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DESIGN AND ANALYSIS OF HIGH-FREQUENCY SQUARE MICROSTRIP PATCH ANTENNA SYSTEM

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ABSTRACT

Microstrip patch antennas are one of the biggest electronics markets being used in several industries and are responsible for many communication networks and systems. This project proposed to create a program using MATLAB to simulate a function that is similar to a high-frequency Microstrip Patch. The produced program was made from MATLAB with the aid of the antenna toolbox. Within this toolbox were custom antennas which means it was possible to create unique antenna geometry and meshes along with being able to determine the impedance needed. Antenna Toolbox and PDE Modeler is a function MATLAB contains commands for viewing the parameters when designing and analyzing MAPs.

Keywords: MATLAB, microstrip antenna, square patch microstrip antenna, rectangular patch microstrip antenna, antenna design, antenna analysis.

1. INTRODUCTION

Over the last four decades, microstrip patch antennas are a class of planar antennas that have been explored and nurtured with full comprehension. They are among the favorites of multiple antenna makers and have been applied in the field of wireless communication systems in many designs and models, bordering the military to commercial sectors [1]. Since they can be reproduced instantly on a circuit board, microstrip or patch antennas have become increasingly useful. Within the cell phone market, microstrip antennas are becoming very popular. Patch antennas have a low cost, low profile, and are easy to produce.

A relatively recent innovation is the Microstrip antenna. It was developed to enable an antenna as well as other operating circuitry of a communication device to be conveniently integrated on a typical printed circuit board or a semiconductor chip. In addition to other resulting advantages, the integrated-circuit technology for antenna manufacturing allowed high dimensional precision, which was otherwise difficult to achieve in conventional manufacturing methods. The structure of a microstrip antenna consists of a dielectric substratum of some thickness having on one of its surfaces a total metallization and the other side a metal patch [2].

There are stripline holes, printed-circuit-board dipoles, and microstrip patches in the antennas. A stripline slot consists of a simple rectangle cut throughout the top stripline ground plane, also with another cut under the same region by inserting the right-center conductor. A linear resonant array of highly correlated openings connects and feeds on by a single center conductor, where the position of this conductor is at the required angle under each slot [3].

Usually, producing dipoles set for low-cost manufacturing, either as a group of dipoles on a single dielectric substratum, with each dipole fed by a balun that is natural to the face of the dipole array, or on a separate dielectric substratum with each dipole and balun [4]. A stack of such sheets contains the series. The boxed stripline is to minimize higher modes.

2. STATEMENT OF THE PROBLEM

Microstrip patch antenna's main disadvantage is the low bandwidth that affects wireless communication applications. By using the transmission line model, the height of the substratum affects the bandwidth of microstrip antennas. When the former increases, the bandwidth does as well. At the same time, this essential parameter often increases the surface waves that pass across the substratum from end to end and scatter at the curves of the radiating area, separating the energy from the signal, making the antenna perform worse. To avoid this issue, the formulation of numerous strategies has arisen. This includes the technique of air gap, in which surface waves are not generated. Further, patch length plays a role in antenna bandwidth. Antennas with the minimum size possible are considered to be accurate.

3. BACKGROUND OF THE STUDIES

The microstrip antenna is an instrument that converts electrical power into the electromagnetic wave, and vice versa. The inherent advantages of these antennas are small scale, low profile, lightweight, cost-effective, and simple integration with other circuits. It's very well suited for wireless communication systems applications. Multiband and wideband patch antennas will become the requirements for accurate transmission of voice, data, video, and multimedia information for today's wireless communications. However, a patch antenna's most vital issue is its limited bandwidth since a patch antenna on a dielectric substratum has losses from surface waves. Because of their attractive advantages, Microstrip antennas are used extensively in commercial and military applications. However, the conventional microstrip antennas have just a few percent impedance bandwidths and an omnidirectional radiation pattern, which does not fulfill the specifications of different wireless applications

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[5]. In fulfillment of the purpose, an investigation of a broad range of topologies for microstrip antennas occurred to meet the required specification. The topologies include various antenna element structures and different microstrip array arrangements. Ultra-large band, high gain, miniaturization, circular polarization, and multi-polarization are among the explored requirements.

