IMPLEMENTATION OF A ROBUST GROUND-STATION FOR LOW EARTH ORBIT (LEO) SATELLITE COMMUNICATION)

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***Abstract*—The Ground station developed by ACCIMT for receiving Amateur band signals utilizes a central Terminal Node Controller (TNC) based on a Gaussian Minimum Shift Keying (GMSK) modem. The TNC is responsible for modulation and demodulation of the communication data. A commercially available actuator and a controller were used for antenna pointing. A computer interface for in-house developed hardware system which is compatible with RS-232 protocol was developed. A Graphical User Interface (GUI) software application running on a standard computer acts as the satellite's operating environment. A commercially available transceiver (ICOM 9100) was used to transmit telemetry control to the satellite and receive the satellite Continuous Wave (CW) beacon and data. In-house developed software was used for satellite tracking and antenna rotor controlling Two Line Element (TLE) file of an interesting satellite is obtained from available sources to feed into the said software. The software generates a serial data stream to the rotor controller via the protocol converter, which converts RS232 data to controller input voltages. Three open-source JavaScript (Google maps API, TLEjs and jspredict) libraries were used as Application Program Interface (APIs) to develop the said software with electron js. These APIs get the TLE as an input and output the accurate orientation data, which is then fed into the antenna rotator so that it can maintain the antenna in the direction of satellites.**

Keywords—Satellite, Ground Station; Tracking; LEO; TLE

I. INTRODUCTION

A robust and inexpensive ground station is a vital segment of any satellite mission. Small satellite missions by their very nature follow a viewpoint of a low cost and a rapid development cycle. Hence, to follow that same design philosophy, the ground station design also needs to comply with this same framework [1][3][7], with very few exceptions. For instance, ground to space communications is mostly made in "Amateur Radio" bands where the hardware requirements are not as critical as for higher frequency communication.

Nano satellites are located in a Low Earth Orbit (LEO) [6] approximately 400-600km altitude, which mean that the data transmission time to the given location is very short. Therefore, the design of the ground station for any space mission is very essential. It is responsible for tracking and communicating with the satellite to retrieve data from the payload, send commands and receive telemetry from the communication subsystem [2].

Usually, these satellites are equipped with a low-power transmitter, which has a transmitting power of less than 1W. The typical operating frequencies are Very High Frequency (VHF) and Ultra High Frequency (UHF) bands, which use standard communication protocols such as "Packet AX.25".

There is commercially available software with a good combination of features to operate a ground station. Nevertheless, some of them have compatibility issues with some operating systems. Thereby, to minimize such circumstances, in-house development of software was considered. A feasibility study was conducted by implementing UHF/VHF ground station design, which can communicate with the RAAVANA-1 Nano-Satellite (first Sri Lankan research cube satellite) that was designed and launched by Arthur C. Clarke Institute for Modern Technologies (ACCIMT).

II. GROUND STATION IMPLEMENTATION

As part of a Nanosatellite program, the ground station was required to fit within the low-cost framework [3] [14] while providing support for multiple missions. To meet this requirement, the ground station was designed to be modular so that future upgrades will have minimal effect on other systems. The ground station implementation has both off-the-shelf and in-house developed hardware and software.

The ground station is required to support communication over UHF (bidirectional) communication channels. The block diagram in Fig. 1 gives an overview of the various hardware and software components that make up the ground station. This included a Cross polarized Yagi-Uda antenna and High sensitivity transceiver for the bidirectional UHF communication with the satellite. All the antennas are mounted on rotator motors to change the antenna azimuth and elevation to allow tracking of the satellite for the entire duration of the pass.

Continuous Wave (CW) signal will be handled by commercially available Transceiver; it is connected to a Terminal Node Controller (TNC). The TNC acts as the modem, modulating and demodulating the digital data packets sent to and received from the satellite respectively. In house developed software and commercially available software applications running on the ground station computer to provide the satellite tracking information used for antenna pointing. Secondly, it calculates the degree of Doppler shift [13] and automatically adjusts the UHF radio frequency to compensate.

