UiTM Amateur Satellite Ground Station: Installation and Performance

S. N. Mohamad Rahim[1], M. H. Azami[1], Z. S. Hamidi[2], S. A. Enche Ab Rahim[1], M. H. Jusoh[1]

***Abstract*— This paper describes the installation of UiTM's Ground Station. UiTM's ground station is a part of BIRDS Ground Station Networks, established to support BIRDS-2 nanosatellite's monitoring. The ground station has been installed with two (2) Yagi antennas which operate in Amateur bands respectively at very-high-frequency (VHF) at 144 MHz - 148 MHz ranges and ultra-high-frequency (UHF) at 430 MHz - 438 MHz ranges. Additionally, a KX-137 antenna, which functions as the APT receiving system also has been installed. As a precaution, a Radio Frequency Interference (RFI) testing was conducted at the perimeter of the ground station to identify the interference sources available within the range of 1 – 2000 MHz. The installation completed and tested with several satellites to ensure the functionality of the station system (amateur radio frequency satellite for Yagi antenna and NOAA satellite for KX-137 antenna). As a result, the hardware and software the ground station system are confirmed to be working as expected with the successful reception of satellite signal from NOAA, UiTMSAT-1 and other satellites.**

Index Terms—Ground station, radio frequency scanning, hardware, software

I. Introduction

Satellite communication connects people to the unreachable matter in space or far away location. The satellite communication system consists of three segments which are the space segment, the ground/control segment, and user segment. Space segment refers to the satellite or the spacecraft while the user segment includes the people who utilize the data received from satellite/spacecraft. The ground/control segment is primarily a satellite ground station [1]. It plays an important part in each of the developed and launched satellite. The satellite ground station main contribution is in tracking and monitoring the satellite. It also functions as the receiver for satellite's beacon and mission data via downlink, besides transmitting command to the satellite via uplink [2][3][4]. Each operator of the ground station is required to confirm/check the status of the launched satellite and to plan the satellite's mission, especially, after the launching or the deployment to ensure the satellite is operating and alive.

BIRDS-2 CubeSats project is the 2nd Joint Global Multi-Nations Birds CubeSat Project which is a multinational involvement in the satellite development education program. UiTMSAT-1 is the first nanosatellite by Malaysian University launched into space. UiTMSAT-1, MAYA-1, and BHUTAN-1; were developed by students from Japan, Malaysia, Bhutan, and the Philippines at Kyushu Institute of Technology (Kyutech), Japan [5]. The CubeSats were successfully deployed into low Earth orbit (LEO) at an altitude of approximately 400 km on August 10th, 2018 [6]. UiTM Shah Alam started the installation of satellite ground station in September 2017 in compliance with the BIRDS-2 project. As one of the members of BIRDS ground station network [7], UiTM ground station has been monitoring and tracking the BIRDS-2 CubeSats since the first broadcast of the beacon.

One of the main operations for the ground station operator is to decode the continuous wave (CW) Morse code beacon which contains the CubeSat's general housekeeping data. The downlink frequency of the BIRDS-2 CubeSats is centered at 437.375 MHz which is in the range of ultra-high-frequency (UHF) of the amateur radio band. The UHF is a radio frequency spectrum in the range of 300 – 3000 MHz as specified by International Telecommunication Union (ITU). Radio frequencies in the range of 420 MHz to 450 MHz are one of the specified UHF amateur radio bands according to the ITU's Radio Regulation (RR). Likewise, radio frequencies ranging between 144 MHz to 148 MHz are included in one of the very-high-frequency (VHF) amateur radio bands. To add, both VHF and UHF amateur radio frequency bands are used in the UiTMSAT-1's design and many other satellites.

Pertaining to the ground station development at UiTM (Malaysia) for UiTMSAT-1, several university/academic institutions of other countries also have been contributing to the development of satellite ground station. Mainly for educational learning purposes, for example, the development of the ground station at the Department of Space Science (IRV), Luleå University of Technology, Sweden at the year 2007 [8], where it is operated at VHF and UHF amateur radio frequency. Another example of the student ground station development can be seen from the neighboring country, Indonesia [9] in which their ground station system uses Yagi antenna for satellite tracking and focusing more on the satellites that orbit on LEO

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altitude. Overall, their works improved the possibility for the student to learn about satellite operation within an academic environment. Similarly, in this work of UiTM's ground station, the aims are to establish a qualified amateur radio satellite ground station and to identify the unwanted signal that surrounds within the ground station's perimeter and the ground station's communication frequency ranges.

