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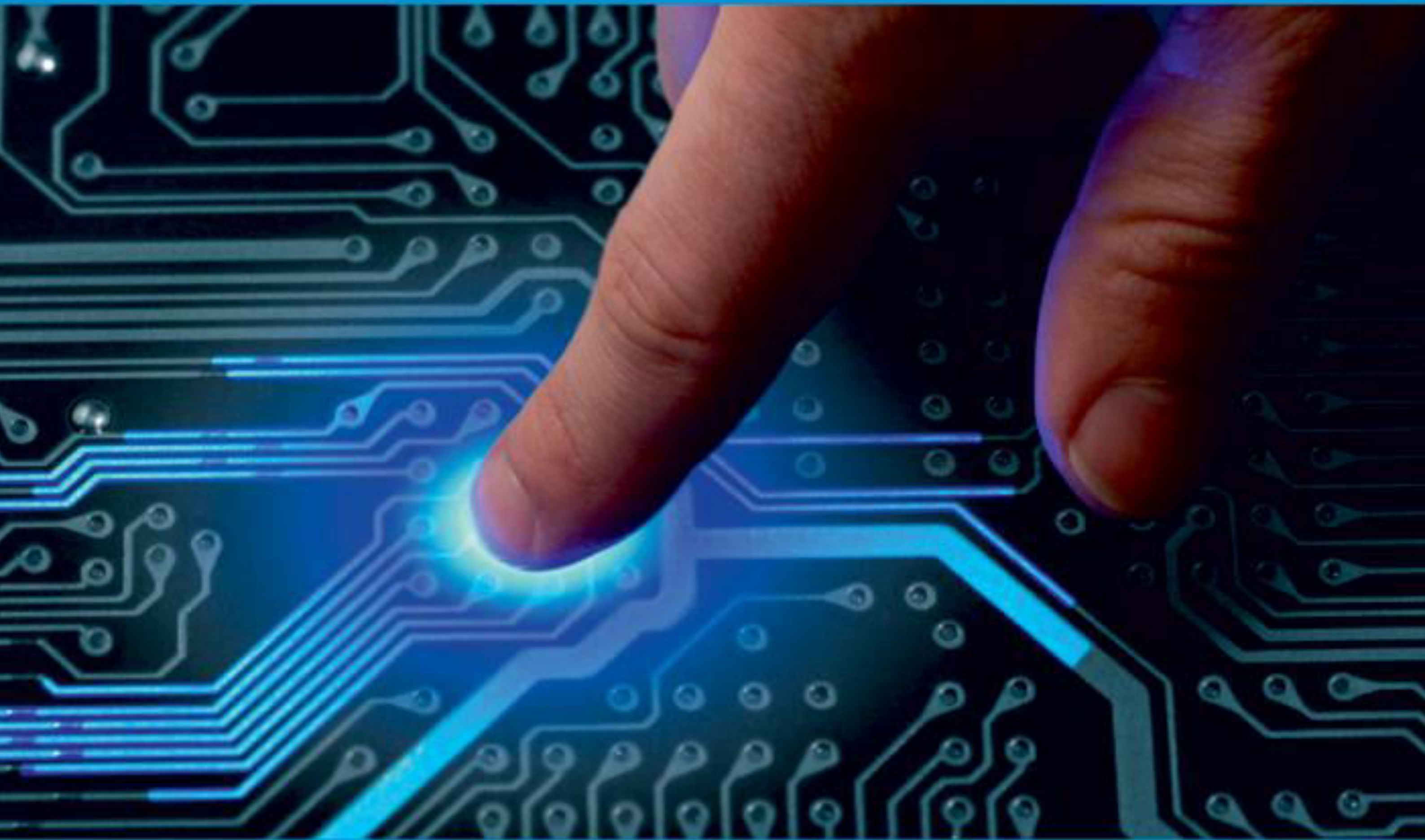

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Design and Analysis of Rectangular Patch Antenna Array

