INTERNATIONAL JOURNAL OF ADVANCE RESEARCH, IDEAS AND INNOVATIONS IN TECHNOLOGY

ISSN: 2454-132X
Impact Factor: 6.078
(Volume 11, Issue 2 - V11I2-1378)
Available online at: https://www.ijariit.com

Ku-Band Microstrip Antenna Array: A Design Approach for Satellite Communication

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ABSTRACT

This work presents the design and simulation of a microstrip single patch element along with two distinct array antenna configurations intended for Ku-band applications, specifically operating at a frequency of 17.16 GHz. The antennas are designed using an FR-4 substrate material with a dielectric constant of 4.3 and a substrate height of 13 mm. Two different two-element array configurations are developed to evaluate the impact of array geometry on antenna performance. The designs are modeled and simulated using CST Microwave Studio. The simulation results demonstrate that both directivity and gain improve significantly as the number of patch elements increases in the array structure. Comparative analysis between the single element and array configurations reveals that array antennas offer enhanced radiation characteristics, making them more suitable for high-frequency satellite communication systems. This study highlights the importance of array design in achieving better antenna performance, especially in applications requiring high gain and narrow beamwidth.

Keywords: *Satellite application, dual-band, patch antenna, Antenna Type, Frequency, Bandwidth and CST.*

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1. INTRODUCTION

The fundamental function of an antenna in wireless communication is to act as a transceiver, sending information through space as electromagnetic waves. Conventional antennas provide the high gain and bandwidth required to create a dependable communication antenna. However, traditional antennas are big and expensive to build. Due to its compactness, MPA emerged as a solution in the process of reducing the antenna's physical dimensions. When used in specific combinations, MPA can provide the features of a traditional antenna. Microstrip Patch Antenna's advantages are its small size, low profile, low cost, ease of production, light weight, flexibility, resilience, and compatibility. Applications for MPAs can be found in the fields of telemetry, satellite communications, radiation direction finding, mobile phones, aviation, the navy, biomedical, radar, and ground positioning systems. A conducting material patch, a ground plane composed of the same material, and a dielectric substrate make up the Microstrip Patch Antenna. Figure 1 displays the components' visual depiction. The microstrip patch is placed on top of the dielectric substrate, which is situated above the ground plane. MPAs come in a variety of shapes, including square, rectangular, concave, triangle, and round.

The most common types of microstrip patch antennas are square and circular. By adjusting the array arrangement, the MPAs' low gain and bandwidth can be increased. Other methods to enhance the MPAs' performance include lowering the ground plane's size, removing the patch's resonant slot, employing a thick dielectric substrate, utilizing different impedance matching strategies, and achieving the best performance outcomes with a low relative permittivity of the dielectric substrate. Antenna size should be λ/2 to achieve efficient radiation. The VSWR and return loss parameters obtained during the electronic simulation of the MPA are necessary for the antenna's real-time implementation. For implementation, configurations with a return loss of less than -10dB and a VSWR of less than 2 are taken into consideration. The MPAs are fed using two different types of feeding schemes: contacting feed and non-contacting feed. Contacting feed techniques include coaxial probe feeding and microstrip line feeding. Both aperture coupling and proximity coupling fall under the category of non-contacting feed methods. Microstrip line feeding is the most practical feed method. There are two different configurations for microstrip line feeding. In one, the feed is connected to the patch's bottom edge. In the other, the patch is cut out to the point where the impedance matching is good, and the feed is connected to the patch at that location. We call this setup "inset feed".

In this work, square and circular Microstrip Patch Antennas are designed at the Ku band of frequencies and CST studio tool is used to simulate the configurations, and also used to calculate the parameters like VSWR, return loss, gain and directivity are considered to analyze the performance of the antennas. Also In this work, both square and circular Microstrip Patch Antenna configurations are simulated with the inset feeding.

