System design of a microstrip antenna by dimension and substrates optimization

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ABSTRACT

The microstrip antennas matured and improved over the last 25 years. Throughout these years, the limitations, and specifications of the said antennas have been overcome and significantly improved. Known to be low-profile, suitable for mobile, and lightweight, these microstrip antennas are the focus of this research. In this paper, the researchers designed a microstrip antenna with varying lengths and substrates. They tested the changes and the effects in microstrip antennas of different lengths, along with altering substrates. To verify the differences, the researchers compared the performance parameters maximum gain (dBi), minimum gain (dBi), and S11 graph on each tested length and changed substrate. The rough set theory was used to determine the optimal design via MATLAB. From there, the researchers analyzed the results gathered and drew their respective conclusions. Additionally, they saw and compared each data result to know what antenna has the best performance parameters. From the results, a change in the dimension will result in a decrease in the said performance parameters. Furthermore, the change in substrate thickness also diminishes these changes.

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1. INTRODUCTION

The antenna is a performance element commonly used in communications, radar systems, and wireless devices [1]. It is a requirement to enable the transmission and reception of electromagnetic energy with properties suitable for its intended application. The microstrip antenna, also known as the micro patch antenna, is an innovative development in antenna systems. Despite being invented almost 65 years now, the said antenna was only used and applied by Kurtulan *et al*. [2]. The microstrip antenna has a dielectric substrate with its ground plane conductor on one side, and a thin conductor that radiates on the other side. Then the radiating element of the antenna is a rectangular conductor that is attached to a microstrip feed line. A microstrip patch antenna has the following advantages, but not limited to low cost, surface comfortable, flexible gain, and low profile. The microstrip antenna is a low cost as there are printed circuit manufacturing methods that can be used to develop it. The surface is comfortable as it can be facilitated with various substrate materials. It has a flexible gain as different gains can be achieved just by using different feed methods and techniques. Low profile, as it has a low profile planar construction. Despite these advantages, the microstrip antenna has a few disadvantages, but not limited to narrow bandwidth, limitation on the maximum gain, low efficiency, and poor cross-polarization [3]. For this study, the researchers aim to see what differences and changes happen when the dimensions and substrates are varied. To know whether there is an improvement or impairment on the antenna, they will look at the performance parameters maximum gain, minimum gain, and S11 graph in every change of dimensions and variations in substrate. Lastly, the students will compare the results from the simulation and determine what microstrip dimension and substrate will yield the best performance parameters. Tu *et al*. [4] state that there has been a rise in research that relates to tunable radio frequency (RF) and microwave components. Reconfigurable microstrip antennas have been a common topic of this research that focus on simplifying multiple tasks in wireless communication. Using these is not only size-wise but it is also cost-efficient. The development of 4G and 5G applications, has increased the demand for reconfigurable components that can be tuned to a wide band of frequencies. Because of this their paper surveyed and gave a detailed discussion on the use of these components. They said that microstrip bandpass filter antennas are used for RF and microwave wireless communications. However, these antennas attenuate the signals found in 5G and 4G applications. With this, they stated that it can have a reconfigurable characteristic when electronic RF components are added. They also stated the microstrip antennas have been eyed by many researchers because of their compact design and because they can be directly printed on a substrate. These types of antennas can also be integrated with software systems for better customization [5]. Microstrip patch antennas have been around since the 70s, however, there are still researches aiming to improve the performance parameters of the said antenna, for instance, is the research by Ekke and Zade [6] to enhance the gain of the microstrip patch antenna, which as stated earlier is a common disadvantage of a microstrip antenna. In addition to that, despite being known to be low profile and compact, there is still research on altering the size of the antenna, such as the paper by Farzami, Forooraghi, and Norooziarab in miniaturizing the microstrip antenna [7]. With these ideas and statements, the researchers want to know what may happen if the dimension of a microstrip antenna is changed. Furthermore, what may also happen if the substrate of a microstrip antenna is also changed? Lastly, what changes may emerge if both dimensions and substrate are changed? from there they will determine what happens when these changes occur. The researchers used MATLAB [8] to simulate the microstrip antenna.

