A Wide Band Antenna for both S-Band and C-Band Satellite Communication Applications

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***Abstract*—For existing and upcoming satellite communications applications on a variety of platforms, including cars, fishing boats, ships, aircraft, and submarines, wide-band antenna technology is currently crucial. These days, platforms are utilized for a variety of tasks, including geographic scanning, mining, depth detection, underwater scanning, and looking for other items like ships, mountains, and erratic geographic areas. It takes effective wide-band antenna technology to carry out such tasks on a variety of platforms. As a wide-band antenna for S-band and C-band satellite communications, a new design of rectangular dual patch antennas with a resistive loading approach has been put forth in this work. The antenna may be made small and compact for high-speed data, voice, and video broadcasts through satellites because it operates in the S-band and C-band frequencies. The simulation results were generated using Computer Simulation Technology Studio software, and analyzed for four important parameters like axial ratio, 3 dB beam width, gain, and Voltage Standing Wave Ratio (VSWR). A broader bandwidth has been attained with the newly developed rectangular twin patch antenna employing a resistive loading method. Finally, it is demonstrated that the recommended rectangular twin patch antenna with resistive loading performs better for both S-band and C-band satellite communication applications.**

***Keywords*—rectangular patch antenna, resistive loading technique, co-axial feeding, S-Band satellite communication, C- Band satellite communication**

I. Introduction

It is impossible to imagine life on Earth without satellites. Satellite use is essential to maintaining our way of life. Satellites can be used for a variety of purposes, such as communication, navigation, positioning, and surveillance. The use of S-band and C-band satellite communications is advantageous for high-speed data, phone, and video communication applications. An antenna, an RF power amplifier, and a high data rate transmitter make up the payload of the S-band communication subsystem (HSTX). The HSTX can send data to the ground station at 10 Mbps data rates in the 2200-2290 MHz frequency band. Five different modulation schemes (BPSK, QPSK, OQPSK, 4 D-TCM-8 PSK –2.0 and 2.5) are available for the downlink signal. The downlink binary stream complies with the Consultive Committee for Space Data Systems (CCSDS) protocol. The telemetry transmission frame protocol is implemented using virtual channels, concatenated coding, and the ASM marker. The first frequency band designated for commercial satellite telecommunications is the C-band for communication. Terrestrial microwave radio relay chains were already using the same frequencies. For their downlinks and uplinks, almost all C-band communication satellites operate in the frequency range of 3.7 to 4.2 GHz and 5.925 to 6.425 GHz, respectively. Both S-band and C-band satellite communications currently require wideband antenna technology.

This work is organized into five sections. Section I offers a brief introduction to the subject. Section II provides the crucial literature review. Section III provides how the antenna design is made in the simulation software with the help of initial dimensions and design parameters. Section IV provides the simulation results, which show the various antenna parameters like Voltage Standing Wave Ratio (VSWR), Axial ratio, 3 dB beam width, and gain. Apart from this, all these parameters are analyzed to determine the performance of the designed antenna. Section V provides the conclusion of the proposed work.

II. Literature Review

A low-frequency patch antenna array and a high-frequency reflect array were used to create a dual-band shared aperture antenna for the S and Ka bands. The suggested antenna produced gains of 13.70 and 27.65dBi, respectively, at 3.5 and 25.8 GHz [1]. Based on the Z-shaped meta surface, a wideband Fabry-Perot antenna for C-band satellite communication was created. Three