II. Methodology

A. Radio Frequency Interference (RFI) Scanning Setup

In order to make sure the performance of the signal received at the UiTM's ground station, the RFI testing has been done. RFI refers to radio frequency interference that occurs in the wireless environment [10][11]. Interference is any signal received which different than the anticipated. Source of RFI includes various electronic devices and object from household appliances, mobile phone operation, and factory machinery [12]. RFI can be categorized into two types which are narrowband and broadband. Narrowband RFI includes digital devices such as mobile phone while broadband RFI is unintentional radiation such as from power transmission lines. For a ground station to communicate with a satellite, it is important to identify the signal interference level at the perimeter of the station. RFI measurement testing conducted at the UiTM ground station perimeter which located at level 21, Menara 2, Faculty of Electrical Engineering, UiTM Shah Alam, Selangor, Malaysia. The ground station is standing at the height of 71-meter from ground level.

The instrument used in the measurement test includes R&S®FSH handheld spectrum analyzer (lightweight and portable[13]) and a multiband discone antenna as shown in Fig. 1. The spectrum analyzer will display the chosen frequency versus amplitude of the RF signals. The purpose of the conducted test is to monitor the level of the signal emitted from various sources and applications around the ground station perimeter. Additionally, another objective of the testing is to identify the RFI sources of a specific frequency radio region. The spectrum analyzer continuously scanned the perimeter with the free-run trigger mode on in order to check the signal's frequency range and its amplitude. The whole testing was executed for 7 times in daytime and nighttime. Each test scanned the frequency from 1 MHz to 2000 MHz and it took approximately 1.5 hours to complete. The testing also includes the condition when satellite passing over UiTM ground station especially in the range of UHF amateur radio frequency. A total of 14 data were collected and tabulated for further analysis.

Fig. 1. The instruments used for the RFI scanning: Spectrum analyzer (left-hand-side); Multiband discone antenna (right-hand-side).

The setup for the testing as follows:

1) Specify a location for setting up the testing's instruments
2) Prepare the range of frequency to scan (make into a table with 3 values to be inputted)
3) Connect the multiband antenna to the spectrum analyzer
4) Take note the date, day, time of testing
5) Turn on the spectrum analyzer and take the measurement of peak value 3 times per each frequency range
6) Key in the data collected into the table and plot it

B. UiTM Ground Station Installation Setup

UiTM ground station is located at the level 21, Menara 2, Faculty of Electrical Engineering, UiTM Shah Alam at the latitude of 3.07306° and longitude of 101.49742°. This coordinate (location) fall into the boundary Regions 3 of ITU regions as specified in RR 5.3 to RR 5.9 (RR: radio regulation)[14]. In addition to ITU which manages the spectrum allocation worldwide, some locations or countries have special regulation in addition to the internationally defined. For example, in Malaysia, the spectrum allocation is coordinated by the Malaysian Communications and Multimedia Commission (MCMC).

Established in 1998, MCMC serves to regulate the communications and multimedia industries in Malaysia. Therefore, for UiTM ground station to be operated, a specific license is required. Designated satellite operator must obtain a license from MCMC according to the desired frequency range. UiTM ground station employs amateur radio frequency for operation. There are two license categories in operating amateur radio frequency which are Class A and Class B[15]. Class A has more privilege for using varies amateur frequency band and has a different limit of power level (25, 50, and 400-Watts PEP) compared to Class B. While in Class B, MCMC specified the maximum power level to be 50 Watts PEP at the allowed amateur frequency bands. Based on the installation requirement and specification, UiTM satellite ground station falls under the Class B license privilege.

1) Block Diagram of UiTM's Ground station

Block diagram of UiTM's ground station as shown in Fig. 2 consists of 'Rooftop' and 'Ctrl room' parts. 'Ctrl room' installation includes the equipment required for controlling and data management inside the control room. This control room located directly under the rooftop for ease of maintenance. VHF, UHF, and APT antennas, rotator, and CCTV which were installed at the rooftop of level 21. In general, there are two computers dedicated to separate tasks. One computer stationed for VHF/UHF satellite monitoring and the other computer works for APT satellite receiving data. Rotator from the rooftop can be controlled from the control room manually but also automatically with a GS-232B device. This device is a USB-PC interface for rotator's control (connected to the VHF/UHF computer)

