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Design and Fabrication of an UWB Patch Antenna with CRLH TL

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ABSTRACT

In this paper, a small sized, low profile and Ultra-wideband (UWB) patch antenna with Metamaterial (MTM) transition line (TL) and two coaxial feed was designed and fabricated. The reduction of the antenna size and increase in bandwidth were achieved through the use of MTM TL and two coaxial feed. The bandwidth was improved by 131% as well as the circular polarization (CP) in a narrow bandwidth was achieved by varying the MTM TL parameter and feed position. To confirm these results, two proposed antenna with different MTM TL and feed position were then fabricated and measured and the measurement results showed a good agreement between simulation and measurement. A conventional antenna of the same size, which resonates at f=10GHz and has a bandwidth of 8% was used as a reference for comparison.

KEYWORDS: compact, MTM TL, miniaturization, CP, UWB antenna.

1. INTRODUCTION

Due to its low profile configuration and relative low cost and ease of construction, the microstrip antenna has received much consideration in many wireless communication applications. This antenna possesses several drawbacks, such as narrow bandwidth and low gain. There are a variety of methods not only for increasing the bandwidth and gain, but also to compact the antenna size. In conventional method, as a consequence of evaluating the substrate thickness the inductance was increased. As a result, the impedance matching occurred in a wider frequency band. Many techniques have devised to improve the bandwidth, including; uslot[1, 2], probe feed [3, 4], shorting wall [2] and shorting pin [2]. Given the fact that these methods increased the substrate thickness, the antenna would be heavy to fabricate.

Today, the MTM TL is used to overcome this drawback. These materials have simultaneously negative permittivity and permeability therefore negative refraction index was first theoretically predicted by Veselago [5].An MTM structure was intended to be used as a transmission line or transmission structure [6, 7and 8].The composite right-left handed (CRLH) TL network is qualitatively a combination of the pure right- handed (PRH) and pure left-handed (PLH) network TL.Propagation of waves with antiparallel phase and group velocity is a phenomenon which is occurred in CRLH TL, so the backward wave is allowed and the negative modes are excited, due to the negative reflection index ($n<0$) in a special narrow frequency band. That's why the antenna becomes multi band by applying the CRLH TL as a patch radiator.The goal of this paper is applying a CRLH TL which possesses the frequency band regions with negative reflection index as well as the region which has $n\approx0$, to make a multi band antenna with satisfactory total gain.(If we use a material with refraction index $n\approx 0$, based on Snell's Law, the ray will be close to the normal of surface and the total directivity will be increased).The narrow band in CRLH TL, with these special properties is a drawback. To overcome this drawback, it should select an appropriate unit cell to design a CRLH TL. Finally, according to the above introduction, the CRLH can excite the negative modes as well as the two feed can improve the impedance matching so we can design an UWB and compact antenna.

In this paper, a CRLH TL was introduced which possessed a big frequency band with $n<0$along with $n\approx0$ in the other frequencies. This unit cell has three resonate frequencies. The first one is weak and the second is placed near the conventional antenna resonance frequency. All of them are in the regions which has $n<0$. It can make a multi band antenna. It can be seen that this unit cell has $n\approx0$ in the other frequencies. If this unit cell is used as radiation patch, based on snell's law, the ray will be close to the normal of surface. So that the total gain reduction is lees end too. Finally, to have a better impedance matching, two feeds are applied.

The remainder of the paper was organized as follows: In section II, the design of unit cell and its properties are described, in section IIIand IV, to study the effects of this CRLH TL on the electromagnetic structures; its application methods for increasing the antenna bandwidth and circular polarization were also studied. The

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simulation results revealed the increase in the bandwidth up to 131%, and finally the miniaturization of the reference antennas because of exciting additional resonance frequency below 10GHz. To validate the proposed design, Finite Element Modeling (FEM analysis by Ansoft HFSS ®) was utilized. Two antenna structures with different dimensions were also used to increase the antenna's bandwidth and to turn it into a circular polarized antenna. Finally, in section V, in order to have a complete conclusion, the extra results such as total gain is shown and discussed.

