Metamaterial Inspired Compact Antenna for UWB and GPS Applications

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Abstract— Three types of UWB antennas are proposed and investigated for UWB communication applications. The proposed antennas consists of a planar circular patch monopole ultrawideband antenna, one of which is incorporated along with the GPS (1.5 GHz) band due to addition of four unit cells of complimentary meander-line and a T-slot on the patch. Simulated S_{11} is -6 dB over 1.46–1.54 GHz and a wide bandwidth starting from a frequency of 3.45 GHz. The antenna is designed on a low-cost FR4 substrate having dimensions $37.5 \times 31.5 \times 1.6\,\mathrm{mm}^3$. It has a uniform gain in the S and C bands. The antenna is fabricated and the match between the simulated and experimental results suggests that the proposed antenna can be a used for GPS, WiMAX, WLAN and other UWB applications.

1. INTRODUCTION

UWB is a radio technology which may be used for short ranges at a very low energy level, with high bandwidth communication which uses a vast portion of the radio spectrum [1]. Printed monopole antennas fabricated on a substrate offers a wide impedance bandwidth that can cover ultrawideband [2]. The frequency band from 3.1 GHz to 10.6 GHz. It is approved as UWB by Federal Communications Commission (FCC) [3]. It has been used for radar, sensing and military communication applications over the past couple of decades [4].

The main challenges faced in the design of UWB antennas are the miniaturization, improving the efficiency, uniform gain, larger operating range, optimized radiation pattern and polarization to provide wide coverage. It has been a greater challenge to accommodate both the UWB and the GPS band for a compact antenna. These problems have become an active topic of research.

In the recent years, efforts have been made by implementing rectangular, circular disc, elliptical and binomial curved-shaped UWB monopole antenna in the designs to overcome the drawbacks [8–17]. In order to keep the antenna footprint unaltered, designers have resorted to the approach of embedding slots of different shapes in the radiating element and/or ground plane of the antenna systems.

One such effort to resolve the drawbacks is the implementation of metamaterial structures [6]. Metamaterials are artificially engineered structures providing electromagnetic properties which are not encountered in nature. These materials simultaneously have negative permeability and permittivity which was first theoretically predicted by Veselago [7].

This paper proposes the design and performance of a compact UWB antennas with fractional bandwidth of $> 100\%$. The need for a compact UWB antenna along with GPS application is given in this paper. The proposed designs are smaller in size compared to the antenna dimensions reported in [8–17].

Section 2 gives a brief theory on how the modifications to the previous designs have helped in overcoming the problems posed. Section 3 showcases the proposed designs and its configuration. Section 4 portrays the results of multiple simulations. Section 5 contains the conclusion of the final proposed design.

2. THEORY AND METHOD

The unconventional electromagnetic characteristics like simultaneous negative permittivity and permeability leading to negative refractive index are exhibited by the addition of metamaterial structures [5]. These structures have inductive and capacitive characteristics which helps in miniaturizing the antenna system. The improvement in the performance and reduction of size in the type-2 antenna design is due to the t-slot made on the patch. This T-slot is a metamaterial inspired structure. Meander line cuts which are meta-structures are implemented in the proposed design such that a new resonant band is formed at a particular frequency.

Ansys package High Frequency Structure Simulator (HFSS) is a 3-dimensional (3D) full wave simulation software based on FEM (finite element method). FEM is a powerful tool used to evaluate the antenna performance. This method subdivides the problem domain into individual simpler parts and then re-assembles the solution for the entire problem. This minimizing the error function. Maxwell's equations are used for solving the problem.

3. PROPOSED DESIGN

Type-1 of the proposed antenna has a planar circular microstrip patch which helps in generating a wide band. With the intention to increase the bandwidth, Type-2 antenna combines a T-slot on the circular microstrip patch which improves the performance. Type-3 is synthesized by including complimentary meander line-cuts along with a T-slot on the circular patch.

The proposed antenna of type-3 possesses a method to miniaturize the UWB antenna, improve the performance and the formation of a new resonant band at 1.5 GHz which is due to the effect of the insertion of meander line-cuts on the patch. The simulated and measured results are in good agreement.

The geometry of the proposed antenna is shown in Figure 1. It is excited by a 50 ohms microstrip line of width 1.95 mm using line feed technique and fabricated on a 1.6-mm thick FR4 substrate with a $37.5 \times 31.5\,\text{mm}^2$ surface area. The relative permittivity and loss tangent of the substrate is 4.4 and 0.02 respectively.

