

THE UOSAT SPACECRAFT PROGRAMME

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Spacecraft - designed, built and operated by traditional means - have proved extremely costly, thus limiting access to space to large organisations working within enormous budgets. The Amateur Satellite Service, over a period of 20 years, has demonstrated that small spacecraft can be built very inexpensively, and act as a low-cost stimulus to technology. The UoSAT Programme at the University of Surrey (UK) has developed highly sophisticated yet inexpensive small satellites through adopting imaginative, cost-effective spacecraft engineering techniques. Two UoSAT spacecraft, UoSAT-1 & 2, have been in orbit since 1981 and 1984 respectively supporting active space engineering research, space science and space education programmes associated with the amateur radio, educational and professional aerospace community worldwide.

INTRODUCTION

Space missions have become synonymous with large budgets and long timescales, executed by national industries or government agencies promoting ever-larger space structures to carry exotic instrumentation or commercial payloads. The financial burden of supporting these space missions has greatly limited direct access to the space environment to only the most committed of nations and agencies. It has become virtually impossible for new ideas, technologies or services to be evaluated in orbit without a protracted lead-time, often resulting in operational obsolescence. Indeed, large, international space projects often find it very difficult to accommodate many small, but nevertheless interesting and valuable, scientific and engineering experiments - within a sensible budget and a useful timescale.

Recent advances in semiconductor technologies, however, have made it possible to achieve increasingly complex electronic functions within ever-shrinking volume and power consumption - thus making it possible to construct highly sophisticated spacecraft functions within a small structural body. As a result, for missions not requiring bulky instruments or communications equipment, the design emphasis can be

directed towards sophisticated electronic rather than mechanical systems.

Further, by adopting imaginative and 'cost-effective' engineering philosophies, the overall cost of these missions can be contained within a level not yet achieved by traditional aerospace industries. This approach opens areas of activity in space which hitherto had been considered simply uneconomical when approached in the traditional manner.

The UoSAT Spacecraft Engineering Research Unit at the University of Surrey (UK) has demonstrated both the feasibility and capability of relatively small, low-cost spacecraft through the UoSAT Spacecraft Programme [1,2] executed in close collaboration with AMSAT and the Amateur Satellite Service.

Two small, inexpensive satellites (UoSAT-1 & 2) designed, built, tested and operated in orbit by the University of Surrey, have demonstrated highly sophisticated functions within small budgets (UoSAT-1 \$375k and UoSAT-2 \$675k). UoSAT-1 was launched in 1981 following a 30 month programme, and UoSAT-2 in 1984 prepared for launch in only 6 months after identification of an unexpected launch opportunity. Both spacecraft continue to be fully operational in low Earth orbit, controlled by a groundstation within the UoSAT Unit on the Surrey campus. Launch support for these 'piggy-back' missions on DELTA was provided on a 'non-interference' basis and at no charge by NASA, whilst the construction of the two satellites was funded primarily from UK industry and the University of Surrey with subsequent orbital operation supported by the UK Science & Engineering Research Council. A university company, Surrey Satellite Technology Ltd., was established in 1985 to provide a means whereby the technologies and techniques developed within the UoSAT Unit could be transferred effectively into industry whilst, at the same time, providing a source of funding for future research into spacecraft engineering topics.

THE UoSAT PROGRAMME

The UoSAT Programme at Surrey is directed specifically towards research into and the development of low-cost space techniques - both for spacecraft and ground station facilities - with particular focus on spacecraft engineering research, space education and the availability to industry & commerce of low-cost in-orbit technology test-beds or proof-of-concept carriers. Research within the UoSAT Unit is supported both by grants from the UK Science & Engineering Research Council (SERC) and from commercial research contracts with space agencies and industry. The Unit comprises 3 academics, 10 full-time research staff, 5 technicians and 5 post-graduate research students housed in five offices, three laboratories and a spacecraft clean assembly area on the University campus.

The mission objectives of the UoSAT spacecraft can be summarised as follows:

- o To investigate the feasibility of, and the problems associated with, the design, construction, test and launch of a relatively small, inexpensive yet sophisticated spacecraft capable of a significant contribution to the engineering, scientific, educational and amateur radio communities.
- o To evaluate the use and performance of novel technologies, spacecraft systems architectures and cost-effective spacecraft engineering techniques to provide a lower cost entry level into space activities.
- o To stimulate and promote a greater awareness of and interest in space engineering and science in schools, colleges, universities and the amateur community by direct, active participation in the satellite experimental programme.

