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Microstrip Patch Antenna Development at K Band for Satellite Communication

R. Arivarasu, N. Ramabasi Reddy, K. Madhavi, A. Niranjan
Department of Electronics and Communications Engineering, Madanapalle Institute of Technology & Science (MITS), Angallu, Andhra Pradesh, India

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ABSTRACT

A four-band microstrip patch antenna is designed to work for satellite applications. Out of four bands, one of the bands has a wide band width up to 8 GHz. These microstrip patch antennas can work in the allocated range of 10–40 GHz. The antenna designed can have low return losses and positive gain, which indicates that it can work for practical applications. The designed antenna added stubs on all three corner sides of the microstrip patch antenna for impedance matching. The design used for VSAT applications is the ANSYS HFSS R21. The HFSS (high-frequency structure simulator) software used for analysis of beamwidth, return losses, voltage standing wave ratio (VSWR), gain, gain polar plot, and 3D gain plot has been evaluated and is going to be verified.
The gain of the antenna is very high, up to 8.25 dB when compared to the previous design, which was 3.25 dB higher.
Keywords : VSAT, HFSS, Beamwidth, k/Ku/ka band, VSAT Applications

I. INTRODUCTION

Microstrip antennas tend to be the most widely used types of printed antennas. It is quite important in the realm of contemporary communication systems today. When constructed using a traditional manufacturing method, microstrip antennas are quite straightforward [1–2]. Because of their intrinsic qualities, such as their light weight, planar configuration, ease of compatibility with MMICs, durability, etc., MSAs are employed in current communication applications. The antenna has the following design: Launch the PC's installed Ansys Electronic Desk program. Open the project and add a fresh 3D design for HFSS. Click the box icon in the toolbar above, rename it "Substrate," create a box with that name, fill it in with the required coordinates, and select FR-4 Epoxy (relative permittivity = 4.4) as the material. Repeat steps 1–3 for Patch, but instead of naming it a box, use a rectangle and call it that. Take a rectangle and give it the moniker "Slot." To build several rectangles and provide accurate location coordinates, click the "Create Rectangle" button located beneath the slot. Make a new rectangle, give it the name "Feed," and enter the patch and slot coordinates.

Make a new box, call it "Boundary," and fill it in with coordinates so that the substrate must completely fit inside it without clashing. Click "Apply" and "OK." Take a rectangle and label it "ground" for the ground plane. After creating a rectangle, give it positional coordinates. Flip the XY axis to the YZ axis in the toolbar above. For the port, take another rectangle and give it a name. Under the port, make a rectangle and give it positional coordinates. To subtract a patch and its associated slot, use the subtract option from the toolbar above.

Prior to doing this, combine the slot's many rectangles into a rectangular form. In the same way, use the combine option from the toolbar to add patches and feeds. Click HFSS design under project, then right-click on port to assign an excitation port. Click the lumped port once the assigned excitation has been selected. Next, pick a new line, click in the center of the port, and drag it to any corner. It must manifest as indicated. Click "Next" to complete the process. In order to provide effective impedance matching and enable big data transmission and reception across a wide spectrum of signals, excitation must be assigned to the port.

Right-click on the patch and choose Perfect E for the border to obtain graphs. After assigning the border to radiation, right- click on it when it's under vacuum. Insert the far field configuration by right-clicking on radiation, then choosing "infinite sphere." Right-click on Analysis, then select Add Solution Setup. Put 20 GHz in the frequency field. After choosing Analysis Setup, sweep frequencies. Select Validation Check from the HFSS toolbar, and confirm that you are getting green ticks. Right-click on the analysis and choose "Analyze all" before saving the project. Click the outcome and use the right-click menu to create a modal solution data report. To get every plot, pick the rectangular plot and click "New Report." Likewise, in the new report box for VSWR, use the same procedure as before. In order to get radiation patterns, choose the 3D polar plot and the new report by clicking on the far-field report.

II. METHODS AND MATERIAL

System Model

A. DRAWING MODEL

You can sketch a model of the electromagnetic structure once a design has been inserted into the ongoing project. Generally speaking, the model is constructed as a set of three-dimensional objects. Every 3D object can have a single material assigned to it. You can draw 2D and 1D things and then modify them to make 3D objects, or you can use the modeler's Draw commands to generate 3D objects. The 3D Modeler window is used to draw objects. Additionally, items from other systems may be imported. To open the modeler window associated with a certain design:
1. In the Project Manager box, select the preferred design.

