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# BILSAT-1: First Year in Orbit- Operations and Lessons Learned

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## ABSTRACT

BILSAT-1 is an enhanced micro satellite designed and manufactured in the framework of a KHTT programme between SSTL (UK) and TUBITAK-BILTEN (Turkey). The satellite was launched by a COSMOS 3M launch vehicle from the Plesetsk Cosmodrome in Russia on September 27, 2003. After being injected in a sun synchronous orbit at a 686 km altitude, it was commissioned successfully via ground control station at TUBITAK-BILTEN. After commissioning, the operations have started. Many images have been taken over Turkey and over various locations around the world.

In contrast to large national Earth Observation satellites such as LANDSAT, EO-1 and Terra, BILSAT addresses similar applications, with an emphasis on temporal resolution. BILSAT is a member of DMC (Disaster Management Constellation) that is an international consortium of which the member countries are UK, Algeria and Nigeria. The DMC satellites share the same orbit and separated from each other with a phase angle of 90 degrees. BILSAT as well as other DMC satellites has an on board propulsion and GPS navigation system by means of which the phasing of the DMC satellites have been managed by the end of first half of February, 2004.

BILSAT also accommodates some experimental payloads on board, including A multi-band Earth imager, an image compression processor, a GPS attitude receiver and a Control Moment Gyro. Two of these payloads are Turkish payloads designed and developed by BILTEN engineers at TUBITAK BILTEN. As well as these experimental payloads, BILSAT also hosts some new technologies such high capacity solid state data recorders and star trackers. These experimental payloads and new technologies are being operated and in orbit performances are being tested.

Since this is the very first LEO satellite that BILTEN has ever operated, some very valuable experience has been gained by BILTEN engineers about the LEO satellite operations.

This paper aims to describe what happened after launch, commissioning and during operations of BILSAT-1. It will detail the experiences gained by the experimental payloads, operations and the lessons learned.

## 1. Overview

BILSAT-1 is an earth observation satellite that was designed and built as a part of a KHTT programme[1], [2] between TUBITAK-BILTEN[1] and SSTL[2] through years 2001-2003. It is based on the enhanced micro satellite bus of SSTL and had a wet mass of 129 kg at the time it was launched.

BILSAT-1 was launched via a COSMOS 3M launch vehicle from a military cosmodrome in Plesetsk, Russia along with two other DMC[3] satellites (UK-DMC and NigerisSAT-1), and KaistSAT-4 small satellite as well as other payloads Larets, RUBIN 4/SL-8 and Mozhayets-4.


**Figure 1- On the launch vehicle:** All DMC satellites as well as other payloads are on the launch vehicle and ready for launch. BILSAT-1 satellite took place on the top to be released first once the upper most stage was in orbit.

The launch took place on September 27th, 2003 – 06:11:42.626 UTC[4]. The satellites were successfully launched into a 686km 10:0AM-10:0PM near sun synchronous orbit.

BILSAT-1; the first earth observation satellite of Turkey accomodates advanced Attitude Determination and Control Systems such as Star Cameras, sun sensors and gyros. The actuators on board allows the spacecraft for fast slew manoeuvres and reduces the ground target revisit time[1].

**Figure 2- Launch:** The launch took place on September 27th, 2003 on a COSMOS 3M Launch Vehicle

The communication system of BILSAT-1 is a hybrid system, featuring a UHF/VHF system and an S-band system. The UHF/VHF subsystem was selected because of its very long heritage on SSTL missions. During the nominal mission, it acts as the backup communications system, but were used as the prime system during the commissioning phase, due to its better omni directional properties. The S-band system is used during the nominal mission phase as the primary communications system, for both data and TT&C communications [5].

The prime payloads of the satellite are the 4-band multi spectral 26 m GSD imaging system and a 12 m GSD panchromatic imager. Other than these payloads, some interesting modules such as star cameras, gyros and high density SSDRs are also present on board BILSAT-1.