These objectives have entailed a return from the traditional aerospace philosophies to a basic engineering approach to spacecraft design - resting more on elegant, flexible engineering based on thorough physical understanding rather than a 'use the best possible' insurance policy. In other words, the spacecraft is designed to do the job with up-to-date technology and calculated safety margins - supported by flexible system design carried out within a short timescale by a compact team of highly competent and motivated engineers.

SPACECRAFT ENGINEERING RESEARCH

The UoSAT Unit is engaged on a wide range of spacecraft engineering research projects associated with novel technologies and systems for space use. The primary research topics within the Unit are associated with:

On-Board Data Handling Systems

- network architecture analyses
- Optical OBDH network design
- On-Board Computer design (hardware and software)
- Large-scale memory management on-board spacecraft

Spacecraft Telemetry and Telecommand Sub-systems

- TT & C architecture, protocols, design
- Custom VLSI implementations

Spacecraft R.F. Systems

- Telecommand receivers, telemetry transmitters

Satellite Attitude Determination, Control & Stabilisation

- Spacecraft attitude sensors

- Active delibration of gravity gradient stabilisation

Low Earth Orbit Propulsion Systems

- Low Earth orbit transfer and maintenance techniques

Spacecraft Power Sub-systems

- Intelligent on-board satellite power management
- Advanced power sub-system control architectures
- Power monitoring sensors

Spacecraft Autonomy and Artificial Intelligence

- Autonomous spacecraft operations software
- Applications of artificial intelligence techniques to satellite operations

Earth Imaging

- Design of inexpensive Earth imaging cameras
- Image processing and data reduction using on-board parallel processing techniques

Space Radiation Environment

- Modelling the Earth's space radiation environment
- Damage mechanisms in VLSI devices
- Analysis of Single Event Upset and hard failure statistics in VLSI devices on-board orbiting spacecraft

Adaptable Modulation Schemes

- Adaptable modulation schemes for spacecraft LEO communications systems

Digital Communications via LEO Satellites

- Studies of traffic requirements for global non-real-time communications services via LEO satellites
- Communications protocols for LEO spacecraft

Satellite Groundstation Autonomy and Artificial Intelligence

- Application of AI techniques to autonomous satellite groundstation operations

These research topics are supported by the UoSAT-1 & 2 spacecraft currently in orbit and also focus on several future applications spacecraft missions currently under development at Surrey, eg:

UoSAT-C a small experimental technology test-bed spacecraft intended for launch into low Earth orbit in late 1988, supporting spacecraft engineering research and space education. UoSAT-C

will focus particularly on digital store-&-forward communications supporting communications to remote areas in developing countries, evaluating GaAs solar arrays and spacecraft data handling systems.

UoSAT-D a further small technology test-bed spacecraft intended for launch into low Earth, polar orbit in 1989 will focus on quantifying the effects of the space radiation environment on new VLSI electronic devices and the use of optical fibre data bus techniques on spacecraft.

UoSAT a 'mini-satellite' platform intended to support very low cost access to space through the STS-GAS programme into low Earth orbit.

T-SAT a 500kg experimental technology and communications satellite intended for Molniya orbit. UoSAT are responsible for the on-board data handling, telemetry, telecommand and power systems.

SPACE EDUCATION

The UoSAT Unit supports, in addition to spacecraft engineering research, several space education initiatives - promoting an international Space Education Programme involving over 2000 experimenters in schools, colleges, universities and amateur groundstations worldwide.

Academic Training

A one-year (full-time) Masters Degree course in Satellite Communications Engineering with Spacecraft Engineering is run at Surrey. Generally 10-12 undergraduate and postgraduate students participate in projects directly connected with the UoSAT spacecraft each year. International participation in the UoSAT Programme is encouraged and visiting Research Fellows from USA, Holland, Germany, China and Pakistan have worked recently with the UoSAT spacecraft team at Surrey.

The research, design, fabrication, integration, test and orbital operation of complete spacecraft - executed all within a single close-knit team on a compact location - provides a unique university research and teaching environment. Each member of the team is exposed to all aspects of satellite missions, and there are numerous opportunities for stimulating student projects and research studies involving direct participation in space-rated hardware, software and spacecraft orbital operations.