2. To center the modeling window on the chosen design, click [solver name]>3D Model Editor.

III. ANTENNA DESIGN METHODOLOGY

Microstrip antennas, especially patch antennas, find their most significant application in satellite systems. For mobile communication, antennas need to be compact, cost-effective, and have a low profile. Microstrip patch antennas fulfill these criteria, offering various designs tailored for mobile communication systems. Circularly polarized radiation patterns are crucial for satellite communication due to the vast distance between satellites and Earth. These patterns are achieved using square or circular patches with one or two feed points. Most microstrip patch antennas operate within narrow-band applications. They typically consist of a continuous metal layer forming the ground plane on one side, while the design pattern is etched onto the metallic surface over a dielectric-insulating substrate, generating a wide beam coverage.

Interestingly, microstrip patch antennas can be crafted into irregular shapes, with square, rectangular, circular, and triangular shapes being the most common. This versatility allows for adaptability to various space and size constraints in different applications. Typical forms are often selected because of their low cross radiation properties, appealing radiation characteristics, simplicity of manufacture, and ease of analysis [12]. Microstrip patch antenna radiation is caused by the fringing fields that exist between the patch's edge and the ground plane. A thick substrate with a very low dielectric constant is suitable for the best antenna performance since it provides better radiation, a broader bandwidth, and enhanced efficiency. Here, though, the antenna grows larger. Therefore, high-dielectric constant substrates—which have a limited bandwidth and are less efficient—must be employed to lower the size. In order to achieve an increase in antenna performance at a specific operating frequency and limited physical dimensions, a correct trade-off must be made during the design stage [13].

IV. MICROSTRIP PATCH ANTENNA

A.DESIGN FORMULAS:

The shape of the effective dielectric constant and the micro- strip line's electric field lines A design process is given based on the simplified formulation that has been provided, leading to designs of rectangular micro-strip antennas that are feasible. The process is predicated on the assumption that the given data comprises the substrate's height(h), resonant frequency (f_r), and dielectric constant (ε_r). The steps are as follows: a workable width that results in high radiation efficiency [16].

where υ_0 is light's free-space velocity. where is the resonance frequency, is the substrate dielectric constant, is the patch width, and is the free space light velocity (3×10^8m/sec). As indicated by Eq. (2) [16], the antenna patch's length may be determined.

$$W = \frac{V_0}{2fr}\sqrt{\frac{2}{\epsilon_{r+1}}} \quad \textbf{(1)}$$

where ΔL is the extended length, L is the patch length, and L_effi is the effective length. [16]

$$\text{L}=L_{eff}\text{-}2\Delta L \quad \textbf{(2)}$$

the effective dielectric constant, denoted as Δ_reff, and the free space velocity of light (3×10^8 m/sec) [16].

$$L_{eff} = \frac{c}{2f_r\sqrt{\epsilon_{reff}}} \quad \textbf{(3)}$$

$$\epsilon_{reff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 2}{2}\left[1 + 12\frac{h}{w}\right]^{-\frac{1}{2}} \quad \textbf{(4)}$$

where h is the substrate height.

$$\Delta L = 0.412h\frac{(\epsilon_{reff}+0.3)\left(\frac{W}{h}+0.264\right)}{(\epsilon_{reff}-0.258)\left(\frac{W}{h}+0.8\right)} \quad \textbf{(5)}$$

B. Micro-strip antenna design methods

Microstrip antennas use two main methods for feeding: contacting and non-contacting. Contacting involves delivering radio frequency (RF) power directly to the radiating patch through a connecting device like a microstrip line or coaxial probe. Non-contacting methods transmit power between the patch and microstrip line through electromagnetic field coupling, with aperture and proximity coupling being examples. In this article, the microstrip line feed technique is utilized. This method is straightforward, essentially extending the patch with strip connections made directly to it. Its simplicity allows for easy replication by adjusting the inset placement. However, increasing substrate thickness amplifies surface waves and unwanted feed radiation. Consequently, bandwidth is limited, and coupling between the feeding line and patch occurs, leading to spurious radiation.

