

# The FedSat Earth Segment

E. S. Seumahu<sup>1</sup>, W. G. Cowley<sup>1</sup>, S. Reisenfeld<sup>2</sup>

Cooperative Research Centre for Satellite Systems

1. Institute for Telecommunications Research, University of South Australia

Mawson Lakes, S. Aust. 5095 AUSTRALIA

Phone: +61 8 8302 5223 Fax: +61 8 8302 3873 E-mail: [steve.seumahu@unisa.edu.au](mailto:steve.seumahu@unisa.edu.au)

2. School of Electrical Engineering, University of Technology, Sydney

PO Box 123, Broadway NSW 2007 AUSTRALIA

## Abstract

A Cooperative Research Centre for Satellite Systems (CRCSS) has been established with a mission to deliver sustainable advantage for Australian industries and government agencies based on the applications of small satellites. FedSat is an innovative research microsatellite designed to help CRCSS realise many of its research and development objectives. The FedSat activities will give Australian scientists and engineers valuable data about the space environment, as well as experience in space engineering and in practical applications of space technologies. This requires the establishment of appropriate earth segment facilities. The present paper briefly describe the various components of the FedSat earth segment.

## 1. Earth Segment Facilities

The FedSat earth segment consists of the following facilities [1]:

- Ka-band:
  - Fixed ground station
  - Transportable terminal
- UHF:
  - Fixed ground station
  - Mobile terminals
    - Land-mobiles
    - Ocean buoys
    - Laptop and Handheld
- S-band:
  - TT&C ground station

## 2. Ka-band Earth Segment

The Ka-band Earth Segment consists of a fixed ground station and a transportable terminal. The fixed ground station will be located in Adelaide at the Institute for Telecommunications Research (ITR), University of South Australia. The ground station can be used for bent-pipe or packet switching communications. The Ka-band transportable terminal will be used on-site at the University of Technology Sydney (UTS) or it can be transported for off-site use.

The term earth station will be used generically for both the ground station and the transportable terminal [2]. The earth station is designed and built by UTS. The block diagram of the earth station is shown in Figure 1. The downlink signal is received from FedSat at a carrier frequency of 20.13 GHz. The signal is low noise amplified and downconverted to 1.53 GHz with a low noise block downconverter. The signal level is then adjusted with a variable attenuator under computer control. The signal is then downconverted to 60 MHz. The 60 MHz signal centre frequency contains Doppler and local oscillator frequency errors. These errors in carrier frequency are estimated by the Doppler processor. The frequency error estimate is transferred from the Doppler processor to the control computer. The control computer commands the downlink direct digital synthesiser to a frequency, which compensates for the downlink Doppler shift and local oscillator frequency error. The frequency corrected 70 MHz signal is then input to the modem/codec in the nonregenerative mode and to the earth station baseband processor in the regenerative mode.

For uplink communications, the modulated 70 MHz signals originates either from the earth station baseband processor for regenerative mode operation or from the modem/codec for non-regenerative mode operation. The uplink Doppler shift is pre-corrected at the earth station. Estimates of the uplink Doppler shift as a function of time are made from a combination of open loop and closed loop data. The open loop information comes from a priori orbital predictions and the closed loop information comes from downlink received signal frequency estimation. In the regenerative mode, received uplink frequency error is estimated by the spaceborne baseband processor, and this error report is transmitted to the earth station baseband processor via a downlink command channel. The earth station baseband processor commands the control computer to implement fine uplink frequency adjustments. In the non-regenerative mode, the uplink Doppler shift is estimated and pre-corrected. The Doppler processor controls a direct digital synthesiser, which is a local oscillator for the uplink signal path.

For the uplink signal path, the 70 MHz signal is mixed with the 10 MHz direct digital synthesiser signal, and the result is a 60 MHz Doppler pre-corrected centre

frequency. The signal is then upconverted to 1.43 GHz and is then further upconverted to 29.93 GHz. At 1.43 GHz, the signal passes through a variable attenuator which is controlled by the control computer. The 29.93 GHz signal is amplified to the 2 Watt RF power level using a solid state power amplifier.

The antenna pointing angle coordinates are output from the antenna control processor into the antenna power control electronics. The power control electronics provides the drive signals for the antenna tracking motors.