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substrate layers—the upper, middle, and lower—all of which are of the FR-4 type with a dielectric constant of 4.3 and a loss tangent of 0.025—have been used in this antenna. At the 5 GHz center frequency, the measured axial ratio bandwidth and IBW are 18% (4.4-5.3 GHz) and 64% (4.4-7.6 GHz), respectively. A measured 3-dB boresight gain bandwidth of 30% (4.3-5.8 GHz) is also achieved by the specified antenna arrangement, with a maximum gain of 12.88dBi at 4.7 GHz [2]. For the transmission of images between satellites and ground stations, a Cube Sat transceiver in the S-band was created. The two passive elements, filters and antennae, served as the foundation for the design of the entire antenna. These two passive components were used to attain the needed bandwidth between 2.2 GHz and 2.29 GHz and between 2.025 GHz and 2.11 GHz for the downlink and the uplink, respectively [3]. Based on the S-shaped meta surface, a broad range of circularly polarized antennas were created for C-band satellite communication. The upper, middle, and bottom substrate layers employed in this antenna are all FR-4 substrates. At the 5.9 GHz center frequency, the observed axial ratio bandwidth and impedance bandwidth were 22% (5.3-6.6 GHz) and 43.22%, respectively (4.05–6.6 GHz). At 5.6 GHz, the planned antenna has a maximum gain of 6.16dBi [4]. For CubeSats, a reconfigurable antenna with adjustable gain, radiation pattern, and polarization has been developed. The antenna achieves a return loss of less than minus 10 dB for both reconfiguration states at the operating frequency of S-band (2.4 GHz) [5]. According to their size, shape, and construction, different types of antennas for wireless communication applications have been introduced, including the wide-band micro strip antenna, wide-band monopole antenna over a plate, wide-slot Ultra-Wideband antenna, stacked patch Ultra-Wideband antenna, taper slot (TSA) Ultra-Wideband antenna, meta material (MTM) structure Ultra-Wideband antennas, elliptical printed monopole UWB antenna, and flexible wearable Ultra-Wideband antenna [6]. For Wireless Personal Area Network and Ultra-Wideband antenna communications, a compact planar monopole antenna with increased bandwidth was created. Fractal geometry ideas and changes to the ground plane were used to obtain a broad bandwidth of 12.1 GHz at –10 dB of S11 [7]. For multi-band satellite communications from Ultra-high frequencies to Ku frequencies, a Tightly Coupled Dipole Array (TCDA) antenna was created. The array is initially intended to operate across the Ultra-high frequencies, L, S, and lower-C bands (0.6–3.6 GHz), with a focus on dual-linear polarization and wide-angle scanning. This is done to facilitate manufacture. For VSWR smaller than 1.8, 2.4, and 3.1 for 0°, 45°, and 60° scans, respectively, the array achieves a minimum 6:1 bandwidth. Furthermore, the upper S, C, X, and Ku bands were displayed with TCDA design (3–18 GHz). For VSWR< 2 at broadside and VSWR < 2:6 at 45°, the array achieves this 6:1 bandwidth [8]. For the frequency range of 2.397 GHz to 2.512 GHz, a circular microstrip patch antenna with circular polarization characteristics has been developed. To achieve circular polarization, two asymmetric slots are etched onto a circular patch at various lengths. With the help of a patch with a 15.5mm diameter and a 1.66mm FR4 substrate thickness, a size reduction of 12% has been accomplished. The measurements revealed a 10 dB return loss and a 3 dB axial ratio [9]. For the two frequency ranges of 3.62 GHz to 4.67 GHz and 4.15 GHz to 4.9 GHz, a square patch antenna was created. Two corners of a square patch antenna have been clipped in order to obtain circular polarization characteristics. An L-shaped probe feeding method was applied at one of the patch edge's centers. It is composed of two lines, each measuring 7.5 mm in length horizontally and 10.5 mm in length vertically. Low measurement values for the L-shaped probe feeding technique are 3 dB axial ratio and 10 dB return loss for frequency bands of 4.15 GHz to 4.9 GHz, respectively [10]. The corner truncated square patch antenna's L-shaped ground plane was created for the 2.4GHz to 2.66GHz frequency band. To achieve improved impedance matching for this antenna, a probe feeding technique has been applied. In addition to this, the lowest measurement results, such as VSWR ≤ 1.5:1 and 3 dB axial ratio are attained [11]. For Wireless Local Area Network Applications, an L-shaped patch antenna has been developed. For this antenna, an air substrate with a thickness of (h) was used in order to get better results. The frequency range of 2.272 GHz to 2.747 GHz had a good measured VSWR ≤1.5:1 and the frequency band of 2.37 GHz to 2.54 GHz had an axial ratio of 3dB. Aside from that, the antenna uses a frequency range of 2.4 GHz to 2.484 GHz [12]. The slotted approach was used to create a circularly polarized patch antenna for GPS applications using two substrates: duroid 5880 and Rohacell foam. In terms of size reduction, the Duroid 5880 substrate yields better measuring results compared to the Rohacell foam substrate [13]. The two frequency ranges that wideband microstrip patch antennas were created for were 1.74 GHz to 2.6 GHz and 1.06 GHz to 2.54 GHz. In the aforementioned two frequency bands, a wideband microstrip patch antenna achieved the 10 dB return loss and 3 dB axial ratio [14]. Aperture coupling [15] and probe feeding [16–19] have been used to design a dual-stacked square patch antenna for two frequencies. Corners are carved in a dual-stacked square patch antenna [17] to obtain circular polarization. The 1.66 mm-thick FR4 substrate was used to manufacture this antenna. The measurement findings for this antenna show gains of 1.5 dBi and 4.5dBi at 1.227 GHz and 1.575GHz, respectively. The antenna [16] is composed of two elliptical patches that operate at 1.227 GHz and 1.575 GHz simultaneously. 45 lines from the major axis to the top patch's center have been drawn to provide circular polarization at two resonant frequencies. Two dielectric substrates were separated by an air gap in the antenna designs in [16–19]. Better impedance matching at two frequencies has been accomplished using the air gap layer, however creating an antenna using this layer is challenging. To reduce complexity, the air-gap layer has been eliminated [20]. The lower patch of this antenna is huge and resonates at 1.227 GHz, while the upper patch is small and operates at

1.575 GHz. A circularly polarized antenna for four frequency bands was created in [21] by layering four-square patches together without an air gap. The lower portion was built on a FR4 substrate, while the top three were built on a R04003 substrate. In order to get rid of the mutual interaction between the patches, two different types of substrates were used. A lengthy probe length has been employed to improve impedance matching. Four frequency bands, including 1.163 GHz to 1.18 GHz, 1.212 GHz to 1.237 GHz, 1.559 GHz to 1.596 GHz, and 2.277 GHz to 2.331 GHz, can be covered by the constructed antenna. For GPS frequencies like 1.227 GHz and 1.575 GHz, EBG's structured dual-band circularly polarized antenna was created [22]. The EBG structure enhanced the axial ratio and gain of the antenna. At 227 GHz and 1.575 GHz, the antenna's gain parameter has improved from 0.8dBi to 2.3 dB. From 2.4dB to 5.4dB, the axial ratio value has increased. Multi-band antennas are simple to construct, but their size prevents them from being used in tiny, portable applications. Multi-band circular polarized patch antennas can also be made smaller using a variety of methods, including folded patches [23] and low temperature co-fire ceramic substrate [24]. The downlink and uplink effects are considered in the design of rectangular dual patch antenna with resistive loading technique [25].