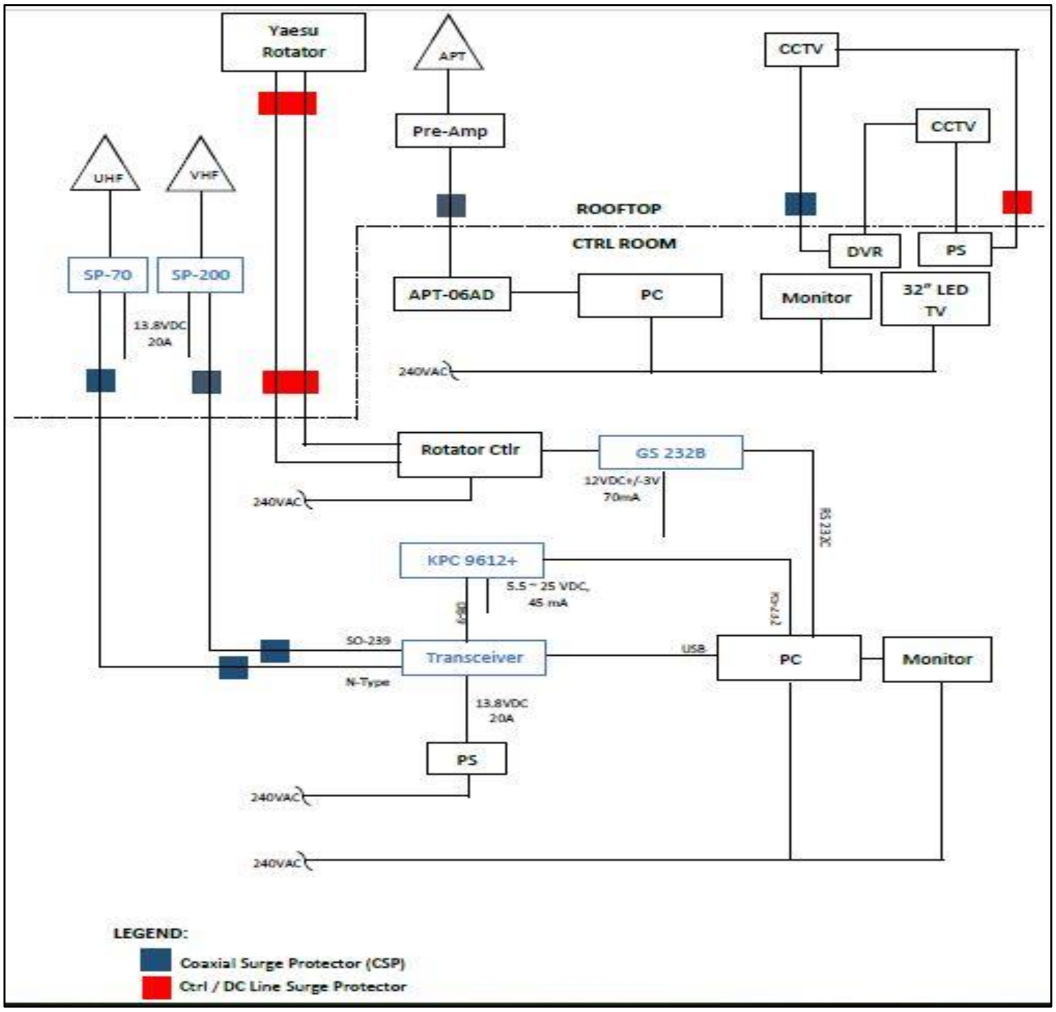


Fig. 2. Block diagram of UiTM's ground station

2) Hardware and software used at UiTM's Ground station

There are a few of hardware and software used in this project as follow:

1) Antenna

Fig. 3 (left-hand-side) shows the installed Yagi antennas on the rooftop. The VHF antenna; model 2MCP22 has a frequency range of 144 MHz to 148 MHz, and the UHF antenna; model 436CP42UG has a frequency range of 430 MHz to 438 MHz. These antennas are circularly polarized with a gain of 14.39 dBic and 18.9 dBic respectively. The antenna tower that holds both antennas is set at 3.5-meter height. Added with the height of antenna's rotator (20 cm), the whole installation conforms safe operation during satellite tracking condition. Table I shows the specification of the UHF and VHF Yagi antenna. In addition to Yagi antennas, an APT antenna also installed on the rooftop as shown in Fig. 4. The APT antenna, KX-137 is a turnstile VHF antenna for polar-orbiting weather satellites. This antenna has a wide-angle reception with its omnidirectional and horizontally mounted cross-dipoles. This design provides reception for the circularly polarized signal. It operates in the 137 MHz bands and can receive the signal from several NOAA (National Oceanic and Atmospheric Administration) satellites such as NOAA 15, NOAA 18, and NOAA 19.

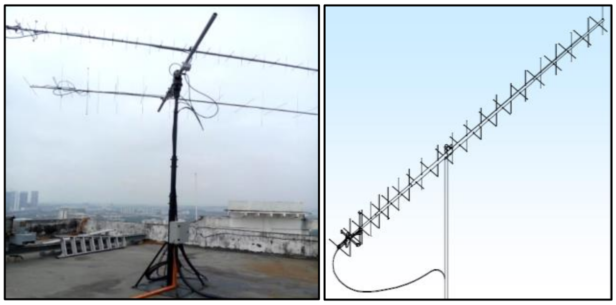


Fig. 3. Left-hand-side: The installed Yagi antennas on top of the antenna tower; Right-hand-side: An illustration of UHF Yagi M2

