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Innovative Stacking Approach for Gain Enhancement in Microstrip Antennas

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Abstract: This paper unveils a revolutionary stacked microstrip antenna design that packs a punch, delivering impressive gains in a compact package. By harnessing the power of IE3D software and carefully selecting FR4 substrate with copper ground plane, we've crafted a 2.4 GHz antenna that's perfect for Wi-Fi applications. Our innovative design outperforms traditional antennas, paving the way for exciting new possibilities in wireless communication, IoT devices, and beyond. Our research opens doors to new possibilities for high-gain, compact antennas that meet the growing demands of wireless communication.
Keywords: Stacked Microstrip Antenna, High-Gain, Compact Antennas, Wi-Fi Applications, Wireless Communication, IE3D, FR4 Substrate.

I. INTRODUCTION

The world of wireless communication is evolving at a breakneck pace. With the rise of smart devices and IoT technology, the demand for efficient and compact antennas has skyrocketed. Microstrip antennas have been a popular choice for many applications, but they often fall short when it comes to gain and bandwidth. To overcome these limitations, researchers have been exploring innovative design approaches.

One promising solution is the stacked microstrip antenna design. By stacking multiple layers, we can create antennas that are not only compact but also high-gain. This design approach has the potential to revolutionize wireless communication systems. Our research focuses on developing a stacked microstrip antenna for Wi-Fi applications.

We'll be using IE3D software to design and simulate our antenna. This powerful tool allows us to optimize our design for maximum performance. With the right materials and design, we can create an antenna that's perfect for modern wireless systems. FR4 substrate and copper ground plane are our materials of choice.

The possibilities for this technology are endless. From smart homes to IoT devices, our antenna design could have a significant impact. We're excited to see where this research takes us and how it can contribute to the development of next-generation wireless communication systems. The future of wireless communication is exciting, and we're proud to be a part of it.

By pushing the boundaries of antenna design, we can enable faster, more reliable connections. This could have a major impact on industries like healthcare, transportation, and education. Our goal is to create an antenna that's not only high-performance but also compact and efficient. With the right design and materials, we believe this is achievable.

The applications of this technology are vast and varied. We're confident that our research will contribute to the development of innovative wireless solutions. By exploring new design approaches and materials, we can create antennas that meet the demands of modern wireless communication systems. This is an exciting time for researchers and engineers working in this field.

II. LITRATURE REVIEW

Researchers have been working hard to improve stacked microstrip patch antenna designs, focusing on boosting gain and bandwidth. These antennas are super popular in modern communication systems because they're compact, lightweight, and easy to make. Let's dive into some of the latest research that's helping us understand how to make these antennas even better, especially when it comes to radiation characteristics and overall performance.

[1] R. Garg, P. Bhartia, I. Bahl, and A. Ittipiboon (2023) explored ways to boost the performance of microstrip patch antennas by stacking multiple dielectric layers and adding parasitic patches. This approach helps to enhance the gain and widen the bandwidth, which are common limitations in traditional patch antennas. By adjusting the spacing between the layers and selecting suitable materials, they managed to reduce energy loss due to surface waves and improve radiation efficiency. Their simulations showed a noticeable increase in gain without making the antenna too bulky, making the design practical for modern wireless systems.

[2] S. Kumar and R. K. Chaudhary (2022) designed a dual-band stacked antenna that can operate effectively at two different frequencies.

They added a shorting post and carefully layered dielectric materials to maintain a low profile while still improving gain. Their design used a simple coaxial feed, which kept the setup efficient and easy to implement. Using simulation tools, they fine-tuned the antenna to get strong performance in both bands. This makes the design suitable for multi-band communication systems where space and performance are both important.

[3] M. T. Iftikhar, A. Basir, and F. A. Tahir (2021) introduced a multi-layer stacked patch antenna that includes a special feature called a Defected Ground Structure (DGS). The DGS helps to eliminate unwanted surface waves, allowing the antenna to radiate more effectively. They used a combination of cost-effective and high-performance substrates to keep the balance between performance and affordability. Their measurements matched the simulations well, showing high gain, wide bandwidth, and clean radiation patterns — key qualities for modern wireless applications.

[4] N. Patel and K. N. Patel (2020) came up with a clever design that uses air gaps between stacked patches to enhance the antenna's directivity and reduce interference between layers. This simple but effective technique gave them better control over the electromagnetic fields around the antenna, leading to a noticeable improvement in gain and radiation quality. Their work showed that even a small design tweak, like adding air as a dielectric spacer, can have a significant impact on performance, especially in compact antenna systems.

