Ultra Wide Band and Minimized Antenna

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***Abstract* — In this paper, a novel ultra-wideband (UWB) miniature antenna based on the composite right-left handed transmission line (CRLH-TL) structure with enhancement gain is proposed and investigated. With CRLH metamaterial (MTM) technology embedded, the proposed UWB and miniature antenna is presented with best in bandwidth, size, efficiency and radiation patterns. To realize characteristics of the antenna, the printed Π-shaped gaps into the rectangular radiation patches are used. This antenna is constructed of the two unit cells, also presented antenna is designed from 2.25 GHz to 4.7 GHz which corresponding to 70.5% bandwidth. The overall size of the presented antenna is 10.8mm×6.9mm×0.8mm or $0.09\lambda_0 \times 0.05\lambda_0 \times 0.006\lambda_0$ at the operating frequency f = 2.5 GHz (where λ_0 is free space wavelength). The radiation peak gain and the maximum efficiency which occurs at 4.6GHz, are 3.96dBi and 63.6%, respectively.**

***Index Terms* — Composite right/left-handed Transmission Line (CRLH-TLs), antenna, wireless.**

1. Introduction

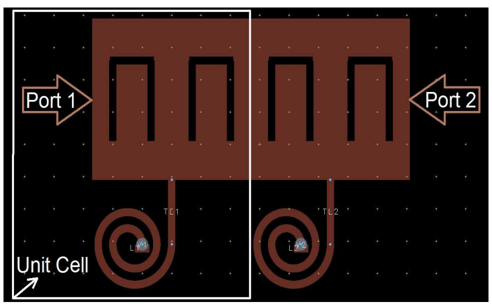
In Recent years, with development of broadband and minimizing technology for high resolution and high data transmission rates and foot print area reduction in modern communication systems, there is increasing demand for small low-cost antenna with unidirectional radiation patterns, dispersive and broad band characteristics. The printed antennas have received great attention in broadband applications due to their advantages of compact, planar, low cost, light weight, broadband, compatibility and easy integration with other microstrip circuits. Applications in present-day mobile communication systems usually require smaller antenna size in order to meet the miniaturization requirements of mobile units. Thus, size reduction and bandwidth enhancement are becoming major design considerations for practical applications of microstrip antennas [1].

Metamaterial (MTM) [2], have recently been extensively discussed and studied for special properties. Metamaterials (MTMs) are manmade composite materials, engineered to produce desired electromagnetic propagation behavior not found in natural media [2], [3]. Those unusual properties were used to improved performances of antennas and circuits. Microstrip antennas had been developed for applications in present communication systems [4], [5], but there is a fact that the size reduction levels remain unsatisfactory to the electromagnetic community. Several techniques were suggested to reduce antenna size [6], however, such techniques usually suffer from increasing the design complexity. The occurrence of metamaterial may be a solution for this challenge [7], [8]. In this work, we using of the metamterial technology and the simple techniques for foot print area reduction, enhancement bandwidth and improvement gain of the antenna, which consist of employing of the printed planar mushroom structure based on CRLH-TL and suitable structural parameters. Various implementations of metamaterial structures have been reported and demonstrated [2]. In this paper a metamaterial CRLH antenna with two unit cells which each unit cell embrace of two printed Π -shaped gaps capacitors and the spiral inductor accompanying a metallic via connected to ground plane is presented. The printed Π -shaped structure exhibit wide bandwidth, miniature and improvement gain property which useful for UWB and miniaturized antennas.

This paper is organized in the following way. A UWB and miniature antenna prototype with high gain and efficiency employing the proposed concept will be depicted in Section 2. Followed by section 3 where various performance including dimension, impedance bandwidth and radiation patterns characteristics of the recommended antenna are demonstrated. Further discussion and conclusion are raised at last.

