RESEARCH ARTICLE

Effect of polarization on the link dynamics of a spinning low-earth orbits satellite aligned with geomagnetic field

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Abstract
This paper discusses the dynamic communication link aspects of IIT Madras student Satellite (IITMSAT). It is a Low-Earth Orbits satellite which has limited Attitude Determination and Control System (ADCS) ability to align one of its body axes with the geomagnetic field in orbit. The ADCS of IITMSAT has no control over its spin with respect to the axis along the geomagnetic field. This has a destructive influence on the link aspects between the satellite and the ground station. As the satellite spins over its axis, given the two-axis attitude control, the gain of the downlink antennas in the direction of the ground station vary all through the pass of the satellite over the ground station, which will, in turn, affect the signal received at the ground station. Similarly, the uplink is also affected. A rigorous analysis of the variation of the link strengths for uplink and downlink along typical passes of the satellite above a ground station located in Chennai, India, is presented, taking into account the geomagnetic field at the altitude of the orbit. This analysis helps in choosing the polarization (LHCP or RHCP) for uplink and stresses the need for polarization diversity at the ground station for downlink. This will ensure the link with the ground station remains robust through the pass of the satellite and hence achieving higher amounts of data transfer with the satellite. Further, this work helps design the satellite onboard antennas for better link performance, taking into account the ground station location and assisting in taking system-level decisions for small satellite missions.

KEYWORDS
antenna, communications, link margin, satellite

1 | INTRODUCTION

Microsats and nanosats in Low-Earth Orbits (LEO) have ever-increasing importance as they can contribute significantly to remote sensing and earth observations, science missions, space weather, meteorology, astronomy, space debris, navigation, and telecommunications. The future large missions with small satellites will include electric and magnetic field
instruments, plasma density and temperature instruments, mass spectrometers, particle detectors, X-ray detectors and advanced radio receivers. These missions require robust communication with the ground stations for maximum data to be downloaded and for efficient signaling purposes. One of the possible options for increasing the data volume is ground station replication, increasing the contact time. But, it also needs to be ensured that the link with a given ground station is reasonably stable for increasing the data throughput.

The small satellites in the question have size and weight limitations and have limited power resources, leading to limited power available for communication subsystem. Apart from it, concerning the Attitude Determination and Control System (ADCS), the satellites may not have full control over their attitude along the orbit or may have requirements that lead to partial control or spin stabilization. The antennas’ gain is one of the main factors dictating the link quality and is an essential parameter in the link budget calculations for uplink and downlink. One of the nulls in the radiation patterns falling in line-of-sight with the ground station due to stumbling or spinning of satellite leads to fading and complete cut-off of the communication.

The link margin calculations for such satellites are usually done with fixed gain values for the spaceborne antennas. As the satellite’s attitude toward the ground station changes through its pass due to spin/tumbling, the antennas’ effective gain varies. This causes oscillations in the signal strength received at the ground station. The received signal’s strength for various small satellites is presented by K.Voormansik, illustrating the oscillations in received signal strengths. It is also suggested that the satellite’s tumbling rate can be estimated from the measured signal strength curves, which elucidate the effect of the attitude of the satellite toward the ground station. Similar oscillations would also occur in the receiver of the satellite as the receiver antenna’s effective gain varies with spin. It leads to fading of the signal and loss of communication if one of the antenna’s nulls points in the direction of the line of sight of the satellite and the ground station. Hence, if it is predictable, the dynamic gain should be included into the link margin calculations.

The analysis of such dynamic links between the satellite and ground station are available for few satellites in the literature. The work by Abbasiet al. proposes a system of planar circular arrays to establish a robust communication between the ground station and a spinning unstabilized cubesat. It is claimed that the approach reduces the requirement for sophisticated on-satellite stabilization for reliable communication with the ground station. But it requires electronic steering of the antenna beam to establish a communication link that adds to the system complexity. Similar solution with phased array antennas is presented by Underwood. Concerning a spin-stabilized satellite Eu:CROPIS, the detailed analysis of destructive phenomena due to the dynamic far-field with amplitude and phase variations is presented by Drobczzyk et al. And a dynamic link budget approach for the verification of the communication subsystem is presented by Drobczzyk et al. These approaches elucidate the importance of considering the dynamic link aspects of the communication subsystem of the satellites.

