover, the characteristics of the antenna can be improved, while its size can be significantly reduced and applicable for WSN application. By using four patches performance of antenna increases significantly. The above mentioned advantages have help to achieve the goal of antenna application for WSN. The designed structures use the concept of the CRLH-TL to achieve negative permeability and permittivity in the LH region.

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