An X Band Downlink Antenna for a CubeSat Mission

Reyhan Baktur, Emerson Oliveira, Lidia Shibuya Sato, and Charles Swenson

Abstract – This article presents a downlink antenna design for a CubeSat mission. The design parameters of the antenna are determined from the CubeSat link budget. The prototype antenna is integrated on the CubeSat frame, and its performances are validated through tests in an anechoic chamber.

1. Introduction

The Scintillation Prediction Observations Research Task (SPORT) is a collaborative CubeSat mission among institutes in Brazil and the United States to explore space weather by providing more data to study how scintillations happen in the ionosphere [1]. CubeSats are small standardized satellites. Details of CubeSat terminology and classification can be found in [2] and [3]. SPORT CubeSat uses an X band radio for the downlink, and this article presents an in-house antenna design that meets the requirements of the mission.

Figure 1 is an illustration of the SPORT spacecraft. The downlink antenna is located at the bottom side of the nadir-pointing CubeSat, which means that the antenna always points to the Earth center. As seen from the figure, the pointing of the downlink antenna **P** and the ground station **R** do not line up on most parts of the orbit. It is assumed in this illustration that the maximum gain of the downlink antenna is along **P**, but one could easily extend the misalignment of **P** and **R** to other basic gain patterns.

The requirement for the SPORT downlink antenna design is to fit a low-cost circularly polarized antenna within an allocated area on the CubeSat and maintain a reliable communication link when the CubeSat rises from the horizon (the sooner, the better).

2. Determination of Antenna Parameters Through Link Budget Analysis

To determine the downlink antenna parameters, it is necessary to examine the SPORT's link budget. A link budget is a comprehensive matrix that includes transmitter power, losses, noise, and channel data rate [4]. In Figure 1, from the CubeSat to the ground, the power generated by the transmitter undergoes losses due to connections and imperfections in the devices before reaching the transmitter antenna. The power transmitted by the antenna then undergoes losses due to the wireless path, atmospheric attenuation, transmitter and receiver antenna polarization mismatch, and losses in the receiver. This part is calculated from the Friis transmission equation [5].

The receiver antenna, in addition to receiving the signal from the transmitter antenna, receives noise from its environment. It also generates heat due to its loss resistance [6]. Similarly, there is heat generated in the receiver. Together, these heat sources account for the noise in the receiver.

The ratio between the power that reaches the receiver and the noise in the receiver is the signal-to-noise ratio (SNR), and it has to be larger than a threshold value in order for the receiver to support a desired data rate. The difference between the SNR in the receiver and the threshold in decibels is called the link margin (1). When the link margin is ≥ 0 dB, the term *link closes* is used, meaning that the receiver could separate and process the signal from the noise floor. In general, one prefers the link margin to be higher than 3 dB. The S/N threshold is determined by the required channel bit error rate (BER) and the modulation method [4]:

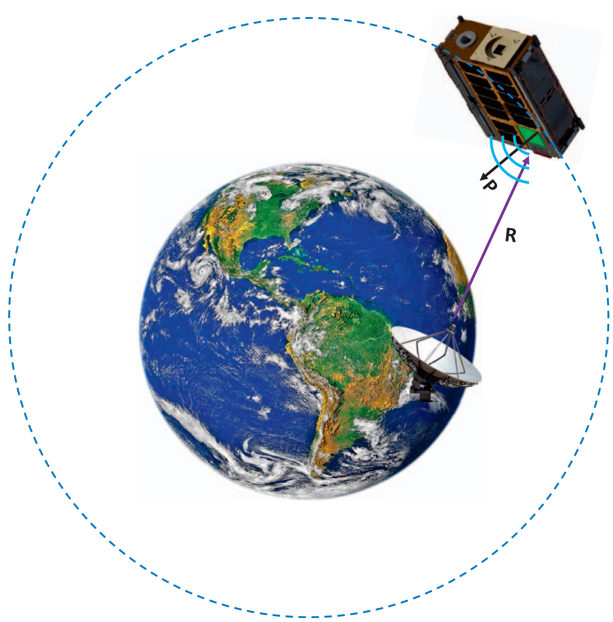

Figure 1. Illustration of the SPORT CubeSat and the ground station.