BILSAT-1, also accommodates various experimental payloads. The satellite has been alive and well for almost one year. The taskings and all operations are being directed via ground control ground station based at TUBITAK-BILTEN facilities.

## 2. Launch, Initial Signal Acquisition, Core Module Commisioning and After

BILSAT-1 together with UK-DMC and NigeriaSat-1 was among the payloads of the 409th Cosmos 3M launch vehicle. The target orbit required a tight launch window, as the spacecraft had to join Alsat-1 in orbit to form part of the constellation. The launch was set for 06:11:42 UTC on September 26th, 2003 from Plesetsk, Russia. Unfortunately 2 hours before, the launch was delayed due to a problem with the automatic fuelling system on

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[1] TUBITAK: Scientific and Technical Research Council of Turkey- A non profit government organization working in various areas of science and technology for the benefit of Turkey.

BILTEN: Information Technologies and Electronics Research Institute – works as an institute of TUBITAK specializing in various fields of information technologies.

[2] SSTL: Surrey Satellite Technology Limited- Leading small satellite company based in University of Surrey campus, Guildford, Surrey, UK

[3] DMC: Disaster Monitoring Constellation: An international constellation of satellites for rapid imaging of disaster zones on earth.

[4] Figure supplied by launch authorities at Plesetsk

the launch pad. The launch was delayed and rescheduled to 06:11:42 on of September 27th, After a successful launch on 27th, BILSAT-1 was delivered to orbit with an 0.0013° inclination error. As a result the contingency propellent for launcher injection errors would not need to be used, and could be budgeted for extending the constellation life time and propulsion experiments.

The first pass over TUBITAK BILTEN ground station occurred at 07:37:20 UTC, on the 1st orbit after separation from the launch vehicle, which was scheduled to occur 2083 seconds after launch. The BILSAT-1 transmitters are designed so that they can be operated in a partial vacuum, and so they could be switched on at the first pass. The initial commands (to power up UHF Tx and BCR, enable telemetry) was continuously transmitted from 07:39:54 around 2 minutes into the predicted pass. The first telemetry frame, which is revealed in figure 3, was received at 07:41:44.

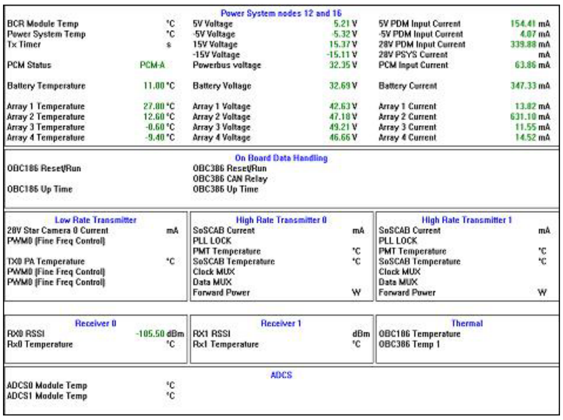



**Figure 3:** Initial Telemetry frame received

Initial telemetry had taken granted the health of the satellite with good power generation capability.

First, whole orbit data surveys revealed that the temperatures of the running modules were cycling between 6 and 14° C. This temperature range was close to the expected range for this low power configuration.

The battery was healthy, supplying 400 mA in eclipse, meaning approximately 6 % depth of discharge.

Once the ADCS module was powered up and the ADCS software was running on flight computer, it was revealed that spacecraft was spinning about an axis that illuminates array 1 & 2 in turn with about a 20 minute period.

When the spin rate of BILSAT-1 was reduced to <3°/s, the spacecraft was placed to Y Thomson orientation on 30th of September. Following the Y-Thomson orientation,BILSAT-1 was succesfully placed to nadir pointing attitude, which completes the attitude acquisition phase of the commissioning.