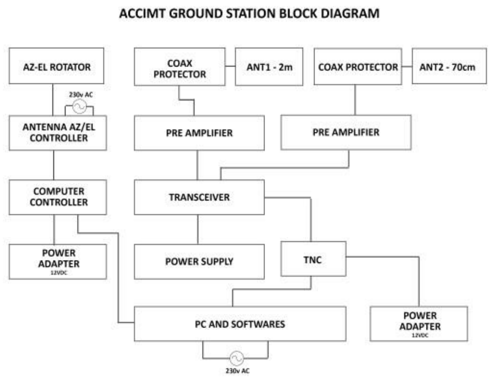

Fig. 1. Overview of the various hardware and software components that make up the ground station

II. HARDWARE OVERVIEW

A. Antenna System

The ground station uses a UHF and VHF Yagi-Uda [6] antennas as shown in Fig. 2 which were manufactured by Maspro Manufacturing. The UHF antenna is circularly polarized (with polarization switch) and has 20 elements with a gain of 13dB at the frequency band of 430MHz. The VHF antenna is circularly polarized (with polarization switch) [11] and has 12 elements with a gain of 12db at a frequency band of 144MHz.

Fig. 2. Yagi- Uda Antenna on ACCIMT premises

B. Software Defined Radio (SDR)

The SDR was used to receive data by the ground station [4][5]. It operates in the HF, VHF and UHF frequency bands (similar to a transceiver). The RTL SDR (R820T2) is a very reliable device that is commonly used by the amateurs and researchers. SDR has full flexibility to do its operation by the software using a computer.

C. Radio

The ICOM IC 9100 transceiver was used for uplink and downlink communication (CW beacon, command/ acknowledgement and Frequency Modulated (FM) modulated data). It operates in all frequency bands (HF, VHF and UHF) [12].

D. Rotor and controller

The rotator has a full Azimuth/Elevation control and it was manufactured by Yaesu and the controller was manufactured by the Kenpro (Model No.KR5600B).

The limit switches on the Azimuth/Elevation axis automatically disconnects power to the motor in the event of over travel. The potentiometers of both azimuth and elevations provide the current antenna position to the controller. Thereafter, this data is passed to the tracking software through the controller [8].

E. Computer Controller

Yaesu GS-232B is a computer controller [9] which converts the Azimuth and elevation rotor controller data to RS-232 protocol data and vice versa. The tracking operation is fully mechanical. Viewing angles are delivered to the positioner via the control port (e.g. RS-232) of the satellite tracking software [10].

F. Terminal Node Controller (TNC)

The central control point of the ground station is the Terminal Node Controller (TNC). The Hardware for the TNC is comprised of a 200MHz ARM-based Single Board Computer (SBC) manufactured by Technological Systems. It runs on an embedded Linux Operating system. It was used to demodulate the GMSK data received from the ICOM IC 9100 radio [12].

III. SOFTWARE OVERVIEW

A. Off-the-Shelf Software

The software used to track satellites from the ground station is SatPc32, Orbitron and PST rotor. SatPC32 was used to track the satellite real-time and the Orbitron was used to predict the future passing over the ground station. Both use Keplerian elements to make all of the calculations. SatPC32 calculates the Doppler Shift of receiving frequency relative to the ground station. This information is automatically transferred to the radio to make necessary adjustments. The PST rotor is used as the interface SatPC32 and the Yaesu rotor controller [15].

B. In house Developed Software

i. Decoding the TLE and extracting the essential data

A two-line element set (TLE) is a data format encoding a list of orbital elements of an Earth-orbiting object for a given point in time, the epoch. Using the File System (FS) module of the node JavaScript (JS), we were able to read the TLE and store them inside an array. The TLE array is then passed through a node JS module called the 'tle.js'. The output of the process is a JavaScript Object Notation (JSON).

