A Novel CRLH-CP Antenna with the Capability to be Integrated Inside RF Components for RF Electronic Devices and Embedded Systems

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Abstract **─** In this paper, design and manufacturing of a composite right/left-handed carved planar (CRLH-CP) antenna with $\varepsilon-\mu$ constitutive parameters is introduced. The composite right/left-handed transmission line (CRLH-TL) is introduced as a general TL possessing both left-handed (LH) and right-handed (RH) natures. The proposed antenna is constructed of four CRLH unit cells, each of which occupies space of $0.004\lambda_0\times0.01\lambda_0\times0.001\lambda_0$, where λ_0 is free space wavelength at 0.5 GHz. The antenna practical bandwidth is 120%, so that the proposed antenna can be used for frequency band from 0.5 GHz to 2 GHz in measurement. Also, the antenna gains and radiation efficiencies at the operational frequencies f=0.7, 1.5 and 2 GHz are 3.8 dBi and 53%, 4.85 dBi and 68.5%, and 4.3 dBi and 60.2%, respectively. According to the results, the proposed minimized ultra wideband (UWB) antenna is a good candidate to use in the RF electronic devices and embedded systems.

Index Terms **─** Carved Circuit Boards (CCBs), Composite Right/Left-Handed Carved Planar (CRLH-CP) antenna, embedded systems, Metamaterial (MTM), Standard Carved Planar Manufacturing Technique (SCPMT), Ultra Wideband (UWB) RF electronic devices.

I. INTRODUCTION

An antenna is a device that is used to transfer guided electromagnetic waves (signals) to radiating waves in an unbounded medium, usually free space and vice versa (i.e., in either the transmitting or receiving mode of operation). Antennas are frequency-dependent devices. Each antenna is designed for a certain frequency band. Beyond the operating band, the antenna rejects the signal. Therefore, we might look at the antenna as a band-pass filter and a transducer. Antennas are an essential part in telecommunication systems; therefore, understanding their principles is important. There are many different antenna types. The isotropic point source radiator, one of the basic theoretical radiators, is useful because it can be considered a reference to other antennas. The isotropic point source radiator radiates equally in all directions in free space. Physically, such an isotropic point source cannot exist. Most antennas' gains are measured with reference to an isotropic radiator and are rated in decibels with respect to an isotropic radiator (dBi).

The multitude of potential techniques proposed over the years to size reduction of the microstrip antennas are mainly based on the reactive loading of a patch antenna with suitably designed slots, shorting posts and lumped elements. These solutions, however, do not usually allow obtaining the drastic reduction of the antenna dimensions needed for the aforementioned applications [9-10-11]. Another possibility to the patch size reduction is

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employment of the dielectric substrates exhibiting high-values of the permittivity. However, due to the increased excitation of surface waves in the substrate, bandwidth, efficiency, and shape of the radiation pattern of the antenna may be significantly deteriorated [1]. Therefore, the aforementioned standard techniques do not represent sufficient tools to beat the challenge of miniaturized antenna design. Some new approaches, based on the use of artificially engineered materials and metamaterials (MTMs), seem to be more promising in this sense, opening the path to substantial achievements for the purposes of size reduction [12-13-14].

In this paper, we have introduced a novel minimized ultra wideband (UWB) carved planar (CP) antenna based on metamaterial (MTM) CRLH-TLs with high gain and efficiency. Recently, MTMs based transmission lines have been developed and have been shown to exhibit unique features of anti-parallel phase and group velocities $(v_p - v_g)$ and zero propagation constant at a certain frequency at the fundamental operating mode [2-3]. Furthermore, metamaterials exhibit qualitatively new electromagnetic response functions which cannot be found in the nature. These metamaterials have been used to realize the novel planar antennas.

The prefix "meta-" has the Greek origin and is translated as "outside of," that allows to interpret the term "metasubstances" as structures whose effective electromagnetic behavior falls outside of the property limits its forming components. The analysis of publications on various aspects of metamaterials technology allows to classify all variety of artificial environments depending on their effective values of permittivity (ε) and magnetic permeability (μ) according to the classification diagram presented in Fig. 1.

