TUUSAT-1A: The First Academic Microsatellite Developed by Universities in Taiwan

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ABSTRACT

This paper describes the mission and current design results of Taiwan Universities-United Satellite NO.1A (TUUSAT-1A), which is a student microsatellite developed by a conjunct program of several universities in Taiwan. The mission goal of TUUSA-1A, according to the priority, includes two CMOS cameras of 1.3 million pixels for Earth imaging, one GPS receiver for orbital determination, and the commercial off-the-shelf (COTS) components for space qualification. The TUUSAT-1A main body is cube-shaped with size of 25 x 25 x 25 cm³ and weight of 26.4 kg. It is expected to be launched into a circular orbit with 500 km altitude and 21 degrees inclination by piggyback from most launch vehicles. Currently, the TUUSAT-1A project is on the design phase and the Critical Design Review (PDR) will be accomplished in October 2007. TUUSAT-1A is expected to be launched in the middle of 2008. This paper describes the mission and current design results of TUUSAT-1A, the results of environmental tests status of the COTS components by using NSPO Integration and Test Facility, and lessons learned from the program.

INTRODUCTION

Taiwan Universities-United Satellite (TUUSAT) is the academic microsatellite research program in Taiwan developed since 1995 and TUUSAT-1 is the first microsatellite project of TUUSAT program which was developed during 1995-1998. TUUSAT-1A is heritage form TUUSAT-1 and is funded by National Space Organization (NSPO) of Taiwan. The participants of TUUSAT-1A project are professors, graduate students and undergraduate students from different universities, currently including National Central University (NCU), Tamkang University (TKU),
National Formosa University (NFU) and National Chiayi University (NCYU) with technical supports from NSPO’s past experiences in YAMSAT\textsuperscript{10-12}. The primary mission of TUUSA-1A includes two CMOS cameras of 1.3 million pixels for Earth imaging, processing and transmission, one GPS receiver for orbital determination, and the commercial off-the-shelf components (COTS) for space qualification. The secondary mission objective is to demonstrate the way in which the microsatellite can be built quickly and inexpensively with minimum industry support for both scientific research and educational purposes, as well as to educate students in design, manufacturing, integration and test, and operation of a real satellite. Currently, the TUUSAT-1A mission is in the design phase and will accomplish the Critical Design Review (CDR) in October 2007. TUUSAT-1A is expected to be launched in the middle of 2008. This paper describes the mission and design results of each subsystem of TUUSAT-1A, the results of environmental tests status of the COTS components by using NSPO Integration and Test Facility, and lessons learned from the program.

**MISSION OVERVIEW**

The TUUSAT-1A is expected to be launched into a circular orbit with 500 km altitude and 21 deg inclination by the launch vehicle (LV) provided by NSPO. Fig. 1 shows the ground track of TUUSAT-1A. There are 15 revolutions, five contacts between the spacecraft and ground station appeared everyday and the average contact duration is 306 seconds (with minimum 15 deg elevation of ground antenna). The mission architecture of TUUSAT-1A is shown in Fig. 2. The initial spin rate of satellite is quite fast (3 cps) and it needs about 3 days for attitude stabilization by a passive magnetic damping approach. For the early orbital acquisition after separation from LV, the satellite will transmit the beacon by 12 sec per 5 minutes to the ground. The beacon is a sentence consisted of the state-of-health (SOH) and GPS data. The ground station will update the orbital elements of the ground track software by the GPS data received from TUUSAT-1A in order to control the pointing of UHF/VUH ground antennas. When the satellite passes into the communication range of Taiwan, the satellite will be controlled by the telecommand instructions transmitted from TGS to take Earth images or download/upload files stored in the onboard memory. There are three ground stations built by the students of TKU, NFU and NCYU respectively. One of them will be operated for TLC and TLM and the others are only for TLM.

Figure 1: TUSAT-1A orbital ground track

Figure 2: TUUSAT-1A mission architecture

The successful criterion of TUUSAT-1A mission is categorized as four levels as follows:

**Level 0** - Complete and pass the ground tests of system/component for space flight via NSPO ground test facilities

**Level 1** - Successfully receive first beacon data from satellite.

**Level 2** - Successfully uplink TLC to TUUSAT-1A and downlink science data from satellite.

- Command the camera to take images
- Command the satellite to downlink the image
• Continuously receive orbit health datum from downlink

Level 3 - Successfully verify the performance of each satellite subsystem.

• Qualification of COTS components

• Verify the performance of payloads

**SATELLITE DESCRIPTION: BUS SEGMENT**

The key features of TUUSAT-1A satellite configured for the mission are summarized in Table 1.