Microstrip antennas, as we know, have a generally narrower bandwidth and lower gain relative to conventional bulk antennas. Some microstrip antennas from distinct topologies could opt to install the traditional bulky antennas, such as quasi-Yagi, a planar reflector antenna [6]. The microstrip patch antennas are known for their durable quality and implementation. Implementation of microstrip patch antennas exists in a range of fields, such as medical, telecommunications, and even military devices, as well as rockets, aircraft missiles, and many more [7]. They have a variety of uses. Prime candidate follows any of these criteria: Mobile and satellite communication, Radio frequency identification, Interoperability for microwave access, Radar application, Global positioning system, reduced size microstrip patch antenna for BlueTooth, and reduced size microstrip patch antenna for BlueTooth [8].

4. SIGNIFICANCE OF THE STUDIES

The findings of this study will redound to benefit the innovations related to microstrip patch antennas. The use of MAPs is widely known to provide benefits more in terms of efficiency and can be helpful in the field of communications. Different companies relating to telecommunications can use this knowledge to implement varying new functions in their products to increase the convenience of their devices to the public. Global Positioning Systems can also benefit from this in terms of a cheaper but more effective antenna, used in modern devices. Companies that focus on producing products that require Blue Tooth in their devices can also greatly benefit from the findings of this study. Most of the cost from these benefactors insinuates complete exploitation of the efficiency of the MAPs, and further increases it by conducting more investigation that can neglect or completely ignore the disadvantages that it can provide.

5. DESCRIPTION OF THE DESIGN

Figure-1 shows the set antenna design.

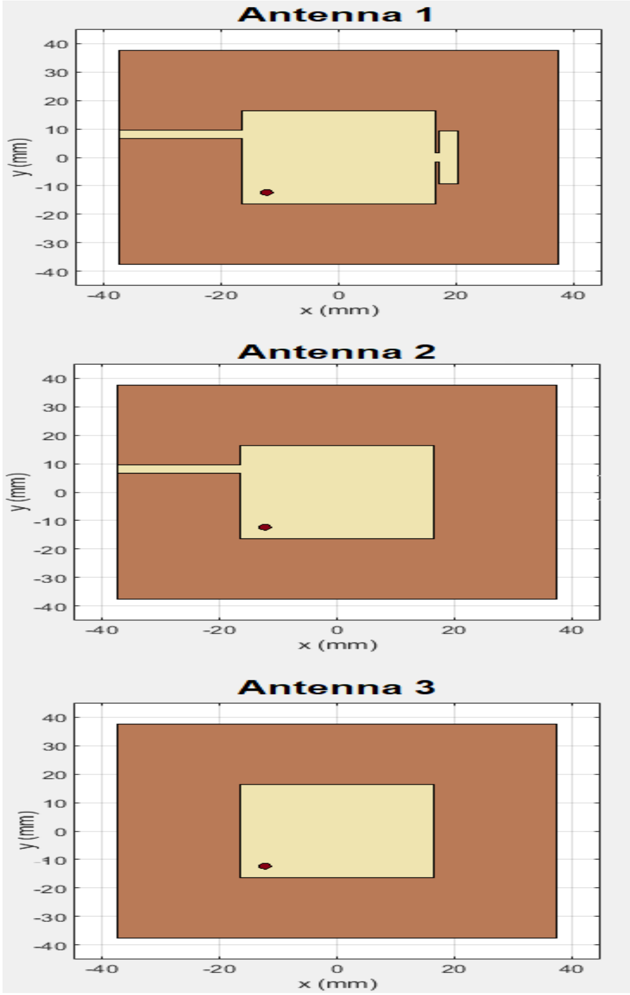

Figure-1. Set antenna design.

The design can achieve resonant frequency at 3.2GHz. With the help of the tuning stub and the additional patch, the accuracy of the reflection coefficient of the system improved. Tables 1 and 2 shows the Antenna Measurement and the Comparison of RT/Duroid 5880 to FR4 as Substrate, respectively.

Table-1. Antenna measurement.

