Design and analysis of a circular polarized S-band antenna for CubeSat communication system

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In this paper, an optimized circular polarized patch antenna is proposed for 1U CubeSat communication system. This antenna consists of a square slotted square patch with full ground plane. The proposed antenna is designed considering small satellite compatibility such as lightweight, small size, single feeding etc. The antenna operates at 2.4 GHz with 80 MHz impedance bandwidth (2.35 GHz to 2.43 GHz) and 3dB axial beamwidth of 135˚ at resonate frequency. The Roger's 5880 substrate material has been adopted considering the harsh environment of the space. Moreover, antenna reflection coefficient and axial ratio of the designed antenna has been investigated for both simulation and measurement with 1U CubeSat body structure. The antenna achieved realized gain of 7.48 dB with 1U small satellite structure. The contribution of this research is to design this small footprint antenna system for S-band small satellite communication.

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Keyword: Antenna, CubeSat, Circular polarization, S-band

1. Introduction

Nowadays, Satellite has become a very well-liked word for professionals or tech enthusiasts and people engrossed in learning, perceiving, and acquiring knowledge. In a broad sense, any small-scaled satellite weighing less than 500 kg is considered as small satellite. CubeSats are the subsets of the small satellites. Some non-standard picosatellites are also covered as small satellites [1, 2]. With the massive changes in space technology, small satellite technology has also been expanded in the late 1980s. The Former Soviet Union was the pioneer to build Strela-1M spacecraft in 1986, where 24 of 25 small satellites were launched and maintained with 1-kg [3]. The execution of the joint Russian American project of the International Space Station (ISS), which transpired in 1998, was an essential milestone in the growth of space utilization and hence the small satellite sector. Different types of small satellites have been launched with a growing number. The number of nations actively engaging in the technical trend of small satellites has increased dramatically during the last several years. The small satellite size is also getting optimized and becoming more advantageous than before. It is facilitated by the shrinking of satellite systems enabled by the development of new technologies and their adjacent areas, notably in computing technology. With small satellites, it is now possible to deliver operational services, which was exclusively possible with larger spacecraft. The mass of small satellites is also diminishing with the uninterrupted blooming of technology and overall small satellites are getting smaller [4].

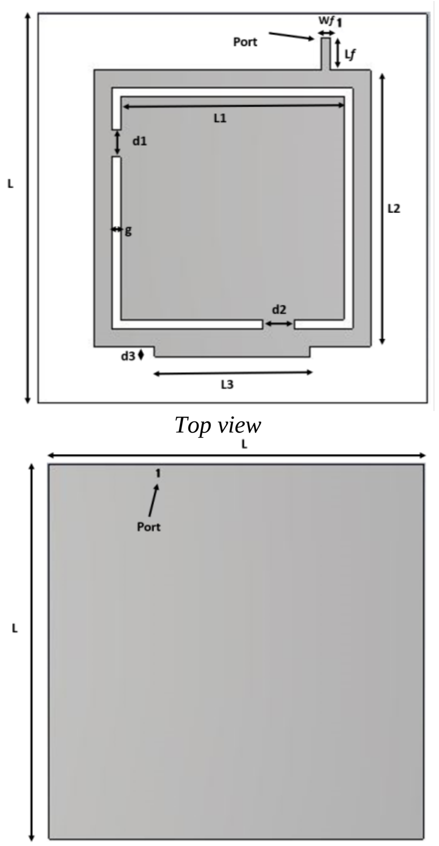
An antenna is a well-known appellation in satellite communication systems for receiving and transmitting different radio electromagnetic waves. Antennas are of various types: wire antenna, traveling wave antenna, reflector antenna, log periodic antenna, aperture antenna, microstrip antenna, and so on [5]. Microstrip patch antenna is one of the most revolutionary technologies among the typical antennas. It is well known for its advantageous properties such as lightweight, narrowband, a planar structure, simplicity, low cost, and mechanical robustness [6-12]. It has notable electromagnetic characteristics like input impedance, resonant frequency, radiation pattern, gain, polarization, etc. Currently, satellite communication is a popular discussion in the field of antenna technology. Satellite communication is benefited tremendously by the miniaturized patch antennas [7]. For designing a satellite antenna, size, low profile, and comprehensive installation should be a matter of consideration. So, a microstrip patch antenna is preferable for S-band CubeSat antenna [2, 13, 14]. In [15], a circularly polarized S-band patch antenna is proposed, where the overall size of the antenna is 96×96×1.575 mm^3

