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Evaluation of Using L-band Patch Antenna to Enhance CubeSates TT&C Subsystem

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***Abstract*—The Communication link of CubeSat satellite suffers from Poor power of received signal, therefore, the link of CubeSat satellite is Susceptible to noise and interference and the signal may be lost because the CubeSat satellite transmit the signal to long distance at UHF, VHF frequency to increase the power received signal the gain of antenna most be increase so the slotted rectangular patch antenna is designed by using trial and error method by using HFSS simulator The slots is made to increase gain and enhance the VSWR and return loss without changing the patch antenna dimensions .This is antenna instead of the dipole antenna that is used in the CubeSat satellite it has gain of 2.5 dBi the slotted patch antenna is used because it has some advantages such as low cost, low profile, easily fabricated, small size. All of these specifications fit with small satellite (cube satellite) it gave us the gain about 8.5 dBi, this is the value of gain is added to power received signal after that the link budget is calculated by using MATLAB simulator and then the link performance is evaluated by calculating the C\No and Eb\No ratios.**

***Keywords:* Cubesat, Rectangular patch antenna, Satellite link budget, TT&C.**

I. INTRODUCTION

A satellite communications system can be broadly divided into three specific segments shown in Figure (1) that must work together for the larger overall system to provide communication, navigation, or any other type of missions:

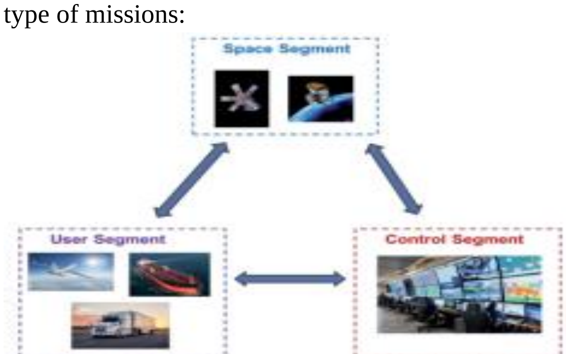

Figure (1). The three main segments for satellite system.

The space segment consisting of all satellites and associated equipment required for the mission applications and the launch vehicles used to deliver those satellites to orbit, but it also includes the ground facilities needed to keep the satellites operational, these being referred to as the telemetry, tracking, and command (TT&C) facilities.

The satellite control (or control) segment consisting of all the personnel, facilities, and equipment that are used to monitor and control all the assets in space. Practically, the control segment is also referred to as satellite ground segment because it is usually located on the ground.

The user segment consisting of all the individuals and groups who use and benefit from the data and services provided by the payloads of the satellite and the equipment that allows this use [1].

In the last years, they have generated a great deal of interest in space research and industry of small satellites, especially for the Low-Earth Orbit (LEO). The LEO small satellites are platforms typically designed to orbit at altitude lower than 1000 km, these satellites, often called picosats, nanosats, or microsats are generally less than 200 kg and, in many cases, are as little as 1 - 5 kg. Traditional space satellites are typified by geostationary communications satellites which range in mass from 500 to 7000 kg Such satellites require millions of dollars to develop and have historically been large expensive projects requiring five to ten years to construct [2].

A CubeSat is a standard Pico-satellite of 1000 cm^3 and a mass of no more than 1.33 kg. CubeSat gives developer's standard specifications for size, weight, and basic construction, which enable parts to be built as a "one-size-fits-all" type of arrangement [3]. thus in environmental conditions that allow the use of the

Commercial Off-The-Shelf (COTS) components. Since they typically have a weight smaller than the geostationary satellites, the small satellites have the benefit of low launch costs, allowing to develop applications based on satellite constellations. However, having a small size, they need integrated electronic equipment that implements a low power consumption digital logic. Even the Telemetry, Tracking & Command (TT&C) subsystem, considered vital for the satellite life. The TT&C subsystem has to satisfy three main categories of requirements:

Mechanicals: It has to be small, compact and low weight so that it is compliant to the standard of small satellites.

