A Low-Cost Modular Nanosatellite Based On Commercial Technology

Dr Craig I. Underwood, Dr Mike J. Crawford,
Dr <u>Jeff W. Ward</u>

Surrey Space Centre
University of Surrey
Guildford, Surrey GU2 5XH, UK

Tel: (44) 1483 259809   Fax: (44) 1483 259503
e-mail: c.underwood@ee.surrey.ac.uk
WWW: http://www.ee.surrey.ac.uk/EE/CSER/UOSAT

ABSTRACT

This paper presents the design of the University of Surrey's *SNAP-1* nanosatellite which is planned for launch in 1999. The satellite is modular in design and is based entirely on "commercial-off-the-shelf" (COTS) technologies. The objective of the "SNAP" Programme is to provide a very low cost orbital test vehicle for micro-electro-mechanical systems (MEMS) and to provide practical education and training for engineers in the techniques and rigours a spacecraft design and construction.

1. BACKGROUND

In the mid-1980's, the availability of commercial microelectronics stimulated a boom in small satellites by enabling the construction of small, yet sophisticated payload instruments and bus sub-systems. In the late 1980's, state-of-the-art technologies enabled satellites of between 50 kg and 100 kg mass with simple solar-panel configurations to carry multiple small payloads managed by highly-automated on-board computers. These so-called microsatellites have proven suitable for a wide range of commercial and scientific missions ranging from store-and-forward communications, to medium-resolution Earth-observation.

Indeed, over the last two decades, the University of Surrey has pioneered the use of these small, low-cost spacecraft through its "UoSAT" programme of 50 kg microsatellites. Sixteen microsatellites have been constructed to date, each within a 6-18 month period and each at a cost of around $2-3 million (USD) at today's prices. Around 60 orbit-years of operational experience in LEO has been gathered and this has, and continues to be, used to stimulate new ideas for advanced small satellites [1,2].

Driven by the personal computer and personal communications markets, microelectronic systems have advanced considerably in the 1990's:

The semiconductor industry has integrated analogue and digital functions into single integrated circuits (ICs); application specific ICs (ASICs) and various forms of programmable gate-array logic devices are now widely available significantly reducing the volume needed to support logic functions; memory densities have increased exponentially, and micro-controllers are now available which combine many peripheral functions with a central processing unit.

These advances in commercial-off-the-shelf (COTS) electronic technologies now make it feasible to construct even smaller satellites in the 1-10 kg mass range (nanosatellites), with virtually the same functionality as the earlier microsatellites, but at an *order of magnitude* less cost.

This opens up the possibility of designing and building satellites - with real applications in mind - as part of an education and training exercise for prospective spacecraft engineers, at a price which is affordable by individual academic institutions.

Work began in this area at Surrey in 1995 when the principal author organised a series of undergraduate student projects examining the feasibility of a "football" sized satellite for Earth imaging. This proved a highly successful educational exercise, and resulted in our first prototype nanosatellite concept: a multi-faceted polyhedral satellite, about the size of a football with a mass less than 10 kg. The students built prototype hardware including an on-board computer based on a Motorola 68HC11; a power system utilising 14V NiCd battery, providing a regulated 5V and 9.5V power supply; and a VHF transmitter. A CMOS video camera payload was also produced, and this was actually incorporated into the *TMSat* microsatellite which was being built at Surrey at the same time [3].

In 1997, Alexander Cropp, a student, joined Surrey to begin a PhD on the topic of "Autonomous Space Vehicle Inspection Using Nanosatellites", and so it was decided that, as part of this work, we would bring together a group of post-graduate and undergraduate students in a series of co-ordinated projects to help produce a practical multi-mission nanosatellite design.

Accordingly, the Surrey Space Centre has embarked upon a programme to design and develop a practical, modular, low-cost nanosatellite platform - the Surrey Nanosatellite Applications Programme (SNAP).

