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DESIGN OF C-BAND PLANAR PHASED ARRAY ANTENNA FOR RADAR APPLICATIONS

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ABSTRACT

In this research, we utilized Ansoft's HFSS v13, which is a Finite Element Method (FEM) based electromagnetic (EM) simulator, to design and analyze two types of patch antennas: a 1x4 circular microstrip patch antenna and a 1x4 hexagonal microstrip patch antenna, operating at 5 GHz. The circular patch antenna was fabricated on a FR4 substrate with a dielectric constant of 4.4dB and a height of 1.6mm. Various antenna characteristics, such as return loss, radiation pattern, directivity, gain, return loss and radiation efficiency, were investigated. The designed 1x4 hexagonal patch antenna and 1x4 circular patch antenna achieved a bandwidth of 3.79% with return loss values well below -30dB. Additionally, a favorable directivity value of 4.5dBi and a gain of 2.7dBi for the 1x4 circular patch antenna and a gain of 3.9dBi for the 1x4 hexagonal patch antenna were obtained. Due to their C-band architecture, these microstrip patch antennas can be employed in various satellite communication applications, such as transponders.

Index Terms: circular micro strips, patch antenna, hexagonal microstrip patch antenna, return loss, d irectivity, antenna gain, HFSS.

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1. INTRODUCTION

Microstrip antennas are widely used in various industries, such as satellite, mobile, and military communications, due to their adaptability and flexibility in terms of resonant frequency, polarization, radiation pattern, and impedance. These antennas are preferred for their small size, low weight, and the ability to customize their performance through the shape of the patch. Rapid and cost-effective manufacturing is crucial for creating prototype antennas for performance testing. With the increasing demand for higher frequencies and larger bandwidths in wireless applications, wideband antennas are becoming more important. The typical components of microstrip antennas include a ground plane, coaxial input/output probe, microstrip transmission line, and patch, all made of highly conductive materials. Hexagonal patches are commonly used due to their advantageous radiation characteristics, such as low cross polarization, and their simple production and analysis processes. The patch is designed to be as normal as possible to achieve optimal performance. By selecting the appropriate mode, end-fire radiators can also be achieved. With a microstrip patch antenna, the metallic patch is typically positioned on top of the substrate, with the ground plane being positioned below the dielectric layer. [1].

Wen-Shan Chen *et al.* (2018) have investigated the design of a 2x2 microstrip patch array antenna for access point applications in the 5G C-band frequency range. The array comprises rectangular microstrip antennas with two vertical slots, specifically designed for 5G C-band operation between 3.4 to 3.6 GHz. Additionally, a microstrip feed network is incorporated in the antenna design to provide efficient feeding to the array. [2].

Shanthi P *et al*. (2019) Microstrip antennas have a small bandwidth and low efficiency, and their performance is highly influenced by the characteristics of the substrate, such as its homogeneity, loss tangent, and dielectric constant. Broadside radiation makes up the majority of the microstrip antennas. [3].

Yashika Saini *et al*. (2017) For Ku band use, a circular microstrip antenna is created. A circular patch with an elliptical slit and a defective ground substrate makes up the design. Analysis has shown that slots and dimensions are crucial for enhancing this geometry's bandwidth. The S-parameters of the antenna are optimised, and it is constructed on a FR4 substrate. [4].

Ms T Yathavi, *et al*. (2020) Microstrip patch antennas are considered practical and widely used antennas. In this research, a novel circular patch microstrip antenna array operating at 24 GHz is proposed. To increase the antenna gain, an array of components is utilized. The antenna array is composed of four identical truncated patches, which are fed through a microstrip line. The proposed antenna comprises a circular patch array with 1x4 elements, etched on an FR4 epoxy substrate having a dielectric constant of 4.4dB.[5].

