Development of a LEO Communication CubeSat

A. R. Aslan, H.B. Yağcı, M.E. Umit, A. Sofyalı, M.E. Bas, M.S. Uludag, O.E. Ozen, M.D. Aksulu, E. Yakut, C. Oran, M. Suer, İ.A. Akyol, A.B. Ecevit, M.S. Ersöz
Istanbul Technical University, Istanbul, Turkey
aslanr@itu.edu.tr

İ. ÖZ, Ş.GÜLGÖNÜL, and TURKSAT NanoSat Group, TURKSAT Inc., Ankara, Turkey

Barış Dinç and Tahir Dengiz
AMSAT-TR, Ankara, Turkey

Abstract— **TURKSAT-3USAT is a three unit CubeSat developed for voice communication at low Earth orbit. The payload is a VHF/UHF transponder operating at amateur bands. The transponder and all other subsystems, except the stabilization, are doubled for redundancy. Where possible, both COTS systems and in-house development is employed. The energy is provided using lithium polymer batteries together with super capacitors. Satellite stabilization is accomplished using passive magnetic attitude control system with hysteresis rods. The TURKSAT-3USAT is launched from JSLC of China, on April 26, 2013.**

Keywords- 3U CubeSat; VHF/UHF Transponder; Voice Communication; Passive Stabilization, Redundancy

I. INTRODUCTION

CubeSats are now considered as a disruptive technology revolutionizing the way satellites are built [1]. Most large satellites involve development of custom equipment while CubeSats mostly rely on COTS components due to modest budgets available for their development [2]. The level of testing is also somewhat reduced since environmental test facilities are expensive and may not be readily available to the developers. The cost and availability of a piggyback launch is currently a major bottleneck, particularly for CubeSat developers from nations without a launch capability.

TURKSAT Inc., Turkey's national communication satellite operator is planning to design and manufacture Turkey's future communication satellites, starting with TURKSAT 6X. This is planned to be a joint effort between related national aerospace companies and research establishments. Currently, there are a number of development efforts towards national Earth observation satellites. Turkey has already three locally developed spacecraft, namely ITUpSAT1 [3], RASAT and Göktürk 2, serving in LEO. Meanwhile, the radio amateur world is also working towards development of small and affordable satellites particularly ones that include a payload which provides a tracking or communication possibility to the radio amateur world (www.amsat.org).

As a preliminary effort for Turkey's national aim of designing native communication satellites, TURKSAT Inc. and ITU along with AMSAT-TR (TAMSAT) has combined their experience and capabilities to build Turkey's first communication CubeSat, TURKSAT-3USAT. It is a 3U CubeSat with sufficient room for all the systems with full redundancy. Both in house developed systems based on COTS components and readily available commercial CubeSat systems (www.cubesatshop.com) are used together to achieve redundancy.

The payload of the 3USAT is an amateur band VHF/UHF transponder to be used for voice communication. The satellite's main structure is the ISIS 3-Unit CubeSat structure (see www.cubesatshop.com), which is a generic, modular satellite structure based upon the CubeSat standard [4]. As a concurrent study, an in house development of a 3U structure is also carried out. The TURKSAT-3USAT contains two on-board computers; two electric power system, and two beacons and modems. Both batteries and super capacitors are employed to store energy. The attitude of the designed satellite is stabilized passively in one axis. That axis is the longer principal body axis that will be aligned with the local geomagnetic field vector owing to a permanent magnet located along that longer axis. The engineering and flight models are built and environmental tests are carried out at related ITU laboratories.

TURKSAT-3USAT is launched on April 26, 2013 from Jiuquan Satellite Launch Center of China. The following sections present the current state of development of TURKSAT-3USAT. During the first day communication with the beacon and the transponder are established.

II. OVERVIEW OF TURKSAT-3USAT

The TURKSAT-3USAT is developed with maximum possible redundancy. All subsystems have a backup system with similar architecture (see Fig. 1). Where possible, both COTS systems and in-house development are employed. The list of development and COTS subsystems is given in Table 1.