Antenna X-Y Measurement (Frequency: 3.2GHz)	
Ground Plane	Area: 75 mm x 75 mm
Square Patch	Area: 33 mm x 33 mm, L: 21mm, B: 21mm
Tuning Stub	Area: 21 mm x 3mm, L: 0 mm, B: 44.25mm
Coupled Patch	Area: 3 mm x 18.75 mm, L: 54.75 mm, B:28.125 mm
Couple Stub	Area: 1 mm x 3mm, L: 52.5 mm, B: 36 mm
Feed Location	L: 46.875 mm, B: 46.875mm
Characteristic Impedance	60Ω

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When using MATLAB, the center of the square is the reference point (See Figure-1). The measurement in Table-1 is optimized to follow the left (L, X-axis) and bottom (B, Y-axis) aspects of the ground plane. The target resonant frequency of the antenna is 3.2GHz.

The substrate used in the design is RT/Duroid 5880. This material has a low dissipation factor and good dielectric constant and has been utilized in higher frequency.

Table-2. Comparison of RT/Duroid 5880 to FR4 as Substrate.

RT/Duroid 5880 @ Z direction	
Dielectric Constant, ε_r	2.20 ± 0.02 spec
Dissipation Factor, tan θ	0.0009
FR4 @ Z direction	
Dielectric Constant, ε_r	4.40±0.3 spec
Dissipation Factor, tan θ	0.017

The thickness of the substrate is 0.787 mm. As the manufacturer noted, non-standard sizes are suppliable up to 457mm x 1219 mm.

6. METHODOLOGY

Figure-2 shows the Flow Chart of the Operations.

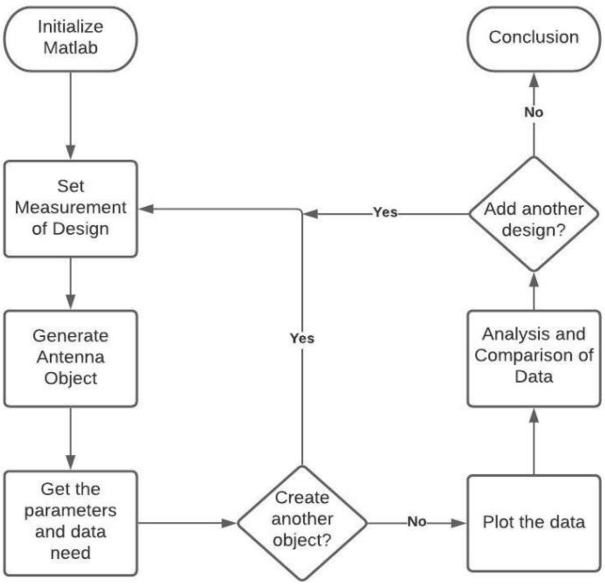

Figure-2. Flowchart of Operation.

6.1 Set Measurement of Microstrip Antenna Design

Enter the necessary measurement of the microstrip antenna as variables for the program. This leads to generating and shaping a simulated structure similar to the antenna. The necessary measurements are as follows: Table-3 shows the System Parameters.

Table-3. System parameters.

Main Parameters	
resonant frequency	**wavelength**
input impedance	
Substrate Parameters	
dielectric constant	effective permittivity of the substrate
thickness	loss tangent
Patch Parameters	
length	width
position/tilt	number of points (mesh)*
Ground Parameters	
length	width

* The lower the number of points, the faster the calculation would be, at the expense of accuracy.

6.2 Generate Antenna Object

MATLAB has several features that help in antenna configuration. The Antenna Toolbox allows extensive design and analysis of antennas using the platform. To generate the object, it is opted to use antenna. Shape. Examples of shape parameters are Rectangle, Circle, and Polygon.

To create the substrate, the *dielectric* command is used. This allows the generation of a material that follows the parameter shown in Step 1. There are also presets of common dielectric material available on the platform. To view, use the *open Dielectric Catalog*. Figure-3 shows the Dielectric Catalog of MATLAB.

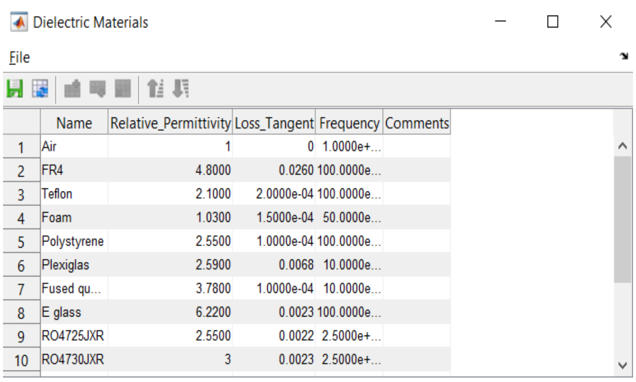

Figure-3. Dielectric catalog of MATLAB.

