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Optimizing Microstrip Patch Antenna Design for Robotics Applications

Mahmoud Shakir Wahhab

Electronics and Control Engineering Department, Technical Engineering College – Kirkuk, Northern Technical University, Iraq

ABSTRACT: Simple design and manufacture have made microstrip patch antennas the possible preference in robotics. These antennas possess very narrow bandwidth and are low profile with very little conformality, thus being suitable for diverse applications in robotics. This presentation shows a numeric study on the newly designed rectangular microstrip patch antenna investigated by finite element method using COMSOL software. The main feed point for the antenna is within a small rectangle on the patch, and analyses on far field radiation, electric field, and impedance were performed. The impedance was set as 50 for the antenna, and the selected frequency range was 1.3-1.7 GHz. The research was very useful for scientific researchers in robotics because it provides the potential use and performance of microstrip patch antennas for different robotic applications. This numerical analysis of this microstrip patch will be of great advantage in antenna design and implementations in robotics. The simple design, low cost, narrow bandwidth, and favorable behavioral understanding it adds towards using this type of antenna would results to many robotics applications-qualified research in robotic context.

KEYWORDS: Robotics, Patch antenna, COMSOL, FEA

1. INTRODUCTION

Due to high demand for miniaturized and light weight communication systems, microstrip patch antennas have become highly significant as an essential component in numerous applications, particularly in the field of robotics. Due to low cost, ease of installation, and tiny size, the antennas have come into prominence during modern times in the application within communication systems [1-4]. Microstrip patch antennas also have the unique property of producing a specified conductive pattern in the surrounding immediate medium and thus are extensively used in satellite communication technology like mobile phones [5]. Their two-dimensional nature distinguishes them from any and every other type of antenna, and their gain characteristics are also superior to the traditional dual-pole or unipolar antennas [6,7]. Microstrip patch antennas are applied in extensive communication systems like satellite communication systems in mobiles. Microstrip patch antennas are of easy design, low profile, and low expense and thus are preferred for most applications. The four main components of the antenna are the substrates, the grounding, the patch, and the feeding. The performance of microstrip antennas is superior to that of traditional antennas because they are thinner and more highly-gain.

Microstrip patch antenna operation depends on four fundamental components: substrates, grounding, patch, and feeding [8]. During the design and fabrication process, the conductive patch is isolated from the ground panel by substrate insulation. During the installation process, a microstrip antenna should possess low-capacity structure. Depending on the intended application, for instance, gain, bandwidth, or efficiency, various shapes of the patch can be obtained [9]. These shapes are determined by the parameters of the patch antenna, which should operate in the frequency of 1 to 7 gigahertz.

A number of researchers and research teams have attempted to model the development of microstrip structures for patch antennas using a wide variety of techniques, including finite element analysis (FEA), momentum method (MoM) in time domain, finite difference technique (FDTD), and transmission line matrix (TLM) [10]. In an attempt to improve the performance of such antennas, researchers have also made attempts to modify the traditional designs in an attempt to improve the bandwidth of the antennas [15,16]. To improve the performance of microstrip patch antennas, researchers have made several modifications to their design, including changing their dimensions and adding modifications to improve the bandwidth [7-10]. The construction and design of a microstrip patch antenna involve creating an isolated conductive patch from the ground panel by substrate insulation [11]. The antenna requires a low-capacity structure during the installation process. The patch shape is derived from the parameters of the patch antenna, including gain, bandwidth, and efficiency [12].

In this project, one potential design of a new microstrip patch antenna was simulated using simulation software and also analyzed by the same software. The selected patch antenna was then numerically analyzed using the widely used finite element software package, COMSOL. This was carried out by first suggesting some measurements for the antenna and then trying out various constants to modify the dimensions and transmittance of the antenna to arrive at the optimum measurements and best transmittance that would lead to a wider bandwidth.

