



UNIMAS ENCONN | 26

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CONFERENCE 2026

**EMPOWERING INDUSTRY AND
SOCIETY THROUGH ENGINEERING
INNOVATIONS**

**28 – 30
APRIL 2026**

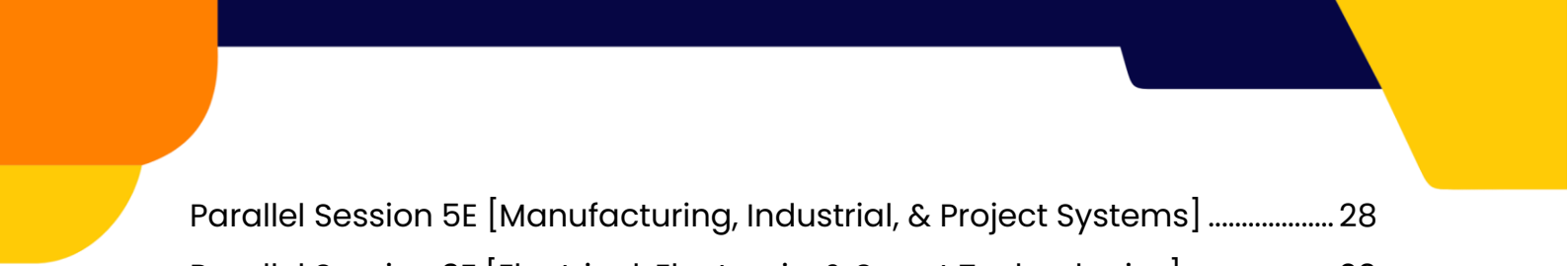
**RAIA HOTEL AND
CONVENTION CENTRE
KUCHING, SARAWAK**

PARALLEL SESSION SCHEDULE

COMMUNITY-DRIVEN UNIVERSITY FOR A SUSTAINABLE WORLD

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DAY 1: 28 APRIL 2026 (TUESDAY)**Special Session: Standards, Quality Assurance, & Regulatory Frameworks****Room Mulu 4****Chairperson: Ir. Jude Ting Mui Heng**

Time	Speaker & Topic
1400 – 1405	Welcoming Remarks & Session Briefing
1405 – 1435	Jabatan Kerja Raya Sarawak Topic: JKR Sarawak Framework in the Application of Engineering Material Standards, Compliance, and Laboratory Testing. Speaker: Adjunct Professor Datu Ir. Ts Gs. Br. PMr. Dr Cassidy Anak Morris Director of Public Works Sarawak
1435 – 1445	Floor Discussion (JKR Sarawak)
1445 – 1515	Watima Testing Sdn Bhd Topic: Transforming Concrete Testing Laboratories: From Manual Practice to Robotic Automation. Speaker: Mr Phang Tze Shing Managing Director
1515 – 1525	Floor Discussion (Watima Testing Sdn. Bhd.)
1525 – 1540	15-Minute Networking / TEA BREAK
1540 – 1620	Department of Standards Malaysia (JSM) Topic: Empowering Engineering Integrity: MS ISO/IEC 17025 Accreditation via the SAMM Scheme. Speaker: Mr Mark Mariba Rantai Senior Assistant Director, Accreditation Division
1620 – 1630	Floor Discussion (JSM)
1630 – 1700	Summary, Photo Session & Presentation of Tokens

DAY 1: 28 APRIL 2026 (TUESDAY)**Parallel Session 1E [Electrical, Electronic, & Smart Technologies]****Room Mulu 5****Chairperson: Assoc Prof Dr Norhuzaimin bin Julai**

Time	Paper ID	Paper Title	Institution
1400 – 1415	EnCon2026: 034-038	Interference Modeling and Mitigation Strategies for Next-Generation Telemetry, Tracking & Command (TT&C) Satellite Ground Stations in the Malaysian Context Ir. Ts. Hamid Salim	Universiti Malaysia Sarawak
1415 – 1430	EnCon2026: 059-046	Lumped Parameter Model Reliability in Blood Velocity and Pressure Analysis during Simplified Cerebrovascular M1 Segment Nabilah Ibrahim	Universiti Tun Hussein Onn Malaysia
1430 – 1445	EnCon2026: 079-071	Mobile Apps: Deep Skin as the Solution for Early Detection Tools for Skin Cancer Carol Oline Chin	Universiti Malaysia Sarawak
1445 – 1500	EnCon2026: 078-070	SAR Distribution of E-slot and U-slot Applicator in Breast Cancer Hyperthermia Treatment Bibi Sarpinah Binti Shnaimullah	Universiti Teknologi MARA
1500 – 1515	EnCon2026: 003-063	Adaptive Iterative Learning Control for the Activated Sludge Process of a Wastewater Treatment Plant Maimun Binti Huja Husin	Universiti Malaysia Sarawak
1515 – 1530	TEA BREAK DAY 1		

Parallel Session 2E [Electrical, Electronic, & Smart Technologies]**Chairperson: Mdm Nur Alia Athirah binti Hj Mohtadzar**

1530 – 1545	EnCon2026: 109-099	Thermal Distribution for Breast Cancer Hyperthermia Treatment Using Rectangular Antenna Integrated with Varies water Bolus Thickness Mazlina Mansor Hassan	Universiti Malaysia Sarawak
1545 – 1600	EnCon2026: 092-082	Performance Characteristics of BOFDA and BOFDR for Distributed Fiber-Optic Temperature Sensing Nazirah Mohd Razali	Smart Sensing Technology Sdn Bhd

Interference Modeling and Mitigation Strategies for Next-Generation Telemetry, Tracking & Command (TT&C) Satellite Ground Station in The Malaysian Context

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Abstract

Malaysia Telemetry, Tracking and Command (TT&C) satellite ground stations are at risk of operational problems caused by over-congestion of Radio Frequency (RF) spectrum, causing severe adjacent channel interference and possible receiver overload. In this study, the local environment was described using a series of 360° azimuth scans of interference frequencies of the S-band facility in the Malaysian Space Agency (MYSA) and recording the Right-hand Circular Polarization (RHCP) and Left-hand Circular Polarization (LHCP) signals. Findings indicated the presence of two different mechanisms: a narrowband spike on RHCP at 2200 MHz (146° azimuth) and broadband noise on LHCP at the S-band (85.2° azimuth). This interference greatly compromises the reliability of links, which points to the impossibility of passive coexistence anymore. The research comes to the conclusion that conventional filtering is not sufficient. Mitigation has to shift to active cognitive agility, which advises high-rejection cavity filters (e.g., greater than 60 dB rejection), deployment of Dynamic Exclusion Zones and adoption of AI-based spectrum awareness systems to protect national space infrastructure.