Practical implementations face challenges due to these limitations. Bandwidth reduction and coupling between the patch and feeding line result in spurious radiation, necessitating matching the microstrip patch with the 50 Ω impedance feeding line. Despite its ease of construction, the microstrip line feed method requires careful consideration of substrate thickness to mitigate these issues and achieve optimal antenna performance. Therefore, while straightforward to build, proper design considerations are crucial for maximizing the effectiveness of microstrip antennas using this feeding technique.

C. Material allocation

Usually, the radiating patch and feed lines on the dielectric substrate are made by photo-etching. The substrate might be thick or thin, and its permittivity should be chosen between 2.2 and 12. The performance of the design can also be impacted by the environment's response to Flame Retardant 4 (FR4) materials, including moisture diffusivity and moisture concentration.

D. DESIGN : STRUCTURE OF DESIGNED MICROSTRIP PATCH ANTENNA

The radiating patch and feed lines on the dielectric substrate are typically created through photo-etching. Selecting a substrate with a permittivity ranging from 2.2 to 12, regardless of its thickness, is crucial. Materials like Flame Retardant 4 (FR4)

can be affected by factors like moisture diffusivity and concentration, which impact the antenna's performance. The standard FR4 baseline, featuring copper foil connected to an Eglass core soaked in unaltered FR4 epoxy resin, is commonly used for evaluating modern materials. Enhancing the electrical performance of designs using standard FR4 can involve modifying its constituents. This ensures better performance and reliability for microstrip antennas by adapting the substrate to suit specific environmental conditions and application requirements.

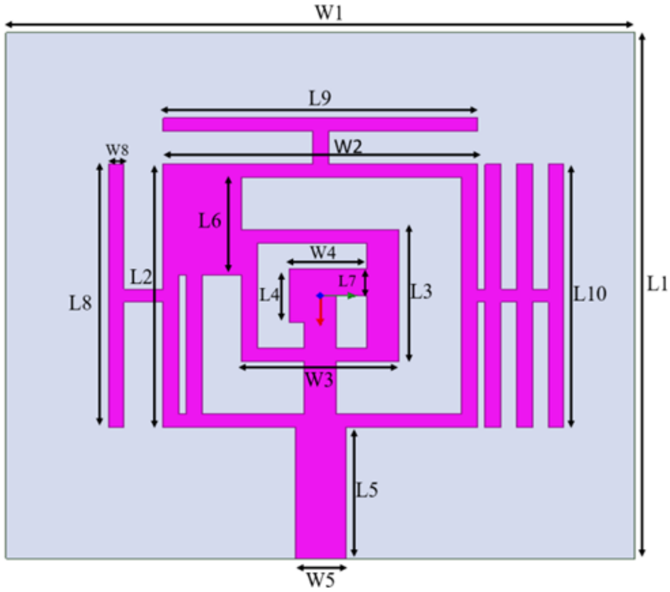

Fig 1.A. Antenna Design Structure with dimensions

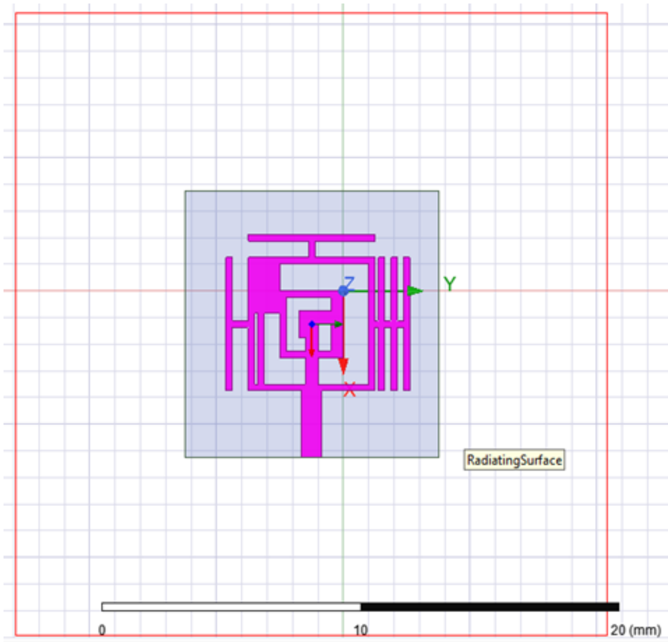

Fig 1.B. Antenna parameters

E. ANTENNA PARAMETERS

Configurations	An explanation	**Quantity (mm)**
W_1	Breadth of substrate and ground	10
L_2	Patch length in outer square length	5

