An S-Band Ground Station for FedSat and CHIPSat Operations

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An Australian micro satellite called "FedSat" was launched by NASDA on December 14 2002 from Tagenashima Space Centre in Japan. This Low Earth Orbit (LEO) satellite is now being used for scientific research and technology demonstration. To control FedSat during the mission a Ground Station (GS) is required. The FedSat Ground Station is located at the Mawson Lakes Campus of the University of South Australia in Adelaide. The GS consists of an S Band tracking antenna, a rack of RF and modem hardware, plus several computers on a dedicated local area network.

While some Ground Stations are only able to communicate with a single satellite the FedSat GS has been modified to act as a secondary GS for an American built satellite named CHIPSat. This 46 kg micro satellite has been designed and built by SpaceDev for the University of California, Berkeley, under a NASA-funded contract. CHIPSat will be the first NASA mission ever to use end-to-end satellite operations over the Internet with TCP/IP and FTP as the only means of communication. This use of TCP/IP as the only means of communications makes it well suited for remote control using alternative ground stations such as the FedSat GS. CHIPSat was successfully launched on January 12 on a Delta II launcher.

This paper describes the functions of the CRCSS Ground Station and gives an overview of its design, implementation and testing. This includes a description of the hardware and software architectures used in the GS for both the FedSat and CHIPSat missions.

1. Introduction

The Australian microsatellite "FedSat" is the flagship project of the Cooperative Research Centre for Satellite Systems (CRCSS). At the time of writing this paper FedSat has been operating for a couple of months and is providing an Australian platform for technology demonstration and scientific research in space. Further information about FedSat may be found in [1] to [4].

FedSat is a low earth orbit (LEO) satellite in a near-polar sun-synchronous orbit, as required by the primary payload on the HII-A launch vehicle. In this orbit FedSat is visible 2 or 3 times each day in late morning passes and a similar number of times 12 hours later. The Mawson Lakes GS communicates with FedSat during most daylight passes, sending telecommands to the satellite or receiving telemetry data from FedSat. Telemetry is derived from the "platform" components (ie on board computer, attitude control, power supply etc) or the payloads. Each pass may last up to about 15 minutes.

FedSat uses S band links for telecommand and telemetry and in Section 2 we describe the tracking antenna, RF equipment and modems which provide these functions. As Fedsat has a number of payloads which collect significant amounts of data, a fairly high rate downlink (1Mbit/s) is required. In contrast the uplink is relatively low data rate (4 kbit/s) which is generally quite sufficient to transfer telecommands to the satellite. (One exception is the "code upload" function which transfers fairly large files and may therefore take a couple of passes to complete.) Since there is only one GS for FedSat the actual "connect" time is fairly low, but this is adequate given the high-rate downlink which can dump stored data during passes, plus the ability to issue telecommands for delayed execution.

FedSat also contains communications links from the Communications Payload at UHF and Ka Bands. These are not described further in this paper since they are not part of the Ground Station functionality. (See for [5] and [6] for details.)

In the case of the CHIPSat Mission, the Ground Station provides secondary telemetry, tracking and control (TT&C) functions. This satellite also uses a low earth orbit. The same dish and RF front end is employed, but a different receiver is required.

Section 3 of the paper describes the Master Ground Station Computer (MGSC) which is responsible for calculation of satellite position during a pass, antenna pointing and control of related electronics. The satellite position (either Fedsat or CHIPSat) is known quite accurately compared to the antenna beamwidth so than "open loop" tracking is used. Manual adjustment of the dish position is possible but has only been employed during testing.

The MGSC is only one component of a local network of computers used in the Ground Station. After the FedSat downlink signal has been demodulated and packetised it is forwarded to computers for the reception of telemetry and transmission of telecommands. These functions are described in Sections 4 and 5., which deal with the Operations Control Centre (OCC) software. In the CHIPSat case a Virtual Private Network (VPN) connects the Adelaide site with the Californian facilities. This gives a very convenient method of distributed control which provides a high level of security by using IPSec authentication and encryption. Finally in Section 6 we describe some of the typical operator functions which are used in the GS.