Computational and model testing methods are used to estimate the behavior of satellite structure with respect to the launch environment. In design phase, finite element analyses were performed to determine the satellite's response due to launch conditions. According to static analysis, maximum stress is occurred as 60 MPa and the first four modes of the nano-satellite system model are computed as 236.5, 244.6, 248.6, 251.6 Hz as a result of modal analysis [5]. In design phase, numerical calculations are performed to predict the satellite's temperature of outer surface and subsystems, which are also compared to analytical solutions, as shown in Table 2. Following TURKSAT-3USAT's design and environmental test

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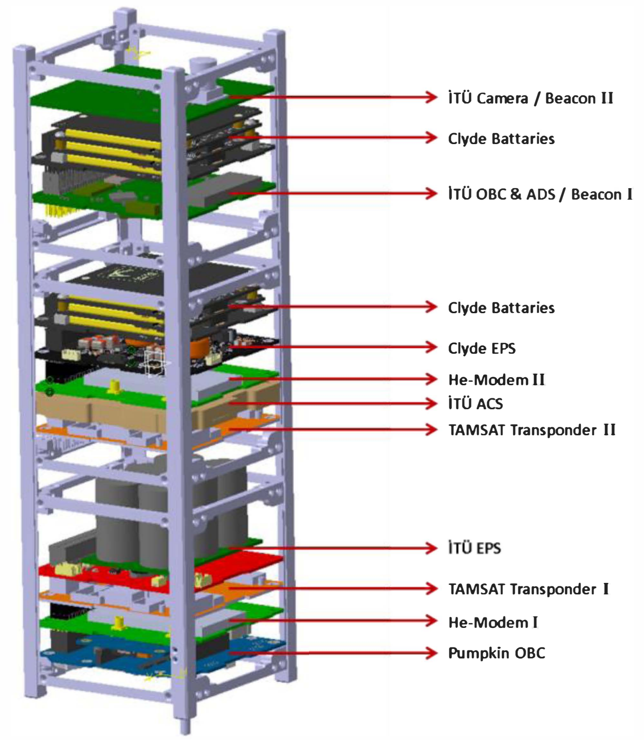


Figure 1. Overview and subsystems of TURKSAT-3USAT

TABLE I. TURKSAT-3USAT DEVELOPMENT

Subsystem	**Development**	**COTS**
Structure	-	www.cubesatshop.com
OBC	İTÜ	www.cubesatkit.com
PMACS (ADC)	İTÜ	-
Modem	-	www.astrodev.com
Beacon	-	BigRedBee
Transponder	TAMSAT	-
Antennae opening	İTÜ	-
Battery	-	www.clyde-space.com
EPS	İTÜ	www.clyde-space.com
Solar Cells	-	www.clyde-space.com
Camera Card	İTÜ	-

periods, its interior design was finalized as shown in Figure 1. The redundant system architecture of the 3USAT is shown in Figure 2. The total mass of the 3USAT is 3154 grs. The mass budget is given in Table 3.

One of the important subsystems is antenna deployment on the satellite because of communication. There are two types of antenna systems and 10 antennas on the satellite because of receiving and transmitting data and voice communications. Four antennas are for uplink and others are for downlink. The first system - consisting of four antennas: two of them are used for transponders (see Fig. 3c) and others are used for modems (see Fig. 3a) - is the 145 MHz receiving unit for uplink. The four antennas of this system are quarter wave dipoles, thus these antennas measure 50 cm length and 3mm wide. The

TABLE II. TURKSAT-3USAT SUBSYSTEMS

Subsystem	Operational Temperature Range	Thermal Analysis Result Range
ADCS	-30°C +85°C	-19°C +44°C
Batteries	-20°C +50°C	-20°C +43°C
EPS	-40°C +85°C	-20°C +53°C
CDHS	-30°C +60°C	-30°C +60°C
Transponder	-40°C +85°C	-19°C +62°C
Communications	-40°C +85°C	-21°C +47°C
OBC	-40°C +85°C	-18°C +33°C
Camera	-40°C +85°C	-22°C +21°C

