The UoSAT-C,D & E Technology Demonstration Satellites

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The University of Surrey (UK) planned a small, inexpensive spacecraft (UoSAT-C) to be launched by NASA on a DELTA launch vehicle as a secondary payload into low-Earth orbit in 1989. This launch has been postponed, but the University has obtained two launch slots on ARIANE. Two spacecraft, UoSATs D & E are currently under construction at The UoSAT Spacecraft Engineering Research Unit at Surrey and they involve collaboration with international experimenters. The spacecraft will carry the majority of the payloads from the postponed UoSAT-C mission.

UoSAT-D & E will develop further the objectives established by the preceding UoSAT-1 and UoSAT-2 spacecraft launched into low Earth, polar orbit by NASA.

The paper describes the architecture and experiments of the satellite including:-

Satellite Communications using digital store-&-forward techniques serving remote and under-developed areas and the amateur radio community.

Space Technology providing an in-orbit demonstration and operational evaluation of novel technologies and techniques such as transputers and solar cell evaluation.

Space Science supporting sophisticated, yet inexpensive space science objectives studying the radiation environment in low Earth orbit such as Cosmic Particle Detection and Radiation Total Dose Measurement.

INTRODUCTION

Changes in the NASA/USAF launch manifest have resulted in the postponement of the University of Surrey's UoSAT-C mission, which was originally scheduled for launch on NASA-DELTA in late 1988. Simultaneous with the news of this delay, however, UoS signed final agreements with Arianespace for the launch of two UoSAT satellites on Ariane with the SPOT-2 primary payload. The Ariane launch opportunity -

secured after long negotiations amongst UoSAT, AMSAT-NA and Arianespace - involves a total of seven payloads: SPOT-2 (a replacement for the SPOT-1 imaging satellite), UoSAT-D, UoSAT-E, and four AMSAT-NA MicroSats. The University of Surrey, through Surrey Satellite Technology Ltd., is acting as the primary customer to Arianespace for all the UoSAT and Microsat satellites on this launch.

UoSAT-D & E MISSION OBJECTIVES

UoSAT-D and UoSAT-E will now take over the mission objectives of the postponed UoSAT-C mission to support:

1. Amateur Radio packet communications using low Earth orbit satellites and the advancement of store-and-forward communications technology,

2. studies of the orbital radiation environment and its effects on semiconductors,

3. in-orbit demonstration and evaluation of novel spacecraft technologies,

4. development of low-cost CCD Earth imaging techniques,

5. refinement of low-cost computer controlled spacecraft attitude determination and control systems providing precision Earth pointing.

The UoSAT-D and E spacecraft, accompanied by the four AMSAT-NA Microsats, will be placed around a new Ariane structure specially designed to provide small secondary payloads with inexpensive launch opportunities on a mass available basis. This new structure, the **Ariane** Structure for **Auxiliary Payloads (ASAP)**, will be flying for the first time carrying the UoSAT and AMSAT-NA satellites.

Due to mass limitations on the Ariane ASAP, the payloads originally intended for UoSAT-C have had to be split between two spacecraft (UoSAT-D & E). Fortunately, UoSAT-C was designed around a new, highly modular concept [Ref 1] which has allowed the rapid reconfiguration necessary to take advantage of the Ariane launch opportunity at such short notice. The original UoSAT-C spacecraft will now be reconfigured with new payloads for a later launch with NASA.

UoSAT-D PAYLOADS

The UoSAT-D and E spacecraft will be structurally identical, and have identical housekeeping subsystems, but will carry different payloads. UoSAT-D will carry an amateur radio digital store-and forward communications transponder operating in the amateur satellite service, and will also investigate the effects of the space radiation environment on spacecraft components. The payloads on UoSAT-D are funded by the University of Surrey, the Royal Aerospace Establishment (UK), VITA (USA), and AMSAT-UK. UoSAT-D will carry Gallium Arsenide solar arrays in collaboration with Mitsubishi (Japan) and NiCd batteries in collaboration with AMSAT-NA in Canada.

UoSAT-D Packet Communications Experiment

The primary payload on UoSAT-D will be the Packet Communications Experiment (PCE). The PCE is an orbiting packet radio node with 4 Mbytes of message storage space and advances the work done on UoSAT-2 with the Digital Communications Experiment [Ref 2]. The PCE system (hardware and software) is being developed under a contract from the Volunteers In Technical Assistance (VITA), who hope in the future to use store-and-forward communications as a link with development workers in remote areas. The flight of the PCE on UoSAT-D and its use by radio amateurs is funded by the University of Surrey and AMSAT-UK.

ALL amateur radio stations with appropriate equipment will have open access to the PCE via AX.25 packet radio. The UoSAT-D PCE will use 9600 bits/sec, frequency-shift-keyed (FSK) uplinks and downlinks. These channels will be compatible with existing modems designed primarily for terrestrial use. The spacecraft will operate with one uplink at VHF and a downlink in at UHF. RF communications links should be good enough to provide a consistent service to groundstations with modest non-steered antennas. An experimental high-power downlink mode for very-small groundstations will also be included.