Following the first phase, all the core modules, including ADCS systems (sun sensors, magnetometers, magnetorquers), RF systems (UHF Tx, VHF Rx, S-band Tx, S-band Rx), on board computers (OBC 186, OBC 386-0, OBC 386-1) and SSDR PowerPC, commissioning was undertaken in a regular fashion. All the mentioned modules were working properly, within the expected temperature limits, drawing designed current values.

The first DMC satellite AlSAT-1 was already launched on November 28th, 2002 with a COSMOS 3M launch vehicle and had been in orbit for about one year.

COSMOS-3M launch vehicle injected the remaining DMC satellites (all three DMC satellites) and Korean KaistSAT-4 into the same orbit that made it pretty difficult to identify the satellites at first instant.

Due to the nature of DMC, in order to be distributed on the DMC orbit evenly, the four satellites were to be phased.

Thanks to their on board propulsion system, the four satellites, by means of several orbital manoeuvres, were placed evenly on the orbit.

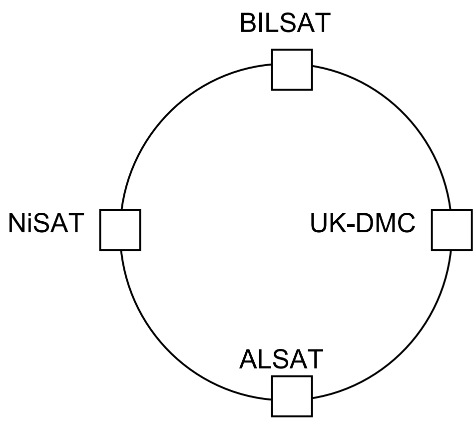



**Figure 4- DMC order:** The DMC satellites were distributed on the same orbit evenly

After phasing has been completed, the DMC satellites have been separated in the BILSAT-1, NigeriaSAT-1 , ALSAT-1, UK-DMC order.

The constellation gives the ability to image any region on the globe at least once per day.

## 3. Now The "EYES" of BILSAT Are On Earth

Once BILSAT-1 was injected into orbit successfully and passed basic health check, it was time to start taking some images of the globe. Taking first images obviously was a great excitement among BILSAT team. A number of images were taken just to adjust and fine-tune the exposure times of the cameras.

The multi-spectral imaging system has four separate cameras in red, green, blue and near infrared channels.

The spectrum ranges for these channels are give in the table below

**Table 1:** Multi spectral Camera Channel Spectrums

| Channel | Spect. Start | Spect. End |
|---|---|---|
| NIR | 774 | 900 |
| Red | 629 | 690 |
| Green | 523 | 605 |
| Blue | 448 | 516 |

As a natural consequence of the physical configuration, the images captured by each channel at one instant had some offset in terms of translation and rotation.


**Figure 5- Multi spectral imaging system channels on the earth facing facet:** Four channels exist in the blue, green, red and NIR (left to right) order. In this picture, temporary caps are closed to protect the lenses against any dust, dirt etc

A software was required to shift and rotate the raw images according to these offset values and combine each channel so as to produce a colourful image.

As can be seen above, in order to generate a RGB colour image, the images must be transformed. This transformation was modeled as a rotation and a translation with respect to a reference channel, which is chosen to be the Red channel.

The process of transformation can be described as calculating the position of a reference pixel on the green and blue images. The relation is formulated as follows:

$$\mathbf{P}_{green} = s_{green}\mathbf{R}_{green}\mathbf{P}_{red} + \mathbf{T}_{green}$$

$$\mathbf{P}_{blue} = s_{blue}\mathbf{R}_{blue}\mathbf{P}_{red} + \mathbf{T}_{blue}$$

where $\mathbf{P}_{green}$ and $\mathbf{P}_{blue}$ are the locations of the pixels on the green and blue images and $\mathbf{P}_{red}$ is location of the reference pixel from the red image. The parameters $s$, $\mathbf{R}$ and $\mathbf{T}$ are scale, rotation and translation values, respectively, which were calculated for once.

