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Abstract

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Keywords

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Telemetry, Tracking and Command Subsystem for LibyaSat-1

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***Abstract*— In this paper we present the design and the analysis of Telemetry, Tracking and Command Subsystem (TT&CS) for Libyan imaging mini-satellite (LibyaSat-1). This subsystem is the brain and the operating system of any satellite or spacecraft as it performs three important functions; tracking mini-satellite position, monitoring mini-satellite health and status and processing received and transmitted data. Moreover, the uplink and downlink budgets for s-band and x-band antennas are presented. We also designed s-band C-shaped patch antenna for command receiver (2.039 GHz). Electromagnetic simulation was performed to this antenna High Frequency Structure Simulator (HFSS). Our results show that the s-band C-shaped patch antenna achieves high gain of 6.45 dB and wide bandwidth; i.e., 1500 MHz. The achieved simulated return loss is -19.6 dB at a resonant frequency of 2.039 GHz.**

Keywords—mini-satellite; TT&C; transponder; telemetry

I. Introduction

Polar orbiting mini-satellites have a wet mass ranging from 100 to 500 kg and are sun-synchronous. They operate at Low Earth Orbit (LEO) at altitudes of 700 to 1000 km [1]. Compared to conventional, medium and mini sized satellites, as set out in Table I, they have lower mass, cost less, and consume less power. Mini-satellites are used for (i) remote-sensing; e.g., land imaging and weather forecasting, (ii) scientific research; e.g., ocean color and communication experiments, or (iii) telecommunications; e.g., rescue in ocean and for general purpose [2].

An example of a mini-satellite is the SATEX I project [3]. It is a Mexican experimental mini-satellite used for electronic telecommunications research at universities and multi-institutional environment. Another example is the SPOT satellites; i.e., SPOT 1, SPOT 2, SPOT 3, SPOT 4, and SPOT 5. They are French mini-satellites and their primary mission is obtaining earth's imagery for land-use, agriculture, forestry, geology, cartography, regional planning, and water resources. For example, SPOT 5 is a sun-synchronous imaginary mini-satellite that orbits at altitude 832 km. This satellite provides high resolution images for Libyan Centre for Remote Sensing and Space Science (LCRSSS) as part of commercial operations between France and Libya. Fig. 1 shows an image of Tripoli international airport in the capital of Libya with a resolution of 2.5 m. This image was captured by SPOT 5 in 2012 and it has been processed at LCRSSS.

TABLE I. COMPARISON BETWEEN SATELLITES

Types	Mass (kg)	Cost (US $)	Power Consumption
Conventional	>1000	0.1-2 B	~ 1000 W
Medium	500-1000	50-100 M	~ 800 W
Mini	100-500	10-50 M	53.2W
Micro	10-100	2-10 M	35 W

Fig. 1. An image of Tripoli international airport

Libyan national agency for scientific research is planning to have its own remote sensing satellite [4]. Therefore, Libyan Satellite project (LibyaSat-1) is planning to develop a mini--satellite program to meet the requirements of LCRSSS. The main aim of this project is to be the first earth observation mini-satellite to serve the needs of Libya and African countries, in the fields of natural resources management and agriculture. Moreover, the main mission of the LibyaSat-1 under the remote sensing program is to monitor terrestrial, marine environment, desertification and resources throughout Libyan landscape and its surrounding waters and possibly over other regions of the world for international cooperation. It is also recognized as an opportunity to validate new technologies in telecommunications, space science and allows achieving skilled human resources for all mini-satellite subsystems.

A critical subsystem of mini-satellite that provides a communication link with the ground stations is Telemetry, Tracking and Command (TTC) Subsystem. It also allows gathering and sending information to help in determining the satellite's orbit and to download images from payloads to control center [5]. An example of a ground station in Libya is Murezeq ground station which receives images and information from SPOT 5; see Fig. 2. In this paper, we focus on the design and requirements of telemetry, tracking and command subsystem for LibyaSat-1. We will present and discuss all key requirements for T&C subsystem and image date downlink. These requirements include T&CS architecture, X-band subsystem architecture conceptual design, hardware components, operation requirements, components requirements and link analysis. We also present s-band patch antennas design for up and downlink communications. The LibyaSat-1 characteristics shown in Table II are considered when designing T&CS requirements.