The first of these nanosatellites "*SNAP-1*" is a 3kg proof-of-concept vehicle, which is intended to demonstrate the nanosatellite platform concept, and to act as an orbital test-bed for several new COTS technologies - including miniature active-pixel-array video cameras; a Global Positioning System (GPS) navigation payload, new solar-cell technologies and an advanced RISC-based on-board computer. Five students were involved in the project, acting under the supervision of two academic members of staff (the authors: CIU and MJC), with additional support from Surrey Satellite Technology Ltd (SSTL) engineers: three undergraduate students worked on the radio-communications, attitude determination, and on-board data handling systems; whilst two post-graduate remain working on the primary on-board computer, power and attitude control systems. The payloads and other platform systems are being developed by Surrey Space Centre research staff.

2. THE *SNAP-1* NANOSATELLITE

For mechanical simplicity, the *SNAP-1* nanosatellite has body-mounted solar panels. However, this immediately introduces an engineering problem: - the small size of the satellite necessarily means a very limited electrical power budget. Thus, much of the external structure of the satellite has been given over to high-efficiency GaAs solar cells, and the shape and orientation of the satellite has been chosen to maximise electrical power generation, whilst maintaining mechanical simplicity and the mission objectives. This has resulted in an hexagonal prism structure with equal area solar panels on seven sides (the Earth facing side is reserved for the spacecraft attach fitting, antennas, and payload cameras - see Fig. 1).

The solar panels each comprise eight 40mm x 40mm GaAs solar cells, generating a maximum power of 4W per panel under normal solar illumination. Each panel is individually controlled by the power-system electronics so that it operates at its maximum power point. The resultant energy is stored in a six-cell Nickel-Metal Hydride (NiMH) rechargeable battery.

Each spacecraft bus or payload sub-system is provided with a switched, regulated, electronically fused, +5V supply, and the raw battery output of 7.5V is available if needed.

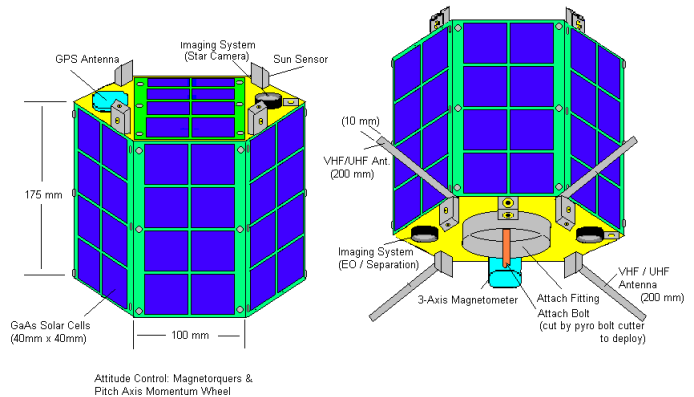In a typical polar low-Earth orbit, a total of 2-3W of processed power is available averaged over the orbit

Fig. 1 : The *SNAP-1* Nanosatellite

Attitude control is achieved by a single pitch-axis momentum wheel, implemented using a miniature commercial electrical motor connected to a fly-wheel. Active momentum dumping is achieved via magnetorquer coils, printed on the back of the solar panels. This enables the satellite to operate in a 3-axis stabilised model, with the -Z facet (attach fitting) maintaining an Earth-pointing orientation. The camera on the +Z facet doubles as a star-sensor, although the primary attitude knowledge comes from a 3-axis flux-gate magnetometer and a series of analogue Sun-sensors.

Because *SNAP-1* is so small, obtaining radar fixes may be difficult - particularly in the early phases of the mission when it is hard to differentiate between the satellite and launcher debris. Thus, the satellite carries a miniature GPS navigation system based upon a commercial GEC-Plessey Orion 12-channel GPS receiver, which will enable the location of the satellite to be determined to better than 100m accuracy.