IITMSAT, a student-satellite from the Indian Institute of Technology, Madras, is a small satellite weighing around 15 kg with a scientific mission of measuring charged particle fluxes in the ionosphere precipitated from the Van Allen radiation belts. The fluxes’ measurement requires the sensor on one of the faces of the satellite pointing in the geomagnetic field direction in the orbit. To facilitate this, the satellite has a limited attitude control system that aligns the spin axis (z), shown in Figure 1(A), along the geomagnetic field in orbit. The geomagnetic field direction is not parallel to the Earth’s surface, leading to variation of the attitude of the satellite toward the ground station as it travels along the orbit in the vicinity of the ground station.

For small satellites without attitude control systems, the tumbling and the consequence of fading of the communication signal is unavoidable. However, for satellites like IITMSAT with a partial attitude control system, proper design of antennas and practical design of the communication subsystem can lead to a robust communication link. For calculating the dynamic link budget, various aspects, including the antenna system, radian patterns, orbital dynamics and link margin calculations, are needed.

The work’s main result is in quantifying the effect of polarization in both uplink and downlink robustness for a spinning satellite aligned with the geomagnetic field. The novelty in this work is in considering the attitude of the small satellites in LEO orbits toward a particular ground station by taking into account the geo-magnetic field in the orbit and evaluating the link margins over the particular ground station’s entire field of view.

The paper is organized in the following way. The properties of the antennas on the satellite are presented in Section 2 and the link margin calculations are presented in Section 3. The geomagnetic field description and its implication on the attitude of the satellite is explained in Section 4. The variation of the link margins along the typical passes of the satellite is presented in Section 5.
ONBOARD ANTENNAS

In the IITMSAT model shown in Figure 1(A), (B), the green rods at the center of the satellite body’s sides are two of the four transmitter (Tx) antennas on the satellite. They are inverted F-antennas tuned for resonance at 437.5 MHz. The four Tx antennas are connected to the transmitter using a 1:4 power divider for both telemetry and beacon. They can be fed in various phase configurations as shown in Table 1. The comparison of the realized gain patterns (in dBi) for the sequential phase conditions are shown in Figure 1 and with all four antennas fed in phase in Figure 3. The three-dimensional radiation patterns are represented as a collection of two-dimensional lines representing planes passing through the satellite’s z-axis. The details of the antennas and their radiation pattern measurements shown here are presented in the thesis of this author.13

The gain pattern in Figure 1(D) corresponds to the four antennas fed in sequential phase condition (T1:0°, T2:90°, T3:180° and T4:270°), for which the maximum radiation is in the z-axis direction of the satellite which, is not desirable for the mission. The gain pattern in Figure 1(C) corresponds to antenna fed in anti-sequential phase condition (T1:0°, T2:−90°, T3:−180°, and T4:−270°), for which there is a lot of variation in the realized gain value around 90° and −90°. The nonsimilarity of the patterns corresponding to sequential and anti-sequential phase conditions is due to the highly asymmetric pattern of the antenna element (F-antenna) on the finite ground plane, which is the metallic satellite structure. The theoretical aspects of such antennas on finite ground planes are analyzed by this authors.14

Owing to the simplicity of the antennas’ feed network and the desired radiation characteristics, which will be discussed further, the equi-phase feeding of the Tx antennas has been chosen. In this configuration, the transmitter is connected to the four Tx antennas through a four way power divider with equi-length cables.

The receiver (Rx) antenna is shown in red in Figure 1(A). The length of the antenna is adjusted for resonance at 145.9 MHz. The Tx and Rx antennas are fabricated and tested. The measured S11 characteristics are shown in Figure 2, indicating the corresponding resonant frequencies. The VSWR values at the resonant frequencies for Tx and Rx are 1.4 and 2.0, respectively.

Realized gain patterns for the satellite transmitter (Tx) and receiver (Rx) for Right Hand Circular Polarization (RHCP) and Left Hand Circular Polarization (LHCP) components are presented in Figure 3. As the antennas are on a finite ground plane of dimension comparable to the wavelength of radiation, the gain patterns have LHCP and RHCP components of

![Figure 1](image)

### Table 1

| Antenna phase (°) | T1 | T2 | T3 | T4 |
|------------------|----|----|----|----|
| Sequential       | 0  | 90 | 180| 270|
| Antisequential   | 0  | −90| −180| −270|
| Equi-phase       | 0  | 0  | 0  | 0  |
Figure 2: The measured S11 (return loss) plots of the Tx and Rx antennas on the satellite.

