Journal of Harbin Engineering University Vol 45 No. 5
ISSN: 1006-7043 May 2024

Comparative Analysis of Hexagonal Stub Antenna for Wireless Applications

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Abstract- This paper presents the design and analysis of a Single-layer and Multilayer Hexagonal microstrip patch antenna with the goal of enhancing bandwidth and directivity in Wireless applications. Microstrip antennas due to their small profile design take less area. Further, they can be modified by two techniques that introduce different dielectric layers by adding an Air gap between the Ground and the conducting surface to improve its Bandwidth, Gain, VSWR, Return Loss, and Directivity. In this paper, we have simulated the Single-layer and Multilayer Hexagonal Stub MSA by studying various Microstrip configurations & Mathematical designs using High-Frequency Structure Simulator (HFSS) software. The main objective of this study is to enhance the antenna's bandwidth in order to fulfill the increasing demands of modern Wireless applications. The proposed antenna enhances both bandwidth and efficiency by employing many layers. To validate the simulation results, an experimental examination was carried out with a Vector Network Analyzer (VNA). The simulated and measured results are highly consistent, indicating the suggested design's accuracy and dependability. The hexagonal multilayer patch antenna significantly enhances the bandwidth, making it suitable for a diverse variety of wireless applications. The antenna's gain, directivity, and emission pattern indicate that it is well-suited for current communication systems.

Keywords: Bandwidth, VSWR, HFSS, Directivity, Multilayer, Techniques.

1. Introduction

Different forms has brought up a novel way for enhancing the bandwidth of the Single-Layer and Multilayer microstrip patch antennas by tweaking the structure instead of changing the dielectric material [1-3]. Different shapes employ modification in the design structure which in general case found to be plane [5]. Many conducting layers separated by dielectric substrates make up a multilayer microstrip patch antenna, a particular kind of antenna [6]. Because of its capacity to operate over a broad frequency range, it is frequently utilized for broadband applications. Antennas have seen an increase in demand due to the wireless technology's quick development and growth. The antenna is one of the essential components for incorporating low-profile wireless communication, hence antenna miniaturization is necessary to get the optimal design [7]. To enable Wireless Local Area Network (LAN) and other next-generation wireless technologies, it is necessary to have the capacity for concurrent operation of wireless antennas in certain wireless applications. [8]. Due to important characteristics including, lightweight, low profile, simplicity of incorporation with planar circuits, and affordable manufacture, microstrip patch antennas have seen increased use in recent years [9]. These benefits are especially important when multiple patches are placed in an array arrangement to create antennas with high gain with suitably designed emission models. For the majority of contemporary remote sensing, communication, and radar, microstrip array antennas are desirable [10].Microstrip patch antennas, on the other hand, could exhibit a narrowband behaviour as a result of their resonant characteristics [11]. Based on the given substrate specifications and thickness, it has been observed that the impedance bandwidth of a microstrip patch typically attains only a fraction of a few percent. This limitation poses a significant challenge in the context of wideband applications [12]. Consequently, contemporary microwave systems are specifically focused on methods and structures that prioritize expanding the range of frequencies. The substrate's characteristics directly determine the antenna bandwidth [13]. The ground plane and microstrip patch may be considered as a capacitor, with the amount of stored energy increasing as the dielectric constant and thickness of the substrate decrease [14]. The antenna's bandwidth is diminished, but, the merit factor of the resonator increases as a consequence. To achieve optimal broadband performance, it is advisable to utilize a substrate that possesses a low permittivity and substantial thickness [15].

The suggested hexagonal multilayer design structure enables the attainment of a substantial bandwidth and gain. The costs associated with processing are similarly low. The HFSS program is capable of analyzing several factors like Radiation Pattern, Return Loss, Directivity, Gain, VSWR, and Bandwidth.

The main contributions of this work are,

- A unique Hexagonal-shaped Single-Layer and multilayer microstrip patch antenna is constructed utilizing HFSS to enhance its overall functioning and optimize its radiation qualities.
- To boost the antenna's bandwidth to satisfy the expanding requirements of modern Wireless applications by experimental Analysis.
- Various performance characteristics, including bandwidth, gain, directivity, return loss, VSWR, and radiation pattern, are utilized to thoroughly evaluate the antenna's performance.