Keywords TT&C · RF Interference · 5G Networks · S-band · Ground Station

Abbreviation	Full Form
5G	Fifth-Generation
BER	Bit Error Rates
BS	Base Station
EES	Earth Exploration Satellite
EMI	Electromagnetic Interference
FSS	Fixed Satellite Services
GEO	Geostationary Earth Orbit
IF	Intermediate Frequency
LEO	Low Earth Orbit
LHCP	Left-Hand Circular Polarization

MCF	Mission Control Facility
MCMC	Malaysian Communication and Multimedia Commission
MOSTI	Ministry of Science, Technology and Innovation
MYSA	Malaysian Space Agency
RF	Radio Frequency
RHCP	Right-Hand Circular Polarization
SDR	Software Defined Radio
SNR	Signal-to-Noise Ratio
TT&C	Telemetry, Tracking and Command

1 Introduction

Telemetry, Tracking and Command (TT&C) satellite ground stations make up a necessary element of the earth segment of a modern satellite mission. They play a crucial role as a connection to control the spacecraft's health, orbital maintenance and proper safe data flow between Low Earth Orbit (LEO) and Geostationary Earth Orbit (GEO) constellations. Operational wise, global activities, in such areas as environmental surveillance, disaster management and safe communications, depend on robust and reliable ground networks. The space infrastructure owned by the government, headed by the Malaysian Space Agency (MYSA) and its primary ground station in Banting, Selangor, is important in Malaysia to maintain national sovereignty and to facilitate different space segment uses in line with the National Space Policy 2030. The safety of the operation of the critical facilities is also at risk in this New Space period because there is congestion of the radio frequency (RF) spectrum. The greatest issue in the contemporary wireless services across the world is the fast, dense deployment of Fifth-Generation (5G) cellular networks. These networks will work with similar C-Band frequencies (3400 MHz-4200MHz) as the traditional Fixed Satellite Services (FSS). According to Al-Jumaily et al. [1] and Lagunas et al. [2], this coexistence causes a serious adjacent channel interference and even receiver saturation in the case of high-power 5G base station (BS) out-of-band emissions and locality [3]. Tropical climate and dense population of peninsular Malaysia provide special problems to the modeling of interference because of localized losses of clutter.

The study will secure the strategic space resources of Malaysia by defining the environment of interference around and devising countermeasures that can be used to help counteract the interference of the next-generation TT&C ground stations. This research addresses these challenges by characterizing the surrounding electromagnetic environment through a 360° azimuth frequency scan and developing a rigorous mathematical framework to evaluate link reliability. The numerical link budget degradation data including delta Signal-to-Noise Ratio (Δ SNR) and Bit Error Rate (BER) for link reliability assessment under interference is demonstrate throughout the research. The overall objectives are to simulate aggregate interference of the nearby terrestrial emitters (e.g., 5G base station), assess its effect on the TT&C link budget margins and propose alternative filtering approaches other than the application of geographical exclusion zones to guarantee effective satellite command and control.

2 Satellite Ground System Overview

2.1 Ground Station System Overview and Configuration

Malaysian Space Agency (MYSA), under the Ministry of Science, Technology and Innovation (MOSTI), has operated its S+X band antenna system, located within the Space Technology Complex in Banting, Selangor, since 2016. This system supports various space missions and research initiatives by easily reliable data transfer between satellites and ground stations [4], [5]. Notably, integrating S+X band antenna technology boosts communication capabilities to promote overall efficiency and effectiveness of space operations, providing the rapid and accurate sharing of critical information.

The antenna system is equipped with S and X band frequencies for primary TT&C operations and for receiving Earth Exploration Satellite (EES) payload data, which can receive several satellite mission RF signals, including Seaview-1, PakTES 1A, Aqua and Terra. Fig. 1 depicts the system block diagram for the downlink chain utilising Software Defined Radio (SDR) baseband equipment.