[5] J. Singh and M. Tripathi (2019) focused on making a compact antenna that works well in the X-band (commonly used in radar and satellite communications). They stacked a circular patch with a parasitic element to improve gain without increasing the size of the antenna. Their design showed that you don't always need a larger antenna to get better performance — smart stacking and optimization can do the trick. Their results confirmed a solid gain boost and reliable performance at the target frequency, making the antenna ideal for space-constrained, high-frequency applications.

III. METHODOLOGY

A. Design Overview

To analyze the performance of the stacked microstrip patch antenna, we begin by calculating key design parameters using the given physical dimensions. These parameters include the resonant frequency, effective dielectric constant, and bandwidth, which are critical for predicting the antenna's behavior at its operating frequency. Since the structure uses air as the dielectric medium and includes an air gap to enhance bandwidth and efficiency, standard theoretical equations were adapted accordingly. Calculations were done assuming operation in the fundamental mode (TM_{10}), and the physical length of the patch was used to estimate the resonance point and other related characteristics. The stacked configuration was particularly chosen to enhance gain and bandwidth, leveraging the benefits of low dielectric loss from the air gap.

Calculations

1. Resonant Frequency (fr)

Formula:

$$fr = c / (2L\sqrt{\varepsilon r\_eff})$$

Given:

$c = 3 \times 10^8$ m/s

$L = 5.4$ cm $= 0.054$ m

$\varepsilon r\_eff = 1$

Calculation:

$$fr = 3 \times 10^8 / (2 \times 0.054) = 2.78 \text{ GHz}$$

2. Effective Dielectric Constant (εr_eff)

Since the substrate is air:

$\varepsilon r\_eff = 1$

3. Bandwidth Estimation (BW)

Formula:

$$BW \approx (h / \lambda_0) \times 100\%$$

Where:

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$h = 0.5$ cm = 0.005 m
$\lambda_0 = c / f_r = 3 \times 10^8 / 2.78 \times 10^9 = 0.108$ m

Calculation:
BW ≈ (0.005 / 0.108) × 100% ≈ 4.63%

4. Radiation Efficiency & Gain (Qualitative)
- Radiation efficiency increases due to low-loss air substrate.
- Gain typically around 7–9 dBi for stacked patches.

B. Flow Chart Of Stacking Antenna

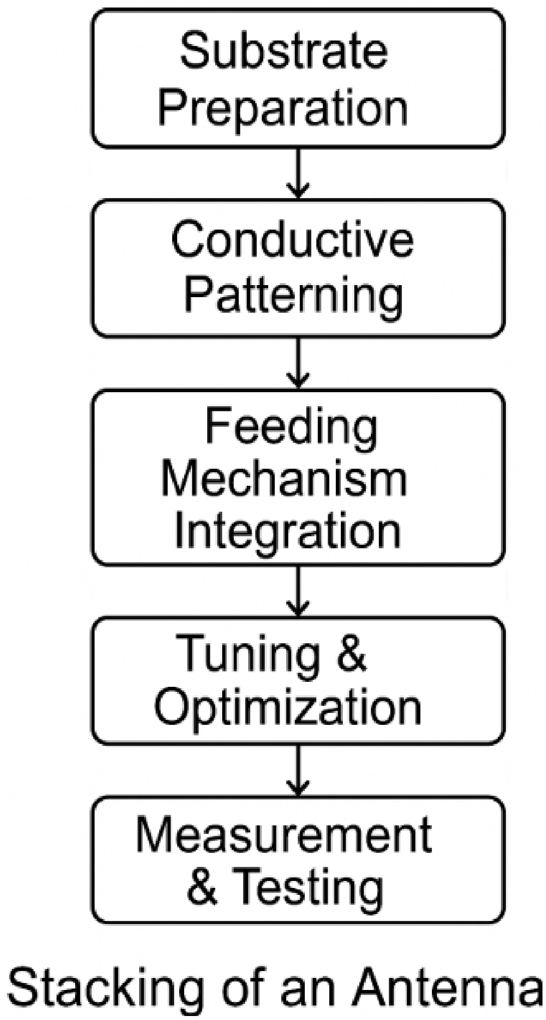

Figure 1 Flow Chart Of Stacking Antenna

The stacking process of an antenna begins with substrate preparation. This is where we carefully select and ready the base material that will support the entire antenna structure. The quality of the substrate plays a critical role in the performance of the antenna. Next, we move to conductive patterning. In this step, we create the actual patch patterns by depositing or etching conductive materials like copper onto the substrate. This defines how the antenna will radiate and receive signals. Once the patterns are ready, we proceed to feeding mechanism integration. Here, we add the structures that will connect the antenna to external circuits. This could involve attaching micro strip lines, coaxial probes, or other feed methods to efficiently transfer energy.

