MICRO-PATCH ANTENNA DESIGN AND FREQUENCY COMPARISON: EFFICIENCY AND PERFORMANCE ANALYSIS

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***Abstract*— This research paper provides an analysis of the efficiency and performance of a micro patch antenna design. The paper examines the design of a micro patch antenna, which is a form of a planar antenna. It also investigates the effects of frequency variation on the antenna's performance. In conclusion, this study provides a comprehensive analysis of the efficiency and performance of a micro patch antenna design and frequency comparison. The results of this research can be used to develop and optimize the antenna for various applications, while also helping to improve its efficiency and performance.**

Keywords—micro patch antenna, frequency variation, efficency, performance, gain, antenna design, antenna stability, band width, return loss, polarization, the voltage standing wave ratio,

I. INTRODUCTION

In today's communication environment, the significance of effective and high-performance tiny patch antennas cannot be stressed. The requirement for antennas that can deliver dependable signal transmission and reception while taking up little space is growing along with the demand for wireless connectivity. Micro patch antennas are a desirable option for many applications because they provide several advantages over conventional antennas. In the realm of wireless communications, microstrip patch antennas are becoming more and more common because of their compact design, low price, and simplicity of manufacture. Mobile phones, radio and television broadcasts, satellite communications, and other uses all make use of these antennas. They can also be used in applications with height restrictions, including mobile phones and portable electrical gadgets, thanks to their modest profile [1][2]. Designing and evaluating a microstrip patch antenna's effectiveness and performance across a range of frequencies is the goal of this thesis. Micro patch antenna design demands considering several variables. The antenna's electrical characteristics, to the same agree the loss tangent and dielectric constant, are influenced by the substrate material choice, which is why it is so important. The operating frequency, bandwidth, and radiation properties of the antenna are influenced by the patch geometry selection, including form and size. The antenna's impedance matching, and radiation efficiency are also impacted by the feeding method used. Engineers can precisely tailor micro patch antennas to satisfy application needs by carefully examining these design factors [3]. The efficiency, bandwidth, and gain of an antenna can be maximized, leading to better signal transmission and reception [4]. In this thesis study, sophisticated simulation and analysis methods will be used to meet these objectives. The micro patch antennas will be modeled and virtually tested using computer-aided design (CAD) software like CST Studio Suite. The program makes it possible to depict an antenna's physical composition accurately and provide details on how it behaves electromagnetically. The optimization process is aided by the ability to simulate the impact of design modifications and parameter changes. This thesis study's comparative investigation of various operating frequencies will play a crucial role. The ideal operating frequency can be identified by evaluating the antenna's performance throughout a variety of frequencies. To determine which frequency delivers the best all-around performance, variables like impedance matching, radiation effectiveness, and bandwidth will be assessed. The outcomes of this study will progress the design of micro patch antennas and deepen our comprehension of their effectiveness and performance traits. In summary, the purpose of this thesis project is to construct and evaluate micro patch antennas with a particular emphasis on their effectiveness and performance at various frequencies. The study will aid in the optimization of micro patch antenna designs and make it easier to choose the best operating frequency by utilizing simulation and measuring approaches. The theoretical background, methods, experimental setup, results, and discussion will all be covered in greater detail in the next sections of this thesis, giving readers a thorough grasp of micro patch antenna design and its significance for contemporary communication technologies.

II. RELATED LITERATURE

The demand for effective and high-performance antenna systems has increased because of the rapid expansion of wireless communication in recent years. Due to its small size, simplicity of integration, and superior radiation characteristics, micro patch antennas have become a prominent contender as a solution. The design and performance analysis of micro patch

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antennas has been the subject of in-depth study, and a wealth of literature studies have provided invaluable insights in this area [5]. Various characteristics, like as patch dimensions, substrate material qualities, and feeding methods, must be optimized while creating micro patch antennas. To improve the performance of the antenna, researchers have investigated fractal shapes, layered configurations, and sophisticated feeding systems. The effectiveness and radiation patterns of various micro patch antenna designs operating at various frequencies have been compared in research [6]. Efficiency is important since it has a direct impact on the antenna's ability to transmit and receive signals. The goal of numerous literary works has been to maximize radiation efficiency while minimizing losses to increase the effectiveness of micro patch antennas. To increase overall efficiency, strategies like impedance matching, using premium substrates, and developing new feeding arrangements have been investigated [7]. Analyzing performance is essential for evaluating the capabilities of micro patch antennas. Studies in the literature have looked at variables including gain, directivity, bandwidth, and radiation patterns to assess how well the antenna performs under various operating circumstances. Advanced measuring methods and simulation tools have been used to validate the theoretical conclusions and offer real-world understanding of the behavior of the antenna. Additionally, a key component of research on micro patch antennas is the comparison of frequency characteristics. Numerous bands, including L-band, Ku-band, X-band, C-band, and S-band, have been researched to determine the appropriate frequency range for a particular application. Studies that compare frequencies have looked at their benefits and drawbacks, considering things like bandwidth, interference, and propagation characteristics. [8]. In conclusion, the literature on frequency comparison and micro patch antenna design provides a thorough overview of the developments in this area. Researchers have significantly improved the effectiveness and performance of micro patch antennas through intensive research and analysis. This corpus of research lays the groundwork for fresh, ground-breaking investigations into the creation of wireless communication technologies for the next generation.

