

# New Traveling-Wave Antenna Resonating at 6 GHz Based on Artificial Transmission Line Metamaterial Structures for RF Portable Devices

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## ABSTRACT

Design of new metamaterial (MTM) traveling-wave antenna with “d-formed” left-handed structure is proposed. The proposed MTM structure is designed at a height of 0.8 mm from the ground plane with almost 2 GHz bandwidth. The most interesting feature of the design is the ability of enhancing the gain and total efficiency of the antenna without negative effects of the other important parameters like bandwidth. By using the “d-shaped” MTM structure and printed planar technique, the bandwidth of the MTM traveling-wave antenna is significantly increased at a resonant frequency of 6 GHz and also a foot print area reduction of the antenna structure is provided. Antenna size is  $7.2 \times 5 \times 0.8 \text{ mm}^3$ . The proposed antenna is suitable for RF portable devices operating at 6 GHz.

**Keywords:** Small Broad Band Antenna; Metamaterial (MTM); d-Shaped Antenna Structure; RF Portable Devices; Traveling-Wave Antenna

## 1. Introduction

A printed patch antenna [1,2] is a low-profile antenna consisting of a metal layer over a dielectric substrate and ground plane. Typically, a printed patch antenna is fed by input signal, but other feed lines such as coaxial and microstrip transmission line can be used. The advantages of printed patch antennas are that they radiate with moderately high gain in a direction perpendicular to the substrate and can be fabricated in a low cost printed circuit board (PCB). The basic operating principle of a printed patch antenna is that the space between the patch and ground plane acts like a section of parallel plate waveguide. Neglecting radiation loss, the edge of the patch is an open circuit, so that energy reflects and remains below the patch. One disadvantage of a high-Q system is narrow bandwidth, so patch antennas have limited bandwidth, meaning that the input impedance of the antenna only remains near the desired value for a small range around the designed center frequency. In this paper, to overcome this challenge we used MTM technology, to extend the antenna bandwidth.

MTMs represent a new paradigm in electromagnetic science and technology [3,4]. Some of the applications of the MTM antennas are RF units, wireless communication,

mobile communication, space communications, global positioning system (GPS), satellites, space vehicle navigation, and airplanes. They have already led to many unprecedented microwave applications, which may be classified in three categories: guided-wave, radiated-wave and refracted-wave applications [5]. MTM antennas configurations may be of two types. The first type consists of conventional radiators (e.g. patches or dipoles) placed above artificial dielectrics [6], where the main benefits of the artificial dielectric MTMs are compactness [7] and slightly enhanced bandwidth in electromagnetically small antennas [8]. These TL MTMs generally exhibit a composite right/left-handed (CRLH) dispersive response [3], or related responses when the line integrates additional lumped elements in its unit cell (higher order TL) [9].

This paper presents an overview on CRLH resonant antennas (RAs) and also a new concept of design of the printed patch traveling-wave antenna resonating at 6GHz based on CRLH-TLs.

## 2. Brief Review of MTM RAs

A CRLH TL MTM is an artificial TL structure composed of the periodic repetition of a CRLH unit cell, as is shown in **Figure 1**. Such a TL exhibits in the lossless



