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# Design of compact patch antenna based on zeroth-order resonator for wireless and GSM applications with dual polarization

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ABSTRACT

One of the main goals to design printed circuit antennas is reducing their size for compact applications, while improving their electromagnetic properties. Using metamaterials with negative permittivity and permeability improve the antenna parameters. Our purpose is antenna miniaturization while other characteristics such as pattern, VSWR and bandwidth are maintained for wireless applications. Composite right/left-handed (CRLH) structures are typical technique to design the compact antenna. A compact and miniaturized antenna is presented in this article for wireless and GSM applications. The final antenna has directional pattern and triple-band at 1760, 2550 and 3850 MHz with gain 2.1, −3.9 and 2.5 dBi, respectively; and it is also dual polarized. The size of prototype patch antenna is 20 mm × 20 mm. In fact, the patch dimensions are reduced about 47% in comparison to conventional patch antenna at 2.5 GHz. It is designed and fabricated on FR4 low cost substrate with $\varepsilon_r = 4.4$ and thickness of 1.6 mm, and it is simulated by HFSS. Also, equivalent circuit and experimental results are presented and compared here.



## 1. Introduction

Nowadays, wireless communication systems progress too fast and became the most important part in notebooks and cellular phones because of mobility and low cost [1]. IEEE 802.11 is a standard protocol for WLAN systems and supports wireless access. IEEE 802.11a standard considers 5.15–5.35 GHz and 5.725–5.825 GHz as sending and receiving band, respectively. IEEE 802.11bg applies 2.4 GHz (2.4–2.484 GHz) for WLAN and 3.3–3.8 GHz for WiMAX applications [2,3]. It is necessary to design small size, easy fed and low cost antenna for multi band applications. Slot antenna is a known antenna for wireless applications, with all attributes that WLAN communication systems need. Methods such as notch technique, metamaterial method, slot technique and fractal method are used to design multi band antennas [4–6].

Using metamaterial with negative $\mu$ and $\varepsilon$ improves some of antenna properties such as bandwidth. Also, EBG (electromagnetic band gap) is a common structure to increase the gain of antenna [7–9]. Metamaterials are widely used in antenna and microwave circuits to increase the miniaturization factor of the antenna, such as metamaterial structure in substrate [10], metamaterial load for miniaturization [11]. Metamaterial-inspired technique is also used for miniaturization of patch antenna with split-ring resonators [12]. Metamaterial transmission line (MTL) is a type of TL structure which contains unit cells with series capacitor and shunt inductor, these elements are added to conventional transmission line model [13]. These new elements provide left-handed (LH) propagation and support backward wave idea. Gap and interdigital capacitors are common types of structure for series capacitance, but actually interdigital capacitors are used to achieve higher capacitance. Vias are used as shunt inductors and this inductance can be increased by combination of these Vias with other types of inductors such as spiral or meander structures [14,15]. Also, we can use spiral or meander structures as shunt inductor by adding virtual ground to them [16]. Zeroth-order resonators (ZOR) have become important structures to design small antennas. They have much smaller size in comparison with traditional microstrip rectangular patch antennas. Composite right/left-handed (CRLH) metamaterials are structures with both of the right-handed (RH) and left-handed (LH) characteristics [17,18].

This article presented a triple band antenna for GSM 1800, WLAN at 2.55 GHz and WiMAX at 3.85 GHz. The size of prototype patch antenna is 20 mm × 20 mm. In fact, the patch dimensions are reduced about 47% in comparison to conventional patch antenna at

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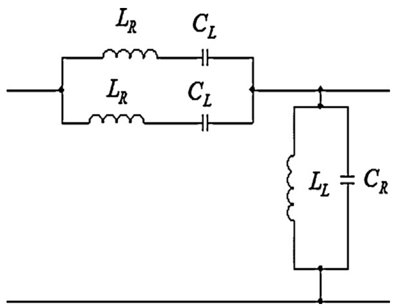


**Fig. 1.** Equivalent circuit model for CRLH TL unit.

2.5 GHz. The antenna has linear polarization at 1760 and 3850 MHz and circular polarization at 2550 MHz. The current distribution of antenna proves that variable capacitance cause to design triple resonance.

## 2. CRLH theory

Equivalent circuit for a CRLH transmission line is shown in Fig. 1. To achieve a structure that has completely left-handed features is nearly impossible. According to the transmission line theory, propagation constant in lossless structure is $\gamma = j\beta = \sqrt{Z'Y'}$ where $Z'$ and $Y'$ are per unit length impendence and admittance, respectively [19].

