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SharjahSat-1 Space-to-Ground Telecommunication Operations

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Abstract

SharjahSat-1 is a collaborative research project by the Sharjah Academy for Astronomy, Space Science, and Technology (SAASST), University of Sharjah (UoS), Istanbul Technical University Space Systems Design and Test Laboratory (ITU-SSDTL), and Sabanci University (SU). The 3U+ CubeSat will host an improved X-ray Detector (iXRD) as the primary payload and a secondary payload system of a dual optical camera system. The X-ray detector's objective is to detect hard X-rays from very bright X-ray sources, and to study the solar coronal holes, whereas the camera system will provide a low-resolution remote sensing application. Although SharjahSat-1 would be the first

CubeSat mission to be developed by SAASST and UoS, it aims to extend the experience for the following CubeSat missions. The anticipated launch date of the CubeSat is by the fourth quarter of 2022.

Many parameters such as emission patterns, data rates, modulation schemes, and the dynamics of the satellites affect the completion of the communication links between the CubeSat and the ground station. Thus, it is crucial to consider all major and minor parameters while designing and performing telecommunication operations. SharjahSat-1 host a transmitter and a transceiver and their antennas to communicate the data from the payloads and telemetry through different frequency bands. It will perform these operations through S-band and VHF/UHF frequency ranges due to its payloads requirement of high data rates. Moreover, SAASST is equipped with an S-Band, a full-duplex VHF/UHF Ground Station, and a Software Defined Radio (SDR) ground station transceiver to fulfill such mission requirements and assure its success. Furthermore, a custom-console software was developed to control SharjahSat-1 while it is in orbit by sending commands to execute diverse types of operations that will directly affect the practicality of mission objectives.

This paper comprises SharjahSat-1 communication subsystem design significance due to the requirements of the payloads. Then it will put forward the composition of the full-fledged SAASST Ground Segment equipped with technologically advanced hardware components that allow full automation during operations as it is remotely controlled. Finally, it will describe the developed custom-console software that aids the mission's operations to formulate a comprehensive End-to-End communication operations process.
Keywords: Telecommunication operations, UHF, VHF, S-Band, Ground Segment, End-to-End Communication, CubeSats.

1. Introduction

SharjahSat-1 is the first 3U+ CubeSat to be launched by Sharjah Academy for Astronomy, Space Science and Technology (SAASST), which is being developed in collaboration with Istanbul Technical University (ITU). SharjahSat-1 hosts two payloads; a primary payload is an improved X-Ray Detector (iXRD) to study the hard X-Ray emissions from the Sun's Coronal holes and other bright X-Ray sources. Also, a secondary payload consists of two optical cameras for remote sensing purposes. The satellite is planned to be launched by the fourth quarter of 2022.

It is essential to have a reliable communication subsystem and a full-fledged ground segment to facilitate the mission's success in aiding SharjahSat-1's objectives. Both the satellite's system and ground station equipment should be compatible in terms of communication frequency bands, data rates, and data demodulation software. Further, the ground station at SAASST will support satellite communication over UHF, VHF, and S-band frequency bands. The iXRD data and images will be transmitted from space to the ground through S-band frequency bands. In contrast, the telemetry and housekeeping data will be transmitted through the UHF downlink transmission. However, the commands uplink will be facilitated through VHF frequency bands [1].

Orbital analyses show that with a pointing capability of ±30° using the ADCS, the S-Band has, on average, 700 seconds of access to the SAASST ground station in a week. While the S-Band has a usable transmission rate of 1 Mbps, the worst case is assumed for the ground station, with a minimum receive rate of 128kbps that restricts the communication rate. Consequently, 11 MB of data can be downloaded per week using the S-Band transmitter. If no pointing is performed, the access duration reduces to 220 seconds, limiting the download capability. On the other hand, using a quality commercial modem in the ground station allows downlink with full capacity, and consequently, around 88 MB of data can be downloaded per week. The onboard computer (OBC) also includes a data compression algorithm that can greatly reduce the sizes of raw images up to 10% of their original size. The data budget according to the minimum communication rate is shown in Table 1. This is the minimum requirement of the mission, and with increased ground station capacity, eight times more data can be downloaded weekly [2].