Reliability: TT&C requirements have to be guaranteed for all mission years in the worst-case conditions.

Functional: It has to be able to establish a reliable communication channel at high throughput so that it can transmit data to GS within the short time of visibility due to LEO orbits [4], [5].

A link budget of an RF communication link is a set of parameters that describe a link in terms of power levels required to establish reliable communication between the transmitter and the receiver. It includes power penalties and gains associated with antennas and phenomena that affect the signal to noise ratio (SNR) in a communication link. The term "link budget" also conventionally refers to the ratio of transmitter power to receiver sensitivity required to obtain a certain bit error rate or signal to noise ratio [6].

Nowadays, satellite communication systems are evaluated and tested by using simulation programs which adds the environmental factors that affects the signals and observes the performance of the satellite link. A RF satellite link consists of an uplink (transmit earth station to satellite) and a downlink (satellite to the receiver earth station). The signal power and quality over the uplink depends on how strong the signal is when it leaves the source (earth station) and how the satellite receives it. While, on the downlink side, it depends on how strongly the satellite can retransmit the signal and how the ground station receives it [7].

The rest of the paper is organized as follows, section 2 explains the different functionalities of the TT&C subsystem, section 3 explains the design of slotted Rectangular patch antenna, section 4 illustrates how to calculate the link budget of CubeSat depends on the design of slotted Rectangular patch antenna to increase the gain, section 5 discusses the results of link budget calculations and Evaluate link performance evaluate by using the MATLAB simulator and compare these results with power budget calculation when to use the dipole antenna, and finally section 6 concludes the paper.

II. TT&C DESCRIPTION

The TT&C module is the main responsible subsystem for the communication with the earth. It is considered as an essential payload of a satellite because without it the satellite monitoring and control would not be possible. TT&C shall transmit the telemetry – set of data and information regarding the "health status" of the satellite and all its subsystems – to the GS and shall receive from it the telecommands – a set of configuration/update data. Thanks to TT&C the ground operators can monitor the satellite life and act in case of issues/faults. In other words, the TT&C assures the reliability of the satellite, trying to guarantee its functions for all years foreseen by the mission. Other secondary (but not less relevant) features, such as tracking and ranging, allow better control of the satellite attitude. The TT&C reliability is strictly related to its functional performance. The TT&C module has to establish a channel communication with the earth and this channel must be effective and reliable. In order to assure the correct transmission and reception of data, the bit error probability must be as low as possible for all conditions which the satellite could be in. The main parameter used to design channel communication is the Bit Error Rate (BER). It is taken into account both in hardware designing and in the Link Budget Analysis (LBA). The LBA is a procedure used to design a channel communication in order to guarantee a specific BER requirement with appropriate margins. Even foreseen by European Cooperation for Space Standardization (ECSS) [8]. The BER requirement is usually given in the worst-case, i.e. when the satellite is farther from the earth. More distance implies more power in order to assure the same error probability, which could be an issue for the small satellites that have typically a limited power budget. BER depends also on bitrate: if it increases, BER could be affected. A higher bitrate is essential to guarantee the complete transmission of the collected data in the few time the satellite is within the GS line-of-sight. The TT&Cs are very complex systems that implement on the same hardware analog and digital functionalities, such as in the Software Defined Radios (SDRs). The SDR approach has the great benefit to simplify complex functionalities, such as the modulation of base-band signals, through the programming of a software or a firmware. In the satellite SDR the modulation/demodulation schemes are typically implemented on Field Programmable Gate Arrays (FPGAs), making the hardware less complex, more compact and with lower power absorption due to digital architecture. Only a few functions, such as the filtering, amplification and frequency conversion, are still implemented by analog components. For all these reasons SDRs are becoming more and more common in the TT&C design [9].

