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A Recent Concise Ultra Wide Band Metamaterial Antenna for Wireless Communications

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Abstract

This paper presents a recent concise ultra wideband (UWB) antenna based on composite right/left handed (CRLH) metamaterial (MTM) transmission lines (TLs) for modern wireless communication applications. The physical size of concise antenna is 17.4 mm x 5.9 mm x 0.8 mm, or, 0.36 λ_0 x 0.12 λ_0 x 0.016 λ_0, in term of free space wavelength at operation frequency f = 6.35 GHz. The proposed antenna covers the impedance bandwidth from 5.6 GHz to 7.1 GHz, which provides 23.62% bandwidth. The antenna gain and efficiency are generally above 1.5 dBi and 18%, and the antenna peak gain and maximum efficiency are 2.95 dBi and 33.4%, respectively at f = 6.4 GHz. Small size, broad bandwidth, high gain, unidirectional radiation patterns and appropriate impedance characteristics are the main features of the proposed antenna.

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Keywords

Concise antenna, composite right/left:handed transmission line (CRLH:TL), ultra wideband (UWB) antenna, metamaterial (MTM), wireless communications.

Introduction

The development of small size broadband antennas for high resolution and high data transmission rates in modern communication systems is growing rapidly due to difficult requirements of small size ultra wideband antennas such as a compact size, dispersive and wide band characteristics.

The commercial uses of frequency band 5.6GHz to 7.1GHz for radar, location tracing, and data transmissions were approved by FCC in 2002 [1]. Recently, the research and development of the UWB systems including antennas have been widely performed [2, 3] and [4]. One of the main devices of the UWB system is an antenna. The low VSWR (VSWR ¡ 2) over 5.6-7.1 GHz band is required. Significant size reduction is also demanded to achieve the minimization of communication systems or devices. Ideally, the UWB antenna should be small, low cost, planar, and reliable. Adaptability and facility of accretion with electronics for mobile communications also desirable. Furthermore, in order to satisfy the different asked for wireless services, miniature antenna with broad bandwidth and acceptable radiation properties are required.

The metamaterials (MTMs) are very attractive for the design of concise antennas and microwave devices [5, 6]. The composite right/left handed transmission lines (CRLH-TLs) provides a conceptual route for implementing concise antennas. By employing MTM technology in this paper, having more small size while maintaining broad bandwidth as well as stable efficiency within band, plus unidirectional radiation patterns are the most crucial specification for developing a successful compact and broad bandwidth antenna so that they can be integrated inside very small size devices with the presence of multiple antennas. Proposed antenna had to small enough to fit on the communication devices, which is 17.4 mm length's, 5.9 mm width's, 0.8 mm height's, also the proposed antenna based on CRLH-TL can be made very broadband to support today's multi band wireless application requirements. This antenna can support all cellular frequency bands from 5.6 GHz to 7.1 GHz, using single or multiple feed designs, which eliminates the need for antenna switches.

In this paper, a recent and simple concise ultra wideband antenna design is proposed by using MTM technology and employing printed planar technique into radiation patches which results to produce gap capacitances and also foot print area reduction. Simulation results show the great performance of the proposed antenna.

The rest of paper is organized as follows. In section 2, we introduce the CRLH MTM antennas. The guidelines for UWB antenna design are discussed in section 3. In section 4 we elaborated the design procedure of the proposed antenna. Followed by section 5 where various performance including dimension, impedance bandwidth and radiation patterns characteristics of the proposed antenna are demonstrated. Further discussion and conclusion are raised at last.

CRLH Metamaterial Antenna

The propagation of electromagnetic waves in most materials obeys the right handed rule for the β, E and H, vector fields, where β is the wave vector, E is the electrical field and H is the magnetic field. The phase velocity is in the same direction of the group velocity. The refractive index is a positive number, such materials are RH. Unlike RH materials, metamaterial can exhibit a negative refractive index with permittivity (ϵ) and permeability (μ) being simultaneously negative. Their phase velocity direction is contrary to the direction of the group velocity where the relative directions of the β, E and H vector fields follow the LH rule. Thus, metamaterials are also called LH materials. Since no metamaterial exists naturally, it can only formed by an artificial structure. Multiple MTMs depicture RH and LH manner and ergo are CRLH MTMs. A CRLH MTM can behave like a LH MTM at low frequency range and a RH material at high frequency range [5]. CRLH MTMs can be structured and engineered to exhibit electromagnetic properties that are tailored for specific applications and can be employed in applications where it may be difficult, impractical for utilize other solutions. Small antenna is one of most important application of CRLH metamaterials. An electrically large but physically minimized antenna can be designed by using the CRLH-TLs while maintaining the same or better proficiency toward conventional compact antennas [5]-[7].

