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RESEARCH PAPER

A compact CPW-fed wideband metamaterial-inspired antenna for GSM, WLAN/Wi-Fi, and WiMAX applications

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A compact coplanar waveguide (CPW)-fed wideband metamaterial-inspired antenna is designed and developed in this paper. The proposed structure is an asymmetric structure in which three rectangular stubs are employed between signal patch and CPW ground plane. It is demonstrated that these stubs provides lumped parameters of conventional epsilon-negative transmission line (ENG-TL). As an advantage of these stubs proposed antenna operates on 1.67–2.76 GHz with −10 dB impedance bandwidth of 49.2%. The proposed antenna having small electrical size of $0.17\lambda_o \times 0.35\lambda_o \times 0.01\lambda_o$ at $f_o = 2.21$ GHz. The simulated average gain and radiation efficiency of the proposed antenna is 1.61 dB and 96.33% respectively throughout the bandwidth. Properties such as smaller electrical size, simpler design, consistent radiation characteristics, and ease of fabrication are making this antenna suitable for GSM, WLAN/Wi-Fi, Bluetooth, and WiMAX applications.

Keywords: Metamaterial-inspired antenna, wideband antenna, WiMAX, epsilon-negative transmission line (ENG-TL)

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I. INTRODUCTION

Compact antennas with wideband and high-efficiency characteristics are essentially required to be used in wireless communication devices such as laptops and mobile phones. Epsilon-negative transmission lines (ENG-TL) has attracted researchers to design compact antennas due to its unique characteristics (antiparallel group and phase velocities, zero propagation constant at non-zero frequencies) [1–4]. Niu *et al.* recently proposed wideband metamaterial (MTM) antenna using three numbers of unit cells and achieved 70% bandwidth [2]. Later on, by introducing backed ground plane concept by same authors [3] are succeed to design dual band and wideband antenna simultaneously with 67.4% fractional bandwidth. Majedi & Attari [4] presented a qualitative structure based on ENG-TL approach and designed two different kind of antennas as dual band and dual polarized respectively by incorporating notches into the patch. Some works have been carried out based on composite right/left handed (CRLH) transmission lines to enhance the bandwidth by using symmetric coplanar waveguide (CPW)-fed [5] and asymmetric CPW-fed structures [6]. It has been observed from the studies that the asymmetric structure offers bandwidth enhancement due to increased shunt inductance incorporated with the CRLH transmission line. Moreover, modes can be introduced by combining the number of elements or unit cells into the structures, which are configurable with varying design dimensions of the elements [7–8].

A novel CPW-fed zeroth-order resonant antenna has been reported in which a single resonant ring is employed to introduce another mode and is achieved 40% fractional bandwidth at 2.09 GHz [9]. Furthermore, a compact tri-band antenna is proposed by incorporating T-junction discontinuity based on the CRLH resonant structure [10]; however, shortcoming of this antenna is having negative gain in the lower band.

In this paper, a triple-stub CPW-fed metamaterial-inspired antenna is proposed. Equivalent circuit of the proposed antenna is presented and concluded that these stubs offer certain lumped parameters associated with the conventional ENG-TL. In addition to this coupling between these stubs introduce another mode, which is responsible for enhancing the bandwidth. The −10 dB bandwidth of 49.2% is achieved at 2.21 GHz. The proposed antenna is suitable for the operation at GSM 1900 (1.85–1.99 GHz), WLAN/Wi-Fi (2.4–2.5 GHz), Bluetooth (2.4–2.49 GHz), and WiMAX (2.5–2.7 GHz). All simulations are carried out by the Ansoft HFSS14.0 EDA tool.