III. METHODS

A. *Micro-patch antenna design*

Numerous wireless applications, including WLAN, Wi-Fi, Bluetooth, and many more, utilize microstrip antennas. A fundamental microstrip patch antenna is made up of a conducting patch, a ground plane, and a substrate made of a dielectric substance with a predetermined dielectric constant. In comparison to the substrate and ground, a patch is smaller in size. The resonance frequency and dielectric constant value affect the size of a microstrip patch antenna [8].

By cause of their low cost, simple production, and compact size, microstrip antennas are among the most significant antenna types that satisfy these characteristics. Despite being created in 1950, the microstrip antenna only really gained popularity in the 1970s. One of the most advanced antenna types in the last fifteen years are microstrip antennas. These antennas are physically robust when used on hard surfaces and can be used to non-planar surfaces as well [9]. The development of useable antennas with low loss tangent, a good substrate, and appealing thermal and mechanical qualities gained momentum in the 1970s. Howel and Munson created the first antenna that was used in everyday life. These investigations have led to the development of low-cost, extremely lightweight, low-volume microstrip antennas that are aesthetically pleasing and can be readily integrated into the surfaces on which they are mounted [10].

1) Parameters changing according to the use of antenna design: This title looks at critical factors that vary depending on how an antenna is used. Return Loss, Gain, Band Width, Polarization, The Voltage Standing Wave Ratio (VSWR), and Efficiency are all important factors in determining antenna performance. These parameters determine crucial antenna attributes including efficiency, transmission capacity, and routing capabilities. This part investigates how these six factors can alter based on the use of antenna design and how their interactions might be evaluated. As a result, it will be clearer how these characteristics might be adjusted to produce optimal outcomes in antenna design.

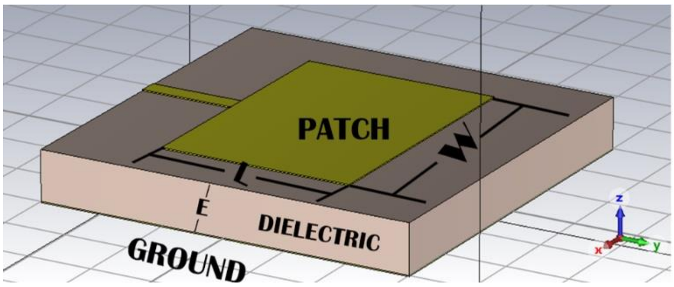

Fig. 1 General Micro Patch Antenna

a) Return Loss: Return loss is a crucial factor to take into account when designing an antenna.The amount of charge lost, or the amount of charge returned from the reflection, is indicated by the return loss, which is a parameter. Standing waves develop in antennas where there is an impedance discrepancy bounded by the transmitter and the antenna. As a result, the return loss is a metric that shows how well the transmitter and antenna match [10]. The fact that this dimension, which is basically unitless, is scaled down to the logarithmic scale is indicated by the use of the unit dB. An antenna can function in that frequency range if its return loss is less than -9.95. As seen below, the return loss is calculated in dB [1]. RL stands for return loss. Reflection Coefficient is referred to as Γ. Amplitude of the reflected wave is called to as V_r. V_i represents for amplitude of the transmitted wave. Z_{in} instands for input impedance. The Characteristic impedance is expressed to Z_s. where $\Gamma = 0$,RL is ∞,where Γ = 1 , RL is 0.

$$RL = -20 \log|\Gamma| \,(dB) \qquad (1)$$

$$\Gamma = \frac{V_r}{V_i} = \frac{Z_{in} - Z_s}{Z_{in} + Z_s} \qquad (2)$$

b) Gain: An antenna's performance is measured and described using a key parameter called gain. The power gain is a measurement that clearly shows the antenna's ability to focus energy in a definite direction as well as its heating performance. The capacity of an antenna to concentrate power within a constrained angular region is used to determine its gain [10]. The power density in the direction of the radiation peak is increased thanks to the gain of a genuine antenna. Gain is a significant factor to consider when assessing the effectiveness of the antenna in this regard [9].

