Microstrip Patch Antenna Miniaturization Using Planar Metamaterial Unit Cell

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Abstract. A Microstrip patch antenna using planar metamaterial unit cell is designed, simulated and analyzed. The metamaterial unit cell is consisting of an interdigital capacitor and a complementary split-ring resonator (CSRR) slot. The antenna is tuned to work efficiently in the frequency range from 3 GHz – 5GHz depending on the geometric specifications of antenna and interdigital finger length. Proposed antenna provides good return loss behavior. The VSWR obtained in this band is very much near to 1. It covers many applications including mobile communication. This Antenna is compared with the conventional patch antenna, which shows the significant miniaturization as compared to conventional patch antenna.

Keywords: Metamaterial, Return loss, CSRR, VSWR.

1 Introduction

Electromagnetic metamaterials have been a field of intense research activity over the past decade. Due to the demand of small, compact, low cost antennas in the various military and commercial wireless communications it has increased tremendously over the past years. Metamaterials are periodic metallic structures exhibiting unique properties not existing in natural materials. Such materials exhibits permittivity and permeability both negative and hence they are known as the Double Negative (DNG) materials, backward wave materials, or left-handed materials (LHM). Since they have Negative Refractive index (NRI) and hence they are also called as the Negative Refractive Index materials or Left handed material LHM (as they follow left hand rule). This idea is proposed by Veselago 1968 [1]. In which the extraordinary electromagnetic features of the negative index medium were predicted. In this paper a new idea is proposed for miniaturization of patch antenna using interdigital capacitor and complementary split ring resonator. The transmission line (TL) approach of metamaterials was established in 2002 [2]–[5]. Metamaterial TLs are called composite right/left-handed (CRLH) TLs because they have both right- and left-handed properties. In other words, a CRLH TL supports not only a positive phase constant, but also a negative phase constant in a specific frequency region and a zero

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phase constant at a nonzero frequency. Because their unusual properties they offer some interesting changes in radiation characteristics of an antenna. The idea of MTMs has been quickly adopted in research, due to rapidly-developing nanofabrication and sub-wavelength imaging techniques. [7].

In this paper, a small and wideband microstrip patch antenna loaded with a planar CRLH unit cell is presented. In order to impose CRLH properties on a patch antenna, the antenna includes an interdigital capacitor for series capacitance and a complementary split-ring resonator (CSRR) slot for shunt inductance. CSRR slots can be coupled with a TL or a waveguide in order to achieve CRLH characteristics. Owing to the CSRR and the interdigital capacitor, a CRLH unit cell is implemented in fully planar technology, and its dispersion characteristics are analyzed for small antenna application. In addition, the current distributions circulating around the CSRR slot induce a unique radiation mode that is orthogonal to the normal radiation mode. Moreover, combining two radiation modes provides a wideband property and a unique radiation pattern with high antenna efficiency, which is verified.

2 Antenna Design

The proposed antenna configuration made up of planar metamaterial unit cell is shown in fig. 1. In order to make a single planar CRLH unit cell, an interdigital capacitor is inserted into the patch which acts as series capacitance and CSRR slot is cut on the ground plane for shunt admittance. The equivalent circuit model of the CRLH unit cell is shown in Fig. 2. Interdigital capacitor ensures negative permittivity and CSRR ensures the negative permeability [8]. When both the structures are combined together then they simultaneously offer negative permittivity and negative permeability and hence it becomes double negative metamaterial.

The proposed patch antenna is designed on Teflon substrate ($\mu_r = 2.1$ and Tanδ = 0.001) with thickness of 1.57 mm and fed by a microstrip transmission line. Patch and

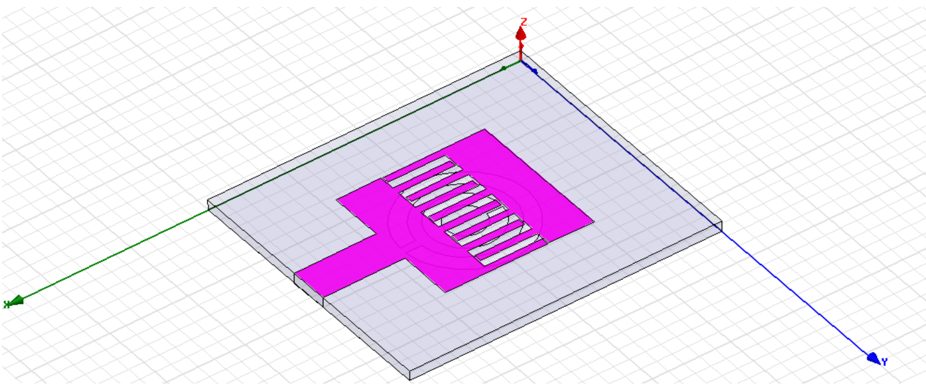

Fig. 1. Proposed antenna configuration in HFSSv12

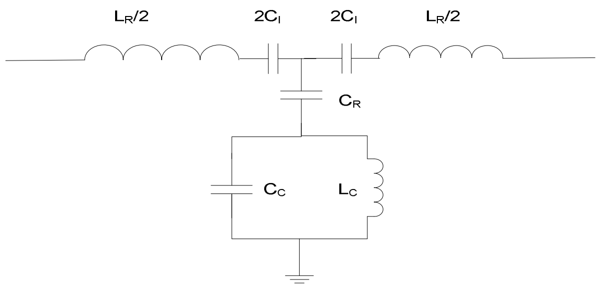

Fig. 2. Equivalent circuit model of the CRLH unit cell of the proposed antenna

ground plane are made of copper having relative permittivity as $\mu_r = 1$. Convergence was tested for each case separately in terms of evaluating S11 (dB) at a single frequency for a number of times. Once convergence was obtained, simulations were conducted in order to obtain swept frequency response extending from 4 to 4 GHz. The swept response gave us the S11, which was used to calculate the VSWR.

