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Development of a design optimization algorithm for a bowtie antenna

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ABSTRACT

A bowtie antenna is one of the simple dipole antennas with an omnidirectional pattern utilized in several applications. It is used in industrial applications, scientific applications, and medical applications. Its elementary design can be subjected to modification to expand the applications of the dipole and improve its performance. This paper aims to develop a design optimization algorithm for a bowtie antenna with an adaptive finite impulse response (FIR) filter. In the paper, the different designs of the bowtie antenna are simulated using MATLAB software. The design of antennas is constructed using the partial differential equation (PDE) toolbox in MATLAB software. The designs explored in the paper are the slotted microstrip bowtie antenna and the double flare bowtie antenna. A traditional bowtie was also simulated to be used as a reference for the evaluation of the modified antennas. The dimensions of the designs are kept closely like draw accurate conclusions about the effects of the refinements done. The effects of the modification of the designs on the directivity and return loss are determined to assess the effectiveness of the design alterations.

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1. INTRODUCTION

The modification of antenna designs expands the practicality of an antenna. The reconfiguration of an antenna can increase gain, increase directivity, reduce the dimensions, or transform a single frequency band antenna into a multiple frequency band antenna. The demand for compact antennas with excellent performance has been increasing as the applications of these antennas are numerous [1]. Design modifications of antennas also aim to decrease the cost of manufacturing and decrease their size, all while keeping the geometry simple [2]. The restructuring of an antenna is often utilized in the communications of commercial and military applications [3]. The alteration of the conformation of an antenna is utilized to construct an antenna for a specific application. The improvement of the performance of the modification can be assessed in the simulated radiation patterns, antenna reflection, and antenna gain [4]. A challenge in the reconstruction of an antenna design is to overcome the conflicting matching requirements of the surrounding environment of the antenna. The alteration of the geometry of the antenna must satisfy the desired performance, the recommended specifications, and the compatibility with the environment [5]. It is important to consider the electromagnetic interaction of the antenna with its environment to evaluate the performance of the antenna [6]. Hence, electromagnetic simulations are used to test the modifications done to the geometry of the antenna. Several design optimization techniques can be applied to a simple geometry design for the enhancement of the antenna's performance. Common antenna geometry modifications are shape bending, the addition of tuning stubs, and integration of a wide slot [7]. The experiment done in the paper is a reconstruction of the dipole bowtie antenna geometry by the integration of a double flare and the incorporation of a slot into the design. An adaptive finite impulse response (FIR) filter was added to improve further the antenna's performance. Using MATLAB software, the designs are constructed and simulated to evaluate the improvement of the performance due to alterations [8].

2. BACKGROUND OF THE STUDY

The bowtie antenna is an antenna that has triangular elements which replace the usual straight rods for the elements of the antenna. These triangular elements resemble a bow tie which is why we call it such. This antenna is also a type of antenna that is considered a ultra high frequency (UHF) fan dipole. These bow tie antennas are not logged periodic antennas [9]. These bow tie antennas are also considered biconical antennas. Due to using triangular elements instead of the usual straight ones, the bandwidth of the bowtie antenna is increased. The bowtie antenna can also receive signals from varying sources due to its ability to receive signals from a 60-degree angle [10], [11]. The antenna is also lighter and becomes wind resistant due to the triangular elements. The design of a bowtie antenna is also easy to construct and relatively cheap. The mesh reflector that is embedded within a bowtie antenna is also more efficient than other types of antennas [12], [13]. The antenna does have some disadvantages such as having poor transmitting efficiency in frequency ranges that are considered as low and using a log periodic antenna may be more beneficial in that situation. The bowtie antenna can be seen to have a polarization that can be considered vertical. Wherever the triangular elements are pointed is where the signals can be received and only in this direction can signals be received [14], [15]. This does not matter anymore if the antenna is being pointed at a television (TV) or radio tower on the horizon. For ultra-high frequency waves, the bowtie antenna is the best option to use. The use of MATLAB for antenna design is also discussed in this study. The partial differential equation (PDE) tool is a tool in MATLAB that stands for a partial differential equation, and with the help of this toolbox, modifications to antenna design may be computed easily.