Table 1. Data Budget Table (Min. data rate)

Data	Data size with Packaging (MB)	#	Total data (MB/week	Download Time (s)	Minutes
5 MP Raw	2	1	2.0	128	2.13
5 MP Jpeg	1.2	4	4.8	307	5.12
2 MP Jpeg	0.5	4	2.0	128	2.13
Subtotal			8.8	563	9.38
iXRD data	0.285	7	1.995	128	2.13
Total			10.795	691	11.5

Many CubeSat missions used similar telecommunications methods in terms of the space segment and ground segment of Sharjah-Sat-1 to achieve their scientific objectives such as PICASSO, which was launched 2020 [3].

This paper will highlight the significance of the work done on SharjahSat-1 in space-to-ground telecommunication operations. First, in section 2, the SharjahSat-1 communication subsystems characteristics are described. Then, section 3 illustrates the ground segment regarding hardware and software used to aid the mission accomplishment. Finally, section 4 summarizes the mission.

2. Communication Subsystem on the Space Segment

SharjahSat-1 has two different communication systems. A UHF/VHF transceiver and an S-Band transmitter are both manufactured by CPUT. The UHF/VHF Modem will be used for receiving commands and downloading the housekeeping data to GS, such as the health status of the subsystems and attitude information of the satellite with all raw values from the ADCS unit. S-Band transmitter will be used to download the payload data, such as camera images and iXRD measurements.

2.1 Ultra-High Frequency/ Very-High Frequency

Radio Frequency (RF) modem communicates between the ground station and the spacecraft's onboard computer. In this context, the modem processes and transmits digital data such as temperature, battery status, system status, and other system parameters received from OBC to the ground station and receives commands from the ground station and transfers these commands to OBC. For the SharjahSat-1, a CPUT UHF/VHF modem will be used as an integrated uplink-downlink transceiver that uses a UHF transmitter and VHF receiver supporting both 9600bps Gaussian Minimum Shift Keying (GMSK) modulation and 1200bps Audio Frequency-Shift Keying (AFSK). The transceiver operates in full-duplex mode. Moreover, if needed, the transceiver can operate as a beacon. Modem operating frequencies are selected as 145.100 MHz for the receiver Uplink and 437.325 MHz for the transmitter Downlink. Desired data rates are 1200 Bits-per-second (bps) for uplink in AFSK modulation and 9600 bps for downlink GMSK modulation. The transmitter's output power is selectable with the values 27, 30, and 33 dBm. For SharjahSat-1, 30dBm (1 watt) configuration is selected as default. Figure 1 represents the system diagram of the CPUT modem.

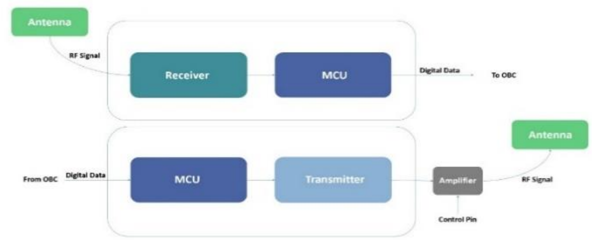

Fig. 1. CPUT UHF/VHF Modem block diagram

Every satellite in space and ground station on Earth has its unique callsign for identification. Callsign is selectable in the CPUT modem. For SharjahSat-1, the SRC callsign (satellite) is selected as "A67DM". While the ground station is "A68SQ". The United Arab Emirates TDRA organization defines prefixes in the callsigns. Callsigns are created by A6 followed by an additional number between 0-9. Suffixes "A67DM" and "A68SQ" are selected by organizations. These callings are used for communication between satellite and ground stations. Therefore, both callsigns are selected and/or added to the CPUT Modem configuration. Communication will be achieved with AX.25 communication protocol. AX.25 protocol is "Link Access Protocol for Amateur Packet Radio".

For the communication modem, CPUT is selected due to its space heritage, receiver sensitivity, data rates, transmission speeds, modulation selections, and compatibility with the SAASST UHF/VHF ground station. In the default configuration, CPUT Modem uses Inter-Integrated Circuit (I2C) interface with the slave address of 0x25 and up to 400kHz (100kHz compatible) bus speed at +3.3V level.

The UHF and VHF systems and the beacon use Omni-directional copper-beryllium monopole antennas with varying frequencies. A different subsystem called the "interface board" is responsible for deploying the antennas, which will be stowed inside the pod. The deployment system for a single antenna consists of a resistor, fish line, and feedback switch. The fish line ties both antenna and the resistor in the stowed position. The feedback switch is placed in a position where the switch is pressed when the antenna is stowed. When the interface board controller receives an antenna deployment command, it enables the resistors to supply the source and starts heating up. When the resistor is hot enough, the fish line breaks, and the antenna is deployed. When this happens, the feedback switch becomes unpressed, and the microcontroller can check whether the antenna is deployed or not. The microcontroller can deploy all antennas at once by enabling all three resistors or can deploy antennas separately. Antenna deployment status can always be accessed by sending a read command to the interface board controller [4].

