The FedSat Communications Payload

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Abstract

FedSat is an innovative research microsatellite developed by the Australian Cooperative Research Centre for Satellite Systems (CRCSS) due for launch in late 2000 to commemorate the Centenary of Australian Federation. Four payloads are provided for FedSat by participating institutions of the CRCSS. This paper gives a brief description of the Communications Payload.

1. Overview

The CRCSS was inaugurated in January 1998, with participation of CSIRO (Commonwealth Scientific and Industrial Research Organisation), universities and industry. The participants aim to undertake a targeted research and development program in communication, space science, remote sensing, and space engineering.

The FedSat mission 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 [1],[2]. FedSat has a mass of approximately 58kg, measures 50cms x 50cms x 50cms and follows an approximately sun-synchronous orbit at a height of 800 km with an inclination of 98.6 degrees. Space Innovations Limited of UK (SIL) provides the satellite platform.

The CRCSS's research programs include space science, satellite communication, remote sensing, satellite systems and satellite engineering. Satellite communications research is carried out by a group consisting of CSIRO Telecommunications and Industrial Physics (CTIP) in Sydney, the University of Technology Sydney (UTS), DSpace Pty Ltd in Adelaide, and the Institute for Telecommunications Research (ITR) at the University of South Australia in Adelaide. The research activities include new Ka, L, UHF and VHF frequency band techniques for communications and data delivery, internet and ATM services via LEO satellites, advanced LEO satellite earth terminals for communications and TT&C, and advanced RF sub-systems. To progress their research activities, the communication group have collectively designed a Communications Payload (CP) for FedSat and the associated earth segments.

Figure 1 is a functional overview of the CP and shows the frequency plan at different parts of the payload. It can be seen that several frequency conversion stages are used throughout the CP. Physically, the CP consists of a Ka-band unit, a UHF unit and a Baseband Processor (BBP) unit. As far as the RF path is concerned, the UHF unit connects directly to the BBP whilst the Ka-band unit connects to the BBP via the UHF unit.

2. Ka-band Unit

The Ka-band unit contains the Ka-band receiver and the Ka-band transmitter that connects to the other communications payloads at an IF of 1.5 GHz [3]. Schematics of the receiver and transmitter are shown in Figure 2 and Figure 3 respectively. The separation of the Ka-band unit from the other payloads enables independent testing and ensures adequate rejection of spurious signals in the RF chain. A 20 MHz bandwidth is possible by the selection of local oscillator frequencies.

The system power levels indicated in Figures 2 and 3 lead to a modest link margin in clear sky and light rain conditions with a 1 to 2 Watt earth station transmitter and a 1.2 m diameter earth station antenna. Propagation is downlink limited with an output effective isotropically radiated power (EIRP) of 26 dBm. Nevertheless bit error rates in excess of 10^{-4} are expected with data rates up to 256 kbps in both bent-pipe and BBP modes of operation, provided that the small carrier-to-noise ratio can be tolerated by the QPSK coding scheme and channel bandwidth. The bent pipe mode of operation also allows for the use of alternative modulation techniques.

The Ka-band unit has been designed using MMIC components specifically developed at CSIRO for this application. These include a CSIRO designed and TRW Inc. fabricated low noise 30 GHz amplifier and mixer receiver chip with a 2.3 to 2.5 dB noise figure and a conversion gain of around 15 dB. A 3 volt, 15 mA/HEMT bias is required for upper-sideband (USB) operation with a 12 dBm local oscillator. Both the dc and the RF levels were chosen to conform with the power constraints of the satellite. One CSIRO designed and fabricated 20 GHz mixer is used as the up-converter, for USB operation with a 12 dBm local oscillator. The conversion loss is 8.5 to 10 dB (circuit to circuit variation), image rejection better than 10 dB and LO to RF rejection between 25 and 35 dB. Another CSIRO designed and TRW Inc. fabricated device is the medium power amplifier MMIC with a measured gain of 20 dBm (±1 dB), a 1 dB compression of output power (P_{1dB}) of 20 dBm (±1 dBm) and return loss > 20 dB.

A power amplifier stage comprising two TRW Inc. supplied APH196C amplifiers in parallel is used to provide a transmitter P_{1dB} of up to 26 dBm, allowing for a small loss in the power combiner circuit and output waveguide run to give the specified 0.25 W output power.

The Ka-band antennas for FedSat have been designed to partially compensate for increasing free-space path loss and atmospheric attenuation as the observed elevation angle of the satellite reduces from zenith. This compensation for the path loss increases access time to the satellite. Simple antennas such as waveguide horns are desired in the present application because of volume, weight and power constraints and also circular symmetry is preferred because the link is circularly polarized. To meet these requirements two similar circular multimode horns have been developed for the transmit and receive bands [3]. These horns have a radiation pattern with a peak gain in excess of 6.8 dBi at an angle of 43 degrees from the antenna boresight and a minimum gain at the edge of coverage (60 degrees) of about 2.6 dBi.