III. ANTENNA DESIGN

The CubeSat belongs to Pico satellites/ Nano satellites. So the rectangular patch antenna is designed to fit with CubeSat size. The patch antenna is slotted with different shapes to get high gain and enhance the power budget of CubeSat link. Adjust the location of the feed point is applied as the matching method to enhance return loss and VSWR. Return loss must be less than -10dB and VSWR value must be between 1 and 2.

A. Rectangular Patch Antenna Design

To enhance link of cube satellite the gain of the antenna must be increased to achieve that the slotted patch antenna is used because the patch antenna has some advantages such as high gain compared to a dipole antenna, lightweight, low volume, low profile; easy fabrication-patch antenna is designed by using HFSS simulator

B. Slotted Rectangular Patch Antenna

The slotted rectangular patch antenna is designed by using trial and error method and the seven different shapes of the slotted antenna are designed to get high gain and suitable return loss &VSWR. each shape of slotted rectangular antenna has slots with specified dimensions the design of each shape is achieved by using HFSS simulator.

C. Design Specifications

The three essential parameters for the design of a rectangular microstrip Patch Antenna:

1). Frequency of operation (fo): the resonant frequency of the antenna must be selected appropriately the CubeSat frequency range from 300 MHz to 1100 MHz. Hence, the antenna designed must be able to operate in this frequency range. The resonant frequency selected for my design is 900 MHz.

2). Dielectric constant of the substrate (εr): based on material of substrate. The dielectric 25 material that is selected for design is Teflon (tm) which has a dielectric constant of (2.1).

3). Height of dielectric substrate (h): the height of the dielectric The substrate is selected as 1mm.

D. Calculations of Parameters

The width (W) and length (l) of the patch antenna are calculated to depend on a dielectric substrate. The width (W) is calculated by using equation (1)

$$W = \frac{C}{2\ f0\ \sqrt{\frac{\varepsilon r+1}{2}}} \tag{1}$$

The length of patch antenna is calculated below equations

$$\varepsilon reff = \frac{\varepsilon r+1}{2} + \frac{\varepsilon r-1}{2}\left[1+(\frac{12h}{w})\right]^{\wedge(-1/2)} \tag{2}$$

$$\Delta L = \left[\frac{0.412h(\varepsilon reff+0.3)\left(\left(\frac{W}{h}\right)+0.264\right)}{(\varepsilon reff-0.258)(\frac{W}{h})+0.8)}\right] \tag{3}$$

$$L = (\frac{Co}{2fr\ \varepsilon reff}) \tag{4}$$

Where: W is the width of the patch antenna, εr is the dielectric constant, h is the thickness of substrate (mm), fo is the frequency of free space. (MHz), εreff is the effective dielectric constant, ΔL is the length extension (mm). For feeding the microstrip patch antenna, microstrip feeding is used. The method is used to match the patch antenna to the transmission line is to adjust the location of the feed (y0) [10].

E. Specifications of Design

In our CubeSat (ISRA SATE 1) the MHX920 transmitter is used that has specifications as shown in the table (1).

Table (1): shows specifications of MHX920 transmitter

Frequency operation	900MHz
Maximum transmits power	1W=30dBm
Data rate	230kbps
Sensitivity	-110dB
Maximum distance	450Km
Maximum gain of AH117 Power amplifier	18.5dB at 900MHz

Modulation scheme	FSK

F. Scenario

The slotted microstrip rectangular patch antenna is designed by using trial and error method by using the HFSS simulator to get high gain needs to increase the power receive of the CubeSat to enhance the performance of the link to be more stable.

- The slotted rectangular patch antenna is designed with specifications as shown in The Table (2):

Table (2): shows specifications of slotted rectangular patch antenna

Item	Quantity
Width of the patch (W)	130mm
Length of the patch (L)	100mm
Feeding of set position (yo)	50mm
Height of the substrate (h)	1mm
Width of the patch (W)	200mm
Width of the ground plane (Wg)	230mm
Dielectric constant (εr)	2.1
Resonant frequency	900MHz

- Slotted Rectangular Patch Antenna

In this section, the rectangular patch antenna is slotted in the E shape scenario by using trial and error method to get high gain and suitable VSWR, return loss.

