

A Modular Small Satellite Bus for Low Earth Orbit Missions

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The University of Surrey has demonstrated its capability in the field of small, low-cost spacecraft with the UoSAT-1 and 2 missions launched into low earth orbit in 1981 and 1984. Surrey Satellite Technology Ltd., a company formed by the University of Surrey, is now developing a flexible spacecraft bus based on the experience gained from these missions.

The paper describes how the design philosophy used on the UoSAT spacecraft has been advanced to produce a bus providing basic power conditioning, telecommand, telemetry and attitude control functions. This basic bus is sufficient to support a variety of payloads, but the architecture is such that bus may be expanded (for example in number of telecommands) to support more demanding payloads. The use of this approach allows a standard proven product to support a wide variety of missions.

The careful selection and screening of components ensures a realistic cost, and the adoption of a fault tolerant 'layered' architecture give a high level of reliability in comparison to the low cost.

INTRODUCTION

In 1978 work commenced on a small scientific, technology and amateur radio spacecraft at the University of Surrey, England. This spacecraft, UoSAT-1, was launched by NASA using a piggy-back configuration on DELTA into a 550km sun-synchronous orbit during 1981 and is still operational today. A second spacecraft, UoSAT-2, was built in response to a flight opportunity with the LANDSAT-D' call-up mission on DELTA in March 1984, the complete design and construction taking just seven months of intense activity. UoSAT-2 is still fully operation after over four years in orbit.

In 1985 a University Company, Surrey Satellite Technology Ltd., was formed to allow this pioneering work on small satellites to be transferred into the commercial arena and to support continued research at Surrey. A third technology demonstration and scientific spacecraft, designated UoSAT-C, has been designed and is awaiting confirmation of

launch on DELTA in 1990/91. Two new spacecraft, UoSAT-D and UoSAT-E are being built for launch on ARIANE with the SPOT-2 Earth resources satellite which is scheduled for 1989. In view of the rescheduling of the UoSAT-C launch, a number of the original payloads intended for UoSAT-C have been transferred onto UoSAT-D and E. These spacecraft, like UoSAT-C, are constructed in a modular fashion, which has considerably eased the problem of re-configuring the payloads at short notice. The UoSAT-D and E spacecraft will represent a major step in the development of a modular spacecraft bus for low Earth orbit applications. UoSAT-C will provide an opportunity to fly new or updated payloads following UoSAT-D/E.

DESIGN METHODOLOGY

Over the past decade the UoSAT programme has developed a design methodology suited to low cost spacecraft engineering. This methodology entails 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. The spacecraft is designed to do its job using modern technology within a system architecture designed to provide flexible operation and acceptable safety margins.

A central factor in keeping the overall cost of the spacecraft to a minimum whilst maintaining sufficient reliability is the basic set of ground rules adopted for the design of the bus. Adopting the traditional space engineering approach throughout would cause the cost to increase, without necessarily improving reliability. The ground rules applied to the design are:

1. Keep it simple. Examine thoroughly the task and environment of each sub-system and specify components/techniques that will accommodate the task with a suitable, realistic safety margin. Unless the function or environment demands it, do not simply go for the highest rated/quality approach as this will generally increase costs dramatically.
2. Essential housekeeping modules should use standard, proven designs and hardware wherever possible.
3. Redundant paths and sub-systems may use less proven designs or technologies, providing these are not associated with potential single point failure nodes.
4. Where possible, use flexible design to provide redundancy via alternative technologies, rather than by duplication.

5. Use easily defined, simple interfaces between sub-systems wherever possible. Sub-systems should run independently of other systems even if that entails duplicate hardware (unless there is an overwhelming advantage to be gained from intimate subsystem interaction).
6. Design essential systems around established, industrial, high-grade, volume production components. If a component has been in volume production it is highly likely that any 'bugs' have been removed. If possible, use high-reliability or Mil-Spec screened versions of these volume production devices. Use exotic technologies only in nonessential or redundant systems.

It is felt that this careful design and procurement procedure results in spacecraft that reliably meet their mission requirements, yet can be produced at much lower cost than spacecraft designed and constructed in the traditional manner.