c) Band Width: Bandwidth refers to the operational frequency range within which an antenna complies with specific performance standards. The bandwidth is determined by the frequency ranges on either side of the central frequency, where various characteristics of the antenna, such as gain, input impedance, heating, and polarization, are established. Quantitatively, the bandwidth is calculated by subtracting the lowest acceptable frequency from the highest acceptable frequency. Bandwidth serves as a measure of the capacity of a transmission medium or communication channel. It represents the maximum frequency signal that can be transmitted through a channel. A wider bandwidth allows for a higher volume of data to be transferred within a given time period [10]. When measuring the bandwidth of antennas, measurements with reflection coefficients around -10dB are typically used. Antennas are categorized into three groups based on their bandwidth ratios: narrowband, wideband, and ultra-wideband [9]. Finding the antenna's bandwidth is a crucial step in figuring out the best operating conditions for the device and selecting the appropriate antenna for the operation that will be used most effectively. The antenna's operational frequency, which found on a number of factors, is displayed as center frequency, low frequency, and high frequency in three portions. The antenna can be referred to as wideband or narrowband depending on how closely the lower and upper frequencies are spaced apart. This antenna is referred to as broadband if the ratio of the two frequencies to one another is two or higher. It is referred to as narrowband if the lower and higher frequencies are 5% of the center frequency. Typically, narrowband antennas are used in communication to block signals at various frequencies. Broadband antennas can be utilized in communication as well as radar, remote imaging, and satellite communication since they can function within the desired performance standards in a variety of frequencies [11]. f_H stands for high frequency. f_L stands for low frequency. f_c stands for center frequency. The bandwidth has been determined, as shown below [12].

$$BW_{broadband} = \frac{f_H}{f_L} \qquad (3)$$

$$BW_{narrowband(\%)} = \frac{f_{H-}f_L}{f_c} x100 \qquad (4)$$

d) Polarization: The term "polarization" describes how the electric field vector changes over time. There are three different types of polarization: circular, elliptical, and linear. The polarization of the wave that the antenna emits is known as antenna polarization. In the case of directional antennas, the polarization of the wave in the direction of radiation or, alternately, the wave's polarization in the direction of highest gain, determines the antenna's polarization [9].

e) Efficency: There are multiple efficiencies associated with the antenna. In general, antenna efficiency can be defined as a combination of different efficiency factors. Total antenna efficiency e_0 uses the losses due to the structure of the antenna and the losses at the input terminal. Total efficiency; The reflection efficiency e_r, the transmission efficiency e_c and the dielectric efficiency e_d are given in the expression in (5). As seen here, there are three main factors that determine antenna efficiency [9].

$$e_0 = e_r e_c e_d \qquad (5)$$

f) The Voltage Standing Wave Ratio: An impedance mismatch arises when the impedance of the transmission line, the source, and the antenna are not in alignment with each other. This discrepancy occurs because the antenna's input impedance typically differs from the impedance of the power source connected to it. As a result of this mismatch, a portion of the power sent to the antenna is reflected back. Additionally, when there is a mismatch at the connection point, power reflection also takes place. The VSWR refers to the ratio betwixt the maximum voltage produced by the reflected and outgoing voltage waves at the antenna input and the minimum voltage [12]. The VSWR demonstrates the compatibility of the antenna input impedance with the transmission line's characteristic impedance. The VSWR reaches infinity, which is the least desirable condition, where the reflection coefficient is either 1 or -1. It gives the value of 1 to VSWR when the desired state is reached [9].

$$VSWR = \frac{V_{max}}{V_{min}} = \frac{1 + |\Gamma|}{1 + |\Gamma|} \qquad (6)$$

B. Design of antennas at different frequencies using the CST program

The CST program will be used to obtain the antenna design. Simulation software like the CST program, which is commonly used in antenna design, is a crucial tool for modeling and evaluating intricate antenna systems. This section looks about how the CST program may provide precise and optimal antenna designs.

The software suite CST STUDIO SUITE has developed since its initial release in 1998 into a complete simulation tool, able to handle not only electromagnetic simulations but also activities relating to temperature, mechanical stress, or circuit modeling. In order to ensure a first-time-right design, it is required to simulate not only individual components but also entire systems due to the complexity of today's antenna systems. This pattern has been apparent for a while and is probably going to become more significant in the future. As a result, it was elevated to the top priority on CST's roadmap [13].