This research was compared to several studies like the study of Panda *et al*. [9], in which they designed a microstrip patch array in the shape of a pentagon. It consists of two elements that are used for applications involving 25 GHz. The length, width, and height of the microstrip are about 50, 65, and 1.5 mm respectively while the substrate they used is an FR4 epoxy. Their results show that the characteristics of the antenna such as the gain and directivity are decent enough to be used for 5G applications. With this, their study set a specific substrate for a 25 GHz antenna. This could mean that varying substrates could also have a specific performance for a specific frequency range. Ihamji *et al*. [10], created a miniature microstrip antenna that is to be used for industrial scientific and medical bands (ISM). Their antenna is set to operate 915 MHz and is used for radio frequency identification (RFID) applications. The substrate they used was FR4 and the total area of the antenna 49.33×55.7 mm^2. With this, the antenna output of their antenna produces a directivity of 1.85 dB and 1.21 dB and has good matching input impedance properties from 909 to 921 MHz. The FR4 substrate is a common substrate that is used for antennas of varying applications. With this, the researchers want to determine if other substrates can have better performances. Janapala and Nesasudha [11], used polydimethylsiloxane as a substrate for their microstrip antenna. This substrate was specifically used to operate at 2.54 GHz so that it can be used for breast cancer diagnosis. Four slabs of their substrates were used as the dielectric resonator. They tested their antenna by placing it beside a model of a female breast with or without a cancer tumor. Their research shows the significance of the substrates on the antenna. They were able to change the purpose of the antenna from being used for radio communications to a cancer diagnosis by selecting a proper substrate. In terms of altering the dimensions of the microstrip antenna, Gupta *et al*. [12] developed a T-shaped microstrip antenna. Their antenna is meant to be used for 5G applications. It can produce a high gain that is intended to operate at 28 or 38 GHz.

Marhoon and Qasem [13], were also able to design a microstrip patch antenna to be used for 5G applications. Their antenna is tunable and it can be in a single or an array microstrip patch antenna. They also used an inset feed technique which is used to access the different frequency bands found in 5G. Their antenna is made of graphene strips mainly because graphene can have an adjustable surface conductivity which can make the antenna have a varying resonant frequency. This can be done by applying a DC bias through the strips until the desired frequency is obtained. Their study shows how the substrate can change the overall functions and performance of the antenna. By analyzing the properties of graphene they were able to figure out how they can be applied to the antenna. Phonkitiphan *et al*. [14] designed a microstrip antenna in the shape of an annular ring. They also used graphene so that it can be applied for dual-band applications. They simulated their antenna using the EMCos software and designed it by using graphene-based layers for the patch and an FR4 epoxy substrate. Their study shows that their antenna can operate at two resonant frequencies. Aside from this, it has a compact design and is cost-effective. Their study shows how graphene can be used to make antennas reconfigurable. They were able to make the antenna operate at two different frequencies. They also used the FR4 substrate which proves that it is a common dielectric substrate to be used with microstrip antennas. Preddy *et al*. [15], had a different approach when it comes to designing a microstrip patch antenna. They designed their antenna by relying on carbon fiber materials. This means that the majority of their antenna is made up of fiber-reinforced plastic. They did this by fabricating immediately to carbon-fiber-reinforced plastic (CRFP) while in the composite manufacturing process. They then stated that this process gives many advantages such as reduced weight and conformation to complex curvatures. Since they used carbon fiber material which is not as reliable in terms of conductivity as compared to other materials in antenna design, they added a copper mesh to improve it.