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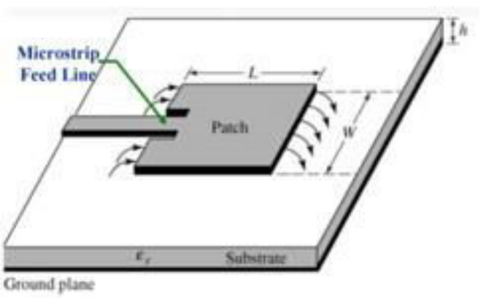
ABSTRACT: This paper deals with the design and analysis of a rectangular patch antenna array is provided in the abstract. The goal of the study is to maximize the antenna array's performance by using sophisticated simulation tools and strict design processes. The performance of the array is carefully examined throughout a range of operating frequencies using a variety of characteristics, including radiation pattern, directivity, gain, impedance matching, and bandwidth. To optimize the array's design parameters while reducing complexity and expense, special emphasis is paid to optimization approaches such as particle swarm optimization and genetic algorithms. In order to provide robustness and dependability in a variety of working circumstances, environmental elements including temperature, humidity, and substrate material qualities are also taken into account. Potential solutions to issues with array integration, impedance matching, inter-element coupling, and mutual coupling effects are discussed.

I. INTRODUCTION

This article focuses on designing a rectangular patch antenna array using CST software and we have compared its performance against a single patch antenna and a eight element array antenna with various feeds of Quarter wave feed, Coaxial feed, Microstrip feed, Inset feed and Offset feed. And we have shown gain difference with different substrate materials such as FR4_epoxy resin, RT/Duroid 5880 and copper.

Microstrip patch antennas represent a pivotal aspect of wireless communication progress, with their design undergoing rapid expansion starting in the late 1970s. This laid a robust foundation for their subsequent deployment across various applications, owing much to advancements since the early 1960s. The physical structure of microstrip patch antennas involves three layers of metal and substrate materials. This multilayer design, typically employing copper and dielectric materials, enables efficient performance across various shapes and configurations, meeting specific communication system requirements.

The microstrip patch antenna is of any continuous shapes like square, rectangular, triangular, circular, hexagonal etc. Out of these shapes square, rectangular, dipole and circular are the most commonly used shapes for the patch because of ease in fabrication. Here we have taken rectangular shaped patch antenna.



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Studies comparing substrate materials like FR-4 and Rogers RT5880 highlight the latter's superiority in achieving optimal antenna performance. Array antennas, composed of multiple radiating elementsarranged in a specific electrical and geometrical configuration, are particularly employed to enhance gain and directivity. They find utility in scenarios where single antennas lack sufficient power handling capacity or require improved performance. However, designing cost-effective, high-gain antenna arrays poses significant challenges in modern wireless communication systems.

	FR-4 SUBSTRATE	ROGERS RT5880
PARAMETER	Value (mm)	Value (mm)
Length(L)	28.60	41.34
Width(W)	36.80	49.41
Ground Length(Lg)	57.20	82.68
Ground Width (Wg)	73.60	98.82
Height (h)	1.6	0.508
Thickness (t)	0.035	0.020
Permittivity ( )	4.3	2.2

TABLE 1

II. LITERATURE REVIEW

A rectangular patch antenna and its linear array implementation is designed and proposed. The proposed antennas have all the advantages of array implementation and its performances parameters are studied by variation in nos. of array elements i.e basic patch .The antenna and its implemented arrays using four elements have much higher values of gain and directivity upto 5 dB and 13 dBi respectively in comparison to its basic patch. Which clearly shows the enhancement in antenna performance parameter while linear array is constructed from its basic patch counterpart? The antenna also has good directional-radiation characteristics [1].

The comparison of antenna parameters [2] for single rectangular patch antenna and 1X2 rectangular patch antenna array at 2.45 GHz frequency is given in Table. From the tabulation values, it is observed that directivity, gain and efficiency are increased and also effective angle, is decreased for the array. So the simulated array obeys the antenna theory. The designed array may be suitable for Wi-Fi application.