<table>
<thead>
<tr>
<th><strong>Table 1: Key features of TUUSAT-1A</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Dimensions</td>
</tr>
<tr>
<td>Mass</td>
</tr>
<tr>
<td>Average power</td>
</tr>
<tr>
<td>Peak power</td>
</tr>
<tr>
<td>Attitude control type</td>
</tr>
<tr>
<td>Attitude accuracy</td>
</tr>
<tr>
<td>Communications</td>
</tr>
<tr>
<td>Telemetry</td>
</tr>
<tr>
<td>Telecommand</td>
</tr>
<tr>
<td>Mass memory</td>
</tr>
</tbody>
</table>

**Structure Mechanical Subsystem**

The configuration of TUUSAT-1A bus structure is based on a cube-shaped module and there are six solar panels mounted on each side of bus structure, as shown in Fig. 3. The main body of TUUSAT-1A consists of four trays made by aluminum alloy 6061. The first tray on the top accommodates the camera circuit board, LPF, HPF and battery charger & regulator, as shown in Fig. 4. The second tray accommodates two magnets, two cameras and the transceiver TH-D7E, as shown in Fig. 5. The third tray accommodates two sets of batteries and four hysteresis rods wrapped with shorted coils, as shown in Fig. 6. The fourth tray on the bottom accommodates the onboard computer MPC-555 and GPS device, as show in Fig. 7.
Attitude Control Subsystem

The TUUSAT-1A ACS adopts the passive magnetic attitude control system (PMACS) consisted of 2 permanent magnets and 4 hysteresis rods wrapped with shorted coils as shown in Figs. 5~6. The PMACS has been applied to several satellites successfully, such as Vanguard satellite (1958), TRANSIT satellites (1960), and early OSCAR series satellites, among others. When the satellite is on the orbit, the magnetic rods will interact with local geomagnetic field like a compass needle such that the z-axis will align with and oscillate about the local geomagnetic field direction (Fig.8) as it is displaced from that direction. The hysteresis rod and wrapped shorted coils are adopted as the dampers to dissipate the rotational energy transferred from the LV.

It is estimated that the components of ACS hardware only cost about $1,350. In order to verify the performance of TUUSAT-1A ACS, the software simulator was developed by the MATLAB computer language. Fig. 9 is the simulation results of TUSAT-1A ACS, and it shows that the deviation from the z-axis to geomagnetic field direction is less than 15 deg in steady-state and it needs about 2~3 days to slowdown the spin rate from 180 rpm to 0.3 rpm.

Thermal Control Subsystem (TCS)

The TUUSAT-1A TCS adopts the passive thermal control approach to achieve the internal thermal balance of satellite. In order to verify the TUUSAT-1A TCS, an analytical thermal (grid nodes) model was developed by the MATLAB computer language. The thermal

Figure 8: The z-axis of TUUSAT-1A will align with the geomagnetic field direction.
analytical parameters and material characteristics of TCS are shown in Table 2–3, respectively. The beta angle of TUUSAT-1A orbit for one year is simulated in Fig. 10 and the result shows that the beta angle is varied between ±44.38 deg. The environmental heating values for the hot and cold cases are shown in Fig. 11. Table 4 shows the operational temperature limits of components of subsystems and it shows that the most critical temperature limit of component for TCS is the battery at Tray 2 which the operational temperature limit is between 5°C to 40°C. Table 5 is the simulation results of the analytical model for the cold and hot cases (beta = ± 44.38 deg). It shows that the temperature of each tray can be controlled within the operational temperature limits of Table 4.

**Table 2 Thermal analytical parameters**

<table>
<thead>
<tr>
<th>Altitude</th>
<th>500km</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inclination</td>
<td>21 degree</td>
</tr>
<tr>
<td>Orbit Period</td>
<td>94.6 min</td>
</tr>
<tr>
<td>Size</td>
<td>25cm×25cm×25cm</td>
</tr>
<tr>
<td>Weight</td>
<td>20kg</td>
</tr>
<tr>
<td>Spin rate</td>
<td>3rps(initial rate) 0.005rps(target spin rate)</td>
</tr>
</tbody>
</table>

**Table 3 Thermal characteristics of materials**

<table>
<thead>
<tr>
<th>Structure materials</th>
<th>Thermal character</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anodized outer surfaces of Aluminum 6061</td>
<td>l=166W/m-K r=2700kg/m3 Cp=895kJ/g-K α =0.14 ε =0.45</td>
</tr>
<tr>
<td>Solar panel (Ga-As)</td>
<td>α =0.92 ε =0.86</td>
</tr>
</tbody>
</table>