2.2 S-Band System

The frequency range for the S-band ranges from 2 to 4 GHz. S-Band modem in SharjahSat-1 will be used only to provide downlink communication from the satellite to the ground station. In SharjahSat-1, CPUT STX S-Band Transmitter will be used. The STX is an integrated RF data transmitter module operating in the S-band and supporting data rates of up to 2 Mbps (1 Mbps user data + 1 Mbps encoding). The transmitter implements OQPSK or QPSK modulation with Intelsat IESS-308-based encoding. The transmitter's frequency of operation is selectable from 2.4 - 2.45GHz. The carrier frequency is adjustable in 500 kHz steps, and the output power is adjustable in 2 dB steps from 24 dBm to 30 dBm. It has four configurable data transfer rates 1/2, 1/4, and 1/8. The transmitter is configured via an I2C data bus, and high-speed payload data is sent via Serial Peripheral Interface (SPI). The system block diagram of the S-Band transmitter can be seen in Figure 2.

CPUT S-Band Modem uses the I2C interface for communicating with the OBC. In a default configuration, the modem uses a 0x26 slave address with up to 400kHz (100kHz compatible) I2C bus speed at a +3.3V level. In addition, SPI interfaced is used for high-speed data transmission at 8 Mbps bus speed.

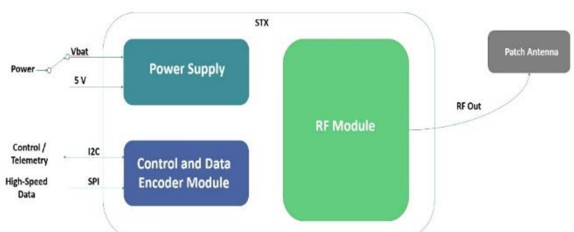

Fig. 2. CPUT STX modem block diagram

The SharjahSat-1 S-band modem will be used at 2405 MHz with 30 dBm (1 watt) output power. For the Downlink modulation method, QPSK will be used. In addition, the consultative Committee for Space Data Systems (CCSDS), 32-bit Attached Sync Marker (ASM), will be used.

The S-Band patch antenna used is CPUT's SANT56, specifically produced for 3U CubeSats and thoroughly tested inside an anechoic chamber. The center frequency of the antenna is 2.425GHz and is left-hand circular polarized. The gain for 2.4 GHz was measured to be 8.63dB.

The link budget analysis was performed, and for the current configuration with 1-watt output power, the system link margin was found to be larger than 5dB for 10 degrees of elevation angle and maximum data rate. Therefore, there should be no constraints on communication.

3. Ground Segment

The Ground Segment at SAASST consists of two ground stations, a UHF/VHF ground station and an S-Band ground station. Both ground stations are located at Sharjah University City and have their separate equipment in terms of hardware and software.

3.1 UHF/VHF Ground Station

The fully automated UHF/VHF ground station system at SAASST consists of three main segments: Front-end, signal processing, and mission-specific. Although, each segment consists of different components, as shown in table 2, all components work together to successfully communicate with the satellite.

Table 2. UHF/VHF Ground Station Components

Front end segment	**Model**	**Specification**
UHF antenna	436CP42UG with 2x21 elements manufactured by *M2 Antenna Systems Inc.*	Frequency range: 430 to 438 MHz Gain: 18.9 dB
VHF antenna	2MCP22 with 2x11 elements manufactured by *M2 Antenna Systems Inc.*	Frequency range: 144 to 148 MHz Gain: 14.39 dB
Rotator	YAESU G-5500	Turning range: 180° elevation 360° azimuth
Signal processing & mission specific segment	**Model**	**Specification**
Full-Duplex Transceiver	ICOM IC-9700	Antenna Connectors: 144, 430/440, and 1200 MHz
Dual controller	G-5500	Elevation-Azimuth

Rotator controller interface	YAESU GS-232B	-
TNC	SCS Tracker/DSP TNC	AX.25 protocol - AFSK/FSK (G3RUH compatible)
Pre-Amplifier	Mirage KP-2/440	430-450 MHz, 15 dB/25 dB Gain

Starting with the front-end segment, full-duplex UHF/VHF antennas operating in the amateur radio frequency bands as per the coordination with the International Amateur Radio Union (IARU). The antennas are joined by a mast and share the same rotator enabling easy satellite tracking and control. The rotator is connected to the indoor signal processing unit through two coaxial cables, one going directly to the 144 MHz connectors in the transceiver, and the second is connected to the 440 MHz connectors in the transceiver through a pre-amplifier.