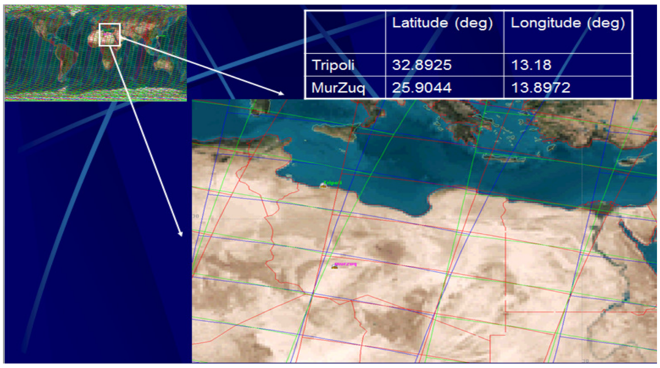

Fig. 2. The geographical locations of Tripoli and Murezeq

II. TELEMETRY, TRACKING AND COMMAND SUBSYSTEM

The aim of this project is to design, construct, implement and test of a RF subsystem to be used on a digital communication link at 2.039 GHz (s-band uplink) and 2.215 GHz (S-band, downlink), for the LibyaSat-1 mini-satellite. The system consists of transmitters, receivers, transponders and antennas. We present and analyse the link budget and the T&C architecture. Hardwar components with their characteristics and performance are also presented. LibyaSat-1 characteristics shown in Table II are considered when designing T&CS requirements.

TABLE II. LIBYASAT-1 CHARACTERISTICS

Mission Orbit	775 km circular, sun synchronous orbit.
Satellite lift-off (Wet) weight	no more than 300 kg.
Mission life	5 years minimum.
Resource of power	solar sell and battery.
Launcher	Falcon 1e.
Data storage volume	no less than 80Gbits.
Satellite reliability	0.6 at the end of the 5-year mission
Swath:30km GSD : 2.5m (PAN) , 10m(MS).	Swath:30km GSD : 2.5m (PAN) , 10m(MS).
Satellite power	3% margin at the end of the 5-year mission.
Downlink rate (x-band	no more than 150 Mbps.
Downlink rate (s-band)	no more than 2.0 Mbps (State-of-Health and Scientific Data).
Attitude control	3-Axis Stabilization.

A. *An Overview*

TT&C subsystem receives commands from Command and Data Handling subsystem (CD&H) and provides health and status of the satellite to CD&H. It also performs antenna pointing and mission sequence operations for each stored software. All these operations are done through communications between the satellite and ground station using telemetry, command and tracking signals.

1) *Telemetry.*

As shown in Fig. 3 telemetry is a set of signals that have one-way direction from satellite to ground station. These signals are the taken measurements on board the mini- satellite of the status of the spacecraft resources, health; i.e., temperatures, voltages, and currents. It also measures the attitude, scientific data, images, spacecraft orbit and timing data for ground navigation etc. Then all these measurements are sent to the control Centre through the ground station by RF system.

2) *Command*

A set of one-way signals that are sent from ground station to the mini- satellite in space. This links is used either for controlling the payload or for sending commands to control the satellite and its attitude at the critical phase. When the solar cells is deployed, commends are then sent to turn on equipment that was off during launching phase; i.e., records and payloads. After the deployment of the solar cells, the mini- satellite should operate automatically and less command will be sent.

3) *Tracking*

For tracking the satellite to accurately locate its orbit, the same link is used to receive different measurements. These measurements include the time taken by RF signals for trip; i.e., station – satellite – station, frequency shift because of the satellite velocity, and the antenna orientation with respect to azimuth and elevation. By using all the aforementioned measurements, the accurate location of the satellite can be determined.