3.1. Circular Microstrip Patch

The design of the proposed type-3 antenna is shown in Figure 1. The antenna consists of a circular planar structure with a feed line length of 15.08 mm with 7.5 mm as radius of the circular structure. A T-slot is made on the circular patch with a width of 1 mm and the meander-line slot with a thickness of 0.4 mm for each unit cell.

3.2. Ground Plane

The ground plane has a surface area of $15 \times 31.5\,\text{mm}^2$. The ground plane is shown in the Figure 1.

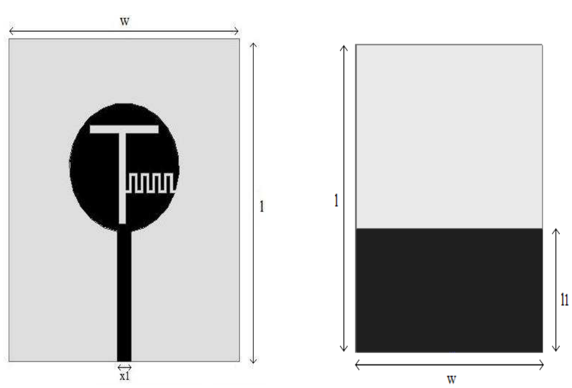


Figure 1: Antenna patch and ground plane (with $w = 31.5\,\text{mm}$, $l = 37.5\,\text{mm}$, $l_1 = 15\,\text{mm}$ and $x_1 = 1.95\,\text{mm}$).

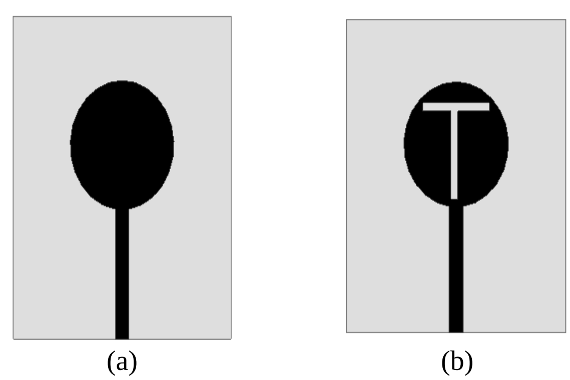


Figure 2: The proposed UWB antennas.

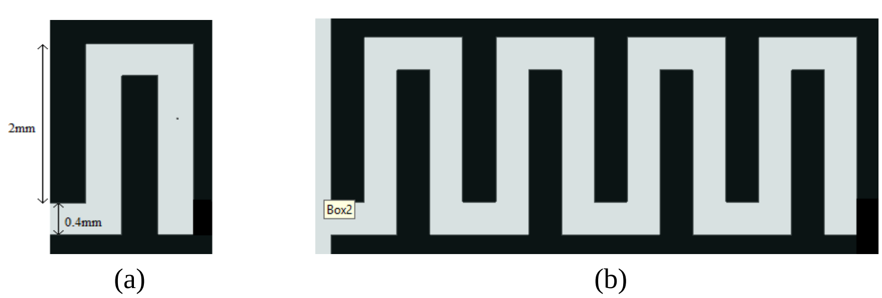


Figure 3: (a) Meander line unit cell. (b) Multiple cells of meander line units.

4. RESULTS AND DISCUSSION

4.1. Planar Circular Patch Antenna (Type-1)

This antenna has a plain circular patch as the radiating element with the size of the antenna being $37.5 \times 31.5\,\text{mm}^2$ and the area of the ground plane is $15 \times 31.5\,\text{mm}^2$. It is shown in Figure 2(a). This antenna has resonances at 4.1 GHz, 6.2 GHz and 10.6 GHz with return losses of -15 dB, -21 dB and -17 dB respectively.

4.2. Planar Circular Patch Antenna with a T-slot (Type-2)

This antenna includes a T-slot which is made on the circular patch which is shown in the Figure 2(b). It yields better return losses than the TYPE-1 antenna by comparison and has an additional resonance at 8 GHz with -12 dB (S_{11}).