MTM technology may be caused to designing antenna structure with physically small size, whereas, this antenna can cover large frequency bandwidth [5-6].

In this paper, the MTM and carved planar technologies on the carved circuit boards (CCBs) by standard manufacturing techniques for downsizing of the antenna structure are applied. Too, with using of the proper inductive and capacitive elements including rectangular inductors, via holes and Y-formed slots with their regulated dimensions, the good performance parameters such as bandwidth, radiation gains and efficiencies have been achieved. The proposed CRLH-CP antenna have advantages of small physical size and UWB and good radiation properties, planar, low loss, unidirectional radiation patterns, simple of construction, and also presented antenna can be integrated within RF components and embedded circuits.

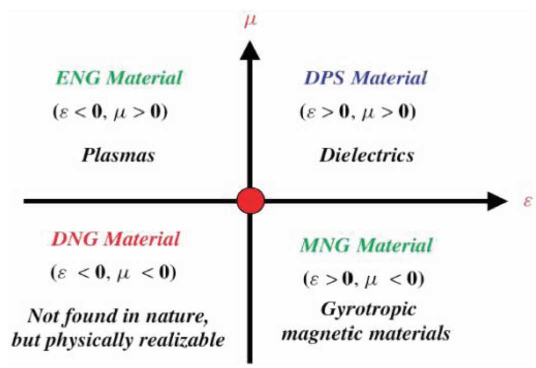


Fig. 1. Classification of physical environments depending on its effective values of permittivity (ε) and magnetic permeability (μ) [4].

The paper is classified as follows. Section II expresses the design procedure of the proposed CRLH-CP antenna. Section III consists of the results. Finally, Section IV concludes the paper.

II. DESIGN PROCEDURE OF THE RECOMMENDED CRLH-CP ANTENNA

The proposed antenna design procedure is based on a simple topology that incorporates the carved planar patches that have been implemented on the carved circuit boards (CCBs) by standard manufacturing techniques, and also rectangular inductors accompanying via holes that are connected to ground plane. This topology makes it possible to combine the antenna with integrated RF electronics. In here, the standard carved planar manufacturing technique (SCPMT) on the radiation patches for production of series capacitances (C_L) have been used, which leads to foot print area reduction. Furthermore, with implement of the minimized Y-formed slots, rectangular inductors with adjusted dimensions and uniform excitation mechanism, which caused to increase the antenna effective aperture [1], the good performance parameters have been provided. The proposed CRLH-CP antenna is composed of four simplified CRLH unit cells, that each are included of a rectangular radiation patch with one **Y**-shaped slot that is carved on the radiation patch by standard manufacturing technique and a rectangular inductor connected to ground plane through a via hole. The equivalent circuit model of the proposed antenna structure is shown in Fig. 2.

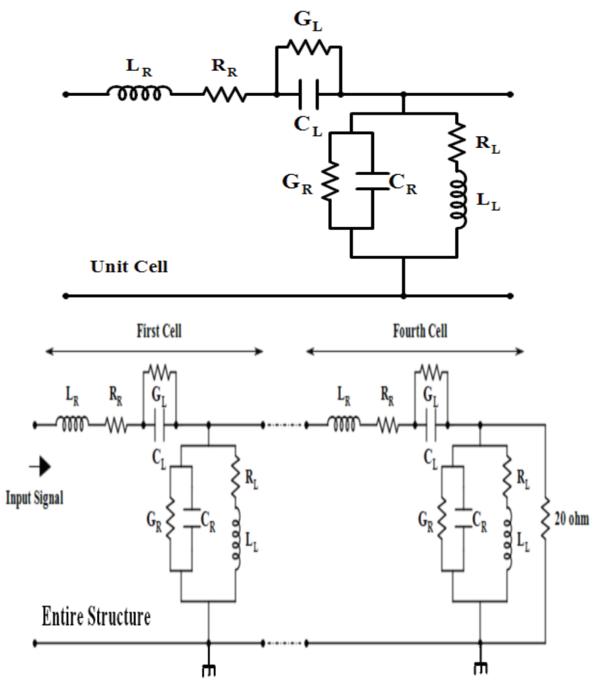
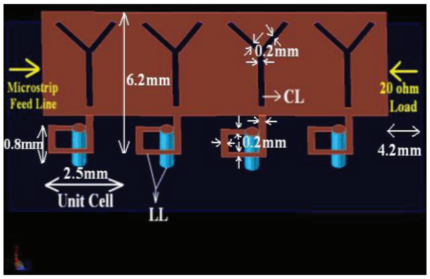
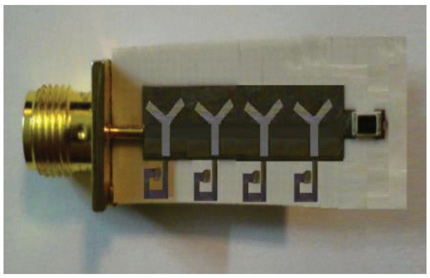