3. STATEMENT OF THE PROBLEM

An antenna can be used for several applications like as industrial, medical, and scientific applications. Due to the bowtie antenna being an antenna that is considered elementary, modifications can be done to the bowtie antenna for more suitable applications of the dipole. The design of an antenna can be very time-consuming and hard to do not to mention that there are various types of antennas that need to be considered. The amount of testing to find the right antenna needs to be considered as well when designing a system. Modifications to the original antenna also bring about corresponding changes to a lot of aspects. Examples that may be subject to change when modifying are the antenna's directivity and return loss among other things. There is also the problem of finding suitable software for the design and simulation of an antenna that can adapt to corresponding modifications that a user wants.

4. SIGNIFICANCE OF THE STUDY

The study being conducted serves as a tool to better understand three types of antennas, mainly the traditional bowtie antenna, the slotted bowtie antenna, and the double flare bowtie antenna. The paper aims to introduce a way to simulate the design for all three types of bowtie antennas in MATLAB. The study will also be able to showcase the corresponding effects of using each type of bowtie antenna. The simulation generated will also be able to handle modifications in the original design. This will be helpful as the program will also be able to calculate the corresponding results that come with the changes from modification such as directivity and return loss. With the help of this study, a better understanding of bowtie antennas and their corresponding variations of slotted and double flare will be accessible to its readers. The most suitable antenna may be chosen among the three types available and demonstrated in the experiment part of the paper. The paper also states that the dimensions of the antenna were kept closely similar to be able to draw accurate conclusions from the differences in the various antennas presented within the experiment. The use of the PDE toolbox from MATLAB can also be seen in this paper and this paper can also show how antenna design can be done through this program.

5. DESCRIPTION OF THE SYSTEM

A reference bowtie antenna is constructed as the point of comparison of the designed antennas. The bowtie has a total length of 45 mm and a total width of 65 mm. The length and width of each triangle are 30 mm and 32 mm. The gap in the middle is 1 mm. The feed is placed in the bottom middle of the antenna.

Figure 1 shows a reference bowtie antenna, Figure 2 shows a slotted bowtie antenna, Figure 3 shows a double flare bowtie antenna and Figure 4 shows a double flare slotted bowtie antenna.

The slotted bowtie antenna has the same dimensions as the reference antenna. The horizontal slot has a width of 60 mm and a length of 1 mm. Figure 3 shows a double flare bowtie antenna. The double flare bowtie antenna has a total length and width of 65 mm and 42 mm. The inner triangle has a length of 24 mm and a width of 20 mm. The trapezius attached to the triangle has short bases of 10 mm and long bases of 20 mm. The double flare slotted bowtie antenna is the combination of the slotted antenna and the double flare antenna previously defined. Figure 4 shows a double flare slotted bowtie antenna.