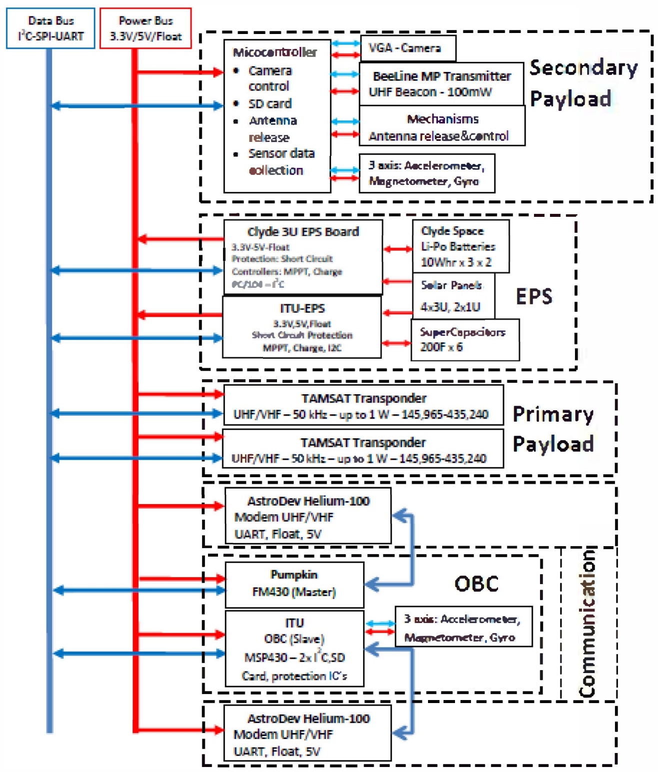
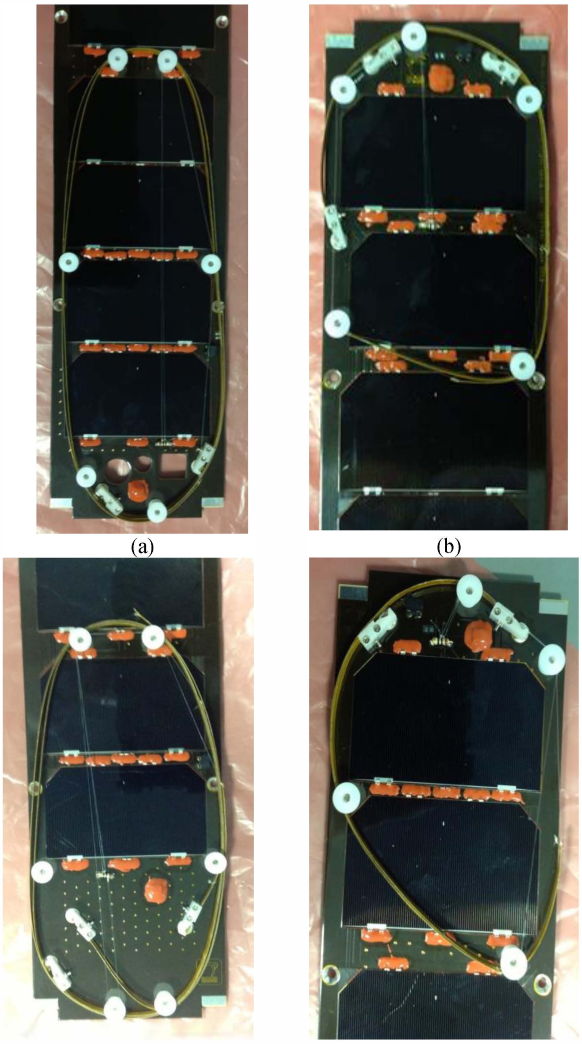


Figure 2. TURKSAT-3USAT system architecture

second system is used for beacons, modems & transponders downlink and comprises 435 MHz transmitting for downlinks and also quarter wave dipoles. As a result, antennas of the second system measure 17.5 cm length and 3 mm wide (see Figs. 3b and 3d). Antenna deployment system is going to melt the fishing line 1 hour and 10 seconds after deployment of the satellite. A similar system was used for the ITUpSAT1 [3].

TABLE III. TURKSAT-3USAT MASS BUDGET

Subsystem	Mass
Structure	620 gr
EPS (controller and batteries)	779 gr
Mechanism	82 gr
Solar Panels	701 gr
Communication	176 gr
C&DHS	169 gr
Cables & Connectors	181 gr
Passive stabilization	220 gr
Transponder	196 gr
Camera-sensors	30 gr
Total	3154



(a) (b) (c) (d)

Figure 3. TURKSAT-3USAT antennae system

III. TRANSPONDER

TURKSAT-3USAT CubeSat contains two transponder modules. These transponder modules are designed to be linear inverting transponders. The task of the transponder is to receive radio communication information on VHF ham radio band (145.940 – 145.990 MHz) and send it back on UHF ham radio band (435.200 – 435.250 MHz) after required amount of amplification and filtering. Inverting transponder is preferred to minimize the Doppler effect on communications (see Table 4). The design and development of the transponder module is conducted by volunteer radio amateurs, who are members of TAMSAT (Turkish Amateur Satellite Organization).

