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DESIGN AND ANALYSIS OF TRIANGULAR PATCH ANTENNA ARRAY

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Abstract:
This paper presents the design and analysis of a triangular microstrip patch array antenna using Computer Simulation Technology (CST) with varying FR-4 substrates. The antenna is designed on a rectangular FR- 4 substrate with dimensions of 10×10 mm, and it operates within the frequency range of 2 GHz to 3 GHz. The design methodology and simulation results for key parameters such as return loss, gain, directivity, and radiation patterns are discussed comprehensively. The triangular microstrip patch antenna offers high performance and is suitable for various wireless communication applications including UMTS and ISM bands. The study provides valuable insights for the development of efficient microstrip patch antennas for modern wireless communication systems with arrays of 2, 4, 6, and 8 elements.
Keywords: Array, CST, Substrate, Gain, 2.4Ghz.

I. INTRODUCTION:

In the realm of modern wireless communication systems, the demand for compact, high-performance antennas continues to surge. Microstrip patch antennas have emerged as promising candidates owing to their low profile, lightweight, and compatibility with integrated circuit technologies. The utilization of antenna arrays further enhances their capabilities in terms of gain, directivity, and beam steering. This report delves into the comprehensive design and analysis of a microstrip patch antenna array comprising 2, 4, 6, and 8 elements. By exploring various design parameters and optimization techniques, this study aims to achieve enhanced performance metrics while ensuring the efficient utilization of resources. Through rigorous simulation and analysis, the report seeks to provide valuable insights into the intricate intricacies of microstrip patch antenna arrays, thereby contributing to the advancement of wireless communication systems. The structure includes a single patch and an array consists of a triangular surface on a grounded dielectric substrate. The single antenna configuration is a Single patch with microstrip leads. to Measure the power transmission capacity of the antenna, It can be a single antenna or an array antenna An identical antenna is placed at a distance 'd' from the antenna. original. That is, the antenna may not be present are aligned in the direction of each other's maximum gain. of the same procedure applies to array antennas. It consists of four triangular faces and a food network. The feeding network distributes energy evenly. Guarantees correct alignment from entry point to point. Any antenna. The operating frequency is 2.4GHz, The substrate is FR4 and the dielectric constant is 4.3.

1.1 PARAMETRIC ANALYSIS

Parametric analysis for a triangular patch array antenna involves studying how changing various parameters affects the antenna's performance. Here's a general guide on how we might conduct such an analysis:

S.no	Antenna Dimension	Value
1.	Resonant frequency(f)	2.4 Ghz
2.	Triangle patch length (a)	48.9
3.	Ground plane length (lg)	100
4.	Ground plane width(wg)	100
5.	Thickness(t)	0.035
6.	Height(h)	1.6

Table 1.1 List of Parameters.

1.1.1 Dimensions of the Triangular Patches:

Length: The length of each side of the triangular patch. It determines the resonant frequency and radiation characteristics.
Width: The width of the patch, measured perpendicular to the length. It affects the input impedance and bandwidth.
Height: The thickness or height of the patch above the substrate. It influences impedance matching and bandwidth.
Spacing Between the Patches:
The distance between adjacent patches in the array. It affects mutual coupling between elements, radiation pattern, and sidelobe level.

1.1.2 Substrate Material Properties:

Dielectric Constant (ε_r): The relative permittivity of the substrate material. It affects the resonant frequency, impedance matching, and dimensions of the patches.

Loss Tangent (tan(δ)): The lossiness of the substrate material. It affects the antenna's efficiency and bandwidth

1.1.3 Feed Position and Type:

Feed Location: The position where the feed is placed on each patch (e.g., center, corner). It affects impedance matching and radiation patterns.

Feed Type: The type of feed used (e.g., microstrip line, coaxial feed). It affects impedance matching, radiation pattern, and polarization.

Number of Patches in the Array:

The total number of triangular patches arranged in the antenna array. It affects the overall radiation pattern, gain, and impedance matching.

1.1.4 Shape of the Patches:

Equilateral Triangle: All sides and angles of the triangular patches are equal. This shape offers symmetric radiation patterns.

Right Triangle: One angle of the triangular patch is a right angle (90 degrees). It may offer different radiation characteristics compared to equilateral triangles.

By varying these parameters, engineers can tailor the performance of the triangular patch array antenna to meet specific requirements such as desired operating frequency, radiation pattern, gain, bandwidth, and impedance matching.