Fig. 2. Equivalent circuit model of the proposed CRLH-CP antenna.

Figure 3 shows the layout structure of the proposed antenna. According to Figs. 2 and 3, in each unit cell, to production of the series left handed capacitance (C_L) and the shunt left handed inductance (L_L) have used a carved **Y**-shape slot and a rectangular inductor that is connected to ground plane through a metallic via hole, respectively. In fact, a purely left/handed TL is not physical and can never be realized because of the parasitic right/handed effects. MTMs with left/handed properties have inevasible right/handed properties, known as composite right/left hand MTMs. Hence, the proposed transmission line structure possesses the right-handed parasitic effects that can be seen as shunt capacitance (C_R) and series inductance (L_R) [15-16]. The shunt capacitance C_R is mostly come from the gap capacitance between the strip and the ground plane, and unavoidable current flows on the patches establishes the series inductance L_R, which indicates that these capacitance and inductance cannot be ignored. The structure losses are modeled by RH and LH resistances and conductance; i.e., R_R, R_L, G_R and G_L. In this antenna structure, the uniform excitation mechanism by implementing of two ports is applied, so that port 1 is excited with input signal and port 2 is matched to a 20 Ohm load impedance of the SMD1206 resistance components, while size of this load is 4.2 mm and is considered into the overall size of antenna structure, and also it is connected to ground plane through a via hole. This point should be noted that, the series capacitances (C_L) and the shunt inductances (L_L) can be adjusted by varying the dimension of **Y**-shape slots and rectangular inductors, respectively. This feature provides another superior capability that can be used to change the performances of the antenna. In this design for reach to the desired performances, the tuned dimensions and the optimized values of the structural components that were obtained of the optimization processes of three 3-D full wave EM simulators, such as Advanced Design System (ADS), High Frequency Structural Simulator (HFSS) and CST Microwave Studio are shown in Fig. 3. Also, the values of these components; i.e., series left handed (LH) capacitances (C_L) and shunt LH inductances (L_L) that were created by implement of the Y-shape slots and the rectangular inductors are equal to 4.9 pF and 6.2 nH, respectively. In additional to C_L and L_L, amounts of the shunt Right Handed (RH) capacitances (C_R) and series RH inductances (L_R), which were created by gap capacitance between strips and ground plane and unavoidable current flows on the patches are equal to 1.6 pF and 1.8 nH, respectively. Also, the losses of the antenna structure that have been modeled by R_R, R_L, G_R and G_L are 2.5 Ω, 2.7 Ω, 1.2 ℧ and 1.4 ℧, respectively.



Simulated prototype



Fabricated prototype

Fig. 3. Configuration of the proposed **Y**-shape CRLH-CP antenna composed of four unit cells.

The CRLH-CP antenna is designed on a Rogers_RO4003 substrate with thickness of h=0.8 mm, dielectric constant of $\varepsilon_r = 3.38$ and tanδ=0.0022. The physical size of the antenna is $0.023\lambda_0 \times 0.01\lambda_0 \times 0.001\lambda_0$, where λ_0 is the free space wavelength at 0.5 GHz; thus, the length, width and height of the antenna are 14.2 mm, 6.2 mm and 0.8 mm, respectively. The recommended antenna has 1.5 GHz measured bandwidth and can be used to frequency band from 0.5 GHz to 2 GHz in measurement for VSWR<1.5, which corresponds to 120% practical bandwidth. In addition, the measured radiation gains and efficiencies of the CRLH-CP antenna at the operational frequencies of f=0.7, 1.5 and 2 GHz are 3.8 dBi and 53%, 4.85 dBi and 68.5%, and 4.3 dBi and 60.2%, respectively. These results express that the proposed CRLH-CP antenna has good radiation properties and ultra wide bandwidth with small size enough to fit on the embedded systems and integration into RF components.