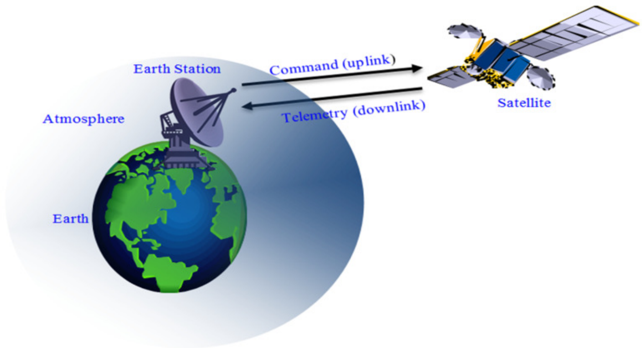

Fig. 3. Communication links between satellite and ground station

B. *TT&C Architecture*

As shown in Fig. 4, S-band TT&C subsystem consists of two TT&C s-band antennas, RF Distribution Unit (RFDU) and two transponders. Each transponder has a receiver, transmitter and duplexer. These two transponders are used to backup each other and to provide RF channels for mini- satellite tracking, telemetry, ranging and command. The duplexer at each transponder is used to switch between receiver and transmitter.

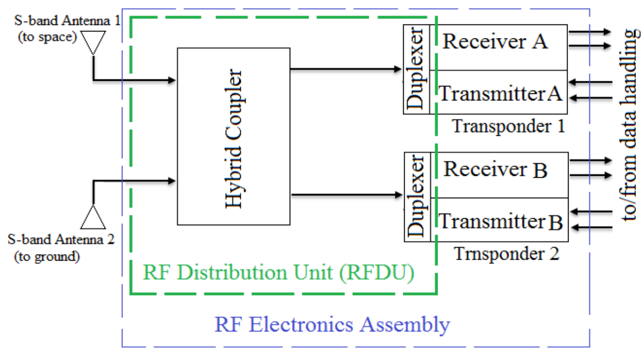

Fig. 4. Mini- satellite TT&C subsystem block diagram

1) Transponder

Two transponders in TT&C subsystem are used to backup each other and to provide RF channels for mini- satellite tracking, telemetry, ranging and command. This redundancy ensures that the TT&C subsystem has reliability should one of transponders fail. In addition, the duplexer at each transponder is used to switch between receiver and transmitter. The requirements and parameters of TT&C transponder (s-band command receiver and s-band telemetry transmitter) of the LibyaSat-1 are shown in Table III. The command receiving sensitivity is –110dBm, noise figure is less than 6 dB and the output power of the s-band telemetry transmitter is about 5 W. Transponders are connected to both antennas via hybrid coupler which distributes signals in both directions; see Fig.4. The polarization of these antennas should be Circular Polarization (CP). This is important as it achieves the best signal strength and mitigates multipath fading.

TABLE III. PARAMETERS OF S-BAND COMMAND RECEIVER AND TELEMETRY TRANSMITTER FOR LIBYASAT-1

S-band Command Receiver	
Frequency	2.039 GHz
Sensitivity threshold for <10-6 bit error rate	-110 dBm
Receiver noise figure, maximum over temperature	< 6 dB
Signal modulation	BPSK +PM
Data Rate	32 kbps
S-band Telemetry Transmitter	
Frequency	2.215 GHz
Output power	5 W
Transmitter error vector magnitude	<10 %
Signal modulation	BPSK
Maximum transmit data rate	2Mbps

2) S-band antennas

As mentioned earlier, s-band command receiver and telemetry transmitter antennas should have resonant frequencies of 2.039 and 2.215 GHz respectively. To this end, we have designed s-band C-shaped patch antenna using the High Frequency Structure Simulator (HFSS) [6-8]. This antenna for s-band command receiver and operates at resonant frequency of 2.039 and meet all aforementioned requirements. For telemetry transmitter, we will purchase s-band antenna that provides the specifications mentioned in Table III above.

a) 2.039 GHz C-shaped patch antenna

Fig. 5 shows the 3D model of s-band C-shaped antenna for command receiver. The dimensions of the upper and lower patches are 69.2×24.4 and 46.8×7.3 mm^2 respectively. Three shorting pins are connected at the edges of the upper patch and are located between the upper patch and 122×122 mm^2 ground plane. Their main purpose is to achieve a wide impedance bandwidth at small antenna size.