II. ANTENNA THEORY

The design methodology of the proposed antenna is based on the ENG transmission line approach as series capacitance is not present (C_L). Figure 1 shows the intuitive equivalent circuit model for the proposed antenna. Figure 2 depicts the schematic of the proposed antenna with respect to modeling of lumped parameters, corresponding to equivalent circuit model given in Fig. 1. Signal patch is modeled by the series

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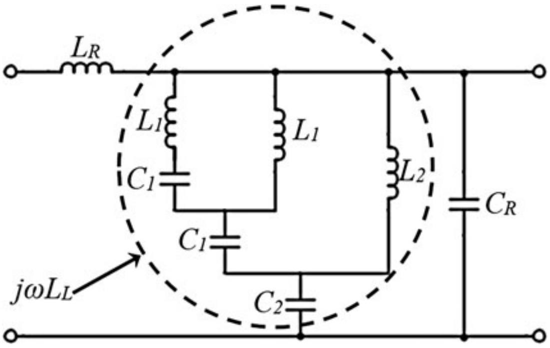

Fig. 1. Equivalent circuit model of the proposed antenna.

inductance L_R. L_1 is associated with the inductance offered by the stub1 and stub2, respectively, since the dimensions of these stubs are same. Similarly the gap between stub-1, stub-2 and stub-2, stub-3 is modeled by the C_1. Moreover, L_2 is the inductance offered by stub-3, and C_2 signifies the gap between stub-3 and ground plane. Finally, whole stubs offer the combining capacitance C_R, which is introduced by the gap between those stubs and ground plane as shown in Fig. 2.

The impedance offered by the specified region in Fig. 1, is calculated and is given by

$$Z = \frac{j\omega\{A(L_2 - C_2) - j\omega L_2 C_2\}}{A + j\omega L_2}, \tag{1}$$

$$A = \frac{j\omega\left[L_1\{L_1 - (1/\omega^2 C_1)\} - (1/\omega^2 C_1)\{2L_1 - (1/\omega^2 C_1)\}\right]}{[2L_1 - (1/\omega^2 C_1)]}, \tag{2}$$

Substituting (2) into (1) we obtain

$$Z = j\omega\left(L_1^2 L_2 - L_1^2 C_2 - L_2 C_2\right) + \frac{1}{(j\omega)^2}\left(\frac{3L_1 L_2}{C_1} - \frac{3L_1 C_2}{C_1}\right) + \frac{1}{(j\omega)^3}\left(\frac{L_2}{C_1^2} - \frac{C_2}{C_1^2}\right). \tag{3}$$

It is perceived from (3) that equivalent impedance is inductive in nature as at high-frequency terms 2 and 3 can be neglected. It is also observed that the left-handed inductance (L_L) depends on the parameters L_1, L_2, and C_2. Therefore variation in dimensions of stubs and gaps controls the parameters involved in the left-handed inductance and thereby the resonant frequency [11]. From (3) equivalent inductance is given by

$$L_L = \left(L_1^2 L_2 - L_1^2 C_2 - L_2 C_2\right). \tag{4}$$

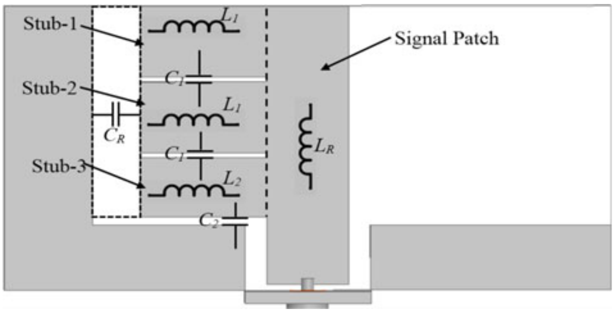

Fig. 2. Modeling of the circuit elements in the proposed antenna.

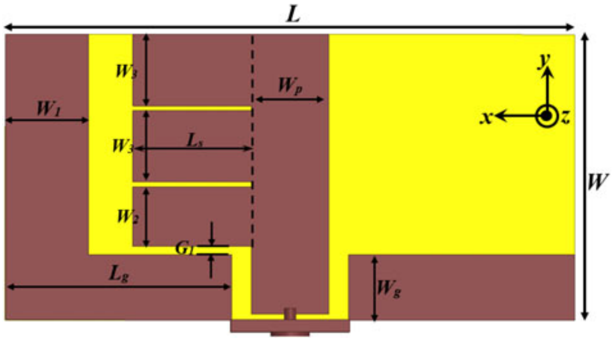

Fig. 3. Configuration of the proposed antenna ($L = 48$ mm, $W = 24$ mm, $L_g = 19.05$ mm, $W_g = 5.5$ mm, $W_1 = 7$ mm, $W_2 = 5$ mm, $W_3 = 6$ mm $L_s = 10$ mm, $W_p = 6.5$ mm, and $G_1 = 0.7$ mm).

