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# SAASST Ground Station: Satellite Tracking and Control for High Data Rates

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**Abstract**

In recent years, nanosatellites have experienced rapid development in light of the launch of hundreds of them in Low-Earth Orbit (LEO). As part of the research investigations conducted in spacecraft operations, the Sharjah Academy for Astronomy, Space Sciences, and Technology (SAASST) is currently developing Sharjah-Sat-1. The 3U X-ray Detector CubeSat is set to launch in the second quarter of 2021. A Ground Station control system is essential for communicating with Sharjah-Sat-1 to facilitate receiving telemetry and sending commands. In support of such a mission and future ones, a full-fledged ground station has been built, which can be useful for multiple satellite missions. The ground station is currently operating on UHF/VHF frequency bands with high gain. An S-band dish antenna system is planned to be installed soon to augment ground station capability to support ongoing CubeSat operations. The Ground Station's hardware is composed of several components, i.e., UHF/VHF antennas, a Software Defined Radio (SDR) transceiver, a suitable Rotator with Elevation-Azimuth dual controller, and a Rotator control interface. As for the software employed, it is mainly the Ham Radio Deluxe package that consists of a Ham Radio Deluxe (HRD) satellite tracking, HRD rotator control, and an HRD rig, along with a custom-designed ground station console software for Sharjah-Sat-1 related data and commands. With the implementation of this system, the ground station is fully automated while tracking and can also be remotely controlled. Besides its satellite tracking use, the ground station will provide practical training for university students in anticipation of future small satellite operations.
**Keywords:** Ground station; CubeSat; UHF-VHF; S-band; Ham Radio Deluxe

## 1. Introduction

The ground segment is the critical part that provides support for space missions, starting from the preparatory stages and to completion. In addition, ground stations provide the necessary communication interface with the spacecraft [1]. Accordingly, the installation work of SAASST UHF/VHF Ground Station was accomplished in February of 2020. Such ground station was a crucial step in the preparation of the launch of the first 3U+ CubeSat of SAASST, Sharjah-Sat-1, which is in collaboration with the Istanbul Technical University (ITU). It also serves to set up the infrastructure in SAASST for backing future satellite missions and be used as an essential educational tool for students.

Sharjah-Sat-1's primary payload is the improved X-Ray detector (iXRD), and its objectives are to investigate hard X-Ray emissions from the Sun's coronal holes and other bright X-ray sources in the universe. The anticipated payload data are to be transmitted via an S-Band transmitter, while a UHF/VHF transceiver would be used for downlinking telemetry and receiving operation commands [2]. This small satellite mission is planned to be launched in the first half of the year 2021. SAASST, along with its ITU partner, would both have the responsibility of operating and monitoring the satellite and supporting the uplink and downlink activities during its lifetime in orbit.

Communicating with the satellite is critical in a space mission to determine the condition of the satellite's health and facilitate the accomplishment of its mission. So, the compatibility of the Ground Station equipment in terms of the supported communication frequency bands and specification is critical to guarantee a successful mission [1]. Therefore, the ground station is expected to support communication with the satellite over UHF, VHF, and S-Band frequency bands. Currently, only UHF and VHF capabilities are present, with the plan of incorporating S-Band equipment and capabilities shortly, to support the downlink of payload data of the mission.

Any CubeSat mission depends on at least one ground station to sustain the communication with the satellite. Additionally, CubeSats typically operate in the amateur UHF-VHF bands. Alternately, the S-band amateur band may be used to transmit science data to the ground [3]. Thus, numerous universities have established their ground stations meant for similar purposes of supporting their small satellite missions' operations. For instance, UiTM (Universiti Teknologi MARA Shah Alam) in Malaysia has established a ground station operating in the UHF/VHF bands, using similar equipment, in support of the BIRDS-2 nanosatellites [4]. Another successful implementation was at the University of Toronto Institute For Aerospace Studies for an S-Band/UHF/VHF ground station for the monitoring and operation of the CanX-2 nanosatellite, that utilizes a 2.08m parabolic dish and radio for the S-Band signal and Yagi-Uda antennas and radios for the UHF and VHF signals. The antennas are mounted on a rotator for targeting capabilities [5].

This paper showcases the implementation of SAASST's UHF-VHF ground station for high-data-rate communication links from small satellites and demonstrates the hardware and software employed for this project. In Section 2, we describe the SAASST Ground Station setup. Section 3 discusses the software. In Section 4, the capacity building and student education are underlined. Section 5 gives our conclusions.