Fig. 4. KX-137 APT antenna

TABLE I
SPECIFICATION OF UHF AND VHF YAGI M2 ANTENNAS

Antenna type	UHF Yagi antenna	VHF Yagi antenna
Boom length	5.75 meter	5.67 meter
Feed type	Folded dipole	Folded dipole
Power	1000 W	1500 W
Director element	36 pieces – varies in length from 0.27-meter to 0.31-meter	16 pieces – varies in length from 0.88-meter to 0.96-meter
Driven element	4 pieces – 0.30-meter	4 pieces – 1.00-meter
Reflector element	2 pieces – 0.34-meter	2 pieces – 1.02-meter

2) Rotator

VHF/UHF Yagi antennas installed fall under the directional antenna category. This antenna category requires an antenna's rotator to point to the right azimuth and elevation as per satellite's movement. The rotator installed for this ground station is Yaesu G-5500 which consist of a unit of azimuth rotator and a unit of elevation rotator unit. The azimuth rotator unit is mounted together with the elevation rotator unit at the top of the antenna tower. The rotator with its height of 0.2-meter as shown in Fig. 5 was installed on top of 3.5-meter's antenna tower and two 1.5-meter's FGCB60 fiberglass booms adjusted at its left and right handler. The fiberglass booms hold both VHF and UHF Yagi antennas securely during rotation for satellite monitoring. Table II shows the specification of the installed rotator for the ground station. During installation and verification of the device, the rotator is calibrated and configured to always point to True North as a default position. With the addition of the rotator, the communication between satellite and ground station becomes better as it helps in moving the antenna as per tracked satellite's passing.

Fig. 5. Left-hand-side: Rotator units and controller; Right-hand-side: The installed rotator units with the fiberglass booms

TABLE II
SPECIFICATION OF YAESU G-5500 ROTATOR

Voltage	Requirement	110 – 120 VAC / 200 – 240 VAC
	Motor	24 VAC
Duration	Rotation time (@ 60 Hz)	Elevation (180°) ~ 67 seconds Azimuth (360°) ~ 58 seconds
	Continuous operation time (max)	5 minutes
Torque	Rotation	Elevation: 14 kg-m Azimuth: 6 kg-m
	Braking	Elevation: 40 kg-m Azimuth: 40 kg-m
Tolerance	Vertical load	200 kg
	Pointing accuracy	~ 4 %
Sizing	Mast diameter	38 – 63 mm
	Boom diameter	32 – 43 mm
	Rotator's weight	9 kg
	Controller's weight	3 kg

3) Terminal node controller (TNC)

TNC is a device used in participating AX.25 packet radio network by the amateur radio operator. TNC consist of microcontroller unit, a modem modulated a 1200 baud AFSK signal, EPROM, and software that implemented the AX.25 protocol. The TNC is connected to the radio transceiver and it is important in ensuring that the received signal can be displayed to the ground station operator. The Kantronics KPC-9612+ as in Fig. 6 is the TNC installed at the UiTM's ground station.

Fig. 6. Kantronics KPC-9612+

4) Radio transceiver

This is the device used in satellite communication. UiTM has installed ICOMM 9100 radio transceiver as the communication device for the ground station. Both the uplink (transmitting) and downlink (receiving) frequencies are synchronized by using satellite tracking software (SATPC32). The radio will automatically follow the changes of frequency based on the software's setting. The RF cables from both Yagi antennas on the rooftop are connected to the back of this radio transceiver. The radio covers High Frequency (HF), VHF, and UHF range while supporting several modes of operation which includes SSB, CW, and FM. It connects to the PC (that was installed with SATPC32 software) via USB and receives the calculated Doppler-compensated frequency of the tracked satellite. Table III shows the frequency coverage and operating power specification of ICOM 9100 radio transceiver required for smooth operation.

TABLE III
FREQUENCY COVERAGE AND REQUIRED OPERATING POWER OF ICOM 9100

	Receiver	Transmitter
Frequency Covered	0.03-60 MHz, 136-174 MHz, 420-480 MHz, 1240-1320 MHz	Includes 21-21.45 MHz, 24.89-24.99 MHz, 28-29.7 MHz, 50-54 MHz, 144-148 MHz, 430-450 MHz, 1240-1300 MHz
Power	13.8 ±15% V-dc, 4.5A Max audio	13.8 ±15% V-dc, Max 20A

5) APT-06

The KX-137 antenna function to receive satellite APT (Automatic Picture Transmission) images on a daily basis. The receiving system is completed with an APT-06 as shown in Fig. 7; a receiver device which handles the received signal from NOAA satellites. It has 5 channels of the 137 MHz band which can be set to track the 137 MHz band's satellite automatically.

