Design, Simulation and Experimental Validation of Patch Antenna in S-Band Satellite Communication

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Abstract In worldwide, almost geosynchronous satellites are using radio communication from broadband to narrowband which include broadcasting, positioning and telecommunication. At present, there are different types of satellite communications starting from UHF to Ka-band. Out of these satellite communications, S-band and C-band satellite communications are the suitable for high speed data, voice and video transmissions. For communicating with a satellite, a special antenna is required, and it should have some unique characteristics such as low VSWR, circular polarization, high gain, reasonable axial ratio and higher beam width. For satellite communication, micro-strip patch antenna is appropriate because it can be designed to use as a circular polarized antenna by modifying its shape and easily developing a 90° phase shift in the antenna. Square patch antenna has been taken and designed for S-band satellite communication. This antenna is designed for receiving purpose. After designing, the antenna is simulated in simulated software for the different values like gain, axial ratio, VSWR and 3 dB beam width. After simulation, the antenna is fabricated and measured for the same characteristics. Moreover, the simulated results are obtained using CST MW STUDIO 2015 software, and the antenna is fabricated using CNC machine. Apart from this, experimental results are obtained using network analyzer and anechoic chamber. VSWR measurement of antennas has been carried out

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using network analyzer. Gain and radiation patterns have been carried out using anechoic chamber. Validation of the antenna has been done based on the comparison of simulation and measurement results in S-band satellite communication.

Keywords Square patch antenna · Rectangular patch antenna · S-band communication

1 Introduction

At present, most of the communication has been done based on the satellites. These satellites are more useful for all network services like 3G, 4G and 5G. The satellites are not only used for network services but also used for positioning and navigation purpose. For these satellites, compact antennas are required for communicating with an allover world. On the satellite, the antenna should have circular polarized characteristics, and at the earth station, the antenna may or may not have circular polarization characteristics. If the satellite antenna and earth station antenna are same circular polarized antennas, then maximum power reception can be possible at satellite as well as at earth station. Patch antenna is the appropriate antenna for satellites as well as earth station because it has tremendous advantages like low cost, low weight, less volume. Moreover, patch antenna will be operated at multi-band operations by incorporating the 90° phase shift in the antenna. Patch antenna with rectangular shape was designed at 2.4 GHz for wireless communication with and without DGS technique. The antenna parameters like return loss, VSWR and beam width have been improved by using DGS technique when compared to the without DGS technique [1]. Rectangular patch antenna was designed at 1.88 GHz for WLL-Cor-DECT Technology. For designing this antenna, the silicon material was used with dimensions of height 31 mm and dielectric constant 11.9. Single feed technique is used for such an antenna. Return loss of −35 dB was obtained at an operating frequency [2]. Based on different values of substrate thickness, two types of antennas are designed such as patch with circular shape antenna and slotted patch antenna with circular shape. When the thickness of the substrate is increased from 1 to 2 mm for both two types of antennas, circular patch with slot antenna gave the better result in terms of gain when compared to the circular patch antenna without slot [3]. Based on the techniques like slotted partial ground and tuning stub, the ultra-wideband rectangular patch was designed, and the same antenna was simulated for different parameters like return loss, gain and radiation patterns in the frequency range of 3.2–15.7 GHz. Highest bandwidth 12 GHz and gain of 7.5 dB were obtained, but high value of return loss −40 dB is achieved [4]. Based on the three orthogonal sector slots, the elliptical antenna was designed, simulated, fabricated and experimented for the different parameters such as VSWR, gain, return loss and beam width. The measured and simulated results were compared. From the comparison results, it is known that antenna performance is slightly improved, and also, size is reduced [5]. For wireless communication applications, patch antenna was designed with the help of coaxial type of feeding technique. The same antenna is operated at 2.4 GHz frequency. The lowest values of gain 8.27 dB and VSWR of 1.18 were obtained for such type of feeding technique [6]. Based on the thickness of the dielectric constant, the rectangular and square patch antennas have been compared at 2.4 GHz frequency. With dielectric substrate, the parameters are improved like beam width, VSWR, gain and return loss when compared to the without dielectric substrate [7]. Symmetrical slotted U patch antenna and asymmetrical slotted U patch antenna are designed for 1.9–2.5 GHz. Symmetrical U-slot patch antenna and asymmetrical U-slot patch antennas have been compared in terms of size, bandwidth and dielectric constant. From the comparison of results, it is noted that patch antenna with symmetrical U-slot has advantages like reduction of size, more bandwidth and less dielectric constant [8]. Merits, demerits of patch antenna and various feeding techniques have been reviewed [9]. Patch antenna with DGS technique was designed for C-band satellite communication applications [10].

