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# Design and Realization of 3D Printed Non-Planar Microstrip Patch Antenna

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***Abstract—*** *In this work, it is aimed to design a low cost, high gain non-planar microstrip patch antenna by using 3D printing technology has been studied. For this mean, firstly a 3D electromagnetic based model of the proposed non-planar microstrip antenna has been modelled in CST Microwave Studio® Environment. The simulation results of the model achieves a gain level of 6 dB with a S11 level of less than -10 dB at 2.4 GHz. Then for justification of the simulation model, the antenna design is prototyped using 3D printing technology. From the experimental results it can be said that the measured characteristics are in line with the simulated results. Thus, with the recent development in the 3D printing technology, it is possible to design and realize non-planar microstrip antennas with very low cost and fast prototyping procces with high performance characteristics to operate at commonly used operation frequencies such as ISM band.*
***Keywords—****3D printing; microstrip antenna; non-planar antenna.*

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## I. Introduction

Microstrip, also known as patch antennas [1][2] are probably the most widely used class of antennas today. They are important in many commercial applications, such as mobile radio, and wireless communications. Microstrip antennas have many advantages such as light weight, easy adaptation to the surface they are applied, ease of production and low cost. These antennas are low-profile and comformable to planar and nonplanar surfaces ranging from aircraft and rocket shapes to human bodies. In addition, the constraints such as narrow bandwidth, low gain and low power capacity decrease the antenna performance and restrict usage areas. Nowadays, many studies are being carried out to reduce these constraints.

A microstrip antenna is characterized by its length, width, input impedance, gain and radiation patterns. The microstrip antenna consists of conducting patch on a ground plane separated by dielectric substrate. With the technological developments in design and analysis, many researchers have developed various methods of mathematical analysis and performed the design and analysis of microstrip antennas with different shapes. As a result of these studies, many microstrip antennas have been developed in different geometries for needs in various fields.

The radiating conductive patch may have different geometries, such as rectangles, triangles, circles, but rectangular and circular configurations are most commonly used, and these antennas are usually named according to patch geometries. The radiating patch and feed line are conductive and are usually placed on the dielectric substrate. The patch is fed with various feeding methods such as microstrip feed line, coaxial feed line, aperture-coupled feed, and proximity-coupled feed.

Microwave Antennas can be manufactured by various methods. One of these methods is three-dimensional (3D) printers [3-7]. Recently 3D printing technology had been applied for manufacturing of Non-Uniform Reflectarrays [3], Multilayered Cylindrical Dielectric Lens Antenna [4], Quasi Yagi Antenna for indoor application [5], realization of Spherical Dipole Antenna [6], or prototyping of Horn Antennas for X band applications [7]. 3D printers are devices that allow 3D output as an alternative to densely used 2D printers. Although they are similar to laser or inkjet 2D printers as operating logic, production in 3D printers is an additive process and this process is also called 'layered production' [8][9].

Herein, it is aimed to design and realize a high gain non-planar microstrip patch antenna by using 3D printing technology. In the next section of the work, firstly design procedure of the traditionally patch antenna has been presented alongside of the theoretical aspects of the microstrip antenna. In section III, the 3D printer technology and its advantages manufacturing capabilities are given. Section IV, presents the design procedure of the proposed non-planar microstrip patch antenna alongside of its simulated performance results. Section V, presents the experimental results of the 3D printed prototyped non-planar microstrip patch antenna. Finally the work ends with a conclusion section.

## II. Microstrip Antenna And Design Parameters

Generally, the microstrip patch antenna consists of three layers, the radiating layer in which the patch is located, the dielectric substrate in the middle and the underlying ground plane. The structure of a standard microstrip antenna is shown in Figure 1.

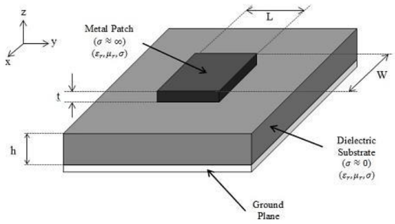



**Figure 1** Structure of a microstrip patch antenna

The underlying ground plane is conductive and allows the microstrip antenna to perform one-way radiation. The middle layer (substrate) is generally non-magnetic ($\mu_r = 1$), the selected material is dielectric and the relative dielectric constant is selected to be less than 2.5 ($\varepsilon_r < 2.5$). The thickness of the dielectric substrate varies between 0.05 mm and 6.35 mm [1].The thickness and relative dielectric constant of substrate directly affect antenna parameters such as radiation values and bandwidth. To improve antenna performance, a thick dielectric layer with a low relative dielectric constant should be selected [12].The layer on which the patch is located is made of metal like gold, silver or copper. The thickness of the patch varies between 0.035 mm and 0.070 mm [1].