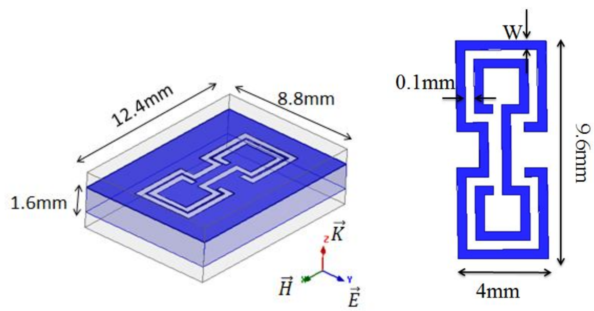
II. Design of MTM TL Unit cell Structure

In this section, the MTM TL is designed and described to act as patch radiator. The dimensions of unit cell are optimized with Ansoft HFSS software tools.

1. Description of MTM TL geometry

In this subsection, the proposed MTM TL unit cell is described. The MTM TL unit cell basic structure is shown in Fig. 1. The proposed unit cell consists of two Complementary Split Ring Resonators (CSRR) connected by two wires, which connect the outer and inner loops to increase the coupling. The CSRR has been used to compact the antenna [9 and 10]. This resonator has a high Q factor. As a result, high current and field are induced in the loops. Thus, it is capable of producing a multi band and UWB antenna. In addition, this unit cell owns a band frequency with n<0 and backward wave.

The thickness of metal layer is considered to be 0.02 mm. Rogers 5880 dielectric is used in all structures, with ε_r = 2.2 and the substrate thickness is supposed to be 1.6 mm.



(a) (b)

Fig. 1.Geometry of the proposed MTM TL unit cell (a) Perspective view. (b) Top view.

2. SIMULATION MODELS

To do numerical simulations, the unit cell was excited with an electric field along the Y-axis and a magnetic field along X-axis as shown in Fig. 1(a). To extract the MTM TL unit cell properties, the NRW method is used which is deduced from the following equation:

$$S_{11} = \frac{\Gamma_{12}(1-e^{j2\theta})}{1-\Gamma_{12}e^{-j2\theta}} \quad (1)$$

$$S_{21} = \frac{e^{-j\theta}(1-\Gamma_{12}^2)}{1-\Gamma_{12}e^{-j2\theta}} \quad (2)$$

Where $\theta = d\beta$, d is thickness of the dielectric and β is phase constant. With a dielectric with narrow thickness, the $e^{-j2\theta}$ can be written in a polynomial form:

$$e^{j2\theta} = 1 - jd\beta \quad (3)$$

and β can be written as (4):

$$\beta = \beta_0\sqrt{\mu_r\varepsilon_r} \quad (4)$$

Where β_0 is the phase constant in free space. From previous equations, the (5) is derived.

$$\sqrt{\mu_r\varepsilon_r} = \frac{(1-S_{11}-S_{21})(\Gamma+1)}{jd\beta_0(1-(S_{11}+S_{21})\beta_0)} \quad (5)$$

Where Γ (reflection coefficient) is:

$$\Gamma = \frac{\eta_2 - 1}{\eta_2 + 1} = \frac{\sqrt{\frac{\mu_r}{\varepsilon_r}} - 1}{\sqrt{\frac{\mu_r}{\varepsilon_r}} + 1} \quad (6)$$

Finally, according to (5) and (6), it can be written:

$$\varepsilon_r = \frac{2}{j\beta_0 d}\frac{1 - S_{11} - S_{21}}{1 + S_{11} + S_{21}}$$
$$\mu_r = \frac{2}{j\beta_0 d}\frac{1 + S_{11} - S_{21}}{1 + S_{11} + S_{21}} \quad (7)$$

So, the unit cell properties can be extracted by (7). The S-parameters are derived from HFSS software and then exported to MATLAB software to achieve the MTM properties using Nicolson-Ross-Wier (NRW) method [11].

3. RESULTS

This unit cell has one free parameter of W. Modifications of this free parameter introduce changes in the series capacitances as well as the shunt inductance. Thus, variations in the operation frequency are obtained.

The simulated frequency response of the new modified MTM unit cell based on the CRLH TL for variable W is presented in Fig. 2b. By increasing the value of W, the total capacitances and inductance due to gaps, are decreased so that an upper resonate frequency will be resulted.