and achieved 7.3dBi gait at 2.45 GHz. In [16], a CPW fed slot antenna is proposed for 2.45 GHz small satellite communication system, where the antenna achieved 8.8dBi of gain with overall size of 90×90×10.5 mm^3. In [16], a coplanar wave-guide -fed triangular slot S-band antenna has been proposed, where the antenna shows 8.20 dBi gain with linear polarization In [17], a circular polarized antenna has been developed for satellite communication system, which can operate at 2.19-2.3 GHz with 5dBi of gain.

Therefore, a circularly polarized small antenna with standard bandwidth and gain is highly required for S-band CubeSat communication system. In this paper, a small satellite antenna with small footprint and high gain has been developed and investigated for small satellite and space communication.

2. Antenna design

The design layout of the proposed antenna is illustrated in Fig. 1. The proposed antenna has been designed considering 1U small satellite standard by the Japan Aerospace Exploration Agency (JAXA). The dimension of the satellite is 100 mm × 100 mm × 113.5 mm and the weight is 1 Kg. The antenna is connected with the backplane of the satellite structure along with solar panel, shown in Fig. 2. As the internal parts, some subsystems and battery, front panel, transmitter, and communication board, etc. are included. The solar panels are attached to the outer surface of the satellite.



Top view

Bottom view

Fig. 1. Antenna design layout

The overall optimized parameters are listed in Table 1. A 50Ω rectangular fed is used to excite the slotted square patch. Two rectangular structures are used to connect with inner square, which creates asymmetrical slots. This configuration gives rise to two orthogonal modes resulting in circular polarization [8,9].

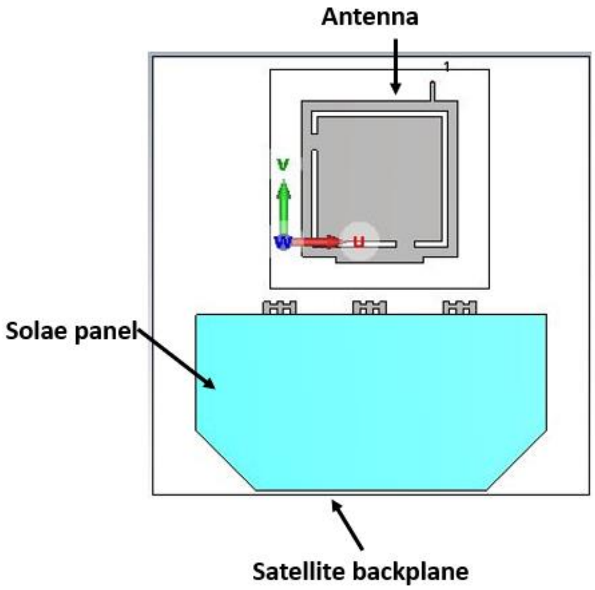


Fig. 2. Antenna with small satellite structure (color online)

Table 1. Antenna design parameters

Parameter	Dimension (mm)	Parameter	Dimension (mm)
L	50	Wf	1.15
L1	28.65	d1	3.54
L2	35.52	d2	4.10
L3	20	d3	1.29
Lf	4.19	g	1.14

3. Results

The simulated and measured reflection coefficient and the efficiency of the proposed antenna has been investigated, shown in Fig. 3. The antenna operates from 2.35 GHz to 2.43 GHz. The total efficiency shows 95%. The axial ratio of the antenna is shown in Fig. 4. The antenna achieved single 3dB AR at resonating frequency. The AR beamwidth at 2.40 GHz is illustrated in Fig. 5, where the antenna achieved wide 3dB axial beamwidth.