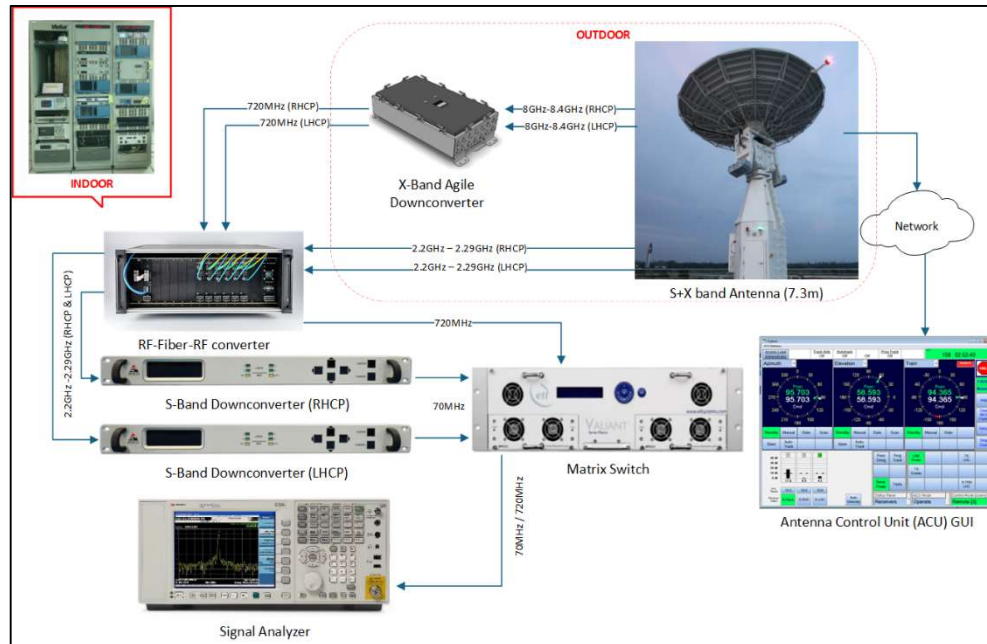


Fig. 1. MYSA's ground station system block diagram (Downlink)

The Radio Frequency (RF) chain forms an essential link, the front-end antenna system is located outdoors and the backend equipment is installed in a controlled environment inside the Mission Control Facility (MCF). This connection is crucial in allowing communication and data to be sent down to the tarmac for all types of missions [6]. At the same time, the downlink and uplink RF signals are each down-converted to an Intermediate Frequency (IF) level of 720 MHz (X-band) and 70 MHz (S-band) at two separate channels, each channel using either Right-Hand Circular Polarisation (RHCP) or Left-Hand Circular Polarisation (LHCP).

However, the system architecture design is particularly customizable, configured to perform several different space missions simultaneously. The highly dynamic configuration allows the flexible channelization required to fill multiple mission profiles [7]. To this end, this flexibility within the system gives the system the ability to reconfigure the channels automatically and in real-time, thus it becomes more receptive to mission-specific demands.

In addition, the signal chain can also be handled using a matrix switch, which is able to direct signals to different chains. This type of functionality is crucial in managing the complexity of various streams of data and its easy integration through the many channels to enable effective post-processing and data distribution. Besides delivering operational efficiency, matrix switch assists in making sure that data with high fidelity can be forwarded to the appropriate stakeholders in order to make the best-in-class decisions and operational preparedness.

Table 1. Ground station antenna system specification

Characteristic	Specification
Reflector diameter	7.30 m
Pedestal axis type	Azimuth / Elevation / Train
Azimuth travel range	$\pm 360^\circ$
Elevation travel range	$0^\circ - 180^\circ$
Train travel range	$\pm 180^\circ$
Angular velocity	Azimuth $20^\circ/\text{s}$, Elevation $20^\circ/\text{s}$, Train $6^\circ/\text{s}$
Feed configuration S-band receive (TT&C); S-band transmit (TT&C); and X-band receive (EES)	2200 to 2290 MHz (Prime Focus feed) 2025 to 2110 MHz (Prime Focus feed) 8025 to 8400 MHz (Cassegrain feed)
Receive data channel G/T at 5° elevation, 23°C , $7.5 \text{ gm}/\text{m}^3$, under clear sky in the absence of outside interference S-band (2200 MHz) X-band (8000 MHz)	18.5 dB/K 31.5 dB/K
Tracking mode	Auto Track Program Track Manual Track

The combination of a highly specialised RF chain architecture with highly dynamic RF capabilities is key to enabling flexibility for multi-mission operations [8]. This system is important in ensuring communication and data management are remarkably effective and efficient in space mission operations due to its potential to flexibly guide signals and effectively handle data [9]. Table 1 is a summary of the ground station antenna system specification under operation at MYSA.

3 Methodology: Interference Frequency Scanning at MYSA's Ground Station

To characterise the radio environment surrounding the ground station antenna, the

interference frequency scanning process is carried out to characterise the RHCP and LHCP radio environment. The antenna is set at an elevation of 0° , which allows it to possibly sweep the full 360° azimuth in order to get spatial variations of possible sources of interference on the horizontal plane. Having a controlled slew rate of $2^\circ/\text{sec}$, the scan provides sufficient temporal resolution to see narrowband and broadband emissions. The measurements are applied according to Table 2 which includes some frequency points of the S-band (2200, 2250 and 2290 MHz) and includes both low and high frequency bands of operation that are attractive in TT&C. Having the RHCP and LHCP information, both using SDR as a spectrum analyser, the technique allows polarization dependent interference profiling, needed to determine the effects of cross-polar leakage, satellite downlink sensitivity and terrestrial emitter influence. The resultant frequency azimuth maps can enable predictive modelling of interference, enhance the link-budgets analysis and inform mitigation strategies which can include adaptive filtering, null-steering and the optimal location of antenna.

Table 2. Interference Frequency Scanning Modelling Methodology

a. Elevation angle	:	0°		
b. Azimuth angle	:	0° – 360°		
c. Antenna Slew Rate	:	2°/s		
d. Resolution bandwidth (RBW)	:	100kHz		
e. Video bandwidth (VBW)	:	10kHz		
f. Detector	:	Peak Detection		
g. Baseline noise floor measured	:	105 dBm		
Polarization	Downlink Frequency S-Band (2200 – 2290 MHz)			
	Low	Medium	High	
Right Hand Circular Polarization (RHCP)	2200	2250	2290	
Left Hand Circular Polarization (LHCP)				

3.1 Link Performance Assessment

The performance of the interfered ground station is determined by several parameters involving ΔSNR and BER which describe as follows:

The presence of terrestrial interference degrades the carrier-to-noise plus interference density ratio ($C/N_0 + I_0$), which directly impacts the achieved Energy per Bit to Noise Power spectral density ratio (E_b/N_0) [10]. The numerical degradation in Signal to Noise Ratio (ΔSNR) is calculated as:

$$\Delta\text{SNR} (\text{dB}) = 10 \log_{10} \left(1 + \frac{S}{N} \right) \quad (1)$$

where:

S : interference power
 N : thermal noise power

4 Result: Empirical Interference Modeling and Quantitative Analysis

Fig. 2 and Fig. 3 demonstrate the empirical findings of the scanning campaign of the interference frequencies at the TT&C ground station of the MYSA. The data is plotted to show the relative scale of electromagnetic interference (EMI) versus azimuth angle (0° to 360°), which essentially developed the anisotropy of directionality of the surrounding radio frequency (RF) environment. The radial axis gives the comparative signal strength of the signal picked up as the interference and it could be used to compare the S-band and frequency of RHCP and LHCP.