A 1×2 patch array antenna is a microstrip antenna configuration that consists of two individual patch elements arranged side by side in a single row. This type of antenna is an extension of the basic single patch antenna, designed to improve performance characteristics such as gain, directivity, and beam shaping. Each patch is typically a rectangular or square conducting surface mounted on a dielectric substrate, with a ground plane on the opposite side. The two patch elements are excited through a feed network, which can be implemented using various methods such as corporate feeding or series feeding. The spacing between the elements is generally around half the wavelength (λ/2) to ensure constructive interference and avoid unwanted radiation patterns known as grating lobes. Compared to a single patch antenna, the 1×2 array offers higher gain and more focused radiation patterns, making it more suitable for applications requiring longer range or more directional coverage.

2. LITERATURE REVIEW

Researchers employ a number of strategies to increase the efficiency and gain of MPA, such as the use of multiple feeding mechanisms and impedance matching, varied slot types above the patch, and a thick substrate with a low dielectric constant. To increase the gain, two connected patches have been placed on either the substrate's upper or lower surface. However, a single patch antenna typically suffers from low gain and narrow bandwidth. To overcome these limitations, researchers have developed array configurations, which involve combining multiple patch elements to enhance gain, directivity, and overall performance. Various feeding techniques like corporate and series feeding have been explored to ensure efficient power distribution among elements. Recent advancements include the use of high-performance substrates, metamaterials, and reconfigurable structures to further improve bandwidth and reduce mutual coupling. These developments make array microstrip patch antennas suitable for modern wireless applications, including radar, satellite, and 5G communication systems.

3. METHODOLOGY

3.1 Theoretic design of a Single Patch

The frequency range of a single patch antenna is 15.65 GHz. A radiating patch, a 50 Ohm transmission line, a ground plane, a substrate, and a 50 Ohm coax connector make up the patch antenna. The substrate utilized is FR-4 (lossy), which has a height of 1.6 mm and a dielectric constant of 4.3. Fig. 1 depicts the single patch antenna's configuration. The coax connector is linked to one end of the transmission line, and the patch is connected to the other end. Inset feed design is used to accomplish impedance matching. The following classical equations are applied to the design.

Width of the patch, W = $\frac{c}{2fo\sqrt{€r+1}/2}$

Length of the patch, L = Leff − 2ΔL

Effective dielectric constant, €eff $= \frac{€r+1}{2} + \frac{€r-1}{2}\left[1 + 12\frac{h}{w}\right]^{-1/2}$

Effective Length, $Leff = \frac{c}{2fo\sqrt{€eff}}$

Extent in Length, $\Delta L = 0.412h + \frac{(€eff+0.3)(\frac{W}{h}+0.264)}{(€eff-0.258)(\frac{W}{h}+0.8)}$

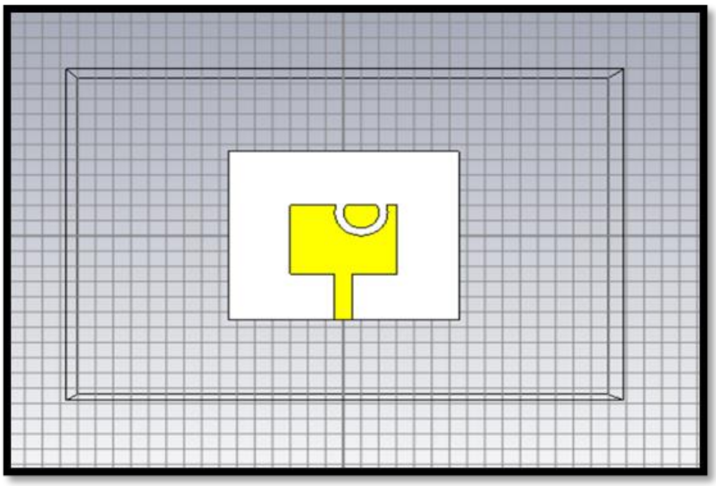

Fig-1: Single Element CST design

TABLE-1
SINGLE ELEMENT PATCH ANTENNA DIMENSIONS

Single Element Microstrip Patch Antenna Dimensions (in mm)	
Patch	
Width	6
length	4
Substrate	
Width	13
Length	11
Feedline	
Width	0.5
Length	11
Slot	
Inner Radius	1.0
Outer Radius	1.5

TABLE-2

SINGLE ELEMENT PATCH ANTENNA PARAMETERS

Antenna Parameters	**Single Element**
S11	-10.60 dB at 14.17 GHz
VSWR	1.83 dB at 14.17 GHz
Gain	3.76 dBi
Directivity	6.92 dBi