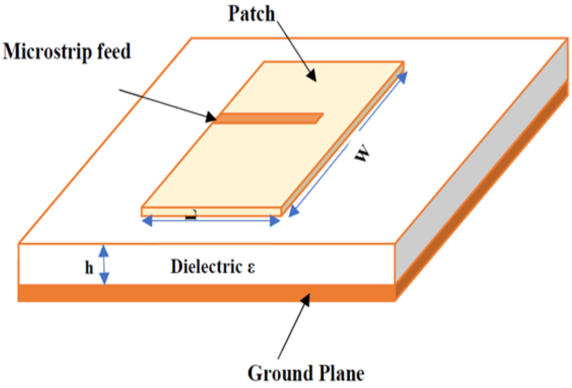


Fig 1: The proposed model of Patch Antenna [23]

2. NUMERICAL MODELING

The approach of designing an economical system of differential and integral equations by the use of numerical modeling is a mathematical method that is stable and reliable. A single field can be considered as being a large or small number of straightforward and uniform geometrical shapes known as entities or finite elements, which are responsible for producing approximation procedures [17]. The problem can be solved in two dimensions by the assistance of quadrangles and triangles of the finite element method (FEM), and in three dimensions by the assistance of tetrahedral or prismatic elements of the finite element method (FEM) [18]. The FEM model provides great solutions at times which can be described as being fast with a set of highly accurate solutions [19]. This is done by solving many differential equations through the application of multi-definition approximation. Through the functions of the 1st order nodal basis as well as the basis of its terminating elements, the precision can be enhanced and enhanced [20]. The time vectors waveforms equation is utilized in an effort to complete the 3D modeling of the antenna. Here, as antennas deal with electromagnetic fields, the Maxwell govern equation [21] must be used to derive the vector form equations, which are then given in the following way.

$$\nabla \times \mu_r(\nabla \times \mathbf{E}) - k_0^2\left(\epsilon_r - \frac{j\sigma}{\omega\epsilon_0}\right)\boldsymbol{E} = 0$$

Noted that:

E is the electrical field, $\boldsymbol{\sigma}$ is the electrical conductivity, k_0 is the wave-number relative permittivity of the system can be noted as $\boldsymbol{\epsilon_r}$, Also, B is noted as the constitutive relation, where:

$$\boldsymbol{B} = \mu_o\mu_r\boldsymbol{H}$$

At the end, we should introduce μ_r as the relative permeability,

We have to first consider the inherent dimensions of the patch's substrate. This is necessary so that the substrate's height (h) will be negligible with respect to the wavelengths trapped within the dielectric region. Thus, the variation of the electric field across the substrate's height (h) of the patch is considered to be negligible. This is because the thickness of the platform is assumed to be extremely small and therefore the variation in electric field is considered constant. Since the electric field at the patch face is normal, the location of magnetization (TM) is introduced. There, the electric field at ground surface base will return to its original status because of this. What is important to observe in this case is that both the top and bottom walls of the patch walls are fully conductive to electricity. Thus, the four edges of the patch would be electronically and magnetically perfect conductors.

3. THE MODEL SIMULATION

Physics of frequency field and electromagnetic waves (EMW) has been employed to design and model the structure of the antenna. The suggested design of the antenna has been modeled and simulated by employing the COMSOL software. The design schematic can be seen in Figure 2. For the purpose of guaranteeing the efficiency of the proposed antenna in air and also in environmental applications, it was positioned inside a spherical field with a diameter dimension of 300mm and depth dimension of 30mm. Air was utilized as the material of choice to fill the spherical cavity.

Table 1 lists the material dimensions considered for application in the design of the antenna. Antennas typically function in the frequency band of 1.4 to 1.67 gigahertz, and the antenna discussed in this research fits into this band. The scientists tend to have the broadest possible breadth of the separating zones, symbolized by W, in order to have the least possible coupling between the small tape and the antenna and ensure that such coupling will not significantly alter the antenna characteristics.