Fig. 7. APT-06

6) SATPC32

It is a computer software program that calculates the position of the satellite and displays its footprint on a world map. The software is linked to the GS-232B (the USB PC controller for rotator). The setup has allowed the antenna to be aligned and rotated according to the satellite azimuth and elevation. SATPC32 software allows prediction of satellite passing and remote controlling of an antenna rotator. Another helpful setting on the software is the overview of satellite's countdown which displayed the AOS/LOS (Acquisition of signal/Loss of signal) and the maximum elevation of the chosen satellite. On the other hand, a specified USB device rotator controller, GS-232B is installed and calibrated with SatPC32 software. Once a satellite is set for tracking, the SatPC32 will keep monitoring its movement and update the azimuth and elevation data. Then, the GS-232B will act as the interface to control the rotator automatically according to azimuth and elevation data.

7) CW Get

A computer programming software that decodes the satellite's CW beacon to readable text. It only requires a radio/receiver and a computer with a sound card. The translation of the CW/Morse code will then be displayed on the software. It can be copied into another document files for recording and analysis purposes. The data are used as an input for the satellite's CW beacon decoder.

8) CW skimmer

This software is created to simultaneously decode all the satellite's CW signals in the receiver's system. The CW signal received is decoded and displayed as dashes and dots. The result will be used as the input for the satellite's CW beacon decoder (for confirmation and redundancy purposes).

9) BIRDS-2 Ground Station Software

This specific software is to analyze the BIRDS-2 nanosatellite's CW beacon and collect the satellite health status/ House Keeping (HK) data. CW beacon of UiTMSAT-1 consists of satellite callsign, satellite ID and 20 characters that contain the HK data. 20 valid hex characters are required for a complete analysis to be done using the BIRDS-2 Ground Station software. An added value from this software is the availability of 'save-to-text' function which helps the process for data storing and report management.

10) WXtoImg

This is a software that is used specifically for KX-137 antenna which operates with the APT-06 device. This software processes the NOAA satellite audio signal received by APT-06 into several readable images. The supported processed images can be customized based on the user requirement via the system settings.

Generally, the installation of the satellite ground station at UiTM Shah Alam can be viewed as Fig. 8 shown. It started with the specification of own satellite for tracking which is UiTMSAT-1. The nanosatellite's communication frequency range is within the VHF and UHF amateur radio bands, which is common with many other available radio amateur satellites. Next, UiTM Shah Alam is chosen as the perimeter for building the ground station, hence RFI testing is conducted to check the level of radio frequency surrounding the perimeter. The rooftop of level 21 building at UiTM Shah Alam is selected for installation. RFI testing done shows an acceptable result, thus the installation started. Finally, after the installation completed, the station operators executed preliminary testing with other satellites within the VHF and UHF radio frequency bands in anticipation of the deployment of UiTMSAT-1.

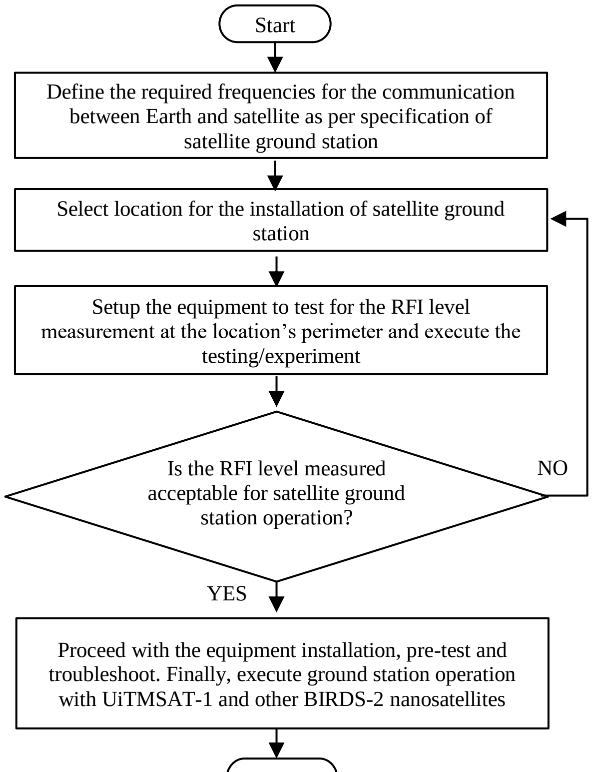


Fig. 8. Flowchart for the process

III. Result and Discussion

A. *Satellite Ground Station Operation*

The operator at the UiTM ground station shall exercise caution when dealing with hardware and software of the ground station. All the devices installed have a specific sequence of turning on and shutting down to ensure correct operation. It is due to the hardware devices and software installed are interconnected with each other. The satellite's tracking/monitoring can be performed with the correct operating sequence.