TABLE 4. TAMSAT TRANSPONDER SPECIFICATIONS

Input Frequency	145.940 – 145.990 MHz
Output Frequency	435.200 – 435.250 MHz
Transponder Type	Inverting – Linear
Modulation	All Mode (AM, FM, SSB, CW, FSK,etc.)
Bandwidth	50 KHz
RF Power (max)	1 Watt - 30 dB

The functions of the transponder blocks shown in Figure 4 can be summarized as follows:

- The RF signals captured by the VHS antenna is fed to a series of LNAs with a controlled amplification (Low Noise Amplifiers) through the VHF band pass filter, which eliminates amplification of unwanted out-of-band signals,
- After amplifying the signals to a certain point that can be fed to the mixers, the signal is mixed with the first local oscillator VCO-1, whose frequency is controlled by the MCU/PLL pair,
- A very sharp SAW fitler with 50 KHz bandwidth is used to limit the bandwidth of the transponder to 50 KHz,
- Then the signal is fed to the AGC (Automatic Gain Coltrol) block, which controls the gain amplification according to the input and output signal of the transponder,
- Then the signal is converted to the output frequency band by mixing the signal with the second oscillator VCO-2 that is controlled by the MCU/PLL pair,
- The output signal at the desired transmitting frequency is filtered and amplified through a series of LNAs and filters,
- The final stage is a band filter to avoid harmonics to disturb other onboard modules.

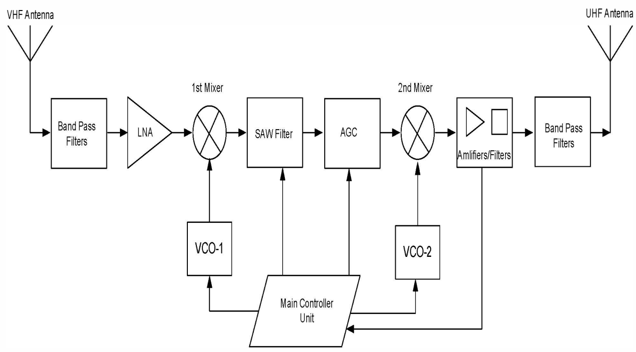


Figure 4. TAMSAT transponder schematic

IV. POWER SUBSYSTEM (EPS)

Power subsystem regulates and distributes power generated by the solar panels to other subsystems. Power from the batteries is also distributed by that system. The data on battery charge level, temperature, voltage and current levels are transferred to the onboard computer by the EPS.

The EPS consists of Clyde-Space 3U EPS and ITU-EPS developed during the project. The overall EPS schematic is shown in Figure 5. When spacecraft is powered on, first, the Clyde EPS (primary) will become active to provide power to the spacecraft. Meanwhile, the microcontroller of ITU-EPS will be powered from main battery to monitor the main EPS. In case of a failure with the main EPS, the ITU-EPS will take over and provide power to the spacecraft. This scheme provides a simple and reliable redundancy. Switching EPS scheme is controlled by OBC automatically or by ground station manually.