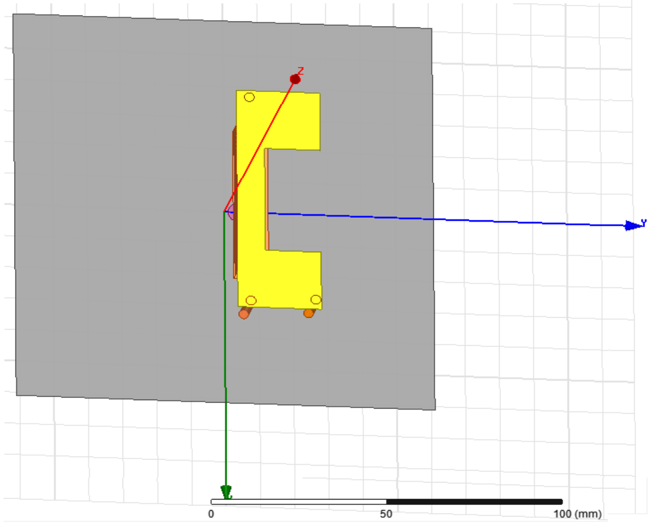

Fig. 5. Geometry of 2.039 GHz C-shped patch antenna

Fig. 6 presents the 3D gains of the s-band C-shaped patch antenna at 2.039 GHz. We see that the antenna has a high gain of 6.4 dB and a uniform radiation pattern. Fig. 7 shows the return losses over varying frequencies for s-band C-shaped antenna. The antenna has a wide -10 dB bandwidth; i.e., 1500 MHz (1.8-3.3 GHz). The return loss at resonant frequency of 2.039 GHz is about -19.6 dB.

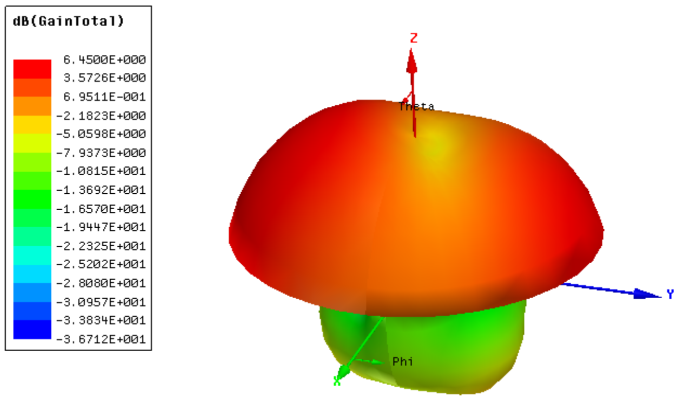

Fig. 6. 3D gain of C-shaped patch antenna at 2.039 GHz

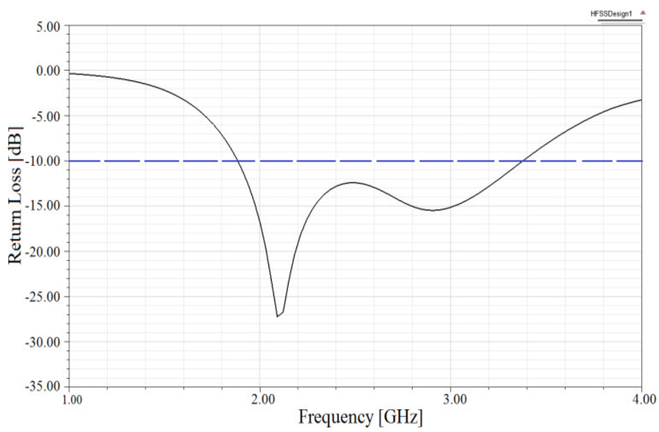

Fig. 7. Simulated return losses (S_{11}) of C-shaped patch antenna

3) Passive components

Passive components that are used in TT&C subsystems are filters, hybrids, diplexers, and transmission lines. A band pass filter with 2.215 GHz center frequency and bandwidth of 50 MHz is used for a telemetry transmitter. The same band pass filter is used by the command receiver but at center frequency of 2.039 GHz. The coupler or divider provides a frequency range that covers 2.039 and 2.215 GHz at coupling rate of 3dB and a maximum insertion loss of 0.4. Another passive component is diplexer which has a maximum insertion loss of 0.5, minimum isolation of 30 dB and frequency range covers 2.039 and 2.215 GHz. Moreover, low loss cables and waveguides are used as transmission lines.