## 2. SAASST Ground Station Setup

*2.1 Block diagram:*

To ease the explanation of the Ground station setup, we are dividing it into three main segments: Front end, Signal processing, and Mission specific (Fig. 1). First, the Front end consists of the two UHF antennas, two VHF antennas, mounted on the Rotator. The Rotator is then connected through two Coaxial cables, one is connected to a Pre-amplifier and goes to the 440 MHz connector in the transceiver, and the other is directly connected to the 144 MHz connector in the transceiver as well. In addition, the transceiver is also connected to a TNC and along with the Pre-Amplifier, making up the second segment, signal processing. Moreover, the segment labeled as Mission specific is the PC that is connected to the transceiver through an RS232 cable and to the TNC through a USB cable, and at last to the Controller interface through an RS232 cable. Additionally, it is also connected to the Rotator to facilitate autonomous control of the Front end through the mission specific. The Ground Station is operating on amateur radio frequency bands as per the coordination with the International Amateur Radio Union (IARU).

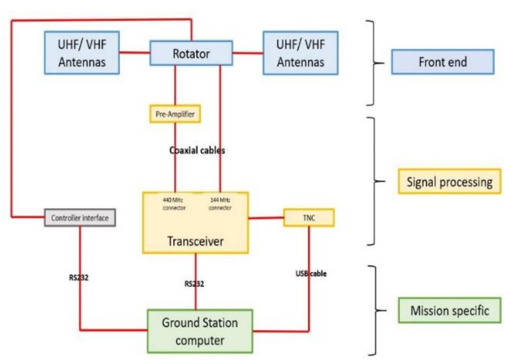


Fig. 1. The block diagram of the Ground Station setup

### *2.2 Outdoor Hardware:*

In terms of the outdoor hardware, which is represented by the Front end segment, it consists of the UHF/VHF antennas and the Rotator (Fig. 2). The UHF/VHF antennas are manufactured by M2 antenna Inc. and are assembled to create a full-duplex communication system. It will serve for satellite tracking and control purposes such as reception of payloads data from Sharjah-Sat-1 and commands the transmission to the satellite. The UHF antennas model 436CP42UG with 2x21 elements operates on amateur radio frequency bands ranging from 430 MHz to 437 MHz and a gain of 18.9 dB. Additionally, the VHF antennas model 2MCP22 with 2x11 elements, which also operates on amateur radio frequency bands ranging from 144 MHz 148 MHz and gain of 14.39 dB. Furthermore, all four antennas are connected through a mast that allows them to share the same Rotator Yaesu G-5500 that has a turning range of 180 degrees in elevation and 360 degrees in azimuth. The Rotator requires elevation and azimuth angles of the targeted satellite as an input to start operation. Finally, the Rotator is connected to the signal processing unit that is placed indoors through flexible Coaxial cables.

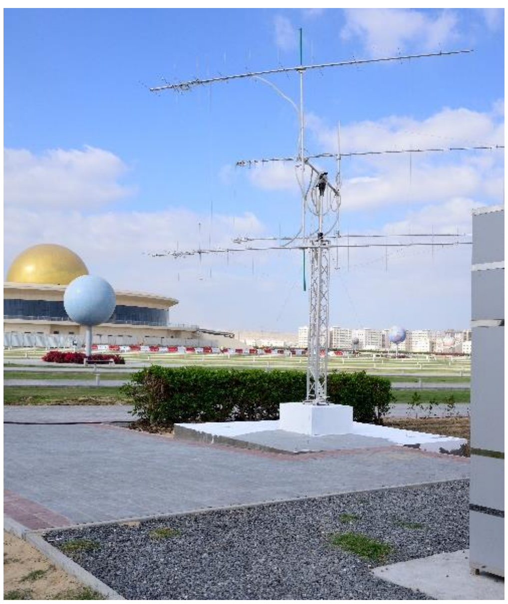

Fig. 2. Outdoor hardware of the ground station

### *2.3 Indoor Hardware:*

The indoor hardware consists of the signal processing and mission specific segments, which includes several components. Since the ground station is built to be used for the Sharjah-Sat-1 mission, the components will be tilting on this mission. First, the ICOM IC-9700 (Fig. 3) is an all-mode tri-Band transceiver with three antenna connectors 144, 430/440, and 1200 MHz. The coaxial cables of the antennas are connected through. This transceiver also allows full-duplex operations for UHF downlink, and a parabolic dish will be installed specifically for S-Band downlink as well as VHF Uplink transmissions. Moreover, the Transceiver is connected to a TNC through a USB cable, which is responsible for the AX.25 protocol processing and transferring the captured data to the mission specific PC. Finally, a controller interface (Fig. 4) is connected from the Front end segment to the mission specific in order to allow full autonomous control of the Rotator through the software as well as facilitating remote control of the ground station from inside the CubeSat Laboratory at SAASST.