In this paper[3] ,a comparison between both rectangular and circular patch array is achieved, for first time up to our knowledge .Several shapes of both rectangular patch antennas and circular patch antennas arrays were designed, specifically, 4x1, 2x1 and single element. All designs are compatible for WLAN and ISM application. Good enhancement, on both gain and directivity, is obtained by employing the array techniques. In this paper, we proved the ability of using circular patch antenna array with same performance of rectangular approximately. Moreover, using rectangular patch antenna array, we could obtain better suppression for side lobe level than that obtained using circular patch antenna array, especially in 4x1 array.

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The performance of the single radiating element [4] and 1 x 2 microstrip patch array obtained using HFSS simulation software. Hence from the results performance of 1 x 2 array is better than single radiating element.

This paper successfully designed a rectangular patch-shaped microstrip antenna that works at a frequency of 2.2 [5]. The frequency lies in the S-band. This study uses fourantenna designs: a single patch, 1× 2 array, 1 × 4 array, and 1 × 8 array.

For space applications, an antenna array [6] that is straightforward,compact, high gain, high directivity, low VSWR, and low return loss is required. Both the proposed 2 × 2 and 3 × 3 MSPAAs, which are tested with RT/Duroid 5880 substrates that are 0.8 and 1.6 mm thick, have these features. At a resonant frequency of 4.1 GHz, the 3 × 3 MSPAA shows a gain of 9.87 dBi, a directivity of 9.97 dB, return loss of −30.66 dB, a VSWR of 1.03, and a bandwidth of 0.1 GHz for both 0.8- and 1.6-mm thick RT and Duroid 5880 substrates.

This research introduces [9], a unique slotted octagonal patch antenna explicitly designed for utilization in 5G communication networks, and this antenna features slots, setting it apart in construction and functionality. These slots contribute to its distinct performance characteristics and enable its operation across a diverse frequency range.The antenna's slotted octagonal shape offers advantages regarding radiation pattern, impedance matching, and bandwidth, making it well-suited for 5G applications. This research explores the innovative design and operational capabilities of the slotted octagonal patch antenna, highlighting its potential contributions to the advancement of 5G communication networks.

In this study[10], a microstrip patch antenna operating at a frequency of 2.4 GHz was constructed and examined as a potential technology for future wireless communication systems. The primary objectives of this study were to reduce the return loss, increase the gain, and minimize the antenna's voltage standing wave ratio (VSWR). These parameters play critical roles in determining the overall performance and efficiency of the antenna. The antenna's ability to transmit and receive signals at thedesired frequency range can be significantly enhanced by optimizing these characteristics. The study aimed to achieve these improvements to pave the way for advanced wireless communication technologies in the future.

III. GEOMETRY AND DESIGN

The essential parameters considered for designing a rectangular microstrip patch antenna areStep 1: Calculation of the Width (W) –

$$W = \frac{c}{2f_o\sqrt{\frac{(\varepsilon_r + 1)}{2}}}$$

Step 2: Calculation of the Effective Dielectric Constant. This is based on the height, dielectric constantof the dielectric and the calculated width of the patch antenna.

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{W}\right]^{-\frac{1}{2}}$$

Step 3: Calculation of the Effective length

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$$L_{eff} = \frac{c}{2f_o\sqrt{\varepsilon_{eff}}}$$

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Step 4: Calculation of the length extension ΔL

$$\Delta L = 0.412h\frac{(\varepsilon_{eff}+0.3)\left(\frac{W}{h}+0.264\right)}{(\varepsilon_{eff}-0.258)\left(\frac{W}{h}+0.8\right)}$$