Figure 3: Polar plots: Realized Gain (in dBi) patterns of the Tx and Rx antennas. (A) Tx Right Hand Circular Polarization (RHCP) realized gain (B) Tx Left Hand Circular Polarization (LHCP) realized gain @ 437.5 MHz; (C) Rx RHCP realized gain and (D) Rx LHCP realized gain @ 145.9 MHz. The polar angle corresponds to the angle with respect to the spin-axis (Z-axis) of the satellite shown in the figures. Various lines represent the equi-angle cuts passing through the spin-axis of the satellite. The shaded regions are the range of angles which fall into the line-of-sight with the ground station through the pass of the satellite.

The realized gain here is defined as the antenna’s gain reduced by the losses due to the mismatch of the antenna input impedance to a 50 Ω impedance and the loss in the antenna itself. The gain of the antennas presented in this paper is relative to an isotropic radiator (in dBi). The shaded regions in the plot correspond to the angles that fall into the ground station’s view. This range of polar angles of the radiation pattern, 40° to 140°, which is essential for the communication link strengths are derived in Section 4.

3 COMMUNICATION SYSTEM

The details of the communication system architecture of both IITMSAT (the satellite) and the ground station, along with the radios used, the constraints on the data volumes, modulation formats and frame structures are presented by Gulati et al. However, a detailed analysis of the link aspects’ dynamic nature due to the satellite’s spin is ignored.

The link margin calculations are presented in Table 2. The numerical values corresponding to elevation angles of both 5° (near the horizon) and 90° (zenith) are presented for both uplink and downlink. Along the pass through the field of view of the ground station, two parameters vary (1) free space loss due to the change line-of-sight distance between the satellite and the ground station and (2) the antenna gain due to the variation of attitude and spin of the satellite. The atmospheric and ionospheric losses are assumed to be constant through the pass, and as they are proportional to 1/f^2 an in ITU-R document, only approximate values are included in the link budget calculations.

For the downlink, transmitted power from the satellite is 0 dBW (1 Watt), and the modulation scheme employed is GMSK with a bit rate of 9600 bps. Overall, the downlink margin is about 3 dB at the horizon and 15 dB at the zenith.
### Table 2 Link margin calculations for both downlink and uplink for elevation angles 5° and 90° are presented

| Downlink Calculation | Value | Units |
|----------------------|-------|-------|
| **Satellite and Transmitting Antenna** | | |
| Downlink Frequency | 437.5 | MHz |
| Transmit Power $P_t$ | 0 | 0 dBW |
| Satellite line Losses $L_{sat}$ | | |
| 4-way Power Divider and feeding Losses | 2 | 2 dB |
| Satellite Antenna Gain $G_{tx}$ | | (Varies with spin of the satellite) |
| Transmitter EIRP $P_{EIRP}$ = $P_t - L_{sat} + G_{tx}$ | -8 | -8 dBW |
| **Downlink Path** | | |
| Orbit Altitude | 600 | km |
| Elevation Angle | 5° | 90° |
| Distance to the satellite $d$ | 2330 | 600 km |
| Free Space Loss | | |
| $L_f = 10 \log \left( \frac{4\pi d}{\lambda_0} \right)^2$ | 152.61 | 140.82 dB |
| Atmospheric Losses $L_{atm}$ | 2.10 | 2.10 dB |
| Ionospheric Losses $L_{ion}$ | 0.40 | 0.40 dB |
| Total Propagation Loss $L_{path} = L_f + L_{atm} + L_{ion}$ | 155.11 | 143.32 dB |
| **Ground station** | | |
| GS Pointing Error | 7° | 7° |
| Pointing Loss $L_{point}$ | 3.0 | 3.0 dB |
| Ground Station feeding Loss $L_{GS}$ | 3.0 | 3.0 dB |
| Rx Antenna Gain $G_{Rx}$ | 18.0 | 18.0 dBi |
| Rx component noise temp $T_{Rx}$ | 94.0 | 94.0 K |
| Rx input noise temp $T_A$ | 300.0 | 300.0 K |
| System noise temp | | |
| $T_{sys} = T_A + T_{Rx}$ | 394.0 | 394.0 K |
| Rx Noise Bandwidth $B$ | 20.0 | 20.0 kHz |
| Rx Power $P_{Rx} = P_{EIRP} - L_{path} + G_{Rx} - L_{point} - L_{GS}$ | -151.11 | -139.32 dBW |
| Rx Noise Power | | |
| $P_{noise} = k \cdot T_{sys} \cdot B$ | -159.63 | -159.63 dB |
| SNR $SNR = P_{Rx} - P_{noise}$ | 8.50 | 20.31 dB |
| Modulation Scheme | GMSK | GMSK |
| Data Rate $R_b$ | 9600 | 9600 bps |
| Eb/No Received $SNR \cdot B / R_b$ | 11.71 | 23.5 dB |
| Eb/No threshold for 1e-5 BER | 8.20 | 8.20 dB |
| **Downlink Margin** | 3.51 | 15.30 dB |