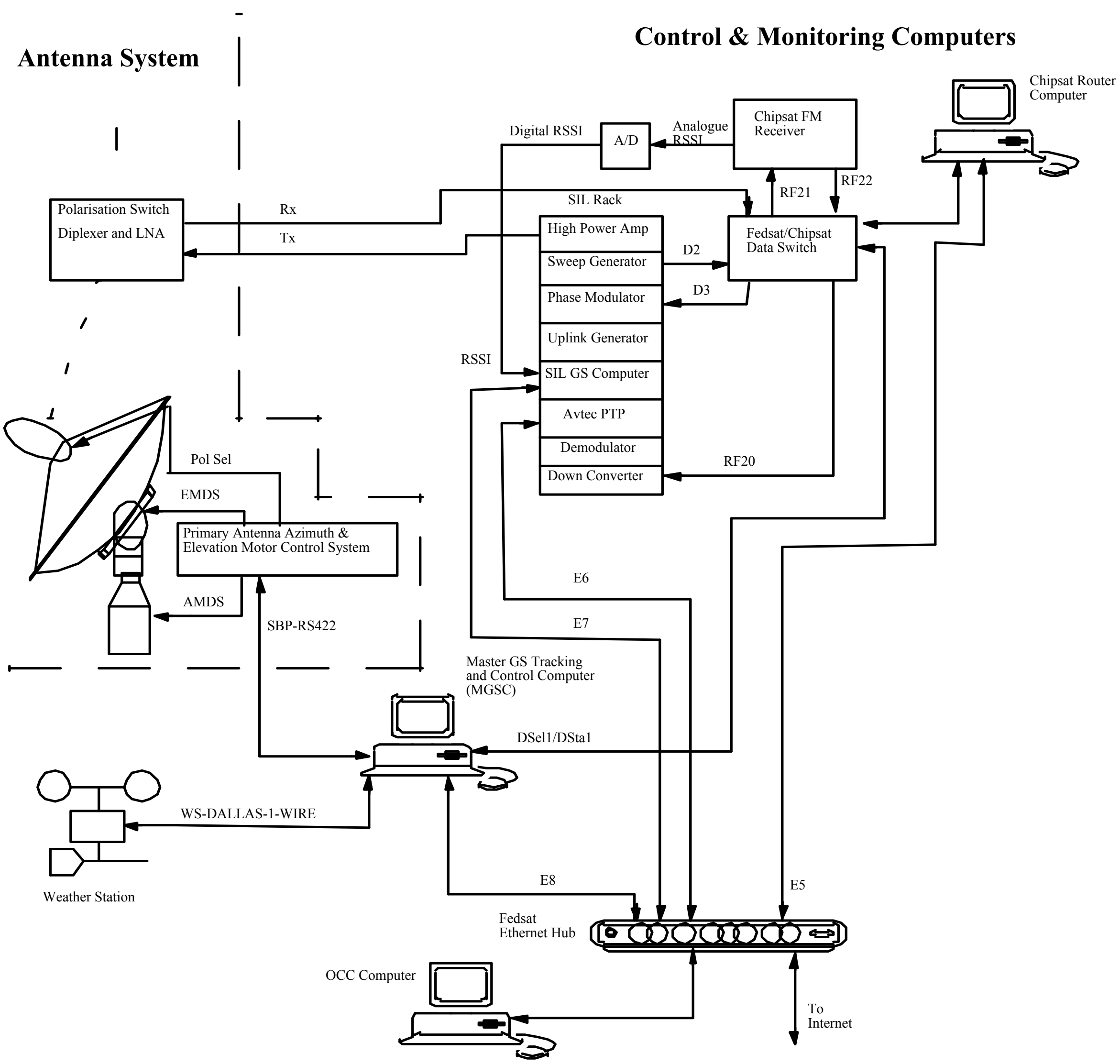

Figure 1 : FEDSat/CHIPSat Ground Station

2. *Tracking antenna, RF equipment and modems*

The FedSat/CHIPSat GS consists of the following facilities shown in Figure 1.

- S-Band Dish and associated Control Components (Antenna System)
- Control & Monitoring Computers
- Space Innovations Limited (SIL) RF Rack

The RF Rack contains the RF and modem electronics which converts the 2.2GHz signal down to packet (TCP/IP) level and also up-converts packets to the correct S-Band transmit frequency (Tx).