Guidelines for the UWB Antenna Design

The transmission coefficient of the antenna system is an important frequency domain indicator of the time domain performance of an UWB antenna [8]. The points summarize in below, are guidelines for the UWB antenna design.

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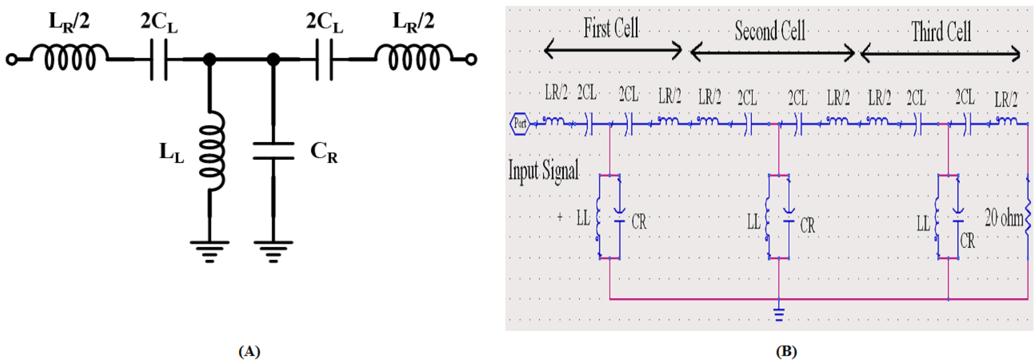

Figure 1: *Equivalent circuit model of the proposed Antenna based on CRLH MTM-TL for: A) One unit cell, B) Entire structure.*

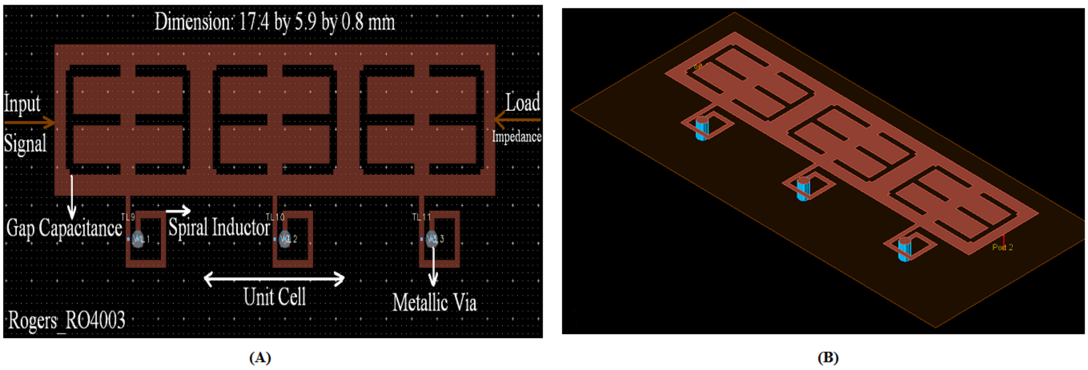

Figure 2: *Configuration of the proposed concise UWB MTM antenna composed of the three unit cells based on CRLH-TL. A) Top view, B) Isometric view.*

1. Travelling wave antennas or antennas having low Q can be very broad band.

2. Antennas incorporating tapers or rounded edges tend to give broad bandwidths because surface currents have a smooth path to follow [9].

3. Linearly polarized transmit and receive antennas are the simplest to implement in a compact planar package.

4. Minimizing the thickness of the substrate and using low loss materials maximizes radiation efficiency.

5. Using of the printed planar technique within radiation patches for antenna

design with minimizing acceptable distance between gap edges results to extended the bandwidth of the antenna.

In this paper, we using of the second, fourth and last proposed approach for increasing the bandwidth and radiation characteristics of the proposed antenna.

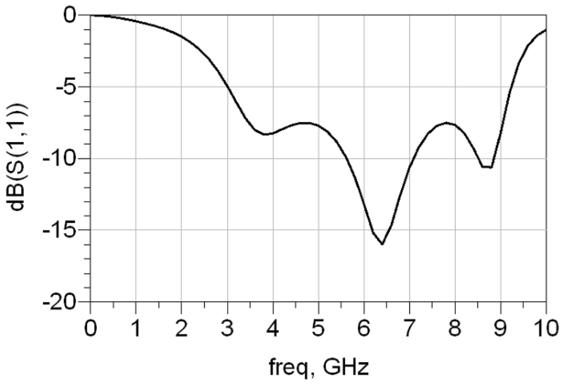

Figure 3: *Simulated return loss (S_{11}) parameter.*

Proposed Antenna Design Considerations

Generally speaking, the realization of the left handed transmission line is regular, the key is to place or print some structures, which is equivalent to capacitance or inductance. There are plenty of methods to achieve it. For example, the most common use and the easy way to achieve series capacitance is printing a gap on the patch to generate a gap capacitance, and the shunt inductance is a bit more difficult, that we using of the rectangular inductor accompanying metallic via hole connect to the ground plane for generate a shunt inductance.