(Continues)
### TABLE 2 (Continued)

| **Uplink Calculation** | **Value** | **Units** |
|------------------------|-----------|-----------|
| **Ground Station and Transmitting Antenna** | | |
| Downlink Frequency | 145.9 | MHz |
| Transmit Power $P_t$ | 7.0 | 7.0 dBW |
| Ground Station line Losses $L_{sat}$ | 6.0 | 6.0 dB |
| Ground station Antenna Gain $G_{tx}$ | 16.0 | 16.0 dB |
| GS Pointing Error | 7.0 | 7.0 ° |
| Pointing Loss $L_{point}$ | 3.0 | 3.0 dB |
| **Transmit EIRP** | | |
| $P_{EIRP} = P_t \cdot L_{sat} + G_{tx} \cdot L_{point}$ | 10.0 | 10.0 dBW |
| **Uplink Path** | | |
| Orbit Altitude | 600 | km |
| Elevation Angle | 5 | 90 ° |
| Distance to the satellite $d$ | 2330 | 600 | km |
| (Varies with elevation angle) | | |
| Free Space Loss $L_{fs} = 10 \log \left(\frac{4\pi d}{\lambda_0}\right)^2$ | 143.07 | 131.29 dB |
| Atmospheric Losses $L_{atm}$ | 1.0 | 1.0 dB |
| Ionospheric Losses $L_{ion}$ | 0.7 | 0.7 dB |
| Total Propagation Loss $L_{path} = L_{fs} + L_{atm} + L_{ion}$ | 144.77 | 132.99 dB |
| **Satellite** | | |
| Rx Antenna Gain (on satellite) $G_{Rx}$ | -8.0 | -5.0 dBi |
| (Varies with spin of the satellite) | | |
| System noise temp $T_{sys}$ | 1500 | 1500 K |
| Rx Noise Bandwidth $B$ | 10.0 | 10.0 kHz |
| Rx Power $P_{Rx} = P_{EIRP} \cdot L_{path} + G_{Rx}$ | -142.77 | -127.99 dBW |
| Rx Noise Power $P_{noise} = k \cdot T_{sys} \cdot B$ | -156.83 | -156.83 dB |
| SNR SNR | 14.06 | 28.84 dB |
| Modulation Scheme | FSK | FSK |
| Data Rate $R_b$ | 1200 | 1200 bps |
| Eb/No Received $SNR \cdot B / R_b$ | 23.27 | 38.05 dB |
| Eb/No threshold for 1e-5 BER | 13.8 | 13.8 dB |
| **Uplink Margin** | 9.47 | 24.25 dB |

The estimated $G/T$ ratio of the ground station receiver system is -8.7 dB/K. For the uplink, the link margins are about 10 and 24 dB at horizon and zenith, respectively.

### 4. ATTITUDE CONTROL SYSTEM AND THE GEOMAGNETIC FIELD

IITMSAT uses magnetic torque rods as control actuators to control its in-orbit attitude. The attitude control of IITM-SAT is programmed to align the spin axis ($z$-axis in Figure 1(A)) with the local geomagnetic field in orbit. The scientific payload of the satellite requires such alignment to detect the surge in charged particle fluxes in the Van Allen radiation belt. This partial control over the satellite's attitude makes it prone to spin, leading to a continuous variation of its attitude toward ground station through its pass. This, in turn, leads to a variation of antennas'
gain in the direction toward the ground station resulting in oscillation and fading of signal strength in uplink or/and downlink.