In the literature now available, researchers have developed a variety of antenna types, including multi-substrate layers based on metamaterials, dual-band antennas, triple band antennas, and FR4-based antennas. Additionally, the majority of the researchers have created the antennas for either S-band or C-band satellite communication. A brand-new wideband, multi-band antenna design concept has been created. For multi-band satellite communication applications like S-band and C-band, a small rectangular twin patch antenna with a resistive loading approach is presented to achieve a wide bandwidth with good gain. For a suggested antenna, the results from simulation and measurement are compared and found to be quite similar.

III. Proposed Antenna Design

Two rectangular microstrip patch antennas with similar dimensions of 20.6mm × 50.31mm and a 0.1mm patch thickness were used in the design of the wideband rectangular dual patch antenna with resistive loading technique (see Figs. 1–4). To create circular polarization features, the two patches are etched in an orthogonal position to one another on the polyurethane foam substrate with a dielectric constant of 2.2. By positioning the upper patch on the right corner of the lower patch, Left-Hand Circular Polarization (LHCP) has been used for this antenna. Both the gain and bandwidth characteristics were enhanced by employing two rectangular microstrip patch antennas as well as simultaneous energy dispersion on the same patch antenna's surface. At the working frequencies of the S-band and C-band satellite communications, a wide bandwidth has been achieved through the energy distribution on the surfaces of the two rectangular microstrip patch antennas. Impedance matching between dual patches and free space has been achieved based on the shared length of the two rectangular microstrip patch antennas. In addition, depending on the design specifications, the size of the dual patches has been optimized. Utilizing resistive loading techniques, the suggested antenna's broad bandwidth has been made possible. The suggested antenna makes use of three resistors. One of the three resistors is wired in between the two patches. Patches are connected to a ground plane by two resistors. The input for the dual patches is fed onto a distinct port. By adding ohmic losses to the dual patches using the resistive loading technique, the quality factor (Q) of the dual patches has been decreased. Because the quality factor and bandwidth are inversely related to one another, the dual patch antenna's bandwidth increases when the quality factor (Q) is decreased. The circular ground plane, which has a diameter of 460 mm and a height of 50 mm, has been used to reduce the current distribution over the antenna. In addition, the antenna's bandwidth is increased by using a foam-type substrate with a 30 mm height. The external input is fed using a co-axial sort of feeding approach. The dimensions for both rectangular microstrip patch antennas in this antenna design are the same.

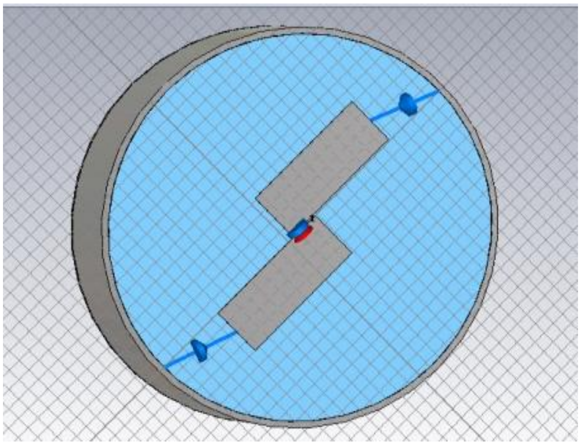

Fig. 1. Wideband rectangular dual patch antenna with resistors.

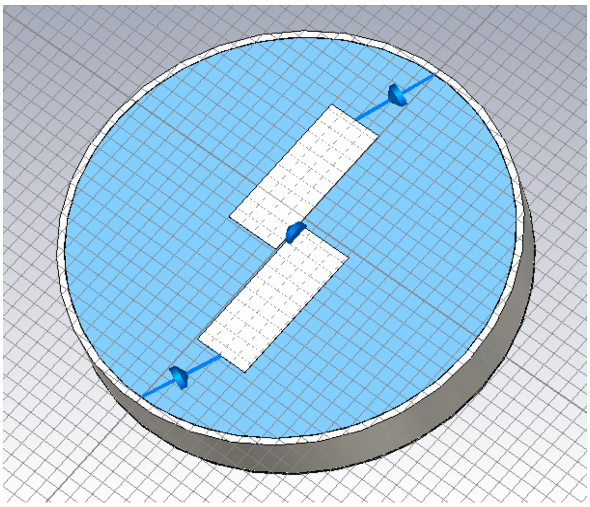

Fig. 2. Connection of resistors (blue color) between ground plane and patches.