1) *Receiving satellite's signal: UiTMSAT-1 (birdmy)*

Few computer software programs have been installed for satellite monitoring and decoding purposes as shown in Fig. 8(a)-8(d). Audacity as in Fig. 8(b) is a software that can record and save the audio received during satellite passing. CW Skimmer as in Fig. 8(c) and CWGet as in Fig. 8(d) are used to read the received satellite's beacon. Above that, the correct ports of TNC and radio selected at the BIRDS-2 ground station software's setting are important to establish the connection between SATPC32 (Fig. 8(a)) software and radio transceiver during satellite tracking. Therefore, with all software correctly arranged, the UiTMSAT-1's received beacon can be decoded by the BIRDS-2 ground station software and can receive the satellite's health status for example battery condition and satellite's temperature.

SATPC32 in Fig. 8(a) shows the tracking of nanosatellite UiTMSAT-1 when it is passing over the UiTM's ground station. The small circle on the map indicates the satellite's covered ground perimeter for communication. As the satellite moves, the ground station's antenna will be rotated according to azimuth and elevation calculated by this software. The readings indicate the position of the satellite when crossing over the ground station's perimeter. For example, a higher elevation means a shorter distance between satellite and ground station compared to a low elevation reading. In B, the audio recorded is displayed continuously and also can be replayed after the satellite passing. On the other hand, in C and D displayed the ongoing process of the UiTMSAT-1's beacon that is being decoded into readable Morse code character. 'JG6YKN' is the registered callsign while 'BIRDMY' is the registered ID of UiTMSAT-1. In case if some of Morse code from C & D cannot be accepted, audio recorded from B will be checked in order to get correct housekeeping (HK) data of the satellite. The code will then be inputted to the BIRDS-2 ground station software to obtain the housekeeping (HK) data.

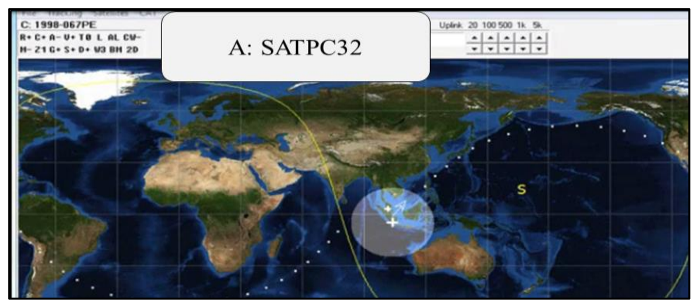


Fig. 8 (a)

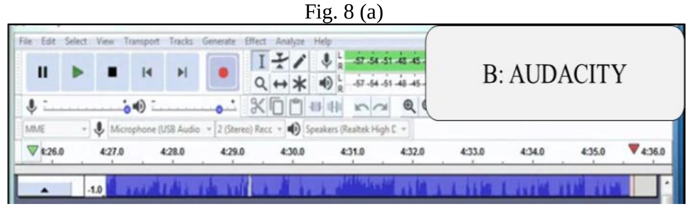


Fig. 8 (b)

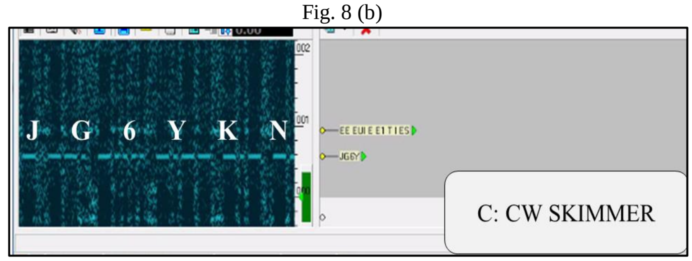


Fig. 8 (c)

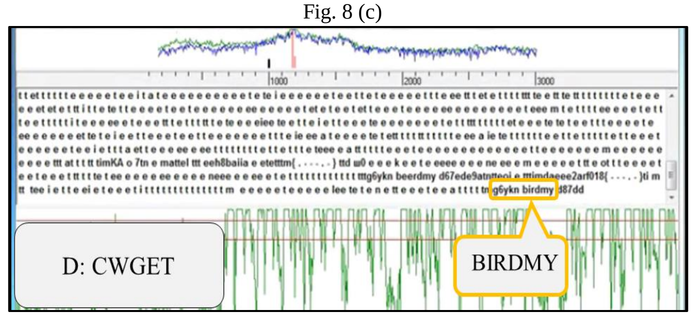


Fig. 8 (d)

Fig. 8(a) – 8(d). Software programs used in monitoring a satellite and decoding purposes

2) Receiving satellite's signal: Satellite B (UHF amateur radio frequency as downlink)

Fig. 10 shows the running state of another tracked satellite at UiTM ground station. This satellite employs UHF amateur radio frequency hence the satellite's CW beacon can be received at this station. SATPC32 software calculates the expected time of the satellite's arrival and loss of signal and informs the operator with its drop-down menu. The radio was tuned into the required frequency upon the satellite's arrival and successfully received the satellite's CW beacon. The CW beacon was then converted into readable Morse code. The Morse code will be used to analyze the satellite's health status using a specific software/decoder. This activity confirms the capability of the system at UiTM's ground station in term of software and hardware in adapting to different satellite's monitoring that may have different operating/communication frequency).