W_2	Widest patch outer square width	5
L_5	Length of microstrip feed line	2.90
W_5	Line width micro strip feeding	0.4
W_3	Middle square width of the patch	2.5
W_4	Patch width inside the square	2
L_1	Length of ground and substrate	10
L_3	Length of Patch central square in patch	2.5
L_4	Inner square length of patch	1
L_6	Length of patch outer slot	1.5
L_7	Inner slot length of patch	2
L8,L9,L10,L11, L12	Stub length	2.375
W8	Stub width	0.125

Table -1

As seen in Fig. 1, the proposed microstrip patch antenna is square in shape with an extra slot positioned in between the square patches. For the best outcomes, the model has been tweaked and refined. Better radiation, a wider bandwidth, and more efficiency are thereby guaranteed [15]. The first slot is 2.90 mm broad and 2.5 mm long, and it is positioned between the center and outside squares. The second slot is 2.00 mm long and 2.5 mm broad, and it is positioned between the inner and center squares. The third slot is 1 mm broad and 2.5 mm long, and it is positioned in between the first two. The antenna's specifications also include a single feeder line, a substrate with a dielectric constant of 4.3, a length of 2.375 mm, and a width of 0.125 mm. It may function at five distinct frequencies: 24 GHz and 26.5 GHz, Ka-band between 26.5 GHz and 40 GHz, and Ku-band between 10 GHz and 18 GHz. In terms of the design process, Eq. (1) [16] may be used to find the width of the antenna patch, and basic formulas have been used to establish the size of the recommended antenna.

Initially, the proposed antenna structure consisted of a 5 mm x 5 mm square patch. In the subsequent phase, there was an outer square patch measuring 0.5 mm in width, which was followed by a square patch with a width of 2.5 mm in the center, 0.5 mm in the middle, and 1.25 mm in the inner. Additionally, there was a 1.95 mm x 1.95 mm slot between the middle and outer square patches and a 0.625 mm × 0.325 mm slot between the middle and inner square-shaped patches.

The original plan for the antenna construction was a square patch measuring 5 mm by 5 mm. In the subsequent phase, there was an outer square patch measuring 0.5 mm in width, which was followed by a square patch with a width of 2.5 mm in the center, 0.5 mm in the middle, and 1.25 mm in the inner. Additionally, there was a 1.95 mm x 1.95 mm slot between the middle and outer square patches and a 0.625 mm × 0.325 mm slot between the middle and inner square-shaped patches.

Electromagnetic energy may be produced from the antenna's own electric energy, which is advantageous for radio transmission and receiving. The antenna might be described as a transitional structure between free space and a directing device. It is the last element on the transmission side when it is the first element on the receiving side. Because of this, the antenna is seen as an essential part of every wireless communication system. The final measurements of the antenna construction were 10 mm by 10 mm with a thickness of 1 mm. The antenna is built atop a Flame FR4 substrate and has a 0.025 dielectric loss tangent [17]. The patch is 5 mm by 5 mm and has a square shape. The spacing between microstrip feedlines is 2.5 mm. From the patch. Table 1 displays the measurements of the antenna parameters.

IV. RESULTS

The simulation results for the proposed antenna are provided together with the research and analysis of the satellite applications, specifically for Ku frequencies running at 12.65 GHz to 12.76 GHz, 14.97 GHz to 15.24 GHz, 17.87 GHz to 18.67 GHz, and K frequencies working at 23.48 GHz to 31.56 GHz. The anticipated five-band antenna's whole simulation and modeling procedure was completed using HFSS software. The suggested antenna was first designed according to the necessary dimensions, and then more slots were added in between the patch square forms of the design. The study and analysis of the satellite applications, especially for Ku frequencies operating at 12.65 GHz to 12.76 GHz, 14.97 GHz to 15.24 GHz, 17.87 GHz to 18.67 GHz, and K frequencies operating at 23.48 GHz to 31.56 GHz, are displayed together with the simulation results for the suggested antenna. HFSS software was used to perform the whole simulation and modeling process for the planned five-band antenna. The proposed antenna was originally developed with the required proportions in mind, and more slots were then added to the patch square shapes of the design.