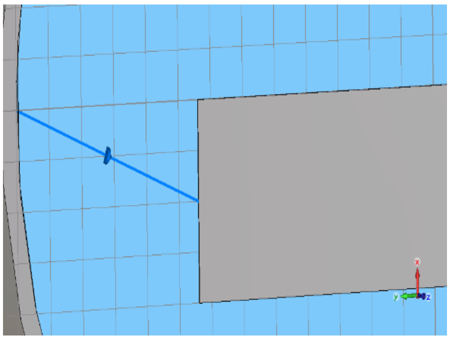

Fig. 3. Closeup of the resistor.

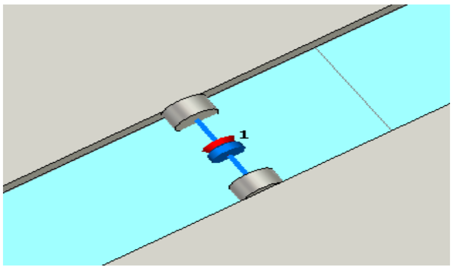

Fig. 4. Closeup of discrete port feeding between patches.

The rectangular microstrip patch antenna is designed [14] based on the following equations.

For an efficient radiator, the formulae for a practical width (W) is given by:

$$W = \frac{c}{2f_r}\sqrt{\frac{2}{\epsilon_r+1}} \quad \text{(mm)} \tag{1}$$

where c is free space velocity, ϵ_r is dielectric constant.

For the rectangular patch antenna, the resonant frequency is given by:

$$\mathrm{f_r} = \frac{\mathrm{C}}{2\mathrm{W}}\sqrt{\frac{2}{\epsilon_r+1}} \quad \text{(MHz)} \tag{2}$$

The effective dielectric constant (ϵ_{reff}) of the microstrip patch antenna is given by the formulae.

$$\frac{\epsilon_r+1}{2} + \frac{\epsilon_r-1}{2}\left(1+12\frac{h}{w}\right)^{-\frac{1}{2}} \qquad \frac{w}{h} > 1 \tag{3}$$

The extension length (ΔL) of the patch is given by the following formulae as:

$$\Delta L = 0.412h\frac{(\epsilon_r+0.3)\left(\frac{w}{h}+0.264\right)}{(\epsilon_r-0.258)\left(\frac{w}{h}+0.8\right)} \tag{4}$$

The effective length (L_{eff}) of the patch is calculated by using the formulae as:

$$L_{eff} = \frac{c}{2f_r\sqrt{\epsilon_{reff}}} \; (mm) \tag{5}$$

The actual length of the patch is determined by using the formulae as:

$$\mathrm{L} = \mathrm{L_{eff}} - 2\,\Delta\mathrm{L} \text{ (mm)} \tag{6}$$

IV. Simulation Results

With the help of simulation findings like VSWR, gain, axial ratio, and 3dB beamwidth, the wideband of the rectangular twin patch antenna with resistive loading technique has been constructed, and its performance has been evaluated. For a more thorough examination of the gain and axial ratio parameters, the antenna is also simulated at several angles, including 0°, –45°, and 45°. Satellite communication applications require either directional radiation patterns or elevation radiation patterns. For this antenna, three-dimensional (3D) radiation patterns were converted into two-dimensional (2D) radiation patterns or elevation radiation patterns by changing the θ for various angles, where an angle of φ is 0°. To ascertain the direction of the proposed antenna's radiated power, 3D radiation patterns have been obtained. By analyzing the 2D radiation patterns, 3dB beamwidth values have been determined.

A. VSWR

A graph between VSWR and frequency is shown in Fig. 5. According to Fig. 5, the frequency at which the maximum VSWR value of 2.5214:1 is attained is 6400MHz. In Fig. 5, it is mentioned that all the VSWR values at all the working frequencies are acceptable for satellite communication applications.

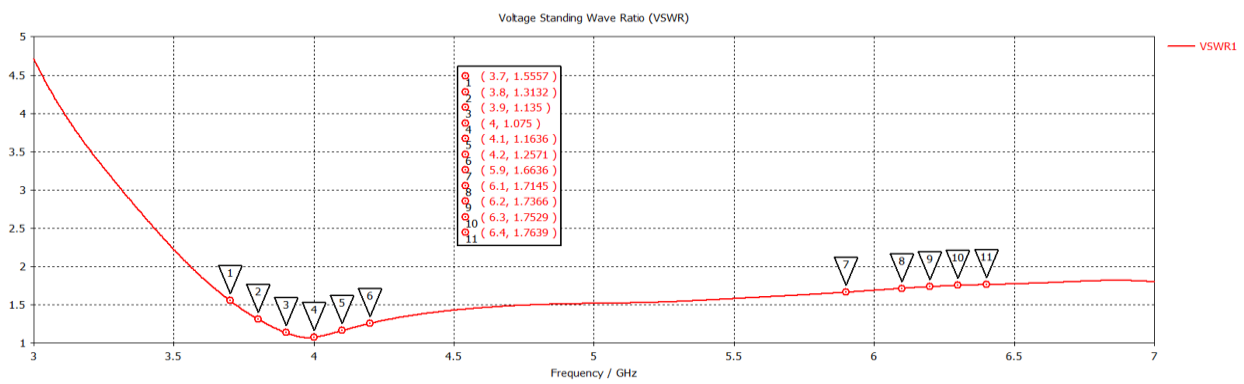

Fig. 5. VSWR versus frequency at different working frequencies.

