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Original Research Article

A Novel CRLH Based on Planar Antenna for Integration in Transceivers and Mobile Handset for Wide-band Applications

Mohammad Alibakhshi-Kenari

Electrical Engineering Department of Shahid Bahonar University of Kerman, Kerman, Iran

E-mail: malibakh@mtu.edu

Abstract

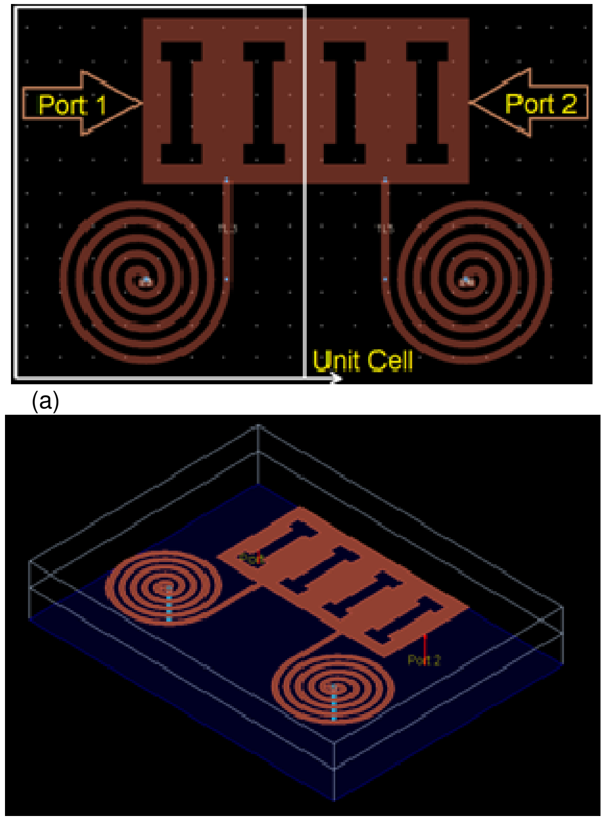
In this paper, a novel compact and wide band planar antenna base on the composite right-left handed transmission line (CRLH-TL) structure with enhancement gain is proposed and investigated on the Rogers_RT_Duroid5880 substrate. With CRLH metamaterial embedded technology, the proposed compact and broadband antenna is presented with best in reduction in size, bandwidth improvement, efficiency and radiation pattern enhancement. To realize characteristics of the antenna, the printed I-shaped gaps into the rectangular patches of the radiation patches are used. The physical size and the operational frequency of the antenna depend on the unit cell size and the equivalent transmission line (TL) model parameters of the CRLH-TL, including series inductance, series capacitance, shunt inductance and shunt capacitance. The compact and antenna accompanying high gain with two unit cell is designed from 0.5 GHz to 3.25 GHz which corresponding to 146% bandwidth, each of which occupies only 7.5mm× 10.5mm or $0.025\lambda_0 \times 0.03\lambda_0$ at the operating frequency f=1GHz (where λ_0 is free space wavelength). The physical length, width and height of the presented antenna are 15 mm, 10.5 mm and 1.6 mm or $0.05\lambda_0$, $0.03\lambda_0$ and $0.005\lambda_0$, respectively, in terms of free space wavelength. The radiation peak gain and maximum efficiency are 7dBi and 99%, respectively.

Keywords: Compact antenna, Wide band antenna, Composite Right/Left-Handed Transmission Line (CRLH-TL), Metamaterial (MTM)

INTRODUCTION

In Recent years, with by development of minimizing and broadband technology for foot print area reduction and high resolution and high data transmission rates in modern communication systems, there is increasing demand for small low-cost antenna, dispersive and broad band characteristics. The printed antennas has been received great attention in for broadband applications due of their compact advantages, 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 (Lee et al., 2008).

Metamaterial (MTM) (Caloz and Itoh, 2005; Shelby et al., 2001; Stutzman, 1997; Aparna, 2007; Wong, 2003; Andrea, 2007; Ourir, 2007; Lai et al., 2004; Lee et al., 2008; Li et al., 2011; Lee et al., 2006; Mohammad, 2014),



(a)
(b)

Figure 1. Configuration of the presented small and wide band antenna composed of the two unit cells based on CRLH-TL. a)Top view, b) Isometric view