The dual polarisation feed horn for the dish, which is a 3 meter Andrews dish with a Azimuth-Elevation mount, houses a Polarisation switch (controlled by the OCC computer via the Master Ground Station Tracking and Control Computer), a diplexer and a Low Noise Amplifier (LNA). The placement of these components at the feed horn is to ensure low noise at the RF Rack.

Once the signal have been amplified in the LNA it is fed into the FedSat/CHIPSat switch and depending on which mode the GS is operating, the signal is routed either into the RF Rack Down Converter or to the CHIPSat Frequency Modulation (FM) Receiver.

During FedSat Mode the signal is downconverted to a 70 MHz Intermediate Frequency and then demodulated in the SIL Variable Rate Demod (VRD) after which packets are sent to AVTEC Programmable Telemetry Processor (PTP) [7]. The AVTEC-PTP uses the Command Operation Procedure (COP) protocol to communicate with the satellite on the uplink and receives messages in the telemetry downlink stream in the form of Command Link Control Words (CLCWs) [8]. The FedSat downlink provides data rates of up to 1 Mbit/s. Suppressed carrier, Binary Shift Keying (BPSK) modulation is employed at a downlink frequency of 2205 MHz [8]. On the uplink the data rate is much lower, between 4 to 8 kbit/s, also BPSK, with a RF power of up to 5 Watts. A sample link budget for the FedSat downlink is shown in Table 1.

The first major difference when operating in CHIPSat mode is that both uplink and downlink employ wide-band FM modulation. A higher Eb/No is therefore required at the GS receiver. It is also necessary to change the polarisation according to the which polarisation (Left or Right) which has the highest Received Signal Strength Indicator (RSSI) level. This is done by digitising the RSSI output (Analogue RSSI) from the Wide-band FM Receiver and reading this signal into the MGSC Computer via the SIL GS Computer. An algorithm implemented in software then makes a decision which polarisation is optimal. This setting may change during a pass several times.

The second major difference is that CHIPSat does not use the AVTEC-PTP but makes use of readily available TCP/IP protocols. In essence CHIPSat can be viewed as a node on a computer network. For example, if a user would like to know if CHIPSat is active (e.g. can be seen by a dish during a pass) the user would issue a ‘ping’ command. This also made test and integration easy in that no complicated interfaces were required during testing - just access to the Internet.

FedSat **DOWNLINK POWER BUDGET**

PARAMETER	CLEAR SKY	RAIN FADED
Satellite Transmitter		
Availability	100.00%	99.99%
Satellite HPA Output Power	3.0dBW	3.0dBW
Satellite Tx to RFSU Cable Loss	0.5dB	0.5dB
Satellite RFSU Loss	0.1dB	0.1dB
Satellite RFSU to Antenna Cable Loss	0.4dB	0.4dB
Satellite Transmit Antenna Gain	0.0dB	0.0dB
Satellite EIRP	2.0dBW	2.0dBW
Free Space Link		
Path Elevation	5.0deg	5.0deg
Orbital Altitude	803.0km	803.0km

Slant Range	2790.3km	2790.3km
Carrier Frequency	2.2050000GHz	2.205000GHz
Free Space Loss	168.2dB	168.2dB
Atmospheric Loss	0.5dB	0.5dB
Rain Attenuation	0.0dB	0.2dB
Ground Station Receiver		
Power Received at the GS Antenna	-166.7dBW	-166.9dBW
GS Receive Antenna Gain	34.5dB	34.5dB
GS Receive Antenna Pointing Loss	0.1dB	0.1dB
GS Receive Polarisation Loss	0.5dB	0.5dB
GS General Losses (Prior to LNA)	1.0dB	1.0dB
GS Receiver Gain (Prior to LNA)	32.9dB	32.9dB
GS System Noise Temperature	610K	610K
Increase in Noise Temperature due to Rain	0.0K	13.2K
GS System Figure of Merit (G/T)	5.05dB/K	4.95dB/K
Thermal C/No	66.9dBHz	66.6dBHz
Ground Station Demodulator		
Bit Error Rate	1.0E-06	1.0E-06
Demodulation Scheme	BPSK	BPSK
Demodulator Implementation Loss	0.5dB	0.5dB
Demodulator Data Rate	1000.0kbps	1000.0kbps
Available Eb/No	6.4dB	6.1dB
Using a RS Decoder		
Required Eb/No	7.0dB	7.0dB
Excess Link Margin @ 5 deg	**-0.6dB**	**-0.9dB**
Using a V Decoder		
Required Eb/No	4.8dB	4.8dB
Excess Link Margin @ 5 deg	**1.6dB**	**1.3dB**
Using a RS+V Decoder		
Required Eb/No	3.3dB	3.3dB
Excess Link Margin @ 5 deg	**3.1dB**	**2.8dB**