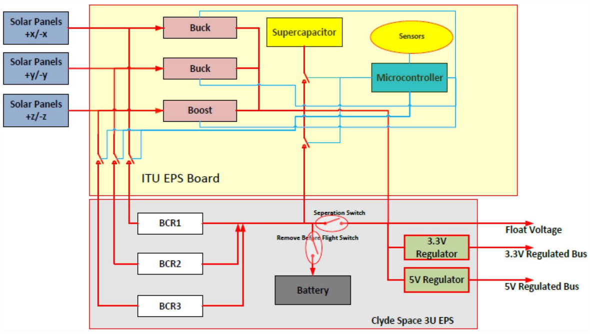


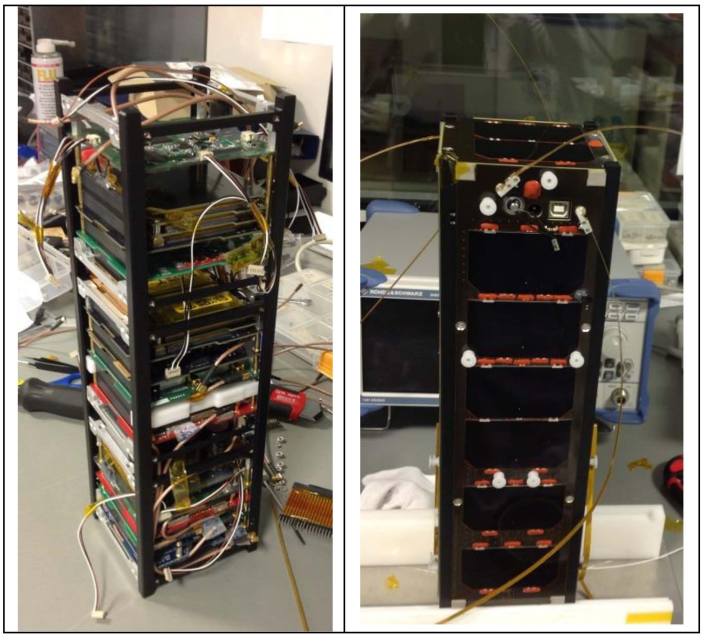
Figure 5. TURKSAT-3USAT EPS schematic

V. PASSIVE MAGNETIC ATTITUDE CONTROL SYSTEM

Since the TURKSAT-3USAT will use monopole antennas for communication (see Fig. 6b), the mission does not require high pointing accuracy. The operation altitude, which is 645 km, makes the usage of passive aerodynamic stabilization method inefficient. Deploying a gravity-gradient boom is impossible due to volume restrictions thus the third passive method that utilizes the geomagnetic field is preferred to stabilize the satellite. This method does not require any substantial amount of power.

The aim of the passive magnetic attitude control system is to keep one of the satellite's principal body axes along the desired direction, which is the direction of the local geomagnetic field vector along the orbit. By utilizing permanent magnets along the longer (3U) axis, the orientation of that axis around the local magnetic field direction can be guaranteed. The stabilization can be achieved only if a damping torque is produced. Hysteresis rods are used to transform the kinetic energy of the satellite to heat while interacting with the Earth's magnetic field. They are placed in the plane perpendicular to the magnet axis, i.e. along the other two principal body axes.

The passive magnetic attitude control subsystem consists of eight sintered permanent magnets of AlNiCo-8H each with dimensions of 9.525 mm (diameter) and 6.35 mm (height) and ten hysteresis rods of HyMu80, six with dimensions of 1x1x80 mm, four with dimensions of 1x1x110 mm. The permanent



(a) (b)

Figure 6. TURKSAT-3USAT without and with solar panels

magnets produce the restoring torque by interacting with the local geomagnetic field vector **B**, which serves to align the body axis that is parallel with the magnets' polar axes (in our case, the longer 3U axis) with **B**. The hysteresis rods are used to reduce the angular kinetic energy, also the angular velocity of the satellite's body by producing the damping torque as a result of variable self-magnetization and interaction with Earth's magnetic field. In the transient regime of the passively controlled attitude motion, the dominant restoring torque carries the body axis aligned with magnets' axes to the steady state angular orientation, which is determined by the direction of the initial angular velocity vector of the satellite and the total magnetic moment value of permanent magnets. The steady state angle value between that body axis and the **B** vector, β, may vary between 0 and 90 degrees according to simulations run with various initial angular velocities. In that regime, the relatively much lower damping torque guarantees that the steady state orientation is reached, and also accelerates the stabilization. During the transient motion, the angular velocity may first increase due the dominating directing effort of the magnets, and it is damped to the steady state value afterwards. The steady state motion exhibits oscillations around constant steady state values of both β and the angular velocity components around the three body axes.