3) Receiving satellite's signal: NOAA Satellites

The APT system installed at the ground station completed by October 2017 and has started receiving data from NOAA satellites since. The system automatically receives NOAA satellite signal daily, which includes the event of Damrey's typhoon. This typhoon which occurred at Vietnam were recorded by NOAA satellites. Table IV shows part of the images that KX-137 antenna received dated from November 1st, 2017 until November 4th, 2017. The images from several NOAA satellites which traveled over UiTM ground station at the time of the event were downloaded by APT-06 device into the system. The 4 selected images distinctly show the day-by-day's event from the accumulation of the typhoon to its dispersion state

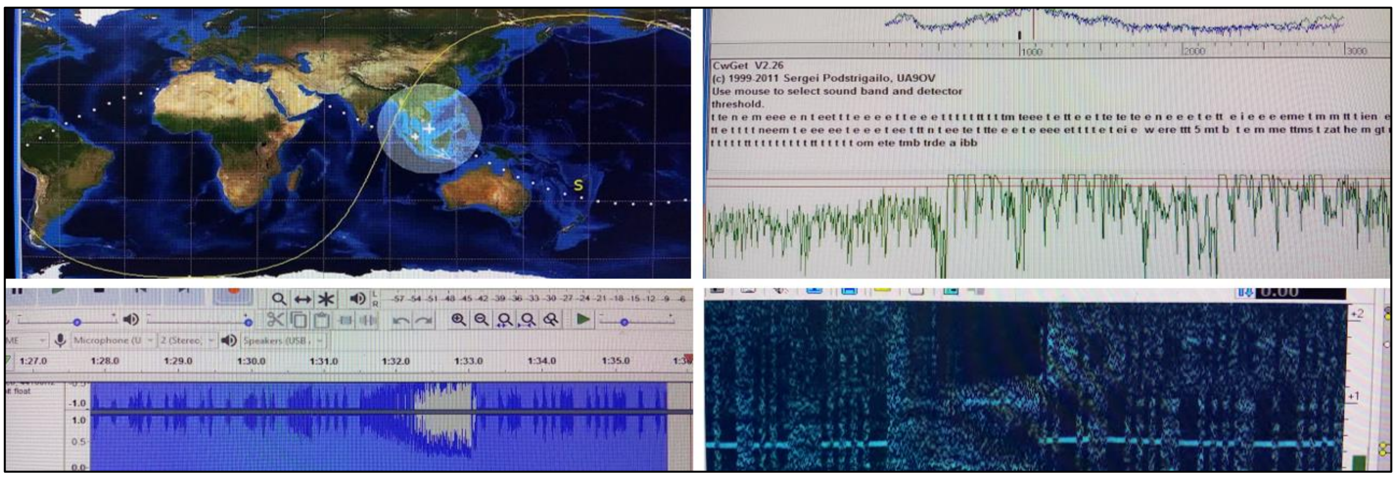
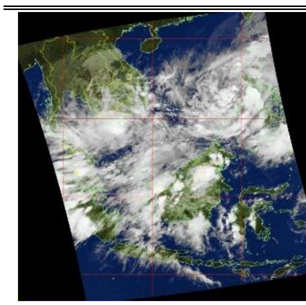
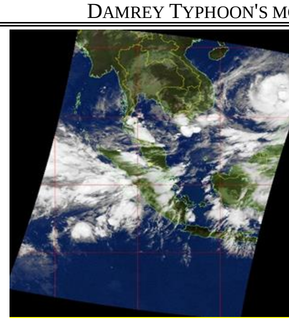
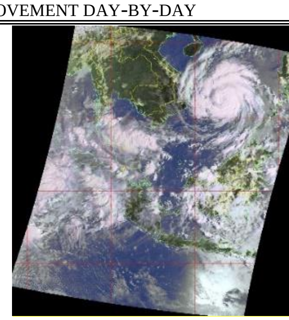
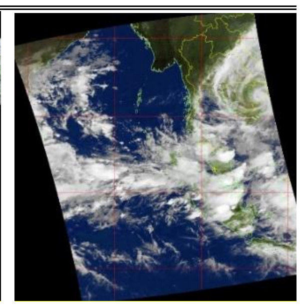