III. RESULTS AND DISCUSSIONS

To validate the design processes, the proposed CRLH-CP antenna was designed by three 3-D full wave EM softwares, they are: Advance Design System (ADS), High Frequency Structure Simulator (HFSS) and CST Microwave Studio and was fabricated on a Rogers_RO4003 substrate with dielectric constant of 3.38, 0.8 mm thickness and tanδ=0.0022. The physical length, width and height of the antenna are $0.023\lambda_0$, $0.01\lambda_0$ and $0.001\lambda_0$, in terms of free space wavelength at 0.5 GHz. Figure 4 shows the reflection coefficients (S_{11}<-10 dB parameters) of the proposed antenna. The antenna bandwidth (S_{11}<-10 dB) achieved from the measurement, ADS, HFSS and CST Microwave Studio simulators are 1.5 GHz and 120% from 0.5 GHz to 2 GHz, 1.68 GHz and 135% from 0.4 GHz to 2.08 GHz, 1.57 GHz and 125% from 0.47 GHz to 2.04 GHz, and 1.65 GHz and 129% from 0.45 GHz to 2.1 GHz, respectively.

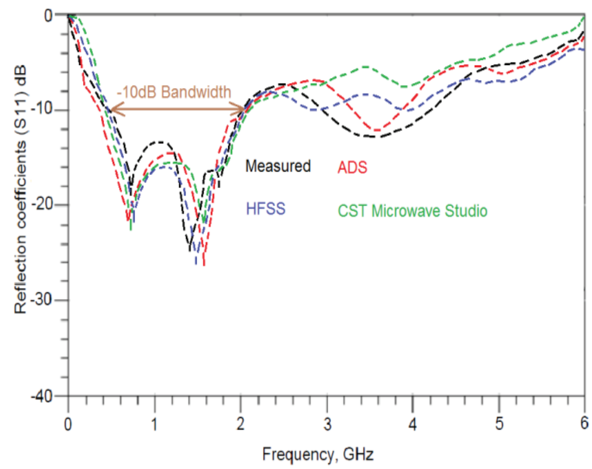


Fig. 4. Reflection coefficients (S_{11}<-10 dB parameters) of the antenna.

The radiation gains patterns of the proposed antenna at the operating frequencies of f=0.7, 1.5 and 2 GHz are plotted in Fig. 5. As is clear from this figure, the radiation patterns have unidirectional specifications. The radiation gains and efficiencies provided from the measurement, ADS, HFSS and CST Microwave Studio at 0.7 GHz are 3.8 dBi and 53%, 3.9 dBi and 57.1%, and 3.95 dBi and 56%, and 3.85 dBi and 55%; at 1.5 GHz are 4.85 dBi and 68.5%, 4.92 dBi and 70%, 4.96 dBi and 71.2%, and 4.9 dBi and 69%; at 2 GHz are 4.3 dBi and 60.2%, 4.35 dBi and 63%, 4.4 dBi and 62.8%, and 4.42 dBi and 64%, respectively.

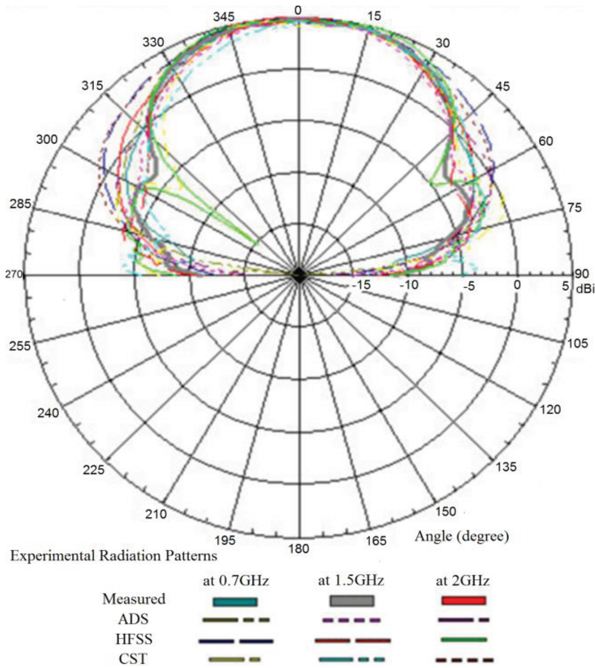


Fig. 5. Experimental radiation gains patterns of the suggested CRLH-CP antenna.