- E shape is created with 5slots different dimensions as shown in the Table (3).

Table (3): shows dimensions of the E shape

Slot number	Size	Position
Slot1	x=50mm y=10mm z=0.01mm	90,60,1.02mm
Slot2	x=50mm y=10mm z=0.01mm	90, 152, 1.02mm
Slot3	x=10mm y=102mm z=0.01mm	80, 60, 1.02mm
Slot4	x=50mm y=10mm z=0.01mm	100, 85, 1.02mm
Slot5	x=50mm y=10mm z=0.01mm	100, 125, 1.02mm

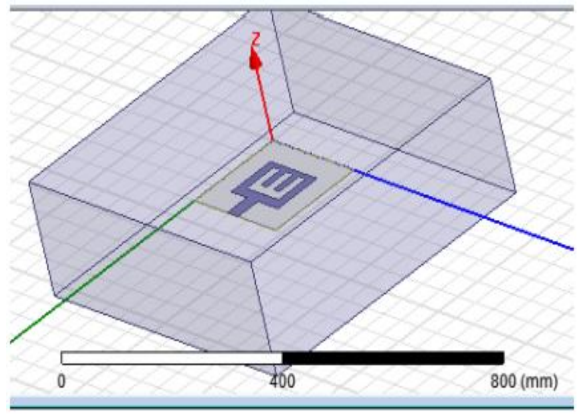

Figure (2): shows E shape

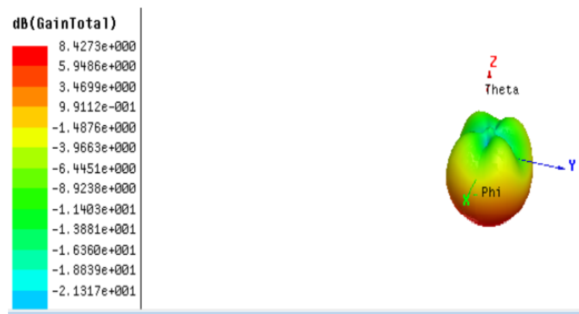

Figure (3): shows Gain pattern of the E shape in far field.