The length, which is symbolized as L, is decreased in an attempt to reduce the reflected force, which is symbolized as S11. The importance of controlling the S11 parameter is that it shows the amount of reflected energy back towards the source and thus determines the performance of the antenna. In most instances, the smaller the value of S11, the better the performance of the antenna in transmitting the electromagnetic signals.

Apart from the W and L parameters, the substrate thickness, metal layer width, and metal layer height also have significant roles to play in determining the performance of the antenna. These parameters must be carefully selected and optimized to achieve the desired outcome. The choice of material for the substrate, metal layer, and other components is also important and affects the efficiency of the antenna. The material's properties such as permittivity, conductivity, and permeability need to be considered during the choice of materials for the antenna.

In short, the design and modeling process of the proposed antenna has been conducted based on the physics of electromagnetic waves (EMW) and frequency field analysis. The design was simulated and constructed based on the COMSOL software, and factors such as the W and L parameters, substrate thickness, metal layer width, and metal layer height were considered and optimized to achieve the desired performance results. The choice of material was equally important and was considered during design.

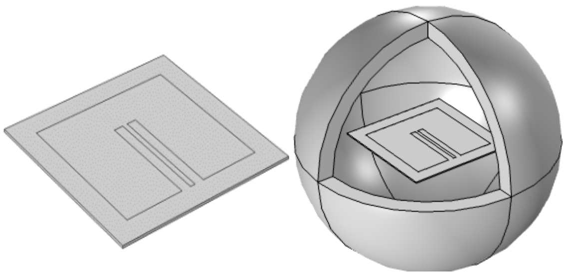


Fig. 2: The spherical field of the proposed antenna model.

Table 1: Dimensions of the reported patch antenna	
Thickness of the Substrate	0.1524 mm
50-ohm linewidth	3.2 mm
The width of the Patch	53 mm
The length of the Patch	52 mm
The width of the Tuning stub	8.4 mm
The length of the Tuning stub	48 mm
The width of the Substrate	100 mm
The length of the Substrate	100 mm
The Dielectric coefficient	3.39

4. RESULTS AND DISCUSSIONS

Model Mesh

1. Figure 2 depicts the mesh type used to mesh the sphere space with the patch antenna elements. To mesh the entire area, we employed a tetrahedral mesh generation form, which is presented in the figure. Experts or interested in numerical methods or FEA are advised to reduce the size of the meshing to a higher meaningful level so that field gradients are much steeper, i.e., ports and patch, in an effort to enhance or enhance the accuracy of the results from of the models. This can be used to improve or augment the accuracy of the outcome from the models. Meshing the sphere space with the patch antenna elements is necessary to guarantee the accuracy of the numerical methods and finite element analysis (FEA) used in their simulation. Figure 2 shows the type of mesh utilized for this, which utilizes a tetrahedral mesh generation form. It is imperative that the users or the interested in numerical methods or FEA pay very keen attention to reduce the sizes of the meshing to a more meaningful extent, particularly in locations where there exist steeper field gradients like the ports and patch.

This advancement of the meshing method can be very useful to increase accuracy of results obtained through the models. In context of patch antenna simulation, meshing is really essential to decide results' precision. The tighter meshing, the better accuracy results, and therefore reducing the meshing dimensions in areas where steep field gradients occur is critically vital. In the case of Figure 3, the use of a tetrahedral mesh generation shape is capable of generating a more refined mesh that captures the intricate details of the patch antenna and its interface to the surrounding space. It should also be observed that this fineness of the meshing process will have to be accomplished with care and detail. A poor meshing process can result in a reduction of accuracy rather than an increase. It is therefore important that experienced professionals or those who have experience with numerical methods or FEA carry out this step in the simulation process. the mesh style used to mesh the sphere space and patch antenna elements is an important component of patch antenna simulation. The application of a tetrahedral mesh generation shape with a reduction in mesh size in regions where the field gradients are sharper, as demonstrated in Figure 2, can be highly effective in enhancing the accuracy of results obtained from the models. The accuracy is essential in ensuring the success of various communications applications of patch antennas based on robotics.