III. ANTENNA DESIGN AND ANALYSIS

Figure 3 shows the configuration of the proposed antenna using three rectangular stubs along with the relevant design dimensions in captions. The whole antenna is fabricated on an FR4 Glass Epoxy substrate ($\varepsilon_r = 4.4$, $\tan\delta = 0.02$) with 1.6 mm thickness.

The proposed antenna is essentially an asymmetric CPW-fed ground plane structure in which three rectangular stubs are incorporated to ensure best impedance matching. In fact, these stubs provide different lumped parameters to realize an ENG transmission line as discussed in the previous section. Thus, by carefully optimizing the dimensions of the stubs, gap between CPW ground plane and stubs, compact antenna structure is obtained. Figure 4 indicates that resonant frequency is significantly decreased by increasing number of

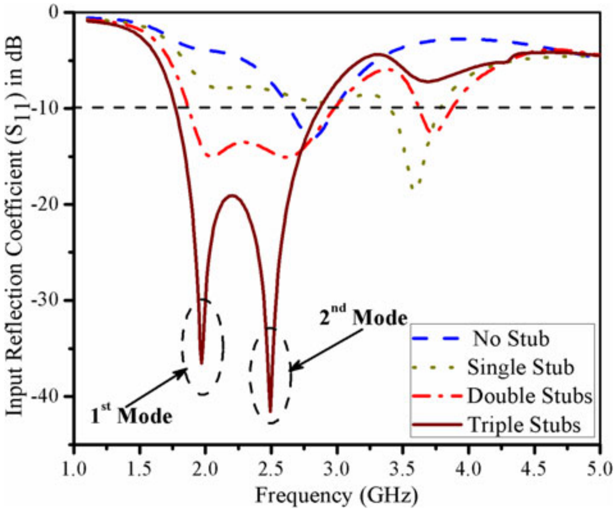

Fig. 4. Comparison of input reflection coefficients of the antenna with (a) no stub, (b) single stub, (c) double stubs, and (d) triple stubs.

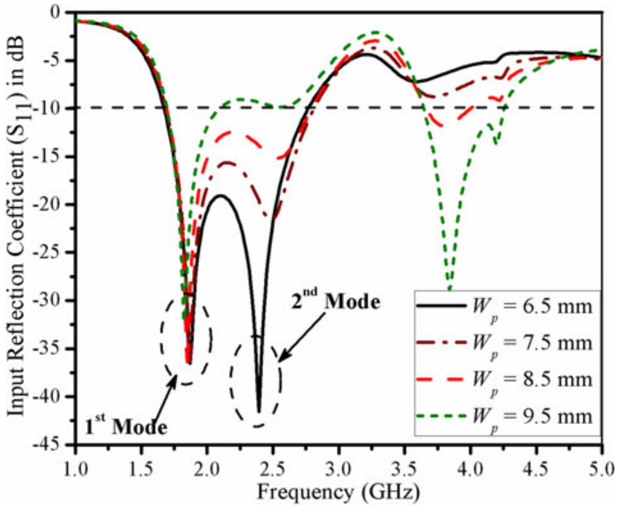

Fig. 5. Input reflection coefficients of the proposed antenna by varying W_p.

stubs. It is observed that second resonant mode is obtained by patch, while first mode is introduced by the coupling between two stubs which are also responsible for band broadening by merging two modes. It is important to note that triple stubs do not offer significant bandwidth improvement with respect to double stubs. In fact, the lumped components involved in third stub are responsible to manipulate the input impedance of the antenna; hence, impedance matching is prominently better as compared with double stubs.

In order to verify the excitation of modes variation in input reflection coefficient by changing dimension W_p is shown in Figure 5. It is observed that second resonant mode is getting extinct by increasing the W_p. This is because as the width of the signal patch (W_p) is increased, the patch is getting closer to the CPW ground plane, which affects the coupling between patch and CPW ground planes.