The antenna pointing angle coordinates are pre-computed for a satellite pass in the control computer. These coordinates are uploaded to the antenna control processor prior to a satellite pass. The antenna control processor has precision timing derived from the GPS receiver. During a satellite pass, the antenna control processor commands the power electronics module which positions the antenna in angular alignment with the FedSat spacecraft. The antenna position shall be updated every 10 milliseconds.

A DSP processor is used to implement a frequency acquisition and tracking algorithm. At the beginning of a satellite pass, the downlink signal carrier frequency is acquired in less than 1 second. The carrier frequency is then tracked using a carrier tracking algorithm. Using the derived frequency estimate, the DSP processing board commands the uplink and downlink direct digital synthesizers to frequencies which remove downlink Doppler and local oscillator frequency shift and pre-corrects for uplink Doppler and local oscillator shift, respectively.

FedSat is equipped with an onboard GPS receiver. The satellite position information is received on the telemetry downlink. A mathematical model of the satellite orbit is formulated from the GPS data. The earth station GPS receiver is used to determine the precise spatial location of the earth station. This data will also be used to derive vectors of time indexed antenna pointing angles for the earth station. These vectors shall be pre-computed before a satellite pass by the control computer. They will then be loaded into the antenna control processor. The antenna control processor shall then command the antenna to the correct spatial coordinates as a function of time during a satellite pass.

### 3. UHF Earth Segment

The UHF earth segment consists of one UHF ground station in Adelaide and many Mobile Terminals (MT) which could be ocean buoys, land-mobile, laptop or hand-held terminals, scattered around Australia and the southern ocean region.

The UHF ground station is used in bent pipe mode for experiments involving voice-band communication (eg voice, data modem, electronic messaging etc) to and from the MTs. In this mode the MT's can also communicate with each other using the ground station as a hub.

In processing mode the UHF MT's work together with an on-board Base-Band Processor (BBP) and the FedSat TT&C subsystem to provide Advanced Data Acquisition and Messaging (ADAM) applications [3]. The configuration of a UHF MT demonstrator used in the ADAM mode is shown in Figure 2.

## 4. S-band TT&C Earth Segment

The functional diagram for the primary S-band ground station is shown in Figure 3. The antenna, tracking system and operational control centre are provided by, and housed at, the Institute for Telecommunications Research in Adelaide. The primary antenna has a diameter of 3 meter. A secondary antenna is also available on-site to backup the primary antenna. Off-site receive-only facilities are also planned at the University of Canberra and DSTO (Defence Science and Technology Organisation) in Salisbury.

The heart of the the S-band TT&C ground station is a SIL satellite ground station (SGS) rack which is designed to work with the SIL platform and the four payloads on board the FedSat spacecraft. As shown in Figure 4, the SIL rack contains the downconverter, variable rate demodulator, de-packetiser, packetiser, sub-carrier BPSK modulator, FM modulator, and high power amplifier. A GPS receiver and antenna are provided for timing purposes.

In the case of failure of the S-band space segment, a back-up subsystem will be set up, consisting of the uplink component of the UHF subsystem and the downlink component of the Ka-band subsystem. To facilitate this, the Ka-band ground station and the UHF ground station are integrated with the SGS rack at the downlink depacketiser and the uplink packetiser levels respectively.

## 5. Ka-band Satellite Tracking

### Spatial Tracking Requirements

The 1.2 meter diameter antenna size has been chosen to provide a design compromise between the antenna gain required to support the transmission data rate and a sufficiently large beamwidth to allow spatial tracking of the satellite. The earth station has some very demanding requirements in relation to both frequency tracking of the FedSat signal and spatial tracking of the rapidly changing FedSat satellite position.

To close the communication link at the required data rate, the antenna must deliver high gain, exceeding 48.5 dBi at 30 GHz and 45.4 dBi at 20 GHz. Consequently, the beamwidth is quite narrow, approximately 0.58 degrees at 30 GHz and 0.88 degrees at 20 GHz. Spatial tracking is achieved in an open loop manner using data derived from the onboard GPS receiver. The tracking angles for each pass is pre-computed and stored in the earth station control computer. The earth station is equipped with a GPS receiver for timing reference. The derived spacecraft orbital model shall be used to compute the pointing angles, which are indexed by time. The earth station design provides the capability of running experiments which fuse open loop data supplied either by NORAD or derived from onboard GPS measurements and closed loop error signals obtained from received signal level measurements. It is intended that communications be available during a pass when the spacecraft elevation angle exceeds 30 degrees.

