Link Analysis for BILSAT-1

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Abstract—BILSAT-1, a 130 kg micro satellite, is Turkey's first Low Earth Orbit Earth (LEO) observation satellite[1,2]. The project was started in August 2001 at Surrey Satellite Technologies Limited (SSTL)'s facilities in Guildford, UK and BILSAT-1 was launched successfully from Plesetsk Cosmodrome, Russia in 27 September 2003. The main objective of the mission is remote sensing. The communications subsystem is a core system for Earth observation satellite. It is generally used for telemetry/ tele-command signaling, software uploading and image/data transfer. The BILSAT-1 communications subsystem is composed of VHF/UHF (amateur space band) and S-Band (commercial space band). Link analysis is essential for design of any satellite communications subsystem to observe the quality of the link. The link budget should be calculated; the positive link margin has to be guaranteed at all elevation angles that the proposed design requires before the actual manufacturing process starts. For BILSAT-1 communications subsystem, the link budget calculator program has been developed at pre-design phase. The program calculates the received Eb/No and the required Eb/No, and gives the difference as the link margin with respect to the elevation angles. The communications subsystem parameters such as RF output power, antenna size/type, power consumption etc. both at ground station and on board have been optimized according to the simulated links. These parameters ultimately effects overall project cost and time schedule. Also, to aid pre–launch/in-orbit test and to observe in-orbit link quality, some status points have been made available at BILSAT-1 satellite telemetry system. The measurements include a Received Signal Strength Indicator (RSSI) that provides an indication of the total signal power received. By using this data, the reliability of the link budget calculator program can be verified. In this paper, the above-mentioned link budget calculator program will be presented and the calculated and the actual link margins will be given and compared.

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1. INTRODUCTION

The BILSAT-1 is Turkey's first LEO satellite and is the member of DMC "Disaster Monitoring Constellation". The satellite was designed and built at SSTL facilities with contribution of Turkish engineers of TUBITAK – BILTEN between 2001 and 2003, and was launched from Plesetsk, Cosmodrome, Russia in 2003. It is at 686km sun synchronous orbit (10.30 AM – 10.30 PM). The picture of BILSAT-1 taken during Thermal Vacuum Test is given in Figure 1.

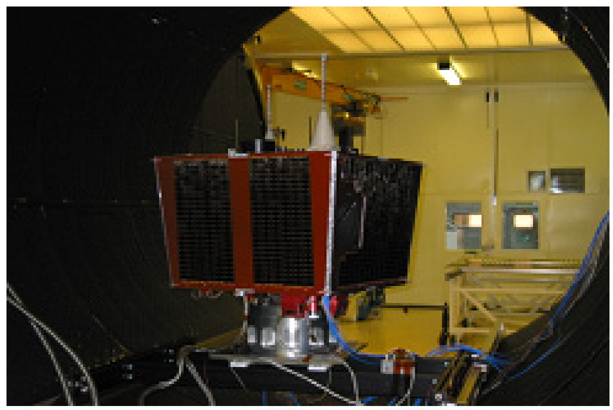

Figure. 1 - BILSAT-1, Thermal Vacuum Test

The main objective of the mission is remote sensing. The satellite has one panchromatic camera and four independent cameras forming a multi-spectral camera on-board. It has been taking and sending photos of Earth for more than two years.

The communications subsystem of BILSAT-1 is composed of VHF/UHF (amateur space band) and S-Band (commercial space band). In mission, uplink is used for tele commanding, software and files uploading; while, downlink is used for telemetry, image and files downloading. On board, there are two primary S-band receivers (in cold redundant manner), two S-Band patch antennas, two back-up VHF receivers (in hot redundant manner), and four VHF blade antennas for uplink. Also, there are two primary S-band transmitters (in cold redundant manner), two S-Band quadrifilar helix antennas, two back-up UHF transmitters

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(in cold redundant manner), and four UHF blade antennas for downloading [1].

There are some status points available in the telemetry system to aid pre–launch and in-orbit testing. For receivers, the telemetry includes an RSSI data that provides an indication of the total signal power received within the receiver bandwidth. Information about channel occupancy, frequency usage or interference level can be obtained by using this telemetry channel. In Figure 2, S-Band Rx_0 receiver RSSI data taken on 31 August 2005 is given in detail as an example.