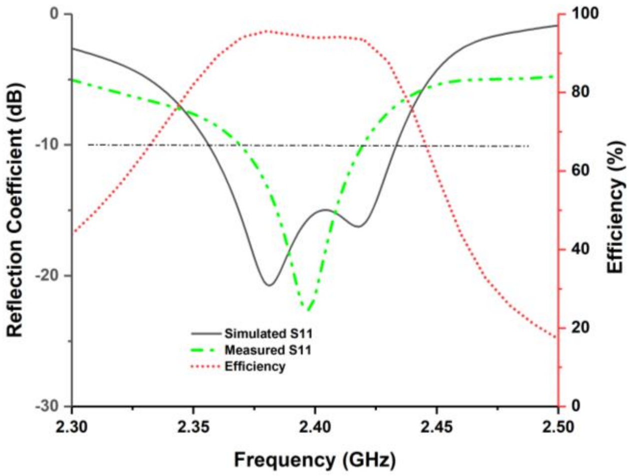


Fig. 3. Reflection coefficient of the proposed cp antenna (color online)

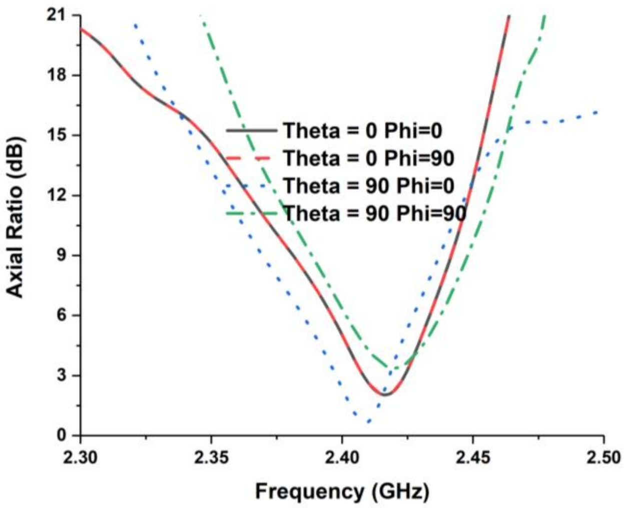


Fig. 4. Axial ratio of the proposed cp antenna (color online)

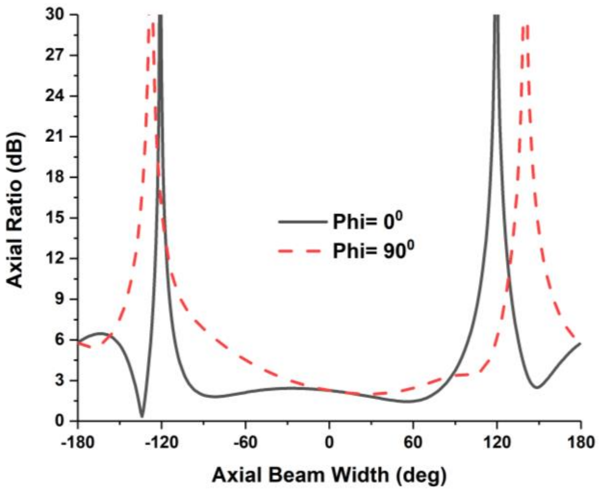


Fig. 5. Axial beamwidth of the proposed cp antenna (color online)

The circular polarization of the proposed antenna can be understood from surface current distributions at different time instants, shown in Fig. 6. At ωt=0˚, the vector sum of the major current flow direction is towards the diagonal of +x and -y axis. And at ωt=90˚, the orientation of the current flow is toward the diagonal of the positive x and y-axis. Similarly, at ωt=180˚, the direction of the current flow is the opposite of 0˚ and at ωt= 270˚ is opposite of 90˚. Therefore, the majority current of the proposed antenna travels in the anti-clockwise direction, which results right hand circular polarization (RHCP).