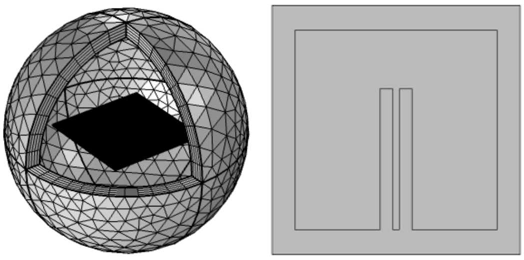


Fig. 3: The FE model and the meshing of the proposed antenna model

Return Loss

2. Having now done prototype and designing of the patch antenna as depicted above based on the measured values in Table 1, it actually now is time to determine the correct frequency for the antenna so that the return loss could be estimated using it. This can be done by the determination of that frequency at which the antenna provides the minimum return loss.

We have carried out research with a view to seeking this frequency via an extensive search on the frequencies via which you can obtain the desired frequency. We used a frequency range that ranges from 1.3 gigahertz to 1.7 gigahertz incrementing by steps of 500 kilohertz (range (1.3 GHz, 500 kHz, 1.7 GHz)). Therefore, the range that was selected is quite reasonable compared to other research that has been conducted in a similar way to the study in question. Concerning the extension (500 kHz), it is acceptable because it will give a wide range, and consequently, we will learn the required frequency which we'll use in the future studies involving sweeps. Figure 4 shows that the antenna response is at 1.607 GHz with -16.3 dB return loss measured. The fact that this figure is negative means that the antenna did not suffer considerable losses during signal transmission as can be seen from the fact that the ratio is negative

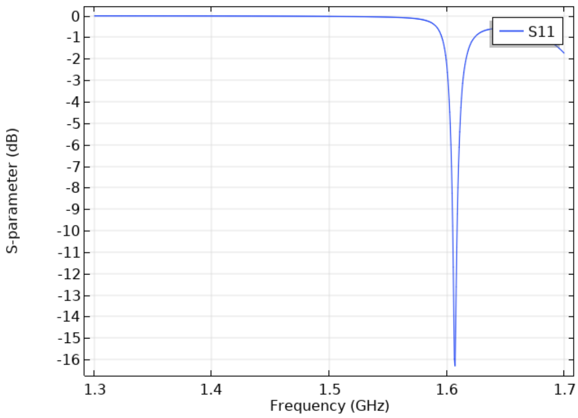


Figure 4: Return losses VS frequency for patch antenna.

Sweep Study

We used this frequency to conduct sweep studies, with some efforts to alter some of the characteristics of the materials of the antenna, as well as altering dimensions and investigating the cases of transmission of the antenna. Once we identified the appropriate frequency through which the loss of transmission can be as little as possible in contrast to other frequencies, we proceeded to employ the frequency in conducting these investigations. At this stage, we adjusted the relative permittivity, symbolized by Er, of the substrate.