2. Theory of the Proposed Antenna

As discussed in [2], [9], several implementations can be used to realize the CRLH-TL unit cell including surface mount technology (SMT) chip components and distributed lines. However, lumped elements are not appropriate in antenna design because of their lossy characteristics and discrete values. We using printed planar technique for our antenna design, since printed planar structures are good candidate for antenna design because of their advantages which include foot print area reduction, loss less and non-discrete values [13], [14]. A novel UWB and miniature antenna with improvement gain based on CRLH-TL presented in here, which consists of two unit cells while each unit cell will be designed by two rectangular radiation patches with printed Π-shaped gaps into patches, and the spiral inductor accompanying metallic via connected to the ground plane. Fig. 1 shows geometry of the proposed antenna and Fig. 2 display equivalent circuit model of each cell as CRLH unit cell. In this structure, port 1 is excited with input signal and port 2 is matched with 20Ω load impedance. The antenna structure is based on a composite right-left handed (CRLH) transmission line (TL) model used as a periodic structure. Because the lowest mode of operation is a LH mode, the propagation constant approaches negative infinity at the cutoff frequency, and reduce its magnitude as frequency is increased. Making use of this phenomenon, an electrically large but physically small antenna can be developed.



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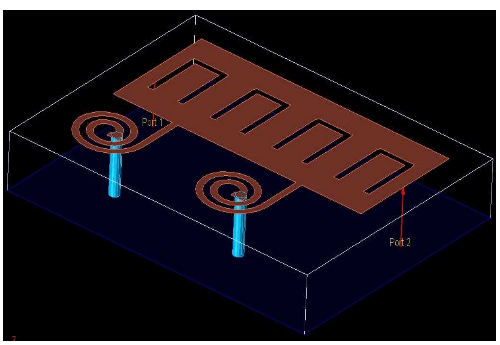

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Fig.1. Configuration of the presented UWB miniature antenna composed of the two unit cells based on CRLH MTM-TL. a) Top view, b) Isometric view.

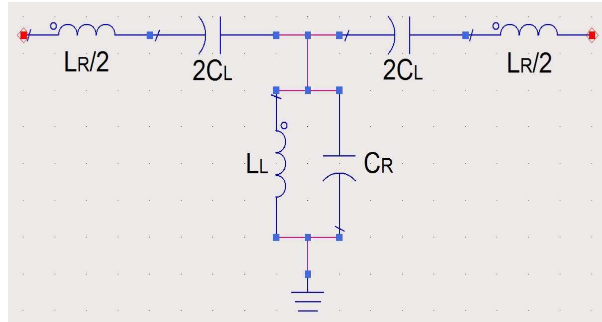


Fig.2. Proposed Antenna: Equivalent circuit model of the CRLH MTM antenna for one unit cell.

By means of the Π-shaped gaps and spiral inductors with shorting via-hole connecting to ground plane, the series capacitance (C_L) and shunt inductance (L_L) can be easily implemented in a compact fashion. The host TL possess the right-handed parasitic effects that can be seen as shunt capacitance (C_R) and series inductance (L_R).

In this paper, we employing of metamaterial (MTM) technology and the printed planar approach that results to foot print area reduction of the proposed antenna. Overall size of this antenna is $0.09\lambda_0 \times 0.05\lambda_0 \times 0.006\lambda_0$ at the operating frequency f = 2.5 GHz where λ_0 is the free space wavelength and also with choosing smaller distance between printed Π-shaped gaps edges, we will be obtained wide bandwidth from 2.25 GHz to 4.7 GHz which corresponding to 2.45 GHz bandwidth. Furthermore, with acceptable selecting of the number unit cells (N) constructing antenna structure and structural parameters of the spiral inductors such as number of turns (N), inner radius measured to the center of the conductor (R_i), conductor width (W) and conductor spacing (S) we will be achieved good radiation performances. The gain and efficiency of the proposed antenna are changed from 0.4dBi to 3.96dBi and 19.5% to 63.6%, respectively, into frequency band 2.25 - 4.7 GHz, that shown very good radiation characteristics. Therefore, the MTM antenna designed is miniature and ultra-wideband with high gain and efficiency. The proposed antenna based on CRLH-TL made very small size and wide bandwidth to support today's multi-band modern wireless applications.