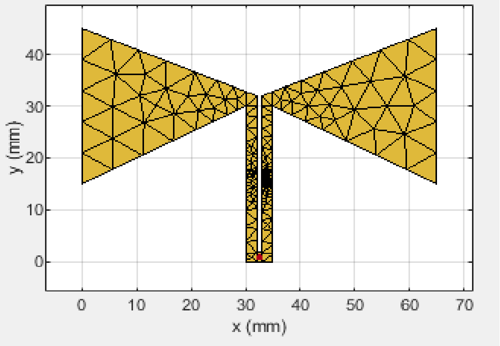

Figure 1. Reference bowtie antenna

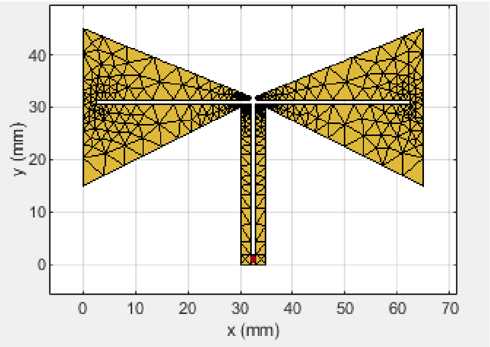

Figure 2. Slotted bowtie antenna

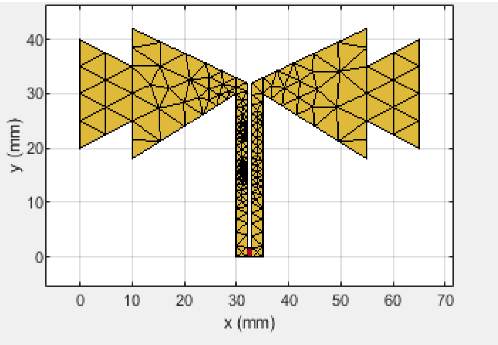

Figure 3. Double flare bowtie antenna

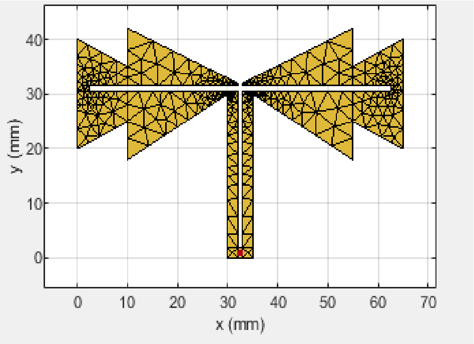

Figure 4. Double flare slotted bowtie antenna

6. METHOD

This section discusses the method. The PDE toolbox was used to construct the design of the antennas. The mesh of the constructed design was exported to the workspace of the MATLAB editor. A custom antenna was simulated in MATLAB using the mesh from the PDE toolbox. A feed was then placed on the antenna. The operating frequency was defined as 3.2 GHz and the frequency range was defined as 1 GHz to 10 GHz with an increment of 100 MHz. The radiation patterns, impedance, and S-Parameter graphs were generated. An RF toolbox and an antenna toolbox are needed to obtain the output plots of the simulation. Figure 5 shows the flowchart of the method.

The bowtie antenna is focused on wireless applications. The antenna will be constructed using the PDE toolbox of MATLAB. The design will then be transferred to the mesh workspace. The feed will then be placed in the custom antenna. The frequency of operation and the frequency range will then be defined. A custom block of an adaptive FIR filter will then be placed on the antenna system. This is for noise filtering. The rough set theory will then be used to optimize the radiation patterns, impedance, and plot of the S parameters. The radiation patterns, impedance, and plot of the S parameters will then be turned into a graphical form.

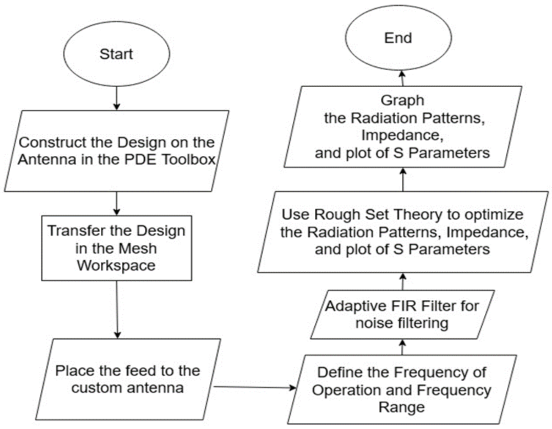

Figure 5. Flowchart of method

7. REVIEW OF THE RELATED LITERATURE

The bowtie antenna has been used in previous studies as well and has also been used in various applications through varying models of the bowtie antenna were used. In a study conducted that involved a multiband and wideband frequency reconfigurable antenna, a slotted bowtie antenna had a stripline in its middle to gain a wideband that ranged from 3.5-9.0 GHz. At the end of the bowtie-shaped, two slotted arms were added to attain the multiband which operated at 1.7 GHz and 2.6 GHz. In the paper, results such as radiation pattern and gain were discussed and showed that in multimode communication systems, the antenna was viable [16].

In a study involving a ground penetrating radar, two types of bowtie antennas were designed and tested, mainly a rounded bowtie antenna and a slotted bowtied antenna. The paper presented requirements and possible disadvantages for the use of each antenna as well as a method for the design. The antennas operated at a frequency band of 1.1-3.5 GHz and were compact. In a similar study, this experiment was also done in novel size and not miniaturized. According to the results of the study, the compact rounded bowtie and the slotted bowtie antenna especially showed great potential for antennas to be used in air-coupled ground-penetrating radar (GPR) systems [17].

