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N95- 17549

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p. 8

GROUND STATION SUPPORT FOR SMALL SCIENTIFIC SATELLITES

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ABSTRACT

In order to keep the cost of a complete small scientific satellite programme low, it is necessary to minimise the cost of the Ground Station Operations and Support. This is required not only for the operations and support per se, but also in the development of Ground Station hardware and the mission associated software. Recent experiences at the Rutherford Appleton Laboratory (RAL) on two international projects, IRAS and AMPTE, have shown that the low cost objectives of operations using smaller national facilities can be achieved. This paper describes the facilities at RAL, and the methods by which low cost support are provided by considering the differing implications of hardware/software system modularity, reliability and small numbers of dedicated and highly skilled operations staff.

INTRODUCTION

Rutherford Appleton Laboratory (RAL) is part of the UK Engineering and Physical Sciences Research Council (EPSRC) - formally the Science and Engineering Research Council (SERC). RAL has a long history of Space Science and Technology going back to the early 1960's, and in more recent times RAL has had TT&C responsibilities for a number of space missions. In 1983, RAL operated the Infra-Red Astronomical Satellite (IRAS) on behalf of NASA, SERC and the Dutch Aerospace Agency NIVR. Operations with IRAS covered all aspects of ground System work, including Mission Planning, Command Generation, Satellite Control, Data Reception, Satellite Health Monitoring, and Detailed Science Analysis. The mission lasted for 10 months, and operations went flawlessly, with no passes being missed. In 1984, the Ground System was re-configured for operations on the Active Magnetospheric Particle Tracer Explorer (AMPTE) mission. AMPTE was a UK sub-satellite operating as part of a NASA, UK, West German mission. Unlike IRAS (which was in a sun-synchronous orbit), AMPTE was in a highly eccentric orbit, taking apogee out to 200,000 km, giving real-time operations of up to 14 continuous hours per day. In both those missions, hardware, software and operations were developed and run by a closely-knit group of experienced space engineers, all contributing to a cost-efficient operational programme, even though in the case of IRAS it was not classified as a 'small' mission.

The RAL Ground Station is currently being re-configured again for operations with Small Satellites. Data reception monitoring will begin shortly on the Space Technology Research Vehicle (STRV) program. STRV is a UK Ministry of Defence mini-satellite, operating at S-band frequency. Once the downlink end-to-end system has been checked out, RAL will finalise plans for complete end-to-end, low cost operations on another mini-satellite programme, called BADR-B. BADR-B (Urdu for full-moon) is a Pakistan mini-satellite programme managed by the Space and Upper Atmosphere Research Commission (SUPARCO) in Karachi. Due for launch in 1995, BADR-B will be placed in a near-polar orbit at an altitude of about 800 km. Prime operations will be run from Karachi and Lahore in Pakistan, and UK operations will be run from RAL, using an ultra-low cost approach as defined in the remainder of the paper.

THEMES FOR LOW COST OPERATIONS

The starting point in defining the requirements on the Ground Station is to consider what the User actually needs (as well as what he wants, which may not necessarily be the same!). Overall, a rough guide to the main requirements may be considered as:

> Lowest possible cost, but reliable operations (not missing passes or losing data), fast return of critical data, regular return of bulk data, rapid response for critical commanding and ease of access to data

In order to achieve the low cost goal, it is not, however, unreasonable to expect some compromises to be made. These may include:

> Acceptance of occasional (1 in 20?) lost passes, acceptance of some (5%?) lost data, and/or non-rapid return of non-urgent data

With these ground rules understood, we can look at some of the potential areas of cost reduction.

COST REDUCING SCENARIOS

The cost of mission operations represents a significant portion of the total programme costs, often 20 to 30%. Thus the ground segment configuration (ie. hardware, software) and the operational modes (ie. complexity) have a significant influence on total costs and must be given serious consideration in overall system design.

The ground segment fulfils several functions:

- mission planning, including command preparation and validation,
- tracking, telemetry and command (TT&C) interface with the satellite,
- status and health monitoring of the satellite,
- reception of mission data via satellite telemetry,
- initial pre-processing of the data prior to distribution from the operations part of the ground segment to the user for final processing and analysis,
- use of EGSE before and after launch.

The following are some general considerations concerning the ground segment configuration and operation.

System modularity

In exactly the same way that satellite costs can be significantly reduced by greater use of common modularised subsystems, ground system configurations can also be modularised. Instead of developing individual EGSE (Electrical Ground Support Equipment) and Ground Segment equipment for every instrument and/or satellite, there are now being developed standardised off-the-shelf equipment that can subsequently be customised to the individual needs, at much lower cost. Within the ground system itself, computing power is sufficient these days to combine the tasks of TT&C into a single low-cost workstation. Of even more potential benefit is the reuse of previous mission software for many of the data analysis functions. As an example of this, the data analysis software for the JET-X instrument, which will fly in 1995 as part of the Spectrum-X mission, is almost entirely based on software developed for the ROSAT mission launched in 1990. This scenario alone has cut the software development cost for this mission by a factor of three.