III. IMAGE DATA DOWNLINK

We now study the key requirements of image data downlink for LibyaSat-1. These requirements include real time transmission, store and dump transmission, the center frequency of x-band transmission, data rate, and type of coding scheme. Fig. 8 shows the architecture design of x-band subsystem for LibyaSat-1 including the x-band antenna and its pointing mechanism. Moreover, the downlink budget of x-band subsystem is presented in Table VI.

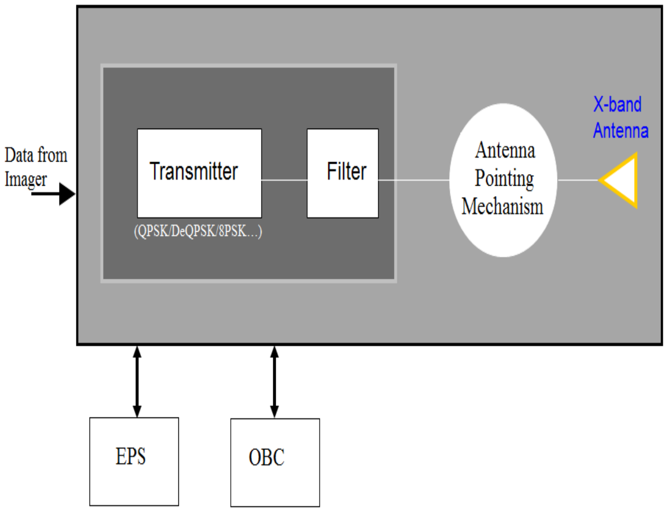

Fig. 8. X-band subsystem architecture

A. Real Time Transmission

The x-band communication link shall be with at least 6 dB link margin in clear sky with a cross-track viewing angle < ±30 degrees toward the ground station. Moreover, the ground station elevation angle should be >20 degrees and passes where maximum elevation angle of ≥30 degrees.

B. Store and Dump Transmission

The store-and-dump transmission capability shall be provided to process the data that is not dumped in real-time downlink.

C. Resonant Frequency of X-band Antenna

The centre frequency of the x-band transmission antenna shall be 8.150 GHz with a minimum gain of 10 dB. The bandwidth of this antenna must be about 150 MHz and should provide right hand circular polarization (RHCP). Next we provide more details about this antenna.

D. Data Rate and Coding Scheme

The data rate shall be 150 Mbps for the operation in QPSK/DeQPSK/8PSK/ mode. The proposed coding scheme is Reed-Solomon (255,223) that implemented in the imager.

IV. MUREZEQ GROUND STATION

This ground station is a multi-mission ground station which was installed by LCRSSS in 2007. The main aim of this station is to send commands to satellites in space and receive images back from these remote sensing satellites; i.e., SPOT 5 and ENVISAT. It uses 5.4 m x-band sub-system dish antenna a diameter of 5.4 m; see Fig. 9. It features an innovative Cassegrain feed and sub-reflector design which leads to high gain, low noise and high antenna efficiency. It feeds with LNA, mono-pulse tracking, and equipment to receive remote sensing data, including a GPS location and timing system. The characteristics of this x-band antenna are set out in Table IV.

Murezeg ground station has five sub-systems as following:

- Antenna sub-system: dish, feed and LNA, pedestal X\Y, control unit, wind gauge, and GPS antenna.
- RF sub-system: fixed frequency conversion from X-band to S-band, RF splitters, and programmable frequency conversion from S-band to FI 720MHz.
- Base band sub-system: demodulation, auto-tracking, time reference, test and measure equipment.
- Supervision sub-system: monitor and control of all equipment, management of tracking sequences, and interface with orbital data source.
- Infrastructure sub-system: radome, temperature and humidity control equipment, and UPS.