Hamza *et al*. [16] created the first foldable origami antenna array. This array is made up of a single rigid printed circuit board whose folding capabilities come from using a hinge structure that makes it fold to 360 degrees. The folding of the antenna gives no degradation in its performance. Their antenna consists of four patches and the hinge at the center and an FR4 dielectric substrate. The proposed antenna gives more opportunities in antenna design mainly because of its physically reconfigurable characteristics. It was proven that the antenna can function properly even if the dimensions are changed. This means that the antenna can be modified for different purposes by simply folding it. For this study, the researchers will analyze the effects of varying dimensions to further prove that this antenna is significant for different applications. Hou *et al*. [17] proposed an end-fire antenna array. It is series fed as well as cavity-backed that has high gain. The use of the cavity makes it physically compact since it can be embedded in the ground plane. The antenna is fed by a microstrip line whose dielectric substrate is air. To increase the end-fire gain, they optimized the coupling level of the cavity slot elements and the microstrip line. Their results show that the gain of the antenna is 11.5 dBi. Although their study is not focused on a microstrip patch antenna, they were able to utilize a microstrip line in combination with the end-fire antenna. This means that the microstrip lines can be used to improve the performance of an antenna. It is important to determine the type of dielectric substrate to be used for it. This could be further backed up by Li and Chen [18] since they designed an antenna that is to be applied for 5G applications. The antenna is a shared-surface dual-band and used the characteristics mode analysis. The surface of the antenna is a combination of a metasurface and a partially reflective surface at the S-band and Ka-band respectively. Its resonant mode is activated by a microstrip by using substrate integrated waveguide (SIW-fed) slots. The output of their antenna gives a 10 dB impedance bandwidth and a 7.27 dBi to 10.44 dBi gain at the S-band and an 11.8 dBi to 14.68 dBi at the Ka-band. With this, their research again shows how microstrips can be used to boost the performance of the antenna. Chen *et al*. [19], designed a microstrip filter antenna. What is new about this is that they used an H slot that is coupled to the antenna. The microstrip lines are fed to these slots on the ground plane. It also feeds the radiating patches which then influence the radiation pattern of the antenna. With this, the bandwidth of the antenna is 0.78 GHz which operates from 3.02 to 3.8 GHz. Li *et al*. [20], proposed a microstrip antenna array that has dual-polarization and at the same time has a dual-mode orbital angular momentum (OAM). This is done by using an antenna array that consists of four elements and each of them is individually excited. Each of these elements is aperture coupled microstrip that has a low profile of a tenth of a wavelength. They are excited by using a U-shaped and M-shaped microstrip feedline. With this, the antenna produces an average impedance matching over 5.4 GHz to 5.6 GHz. What is important in this study is that they were able to change the type of polarization of the antenna that could now be applied to more applications.

Dang *et al*. [21] have developed an antenna that is to be applied for wireless local area network/worldwide interoperability for microwave access (WLAN/WiMax) applications. The antenna is a triple-band microstrip slot antenna that has a simple structure compared to other existing antennas with triple-band characteristics. It consists of a microstrip feed line, a substrate, and a ground plane. The substrate they used is an FR4 substrate which is common among many designs. The output of their design shows that the antenna has three impedance bandwidth which is 600 MHz, 430 MHz, and 1,300 MHz which is centered at 2.7 GHz, 3.5 GHz, and 5.6 GHz respectively. Their study shows how important the microstrip antennas are for 5G. They are more easily reconfigurable as well as have a simple design. This means that it is very important to make further developments with these antennas to ease into the transition of 5G. Yang and Rahmat-Samii [22] designed patch antennas with switchable slots (PASS) for various purposes. They aim to design the PASS capable of wireless communication. They have designed distinct antennas, each with different radiation features to show how versatile a PASS is. It is noted in the paper that in the design of the antennas, control of frequency ratio and tuning of input impedance is important. As a result, the dual-band performance has the potential to be used for GPS while circular polarization has the potential to be used for WLAN. Additionally, the designed PASS can be utilized for mars missions as it ensures performance. Mydhili *et al*. [23] presented a paper with their design and simulation of a microstrip patch antenna array with an operating frequency of 1.48 GHz. They implemented four antenna arrays, which are a singular rectangular patch, 1×4 rectangular patch, 2×2 rectangular patch, and 4×4 rectangular patch, with a substrate of FR4 dielectric. The software used for this is Computer Simulation Technology (CST) microwave studio for both designing and simulation. From the results, it can be seen that the 4×4 rectangular patch has the greatest directivity among them. Therefore, it can be concluded that in an antenna array, increasing the number of arrays means an increase in the directivity of the antenna. Additionally, an antenna array is better in performance than a singular-fed antenna.