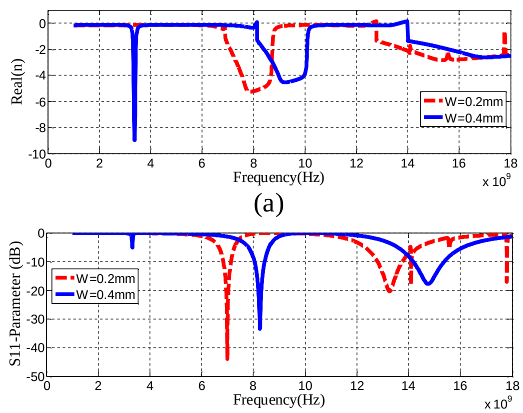


Fig. 2.Properties of MTM TL unit cell (a) reflection index (n). (b) S_{11}-Parameter

The reflection index (n) diagram for the structure is shown in Fig. 2a. It is shown that the value of W has an important key to identify the backward wave region. It can be depicted that the unit cells support two big and one small regions with negative refraction index for both different W. The first region is placed in a narrow frequency band which is around 3GHz. Another two regions are shifted to upper frequency band by increasing the value of W.Thus, it can be stated that the new modified MTM unit cell exhibits a CRLH behavior. Another characteristic is that the refraction index value is near zero in other frequency. So the gain can be improved.

For bigger value of W, the negative refraction index region is shifted to higher frequency.

The possibility of controlling the electrical characteristics (n) is the key point to use this kind of CRLH TL unit cell in order to design an UWB patch antenna.

For a specific operating frequency, the unit cell can be designed to provide desired bandwidth (a bandwidth with $n<0$) by changing the value of W.

To have a glance, an outline of simulation results such as the resonance frequency and negative index regions are depicted in Table 1.

It can be shown in Fig. 2(b), the unit cell has a weak resonance frequency about 3.3GHz.

According to Table 1 , It can be seen that the proposed unit cell has three different regions with $n<0$. These regions excite the negative modes. So, a multi band antenna is produced. By using two feed structure, the impedance matching is improved that brings about an UWB antenna. Finally, it is expected to excite the negative modes in the first region when it is loaded with the patch antenna.

Note that the frequency band from 1GHz to 18GHz is considered.

Table 1. Simulation results of unit cell

W(mm)	F_r(GHz)	1st region(GHz)	2nd region (GHz)	3rd region
0.2	6.9 and 13.2	near 3.3	8.1-10	above 13.9
0.4	8.2 and 14.8	near 3.3	6.8-9.8	above 12.7-…

III. Antenna Incorporated with CRLH TL

In this section, the CRLH TL is used as radiation patch and two coaxial feed are utilized. The geometry of the proposed UWB patch antenna with a CRLH TL and two coaxial feed is shown in Fig. 3.

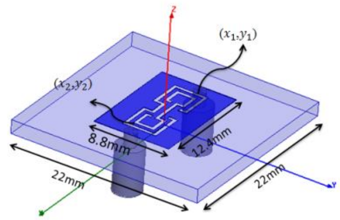


Fig. 3.Geometry of the proposed patch antenna

Today, two coaxial feed are useable [12and 13]. For feeding of the antenna, a wideband 180° power divider was utilized to transform a single-ended signal to two signals, in which one travels out-of phase with the other [14].

Two prototypes of the proposed design with various dimensions of the W and feed positions have been conducted and studied while Optimal dimensions of W and feed positions for widened bandwidth are selected. In addition Details of the proposed design and obtained experimental results are presented and discussed.

There are three free parameters in the proposed antenna such as (x_1, y_1), (x_2, y_2) and W.

A parametric study is investigated and demonstrated that the following parameters influence the performance of the proposed antenna most effectively.

1. Variable W

This subsection deals with the effect of different values of W in antenna matching. Two different coupling can be considered in the proposed antenna are the capacitive coupling through the ring slot and the magnetic coupling through the splits of the rings.

The variable W is capable of changing the unit cell resonance frequency (see Fig. 1(b)). In the other hand, it can change the total capacitance and inductance. The S_{11}-Parametter of the antenna versus different values of W is shown in Fig. 4. A conventional antenna of the same size is used as a reference for comparison which resonates at f=10GHz and has a bandwidth of 8%.

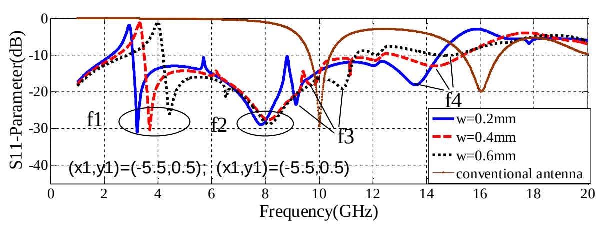
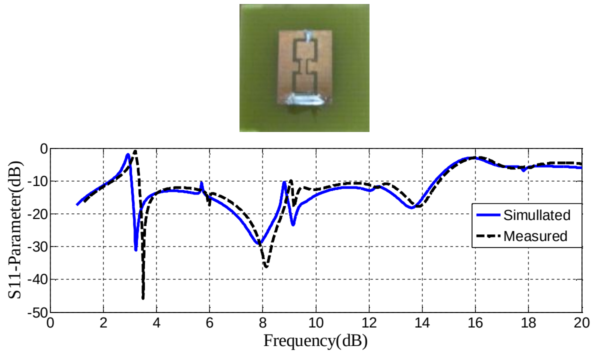