After integrating the feed, the antenna is not yet ready. It needs tuning and optimization. During this phase, we tweak the design — adjusting the patch size, feed location, or air gap height — to ensure that the antenna resonates at the desired frequency and performs optimally.

Following optimization, we carry out measurement and testing. This is where we evaluate the antenna's real-world behavior using instruments like a vector network analyzer (VNA). We check parameters such as return loss, bandwidth, gain, and radiation pattern. Each stage feeds into the next, requiring careful attention to detail. Small mistakes early in the process can affect final performance. That's why the flow is systematic and iterative if needed.

Stacking antennas adds complexity but also boosts bandwidth and gain compared to single-layer designs. Adding an air gap or an extra patch layer helps in achieving better overall efficiency. Throughout the process, teamwork among designers, fabricators, and test engineers ensures success.

C. Implementation Of Stacking Antenna

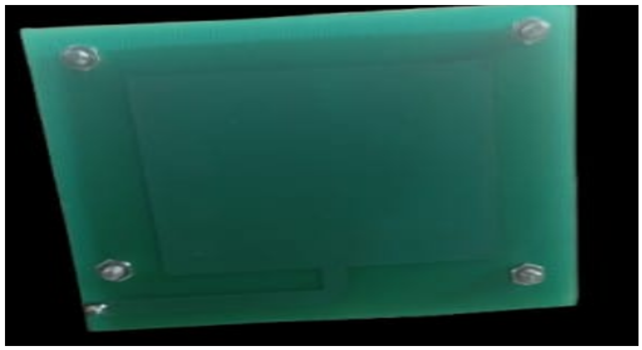

Figure 2 Stacking of Single Element

Here W= 5cm and L=5.4cm and Air gap=0.5cm.Its same for all

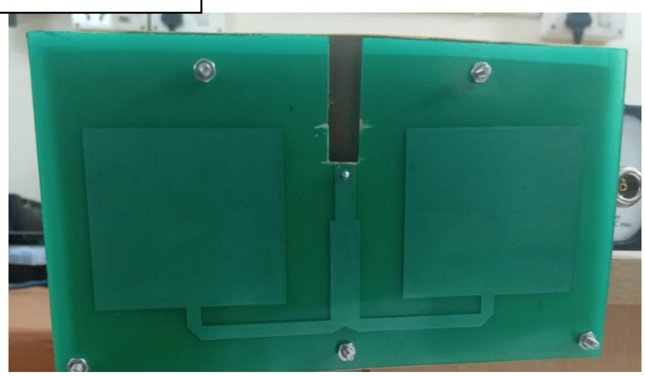

Figure 3 Stacking of two element

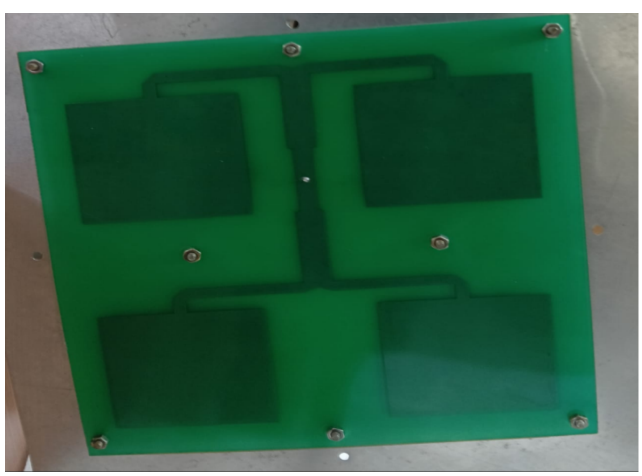

Figure 4 Stacking of four Element

Stacking antennas is basically about combining multiple antenna elements to boost performance — mainly by increasing the gain and focusing the signal more sharply. With just one antenna (a 1-element setup), the signal spreads out broadly, with limited strength, but it's simple and easy to build. When we move to a 2-element stack, we place two antennas about half a wavelength apart, allowing their signals to combine. This gives us stronger, more focused transmission, but it also means we have to carefully align the phases so everything adds up properly. If we take it further and stack 4 elements arranged vertically, horizontally, or even in a 2x2 grid we get even more gain and a much narrower beam, perfect for long-distance and very targeted communication. Of course, it also makes the design more complicated and bulkier. To imagine it simply: a 1-element antenna is like shouting normally, a 2-element stack is like cupping your hands to direct your voice, and a 4-element stack is like shouting through a megaphone to send your voice even farther and more precisely.

D. Software Requirement

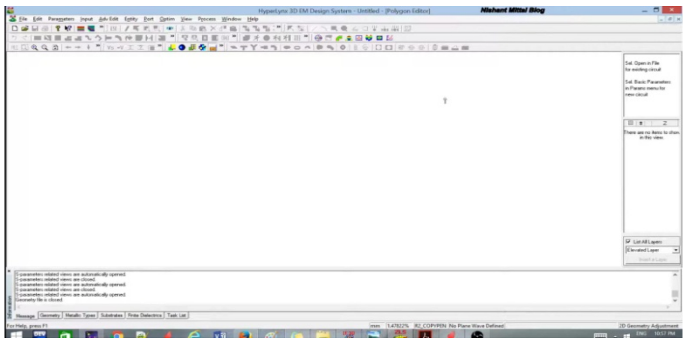

Figure 5 IE3D Software

In stacking antenna design, IE3D software serves as a powerful simulation tool that allows antenna engineers to accurately model and predict the electromagnetic behavior of their antenna structures before proceeding to physical fabrication. With IE3D, one can adjust important design parameters such as the length, width, air gap, substrate properties, and feeding techniques, and observe their impact on key performance indicators like return loss (S11), VSWR, impedance, gain, bandwidth, and radiation patterns. The software also offers visualization of electric and magnetic field distributions, enabling a deeper understanding of how stacking affects antenna performance, especially in enhancing bandwidth and gain. By simulating various configurations rapidly, IE3D helps designers fine-tune the antenna for optimal performance, reducing trial-and-error during manufacturing. After the antenna is fabricated,