The microstrip antenna is characterized by the length (L), width (W) of the patch and the thickness (h) of the dielectric substrate [1]. Dielectric permittivity of the gap is $\varepsilon_0 = 8{,}85 \times 10^{-12}$ F/m and magnetic permeability of the gap is $\mu_0 = 4\pi \times 10^{-7}$ H/m, the velocity of the electromagnetic wave in the gap is $c = 3 \times 10^8$ m/s. The thickness of the dielectric substrate and its relative dielectric constant ($\varepsilon_r$) directly affect antenna parameters such as radiation values and bandwidth. The patch width of the microstrip antenna with the operating frequency$f_0$is calculated by Equation (1).

$$W = \frac{c}{2f_0}\sqrt{\frac{2}{\varepsilon_r + 1}} \quad (1)$$

Due to the fringing effect, the physical dimensions of the microstrip patch antenna appear longer ($L_{eff}$) and wider ($W_{eff}$). The relative dielectric constant multiplies the fringing areas ($\Delta L$ve $\Delta W$) and this is one of the factors affecting the radiation. The effective dimensions of the patch due to the fringing areas are different from their physical dimensions and these difference values are given in Equation (2).

$$\Delta L = 0.412 \times h\frac{(\varepsilon_{reff} + 0.3)\left(\frac{W}{h} + 0.264\right)}{(\varepsilon_{reff} - 0.258)\left(\frac{W}{h} + 0.8\right)} \quad (2)$$

$$\Delta W = 0.44 \times h$$

$\varepsilon_{reff}$, is the effective relative dielectric constant and is calculated as seen in Equation (3).

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{W}\right]^{-\frac{1}{2}} \quad (3)$$

When $L_{eff} = \frac{c}{2f_0\sqrt{\varepsilon_r}}$,the physical dimensions of the patch are found by Equation (4):

$$L_{eff} = L + 2\Delta L$$
$$W_{eff} = W + 2\Delta W \quad (4)$$

## III. 3D Printing Technologies Applications, Advantages And Disadvantages

Technological studies are shaped in line with people's needs and many technological innovations take place in people's lives. 3D modeling and 3D printing technology are among the innovations that take place in people's lives. The development of 3D printers in the control of individual users has enabled different solutions to be produced for different purposes, thus revealing the different types of production for the solution and the types of raw materials intended for use.

Prototype and mold creation, topographic solid modeling, medical and dental applications, spare parts production are among the main uses of 3D printers. Printing technology and required raw materials are determined according to usage purpose. The limitations of 3D printer technology should also be considered at this stage. Low diversity in terms of raw material, color and surface properties, low durability in terms of temperature, humidity and brittleness, increase in cost as product size grows, lower sensitivity than other production techniques are the limitations of 3D printing technology [9].

The efficiency of investment and production, transferable and shareable design consisting of digital data, making changes and corrections quickly and easily, enabling personalized production, calculating the product price before production, using transformable, environmentally friendly raw materials are the advantages of this technology [9].

Almost all mechanical parts, except electronic parts and motors, can be printed by a 3D printer. Three-dimensional models are designed by CAD (Computer Aided Design) programs such as AutoCAD®, SolidWorks®, Google Sketchup®, Rhino3D®. The designed three-dimensional models are exported in STL file format and printed via 3D printer. The STL file also contains information about all movements that the 3D printer should perform during printing. Material used in production is of great importance in this technology. The raw material loaded as filament into the printer varies according to the intended use and the product to be obtained [11]. However, the choice of 3D printer and printing technique suitable for the raw material is also important. Nowadays, 3D printing techniques such as FDM (Fused Deposition Modeling), PolyJet (Multi-Jet), SLS & SLM (Selective Laser Sintering and Melting), SLA (Stereo Lithography Apparatus), SGC (Solid Ground Curing), LOM (Laminated Object Manufacturing) , EBM (Electron Beam Melting), Binder Jet are used [8][9].

## IV. Design And Fabrication

In Fig. 2 the 3D view of the proposed non-planar microstrip patch antenna has been given alongside of its design parameters. The optimal design parameter values given in Fig. 2 are obtained via the theoretical equations in section II alongside of local optimization algorithms in CST Microwave Studio®.

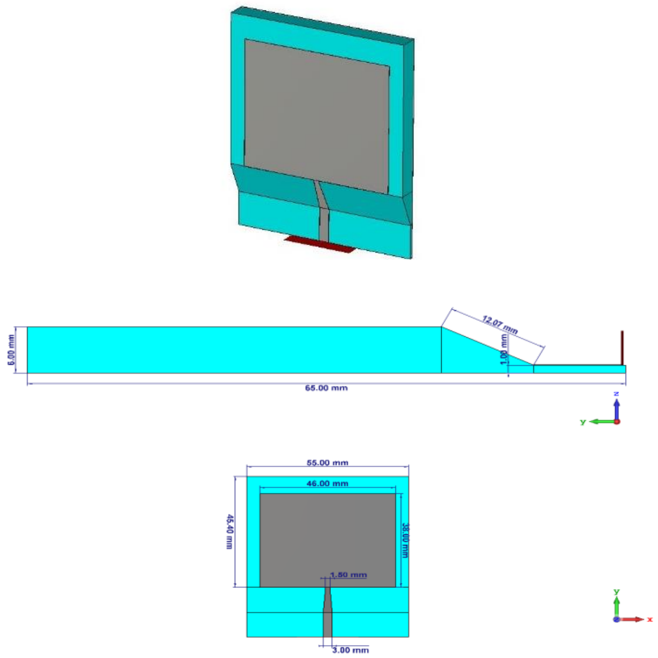



**Figure 2** Non-planar microstrip antenna

The simulated far-field and return loss charateristics of the antenna are given in Figs. 3-4. As it can be seen form the simulated results the proposed antenna achives a high gain (7dB) alongside of good return loss characteristics. In the next section,