Fig. 9. X-band dish antenna at Murezeq station

All the functions of Murezeq ground station are performed by the RF sub-system, baseband sub-system, and supervision sub-system. It is main objective is to receive data directly from French satellites; i.e., SPOT 5, 6 and 7, at frequency of 8.15 GHz with the occupied bandwidth of ≤ 250 MHz, the bit data rate of 310 Mbps (Reed Solomon coding included), the EIRP of 26 dBW, a minimum flux density of -123 dB/m^2, and the modulation used is D-QPSK. Nevertheless, it has the ability to receive from other satellites such as Envisat ASAR, GPS, and Vsat. Moreover, the system can automatically track the satellites, acquire, demodulate and archive the telemetry from remote sensing satellites.

TABLE IV. CHARACTERISTICS OF X-BAND DISH ANTENNA

Parameter	Specification
Diameter of dish	5.4 m
Frequency	8000 – 8500 MHz
LNA gain	≥ 40 dB
Polarization	R/L HCS selectable
G/T at 5^0 elevation	30.5 dB/K
Side lobes	< 14 dB

A. Link Budget Analysis

We now provide a link analysis for x-band downlink and s-band up and downlinks. As mentioned above, the C-shaped patch antenna is proposed to be used for s-band uplink for command receiver. Currently the LCRSSS is using a parabolic antenna for uplink communication with SPOT 5 as command transmitter. This antenna operates at a resonant frequency of 2.039 GHz and provides high directivity. Moreover, it has a diameter of 2.4 m and an aperture efficiency of 0.65%. Although the designed C-shaped patch antenna provides a gain of 6.45 dBi, we have used a gain of 5 dB in the link budget calculation as a worst case scenario. The link budgets for s-band up and down links and x-band image downlink are presented in Table V and VI. Fig. 10 shows the key parameters of the link analysis. These parameters are calculated using the equations in [9] as following,

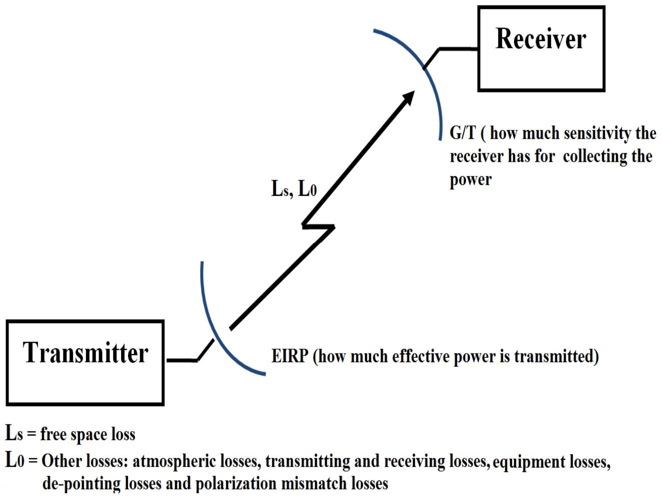

Fig. 10. Key parameters of a link analysis

$$G_t = 10 \times \log(e_A (\pi D/_\lambda)^2) = 32.3\ dBi.$$

With a maximum transmitted power of 100W and feeder loss of 1dB, the EIRP is:

$$EIRP = G_t + P_T - L_{co} = 32.3 + 10 \times \log(100) - 1 = 51.3\ dBW.$$

At satellite altitude of 775 km and elevation angel of 10^o, the slant range is equal to:

$$= \sqrt{r^2 - (R_e \cos \emptyset)^2} - R_e \sin \emptyset = 2315 \text{ km}$$

The power flux density radiated from the ground station to the satellite can be calculated as following:

$$\beta = \frac{P_t G_t}{4\pi d^2} = EIRP - 10 \times \log(4\pi d^2) = 51.3 - 138. = -86.98\ dBW/m^2$$

The uplink space loss is equal to:

$$L_s = \left(\frac{c}{4\pi d f}\right)^2 = 147.55 - 20\log(d) - 20\log(f) = -165.93\text{dB}$$

The received power at the satellite:

$$P_r = EIRP + G_r + L_a + L_s = 51.3 + 5 - 11.5 - 165.93 = -121.13 dBW$$

The system noise temperature (T_s) of the satellite communication link is the sum of the antenna noise (290K), line loss noise (35K) and receiver noise (289K).