II. TYPES OF FEEDLINE

Triangular array antennas can be fed using various feedline configurations, each offering different advantages and characteristics. Here we described some common feedline configurations used for triangular array antennas:

a. Microstrip Feedline:

Microstrip feedlines are commonly used in planar antenna designs, including triangular patch array antennas. The feedline is typically etched onto the same substrate as the triangular patches in this configuration. The feedline connects each patch to the transmission line, providing the necessary RF signal to excite the antenna elements. Microstrip feedlines offer ease of integration, low profile, and the ability to control impedance matching.

b. Coaxial Feed:

Coaxial feed involves using coaxial cables to connect each triangular patch to the transmission line. A coaxial connector is attached to each patch, with the center conductor connected to the patch and the outer conductor serving as the ground plane. The coaxial feed provides good impedance matching and isolation between antenna elements. This configuration is suitable for applications where low-loss transmission and high isolation between elements are critical

c. Corporate Feed:

Corporate feed involves combining signals from a single feedline and distributing them to multiple patches in the array. A power divider network is used to split the signal and feed it to each patch element. Corporate feed simplifies the feeding structure and reduces the number of feedlines required, especially in large array configurations.

However, it may introduce additional losses and impedance-matching challenges compared to individual feedlines.

d. Inset Feed:

Inset feeding involves directly connecting the feedline to the patch antenna element within a specific distance from the edge of the patch. By adjusting the position of the feed point along the edge of the patch, designers can control impedance matching and radiation characteristics. While inset feeding offers simplicity in design and fabrication, achieving precise impedance matching may require careful tuning of the feed position. Additionally, mutual coupling between adjacent elements can affect antenna performance, especially in densely packed arrays.

e. Quarter-Wave Feedline

Quarter-wave feedlines use transmission lines approximately one-quarter wavelength long to match the high impedance of the antenna element to the characteristic impedance of the transmission line. This impedance transformation results in efficient power transfer and reduced spurious radiation, improving antenna efficiency. Quarter-wave feedlines can be implemented using various transmission line technologies, such as microstrip lines, stripline, or coaxial cables. However, they may require more complex design and fabrication compared to inset feeding techniques, and the length of the feedline may restrict the physical layout of the antenna system, particularly in compact or miniaturized designs.

III. PROPOSED METHODOLOGY

a. DESIGN AND ANALYSIS OF THE ARRAY

Quarter-wave array antennas come in various configurations depending on the number of elements in the array. Here are descriptions of 1, 2, 4, 6, and 8-element quarter-wave array antennas:

3.1.1. Single Element Quarter-Wave Array

The single-element quarter-wave array is an antenna system that consists of only one radiating element. Usually, the radiating element is a quarter-wavelength monopole or dipole antenna. The element is fed at the base using a quarter-wave transmission line, which helps in providing impedance matching between the feedline and the antenna element. This type of configuration is generally used in applications where a simple, omnidirectional radiation pattern is required, such as in wireless communication systems. In our project, we have developed a single element with a dielectric constant of 4.4 FR-4 substrate. The patch dimension is a=43.5.

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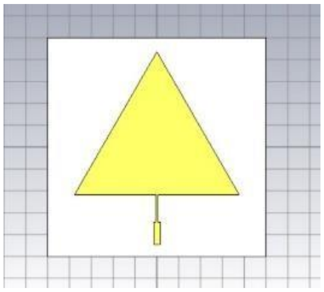

Figure 3.1: Single element quarter wave feed array antenna

3.1.2. Two-Element Quarter-Wave Array:

The two-element quarter-wave array is made up of two quarter-wavelength elements that are positioned at a certain distance from each other. The elements are synchronized to generate constructive interference in the desired direction and destructive interference in other directions, resulting in a directional radiation pattern. This setup is commonly used in applications that require moderate directional gain, such as point-to-point communication links. The dimensions of the ground and substrate are lg=120 and wg=220 respectively, while the patch dimension a is 43.5

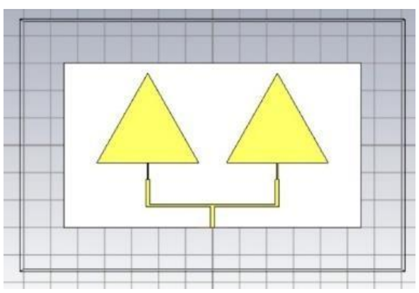

Figure 3.2: 2-element quarter wave feed array antenna

3.1.3. Four-Element Quarter-Wave Array:

The four-element quarter-wave array consists of four quarter-wavelength elements arranged in a linear or planar configuration. The elements are typically fed with equal amplitude and progressive phase differences to create a narrow beam radiation pattern with increased gain in the desired direction. This configuration offers improved directivity and gain compared to two-element arrays. It is commonly used in applications that require higher gain and narrower beamwidth, such as radar systems and wireless base stations. The dimensions for the ground and substrate of the 4-element quarter-wave feed is lg=250 and wg=207.5, and the patch a is 42.5 in length.