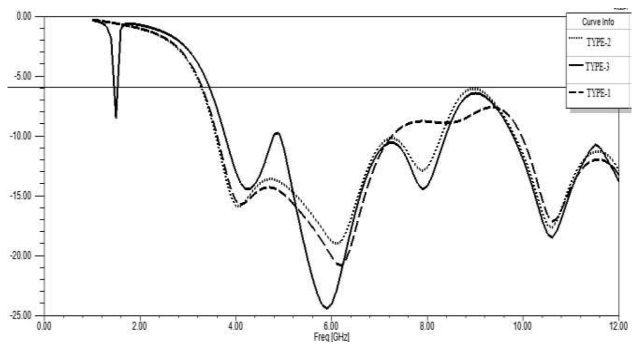
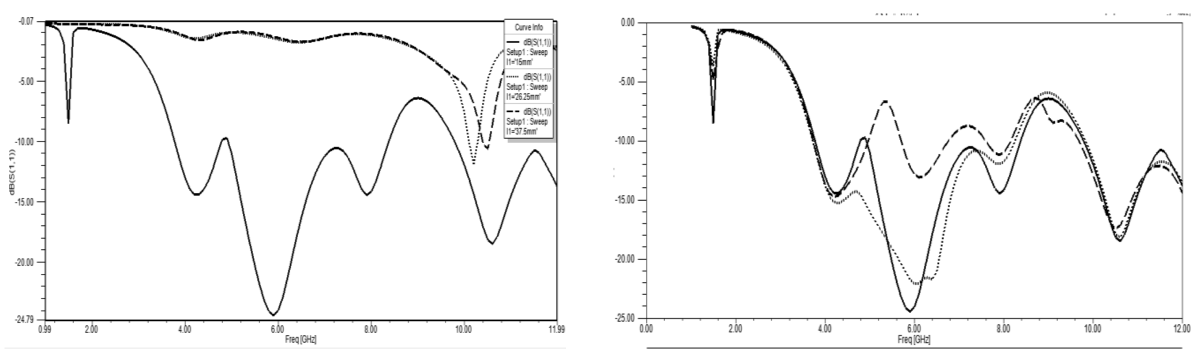
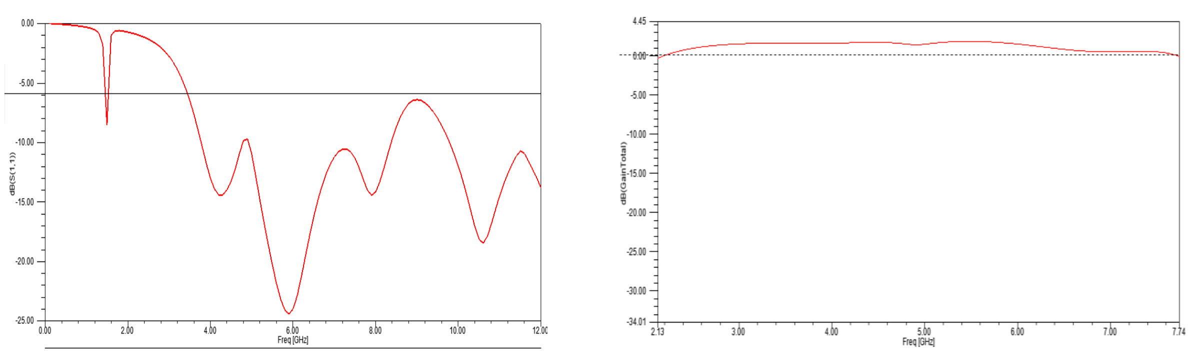


Figure 4: The S_{11} graph for all 3 types of proposed antennas.



(a) (b)

Figure 5: Parametric analysis performed (a) for different lengths on the ground plane and (b) for different positions of meander line along T-slot.



(a) (b)

Figure 6: (a) The S_{11} graph and (b) gain plot for the proposed type-3 antenna.

4.3. Planar Circular Patch Antenna with a T-slot and Meander-line Slots (Type-3)

This antenna incorporates the meander-line slots for type-2 antenna which results in improving the S_{11} parameter along with it, a new band resonating at 1.5 GHz is obtained. This band has a return loss of magnitude −8.5 dB and a bandwidth of 100 MHz at −6 dB [18]. The return losses at 4.2, 5.9, 7.9 and 10.6 GHz is −14.4, −24.4, −14.4 and −18.5 dB. The UWB starts at 3.45 GHz. This antenna is shown in Figure 1.

The S_{11} graphs, parametric analysis and radiation patterns for the proposed antennas are shown in Figures 4–6.

The S_{11} graph for the proposed type-3 antenna was simulated and observed as shown by the

