Compact and Triple Band Meta-material Antenna for All WiMAX Applications

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1. Introduction

The electric permittivity (ε) and magnetic permeability (μ) of a medium are the electromagnetic constitutive parameters of the medium which are used to describe the material behavior on applying an electromagnetic wave. In general, metamaterial artificial effective medium are electromagnetic ordered array scatters satisfying a sufficient long wavelength condition at RF/microwave frequencies to demonstrate particular electromagnetic properties. Since the emerging of metamaterials, electromagnetic community has been making great effort in utilizing their unique properties. Planar left handed (LH) transmission media have been realized using different techniques. They can be based on loading a hosting transmission line (TL) with series capacitors and shunt inductors [1,2]. This approach is a non resonant approach and has advantage of compactness in addition to the broad bandwidth. Due to the parasitic shunt capacitor and series inductor effects of the hosting transmission line, this TL can be named as composite right/left-handed (CRLH) TLs [1]. This approach has led to development of novel guided and radiated microwave devices and components. Many antenna performance and size enhancement have been introduced employing different metamaterial LH TL structures [3-6].The CPW configuration is preferred rather than microstrip configuration in many applications. Such configuration makes the implementing of shunt inductive required for LH TL becomes more simple and hence inexpensive fabrication procedures in addition to their simple cascading with active components.

WiMAX equipments may operate at different frequency bands. Some of the most commonly used license free frequencies in RF/microwave frequencies are mainly at lower WiMAX band at 2.4 GHz, medium WiMAX band at 3.5, 3.65, and higher WiMAX band at 5.2/5.3/5.8 GHz. The RF/microwave community has a challenge to produce compact equipments that can deal with these different frequency bands at once.

In this paper we propose a compact triple band metamaterial antenna in CPW configuration to cover all the operating frequencies of WiMAX (2.1-2.6 GHz band, 3.3-3.7 GHz band, and 5.2-5.9 GHz band) in one device. The overall antenna dimensions are only 4 cm X 3 cm approximately. Compared with the conventional antenna, the reported antenna presents at least 66% size reduction at lower band. The reported antenna was designed using a monopole antenna loaded by two LH unit cells formed by inductive slots and interdigital capacitors. The antenna performance using the electromagnetic full wave simulations confirmed by experimental results are introduced at the whole designed frequencies.

2. Theory and Structure

The 3D structure configuration of the proposed triple band metamaterial antenna is shown in Fig. 1 (a) whereas the fabricated antenna prototype is shown in Fig. 1 (b). The used substrate is druid with ε_r=2.2, and 1.59 mm. The designed antenna was designed using a monopole rectangular patch loaded with two metamaterial LH transmission line cells. Each cell was constructed using an inductive slot with 0.5 gap and 6.5 mm length along the patch length and a shunt connected an interdigital capacitance has 7 fingers with length = 1.5 mm, finger spacing/width = 0.25 mm. The input CPW line is connected to a 50 Ω RH feeding line of length 15 mm. The monopole patch size is 15 mm X 7.2 mm. Comparing the radiator patch to conventional single band patch antenna; we can claim that reported triple band radiator patch length has been reduced by 66% at 2.4 GHz, 50 % at 3.5 GHz and 25% at 5.5 GHz.

By using Babinet's principle, we can conclude that the loading two unit cells are identical to LH unit cells. It can be observed that the two employed LH cells are not identical. Thus, each cell can be designed individually so that it can resonate at different frequency to introduce two operating antenna bands. The third band can be achieved by the contribution of the employed monopole patch. The monopole was designed to demonstrate the 3.5 GHz band. The nearest LH cell to the feeding line was designed to introduce the upper WiMAX band (centred at 5.5 GHz). Finally, the second LH unit cell was designed to introduce the lower WiMAX band (centred at 2.4 GHz). Each operating frequency band was designed by the proper selection of the loading elements and monopole patch. Each band of these three band was designed individually and hence they re optimized all together in the final design. The For the sake of paper length, the antenna analysis and design was out of this manuscript scope and could not be included in this manuscript.