Table 1

3. Master Ground Station Computer (MGSC)

The MGSC and its connected hardware subsystems are the controlling arms of the OCC software, which is the main user interface for controlling and monitoring all Ground Station operations. The MGSC directs all the antenna movements and controls the physical systems within the FedSat TT&C Ground Station. The MGSC was designed by ITR and resides on a Linux operating system.

The MGSC is primarily designed to provide services to the OCC for the tracking of FedSat and CHIPSat satellites. These services are provided by both the MGSC itself and on behalf of other software/hardware entities that in turn provide services to the MGSC. In this aspect, it can be said that the MGSC acts as a message handler to some of the lower level services. Figure 2 shows all the software/hardware modules within the MGSC itself and also the modules that are connected to the MGSC externally.

The MGSC provides the following broadly defined services to the OCC:

- Pass summary information for all satellites of interest over the ITR Ground Station antenna.
- Pass scheduling controls

- Ingress and Egress times for all satellites of interest
- Low level antenna tracking control and monitoring
- RF Rack equipment control and monitoring
- Ground Station weather information
- Ground Station equipment connection status
- Visible/audible alarm indicators

The Mode Controller Module (MCM) is the core software residing within the MGSC, which coordinates the functionality between other modules or components. Nine of the modules communicate with the MCM via TCP/IP interfaces, where the MCM is the client in all cases except for the OCC connection where it is a server, and the TLE Update Module where communication is via a file and unix signals.