STRUCTURAL DESIGN

The electronic sub-systems are housed in module boxes which are 330mm x 330mm. The minimum height of the boxes is 26mm, and this is standard for most types of module. Exceptions are modules, such as the power conditioning system, which require the use of components (e.g. inductors) which would exceed this height. Also, the module containing the spacecraft battery is of a different design and it is about twice as high as a normal module.

These modules are stacked vertically to form the main structure of the spacecraft. The stack height is typically 600 mm. Solar panels are attached to the stacked boxes on the four large faces.

This type of structure has several major benefits:

1. The need for separate electrical enclosures and mechanical structures is obviated. This reduces cost, complexity and mass.
2. The height of the basic structure can be readily altered without the need for major mechanical re-design. This allows ease of accommodation on a variety of launch vehicles, and with the variable constraints imposed by different primary payloads.
3. The inter-module wiring is limited to one face of the spacecraft which should reduce the length of the interconnects required, and may eventually allow the use of a backplane or motherboard type of module interconnection system.

The basic bus hardware for a spin stabilised spacecraft requires a stack height of 221 mm. With a total stack height of 600 mm a volume of 40,000 cm³ (40 litres) is available.

SPACECRAFT BUS SUB-SYSTEMS

The basic spacecraft bus electronics comprises the power system, telemetry system, telecommand system and housekeeping computer. The bus provides basic facilities, which may be sufficient for some missions. The telemetry and telecommand systems are designed to support expansion if required by payloads through the addition of a minimum of extra hardware to provide more channels.

The bus conforms to the to the 'layered architecture' principles adopted for the earlier UoSAT spacecraft. The basic idea behind this approach is to use layers of complexity so that if the most complex systems fail operation is still possible using the lower layer, less complex systems. In the basic bus there are two layers; the on-board computer, and the hardware telemetry and telecommand systems. A third layer may be formed by the payload itself, if it has sufficient computing power to interpret the telemetry and generate telecommands.

Power System

A switching regulator is used to convert the nominal 30V from the four solar panels to a nominal 12V to charge the batteries and run the voltage regulators. Two BCRs are used in a Prime/Redundant configuration with automatic switching in the event of a failure. Switching regulators provide rails of -10, +10 and +5 volts for both the bus electronics and the payload. An unregulated rail of nominally 12-14 V is also available to the payload and the bus, and is used to drive relatively high power devices such as transmitters and attitude control magnetorquers.

The battery is made up of 10 NiCd cells, giving a nominal 12V with 6 Amp Hour capacity. The batteries used are of a similar type to those used on UoSAT-2, which have been operating in orbit for over four years. The cells, which are not space qualified by the manufacturer, are suited to the vacuum and vibration requirements. To ensure good reliability the cells are subjected to a stringent mechanical and electrical examination and the best from a relatively large batch selected.

Solid state power switches are used to control the power to sub-systems, and to the payload. These switches also act as resettable fuses. When they reach a pre-determined current limit they trip out, and to reset them they must be commanded off and then on again. This mechanism has been used successfully on both UoSAT-1 and 2 and provides protection against subsystems failures drawing excessive power.

The exact power available to the on-board systems and payloads is obviously a function of the orbit geometry, the spacecraft stack height and the efficiency of the cells used. With 600 mm high panels and GaAs solar cells an orbit average power of about 13W is available to the combined bus and payload.

Telecommand System

The telecommand architecture is again derived from the system flight-proven on earlier UoSAT missions. The output from the basic system consists of 64 latched lines. These lines may be commanded on or off by direct control from ground telecommand, and also by the on-board computer. The control information to the telecommand system uses standard asynchronous characters. Inputs are provided to the command system to allow the payload to issue commands using a simple six byte format.

The system architecture is such that additional latched commands, up to a total of 128, may be incorporated into the payload with a minimum of extra hardware.

Telemetry System

The basic telemetry system can provide 32 analogue channels with a resolution of 10 bits. It also provides 96 single bit digital status channels, of which at least 64 are used to provide verification of telecommand operation. The design is derived from that used on UoSAT 2, but substantial enhancements have been made. The system can operate in two modes; either driven directly from the on-board computer or as a backup in an autonomous mode where frames of telemetry are generated completely independently of the computer and sent to the downlink transmitters. To reduce the overhead imposed by the back-up mode all of the logic required is incorporated into a custom-designed single 40 pin VLSI gate array chip.