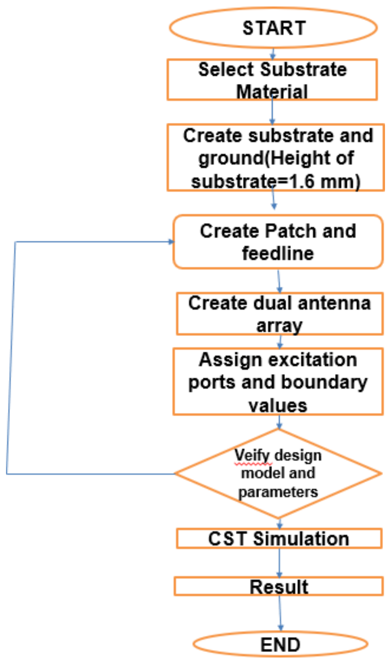
Step 5: Calculation of actual length of the patch

$$L = L_{eff} - 2\Delta L$$

f0 is the Resonance Frequency = 2.4 GHz W is the Width of the Patch = 38.393 mmL is the Length of the Patch = 29.778 mm

Height of the dielectric substrate (h) = 1.6 mm Thickness of the dielectric substrate (t) = 0.035 mm
Relative Permittivity of the dielectric substrate (εr)= 4.3 (for FR-4 Substrate)c is the Speed of light: 3 x 10^8

IV. MATERIALS AND METHODS



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ARRAY TYPE	FREQUENCY (GHz)	S-PARAMETER	VSWR	GAIN (dBi)	DIRECTIVITY
1	2.4GHz	-46.771	1.010	3.025	6.833
1X2	2.4GHz	-17.436	1.310	4.707	8.346
2X2	2.4GHz	-20.246	1.215	7.262	11.147
2X4	2.4GHz	--11.213	1.758	9.840	12.250

TABLE 2

4.1 ANTENNA PARAMETERS

A rectangular patch antenna array's performance parameters, including gain, directivity, efficiency, bandwidth, and radiation pattern, are greatly influenced by its design. With meticulous array shape and excitation parameter optimization, gain—which is defined as the total radiated power in the desired direction relative to an isotropic radiator—is increased. The geographical distribution and elemental organization shape directivity, which reflects radiation concentration. The measurement of power conversion effectiveness, or efficiency, is influenced by feed mechanism optimization, loss reduction, and material selection. The parameters of the substrate, the size of the patch, and the arrangement of the array all affect bandwidth, which indicates the frequency range of acceptable performance. Finally, the array geometry, excitation, and polarization selections shape the radiation pattern, which represents the power distribution in space. Engineers customize antenna arrays to satisfy particular application needs in the wireless communication, radar, and sensing domains by carefully selecting and optimizing parameters.A comparision between various elements of an array is analysed.

4.2RETURN LOSS

Assessing antenna performance relies heavily on the reflection coefficient, also referred to as return loss. A return loss value below -10 dB signifies efficient communication with minimal signal reflections. The resonance frequency and bandwidth of antennas are analysed through their S-parameters, as depicted in Figure for proposed patch antennas employing FR-4 substrate materials. Operating at 2.4GHz resonance frequency, the FR-4 antenna exhibits a bandwidth of 3.4379-3.5588 GHz with a returnloss of -11.24 dB. Conversely, the Rogers RT5880 antenna operates within 3.4903-3.5139 GHz bandwidth with a return loss of -10.024 dB. These measurements offer insights into antenna performance, with bandwidth indicating effective operational frequencies and return loss values reflecting signal reflection and efficiency at 2.4 GHz resonance frequency.