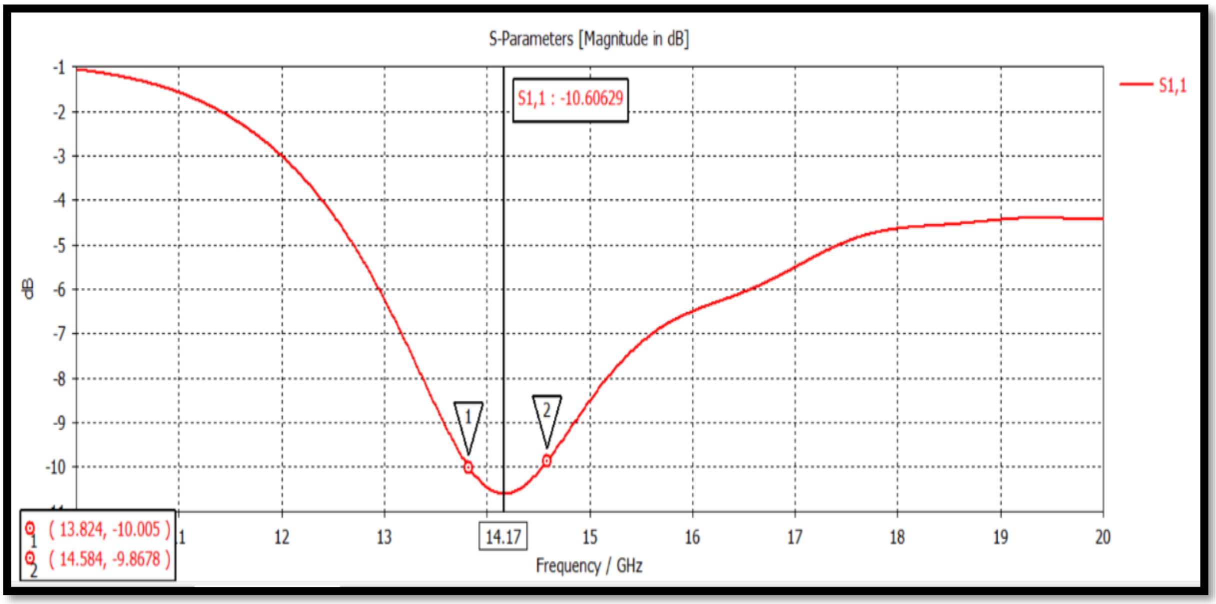

Fig-2: Single Element Patch Antenna SI1 Plot

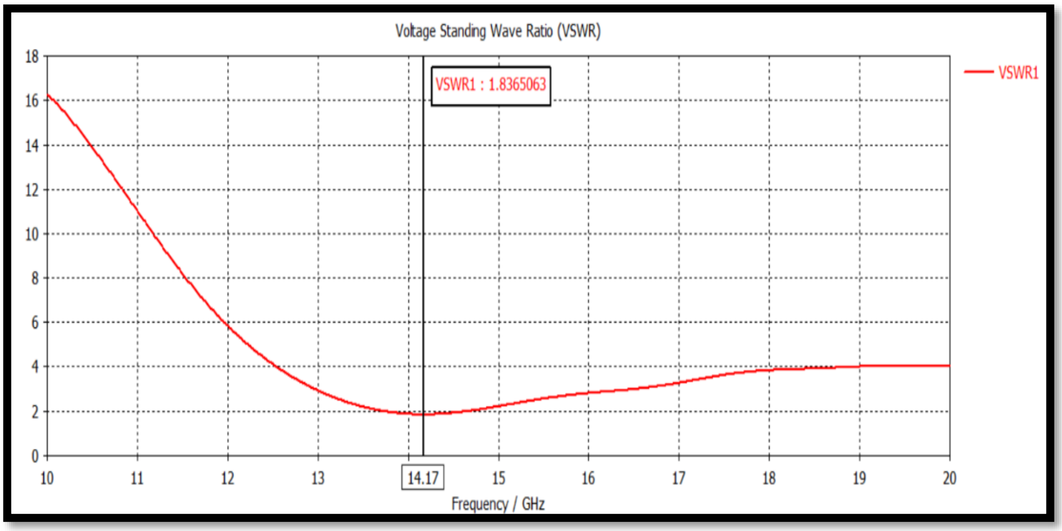

Fig-3: Single Element Patch Antenna VSWR Plot

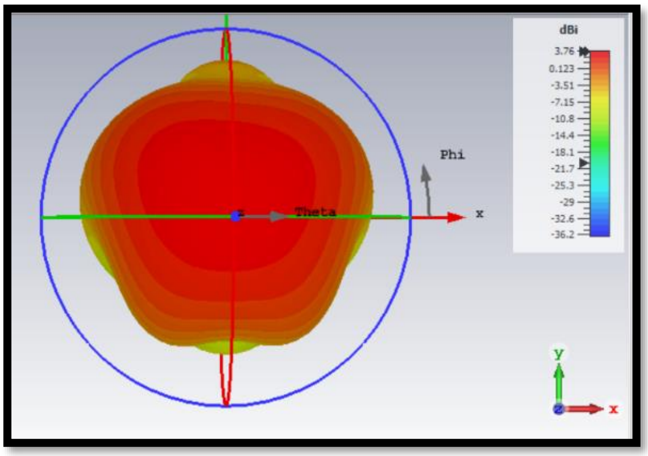

Fig-4: Single Element Patch Antenna Gain

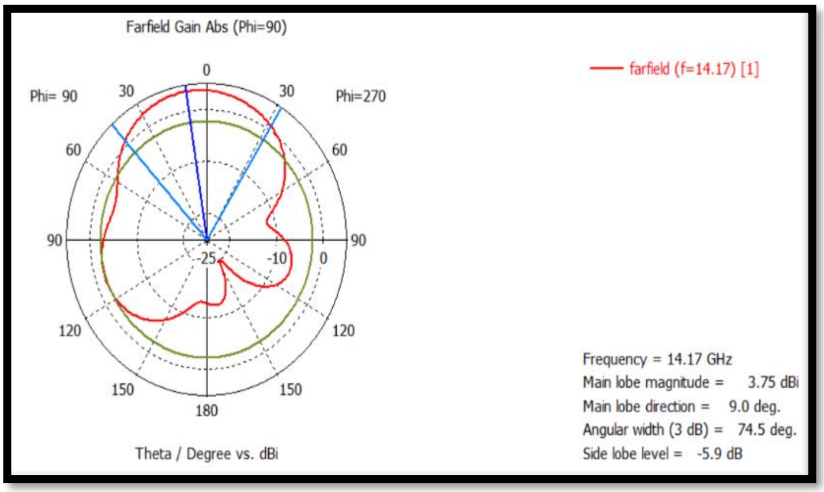

Fig-5: Single Element Patch Antenna Radiation Pattern Plot

3.2 Theoretic design of a 1 by 2 Array Antenna

Table 3 exemplifies the summary of results of 1 by 2 array. The CST model of 1 by 2 array is demonstrated in fig. 6 and fig. 7 shows the S11 response is -19.40 dB at 17.16 GHz. The Directivity is 7.86 dBi and gain is 5.24 dBi in fig. 9. The radiation efficiency is 0.4246. And fig. 10 demonstrate the 1 by 2 Patch Array Radiation Pattern Plots.

TABLE-3

1 BY 2 PATCH ANTENNA ARRAY DIMENSIONS

Microstrip Patch Array Antenna Dimensions (in mm)	
Patch	
Width	6
length	4
50 Ohms Transmission Feedline	
Width	7
Length	11
70 Ohms Transmission Feedline	
Width	16
Length	7
100 Ohms Transmission Feedline	
Width	0.5
Length	14
Slot	
Inner Radius	1.0
Outer Radius	1.5
Substrate	
Width	28
Length	13

TABLE-4

1 BY 2 PATCH ANTENNA ARRAY PARAMETERS

Antenna Parameters	Single Element
S11	-19.40 dB at 17.16 GHz
VSWR	1.23 dB at 17.16 GHz
Gain	5.26 dBi
Directivity	8.96 dBi