#### **Frequency Tracking Requirements**

The maximum Doppler shifts of the signals are +662.1 kHz for the 30 GHz uplink frequency and +441.4 kHz for the 20 GHz downlink frequency. Additionally, there will be large frequency errors from the transmit and receive earth station local oscillators and from the spacecraft local oscillators. The rapidly changing Doppler shift and slowly varying oscillator drifts are accommodated by the utilisation of a frequency acquisition and tracking algorithm. The combined Doppler shift and local oscillator error is removed with less than a 1 KHz residual error for both the uplink and the downlink. The total range of frequency correction in the design is  $\pm 2$  MHz relative to the nominal centre frequency for both the uplink and the downlink.

#### **Suitability of Using NORAD TLE's**

The operational requirements of FedSat (low link margin and narrow beamwidth) dictate that the Ka-band earth station must track the satellite with an accuracy better than 0.3 degrees. UTS has conducted a study on the suitability of using NORAD TLE's (Two-line Elements) alone for satellite tracking at Ka-band [4]. The results show that, while the use of SGP tracking algorithm and publicly available TLE's is able to reasonably predict the orbital path of the satellite, it failed to accurately predict the time at which the satellite is at a particular point on this path. The timing error ranges from 0.75 to 41.75 seconds at an elevation of 20 degrees.

#### **Frequency Assisted Spatial Tracking**

To meet the operational requirements of FedSat, UTS has developed a special tracking system called FAST (Frequency Assisted Spatial Tracking) [5]. Assuming that the altitude and inclination of the orbit is known, the Doppler and Doppler rate are sufficient to specify the satellite position. This allows the Doppler and Doppler rate measurements to be used to compute the

satellite position and hence point the antenna. UTS has also developed a new robust, low-complexity frequency estimation algorithm for Doppler compensation.

## **6. Conclusion**

FedSat is a multi-mission satellite, carrying 4 payloads with more than a 15 operational modes. The Earth segment has been designed to service all the different kinds of research and applications to be conducted using this satellite. A multitude of terminals and ground station types have been studied, designed and developed to work in this environment,

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Figure 1  
FEDSAT  
K Band Earth Station Block Diagram