National facilities

Probably the greatest potential for cost reduction of the ground system is by making greater use of national facilities. Agency facilities are clearly required for large (manned and unmanned) missions, but are often too cumbersome and inflexible for small missions. It has usually proven far more cost-effective to employ national facilities - ideally utilising just a single ground station. For instance, the two European AMPTE spacecraft were controlled from single stations in Germany and England, respectively. The UK station was developed at very low cost by updating the original IRAS control centre to the requirements of the AMPTE mission. Although new software and operational procedures were necessary, very little new hardware was required. As an example, the 12 m S-band tracking station and control centre at the Rutherford Appleton Laboratory can be used for TT&C on an "as required basis", the operations staff being redeployed to other tasks during non-active satellite periods, thus significantly cutting down the running operations costs even for satellites producing many hundreds of Mbits/day. Similarly, for low-cost satellites producing kbits rather than Mbits of data, it is now possible to receive data using rooftop antennae and to command/receive using desktop PCs.

Reliability versus cost

For larger missions, it has always been normal practice to maximise the reliability of the ground system despite the associated increase in cost. This is not unreasonable for man-rated missions, but is often an unnecessary expense for most other missions. There is a very sizeable potential reduction in cost to be obtained by accepting just a small reduction in system reliability. It is proposed here to agree "up-front" that a small percentage (perhaps 5%) of satellite passes can be lost through ground system outage. This may (though not necessarily) lead to some data loss, but even so a data loss of a few percent is not usually significant. By agreeing to this reduction in reliability, the level of hardware redundancy (and perhaps software complexity) required in the ground system can be significantly reduced, and hence the cost is lower. Likewise, if the number of passes required per day to support the mission operation can be reduced through a slightly less than optimal coverage programme, the cost of operations can also be reduced.

Data availability

There is no doubt that for all missions it is essential to be able to process some subsets of the data in Real-Time and/or Near Real-Time. However, the less data that has to be processed in this manner the simpler the immediate ground system complexity becomes. For the majority of small satellite missions, it should only be necessary to process instrument/bus health data as a matter of urgency, thus decoupling the task of satellite "operations" from that of off-line data processing.

Data transfer

There are basically two different methods of transferring data from the operations part of the ground system to the user or data processing centres. The first (and most expensive) is via one of the many space or terrestrial data links. This is the common route for most satellite data and gets the data to the end user very quickly. However, it is more often the case that although the end user likes to have this data "as quickly as possible" it is not often an absolute necessity. In this case an alternative route via mailed magnetic tapes/optical disks can be just as satisfactory; possibly some (small) percentage of the data can still be transmitted via a low bandwidth (and lower cost) data link; it is important to try to avoid the exclusive dedicated use of these links as this too adds to the cost.

Data access

There are as many different philosophies regarding methods of data access as there are concerning designs of satellite. Generally however, the most cost efficient and practical method is the concept of a Centralised Data Handling Facility which is accessible by users over local data networks. This concentrates the pipeline data processing in one place, whilst allowing the individual users both to develop their own specialised software and to make full use of centrally developed software.

With these principles addressed, we now look at the Ground Station and Operations facility at RAL.

RAL GROUND STATION HARDWARE

The Science and Engineering Research Council's Rutherford Appleton Laboratory (RAL) operates a Ground Station and Control Centre on its site at Chilton, Oxfordshire, UK. (51.57°N, 1.31°W).