2. Literature review

Jothilakshmi, P., et al [16] have suggested a unique 2 GHz mobile satellite service (MSS) application-specific small microstrip stacked patch antenna. To reduce coupling loss, an air gap was used to separate the two stacked patches of the antenna. The ground plane had a slot that facilitated the passage of microwave energy from the feed line to the radiating patch. The multilayer aperture-coupled antenna design was constructed using an inexpensive FR4 substrate, with log slots arranged in the form of a plus symbol.

Venkatesh, P., et al [17] have created the 2.45 GHz microstrip patch antenna for use in Wi-Fi applications. The recommended antenna was developed using computer simulation technology (CST) microwave studio. In this study, Microstrip Patch Antennas were created to meet the requirements of low profile and acceptable gain, despite the existence of other antenna designs already in use. The simulation data were discussed with regards to the key assessment parameters of return loss, gain, radiation power, and directivity of the antenna.

Bansode, P., [18] designed a Microstrip patch array antenna operating at a frequency of 5.62 GHz. The antenna was fabricated on a FR4 substrate with a dielectric constant of 4.4.The antenna was designed for use specifically with the affordable imaging radar, MicroSAR. The ground plane, formed by the close proximity of the two substrates, consisted of a shared copper layer.

Srivastava, H. and Tiwari, U. [19] have conducted research on the design, evaluation, and simulation of microstrip patch antennas with both rectangular and circular shapes. The patch antennas were constructed using Rogers RT/duroid 5880 material using Ansys HFSS software. Their resonant frequency was 9 GHz, falling inside the X band spectrum. It was found that the rectangular MPA had greater values compared to the circular MPA.

3. Desıgn Steps of Mıcrostrıp Antenna

To construct a hexagon structure at Frequency of operation (f^o): 2.4 GHz, Height of dielectric substrate (h): 1.6 mm, Dielectric constant of the substrate (ε^r): 4.4 first, it is required to decide about one side which is called as 'a' for which circular equation is used and the Fundamental mode resonant frequency of such antenna is given by

$$f_0 = \frac{2C}{6a\sqrt{\square}} \quad (3.1)$$

Where: c is the speed of light, and ε_r - relative permittivity of substrate.

$$a=\frac{2C}{6f\sqrt{\square}}=\frac{2*3*10^{8}}{2.4*10^{9}\sqrt{4.4}} = 20.5\text{mm} \qquad (3.2)$$

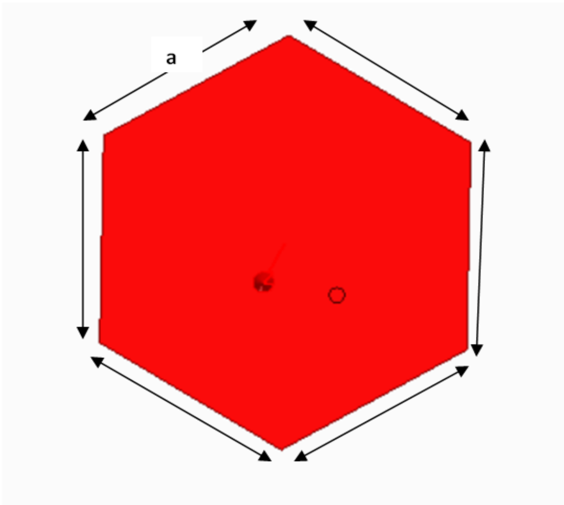

Fig. 1 Basic Structure of Hexagonal Antenna

Calculation of Lambda

$$\text{Lambda } (\lambda) = \frac{c}{f} = \frac{3X10^{8}}{2.4X10^{9}} = 125 \text{ mm}$$

(5.3)

Step 2: Calculation of Substrate dimension-

For Hexagonal design the substrate dimension would be Lambda/2

$$Ls = Ws = \frac{\lambda}{2} = \frac{125}{2} = 62.5 \text{ mm}$$

(5.4)

After optimization substrate dimension Ls = Ws =58 mm is taken.

