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Squeeze Broad-Band Patch Antenna Based on Metamaterial Transmission Line for Portable Apparatus

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Abstract

In this paper, a squeeze broad-band antenna based on the composite right-left handed transmission line (CRLH-TL) structure with enhancement gain is proposed and investigated. With CRLH metamaterial technology embedded, the proposed squeeze broad-band antenna is presented with best in bandwidth, size, efficiency and radiation patterns. To realize characteristics of the antenna, the printed I-shaped gaps into the rectangular radiation patches are used. This antenna is constructed of the four unit cells, also presented antenna is designed from 2.2 GHz to 3.05 GHz which corresponding to 32% bandwidth. The overall size of the presented antenna is 22

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mm x 7 mm x 0.8 mm or $0.16\lambda_0$ x $0.05\lambda_0$ x $0.006\lambda_0$ at the operating frequency f = 2.2 GHz (where λ_0 is free space wavelength). The radiation peak gain and the maximum efficiency which occurs at 3.05 GHz, are 4.1 dBi and 68.86%, respectively.

Keywords

Squeeze Antenna, Broad-band Antenna, Composite Right/Left-Handed Transmission Line (CRLH-TL), Metamaterial (MTM).

Introduction

Microstrip patch antennas have found extensive application in wireless communication systems due to their low profile, low cost, relatively simple fabrication, compatibility with planar circuitry, planar structures, unidirectional radiation capability. Antenna miniaturization is extremely important for modern wireless communication systems. The conventional approach for miniaturizing the antenna size is to print the radiator on a high dielectric substrate. However, because of the capacitive nature of the patch geometry and the existence of strong impedance contrast between the antenna substrate and the free space surrounding region, a large amount of electric energy is trapped inside the dielectric material resulting in a narrow antenna bandwidth and radiation loss. To overcome these problems we using of the MTM technology and the printed patch technique. These ways the antenna can be miniaturized while the system bandwidth and radiation characteristics are automatically improved.

In recent years, metamaterials have been used for the patch antenna substrate to miniaturize it. Recently, novel antennas have been designed by using composite right/left-handed transmission line (CRLH-TL) metamaterials [1, 2]. Unlike traditional right-handed (RH) transmission materials, metamaterials based on left-handed (LH) transmission lines (TLs) have unique features of anti-parallel group and phase velocities [1]-[3]. Pure LH TLs cannot be implemented due to the existence of RH parasitic effects that occur naturally in practical LH TLs. CRLH-TL structures have been proposed, which also include RH effects. In this article, a squeeze broad-band patch antenna filled with CRLH structures is proposed.

CRLH-TL Theory

The concept of LHMs was first theorized by the Russian physicist Veselago in 1967 [4]. Metamaterials (MTM) are artificial structures that can be designed to exhibit specific electromagnetic properties not commonly found in nature. Recently, MTM with simultaneously negative permittivity (ϵ) and permeability (μ), more commonly referred to as left-handed (LH) materials, have received substantial attention in the scientific and engineering communities. The unique properties of LHMs have allowed novel applications, concepts, and devices to be developed. LHMs are considered to be a more general model of composite right/left hand (CRLH) structures, which also include right-handed (RH) effects that occur naturally in practical LHMs [1]. LHMs support electromagnetic waves with group and phase velocities that are anti-parallel, known as backward waves. Since resonant structures such as SRRs are lossy and narrow-banded, they are often difficult to implement for microwave applications. The general TL approach provides insight into the physical phenomena of LHMs and provides an efficient design tool for LH applications [1]. The TL approach of LHMs, presented in this article, has led to non-resonant structures with lower loss and wider bandwidth. In particular, MTM with RH and LH properties known as CRLH MTM have led to the development of several novel microwave devices.

As illustrated in figure 1 the composite right/left-handed (CRLH) transmission line (TL) [5] is a TL composed of the periodic repetition of a unit cell comprising a series inductance and a shunt capacitance as well as a series capacitance and a shunt inductance. The series capacitance and shunt inductance provide left-handedness (anti-parallel phase and group velocities) [5, 6] at lower frequencies, whereas the series inductance and shunt capacitance provide the right handedness (parallel phase and group velocities) at higher frequencies. The CRLH-TL is intrinsically non-resonant and thereby presents the advantages of lower loss and broader bandwidth than resonant-type left-handed (LH) materials [6]. In addition, the CRLH TL appropriately represents real distributed LH structures [5], which have inevitable distributed parasitic series inductance and shunt capacitance, in contrast to the idealized LH TL which represents only a series capacitance and shunt inductance in the unit cell. The CRLH-TL can be implement in the two cases, balance and unbalance cases, and there is the unique phenomenon of vanishement of the bandgap between the LH and RH modes in the balanced CRLH TL. In the particular *balanced* case when the inductance and capacitance ratios of the LH and RH components of the unit cell are identical, that is, $\frac{L_L}{C_L} = \frac{L_R}{C_R}$ is satisfied, and the band-gap vanishes.