The scale, rotation and translation parameters were obtained after capturing several clear images with the MSI camera. Firstly, a sub-pixel corner detection was applied and several corners were extracted from each image. Then 30 corners were manually matched between each image. With the corner pairs, the unknown scale parameter, rotation matrix and translation vector were calculated using a least square sense algorithm. The calculated values are given in table 2 below.

**Table 2** MSI cameras offset parameters

| Channel | Scale | Rotation(°) | Shift(pixels) |
|---|---|---|---|
| Green | 0.9872 | -0.36 | [16,-143] |
| Blue | 0.9898 | 0.09 | [29,-103] |
| NIR | 0.9896 | 0.05 | [-65,11] |

Once these parameters were available, software for raw image processing was written. This software polls the storage area of the raw BILSAT-1 images and when a new image is downloaded it automatically acquires the data from the raw file. According to the chosen options it extracts the channels and forms the colored RGB images. An example image is given in the figures below. The first four images are the red, green blue and NIR channels of the MSI camera. The next picture is the transformed and combined version of the separate images obtained from red, green and blue channels.

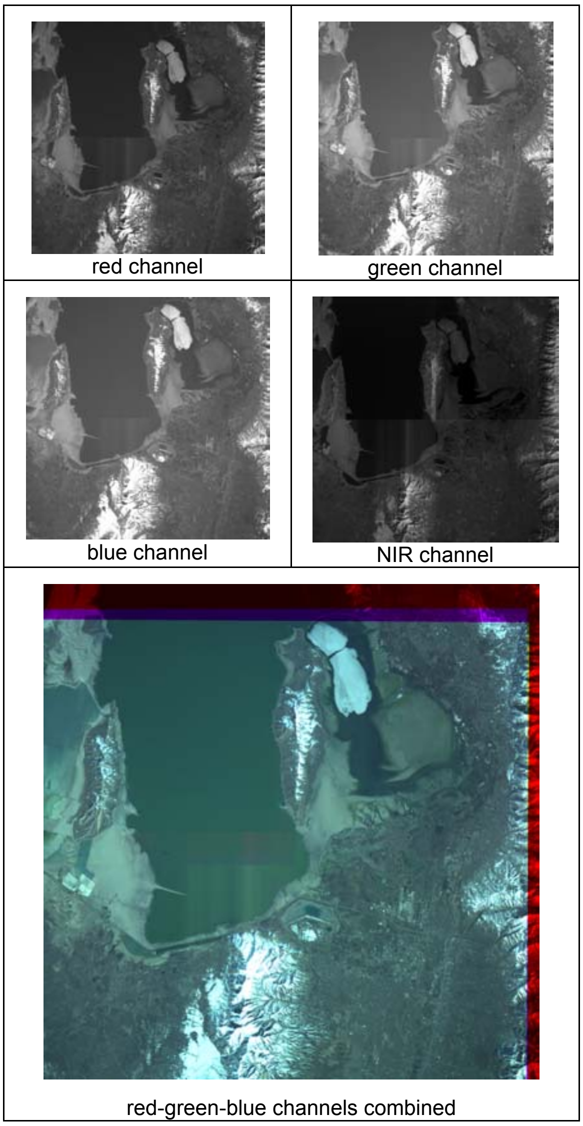



**Figure 6-** MSI Bands and combined image

In the picture above, it is easy to see that the channels do not overlap 100% and there is some offset on the edges. (right and top edges)

Once BILSAT-1 was operational the first target was to take as many images of Turkey as possible. Since the satellite was launched in winter, many of the first images over Turkey were cloudy. BILSAT team is hoping to take better pictures over Turkey by the summer season and targeting to image at least 75% of Turkey by the end of October 2004. Currently imaging tasks have been focused on this issue.

