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A compact metamaterial multiband antenna for WLAN/WiMAX/ITU band applications

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ABSTRACT

In this paper, a compact metamaterial multiband antenna is proposed for wireless local area network (WLAN), worldwide interoperability for microwave access (WiMAX) and international telecommunication union (ITU) band applications using a modified Triangular Split Ring Resonator (TSRR). In this work, we designed a modified TSRR with metamaterial property to obtain desirable negative permeability bands that help in accommodating all three frequency bands of interest in a single device. This approach leads to the considerable reduction of the device structure. The overall dimension of the proposed antenna structure has a compact size of $25.7 \times 23.2 \times 1.6\,\text{mm}^3$ and covers specific bands from the frequency spectra of 2.4/5.2/5.8, 3.5, and 8.2 GHz for WLAN, WiMAX, and ITU, respectively, with uniform radiation characteristics. The designed antenna structure is simulated using the High Frequency Structural Simulator (HFSS), and a prototype is developed and tested. The detailed analysis of the results obtained is presented. It is determined that the performance of the proposed antenna is superior to that of the existing antennas in the literature.

1. Introduction

Increased demand for wireless applications has created a need for improvement in the existing multiband antenna techniques. The required antenna must be low-cost and compact and must cover various operating frequencies (e.g., 2.4–2.484 GHz [IEEE 802.11b/g] and 5.15–5.35/5.75–5.825 GHz [IEEE 802.11a] for WLAN, 3.4–3.69 bands [IEEE 802.16e] for WiMAX and 8.025–8.5 GHz for the ITU Band).

The multiband technique for wireless application can be achieved by various approaches, such as employing different stub shapes and microstrip fed slot techniques. However, this technique results in a large device size and resonance at undesirable random frequency bands.

The use of metamaterials helps to reduce the device size and obtain the desired resonant frequencies bands in a single device. Metamaterials are artificial materials that exhibit simultaneously negative permittivity and permeability properties for particular frequency regimes [1,2]. The split ring resonator (SRR) is a basic building block of metamaterials. The properties of metamaterials make them an appropriate candidate to enhance the electromagnetic properties of antennas, enhance filter performances, and achieve both structure miniaturisation and a desirable bandwidth of the device [3,4]. The compact microstrip dual band antenna was attained for higher frequency applications [5]. In Ref. [6], a multiband antenna was implemented by loading a SRR with a microstrip slot to achieve miniaturisation. The WLAN and WiMAX applications were covered using a complementary SRR in [7]. Miniaturisation and radiation characteristics were achieved in [8], but the device does not cover the ITU frequency band. The reconfigurable antenna performance is also possible using SRR in [9]. Several antennas have been proposed in the literature that exhibit multiband performances without using SRR/CSRR structure. However, such antennas require large area for implementation [10,11]. The recent research works [12–16] on metamaterial multiband antennas focus on miniaturisation, frequency selection and performance enhancement by loading two dimensional (2-D) metamaterial transmission lines and fractal shaped structures.

Several works reported earlier [4,6–11] cover multiband antennas with WLAN, WiMAX, or both applications, and it is observed that most of the multiband antennas are not covering ITU band along with WiFi and WiMAX. To cover the WLAN/WiMAX/ITU band, existing multiband antennas require an extra device to be included to cover all the desired bands; hence, there is a trade-off between frequency bands and device size. The proposed multiband antenna

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is designed to satisfy both constraints in a single device. The proposed multiband antenna is designed to satisfy both constraints in a single device.

In this paper, a compact metamaterial multiband antenna is proposed to cover WLAN/WiMAX along with ITU band applications. For this antenna, a combination of a modified TSRR and a trapezoidal shaped ground plane are used to enhance the antenna performances. The TSRR acts as a radiating element of the device. The proposed antenna covers all of the frequency bands of interest: 2.4/5.2/5.8 GHz WLAN bands, 5.5 GHz WiMAX bands and 8.2 GHz ITU band.

2. Proposed antenna configuration

The proposed multiband antenna is designed on a commercially available FR-4 substrate with a dielectric constant of 4.4, thickness of 1.6 mm, and loss tangent of 0.02. The multiband antenna has a compact size of 25.2 $(L) \times 23.7$ $(W)\,\mathrm{mm}^2$ and is fed by 50 Ω transmission line using the coplanar waveguide (CPW) method.

The CPW fed method consists of a source and two ground planes. In this design, the conventional ground plane of CPW is modified into trapezoidal shaped ground planes, as shown in Fig. 1. The geometrical parameter of the multiband antenna is given in Table 1 (Fig. 2). The antenna is fabricated with the above-described specified dimensions, as shown in Fig. 3.