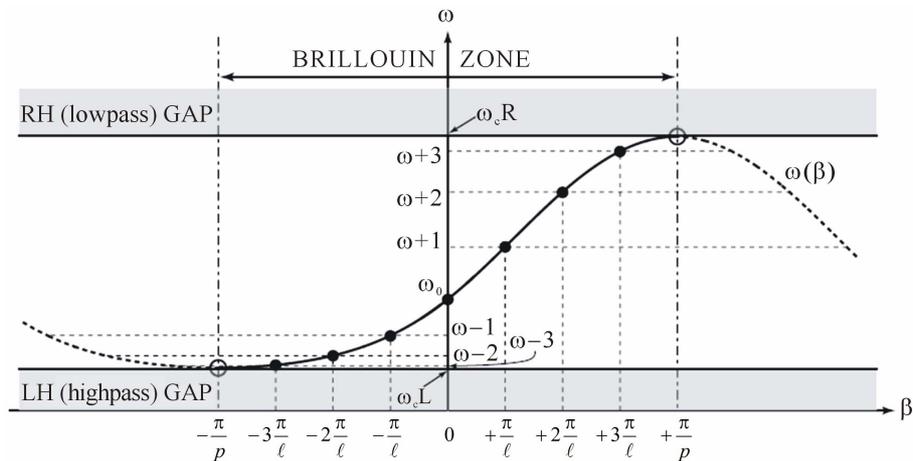


Figure 2. Resonances of the (balanced) CRLH TL resonator shown in Figure 1. The length  $l$  and the period  $p$  of the resonator are related by  $l = Np$ , which results in Brillouin zone edges of  $\beta_{BZE} = \pm \frac{\pi}{p} = \pm N\pi/l$ .

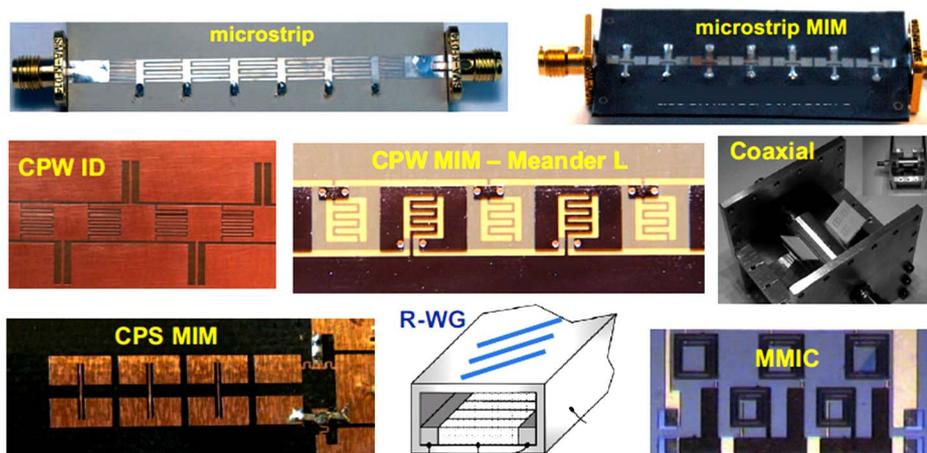


Figure 3. Typical 1D CRLH TL implementations [5].

also on the choice of the technology, configuration, and LC elements.

### 3. Design Methodology of Proposed Traveling-Wave Antenna Structure Resonating at 6 GHz

This paper introduces a new and distinct MTM structure named to “printed **d**-formed antenna” as is shown in **Figure 4**. The proposed antenna is constructed of two **d**-shaped unit cells. Each of unit cells consists of **d**-formed gaps printed on a rectangular radiation patch. These gaps act like series capacitances ( $C_L$ ). Also, from spiral inductors with two turns that through metallic via holes are connected to the ground plane and perform the roles of shunt inductors ( $L_L$ ).

The dimension of printed patch antenna is  $7.2 \text{ mm} \times 5 \text{ mm} \times 0.8 \text{ mm}$ , which are shown in **Figure 4(b)**. This

antenna is designed on FR-4 (Lossy) substrate with  $\text{Tan}\delta = 0.001$ , dielectric constant of  $\epsilon_r = 4.6$  and height from the ground plane of  $h = 0.8 \text{ mm}$ . Two waveguide ports were defined at the left and right of the x-axis in order to calculate the  $S_{11}$  and  $S_{21}$  parameters as are shown in **Figure 4(a)**. Port 1 is excited by input signal and port 2 is matched to 20 ohm load impedance of the SMD components which is connected to ground through via hole.

To implement a small antenna, we used MTM technology and printed planar technique, as printed gaps acts like left-handed capacitors ( $C_L$ ) and leads to foot print area reduction, and also to create broadband performances have used of spiral inductors, so these inductors performs the role of left handed inductors ( $L_L$ ). In addition, new hypotheses will be discussed in the following referred to it. Overall size of the proposed antenna is  $7.2 \times 5 \times 0.8 \text{ mm}^3$  or  $0.11\lambda_0 \times 0.079\lambda_0 \times 0.012\lambda_0$ , where  $\lambda_0$  is free space wavelength at 4.7 GHz.