Whilst the UoSAT/AMSAT-UK PCE will use standard AX.25 communications links, it will also provide a platform for experimentation with higher-level packet communications protocols. Current 'PACSAT' systems employ ALOHA access (each station transmitting when it wishes to) and user interfaces based on terrestrial bulletin board software. The PCE will employ experimental access techniques aimed at more efficient machine-to-machine communications. The user-friendly BBS-like interface will be on the ground, in the groundstation's personal computer or packet radio node controller. The groundstation and the satellite will communicate using high-level protocols, making the best use of short satellite passes. Software to support these groundstation-to-satellite protocols (along with complete specifications of the protocols) will be developed at UoSAT and made available to the Amateur community.

The PCE will be controlled by an 80C186 microprocessor running at 8 MHz. The 80C186 is a highly integrated microcontroller with integral direct memory access (DMA) controller, interrupt controller, timers and other peripherals. With a full 16-bit bus running at such a high speed, this processor will have adequate computing power to control all of UoSAT-D's housekeeping concurrent with the packet radio communications system.

Cosmic Particle and Total Dose Experiments

The Earth's magnetic field and atmosphere shield the surface of the planet from much of the radiation emitted by the sun and other cosmic sources. Satellites in orbit, however, are not protected by this atmospheric and geomagnetic shield, and they receive high levels of cosmic radiation. In addition, particles trapped in the geomagnetic field oscillate between the magnetic poles in the Van Allen radiation belts and further increase the radiation received by objects in orbit. Thus, satellite electronic subsystems are in a much harsher radiation environment than terrestrial systems.

Radiation damage is the primary threat to a satellite's electronic systems once the satellite has survived the rigours of launch. Effects due to the total dose of radiation absorbed by on-board semiconductors causes them sooner or later to fail permanently. Less dramatic but equally serious are the temporary effects of energetic cosmic particles entering semiconductor memories. These particles cause Single Event Upsets (SEUs) - changing the contents of memory bits. This can cause computers to crash or stored data to be corrupted. As satellites become more sophisticated they also become more reliant on microprocessors, peripherals and memories, and as more functions are placed on smaller and smaller ICs, the ICs become increasingly radiation sensitive. Measurements of radiation levels experienced by satellite systems in space, and observations of radiation effects on satellite electronics, help designers evaluate new semiconductor technologies and select the correct components for future satellite missions.

With this in mind, the UoSAT Unit has conducted a series of in-orbit radiation experiments over the last seven years. UoSAT-1 carried Gieger detectors for measuring radiation, and the On Board Computer (OBC) has a SEU counter on its memory. On UoSAT-2, monitoring radiation effects was taken a step further. The Particle Wave Experiment monitors the electron flux spectrum at eight energy levels. The 1802 OBC has an SEU counter, while the Digital Communications Experiment (DCE) and Data Store and Readout (DSR) monitor SEUs in a total of 300 kbytes of memory. UoSAT-2 is currently involved in a long-term experimental programme supported by ESA to investigate the statistics of SEU's.

UoSAT-D will continue this series of experiments with a Total Dose (TDE) monitor and a Cosmic Particle (CPE) detector. The TDE will provide, for the first time, direct measurement of the absorbed radiation dose at various points in the satellite. This will allow assessment of shielding provided by the satellite structure. The TDE uses 7 radiation detecting field effect transistors (RADFETs) monitored by an 80C31 microcontroller. The CPE detects cosmic particles as they pass through a diode array. As particles pass through the diodes, they deposit charge, which is measured by a charge integrator circuit, again interfaced to the 80C31. The measured charge can reveal the energy of the particle and the angle at which it entered UoSAT-D. This CPE/TDE package, along with SEU monitoring on the 4 Mbytes of PCE memory will significantly increase the amount of information available to designers of computer systems for satellite use. The CPE/TDE will send its data to a 'file' in the PCE, where it will be available to groundstation. The CPE/TDE is funded by the Royal Aerospace Establishment and built in conjunction with the Harwell Laboratory (UK).

On-Board Data Handling

UoSAT-D will have a standard UoSAT 1802 OBC to assist the 80C186 as necessary. Both computers will be interfaced to a central telemetry system monitoring 32 analogue channels throughout the satellite. Telemetry will be available direct to the downlink through hardware interfaces, or it can be gathered by the 80C186 and presented as AX.25 packets. This combination results in a failure-resilient system with the flexibility of computer-driven packet telemetry backed-up by an all-hardware system.

The three computers on UoSAT-D (1802, 80C31, 80C186) will be linked to each other and to uplinks, downlinks, telemetry and telecommand through a multiple access serial data-sharing bus. This bus eliminates many of the dedicated serial links present in UoSAT-1 and UoSAT-2, without eliminating the redundant data paths which are available should primary paths fail. The bus interface is a simple circuit which can be added to any UART serial chip.