Md. Sohel Rana1 (2022) the development of contemporary wireless communication systems depends more and more on microstrip patch antennas. The key reason for this is that more and more individuals want to use various wireless apps. Because there are so many applications for wireless technology, scientists and researchers have been working in this field. The patch antenna's general design [6].

P.V. Lokhande *et al*. (2020) a circular microstrip patch antenna with a Defected Ground Structure (DGS) has been investigated and simulated for WLAN (Wireless Local Area Network) applications. The antennas were designed with two configurations: A standard circular microstrip patch antenna and a circular microstrip patch antenna incorporating an L-shaped defected ground structure (DGS). The simulations were carried out using the High Frequency Structure Simulator (HFSS) at a frequency of 2.45 GHz, employing a coaxial feeding technique. The proposed antennas were analysed, and the simulated results were compared in terms of bandwidth, return loss, VSWR, and radiation pattern for this study. [7].

Chaitali Mukta (2021) Microstrip patch antennas are planar antennas composed of three layers: a central insulating substrate layer with a metallic radiating patch on one side and a metallic ground plane on the other side. The radiation from the patch antenna occurs through the fringing fields that emanate from the edges of the conducting patch. Various shapes of radiating patches are available for microstrip antennas, including rectangular, circular, square, triangular, elliptical, and others. [8].

Sandeep Kumar Vasa *et al*. (2017) Antennas serve as transducers, converting electric power currents into electromagnetic waves, and vice versa when receiving signals. Antennas play a critical role in establishing communication links. There are various types of antennas, such as parabolic reflector, patch antenna, slot antenna, folded dipole antenna, and others, each designed for specific purposes and locations. [9].

Ali el alami *et al*. (2015) are one of the most cutting-edge areas of antenna theory and design, which has been microstrip antennas. The fundamental concept behind microstrip antennas was inspired by the use of printed circuit technology for both the radiating components and transmission lines of an electronic system. Because of their ease of usage and compatibility with printed circuit technology, they are employed in a variety of contemporary microwave applications. [10]. U. Srinivasa Rao *et al.* (2019) Due to various benefits provided by its conformal and straightforward planar shape, microstrip patch antennas are widely used. All of printed-circuit technology's benefits are possible. Many articles exploring various facets of microstrip antennas are accessible in the literature. [11].

P. Sai Vinay Kumar *et al*. (2016) A phased array antenna is a multiple-antenna system that allows the radiation pattern to be strengthened in one direction and muted in another. This may be done by electrically changing the radiating components' phase, which produces a pattern with high efficiency that manages to acquire narrow beam widths and minimal side lobe levels.

The direction of phased array radiation can be electrically guided rather than having a mechanical rotating mechanism for the complete antenna. Since the invention of this technology, phased arrays have been used for a wide variety of purposes because of these distinctive features. [12].

Habeeba Khan *et al*. (2021) In its simplest form, a microstrip antenna is made up of two thin metallic layers that are separated from one another by a dielectric. The bottom metallic layer serves as a ground plane and a dielectric substrate between the two plates, while the top metallic layer, which has a specified form, functions as a radiating patch. Due to their high conductivity, metal radiating layers often consist of copper and gold. [13].

B. Ramya *et al*. (2018) Wireless local area networks (WLANs) are widely utilized in various settings such as homes, schools, computer labs, and office buildings. A WLAN is a type of wireless computer network that connects multiple devices employing wireless distribution techniques, such as spread-spectrum radio or OFDM, inside a constrained region. Users can move freely within the coverage area while remaining connected to the network, allowing for increased mobility. Additionally, WLANs can provide access to the larger Internet, similar to cellular networks. [14].