Fig. 10. CW beacon reception (Downlink) during Satellite B passing

TABLE IV
DAMREY TYPHOON'S MOVEMENT DAY-BY-DAY

			
November 1st, 2017	November 2nd, 2017	November 3rd, 2017	November 4th, 2017

B. Result of Radio Frequency Interference (RFI) Scanning

The result of the RFI scanning test collected was plotted based on the average as Fig. 11 shows. This preliminary testing of the RFI scanning shows that in the range of 1 MHz to 2000 MHz, there exist constant signal level at specific frequencies as shown in Fig. 11 such as in the 400-600 MHz and 1800-2000 MHz. These frequency ranges sources are related to broadcasting and mobile operation (GSM) such as Maxis, DIGI, and Celcom. While in Fig. 12.1, it shows that in all 7 times testing executed, at narrowed UHF range (400 – 500 MHz), the peak is determined to constantly appear at 420 MHz range. The peak always appears in daytime and nighttime, also in the no-satellite passing and with-satellite passing condition. According to the MCMC spectrum allocation plan of 2017 [16], the range of 420 MHz is mostly used for radio and mobile. Additionally, based on Fig. 12.2, in the range of narrowed VHF (100 – 200 MHz), the peak signal level is constantly at the range of 180 – 200 MHz. This peak is under the category in which MCMC specified for mobile and broadcasting. In the whole, it is shown that there is not much different observed on the level of the RFI signal for the daytime and nighttime. Additionally, the tests show that two specific range of radio bands of VHF (from 140 – 150 MHz) and UHF (from 430 - 440 MHz) are in the acceptable level.

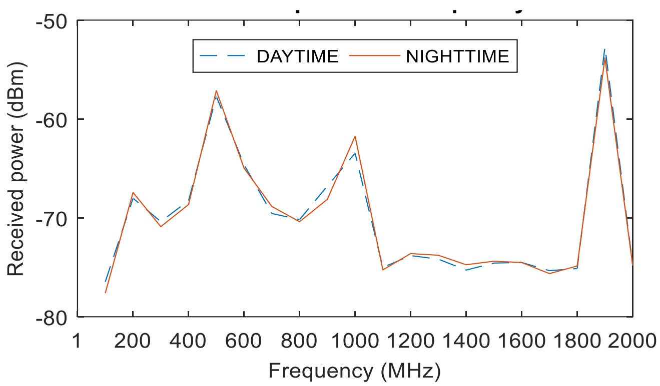


Fig. 11. Received power vs frequency scanned for the whole scanning range

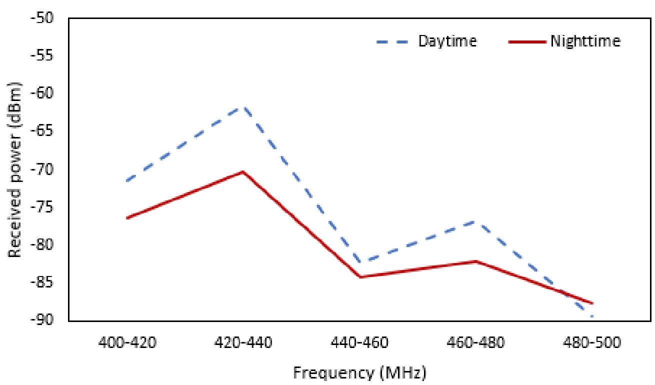


Fig. 12.1. Received power vs frequency scanned for UHF (400-500 MHz)

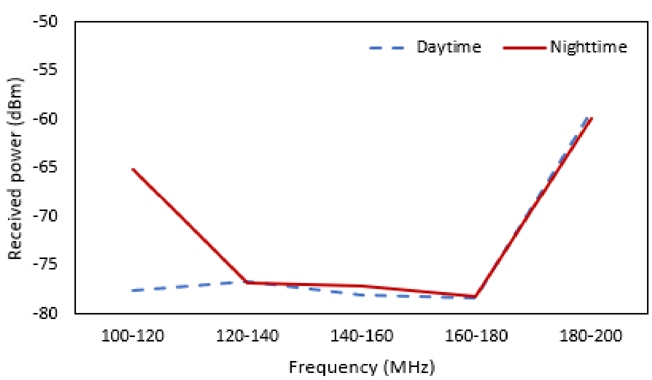


Fig. 12.2. Received power vs frequency scanned for VHF (100-200 MHz)

IV. Conclusion

In preparation for the deployment of UiTMSAT-1, UiTM has installed a satellite ground station. The purpose of this station is to monitor and communicate with UiTMSAT-1 and track other satellites that use the VHF/UHF amateur frequency ranges as the communication medium. This paper describes the satellite ground station's block diagram, installation and testing results. Additionally, the paper also presented the RFI level measurement experimented at the ground station's perimeter. Overall, the UiTM ground station performs its function as expected as the ability to receive NOAA satellite images and tracking also decoding the CW beacon from amateur radio frequency satellite includes UiTMSAT-1 and BIRDS-2 nanosatellites.

Acknowledgment

We would like to thank the Faculty of Electrical Engineering, UiTM Shah Alam for financial support on this project. We also would like to extend our appreciation to BIRDS-2 team members from the Kyushu Institute of Technology (KyuTech), and the company who have helped in the installation of UiTM's Ground Station.

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