The generated meshes using this procedure are an antenna object which can be attached with a feed. To attach the feed generate a variation of microstrip antenna, the code pcbStack is used. This allows the stacking of layers of materials and objects to emulate a similar design. Configuration of the properties of the object is set with various parameters that are created when the object is created.

6.3 Get the Parameters

The parameters being checked in designing antennas are the antenna gain, the reflection coefficient, power transfer efficiency.

These parameters are further sectioned into directivity, radiation pattern, and beamwidth. The antenna gain, radiation pattern as well as directivity can be defined using the pattern command. The beamwidth code allows seeing the beamwidth and directivity of the antenna.

Sparameters allowed to generate the is used to understand the return loss, and in relation, the reflection coefficient of the design based on the range of frequencies. For power transfer efficiency, the *VSWR* and *rfparam* are available to generate the data.

6.4 Plot the Data

Plot the data calculated using the commands from procedure 3. To plot data involving antenna communication, the *rfplot* is a feature provided by the programming platform.

6.5 Analysis and Comparison

Given that there are several antenna designs to be established. The collected data is tabulated and stored in the workspace of MATLAB. This served as a reference for the conclusion.

7. REVIEW OF RELATED LITERATURE

A wideband right-handed circularly polarised series of microstrip patch antennas have been introduced in this study by Kola *et al* [1]. for direct satellite broadcast services. The single element of the array is a resonating frequency 12.49 GHz, a two-dimensional mushroom-shaped fractal antenna with an impedance bandwidth of 1.12 GHz. The proposed single element is constructed by etching a pair of Minkowski squares in a regular octagon on one of the two opposite sides. Also, a thin slot of length equal to one side of the normal octagon is positioned between the two Minkowski boxes resulting in the proposed radiating portion in the form of a mushroom and experimentally tested with fair agreement and size reduction up to 89.9 percent.

A dual-polarized cross-dipole antenna is proposed by Hao, *et al*. [2] and developed for a base station with a broad beam and high insulation. The antenna proposed comprises 2 planar cross dipoles with 4 square patches, two L-shaped microstrip lines, two ground plates, four parasite patches, and a reflector. The square patches are mounted to pair with L-shaped microstrip lines between the middle of the cross-dipoles. The big beam can be realized by adding the parasitic patches.

Saroj and Ansari [3] proposed a multiband rhombic shaped microstrip antenna (RMRS-MSA) which can be reconfigured up to 20 GHz based on wireless smart applications. In this document radio frequency (PIN diodes are prepared for frequency switching with a microstrip feed line on the radiating area. It has a radiating patch filled with rhombic shaped copper. The radiating patch contains two more rhombic patches attached within, with just a 1 mm gap called patch 1 radiating and patch 2 radiating. To achieve a directional radiation pattern, such rhombic shaped radiating patches are enclosed with a square parasitic patch.

Keshwala *et al*. [4] discussed the configuration and study of Terahertz frequencies with inverted K-shaped super wideband antennas. The initial configuration of the square patch antenna is changed by inserting triangular slots in the patch to an inverted K-shaped antenna (proposed prototype). The parametric analysis is performed to maximize the partial ground dimension, and the impedance bandwidth is increased by etching slots in the patch of the antenna, thereby rendering it an inverted K-shape. Besides the broad bandwidth, a very high gain of 22.1 dB is achieved at 8.8 THz.

Srivastava *et al.* [5] represented the design and study of a new, circularly polarised single-fed triple-band antenna for C- and X-band applications. The proposed antenna spans C-band and X-band downlink frequencies for satellite applications. The antenna radiator consists of a 50 microstrip feed line F-shape radiating layer. The calculated and observed results of the proposed antenna were checked, and minor differences were found between simulated and measured results.

A single layer reflectarray antenna with variable patch sized unit cells was proposed by Bodur and Cimen [6] and suggested for enhancing the bandwidth for X-band applications with limited overall dimensions. The novel unit cell is made up of geometry with a double-cut band. 13 Each of the 13 unit cells covers an ultrathin square substratum of 162, 5 mm2 with a dielectric permittivity of πr = 6, 15 and a thickness of 0,042 mm. The measurements were taken in an anechoic shielded chamber. The outcomes of the analysis and calculation are mutually accepted.

