Metamaterial Loaded Microstrip Patch Antennas

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INTRODUCTION

Nowadays, compact antennas are becoming the backbone of different RF communication systems and handheld communication devices such as wireless networks, RF tagging, MIMO systems, sensor network, Bluetooth, public safety devices, PDAs, BAN, PAN, wearable devices, etc. to communicate voice, video, data and multimedia information at higher data rates. These antennas are also becoming a prime need for future 4G/5G communication technologies. The size of handheld communication devices is progressively becoming portable because these systems are becoming part and parcel of the everyday activities of human life. This needs the miniaturized antenna systems to be integrated with the printed chip and functional electronic circuitry involved in the devices. It is a great challenge for the antenna designers to develop compact antennas for such applications.

The microstrip antennas consist of a radiating patch of variety of regular geometrical shapes like rectangular, triangular, circular, square, ring, elliptical etc. and some complex shapes such as bow-tie. The shape and dimensions of the patch can be designed according to the resonant frequency with respect to application, gain, bandwidth and availability of space to install the antenna for a particular application. The desired resonant frequency, bandwidth, gain, and size of the antenna can be achieved by using various techniques such as making slots, meandering, shorting pin, stacking of substrates, etc. These limitations of microstrip patch antennas restrict the existing antennas to meet the challenges of present RF communication systems and devices (Bahl, 1980; Garg, 2001; Joshi, 2011, 2010, 2011, 2012; Pozar, 1995).

Metamaterial loaded microstrip patch antennas of size significantly lesser than usual half wavelength with higher gain, larger bandwidth and directivity are found to be suitable elements to overcome these limitations.

BACKGROUND OF METAMATERIAL AND ITS IMPORTANCE IN MICROSTRIP PATCH ANTENNAS

Most recently, antenna researchers have verified and evidenced an innovative approach to overcome the limitations of microstrip patch antennas by using metamaterial. In 1968, the Russian physicist Viktor Veselago theoretically predicted that metamaterial possesses negative values of magnetic permeability (μ) and/or electric permittivity (ε) (Veselago, 1968). Metamaterial structure consists of split ring resonators (SRRs) to produce negative permeability and thin wire elements to generate negative permittivity Metamaterial possesses both negative permeability (μ) and/or negative permittivity (ε). Hence, they are termed as double negative (DNG) or single negative (SNG) metamaterials. In SNG metamaterials either single of the property i.e. permeability or permittivity is negative. The permeability (μ) negative materials are called mu negative (MNG) and permittivity (ε) negative materials are termed as epsilon negative (ENG) materials. Researchers have reported the metamaterial properties of different SRRs. (Veselago, 1968; Pendry, 1999; Smith, 2005; Ziolkowski, 2003; Bilotti, 2007; Marques, 2003).

Metamaterial is used to load the microstrip patch antennas either by partially filling it beneath the substrate of patch or placing it as superstrate on the top of microstrip patch. The metamaterial SRRs may also

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be used directly to load the patch antenna on the same substrate. These techniques leads to enhance the gain, bandwidth, directivity of the microstrip patch antennas with considerable size reduction. Under loading condition, the microstrip patch antenna generates sub-wavelength resonances due to the modifications of the resonant modes. This loading leads to reduce the size of antennas by generating the sub-wavelength resonances. This article presents the following configurations of metamaterial loaded microstrip patch antennas.

- When a metamaterial unit cell is placed adjacent to the antenna for loading, due to mutual coupling between them the resonant frequency of the resulting antenna is shifted away than the resonant frequency of unloaded antenna and the unit cell. Under loading condition, the condition of electrically small antenna (ESA) that is $ka<1$ has been satisfied.
- Metamaterial resonators are used to design the magneto-inductive (MI) waveguides. The design of MI waveguide using different metamaterial resonators is an important feature of this article. Further, these MI waveguides are used to load the microstrip patch antennas for miniaturization as well as to enhance the bandwidth and gain.

ELECTRICALLY SMALL RECTANGULAR MICROSTRIP PATCH ANTENNA LOADED WITH SQUARE SRR

Figure 1 and 2 respectively depict the geometry and cross sectional view of square SRR loaded electrically small rectangular microstrip patch antenna. In this composite structure, the rectangular microstrip patch antenna is loaded with a planar metamaterial square SRR. The distance between rectangular microstrip patch antenna and the square SRR is d = 0.50 mm. The dimensions of the rectangular patch antenna are; length L_r= 5 mm and width W_r= 0.5 mm. The antenna is coaxial fed at x = -3.2 mm and y = -2.2 mm. This antenna structure is designed and simulated using RT Duriod 5880 substrate of thickness h = 3.175 mm and ε_r = 2.2 is used to design the antenna. The dimensions of the square SSR are; L_s= 5 mm, gap at split of rings (g), separation between inner and outer rings (s), and the width of rings is (w) are set to g = s = w = 0.2 mm.

Initially, an unloaded rectangular microstrip patch antenna is designed and simulated which resonates at 23 GHz when this antenna is loaded with square SRR it resonates at 9.51 GHz and wavelength of loaded antenna is 31.54 mm. Therefore; $k = \frac{2\pi}{\lambda} a = 0.775 < 1$, which satisfies the condition that designed antenna is an ESA (Chu 1948; Joshi 2010; Thiele 2003; Wheeler 1947). The SRR unit cell is closely placed near to rectangular microstrip patch hence due to magnetic coupling the electric field gets induced in the SRR unit cell and both the outer and inner split rings get excited that makes the SRR unit cell to produce metamaterial characteristics. After loading the patch antenna with a square SRR, resonant frequency of rectangular microstrip patch is reduced thus, making entire structure as an ESA. Initially, metamaterial characteristics of the designed square SRR have been verified.

Figure 3(a) and 3(b) respectively shows reflection (S_{11}) and transmission (S_{21}) coefficient characteristics of square SRR and zoom of this characteristic. Figure 3 (b) shows zoomed resonance behaviour of the structure at 4 GHz to 6 GHz band. It shows that the SRR resonate at 5 GHz. The effective medium theory is used to obtain permeability (μ_r) and permittivity (ε_r) from the reflection and transmission coefficient parameters (S-parameters) using NRW approach (Joshi, 2012, 2012, 2013; Pendry, 1999; Smith, 2005; Ziolkowski, 2003). The expressions of equations (1) and (2) are used to determine the effective medium parameters. In this work, IE3D electromagnetic simulator is used to get the S-parameters and subsequently using the mathematical equations and MATLAB code the metamaterial characteristics have been verified.

$$\mu_r = \frac{2}{jk_0 h}\frac{1-V_2}{1+V_2} \quad (1)$$

$$\varepsilon_r = \frac{2}{jk_0 h}\frac{1-V_1}{1+V_1} \quad (2)$$

where k_0 is wave number, h is substrate thickness, V_1 and V_2 are composite terms to represent addition and subtraction of S-parameters. The values of V_1 and V_2

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