B. Gain

Figs. 6–8 represent the graph between gain and frequency at different angles like 0°, −45°, and 45°. According to Figs. 6–8, the highest gain values are obtained at an angle of 0° when compared to −45°, and 45°. Additionally, all working frequencies of C-Band satellite communication, with the exception of the uplink frequencies, yield a gain of 3dBi. Gain measurements that are negative have been made for the C-Band uplink frequency at angles of −45° and 45°. The proposed antenna does not accept these negative gain values. The proposed antenna is most effective for utilizing the signals in S-band reception, S-band transmission, and C-band reception modes of operation, according to the simulation findings of gain.

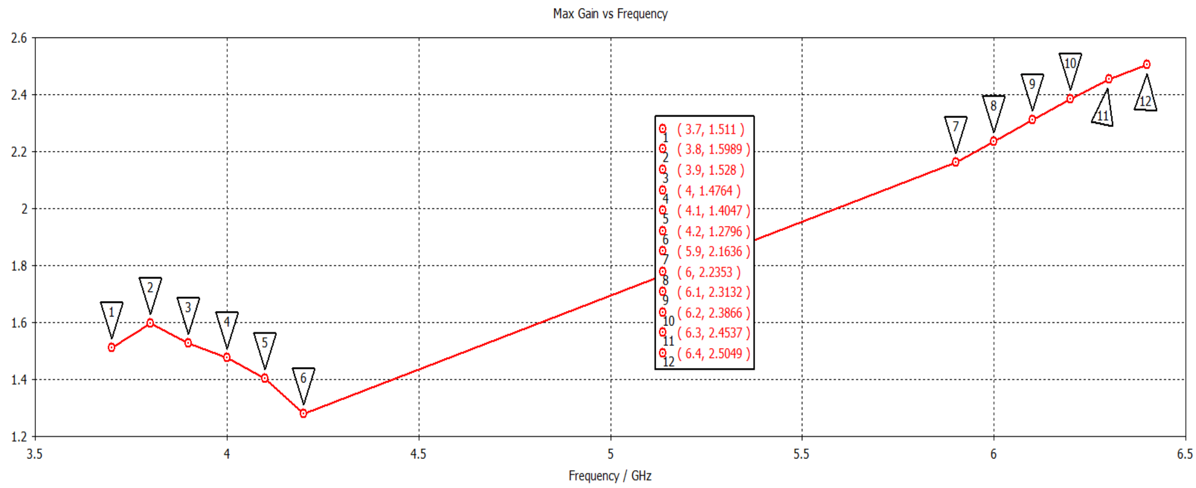

Fig. 6. Gain at θ = 0° for various working frequencies.

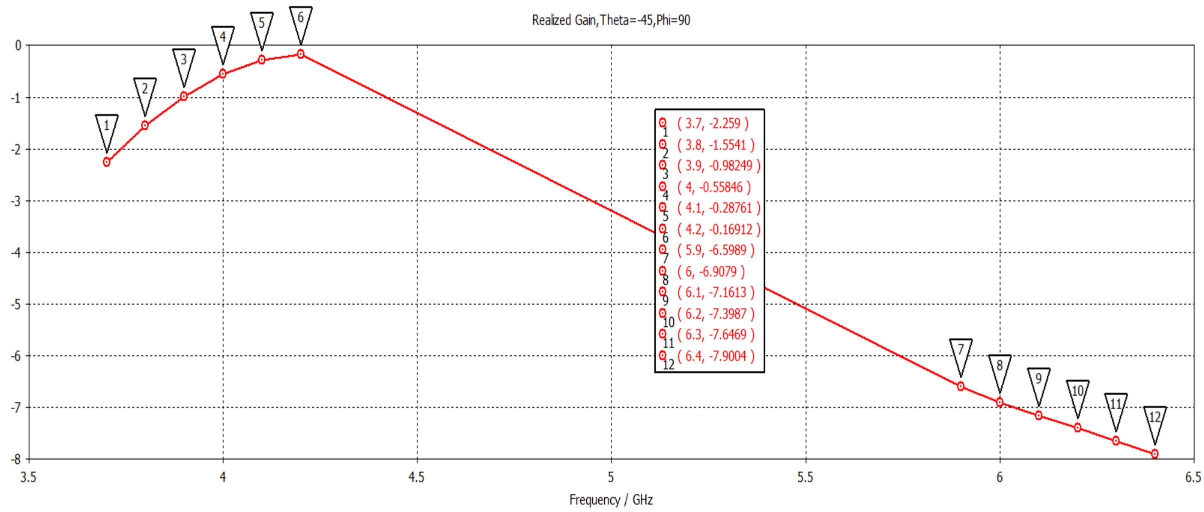

Fig. 7. Gain at θ= −45° for various working frequencies.