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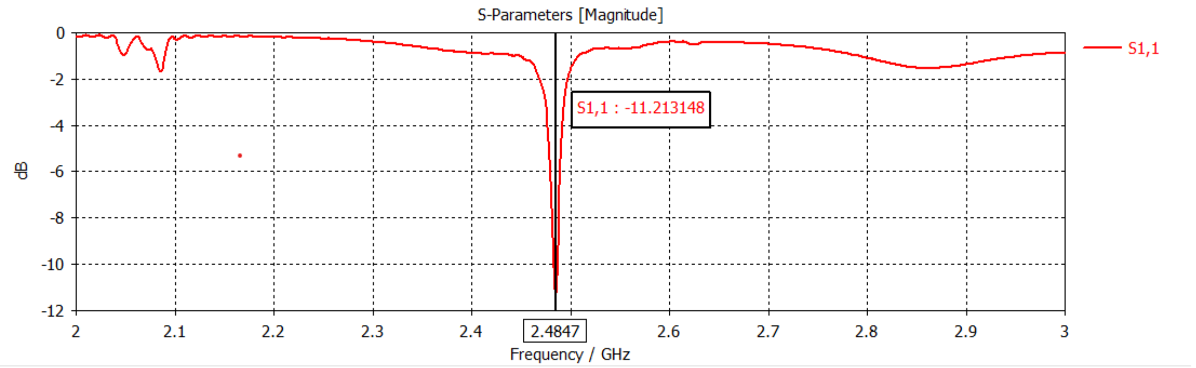
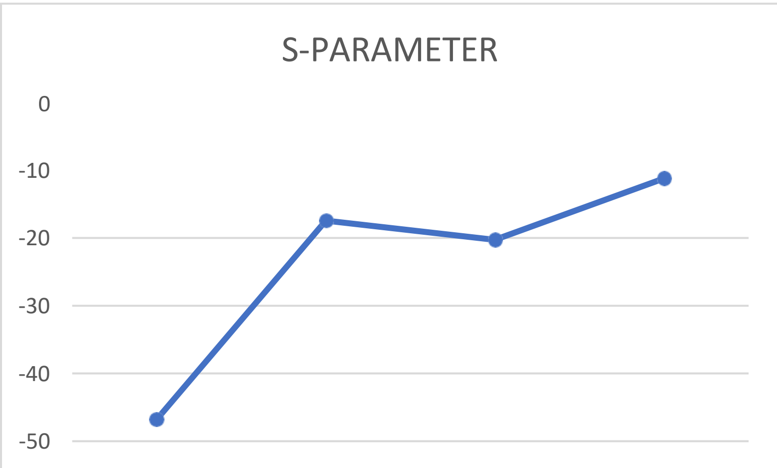


2.4GHz	2.4GHz	2.4GHz	2.4GHz
1	1X2	2X2	2X4



4.3 VSWR AND BANDWIDTH

The Voltage Standing Wave Ratio (VSWR) serves as a crucial gauge for power transmission efficiency in antenna systems. Typically, an optimal VSWR ranges between 1 and 2, with lower values indicating better power transfer. Additionally, VSWR assessment offers insights into impedance characteristics of transmission lines and antenna performance. By minimizing signal reflection and optimizing power transfer, antenna designs aim for low VSWR values, ensuring reliable communication. At a frequency of 2.4 GHz, the computed VSWR for antennas made of FR-4 and Rogers RT5880 materials are 1.758 and 1.921 respectively, falling within the desired range and indicating efficient power transmission and impedance matching.