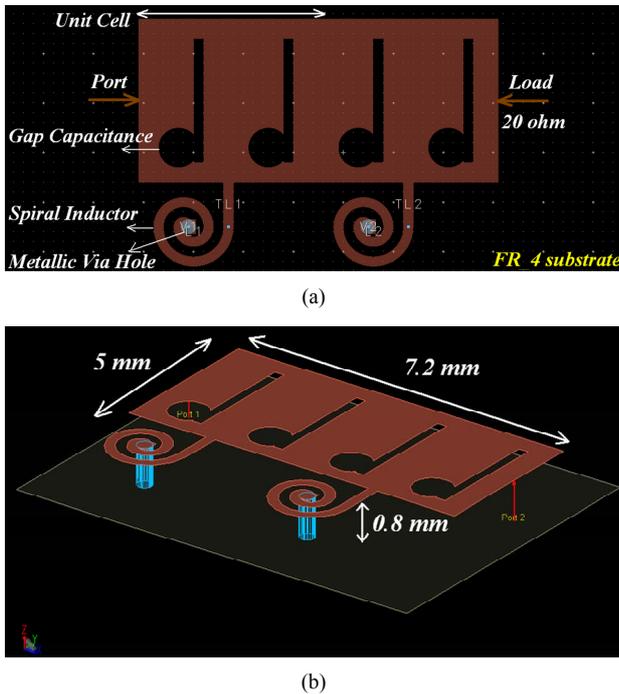


Figure 4. Configuration of the proposed traveling wave antenna constructed of two unit cells. a) layout of the top view, b) layout of the isometric view.

This antenna covers frequency bandwidth from 4.7 to 6.7 GHz and from 4.9 to 6.6 GHz that were derived from ADS and HFSS softwares, respectively. Equivalent circuit model of the **d**-formed antenna is displayed in **Figure 5**.

Shunt capacitance ( $C_R$ ) and series inductance ( $L_R$ ) are right-handed parasitic effects which unavoidably are created due to existence of spaces between patches and ground plane and current flows on the patches. Losses of the structure are modeled by  $R_R$ ,  $G_R$ ,  $R_L$  and  $G_L$ .  $R_R$  and  $G_R$  are right-handed losses and  $R_L$  and  $G_L$  are left-handed losses.

In this paper, for realization of the small wideband antenna [10], we employed new ideas based on MTM technology of printed planar patches and smaller value of the loaded series capacitance. For implementation of the small dimensions, **d**-shaped copper artwork is printed directly on a printed circuit board using standard printed circuit board manufacturing techniques, so leads to output series capacitor ( $C_L$ ), thus can be leading to a reduction in antenna dimensions. In addition, for implementing a smaller value of the loaded series capacitance, we utilized the least of spaces that are printed on radiation patches which provides series capacitances and leading to reduce of the printed area and its effect bandwidth of

