Miniaturized Multiband Antenna with Modified Split-ring Resonator for WLAN/WiMAX Applications

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Abstract— A novel compact and planar tri-band antenna having frequency beam-scanning ability is designed using a metamaterial-inspired structure. The metamaterial (MTM) configuration consists of a marginally remodeled split-ring resonator (SRR). The antenna has a unique ground plane with a comb structure. The proposed design has dimensions $20 \times 20 \times 1.6\,\text{mm}^3$. It resonates at 2.351, 3.635 and 5.121 GHz respectively which is suited for LTE2300, WiMAX and WLAN applications. Radiation pattern shifts 90° for a change 0.2 GHz in the range 3.8–4 GHz providing beam steering applicable for MIMO LTE (4G) and WiMAX.

1. INTRODUCTION

As a consequence of rapid development in wireless communication, compact multi-band antennas attracted research interest. Significant progress is seen in the field of microstrip antenna due to its convenient features such as low cost, light-weight and flexibility. Several antennas operating in various bands such as GSM, GPS, WiFi, and WiMAX are essential in mobile phones [1]. It is desirable to have a single antenna operating at multiple bands. This enhances compactness which reduces VLSI real estate, cost and volume required in the casing of the device.

The challenge is to miniaturize the antenna to the maximum degree while retaining resonance at multiple bands. Various mulitband antennas involving inverted F, slot and planar arrangement show limitations of increased size and complexity [2–4]. Several successful attempts have been made to develop compact antennas using MTM configuration [5–7]. An attempt has been made to improvise on a conventional SRR to scale-down the dimensions while retaining multifrequency functionality. Additional splits/gaps are introduced and repositioned in each ring of the SRR. The thickness is maintained standard at 1.6 mm [8, 9]. The design uses only one set of simple SRR structure and the dimensions are reduced to 20 mm × 20 mm. The proposed design has multiple frequency bands at 2.351, 3.490–3.770 and 5.041–5.256 GHz with reflection co-efficient greater than −6, −10 and −10 dB respectively. It covers LTE2300 (2300–2400 MHz), WiMAXat 3.5 GHz and WLAN at 5.2 GHz.

The radiating face of the antenna consists of a remodeled SRR. Resonant frequencies are created by fine tuning the gaps and embedding dielectric slots in the ground plane whose positions were realized through a parametric study. Out of a total of four gaps/splits, three have a width equal to the thickness of the ring and the fourth is slightly smaller.

In addition to triple band operation, the antenna exhibits frequency beam-scanning ability inherent in a leaky wave antenna. Beam steering up to 90 degree can be achieved between 3.5–4 GHz. One of the LTE bands is centered at 3.5 GHz which is also applicable for WiMAX. This feature is similar to the property of a smart antenna used in MIMO system [10].

The paper is organized as follows. Section 2 contains the principle behind metamaterials. Design parameters are introduced in Section 3. Results are discussed in Section 4. The work is concluded in Section 5.

2. METAMATERIALS

Metamaterial is an artificial material exhibiting electromagnetic responses like negative permittivity and negative permeability which are not found in naturally available substances [11]. An SRR is one of the common metamaterial configurations [12, 13]. They form the basis for miniaturization of antennas. Conventional antennas need to be at least half the size of the wavelength they are operating in. Inclusion of metamaterial reduces the size to immensly. SRR is a composite metamaterial. It consists of concentric rings made of non-magnetic material (here, copper) separated by a gap which yields effective negative magnetic permeability [14, 15].

3. ANTENNA CONFIGURATION

The geometry of the proposed antenna is shown in Figure 1. It is fabricated on FR4 epoxy substrate of dimension 20 mm × 20 mm × 1.6 mm with dielectric constant 4.4 and loss tangent of 0.02. The patch consists of a metamaterial structure comprising a rectangular split-ring configuration with two non-opposite slits in each ring which are repositioned. The design uses a novel ground plane configuration. The size of ground plane is half the overall size, i.e., 20 mm × 10 mm. It is slotted with a wide gap at the centre and narrower gap on either sides. Gap between slots on either sides of the centre remains constant. It is fed by a microstrip line which can be connected by an SMA. Ansys HFSSsoftware is used to evaluate the antenna performance. The other optimal parameters are $W = 20\,\text{mm}$, $d = 2\,\text{mm}$, $d_1 = 1.5\,\text{mm}$, $d_2 = 7\,\text{mm}$, $d_3 = 9.75\,\text{mm}$, $d_4 = 4\,\text{mm}$, $t = 1\,\text{mm}$, $g = 1\,\text{mm}$, $g_2 = 10\,\text{mm}$.

