A Compact D-CRLH Metamaterial Antenna for WLAN and WiMAX Multiband

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***Abstract*—This paper presents a compact multiband antenna formed from only one cell of dual composite right left handed transmission line (D-CRLH TL), which employs metamaterial loading on a conventional monopole to attain a certain degree of miniaturization. The proposed configuration is simple as uniplanar structure, and is operating at 2.45, 3.60 and 5.60 GHz, covering the WLANs and WiMAX bands, and its dimension is only 20 × 16 × 1.6 mm^3. The design concepts, the simulation and the experimental results are reported.**

***Index Terms*—D-CRLH TL, metamaterial, multiband, WLANs, WiMAX.**

1. Introduction

In recent years, the Composite Right/Left Handed Transmission Line (CRLH TL) metamaterials are introduced as one of the methods for implementing compact multiband antennas [1]. The CRLH TL metamaterials using zero-th order resonance are popular for their inherent multiband property which can be extensively exploited to meet various demands. Another advantage of the CRLH TL is that the resonant frequency is independent of the physical dimensions of the antenna at the zero-th order mode. In 2006, Caloz proposed the equivalent circuit models of dual CRLH TL (D-CRLH TL), exhibiting a left-handed band at the high frequencies and a right-handed band at the low frequencies [2]. The fast development of CRLH TL and D-CRLH TL provides new ways to design microwave instruments with good electromagnetic performances [3]–[4].

A compact antenna employing D-CRLH metamaterial, developed for the WLANs (2.45, 5.60 GHz) and WiMAX (3.60 GHz) applications, have been proposed by us [5]. In this study, we shall explain more detail about the antenna design concepts, the theoretical analysis and the antenna characteristics.

2. Antenna Analysis and Design

A. Theoretical Analysis

Fig. 1 shows the equivalent circuit model for a D-CRLH transmission line. The transmission line consists of a series circuit of C_L, L_R, L_S, and a shunt circuit of C_R, L_L and C_P. The resonant frequency of the antenna can be calculated from the equivalent circuit. By using the Bloch-Floquet theorem,

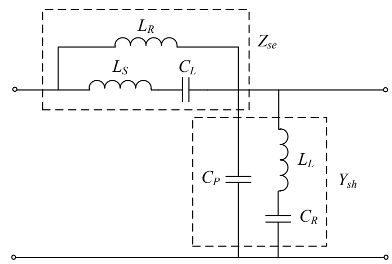

Fig. 1. Equivalent circuit of proposed antenna.

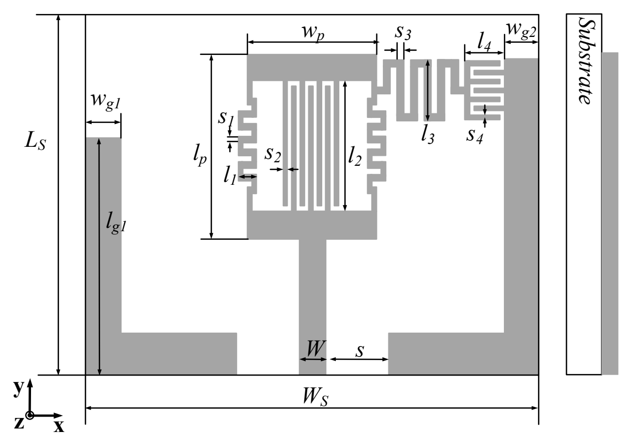

Fig. 2. The configuration of the proposed antenna (W_s = 16 mm, L_s = 20 mm, W = 2.0 mm, s = 0.3 mm, l_1 = 1.5 mm, s_1 = 0.2 mm, l_2 = 6.0 mm, s_2 = 0.2 mm, l_3 = 2.9 mm, s_3 = 0.3 mm, l_4 = 1.25 mm, s_4 = 0.2 mm, l_p = 8.2 mm, w_p = 5.7 mm, l_{g1} = 14 mm, w_{g1} = 2.0 mm, l_{g2} = 3.4 mm).

the resonant modes of D-CRLH TL can also be obtained by following condition:

$$\beta d = \cos^{-1}\Big[1 + \frac{\omega^2}{2\omega_s^2}\Big(\frac{1-\frac{\omega^2}{\omega_0^{se2}}}{1-\frac{\omega^2}{\omega_\infty^{se2}}}\Big)\Big(\frac{1-\frac{\omega^2}{\omega_0^{sh2}}}{1-\frac{\omega^2}{\omega_\infty^{sh2}}}\Big)\Big] = n\pi, \quad (1)$$

with ω_0^{se}, ω_∞^{se}, ω_0^{sh}, ω_∞^{sh}, ω_0^{se} and n are showed in Ref. [5].