E. Hardware Requirements

Figure 6 Taking Readings Of antennas Using Vector Network Analyzer (VNA)

A Vector Network Analyzer (VNA) is like the "truth detector" for antennas. After designing and building an antenna, especially a stacked microstrip patch antenna, you need to check if it actually works the way you intended — and that's exactly what the VNA helps you do. It measures how signals behave when they pass through or reflect back from the antenna. One of the most important things it tells you is the return loss (S11) basically, how much of your signal is being reflected instead of being radiated.

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If too much signal is reflected, it means the antenna is not properly matched and won't work efficiently. The VNA also helps you measure the bandwidth showing over which range of frequencies the antenna performs well. Another thing it checks is impedance**;** ideally, the antenna should have around 50 ohms impedance to match the transmission line and minimize power loss. When you connect your stacked antenna to the VNA, you get live graphs (like S11 vs frequency), and from these curves, you can see at which frequency your antenna resonates and how good the matching is. In simple terms, using a VNA is like having a real conversation with your antenna asking it, "Are you ready? Are you working properly?" and getting a very honest and detailed answer. It's a must-have tool for antenna testing because no matter how perfect your simulations look, only the VNA can confirm if the real antenna behaves correctly in practice.

F. Fabrication

Fabrication of an antenna is the exciting phase where your design ideas and simulations are finally brought to life in the real world. It starts with selecting a good substrate material the base layer that supports the entire antenna structure. Materials like FR4, Rogers, or even air (for air gap stacking) are chosen based on the frequency and performance needs. Then comes patterning the conductive layer, usually made of copper. Using processes like photolithography or etching, the patch shape is accurately created on the substrate. This patch is what actually radiates the electromagnetic waves. For stacked antennas, an extra layer (or patch) is placed carefully above the first, separated by an air gap or a low-dielectric material, making sure the gap height is precise (like 0.5 cm) to enhance the antenna's bandwidth and gain. Feeding structures like microstrip lines, probes, or coaxial feeds are then attached, allowing energy from a source to be delivered efficiently to the antenna. After assembly, the antenna might be held together using spacers, screws, or adhesives to maintain the correct alignment and air gap. Precision during fabrication is extremely important even small errors in dimensions can shift the resonant frequency or reduce efficiency. Finally, the fabricated antenna is tested using tools like a Vector Network Analyzer (VNA) to check if it behaves as expected. In short, antenna fabrication is a beautiful blend of engineering precision, craftsmanship, and creativity, where a well-thought-out simulation transforms into a working physical device ready to transmit and receive signals in the real world.