The parameters that need to be calculated while designing the microstrip patch antenna are formulated [14]. First, the patch width calculation is calculated with the following formula. Here W represents the patch width. c stands for velocity of light. ϵ_r stands for dielectric constant. f_r represents the operating frequency.

$$W = \frac{c}{2f_r\sqrt{\frac{\epsilon_r + 1}{2}}} \qquad (7)$$

Patch length calculation is made with the following formula. Here L represents the patch length. L_{eff} represents the effective length. ΔL stands for length extension.

$$L = L_{eff} - 2 * \Delta L \qquad (8)$$

The following formula is applied to find the effective length parameter in the patch length. The new parameter in this formula is Effective dielectric constant and is expressed as.

$$L_{eff} = \frac{c}{2f_r\sqrt{\epsilon_{reff}}} \qquad (9)$$

In order to apply the Effective length formula, the Effective dielectric constant value must be found. It is found by applying the following formula. Here, the h value is the Height of dielectric material.

$$\epsilon_{reff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2}[1 + 12\frac{h}{2}]^{-1/2} \qquad (10)$$

The Length extension calculation is done as follows.

$$\Delta L = 0.412 * h\{\frac{(\epsilon_{reff} + 0.3)(\frac{W}{h} + 0.264)}{(\epsilon_{reff} - 0.258)(\frac{W}{h} - 0.8)}\} \qquad (11)$$

The following formula is used to calculate the length and width of the ground plane.

$$L_g = 2 * L \qquad (12)$$
$$W_g = 2 * W \qquad (13)$$

Antenna design studies were carried out at 3 different frequencies using the CST program. Antenna designs with 3 different frequencies are 3.5 GHz, 2.4 GHz and 1.8 GHz.

Because the simulation results of the micro-patch antenna, which were modeled with numerical values derived from theoretical calculations, were not at the intended level, several parameters were also adjusted to produce adequate results.

a) 1.8 GHz antenna design: Some values need to be known for microstrip patch antenna design. The following values were found by using the formulas in the previous section.

TABLE I.

1.8 GHz antenna	1.8 GHz antenna parameters	
	Criterion and Definition	***Equivalent***
	Material for the dielectric substrate	FR-4
	Dielectric Constant	4.3
	The substrate's thickness	0.035mm
	The substrate's height	1.6mm
	The frequency of operation	1.8GHz
	The patch's width	51.156mm
	The patch's length	39.768mm
	The ground plane's length	80mm
	The ground plane's width	100mm