Attitude Control & Stabilisation

UoSAT-D will be an Earth-pointing satellite, using a gravity gradient boom augmented by computer controlled magnetorquing. This system, which uses no continuously-moving parts or expendable fuels, is ideal for small, inexpensive satellites in low-Earth orbit. UoSAT-2 has maintained a pointing stability of within 5 degrees using this system, and it is hoped that improved algorithms and increased computing power available on UoSAT-D will result in even better results. Satellite attitude is calculated from magnetometer measurements of the Earth's local magnetic field. UoSAT-D will carry a flux-gate magnetometer measuring the geomagnetic field in the satellite's three axes. Direct interface to the 1802 and 80C186 OBCs will provide resolution to 8 nanoTesla over a 100 microTesla range, whilst slightly reduced resolution will also be available through the satellite's standard telemetry system.

UoSAT-D and UoSAT-E Modular Design

The modular design concept developed for UoSAT-C proved itself when the UoSAT team had to change emphasis to the UoSAT-D and UoSAT-E missions at very short notice. This is described in more detail in Reference 1.

UoSAT-E PAYLOADS

The UoSAT-E satellite will be based on an identical 'bus' as UoSAT-D; OBC, telemetry, telecommand, power generation and conditioning, and mechanical structure will remain the same. The compliment of payloads and experiments, however, will change - funded by the European Space Agency, the Royal Aerospace Establishment (UK) and the University of Surrey. UoSAT-E will be primarily a technology demonstration mission, flying the Transputer Data Processing Experiment (TDPE), Solar Cell Experiment (SCE) and CCD imaging system which were to fly on UoSAT-C.

Transputers

The TDPE is a parallel computing system based on three Transputer parallel processing microcomputers. The three Transputers can be used in parallel on different parts of a single task simultaneously, greatly improving computing speed. They can also be used to monitor one another, watching for erratic behaviour which might result from radiation induced SEU. Both the increased performance of the parallel processing arrangement and the increased reliability of the 'watch-dog' arrangement will be studied. Results of this study will be used by the European Space Agency Technical Labs (ESTEC) in the design of high-performance On-Board Data Handling systems for future satellites.

Advanced Solar Panel Technology

The UoSAT-E Solar Cell Experiment comprises an array of solar-cell samples from several manufacturers which will be constantly monitored for changes in performance caused by radiation, temperature, and other environmental effects. The cells will represent the complete range of solar generator technologies under development: Gallium Arsenide, Indium Phosphide and Silicon. The cells will be covered by various cover slides designed to enhance panel efficiency and/or reduce panel degradation due to radiation. The SCE will be mounted on a panel that will replace part of a solar panel on the side of the UoSAT-E spacecraft.

The SCE monitoring system will wait until the sun is directly upon the SCE, and then make a series of 100 current/voltage measurements on each cell sample. These data will be sent in a burst to the satellite's 1802 OBC, for storage prior to transmission later to ground.

In addition to the SCE, UoSAT-D will carry the first Gallium Arsenide solar arrays manufactured by FIAR/CISE (Italy) and EEV/MSS/RAE (UK).

CCD Imaging Experiment

The CCD camera will continue the series of UoSAT experiments with low-cost Earth imagers on satellites. UoSAT-1 carried one of the earliest two-dimensional CCD arrays - certainly the first low-cost CCD camera in orbit. The results from this imager were spectacular when one considers the novelty of the technology, although the fact that UoSAT-1 failed to achieve gravity gradient Earth-pointing makes the imaging somewhat random. The UoSAT-2 CCD camera is a high-sensitivity system intended to take images of the auroral oval as UoSAT-2 passes over the poles. It is connected to two 96 kbyte memory banks with serial readout and error-detection-and-correction coding. Unfortunately, results from UoSAT-2 have been inconclusive, and it has so far proved difficult to adjust the sensitivity of the camera to retrieve readily-identifiable images. UoSAT-E will carry a more recent CCD device, optimised for meteorological scale imaging. The Earth surface resolution of the system will be on the order of 1-2 km, with a field of view 1000 km square. The inclusion of this system on UoSAT-E is a response to widespread interest in medium resolution imaging for low-cost meteorology satellites.

The UoSAT-E camera will generate a 96k byte raw image, which will be sent to the TDPE, where the parallel processors will compress the image onboard the satellite ready for transmission to ground. The data compression stage will provide between 50 and 90 percent reduction in the amount of memory required to store an image, which will also decrease the downlink time required to transmit a picture to a groundstation.

CONCLUSION

The launch of SPOT-2 with the UoSAT and Microsat spacecraft is currently scheduled for January 1989, and the UoSAT Team at Surrey is occupied on an urgent programme to develop these satellites within this very tight timescale.

When UoSAT-D and E, and MicroSats-A through to D are in orbit and operational, the Amateur Satellite service will again have demonstrated the ability to respond imaginatively to short-notice launch opportunities. The PCE on UoSAT-D will provide a packet-radio networking experiment and a service to Radio Amateurs world wide. The various technology and engineering experiments on UoSAT-D and UoSAT-E will continue the important transfer of information between Amateur Radio and the professional engineering community.

REFERENCES

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2. J.W. Ward and H.E. Price, "The UoSAT-2 Digital Communications Experiment", Journal of the Institute of Electronic and Radio Engineers Vol 57 No 5 pp S163-S173