Manuscript received 4 February 2022.

This project is funded by: (1) FUNDAÇÃO DE AMPARO À PESQUISA DO ESTADO DE SÃO PAULO (FAPESP) FAPESP process: 2016/24970-7, and (2) NASA SMD SPORT mission via MSFC contract 80MSFC18C0010.

Reyhan Baktur and Charles Swenson are with Utah State University, 4120 Old Main Hill, Logan Utah 84322, USA; e-mail: reyhan.baktur@usu.edu.

Emerson Oliveira and Lidia Shibuya Sato are with the Instituto Tecnológico de Aeronáutica, Praça Marechal Eduardo Gomes, 50–Vila das Acácias, São José dos Campos, São Paulo 12228-900, Brazil; e-mail: shibuya@ita.br.

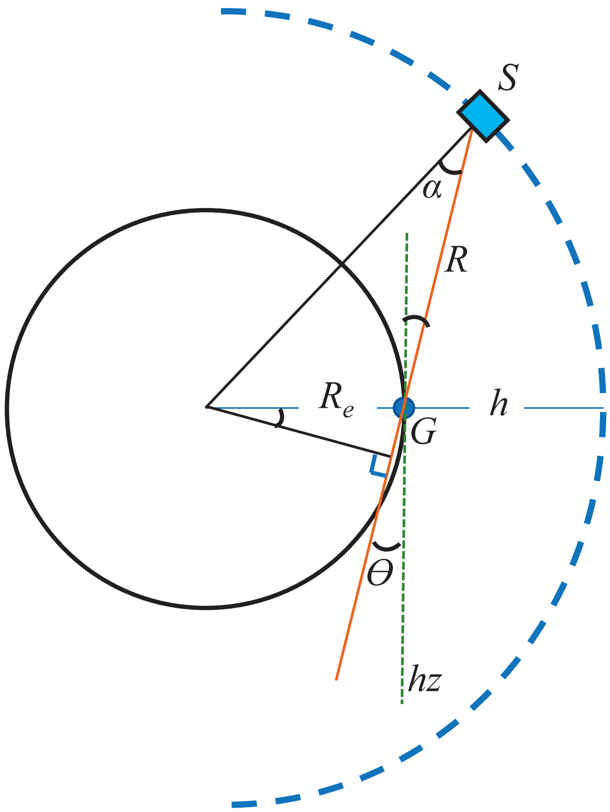

Figure 2. SPORT orbit geometry.

$$\text{Link Margin } = \frac{S}{N} - \left(\frac{S}{N}\right)_{\text{required}} \text{(dB)} \tag{1}$$

2.1 SPORT Orbit Information

The SPORT spacecraft is in low earth orbit (LEO) at an altitude of 400 km and operates at nadir-pointing mode. Figure 2 illustrates the elevation and pointing of the satellite, where R_e is the radius of Earth, h is the satellite (S) altitude, and R is the distance between the satellite and the ground station (G). The pointing angle α is the angle between the satellite's nadir direction and the line R. From transmitter power, the downlink antenna's gain pattern, and α, one could use Friis transmission equation to calculate the power that reaches the ground station. As seen from Figure 2, the pointing angle is related to θ, which describes how many degrees the satellite is above the horizon. A basic examination into geometry yields (2). Accordingly, the path length R can be calculated from (3):

$$\alpha = \arcsin\left(\frac{R_e \cos\theta}{R_e + h}\right) \tag{2}$$

$$R = \sqrt{(R_e+h)^2 - R_e \cos^2\theta} - R_e \sin\theta \tag{3}$$

Table 1. Pointing angle and path length.

θ	10°	15°	20°	23°
α	67.9°	65.4°	62.2°	60°
R	1439.8 km	1175.5 km	984.2 km	895.1 km

As a reference, a few pointing angles and path lengths are calculated and listed in Table 1 for different θ. The radius of Earth is taken as $R_e = 6378.14$ km.