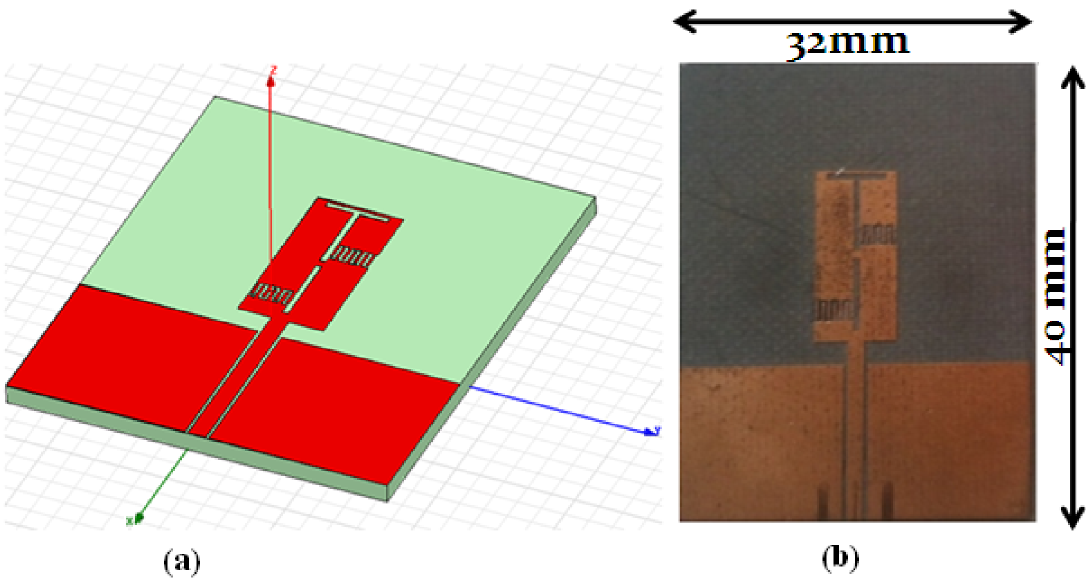

Figure 1: Geometry of the metamaterial tri-band antenna (a) 3-D structure (b) Fabricated layout

3. Results and Discussions:

The design of the proposed antenna has been done by the proper selection of the loading left handed elements. This has been checked by using electromagnetic full wave simulation (HFSS) and confirmed experimentally. The simulated reflection coefficient of the proposed antenna is shown in Fig. 2. It is obvious that the reported antenna can operate in three different bands. The first operating band is centred at 2.43 GHz with -10 dB bandwidth which extends from 2.12 GHz to 2.65 GHz. Similarly, the second operating band is centred at 3.5 GHz and extends from 3.34 GHz to 3.73 GHz. The third band is centred at 5.53 GHz and extends from 5.12 GHz to 6 GHz. So, it is quite clear that these operating bands meet the design requirements of all WiMAX standard operating frequencies mentioned above.

For validation of the antenna performance, the measured reflection coefficient of the fabricated antenna, shown in Fig. 1 (b), is plotted in Fig. 2 for good comparison with the aforementioned simulated results. These results were measured using HP 8504C network analyzer. As shown in the figure, the measured results agree reasonably with the simulated results. The first measured operating band is almost identical with the simulated one. However, there is no more than 0.1 GHz in the centre frequency of the second measured band and it extends from 3.1 GHz to 4 GHz which is wider than the simulated one and hence still covers the medium WiMAX band. Also, the third band is reasonably agree with the simulated one from almost 5.2 GHz to 5.9 GHz with better matching of the centre frequency (5.5 GHz) can be observed in the third band in measured results.