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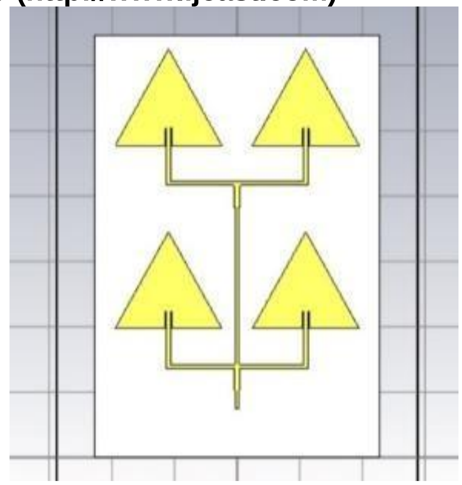

Figure 3.3: 4-element quarter wave feed array antenna

3.1.4. Six-Element Quarter-Wave Array:

The six-element quarter-wave array is composed of six quarter-wavelength elements that are arranged in a linear, planar, or circular configuration. These elements are fed with appropriate amplitude and phase distributions to shape the radiation pattern following the specific requirements of the application. In this particular case, we have provided the length (lg) and width (wg) of the ground and substrate as 200 and 300 respectively. The length of the patch 'a' is 36 each. This configuration provides further improvement in gain and directivity when compared to four-element arrays. It can be used in applications requiring even higher gain and more precise beam shaping, such as satellite communication systems.

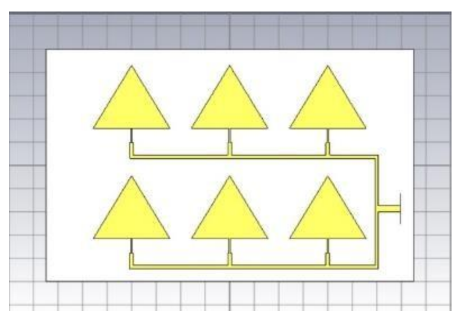

Figure 3.4: 6-element quarter wave feed array antenna

3.1.5. Eight-Element Quarter-Wave Array:

The eight-element quarter-wave array comprises eight quarter-wavelength elements arranged in a linear, planar, or circular configuration. It offers even higher gain and more precise control over the radiation pattern compared to six-element arrays. Eight-element quarter-wave arrays are commonly used in applications requiring very high gain and directional control, such as phased array radar systems and

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long-range communication links. These are just a few examples of quarter-wave array configurations, each offering different levels of gain and directivity.

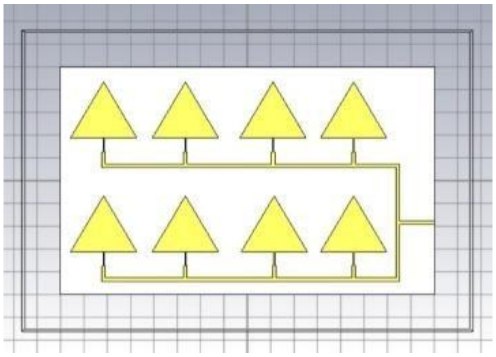

Figure 3.4: 8-element quarter wave feed array antenna

IV. RESULT & DISCUSSION

a. : Return loss: The analysis of the return loss remains a primary focus, which involves examining the shape and directionality of the electromagnetic waves emitted from the triangular array. To compare the S parameter or return loss of a 1-element and 8-element quarter-wave feed array antenna, we can consider the return loss for each element. The return loss for a single element is -17.33, for 2 elements it is -11.06, for 4 elements it is -12.263, for 6 elements it is - 26.7789, and for 8 elements it is -43.0652. These findings suggest that the return loss has gradually decreased as the number of elements has increased.

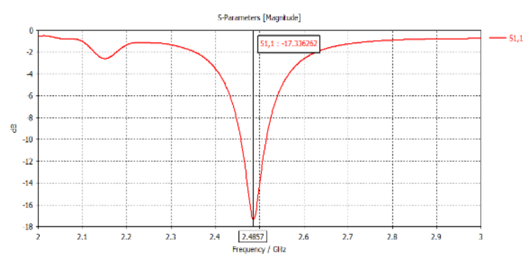

Figure 4.1.1: S-parameter of 1 element quarter wave feed

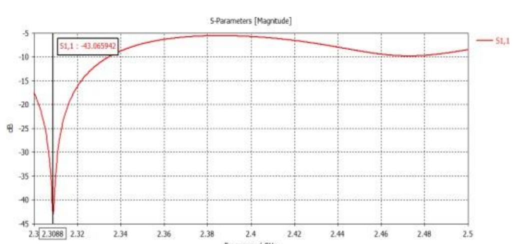

Figure 4.1.2: S-parameter or return loss of 8 element quarter wave array.