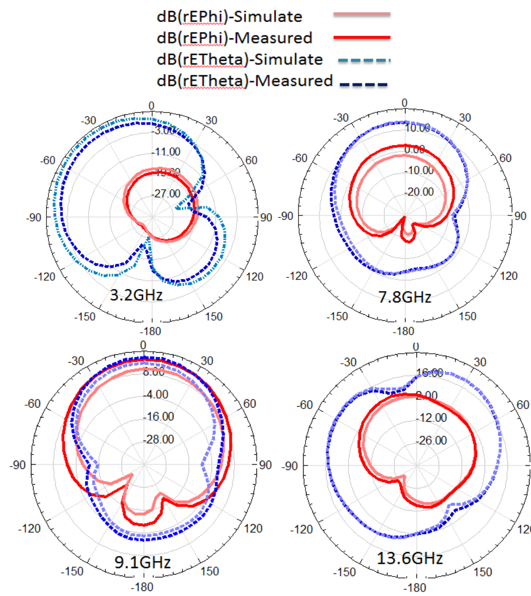
Fig. 4.The S_{11}-Parameter of the antenna versus different values of W

According to Fig. 4, it can be deduced that the proposed antenna has four resonance frequencies because the backward wave occurred by CRLH TL excites the negative mode. In addition, this configuration can improve the bandwidth by 131%, as compared to the conventional patch antenna which resonates at f=10GHz and has a bandwidth of 8%. As it is discussed, for bigger value of W, the negative refraction index region is shifted to higher frequencies. As a result, it is expected that the resonance frequency is shifted to upper frequencies. By considering the first resonance, there is a reduction of 68% in the size of the simulated antenna. Nonetheless, the total gain will remain satisfactory. (It is shown in the next section)

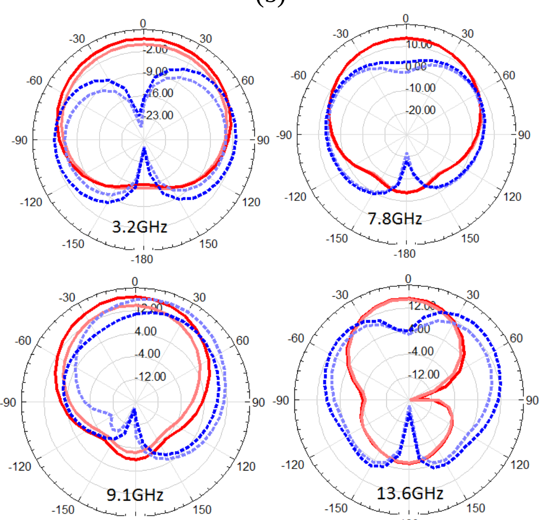
In comparison with recent studies about application of CRLH TL in the UWB antenna in [15] and [9], not only this proposed antenna has wider bandwidth and higher gain, but also it has a simpler design. To conclude, a particular example, fabricated prototype will be studied in terms of return losses, gain and radiation pattern. The antenna with W=0.2mm is fabricated and measured results for f_1=3.2GHz, f_2=7.8GHz, f_3=9.14GHz and f_4=13.6GHz are depicted in Fig. 5.



(a)



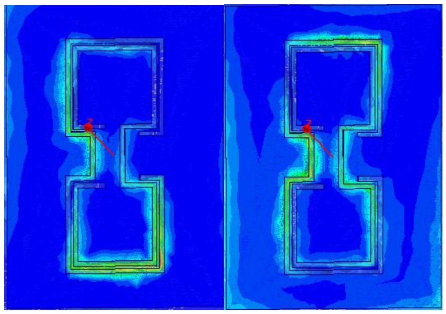
(b)



(c)

Fig. 5 Measured and fabricated results for antenna with w=0.2mm in Fig. 4(a) S_{11}-Parameter and fabricated antenna (b) radiation pattern @Phi=0^0 (c) radiation pattern @ Phi=90^0

As it can be seen, the cross and co polarization at f=9.14GHz are very close. To have a better understanding of the results, the electric-field distribution at f=9.14GHz and f=7.8GHz is shown in Fig. 6.From Fig. 6, it can be realized that the electric field distribution at two different frequencies occurs in opposite patch edges. So it is capable to excite these two resonances with a 90º Phase difference. Finally, the circular polarization can be applied. At the next section, the free parameters are optimized to achieve the best answers.