4. RESULTS AND DISCUSSION

Frequency bands at 2.351, 3.635 and 5.121 GHz with reflection co-efficient −6.467, −13.494, −15.201-dB respectively are presented in Figure 2(b). Bandwidths for resonances with S_{11} better than −10 dB at 3.635 GHz is 140 MHz and at 5.121 GHz is 96 MHz. The approach taken to arrive at the final design can be explained using antennas 1, 2, 3 and 4 (Figures 2(c) and 2(d)). Photograph of the fabricated antenna next to a scale is shown in Figure 2(a).

Step 1. A full patch (complete copper surface) with slotted ground is considered. Ground plane resembles comb structure with gap "2t" at the center and gap "t" between slots on either sides. It results in resonance at 3.4 and 4.4 GHz with S_{11} less than −4 dB.

Step 2. Next, a conventional SRR with a complete copper ground plane of dimensions 20 mm ×

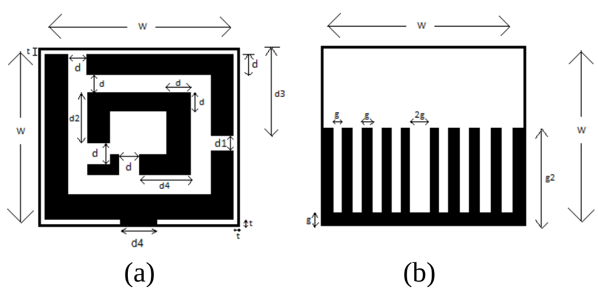

Figure 1: (a) Radiating surface and (b) ground plane of final design (antenna 4).

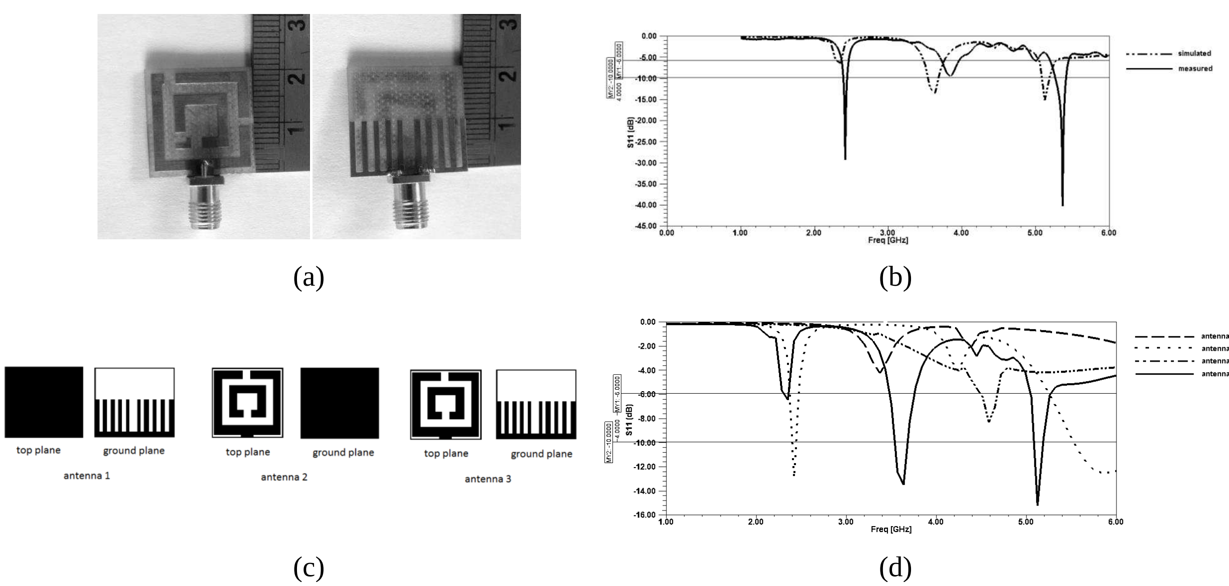

Figure 2: (a) Photograph of the fabricated antenna (1) top plane (2) ground plane. (b) Simulated and measured S_{11} for final design. (c) Preliminary designs. (d) Simulated S_{11} for antenna 1, antenna 2, antenna 3 and antenna 4.