Osama Siddique *et al.* (2013) Momentum, which is a component of Advance Design System, offers the simulation tools needed to assess and create products for contemporary communication networks. For typical planar circuits, including microstrip, slotline, stripline, coplanar waveguides, and many more topologies, Momentum is an electromagnetic solution in the form of a simulator that computes the S-parameters. ADS Momentum also allows for precise simulation of multilayer communication circuits and printed circuit boards. [15]

2. MATERIALS AND METHODS

A. Layout of Antennas

In this work, two types of patch antennas, namely 1x4 Circular patch antenna and 1x4 Hexagonal patch antenna, were investigated as shown in Figure-1(a-b). The coupling between adjacent components in the circular microstrip patch and hexagonal microstrip patch was found to be dependent on their relative alignment. The coupling values for two examples were plotted in the E plane and H plane, demonstrating the measure of coupling against the separation between the centers of nearby circular patch and hexagonal patch antennas.

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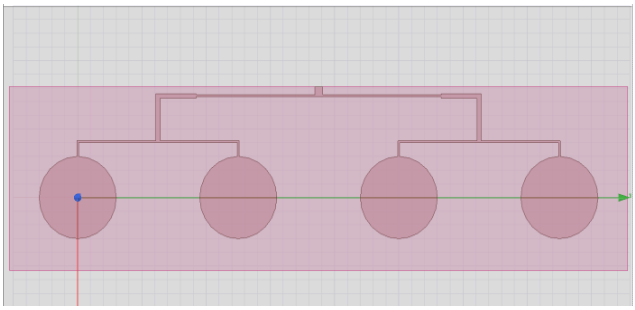

Figure-1(a).

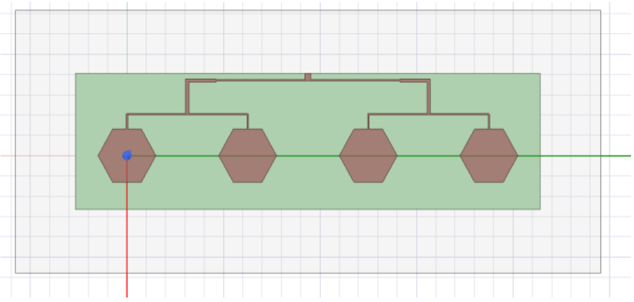

Figure-1(b).

B. Substrate Set-up

In a microstrip patch antenna, the substrate setup refers to the arrangement and characteristics of the substrate material used in the antenna design. The substrate is the dielectric material that supports and provides insulation to the conductive elements of the antenna, such as the patch and the ground plane.

Substrate material: The choice of substrate material is critical in microstrip patch antenna design as it determines the overall performance and characteristics of the antenna. Common substrate materials used include FR4, Rogers, Duroid, and Teflon, among others. The substrate material should have a low dielectric constant (εr) and low loss tangent (tan δ) to minimize signal losses and maintain high antenna efficiency.

Substrate thickness: The thickness of the substrate also plays a crucial role in the performance of the microstrip patch antenna. It affects the impedance matching, bandwidth, and radiation pattern of the antenna. The substrate thickness is typically chosen based on the desired operating frequency, and it is typically in the range of 0.1 to 0.2 wavelengths (λ) of the operating frequency.

Substrate dimensions: The dimensions of the FR4 substrate, particularly its height and breadth, define the size and design of the microstrip patch antenna. Based on the antenna's intended operating frequency, desired radiation pattern, and other performance criteria, these dimensions are selected. To ensure resonant functioning, the height and width of the FR4 substrate are generally designed to be a small portion of the wavelength of the operating frequency.

Surface roughness of substrate: The performance of the micro strip patch array antenna can also be impacted by the FR-4 substrate's surface roughness, particularly at higher frequencies. To reduce scattering losses and maintain high radiation efficiency, a smooth substrate surface is desirable.

Substrate alignment: The appropriate alignment and positioning og the substrate within the patch antenna necessitate thorough deliberation. The substrate should be accurately aligned with the conductive elements of the antenna, such as the patch and ground plane, to ensure proper impedance matching and radiation pattern.