Ghosh *et al*. [24], designed a slotted microstrip antenna with the use of the software Zeland as their simulator. In their design, the rectangular microstrip antenna has a dimension of 18×26×12 mm and has a substrate of FR4. The resonant frequency of this antenna is 3.5 GHz, without any slot inserted into it. In gathering their results, they simulated 4 different situations which are without slot, with one slot, with two slots, and with three slots. Their results show that as the slots increase, the operating frequency and gain decrease. Without a slot, the frequency is at 3.5 GHz and the gain is 3.96 dB, while at three slots is 2.72 GHz and 0.67 dB. Sudarsan and Prabhu [25] designed and simulated a microstrip patch antenna for the frequency range of 1 to 2 GHz. For their designing, modeling, and simulating, they used the Zeland IE3D software and determined the parameters to see whether their designed antenna operates well. With the dimensions of 81.8×82.7 mm. their antenna has the performance parameters of S11, gain, and antenna efficiency equal to -27.439 dB, 6.25 dB, and 78.16% respectively. The resonant frequency of the said antenna is at 1.176 GHz and the substrate of FR4. Kumar *et al*. [26] discussed different feeding methods and different techniques to enhance a microstrip patch antenna's gain and bandwidth. Lastly, introducing a dual-feed structure of the antenna will enhance the bandwidth. Li and Luk [27] developed a microstrip antenna array for wideband applications. Their designed antenna is low-cost and made for the operating frequency of 60 GHz [27]. Microstrip antennas are popular because they are lightweight, low profile, and easy to integrate with microwave circuits. To design microstrip antennas several parameters should be taken into consideration. It is challenging to optimize this parameter [28]. One way to optimize it is to use rough set theory. This theory is a mathematical tool that deals with the vagueness and uncertainty of data. Since its discovery, it has been used in several fields like pattern recognition, data mining, and decision-making. Rough set theory is based on the concept of lower and upper approximation of sets. The lower approximation contains the elements that are certain in the set. While the upper approximation contains the set of elements that are possible in a set. Microstrip antennas have various parameters like substrate thickness, patch size, and dielectric constant, that affect their performance. The optimization of these parameters involves determining the optimal combination of these parameters. There are traditional techniques like genetic algorithms and gradient-based methods. However, these methods are incapable of handling uncertain or incomplete data. Rough set theory can be used to handle incomplete data for a microstrip antenna. This theory can be the framework for handling incomplete data by handling the essential attributes for classification [29]. Using the rough set theory in the design optimization of a microstrip antenna has several advantages. This theory provides a framework for handling uncertain or incomplete data. It can also identify the parameters that can affect the performance of the antenna which in turn reduces design complexity [30].

A microstrip patch antenna is a composition of any metal of any geometry from one side of a printed circuit board (PCB) substrate while the other side is grounded. Now, this antenna is a choice in different applications as it has low weight, has low cost, and can be conformed to any geometrical shape. Extensive studies are being implemented to enhance the performance and parameters of this antenna. Additionally, the common trends in research for this antenna today are wide bandwidth performance and multi-band functionality [31]. Because of these ideas, researchers want to know whether the dimensions of microstrip patch antennas and substrates improve or impair the said antenna. Figure 1 shows the geometrical shapes of microstrip patch elements. Figure 1(a) shows the rectangle, Figure 1(b) shows square, Figure 1(c) shows circle, Figure 1(d) shows triangle, Figure 1(e) shows donut and Figure 1(f) shows dipole system designs.

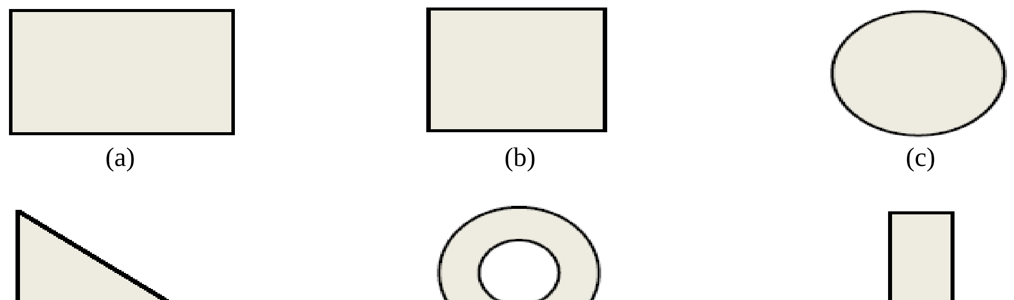

Figure 1. Geometrical shapes of microstrip patch elements; (a) rectangle, (b) square, (c) circle, (d) triangle, (e) donut, and (f) dipole