Fig. 1 shows configuration of the recommended antenna constructed of the two unit cells based on CRLH-TL structure that was designed on a FR_4 substrate, with a dielectric constant of 4.6, a thickness of 0.8mm and Tan δ=0.001. This mushroom type unit cell consisted of 5.4 mm×6.9 mm or $0.045\lambda_0 \times 0.05\lambda_0$ patch, printed on top of the Substrate which in each unit cell, the series capacitance (C_L) is developed by two the printed Π-shaped gaps into radiation patches, and the shunt inductance (L_L) is resulted from the spiral inductor shorted to the ground plane through the metallic via. The structure possess the right-handed parasitic effects that can be seen as shunt capacitance (C_R) and series inductance (L_R). The shunt capacitance C_R is mostly come from the gap capacitance between the patch and the ground plane, and the unavoidable currents that flow on the patch establish series inductance L_R, which indicates that these capacitance and inductance cannot be ignored. In this structure, port 1 is excited with input signal and port 2 is matched to 20Ω load impedance, as illustrated in Fig.1. The proposed design keeps the overall size of the unit cell compact while aims at reducing the ohmic loss to improve gain and radiation efficiency. This antenna can support all cellular frequency bands from 2.25 GHz to 4.7 GHz, using single or multiple feed designs, which eliminates the need for antenna switches. All of these attributes make the proposed antenna is well suitable for electromagnetic requirements such as millimeter waves and emerging wireless applications [10], [11].

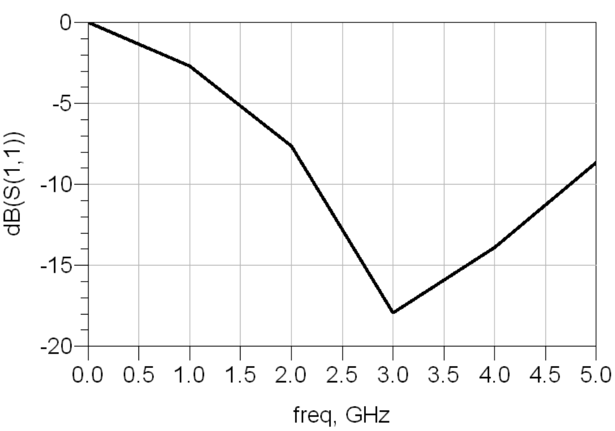
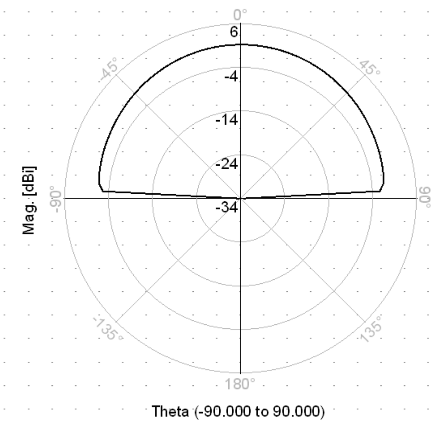


Fig.3. Simulated reflection coefficient S_{11}.

3. Simulation Results and Discussion

The proposed metamaterial antenna is designed as a CRLH antenna where the substrate has dielectric constant ε_r = 4.6, thickness h = 0.8 mm and Tan δ=0.001. UWB and miniature recommended antenna is simulated by using the full-wave simulator (ADS). The simulated reflection coefficient (S_{11} parameter) displayed in Fig. 3, and simulated radiation gain patterns in 2.3, 3.4 and 4.6 GHz are plotted in Fig. 4. The radiation patterns are unidirectional characteristics. The radiation gains at 2.3, 3.4, 4.6 GHz are 0.4, 2.8, and 3.96dBi, respectively. The radiation efficiency is 19.5% at 2.3 GHz, 47.8% at 3.4 GHz, and 63.6% at 4.6 GHz. To validate the design procedure the proposed antenna was compared with some of the antennas and their dimension and radiation characteristics were summarized in Table 1.