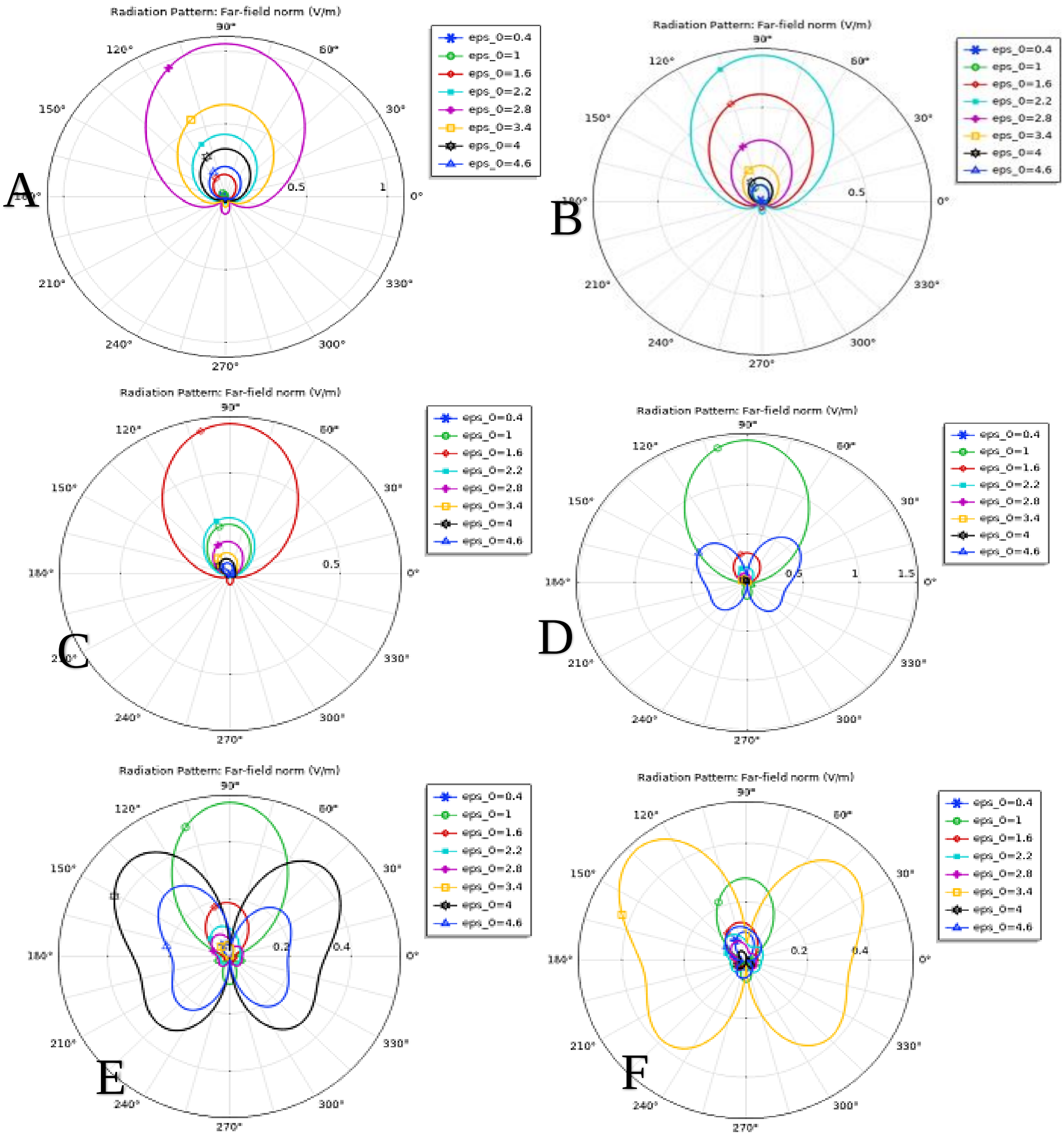
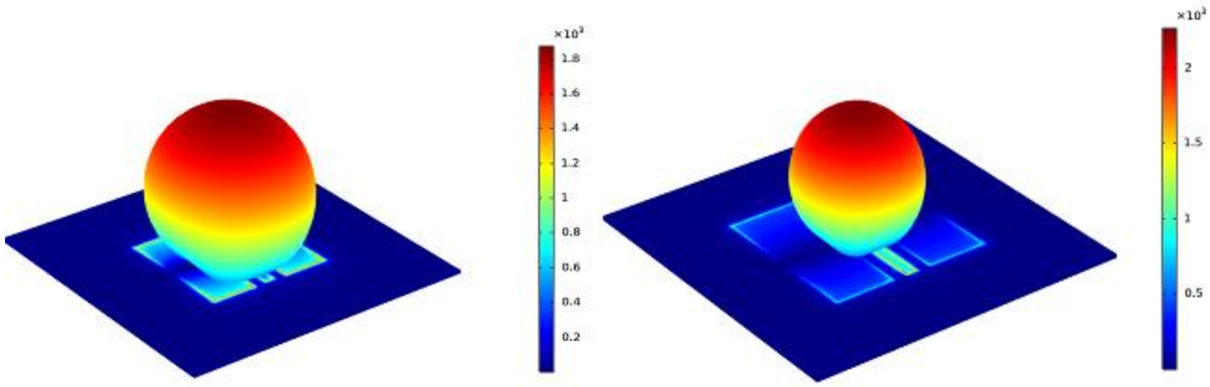