The quantity of energy that was returned to the antenna's port as a result of transmission line mismatch is depicted by the reflection coefficient in Fig. 2; if s_11<-10dB, this indicates that 90% of the power stimulated has been transferred [19]. The return loss response for the proposed design is measured between 10 GHz and 40 GHz, with a return loss parameter of 0 to -60 dB. At the Ku band, the return loss is -15.4821 dB at 18.1 GHz and -14.65313 dB at 15.1 GHz. In the K band, which is a wide band, the return loss is -14.43948 dB at a wide band frequency of 23.48–31.56 GHz. The extended antenna radiating distance is ensured by this good matching. The range of frequencies with which the antenna's performance, in terms of a certain attribute, complies with a given standard is known as its bandwidth. The impedance bandwidth is the range of frequencies that, from an impedance standpoint, accept more than 90% of the power applied to the antenna's input terminals. The impedance bandwidth over a variety of frequencies can be expressed in terms of return loss (S parameters). The wide band at both frequencies of the proposed antenna meets the needs of satellite applications [20].

With a bandwidth of 0.11 GHz, the Ku band works between 12.7 GHz and 15.1 GHz; a second band runs between 18.4 GHz and 25.0 GHz; and a third band operates between 23.48 GHz and 31.56 GHz with a bandwidth of 0.25 GHz.

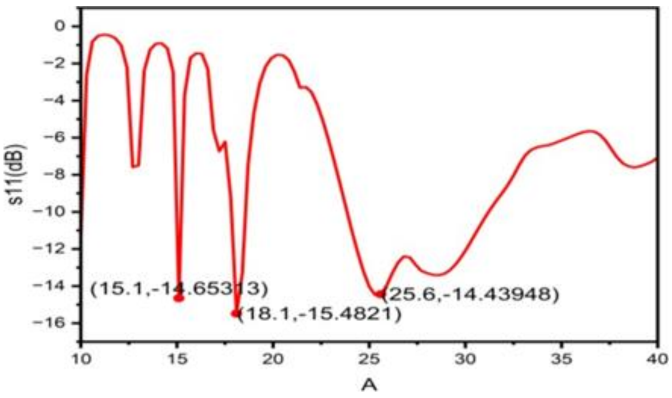

Fig.2. Antenna return loss (S11)

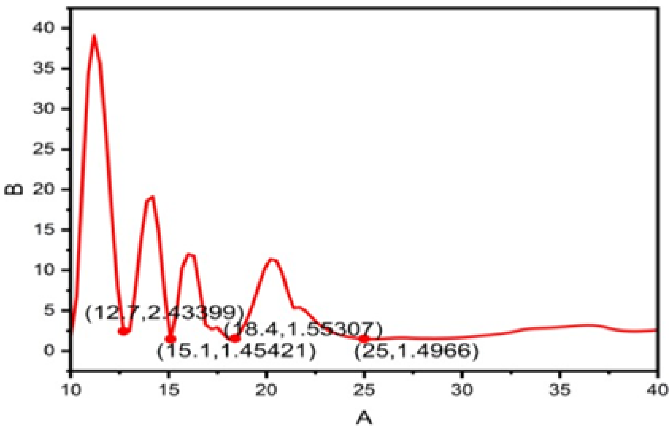

Fig.3. Antenna VSWR

The impedance bandwidth in wireless communications refers to the frequency range where the antenna return loss exceeds 10 dB or has a Voltage Standing Wave Ratio (VSWR) of no more than 2dB. This range indicates how well the antenna can handle signals across various frequencies.

The reflection coefficient, which measures the ratio of reflected to incident waves, impacts both VSWR and return loss. For antennas, a VSWR below 2 dB indicates good performance, translating to a favorable radiation pattern. Fig. 3 illustrates the VSWR of a typical configuration. A well-matched antenna demonstrates low VSWR across a specified frequency range. In one study, a design achieved a good match with VSWR values of 1.76 dB for the Ku band, 1.40 dB for the K band, and 1.32 dB for the Ka band, with a maximum VSWR of 16 dB. With the gain difference between these bands being less than 2 dB, this design meets the requirements for operation across five band frequencies, making it suitable for satellite applications.