The structure of the paper is that section 1 shows the introduction of the research. Section 2 shows the methods of the research. Section 3 provides a results and discussion of the paper. Section 4 gives the conclusion of the paper.

2. METHOD

The researchers used the antenna designer app to set the specific dimensions of the antenna that operates under 500 MHz. After this, they changed the length of the antenna by increasing it by 0.1 m three times which are 0.2878 m, 0.3878 m, and 0.4878 m. This antenna had an air substrate thickness of .0059958 m. They then recorded the maximum gain, minimum gain, and lowest S11 value that happens between 450 MHz and 550 MHz. This was then repeated for three more substrates which are teflon, foam, and polystyrene. These substrates were chosen mainly because it has less computational time in MATLAB. For varying the width of the antenna, the substrate thickness was changed to .0069958 m and the values used for the width are 0.3747 m, 0.4747 m, and 0.5747 m. They then repeated the same procedure when the length was varied. To better represent this, Figure 2 shows the flowchart for the method.

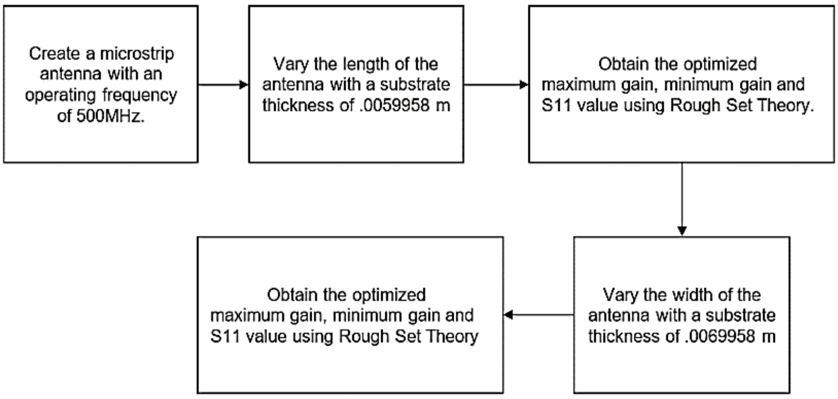

Figure 2. Flowchart of the method

3. RESULTS AND DISCUSSION

The geometry information of a microstrip antenna gives the configurations and physical dimensions of the antenna. This information plays an important role in determining the performance characteristics and electrical properties of the system. The parameters of the geometry information are as follows: I=length, w=width, I_1=ground plane length, w_1=ground plane width, I_2=notch length, w_2=notch width, and w_3=strip line width. The geometry information of the antenna is shown in Figure 3.

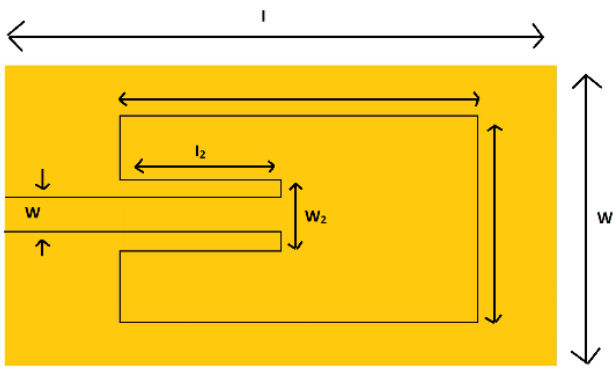

Figure 3. Geometry information of the antenna

Tables 1 and 2 show the values obtained when the length was varied while the width was held constant. On the other hand, Tables 3 and 4 show the results when the width was varied. As can be seen in