Since BILSAT-1 has a 2048x2048 pixel CCD array (i.e. not push broom), images are taken as snapshots. One square of MS image roughly corresponds a 50kmx50km area on the ground. So in order to make a continuous swath, images should be stitched one after the other.

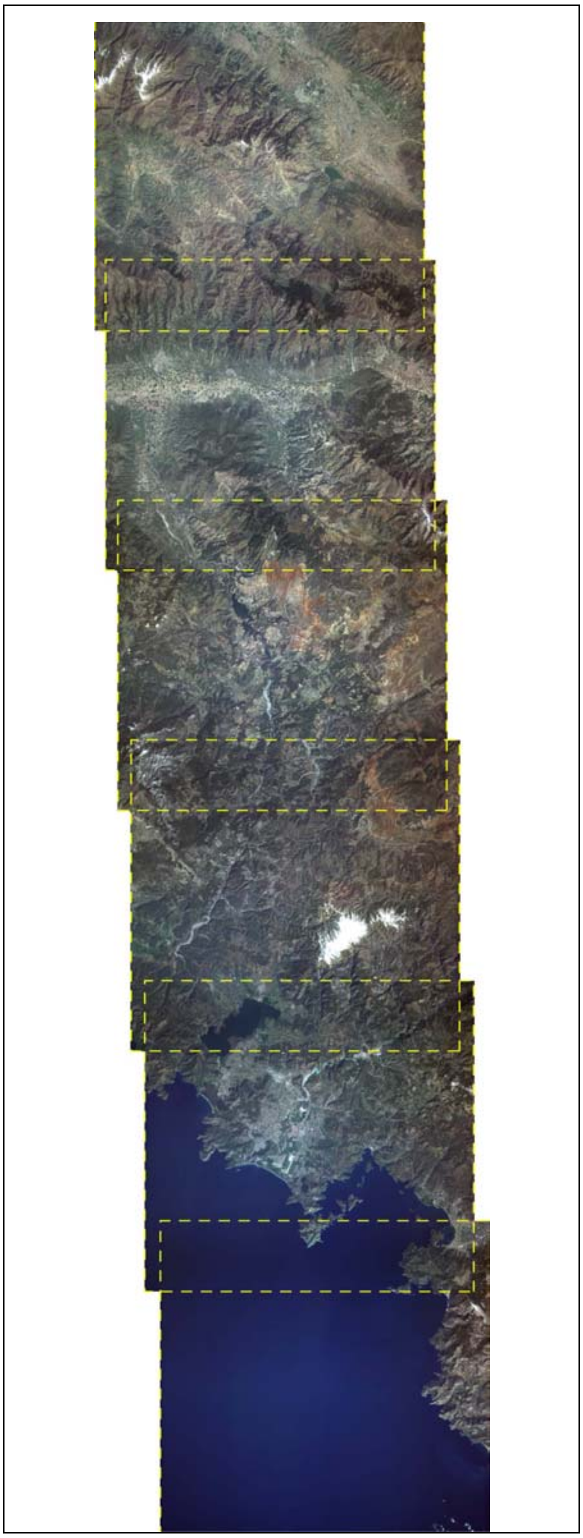


**Figure 7- Stitched images:** The bottom of the image corresponds to Fethiye-Oludeniz in the southern Anatolia (Mediterranean coast of Turkey)

The strip in figure 7 is created by stitching six snapshots taken one after the other. The overlap ratio between images can be adjusted by choosing suitable frame separation times.

Obviously, the more the frame separation time, the less the overlapping ratio.

Each square of image is shown by dashed lines (added artificially) in the picture. Since the satellite flies in the south-north direction (day time pass), the image on the bottom corresponds to the first image in the set. The shift in the east-west direction among the images is due to the rotation of the earth.

BILSAT-1 is also a member of an international consortium which is known as DMC (Disaster Monitoring Constellation). This constellation guarantees to image any location on the globe at least once per day. Currently there are four satellites in this constellation.