2 Antenna Design

Directly, square patch antenna can be designed in the simulation software by taking the equal lengths which shows that length and width of the square patch antenna. Theoretically, the square patch antenna cannot be designed directly, first design a rectangular patch antenna and then design a square patch antenna with the help of ratio of equating lengths. For satellite communication, circular polarized antennas are required, and the patch antenna can also be used as a circular polarized antenna by modifying its shape and providing a 90° phase shift in the antenna. For circular polarized antenna, 90° phase shift is required between the horizontal and vertical components of the radiated wave. There are so many techniques to develop a 90° phase shift in the antenna. One way of easy technique is to provide the feeding in the diagonal of the patch antenna. From the patch antenna, LHCP or RHCP can be developed by incorporating the feed point in the diagonal of the patch. Left-hand circular polarization (LHCP) may be obtained by incorporating a feed point along the right corner diagonal. Right-hand circular polarization (RHCP) may also be obtained by incorporating a feed point along the diagonal opposite to the left-hand circular polarization. The equations in [10] are used to calculate the design parameters of the rectangular patch antenna.

2.1 Patch Antenna

Figure 1 shows the simulated receiving patch antennas. This antenna is designed based on the design parameters which are presented in Table 1. The design parameters are calculated with the help of design equations in [10]. Probe method of feeding is used for this antenna.

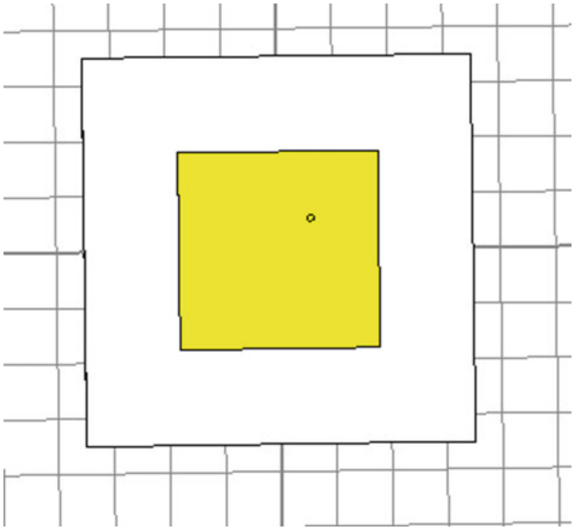


Fig. 1 Simulated patch antenna

Table 1 Antenna design parameters

S. No.	Design parameter	Antenna dimensions	Design specifications	Specification values
1	Resonant frequency	2.5 GHz	R_x antenna freq. range	2.5–2.52 GHz
2	Length of the ground plane	80 mm	VSWR	3:1(max)
3	Width of the ground plane	80 mm	Gain	−3 dBi (min) to 3 dBi (max)
4	Substrate (RT Duriod 5880)	1.5 mm	Polarization	LHCP
5	Substrate dielectric constant	2.2	Beam width	±45° from vertical
6	Patch (Copper)	0.1 mm	Axial ratio	<5 dB
7	Patch length	40 mm	Spatial coverage	Overtop hemisphere
8	Patch width	40 mm	Connector	SMA

Left-hand circular polarization technique is used for this antenna in S-band satellite communication. LHCP or RHCP may be used based on the user requirements. The specifications [10] in Table 1 are considered for receiving patch antenna. The specifications should be satisfied for proper working of an antenna in S-band communication.