IV. EXPERIMENTAL RESULTS

Figure 6 shows the photograph of the fabricated prototype. Input reflection coefficients (S_{11}) measurement has been carried out by using Anritsu VNA master MS2025B. Good agreement in the simulated and measured input reflection coefficients has been observed as shown in Fig. 7, with small shift in center frequency. This is because of non-uniform substrate and imperfection in soldering.

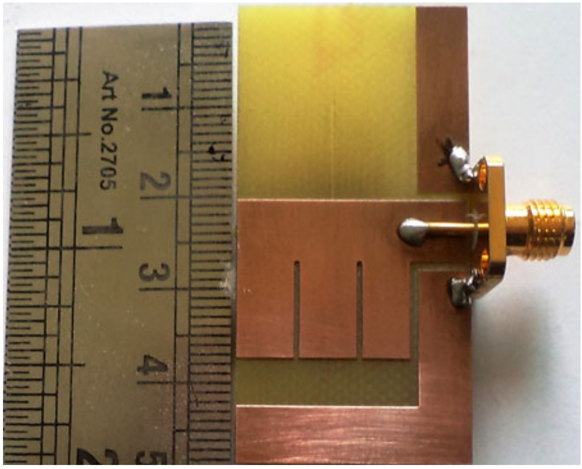

Fig. 6. Photograph of the fabricated prototype.

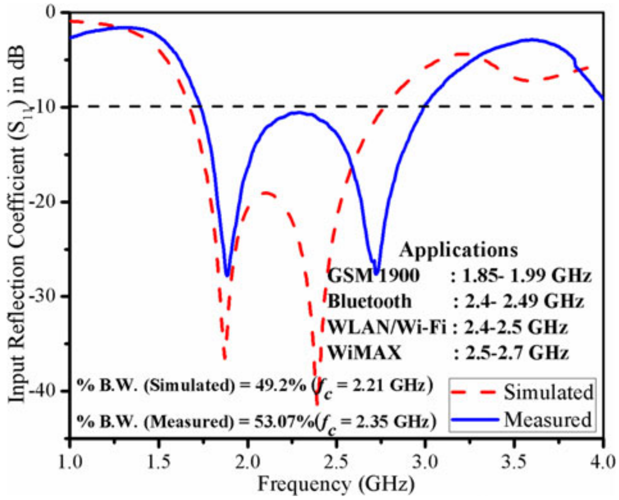

Fig. 7. Simulated and measured input reflection coefficients of the proposed antenna.

Figure 8 shows the simulated and measured radiation patterns of the proposed antenna at two resonant modes, obtained by the simulation. It is observed that radiation patterns are consistent throughout the bandwidth and exhibits dipolar-type radiation pattern in the *xz*-plane (*E*-plane), while omnidirectional type pattern in the *yz*-plane (*H*-plane). Measured radiation patterns are in good agreement with the simulated one, except minor asymmetry in cross-polarization. Radiation characteristics of the prototype are carried out in free space environment by using log periodic antenna as a reference antenna. Cross-polarizations are affected by the radiations from the free space without absorbers. Figure 9 shows the peak gain and radiation efficiency profile for the proposed antenna. This antenna offers simulated peak gain of 1.73 and 1.27 dB at the first and the second resonant mode. The radiation efficiencies are 94.4 and 98.3% corresponding to the observed mode. One can see that the measured gain observed in Fig. 9 is lower than that of the simulated gain. It may be due to the interference by the free space radiation resulting deterioration in received power.

V. CONCLUSION

A compact CPW-fed metamaterial-inspired antenna based on ENG-TL is proposed in this paper. To improve the bandwidth and impedance matching, rectangular stubs have been used. It is observed that an extra resonant mode is introduced due to the coupling between two stubs and another stub is used to improve impedance matching. Thus, a fractional bandwidth of 49.2% is achieved at center frequency 2.21 GHz. The far-field parameters are consistent throughout the operating band. This antenna can cover GSM 1900 (1.85–1.99 GHz), WLAN/Wi-Fi (2.4–2.5 GHz), Bluetooth (2.4–2.49 GHz), and WiMAX (2.5–2.7 GHz) to be used in mobile phones and laptops.