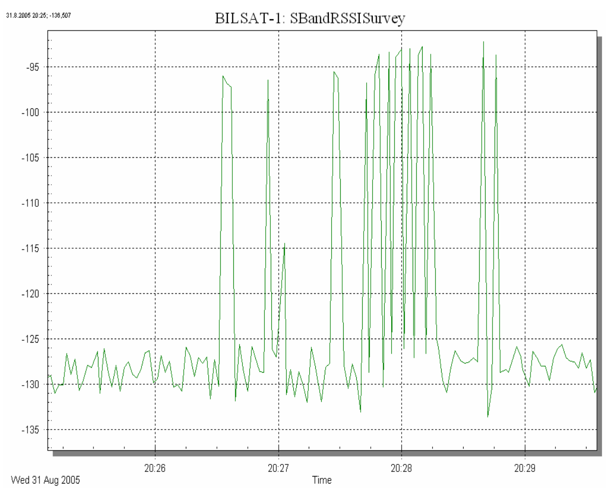

Figure. 2 - BILSAT-1 S-Band_ Rx0, RSSI Data

2. BILSAT-1 LINK BUDGET CALCULATOR

Complete analysis of the link quality is essential for any communications system design. For space communications, the factors that have relative importance on radio-wave propagation can be summarized as: the frequency of operation, the local climatology, the local geography, type of transmission, and the elevation angle. In detail, there are some mechanisms such as fading, absorption, scattering, refraction, diffraction, multi-path distortion and frequency dispersion. These propagation mechanisms have detrimental effects on the signal's amplitude, phase, frequency, polarization, angle of arrival and the bandwidth; therefore they have to be considered by the design engineers during the design phase. For space communications, the radio waves are primarily affected by the factors produced in two space regions, namely the troposphere and the ionosphere. At frequencies higher than 3GHz, the effects are primarily produced in the troposphere; however, at frequencies lower than 3GHz, the ionosphere primarily determines the effects. In troposphere the problematic factors are gaseous (mostly oxygen and the water vapor), rain, snow, fog, ice, clouds, and natural or the man-made noise. But, in ionosphere, the most important factor is the electron density irregularities [2-3].

For BILSAT-1, the link budget calculator program has been developed considering all loss mechanisms, detrimental effects, the overall satellite system criteria, time schedule and the project budget. In this link budget calculator program, the losses such as free space, rain attenuation, gaseous absorption, and antenna feeder/pointing/ polarization are calculated by using the formulas given in [2-3]. Also, for any ground station position in Turkey, the program can add the local climatology effects into calculations by using its weather forecast database. There are three main screens: definition of the parameters, the link budget table and the link budget graph. The examples of the program screenshots are given in Figure 3.

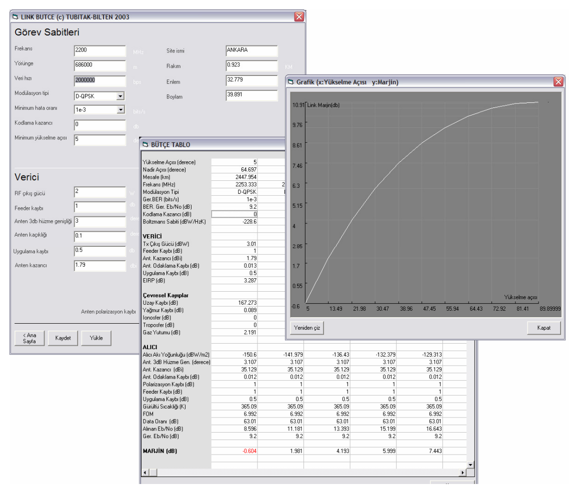

Figure. 3 - BILTEN-LINK Budget Calculator Screenshots

This tool has been used to simulate all up/down links. The goal is to maintain positive link margin at all elevation angles that the proposed design required by also considering the other factors such as DC power consumption, RF output powers, antenna sizes/types, and the cost for both ground station and on-board communications subsystems.