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

$$Y = j\omega C_R // \left(j\omega C_C + \frac{1}{j\omega L_C} \right)$$

Simulations were performed using HFSS™ [12]. HFSS (High Frequency Structure Simulator) is the industry-standard simulation tool for 3D full-wave electromagnetic field simulation. HFSS provides E- and H-fields, currents, S-parameters and near and far radiated field results. It integrates simulation, visualization, solid modeling, and automation. Ansoft HFSS employs the Finite Element Method (FEM) for EM simulation by developing/ implementing technologies such as tangential vector finite elements and adaptive meshing.

3 Results Analysis

The proposed antenna contains a single planar CRLH unit cell composed of a CSRR slot and an interdigital capacitor. By increasing the interdigital finger length, the electrical size of the antenna was decreased due to the increased series capacitance. The proposed antenna achieves a 45% reduction in patch size compared to a conventional patch antenna. Additionally, the increased interdigital finger length along with the CSRR slot generates the mode radiation, which can be combined with the normal mode. The combination of these two modes provides a wideband property (6.8%) and unique radiation pattern that are near-isotropic for the horizontal polarization and dipolar for the vertical polarization. Regardless of the small size of the proposed antenna, very high efficiency (96%) and moderate gain (3.85 dBi) are attained. The gain of the proposed antenna is only 2.2 dB lower than that of a conventional one operating at the same frequency band with the same ground size. Based on the antenna performances mentioned in the previous sections such as small size, high efficiency, and near-isotropic radiation pattern, one can conclude that the proposed antenna is applicable for a mobile RFID reader system requiring isotropic coverage

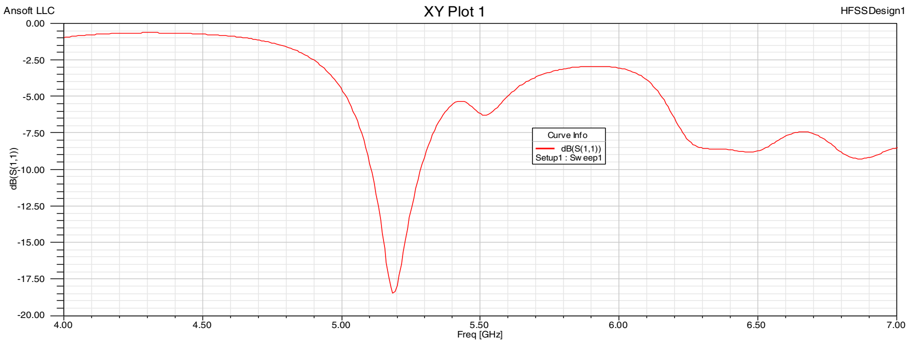

Fig. 3. Simulated Return loss of proposed patch antenna

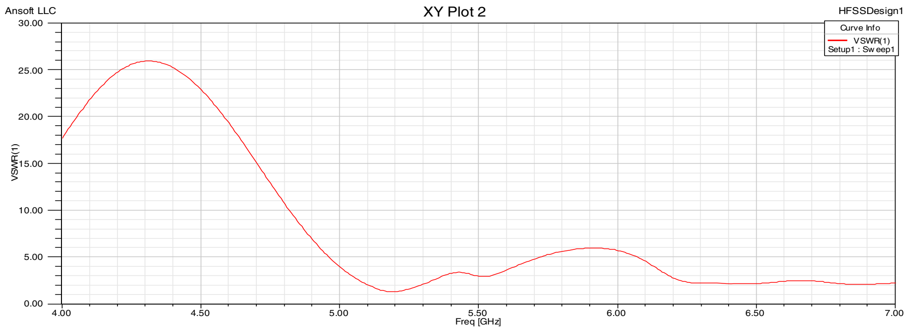

Fig. 4. Simulated VSWR of proposed patch antenna

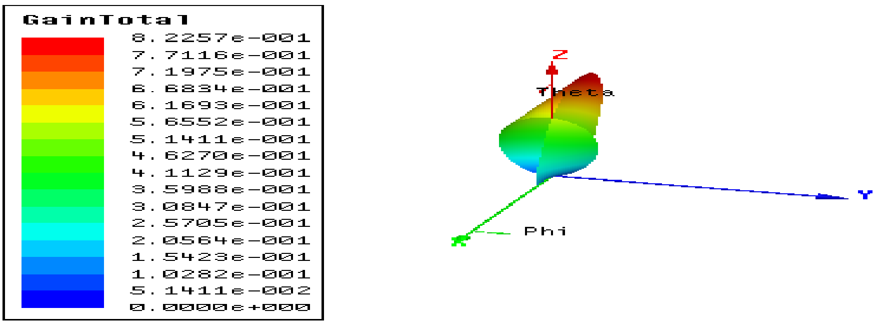

Fig. 5. 3D Polar plot of proposed patch antenna

4 Conclusion

Return loss characteristics of the proposed patch antenna with CSRR and inter digital capacitor is observed and plotted in Fig. 3. From the Figure it is concluded that antenna gives better return loss in between 3GHz to 5GHz. The percentage Bandwidth observed at -10 dB return loss is 2.4 and the gain of antenna is around 8. The corresponding VSWR plot for the same antenna is shown in the Fig. 4 VSWR values obtained as 1.3572, which is very much nearer to ideal value 1 for each case. The proposed antenna is suitable for RFID and mobile communication Application.

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