2.2 Antenna Parameters and Link Budget

The design goal for the SPORT downlink antenna is that the ground station can receive data as soon as the spacecraft is 10° above the horizon. More detailed information of the SPORT link budget, including the frequency and data rate, is listed in Table 2, where the link loss is calculated from $L_s = 20\log_{10}[\lambda/(4\pi R)]$. From Table 1, it is seen that the design goal sets a minimal gain for the antenna at 68° from the spacecraft nadir direction.

The ground station antenna is a parabolic reflector of 52 dB gain, right-hand circular polarization (RHCP), and 70% efficiency. From the link budget (Table 2), it is seen that as long as the downlink antenna has 0 dB gain at $\alpha = 68°$, the link closes. This means that a basic microstrip patch antenna of RHCP can be sufficient for the task. Since a circular polarization of a patch antenna reduces to an elliptical and then linear polarization away from its bore sight, a polarization mismatch loss of 3 dB is taken.

3. Antenna Design and Results

Based on the link budget analysis, a basic quasi-square probe-fed patch antenna is chosen. A spacecraft antenna is required to withstand extreme temperature fluctuation and has low outgassing. To meet these needs, Rogers RT Duroid 6002 was chosen as the substrate.

Table 2. SPORT link budget.

Parameter	Symbol	Unit	Value
Frequency	f	GHz	8.04
Transmitter power	P_{TX}	Watts	2
CubeSat antenna gain	G_{TX}	dB	0
Transmitter loss	L_{TX}	dB	0.5
Power transmitted	P_t	dBW	2.51
Angle above horizon	θ	°	10
Path length	R	km	1439.8
Path loss	L_s	dB	173.72
Atmospheric loss	L_a	dB	2
Polarization loss	L_p	dB	3
Ground antenna gain	G_{RX}	dB	52
Receiver loss	L_{RX}	dB	0.5
Pointing loss	$L_{\theta RX}$	dB	0.5
System noise temperature	T_{sys}	K	150
Data rate	R_d	Bps	2E+7
Bit error rate	BER	—	1E−5
Required S/N	$(E_b/N_0)_{rq}$	dB	5.8
Link margin	LM	dB	4.65

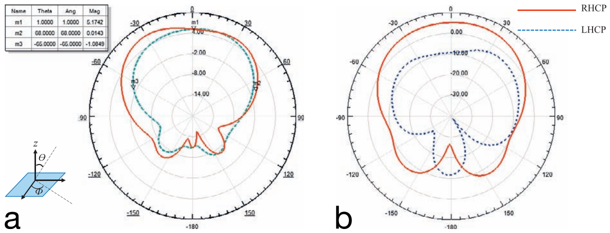

Figure 3. Simulation results.

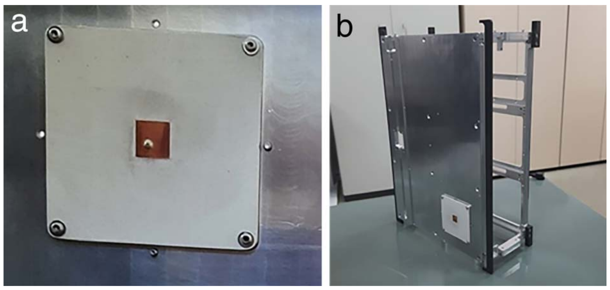

Figure 4. Final prototype. (a) Fabricated downlink antenna. (b) Downlink antenna integrated on the SPORT CubeSat frame.

3.1 Design Parameters

The housing size allocated for the antenna is a 61.6 cm square, and that value is taken as the dimension of the patch antenna's substrate and ground plane. The height of the substrate is 1.524 mm. The parameters of a RHCP quasi-square antenna and probe position are calculated following the design equations [5] and then fine-tuned using Ansys HFSS.

The simulation results are presented in Figure 3. Figure 3a shows the gain patterns in two ϕ cuts. It is seen that along one cut, the antenna's gain is 0 dB at 68° from the bore sight, meaning that the design goal has been met. The gain along the other cut is slightly lower, but it is seen from Table 2 that the link still closes. Figure 3b shows that the antenna is of RHCP.