In this paper, we employing the Electromagnetic Band Gap (EBG) unit to act as the radiation unit, which is the simplest way to achieve the series capacitance and shunt inductance. The proposed antenna design procedure is based on a simple topology that incorporates printed planar patches and rectangular inductors accompanying metallic via-holes connected to ground plane. This topology makes it possible to combine the antenna with integrated RF electronics. We employing of the printed planar technique into radiation patches which cause gap capacitance and results to foot print area reduction, furthermore, with designing a smaller value of the gap capacitance created into radiation patches can obtain wide bandwidth, therefore, our antenna have a small size and broad

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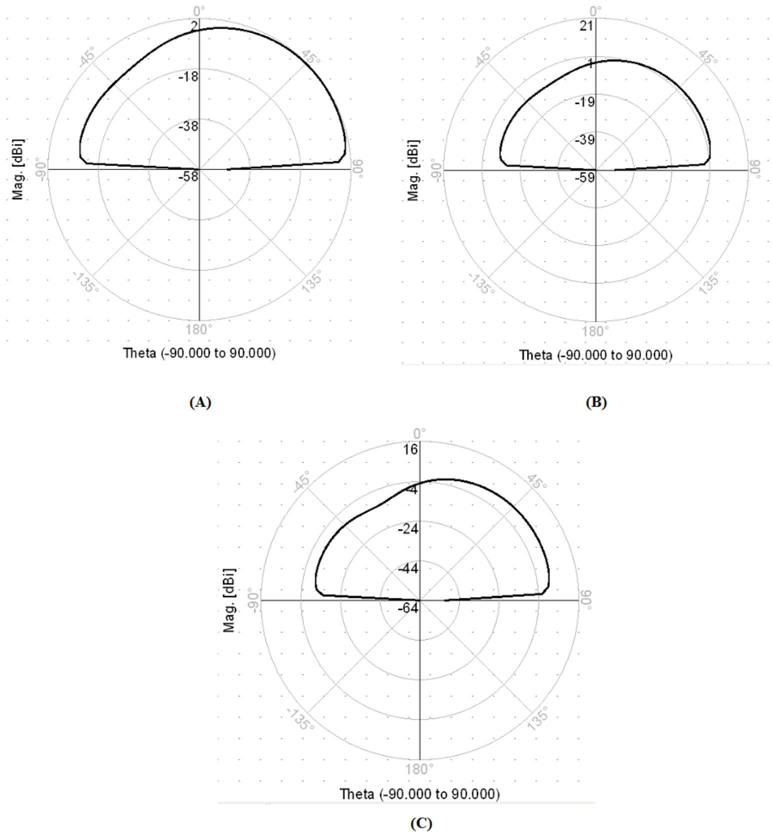

Figure 4: *The Radiation Patterns (Gains) of the proposed antenna in elevation (ϕ=0 degree), A) 5.6 GHz, B) 6.4 GHz and C) 7.1 GHz.*

bandwidth. Also beside the small size and the broad bandwidth properties, the radiation characteristics of the antenna are very important. With utilizing of the three unit cells in form E-shape, designing appropriate inductive elements such as rectangular inductor and metallic via hole, employing the larger aperture size, the uniform excitation mechanism and using suitable structural parameters, good radiation performances can achieve. The recent concise ultra wideband antenna with appropriate radiation performances, presented in here, is based on three simplified mushroom structure unit cells of the CRLH-TL, which each unit cell include of a rectangular radiation patch with two printed E-shaped gaps into radiation patch and a rectangular inductor connected to ground plane through a metallic via. The equivalent circuit model of the proposed antenna for one unit cell and entire structure are shown in Figure 1(a and b), respectively.