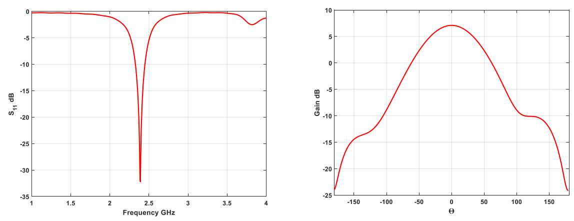



**Figure 3** Simulated (a) $S_{11}$, (b) Far-Field Gain characteristic at 2.4 GHz of the proposed non-planar microstrip patch antenna.

## V. Experimental Results

For prototyping of the non-planar antenna using 3D printer the model should be exported in '.STL' file format in order to create a G-code to be used by the 3D printer [13] (Fig. 5). The material used for 3D printer is PLA 'Polar White' [14] with a dielectric constant of 2.4 and the layer height of 0.1 mm had been used to prototyped the antenna given in Fig. 5.

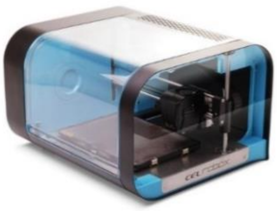


**Figure 4** CEL Robox® Desktop 3D printer and micro-manufacturing platform [13].

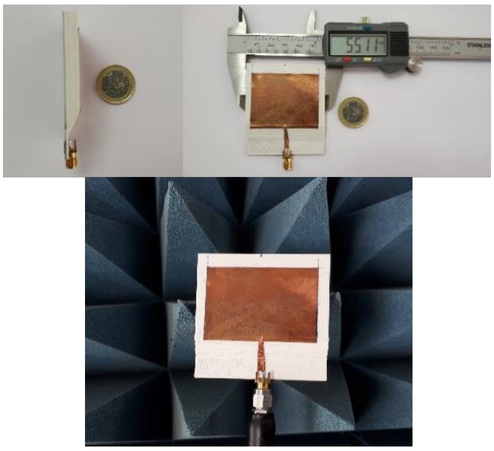
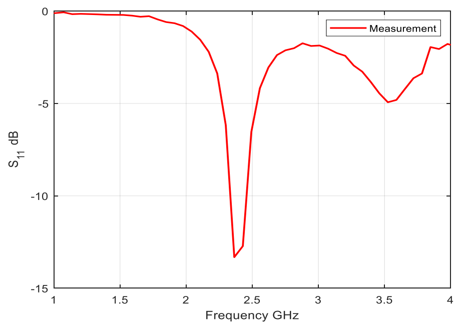
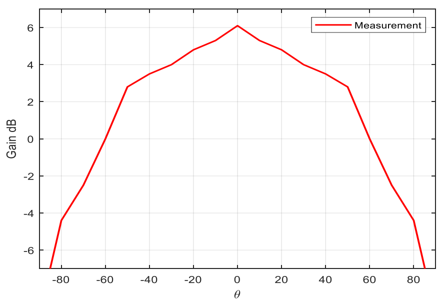


**Figure 5** 3D printed non-planar microstrip antenna

The measured $S_{11}$ and gain characteristics of the antenna are given in Fig. 6. As it can be ssen the performance results of the 3D prototyped antenna are hand to hand with the simulated results.




**(a)**




**(b)**

**Figure 6** Measured (a) $S_{11}$, (b) Far-Field Gain, of the 3D printed non-planar microstrip antenna

## VI. Conclusion

Herein, design and realization of a non-planar microstrip patch antenna had been achived via the use of a fast, accurate and low cost prototyping method 3D printer. For this mean, firstly a 3D electromagnetic based model of the proposed non-planar microstrip antenna has been modelled in CST Microwave Studio® environment. The simulation results of the 3D electromagnetic based model achives a gain level of 7 dB with a $S_{11}$ level of less than -10 dB at 2.4 GHz, where the experimental results of the 3D printed non-planar antenna were 6 dB and a $S_{11}$ less than -10 dB. From the experimental results it can be said that the measured characteristics are in line with the simulated results. Thus, it can be said that 3D printing technology is a fast, accurate and low cost prototyping method for design and realize non-planar microstrip antennas or similar antenna design that can not be prototyped with traditionally prototyping methods.

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