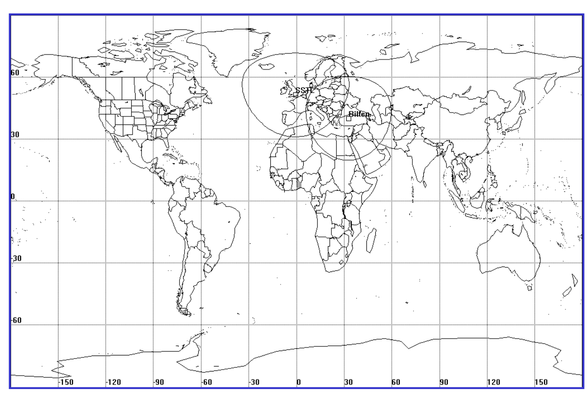

Figure 4 - BILSAT-1 Service Area (AGI – STK 5)

3. BILSAT-1 GROUND STATION

For BILSAT-1, there are two established ground stations. One of these stations is in Ankara, Turkey and the other is in Guildford, UK. The ground stations are capable of telemetry/tele-command signaling and data/image transfer. The service area that has been obtained by Satellite Tool Kit (STK) is shown in Figure 4. In this graph, the minimum elevation angle and the satellite orbit are assumed as 5 degrees and 686 km, respectively [4]. Ankara ground station was built at TUBITAK-BILTEN facilities in Middle East Technical University. The building and the ground station control room are given in Figures 5 and 6, respectively. Also, the ground station equipment rack configuration is seen as in Figure 7.

Figure 5 - TUBITAK-BILTEN Building

Figure 6 - BILSAT-1 Ground Station Control Room

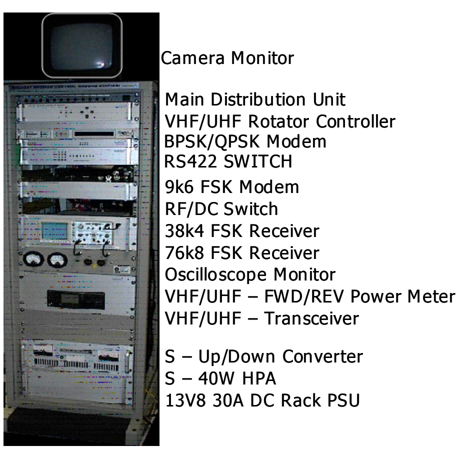

Figure 7 - BILSAT-1 Ground Station Equipment Rack

There are four links namely, VHF uplink, S-Band uplink, UHF downlink and S-Band downlink, for BILSAT-1. For all links, the data rate, modulation type and the frequency band are summarized as in Figure 8.

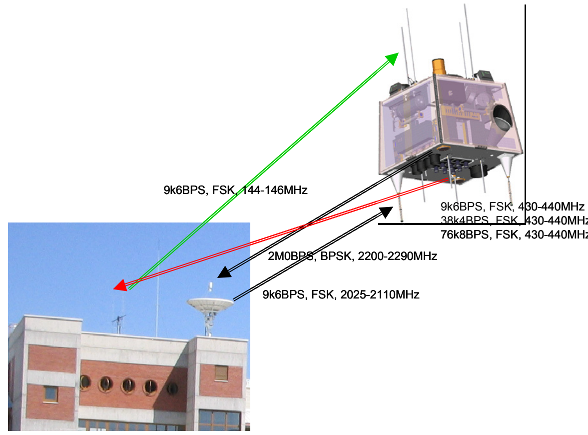

Figure 8 - BILSAT-1 Links

4. S-BAND LINK MARGIN AND THE RSSI TEST

The S-band receiver consists of three modules: the front-end band pass filter, the S-band down converter and the IF module. The front-end filter and the S-band down converter are fitted into the same nano-tray, and the IF module is housed in separate nano-tray. In Figures 9 and 10, the S-band down converter and the IF module are shown, respectively.

On-board, omni-patch antennas are used for the S-band reception. One patch antenna supplies to one receiver. The antennas were placed on the earth-facing facet of the spacecraft. The earth facet of BILSAT-1 and the patch antennas are shown in Figure 11.