The maximum Gain of antenna is 8.427dBi ≈ 8.5dBi

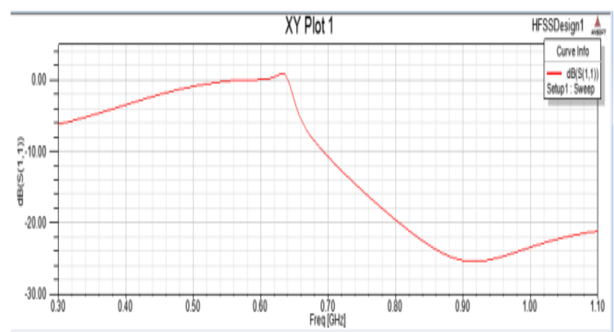

Figure (4): shows S- parameter of the E shape

The return loss of the antenna at resonant frequency 0.9GHz is -25.2dB

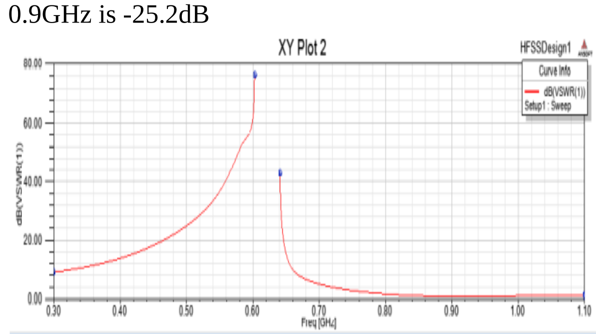

Figure (5): shows VSWR of the E shape

The VSWR of the antenna at resonant frequency is 0.9GHz is 0dB= 1

IV. RF SATELLITE LINK BUDGET

The purpose of a satellite system is to provide reliable transmission with a specified quality of the received signal. The transmitted information has to be modulated on an RF carrier. In analog systems, the frequency modulation (FM) is the dominating modulation method, the signal-to-noise ratio (S/N) after the demodulator is the measure of signal quality. In digital satellite links, the measure of quality is the bit error rate (BER). In both analog and digital systems, there is a unique relationship between the carrier-to- noise ratio (C/N) and the signal-to-noise (S/N) ratio or the bit error rate (BER). In order to establish the link quality, we need to calculate the carrier power (C) and the noise power (N) at the receiving station. [11]. Figure (4) shows the main parts of a satellite communication system.

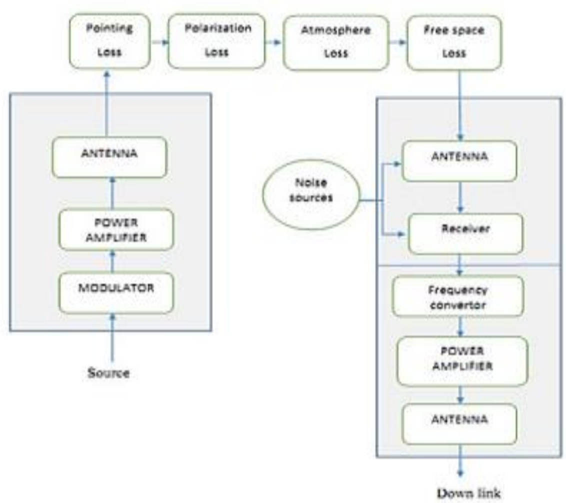

Figure (6). Main parts of a satellite communication system.

A. Transmitter Station

The discussion in this section is about the ground station, the main process on the signal will be to modulate the signal or change the form of the signal then it is to convert the band of the signal from intermediate frequency band L- band to C, X or Ku band, then amplifying the signal by power amplifier to increase its amplitude and its power. After that the signal is directed to the satellite by a reflector antenna, which gives the signal extra gain with respect to isotropic radiation, that signal called (power flux density), The slotted rectangular patch antenna is designed to increase the gain to get high level of receive signal strength to enhance the performance of CubeSat link The gain obtained from the antenna is about 8.5 dBi, the Effective isotropic radiated power (EIRP) is:

$EIRP = PT\ GT$ in (watt). (5)

Or

$EIRP = PT\ (\text{dB}) + GT(\text{dB})$ in (dB). (6)

The slotted patch antenna is designed to use in the CubeSat.

Gt = Gr = 8.5 dB

Adding to that, some kind of loss must be consecrate in this stage like modulation process loss, connection and cable loss,

$EIRP = PT + GT - Lt$ in (dB). (7)

Where Lt is total of transmission loss in dB.

B. Space Channel Part

The biggest attenuation on the signal happens in this section. Where the constitute path losses in the link equations. These losses include system loss (due to thermal noise), transmission loss due to ionosphere (cloud, rain, fog and gazes), and directional (pointing) loss.

Free space loss (FSL) have two important factors which are frequency F and the range R or distance between earth station and the satellite, so that, it can be calculated by the following equation:

$FSL = 32.4 + 20 \log R + 20 \log F$ in (dB). (8)

Where R in Km and F in MHz.

The other losses also must be considered for final calculation, and these are simply added to FSL. The losses for clear –sky condition is

$Total\ losses = FSL + AML + AA + P$ in (dB). (9)

where AML is antenna misalignment loss in (dB), This loss occurs because the antennas are not aligned perfectly, our calculations do not include these losses, it is ignored. Therefor the Pointing loss = 0dB. AA is atmospheric absorption loss in (dB), these losses are about 2 to 3 dB in total, PL is polarization mismatch loss in (dB), and some other loss such as cables and connecters loss in the transmitter and the receiver, that will call as (Rx) in (dB), Depend on the MXH920 transmitter the cable loss at the transmit side is 2dB. At the receive side, the cable loss is about 2 dB [12].