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 (Caloz and Itoh, 2005; Shelby et al., 2001). Those unusual properties were used to improved performances of antennas and circuits. Microstrip antennas had been developed for applications in present communication systems (Stutzman, 1997; Aparna, 2007), but there is a fact that the size reduction levels remain unsatisfactory to the electromagnetic community. Several techniques were suggested to reduce antenna size [(Wong, 2003), however, such techniques usually suffer from increasing the design complexity. The occurrence of metamaterial may be a solution for this challenge (Andrea, 2007; Ourir, 2007). 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 (Caloz and Itoh, 2005; Shelby et al., 2001; Stutzman, 1997; Aparna, 2007; Wong, 2003; Andrea, 2007; Ourir, 2007; Lai et al., 2004; Lee et al., 2008; Li et al., 2011; Lee et al., 2006; Mohammad, 2014; Mohammad, 2014; Mohammad, 2014). In this paper a metamaterial CRLH antenna with two unit cells which each unit cell embrace of two printed I-shaped gaps capacitors and the spiral inductor accompanying metallic via connected to ground plane is presented (Mohammad, 2014). The printed I-shaped structure exhibit compact, broadband and improvement gain property which useful for compact and wideband antennas.

This paper is organized in the following way. A small and wide band 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.

Theory of the Proposed Antenna

As discussed in (Caloz and Itoh, 2005; Lai et al., 2004),

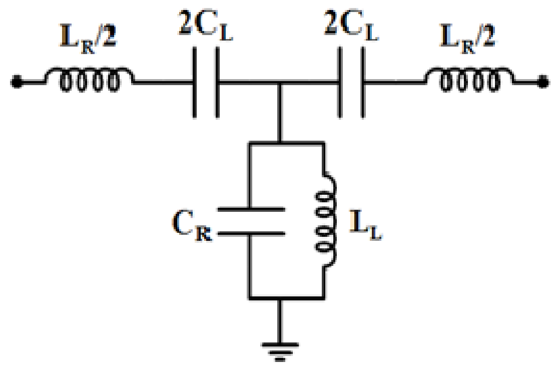


Figure 2. Proposed Antenna: Equivalent circuit model of the CRLH MTM antenna for one unit cell

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 are 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. A novel compact and wide band antenna with improvement gain based on CRLH-TL presented in here, which consists of two unit cells while each unit cell built by two rectangular patches with printed I-shaped gaps into patches, and the spiral inductor accompanying metallic via connected to the ground plane. Figure 1 shows geometry of the proposed antenna and Figure 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 50Ω 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.

By means of the I-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 effect 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 those results to foot print area reduction of the proposed antenna. Overall size of this antenna is $0.05\lambda_0 \times 0.03\lambda_0 \times 0.005\lambda_0$ at the operating frequency f=1GHz where λ0 is the free space wavelength and also with choosing smaller distance between printed I-shaped gaps edges, we will be obtained wide bandwidth from 0.5 to 3.25 GHz which corresponding to 2.75 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 (Ri), conductor width (W) and conductor spacing (S) we will be achieved excellent radiate performances. The gain and efficiency of the proposed antenna are changed from 0.2dBi to 7dBi and 25% to 99% into frequency band 0.5-3.25 GHz, respectively, that shown very good radiation characteristics. Therefore, the MTM antenna designed is compact and wide band with high gain. The proposed antenna based on CRLH-TL made very small size and broadband to support today's multi-band modern wireless applications and mobile handsets.

Figure 1 shows configuration of the recommended antenna constructed of the two unit cells based on CRLH-TL structure that was built on a Rogers_RT_Duroid5880 substrate, with a dielectric constant of 2.2 and a thickness of 1.6mm. This mushroom type unit cell is consisted of 10 mm×10.5 mm or $0.03\lambda_0 \times 0.03\lambda_0$ top patch, printed on top of the Substrate which in each unit cell, the series capacitance (C_L) is developed by two the printed I-shaped gaps into patches, and the shunt inductance (L_L) is resulted from the spiral inductor shorted to the ground through the metallic via. The structure possess the right-handed parasitic effect 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