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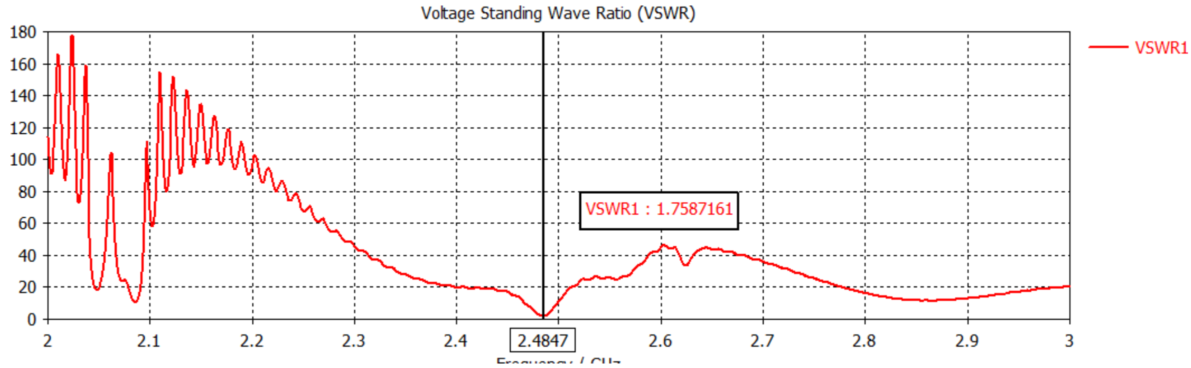
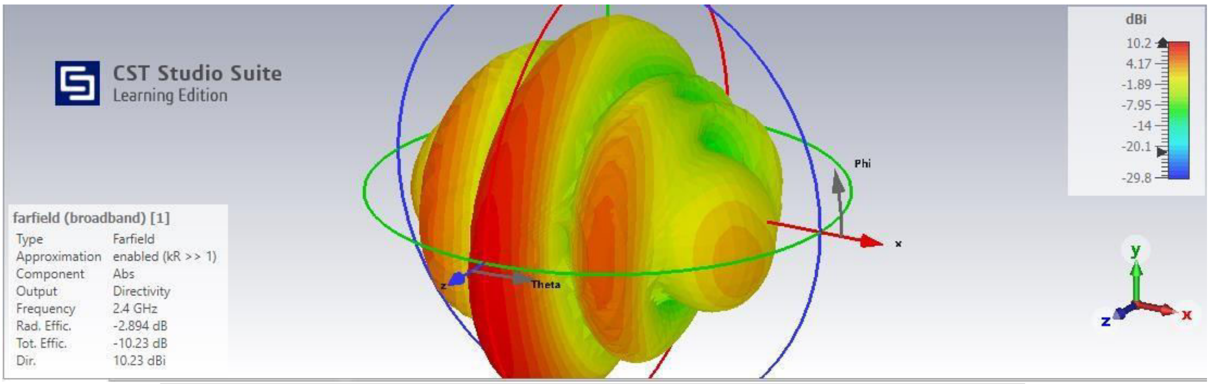


4.4 GAIN AND DIRECTIVITY

The term "gain" denotes the amplification in power density of a directional antenna relative to an isotropic antenna, which emits uniformly in all directions, when both antennas receive the same power. It reflects the antenna's capability to focus and channel transmitted or received power towards a specific direction. The gain values for a rectangular patch antenna design using FR-4 and Rogers RT5880 substrate materials are illustrated in Figure 7. At a frequency of 2.4 GHz, the gain measures 9.336 dB for FR-4 and 10.99 dB for Rogers RT5880. This design achieves a gain of dB, highlighting its efficiency in concentrating radiated power directionally. Directivity, depicted in Figure 8, indicates the ratio of radiation intensity in a specific direction from the antenna to the average radiation intensity across all directions.



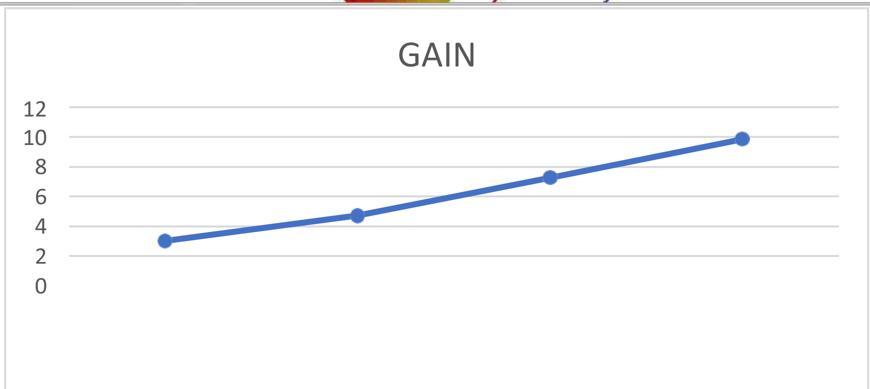


Figure is an illustration showing a representation of the polar radiation pattern. The central lobe of the radiation reflected off of FR-4 Substrate material has an intensity of 3.33 dB, and its angle of incidence is 3.0 degrees. The 3dB angle has a value of 85 degrees, and that value has been assigned to it. This antenna has a sidelobes level of -11.4 dB on the sidelobe scale. To reiterate, the magnitudeof the center lobe is 7.56 dBi, and the angle is 3 degrees. This applies to the buried material used by Rogers RT5880. A figure of 72.5 degrees represents the 3dB angular value. Regarding this

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antenna's sidelobe level, the measurement comes in at -14.4 dB.