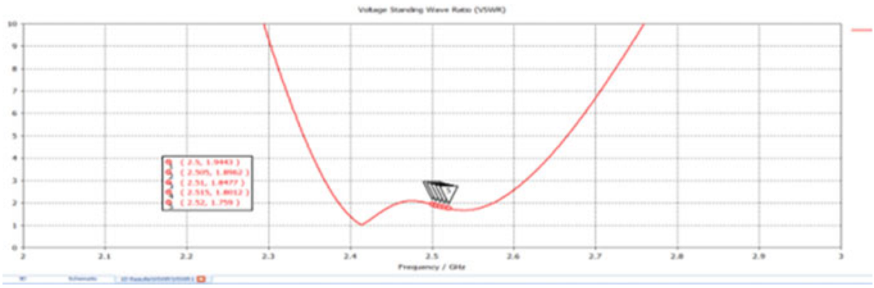


Fig. 2 VSWR curve

Table 2 VSWR at receiving frequencies

Freq. (GHz)	VSWR
2.5	1.9443
2.505	1.8962
2.51	1.8477
2.515	1.8012
2.52	1.759

3 Simulation Results

After designing a receiving antenna in simulation software, that is analyzed for the different parameters like gain, axial ratio, VSWR and 3-dB beam width at antenna operating frequencies. The operating frequencies of the S-band satellite communication are 2.5–2.52 GHz. The 2D radiation patterns are used to get the beam width values at receiving frequencies. 2D radiation patterns are obtained from 3D patterns by using different techniques.

3.1 Simulated VSWR

Figure 2 shows the VSWR against various receiving frequencies. The VSWR values are obtained from the VSWR curve and which are tabulated in Table 2. From Table 2, it is seen that the VSWR values are low values according to given specifications.

3.2 Simulated Gain

The receiving patch antenna is simulated for gain at 0°. Figure 3 shows the gain at 0° against frequency. From Table 3, it is known that highest gain values are obtained

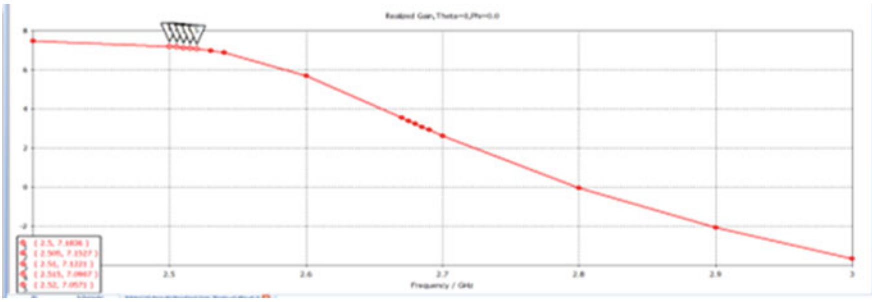


Fig. 3 Gain at $\theta = 0°$

Table 3 Gain at receiving frequencies

Freq. (GHz)	$\theta = 0°$
2.5	7.1836
2.505	7.1527
2.51	7.1221
2.515	7.0907
2.52	7.0571

at the operating frequencies.

3.3 Simulated Axial Ratio (AR)

Like gain, the axial ratio is obtained at 0° for different receiving frequencies. From Table 4, it is known that higher axial ratio values are obtained, and they are not a constraint for a receiving antenna (Fig. 4).