To quantify the effect of this change in the satellite’s attitude on the link performance, the local magnetic field characteristics in the orbit of the satellite is required. The geomagnetic field data in terms of inclination and declination at 600 km altitude is obtained from the World Magnetic Model (WMM) grid calculator.\(^1\) Inclination is the angle between the magnetic field and the surface (or horizontal plane at the point of measurement), and declination is the deviation of the magnetic field projected on the horizontal plane from the true north as shown in Figure 4. As the satellite’s communication with the Chennai ground station is of interest, the inclination and declination angles in its field of view of the LEO orbit at 600 km are shown in Fig 4. Inclination varies drastically from \(-60^\circ\) to \(+80^\circ\), whereas declination varies from \(-9^\circ\) to \(+4^\circ\) over the field of view, which implies that the magnetic field lines do not run parallel to the Earth’s surface. This behaviour of magnetic field direction affects the attitude of IITMSAT with respect to the ground station vary along its pass in orbit.

The satellite’s attitude toward the ground station in terms of view-angle is defined as the angle between the line joining the ground station with the satellite and the satellite’s spin-axis. Based on the data in Figure 4, view-angle for the entire field-of-view of Chennai ground station for 600 km orbit is shown in Figure 5(A), which includes just geometric calculations. To calculate the link margins through the pass of IITMSAT over the Chennai ground station, typical passes of another launched LEO satellite ZACUBE-1\(^{19}\) (Sun-synchronous near-circular orbit at altitude = 600 km) obtained using Gpredict software\(^{20}\) are used. The Two-Line-Element set of the ZACUBE-1 are presented in Table 3. Two of the typical passes of ZACUBE-1 are plotted over the field of view in Figure 5(A) for reference. The pictorial representation of this

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**F I G U R E 4** Description of inclination and declination angles of the geomagnetic field. Zenith is perpendicular to the horizontal plane containing true north and true east directions. The angle between true north and projection of Magnetic field (M) on the horizontal plane is Declination (Dec). The angle between the Magnetic field (M) and the horizontal plane is Inclination (Inc). Contour plots of Inclination and Declination angles at 600 km orbit around the ground station at Chennai, India. The x-axis and y-axis correspond to the the latitude and longitude. The contour plots are overlaid on the geographical plots for clarity

**F I G U R E 5** (A) Contour plot of variation of the view-angle over field-of-view of Chennai ground station. Two typical passes over the field of view are shown to exemplify the variation of view-angle along the pass. (B) The geomagnetic field direction in the arrows along the passes and the resulting view-angle are represented by the color of the arrow and the corresponding values are shown in the colorbar
view-angle is presented in Figure 5(B). The alignment of the spin-axis of IITSAT, through the pass in orbit over Chennai ground station, is shown as arrows, and corresponding view-angles are marked in the colorbar below.

The range of variation of the view-angle is $42^\circ$ to $126^\circ$ over the field of view of the Chennai ground station, corresponding to the polar angle range $40^\circ$ to $140^\circ$ (approximately) in the radiation patterns of the Rx and Tx antennas of the satellite. This range of angles which is of importance for the link aspects, is highlighted in the radiation plots shown in Figures 1(C),(D) and 3.

## 5 | LINK DYNAMICS

By taking into account the variation of view-angle (attitude) of the satellite toward the Chennai ground station, shown in Figure 5(A), along with the realized gain patterns in Figure 3, link margins can be calculated for a given pass. This involves varying the corresponding values of distance and antenna gains in the link margin calculations in Table 2. Considering the spin velocity of the satellite to be $10^\circ$/s, the resulting link margins for four passes which occur within a typical day are presented in Figures 6 and 7.

Figure 6 show the expected uplink link margins for LHCP and RHCP polarizations against time for the respective passes shown in the inset. It is observed that the link with LHCP transmission from the ground station leads to multiple fades along the passes resulting in poor communication, and the link with RHCP transmission has fairly good link margin. One can infer such results from the Rx antennas’s LHCP and RHCP radiation patterns shown in Figure 3(C) and (D). The LHCP pattern in Figure 3(D) has nulls less than $-20$ dB in the shaded regions where as the RHCP pattern shows gain greater than $-8$ dB in the shaded areas.