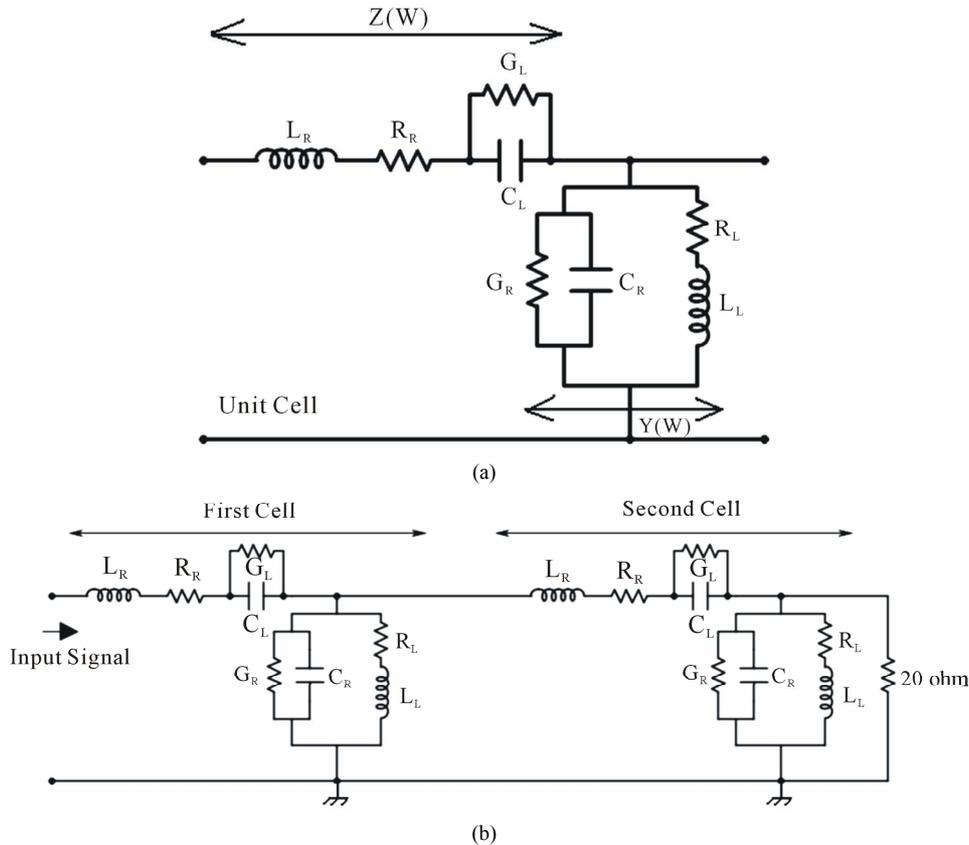
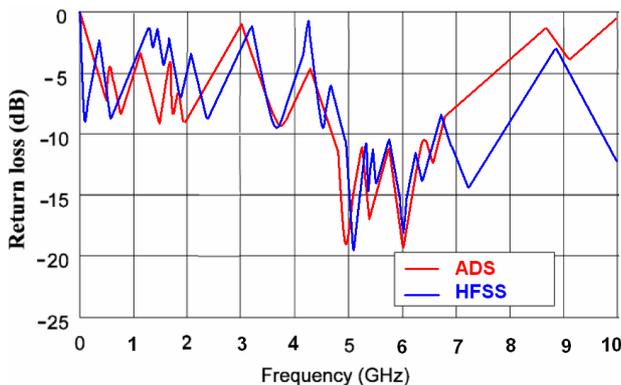


Figure 5. Equivalent circuit model of the minimized traveling wave antenna. a) unit cell, b) entire structure.

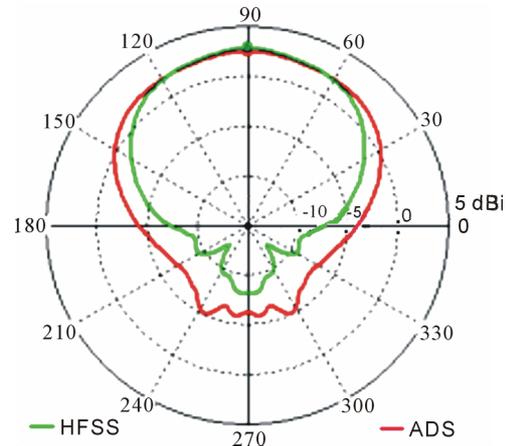
the antenna has been extension. The length, width and height of proposed antenna are 7.2 mm, 5 mm and 0.8 mm and the structure can be used for an impedance bandwidth ( $S_{11} < -10$  dB) from 4.7 to 6.7 GHz that is obtained by using ADS simulator and from 4.9 to 6.6 GHz that was obtained by using HFSS simulator, that are equal to 2 and 1.7 GHz bandwidth which corresponds to 35.08% and 29.56% practical bandwidth, respectively. The reflection coefficients ( $S_{11} < -10$  dB) of the proposed traveling-wave antenna are exhibited in **Figure 6**.