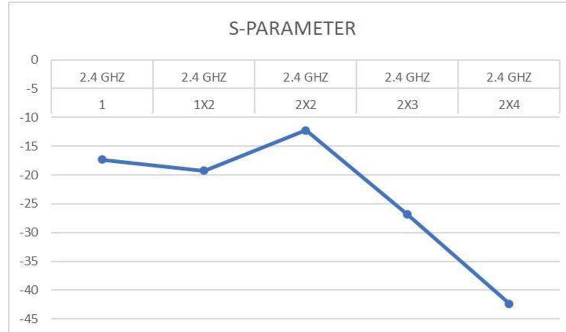

Figure 4.1.1: S-parameter quarter wave feed array antennas

b. : Gain: Gain is a term used to denote the increase in power density of a directional antenna when compared to an isotropic antenna. An isotropic antenna radiates equally in all directions whereas a directional antenna has the ability to focus and direct the transmitted or received power in a specific direction.

In Figure 4.2.3, you can see the gain values for the triangular patch antenna design which uses FR-4 for different arrays. The gain is measured at 2.4 GHz. The proposed design achieves a gain of 5.28 dB for a single element, and 7.2, 11, 10.4, and 10 for 2, 4, 6, and 8 elements respectively. This demonstrates the antenna's efficiency in concentrating the radiated power in a specific direction.

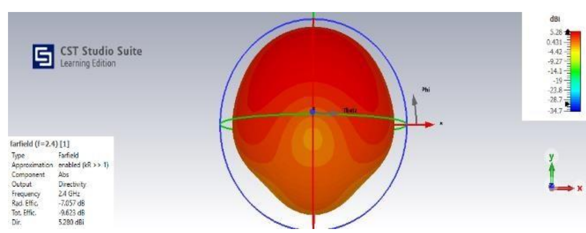

Figure 4.2.1: Gain of 1 element quarter wave feed

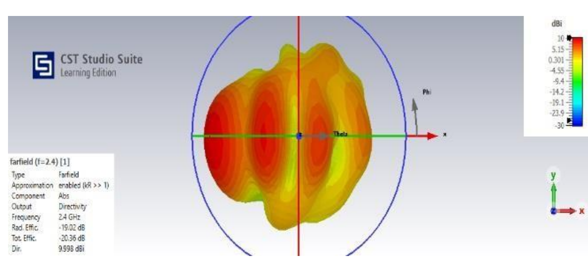

Figure 4.2.2: Gain of 8 element quarter wave feed

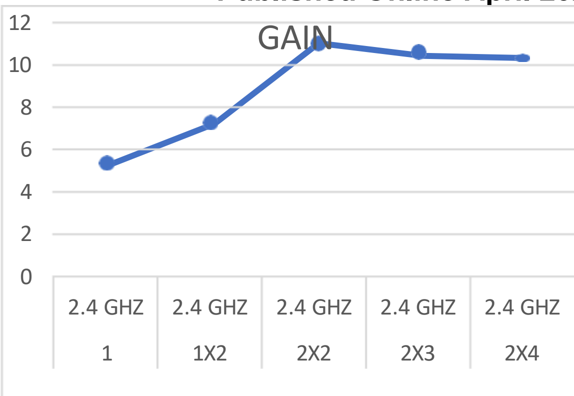

Figure 4.2.3: GAIN of quarter wave feed array antennas

c. : VSWR: The Voltage Standing Wave Ratio (VSWR) stands as a critical metric for assessing the efficiency of power transmission from a power source to a load via a transmission line within an antenna system. It plays a central role in evaluating antenna performance, with an optimal range typically falling between 1 and 2. Values closer to 1 denote superior impedance matching and more effective power transfer. Additionally, VSWR measurement provides valuable insights into the impedance characteristics of the transmission line and the antenna's efficacy in power transfer. By meticulously designing antennas to achieve low VSWR values, signal reflection is minimized, and power transfer is maximized, thus contributing to reliable and efficient communication.

The results of the computed VSWR values for the antenna design operating at a frequency of 2.4 GHz are shown in Figure 4.3.3. For the antenna that was built using FR-4 material, the VSWR values for a single element and for 2, 4, 6, and 8 elements are determined to be 1.3145, 1.2433, 1.6443, 1.095, and 1.0154 respectively. These values fall within the desired range, indicating that antenna designs have commendable impedance matching and efficient power transmission..