Table 1, as the length of the antenna increases, the maximum gain, and the minimum gain decrease. This also applies to S11. However, since the researchers chose a bandwidth from 450 to 550 MHz where the S11 is based, the obtained value in the table is only the lowest value found in that range. This means that varying the length can drastically change the operating frequency of the antenna. This is also present when the substrate used is teflon. As seen in the table, the maximum gain and S11 fluctuate as the length increases. It decreases at 0.3878 m and increases at 0.4878 m, this could mean that there should be a specific length to obtain the maximum gain and the lowest S11 value. It could also mean that the length must be shorter than the width to increase gain and lower the S11. The first part of the simulation has a width of 0.3747 m and a substrate thickness of 0.0059958 m as shown in Tables 1 and 2. The second part of the simulation has a length of 0.2878 m and a substrate thickness of 0.0069958 m as shown in Tables 3 and 4.

Table 1. Varying length with substrates air and teflon

	Air			Teflon		
Length	Maximum gain (dBi)	Minimum gain (dBi)	S11	Maximum gain (dBi)	Minimum gain (dBi)	S11
0.2878	10.1	-31	-24.28 dB at 500 Mhz	7.83	-31.5	-7.404 dB at 545 MHz
0.3878	5.45	-18.9	-0.08846 dB at 550 Mhz	5.61	-23.6	-3.678 dB at 550 MHz
0.4878	6.55	-8.1	-0.1797 dB at 550 Mhz	8.28	-17.2	-3.994 dB at 550 MHz

Table 2. Varying length with substrates foam and plexiglas

	Foam			Flexiglass		
Length	Maximum gain (dBi)	Minimum gain (dBi)	S11	Maximum gain (dBi)	Minimum gain (dBi)	S11
0.2878	10.1	-29.4	-13.21 dB at 490 Mhz	8.26	-40.1	-2.69236 dB at 475 MHz
0.3878	5.56	-19.4	-0.09182 dB at 550 Mhz	7.82	-33.9	-5.8863 dB at 475 MHz
0.4878	6.84	-22.3	-0.22955 dB at 550 Mhz	8.34	-20.7	-4.89331 dB at 475 MHz

Table 3. Varying width with substrates air and teflon

	Air			Teflon		
Width	Maximum gain (dBi)	Minimum gain (dBi)	S11	Maximum gain (dBi)	Minimum gain (dBi)	S11
0.3747	10.1	-31	-24.28 dB at 500 MHz	7.88	-32.3	-3.515 dB at 550 MHz
0.4747	10.5	-28.24	-14.08 dB at 500 MHz	6.3	-17.9	-1.226 dB at 550 MHz
0.5747	9.64	-25	-5.23 dB at 500 MHz	5.57	-35	-8.805 dB at 500 MHz

Table 4. Varying width with substrates foam and plexiglas

	Foam			Plexiglas		
Width	Maximum gain (dBi)	Minimum gain (dBi)	S11	Maximum gain (dBi)	Minimum gain (dBi)	S11
0.3747	10	-27	-3.47828 dB at 500 MHz	8.24	-32.3	-4.2116 dB at 475 MHz
0.4747	10.4	-24.8	-2.83978 dB at 500 MHz	5.62	-31.9	-10.620 dB at 500 MHz
0.5747	7.67	-33.4	-2.97686 dB at 500 MHz	5.71	-24.4	-15.081 dB at 450 MHz

For Table 2, it can be seen that the results are also similar to Table 1, where an increase in length is the decrease of the performance parameters maximum gain, minimum gain, and S11. For Table 3, which shows the results of changing the width for air and teflon substrates, it can be seen that increasing the width also decreases the maximum gain, minimum gain, and S11. The bandwidth analysis from the simulation is from 450 MHz to 550 MHz. This analysis refers to the process of evaluating the frequency range over which a component can effectively operate. From the analysis, it was discovered that the decrease is not as significant as compared to varying the length. This could mean that if a certain parameter should be slightly adjusted then increasing or decreasing the width can be a solution. For teflon, the maximum gain decreases and the minimum gain fluctuates. However, when the width of the antenna is 0.5747 m, the lowest S11 value happens at 500 MHz which proves that there is a specific dimension where teflon substrates can work with the desired requirement. For Table 4, it can be seen that as the width increases, the maximum gain, minimum gain, and S11 also decrease. However, at the width of 0.4747 m and substrate foam, there is a slight increase in maximum gain, minimum gain, and S11, despite an increase in width. To make sure that this result is accurate, the students simulated these settings twice, yielding the same results. Compared to the tables, it can be seen that changing the substrate thickness also affects how the microstrip antenna functions.