**Table 4: Operational temperature limits of components**

<table>
<thead>
<tr>
<th>Component</th>
<th>Operational temperature</th>
<th>Margins</th>
<th>Acceptable temperature</th>
<th>Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>MPC555</td>
<td>-20°C 60°C 5°C -15°C 55°C</td>
<td></td>
<td></td>
<td>2.5W</td>
</tr>
<tr>
<td>Battery (charge)</td>
<td>0°C 45°C 5°C 5°C 40°C</td>
<td></td>
<td></td>
<td>13.71W</td>
</tr>
<tr>
<td>Battery (discharge)</td>
<td>-20°C 50°C 5°C -15°C 45°C</td>
<td></td>
<td></td>
<td>1.235W</td>
</tr>
<tr>
<td>TH-D7E</td>
<td>-20°C 60°C 5°C -15°C 55°C</td>
<td></td>
<td></td>
<td>17.28W</td>
</tr>
<tr>
<td>GPS 12</td>
<td>-20°C 60°C 5°C -15°C 55°C</td>
<td></td>
<td></td>
<td>1.65W</td>
</tr>
<tr>
<td>CCD</td>
<td>0°C 75°C 5°C 5°C 70°C</td>
<td></td>
<td></td>
<td>0.495W</td>
</tr>
</tbody>
</table>

**Figure 9: ACS simulation results**

**Figure 10: Beta angle simulated for one year**

**Figure 11: Environmental Heating Value**

coke and tape.
Table 5: Simulation of Max./Min. temperature of each tray for Hot/Cold cases (beta =± 44.38 deg)

<table>
<thead>
<tr>
<th>Tray</th>
<th>Max. temperature</th>
<th>Min. temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>30.39 °C</td>
<td>15.81 °C</td>
</tr>
<tr>
<td>2</td>
<td>30.89 °C</td>
<td>16.44 °C</td>
</tr>
<tr>
<td>3</td>
<td>31.38 °C</td>
<td>17.06 °C</td>
</tr>
<tr>
<td>4</td>
<td>31.87 °C</td>
<td>17.68 °C</td>
</tr>
</tbody>
</table>

Onboard Computer Subsystem

The onboard computer subsystem of TUUSAT-1A is designed with multiprocessors in order to have a stable hardware and software in space. As shown in Fig. 12, the 32-bit MPC555 processor is responsible for the payload management, and the 16-bit dsPIC30F is responsible for the telecommd. The MPC555 is ported with a real-time and multi-task operation system (RTOS) and performs the operation of camera payload. It works for the identification of Sun orientation, photographing and storing image in memory as well as to read the output of radiometer and collect the soft error of memory. Both processors can communicate with CAN (Controller Area Network) interface. The command processor dsPIC30F can also perform the operation of camera payload and read the radiometer in case of that the MPC555 is malfunction.

Communication Subsystem

The communication subsystem has a simple and stable program working in the dsPIC30F, in which the SOC processor plays the role of health keeper for the transceiver and MPC555. It can not only monitor the health of transceiver/MPC555, but also reset them if necessary. The dsPIC30F can also execute the telecommand instructions from TGS; read the sampling data of health sensors and the GPS orbital data; transmit the SOH and GPS data to ground via the transceiver. The transceiver TH-D7e is an amateur radio transceiver for VHF/UHF frequencies, but it only operates with UHF frequency for the TUUSAT-1A mission. The link budget of downlink margin is 7.87dB and the uplink margin is 23.46dB for the max transmitting power and communication distance.

Figure 13: Architecture of communication subsystem

Electrical Power Subsystem

The designed requirements of the EPS will be determined according to the mission objectives and orbital specifications of TUUSAT-1A. There are five objectives of the EPS are included and listed as follows:

1. Generation, storage, conditioning and distribution of electrical power.
2. Power generation provided by Si solar array fixed to the body of the SC.
3. Ni-Cd battery used to store solar energy and provide energy to peak power demands and eclipse periods.
4. Switching of the power lines to units controlled through OBC commands.
5. Provision of status monitoring and telecommand interfaces necessary for operation of the power system.
Then the architecture and circuit hardware will be designed according to the operational requirements of power subsystem. The effective area of solar cells and discharge depth of batteries will be evaluated according to the power budget for selecting the proper amounts of solar cells and batteries. The power budget is evaluated and listed as Table I. The EPS adopts the direct energy transfer architecture and the power management and distribution unit. To improve the system efficiency, the DC/DC converters adopt the switching topology with the regulated multi-output voltages of 3.3V, 5.0V and 12V. The storage battery pack uses the Ni-Cd batteries and the battery charger adopts the switching buck converter and is charged with a constant current.

SATELLITE DESCRIPTION: PAYLOAD SEGMENT

The payload subsystem includes the GPS, Camera and radiometer described as follows:

GPS

TUUSAT-1A adopts the space qualified GPS-12 module as shown in Fig.14. The main specifications are 12 channels, -135 dBm tracking sensitivity, 5m position accuracy, 45 seconds warm start, 50 grams. It will provide the output of altitude, position, velocity and acceleration of the satellite in orbit.