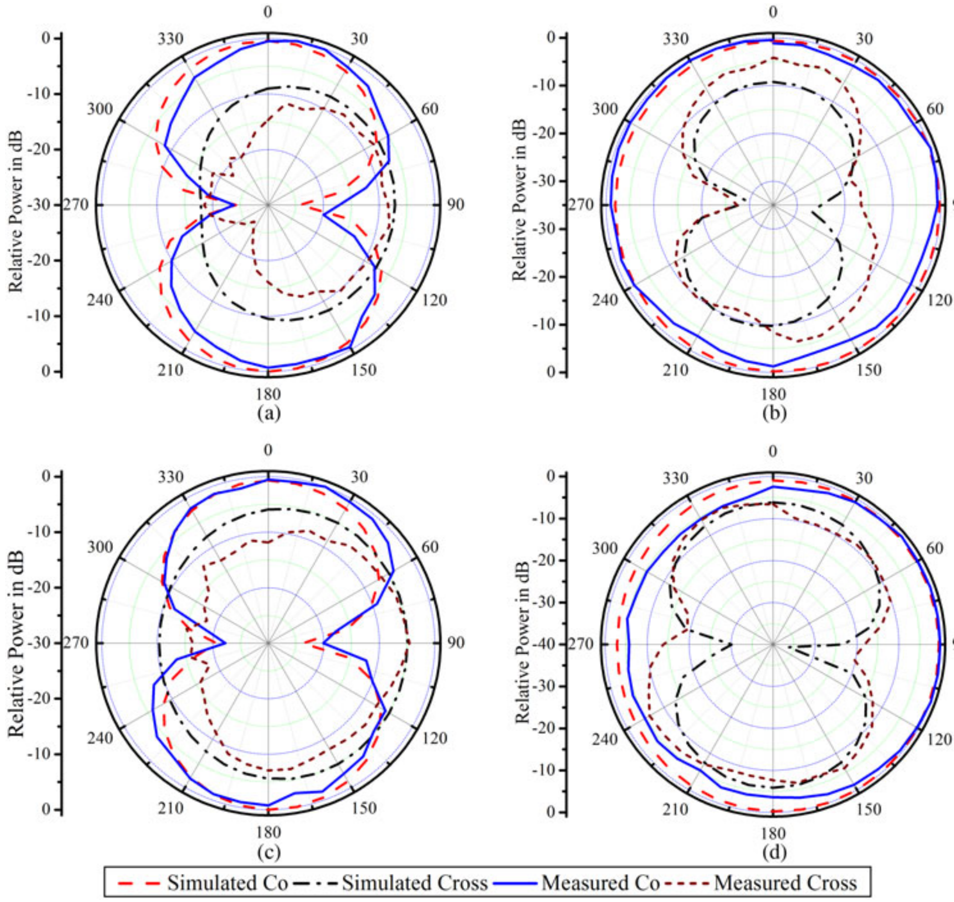

Fig. 8. Simulated and measured radiation patterns of the proposed antenna. (a) *xz*-plane at 1.87 GHz, (b) *yz*-plane at 1.87 GHz, (c) *xz*-plane at 2.39 GHz, (d) *yz*-plane at 2.39 GHz.

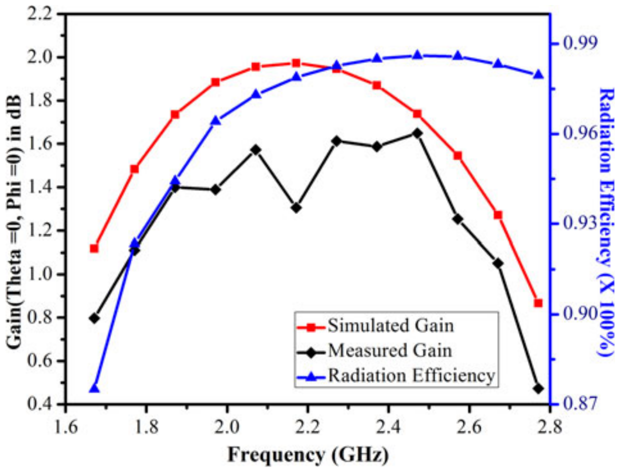

Fig. 9. Gain and radiation efficiency profiles of the proposed antenna.

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