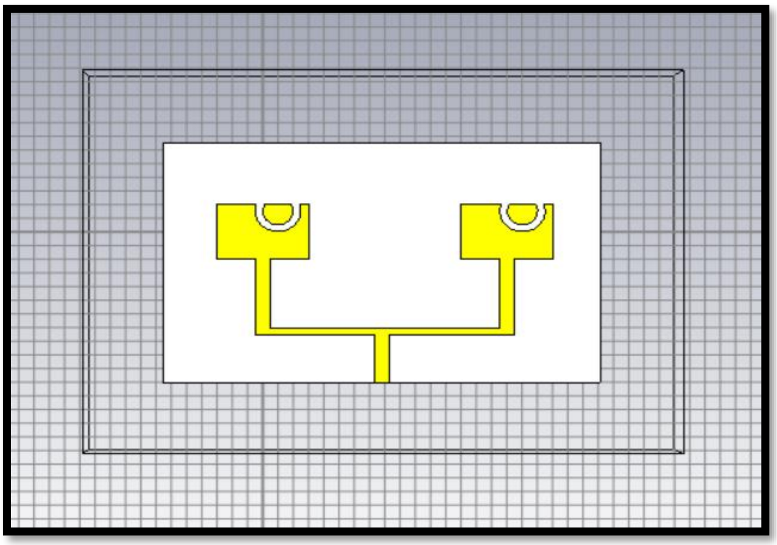

Fig-6: 1 by 2 Patch Array CST design

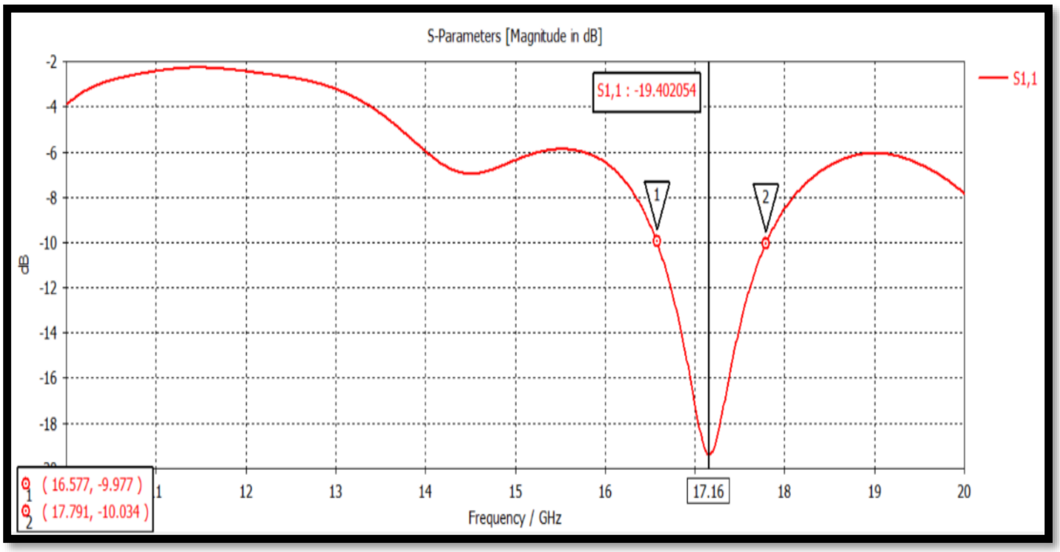

Fig-7: 1 by 2 Patch Antenna Array SI1 Plot

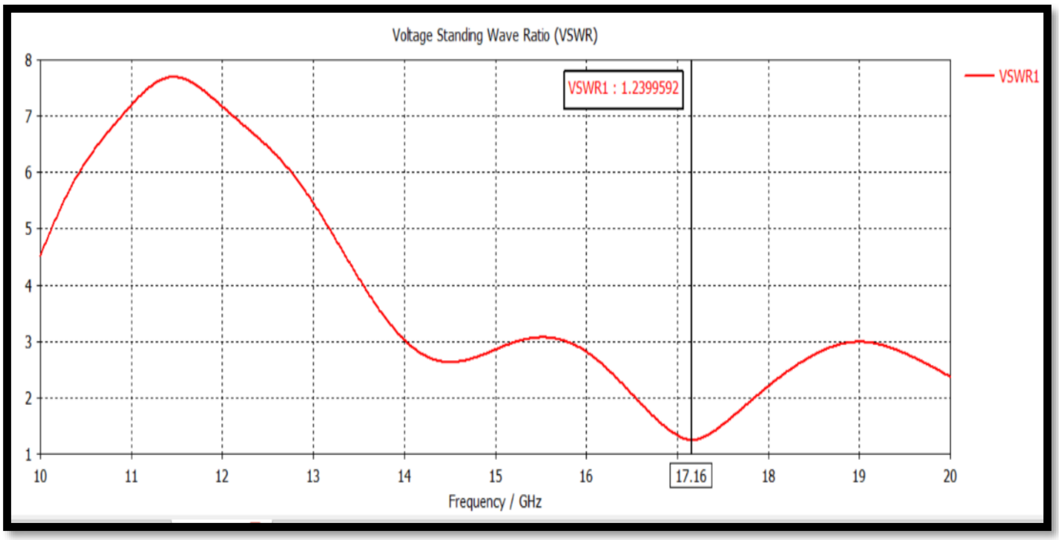

Fig-8: Single Element Patch Antenna VSWR Plot

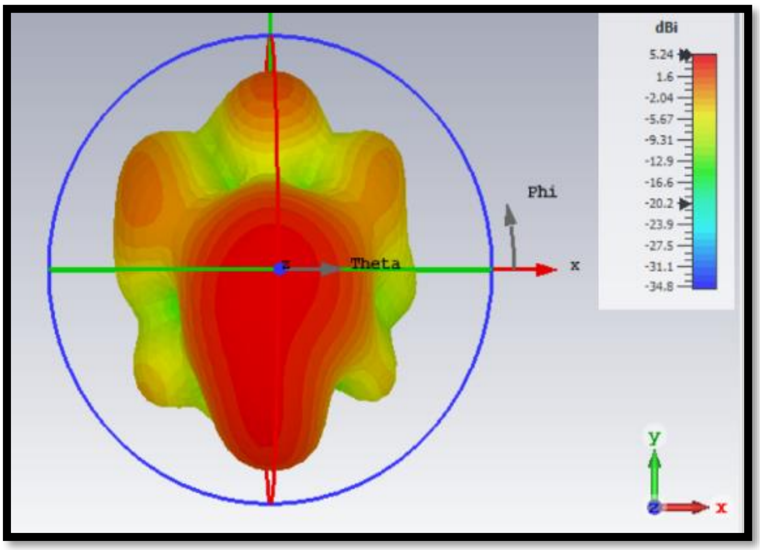

Fig-9: 1 by 2 Patch Antenna Array Gain

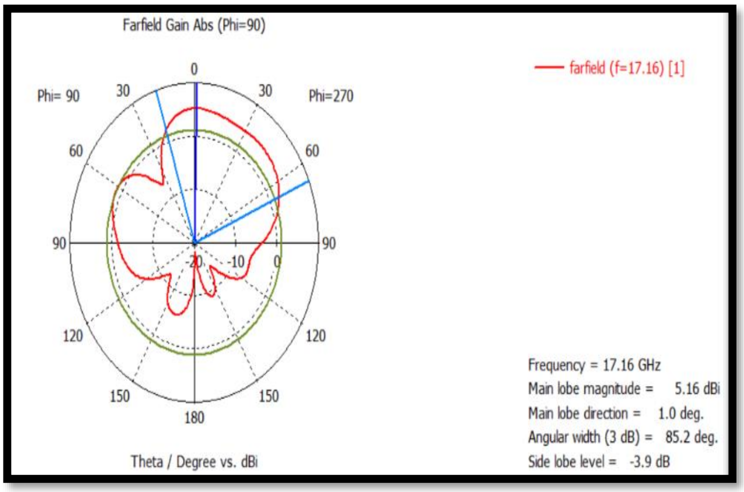

Fig-10: 1 by 2 Patch Antenna Array Radiation Pattern Plot

4. CONCLUSION & RESULTS

This work implements array configurations for Microstrip Patch Antennas. The outcome demonstrates that, when compared to single microstrip patch antennas, the gain and bandwidth of the arrays of microstrip patch antennas is higher over the Ku range of frequencies.