Other important issue in design of the antenna systems is radiation pattern. Therefore, acceptable radiation characteristics are necessary properties of the antenna systems. In this framework, beside small size and wide bandwidth characteristics, we have suggested a new idea for providing good radiation performances. For obtaining suitable radiation properties, we have employed of the uniform excitation mechanism by utilizing two ports, as port 1 is excited by input signal and port 2 is matched to 20 ohm load impedance. Furthermore, in design procedure of the proposed antenna for obtaining appropriate radiation performances is used of inductive and capacitive elements with optimized values, so that lead to expansion of the aperture efficiency, therefore radiation characteristics have been increased. Maximum radiation gains and efficiencies of the proposed small and wide-band antenna at 6 GHz, derived from ADS and HFSS simulators, are 3.6 dBi and 60.3%, and 3.3 dBi and 48.2%, respectively. The radiation gains patterns of the antenna at 6 GHz are plotted in **Figure 7**. It is clear that, radiation patterns of the proposed antenna have unidirectional characteristics.

Therefore, suggested antenna is include advantages of small size, in other hand, has dimension of  $7.2 \times 5 \times 0.8$  mm<sup>3</sup> or  $0.11\lambda_0 \times 0.079\lambda_0 \times 0.012\lambda_0$ , wideband performances with about 2 GHz bandwidth from almost 4.7 to almost 6.7 GHz, which are related to approximately



**Figure 6.** Return losses ( $S_{11} < -10$  dB) of the proposed d-shaped antenna which were obtained from ADS and HFSS simulators.



**Figure 7.** Radiation gains patterns of the traveling-wave antenna in elevation plane ( $\Phi = 0^\circ$ ) at 6 GHz, which were derived from ADS and HFSS simulators.

35.08% practical bandwidth and excellent radiation properties with maximum gain of 3.6 dBi and radiation efficiency of 60.3% that were obtained from ADS simulator, so that highest these parameters derived from HFSS simulator are equal to 3.3 dBi and 48.2%, respectively, that occurs at resonating frequency  $f = 6$  GHz.

It is noteworthy that, increase the number of unit cells will lead to the relative increase in gain, but in return, it will adversely affects on the size and bandwidth of the antenna, so that leads to somewhat lower bandwidth and increase the size.

To validate the design, the simulation processes of the antenna are done using Advance Design System (ADS) and High Frequency Structure Simulator (HFSS) simulators.

According to obtained results the proposed traveling-wave antenna resonating at 6 GHz based on CRLH MTM-TLs can be appropriate nominee for wireless applications and RF portable devices.

## 4. Conclusions

In this paper, we presented new concepts of design of the small wideband traveling-wave antenna resonating at 6GHz based on MTM technology, printed patch technique, smaller value of the loaded series capacitance and use of suitable inductive and capacitive components with their optimized amounts.

The “d-shaped” MTM structure with rectangular patch antenna is proposed. Overall size of this antenna structure is very compact in comparison to conventional antennas. On making d-shaped structure by double negative left-handed MTMs, antenna parameters such as dimension, gain, efficiency, and bandwidth can be improved up to a desired limit but practical limitations should be taken care of while fabricating the structure with ADS and

HFSS softwares. The proposed antenna has benefits of low cost, ease of implementation, unidirectional radiation patterns, high gain and efficiency, broader bandwidth than conventional wideband antennas and smaller size than conventional compact antennas and this antenna can be fabricated in a low cost and low-profile printed circuit board (PCB) using standard PCB manufacturing techniques.

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## 6. Author Biography



**Mohammad Alibakhshi Kenari** was born in 1988 at Iran, Mazandaran, Freydunkenar. He received the B.S. and M.S. degrees in communication engineering from the university of Najafabad at Iran, in 2009 and the university of Shahid Bahonar at Iran in 2013, respectively.

His research involves microwave and millimeter wave circuits, minimized and wideband antennas, MTM CRLH-TLs implementations, FR portable devices and embedded systems.

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