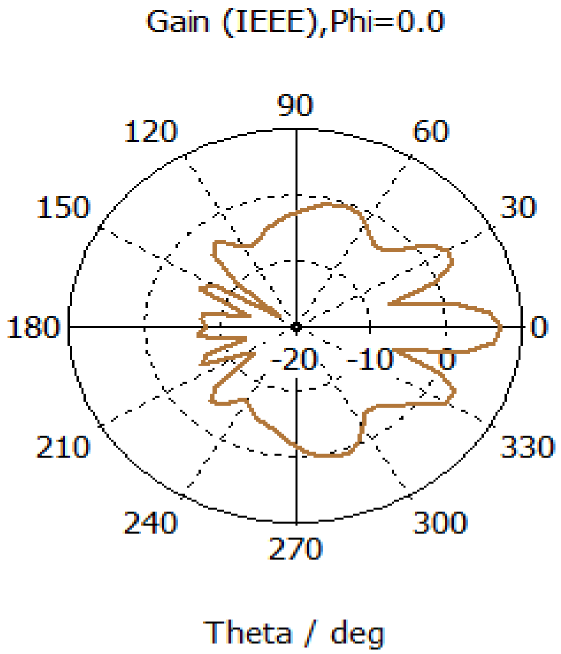
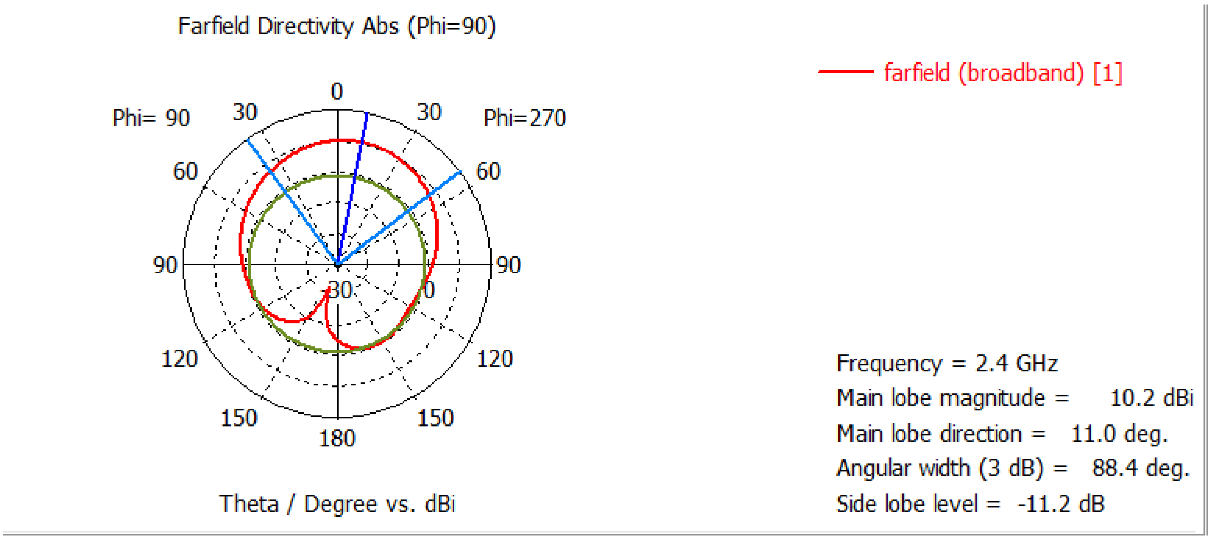


Figure represents the polar directivity, where the main lobe's magnitude measures 10.2 dBi with an angle of 11.0 degrees for the FR-4 substrate material. The previously mentioned 3dB angular value iscalculated at 88.4 degrees. The sidelobes' intensity generated by this antenna is 11.2 dB lower than the average. For the Rogers RT5880 material, the main lobe's magnitude is 7.87 dBi with an angle of 3 degrees. The calculated 3 dB angular value is 60.3 degrees, and the sidelobe measures -9.8 dBi.

