Progress In Electromagnetics Research Letters, Vol. 43, 25–34, 2013

WIDEBAND MONOPOLE ANTENNA BASED ON CRLH FOR MOBILE APPLICATIONS

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Abstract—In this paper, we present a wideband monopole antenna loaded with Composite right/left-handed (CRLH) unit cell for mobile applications. By loading one CRLH unit cell, the monopole antenna can achieve wideband and generate an additional resonant mode much lower than the unloaded antenna's normal frequency. The antenna has a compact size of $0.1\lambda_0 \times 0.15\lambda_0$ at the lowest resonance frequency. Measured impedance bandwidth is 2000 MHz (1710$\sim$3810 MHz), which can cover one more frequency band for WiMAX applications than conventional antenna. Furthermore, it introduces a narrow band for LTE700 applications. Stable omni-directional radiation patterns make it suitable for mobile terminals.

1. INTRODUCTION

Modern mobile communication devices are required to have features of light weight, small size, wide band operation, and high transmission efficiency for the forth generation mobile system [1]. New communication system requires operating at new bands and multiband with small size to be integrated into the wireless handheld devices [2]. Typical frequency bands for mobile applications include LTE700 (698–787 MHz), GSM850 (824–890 MHz), GSM900 (890–960 MHz), DCS (1710–1880 MHz), PCS1900 (1850–1990 MHz), WCDMA (1920–2170 MHz), LTE2300 (2305–2400 MHz), Bluetooth (2400–2483.5 MHz), Wi-Fi

Received 15 August 2013, Accepted 10 September 2013, Scheduled 11 September 2013

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Table 1. Size and bandwidth of different antennas.

Reference	10	11	12
Size/mm	96×36	122×46	105×45
Bandwidth /GHz	0.82–0.97, 1.71–2.22	0.69–0.96, 1.71–2.69	0.76–0.96

(2400–2480 MHz), LTE2500 (2500–2690 MHz) and WiMAX (2500–2690 MHz, 3400–3690 MHz) [3–8]. Many researchers focused on covering most of the frequencies in a single antenna [9–16], including using meandered line with perpendicular feed and open-stub structure [17], a coupled loop with two branch lines [18], and adding a branch line in the feed point [19], which is shown in Table 1. However, these antennas either have large size or cover only few frequency bands. Some concepts rely on using the ground plane as main radiators resulting in small elements for covering several 2G, 3G, and 4G standards.

Recently, the concept of composite right- and left-hand (CRLH) structure is adopted to realize miniaturization for handset terminals [20]. A typical CRLH unit cell consists of a feed line that is electromagnetically coupled to a metallic patch and a meandered line connected to the ground plane through metallic via [21]. Antenna designers have demonstrated the concept of loading conventional microstrip-fed monopole antenna with CRLH unit cell [22, 23].

In this paper, we present a wideband monopole antenna 1oaded with one CRLH unit cell for mobile applications. Wideband is formed by one resonant mode generated by conventional monopole antenna and the other three by CRLH unit. Furthermore, the antenna can generate an additional resonant mode by CRLH unit, which is much lower than resonant mode by monopole. The details of antenna design and measurement are carefully examined and discussed below.

2. ANTENNA DESIGN

The configuration of the proposed antenna is shown in Fig. 1. The radiation element consists of a planar monopole and a CRLH unit. The monopole antenna is designed to operate at 2 GHz, which is about $\lambda/4$ at 2 GHz. In design of CRLH unit cell, the inter-digital capacitor is designed to achieve series capacitance, and the meandered short-circuited stub is used to achieve the shunt inductance. Due to the meandered line, the antenna can generate the lowest mode at 0.75 GHz. Meanwhile, the meandered line is placed very close to the strip on the top, which can generate the highest mode at 3.6 GHz. Moreover, it can