Table 4 AR at receiving frequencies

Freq. (GHz)	$\theta = 0°$
2.5	10.227
2.505	10.755
2.51	11.28
2.515	11.802
2.52	12.318

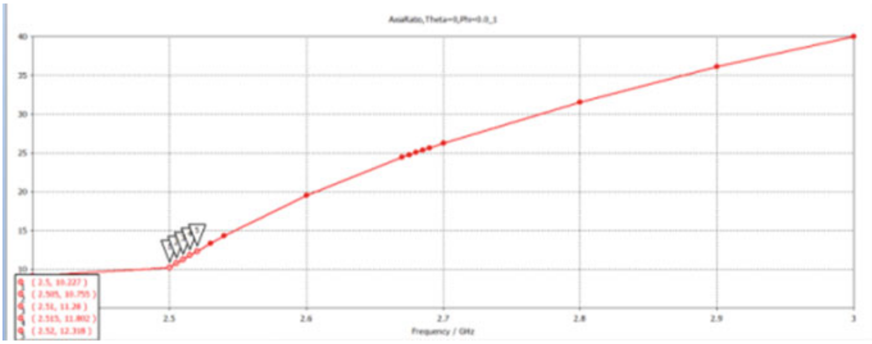


Fig. 4 Axial ratio at $\theta = 0°$

3.4 Simulated 2D Patterns at the Receiving Frequencies

The 3-dB beam width values in Table 5 are obtained from the 2D patterns. These are suitable for receiving antenna (Figs. 5 and 6).

Table 5 3-dB beam width at different frequencies

Freq. (GHz)	Beam width (°)
2.5	65.3
2.505	65.1
2.51	64.9
2.515	64.7
2.52	64.6

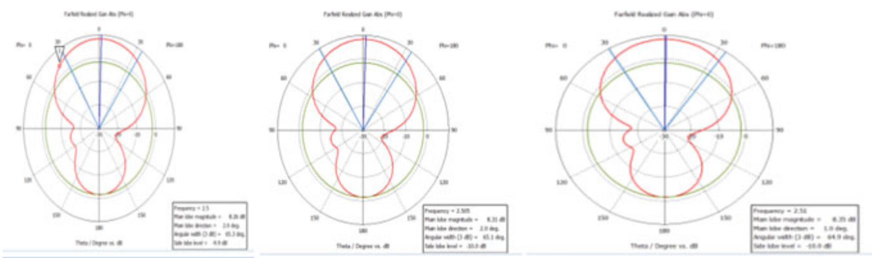


Fig. 5 2D radiation patterns at 2.5, 2.505 and 2.51 GHz frequencies

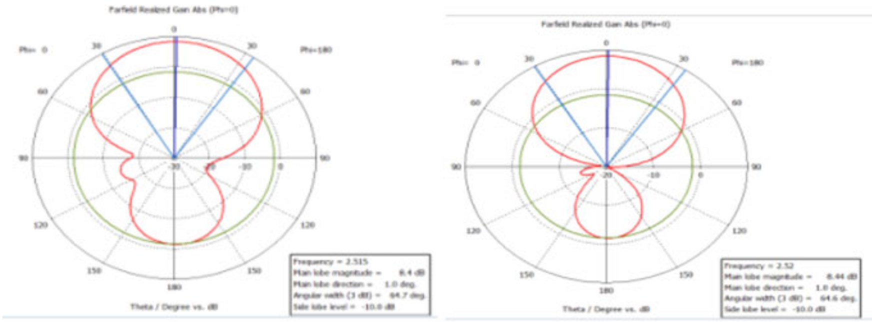


Fig. 6 2D radiation patterns at 2.515 and 2.52 GHz frequencies

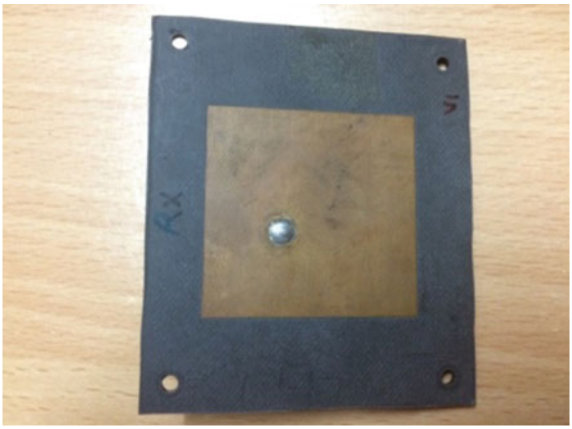
4 Measurement Results

The receiving patch antenna is fabricated and measured for different parameters at its operating frequencies. Also, antenna is measured in two types of polarizations like horizontal polarization (HP) and vertical polarization (VP) (Figs. 7 and 8).