C. Noise and Noise Figure

Receiver noise includes contributions from thermal noise, short noise and possibly flicker noise. These may arise in the input RF section of the receiver. The system noise temperature Ts can be calculated from the following equation.

$$Ts = TRF + Tin + \frac{Tm}{Gr} \quad \text{in (K).} \quad (10)$$

Where TRF is the temperature on the front end of RF part in the receiver, Tin is the input temperature to the receiver, Tm is the frequency convertor unit or the mixer temperature, all in Kelvin (K), and Gr antenna gain. An alternative way of representing amplifier noise is by means of its noise factor, F. In defining the noise factor of an amplifier, the source is taken to be at System line temperature, denoted by T0, usually taken as 290 K. the noise figure can be calculate by this equation;

$$F = \frac{TS}{T0} + 1 \quad (11)$$

Or

$$F = 10\log F \quad \text{in (dB).} \quad (12)$$

Noise power depend on the bandwidth of the receiver (B) and noise figure (F) so the noise power is given by

$$N = K\,T0\,B\,F = N0\,B\,F \quad \text{in (watt).} \quad (13)$$

N0 = K T0 is the noise spectral density (W/Hz).

Where k is Boltzmann's constant= 1.38062*10-23 (J/K), B is the bandwidth in (Hz).

B is bandwidth of carrier = 928-902 = 26MHz

And it can be simplified that equation (11) in (dB) with T0 = 290 k.

$$N = -174\left(\frac{dB}{Hz}\right) + 10\log(B).Hz + F.(dB) \quad \text{in (dB).} \quad (14)$$

Or

$$N = -114\left(\frac{dB}{MHz}\right) + 10\log(B).MHz + F.(dB) \text{in (dBm).} \quad (15)$$

- *Figure of Merit G/T*

The G/T ratio is a key parameter in specifying the receiving system performance. the antenna gain Gr and the system noise temperature Ts can be combined in the following equation.

$$Gr = -42.2 + 20\log(F).MHz + 20\log(D).m \quad \text{in (dBi).} \quad (16)$$

$$\frac{G}{T} = Gr - 10\log Ts \quad \text{in (dBi).} \quad (17)$$

by adding antenna receiver Rx loss in (dB) to G/T, then

$$\frac{G}{T} = Gr - 10\log Ts - Rx\ loss \quad \text{in (dB).} \quad (18)$$

Signal power received (Pr) can be calculate by the following equation

$$Pr = EIRP - total\ losses + G/T \quad \text{in (dB).} \quad (19)$$

That power must be greater than minimum signal power requires (C min) to the receiver.

D. *Link Performance*

The performance of link is evaluated by calculate SNR, C/N0, Eb/N0 ratios and calculate the BER.

- *Signal to Noise Ratio (SNR)*

SNR is the ratio between the power of the information carrying signal and the power of the unwanted noise it uses to evaluate performance of analog and digital communications system [13].

$$SNR = \text{Pr} - \text{N} \quad \text{in } (dB). \quad (20)$$

Where: Pr is the signal power received (dBm), N is the power noise (dB).

- *Carrier to Noise Power Spectral Density Ratio (C/N0)*

C/No is the ratio of the power level to the noise power spectral density (normalized noise level relative to 1 Hz) in a system.

Similar to C/N but C/No does not factor the actual noise bandwidth in. This simplifies analysis of systems where variation of the (utilized) BW

Where: C is The carrier power of modulated signal may apply, No is the Noise power spectral density (W/Hz).

$$C/N0 = Pt + Gt + Gr - Lt - 10\log Ts - 10\log K \quad \text{in } (dB). \quad (21)$$

- *Energy Per Bit to Noise Spectral Density (Eb/N0)*

We may now introduce the universal Signal-to-Noise Ratio for digital communication. This ratio uses to evaluate the digital communication system.