Figure 5: The radiation pattern when the relative permittivity is varied as shown in the legend where: A) The patch is measured as (53*52)*1 ; B) The patch is measured as (53*52)*1.2 ;C) The patch is measured as (53*52)*1.4 ; D) The patch is measured as (53*52)*1.6 ; E) The patch is measured as (53*52)*1.8 ; F) The patch is measured as (53*52)*2



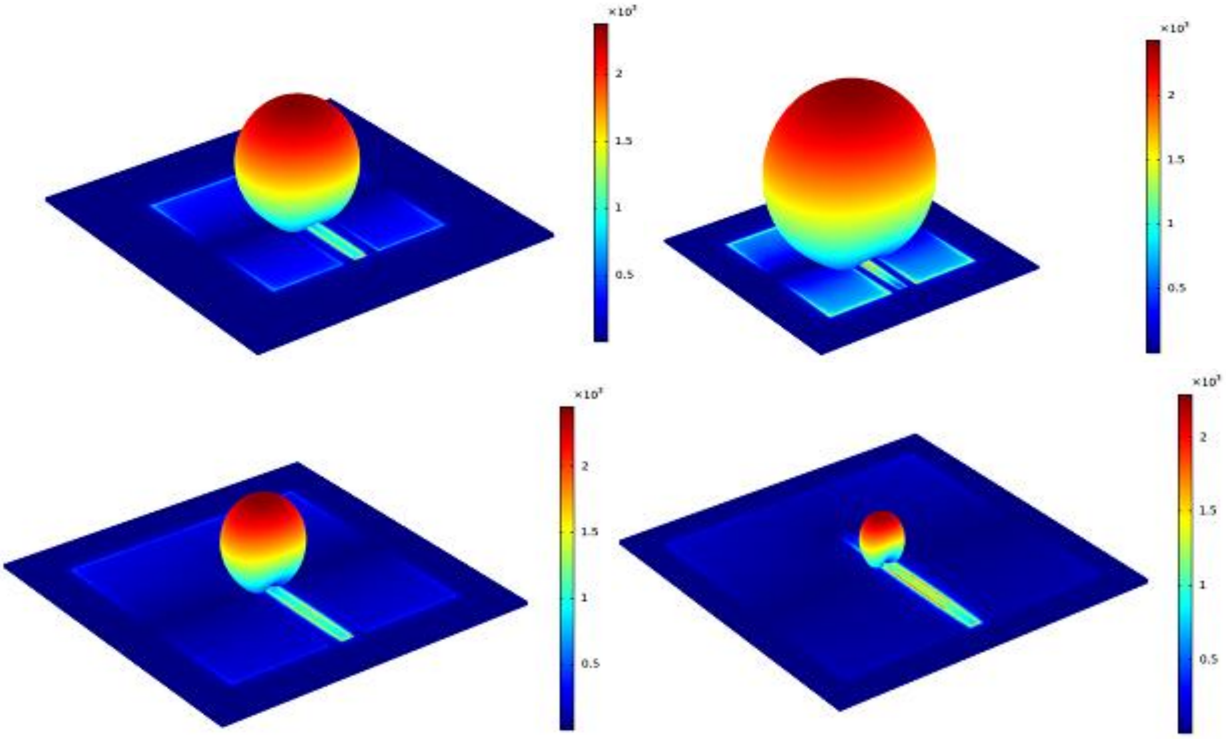


Figure 6: The radiation pattern norm and the electric field distribution where: A) The patch is measured as (53*52)*1 , the relative permittivity is 2.8; B) The patch is measured as (53*52)*1.2 , the relative permittivity is 2.2; C) The patch is measured as (53*52)*1.4 , the relative permittivity is 1.6 ; D) The patch is measured as (53*52)*1.6 , the relative permittivity is 1; E) The patch is measured as (53*52)*1.8 , the relative permittivity is 1; F) The patch is measured as (53*52)*2 , the relative permittivity is 1.

Figure 6 depicts the propagation of the electric field over the antenna model when relative permittivity is chosen as the most uniform distribution. The radiation and electric field as depicted in the figure is varied according to the size of the patch as well as the relative permittivity.

The variations were in an acceptable range, i.e., range (0.4,0.4,5). This will further provide us with an idea of the behavior of the antenna when the frequency is fixed and one of the parameters of the material the antenna is made of is varied. Further, we will be able to determine the different kinds of applications for which this antenna can be used. In addition, we modified the width and length of the patch antenna. The patch width is now (W =52 mm), while the patch length was originally set at (L = 53 mm). After we adjusted these, we modified the surface W*L by aa (W*L) *aa. In this example, we adjusted the value of the aa parameter to 2 from 1.

If one looks at figure 5, then one can see that the transmission distribution or the propagation is irregular, and this is because the selected constants Er (0.4 - 1) are not within the antenna field. In other words, the constant or the set of constants chosen are not qualified to deal with this kind of antenna, or that the dimensions that have been designed are not precise enough. The choice made for it and the frequency chosen do not match the constants that are displayed in the figure. But the other subplot, which carries the other occurrences