4.1 Measured VSWR

Figure 8 shows the VSWR against frequency. From this VSWR curve, the VSWR values are obtained and given in Table 6. The tabulated VSWR values are very low values and suitable for receiving antenna.

Fig. 7 Fabricated patch antenna



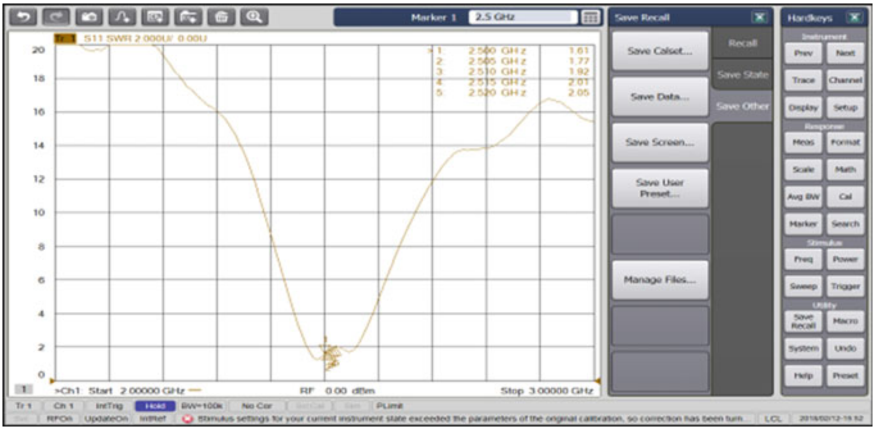


Fig. 8 VSWR curve

Table 6 VSWR at receiving frequencies

Frequency (GHz)	VSWR
2.5	1.81
2.505	1.77
2.51	1.92
2.515	2.01
2.52	2.05

4.2 *Measured Radiation Patterns of Receiving Antenna in Horizontal and Vertical Polarizations*

See Fig. 9.

4.3 *Measured Gain, Beam Width and Axial Ratio at the Receiving Frequencies*

Gain of the receiving patch antenna is measured in horizontal and vertical polarizations. In Table 7, the antenna under test (AUT) gain is calculated based on the equation in [10]. Moreover, the axial ratio in Table 7 is determined using the equation in [10]. The beam peak values in horizontal and vertical polarizations and 3-dB beam width values are obtained from the measured radiation patterns which are presented in the Sect. 4.2.