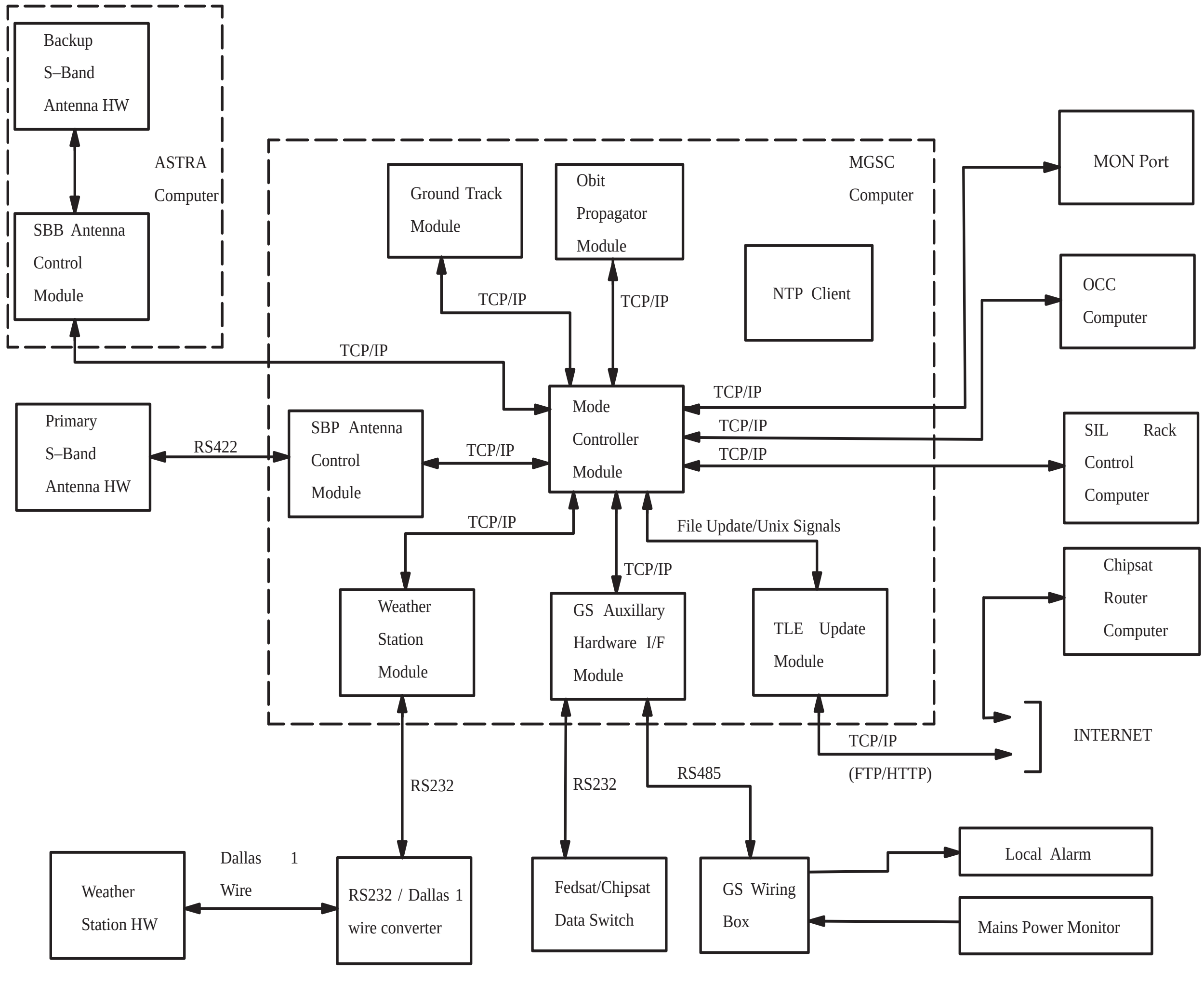

Figure 2 : Software Architecture of MGSC with interfaces

Below are brief descriptions of the major modules coordinated by the MCM.

1. Orbit Propagator Module (OPM)
   - process TLE sets for various satellites and generate high accuracy satellite position data for the tracking of the satellites.
2. S-Band Primary Antenna Control Module (SBPACM)
   - provides the interface to the Primary S-Band antenna system smart controller and hardware.
3. SIL Rack Control Computer (SIL)

- controls and monitors the S-Band RF Uplink and Downlink components which are physically located in the SIL Equipment Rack.

4. TLE Update Module (TLE)
   - updates the master TLE sets file on an 8-hourly basis by using ftp to the appropriate Internet sites.
5. Weather Station Module (WXS)
   - provides weather data on the Ground Station.
6. GS Auxiliary Hardware Interface Module (GSH)
   - provides an interface to all auxiliary Ground Station hardware components excluding the main antenna and the weather station.

4. Operations Control Centre (OCC)

The Operations Control Centre (OCC) provides the operator with a control and monitoring interface to all the Ground Station components and control and monitoring of communications to the satellite. It is a software program that is written in Visual Basic and provides a visual windows style interface that is user friendly and efficient to operate during the relatively short passes that occur for low earth orbit satellites such as FedSat. The OCC was written by ITR in Adelaide and CRCSS staff in Canberra.

The OCC consists of three main sections. These are telemetry processing, telecommand building and processing and Ground Station tracking, control and monitoring. The first two of these provide the communications to control and monitor satellite operations. The latter provides Ground Station component monitoring and control. A block diagram of the OCC and its interfaces are shown in Figure 3.

The telecommand building and processing section provides the mechanism for the operator to build sequences of basic telecommands and save them as stacks. These are usually pre-built prior to each pass for rapid transmission to the satellite as each pass is relatively short. Telecommand stacks are placed on a queue in the Telecommand Generator. The Telecommand Generator sends the telecommands to the satellite by communicating with the CCSDS Telecommand Encoder located in the Avtec Packet Telemetry Processor (PTP). This hand shaking is provided by four TCP/IP interfaces between the Avtec PTP computer and the OCC computer. The uplink protocol used to guarantee packet delivery, the CCSDS Command Operation Procedure (COP-1), is implemented on the ground in the Avtec PTP and there is a corresponding receiving module in the satellite. The Avtec PTP then de-packetises the telecommand packets for sending to the RF section for modulation and transmission to the satellite.