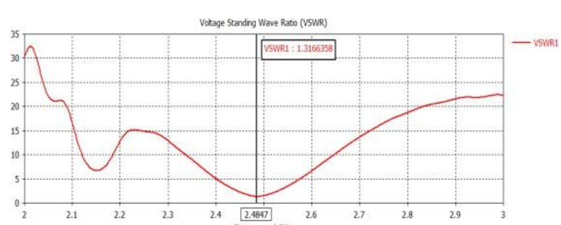

Figure 4.3.1: VSWR for 1 element quarter wave array.

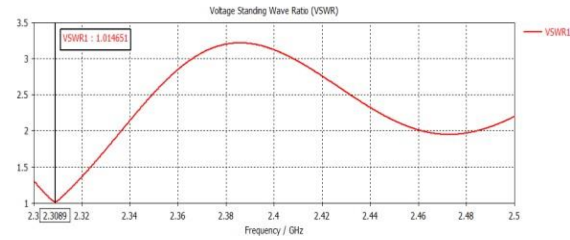

Figure 4.3.2: VSWR for 8 element quarter wave arrays.

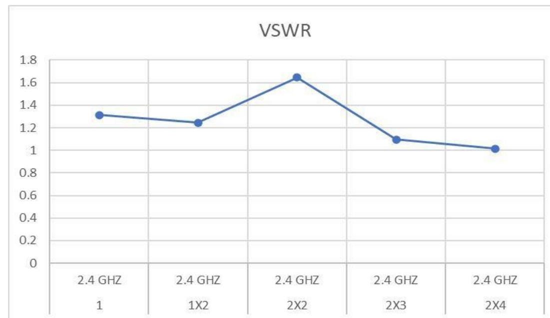

Figure 4.3.3: VSWR of quarter wave feed array antennas

d. : Beamwidth and Sidelobe Levels: Examining the beamwidth and sidelobe levels of the radiation pattern would provide insights into the array's ability to focus energy in the desired direction while minimizing unwanted radiation in other directions.

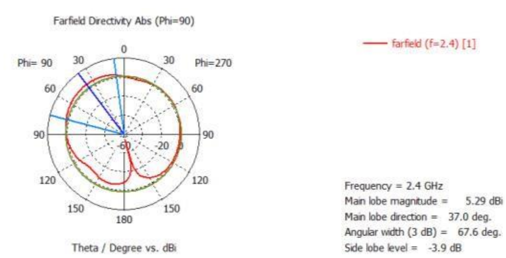

Figure 4.3.3: Antenna pattern of singe quarter wave feed

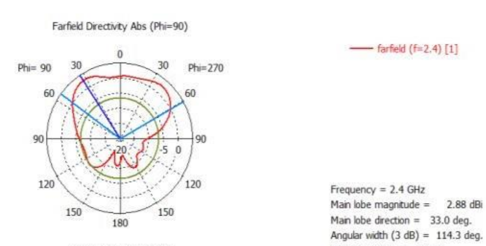

Figure 4.3.3: Antenna pattern of 8 quarter wave feed

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Table 2 summarizes the simulation results, providing a concise overview of the findings.

Array	S-PARAMETER	VSWR	Gain	FREQ
1	-17.3343	1.3145	5.28	2.4 Ghz
1X2	-19.2934	1.2433	7.2	2.4 Ghz
2X2	-12.2618	1.6443	11	2.4 Ghz
2X3	-26.8646	1.095	10.4	2.4 Ghz
2X4	-42.3344	1.0154	10.3	2.4 Ghz

V. CONCLUSION

In conclusion, the study and design of the triangular antenna array have significantly advanced our understanding of its operational properties and capabilities. Through meticulous modeling, simulation, and optimization, we have crafted an array configuration that meets specific requirements, including desired radiation patterns, gain, and bandwidth. By employing techniques such as beamforming and impedance matching, we have further refined the array's directional characteristics and efficiency, enhancing its performance across various applications. Critical considerations such as feed network architecture and substrate material selection have contributed to developing a practical and reliable antenna system. This project underscores the importance of systematic design methodologies in the creation of efficient antenna arrays for diverse applications, spanning radar and remote sensing technologies to wireless communication systems.

Moving forward, the insights gained from this endeavor will pave the way for the continued advancement and innovation in triangular antenna array design, enabling the realization of sophisticated and high-performance antenna systems to meet the evolving demands of modern communication and sensing technologies

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