of Er, now has a constant distribution of power with the highest value at the point where its value is 2.8, 2.2, 1.6, and 1 as in figure 5, although its length and breadth vary between 1 to 2 with a change of 0.2. The return losses are graphed against the relative permittivity in Figure 6, with a higher return loss indicating that the far-field norm and electric field propagation are at their highest values.

From Figure 6, we provided a three-dimensional plot for a few examples in which the relative permittivity is varying with no variation of frequency and dimension. The three-dimensional chart of the different scenarios with a changing permittivity is shown in Figure 6. The change in propagation pattern can be noticed, not only in terms of intensity but also in terms of its shape, as shown in the figure. This means that the magnitude of the power in the far-field is a function of the value of relative permittivity that was utilized when the frequency was kept constant. It is also clear that the strongest and most ordered signal can be terminated to achieve at the relative permittivity is higher when the patch size is smaller. This means that the signal can be calculated to be most abnormal when the relative permittivity is 1 or less.

V. CONCLUSION

COMSOL Multiphysics software was used in modeling and design of a Microstrip patch antenna. COMSOL Multiphysics is among the widely used finite element software employed. Simulation was conducted to obtain behavior of the microstrip patch antenna like its far-field radiation, polarity patterns, and input losses. To complete the results, two sweep studies with a good set of values each were executed. The goal of the first sweep study was to determine at what frequency the patch antenna had the lowest return loss. That frequency, 1.607 GHz, was determined by the study, and the return loss at that frequency was -16 dB. The second study was trying to determine the optimum relative permittivity, and this was found to be greater when the patch size was reduced until the width of the patch was equal to its length. More far-field norm can be obtained using the patch antenna reported, and the antenna had a great performance using the values that were obtained. In subsequent work, we are going to run additional simulation cases in order to investigate the finer facets of this microstrip antenna.

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