Effective permeability and permittivity can be achieved for MTL by calculation of $Z'$ and $Y'$ as presented in (1) [19]:

$$\begin{aligned}\mu &= \mu(\omega) = L_R - \frac{1}{\omega^2 C_L} = \frac{Z'}{j\omega}\\ \varepsilon &= \varepsilon(\omega) = C_R - \frac{1}{\omega^2 L_L} = \frac{Y'}{j\omega}\end{aligned} \tag{1}$$

where

$$\begin{aligned}Z' &= j\left(\omega L_R - \frac{1}{\omega C_L}\right) \quad \Omega/\mathrm{m}\\ Y' &= j\left(\omega C_R - \frac{1}{\omega L_L}\right) \quad \mathrm{S/m}.\end{aligned} \tag{2}$$

$\omega_L$ is left-handed resonance frequency ($\omega_L = 1/\sqrt{C_L L_L}$), $\omega_R$ shows right-handed TL equivalent circuit resonance frequency ($\omega_R = 1/\sqrt{C_R L_R}$). Also, series and shunt resonance frequencies are presented by $\omega_{se}$ ($\omega_{se} = 1/\sqrt{C_L L_R}$) and $\omega_{sh}$ ($\omega_{sh} = 1/\sqrt{C_R L_L}$).

There is a frequency that separates the left-handed region from the right-handed one, it is called the transmission frequency and it is calculated by the following equation [19]:

$$\omega_0 = \sqrt{\omega_R \omega_L} = \frac{1}{\sqrt[4]{L_R C_R L_L C_L}} \tag{3}$$

The left- and right-handed capacitances are calculated by Eqs. (4) and (5). The values are $C_R = 0.69$ pF and $C_L = 0.32$ pF. The bent interdigital model has two essential benefits: the first one is the size of interdigital capacitance and the second one is that it shows more inductance characteristic such as microstrip bent line; thus, $L_R$ will be increased more because of mutual coupling.

$$C_L = -\frac{Im(Y_{21})}{\omega_0} \tag{4}$$

$$C_R = \frac{Im(Y_{11} + Y_{12})}{\omega_0} \tag{5}$$

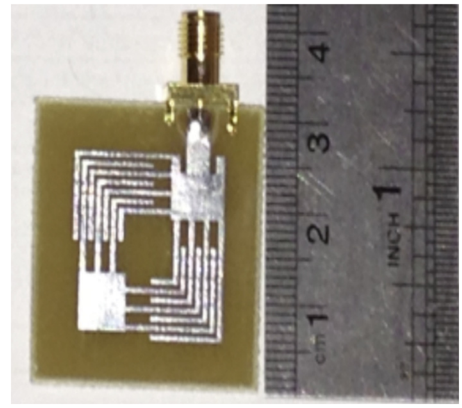

**Fig. 2.** Geometrical model of the antenna with size of 20 mm × 20 mm and substrate with permittivity of 4.4 and $h = 1.6$ mm.

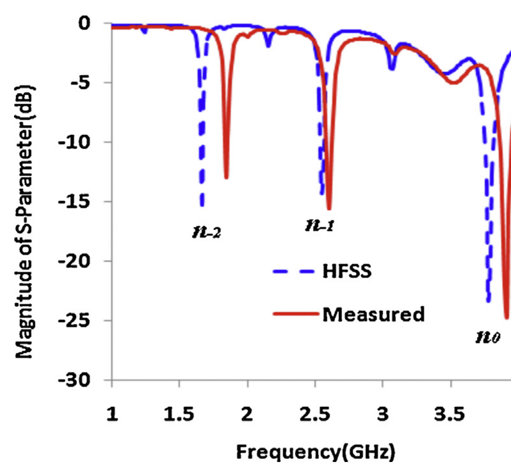


**Fig. 3.** Return loss of the proposed antenna at $n = 0$ mode.

## 3. Antenna structure

Fig. 2 shows the prototype ZOR antenna. The final antenna model contains two parallel interdigital capacitors. Thus, it helps to increase the series capacitance and reduces the zeroth order resonator size and achieves more miniaturization factor. In fact, interdigital capacitor with L shape fingers is presented which increases the capacitance value.

The rectangular patch antenna is fed by inset microstrip line with length of 7 mm and width of 3 mm which is connected to the 50 Ω SMA connector. Two parallel interdigital capacitors have connected this part to the other rectangular patch. The antenna is fabricated on FR4 low cost substrate with a dielectric constant of $\varepsilon_r = 4.4$ and thickness of 1.6 mm. Total size of substrate is 30 mm × 30 mm and patch total size is around 20 mm × 20 mm. Therefore, the miniaturization factor is 1.9.

## 4. Simulation and experimental result

The antenna is designed based on CRLH-TL technique. The measured and simulated return losses of the antenna are presented in Fig. 3. The final model of antenna has three bands with around 25 MHz, 32 MHz and 100 MHz bandwidth at 1.76 GHz, 2.55 GHz and 3.85 GHz, respectively.

The equivalent circuit parameters which are extracted from full-wave simulation data of the unit cell are $C_R = 0.69$ pF, $L_R = 4.8$ nH, $C_L = 0.32$ pF and $L_L = 2.5$ nH. Therefore, $f_{sh} = 3.88$ GHz and $f_{se} = 4.08$ GHz so $f_0 = 3.9$ GHz can be obtained. The ZOR mode ($n = 0$)