It should be noted that at $\beta = 0$ the wavelength is infinite ($\lambda_g = \infty$) and the structure is perfectly homogeneous. In the balanced CRLH TL, we can have a seamless transition between the LH and RH ranges with infinite-wavelength wave with energy transmission ($v_g \neq 0$). In contrast, when $\frac{L_L}{C_L} = \frac{L_R}{C_R}$ is not satisfied (unbalanced case), the group velocities become zero, and there is therefore no propagation ($v_g = 0$).

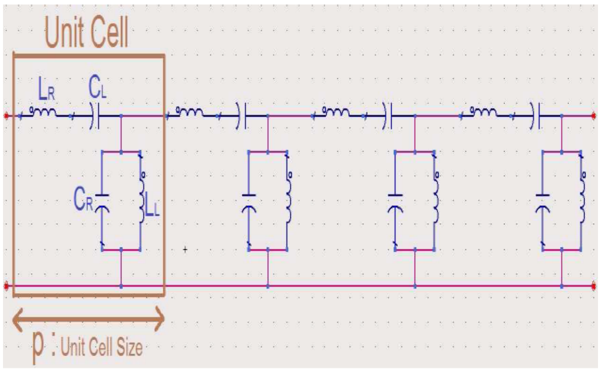


Figure 1: *The infinitesimal equivalent circuit model of the CRLH-TL composed of N unit cells.*

Proposed Antenna and Design Procedure

In this paper, we employing printed planar technique for our antenna design, since printed planar structures are good nominee for antenna design because of their advantages which include foot print area reduction, loss less and non-discrete values [7, 8]. A squeeze broad-band patch antenna with improvement gain based on CRLH-TL presented in here, which consists of four unit cells while each unit cell will be designed by two rectangular radiation patches with printed I-shaped gaps into patches, and the spiral inductor accompanying metallic via connected to the ground plane. Figure 2 display equivalent circuit model of each cell as CRLH unit cell. 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 cut-off frequency, and reduce its magnitude as frequency is increased. Making use of this phenomenon, an electrically large but physically small antenna can be developed. Figure 3 shows configuration of the proposed antenna, in this structure, port 1 is excited with input signal and port 2 is matched with 20Ω load impedance.

In this article, we using of MTM technology and the printed planar patches approach that results to foot print area reduction of the proposed antenna. Figure 3 shows configuration of the recommended antenna constructed of the four 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 0.8 mm and TanD = 0.001. 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 squeeze fashion. In each unit cell, the series capacitance (C_L) is developed by two the printed I-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 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, which indicates that these capacitance and inductance cannot be ignored. The proposed design procedure keeps the overall size of the unit cell compact while aims at reducing the ohmic loss to improve gain and radiation efficiency. Overall size of this antenna is $0.16\lambda_0$ x $0.05\lambda_0$ x $0.006\lambda_0$ at the operating frequency f = 2.2 GHz where λ_0 is the free space wavelength. With choosing smaller distance between printed I-shaped gaps edges, will be obtained wide bandwidth from 2.2 GHz to 3.05 GHz which corresponding to 850 MHz bandwidth. Furthermore, with appropriate selecting of the number unit cells (N) constructing antenna structure and structural parameters, will be achieved good radiation performances. The

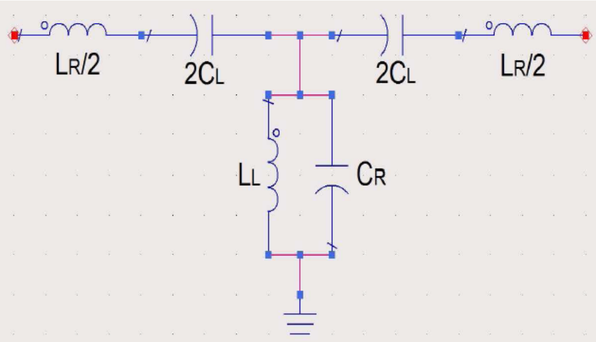


Figure 2: *Proposed Antenna: Equivalent circuit model of the CRLH MTM antenna for one unit cell.*

gain and the efficiency of the proposed antenna are changed from 0.54 dBi − 4.1 dBi and from 9.6% − 68.86%, respectively, into frequency band 2.2 − 3.05 GHz, that shown good radiation characteristics. This antenna can support all cellular frequency bands from 2.2 GHz to 3.05 GHz, using single or multiple feed designs, which eliminates the need for antenna switches. All of these attributes make the proposed antenna based on CRLH-TL is well suitable for the wireless communication applications and mobile handsets.