Fig. 3. ICOM IC-9700 Transceiver


Fig. 4 YAESU G-5500 Elevation- Azimuth dual controller and YAESU GS-232B Rotator control interface

## 3. Software

The software segment consists of three different subsections such as Ham Radio Deluxe (HRD), SAASST Ground Station (G.S.) Console Software, and Functions of the SAASST GS software.

### *3.1 Ham Radio Deluxe (HRD):*

Ham Radio Deluxe is an integrated suite of software products for amateur radio. There are three modules used by the SAASST Ground Station, the rig control, satellite tracking, and the rotator control. These three modules can be generally used to track satellite signals in the VHF/UHF amateur frequency bands.

- **The Rig Control Display** is a generic representation of the radio's front panel. It contains most of the operating functions and controls of the actual radio it is connected to.

- **Satellite Tracking Display** enables the user to select a satellite to locate and track, with respect to the set location of the ground station.
- **Rotator Control** is the module that provides support for controlling the Rotator according to the information from the Satellite Tracking module and facilitates the tracking of the chosen satellite.

*3.2 Sharjah-Sat-1 Ground Station Console Software:*

The GS Console software was designed to provide mission control attributes such as issuing telecommands and monitoring data for the CubeSat mission Sharjah-Sat-1.

The Sharjah-Sat GS Console Software makes uses of the following software to provide the user with a practical and simple method to interact with Sharjah-Sat-1 in orbit.

- Ham Radio Deluxe: For tracking the satellite and sending the azimuth and elevation angles to the Rotator.
- AGW Packet Engine: To modulate/demodulate UHF & VHF signals and transmit them to the sound card.
- SDR#: To receive the signal to be demodulated from the radio.
- DSD: To demodulate the QPSK signal received from the S-Band Modem.
- Virtual Cable Driver: To transmit signals from one software to another.

A schematic of how this software interacts with each other can be seen in Fig. 5 block diagram.

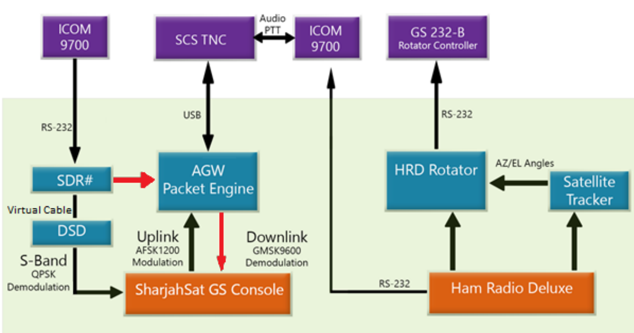

Fig. 5. Block Diagram of Ground Station Interfaces

Due to available expertise and experience, the software was developed on Windows OS, on the Visual Studio 2019 platform using the .NET framework. The programming languages were chosen as C# and XML as they are the best supported and most frequently used languages on the .NET framework.

*3.3 Functions of the SAASST GS software:*

There are three different functions in the GS software, such as Issue Telecommands, Process & Display Telemetry, and Export Telemetry & Photo.

*3.3.1 Issue Telecommands:*

All available telecommands for Sharjah-Sat-1 are implemented in the software as buttons that the user can simply push (Fig. 6). Some telecommands require additional parameters, and the user has to enter those manually. The data is then packaged into the appropriate format for Sharjah-Sat-1, modulated with the help of the AGWPE software and sound card (TNC), and sent to the radio as a PPT signal.

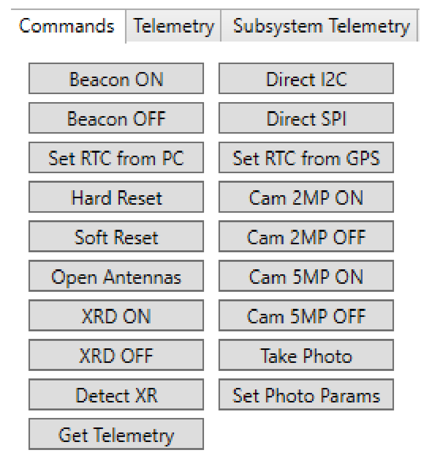

Fig. 6. Available Telecommands

*3.3.2 Process and Display Telemetry:*

Upon reception, the AGW Online Kiss software demodulates the received AX.25 frames and sends them to the Sharjah-Sat GS Console software via AGWPE. The obtained values are then displayed on the appropriate boxes.