Srivastava *et al.* [7] proposed a device uses a novel strategy that simultaneously proves to increase both the bandwidth and the gain to a great extent. By incorporating slots into the suggested Rectangular Microstrip Patch Antenna, often regarded as the slotted array technique, we have tried to solve those limitations. The suggested antenna was designed for a 9 GHz operating frequency which lies within an electromagnetic system's X-band. It was simulated using HFSS software over an RT Roger / Duroid 5880 material which has a dielectric constant of 2.2.

Dwivedy and Behera [9] presented and experimentally verified the design of a frequency-switchable, square-shaped microstrip patch antenna with simultaneous circular-polarization (CP) reconfigurability. The frequency with CP-reconfiguring features showed that the proposed antenna ideal for specialized wireless communications functioning in the S-band, which can handle both frequency-based challenges as well as signal-quality issues resulting from climate change.

8. THEORETICAL CONSIDERATION

The major contributors in designing microstrip antennas fall into these parameters: frequency of operation and the substrate used in the design [10]. The frequency operation is the resonant frequency in a determined

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bandwidth of operation. It is one of the significant features that put microstrip antennas in multiple antenna designs. This class of antenna has several resonant modes that detail different sets of bandwidth, each with their respective resonant frequency [11]. Narrow bandwidth is a feature of the microstrip patch antenna, which is both its perk and burden when in consideration [12].

The substrate affects RF waves directly as materials used in the substratum exhibit dielectric properties. The material plane serves as a waveguide to the captured signal [13]. The bandwidth and the return loss are the parameters and are dependent on the substrate. [14] As a waveguide feed line, it affects the general impedance of the antenna [15, 16]. The resistance and reactance of the antenna are introduced to the feed, thus initiating a power transfer system. MATLAB has the function handle impedance to see the resistance and reactance of the antenna object.

For square microstrip patch antennas, while it follows the rectangular patch characteristic equation, the effective length computed will be the length and width of the patch design [17]. The accuracy of the antenna varies based on the effective length of the patch. To compensate, the engineer established advance conventions and adjustments for the phase attenuation. The process includes adding slots, band, and arrays and creating multiple layers [18]. In this design, there exists a coupling dipole band between the main patches. The presence of the coupling adjusts the narrow bandwidth of the operating frequency desired. [19, 20].

9. DATA AND RESULTS

Section 9 presents the Data and Results. Figures 4 to 10 shows the output of the Antenna Design.

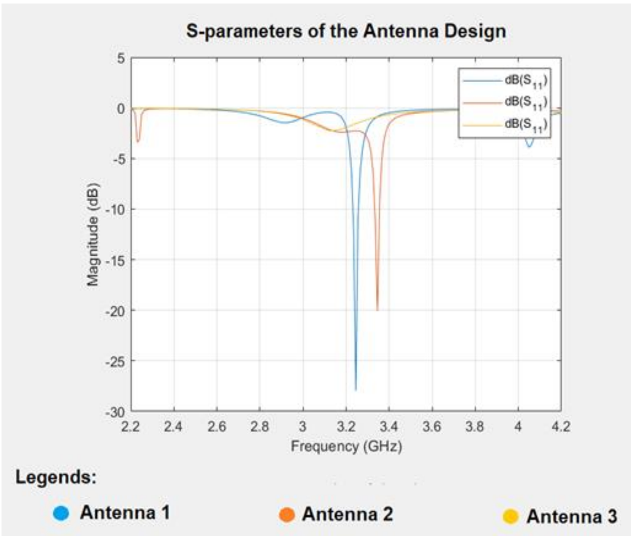

Figure-4. S-Parameter of antennas.