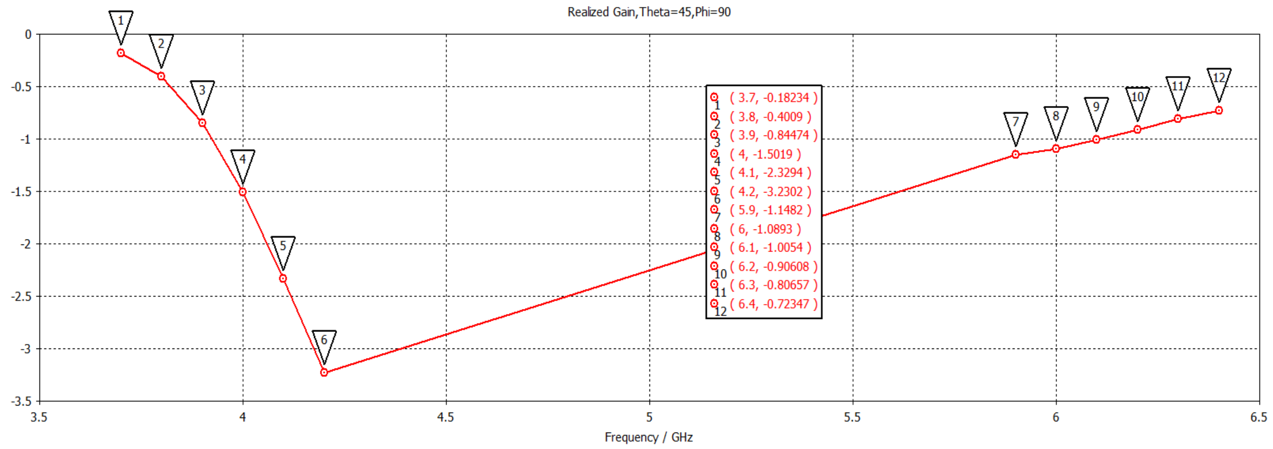

Fig. 8. Gain at θ = 45° for various working frequencies.

C. *Axial Ratio*

Figs. 9–11 represent the graph between axial ratio and frequency at the different angles of θ like 0˚, 45˚ and −45˚.

On the basis of Figs. 9–11, it can be concluded that, when compared to −45˚, and 45˚, the angle of 0˚ yields the lowest axial ratio values, which are less than 5dB. The axial ratio of less than 5dB is reached at all operating frequencies, with the exception of a few.

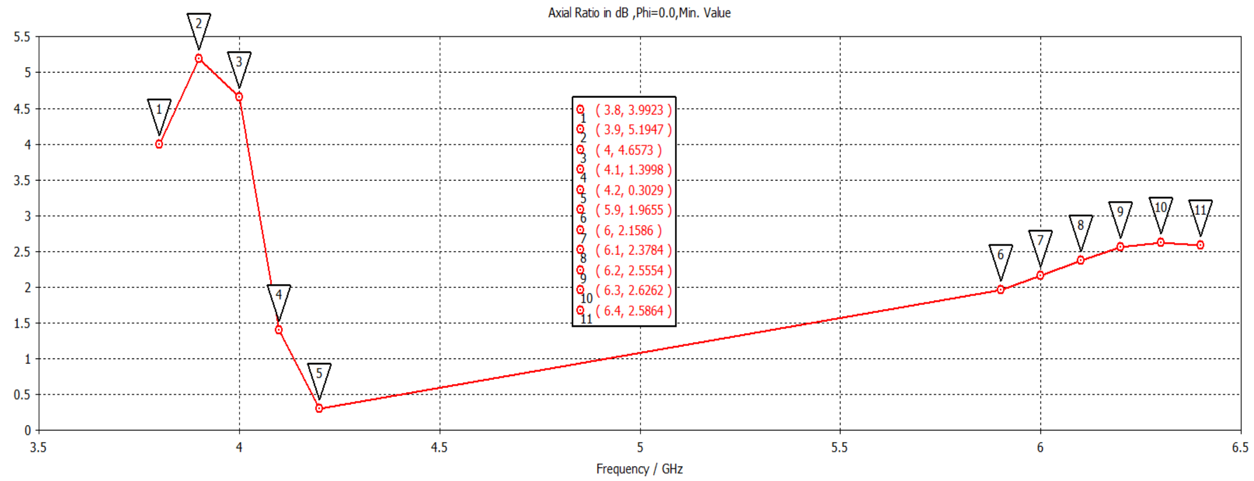

Fig. 9. The axial ratio at θ =0° for various working frequencies.