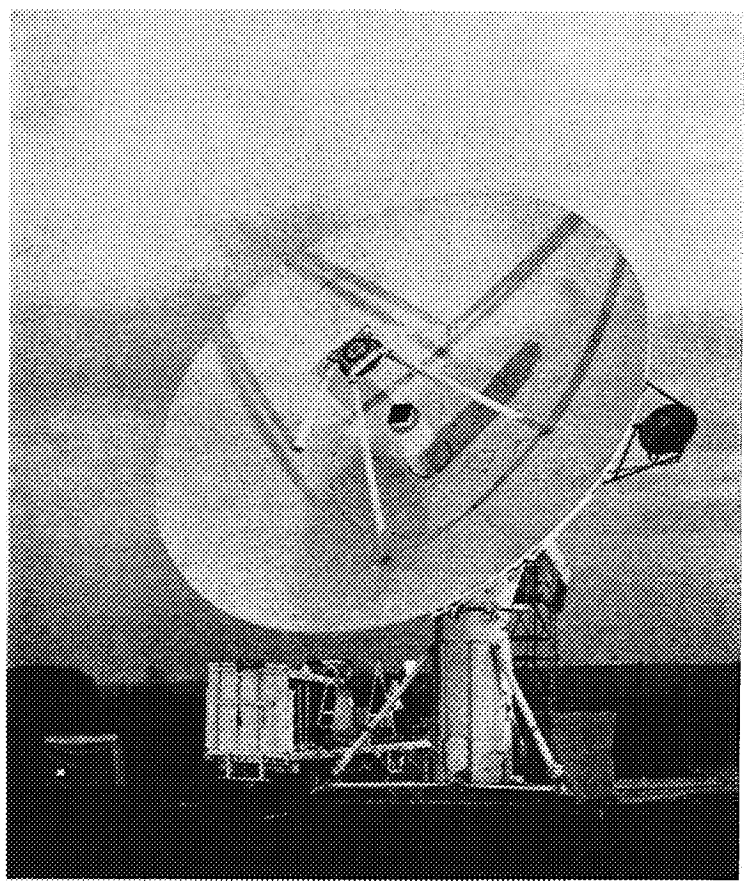

Fig. 1 RAL 12 m Antenna

The main antenna is a transportable 12 metre S-band cassegrain instrument (Fig. 1). Built in 1965 by the North American Aviation Company for the ATS project, it was re-commissioned in 1980 on the Chilton site as the prime antenna for the joint UK/US/Dutch mission IRAS (low-Earth polar orbit).

Antenna System

The main reflector of the antenna is a hyperboloid section, made with 20 petals constructed from 2 in thick aluminium honeycomb and faced with aluminium sheet. The reflector, the radio frequency feed, cassegrain sub-reflector and equipment cabinets are supported on elevation over azimuth bearings at the top of a cylindrical steel pedestal. Three tubular steel legs provide support for the pedestal and, with screw jacks, allow accurate levelling of the antenna structure. The whole antenna weighs approximately 32 tons. Attached to the edge of the main reflector is a 1.2 metre diameter paraboloid antenna which, because it has a wider beamwidth (ie. field of view) is used to locate satellites whose position is uncertain.

The radio frequency feed mounted at the vertex of the main reflector is a complicated waveguide structure. It is able to transmit and receive simultaneously at S-band frequency, in either right-hand or left-hand circular polarisation. In the receive mode, three output ports are available: one is the channel containing the received signal, the other two provide error signals (one each for azimuth and elevation axes) so that, with a servo loop, the antenna can lock on to an incoming transmission, allowing very accurate tracking of selected satellites. In addition to this autotrack mode, the antenna can be driven along a predicted path by computer.

The pointing error of the antenna is approximately 1 arc minute. The success of the antenna, as a machine for tracking moving sources, depends ultimately on the quality of the servo mechanism. The electric drive system incorporates two motors per axis and a redesigned set of servo amplifiers, aimed at maintaining the peak tracking error within 6 arc minutes, at mean wind speeds of up to 30 knots. Tests have shown that this figure is easily met and a typical peak tracking error is 2 arc minutes in a mean wind speed of 20 knots with gusts above 30 knots.

A summary of the technical details of the antenna are as follows:

Mechanical

- Cassegrain configuration
- 12 m diameter paraboloid primary reflector, f/d ratio 0.325
- 1 m diameter hyperboloid secondary reflector
- Eccentricity 1.413
- Main reflector surface accuracy 0.89 mm rms
- Mount: elevation over azimuth, Azimuth rotation ± 270 deg , Elevation rotation -5 deg to +95 deg

Drive

- Electronically servo-controlled electric motors
- Two motors in tandem in each axis
- Static pointing accuracy ± 3.5 sec arc rms, Tracking accuracy ± 2 min arc rms
- Velocity, azimuth and elevation 7 deg/sec max
- Acceleration, azimuth and elevation, 4 deg/sec^2 max
- Modes of operation: Standby, Manual or Program-Track

Data output: Position encoder 20 bits, Accuracy ± 1.23 sec arc

RF	Transmit	Receive
Antenna gain	45.8 dB	46.5 dB
Beamwidth (3 dB)	0.9 deg	0.8 deg
Nominal frequency	2075 MHz	2253 MHz (IRAS)

Transmitter power into antenna 10 watts
Max side lobe - 18 dB from main lobe
System noise temp 115 K at zenith
Feed: Four horn monopulse
Left or Right hand circular polarisation receive and transmit
Output: 3 channels - sum and two orthogonal error channels

Acquisition Aid

1.25 m diameter paraboloid reflector (fixed to rim of main antenna)
Receive only
Antenna gain 26 dB
Beamwidth 6 deg
Nominal frequency 2253 MHz
RH circular polarisation
Output: 3 channels - sum and two orthogonal error channels

Receive/Transmit System

The receivers and exciters were previously sited at the NASA STDN ground station at Madrid and were used on the Apollo programme. They are based on the NASA unified S-band system.