The simulated results show that the designed antennas operate effectively at 17.16 GHz for Ku-band applications. The single patch element achieved a bandwidth of 0.76 GHz and a gain of 3.76 dBi. The first two-element array configuration improved the performance with a bandwidth of 1.22 GHz and a gain of 5.24 dBi. These results confirm that increasing the number of array elements enhances both gain and bandwidth, making the array design more suitable for satellite communication systems.

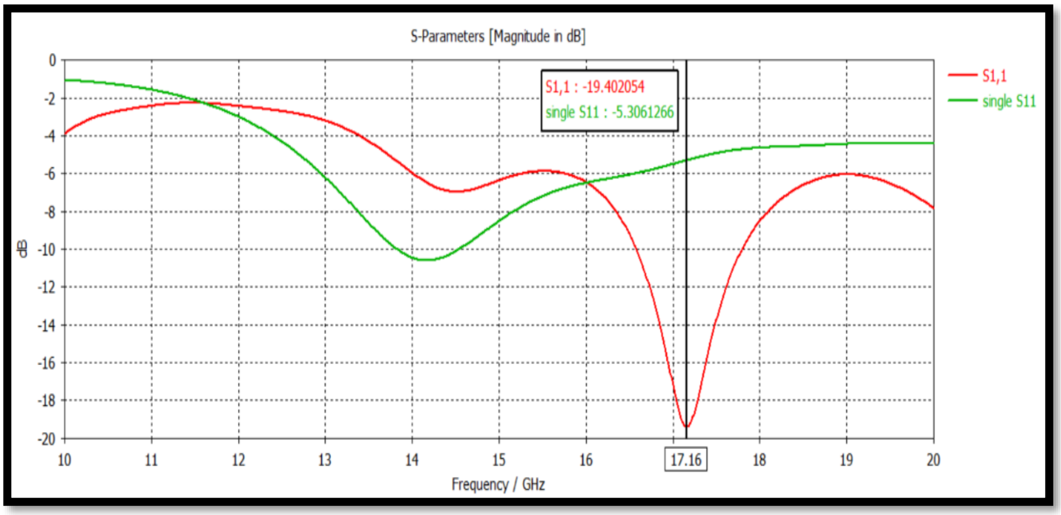

Fig-11: Performance Analysis of Single and Array Patch Antenna

5. FUTURE SCOPE

i. **Integration with 5G and Beyond**:
The designed antenna can be adapted for integration into next-generation satellite communication systems, including 5G and upcoming 6G technologies, which demand higher data rates, lower latency, and wide bandwidth.

ii. **Miniaturization and System-on-Chip (SoC) Integration:**
Further research could focus on minimizing the antenna size while maintaining performance, allowing integration into compact satellite modules or chip-level platforms, which is crucial for small satellites (CubeSats, nanosatellites).

iii. **Reconfigurable and Smart Antennas**
Incorporating tunable or reconfigurable elements using MEMS, varactors, or PIN diodes could make the antenna adaptable to multiple frequency bands or dynamic beam steering, enhancing functionality in versatile mission profiles.

iv. **Advanced Materials and Substrates**:
Exploring novel dielectric materials such as metamaterials, graphene-based conductors, or flexible substrates could enhance performance characteristics like bandwidth, gain, and thermal stability, making the design more robust in harsh space environments.

v. **MIMO and Beamforming Applications**:
Expansion into larger arrays (e.g., 4×4 or 8×8) with beamforming capabilities can support Multiple-Input-Multiple-Output (MIMO) systems for satellite links, improving spectral efficiency and channel capacity.

vi. **AI-Based Optimization**:
Machine learning techniques can be employed to optimize the antenna design parameters automatically for varying operational requirements, improving the development cycle and performance tuning.

vii. **Environmental and Space Qualification**:
Future studies could include environmental testing under space conditions (thermal cycling, radiation exposure, vacuum) to qualify the antenna for deployment in long-duration space missions.

viii. **Multi-Band and Dual-Polarized Designs**:
Designing the antenna for more frequency bands or dual-polarization can cater to diverse satellite services like telemetry, tracking, and command (TT&C), as well as commercial broadcasting.

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