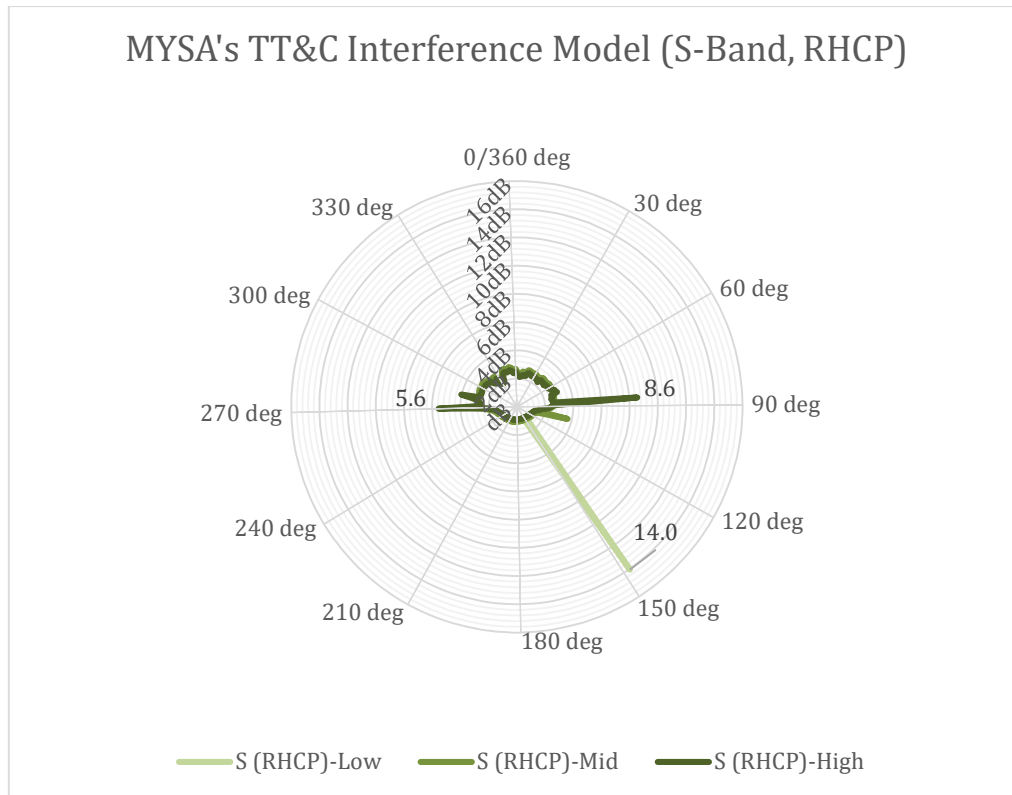


Fig.2. S-Band, RHCP Polar Plot

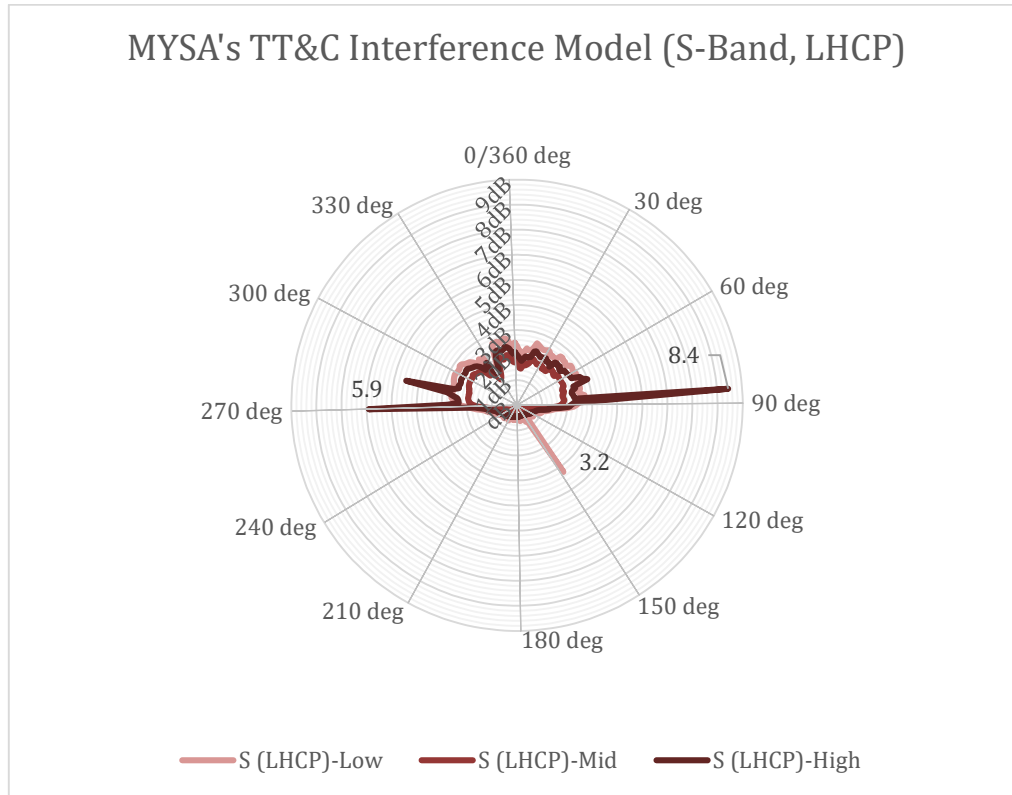


Fig. 3. S-Band, LHCP Polar Plot

4.1 S-Band (RHCP) Analysis

The interference profile of the RHCP channels is a frequency-dependent profile. The results of the RHCP polar plot in the finer details, as presented in Fig. 2, are:

- **Dominant Interference Vector (146 ° Azimuth):** A significant interference spike that appears in the S-Band Low channel (2200 MHz) only (and is indicated by the light green trace) is the most critical observation in the RHCP spectrum. This signal is harshly collimated within 155° and 160° of azimuth with the magnitude of 14.0 dB (-44.0 dBm).
- **Narrowband Characteristics:** This interference is located at the low-end of the frequency range, unlike the LHCP results. The traces of S-Band Mid (2250 MHz) and S-Band High (2290 MHz) (darker greens) are also close to the origin and are only slightly deviated. This means that the effect is narrowband, and it only affects the carrier frequency of 2200 MHz.
- **Source Probability:** Rich polarization purity (RHCP) and narrow band frequency containment also indicate that the source is probably a localized terrestrial transmitter, e.g., a localised microwave link or a radar sidelobe near the 2200 MHz threshold.

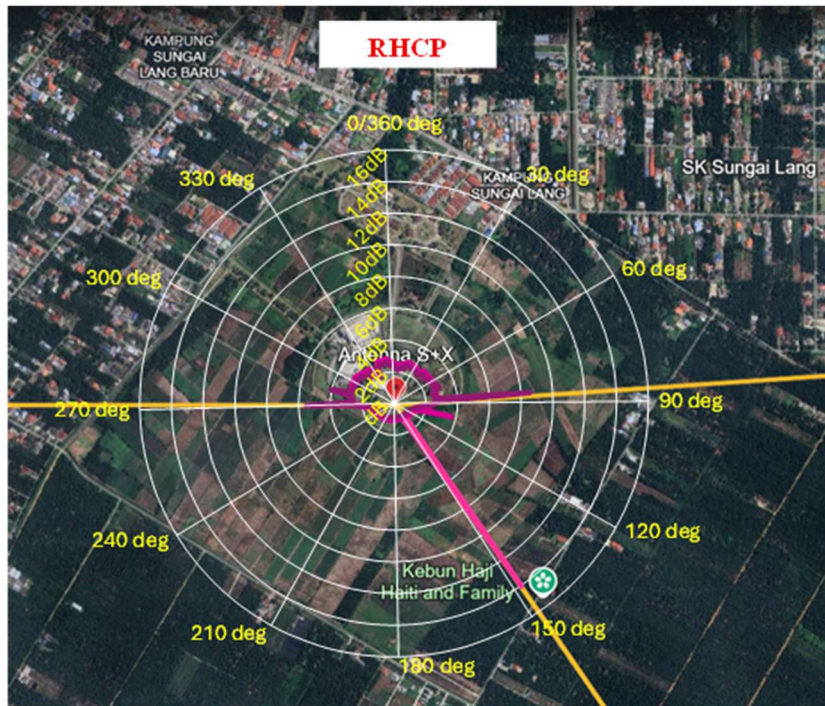
4.2 S-Band (LHCP) Analysis

The LHCP channels show unlike interference, where the interference is broadband and has a separate spatial origin. The finer results of the LHCP polar plot, Fig. 3, are as follows:

- **Dominant Interference Vector (85.2o Azimuth)):** A consistent interference pattern is observed due West, at approximately 270o azimuth with the magnitude of 8.4 dB (-38.4 dBm). Unlike the single-frequency spike in RHCP, distinct spikes are visible across all three monitored frequencies: Low 2200 MHz, Mid 2250 MHz and High 2290 MHz (represented by orange, light brown and dark brown traces).
- **Broadband Characteristics:** The presence of interference at the same azimuth across the entire 90 MHz span of the S-band indicates a broadband noise source. The signal strength is relatively consistent across Low, Mid and High channels, suggesting the emitter has a wide spectral output rather than a single carrier frequency.
- **Source Probability:** This broadband signature is suspected of pointing from an unknown sources such as from high-power industrial machinery, unshielded electronics or wideband communication systems (like Wi-Fi or spread-spectrum devices) located in the western sector of the ground station's perimeter. Based on the geographical map overlay, the potential source is pointing towards KLIA, Sepang, which is significant for communication and radar systems.

4.3 Synthesis and Operational Implications

Based on the overlaid polar plot diagram displayed on the geographical map of the TT&C ground station, as illustrated in Fig. 4 and 5 below, future investigations should focus on assessing the probability of interference sources, particularly if a nearby terrestrial 5G base station or any other unauthorized RF source is in operation.