BILSAT-1 was the first to take a disaster image in the constellation when a number of images of the flooded regions in Jimani were taken.

**Figure 8-** Jimani, Flooded region (above). The flooded region was imaged by BILSAT MSI system on May 30th, 2004 (below)

BILSAT-1 is a three axis controlled satellite which means that the satellite can be rotated about any defined body axis to point the payloads (or the nadir vector) to a desired direction. To demonstrate this feature of the satellite, an experiment was done. The satellite was rolled about x axis to image the earth horizon.

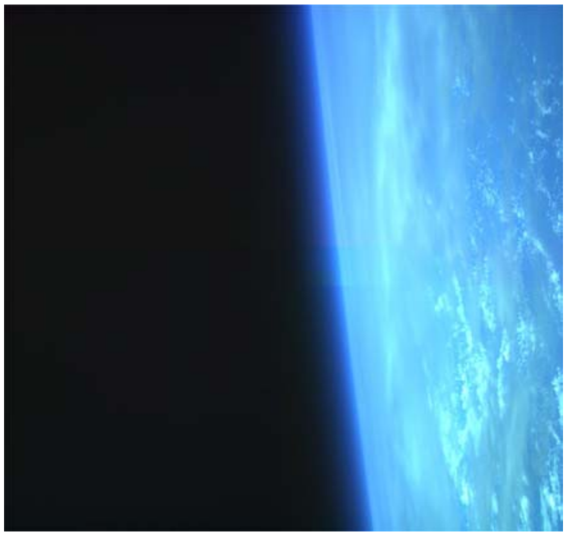


**Figure 9-** The earth horizon was imaged by rolling the satellite about X axis.

## 4. Experimenting With The Payloads

BILSAT-1 accommodates two experimental Turkish payloads that are known as GEZGIN and COBAN.

GEZGIN is a real time, JPEG2000 image compression subsystem and COBAN is a multi band camera.

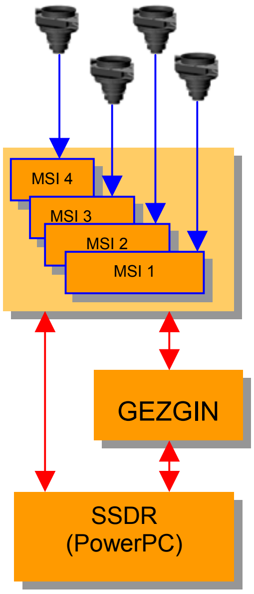
**Figure 10-** Real time image compression system GEZGIN

BILSAT-1 has a total access time of around 40 minutes per day to the ground station at BILTEN and the image downlink rate is 2 Mbps (Best conditions). Under these circumstances, it takes quite a long time to download large images, for example strips of images. Most times it takes a few passes to download all the images stored in SSDR (solid state data recorder)

GEZGIN can compress MSI (multi spectral imaging) system images up to a few hundred times in which case the size of large images drop down dramatically.

If a GEZGIN image as well as an MSI image of a certain location is taken, then simply downloading compressed GEZGIN image before downloading the original image will help to investigate the image quickly. If after investigation, it is decided that the image is of no use (i.e. mostly cloudy, or not desired any more), then time will not be wasted by downloading the original image for a longer duration.

GEZGIN is connected such that the image captured by MSI system can be compressed by GEZGIN at the same time and can be stored as a different file.




(SSDR = Solid State Data Recorder)

**Figure 11-** MSI System, SSDR and GEZGIN connections

As an example, below (figure 12) you can see an image taken by BILSAT MSI system (no compression).

The image in figure 13 is the image of the same area compressed by GEZGIN at the same instant.

**Figure 12-** MSI Image

**Figure 13-** Compressed GEZGIN image

Note that GEZGIN compression rate is adjustable via telecommand and in this example, the image was compressed 120 times

One can clearly see that although the image was compressed around 120 times, it is still possible to see almost the same level of detail as the original image.