Figure 9 - S-Band Down Converter

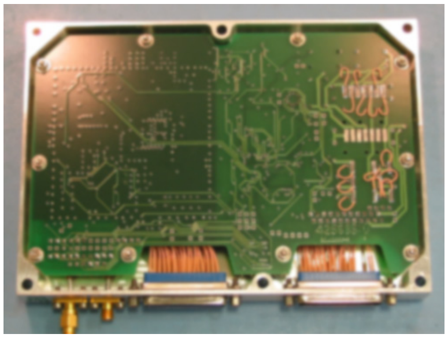

Figure 10 - S-Band IF Module

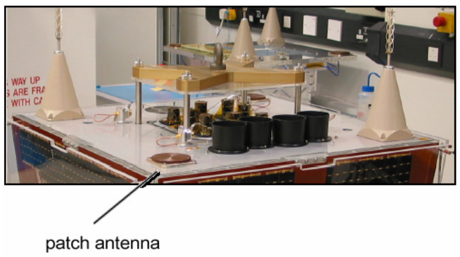

Figure 11 - BILSAT-1 Earth Facet

For RSSI measurement, there are internal op-amp and the micro controller in S-Band receiver IF modules. The gain of the op-amp is adjusted to achieve the full 0 - 4.1V range of the micro-controller analogue inputs. Inside the micro-controller, the RSSI voltage is converted into a count. Then, this count is returned as an RSSI telemetry data when the request is made. The count 1023 corresponds to the maximum voltage, 4.1V.

At ground station, there is a 3.7m dish with the gain of 34 dB within 2025-2100 MHz band. It was installed on the ground station roof. The backside of its reflector was covered with heating wires. The dish is used for both reception and the transmission at S-Band. The photos of the S-band dish and the VHF/UHF ground station antennas are given in Figure 12.

Figure 12 - Ground Station Antennas

For S-Band, the cable losses from ground station equipment rack to S-Band antenna feeder are depicted as in Figure 13.

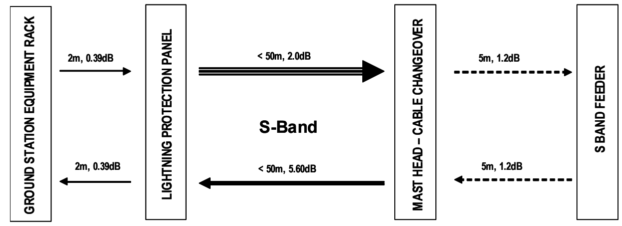

Figure 13 - Ground Station Cable Losses

So, the S-Band output power can be calculated as 12.89 W by using the following equation.

S BAND O/P: ~40W (16dBW) – Cable Loss (3.6dB) – Cons/Filter (0.5dB+0.7+0.1dB) = 12.89W (11.10dBW) (1)

A test was conducted to observe the S-Band uplink quality by using on-board RSSI data. During the test, RSSI telemetry data from S_Band_Rx_0 was taken. This data has been compared with the simulated values obtained from the link budget calculator program. The comparison is given in Figures 14 and 15. Also, the corresponding slant ranges with respect to time are graphed in Figure 16.

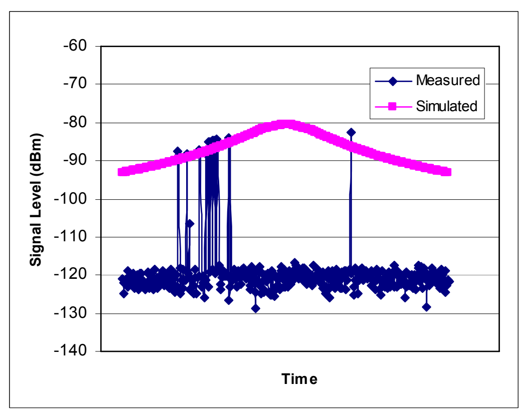

Figure 14 - Measured and Simulated Signal Levels

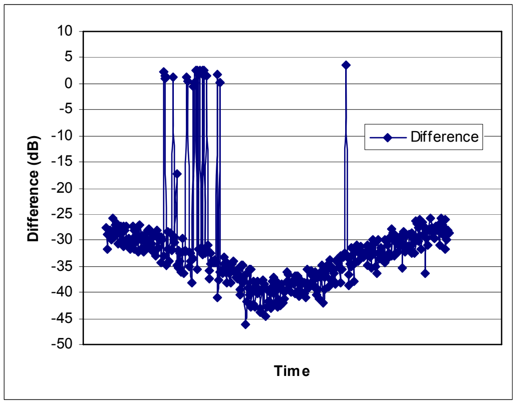

Figure 15 - Difference Between Measured and Simulated Signal Levels

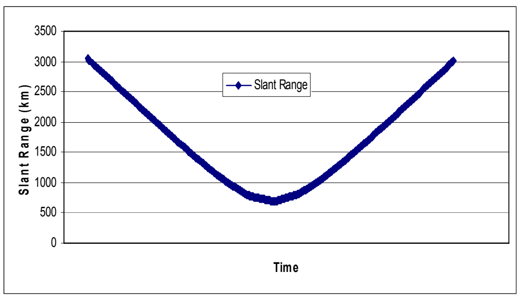

Figure 16 - Slant Range

The following procedure was used to compare the measured data to the simulated data. After the telemetry data were collected for a defined time interval, simulated slant range values between BILSAT-1 and BILTEN ground station were calculated using STK tool for the same time interval. In the next step of the procedure, the calculated slant range values, or the coresponding elevation angles, were input to the link budget calculator program, which in turn produced the simulated received signal strength values. Simulated and the actually received signal strength data were matched and compared by using their UTC time codes.

