Composite Right/Left-Handed Transmission-Line Based Wideband Antenna for WLAN, WiMAX and WiFi Applications

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***Abstract* - In this article, a new and compact wideband antenna is presented based on metamaterial composite right/left-handed transmission-line (CRLH-TL) structures. The proposed wideband planar antenna provides enhanced gain performance and is optimized for bandwidth, efficiency and radiation patterns. The CRLH-TL is realized by embedding two inverted F-shaped slots inside a rectangular radiation patch which is inductively grounded through a metal via-hole. The antenna is constructed using two CRLH-TL unit-cells to cover the frequency span from 3.1 GHz to 5.4 GHz, which corresponds to a fractional bandwidth of 54.11%. The overall size of the antenna is 11 mm × 7.4 mm × 0.8 mm or $0.15\lambda_o \times 0.1\lambda_o \times 0.011\lambda_o$, where λ_o is free space wavelength at the operating frequency of 4.25 GHz. The antenna has a maximum gain and radiation efficiency of 6.4 dBi and 89.04%, respectively, at 5.4 GHz. The proposed antenna finds application in various wireless technologies including WLAN, WiMAX and WiFi.**

***Index Terms* - Small antenna, composite right/left-handed transmission line (CRLH-TL), wideband antenna, wireless communication systems, F-shaped slots.**

I. INTRODUCTION

In recent years modern wireless communications systems are required to increasingly handle higher and higher data transmission rates using antennas with a small foot print. Hence there is currently a strong demand for antennas that have the following qualities: (i) small size; (ii) having wideband characteristics; (iii) can be easily integrated in portable wireless communications systems; and (iv) is low-cost [1-3]. These requirements are now becoming possible with the advent of UWB technology. In particular, implementation of such antennas using printed circuit boards is attractive as it offers advantages of compactness, planar profile, low-cost, light weight and broadband features. Furthermore, these antennas are compatible with microwave integrated technology that eases integration in RF systems.

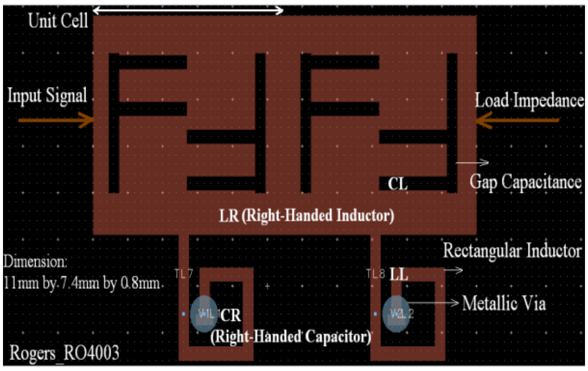
Over recent years composite right/left-handed transmission lines (CRLH-TLs) have drawn broad interest and have led to utilization in many electromagnetic applications from the microwave to optical regime, especially for the radiated-wave devices. CRLH-TLs are manmade composite materials, engineered to produce electromagnetic propagation behavior not found in natural media [4-5]. These unusual properties have been used to improve the performance of microwave devices including antennas. Although microstrip antennas with wideband performance have been developed for application in modern wireless communications systems [6-7], however the size of these antennas is considered to be unsatisfactory to enable system miniaturization. Several techniques have been investigated to reduce the size of such antennas [8]; however such techniques result in increased design complexity that is expensive to implement. To overcome this deficiency antenna realized using CRLH-TL is yielding promising results [9-18]. Various implementations of CRLH-TLs structures have been reported and demonstrated [19-23].

In this paper, we have used the CRLH-TL technology to achieve a wideband antenna with a small foot print area and with enhanced gain performance. The proposed antenna consists of two unit-cells implemented with two inverted F-shaped slots etched in a rectangular patch which is inductively grounded through a spiral. The F-shaped slots create series capacitances (C_L), and the inductive stub which is grounded through a metallic via-hole creates shunt inductance (L_L). Unwanted right-handed parasitic effects associated with the unit-cells generate right-handed capacitance (C_R) and inductance (L_R) that need to be considered in the antenna analysis. The proposed structure exhibits the required wide bandwidth and miniaturization along with enhanced radiation properties such as gain and efficiency. These features make the proposed antenna applicable in UWB systems.

II. DESIGN OF THE WIDEBAND PROTOTYPE ANTENNA

The CRLH-TL unit-cells can be implemented using either surface mount chip components and/or distributed transmission-lines as discussed in [11-23]. Lumped components are not preferred in antenna designs because they are lossy and have limited discrete values. Here we have used printed circuit board techniques to implement the proposed antenna structure as it has advantages of reduced foot print area, low-loss and low-profile.