(a) (b)

Fig. 6 Theelectric-field distribution at(a) f=9.14GHz (b)7.8GHz

2. Variable feed position

In this section, we focus on variable fed position effect on impedance matching. In previous section, it was shown the CRLH TL excited the negative mode. By changing the feed position, the coupling can increase. As a repercussion not only is the impedance matching improved, but also the bandwidth will be ameliorate. The tolerance of the feeding position has been checked in simulations and is represented in Fig. 7.

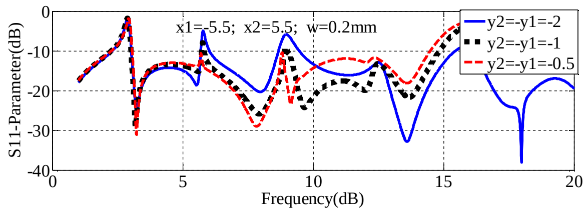


Fig. 6 Effect of fed position on bandwidth

The patch radiator has a high surface density current in the higher frequency band and thus the mutual coupling needed to create an excitation of this last. In this study, it was shown that the variations of feeding position can control the higher frequency band. As long as, the position will be close to the patch edges, the matching on the higher frequency band will be better.

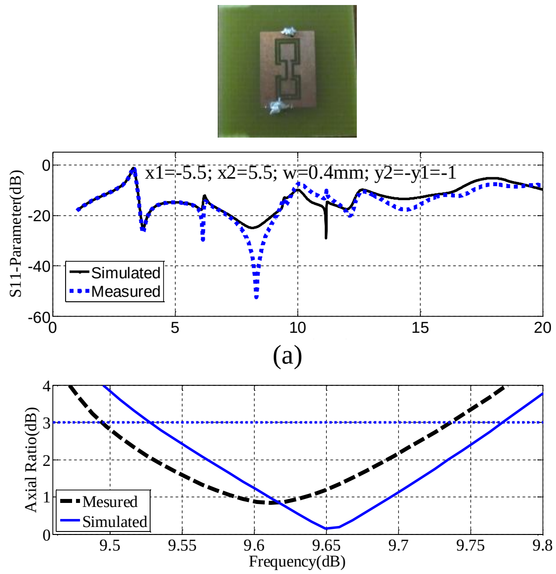
IV. Circular Polarized Antenna

In circular polarization, the phase of the electric field changes with a constant speed and causes the electric field to move along a circle.

By changing the fed position, the resonance frequencies can be excited with a 90^0 phase difference.

In previous section, it was seen the electric field distribution was focused in the patch edges in two different frequencies. So, by changing the feed position along y direction (to close to edges), the electric field can be increased. As a result, the 90^0 phase difference is occurred at two frequencies.

After optimization, the antenna is fabricated and the results are shown in Fig. 7.



(a)

(b)

Fig. 7 (a) S_{11}-Parameter and (b) axial ratio of the second fabricated antenna

V. Total Gain

To have a comprehensive results, the realized total gain for the conventional, the first fabricated and the second fabricated patch antenna are shown in Fig. 8.

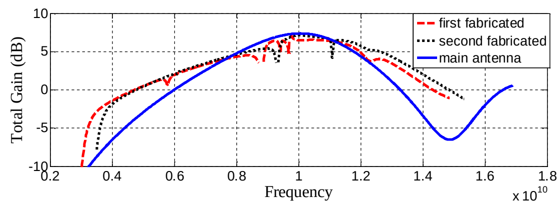


Fig. 8 The measured total gain

A maximum realized gain value of about 7.4 dB has been measured at 10 GHz. It can be shown the gain is satisfactory whereas the antenna became UWB and compact.

Moreover, as compared with the conventional antennas, the proposed antenna has better gain at lower and upper frequency bands. For other frequencies, the proposed antenna gain is about the same for the conventional antenna without CRLH TL.

VI. Conclusion

The purpose of this project was to construct an UWB patch antenna with CRLH TL. Two different prototypes of this antenna was fabricated and measured. The bandwidth is improved by 131% as well as a weak circular polarization (CP) is achieved by varying the MTM TL parameter and feed position. The total gain was satisfactory. As well, the proposed antenna is low profile and has a simple design to fabricate.

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