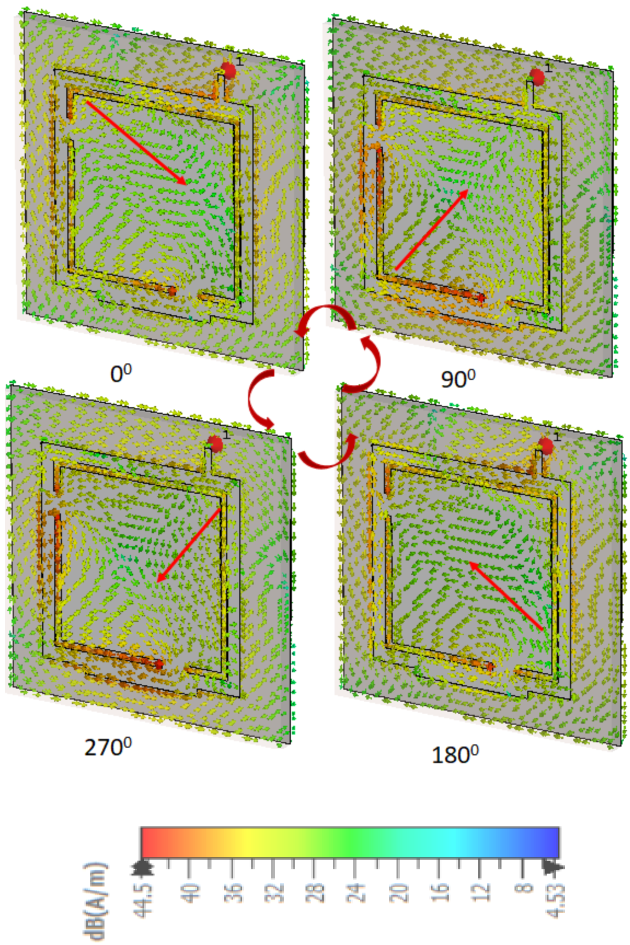
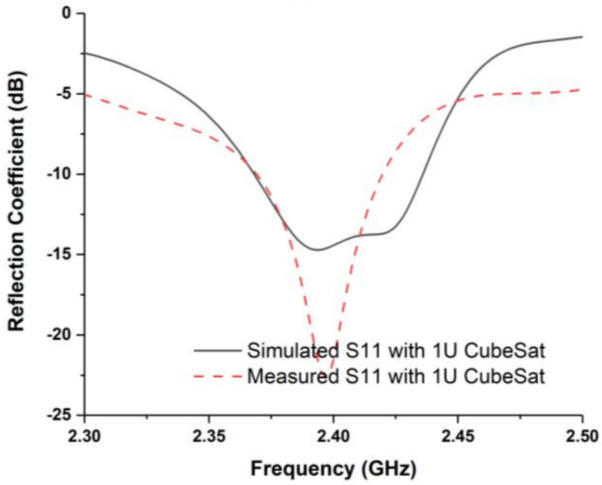


Fig. 6. Surface current distribution of the proposed antenna (color online)

(a)



(b)

Fig. 7. (a) Antenna mounted with 1U CubeSat structure (b) Reflection coefficient of the proposed cp antenna with 1U CubeSat (color online)

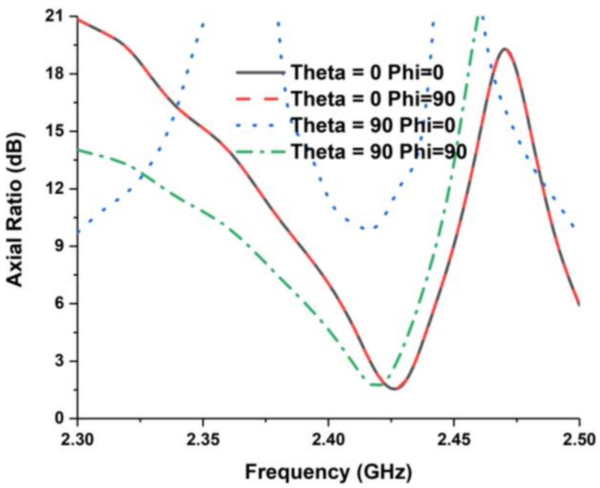


Fig. 8. Axial ratio of the proposed cp antenna with 1U small satellite (color online)