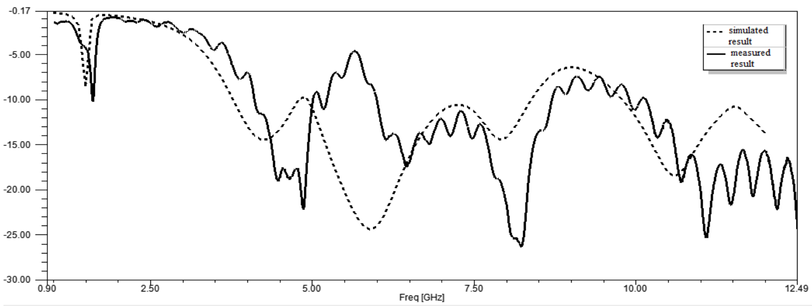
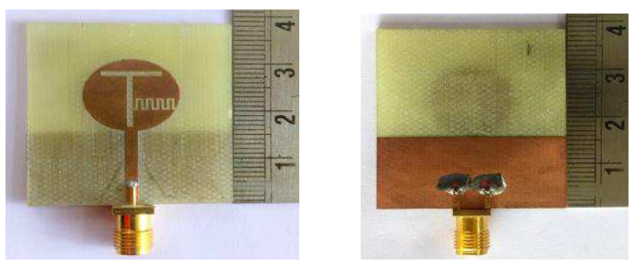


Figure 7: Simulated and measured results.



(a) (b)

Figure 8: The fabricated type-3 antenna. (a) Top view. (b) Bottom view.

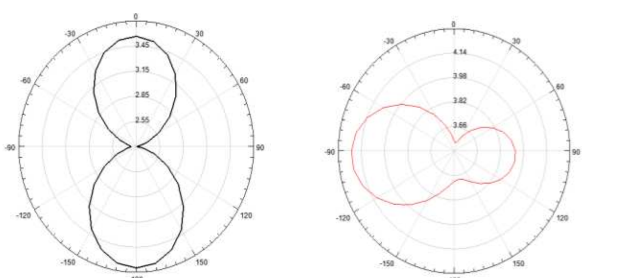


Figure 9: Radiation pattern along E-plane and H-plane at 1.5 GHz (GPS) respectively.

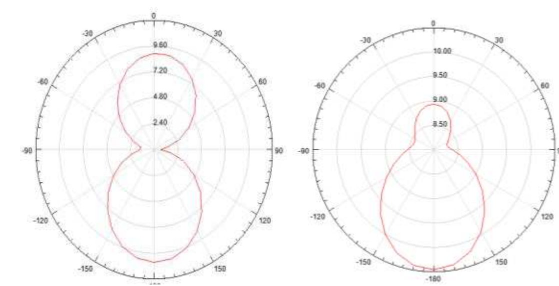


Figure 10: Radiation pattern along E-plane and H-plane at 3.8 GHz (WiMAX) respectively.

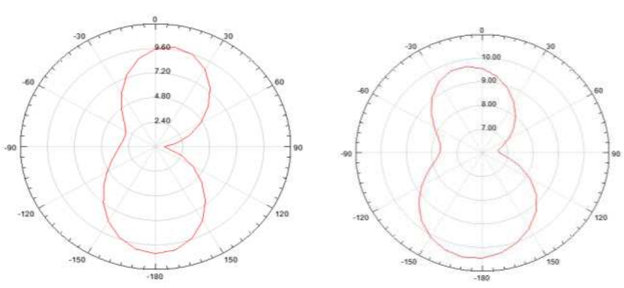


Figure 11: Radiation pattern along E-plane and H-plane at 5.5 GHz (WLAN) respectively.

dashed line. The fabricated antenna has S_{11} as shown by the solid line in the Figure 7.

The fabricated antenna has better S_{11} characteristics at a number of frequencies in comparison to the simulated results. Apart from this, the frequencies of resonance of the fabricated antenna are comparably similar to that of the simulated antenna.

All the radiation patterns shown below are with respect to the proposed TYPE-3 antenna. The graphs in the following section shows that the radiation pattern at specific frequencies which are commonly utilized, having a fairly omni-directional pattern which is useful in most of the wireless communication devices. Besides, these radiation patterns exhibit a wide beam width.

5. CONCLUSION

This paper presents an antenna design that includes a circular planar monopole microstrip antenna incorporating a metamaterial inspired T-slot structure and Complimentary Meander-Line (CML) unit cells. The T-slot is used to improve the bandwidth, reduce size, and increase the gain of the antenna. The experimental results demonstrated that CML can be a viable alternative to the existing techniques in creating a narrowband resonator at lower frequencies in UWB antennas. The measured data agrees well with the simulated results successfully demonstrating that the CML in the design can be incorporated to an UWB antenna system to provide extra functionality without compromising the antenna's performance and also helps in miniaturizing the system.

The proposed antenna achieves a return loss of over -10 dB having a bandwidth of $> 100\%$ (i.e., 3.45 GHz onwards). It has a uniform gain in the S and C bands and the proposed type-3 antenna can be a used for GPS (1.5 GHz), WiMAX (3.45–3.8 GHz), WLAN (4.9–5.8 GHz) and other UWB (3.45–10.6 GHz) applications.

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