The JSON array consists of all encoded data inside the TLE which are the: Satellite name, Satellite number, Classification, Designation year, Designation launch number, Designation piece of launch, Epoch year, Epoch day, Inclination, Ascension, Eccentricity, Perigee, Mean anomaly, Mean motion, Elevation, Azimuth, Range, Satellite latitude, Satellite longitude, Satellite velocity, predicated orbit coordinates respectively. The Graphical

Use Interface with all the above information and the live digital tracking of the satellite is shown in Fig. 3.

Fig. 3. GUI of tracking-ho use developed tracking software

ii. Serial communication with Antenna Rotator Controller

A two-line element set (TLE) is a data format encoding a list of orbital elements of an Earth-orbiting object for a given point in time, the epoch. Using the File System (FS) module of the node JavaScript (JS), we were able to read the TLE and store them inside an array. The TLE array is then passed through a node JS module called the 'tle.js'. The output of the process is a JavaScript Object Notation (JSON).

The decoded information from the TLE was transferred to the Antenna Rotator Controller to control the rotation mechanism based on the current position of the satellite. A separate window is available to select the serial communication [10], where the user is given the option to choose the COM ports of the Antenna Rotator Controller and their desired baud rate for the data transmission as shown in Fig. 4. Thereafter, the serial transmission will be initiated (The string which we send has a particular format which the controller can recognize and start controlling the Antenna Rotator).The JSON array consists of all encoded data inside the TLE which are the: Satellite name, Satellite number, Classification, Designation year, Designation launch number, Designation piece of launch, Epoch year, Epoch day, Inclination, Ascension, Eccentricity, Perigee, Mean anomaly, Mean motion, Elevation, Azimuth, Range, Satellite latitude, Satellite longitude, Satellite velocity, predicated orbit coordinates respectively. The Graphical Use Interface with all the above information and the live digital tracking of the satellite is shown in Fig. 3.

Fig. 4. Serial Communication Module

IV. RESULTS AND DISCUSSION

A. Antenna Performance

The characteristic impedance of the UHF antenna is shown in the Smith Chart in Error! Reference source not found.. According to the test results the measured impedance is 50.1Ω (which is the centre of the Smith Chart) and is very close to the ideal situation which is 50Ω.

Fig. 5 Smith Chart for the UHF antenna

Voltage Standing Wave Ratio (VSWR) of the UHF antenna is shown in Fig. 6. According to the test results the measured VSWR value is 1.12 (value of the VSWR at an interesting frequency, which 437MHz in the VSWR chart) and is very close to the ideal situation which is 1.

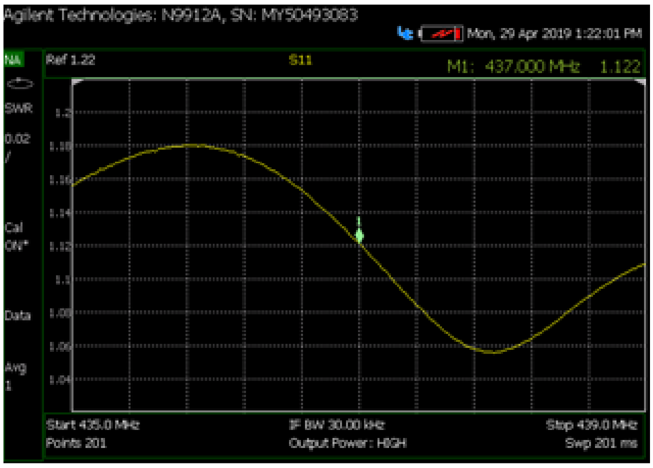

Fig. 6 Voltage Standing Wave Ratio (VSWR) Chart for the UHF antenna

B. Images

Using the above-discussed ground station, Audio Picture Transmission (APT) format images were downloaded from the National Oceanic and Atmospheric Administration (NOAA) weather satellite. The APT was then processed to obtain the images in Fig. 7 (data downloaded from NOAA-15 satellite) and Fig. 8 (data downloaded from NOAA-19 satellite).