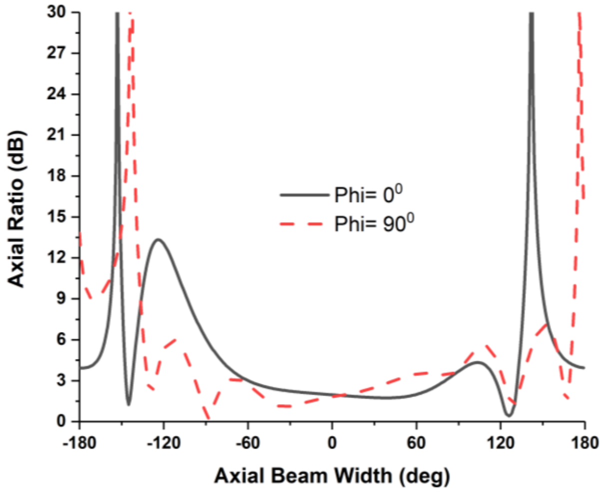
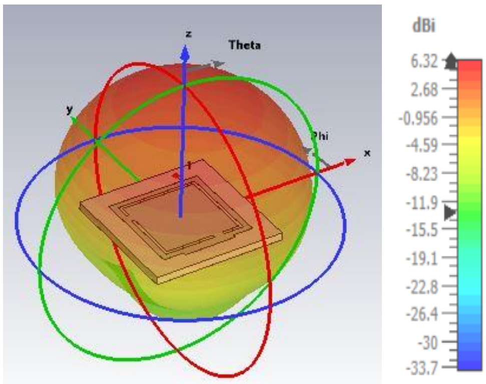
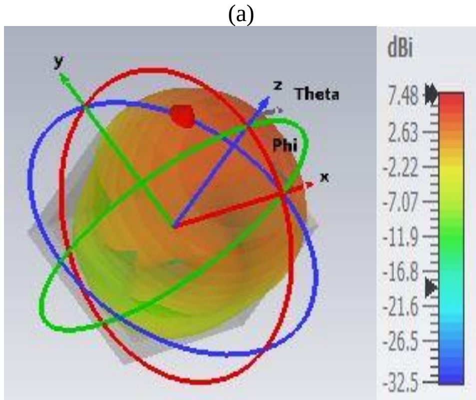


Fig. 9. Axial beamwidth of the proposed cp antenna with 1U small satellite (color online)

The proposed antenna performance has been investigated with 1U small satellite structure, shown in Fig. 7a. The antenna reflection coefficient and total efficiency has been simulated and measured with nanosatellite structure and found similar response of the free space antenna. The axial ratio and axial beamwidth at 2.4 GHz are illustrated in Fig. 8 and Fig. 9, respectively. Comparing with Fig. 3 and Fig. 4, a slight discrepancy is observed in Fig. 8 and Fig. 9. This discrepancy is occurred due to proximity between antenna and satellite structure.



(a)



(b)

Fig. 10. 3D radiation pattern proposed cp antenna, (a) without and (b) with 1U small satellite (color online)

The 3D radiation pattern of the proposed antenna with and without satellite structure is presented in Fig. 10, where the antenna achieved 7.48 dB of realized gain with directional pattern. A comparison with some existing satellite antenna is tabulated in Table 2.

Table 2. Comparison with existing works

Ref.	Operating frequenc (GHz)y	Gain	Antenna size (mm^3)	Polarization
[16]	1.6-2.97	8.8 dBi	90×90×10.5	LP
[17]	2.19-2.3	5dBi	36×43×2.1	CP
[18]	2.00-2.12	7.2 dBi	51.0× 49.75×3.404	CP
[19]	2.275-2.47	5.35 dBi	99 ×99 × 21.485	CP
[20]	1.558-1.593	5.3dB	40×40×1.57	LP
[21]	1.9-2.63	2.52	60×60	LP
Proposed	2.35 -2.43	7.48	50×50×1.57	CP

4. Conclusion

This research proposed a small satellite antenna that is optimized for the 1U small satellite communication system. The parameters have been optimized considering CubeSat size to get the best gain and efficiency. The antenna exhibits circular polarization at 2.4 GHz with 7.48 dB of realized gain. The overall antenna size is 50 mm × 50 mm, which compatible with 1U small satellite. Moreover, the antenna facilitates free space for solar panel placement to ensure sufficient power.

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