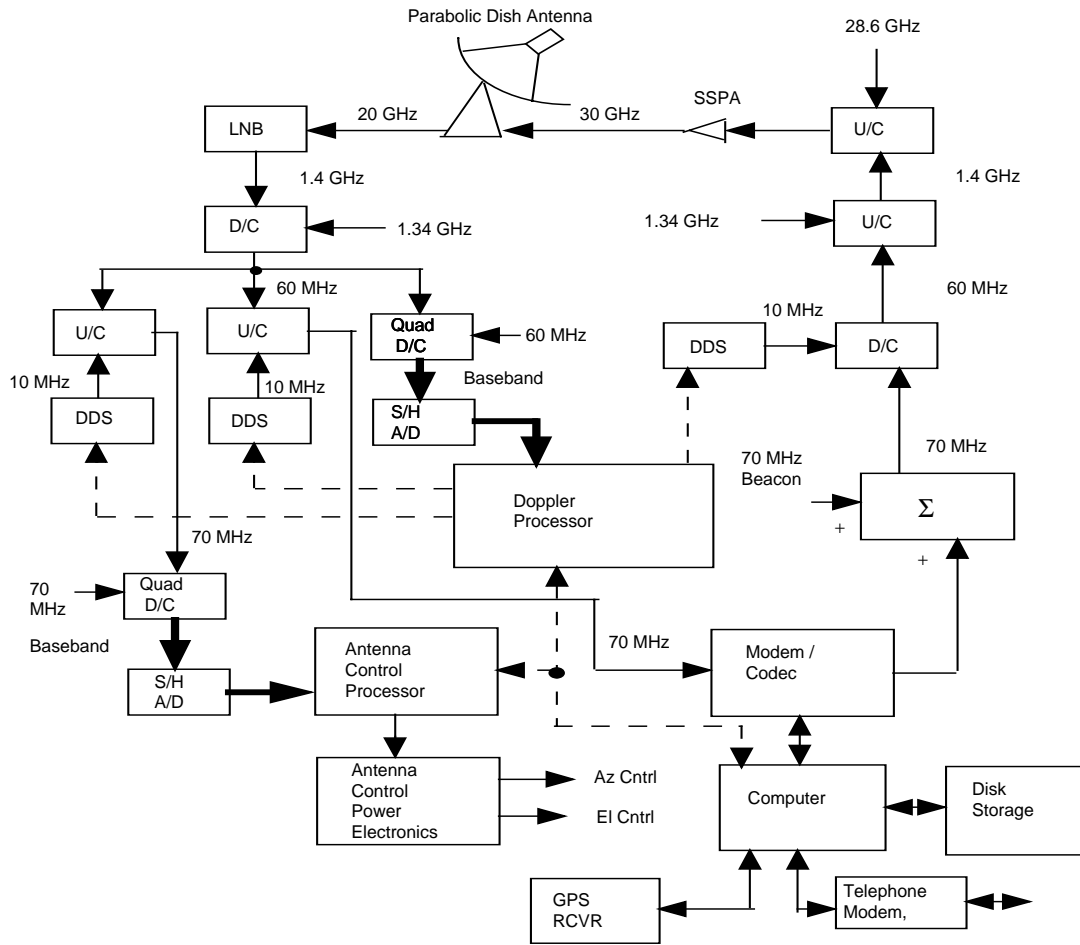


Figure 1 Ka-band earth station

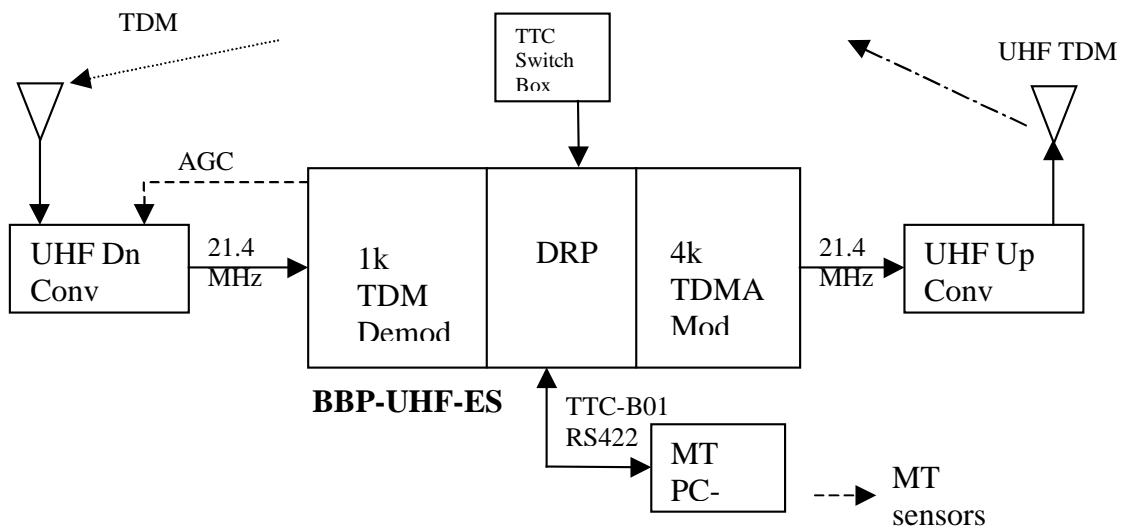


Figure 2 UHF mobile terminal demonstrator