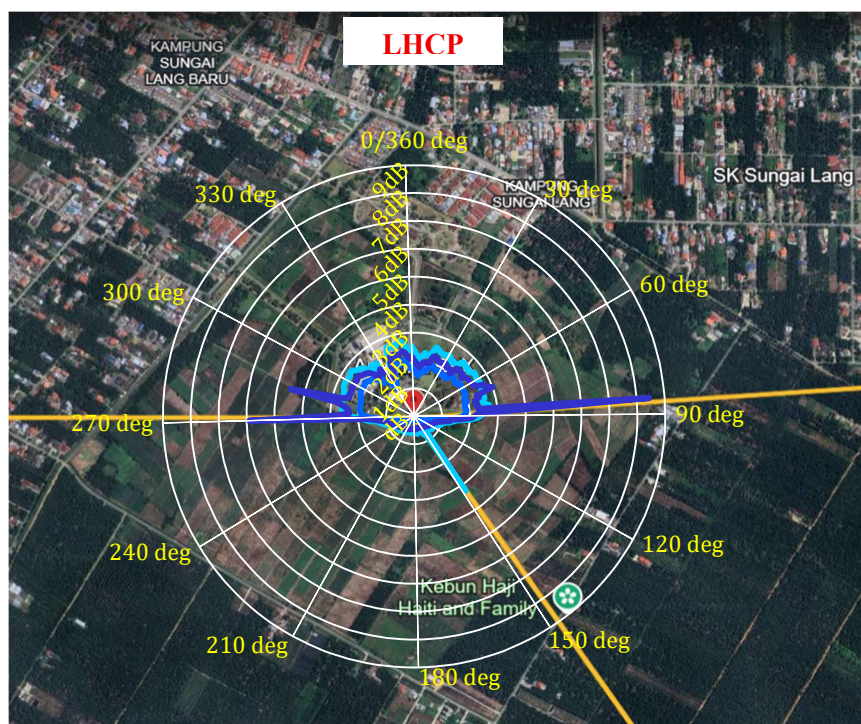
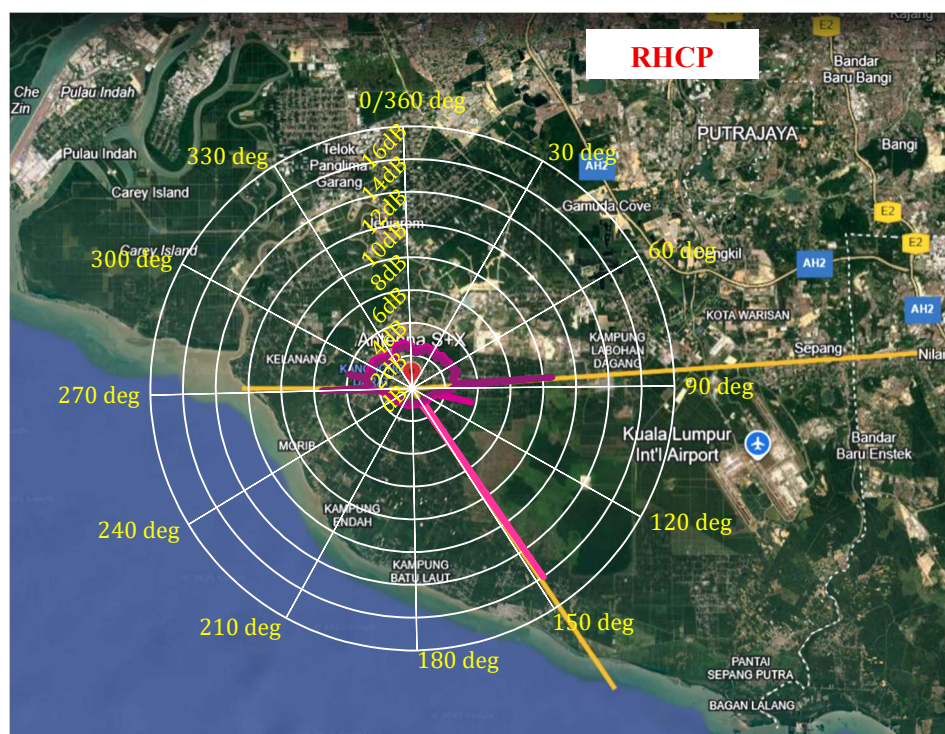


Fig.4. Overlaid Polar Plot Diagram (<1km radius) for RHCP and LHCP



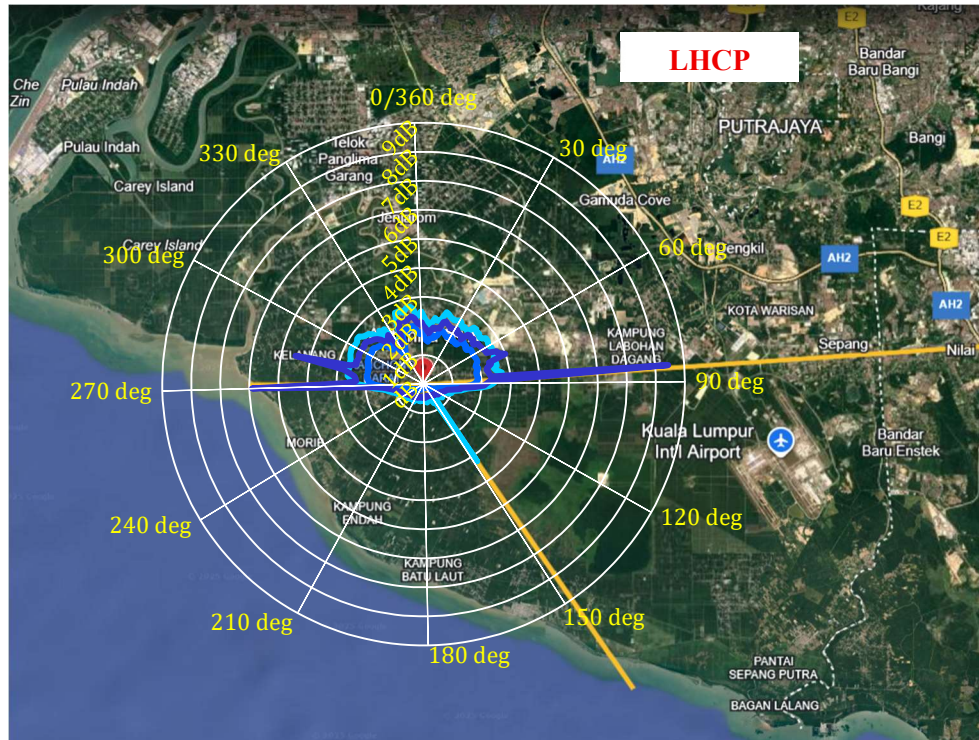


Fig. 5. Overlaid Polar Plot Diagram (>10km radius) for RHCP and LHCP

The synthesis of these distinct RHCP and LHCP datasets provides a clear roadmap for a proposed mitigation strategy for the interference surrounding the TT&C ground Station as below:

- Selective Sector Blanking:

For RHCP Operations: Critical blanking is required only in the South-East sector (155°- 160°) and specifically for operations near 2200 MHz. Increased frequency of RHCP connections is possibly not affected.