Overall, the substrate setup in a microstrip patch antenna is a critical aspect of the antenna design process and needs to be carefully optimised to achieve the desired performance in terms of impedance matching, bandwidth, radiation pattern, and efficiency. The selection of appropriate substrate material, thickness, dimensions, permittivity, surface roughness, and alignment are key considerations in designing an efficient and high-performance microstrip patch antenna.

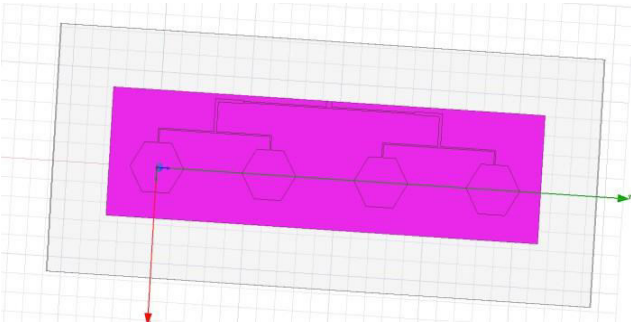

Figure-2(a). Substrate for 1x4 hexagonal patch antenna.

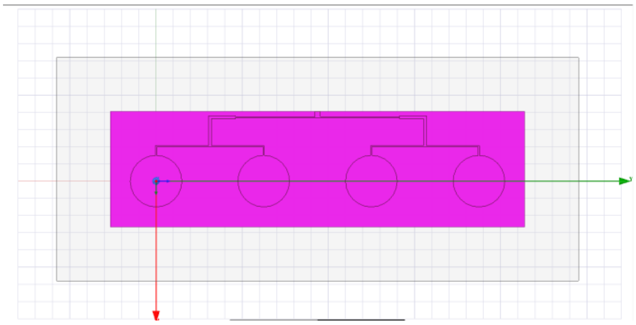

Figure-2(b). Substrate for 1x4 circular patch antenna.

C. Methodology

The array consists of a circular patch and hexagonal patches that are of equal size and evenly spaced on the substrate. The circular patches are fed from the center and have the same phase in their inputs, considering the shapes of the feed lines for each patch. The antenna arrays are designed and simulated on an FR4 substrate and are excited using probe and edge feeding techniques.

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Parameters such as gain return loss, radiation pattern, and VSWR are evaluated at various frequencies.

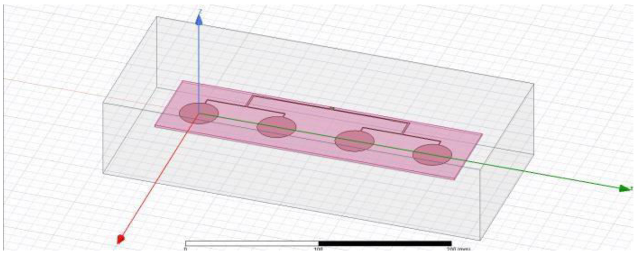

Figure-3(a). Design for circular patch antenna.

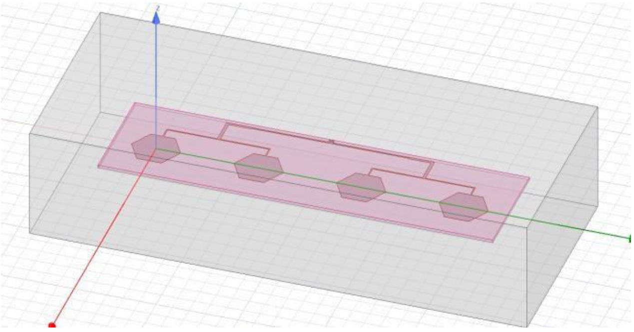

Figure-3(b). Design for hexagonal patch antenna.