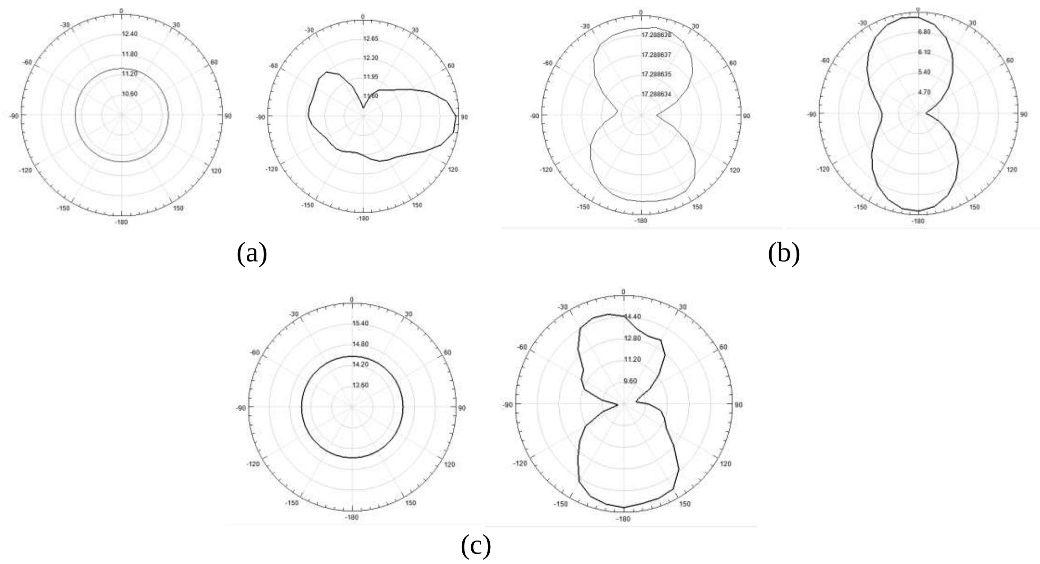

Figure 3: (a) Radiation pattern along E plane and H plane at 2.35 GHz respectively. (b) Radiation pattern along E plane and H plane at 3.63 GHz respectively. (c) Radiation pattern along E plane and H plane at 5.12 GHz respectively.

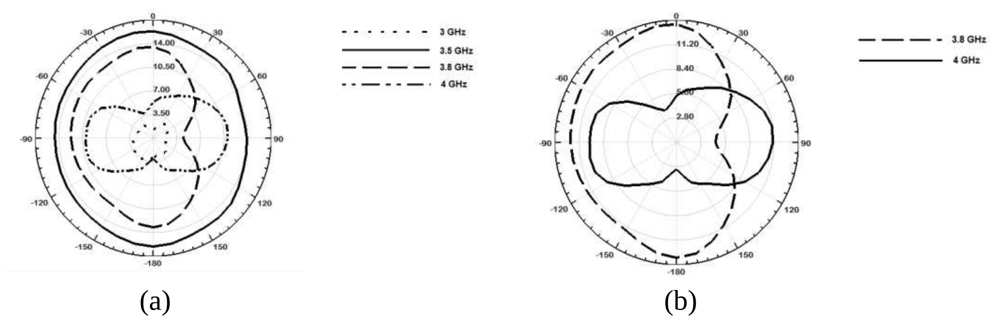

Figure 4: (a) Radiation pattern along H plane at frequencies 3, 3.5, 3.8 and 4 GHz. (b) 90° shift in radiation pattern seen between 3.8–4 GHz

10 mm is designed and simulated. Results show resonance at 2.4 and 5.9 GHz with S_{11} greater than -10 dB with approximate bandwidths 42 MHz and 500 MHz respectively.

Step 3. A typical SRR with slotted ground plane are now combined and checked. This configuration yields only one frequency band at 4.5 GHz with bandwidth 159 MHz at -6 dB.

Addition of a new set of gaps/splits resulted in multiple bizarre resonances. The position and width of each gap were tweaked to get the final result through parametric analysis.

Radiation pattern along E and H planes at resonant frequencies 2.35, 3.6 and 5 GHz is shown in Figures 3(a), (b) and (c) respectively. It can also be observed that the radiation pattern changes with frequency variation in the range 3.8–4 GHz which is a characteristic of leaky-wave antennas. A change of 0.2 GHz returns a 90 degree shift in radiation pattern along H plane. This is depicted in Figure 4. Measured S_{11} is -29.3, -9.22 and -40.3 dB at 2.416, 3.865 and 5.361 GHz respectively. The discrepancy between simulated and measured return loss could be attributed to the interface with the connector.

5. CONCLUSION

A highly compact tri-band antenna with a modified SRR is designed and studied. In this letter, we explore improvisations on SRR architecture as well as ground plane which display simultaneous performance in WLAN and WiMAX bands. The frequency bands are centered at 2.351, 3.635 and 5.121 GHz. The design occupies a meager volume of $0.156\lambda_0 \times 0.156\lambda_0 \times 0.012\lambda_0$. Besides, beam scanning of 90° can be achieved. This feature finds applications in LTE2300 and WiMAX.

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