Design of Electrically Small Metamaterial Antenna

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Abstract-— **Two novel metamaterial antennas applied forWLAN and WiMAX are proposed in this letter. Antenna 1 is composed of a monopole radiator with an electric-LC (ELC) element. By employing these structures, three frequency bands of 2.49 ∼2.55 , 3.0 ∼ 3.68, and 5.03 ∼ 6.04 GHz are achieved. Each band is well matched and can be easily adjusted. Antenna 2 is integrating with EBG structure, which has a good impedance matching in 2.49 ∼ 2.53 GHz, together with an ultrawideband of 2.95 ∼ 6.07 GHz. Both antennas have operational bands covering WiMAX in 2.5/3.5/5.5-GHz and WLAN in 5.2/5.8-GHz, omnidirectional radiation patterns over the operating bands. The proposed antennas have the advantages of simple fabrication, miniaturization, and compactness, which can be applied to wire-less mobile communication system.**

Keywords:- Electronic band-gap EBG, electric-LC (ELC), metamaterial antenna, omnidirectional antenna.

I. INTRODUCTION

R ECENTLY, rapid developments have taken place inwireless communication technology. Portable wireless terminal devices, such as handheld computers and smartphones that are capable of integrating both wireless local area net-work (WLAN) and Worldwide Interoperability for Microwave Access (WiMAX), are in great demand. Antenna design is focused on multiband with small simple structures. Various types of multiband antenna designs have been reported in [1]–[4]. In [1], a dual-band meander T-shape monopole was presented; it has a simple structure to be fabricated, but only two operation bands are supplied the same as the antenna in [2]. The antenna in [3] is composed of a simple printed monopole with a trapezoid conductor-backed plane, covering the lower and higher bands of WLAN and WiMAX, but the size of the antenna is too large for a limited space. As the wireless mobile communication technologies is growing very rapidly, microstrip antenna have various applications because of their small size, low weight, low cost, low planar configuration and can be easily. Compared to other EBG Structures such as dielectric rods and others, this structure has winning features of compactness, which is important in communication antenna applications. Its band gap features revealed in two ways: the suppression of surface wave propagation and the in phase reflection coefficient. The features of surface wave suppression help to improve antenna’s performance such as increasing antenna gain and reducing back radiation. Meanwhile, the in phase reflection the in phase reflection features lead to low profile antenna design. However, the utilization of high dielectric constant substrate has some drawbacks. Application of microstrip antennas on high dielectric constant substrate are of special interest due to their compact size and conformability with the monolithic microwave integrated circuit.

Application of microstrip antennas on high dielectric constant substrate are of special interest due to thei compact size and conformability with the monolithic microwave integrated circuit. In recent year ,there has been growing interest in utilizing electromagnetic band gap(EBG)structure in electromagnetic and antenna community. The EBG terminology has been based on the photonic band gap (PBG) phenomena in optics that are realized by periodical structures. There are diverse forms of EBG structures integrated with other microwave circuits. They are very compact and wideband antennas for the transmission of video, voice and data information. The various applications for microstrip antennas are wireless communication systems, satellite communication systems, cellular phones, pagers, radars, etc. Metamaterials including left-handed materials (LHMs) and electromagnetic band-gap (EBG) structure have been widely used in antenna designs [5]–[12]. Complementary split resonant ring (CSRR) and electric-LC (ELC) structure have the feature of exhibiting a quasi static resonant frequency at wave-lengths that are much smaller than the guided wavelength, there-fore they have been applied to the design of multiband antenna and the miniaturization of antennas [7], [8]. In [9], a single-cell metamaterial is loaded in the monopole that operates in three bands. Moreover, the band- gap characteristic of EBG has been widely used to improve the efficiency and impedance matching of printed antennas [10], [11] and reduce mutual coupling between antennas [12].