4. Simulation Tool

Now that we have the measurements, it is necessary to create a model of the design using a software-based tool, such as Ansoft's HFSS program. Accurate antenna modeling software with a user-friendly interface has been found in the market. HFSS's dynamic form selection greatly simplifies the process of making a 3-D graphic. By employing the Boolean and subtraction operations in HFSS, three separate ground planes are generated.

5. Simulated Results of Hexagonal Stub MSA

The objective of this work is to analyze the impact of altering the dielectric materials and including a Stub of Microstrip patch antenna on the Bandwidth, Return loss, VSWR, and radiation pattern of Single-Layer and Multilayer Hexagonal MSA. The following models in Fig.2 and Fig.3 respectively shows the different model of Single-Layer and Multilayer Hexagonal MSA.

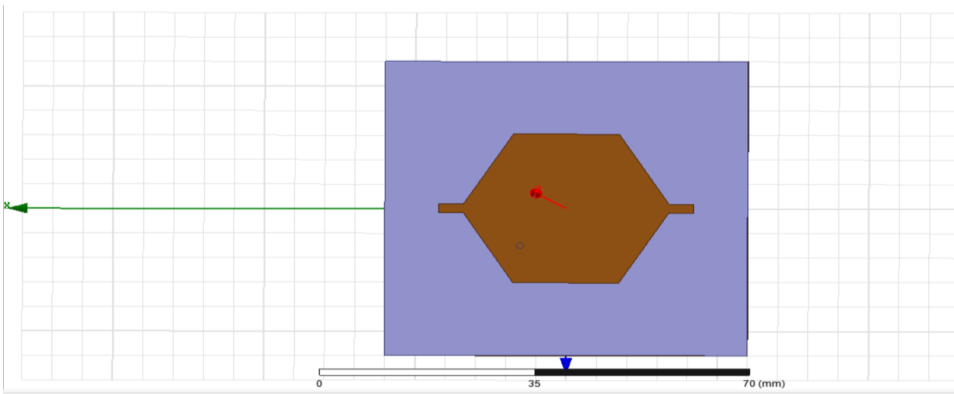

Fig.2 Single-Layer Hexagonal Stub MSA

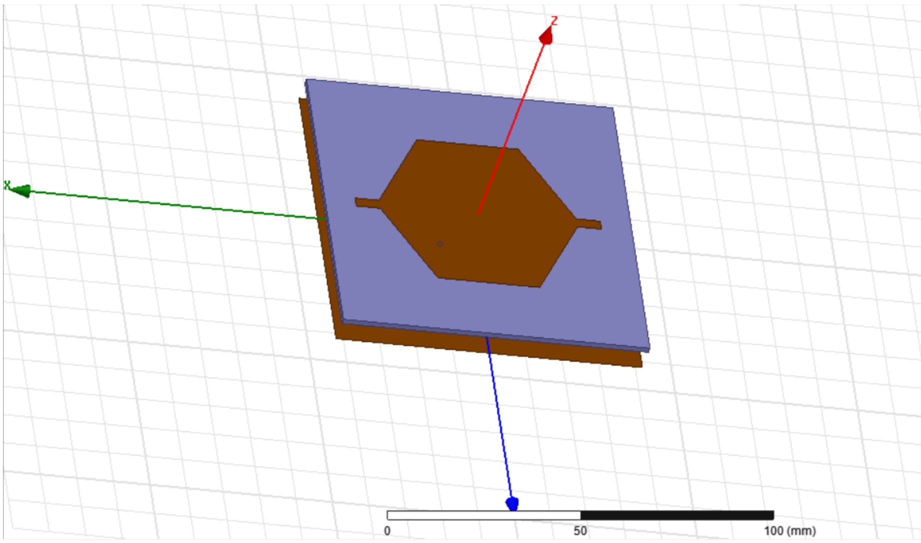

Fig.3 Multilayer Hexagonal Stub MSA

5.1 Return loss & Bandwidth

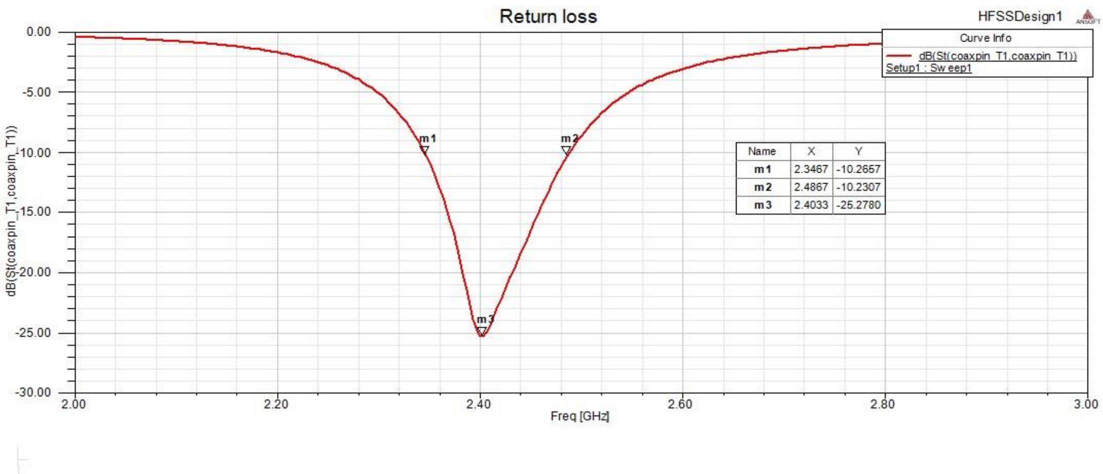

Fig.4 Return Loss & Bandwidth of *Hexagonal* MSA with Stub