Satellites in Schools

The availability of microcomputers in every UK school alongside inexpensive, easily available reception equipment has stimulated the direct use of the two UoSAT satellites in classroom demonstrations of such otherwise rather dry subjects as orbital physics, data processing, statistics and information technology. Over 900 schools in the UK alone,

and many others worldwide, are involved in the UoSAT Programme to some degree. The UoSAT Unit houses at Surrey the UK National Resource Centre for Satellites In Education, actively supporting the use of satellites in schools by providing an information service, texts, demonstrations, equipment evaluation, lectures and teacher training courses.

Amateur Radio

Over 1000 stations in the Amateur Satellite Service worldwide are actively involved in tracking, reception and analysis of data from the UoSAT satellites. Apart from stimulating a greater interest in and understanding of space technology as an educational objective, these stations provide an invaluable groundstation network supporting data retrieval and a global communications network ideal for traffic analyses of the spacecraft communications experiments described later.

THE UoSAT-1 & 2 SPACECRAFT

Two satellites, UoSAT-1 & 2, are in low-earth, polar orbits at a height of 475 km & 700 km sun-synchronous at 3 am-pm and 9 am-pm respectively. Thus one or other of the UoSAT spacecraft is visible every one and a half hours, day and night at European latitudes - more often at higher and less often at lower latitudes. The spacecraft are visible for 10-12 minutes on overhead passes.

Both spacecraft were built within very modest budgets and short timescales, and both are still fully operational in orbit. Problems that have been encountered in each mission have been successfully overcome - largely as a result of the extremely flexible spacecraft system design. UoSAT-1 executes a formal weekly experimental schedule, supporting engineering and educational studies, whilst UoSAT-2 is engaged primarily in spacecraft systems, particle/wave, imaging and communications experiments. The engineering data retrieved from both spacecraft, particularly relating to the space radiation environment, have proved invaluable in the design of later spacecraft, such as those missions identified above, and in studies supported by the European Space Agency.

A detailed description of the spacecraft, its sub-systems and experiments [3] is beyond the scope of this paper, however the main features of the two satellites can be summarised as follows:

- Structure** - cuboid (0.75 x 0.45 x 0.45 metres), weight 60 kg.
- Thermal Control** - passive, OSR and kapton blankets.
- Power System** - commercial-grade batteries, battery charge regulator, power conditioning and distribution system, silicon solar cells (30W).
- Telecommand System** - 3 command receivers in the 144, 438 and 1268 MHz bands, 112 discrete command functions.
- Downlink Beacons** - transmitting on 145.825, 435.025 and 2401.5 MHz,

AFSK/PM and BPSK.

Telemetry System - 60 analogue and 96 digital readings, spacecraft identifier and real-time clock.

On-board Computer - RCA1802 with 48kb of RAM, real-time clock, bootstrap loader, communications ports to command, telemetry and experiment sub-systems.

Attitude Control System - three-axis magnetorquer coils and a deployable gravity-gradient stabilisation boom. Active magnetic delibration algorithms executed via the spacecraft on-board computer.

Attitude Determination - 6 Digital sun sensors, Earth Horizon sensor, 3-axis flux-gate magnetometer providing ± 25 nT resolution of geomagnetic field.

The ability of the spacecraft to support worthwhile payloads has been demonstrated by the following experiments,

Digital Communication Experiment - NSC800 with 128kb of static RAM for digital message store-&-forward communications.

CCD Camera - a camera based on a GEC two-dimensional CCD array capable of taking and storing on-board pictures of the Earth beneath the spacecraft.

Particle/Wave Experiment - comprising Geiger Detectors, Multi-channel Electron Spectrometer, three-axis Magnetometer, Particle/Wave Correlator

Digital Store & Readout - two banks of 96kbyte static CMOS RAM to store the camera pictures and information from the on-board computer and the particle/wave experiment.

Space Dust Experiment - a piezo-electric and capacitative sensor to detect and measure the momenta of small particles hitting the spacecraft.

Ionospheric Studies - four phase-related H.F. radio beacons on 7, 14, 21 & 28 MHz.

The educational interest in space stimulated by first-hand participation in schools, colleges, universities and within the Amateur communities by:

simple VHF downlink - using AFSK/PM in Amateur Radio Bands

low-cost equipment - inexpensive F.M receivers & simple, fixed aerals
data formats - directly compatible with 'home' computers

DIGITALKER

- synthesised speech experiment with a 550 word vocabulary.

direct access

- to 'live' spacecraft housekeeping telemetry and experiment data

COMMUNICATIONS EXPERIMENTS USING THE UoSAT-2 SATELLITE

Whilst the UoSAT spacecraft support a wide range of experiments, one has proved to be of particular interest to both radio amateurs, aid organisations and commercial services. UoSAT-2 carries a 'proof-of-concept' digital communications experiment (DCE) exploring the problems associated with, and the applications of, store-and-forward communications techniques using low Earth orbiting satellites [4].