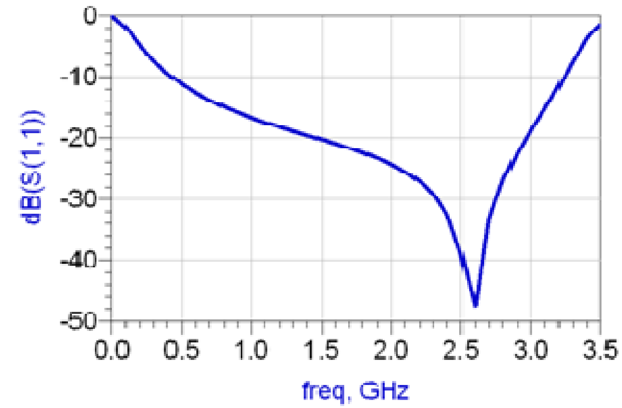
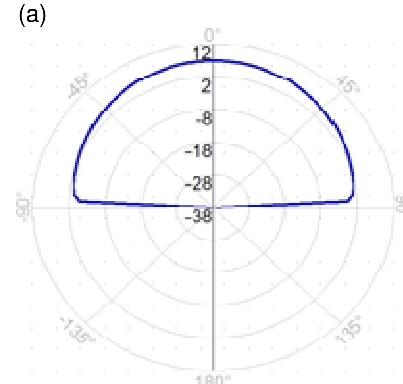
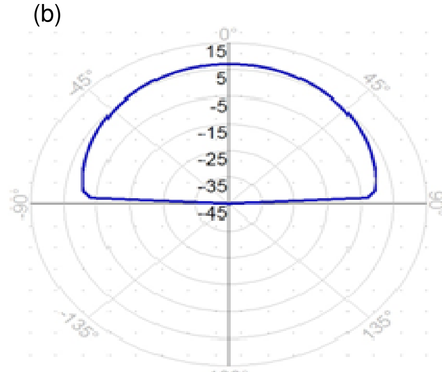


Figure 3. Simulated return loss (S_{11}) parameter

(a)



(b)



(c)

Figure 4. Radiation pattern (gain) in elevation ($\Phi = 0$ degree), a) f=1.4 GHz, b) f=2.4 GHz, c) 3.2 GHz

Table 1. Dimension and radiation characteristics of the antennas

Parameters	Proposed Antenna	(Lee et al., 2006)	(Li et al., 2011)
Dimension	$0.05\lambda 0 \times 0.03\lambda 0 \times 0.005\lambda 0$	$0.07\lambda 0 \times 0.07\lambda 0 \times 0.03\lambda 0$	$0.4\lambda 0 \times 0.03\lambda 0 \times 0.03\lambda 0$
Gain	7dBi	0.6dBi	0.45dBi
Bandwidth	0.5-3.25GHz	1-2GHz	0.8-2.5GHz
Efficiency	99%	26%	53.6%

matched to 50Ω 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 radiation efficiency. This antenna can support all cellular frequency bands from 0.5 GHz to 3.25 GHz, using single or multiple feed designs, which eliminates the need for antenna switches. All of these attributes make the proposed antenna well suitable for the emerging wireless applications (Lee et al., 2008; Li et al., 2011) and mobile handsets.

SIMULATION RESULTS AND DISCUSSION

The proposed metamaterial antenna is designed as a CRLH antenna where the substrate has dielectric constant ε_r = 2.2 and thickness h = 1.6 mm. Compact and broad band recommended antenna is simulated by using the full-wave simulator (ADS). The simulated reflection coefficient (S_{11} parameter) displayed in Figure 3 and simulated radiation gain patterns in 1.4, 2.4 and 3.2GHz are plotted in Figure 4. The radiation patterns are unidirectional characteristics. The simulated gains at 1.4, 2.4, 3.2 GHz are 2.6, 6.9, and 7dBi, respectively. The simulated radiation efficiency is 37.7% at 1.4 GHz, 95% at 2.4 GHz, and 99% at 3.2 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.

The two unit cell compact and broadband antenna is designed from 0.5 GHz to 3.25 GHz and this antenna exhibit good matching between this frequency band for 50Ω impedance port. The physical length, width and height of the suggested antenna are 15 mm, 10.5 mm and 1.6 mm ($0.05\lambda_0 \times 0.03\lambda_0 \times 0.005\lambda_0$), respectively. In the center frequency 1.87 GHz, the gain and efficiency are 6.8dBi and 90%, respectively.

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 compact, broad band and high gain antenna with a simple feed structure and planar circuit integration possibilities has been demonstrated. Overall size of the recommended antenna is 15 mm× 10.5 mm× 1.6 mm or $0.05\lambda_0 \times 0.03\lambda_0 \times 0.005\lambda_0$ at the operating frequency f=1 GHz where λ0 is free space wavelength. A return loss below -10dB from 0.5-3.25 GHz was obtained which corresponding to 146% bandwidth. The peak gain and the maximum efficiency of the proposed antenna are 7dBi and 99%, respectively. This antenna has the advantages of compact size, broadband, high gain, unidirectional radiation pattern and simple implementation. The recommended antenna can be used for integration in transceivers, mobile handset and wireless communication applications in wideband applications,

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