One square of image captured by a single MSI channel has a size of around 4 MB which means that one square of MSI image is around 16 MB (all four channels). So the original image has a size of about 16 MB whereas compressed GEZGIN image has a size of a few hundred kilo bytes (depending on the compression rate)

Currently GEZGiN team are working on GEZGiN-2 image compression system which will be an improved version of GEZGiN-1. It is planned that GEZGiN-2 will fly in the next satellite that BILTEN is planning to design and build in the next few years.

## 5. Some Problems Faced And Lessons Learned

Due to the nature of the climate in Ankara (where the ground station takes place), the temperature goes down to about –30 degrees Celcius, and the snow stays for weeks. Due to these conditions, the joints of the dish antenna get frozen from time to time during nights. Once the joints get frozen, it is impossible to track the satellite and sometimes we have to wait until the sun melts the frozen ice. As a temporary solution to this problem, we configured the ground station such that it tracks satellites other than BILSAT from time to time, so there is a periodical activity such that we can avoid a long term of inactivity to let the melting snow accumulate on the joints and have enough time to freeze again.

**Figure 14- Ground station dish:** Due to freezing snow, the joints of ground station dish have been frozen many times

During the summer, again the antenna equipment experience high temperatures going up to +40 degrees Celsius which may cause some malfunctions on the control electronics. So the ground station team are planning to fit a cooling unit on the driving electronics box of the dish antenna.

BILSAT-1 has two VHF receivers and two S Band receivers on board. Before the flight it was planned to perform all TC / TM operations via UHF-VHF system, and the image downloading operations via S Band Tx/Rx system. However, after launch it was observed that the VHF Rx system could not be used effectively due to the fact that there was too much traffic on VHF frequency from other sources. So ground station team started to use S Band uplink even for the TM/TC operations.

The satellite accommodates two UHF transmitters one of them being 3 Watts and one of them being 10 watts. There are three downlink rates for TM which are 9.6 kbits/s, 38.4 kbits/s and 76.8 kbits/s. The 3 watt chain was designed to transmit upto 38.4 kbits/s and the 10 watt chain was designed to transmit up to a rate of 76.8 kbits/s, however it was observed that the link margin for 3 watt chain was quite sufficient to transmit with 76.8 kbits/s when the elevation angle was high enough.

BILSAT-1 has two 80386 processor based on board computers. At the design phase, it was planned that one of the OBC's will be used for house keeping tasks while other OBC would handle the ADCS tasks. However after launch, it was observed that one OBC386 could handle both housekeeping tasks and ADCS task without any problem so the nominal operations have been performed with one OBC386 only in order to keep the other OBC as a back up.

The satellite is scheduled to take an image according to time basis. This means, with a priori knowledge of satellite location when the time is given, the satellite imaging system can be scheduled to take a number of snapshots at that specific time. In order to calculate the satellite location at a given time, orbital prediction models should be accurate enough. The orbital prediction model used at the ground station, uses TLE (two line element) set given by NORAD (North American Aerospace Defense Command) It was observed that updating TLE set once a week is sufficient enough to shoot the image at the desired target without missing it.

## 6. CONCLUSION

There is still a lot of work going on with the subsystems of the satellite.

BILSAT team is trying to improve the control accuracy of the satellite by incorporating the star cameras of BILSAT.

Also SSDR (solid state data recorder) software is being updated such that the image file headers will involve various information about roll, pitch yaw values and GPS coordinates at the instant that image is taken.

A new Strong Arm 1100 based SSDR is also accommodated on board, the software for this SSDR is being designed.

A calibration campaign for the satellite images will be held during the summer of 2004 to solve various issues for the images obtained by imaging system of the satellite.

A lot of experience about satellite operations have been gained by BILSAT team which will form a precious basis for the design phase of the next satellite project that will be held at TUBITAK-BILTEN facilities.

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