In the signal processing and mission-specific segment, the ICOM transceiver is connected to the Terminal Node Controller (TNC) and then to the ground station computer through a USB cable. The same transceiver is also connected directly to the ground station computer through an RS232 cable and from the computer to the controller interface. This is, in turn, connected back to the rotator to control the Front-end unit using the ground station computer. These connections are summarized in Figure 3 [5].

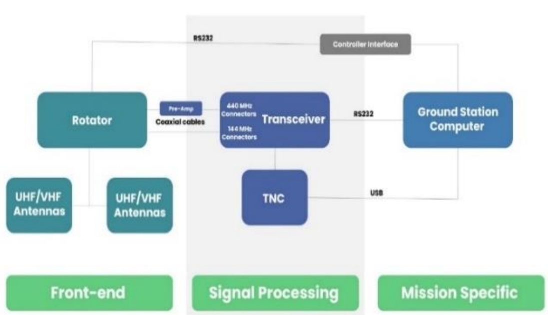

Fig. 3. UHF/VHF Ground station setup

3.2 S-Band Ground Station

The S-Band ground station system at SAASST consists of the same segments as the UHF/VHF station with different components. The hardware list is given in Table 3.

Table 3. S-Band Ground Station Components

Front end segment	Model	Specification
Antenna Dish	FPD 4M5 KIT by *rfhamdesign*	4.5 m diameter dish. F/D = 0.45.
Dish Feed	FPF R2313 by *rfhamdesign*	Dual mode LHCP/RHCP dish feed, 2320 MHz, RX & TX N-Connector (F)
Rotator	SPID BIG-RAS/HR	Turning range: 180° elevation 360° azimuth Resolution: 0.1 deg
Signal processing & mission specific segment	**Model**	**Specification**
Receiver	QubeFlex CubeSat Modem by Teledyne	50 Mbps data rate, 2.2 to 2.45 GHz
Rotator controller interface	SPID MD-01	RS232, rotor driver

Firstly, the front-end segment of the S-Band Ground station consists of a SPID BIG-RAS/HR rotator with turning range capabilities, enabling it to have 0.1 deg resolution. The Antenna and Dish feed are fixed on the rotator to allow full automated control. The S-Band Antenna operates in S-Band radio frequency bands. The Front-end segment is connected to the indoor signal processing unit through two control cables, CC4-001/25 and CC6-003/50.

In the signal processing and mission-specific segment, QubeFlex Receiver is connected directly to the ground station computer through an RS232 cable. Then the computer is connected to the controller interface, SPID MD-01, which is connected back to the rotator to control the Front-end unit using the ground station computer. These connections are summarized in Figure 4.

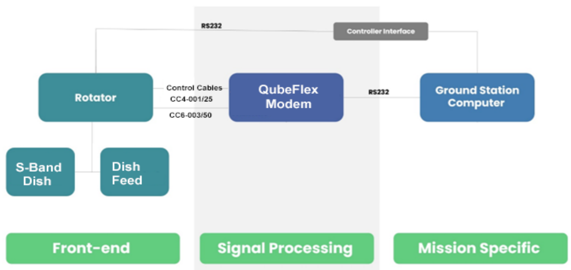

Fig. 4. S-Band Ground Station Setup

SAASST Ground Segment is part of the capacity-building plan for SharjahSat-1. All future missions will be operated from the main ground segment cabin or remotely from the CubeSat laboratory at the Academy. The key role of the ground segment is to track, control, and receive data from the satellite. The two UHF antennas will downlink the telemetry and data that goes through the TNC for AX.25 protocol processing and pass the data to the mission-specific computer. The other two VHF antennas are for Uplink transmissions to the satellite allowing the operator to control and command the satellite as it passes over the ground station. In addition, the S-Band ground station will be used to downlink data at high data rates from the iXRD, which is the primary payload of SharjahSat-1.