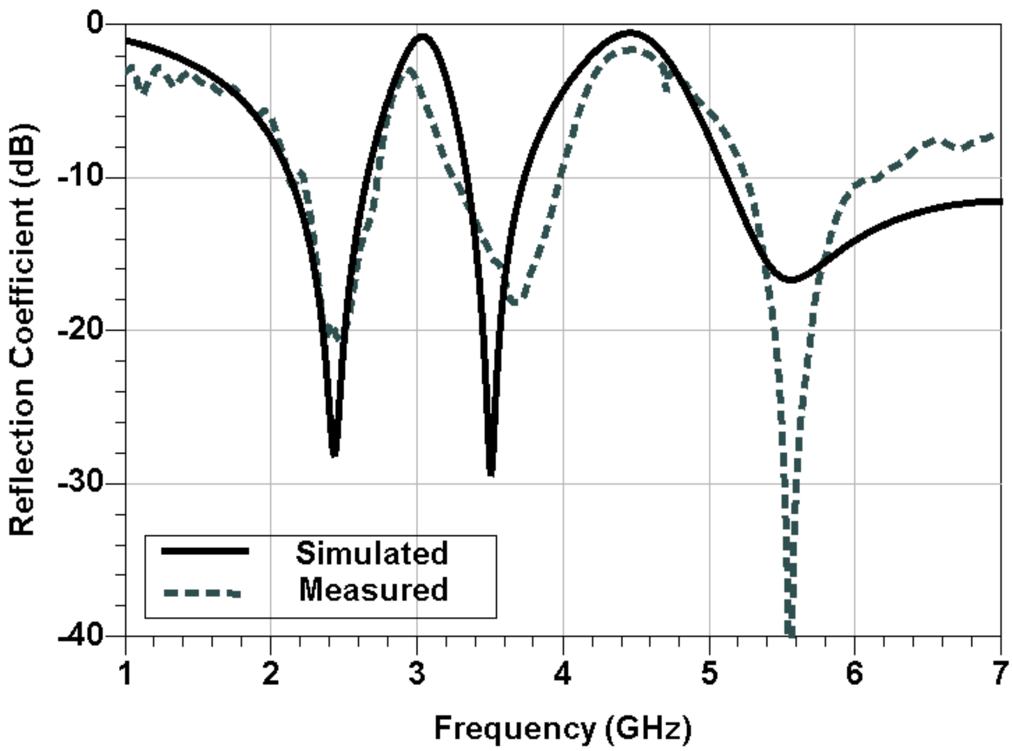

Figure 2: Simulated and measured reflection coefficient of tri-band antenna.

The antenna radiation performance at the three operating band has been checked by investigating the radiation pattern at each band centre frequency. It is obvious that the triple band antenna has an omni-directional radiation pattern with maximum radiation in Z direction, perpendicular to the antenna. Such radiation pattern is appreciated in the WiMAX applications.

For investigation of the polarization properties of the antenna, the co-polarized and cross-polarized gains were compared and plotted in Fig. 4 at the three previous frequencies in both H plane (YZ plane, phi=90) and E plane (XZ plane, phi=0). It is quite clear that in E plane, co polarized antenna gain component is directional one with maximum along z direction (θ=0). The difference between the co polarized and cross polarized antenna gain components is better than 15 dB in the average and it reaches better than 30 dB in the case of 2.4 GHz band. On the other hand in the H plane, the co-polarized antenna gain is isotropic. Similar results can be observed for the difference between the co-polarized and cross polarized antenna gain components is better than 15 dB.

It is worth to mention that the performance of the reported antenna has been verified over the whole frequencies of the three operating three bands which could not be included in this paper for paper length. Also, the experimental radiation properties of the proposed antenna are scheduled for measurement for more confirmation.

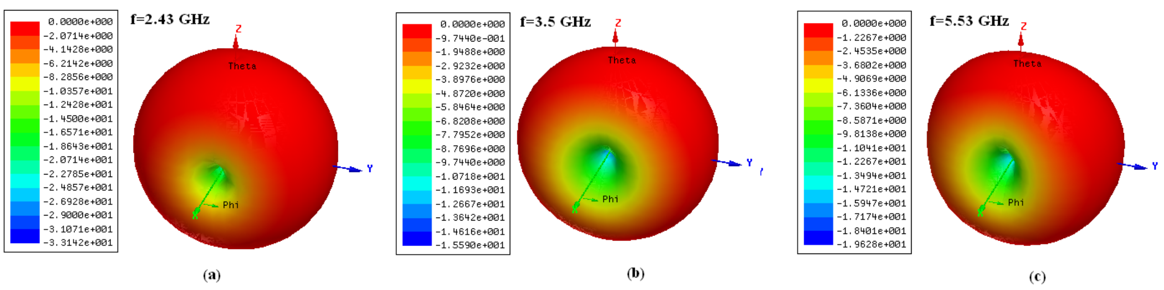

Figure 3: The 3D normalized radiation pattern at 2.43 GHz, 3.5 GHz, and 5.53 GHz.