As it seems from the above figures, there were two-communication time intervals between the S-band receivers and the ground station. The first interval was when the satellite approaching from the horizon and the second one was when the spacecraft leaving from the horizon. According to the figures 14 and 15, the measured and the simulated received signal strength values are within ±2dB. In reality, it is expected that the simulation results are the worst case. In practice, the signal power level should be higher than the expected worst-case scenario.

The link margin is the measure of the link quality. It is the difference between the received and the required Eb/No in dB. To guarantee the link that is defined in the satellite design criteria, the link margin should be positive at all defined elevation angles. In Figure 17, the measured and the simulated link margins for S-Band uplink is given. For, BILSAT-1 S-Band uplink, the design criteria include 9k6bps data rate, FSK modulation with 10^{-6} BER at minimum 5 degree elevation angle. As it seems from the figure, the link margins are all positive during the communication times.

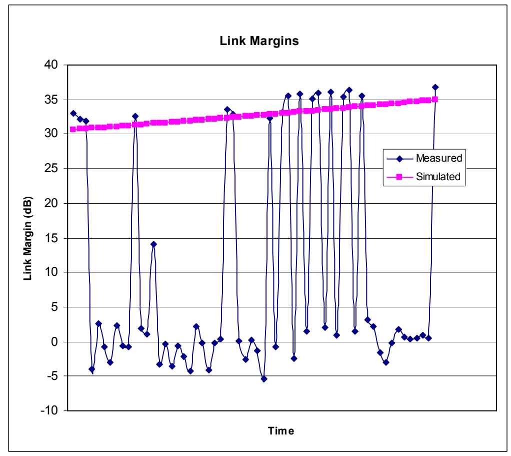

Figure 17 - Measured and Simulated Link Margins

5. Conclusion

BILSAT-1 is Turkey's first LEO Earth observation satellite and it is in orbit for more than two years. It has two communications subsystems namely VHF/UHF and the S-band. These links are used for tele-command/software/data uploading and telemetry /data/image downloading.

During the design phase, the link budget calculator program was developed. This program is used to observe the link quality by means of link margin before the actual design. For receivers, the telemetry data includes an RSSI value among others. This value is the indication of the total signal power measured within the receiver bandwidth. In this paper, the measured and the simulated RSSI data were compared in order to test if the S-Band uplink quality is within the design criteria, to identify the communication time slots and to check the applicability of the link budget calculator program in practice. Up on the obtained results, it is seen that the measured and simulated received signal strength values are within ±2dB. Moreover, the S-band uplink margins are all positive during the communication time slots showing that the design criteria have been met.

References

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Biography

Ali Telli received his BSc degree in EE Engineering from Hacettepe University in 1998, and his MSc degree in EE Engineering from Middle East Technical University in 2001, Ankara, Turkey. Between 1998-2000, he worked at ASELSAN Inc. as a "hardware systems engineer". In 2000, he joined to TUBITAK, and till 2001, he worked with Communications and Computer Networks Group. In 2001, he started to work as a " BILSAT-1 know how transfer team communications subsystem responsible engineer” at SSTL, in Guildford, UK. Since 2003, he has been working with Satellite Technologies Group at TUBITAK. His research areas include satellite communications, RF/Analog/Mixed Signal IC and MEMS Design.

Alphan Es is a PhD student at the Middle East Technical University (METU) in Turkey. He recevied his BSc degree in computer engineering from Ege University in 1996, in Izmir, his MSc degree in computer engineering from METU, in 2000, in Ankara, Turkey. He has been working at TUBITAK since 1997. His research interests include multi-disciplinary software application development, scientific visualization, real-time rendering, photo-realistic rendering, and GPU based algorithms. He is a member of ACM since 1998.