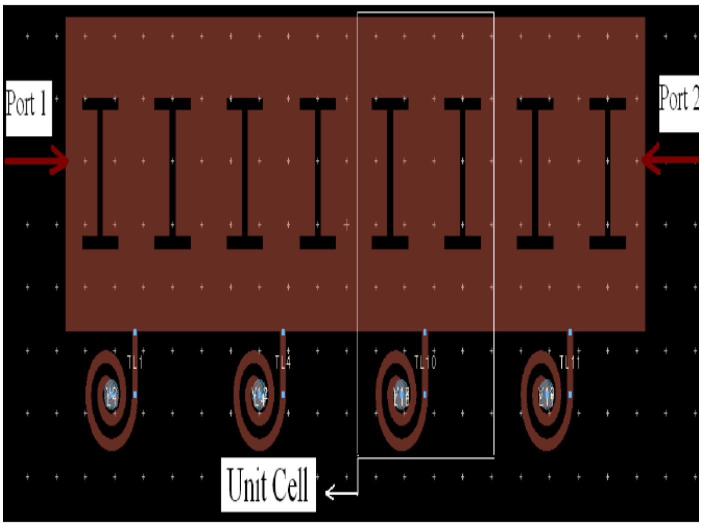
Simulation Results and Discussion

The proposed MTM antenna is designed as a CRLH antenna where the substrate has dielectric constant $\epsilon_r = 4.6$, thickness h = 0.8 mm and TanD = 0.001. Squeeze broadband recommended antenna is simulated by using ADS full-wave simulator. The simulated S_{11} parameter displayed in figure 4 and simulated radiation gain patterns in 2.2, 2.5 and 3.05 GHz are plotted in figure 5, 6 and 7. The radiation patterns are unidirectional characteristics. The simulated gains at 2.2, 2.5, 3.05 GHz are 0.54, 2.63, and 4.1 dBi, respectively. The simulated radiation efficiency is 9.6% at 2.2 GHz, 43.18% at 2.5 GHz, and 68.86% at 3.05 GHz.

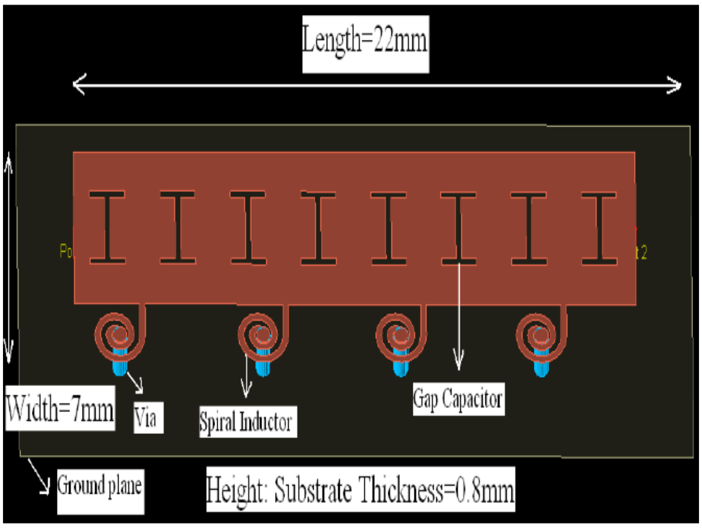
The four unit cells squeeze broad-band antenna is designed from 2.2 GHz to 3.05 GHz and this antenna exhibit good matching between this frequency band for 20Ω impedance port. The physical length, width and height of the suggested antenna are 22 mm, 7 mm and 0.8 mm ($0.16\lambda_0$ x $0.05\lambda_0$ x $0.006\lambda_0$), respectively. The gain and the radiation efficiency of this antenna are varies from 0.54 dBi to 4.1 dBi and from 9.6% to 68.86%, respectively, into the frequency range 2.2 GHz - 3.05 GHz.

