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Dual band microstrip patch antenna array loaded with split ring resonators and via holes

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ABSTRACT

Reduction in antenna size by using multi-band radiators play a vital role in the miniaturization of present world wireless handheld devices, as dual band behaviour of the antennas result in the integration of more than one communication standard in a single system and thus, saving the installation space required for separate antennas. In this context, this communication presents a shorted-pin dual band metamaterial inspired microstrip patch antenna array. Under the unloaded conditions, the traditional patch antenna array resonates at 5.8 GHz with gain of 9.8 dBi and bandwidth of 540 MHz. However, when each patch of this traditional antenna array is loaded with split ring resonator (SRR) and a metallic via hole is introduced in the patch, the same antenna array produces an additional resonant frequency in IEEE 802.11b/g/n 2.45 GHz Wi-Fi band with bandwidth and gain of 290 MHz and 5.6 dBi, respectively, while the initial resonant frequency (i.e. 5.8 GHz) gets shifted to IEEE 802.11ac 5 GHz Wi-Fi band, providing the gain and bandwidth of 11.4 dBi and 510 MHz, respectively. The proposed antenna array has been fabricated, and the measured results are presented to validate the proposed array. Moreover, the equivalent circuit of the proposed antenna array has been designed and analyzed to validate the simulated, measured and theoretical results. Attainment of dual band characteristics by incorporating the metamaterial with single band traditional patch antenna array makes this structure novel, as this has been achieved without any extra hardware cost, size and loss of structural planarity. Also, both the frequency bands of this proposed metamaterial inspired antenna array possess considerable gain and bandwidth.

1. Introduction

In order to accomplish the demand of two most commonly used Wi-Fi bands, i.e. IEEE 802.11b/g/n 2.45 GHz band and IEEE 802.11ac 5 GHz band, a single, dual band antenna is desirable, as it squeeze the resonant dimensions of the antenna. To achieve multi-band operation, several traditional approaches have been reported in the literature. These techniques include- introduction of perturbation by cutting slots into the radiator [1], by truncating the ground plane of traditional patch antenna [2], by stacking two resonant structures together [3], by use of stubs [4], etc. However, most of these techniques increase the size of antennas and make them bulky. In order to overcome the drawbacks faced by these conventional techniques, recently, due to their peculiar properties, antenna researchers worldwide have been attracted by the artificially engineered single/double negative metamaterials, also called zero index materials. Incorporation of metamaterials with conventional antennas, results in their size reduction and performance enhancement [5–14]. These artificial materials are characterized by either dispersion relations or by constitutive electromagnetic parameters. In 1968, Veselago, in his paper [15], first time gave the theoretical explanation on materials with negative permittivity and permeability, simultaneously, and also predicted some peculiar phenomena obtained from them. After a long time in 1990s, Pendry et al. demonstrated electric plasma (negative permittivity) from wire structures [16] and then magnetic plasma (negative permeability) from ring shaped structures [17]. In [18], Smith et al. were the first to experimentally demonstrate the double negative materials.

Since then, due to their novel properties, they have been deeply studied as potential artificial materials for a large number of applications in the microwave and optical region [5,19]. They exhibit unusual and useful phenomena due to their controllable electric and magnetic responses [15]. Therefore, in metamaterial loaded conventional antennas, matching of impedance occurs at frequency which is lower than the initial resonant frequency of their conventional counterparts. Also, the metamaterial act as reflective surface and generate sub-wavelength resonance due to modifications of the modes. These interesting

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anomalous electromagnetic features result in size reduction and performance improvement of conventional antennas at no extra hardware cost and size.

2. Past research

In the literature, various techniques to load the microstrip patch antennas with metamaterials have been reported [5–14]. In [5], Andrea Alu et al. enhanced the radiation performance of the circular patch antenna by using metamaterial inclusions that fit in the dielectric region between the patch and the ground plane. In [7], Chen and Alu combined two resonances to enhance the antenna bandwidth by loading the elliptical patch antenna with mu-negative metamaterial. Joshi et al. in [8], embedded the SRR into the slot of a slotted patch antenna to match the impedance at the desired frequency band. In [9], Arora et al. loaded the feed line of the conventional patch antenna array with a pair of split ring resonators to enhance its bandwidth. The same group, in [11], designed a metamaterial superstrate to improve the gain of patch antenna array. These artificially engineered materials can also be directly connected to the antenna for size reduction and enhancement of gain and bandwidth, like in [12], where Palandoken et al. directly connected the unit cell of left handed metamaterial to a dipole antenna for obtaining the broadband performance and in [13], where Du et al. connected the modified S-shaped resonator directly to the monopole antenna to achieve the multiband operation. However, most of these researches were associated with the performance enhancement of single patch antennas only. Therefore, a method is required, which should not only improve the performance of the antenna, but should also be capable to reduce its dimensions by lowering the existing resonant frequency or by generating an additional lower resonant frequency band.