The PTP receives raw digital data from the downlink RF demodulator, performs Reed Solomon decoding and reconstructs the data into telemetry packets. The telemetry processing section of the OCC receives the reconstructed telemetry packets from the Avtec PTP via a TCP/IP link. All packets are then logged to a log file as well as being sorted for use in other sections of the OCC. All real time packets during a pass are displayed on a telemetry viewer window. In addition the housekeeping data packets are decoded for display in a "parameter viewer" window which displays real time operational parameters to the operator. These include parameters such as battery voltages, attitude control angles, etc.

The Large File Executive provides a window to the operator that enables large files to be uploaded to and downloaded from various memory stores on the satellite for payload experiments and for platform operations.

The Ground Station tracking, control and monitoring section of the OCC provides graphical screens for displaying the status and providing control of:

- the S-Band antenna;
- the RF systems for both uplink and down link;
- the weather station;
- the selection of passes to be tracked;
- the progress of each pass as it progresses;

- and the status of TCP/IP links between various computers that make up the Ground Station.

An error executive also displays any errors and important information that occurs anywhere in the Ground Station immediately to the operator.

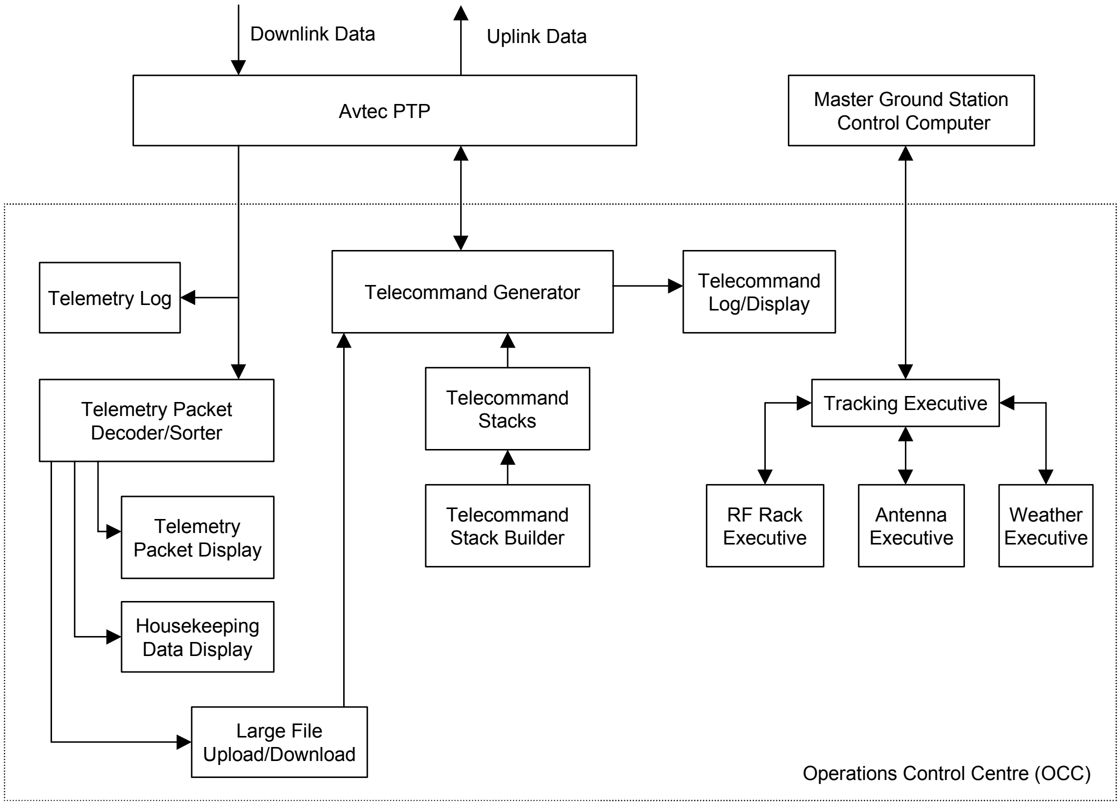

Figure 3 Block Diagram of the Operations Control Centre (OCC)