To validate the design and fabrication procedures, the proposed CRLH-CP antenna was compared with several conventional antennas and their specifications were summarized in Table 1.

Table 1: Characteristics of some of the conventional antennas in comparison to the proposed PPMTM antenna

Table 1-1: Dimensions

[5]	50.8×25.2×1 mm^3 & $0.404\lambda_0 \times 0.2\lambda_0 \times 0.007\lambda_0$ at 2.39 GHz
[6]	12×12×3.33 mm^3 & $0.093\lambda_0 \times 0.093\lambda_0 \times 0.026\lambda_0$ at 2.34 GHz
[7]	60×5×5 mm^3 & $0.164\lambda_0 \times 0.013\lambda_0 \times 0.013\lambda_0$ at 0.82 GHz
[8]	20×25×0.8 mm^3 & $0.23\lambda_0 \times 0.287\lambda_0 \times 0.009\lambda_0$ at 3.45 GHz
PROPOSED	14.2×6.2×0.8 mm^3 & $0.023\lambda_0 \times 0.01\lambda_0 \times 0.001\lambda_0$ at 0.5 GHz

Table 1-2: Bandwidths

[5]	2.39-2.87 GHz & 18.25%
[6]	2.34-2.54 GHz & 8.2%
[7]	0.82-2.48 GHz & 100.6%
[8]	3.45-3.75 GHz & 8.33%
PROPOSED	Measured: 0.5-2 GHz & 120%
	ADS: 0.4-2.08 GHz & 135%
	HFSS: 0.47-2.04 GHz & 125%
	CST: 0.45-2.1 GHz & 129%

Table 1-3: Gains in dBi (for proposed antenna at 0.7, 1.5 and 2 GHz, respectively, in each of four cases)

[5]	2.2	
[6]	1	
[7]	0.4	
[8]	2	
PROPOSED	Measured	3.8-4.85-4.3
	ADS	3.9-4.92-4.35
	HFSS	3.95-4.96-4.4
	CST	3.85-4.9-4.42

It should be noted that, the simulation processes were performed on the infinite GND, but due to size limitations and requirements for design of the small structure to fit on the RF electronic devices and embedded systems, the fabrication procedures have been performed on the finite GND. Hence, the simulation and measurements results have slightly differences.

IV. CONCLUSION

A novel composite right/left-handed carved planar (CRLH-CP) antenna with minimized size, ultra wide bandwidth and good radiation properties has been presented and fabricated. In the design procedure, for producing series capacitances with smaller amounts, the Y-form slots with minimized sizes have been implemented on the carved circuit boards (CCBs) by the standard manufacturing techniques (SMTs); also, to obtain the good performance parameters, the suitable inductive elements such as rectangular inductors with regulated dimensions were designed, and for the uniform excitation mechanism by applying two ports for increase of the antenna, effective aperture have been used, so that these ways have caused to provide a UWB minimized antenna with appropriate radiation characteristics. The physical dimension of the proposed CRLH-CP antenna is $0.023\lambda_0$ by $0.01\lambda_0$ by $0.001\lambda_0$, in terms of free space wavelengths at 0.5 GHz, which corresponds to overall size of $14.2\times6.2\times0.8$ mm^3. As well as, this antenna has 120% practical bandwidth from 0.5 GHz to 2 GHz with maximum of 4.85 dBi radiation gain and 68.5% efficiency that occur at 1.5 GHz. According to the results, the carved planar (CP) UWB minimized antenna based on MTM CRLH-TL is sufficiently small for integration into RF components for use in the UWB RF electronic devices and embedded systems.

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