Table 1- 1.8GHz antenna design parameters

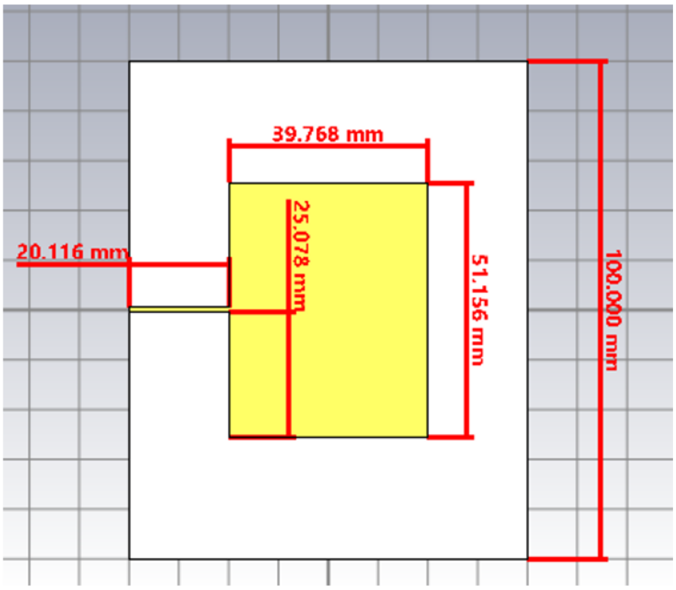

Fig. 2- 1.8Ghz antenna design, length measurements

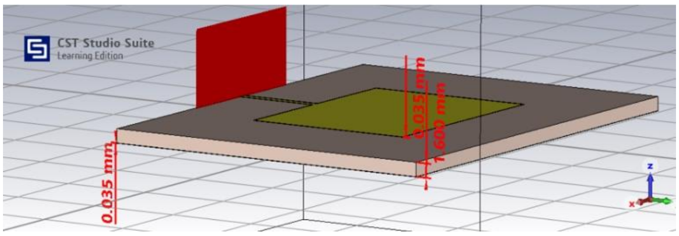

Fig. 3- 1.8 GHz antenna design, thickness measurements

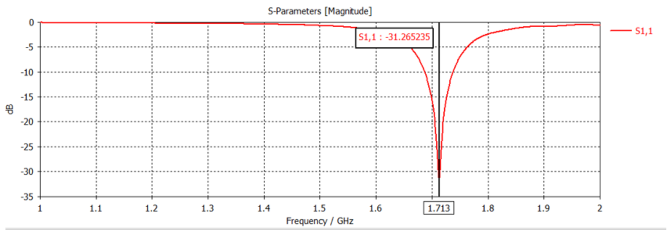

Fig. 4- 1.8GHz S-Parameters

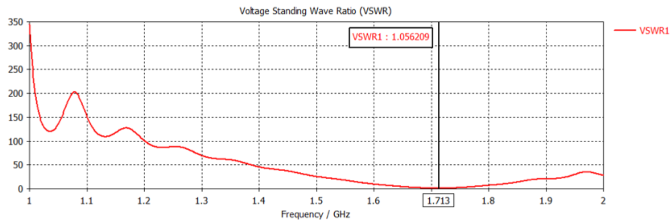

Fig. 5 VSWR for 1.8GHz

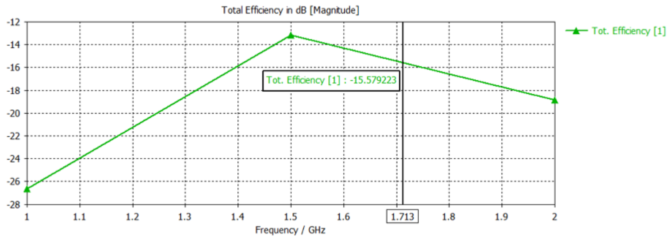

Fig. 6 Total Efficiency for 1.8GHz

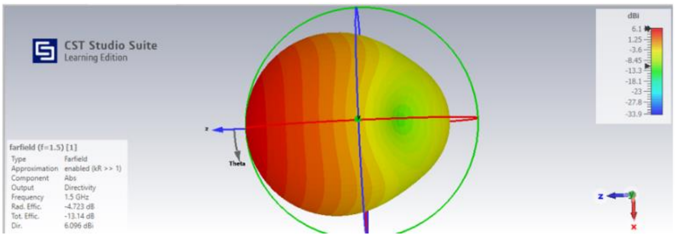

Fig. 7 Three-dimensional gain graph of a coaxial powered antenna for 1.8GHz

b) 2.4 GHz antenna design: Some variables must be understood beneficial to construct a microstrip patch antenna. Using the formulas in the previous section, the following values were discovered.

TABLE II.

2.4 GHz antenna	**2.4 GHz antenna parameters**	
	Criterion and Definition	***Equivalent***
	Material for the dielectric substrate	FR-4
	Dielectric Constant	4.3
	The substrate's thickness	0.035mm
	The substrate's height	1.6mm
	The frequency of operation	2.4GHz
	The patch's width	36.489mm
	The patch's length	28.483mm
	The ground plane's length	56.966mm
	The ground plane's width	72.979mm