5. Platform and Payload Data Analysis and Display via Telemon

Telemon is a custom configurable data display & analysis system that provides data monitoring and processing services for complex systems. For FedSat, Telemon uses CCSDS packets along with an AVTEC™ baseband processor providing TCP/IP access. The Telemon software package, written in LabVIEW™ by Andrew Bish was originally developed for system level testing during the Spacecraft AIT phase in Canberra where it was chiefly used for ACS (Attitude Control System) test, PCS (Power Conditioning System) tests and payload data processing.

For Satellite operations, Telemon was upgraded to provide data analysis support for the SIOC phase and is now used for operational analysis for the FedSat mission for platform and payloads. Telemon's functions currently include:

Monitoring and analysis of the spacecraft system:

- An instant display of all monitored voltage, current, power, temperature and status monitoring for the platform and payloads during passes to enable fast analysis of performance (see example in Figure 4).
- Error warnings and advice for FedSat DHS (Data Handling System) Telecommands.
- Operational and debug analysis for the DHS.
- Automatic stack creation for spacecraft ACS time and TLE updates, enabling updates during passes.
- Automatic stack creation for next dataset requests to reduce operator workloads.
- Instant display of spacecraft attitude information.

- Spacecraft position information to monitor performance of attitude, power, temperature and payload performance as shown in the figure below (Spacecraft Attitude Error versus Position).

Figure 4 Telemon platform monitor screen showing five orbits of FedSat

Payload Tasks include:

- Processing and correlating time data from the GPS payload to give accurate spacecraft system time knowledge.
- Processing the NewMag magnetometer data (axis rotation, concatenation, time and position correlation and field analysis) to provide automatic data dissemination for science groups at the University of Newcastle & NASDA.
- Automatic Processing of Star Camera images and centroids (star locations) to provide Star Camera status and accurate spacecraft Attitude knowledge by fitting to the ACS attitude quaternion.
- Basic analysis for the UHF and Communications experiment payloads.
- Raw data analysis for the High Performance Computing Experiment.

As the operation of the FedSat Ground Station necessarily becomes automated, Telemon's status analysis facility will be used to provide alarms to system and payload operators in the event of out of limit or abnormal behaviour of the satellite platform or payloads.

6. Operator Functions in the Ground Station

As mentioned earlier, FedSat passes the CRCSS ground station at least 4 times per 24 hour period with length of passes ranging from 5 minutes to 13 minutes. Any commands to the spacecraft or data retrieval from the spacecraft must occur during these passes. The Ground Station operator is responsible for tracking the spacecraft, sending commands and collecting its data.

Currently two OCCs are used, with the ground station tracking system on one of the twin screened OCCs and the Spacecraft Command and real time telemetry windows on the other. In addition the real time and stored data from the spacecraft is piped to a third computer as described in Section 5.

The sequence below describes an operators function for a typical FedSat pass:

- Select appropriate pass to track with command stacks prepared and tested
- Ensure Ground Station has this pass “toggled” to track, all modules are running and error executive shows no alerts
- Ensure Avtec (Packetiser / Depacketiser) is enabled and “Data Slurper” log file ready
- Set ground station downlink data rate and coding to that of the spacecraft.
- Select Pass mode on OCC and ensure appropriate sockets are connected.
- At predicted AOS, use BD mode, and send about 5 Advanced Telecommands “TX ON” to Telecommand Generator (This mode allows uplink commands without downlink acknowledgements). Send these commands sequentially until the receive spectrum is observed and carrier, and timing are both locked.
- When frames are received on Avtec and CLCWs ticked in uplink status window of Telecommand Generator, select AD Mode and “Initiate AD Comms” (This mode provides acknowledgement of uplink telecommands).
- Load Telecommand Stack with appropriate prepared stack. Generally the initial stack requests housekeeping and stored data from the spacecraft.
- Transmit all commands through high priority queue before loading other stacks which may be housekeeping commands or payload commands ratified by Mission Operations.
- Large File Uploads or Downloads may be initiated. These files are loaded on to the low priority queue, and may take a number of passes to complete.
- While the pass is happening, the operator observes the Telecommand Log, Telemetry Log and SpaceCraft Parameter Identification (Scpid) Viewer to validate commands and telemetry as well as monitoring satellite real time housekeeping parameters which may require attention.
- When the pass is completed, logs are written and archived. Data from pass is analysed and preparation for next pass is commenced.