IV. RESULTS

A. Simulated Results

1) Simulated Results of Stacked Single Antenna

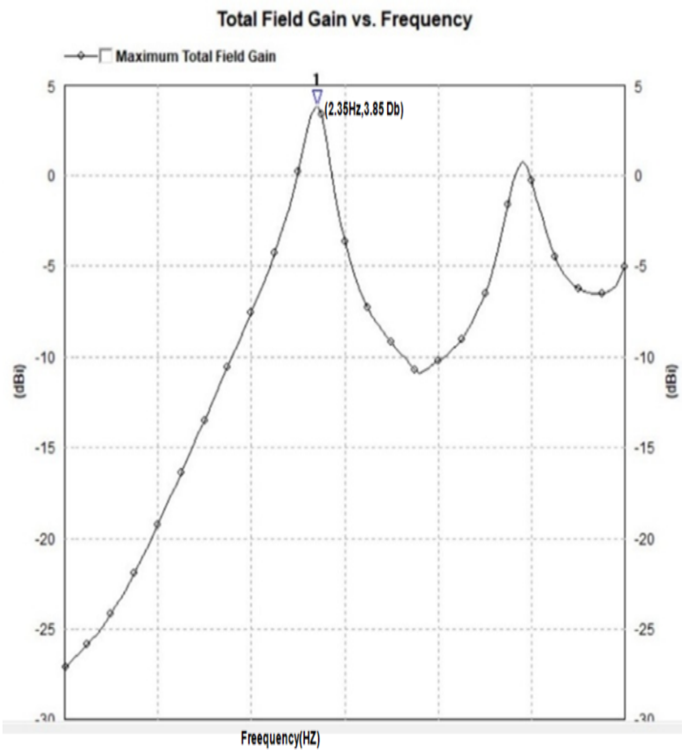

Figure 7 Gain vs Freequency of single element

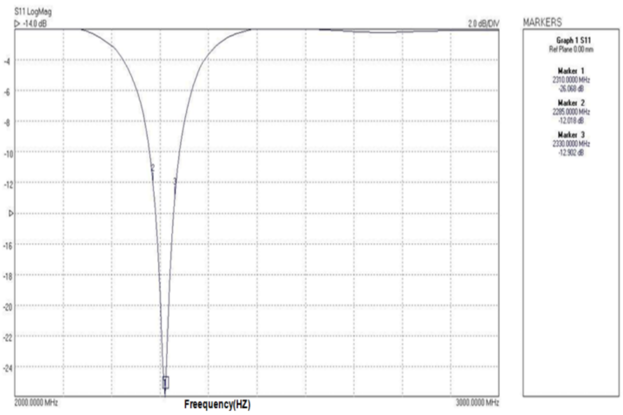

Figure 8 Return Loss of Single element

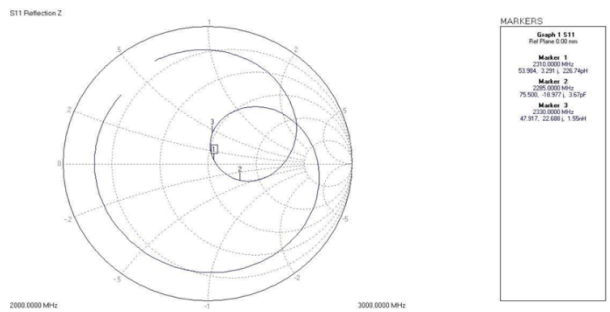

Figure 9 Smith chart of single element

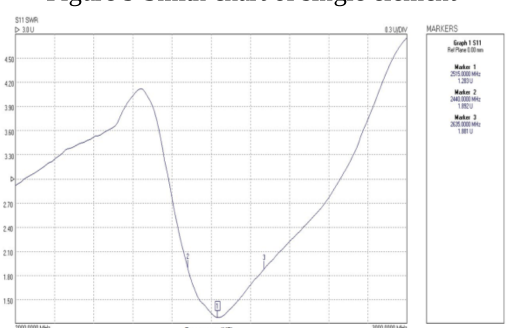

Figure 10 VSWR Of single element

2) *Simulated Results of Stacked Two element*

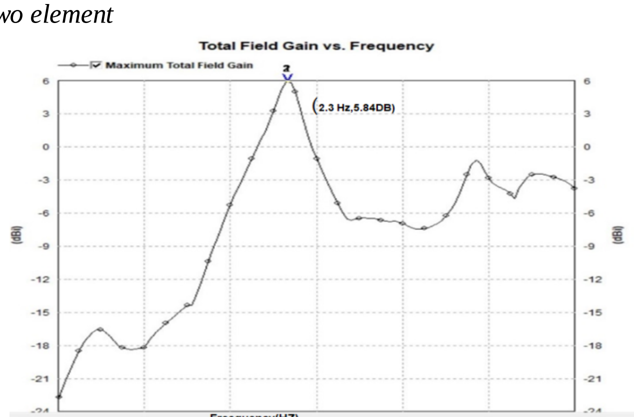

Figure 11 Gain Vs Freequency Of Two Element

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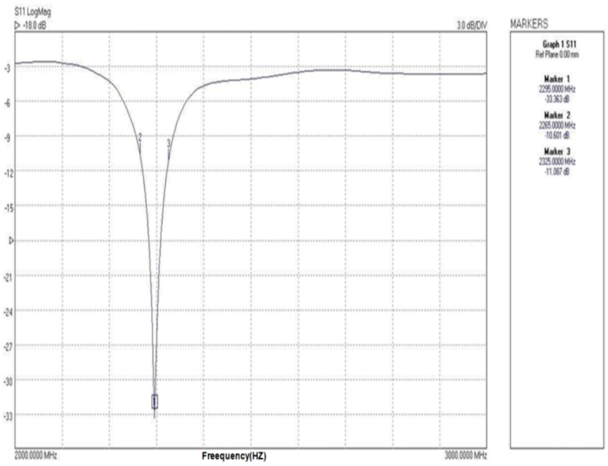