3. UHF Unit

The UHF unit was designed and built at ITR. It contains the UHF receiver, the L-band/UHF down converter, the UHF/HF downconverter, the BBP HF by-pass circuitry, the HF/UHF upconverter, the UHF transmitter, and the UHF/L-band upconverter. The frequency converters and by-pass circuitry are housed in the UHF unit, but they also support Ka-band operation by providing a path between the Ka-band unit and the BBP.

The UHF unit can function in a bent-pipe or a store & forward (S&F) mode. In the S&F mode, the UHF unit and the BBP will be used for Advanced Data Acquisition and Messaging (ADAM). This combination will be duplicated as a stand-alone payload to be flown on other satellites in the future, for example KAISTSAT-4. Such a payload is illustrated in Figure 4.

4. Baseband Processor

The Baseband Processor provides advanced on-board communications processing for the CP. The BBP is a packet modem with low power and flexible rate operation. DSpace Pty Ltd and ITR are responsible for the design, development and testing of the BBP [4].

The BBP supports both the Ka-band and the UHF operations. For Ka band operation the CP supports both “bent pipe” and on-board processing modes. The BBP employs a TDMA uplink and TDM downlink. The frame rate is selected to suit multimedia applications. Uplink and downlink symbol rates are the same, although there is slightly more downlink capacity due to the uplink overheads such as guard bands. The downlink is a continuous TDM signal since, when low-gain iso-flux antennas are employed on the satellite, there is no advantage to be gained with a TDMA downlink. Each earth terminal derives its frame timing from the TDM downlink. The first downlink slot is used for reservation acknowledgments and status information. The remaining slots may be used to forward uplink slots, or for “broadcast mode” applications.

For UHF operation, the BBP is needed to implement a two-way messaging system which provides robust data collection and store-and-forward services to low cost mobile terminals (MT). Efficient use of the narrowband UHF frequency allocations is required and several MTs must be able to access the system at any time. To satisfy these requirements a TDMA and TDM access technique is also used, with a reservation-based allocation system, but the frame periods are much longer.

A number of frame formats are envisaged in this service. For example, the mode primarily suited to remote data collection employs a 4 kbps, half-rate coded, QPSK uplink and an uncoded, 1kbit/s, BPSK or FSK downlink. In this case the downlink is mainly used for acknowledgments, status information and short messages. A lower rate downlink allows more link margin suitable for uncoded low-cost MTs, for example for oceanographic data collection applications. Another mode of operation is better suited to messaging between MTs and employs equal uplink and downlink transmission rates of 4 kbps.

The on-board SIL data handling system (DHS) computer will be used to store messages from, or to, MTs. Messages received from the “data collection” MTs will be stored in the DHS until they can be returned to the TT&C station in Adelaide via the S band telemetry system.

In the UHF MTs, Doppler and slot timing compensation is not possible since the MTs are low cost and don’t know their own locations. Consequently the MT must be able to estimate the frequency offset and remove it. Also the TDMA guard bands must be large enough to accommodate variations in packet transmission time.

In general, the BBP employs feedforward synchronisation approaches to achieve burst-mode packet processing plus IF sampling and synthesis. Figure 5 shows a block diagram of the demodulator processing for the Ka band rate. As previously explained, Doppler offsets will be removed in this situation, so the NCO #1 represents a very simple fixed-frequency down-conversion operation.

The feedforward phase estimator shown in Figure 5 accepts one-sample-per-symbol-period samples and estimates the phase offset over a limited number of symbols. Although most of the frequency offset has been removed at this stage, the residual offset still proves difficult to handle due to the significant rate of Doppler change.

UHF processing involves a lower symbol rate but is complicated by the need to estimate and remove Doppler frequency offsets. A rate-half turbo coding scheme is envisaged on the UHF uplink, with interleaver sizes selected to match the slot durations.

The BBP architecture can be divided into three main modules: modulator, demodulator and a data routing processor (DRP). Both modulator and demodulators are to be implemented solely using FPGAs, in order to meet the speed requirements, whilst minimising power usage. To implement the demodulator using a processor, it is expected that a high power DSP would be required which would exceed the power budget.

The DRP is to be implemented using a simple microcontroller as its main task is to shift data packets, interfacing between the modulator, demodulator and the central storage system onboard the satellite. In addition, the DRP is required to implement simple channel allocation and UHF ARQ protocols. The DRP interfaces to the modulator and demodulator via a single bus, with a DMA facility included to allow for high throughput.

Figure 6 provides a high level architecture of the BBP, highlighting the three modules and indicating the main components. It can be seen that the demodulator will be implemented using 2 FPGAs; Actel (OTP) for prefiltering and Xilinx for the main acquisition and synchronisation tasks. An additional Xilinx FPGA is required for decoding tasks.