For LHCP Operations: The sector of the west (85°) is faulty throughout the S-band. Any tracked satellite that is in this azimuth is likely to experience loss of Signal to Noise Ratio (SNR) across any frequency of the downlink.

- Mitigation Strategy:

Physical Shielding: The fact that the RHCP source is directional (146°) makes it a good candidate for physical RF fencing.

Filter Installation: The RHCP interference is narrowband and a notch filter at 2200 MHz would be useful. Nonetheless, the LHCP interference (85°) is broadband, so the desired satellite signals cannot be blocked in favor of spatial avoidance or digital noise cancellation.

- Cross-Polarization Isolation:

The absence of the RHCP interference at 146° and the LHCP interference at 85.2° is an indication that the antenna system has a good cross-polarization isolation. This enables possible "frequency/polarization diversity" maneuvers between polarization modes in case the satellite is a dual-polarization downlink in order to circumvent interference sectors.

4.4 Link Performance Impact

Based on the interference modelling development as shown in section 4.1 until 4.3 above, the link performance parameters for Δ SNR and BER is determined and explained as below.

Table 3. Interference Impact on Δ SNR

Azimuth	Polarization	Interference (dBm)	Noise (dBm)	Δ SNR (dB)
146°	RHCP	-44.0	-105.0	61.0
85.2°	LHCP	-38.4	-105.0	66.6

The Δ SNR ratio calculated is 61.0 dB which show that the interference power is much more higher than the noise floor level in RHCP at 146° azimuth while in LHCP at 85.2° , the degradation result is 66.6 dB far exceeding the typical satellite link margins calculation.

Another crucial element in determining link performance is the BER. For a typical modulation technique such as Quadrature Phase Shift Keying (QPSK) used for TT&C, a BER level of 10^{-5} requires an E_b/N_0 of approximately 9.6 dB. Based on the Δ SNR calculated in Table 3 above, it is absolutely unacceptable and a very poor communication link performance, especially for the satellite pass at the particular azimuth pointing. The BER rises to nearly 0.5, indicating pure noise interference.

5 Mitigation Strategies for Next-Generation TT&C Ground Stations

In order to counter the identified confirmed interference issues, this paper outlines a set of measures that would be used to improve the performance of the next-generation TT&C ground stations in Malaysia. These mitigation measures can be categorized into two broad segments: technical solutions and regulatory policies.

5.1 Technical Solution

Technically, the Enhanced Cavity Bandpass Filters are of first priority to enhance the front-end protection. Experiments indicate that the usual waveguide filters that usually provide about 20 dB attenuation at the band edge can no longer reliably manage the power levels produced by the 5G networks. Instead, highly developed cavity filters with a rejection of more than 60 dB are suggested. They can successfully suppress powerful undesired signals prior to reaching sensitive receivers, avoiding the saturation effects as pointed out by Al-Jumaily et al. [3]. Physical shielding and site hardening are suggested in order to enhance protection. Ground stations can be enclosed by earthen berms or artificial blockers to the natural terrain of the land of Malaysia, which will cut the interference by 15-20 dB without affecting the visibility of satellites.

In addition to the hardware, adaptive and intelligent systems are needed to control real time

interference. Peng et al. [11] and Oyedare et al. [12] report that incorporating Adaptive Antenna Systems with null-steering functions will enable antennas to electronically steer signal nulls towards neighbouring 5G towers to enhance signal quality. Besides, interference detection based on AI and machine learning will be able to track the spectrum continuously, forecast the interference peaks and automatically rearrange frequencies or modulation levels. Even these systems had the capacity to predict interference during the busiest periods and plan the operations to avoid it.

5.2 Policy Enforcement by Local Authority

Policy making-wise, policy regulators (e.g., Malaysian Communication and Multimedia Commission, MCMC) in Malaysia ought to apply the Dynamic Exclusion Zones with a flexible and real-time boundary in which other terrestrial transmission operators would optimize the power of transmission to meet the satellite requirements. Together with live spectrum monitoring, such precautions greatly decrease the risk of interference.

6 Discussion

This paper has indicated a major weakness in the TT&C infrastructure in Malaysia, which has experienced an increasing vulnerability in the reliability of the operation of the satellites in the S-band owing to the congestion in frequency bands in the adjacent frequency band (e.g., 5G networks roll-out). The reported increase in the level of operational noise floor and prevalence of frequent receiver saturation incidences is directly associated with the increase in the BER in telemetry downlinks. This is not only a technical but also a strategic problem. For an 18% probability of exceedance of interference, the ground station turns unreliable, almost a fifth of its time an insignificant margin in mission-critical or emergency cases [1], [3]. The results are clear evidence that the model of the long-standing “passive coexistence” between satellites and terrestrial networks cannot be maintained in densely populated areas of Malaysia.

Analyzing the mitigation strategies, the paper demonstrates that conventional methods, including bandpass filtering, are not very effective. Even though filters have the ability to suppress unwanted emissions, they cannot recover non-linear distortion by powerful interference signals that saturate front-end amplifiers, which is also in agreement with the results of Lagunas et al. [2]. As a result, dynamic exclusion zones that are adjusted to the beamforming properties of 5G antennas become the most common but politically challenging solution. This plan allows the regulators to protect ground stations without interfering with the national digital connectivity ambitions. Moreover, the methods based on AI and machine learning, as demonstrated by Oyedare et al. [12], have a high potential for so-called “cognitive” ground stations that can forecast and respond to interference in real time.

Outside of Malaysia, these findings are also applicable to other tropical countries that are highly humid, with thick vegetation and extreme urbanization. The next-generation design of ground stations should focus more on terrain shielding and implement adaptive and software-defined designs that are sensitive to dynamic spectrum conditions. Whereas the current study concentrates on TT&C S-band sources of interference, future studies ought to consider the effects at the millimeter-wave and 6Gs through long-term, real-world measurement and joint

frameworks of spectrum sharing [11], [13], [14].