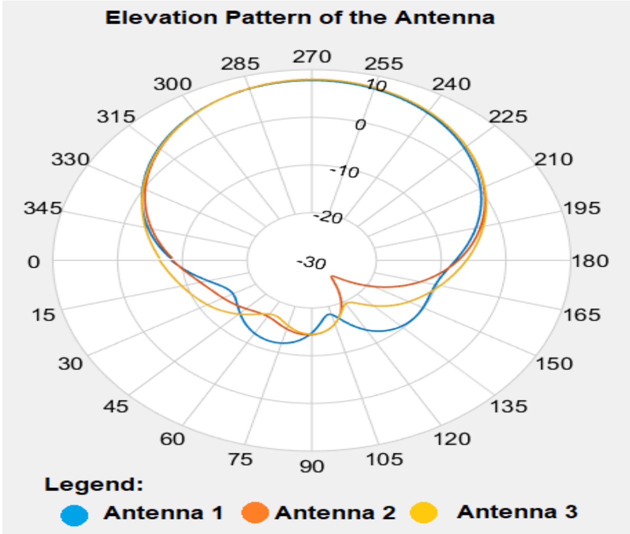

Figure-5. Antenna 1 radiation patterns.

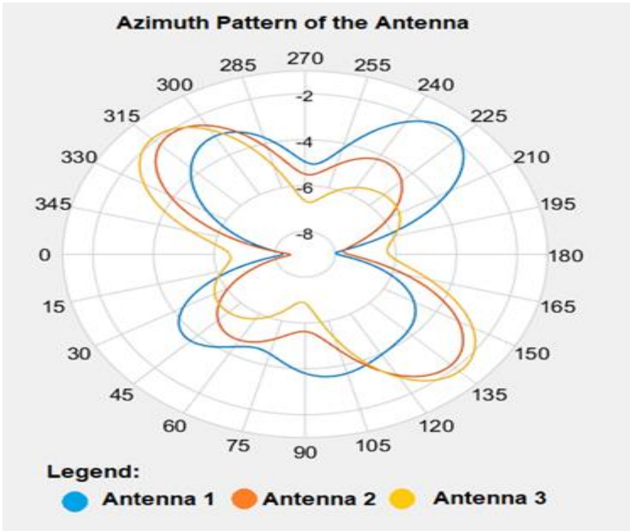

Figure-6. Antenna 2 radiation pattern.

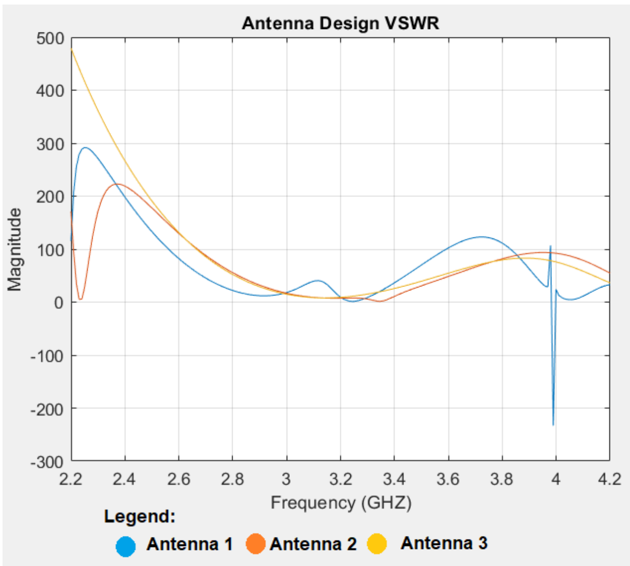

Figure-7. VSWR of the antennas.

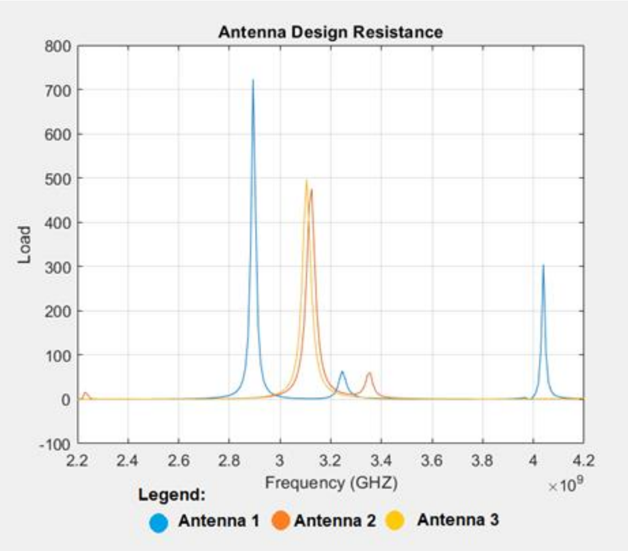

Figure-8. Real part of the impedance of the antennas.