3.3 Telecommunication Operations Software

Custom-made console software was designed to provide the SharjahSat-1 team with a dashboard that provides mission control attributes, such as issuing various telecommands and monitoring the received data from the CubeSat. This software integrates different applications to simplify the communication with SharjahSat-1 while in orbit. Figure 5 illustrates how these applications are linked, and they are [5]:

- HRD Rotator: The azimuth and elevation angles are sent to the rotator to track and follow the satellite as it passes by the ground station.
- HRD Satellite Tracker: Tracks the satellite using its TLE and calculates the azimuth and elevation angles to pass to HRD Rotator. Also calculates the doppler shift and transmits the frequency to SDR#.
- AGW Packet Engine: The received UHF signals are processed from the sound card and demodulated using this application. The VHF signals to be sent are modulated, AX.25 framed, and then sent to the TNC.
- SDR#: This is for the signals to be demodulated to be received from the radio.
- Virtual cable driver: Utilized to transmit signals from one software to the other.
- GNU Radio: To demodulate the QPSK modulated S-Band data in the absence of QubeFlex Modem.

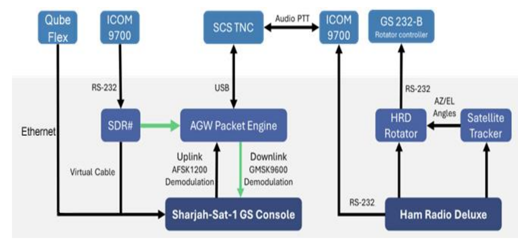

Fig. 5. Block diagram of Ground segment Interface

The GS Console software was designed to provide mission control attributes such as issuing telecommands and monitoring data. Its functions are given as follows:

- Issuing Telecommands
- Telemetry reception and processing
- Displaying and storing data
- Real-time update

The software was developed 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 this framework.

The dashboard has several tabs with the different operations divided into each to ease the use of the console to the user. These tabs are Commands, Telemetry, Subsystem Telemetry, System Info, Photo, ADCS, and SBand.

Through the commands tab, shown in figure 6, the user can issue a telecommand with the press of a button. For telecommands that require additional parameters, the user can input those manually into the input fields that appear after pushing the button. All the data is then packaged in the proper format, modulated using the AGWPE software and sound card (TNC), and finally forwarded to the radio as a PPT signal.

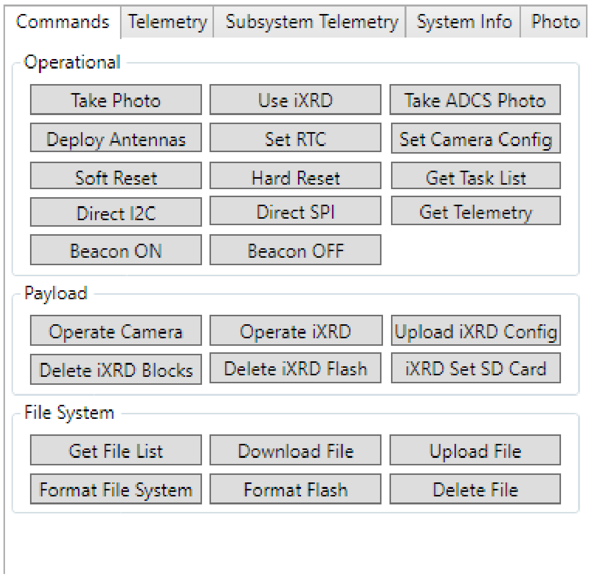

Fig. 6. the commands tab with the available telecommands buttons

In the Telemetry and Subsystem Telemetry tabs, presented in figures 7 and 8, the general telemetry package and the individual subsystem telemetry packages are displayed upon demand. Once the telemetry is received as AX.25 frames, the AGW Online Kiss software demodulates them and sends them to the console software using the AGWPE application, where the different parameters are displayed in their allocated boxes. The GS Console software also includes the compression library onboard the satellite; thus, it can automatically decompress the received data.