In the ChipSat case most of the operations are carried out remotely from the mission control facility in the US. The GS normally operates in unattended mode for CHIPSat passes, although during the satellite commissioning phase there has been quite regular assistance from local staff to optimise the downlink receive performance. Figure 5 shows a diagram of the CHIPSat data network.

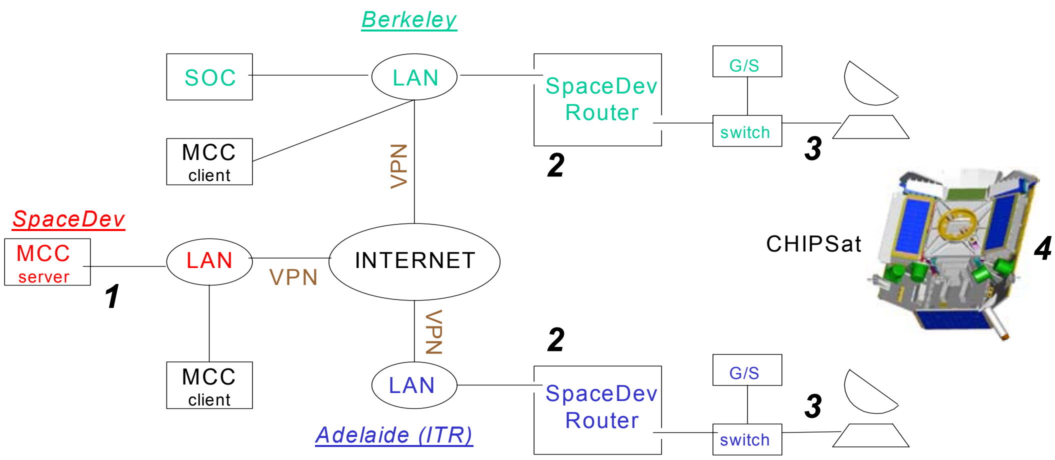

Figure 5 Overview of CHIPSat Data Flow

7. Conclusions

The CRCSS Ground Station plays a critical role in the FedSat Project and now forms the focus for FedSat activity. For the CHIPSat project the GS provides an important link which allows contact with the satellite while it's over Australia. This paper has described the hardware and software architectures which are used to control and monitor the FedSat and CHIPSat satellites. GS systems have been fine-tuned during the satellite commissioning phases and this is likely to continue over the next several months as we enter a stable operational phase.

Acknowledgements

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References

[1] Graham C, Petkovik M, Russell S, Seumahu S, Vesely M. The FedSat Microsatellite. International Conference on Information and Communication Systems. Singapore, 1999.

[2] Russell SC and Vesely M. (2003) FedSat in Orbit – The Operations. 10th Australian International Aerospace Congress (incorporating the 14th National Space Engineering symposium). Brisbane, July 2003.

[3] CRCSS web site URL - http://www.crcss.csiro.au/

[4] ITR web site URL - http://www.itr.unisa.edu.au/

[5] Tykesson M, Parfitt A, Cowley WG, Kotchetygov V and Rao N. (2003) Design, Implementation and Testing of the Communications Payload (CP) for FedSat. 10th Australian International Aerospace Congress (incorporating the 14th National Space Engineering symposium). Brisbane, July 2003.

[6] *http://www.itr.unisa.edu.au/crcss/UTS/TIP Ka Band Pres at IFAS Tokyo, Nov 2000*

[7] AVTEC Systems Inc. *"PTP-NT Programmable Telemetry Processor for Windows NT: User's Manual"*, Document No. TM 00-005, Version 1.50, April 2000.

[8] Consultative Committee for Space Data Systems (CCSDS), *"Part 2: Telecommand Data Routing Service"*, CCSDS 202.0-B-2 Blue Book, November 1992.