In this letter, we propose two novel tribandmetamaterial antennas. With one ELC element loaded in the monopole, Antenna 1 operates in three bands at 2.5/3.5/5.5 GHz, which covers the desired bands for WLAN and WiMAX applications. In Antenna 2, the EBG structure is employed further to im-prove the impedance matching. Antenna 2 exhibits a wide band from 2.95 to 6.07 GHz, which covers the two higher bands of Antenna 1, and the lowest band of Antenna 1 is not influenced by the introducing of EBG. The experiments were conducted to demonstrate the effectiveness and validation of the proposed antennas.

II. ANTENNA DESIGN

The radiating element is a rectangular patch that is printed on dielectric substrate with relative permittivity of 2.65 and thickness of 1 mm. The overall dimension is $1 \times 35 \times 35$ mm^3, as shown in Fig. 1(a) . The antennas have an operational band covering the WiMAX 3.5 GHz, and they are fed by a microstrip line that can be easily integrated with the patch on the same side

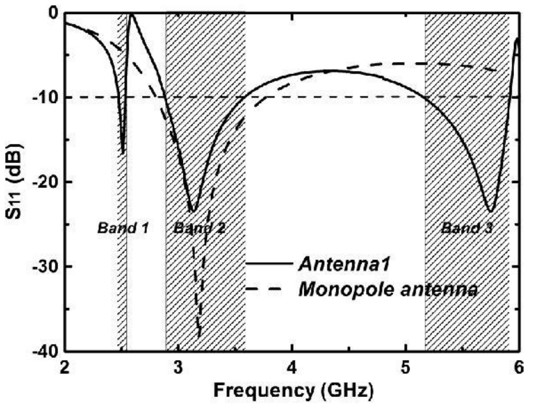

Fig. 2. $|S_{11}|$of the monopole and triband antenna.

of the substrate. The microstrip feed is connected to the coaxial cable through a 50Ω SMA connector. All the structures are simulated by using ANSYS HFSS based on the finite element method (FEM).

A. Antenna 1 With ELC Loading

The structure of Antenna 1 is shown in Fig. 1, and the main dimensions are listed in Table I. The antenna consists of a monopole radiator and an ELC element. The monopole has only a single band, as shown in Fig. 2. However, by loading the ELC under the patch, the proposed Antenna 1 can operate in three bands, which are also shown in Fig. 2. The operating bands can cover 2.5/3.5/5.5-GHz WiMAX and 5.2/5.8-GHz WLAN. Comparing the S_{11} of Antenna 1 to that of an un-loaded monopole antenna, two additional operational bands are achieved. At the same time, the fundamental band of the monopole antenna is kept in Antenna 1. In order to adjust the impedance matching of Bands 1 and 3, the width of microstrip feed line is optimized, and two rectangular slots are etched on the patch.

In order to find the influences on the resonant frequencies and bandwidths of corresponding structural parameters, a parametric study has been carried out. By altering W_2 and L_2 and fixing other parameters, the simulated S_{11} of Antenna 1 is shown in Fig. 3. The second band changes negligibly with the variation of W_2 and L_2 , which indicates that the influence of the ELC on the original resonant frequency of the monopole is small. In Fig. 3(a), the value of W_2 varies from 13.2 to 14 mm, while the value of L_2 maintains at 10.1 mm. The center frequency of the Band 1 decreases with the increase of W_2 , and the other two bands remain stable. With L_2 increasing from 10.1 to 10.5 mm as well as the value of W_2 kept at 13.6 mm, the center frequency of Band 3 decreases, and Band 1 changes slightly as shown in Fig. 3(b). Thus, by altering these parameters, the operating bands can be adjusted to the requirement.