In order to design a multiband antenna for WLANs and WiMAX applications, the resonant frequencies of the proposed antenna are chosen as f_1 = 2.45 GHz, f_2 = 3.60 GHz and f_3 = 5.60 GHz, respectively. Here, the resonant frequencies f_2, f_3 may be defined from the zero-th order mode (n = 0), and frequency f_1 can be determined by the first order mode (n =

1) defined from (1). These frequencies can be expressed as the following formulas:

$$\frac{(2\pi f_1)^6}{\omega_0^{se2}\omega_0^{sh2}} - (2\pi f_1)^4\left[\frac{1}{\omega_0^{se2}} - \frac{1}{\omega_0^{sh2}} - \frac{4\omega_s^2}{\omega_\infty^{se2}\omega_\infty^{se2}}\right]$$

$$+(2\pi f_1)^2\left[1 - \frac{4\omega_s^2}{\omega_\infty^{se2}} - \frac{4\omega_s^2}{\omega_\infty^{sh2}}\right] + 4\omega_s^2 = 0, \quad (2)$$

$$f_2 = \frac{\omega_0^{se}}{2\pi} = \frac{1}{2\pi\sqrt{L_S C_L}} = 3.60 \times 10^9, \quad (3)$$

$$f_3 = \frac{\omega_0^{sh}}{2\pi} = \frac{1}{2\pi\sqrt{\frac{L_L C_R C_P}{C_R + C_P}}} = 5.60 \times 10^9. \quad (4)$$

Then, we can assume two cut-off frequencies f_{c1}, f_{c2} defined as ω_∞^{se}, ω_∞^{sh} are equal to 2.3 GHz and 3.0 GHz, respectively. These frequencies f_{c1}, f_{c2} can be expressed as:

$$f_{c1} = \frac{\omega_\infty^{se}}{2\pi} = \frac{1}{2\pi\sqrt{(L_S + L_R)C_L}} = 2.30 \times 10^9, \quad (5)$$

$$f_{c2} = \frac{\omega_\infty^{sh}}{2\pi} = \frac{1}{2\pi\sqrt{L_L C_R}} = 3.0 \times 10^9, \quad (6)$$

Therefore, from (1) $\sim$ (6), the lumped parameters can be calculated by setting L_R = 3.2 nH as L_R = 3.2 nH, C_P = 0.11 pF, C_R= 0.28 pF, L_S = 2.5 nH, L_L = 10.2 nH, C_L= 0.79 pF, respectively.

B. Antenna Design

The antenna considered in this study is designed on a FR4 substrate with the following parameters: relative permittivity ϵ_r = 4.4, dielectric tangential loss δ = 0.02, and thickness h = 1.6 mm. The antenna is fed by a 50 Ω coplanar waveguide to integrate with the communication circuits. The geometrical configuration of the proposed antenna is shown in Fig. 2.

3. Results and Discussion

Fig. 3 presents the prototype of the proposed antenna, which is fabricated on the FR4 substrate with a thickness of 1.6 mm. The proposed antenna uses a D-CRLH TL unit cell as a multiband radiator. It is fed by a coplanar waveguide whose characteristic impedance is equal to 50 Ω.

The measured reflection coefficient $|S11|$ of the proposed antenna is plotted in Fig. 4. The measured result exhibits a good performance of below –10 dB in three frequency bands: 2.51 $\sim$ 2.64 GHz, 3.34 $\sim$ 4.03 GHz and 5.40 $\sim$ 6.03 GHz. High relevance with the simulated result has been found. The observed minor difference is due to the effect of the connector of the feeding coaxial line and the substrate un-uniformity, which can cause calibration errors.

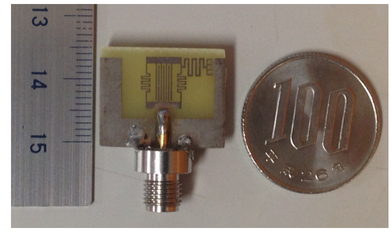

Fig. 3. The prototype of the proposed antenna.

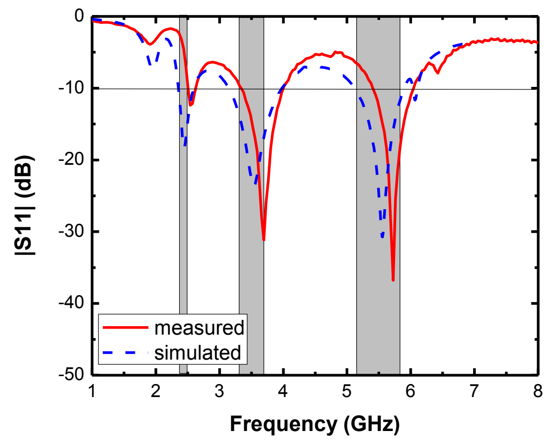

Fig. 4. The measured reflection coefficient of the proposed antenna.

4. Conclusion

A compact multiband metamaterial antenna is presented in this study. The proposed antenna is based on a unit cell of D-CRLH TL which employs metamaterial loading on a conventional monopole to attain a certain degree of a miniaturization. The antenna is fabricated and the measurement of S11 parameter shows good agreement with the simulation results. The antenna has three operating bands at 2.45, 3.60 and 5.60 GHz for the WLANs and WiMAX applications.

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