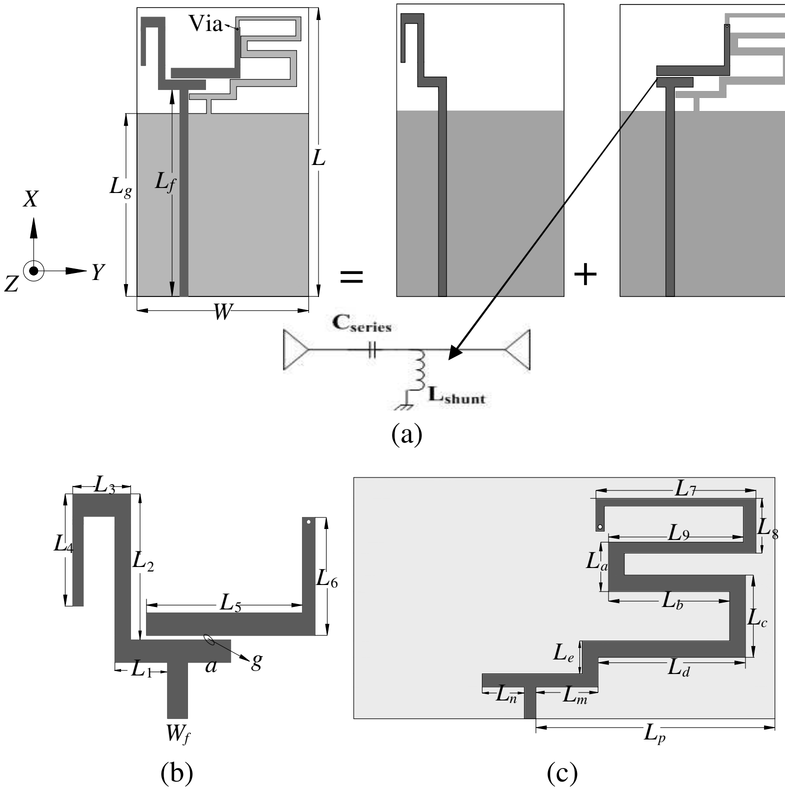


Figure 1. Geometry of the proposed antenna. (a) Proposed antenna, (b) top view, (c) bottom view.

broaden the operation band at high frequency.

The antenna is fabricated on a 1-mm-thick FR4 substrate with permittivity of 4.4 and loss tangent of 0.02. Compared with conventional monopole antenna, one narrow band and one wide band can be obtained (Fig. 3). The dispersion relation of the CRLH cell calculated for the case of microstrip feed is shown in Fig. 2. The narrowband located at 0.74 GHz is within the lower stop-band of the CRLH unit cell, in which the series capacitor can be considered as open circuit. Thus, the resonant mode at 0.74 GHz is mainly controlled by the shunt inductor. The third resonant mode at 2.75 GHz lies in the left-hand region of the CRLH cell, while the forth resonant mode at 3.2 GHz lies in the right-hand region. The geometric parameters of the antenna are optimized as follows: $W = 40\,\text{mm}$, $L = 60\,\text{mm}$, $L_g = 38\,\text{mm}$, $L_f = 43\,\text{mm}$, $W_f = 1.9\,\text{mm}$, $L_1 = 5\,\text{mm}$, $L_2 = 13\,\text{mm}$, $L_3 = 4.5\,\text{mm}$, $L_4 = 10\,\text{mm}$, $L_5 = 16\,\text{mm}$, $L_6 = 10.5\,\text{mm}$, $L_7 =$

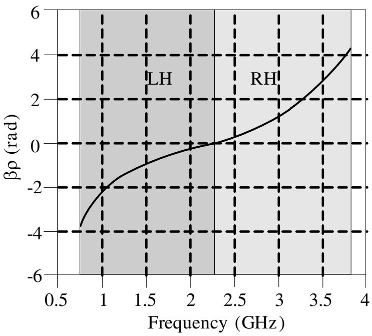


Figure 2. Dispersion relation calculated for CRLH unit cell.