3. RESULTS AND DISCUSSIONS

A. H-Plane Results for Circular and Hexagonal Patch Antennas

The H-plane, also known as the magnetizing field plane, serves as a reference plane for microwave devices such as waveguides and antennas. Similar to electric circuits, it is often necessary to split power into multiple fractions in waveguide systems. In vertically polarized antennas, the H plane is typically aligned with the magnetic field, while in horizontally polarized antennas, it is aligned with the vertical or elevation plane. When considering a position on the y-axis where fields are located, the propagation path is in the y direction, the H-field is oriented in the negative x direction, and the E field is oriented in the negative z direction. The direction of greatest radiation from the antenna is broadside, and any plane that includes the H-field and represents this direction is referred to as the H-plane. Figures (1, 2) depict the H-planes of circular and hexagonal patch array antennas.

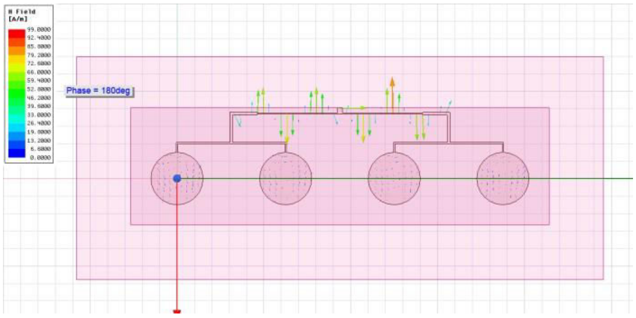

Figure-4. H-plane for 1X4 circular patch antenna.

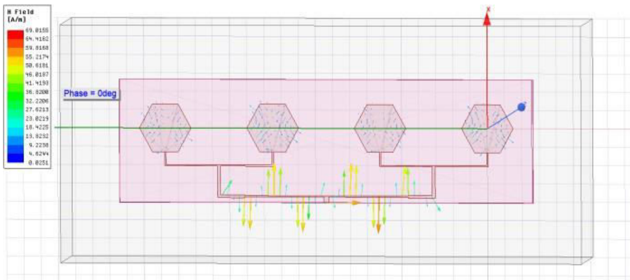

Figure-5. H-plane for 4X1 hexagonal patch antenna.

B. E-plane Results for Circular and Hexagonal Array Antennas

The electric field (E-field) of a radio wave controls its polarization, determining the orientation of the wave. For vertically polarized antennas, the E-plane aligns with the vertical/elevation plane, while for horizontally polarized antennas, it aligns with the horizontal/azimuth plane. In the described scenario where the propagation direction is in the H field is oriented in the negative x direction, the E field is pointed in the positive y direction, and (the direction of greatest radiation), any plane that includes the z-axis would be considered the E-plane. This means that the E-plane is the plane that has the highest radiation and includes the z-axis, such as the xz-plane or yz-plane. The E-plane radiation pattern would demonstrate changes in radio wave intensity based on the polar angle (θ), measured from the z-axis. However, it's worth noting that the E- plane cut is not limited to this specific scenario.

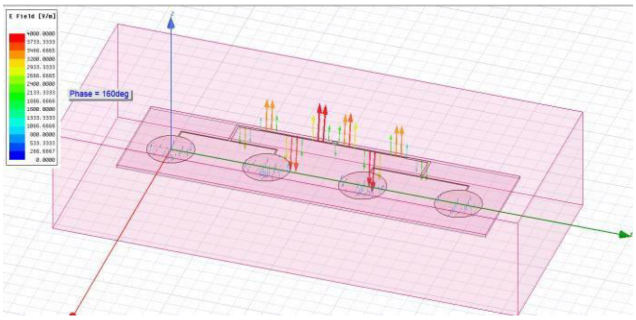

Figure-6. E-plane for 1X4 circular patch antenna.