Figure 12 Return Loss of Two element

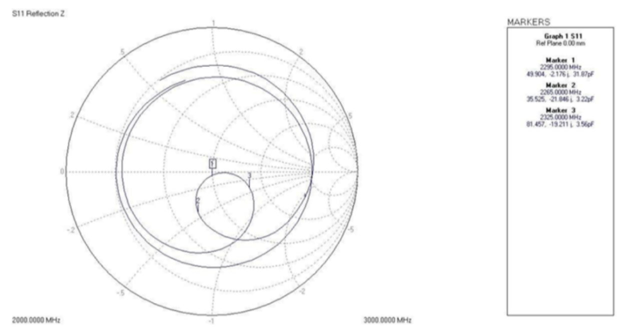

Figure 13 Smith Chart Of Two element

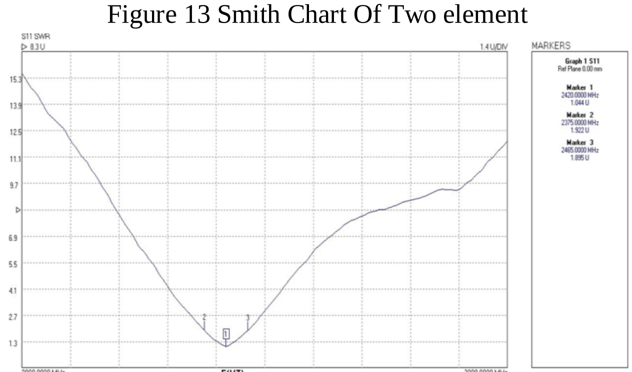

Figure 14 VSWR Of Two element

3) *Simulated Results Of Stacked Four Antenna*

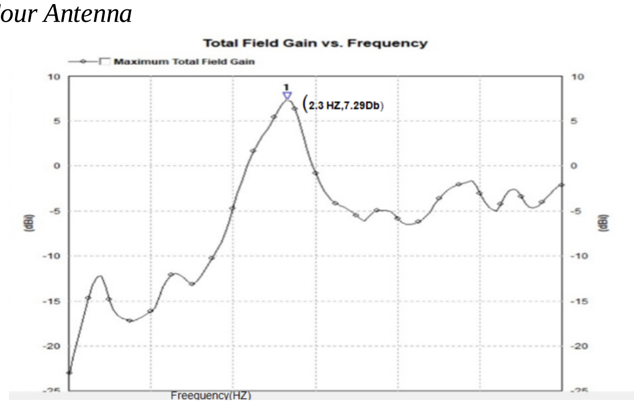

Figure 15 Gain Vs Freequency of four element

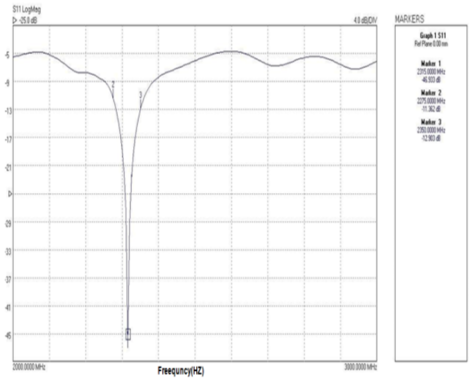

Figure 16 Return Loss of Four Element

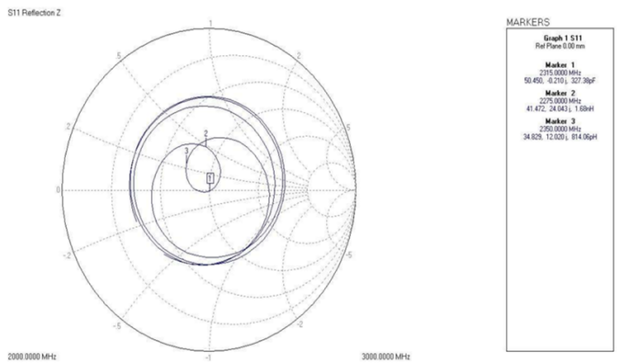

Figure 17 Smith Chart of Four Element

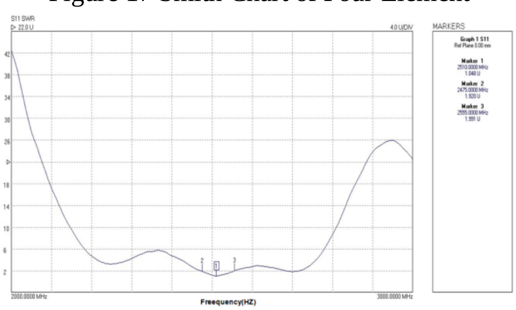

Figure 18 VSWR Of The Four element

Simulation results Comparison Table

SL NO	ELEMENTS	RESONANT FREQUENCY		GAIN	Return loss	Bandwidth
		Sim	Practical			
1	1 ELEMENT	2.37	2.3	3.8538	-26.068	1.94%
2	2 ELEMENT	2.37	2.3	5.840	-33.36	2.61%
3	4 ELEMENT	2.37	2.3	7.59	-46.93	3.23%

Figure 19 Comparison Table

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V. DISCUSSION

Stacking elements in antenna design is a clever and popular trick that engineers use to make basic microstrip patch antennas perform much better. Normally, a single patch antenna has its limitations its bandwidth is quite narrow and the gain isn't very strong. But when you add another radiating patch above the first one, separated by a small air gap or a thin spacer, things start to improve. These two patches start working together, creating multiple resonances that blend nicely, which makes the antenna work over a wider range of frequencies. Along with that, stacking also boosts the gain, helping the antenna focus its energy more efficiently without having to make the antenna bigger. Using an air gap, like 0.5 cm, really helps too because air has a dielectric constant of almost 1, meaning very little energy is lost — most of it gets radiated out properly. Of course, stacking isn't without its challenges. The design becomes a bit more delicate you have to tune things carefully and make sure everything is aligned just right during fabrication. If you mess up the gap or the patch alignment, you can end up with poor performance or unexpected resonances. Still, even with a little extra effort, stacking is totally worth it because it offers a perfect balance between complexity and performance. That's why it's so popular in real-world applications like Wi-Fi systems, satellite communication, and radar, where you need antennas that are compact but still powerful and efficient

VI. CONCLUSION

Stacking in antenna design is a smart and effective method to overcome the limitations of simple patch antennas. By adding an extra radiating patch with a controlled air gap, designers can achieve significantly higher bandwidth and improved gain without increasing the overall size too much. Although stacking introduces some complexity in design and fabrication, the benefits it offers like better radiation efficiency, wider frequency coverage, and stronger signal focus — make it a highly valuable technique. It strikes a perfect balance between performance and practicality, making stacked antennas a popular choice in modern communication systems like Wi-Fi, satellite links, and radar applications. With careful tuning and precision, stacking truly elevates the performance of antennas to meet the growing demands of advanced wireless technologies.