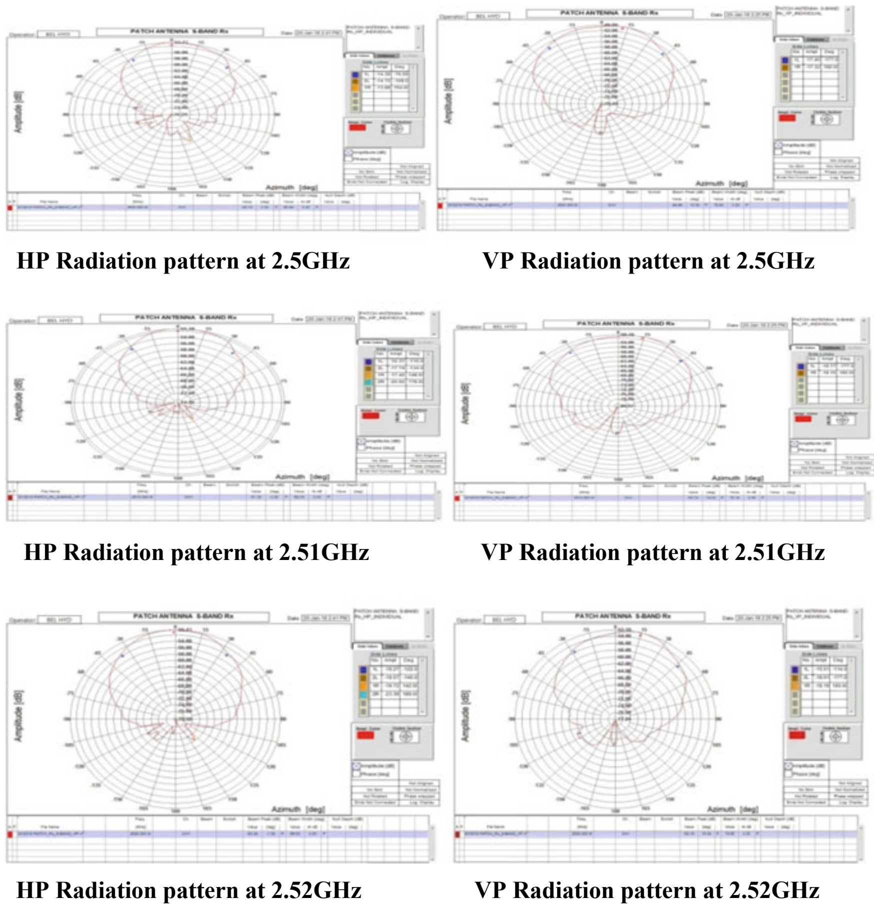


Fig. 9 HP and VP patterns of receiving antenna at the receiving frequencies

4.4 Comparison of Simulated and Measured Results of Receiving Patch Antenna

The simulated and measured results are compared in terms of VSWR, gain at 0° in vertical polarization, 3-dB beam width and axial ratio at the receiving frequencies. From the comparison of results, it is known that all the simulated and measured values match very well (Table 8).

Table 7 Gain, beam width and axial ratio at the receiving frequencies

Freq. (MHz)	Beam Peak in HP (dB)	Beam peak in VP (dB)	Beam width in HP (°)	Beam width in VP (°)	STD peak (dB)	STD gain (dB)	AUT gain with polarization loss in HP at 0°	AUT gain with polarization loss in VP at 0°	Axial ratio (dB)
2500	−52.73	−49.99	65.84	78.84	−37.85	17.05	7.17	9.91	2.74
2510	−51.3	−50.7	68.34	76.18	−38.01	17.06	8.77	9.37	0.6
2515	−51.12	−51.78	68.14	75.34	−38.3	17.065	9.245	8.585	0.66
2520	−50.43	−52.19	69.53	74.85	−38.35	17.07	9.99	8.26	1.76

Table 8 Comparison of VSWR, gain, beam width and axial ratio

Freq. (MHz)	Simulated VSWR	Measured VSWR	Simulated gain at 0°	Measured gain at 0° in VP	Simulated 3-dB beam width	Measured 3-dB beam width in VP	Simulated axial ratio at 0°	Measured axial ratio at 0°
2500	1.9443	1.81	7.1836	9.91	65.3	78.84	10.227	2.74
2510	1.8477	1.92	7.1221	9.37	64.9	76.18	11.28	0.6
2515	1.8012	2.01	7.0907	8.585	64.7	75.34	11.802	0.66
2520	1.759	2.05	7.0571	8.26	64.6	74.85	12.318	1.76

5 Conclusion

Square patch antenna is designed, simulated, fabricated and experimentally validated for the reception of the signals in the S-band satellite communication. This antenna is used as a receiving antenna in the range of frequencies from 2.5 to 2.52 GHz. The receiving patch antenna has been simulated and experimentally tested for the required parameters like gain, VSWR, beam width, radiation patterns and axial ratio at the receiving frequencies. Apart from this, the simulated and measured results are compared to get the validation of the antenna in S-band satellite communication. From the comparison of results, it is known that patch antenna is suitable for the reception of signals in S-band satellite communication.

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