4.5 RADIATION EFFICIENCY

"Efficiency" pertains to the energy input required for efficient communication through an antenna [18]. Assessing the power supplied to an antenna and the power it emits or dissipates provides insights into its effectiveness. In antennas with low efficiency, a significant portion of the input power is lost either due to internal losses within the antenna or is reflected away due to impedance mismatches [19].

∴ Antenna efficiency = Gain/Directivity× 100%



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4.6 FABRICATION AND TESTING:

To make sure a rectangular patch antenna array performs as intended, there are a few crucial stepsin the fabrication and testing process. Preparing the substrate material—typically a dielectric substrate like FR4—and installing conductive layers using methods like photolithography or screen printing are the usual first steps in fabrication. Then, the patch elements and feedlines are defined via precise etching. Extensive testing is carried out after fabrication to verify the performance of the array. This involves taking measurements of variables such as gain across desirable frequencies, radiation patterns, and return loss.

V. RESULTS AND DISCUSSION

A rectangular patch antenna array's results and discussion usually cover a wide range of topics, including radiation pattern, gain, bandwidth, and impedance matching. The results could include measurements or simulation data that show how well the antenna performs in terms of beamwidth, sidelobe levels, and directivity. A lot of the time, the analysis focuses on elements like substrate type, element spacing, and feeding methods that affect how well the array performs. To verify the array's design, comparisons with theoretical predictions or other antenna layouts could be investigated. To provide light on limitations and real-world applications, practical issues like as cost-effectiveness and difficulty of fabrication may also be covered.

S. NO	ARRAY TYPE	GAIN(dB)	DIRECTIVITY	RETURN LOSS(dB)	VSWR	BANDWIDTH(dB)	EFFICIENCY	MATERIAL USED
[1]	2*2 3*3	8.1 9.81	8.56 9.95	-15.23 -30.66	1.14 1.12	0.18 0.1	-	RT/Duroid 5880
[2]	2*1	8	9.88	-37.67	1.02	79.2	-	FR4
[3]	2*1 4*1	9.24 10.29	-	-7.25 -8.25	2.54 2.26	-	-	
[4]	1*2 1*4 1*8	5.52 7.84 9.64	-	-25.9 -15.3 -20.2	1.1 1.4 1.2	110 180 170	-	FR4
[5]	1*2	7.84	8.38	-	-	-	88.27	
[6]	1*2 1*4 1*8	9.64 12.40 12.40	10.31 13.26 17.21	-40.14 -40.11 -38.04	-	-	-	RT/Duroid
[7]	1*2 1*4	9.6 12.5	10.5 13.6	-	-	-	-	FR4

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[8]	1*2	7.5021	-2.884	-	2.5433	-	-	FR4_epoxy
[9]	1*2 2*2	4.58 4.714	-	-	1.211 1.284	83 83.6	-	FR4
[10]	1*2 1*4	5 5	12 14	-	-	-	25 15	FR4

VI. CONCLUSION

In summary, the study and design of the rectangular patch antenna array have provided important new understandings of its operational properties. We have designed an array configuration that satisfies particular needs, including desired radiation patterns, gain, and bandwidth, by carefully modeling, simulating, and optimizing. We have enhanced the array's directional characteristics and efficiency by utilizing methods such as beamforming and impedance matching. A practical and dependable antenna system has also been realized thanks to factors like feed network architecture and substrate material selection. All in all, this project highlights how important methodical design approaches are to building efficient antenna arrays for a range of uses, including radar and remote sensing technologies as well as wireless communication systems.

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