Through UoSAT-2, techniques have been developed at Surrey for the provision of effective, highly compact, portable and low-cost digital store-&-forward communications to and from remote areas where no established trunk communications infra-structure exists - such as the polar regions below the geostationary horizon.

The use of low-Earth orbiting spacecraft reduces the communications link budget necessary by a factor of 30 dB when compared to a similar geostationary link, thus significantly reducing the spacecraft and ground communications terminal requirements. In addition, the use of a polar orbit allows the reuse of UHF and SHF link frequencies and relieves the r.f. congestion experienced at these frequencies in the geostationary 'belt'.

To this end, UoSAT-2 carries a prototype digital store-&-forward communications experiment (DCE) to evaluate the real problems associated with providing a reliable but cost-effective 'near-enough' real-time communications service that has truly global coverage with a single satellite. The UoSAT-2 DCE has been in operation, supporting daily traffic between international 'Gateway' stations in the Amateur Satellite Service at UoS and in the USA, New Zealand, Australia, Germany, Pakistan and Japan, for one and a half years. Each of the 'Gateway' stations then serves as a node for links into the national terrestrial VHF packet radio networks thus providing international packet communications between several thousand radio amateur operators. The involvement of the Amateur Satellite Service in this communications experiment has enabled Surrey to study traffic handling, protocol and user terminal problems in a real operational environment without having to establish a prohibitively expensive network.

The DCE has thus focussed research into the optimum spacecraft and ground terminal configurations and technologies, covering topics such as spacecraft computers, memories, radiation effects, transmission link and radiation-induced error control, transmission link modulation schemes, antennas and ground terminal computers and software.

The results of the UoSAT-2 DCE orbital experience are being employed

directly in proposals to provide communications services based around small, low-cost spacecraft launched as secondary payloads into polar orbit. Examples of these proposed services are the Swedish Space Corporation's MAILSTAR and VITA's (Volunteers In Technical Assistance) PACSAT spacecraft, both of which are drawing on the UO-11 DCE for proof-of-concept and basic technical parameters. Recent studies of radiation induced single event upsets in VLSI memory devices on-board UoSAT-2 using the DCE [5] have been supported by the European Space Agency (ESA).

SURREY SATELLITE TECHNOLOGY LTD

Surrey Satellite Technology (SST) provides a means whereby the technologies and techniques developed within the UoSAT Unit can be transferred effectively from a university environment into industry whilst, at the same time, providing a source of funding for future research into spacecraft engineering topics.

SST thus makes the experience and expertise of the UoSAT Unit available to external organisations through contracts based on standard commercial practice. Typical contracts executed by SST and the UoSAT Unit are:

European Space Agency

- o Low-cost Applications Spacecraft Mission Study
- o Study of Radiation Induced Single Event Upsets on spacecraft VLSI electronics

Swedish Space Corporation

- o Mission Study for a Store-&-Forward Communications Satellite (MAILSTAR)

SUPARCO

- o Satellite Tracking Groundstations

Deskin Research Group

- o Study of Spacecraft Power Subsystems
- o Study of Spacecraft Attitude Stabilisation

CONCLUSIONS

The UoSAT Spacecraft Research Programme has demonstrated clearly that relatively small yet complex spacecraft can be built and successfully operated in orbit on a budget that is at least an order of magnitude smaller than that associated with a traditional approach. This has been achieved by forming a highly competent, motivated and compact team of

university research engineers, who have adopted a down-to-earth, cost-effective engineering philosophy. It has been seen that it is possible for such a team working to muster and organise the necessary resources, solve the associated technical problems and complete complex spacecraft within extremely tight schedules and financial budgets.

Whilst the design, construction and test of small spacecraft is a significant undertaking - the subsequent orbital operation may prove to be equally demanding [6,7] (or more so!) and should not be underestimated. The UoSAT team has accumulated more than a decade of experience of LEO spacecraft operations, and this expertise is linked closely with the design of future missions.