The results of a simulation, in which the hysteresis mathematical model used in [6] is utilized, initialized with β=130° and zero angular velocity can be seen in Figs. 7 and 8. In Fig. B, *w1* corresponds to the angular velocity component around the 3U body axis whereas *w2* and *w3* are the components around the other two 1U body axes. The attitude sensing system consists of a 3-axis MEM magnetometer and 3-axis MEM gyroscope providing the onboard computer with the three components of the local **B** vector and the three components of satellite's angular velocity along the body axes. It includes also a 3-axis MEM accelerometer to sense the aerodynamic deceleration of the satellite in long while. No determination is carried out onboard because the passive attitude control system requires no measurement feedback.

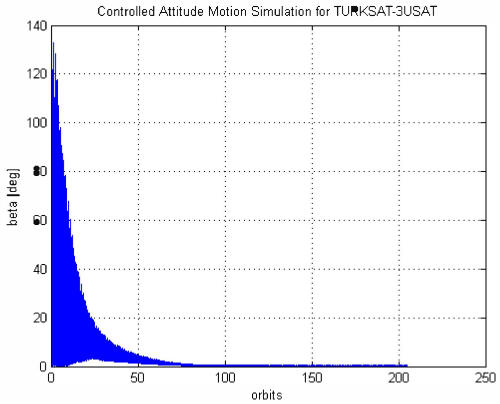


Figure 7. Angle between 3u axis and **B** vector

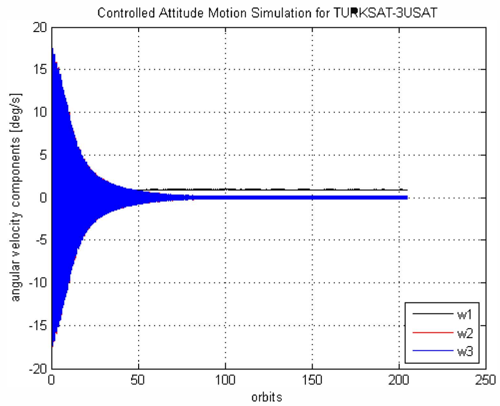


Figure 8. Angular velocity components

VI. CABLING

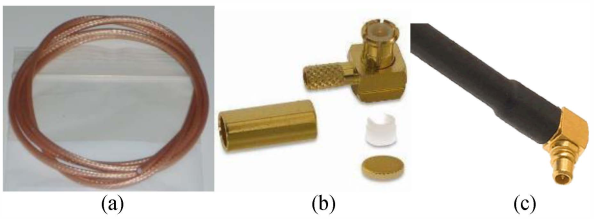


Figure 9. (a) RG-316 cable, (b) MCX connector, (c) MMCX connector with shrink cover

RF (Radio Frequency) cables are RF signal pipelines of the TURKSAT-3USAT. There are ten cables in our topology. Four of the cables are for Modem-1 and Modem-2 as Rx and Tx cables. Transponders also have four cables for receiver and transmitter terminals. Remaining two cables are for the beacons of the camera and the OBC. Lengths of the cables are determined as equal to minimum possible distances from the circuit to the antenna (see Table 5). Cables have MCX (se Fig. 9b) and MMCX (see Fig. 9c) connectors because of their small size. They also have shrink coverings to avoid any distortion on the cable. Objectives of the RF cables are transporting the RF signal from hardware to antennas of the satellite and from the antenna to the Rx input of the circuit board. Thus they must have quite low signal attenuation and for that reason RG-316 cables (see Fig. 9a) are used. The cables must also be subjected to short circuit test. If any cable is short circuited, it cannot transmit or receive the signal. Lastly, Rx and Tx cables should not overlap each other because Tx cables carry more power than Rx cables, and their harmonics may harm the Rx port.

TABLE 5. TURKSAT-3USAT HARNESS INFORMATION

Cable ID	Cable Name	Lenghts (±8 mm)
1	Modem-1 Rx	265
2	Modem-2 Rx	345
3	Modem-1 Tx	400
4	Modem-2 Tx	320
5	Camera Beacon	85
6	Transponder-1 Rx	180
7	Transponder-2 Rx	80
8	OBC Beacon	355
9	Transponder-1 Tx	320
10	Transponder-2 Tx	340

CONCLUSION

A nano-satellite with full redundancy is developed for voice communication at low Earth orbit. It can be considered as a preliminary effort for Turkey's national aim of designing native communication satellites considering Turkish national satellite operator TURKSAT's plan to produce the first GEO communication satellite towards 2020.

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