Figure 2 shows the geometric structure of the proposed antenna. In the each unit cell, the printed E-shaped gaps into rectangular radiation patch establish series capacitance (C_L), and rectangular inductor accompanying metallic via acts like shunt inductance (L_L). The transmission lines 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 often get from the gap capacitor between the patch and the ground plane, and unavoidable current flows on the patch, provides series inductor L_R that shows that these capacitance and inductance cannot be overlooked. In the structure, we have employed of the uniform excitation mechanism by using port 1 and port 2, whiles port 1 is excited with input signal and port 2 is matched to 20Ω load impedance. Series capacitance can be adjusted by varying distance between printed E-shaped gaps edges, this feature provide another superior capability that can be used to change the performance of the antenna. We using of the printed planar approach for produce gap capacitance and designing smaller values gaps into rectangular patches of the radiate patches and also employing uniform excitation mechanism accompanying suitable structural parameters which provides a small size and ultra wideband (UWB) antenna with appropriate radiation characteristics.

The CRLH MTM antenna is design on a $Rogers\_RO4003$ substrate with thickness h = 0.8 mm, dielectric constant $\epsilon_r = 3.38$ and tan$\delta = 0.0022$. The physical size of this antenna is 17.4 mm x 5.9 mm x 0.8 mm (0.36 λ_0 x 0.12 λ_0 x 0.016 λ_0, where λ_0 is the free space wavelength at 6.35 GHz), and recommended antenna has bandwidth from 5.6 GHz to 7.1 GHz, which corresponds to approximately 23.62% bandwidth. This make the proposed antenna had to be broad bandwidth and small size enough to fit on the communication devices and this antenna is much smaller in the size and wider in the bandwidth than conventional antennas. In addition, the maximum gain and efficiency occurs at f = 6.4 GHz which are equal to 2.95 dBi and 33.4%, respectively. Proposed antenna is attractive and suitable for modern wireless communication systems and UWB applications.

Simulation Results and Discussion

The antenna was designed on a $Rogers\_RO4003$ substrate with dielectric constant of 3.38, 0.8 mm thickness and tan$\delta = 0.0022$. The physical length, width and height of the concise antenna shown in Fig. 2(a), are 17.4, 5.9 and 0.8 mm and or are $0.36\lambda_0$, $0.12\lambda_0$ and $0.016\lambda_0$, in terms of free space wavelength at operation frequency f = 6.35 GHz. The simulated results were obtained using Agilent ADS full-wave simulator. Fig. 3, shows the simulated return loss (S_{11}

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parameter) of the proposed antenna. The simulated return loss bandwidth (-10 dB) is equal to 1.5 GHz (5.6 - 7.1 GHz), this corresponds to 23.62% bandwidth, which is very more than conventional antennas. The simulated radiation gain patterns of the designed antenna at 5.6, 6.4, and 7.1 GHz are plotted in Fig. 4.

The radiation patterns have unidirectional characteristics. The simulated gains at 5.6, 6.4, 7.1 GHz are 1.57, 2.95, and 2.83dBi, respectively. The simulated radiation efficiency is 18.44% at 5.6 GHz, 33.4% at 6.4 GHz, and 29.26% at 7.1 GHz. The antenna gain and efficiency are generally above 1.5 dBi and 18%, the peak gain and the maximum efficiency are equal to 2.95 dBi and 33.4%, respectively. For validate the design procedure the suggested antenna was compared with many antennas and their radiation characteristics and dimension were tabloid in Table 1.

Table 1: *Dimension and Radiation Characteristics of some of the Antennas in Comparison to the proposed Antenna Design.*

Paper Name	**Dimension** (in mm^3)	**Bandwidth** (in GHz)	**Gain** (in dBi)
Broad Band Small Antenna For Portable Wireless Application	12x12x3.33	2.34-2.54	1
A Compact Based on MTM For WiMAX	20x25x0.8	3.45-3.75	2
Compact Heptaband Reconfigurable Loop Antenna For Mobile Handset	60x5x5	0.824-2.484	0.45
Planar E-shaped Antenna	17.4x5.9x0.8	5.6-7.1	2.95

Conclusion

A practical concise ultra wideband (UWB) CRLH MTM antenna accompanying good radiation characteristics with a simple structure and planar circuit integration possibilities has been elaborated. The compact dimension, broad bandwidth and well radiation characteristics of the MTM antenna were modelled employing the full-wave simulation. A CRLH MTM antenna with three simplified planar mushroom structure unit cells was designed, and footprint area reduction, wideband performance, high gain and high efficiency were achieved. A return loss bellow -10 dB from 5.6 - 7.1 GHz was obtained. This antenna has the advantages of small size, UWB, high gain, unidirectional radiation patterns, low cost and simple implementation. This paper shows that presented design approach leads to produce a suitable CRLH MTM antenna for modern wireless communication systems and UWB applications.

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