Table 2- 2.4GHz antenna design parameters

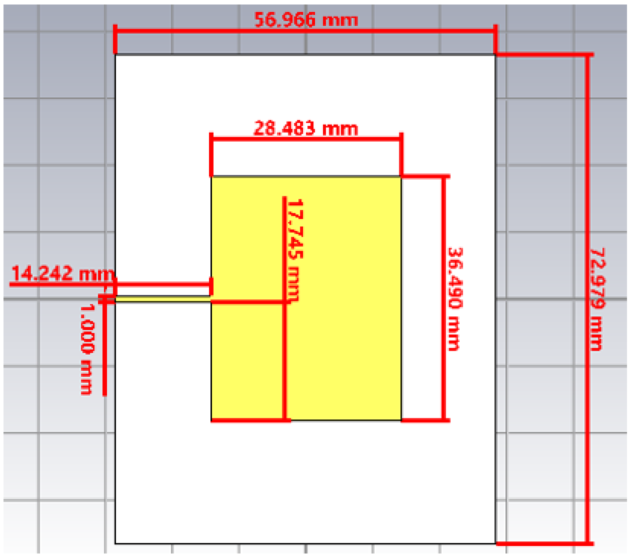

Fig. 8- 2.4 GHz antenna design, length measurements

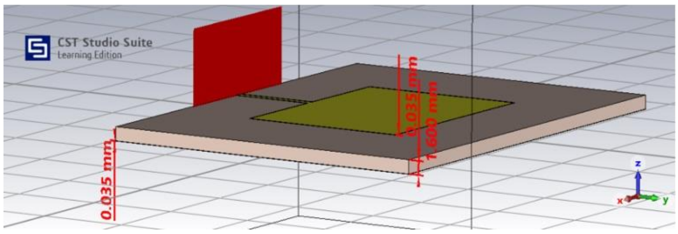

Fig. 9-2.4 GHz antenna design, thickness measurements

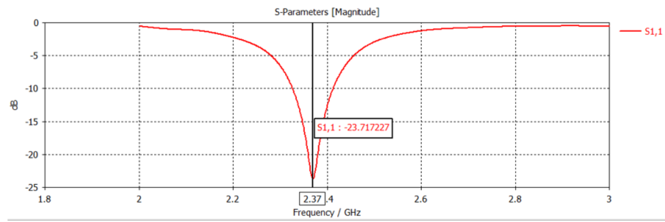

Fig. 10- 2.4GHz S-Parameters

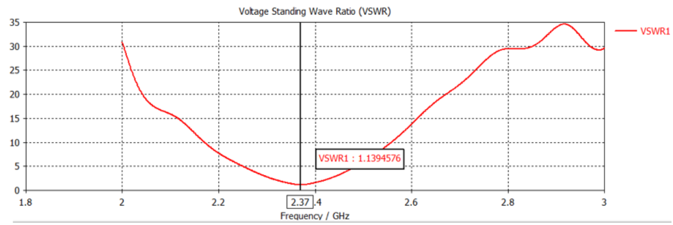

Fig. 11 VSWR for 2.4GHz

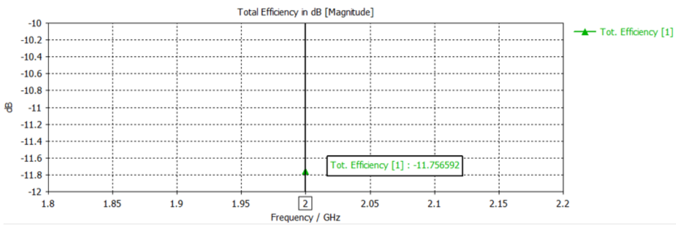

Fig. 12 Total Efficiency for 2.4GHz

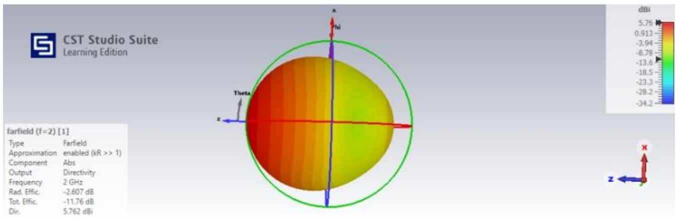

Fig. 13 Three-dimensional gain graph of a coaxial powered antenna for 2.4GHz

c) 3.5 GHz antenna design: For the arrangement of a microstrip patch antenna, some values must be known. Using the formulas from the previous section, the following values were discovered.

TABLE III.

3.5 GHz antenna	**3.5 GHz antenna parameters**	
	Criterion and Definition	***Equivalent***
	Material for the dielectric substrate	FR-4
	Dielectric Constant	4.3
	The substrate's thickness	0.035mm
	The substrate's height	1.6mm
	The frequency of operation	3.5GHz
	The patch's width	25.578mm
	The patch's length	19.485mm
	The ground plane's length	38.970mm
	The ground plane's width	51.156mm