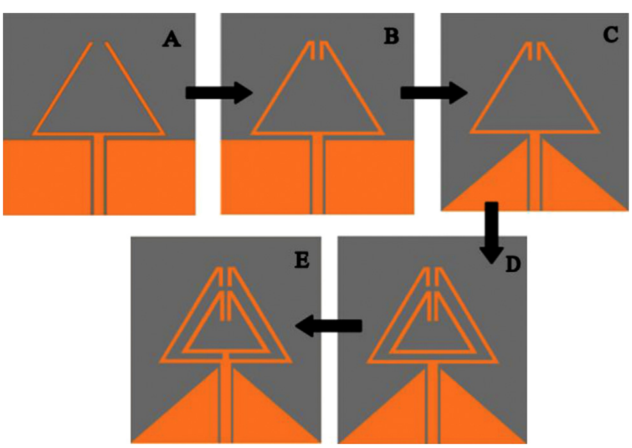

Fig. 1. Evolution of the proposed multiband antenna.

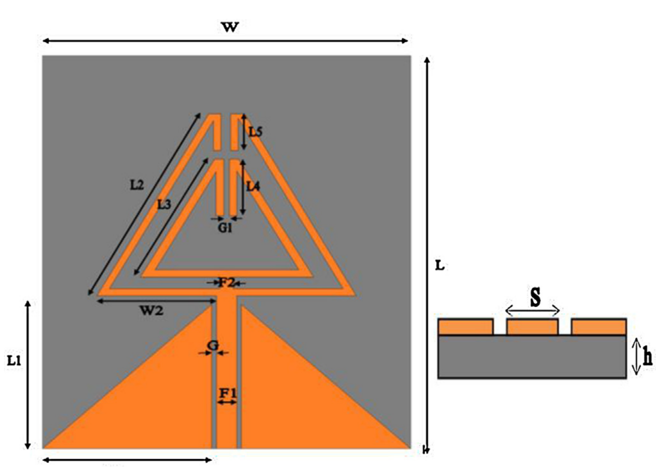

Fig. 2. Geometry of the proposed antenna and the side view.

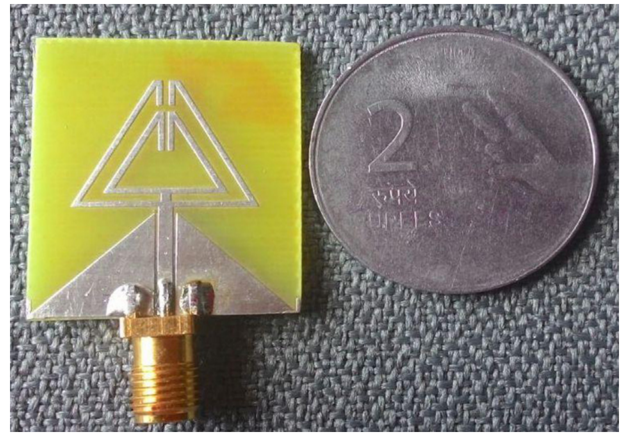

Fig. 3. Photograph of the fabricated multiband antenna.

The antenna design is evolved in various stages to obtain all the required frequency bands 2.4/3.5/5.2/5.8/8.2 GHz by optimising its parameters.

Basically, the antenna structures are based on the RLC combinations.

The capacitance value of TSRR is obtained based on the parallel plate formula

$$C = \varepsilon_0 \varepsilon_r \frac{A}{d}\,(\mathrm{F}) \tag{1}$$

where, ε_0 is the free space permittivity, ε_r is the relative permittivity, A is the cross-sectional area of loop and d is the gap length. Using Eq. (2), the inductor value of TSRR is obtained.

$$\mathrm{L} \approx \frac{3l\mu_0\mu_r}{2\pi}\left[\ln\left(\frac{l}{\rho}\right) - 1.4056\right]\,(\mathrm{H}) \tag{2}$$

where l is one side length of the structure, and ρ is the radius of the loop. The inductance and capacitance values are obtained based on [17,18]. The above values are adjusted using the resonance frequency (f_r) formula to obtain the desired frequencies.

$$f_r = \frac{1}{2\pi\sqrt{LC}}. \tag{3}$$

In this equation, L and C are represent inductance and capacitance of the TSRR, respectively. In calculating the capacitance value using parallel plate mechanism, the fringing field capacitance effects are considered.

3. Extraction of the negative permeability

The negative permeability from the S-parameters is retrieved based on the work of Smith et al. [19]. In this study, the Nicolson–Ross–Wier method is considered to obtain the negative permeability of the proposed TSRR structure.

Fig. 4 depicts the waveguide set up for retrieving the S-parameters of modified TSRR structure using the HFSS. In this figure, the proposed TSRR structure is placed inside the waveguide structure, where the incident electromagnetic field is passed through Port1 and Port2 along the X-axis, Perfect Electric Conductor (PEC) fields are assigned in other two sides of the waveguide structure along Y-axis, and Perfect Magnetic Conductor (PMC) fields are assigned at the top and bottom of the waveguide structure along the Z-axis in the HFSS, as in [20], to compute transmission (S_{21}) and reflection coefficients (S_{11}).

The obtained S_{11} and $S_{21}$of the modified TSRR are used to retrieve the negative permeability characteristics. Fig. 5 shows the