Inexpensive spacecraft rely on low-cost launch opportunities, and these are available for relatively small spacecraft as secondary payloads accompanying major missions or, particularly, using the Shuttle-GAS configuration. Small spacecraft of the UoSAT class have a wide range of very relevant applications in research, education and industry/commerce - the University of Surrey and SST are actively pursuing and catalysing these opportunities.

Finally, the UoSAT Programme has shown that a small satellite programme is not only valuable, but practicable and economic. It has provided an inexpensive mechanism for in-orbit technology assessment and service proof-of-concept whilst stimulating educational interest in space technology on which the space industry relies for continued supply of qualified engineers.

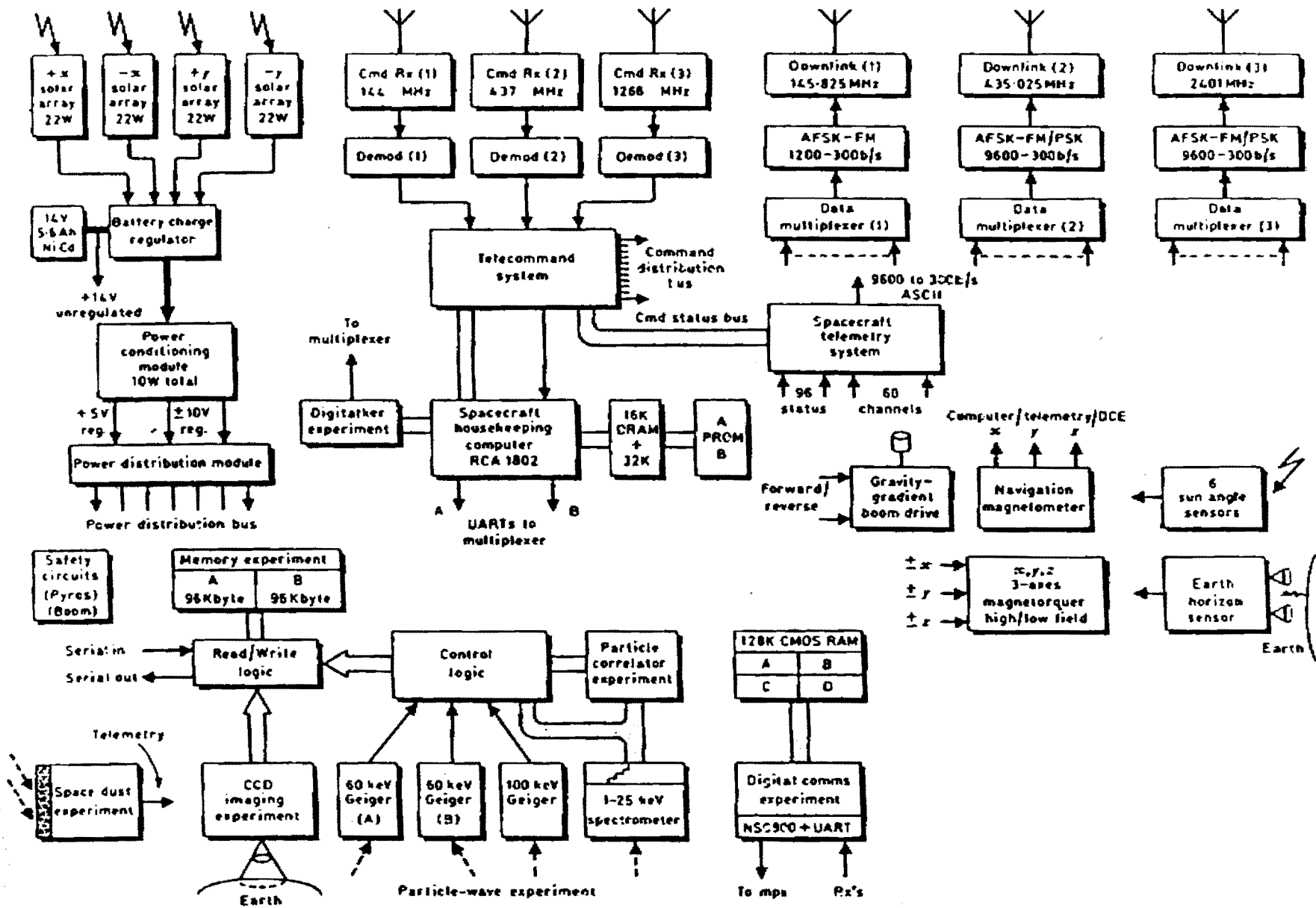
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UoSAT-2 spacecraft system diagram.