The reflection coefficient vs frequency graphs are also known as reflection spectrum or frequency response and provide information on how the system responds to various frequencies of the input signal. MATLAB was used to graph the reflection coefficient versus frequency graphs of the system at .2878 meters length and .5747 meters width. Figure 4 shows the reflection coefficient vs frequency graphs.

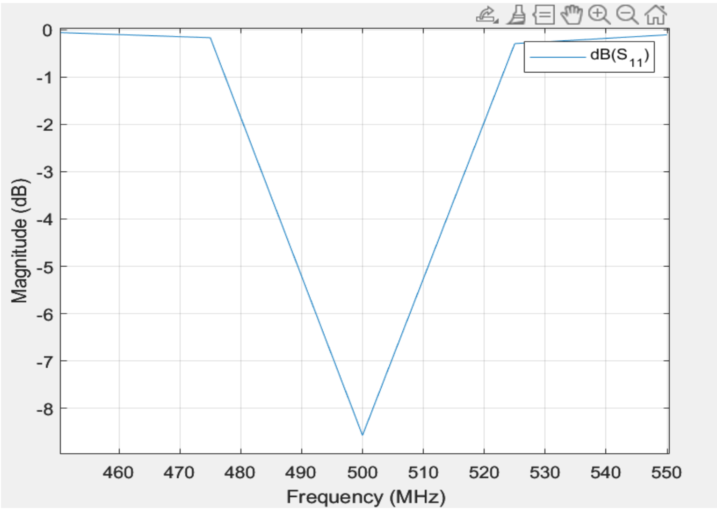

Figure 4. Reflection coefficient vs frequency graphs

4. CONCLUSION

This paper performed a simulation to determine what are the effects of varying dimensions and changing substrates on a microstrip antenna. For the simulation, the researchers used MATLAB antenna designer app to model their antenna, change the dimensions, and alter the substrates. In total, the researchers simulated twice to gather their results. The first simulation is about a constant width and substrate thickness while the length increases. The second simulation is about a constant length and an increased substrate thickness than the first simulation while the width increases. For the substrates, the student used four substrates for this paper which are air, teflon, foam, and plexiglas. For the bandwidth, the researchers only used frequencies between 450 MHz to 550 MHz. To compare the microstrip patch antennas, the researchers gathered and compared the performance parameters maximum gain, minimum gain, and S11. This study focused on identifying the effects of varying the length, width, and substrate on the performance of the microstrip antenna. They used four types of substrates which are air, teflon, foam, and polystyrene. They also used three values for the length and the width of the antenna and used two values for the thickness of the substrate. It was analyzed with the radiation pattern and the S11 from 450 MHz and 550 MHz. With this, further research should be done for other types of substrates such as polystyrene and FR4. As was previously mentioned, the three substrates were chosen mainly because MATLAB did not have a hard time computing the S11 graph or because it has less RAM usage as compared to the other unused substrates. Furthermore, the S11 values should be graphed to a wider bandwidth. Since the frequency range is only from 450 MHz to 550 Mhz, the operating frequency or the lowest S11 value cannot be completely computed because of it. This is important as it determines where the substrate with a specific length, width, and height can operate properly. It helps determine the proper effect of varying the length, width, and type of substrate. This paper could be further improved if other parameters are involved. This research is pure simulation only using MATLAB. In actual use the reflection coefficient can still be improved by refining the placement to make sure that the antenna is correctly installed and positioned.

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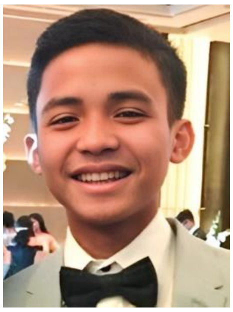

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