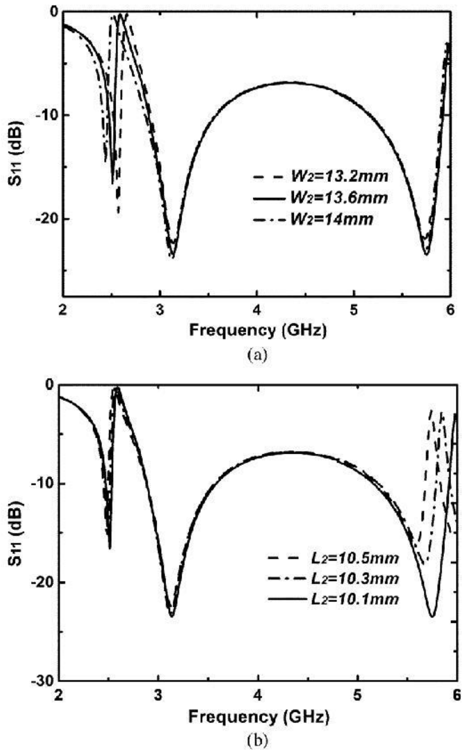

TABLE I
DIMENSIONS OF THE PROPOSED ANTENNA

L	*22 mm*	*W*	*14 mm*
L_1	*14 mm*	W_1	*17 mm*
L_2	*10.1 mm*	W_2	*13.6 mm*
g_1	*0.5 mm*	g_2	*2.5 mm*

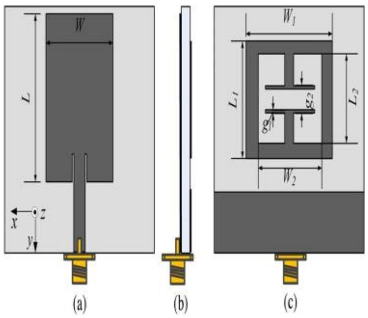

Fig.1 configuration of antenna1 (a)top view(b)side view (c)bottom view

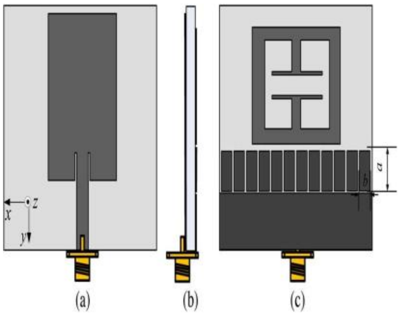

Fig.1 configuration of antenna2(a)top view(b)side view (c)bottom view

B. Antenna 2 With ELC and EBG Loading

By adding EBG in Antenna 1, the structure of Antenna 2 is obtained as shown in Fig. 4. The unit cell of the planar EBG employed here is periodic metallic patches printed on the same side of the ground. As the periodicity of the metallic patches is usually much smaller than the wavelength, it could be used in a limited space to improve the performance of antenna. The simulated S_{11} of Antennas 1 and 2 are shown in Fig. 5. The first band of Antenna 1 is kept in Antenna 2, and the Bands 2 and 3 in Antenna 1 are connected and extended to a wider band. The effect of the EBG on the impedance matching of the antenna is significant, especially in the ultrawideband.

The effects of the EBG dimension on the S_{11} of the antenna are analyzed and shown in Fig. 6. As it is shown, with the increase of a and the width of slots between EBG elements staying at 0.2 mm, a significant impedance matching improvement of the ultrawideband of Antenna 2 takes place, while the impedance matching of the lower band around 2.5 GHz deteriorates.

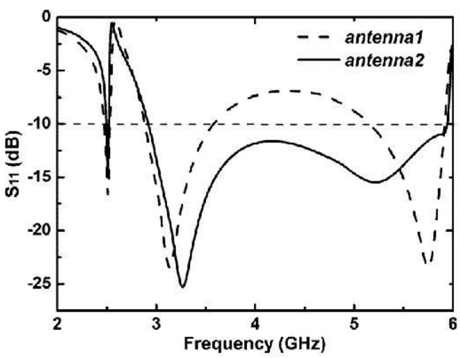

Fig. 5. performances comparison between Antennas 1 and 2.

To change the spacing of EBG loading , periodic to aperiodic we can obtain reduced impedance matching.

III. EXPERIMENTAL RESULTS

According to the design dimension given above, the two kinds of metamaterial antennas have been fabricated and measured as shown in Figs. 7–10. The S_{11} of the fabricated antennas were measured by using a network analyzer Agilent 8719ES. The measured working bandwidths of Antenna 1 are 60 MHz (2.49-2.55 GHz), 680 MHz (3.0-3.68 GHz) and 1.01 GHz (5.03-6.04 GHz) shown in Fig. 8. Fig. 10 shows the measured working bandwidths of Antenna 2 are 40 MHz (2.49 2.53 GHz), 3.12 GHz (2.95 -6.07 GHz).