Digital Camera

Two commercial 1.3 Mega pixels cameras are installed at the opposite lateral sides of TUUSAT-1A satellite for the Earth image photographing. Six solar cells are adopted as the sun sensors and mounted at the edge of six solar panels of satellite respectively. A mathematical algorism is developed in order to determine the correlation of the spacecraft and the sun orientation, such that we can identify the pointing of camera as it is pointing to ground and determine the opportunity of photographing.

Radiometer

Electronic parts are usually degraded by the effect of space radiation, especially is the soft error of memory. It will be investigated by the radiometer which is the secondary payload of TUUSA-1A. Fig.15 shows the radiometer which is a room temperature semiconductor that directly converts X-ray or Gamma-ray photons into electrons. The sensor can process over two million photons at each mm² area per second. When ionizing radiation interacts with the sensor, it collects the oppositely charged electrode. The resulting charge pulse is then detected by the preamplifier, which produces a voltage pulse whose height is proportional to the incident energy of the incoming photon. The signal can then be fed into a standard counting system to generate the characteristic spectrum for the incoming photons.

GROUND SEGMENT

Block diagram of the TGS is shown in the Fig. 16, which consists of VHF/UHF satellite communication equipments, antennas, computers and satellite orbit predication software, etc. Customized mission control and operation software for operating satellite TUUSAT-1A are required to be developed in-house as well. All these hardware and software components will be designed/purchased, developed, and integrated as a complete ground station in this project.
The proposed TUUSAT-1A Ground Station (TGS) is designed for operating and supporting of multi-mission satellites, i.e., it not only can support the mission operation and control for TUUSAT-series micro-satellites, but also support other satellite with UHF/VHF frequency band amateur satellites or payload, such as Marine Data Relay Payload (MDRP) of ARGO satellite. The integration and testing of TGS can be categorized into four segments, which are commanding, telemetry, satellite tracking and orbit prediction and TGS peripheral parameters configuration as shown in Figure 17-20, respectively. Figure 17 shows the command function of the TGS mission operation software, which is used to configure the ground equipments and send out the pre-arranged commands to the designed satellites/payloads. Figure 18 shows the telemetry function page of the TGS mission operation software, which is to display the received satellite/payload’s telemetry in the PC of the ground station such that the health and status of the satellites/payloads can be examined from the ground station.
Figure 19 shows the satellite tracking function page of the TGS mission operation software, which provides the satellite’s orbit prediction and tracking status.

Figure 20: Peripheral and equipments parameters of the TGS mission operation software

Figure 20 shows the peripherals and equipments parameters page of the TGS mission operation, which provides the peripherals and equipments parameters configuration function for operating the TGS.

**SYSTEM VERIFICATION PLAN**

The verification philosophy of TUUSAT-1A System Verification Plan is to test what we fly and verify on the ground that all elements of system will perform satisfactorily when TUUSAT-1A is operational on orbit. The verification concept of TUUSAT-1A mission is to analysis, inspect, test and demonstrate the performance and functionalities of the systems/components of spacecraft in different levels, which include the Software Analysis, Hardware Functional Test, System Demonstrate and Mission Verification levels, as shown in Fig. 21. In the Software Analysis level, the subsystems will individually develop the analytical computer codes or use the hand-on software for the analysis and design purposes. Dr. C. H. Lin and the students of Mechanical Subsystem Research Team are trying to integrate these codes and to develop the full-software analytical tool, TUUSIM (TUUSAT-1A Simulator), by the MATLAB computer language for achieving more realistic simulation and performance analysis.

In the Hardware Functional Test level, we have accomplished and passed the thermal cycling test of the COTS components and will implement the vacuum test during June 2007. These environmental tests are implemented at the NSPO Ground Support Equipment & Facilities. Fig. 22 is the configuration of COTS components in the thermal cycling chamber of NSPO. The TUUSAT-1A Team and the students of Electrical Subsystem Research Team are developing the TUUSAT-1A Electrical Test Bed consisted of all the electrical components of TUUSAT-1A for the functional integration test. Fig. 23 is the architecture of TUUSAT-1A Electrical Test Bed and it is estimated to be accomplished before October 2007.

The System Demonstrate and Mission Verification levels will be implemented in the system integration and test phase during 2008.

Figure 21: Verification concept of TUUSAT-1A mission

Figure 22 Thermal cycling test at NSPO GSEF
Figure 23 Architecture of TUUSAT-1A Electrical Test Bed

CONCLUSION

The TUUSAT-1A is the first academic microsatellite developed by the joint program of universities in Taiwan with supports from NSPO. The design results of each subsystem of TUUSAT-1A and the results of environmental tests of the COTS components by using NSPO Integration and Test Facility are presented in this paper. Currently the TUUSAT-1A is still in the design phase and will start the integration and test phase in early 2008. The results of TUUSAT-1A project, lesson learned from this program, as well as the system I&T and verification, will be presented in the future.

Acknowledgement

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Reference


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