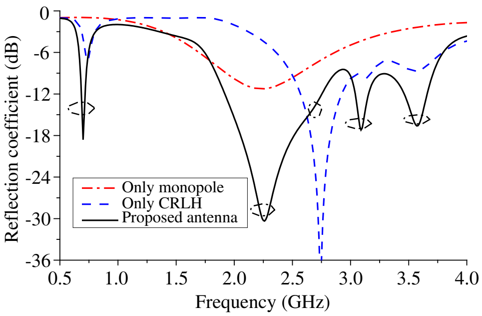
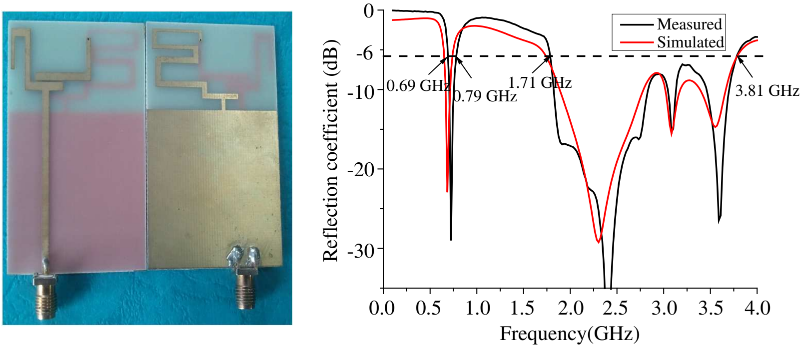


Figure 3. Simulated reflection coefficient for monopole, CRLH and proposed antenna.

15.2 mm, $L_8 = 5$ mm, $L_9 = 14$ mm, $L_a = 4.5$ mm, $L_b = 13$ mm, $L_c = 7.5$ mm, $L_d = 14$ mm, $L_e = 3$ mm, $L_m = 7$ mm, $L_n = 3$ mm, $L_p = 22.7$ mm, $a = 4.1$ mm, $g = 0.4$ mm.

3. RESULTS AND DISCUSSIONS

The simulated and experimental studies of the proposed antenna were accomplished by utilizing Ansoft HFSS V13 and Agilent E8363B vector network analyzer. A photograph of the fabricated antenna is shown in Fig. 4(a), and the results of simulation and measurement are shown in Fig. 4(b). It can be observed that good agreement between simulation