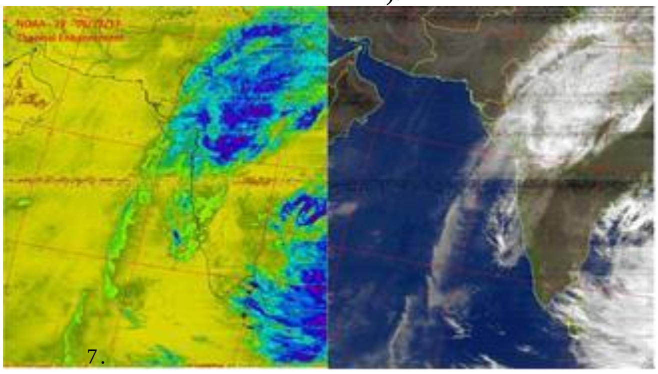

Fig. 7. NOAA weather satellite images with thermal enhancement on 05/12/201

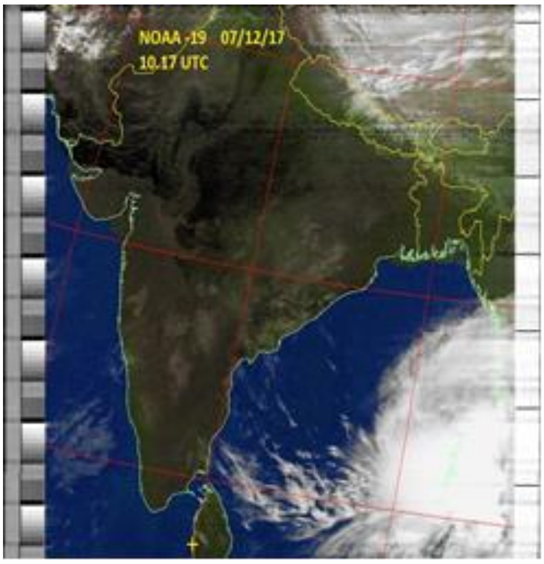

Fig. 8. NOAA weather satellite image 07/12/2017

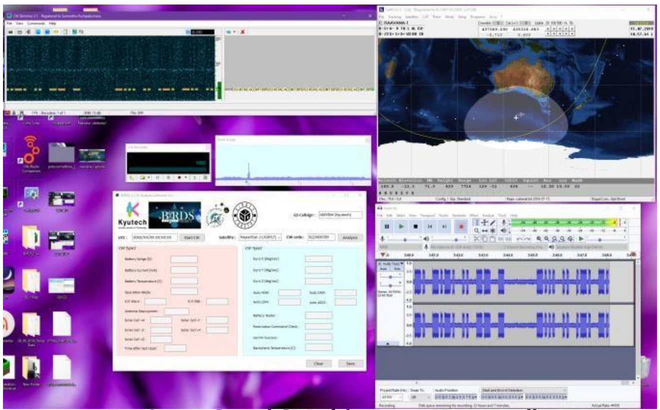

Fig. 9. Copied CW of the Raavana-1 Nano satellite

V. CONCULSION

Software and hardware used for this ground station were designed to be modular, so these ground stations can be set up all across the country to facilitate national educational and technological needs in this context. The system can be easily modified and upgraded to meet the needs of future missions. The number of satellites that can be tracked depends on the frequency bands and antenna gain. Thus far, this system is used to track and communicate with four Nano-Satellites successfully which operates in LEO (Maya-1, Butan-1, Horyu4, Uitmsat-1).

After the successful deployment of the three cube satellites of Sri Lanka, Nepal, Japan (Raavana-1, Nepalisat-1, Uguisu-1 respectively), the ground station facility was able to tele- command and receive data from them also. At the time of this paper writing, we received the CW identifications of the above three satellites deployed to the 400km orbit on 17th June 2019 using the ground station facility discussed here.

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