3. Motivation for the problem formulation and organization of the article

Requirements to design this proposed antenna array are discussed in this section. To increase the readability of this paper, it is sub-divided into several fragments. The organization of these fragments is also discussed in this section.

3.1. Motivation for problem formulation

In most of the past work discussed in Section 2, efforts were made to improve the gain and bandwidth of single patch antennas and less attention was paid towards their miniaturization. However, there are certain applications which require very high gain and bandwidth, along with the compact size. For such areas, arrays of microstrip patch antennas, presenting dual band behaviour, can be used. But the arrays increase the physical dimensions of the radiator. Therefore, to minimize the size of the antenna array, a method is to be devised in which an antenna array can provide high performance and compact size, with the requirement of a minimum number of patch elements. Loading of metamaterials to the single band conventional microstrip patch antenna array is one such method. However, to the best knowledge of the authors, till date, much research has been done on the metamaterial loading of single patch antennas [5–8] for their performance enhancement, and limited research has been conducted in the direction of loading the arrays with metamaterials for the size miniaturization and performance improvement. To throw the light in this direction, the authors, in [20,21], placed a reflecting surface over the conventional patch antenna array to enhance its gain and bandwidth, simultaneously. This technique achieved a considerable improvement in the performance of the conventional patch antenna array, but at the cost of size and structural planarity.

To overcome these drawbacks, the authors, in [22], directly connected an SRR to each patch of a conventional 4-element, single band microstrip patch antenna array to obtain dual band behaviour at IEEE 802.11ac 5 GHz Wi-Fi band and IEEE 802.11b/g/n 2.45 GHz Wi-Fi band, with considerable gain and bandwidth at both the frequency bands, while maintaining the size and planarity of the proposed antenna array exactly same as that of its conventional counterpart. A metallic via hole is introduced on each radiating patch to tune the obtained additional resonant frequency to some desirable value. Thus, a miniaturized, dual band shorted pin antenna array, with considerable gain and bandwidth, at both the operating frequencies, has been obtained by incorporating the metamaterials with the designed traditional patch antenna array.

In this communication, the authors have extended the work of [22] by presenting the measured results and designing the equivalent circuit of the proposed dual band shorted pin patch antenna array. Detailed analytical analysis of this proposed antenna array and its equivalent circuit has also been presented in this paper.

3.2. Organization of the article

This paper is organized into seven different sections. Introduction and literature review of metamaterials and multi-band antennas has been discussed in first two sections of the paper. Requirement to design the proposed antenna array is illustrated in the third section of this communication. Fourth section presents the structure and characterization of SRR unit cell by using effective medium theory. The detailed geometry and design of conventional and proposed antenna array is presented in Section 5. Equivalent circuit and principle of operation of the proposed antenna array, along with measured and simulated results are discussed in the sixth section of the paper. Finally, the communication is concluded in Section 7.

4. Design of metamaterial unit cell and its characterization using effective medium theory

This section deals with the design methodology of a unit cell of the proposed SRR. In order to verify the metamaterial characteristics of this proposed metamaterial unit cell, effective medium theory has been applied to it and the results so obtained, are presented in this section.

4.1. Design of metamaterial unit cell

The structure of the SRR unit cell is depicted in Fig. 1. The dimensions of this SRR unit cell are; length of outer split ring (Ls) = 11.95 mm, ring width (w) = 0.2 mm, split gap (g) = 0.3 mm and the gap between inner and outer split rings (s) is set to 1 mm. The dimensions of the SRR unit cell are chosen in such a way that the overall size of the proposed antenna array does not increase at all. FR-4 substrate of thickness (h) = 1.48 mm, dielectric constant (ε_r) = 4.3 and

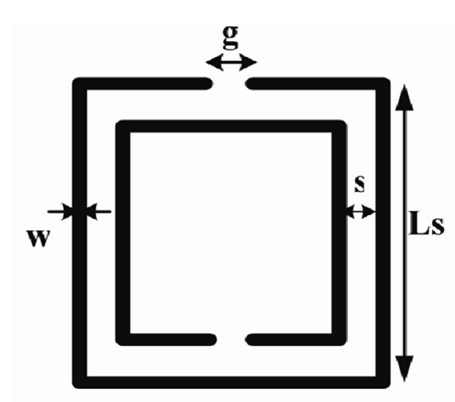

Fig. 1. Geometry of proposed SRR unit cell.