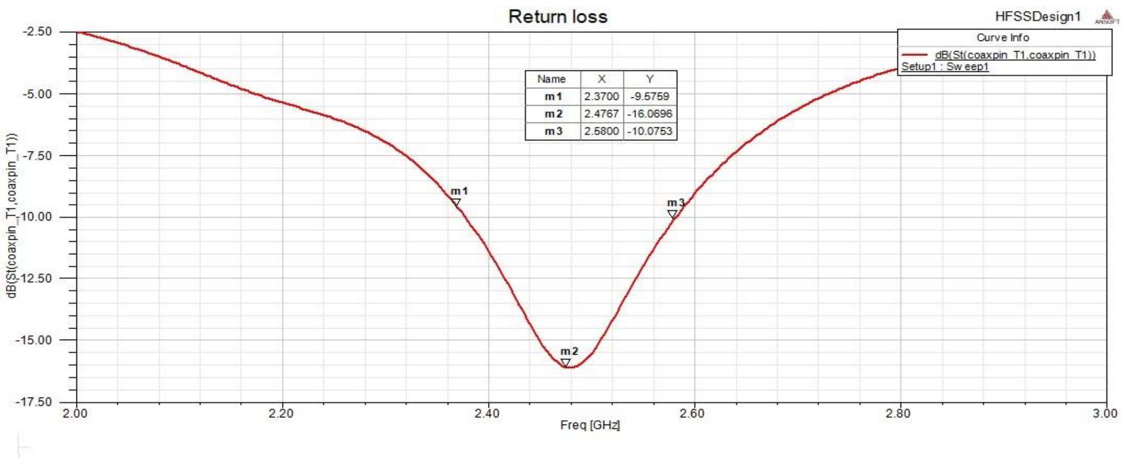

Fig.5 Return Loss & Bandwidth of Multilayer *Hexagonal* MSA with Stub

5.2 VSWR

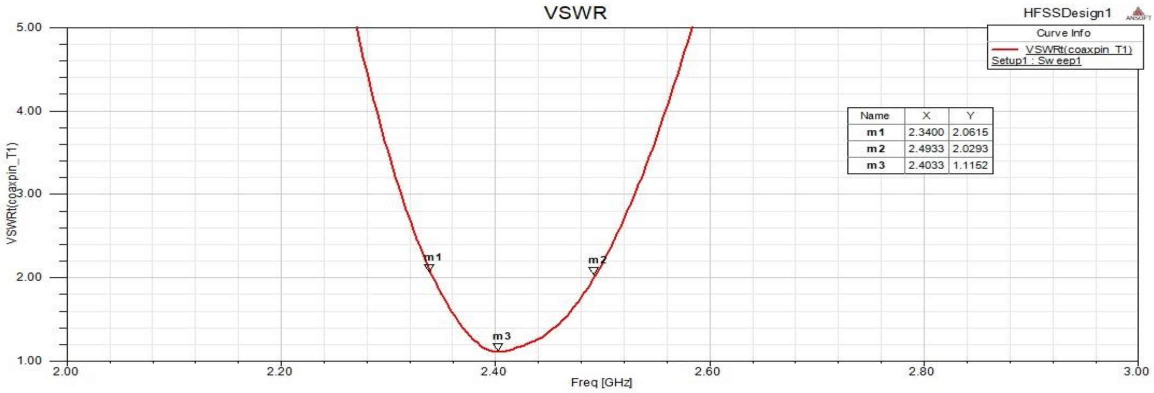

Fig.6 VSWR of *Hexagonal* MSA with Stub

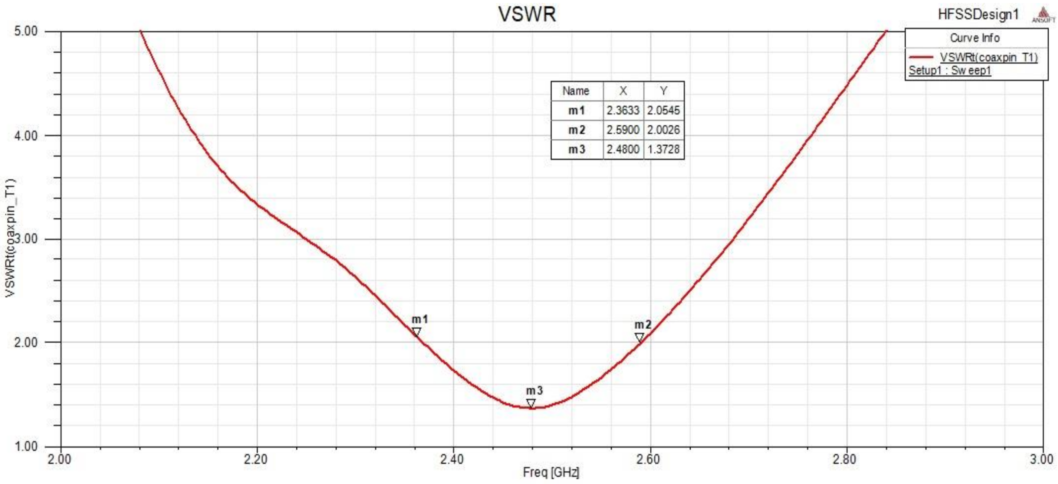

Fig.7 VSWR of Multilayer *Hexagonal* MSA with Stub

5.3 Directivity

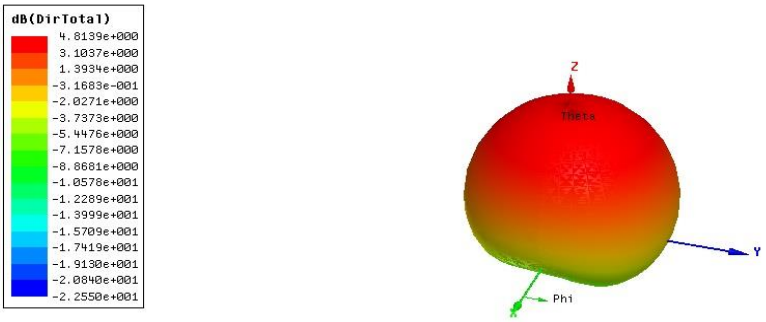

Fig.8 Directivity of *Hexagonal* MSA with Stub

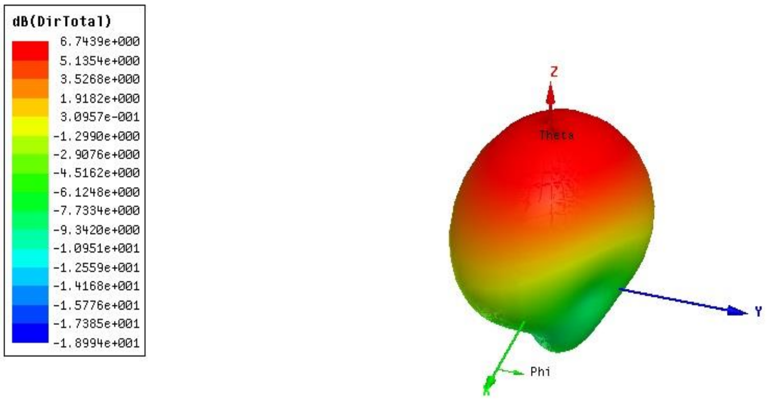

Fig.9 Directivity of Multilayer *Hexagonal* MSA with Stub

5.4 Gain

Fig.10 Gain of *Hexagonal* MSA with Stub