The proposed antenna, which is based on two CRLH-TL unit-cells, has wideband characteristics and is miniature in size. The unit-cell is composed of two inverted F-shaped slots that are facing each other and are in close proximity. The unit-cell is etched inside a rectangular patch which is grounded through an inductive stub, as shown in Fig. 1. The equivalent circuit model of the antenna is shown in Fig. 2, where the series capacitances (C_L) represent the F-shaped slots, and the shunt inductance (L_L) represents the inductive stub which is grounded through a metallic via-hole. The parasitic effects associated with the unit-cells are represented by the right-handed capacitance (C_R) and inductance (L_R). In this structure, port-1 is excited with the input signal and port-2 is matched to 20 Ohm load impedance, which is an SMD component. Because the lowest mode of operation is a left-handed mode, the propagation constant, which approaches negative infinity at the cutoff frequency, reduces in magnitude as the frequency increases. This phenomenon makes the antenna physically small but is electrically large.



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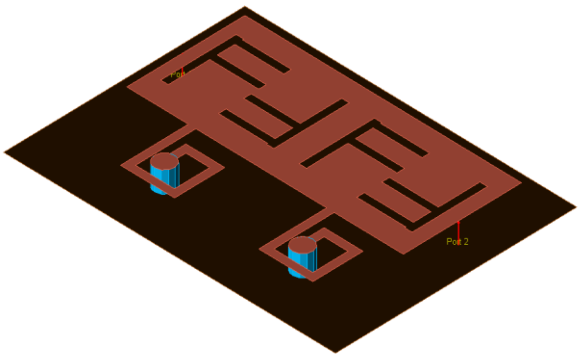

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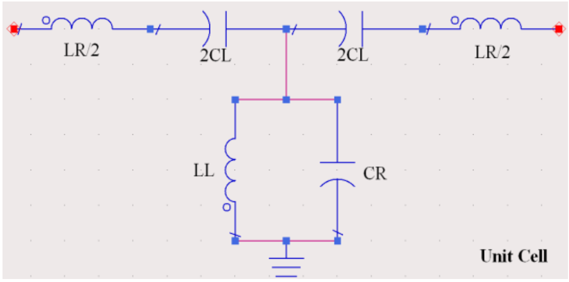
Fig.1. Configuration of the proposed UWB antenna composed of the two unit-cells based on CRLH-TL, (a) Top view, and (b) Isometric view.



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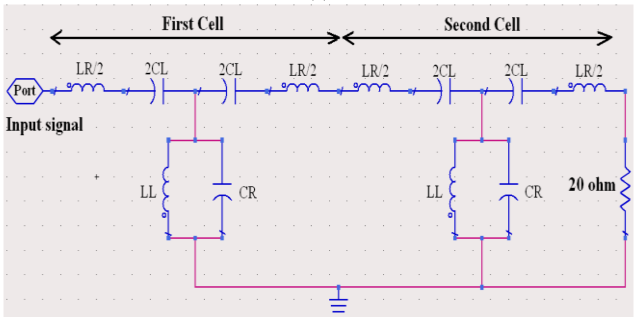

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Fig.2. Equivalent circuit model of the proposed CRLH-TL antenna, (a) unit-cell, and (b) overall structure.

III. RESULTS AND DISCUSSIONS

We have used CRLH-TL technology and printed circuit planar approach to realize a wideband antenna with a small foot print area. The total size of the antenna is $0.15\lambda_o \times 0.1\lambda_o \times 0.011\lambda_o$, in terms of the free space wavelength (λ_o) with an operating frequency of 4.25 GHz. The CRLH-TL based antenna was designed on a Rogers RO4003 substrate with dielectric constant of 3.38, thickness of 0.8 mm and Tanδ of 0.0022. The gap between the F-shaped slots was optimized to realize an impedance bandwidth of 2.3 GHz extending from 3.1 GHz to 5.4 GHz, which corresponding a fractional bandwidth of 54.11%. The antenna was analyzed using Advanced Design System (ADS) full-wave electromagnetic simulator. Fig. 3 shows the reflection coefficient response of the antenna, where the bandwidth is defined for $S_{11} \leq$ -10 dB. The radiation characteristics were improved by optimizing the structural parameters of the antenna including the number of spiral turns (n), spiral inner radius (Ri), spiral width (Ws) and spacing between spiral turns (Ss), width of the metallic via-holes the good radiation performances have been achieved. Gain and efficiency of the proposed antenna varied from -1 dBi to 6.4 dBi and from 15.25% to 89.04%, respectively, over the frequency span 3.1 GHz to 5.4 GHz.

The antenna radiation gain patterns have plotted in Fig.4. As is clear, the radiation patterns have the unidirectional characteristics. The characteristics of the proposed antenna are compared with some other CRLH-TL based antennas in Table I. It is evident from this table compared to antennas reported in [26] and [27] the two unit-cells CRLH-TL antenna has a significantly higher gain of 6.4 dBi, a much wider bandwidth of 2.3 GHz from 3.1 GHz to 5.4 GHz, and much higher radiation efficiency of 89.04%. The CRLH based-antenna has benefits of small dimensions, wide operational bandwidth, and has a high gain and high efficiency. These features make it suitable to support today's multiband wireless systems as well as emerging applications [24-25].