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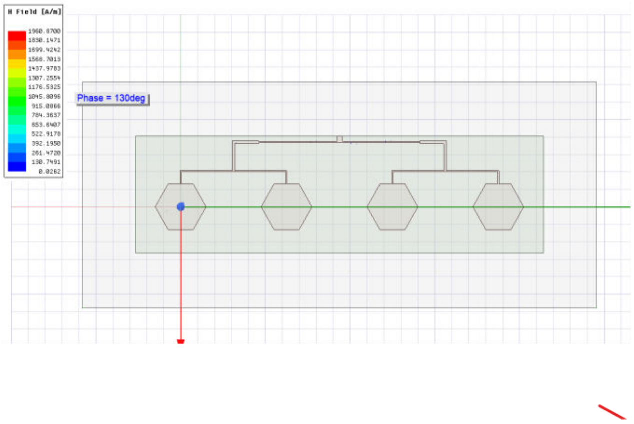

Figure-7. E-plane for 1x4 hexagonal patch antenna.

Table-1. Comparison between hexagonal and circular antenna.

PARAMETER	1X4 HEXAGONAL	1x4 CIRCULAR
	ANTENNA	ANTENNA
Operating Frequency	5.5GHz	5.5GHz
Patch Size	15mm side	15mm
Substrate Height	1.3mm	1.3mm
Patch Thickness	0.035mm	0.035mm
Return Loss	22.869dB	36.589dB
Gain	3.9dB	2.7dB
VSWR	1.054dB	1.168dB

The graphics depicting the S (1, 1) gain return loss, and radiation pattern of the designed antenna were analyzed, and the results were interpreted.

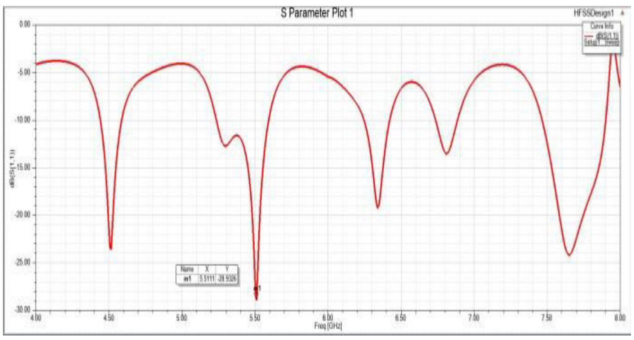

Figure-8(a). S-Parameter for 1x4 circular patch antenna.

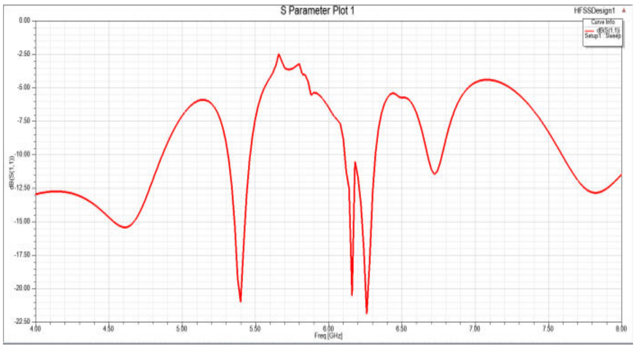

Figure-8(b). S-Parameter for 1x4 hexagonal patch antenna.

The voltage standing wave ratio (VSWR) charts for the two scenarios showed that at a frequency of 5 GHz, the patch antenna array had VSWR values of 1x4 circular patch 1.168dB and 1x4 Hexagonal patch 1.054dB, respectively.

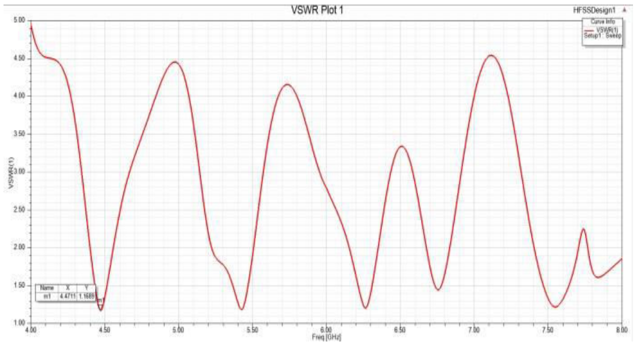

Figure-8(c). VSWR for 1x4 circular patch antenna.