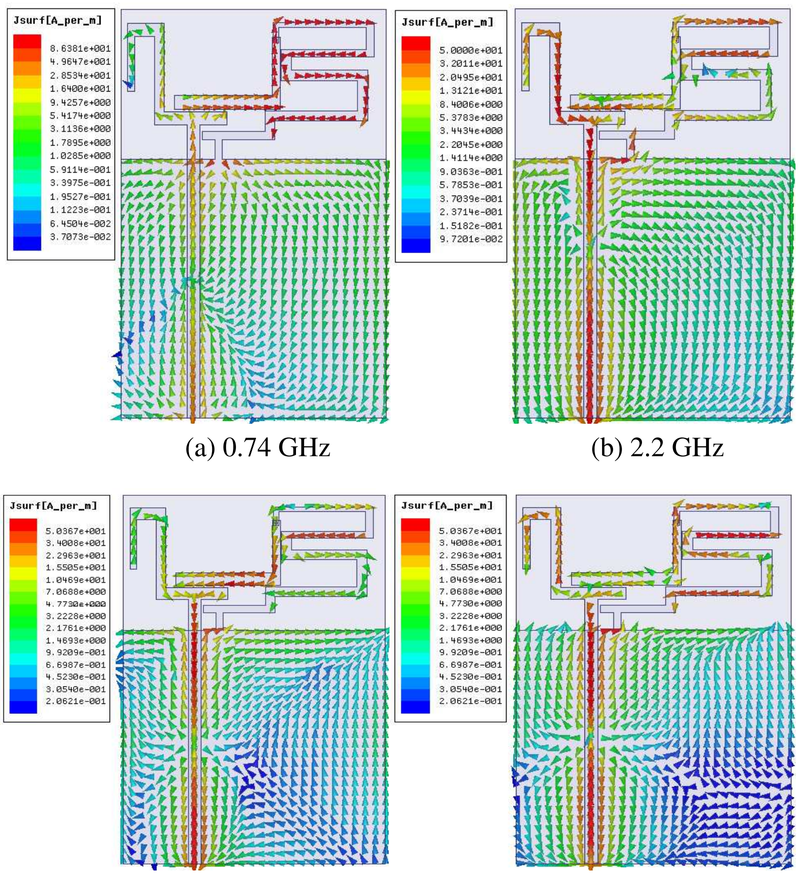


(a) (b)

Figure 4. (a) Photograph of the fabricated wideband antenna. (b) Measured and simulated return losses of the proposed antenna.

and measurement results has been achieved. The measured impedance bandwidth for narrow band is 100 MHz (690 MHz∼790 MHz), while the wideband is 2000 MHz (1710∼3810 MHz). Measured impedance bandwidth is sufficient for mobile applications.

The antenna operation is further studied using current distributions at 0.74, 1.9, 2.6 and 3.5 GHz in Fig. 5. It could be found that the current was mainly distributed on the coupling line and the strip on the back side at 0.74, 2.6, and 3.5 GHz, while the current density was high on the left part of transmission line at 2.2 GHz. It is demonstrated that only the 2.2 GHz resonant mode is generated by the monopole an-



(a) 0.74 GHz (b) 2.2 GHz

(c) 2.6 GHz (d) 3.5 GHz

Figure 5. Simulated surface current distribution of the proposed antenna.

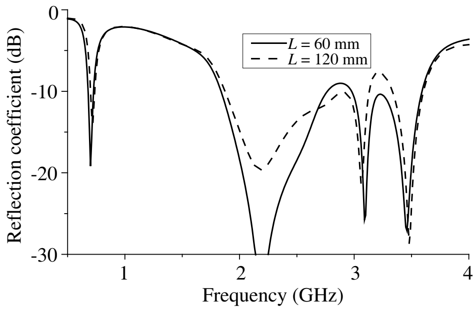


Figure 6. Simulated reflection coefficient for different length of L.