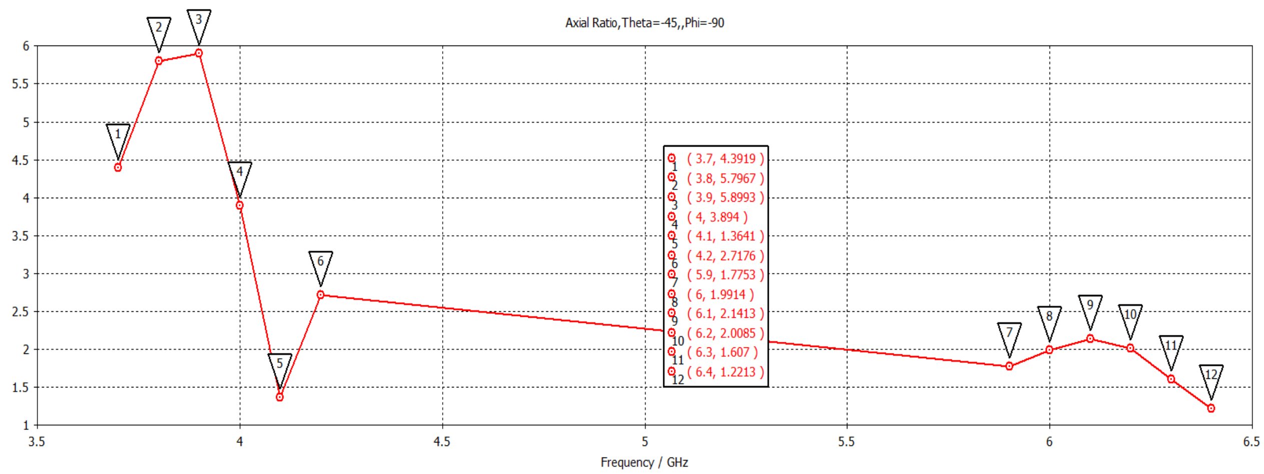

Fig. 10. Axial ratio at θ = –45° for various working frequencies.

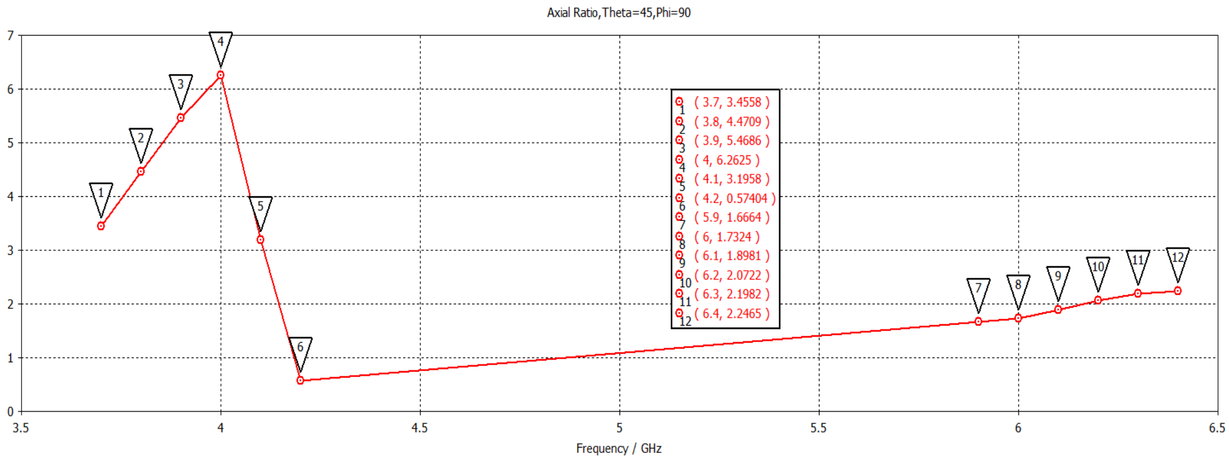

Fig. 11. The axial ratio at θ = 45° for various working frequencies.

D. 3D and 2D Radiation Patterns

Figs. 12–17 represent the 3D and 2D radiation patterns at various working frequencies. The 3dB beamwidth values are obtained from the 2D radiation patterns, which are shown in Figs. 13, 15, 17. According to Figs. 13, 15, 17, a minimum 3dB beamwidth value of 62.8^0 is attained at a frequency of 6400MHz. This suggested antenna's minimum beamwidth of 3dB is acceptable.

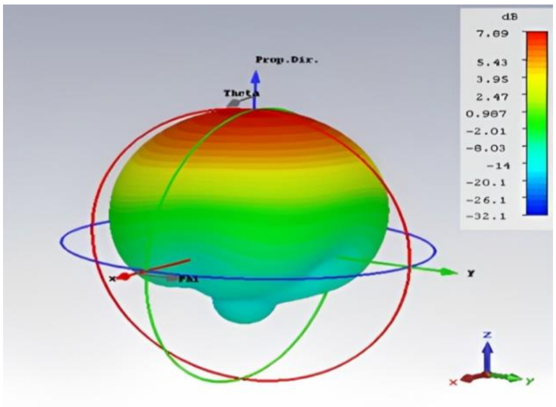

Fig. 12. 3D radiation pattern at 2500 MHz.

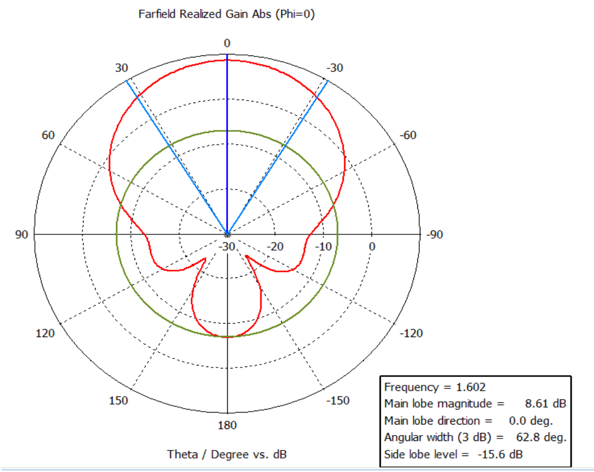

Fig. 13. 2D radiation pattern at 2500 MHz.