Different telemetry packages can be requested. Fig. 7 shows the general telemetry package, which is under the Telemetry tab, and Fig. 8 shows the telemetry packages for all individual subsystems.

Additionally, system parameters can be requested and updated from the relevant tab, as shown in Fig. 9.

*3.3.2 Export Telemetry & Photo:*

The software allows for the received telemetry data to be saved on the hard drive as a Microsoft Excel or a comma-separated text file. By default, all the received data and sent commands are logged in a csv file.

The photo functionality is related to S-Band communication and is currently under development.

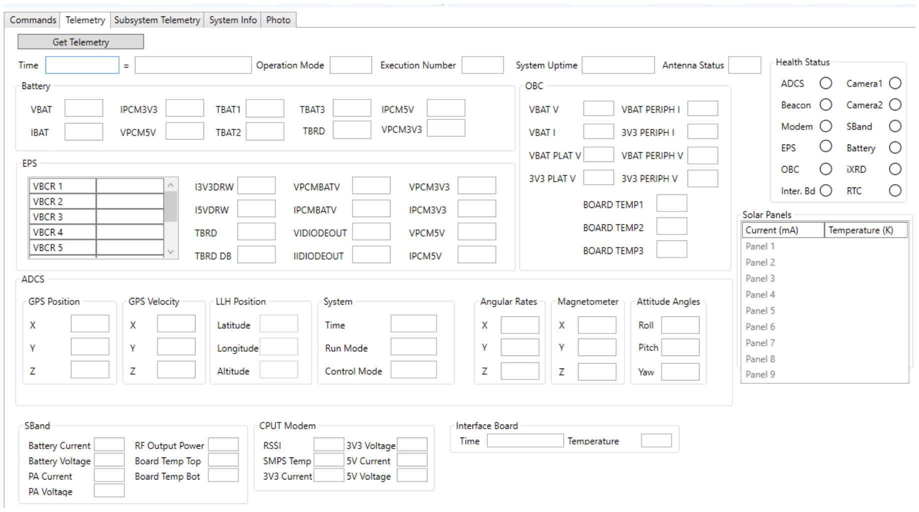


Fig. 7. General Telemetry Tab

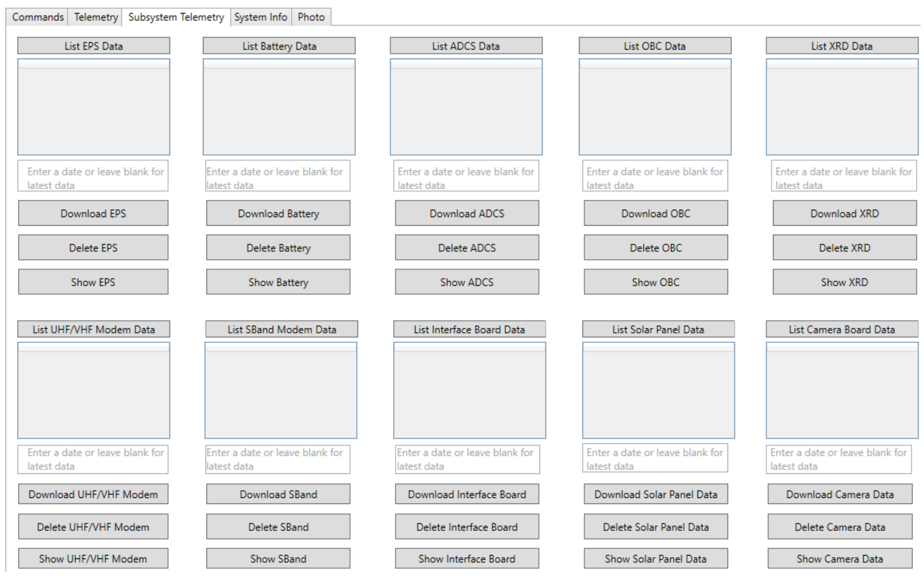


Fig. 8. Subsystem specific telemetry tab

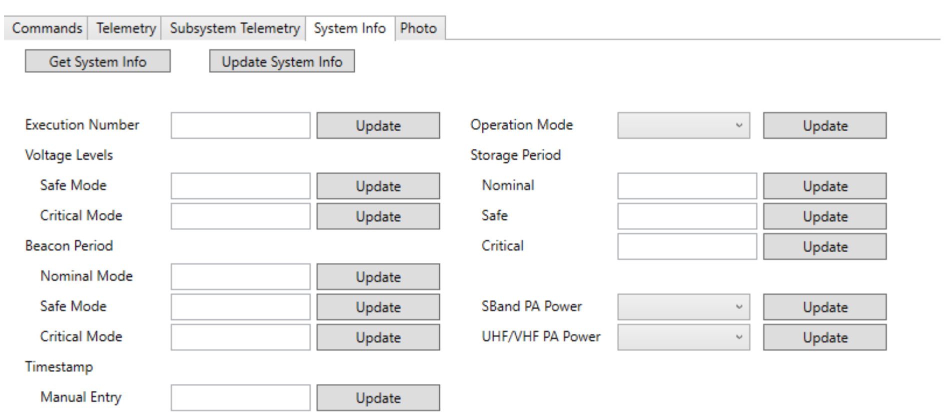


Fig. 9. System Info Tab

## 4. Capacity Building and Student Education

*4.1 University-Class space missions and their educational Challenges*

With the exponential growth of our scientific knowledge in space sciences and technology, more countries and institutes are now aiming to have their satellite in space to benefit from the various space applications that such missions can provide (educational, sciences, Earth observations, atmospheric studies, defense, and more) especially when the future of our planet depends on the missions mentioned above [6].

Smaller satellites with their low cost and fast delivery encouraged universities and young institutes to start their journeys in the space sector. These missions will support their academic work and research. Consequently, CubeSat missions have increased significantly in the last five years, and most of the missions are classified as university class missions. From 2000 until 2012, more than 100 CubeSats were launched. More missions were later launched. Up until today, more than 1000 CubeSat missions have been launched into space [7] [8].

Although the space industry is experiencing this significant growth in university-class spacecrafts, this increase is raising more concern due to the rising numbers of space junk, in addition to the high risks due to time limitations, lack of experience, and the reduced cost. This makes such missions hazardous. In fact, according to [9], university missions have a 40% failure rate. The question that should be asked is, "is it worth investing in such missions?" And to answer such a question his question, we must look at their educational benefits and outcomes.

*4.2 SAASST Ground Station capacity building*

As mentioned in our previous work [2], one of our main objectives is to have an in-orbit tool that can be used to support the educational activities at the University of Sharjah (UoS). This requires building and expanding the laboratory, which includes the high-performance workstation loaded with all the required software to design and simulate the mission in a space environment, the certified ISO 6 cleanroom to integrate and test the satellite in a controlled environment, and the ground station (VHF/UHF and S-Band) to communicate and collect the scientific data once Sharjah-Sat-1is in orbit.