The simulated and measured S_{11} of two antennas show a good agreement. The discrepancy between the simulations and measurements could be attributed to the factors as the effect of connector, the manufacturing tolerance, and the measurement environment. Meanwhile, the simulated radiation efficiencies at 2.5/5.5/3.5 GHz of Antenna 1 are 98.1%, 99%, and 99.5%, and those of Antenna 2 are 95.8%, 99.5%, and 99.3%.

The measured and simulated E-plane and H-plane radiation patterns of the proposed antennas at three resonant frequencies of 2.5, 3.5, and 5.5 GHz are shown in Figs. 11 and 12. It can be seen that the measured results are in good agreement with simulated results. From the results above, it is observed that both antennas have stable omnidirectional radiation pattern in H-plane and figure-8-shape radiation pattern in the E-plane. Meanwhile, for both antennas, the radiation patterns of each resonant frequency show great similarity, which demonstrates that the impedance matching of the lower band around 2.5 GHz.

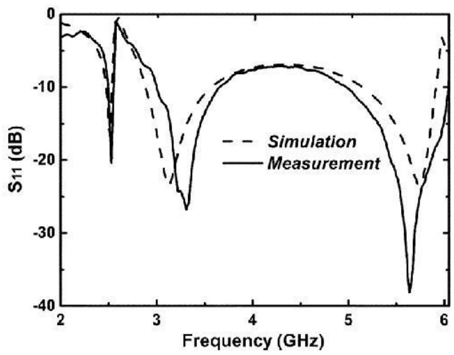

Fig. 8 measured and simulated $|S_{11}|$ of Antenna 1

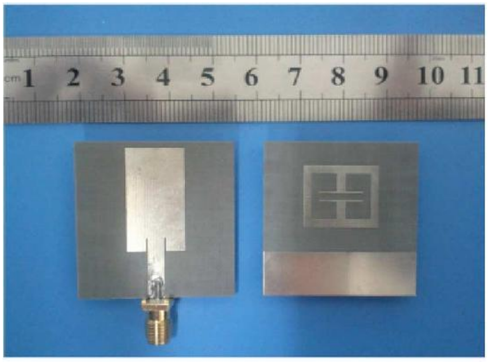

Fig.7 Photograph of Antenna 1

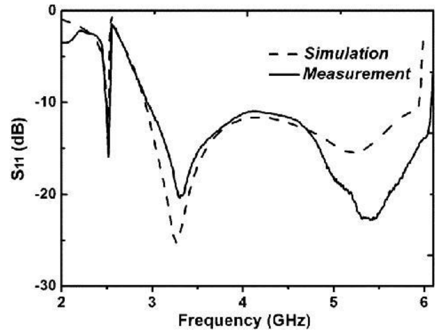

Fig. 10 Measured and simulated $|S_{11}|$ of Antenna 2

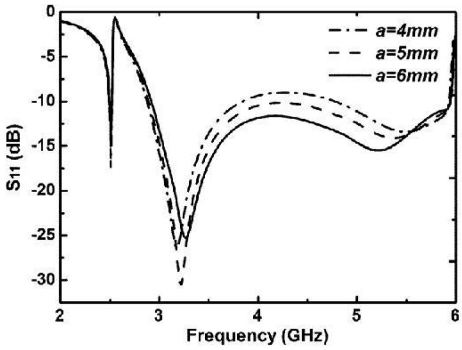

Fig. 6.Effects of variation of EBG dimensions on the $_{11}$ performances.