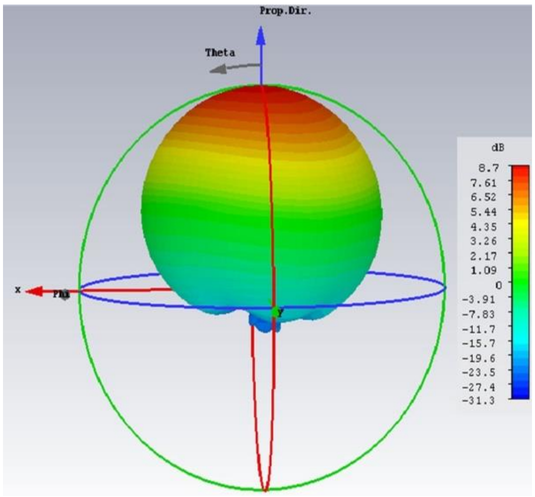

Fig. 14. 3D radiation pattern at 4000 MHz.

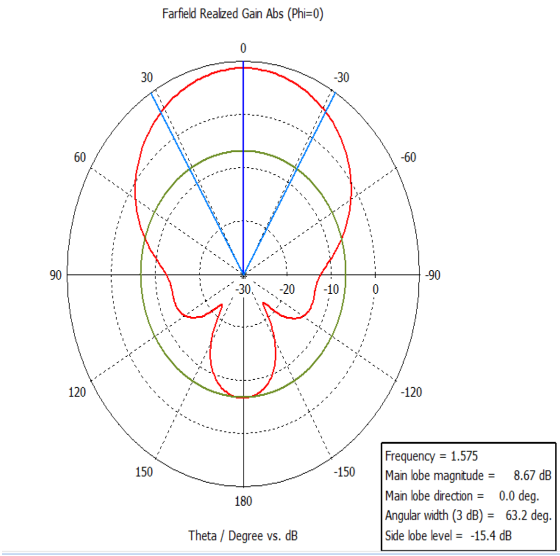

Fig. 15. 3D radiation pattern at 4000 MHz.

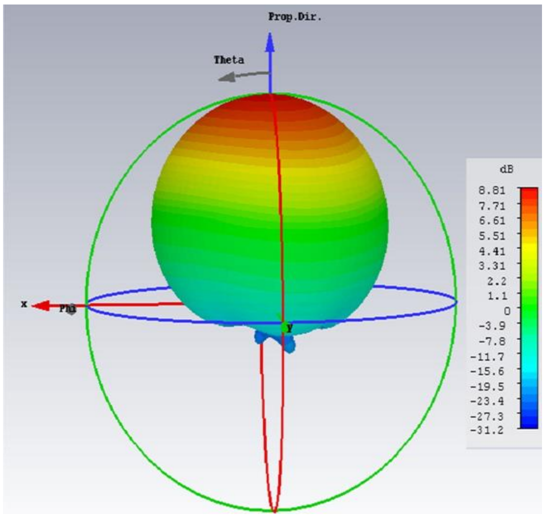

Fig. 16. 3D radiation pattern at 6400 MHz.

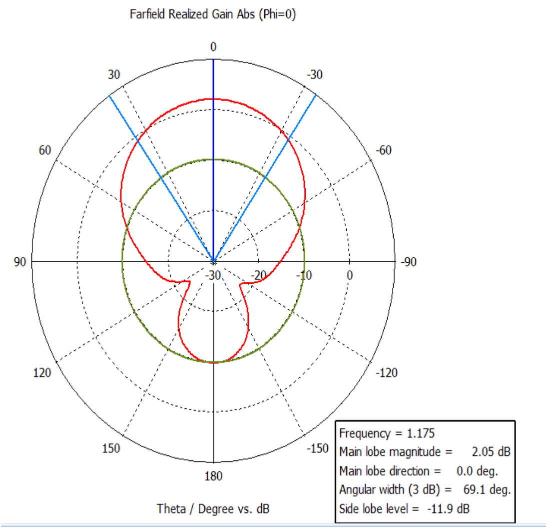

Fig. 17. 2D radiation pattern at 6400 MHz.

V. Conclusion

A rectangular twin patch antenna with a resistive loading method has been proposed as a wide band multiband antenna for S-band and C-band satellite communications. The VSWR, axial ratio, gain, and 3 dB beamwidth of the proposed antenna have all been simulated and examined. The newly constructed rectangular twin patch antenna using a resistive loading method has been shown to achieve a wider bandwidth based on the performance of the parameters. Ultimately, it is shown that the suggested rectangular twin patch antenna with resistive loading offers superior performance for both S-band and C-band satellite communication applications.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

D. Nataraj and K. Chitambara Rao, have collected the data and designed the antenna in the simulation software to get simulation results. K.S. Chakradhar and G. Vinutna Ujwala have analyzed the simulation results in terms of antenna parameters. B. Sadasiva Rao and Y.S.V. Raman have checked the performance of the antenna for specified satellite communication applications. Finally, all the authors have approved the final version of the paper.

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