Antenna gain is a crucial measure of performance, reflecting both radiation efficiency and directivity. It quantifies how effectively an antenna converts input power into radio waves directed towards a specific direction. The gain graph in Figure 4 illustrates the proposed antenna's response at a given frequency range. Another graph, Figure 5, demonstrates the antenna gain across frequencies from 10 GHz to 40 GHz, ranging from -1.7459 dB to 1.3490dB.

The antenna exhibits three peak gains: 1.3490 dB at 12.70 GHz, 8.0724 dB at 15.1 GHz, and 1.8126 dB at 18.4 GHz. Notably, it showcases respectable gain levels at 12.7 GHz for the Ku band and 33.8 GHz for the Ka band. Although there's slight gain reduction in the K band, it maintains a maximum gain of around 2.5dB. This information helps assess how efficiently the antenna radiates electromagnetic energy in the desired direction across different frequency bands.

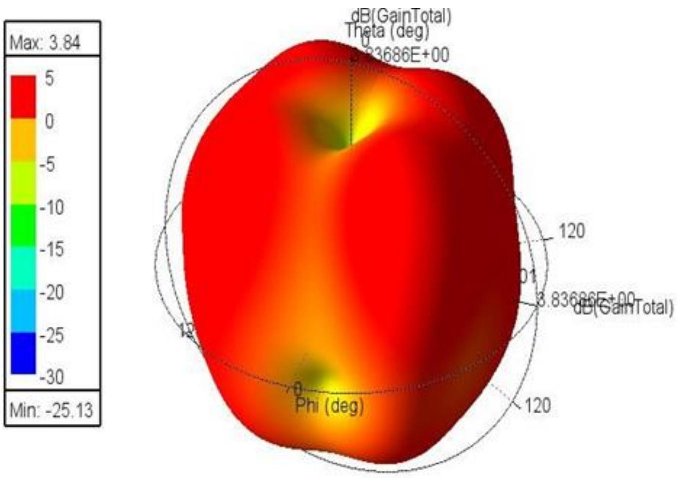

Fig 4 : 3D Gain plot

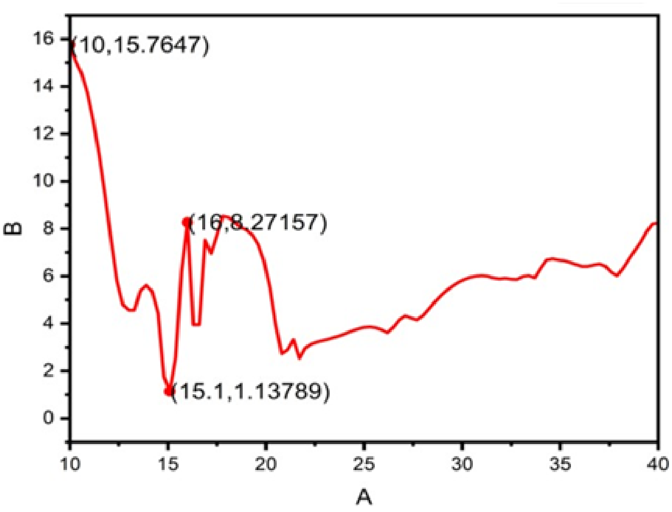

Fig 5 : Peak gain

By increasing the probability of a successful packet transfer between a transmitter and receiver in dynamic situations, antenna directivity improves radio communication. To do this, the method uses a carrier sense (CS) algorithm. Essentially, it entails placing many antennas at the communication link's ends. By capturing several transmissions of the signal, these antennas lessen the impact of signal fading, interference, and other outside influences that might deteriorate communication quality. In order to help choose the best antenna to employ for transmission at any given time, the CS algorithm continually scans the wireless medium for signal presence. By utilizing the most dependable signal channel, this dynamic selection procedure enhances overall communication resilience and lowers the risk of packet loss or corruption [25].

By using the CS algorithm, antenna directivity improves radio communication performance by instantly adjusting to changing conditions and guaranteeing dependable data transfer in dynamic contexts. In Figure 6, the directivity graph is displayed.