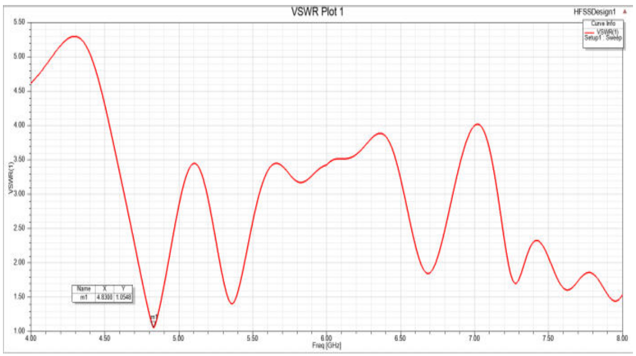

Figure-8(d). VSWR for 1x4 hexagonal patch antenna.

The radiation patterns of the patch antennas, 4x1 hexagonal patch antenna array and 1x4 circular patch antenna in the E- plane and H-plane at a frequency of 5 GHz were analyzed.

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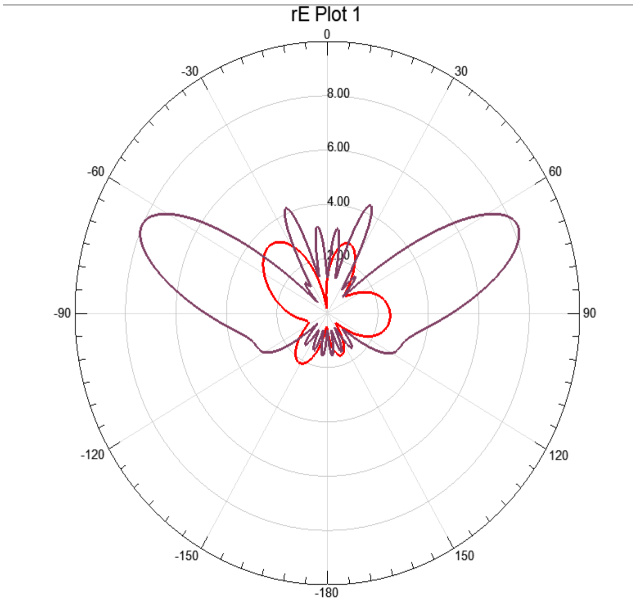

Figure-9(a). Radiation for 1x4 circular antenna.

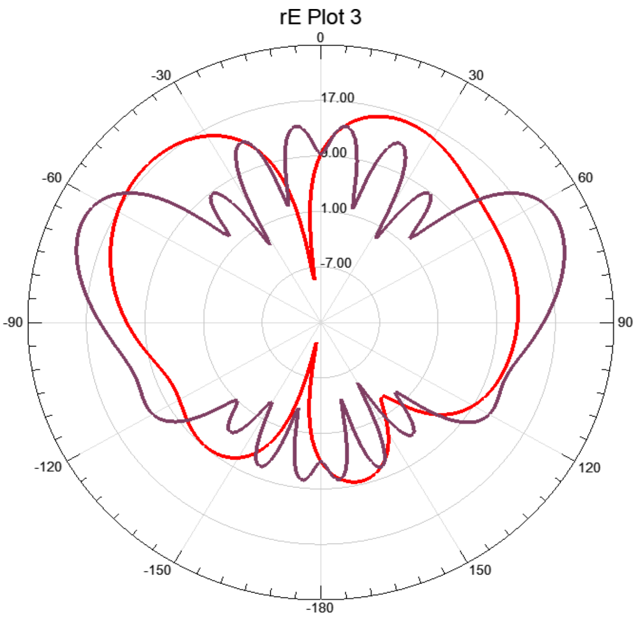

Figure-9(b). Radiation for 1x4 hexagonal antenna.