In a study conducted by a group of researchers, a broadband bowtie antenna was used that had a metamaterial periodical structure for broadband wireless systems and a communication frequency band that would come with the emergence of 5G technology. The proposed antenna operated at a frequency of 4-6.8 GHz and used ECSSR unit cells, known as an electrically coupled split-ring resonator, and was studied. The results of the experiment showed that the major lobe of the antenna could achieve a maximum gain of 9.8 dBi with tilting [18].

The use of a planar bowtie antenna was shown in a study entitled “220 GHz focal plane imaging demonstration using integrated terahertz array detector” in 2020. In the experiment, the planar bowtie antenna was equipped with every detector chip. The detector chip was able to show excellent performance by the standards of the researchers. The final results showed that the achieved result was approaching the theoretical result that was computed [19].

A high directional antenna for ultra high-frequency radio frequency identification (RFID) used the composite structure of a bowtie dipole in conjunction with a miniature Moxon antenna for feed balance. The experimental results showed that in a frequency band of 865-1954 MHz the reflection coefficient was less than-10 dB with a gain of more than 3.5 dB. The relative operating bandwidth was also able to attain 20% [20].

A group of researchers generated a design of a compact planar microstrip bowtie-shaped antenna for wireless applications and used three rejection bands for interference to be avoided. Using HFFS, which stands for high-frequency structure simulator, the proposed antenna was analyzed and showed results such as a maximum gain of 5.85 dB and an omnidirectional pattern at low frequencies [21]-[23]. The same group of researchers also proposed a design for a miniature meandered microstrip bowtie-shaped antenna for the same application as the previous study stated. This experiment had multiband characterization and used six rejection bands instead of three rejection bands like the previous study. The antenna was analyzed using HFFS as well and showed results such as a maximum gain of 4.42 dB and a radiation pattern that was directional in the E-plane and omnidirectional in the H-plane at low frequencies [24]-[26].

In a study conducted by a group of researchers, a single and dual element bowtie microstrip antenna with an embedded planar long wire was studied and proposed for its utilization in 5G wireless applications.

Using the proposed bowtie structure, two element arrays were also studied. The paper published the results of gain, radiation characteristics, and return loss from the proposed design of the antenna [27], [28]. The antenna was found to be suitable for 5G applications as it produced a high gain at the operating frequency and works within a frequency bandwidth of 27-29 GHz. The results of the simulation were validated due to the fabricated prototypes' previous results [29]-[31].

8. DATA AND RESULTS

In this section, we will be discussing the data and results of a bowtie antenna with an an adaptive FIR filter. We will go over what the antenna is, how it works, and what the results were. This information is important for anyone who wants to know more about how this type of antenna functions. Figures 6, 7, and 8 shows the 2D and 3D radiation patterns, RF plot of S-parameters and impeadance of the reference bowtie antenna respectively.

The next part of the simulation will focus on the slotted bowtie antenna. MATLAB/Simulink will be used for the simulation. Figures 9, 10, and 11 shows the 2D and 3D radiation patterns, RF plot of S-parameters and impeadance of the slotted bowtie antenna respectively. The next part of the simulation will focus on the double flare bowtie antenna. MATLAB/Simulink will be used for the simulation. Figures 12, 13, and 14 shows the 2D and 3D radiation patterns, RF Plot of S-parameters, and Impeadance of the double flare bowtie antenna respectively.