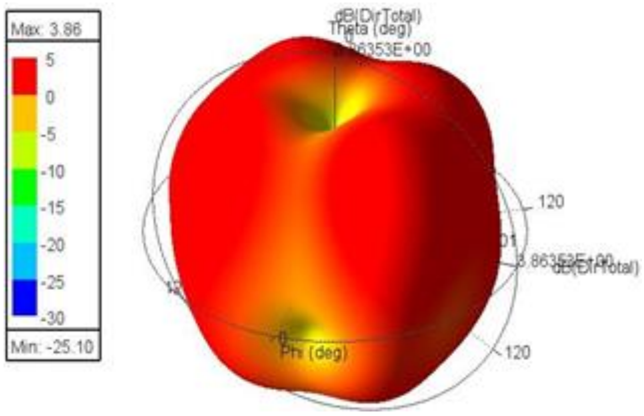

Fig 6 : Directivity

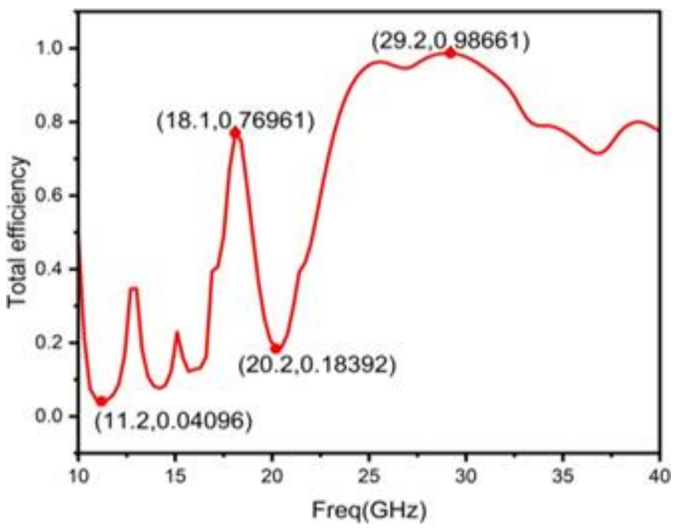

Fig 7 : Total efficiency

V. CONCLUSION

This paper presents and simulates a four-band microstrip antenna for satellite applications using the HFSS studio suite. The creative design microstrip patch antenna can be any shape for this design is used square-shaped, with the first slot between the outer and middle squares measuring 1.2501 mm 2.9010 mm, the second slot between the middle and inner squares measuring 0.501 mm 2.2501 mm, and the third slot between the middle and inner squares measuring 1.2502 mm 4.2502 mm. The L3, W3 slots are both located between the middle and center squares. The antenna is 10 mm in length, has two profile sizes, and is made of FR4 to deliver the best executed results for the loss due to mismatch between source and destination, voltage standing wave ratio, output power to input power, and half power beam width. All of the data show that the suggested design is operating successfully and with excellent results at the Ku/K/ Ka bands for satellite space applications.

The antenna can work in the Ku Band at 12.7 gigahertz, the K band at 28.3 GHz, and the Ka band at 25.00 GHz. The simulated design demonstrated a wide range of RF Ku bandwidth of 0.5055 gigahertz at 12.65 gigahertz to 12.76 gigahertz, a loss due to mismatch between the source and destination of - 11.2414dB at 12.7 GHz, and a total gain of 3.81dBi. The 15.1GHz Ka band included a broad 0.8GHz Ka bandwidth (from 14.97 GHz to 15.24 GHz), a return loss of - 16.0819dB, and a output power to input power of 5.90dBi. The broad K bandwidth of 0 GHz at (17.87GHz to 18.67 GHz) and the total gain of 8.27dBi, the wide K bandwidth of 8.06 GHz at (23.48GHz to 31.56GHz), and the return loss of-17.1664dB were observed in the K band at 18.4 GHz. Ku band had a good VSWR match of 1.40dB, K band had a good VSWR match of 1.37dB, and Ka band has a good voltage standing wave ration match of 1.32 db. This is because VSWR values below 2 dB are most suited for antenna applications. The half power beam width for the Ku Band revealed a greater than zero measured value is 8.27 dB, the gain at the Ka band was 5.28 dB, and the gain at the K band was 2dB. Gain is required to achieve wave propagation. At E-Field, the Ku band's beam width beam width means most of the power radiated in these angle measured 70.6740 degrees, the K band's beam width beam width means most of the power radiated in these angle 64.0146 degrees, and the Ka band's beam width beam width means most of the power radiated in these angle 67.1966 degrees.

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