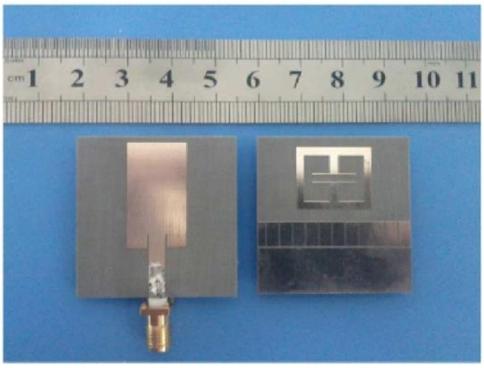

Fig.7 Photograph of Antenna 2

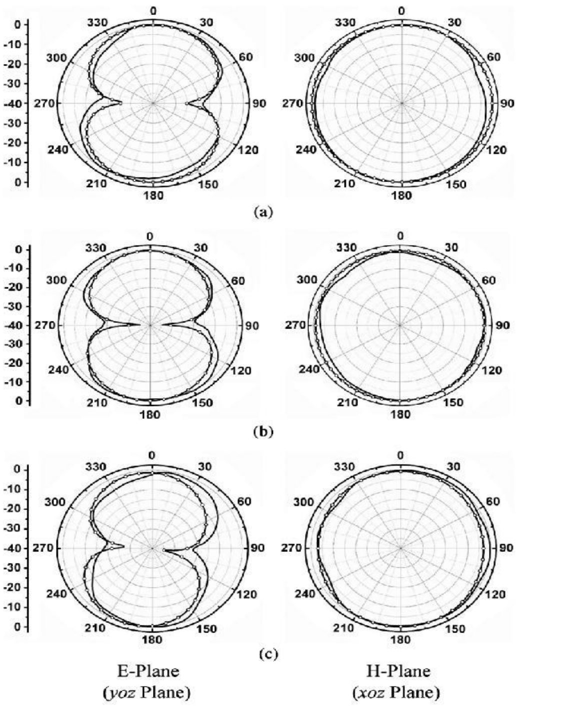

Fig. 11. Measured (solid line) and simulated (dotted line) radiation patterns

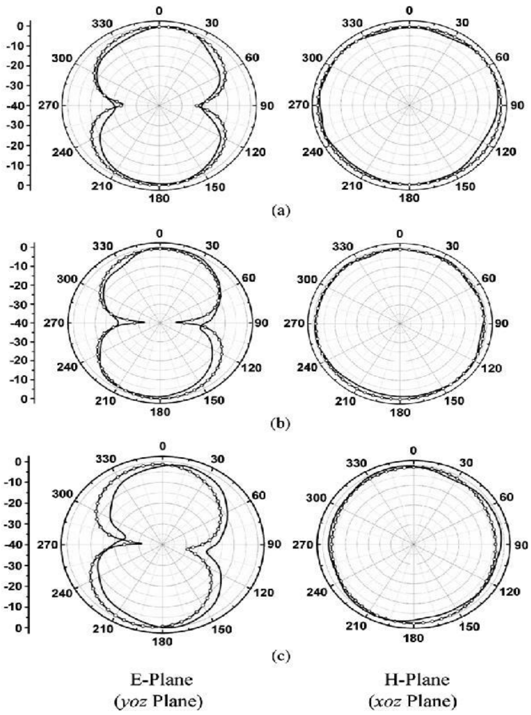

Fig. 12. Measured (solid line) and simulated (dotted line) radiation patterns

EBG loading on Antenna 2 has little influence on the radiation

EBG loading on Antenna 2 has little influence on the radiation pattern compared to Antenna 1.

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IV. CONCLUSION

In this letter, two novel multiband antennas have been proposed to cover the WiMax 2.5/3.5/5.5-GHz and WLAN 5.2/5.8 -GHz bands. Antenna 1 is a monopole radiator loaded by an ELC element. The first (2.49 2.55 GHz) and the third (5.03 6.04 GHz) operational bands are achieved by the loading of ELC, and the second band (3.0 3.68 GHz) is attributed to the monopole. By loading EBG into Antenna 2, a good impedance matching is obtained from 2.95 to 6.07 GHz, and the lower band at 2.5 GHz is also kept. It has been observed that the resonant frequencies of the antenna can be easily ad-justed. The antennas show an omnidirectional radiation pattern for WLAN and WiMAX frequency bands. The proposed two antennas have a simple configuration and could be applied in different wireless devices. Future work is to change the spacing of EBG loading , periodic to aperiodic.

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