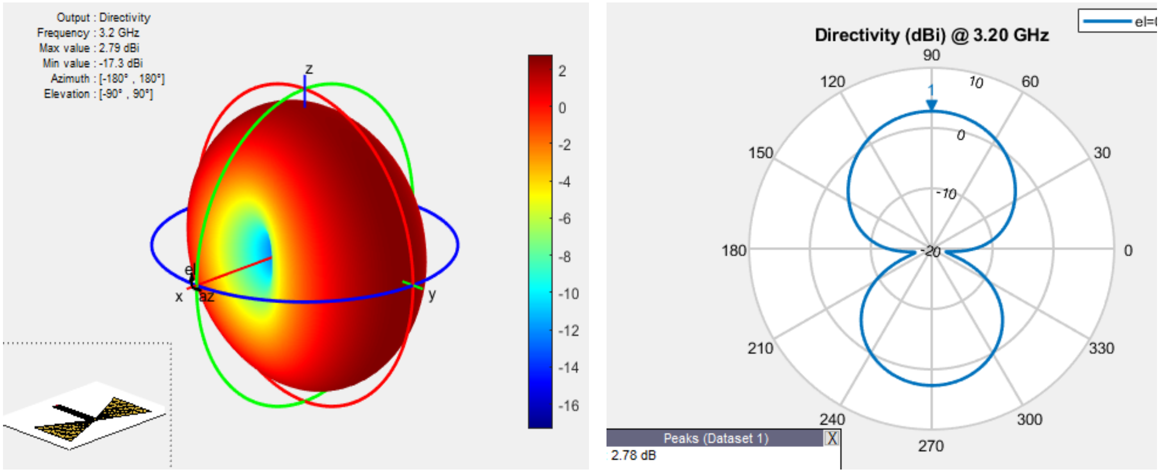

Figure 6. 2D and 3D radiation patterns

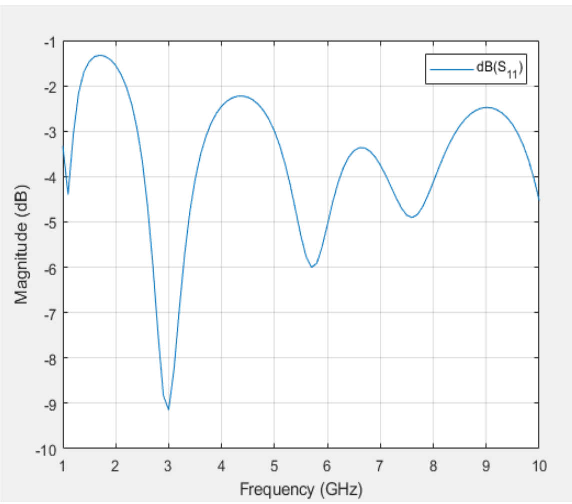

Figure 7. RF plot of S-parameters

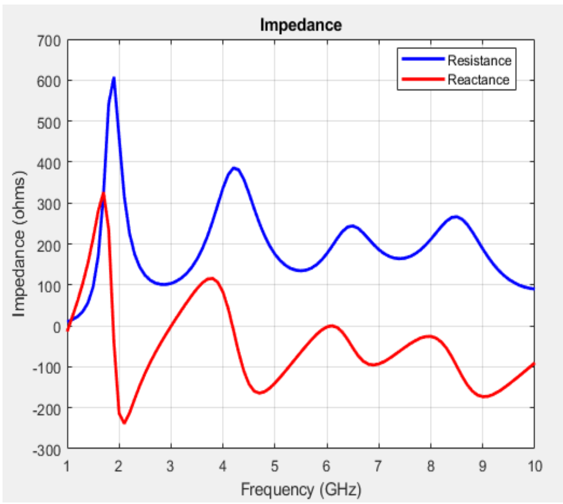

Figure 8. Impedance

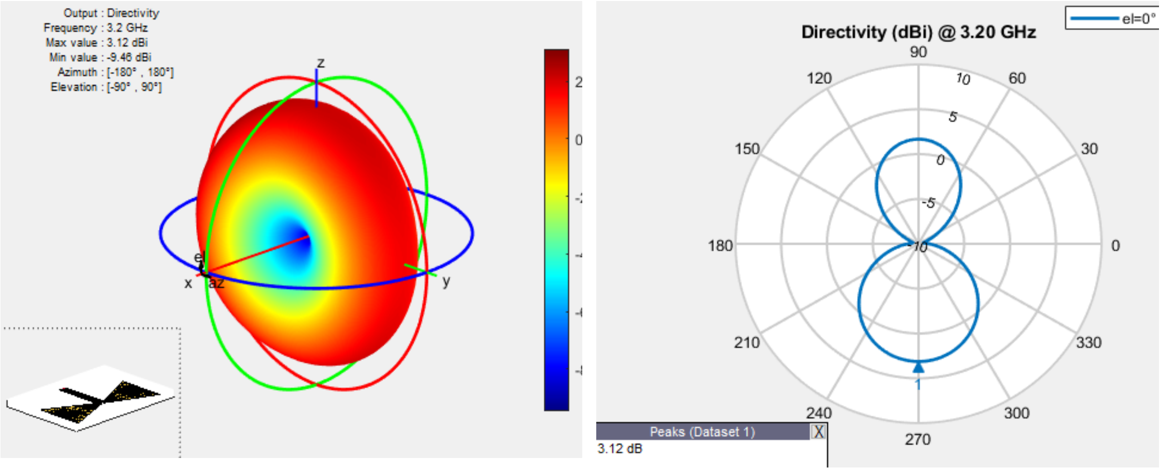

Figure 9. 2D and 3D radiation patterns

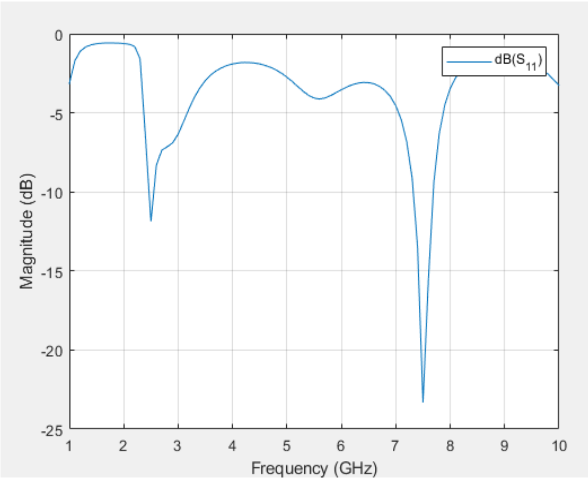