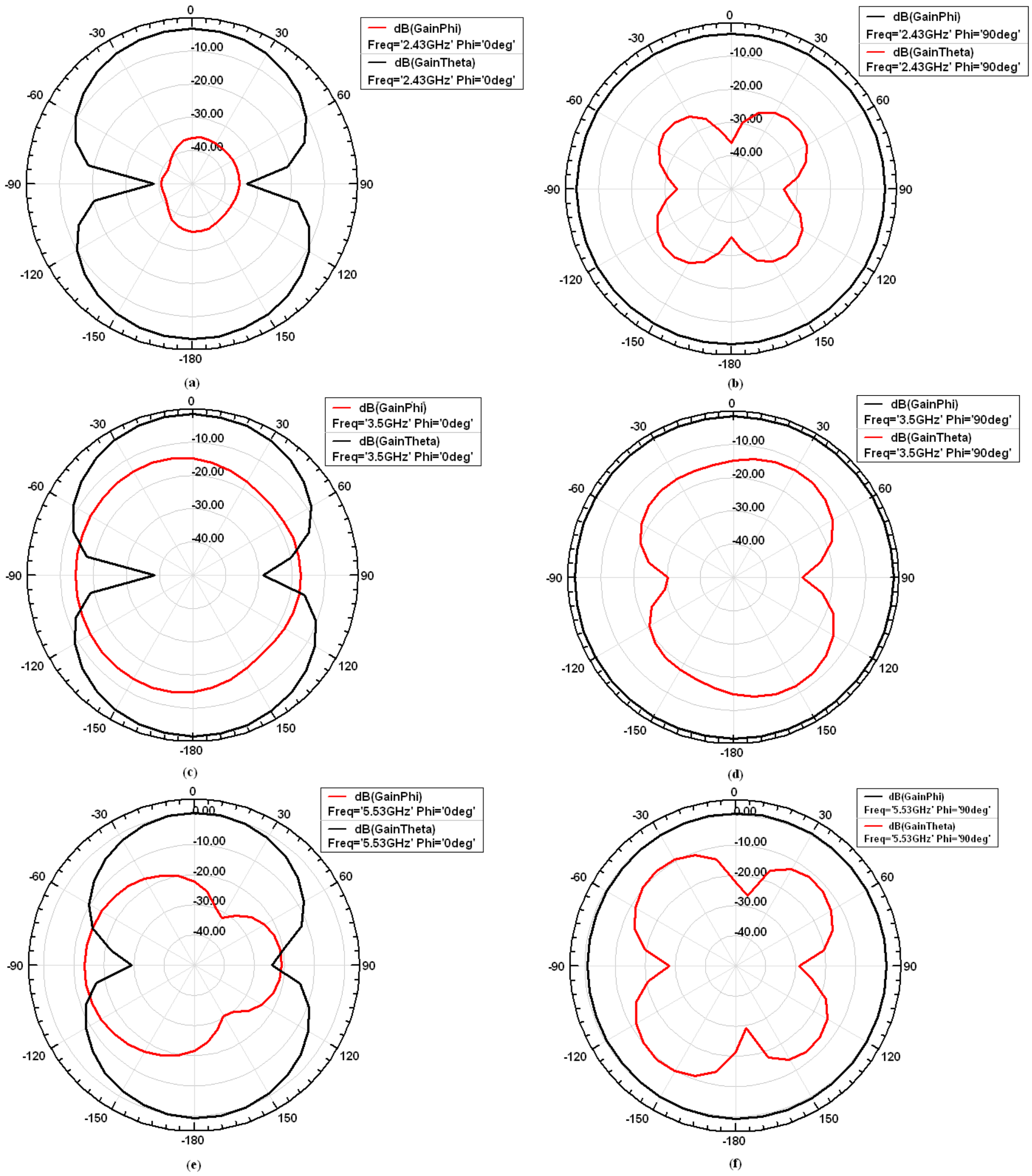

Figure 4: Comparison between the co-polarized and cross-polarized gain in H/E planes at 2.43 GHz, 3.5 GHz, and 5.53 GHz.

References

[1] C. Caloz and T. Itoh, Electromagnetic Metamaterials Transmission Line Theory and Microwave Applications. New Jersey: John Wiey & Sons, 2006.

[2] G. V. Eleftheriades and K. G. Balmain, Negative Refractive Metamaterials. New Jersey: John Wiey & Sons, 2005

[3] A. Rennings, T. Liebig, S. Otto, C. Caloz, and I. Wolff, “Highly directive resonator antennas based on composite right/left-handed (CRLH) transmission lines,” in Proc. 2nd International ITG Conference on Antennas (INICA), Munich, Germany, March 2007, pp. 190–194.

[4] T. Liebig, A. Rennings, S. Otto, C. Caloz, D. Erni, "Comparison between CRLH zeroth-order antenna and series-fed microstrip patch array antenna", in Proc EuCAP Int. Antennas and Propagation Conference, Berlin, Germany., 2009, pp. 529 – 532.

[5] A. Rennings, T. Liebig, C. Caloz, and P. Waldow, “MIM CRLH seriesmode zeroth-order resonant antenna (ZORA) implemented in LTCC technology,” in Proc. Asia-Pacific Microwave Conference (APMC), Bangkok,Thailand, Dec. 2007, [pp. 191-194.

[6] J. Zhu and G.V. Eleftheriades, Dual-band metamaterial-inspired small monopole antenna for WiFi applications", ELEC. Lett. 2009 Vol. 45 No. 22, pp 1104 – 1106.