Table 3- 3.5GHz antenna design parameters

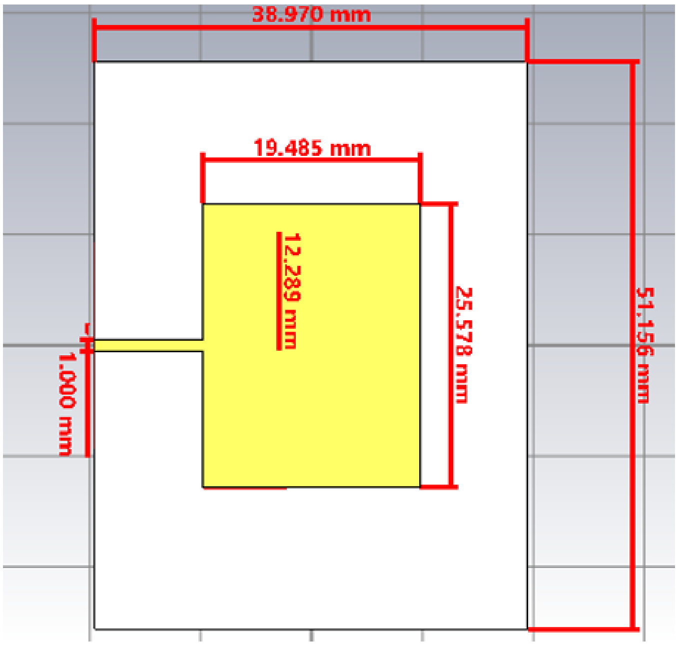

Fig. 14- 3.5Ghz antenna design, length measurements

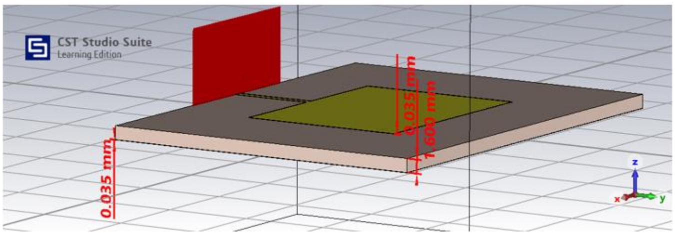

Fig. 15- 3.5 GHz antenna design, thickness measurements

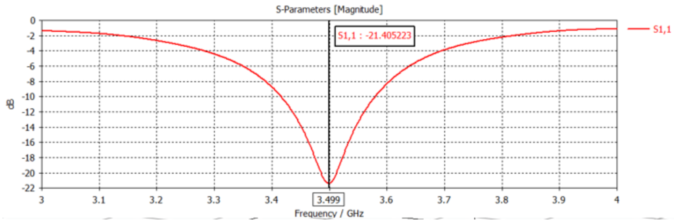

Fig. 16- 3.5GHz S-Parameters

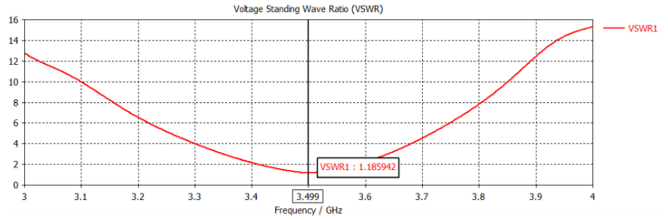

Fig. 17 VSWR for 3.5GHz

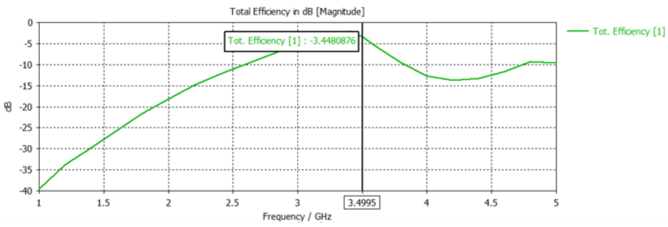

Fig. 18 Total Efficiency for 3.5GHz

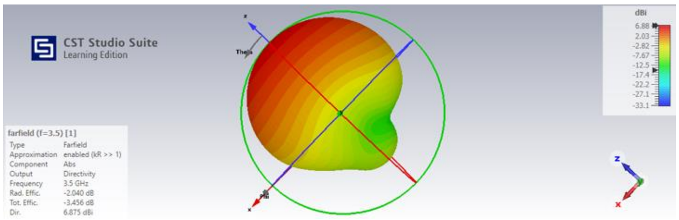

Fig. 19 Three-dimensional gain graph of a coaxial powered antenna for 3.5GHz

C. Comparison of antennas obtained at different frequencies in terms of efficiency and performance

The outcomes of the antenna designs will be examined in this section. This evaluation is broken into two sections: performance and efficiency.

a) Efficiency: It is aimed to find efficiency in antennas designed by looking at the bandwidth obtained from the S-parameter.

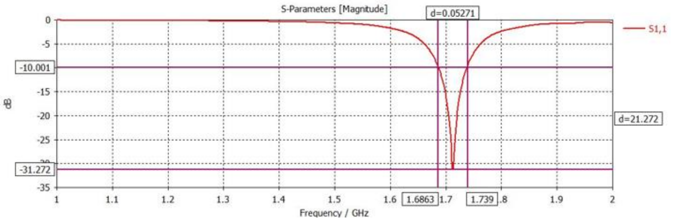

Fig. 20- 1.8GHz return loss graph review.

When the return loss graph is studied, the resonance frequency is found to be 1.713 GHz. At antenna frequency, it exhibits a return loss of -31.272 db. The frequencies corresponding to the -10dB value of the designed antenna are 1.6863 GHz and 1.739 GHz, respectively. The bandwidth value is calculated as 53 MHz (3.09%).

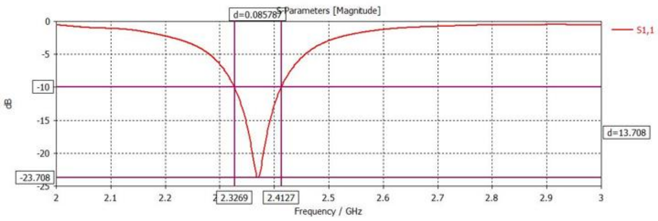

Fig. 21- 2.4GHz return loss graph review.

Looking at the S-parameters graph, the resonant frequency is 2.37 GHz. The antenna resonance frequency is -23.708 dB. The frequencies corresponding to -10 dB in the design are 2.3269 GHz and 2.4127 GHz, respectively. Bandwidth is 85.8 MHZ (3.62%).

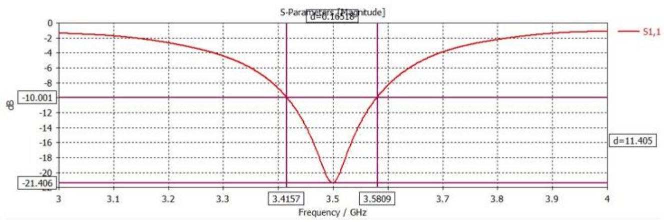

Fig. 22- 3.5GHz return loss graph review.

As seen in the graph, the resonant frequency is 3.499 GHz and -21.406 dB. The values of -10 dB are 3.4157 and 3.5809 respectively. Bandwidth is 165.2 MHz (4.72%).