Figure 10. RF plot of S-parameters

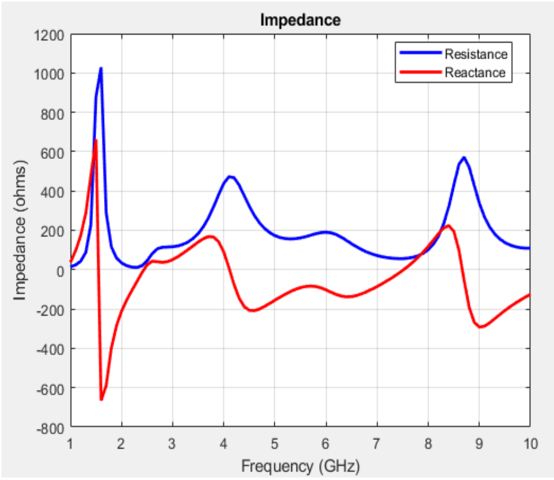

Figure 11. Impedance

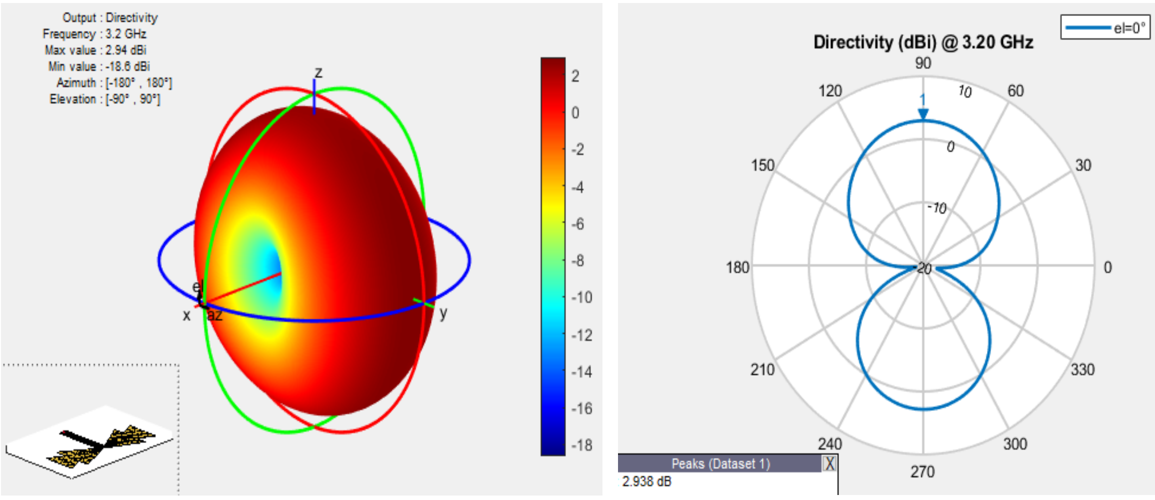

Figure 12. 2D and 3D radiation patterns

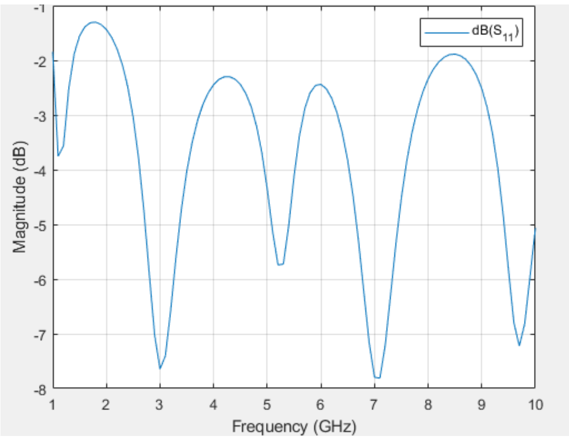

Figure 13. RF plot of S-parameters

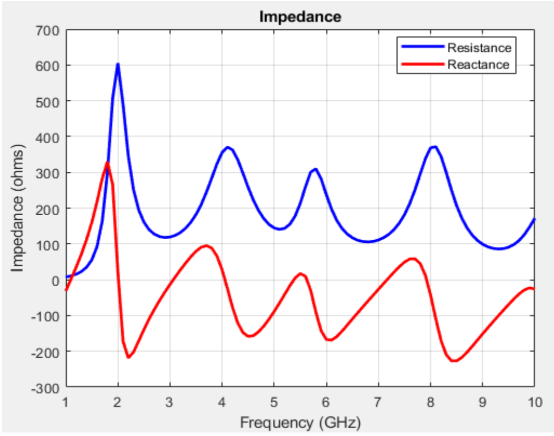

Figure 14. Impedance

The next part of the simulation will focus on the double flare slotted bowtie antenna. MATLAB/Simulink will be used for the simulation. Figures 15, 16, and 17 shows the 2D and 3D radiation patterns, random forest (RF) Plot of S-parameters and Impeadance of the double flare slotted bowtie antenna respectively.