Eb is Energy per information bit, Carrier power divided by actual information bits

Eb= C/R, where C is the carrier power and R is the actual information bit rate.

Using the Eb rather than overall carrier power (C) allows comparing different modulation schemes easily. N0 is the noise spectral density.

Eb/N0 Allows comparing bit error rate (BER) performance (effectiveness) of different digital modulation schemes. Both factors are normalized, so actual bandwidth is no longer of concern. Modulation schemes are compared through BER plots against Eb/N0

The modulation scheme is used in our CubeSat is FSK modulation

$Eb/No = EIRP + GT + 169.15 - Losses - 10\log(R)$ in (dB). (22)

Where: R is the data rate of the system, T is ratio between gain at receive side and temperature at the receiver [14].

- *BER Estimation*

To be able to assess the quality of our radio link relation between Eb/N0 and the error rate of the received the bits must be established the bit error rate must be low but at a reasonable cost only. FSK is used because it is simple and Consumes low power

BER of FSK modulation scheme is:

$BER = 0.5e - Eb/2No$ (23)

- *Link Margin*

Link margin is the difference between the minimum received signal level and the actual received power. The link margin must be positive, and should be maximized (should be at least 10dB or more for reliable links).

Link margin = received power sensitivity of receiver

$Lm = \mathrm{Pr} - S$ in (dB). (24)

Where: Lm is the margin (dB), Pr is the power received (dBm), Cmin is the minimum signal power requires (sensitivity of the receiver) (dB). The link status depends on the value of link margin, which will be close for positive value, that means the system is working well, and if the negative value for the margin is open, it is means that the system is not working [2].

V. SIMULATION OF THE RF LINK BUDGET

This program is designed to show all the input and output parameters together on an active screen in order to study the effects on the output results when one or more parameter is changed. The program has many variables that must be given to that program, such as the following parameters which are shown in Table (4).

Table (4). Input measurement

No	Input parameters	Units
1	Transmitter Power (Pt)	30 dB
2	Transmission Antenna Gain (GT)	8.5 dB
3	Back-off- Loss	0 dB
4	Feeder Loss	4 dB
5	Range or Distance between earth station and the satellite (R)	450 Km
6	Frequency (F)	900 MHz
7	Bandwidth of carrier (B)	26 MHz
8	Antenna Misalignment Loss (AML)	dB
9	Atmospheric Absorption Loss (AA)	0.5 dB
10	Polarization Mismatch Loss (PL)	3 dB
11	System noise temperature (Ts)	523.15 K
12	System line temperature (T0)	290 K
13	Antenna Gain Received (Gr)	dB
14	Received Losses (Rx loss)	dB
15	Minimum signal Power requires (Cmin)	-110 dB
16	Bit Rate	230 kbps

Then the MATLAB program is going to calculate the require parameters which are shown in the Table (5). After entering the parameters, the program decides if the link is closed or not. Depending on the condition that if PR is greater than the threshold level the link is closed, and if PR is less than threshold level the link is open. The link status depends on the value of link margin, it will be closed for positive value, that means the system is working well, and negative value for the margin is open and it is means the system is not working [15]. By using CODE/ MATLAB program to design the simulation.

Table (5). Output measurements

No	Output measurements	Units
1	EIRP	dBm
2	Free Space Loss (FSL)	dB
3	Total Losses	dB
4	Noise Figure (F)	dB
5	Figure of Merit (G/T)	dB
6	Signal Power Received (Pr)	dB
7	Carrier power density at earth station antenna (C)	dBw
8	Noise power (N)	dB
9	C/No at the earth station receiver	dB
10	Eb/No	dB
11	Signal to Noise Ratio (SNR)	dB
12	for a minimum bandwidth system, C/N	dB
13	Eb/No(overall)	dB
14	Bit error rate (BER)	
15	Link Margin	dB

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