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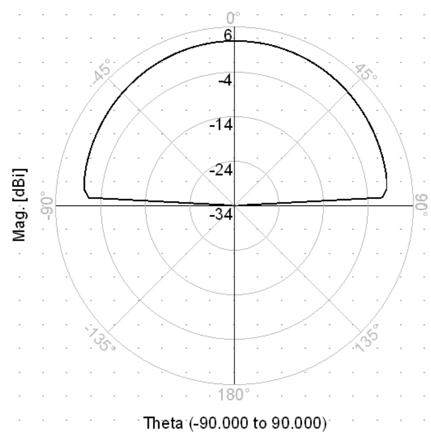

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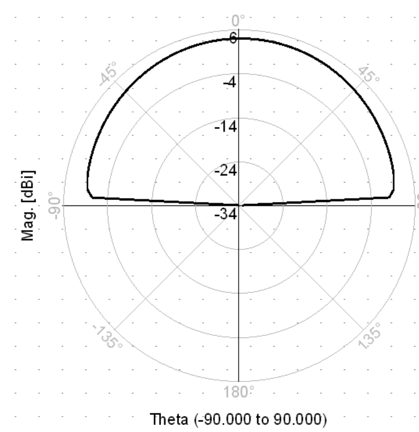

(C)

Fig.4. The Radiation Patterns (Gains) of the proposed antenna in elevation ($\Phi = 0$ degree). a) 2.3 GHz, b) 3.4 GHz, and c) 4.6 GHz.

The two unit cells of the UWB and miniature antenna is designed from 2.25 GHz to 4.7 GHz and this antenna exhibit good matching between this frequency band for 20Ω impedance port. The physical length, width and height of the suggested antenna are 10.8 mm, 6.9 mm and 0.8 mm ($0.09\lambda_0 \times 0.05\lambda_0 \times 0.006\lambda_0$), respectively. The gain and the radiation efficiency of this antenna are varies from 0.4dBi to 3.96dBi and from 19.5% to 63.6%, respectively, into the frequency range 2.25 GHz to 4.7 GHz.

Table 1. Dimension and Radiation Characteristics of the Some of the Antennas in Comparison to the Proposed Antennas.

Parameters	**[11]**	**[12]**	**Proposed Antenna**
Gain	0.45 dBi	0.6 dBi	3.96 dBi
Bandwidth	0.8-2.5 GHz	1-2 GHz	2.25-4.7 GHz
Efficiency	53.6%	26%	63.6%
Dimension	$0.4\lambda_0 \times 0.03\lambda_0 \times 0.03\lambda_0$	$0.07\lambda_0 \times 0.07\lambda_0 \times 0.03\lambda_0$	$0.09\lambda_0 \times 0.05\lambda_0 \times 0.006\lambda_0$

4. Conclusion

In this paper, we introduced a new concept of antenna size reduction with broad bandwidth accompanying enhancement gain based on a metamaterial design methodology. A practical UWB, miniature and high gain antenna with a simple feed structure and planar circuit integration possibilities has been demonstrated. Overall size of the recommended antenna is 10.8mm× 6.9 mm× 0.8 mm or $0.09\lambda_0 \times 0.05\lambda_0 \times 0.006\lambda_0$ at the operating frequency f=2.5 GHz where λ_0 is free space wavelength. A return loss below -10dB from 2.25 GHz - 4.7 GHz was obtained which corresponding to 70.5% bandwidth. The peak gain and the maximum efficiency of the proposed antenna which occurs at f = 4.6 GHz, are 3.96dBi and 63.6%, respectively. This antenna has the advantages of ultra-wideband, compact size, high gain, unidirectional radiation patterns, low cost and simple implementation. The recommended antenna can be used for millimeter wave applications, mobile handsets and wireless communication implementations.

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