The satellite’s attitude is only controlled and not the spin over its axis pointing with the geomagnetic field. For higher spin rates, the fades seen in LHCP link margins become more frequent with time during the satellite’s pass. On the other hand, the link with RHCP transmission will remain reasonably constant, leading to a robust communication link. Hence
the transmitter antenna in the ground station should be set for RHCP polarization for efficient uplink communication with the IITMSAT.

Figure 7 show the expected downlink margins with the LHCP and RHCP link margins form a complementary pair. The cross over of one dominating the other occurs midway through the pass and it happens only once through the pass. One can infer from the RHCP and LHCP radiation patterns of the Tx antennas on the satellite having complementary shapes with respect to the polar angle $90^\circ$ as shown in Figure 3(A),(B).

For a reasonable downlink margin along satellite’s pass, there is a need to switch the polarization of the received signal at the ground station. Such switching achieved with polarization diversity at the ground station. The polarization diversity scheme can configured in various ways as explained in the work by Vazquez-Alvarez et al.\textsuperscript{21} One of the generalized implementations is shown in Figure 8. In this scheme, two antennas with RHCP and LHCP polarization are employed with separate RF chains, transceivers and modems. As the intended polarization diversity scheme is only for downlink, the transceivers shown in Figure 8 can be replaced by receivers and the modems by demodulators. Though both the received demodulated signals are saved for rigorous offline processing later, the receiver chooses the signal with higher strength from both polarization chains to make the link robust.

According to the data presented by Gulati et al.,\textsuperscript{15} the downlink data requirement is 2 MB per day (including the channel coding data). Four passes of a LEO satellite in the Sun-synchronous orbit occur on a typical day for a given ground

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure7.png}
\caption{Downlink margin variation from Right Hand Circular Polarization (RHCP) and Left Hand Circular Polarization (LHCP) reception at the Chennai ground station. It can be observed that the RHCP and LHCP signals are complimentary in terms of strength through the pass of the satellite. This is due to the complimentary nature of the RHCP and LHCP radiation patterns of the Tx antennas on the satellite as shown in Figure 3(A),(B).}
\end{figure}

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure8.png}
\caption{The open-loop polarization diversity system employed at the ground station receiver. The receiver will have separate receiver chains for Right Hand Circular (RHCP) and Left Hand Circular (LHCP) polarizations and the software implementation of diversity selection is done after demodulation on each chain.}
\end{figure}
station, as shown in Figures 6 and 7. All of them show a pass time of more than 500 s each totaling to 2000 s. With 9.6 kbps data rate, the total amount of data downloadable amounts to 2.34 MB. As some of the pass time will be dedicated to uplink to deliver the commands and house-keeping of the satellite, the communication subsystem with the link aspects presented above will be able to achieve the required throughput. Some of the passes in Figure 7 show link margins for downlink in excess 3 dB for a significant part of time over the ground station’s field of view. The excess margin can be utilized to increase the throughput by employing a faster data rate or reduce the power transmitted for the throughput. But to keep the communication subsystem simple, the transmitter is programmed for constant data rate and constant output power in the present design.

6 | CONCLUSION

The rigorous uplink and downlink analysis presented in this paper signify the effect of polarization on the performance of the communication link of IITMSAT. The satellite’s spin on one of its axis aligned with the geomagnetic field is taken into account, to quantify the change in the antennas’ gain for calculating the link margins for both uplink and downlink.

It is shown that for the presented design of Rx antenna on the satellite, RHCP signal transmission from the ground station is required for stable communication link. The downlink analysis exemplifies the need for polarization diversity at the ground station in which the signals of both polarizations are processed to select the one with better SNR.

Though this analysis is specific to IITMSAT, it can be replicated for other small satellites with various antenna configurations and constraints on attitude control. As each small satellite has unique constraints on the antenna specifications, size, placement and frequency bands in use, the solution to mitigate the effect of tumbling or spin cannot be generalized.

Nevertheless, this analysis is useful as a guide in designing a robust RF link for communication for small satellites with limited attitude control systems and can help in mitigating fading and oscillations of signal as observed in the measurements shown in the work by Voormansik. 7

PEER REVIEW INFORMATION

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DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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