7 Conclusion

To conclude, this study presents a conclusive evaluation of interference issues that pose a threat to the next-generation TT&C activities in the Malaysian radio frequency environment. The experiment was able to measure the drastic effect of RF terrestrial network proliferation on the dependability of satellite links and found receiver saturation and aggregate noise increasing to be the key processes that lowered telemetry reception. The major results indicate that the likelihood of dangerous interference is beyond the safe operating limits of operations, especially on low-altitude flights over dense urban areas in the absence of an intervention. As a result, it is suggested that Malaysian operators of ground stations should immediately switch to using high-rejection cavity filters instead of standard waveguide filtering and work jointly with regulators to use dynamically changing, contour-based exclusion zones that consider local propagation effects.

With that in mind, the control of interference in Malaysian TT&C ground stations should transform from a non-static defence to an active cognitive agility. As ground systems, such as 6G and satellite networks, overcome the barriers to migration, ground stations of the future will need AI-based spectrum awareness solutions that can autonomously negotiate frequencies and modify the transmission in real time. Through these developed mitigation measures, Malaysia is able to safeguard its national space infrastructure in a way that its strategic quest for space capability will be robust against the unavoidable congestion of the global electromagnetic spectrum.

Conflicts of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgement

Not applicable.

Reference

1. A. Al-Jumaily *et al.*, 'Evaluation of 5G Coexistence and Interference Signals in the C-Band Satellite Earth Station', *IEEE Trans. Veh. Technol.*, vol. 71, no. 6, pp. 6189–6200, Jun. 2022, doi: 10.1109/TVT.2022.3158344.
2. E. Lagunas, C. G. Tsinos, S. K. Sharma, and S. Chatzinotas, '5G Cellular and Fixed Satellite Service Spectrum Coexistence in C-Band', *IEEE Access*, vol. 8, pp. 72078–72094, 2020, doi: 10.1109/ACCESS.2020.2985012.
3. A. Al-Jumaily *et al.*, 'Evaluation of 5G and Fixed-Satellite Service Earth Station (FSS-ES) Downlink Interference Based on Artificial Neural Network Learning Models (ANN-LMS)', *Sensors*, vol. 23, no. 13, p. 6175, Jul. 2023, doi: 10.3390/s23136175.
4. T. J. Daim, M. Ismail, H. Salim, M. K. H. Ismail, and H. Mustapha, 'A review of S-band antenna system G/T measurement technique', in *2015 10th Asian Control Conference (ASCC)*, Kota Kinabalu, Malaysia: IEEE, May 2015, pp. 1–6. doi:

- 10.1109/ASCC.2015.7244490.
5. E. Al. Ramandeep Kaur, 'A SIW Based Leaky Wave Antenna for Aerospace Applications in X Band', *Int. J. Recent Innov. Trends Comput. Commun.*, vol. 11, no. 10, pp. 130–134, Nov. 2023, doi: 10.17762/ijritcc.v11i10.8474.
6. S. S. Kabir, M. H. Khan, and S. I. Latif, 'A Multi-Band Circularly Polarized-Shared Aperture Antenna for Space Applications at S and X Bands', *Electronics*, vol. 12, no. 21, p. 4439, Oct. 2023, doi: 10.3390/electronics12214439.
7. P. Grislain *et al.*, 'Rethinking LEO constellations routing', *Int. J. Satell. Commun. Netw.*, p. sat.1514, Apr. 2024, doi: 10.1002/sat.1514.
8. A. Mehboob, K. J. Layton, G. Lechner, and W. G. Cowley, 'Wiener predistorter for nonlinear satellite downlinks', *Int. J. Satell. Commun. Netw.*, vol. 41, no. 4, pp. 392–405, Jul. 2023, doi: 10.1002/sat.1474.
9. G. Liao and F. Zhao, 'Dynamically Subarray-Connected Hybrid Precoding Scheme for Multiuser Millimeter-Wave Massive MIMO Systems', *Wirel. Commun. Mob. Comput.*, vol. 2021, no. 1, p. 5528522, Jan. 2021, doi: 10.1155/2021/5528522.
10. *Determination of The Interference Potential Between Earth Stations of The Fixed-Satellited Services and Stations in The Fixed Service*, Recommendation ITU-R SF.1006. [Online]. Available: https://www.itu.int/dms_pubrec/itu-r/rec/sf/R-REC-SF.1006-0-199304-I!!PDF-E.pdf
11. D. Peng, D. He, Y. Li, and Z. Wang, 'Integrating Terrestrial and Satellite Multibeam Systems Toward 6G: Techniques and Challenges for Interference Mitigation', *IEEE Wirel. Commun.*, vol. 29, no. 1, pp. 24–31, Feb. 2022, doi: 10.1109/MWC.002.00293.
12. T. Oyedare, V. K. Shah, D. J. Jakubisin, and J. H. Reed, 'Interference Suppression Using Deep Learning: Current Approaches and Open Challenges', *IEEE Access*, vol. 10, pp. 66238–66266, 2022, doi: 10.1109/ACCESS.2022.3185124.
13. C. Zhang, C. Jiang, L. Kuang, J. Jin, Y.-Z. He, and Z. Han, 'Spatial Spectrum Sharing for Satellite and Terrestrial Communication Networks', *IEEE Trans. Aerosp. Electron. Syst.*, vol. 55, pp. 1075–1089, Feb. 2019, doi: 10.1109/taes.2018.2889585.
14. S. Kang *et al.*, 'Cellular Wireless Networks in the Upper Mid-Band', *IEEE Open J. Commun. Soc.*, vol. 5, pp. 2058–2075, 2024, doi: 10.1109/OJCOMS.2024.3373368.