The noise power at the receiver can be calculated to be:

$$N_o = kT_s = -228.6 + 27.9 = -200.7\ dB/Hz$$

The carrier to noise density ratio is equal to:

$$\frac{C}{N_o} = -121.13 + 200.7 = 79.57\ dB - Hz$$

The receiver figure of merit (G/T)= 5-27.88 = -22.88 dB/K.

At uplink data rate of R=32 kbps, the ratio of received energy per bit (Eb) to noise density (No) is equal to:

$$\frac{E_b}{N_o} = P_r + 228.6 - 10\log(T_s) - 10\log(R) = 34.52\ dB.$$

Modulation and coding techniques are very important for link budget calculation, satellite system with BPSK/PM technique and bit error rates (BER) of $<10^{-6}$, the required Eb/N_0 can reach to 15.8 dB.

TABLE V. S-BAND UP AND DOWNLINK BUDGETS

Feature	Uplink	Downlink
Frequency	2.039 GHz	2.215 GHz
Satellite Altitude	775 km	775 km
Elevation Angel (deg)	10^0	10^0
Transmitter Power(Pt)	20 dBW	7 dBW
Ground Sation Antenna Gain (Gt)	32.3 dB	6.4 dB
EIRP Power	51.3 dBW	13.4 dBW
Space Loss	-165.93 dB	-166.63 dB
Atmospheric Losses	-0.5 dB	-0.5 dB
Rain Loss	-0.5 dB	-0.5 dB
Polarization Loss	-0.3 dB	-0.3 dB
Pointing Loss	-0.2 dB	-0.2 dB
On-Board Losses	-10 dB	-4.5 dB
System Noise Temperature(Ts)	27.9 dB/k	24.6 dB/k
Satellite Antenna Gain	5 dB	5 dB
Figure of Merit (G/T)	-22.88 dB/k	-18.2 dB/k
Bite rates	32 Kbps	2000 Kbps
C/No Received	79.57 dB-Hz	77.07 dB-Hz
Eb /No Received	34.52 dB	14 dB

Bit Error Rate (BER)	10^{-5}	10^{-5}
Required Eb /No	11.8 dB	9.6 dB
Implementation Loss	-2.5 dB	-1 dB
Margin	20.72 dB	3.4 dB

TABLE VI. X-BAND DOWNLINK BUDGET

Link Parameters	Data
Frequency	8.1 GHz
Elevation Angle	20^0
Satellite Altitude	775 – 800 km
Satellite slant range	1723 km
Bit rate	150 MHz
Transmitter power	6 W
Transmitter imperfection losses	-2.5 dB
Transmitter feed losses	-0.5 dB
Antenna gain	15 dBi
EIRP	19.7 dBW
Propagation loss	-175.4 dB
Atmospheric losses	-1.5 dB
Rain losses	-0.5 dB
Polarization losses	-0.2 dB
Pointing losses	-0.3 dB
G/T ground station	32 dB/k
Eb/N0 received	20.7 dB
GS implementation losses	-2.0 dB
Eb/N0 achieved	18.7 dB
Eb/N0 required	6.5 dB
TM margin	12.23 dB

V. CONCLUSION

We have presented a conceptual design of telemetry, tracking and command subsystem for LibyaSat-1. The most important characteristics of TT&C subsystem were presented in this paper, explaining the uplink and downlink budgets. We also presented the design of s-band C-shaped patch antenna for command receiver. Simulation results show that the C-shaped patch antenna has a return loss that is well below -10 dB at the operational frequency of 2.039 GHz, and achieves an impedance bandwidth of 1500 MHz. The achieved simulated 3D gain is 6.4 dB at 2.039 GHz. We have obtained a margin > 3 dB, which means the calculation of link budget is good and within the range. In addition, the calculated and estimated values for budget links are acceptable and within the range for a real current model satellite.

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