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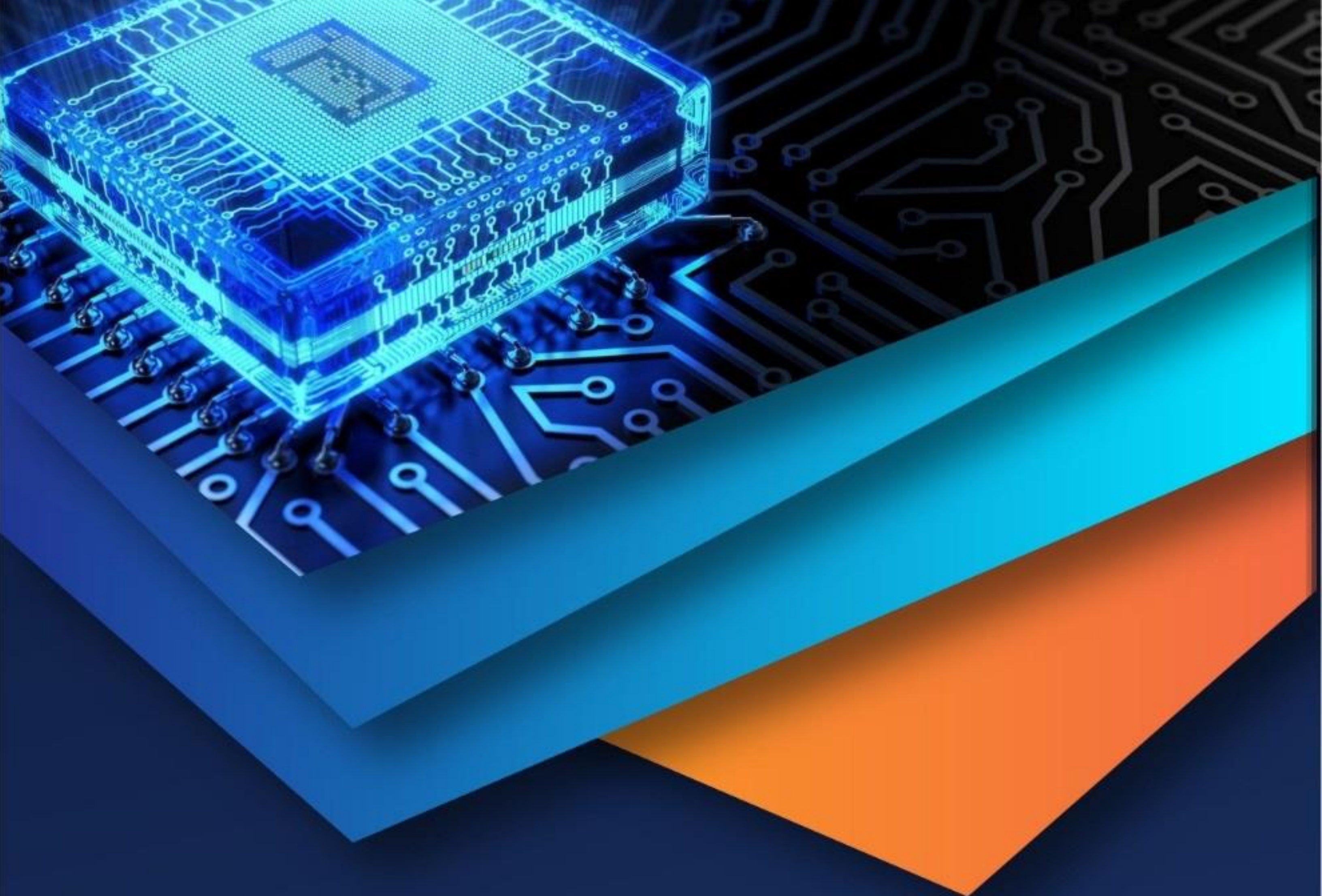

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