The communications systems of the satellite are miniaturised and simplified versions of those we fly on the UoSAT microsatellites: There is a VHF (2m wavelength) uplink and a UHF (70 cm wavelength) downlink operating at 9600 bps, using asynchronous FSK modulation. This makes the satellite compatible with the existing Mission Operations Control Centre at Surrey, as well as potentially making the satellite available to the amateur radio satellite community. The downlink power is limited to 750 mW, fed to an (essentially) omni-directional antenna comprising four VHF monopoles (harmonically driven at UHF).

Operating the satellite in the amateur radio service would enable many hundreds of operators world-wide to participate in the satellite programme, downloading images of the Earth and performance data. However, we are also considering an alternative arrangement whereby SNAP will transmit at VHF so that its signals could be received by the Digital Signal Processing Experiment payloads operating on-board other SSTL satellites. This would enable inter-satellite links to be demonstrated using low-cost spacecraft.

The interior of the satellite comprises a set of stacked, standardised Duralumin module boxes, each capable of holding one or two standard "Eurocard"-sized PCBs. The module boxes provide radiation shielding for the COTS electronic components, as well as acting as the primary load-bearing mechanical structure.
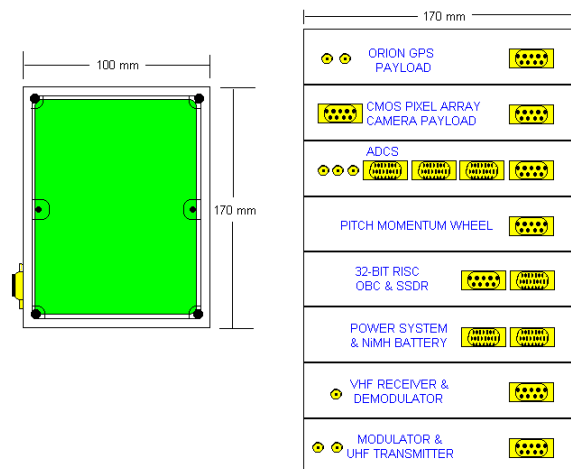

Fig. 2. : The *SNAP-1* Module Box Stack

This modular stacked structure concept follows on from the UoSAT microsatellite design, which has proven so successful in enabling satellites to be designed and constructed within very short time-scales.

Much of the complexity of modern spacecraft arises from the need to interconnect the sub-systems that comprise them, resulting in complex wiring harnesses. To avoid this, the interfaces on the SNAP satellites are deliberately kept very simple - basically each system or payload has a power, ground, serial data input and serial data output - four connections. The control and communication for each system, is implemented using tiny commercial Microchip Technology "PIC" microcontrollers. These provide all the local telemetry and telecommand functions required via the internal serial data links (operating at 76.8 kbps).

Central control is held by the on-board computer which is based on the low-cost GEC-Plessey "Butterfly" 32-bit RISC micro-controller. This accesses a 4M-bit, triple-modular-redundant memory system. An error-detection and correction (EDAC) circuit provides protection against ionising radiation induced single-event upset (and the power system electronic fuses give protection against the destructive effects of single-event latch-ups - should they occur) [4].

The "Butterfly" micro-controller also provides the interface between the spacecraft's systems and the up and downlink - although there is a hardware by-pass in-case of system malfunction.

3. THE *SNAP-1* MISSION

Although the SNAP nanosatellite is intended to be a generic nanosatellite bus, the first mission: *SNAP-1*, has a specific purpose - that of providing in-orbit imagery of other space-vehicles. Its imagery will be used to test algorithms required in later autonomous inspection missions.

Thus, *SNAP-1*'s principal payload comprises three advanced CMOS active pixel array video-cameras, operated in a multiple-still image mode. These cameras each comprise a 384 x 287 CMOS pixel array, where each pixel is 12 μm x 12 μm square. The 25mm focal-length refractive optics gives an 8° x 10° field of view for each camera.