SAASST ground station is located at the academy and is approximately a 5 minutes' walk from the CubeSat lab. It can also be controlled remotely. One of the main reasons behind the installation of the ground station is that it will not only support our Sharjah-Sat-1 mission, but it will also train students and young engineers in the UAE, which plays a critical role in the mission success and the following future missions.

The GS operator will be responsible for tracking and receiving the payload data along with the satellites' health status. The training is not only to have people able to operate and track the satellites but also to have the ability to differentiate between different problems and their causes to make sure the data collected is not corrupted. As the operator gains more experience, the limitations of the equipment, along with the other factors that might affect the performance, will be well understood. It is currently being used by students and researchers, who are able to check satellite passes, track the satellite as the ground station enters the footprint, and use the radio to listen to the CW or AFSK signals and later decode the signal.

The Telecommunications Regulatory Authority (TRA) officially licensed the technical team at SAASST after undergoing intensive training sessions organized by the Emirates Amateur Radio Society (EARS) to operate the ground station in the amateur frequency bands. This radio frequency spectrum is being used for training and non-commercial purposes. This will provide an excellent opportunity for cooperation with EARS and allow students to get support from the amateur radio community by participating in various amateur radio activities and events. It will encourage the youth to be part of this society as a licensed operator in the future.

## 5. Conclusions

The SAASST ground station is fully operational in the UHF-VHF frequency ranges and has been successfully tested with amateur satellites to verify its capabilities. This ground station was established in preparation for the launch of the first SAASST CubeSat, Sharjah-Sat-1. Aside from that, SAASST ground station serves in the training and education of students interested in the field of space sciences and technology.

Future work includes the installation of an S-Band dish antenna and the required amendments to the current system to support the download of the Sharjah-Sat-1 payload data. This is currently in progress and expected to be concluded in time before the launch of the mission.

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