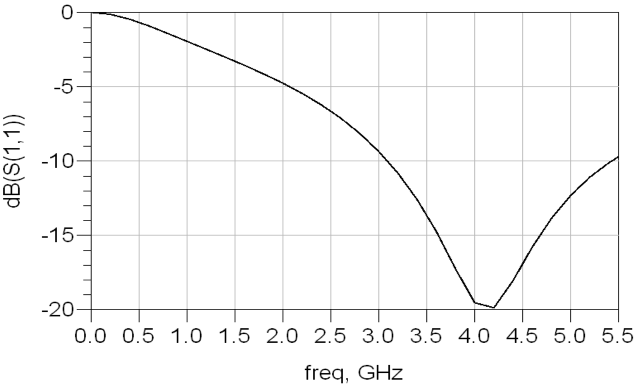
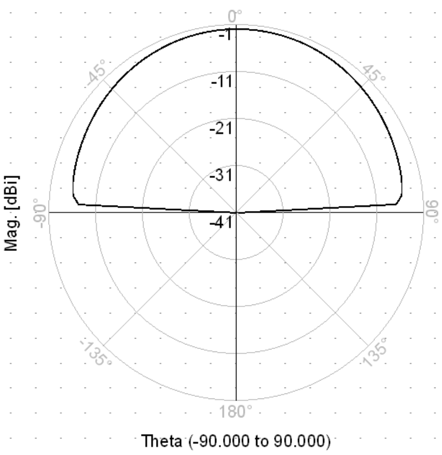


Fig.3. Reflection coefficient of the proposed antenna.

Table I. Comparison of dimensions and radiation characteristics of the proposed antenna with other CRLH-TL antennas.

Parameters	**[26]**	**[27]**	**Proposed Antenna**
Gain (dBi)	0.45	0.6	6.4
Bandwidth (GHz)	0.8-2.5	1-2	3.1-5.4
Efficiency (%)	53.6	26	89.04
Dimensions	$0.4\lambda_o \times 0.03\lambda_o \times 0.03\lambda_o$	$0.07\lambda_o \times 0.07\lambda_o \times 0.03\lambda_o$	$0.15\lambda_o \times 0.1\lambda_o \times 0.011\lambda_o$



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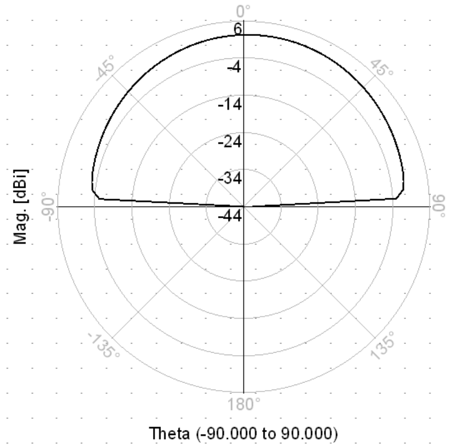

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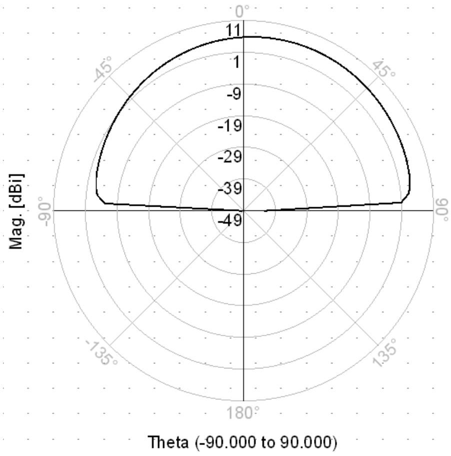

(c)

Fig.4. Radiation gain patterns of the proposed antenna in elevation plane ($\Phi=0^{O}$ degree), (a) 3.1 GHz, (b) 4.25 GHz, and (c) 5.4 GHz.

IV. CONCLUSIONS

A new wideband antenna is presented in this paper that has a small foot print and excellent gain and radiation performance. The antenna design is based on CRLH-TL unit-cells realized using two inverted F-shaped slots embedded inside a radiation patch which is terminated to ground with an inductive stub in the shape of a spiral. The overall size of the antenna is 11× 7.4×0.8 mm^3 or $0.15\lambda_o \times 0.1\lambda_o \times 0.011\lambda_o$. It has an impedance bandwidth of 2.3 GHz from 3.1–5.4 GHz, which corresponding to a fractional bandwidth of 54.11%. The antenna has a peak gain of 6.4 dBi and maximum radiation efficiency of 89.04% at 5.4 GHz. These features make the antenna suitable for wireless communication systems such as WLAN, WiMAX and WiFi.

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