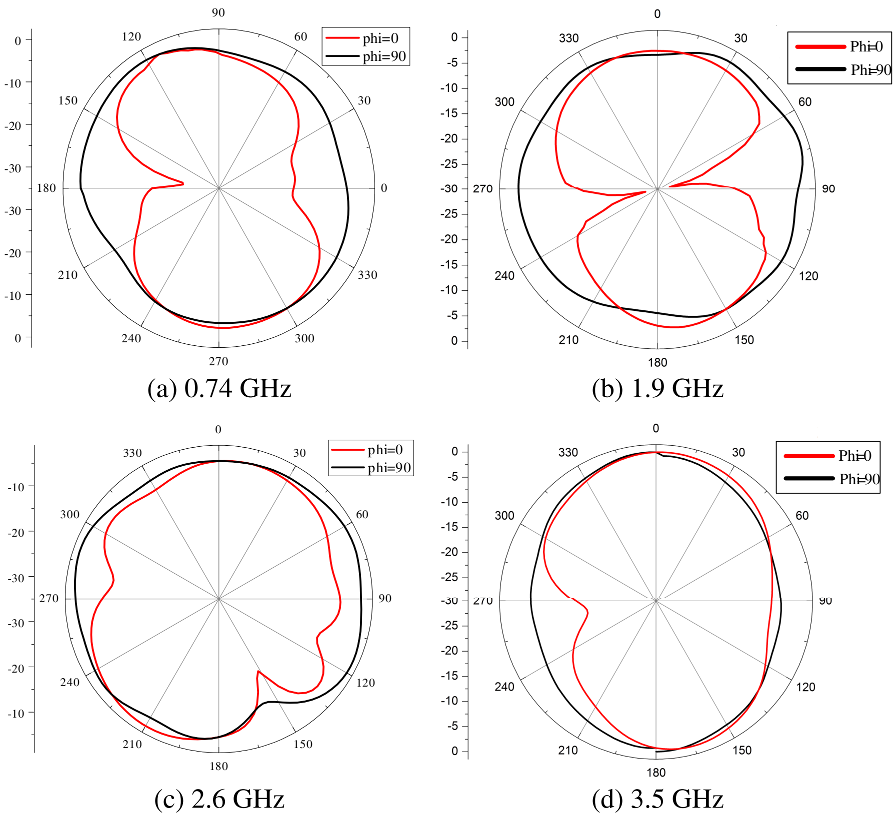


Figure 7.

tenna, while the others are generated by CRLH unit cell. The current distribution at 0.74 GHz was high on the meandered line, which can explain that the resonant mode at 0.74 GHz is mainly controlled by the shunt inductor of CRLH cell.

The influence of the length of antenna (L) is showed in Fig. 6. It can be clearly seen that there is almost no effect on the antenna's bandwidth.

The measured far-field radiation patterns of the fabricated prototype at 0.74/1.9/2.6 and 3.5 GHz are shown in Fig. 7. The E-plane (phi $= 0°$) is a figure-eight radiation pattern and the H-plane (phi $= 90°$) nearly omni-directional radiation pattern. Although the radiation patterns of E-plane in higher band is not as good as a conventional simple monopole antenna, they are still monopole-like patterns. The efficiency of the antenna is measured by using 3D pattern integration. Measured peak gains and efficiency are illustrated in Fig. 8. The gain of the proposed antenna has peak values of 1.5 dBi at 0.74 GHz, 1.9 dBi at 1.9 GHz, 1.85 dBi at 2.6 GHz and 2.2 dBi at 3.5 GHz. It is clearly seen that the antenna in high band has higher gain than in low band. It is mainly because the radiation pattern in high band has a relatively narrower field than in low band. Moreover, the measured radiation efficiencies of the narrow band are 51.2∼71.5%, and those of the wide band are 31.2∼85.3%. However, the efficiency has a dip to 30% at 3.1 GHz. It may be because this frequency is inside the stop band caused by the unbalanced CRLH unit-cell so that the antenna can not efficiently radiate in this region. Both the peak gains and the radiation efficiencies are degraded at the edge of each band as we expected and satisfy the gain requirements of the current mobile phones.

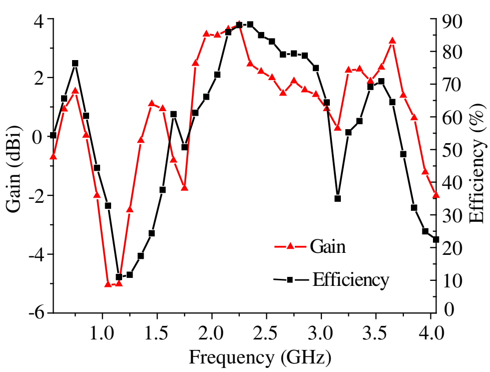


Figure 8. Measured peak gain and efficiency of the proposed antenna.

4. CONCLUSION

A wideband antenna based on CRLH structure has been developed for mobile handsets. It can achieve a wideband of more than 70% covering frequency range from 1710 to 3810 MHz and a narrow band of 100 MHz (690∼790 MHz). The designed antenna covers the LTE, DCS, PCS, WCDMA, Wi-Fi (2.4 GHz) and WiMAX bands. Good radiation patterns and measured peak gains make it suitable for mobile applications. Furthermore, the proposed antenna can be easily fabricated and modified for various mobile phones as a compact internal antenna.

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