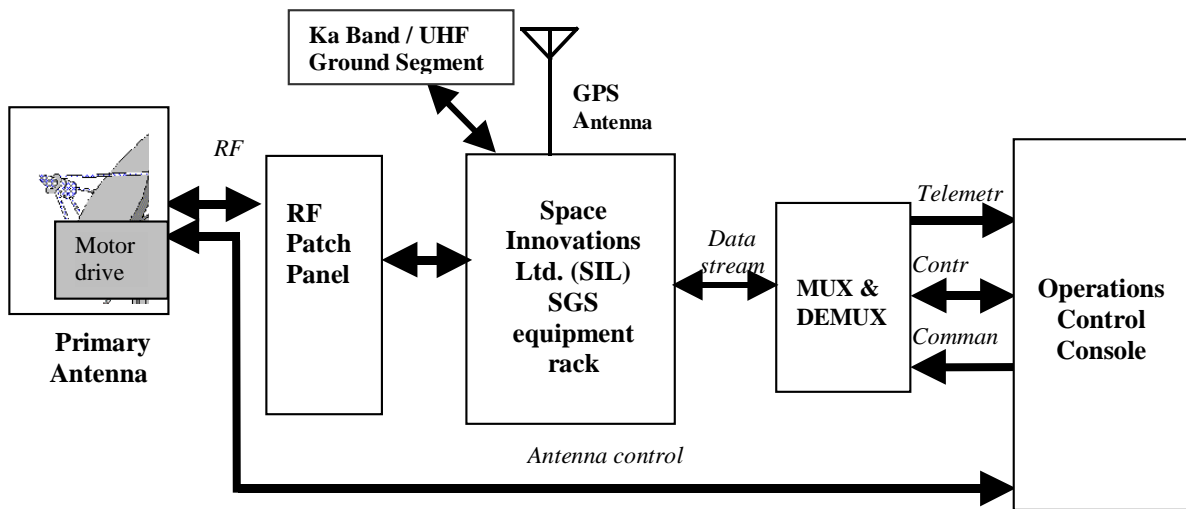


Figure 3 S-band TT&C ground station

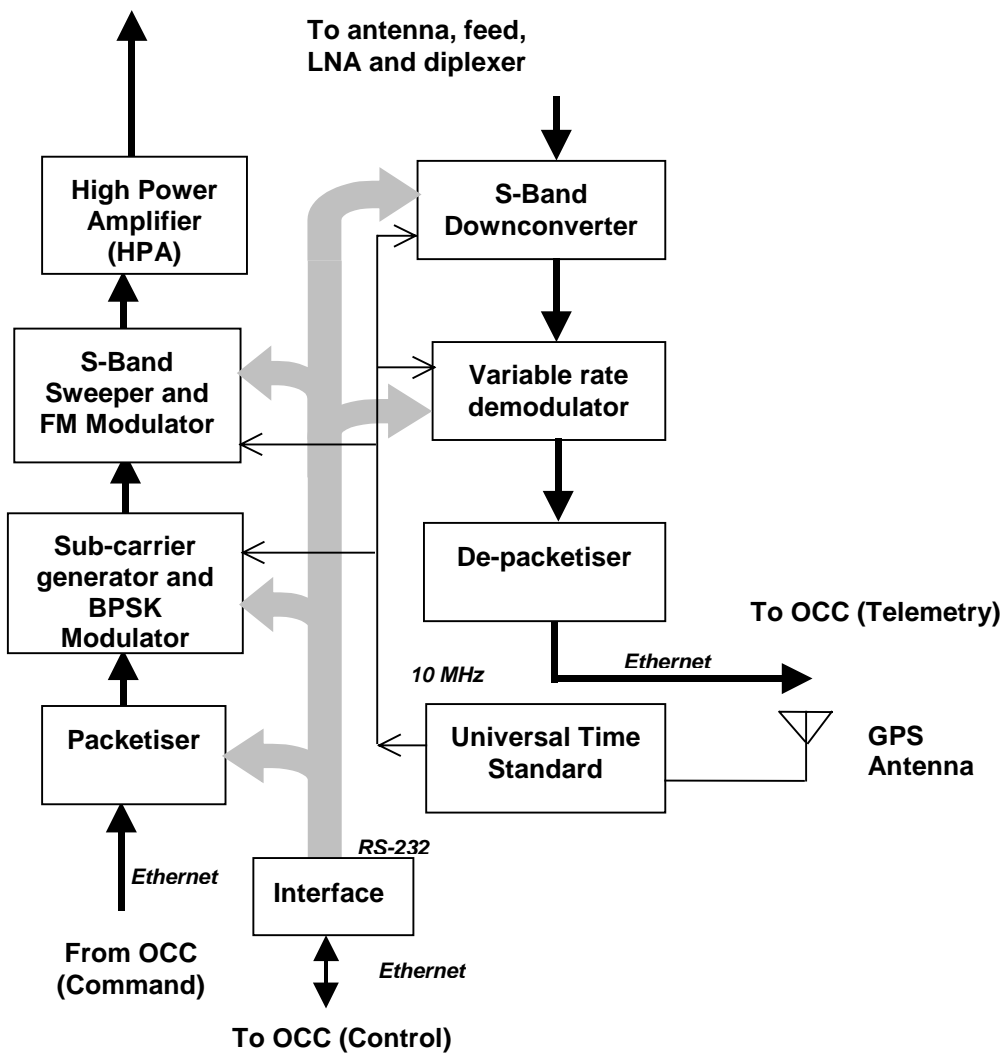


Figure 4 SGS equipment (Source: Space Innovations Limited, 1998)