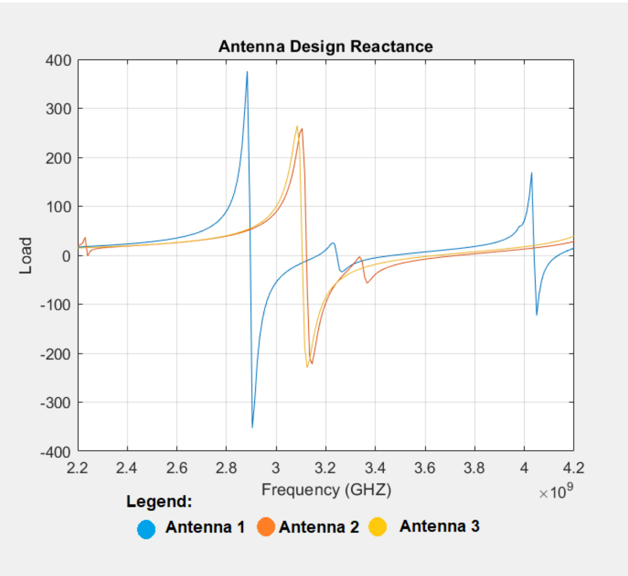

Figure-9. Imaginary part of the impedance of the antennas.

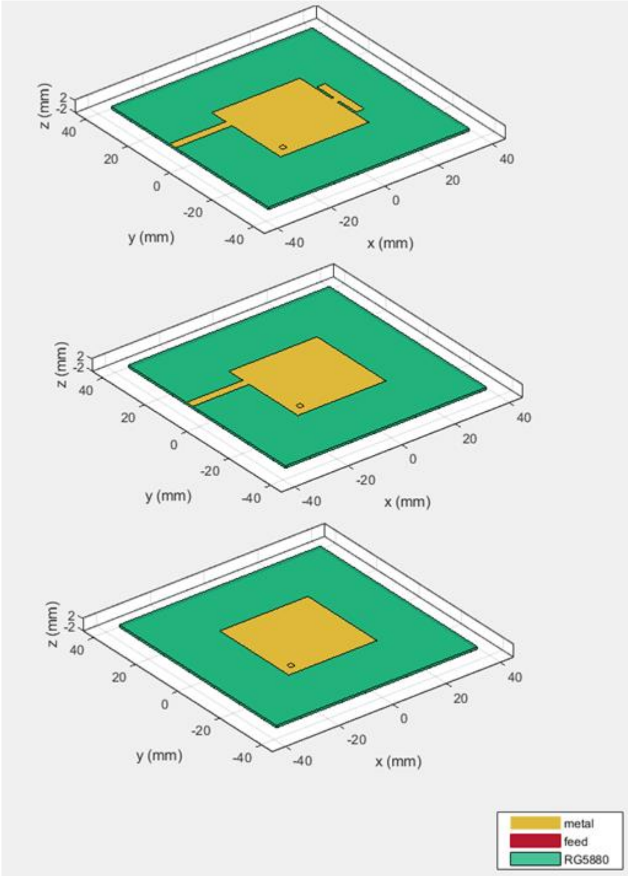

Figure-10. pcbStack of the antenna.

10. ANALYSIS OF DATA

Using the analysis functions handles that are available on MATLAB [21], the parameters have sets of data used to confirm the use of the design.

In Figure-5, the data set plot describes the s-parameters of the antenna design. This parameter is related to the reflection coefficient, which determines the return loss. The latter is the power loss from reflection or return as an effect of the discontinuity between the channels.

In Figure-5, the data set plot describes the s-parameters of the antenna design. This parameter is related to the reflection coefficient, which determines the return loss. The latter is the power loss from reflection or return as an effect of the discontinuity between the channels. For the first, the magnitude at 3.2GHz is about -27.95 dB. For the second antenna, the magnitude at the same frequency is about -2.288 dB. It is also resonant at the frequency of 3.33GHz, which falls on about -20dB magnitude. The third antenna has a magnitude of -2.05 at the target frequency.