According to the S-parameters of the antennas, their bandwidth is between 2-5%. It proves the suitability of the antennas designed to be in this value range.

b) Performance: It is aimed to examine the performance status of the antennas designed by looking at the 3-dimensional gain graph and the voltage standing wave ratio (VSWR).

- *Three-dimensional gain:* It is thought that the gain value in micro-patch antennas is in the range of 5-6 dB [15]. The effect of the gain values obtained in the designed antennas on the performance will be examined. The gain of the 1.8 GHz antenna in figure 7 is 6.1 dB. The gain of the 2.4 GHz antenna in figure 13 is 5.76 dB. The gain of the 3.5 GHz antenna in figure 19 is 6.88 dB. It becomes clear that the gain values of the designed antennas are at the proper level when we examine the gain graph of the antennas.
- *The Voltage Standing Wave Ratio:* The VSWR values are checked for impedance matching of antennas. The antenna's VSWR value at its resonant frequency is close to one, suggesting that the antenna is well matched to the impedance [16]. The VSWR value in Figure 5 is 1.056209 for 1.8GHz. Figure 11 shows a VSWR of 1.1394576 for 2. 4GHz.The VSWR value in Figure is 1.185942 for 3.5GHz. The VSWR values of the antennas give a value of approximately 1. From this we can see that the impedance matching of the antennas is well achieved.

IV. RESULTS AND DISCUSSION

Antennas are components that are essential to wireless communication systems because they transmit and receive electromagnetic waves as well as data. The uses for antennas, which can be made in a broad variety of sizes and shapes, are numerous today. Many industries, including mobile communication, television transmission, wireless networks, satellite communication, and radar systems, frequently use antennas. Antennas are made to transmit electromagnetic waves, which they also receive from transmitting equipment. Antennas are also utilized in receiving devices to transform electromagnetic waves into data.

The significance of antenna design is growing due to the fast-evolving technology and communication requirements of today. With the increased adoption of wireless communication in daily life, the job of antennas has taken on greater importance alongside improved communication technologies. Antennas that are properly designed offer advantages like effective communication, improved signal quality, and extensive coverage. It also takes into account crucial elements including antenna design, energy efficiency, frequency bandwidth use, and electromagnetic compatibility. Stronger and more effective communication systems are currently emerging because of research and improvements in antenna design.

Antenna designs in several frequency ranges (1.8 GHz, 2.4 GHz, and 3.5 GHz) were carried out in this work, and simulation results were produced. The purpose of the research is to analyze the performance of antenna designs optimized at these frequencies and to evaluate the results.

As a first step, the S-parameters (S11) were evaluated as a parameter that indicates the return loss of the antennas. The simulation results revealed that the designed antennas had a low return loss at various frequencies. An effective transfer of energy is demonstrated by the fact that the antennas are compatible with the transmitter.

Values for VSWR were also considered to be crucial performance indicators. Low VSWR values demonstrate compliance of the antenna and non-reflective energy transfer.

According to the simulation's findings, the developed antennas exhibit low VSWR values over a range of frequencies.

The 3D gain graph was also examined. This graph illustrates how antenna gain varies with frequency. The designed antennas are seen to demonstrate a significant gain in the intended direction at the target frequencies.

As a result, in this project, the performance of antennas designed for different frequencies has been assessed. According to the simulation findings, the developed antennas have a low return loss, a low VSWR value, and a high gain in the intended direction. These findings support the efficacy of the methodologies and parameters employed in the design process. Future studies with various frequency ranges and varied factors are expected to provide a more comprehensive understanding in the realm of antenna design.

V. CONCLUSION

By investigating the revolutionary micro patch antennas in wireless communication systems in terms of design and performance analysis in different frequency ranges, this work opens up new frontiers in the field of advanced technology communication. The results of detailed simulation-based evaluations reveal that micro patch antennas can deliver robust and consistent communication. S-parameters (S11) are deemed to be crucial in terms of providing optimal harmony between the transmitter and receiver and minimizing energy reflections. By properly tuning these parameters, the antennas' transmission and reception performance is optimized, considerably enhancing signal integrity and communication quality. Furthermore, the energy efficiency and compatibility of the antennas are improved in the study, which takes VSWR (voltage standing wave ratio) data into account. Optimal VSWR values guarantee that power transfer is as efficient as possible, allowing signals to be sent with minimal loss. The visual information gleaned from the 3D gain graph is another outstanding outcome of this investigation. The Micro patch antennas' high gain values enable them to transmit strongly and cover a large region. Finally, this work emphasizes the significance of designing and testing micro patch antennas at various frequencies. The simulation results show that the designed antennas work as expected in the stated frequency ranges. This research gives fundamental knowledge that will help to progress wireless communication technology and the construction of more efficient communication networks. We expect that future research will focus on progressing antenna design and pushing the frontiers of communication technologies.

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