The two -Z-facet cameras will be activated just prior to the separation of *SNAP-1* from the launch vehicle, and will be set to acquire up to 40 images each (1 per second per camera) of the launch vehicle during the separation event. At the expected parting velocity of 1 ms^{-1}, this should allow the satellite to image a target area of up to 7.3 m x 5.4 m at a minimum pixel resolution of 2 cm.

If (as currently planned) *SNAP-1* is launched alongside Surrey's 400 kg mini-satellite: *UoSAT-12*, the +Z facet camera will be used to image the separation of this vehicle prior to the deployment of *SNAP-1* [5].

The images will be stored on-board in the camera payload module, prior to downloading over Surrey's ground-station at Guildford.

Once this phase of the mission is over, *SNAP-1* will use its cameras for Earth imaging and stellar observation, whilst providing performance data on its internal systems - particularly its guidance, navigation and control systems and solar cells.

5. CONCLUSIONS

The development of SNAP nanosatellite bus has demonstrated how advances in COTS technologies can be used to produce extremely low-cost, yet

practical satellites within short timescales. This in itself has proven a useful education and training vehicle for both undergraduate and post-graduate engineering students, as well as acting as a stimulating exercise for young practising engineers working within the University's spacecraft engineering company: SSTL.

The opportunity to see *SNAP-1* develop from concept to flight-hardware within a year means that practical performance data should be available in time to make a real contribution to student's research projects - something inconceivable within a traditional satellite construction programme.

The SNAP nanosatellite bus continues Surrey's commitment to innovative engineering making space accessible at low-cost to the educational and professional community.

6. ACKNOWLEDGEMENTS

7. REFERENCES

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8. BIOGRAPHIES

Dr Craig Underwood graduated from the University of York in 1982 with a BSc in Physics with Computer Science. After gaining a Post Graduate Certificate in Education (PGCE) from York in 1983, he began a teaching career at Scarborough Sixth-Form College where he developed satellite activities. In January 1986, Craig joined the University of Surrey as a Research Fellow responsible for the generation and maintenance of software for the UoSAT Satellite Control Ground-Station. In 1988, as a Senior Engineer with SSTL, he became responsible for mission analysis and the thermal design of the UoSAT spacecraft, including: *UoSAT-3, -4*, and *-5, KITSAT-1, S80/T, HealthSat-II, PoSAT-1, FASat-A,- B and TMSat*. From 1990 he has been the Principal Investigator of space radiation effects on the UoSAT satellites, completing a PhD in this area in 1996. In 1993, Craig became a Lecturer in Spacecraft Engineering, and is pursuing research interests in space radiation environment and effects, satellite remote sensing and nano-satellite technologies.

Dr Mike Crawford is an academic within the School of Electrical and Electronic Engineering, Information Technology and Mathematics at Surrey. He has recently formally joined the Surrey Space Centre as a member of its academic research staff. Mike is currently pursuing research interests in Adaptive Control Theory - including all the control aspects of *SNAP-1*.

Dr. Jeff Ward received his BSc degree in Electrical and Computer Engineering from the University of Michigan (USA). Following this he worked for three years at the American Radio Relay League (Connecticut, USA) as a technical author and as a research engineer working on terrestrial packet radio technology. Dr. Ward is one of the founding employees of SSTL, having been a key researcher with the company since 1985. His research has concentrated on communications protocols and on-board computing for small satellites. As Principal Investigator for digital communications, he was responsible for all phases of the *UoSAT-3* PACSAT Communications Experiment payload, launched in 1990. This was the first sophisticated store-and-forward communications transponder in low-Earth orbit, and this pioneering work led directly to the present commercial Little LEO communications services. Dr. Ward became Technical Director of SSTL in 1994, and is presently responsible for contributing to overall company direction, establishing corporate technical policy and strategy, and managing SSTL's engineering teams.