The data for the radiation pattern establishes a graph shown in Figure-6 and Figure-7. The radiation pattern states the intensity of the radiation emitted with the antenna in that specific direction. On the Elevation pattern, the first design has an eccentric directivity. While having similarity with the radiation pattern emitted from standard square patch microstrip antennas, the directivity at 0° to 180° is rounder and folded somewhere in the transition from 60° to 75°. For the second antenna, it is still similar to the standard radiation expected, with a more bean-like or butterfly shape in directivity. The third one is the standard radiation pattern of square patch microstrip antenna, with an intense side lobe due to the location of the feed.

The data in Figure-8 shows the Voltage Standing Wave Ratio of the antenna design. The VSWR of the three antennas varies at the frequency of 3.245GHz on a load of 60Ω. The first antenna has a VSWR of 1.083 at the target frequency, the second antenna has 7.681, and the last has 11.15.

Figures 9 and 10 display the graph for the impedances as referred to frequency. The former shows the resistance referred to as the real part of the impedance, and the latter shows the imaginary part. As seen in the resistance part, the first antenna matches its impedance at 3.245GHz. The second antenna, while it has low impedance at the target frequency, parallels at 3.33GHz. The third antenna requires high resistance to operate efficiently in the designed resonant mode. The imaginary part data also shows the capacitive nature of the antenna. For the first antenna, the reactance is -j3.221Ω at 3.245GHz. The second and third antenna has a reactance of -j60.24Ω.

11. CONCLUSIONS

The first step of the antenna design is to establish the objectives. In this case, the antenna must be able to match at 32.2GHz given a load of 60Ω. In antenna designing, consideration falls upon several parameters shed from the decade of study and experiment. These require thorough and disciplined learning to establish the characteristics of an efficient design. In designing the antenna, several proven factors create the foundation in drafting the antenna. For example, using the established design of the first antenna, increasing the area by adding arrays and stubs will alter the efficiency and directivity of the antenna. The phenomenon increases the characteristic impedance of the antenna and would result in mismatching load as well as renavigate the EMF field of the antenna. Therefore, mathematical procedure and thorough analysis of the properties is essential in the expertise.

The third antenna is used as a basis since it is the standard square patch microstrip antenna. The low return loss factor stems from the dielectric substrate. The substrate board used in the simulation is RT Roger/Duroid 5880, with a dielectric constant of 2.2 and a loss tangent of 0.0009.

For the first antenna design, the microstrip excels in having high return loss. Insertion loss is minimized and would result in efficient power transfer at the target frequency of 3.2GHz. Its directivity, however, has certain limitations due to its poofy pattern inherently differs from most square patch microstrip antennas.

For the second antenna, the tuning stubs alter the impedance of the antenna to have a similar effect to the standard square patch microstrip antenna. At 60Ω, the frequency with the best condition for return loss as calculated by MATLAB is at 3.33GHz. While the design is optimal for 3.33GHz, it fails to follow the objective to get a resonant frequency at 3.2GHz range.

12. RECOMMENDATIONS

The whole experiment is a simulation product of the MATLAB. For generating the various types of antenna design simulations, MATLAB is a well-suited computer program, with optimal functions and command. With the potential to be applied in different scenarios, the creators of the tool installed an easy way to generate the different types of signals of these diagrams. Engineers and designers are ecstatic to have a utility tool that shows efficiency when performing their tasks.

In generating the different types of signals and functions of these diagrams, it is vital to correct data to decrease the possibility of getting an error in the plots. Properly learning the language is required to make the least number of mistakes possible in creating a code that provides the required output.

Another recommendation is the fabrication of the antenna. However, due to time constraints and limitations, this has been impossible. MATLAB is a capable platform in handling physical products and systems.

As 5G becomes more prevalent, the engineering could be applied in this experiment. The 5G uses millimeter waves which means that the antenna gets smaller and smaller which amplifies the effect of losses such as penetration loss and scatter loss. There are also several new techniques in designing microstrip patch antennas. As discussed in Low-Profile Slotted Metamaterial Antenna Based on Bi Slot Microstrip Patch for 5g Application, the platform for antenna design continues to grow. Furthermore, several substrates have been introduced to the market that may be used to challenge 5G. For example, polytetrafluoroethylene or PTFE as well as liquid-crystal polymer has been on the rise on the market that would expand in the future generation of communication systems.

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