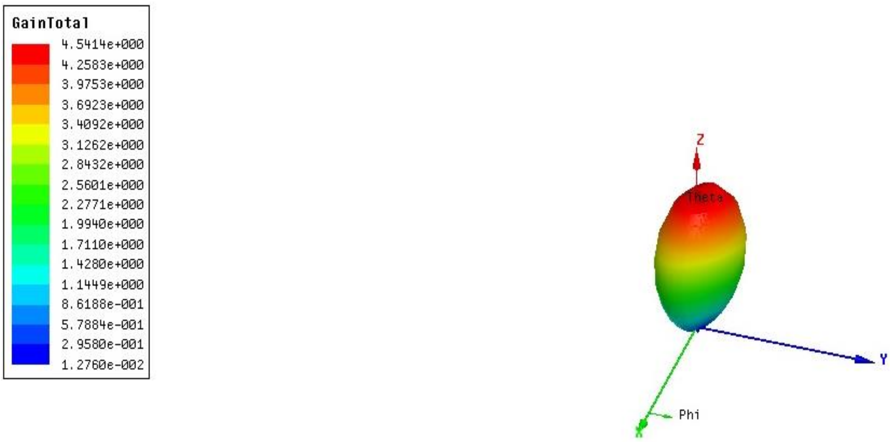

Fig.11 Gain of Multilayer *Hexagonal* MSA with Stub

5.5 Radiation Pattern

Name	Theta	Ang	Mag
m1	360.0000	-0.0000	4.8139

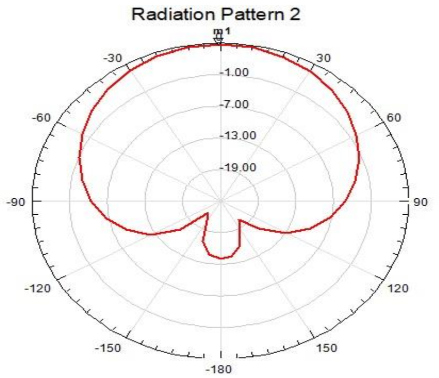

Fig.12 Radiation Pattern of *Hexagonal* MSA with Stub

Name	Theta	Ang	Mag
m1	360.0000	-0.0000	6.7439

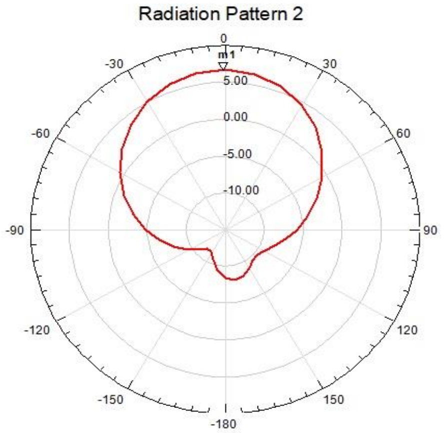

Fig.13 Radiation Pattern of Multilayer *Hexagonal* MSA with Stub

6. Fabrication & Experimental results of Single Layer Hexagonal Stub MSA

Some photograph of fabricated Single Layer Hexagonal Stub MSA has shown below:

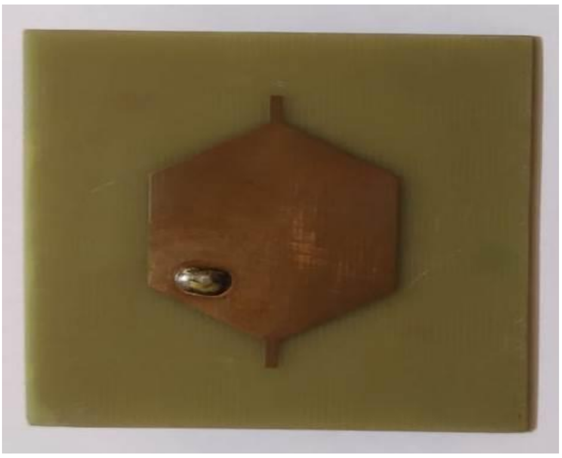

Fig.14 Top view of Fabricated Single Layer Hexagonal Stub MSA

Fig.15 Probe feed point with SMA connector

Return loss, VSWR, and bandwidth were all evaluated utilizing a Vector Network Analyzer (VNA).

6.1 Return loss and Bandwidth of Fabricated Hexagonal Stub MSA

The results of the measurement are compared to the simulated results once the measurement is complete. The return loss of the manufactured Single Layer Hexagonal Stub MSA is -28.225dB at the center frequency of 2.461 GHz, as illustrated in Figure 16. The antenna's bandwidth is approximately 202 MHz.