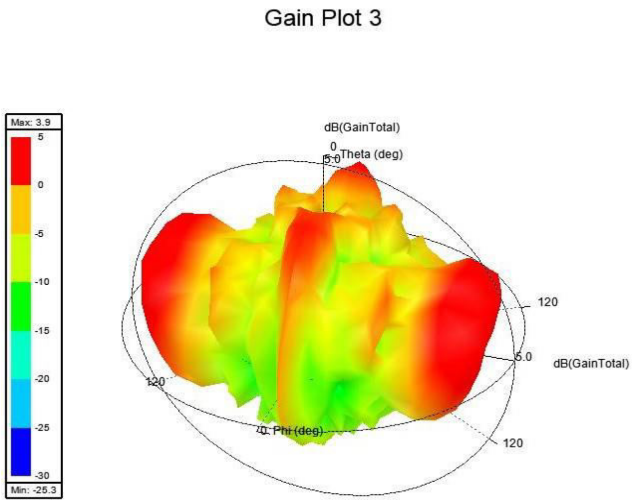

Figure-9(c). Gain for 1x4 hexagonal patch antenna.

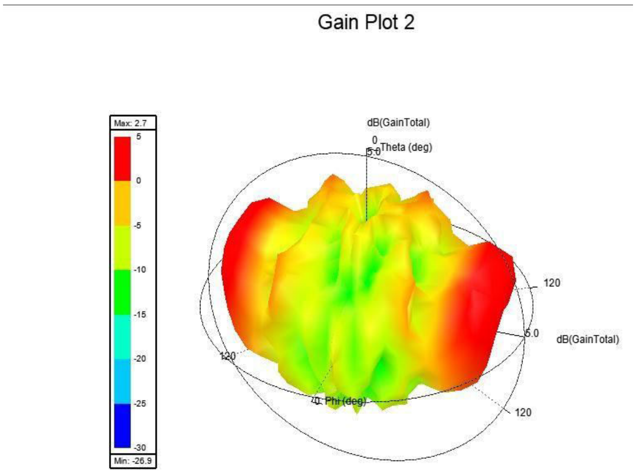

Figure-9(d). Fig.4 (c) gain for 1x4 circular patch antenna.

C. Comparative Analysis of Antenna Models

The regression models were compared for two types of patch antennas, and the best prediction results were obtained as follows: the 1x4 circular patch antenna showed a gain of 2.27 dB and a VSWR of dB, while the 1x4 hexagonal patch antenna showed a gain of dB and a VSWR of 1.054 dB.

4. CONCLUSIONS

In our project, we have designed and implemented microstrip patch antenna arrays with circular-shaped radiating elements and hexagonal-shaped elements on an FR4 epoxy substrate with a height of 1.6mm and a gain of 4.1dB. Through analysis using HFSS simulation software, we found that the antenna resonated at a frequency of 5 GHz. The edge feed technique was utilized to simulate the 4x1 circular patch antenna array and 4x1 hexagonal patch antenna array, while the probe feed technique was used for the patch antenna. The maximum achieved gain was 3.9dB for the 4x1 hexagonal antenna and 2.7dB for the 1x4 circular antenna, as per the proposed simulation design. We compared circular patch antennas and hexagonal patch antennas for parameters such as operating frequency, patch size, substrate height, patch thickness, return loss, gain, and VSWR. Graphs were also drawn for return loss of circular and hexagonal patches, as well as H plane and E plane at 5 GHz for both types of patches. The C-Band patch antenna showed a high return loss beyond 22.862 dB for a 1x4 circular patch antenna and 36.589dB for a 1x4 hexagonal patch antenna, making it suitable for satellite-based military communication applications. Further studies will be conducted to investigate the VSWR and signal return loss improvement factor to achieve high gain, small size, and larger packing efficiency for military satellite devices.

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