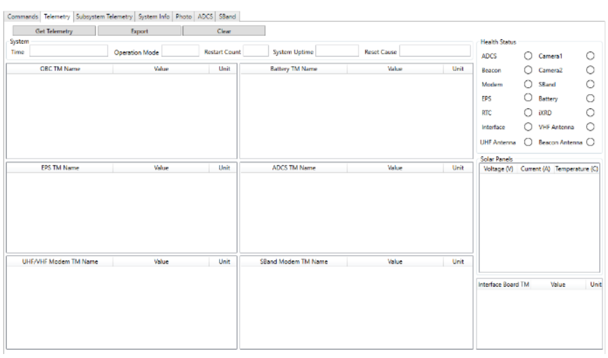

Figure 7. The Telemetry Tab

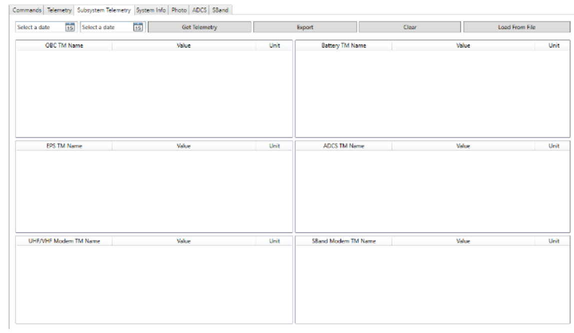

Figure 8. The subsystems telemetry Tab

The system info tab (figure 9) allows users to request and update certain system parameters. The photo tab is for displaying the received photo. The software automatically detects the format of the image (jpg, raw, or bmp) and attempts to decode the packet. This is done by checking the header of the received telemetry packet. The ADCS has its own tab (Figure 10) because of the amount of functionality and telemetry it includes. The TLE can be automatically fetched from the internet and updated with a single click, and other parameters can be accessed easily as well. Lastly, the S-Band tab communicates with the QubeFlex modem using a C# library called SharpPcap that can easily receive UDP packets from an ethernet connection. The received data is then displayed as both raw and processed packets.

In addition to the mentioned functionalities, the dashboard allows the user to save the received data on the hard drive as a comma-separated values (CSV) text file or a Microsoft excel file. As a predefined setting, the received data and sent telecommands are logged in a separate file, as shown in Figure 11.

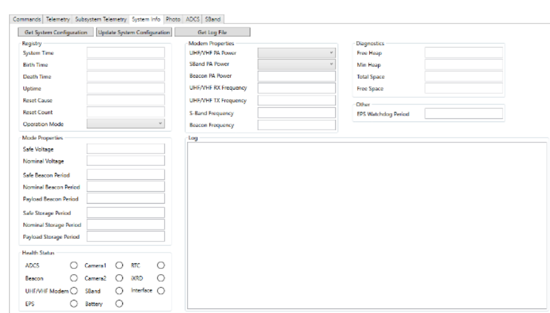

Figure 9. The system info Tab

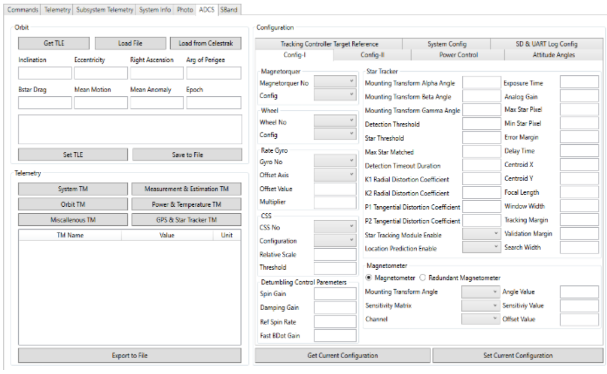

Figure 10. The ADCS Tab

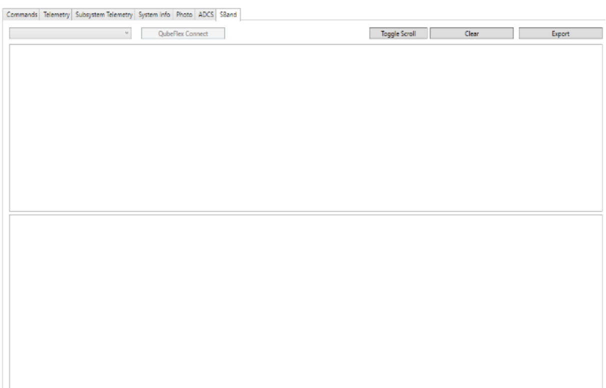

Figure 11. The S-Band Tab

4. Conclusion

SAASST Ground Segment is fully operational in UHF/VHF and S-Band frequency ranges. The ground segment was fully tested and illustrated high reliability to aid the SharjahSat-1 mission, as well as future missions in terms of telecommunications operations. The combination of operating at different frequency bands was used in this mission to pave the way for achieving science through conducting studies on phenomena using low-cost satellites such as CubeSats. Nowadays, CubeSats are becoming the tools to achieve science for university class missions and accelerate its technological advancement. This will help access space frequently and at a low cost, resulting in a better understanding of existing phenomena [6].

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