3.2 Prototyping and Tests

The patch antenna is in-house fabricated at Utah State University using an LPKF circuit board milling machine. The final prototype is shown in Figure 4. The antenna is then integrated with the SPORT CubeSat frame and tested in an anechoic chamber for its gain pattern at Instituto de Fomento e Coordenação Industrial, arranged by Instituto Tecnolégico de Aeronáutica. The test setup is as shown in Figure 5.

3.3 Results and Discussion

Measured results from the tests in the anechoic chamber are presented in Figure 6. It is seen that due to the effect of the CubeSat frame, the antenna's gain pattern shifted slightly such that when the antenna's gain is 0 dB, the angle away from the bore sight is 74° on one side and 62.5° on the other side. For the 62.5° pointing angle, it is seen from Tables 1 and 2 that the link closes with a decent margin when the satellite is 20° above the horizon. This is deemed as acceptable in terms of how soon the ground station receives data. On the other hand, Figure 6 shows a gain of –1 dB at $\theta =$ –68°, which means that the link still closes. So, with either criterion, the antenna design meets the goal of the SPORT mission.

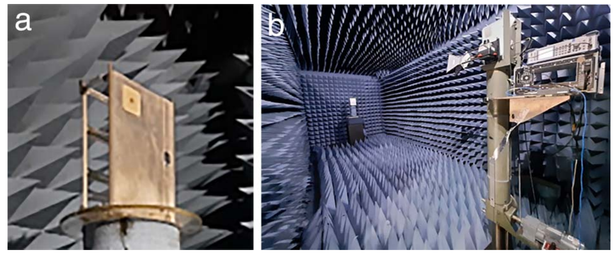

Figure 5. Measurement setup in an anechoic chamber.

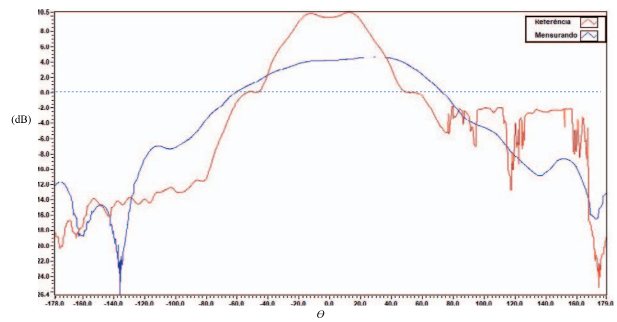

Figure 6. Measured results.

4. Conclusions

An X band downlink RHCP antenna is designed for a CubeSat mission. The antenna supports a data rate of 2E+7 bit/s for the CubeSat in LEO from when it rises 10° from the horizon to when it goes down at 170°. The antenna's properties and design parameters are determined from the link budget analysis. and the material selection is suitable for space application. The antenna design is verified through measurements when it is integrated with the CubeSat's frame. The measured results show that the antenna's performance meets the CubeSat mission requirements.

5. References

1. L. da Costa, L. Sato, M. Abdu, V. Carrara, P. Albuquerque, et al., "The Scintillation Prediction Observations Research Task (SPORT): A Spacecraft Development for an International Mission," 32rd Annual AIAA/USU Conference on Small Satellites, Session 4: Instruments/ Science I, 2018.
2. S. Gao, M. Sweeting, S. Nakasuka, and S. Worden, "Special Issue: Small Satellites," *Proceedings of the IEEE*, **106**, 3, 2018.
3. Y. Rahmat-Samii, "Special Issue on Antenna Innovations

for CubeSats and SmallSats,'' *IEEE Antennas and Propagation Magazine*, **2**, 2017, pp. 16-127.

4. J. H. Yuen (eds.), *Deep Space Telecommunications Systems Engineering*, New York, Plenum Press, 1983.
5. C. A. Balanis, *Antenna Theory: Analysis and Design*, New York, Wiley, 2016.
6. J. D. Kraus and R. J. Marhefka, *Antennas for All Applications*, New York, McGraw-Hill, 2002.