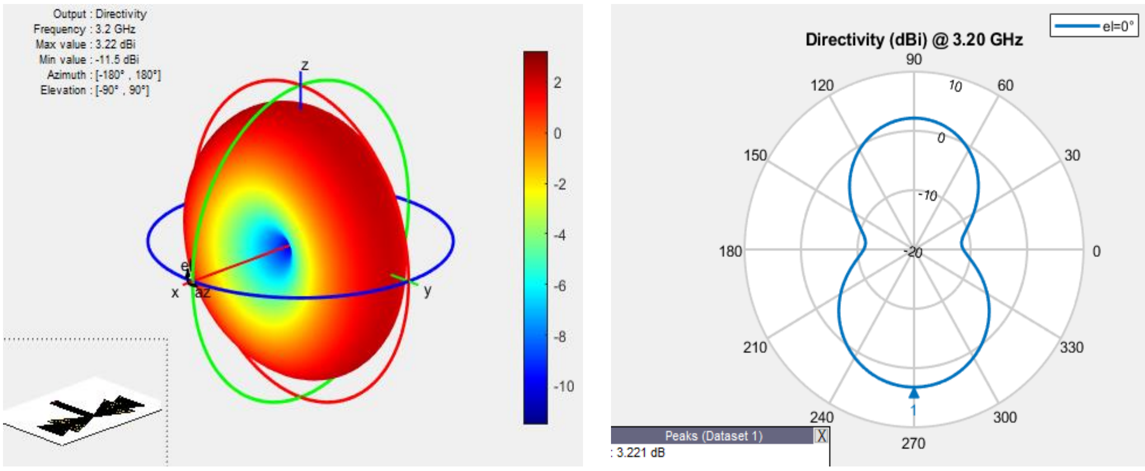

Figure 15. 2D and 3D radiation patterns

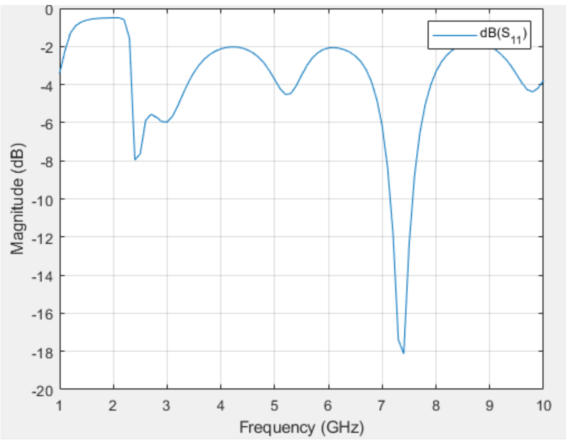

Figure 16. RF Plot of S-parameters

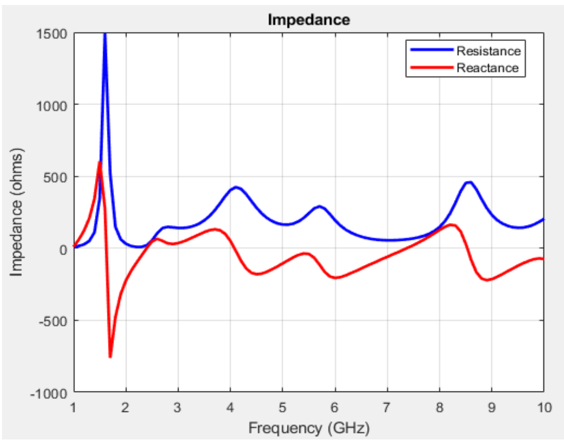

Figure 17. Impedance

9. ANALYSIS OF DATA

The effects of modifying the design of the bowtie antenna by the addition of a slot and the addition of a flare were determined using the simulation of the designs in MATLAB software. At the operating frequency of 3.2 GHz, the modified antennas have a slightly higher directivity compared to the reference bowtie antenna. The slotted bowtie had the most antenna directivity compared to the double flare and the traditional bowtie antenna. The radiation pattern of the slotted bowtie antenna showed that it was more directive than the two other designs. The double flare slotted bowtie antenna had a directivity higher than the double flare design but lower than the slotted design. Its radiation pattern is different from the two modified designs. The S-Parameters of the designs were then generated. The S-parameter shows the return loss of the antenna, which measures the power absorbed by the antenna. The lower the magnitude of the return loss, the more power the antenna can transmit to the transmission medium or the connected device, which is the desired characteristic of an antenna.

10. CONCLUSIONS

Through a simulation using MATLAB software, the analysis of the effects of the modifications on the bowtie design was done. The designs of the antenna were simulated several times, and certain parts of the design were modified to analyze the effect of the parameters of the modifications on the directivity and return loss of the antenna. The output graphs generated in the MATLAB software showed that the integration of a slot in the bowtie antenna improved its return loss. The lower magnitude of the return loss, the less energy will be absorbed in a slotted bowtie antenna and more power can be delivered to the designated recipient. On the other hand, the addition of another flare in the bowtie design increased the number of frequency operation bands. An antenna with multiple bands can function properly on more than one frequency of operation. Consequently, the antenna design can be utilized in more applications without changing its physical structure. A multiband antenna can be mass-produced without comprising the cost efficiency.

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