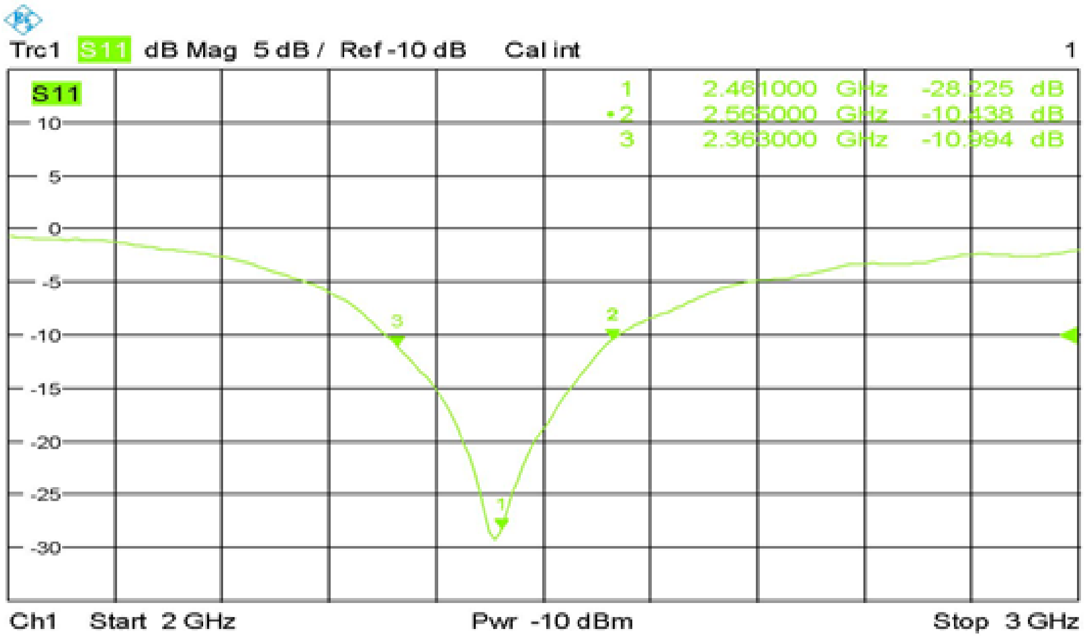

Fig.16 Return loss and Bandwidth of Fabricated Single LayerHexagonal Stub MSA

6.2 VSWR of Fabricated Hexagonal Stub MSA

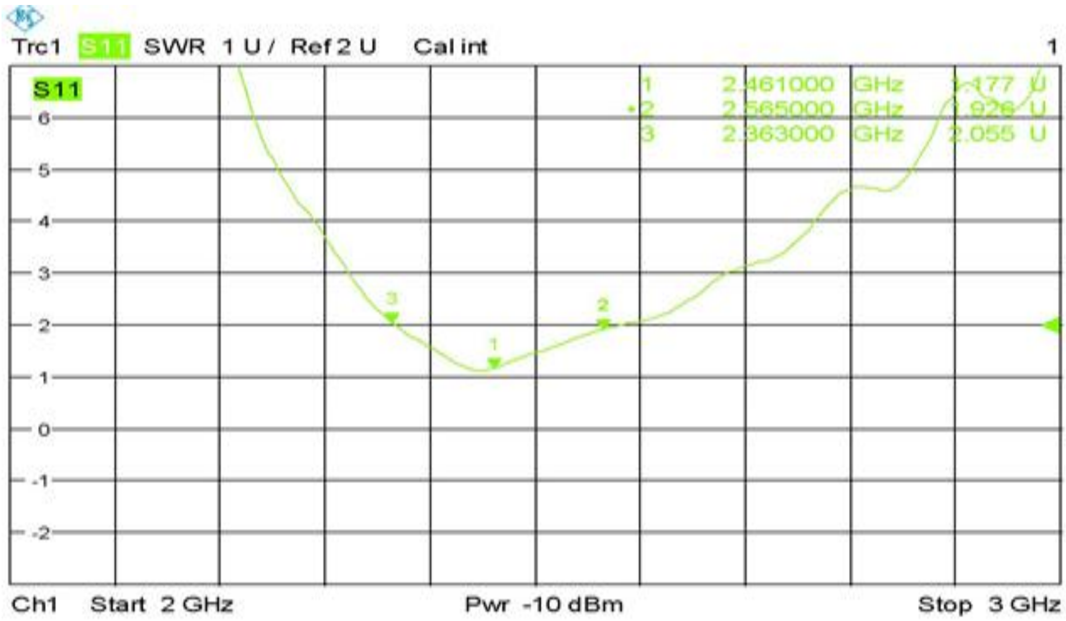

Fig.17 VSWR of Fabricated Single Layer Hexagonal Stub MSA

VSWR obtained on Vector Network Analyzer is 1.177 at a Centre frequency of 2.461GHz.

7. RESULT ANALYSIS

Table No.1 Comparison table for Single-Layer, Multilayer, and Fabricated Single-Layer Hexagonal MSA with Parameter

Parameters	**Single-layer Hexagonal with Stub**	**Multilayer Hexagonal with Stub**	**Fabricated Single-Layer Hexagonal with Stub**
Operating Frequency (GHZ)	2.3433-2.4933	2.3700-2.5800	2.3630-2.5650
Return Loss(dB)	-25.27	-16.07	-28.225
Bandwidth (MHz)	150	210	202
VSWR	1.11	1.37	1.177
Directivity (dB)	4.8	6.74	_
Total Gain (dB)	*1.4544*	*4.54*	_

8. Conclusion

An investigation is conducted into the feasibility of implementing a single-layer and multilayer hexagonal-shaped microstrip patch antenna as a means to augment the bandwidth of wireless applications. The antenna's performance was comprehensively assessed using a variety of performance parameters, such as bandwidth, gain, directivity, return loss, VSWR, and radiation pattern.The HFSS simulation outcomes were verified through experimental measurements conducted with a VNA. The findings indicate that the proposed antenna configuration adequately addresses the challenge of increased bandwidth for wireless applications. The exceptional bandwidth of 210 MHz significantly surpassed the performance of conventional patch antennas. In modern communication systems that require higher data transfer rates, this expanded bandwidth ensures efficient data reception and transmission. Moreover, the performance measurements of the antenna provide evidence that it is viable for practical deployments of wireless applications. Achieving a VSWR below 1.37 at 2.48 GHz across the entire operational bandwidth guarantees minimal signal attenuation and efficient power transfer between the feed line and the antenna.By focusing and directing the radiation pattern, the antenna is capable of increasing signal strength and coverage, as evidenced by its directivity of 6.74 dBi and gain of 4.54 dBi. This is paramount in order to attain a dependable and superior wireless connection. The findings presented herein establish fresh pathways for research and development in the domain of high-performance antenna design and contribute to the advancement of multilayer antenna technology.

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