The system comprises:

(1) Two identical receivers with a common phase reference generator,

(2) Two identical transmitters with a common phase modulation drive,

(3) An RF path-switching sub-system,

(4) The Control and Monitor sub-system,

(5) The Calibration and Test sub-system.

These sub-systems are physically distributed between an inner cabin on the antenna pedestal (S-band components, adjacent to the antenna feed), outer equipment cabinets, also moving with the antenna, and the remainder within the Operations Control Centre about 250 m from the antenna pedestal base. Almost all of the OCC sub-systems operate at 50 MHz and below (Receive) and 65 MHz and below (Transmit). However, low-loss coaxial feeder is used between OCC and antenna.

Each receiver comprises three channels. The Reference/Telemetry Channel establishes carrier phase-lock, supports wide-band (Dump) telemetry and outputs video TLM. Two Angle-Error Channels detect the angular deviation from antenna boresight in the X and Y planes relative to the antenna feed, and output error signals for feedback to the antenna servo drive to establish autotrack.

Each transmitter comprises a multiplier chain to raise the phase-modulated RF drive to the Uplink frequency and a stage of power amplification to produce the final RF level of 10 W into the diplexer.

An associated Translator unit samples the outgoing Uplink and converts this to the Downlink frequency, as a Test Input to the down-conversion stages of the receiver. The common phase-modulation drive is derived from a VCO, tripled and modulated with the Command Sub-Carrier which is itself modulated with command messages generated in the computer.

Control Centre Equipment

Equipment located in the Control Centre comprises a Unified S-Band (USB) TT&C set, PCM bit conditioners, a time standard, two wide-band instrumentation tape recorders and test gear. Control of the antenna and handling of the telemetry is accomplished with two desktop computers, which monitor the status and health of the Ground Station and satellite as well as generating the satellite commands for uplinking during each pass. At the modest data rates generated by small satellites, modern desktop PC's are quite capable of acquiring telemetry and processing it in real time, using hard disk as the primary storage medium.

Ground Station Performance

During the IRAS Mission, the antenna system successfully tracked over 1500 consecutive passes. Following the IRAS mission, the system was reconfigured for operations with the UK sub-satellite of the AMPTE mission (apogee 125,000 km), where passes over several hours duration were taken every day of the mission. Additionally, the ground station has been used to track several other spacecraft including LANDSAT-IV, IUE and EXOSAT. In all cases, command and control down to 8° elevation is possible, and for the majority of cases elevation down to 2¼° is possible.

GROUND STATION SOFTWARE

It is a traditionally held view that ground software has to cope with all of the problems which have been left by the hardware engineers. This may always be true to a certain extent, but the trade-offs for low cost need to be made in a detailed way early in the planning of a mission. A number of early decisions may, on the one hand, allow the in-flight component to be simplified, but at the expense of more complex operations and software. Alternatively, decisions on whether to adopt for instance, a standard telemetry format (CCSDS) would permit standardisation of ground software and minimal changes for successive missions. Thus the ground segments should always be considered to be an essential, integrated part of the mission right from the start.

Advantage can be taken of the increasing power and modularity of computers, both on the ground and in space. Thus, there is an opportunity to provide flexibility on-board the satellite to reduce data telemetry volumes, without the fear, which has existed up to the present, that irrevocable techniques could lead to at least partial mission failure if the instrumentation subsequently performs unpredictably. On the ground, sufficient checks can be built in to permit the use of automated passes, eliminating the need for expensive shift working. However, for this to be viable, the hardware design has to build in this requirement from the start and the control station hardware and software also.

The experience of RAL on many scientific missions has been that high efficiency and low costs can be achieved by using highly qualified and experienced staff throughout the design, development and operation of the ground systems. Despite the additional costs per staff year, there are significant gains in productivity from adopting this philosophy. Team members are selected to ensure a mixture of backgrounds in operations, formal computing training and research in the subject area of the spacecraft. Benefits are seen to be greater motivation, a strong understanding of mission objectives, which in turn makes the teams very adaptable and capable of proposing and implementing solutions to problems. Producing systems which the team themselves will have to run is a strong concentrator of the mind and the considerable costs of training and detailed documentation as the project progresses are significantly reduced.

It is not only in formatting that the adoption of standards can be of benefit. The existence of co-ordinated national facilities in the UK such as Starlink in the Astronomy area and the British Atmospheric Data Facility (formerly GDF) has also led to standardisation of data handling tools and data bases, allowing the reuse of software for analysis despite the widely differing instrumentation being flown. More could be done to exploit these universal tools, but a start has been made, although each project may have to accept compromises and possible lower performance if the goal of minimal new software is to be achieved.

CONCLUSIONS

It has been shown that mission costs for the Ground System can be significantly reduced by making just small compromises in data return, together with standardisation of hardware and particularly software subsystems, and in greater use of National facilities.