On-Board Computer

For most missions some form of on-board computer is essential. This can either be supplied as part of the spacecraft bus, or in some cases be a part of the payload.

The role of the on-board computer is flexible, it can provide a number of services to the bus and the payload depending on the mission profile. Typical functions include:

1. Attitude control algorithms. The computer must acquire data from the attitude sensors, use this to determine the actual spacecraft attitude, and pulse the three axis magnetorquers to effect the desired attitude changes.
2. Spacecraft Housekeeping/Scheduling. The computer can be used to turn systems on and off at pre-determined times. It can also gather data throughout the whole orbit while the spacecraft is out of range of the groundstation. Such software is run on the RCA 1802 based computers on both UoSAT-1 and 2.
3. Uplink/Downlink formatting and error control. Data can be taken from the payload and formatted into a suitable format for the prevailing downlink conditions. Conversely, the computer can provide the payload with an error free uplink data link.

Stabilisation and Attitude Control

Two primary options are available for spacecraft stabilisation; spin stabilisation and gravity gradient stabilisation. In both cases attitude adjustments are expedited by magnetorquers. Three class of attitude control performance are envisaged:

1. Spin stabilisation. This option uses magnetorquers under computer control to adjust the spin rate and spacecraft orientation. It is of use for missions that do not require Earth pointing. This configuration allows the power budget to be maximised by maintaining a constant angle to the sun. The necessity for omnidirectional antennas preclude the use of low gain earth stations and so this configuration is not particularly suited to communications payloads. The advantage is that the hardware required to for the attitude control sub-system represents a minimum overhead, essentially being only the magnetorquer coils which take very little mass or volume. As they are operated intermittently they are also negligible in terms of the power budget.
2. Gravity Gradient Stabilisation - Low Pointing Accuracy. This option again requires the magnetorquer coils, but in addition a gravity gradient boom is required. Typically the boom is deploys a mass of between 3 and 6 kg to a distance of 5 to 10 metres. A three axis magnetometer can be used for attitude determination. This scheme has been successfully demonstrated on the UoSAT-2 spacecraft over the past four years. Pointing accuracy of ± 5 degrees is attainable with this technique. The attitude control algorithms need not be active continuously, periodic Z axis spin rate adjustments and de-libration measures are required. This type of stabilisation will be flown on the UoSAT-D spacecraft.

3. Gravity Gradient Stabilisation - High Pointing Accuracy. The hardware described above can be augmented by sun angle and earth horizon sensors to give pointing accuracies of better than 1 degree. To achieve these pointing precisions the attitude control algorithms will be run continuously as a background task in the on-board computer software. This type of stabilisation will be flight tested on the UoSAT-E spacecraft.

RF Systems

The RF systems configuration can depend to a large extent on the payload requirements, and may require special purpose development. As the modulators and demodulators are housed with the RF system these can be also customised to some extent. In general two modules would be allocated to the RF systems, one containing the receivers and baseband demodulators and one containing the transmitters and baseband modulators.

A typical configuration, as used on UoSAT-D, might have uplinks on VHF and downlinks on UHF. Three separate receivers are provided, each with 1200 baud AFSK and 9600 baud FSK demodulators. This configuration is suited to a communication system where the users have direct access via two of the uplinks, and the third is reserved for the command uplink.

Two UHF downlink transmitters are used, configured as a prime and redundant. These are essentially single channel FM transmitters with Class C output stages for high efficiency. Baseband modulators are provided for 1200 baud AFSK and 9600 baud FSK.

Separate antenna systems are used for transmitters and receivers. On transmit a $\frac{1}{4}$ wave monopole is used, and on receive a four element canted turnstile antenna is used.

CONCLUSION

The modular spacecraft bus developed by the University of Surrey will provide a flexible, low cost method of supporting low Earth orbit missions. The basic concepts described will be flight tested on the upcoming UoSAT-D and E spacecraft, to be launched on ARIANE during 1989. A range of options are available for stabilisation and payload support, allowing easy integration to a variety of launch vehicles.