Conclusion

In this paper, we introduced a new concept of antenna size reduction with wide bandwidth accompanying enhancement gain based on a MTM design methodology. A practical squeeze, 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 22 mm x 7 mm x 0.8 mm or ($0.16\lambda_0$ x $0.05\lambda_0$ x $0.006\lambda_0$) at the operating frequency f=2.2 GHz where λ_0 is free space wavelength. A return loss below -10 dB from 2.2 GHz − 3.05 GHz was obtained which corresponding to 32% bandwidth. The peak gain and the maximum efficiency of the proposed antenna which occurs at f = 3.05 GHz, are 4.1 dBi and 68.86%, respectively. This antenna has the advantages



Top View



Isometric View

Figure 3: *Configuration of the presented squeeze broad-band patch antenna composed of the four unit cells based on CRLH MTM-TL.*

of wide-band, compact size, high gain, unidirectional radiation patterns and simple implementation. The recommended antenna can be used for portable apparatus such as mobile handsets and wireless communication applications.

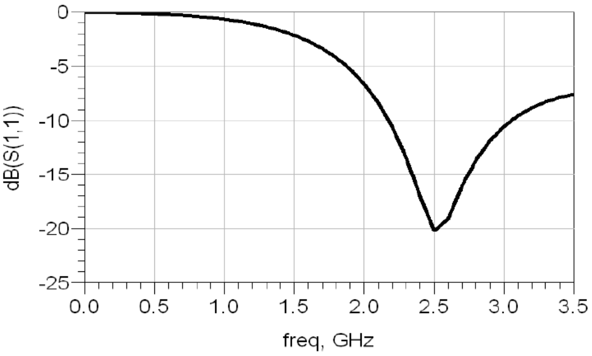


Figure 4: *Simulated reflection coefficient* S_{11}.

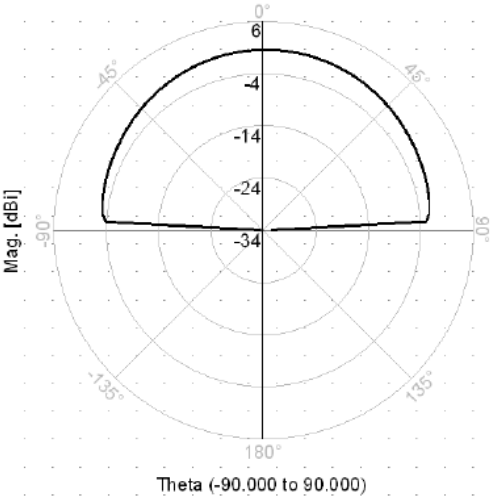


Figure 5: *The Radiation gains of the proposed antenna in elevation* ($\phi = 0 degrees$) *at 2.2 GHz.*

Acknowledgement

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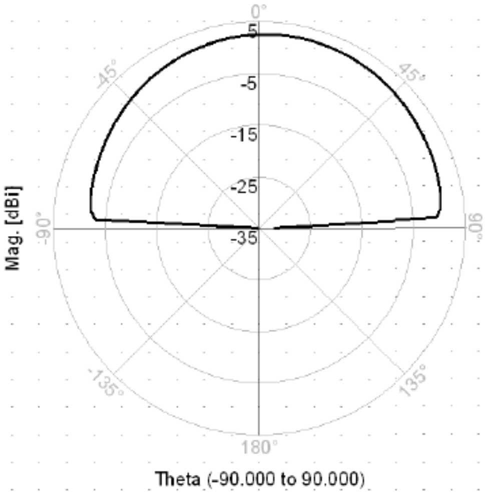

Figure 6: *The Radiation gains of the proposed antenna in elevation ($\phi = 0 degrees$) at 2.5 GHz.*

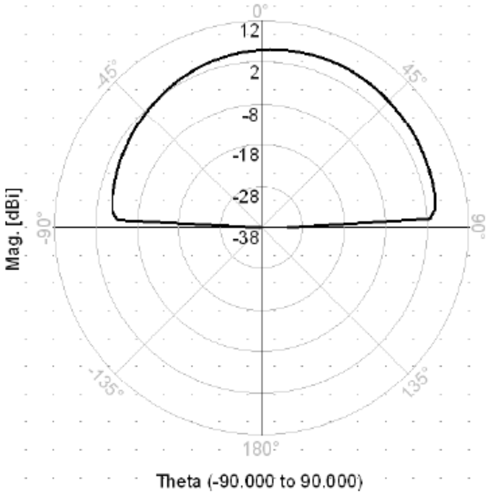

Figure 7: *The Radiation gains of the proposed antenna in elevation ($\phi = 0 degrees$) at 3.05 GHz.*

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