5. Operational Modes

The CP mission includes research, proof of concept, technology development and satellite application functions. The design of the CP enables it to operate in several different modes, including UHF S&F, Code upload, UHF beacon, UHF bent-pipe, Ka switching at 128 kbps, Ka switching at 256 kbps, TT&C backup at 128 kbps, TT&C backup at 256 kbps, Ka beacon, Ka warm-up, Ka bent-pipe, and receive-only TT&C backup.

6. Conclusion

The Communication Payload is a versatile payload for FedSat. It will operate in many modes using the UHF as well as Ka-bands to provide bent-pipe, on-board processing, and store & forward communications to support CRCSS satellite communications research and development programs. By providing backup TT&C functions, the CP will also support the platform and the other payloads on board FedSat.

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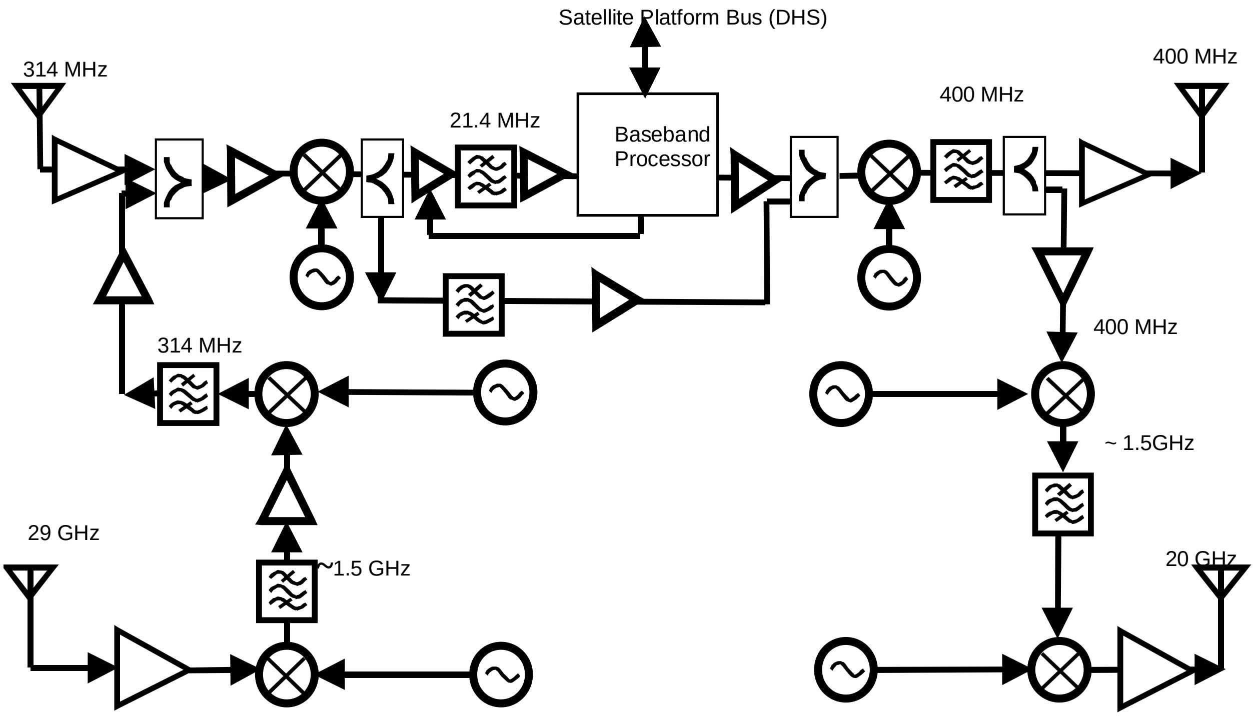

Figure 1 Communications payload components

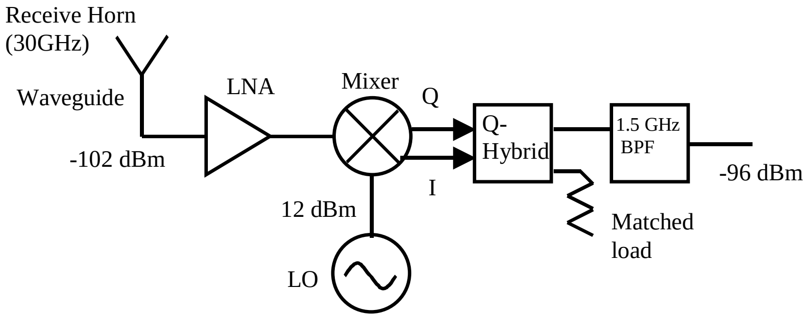

Figure 2 Ka-band receiver

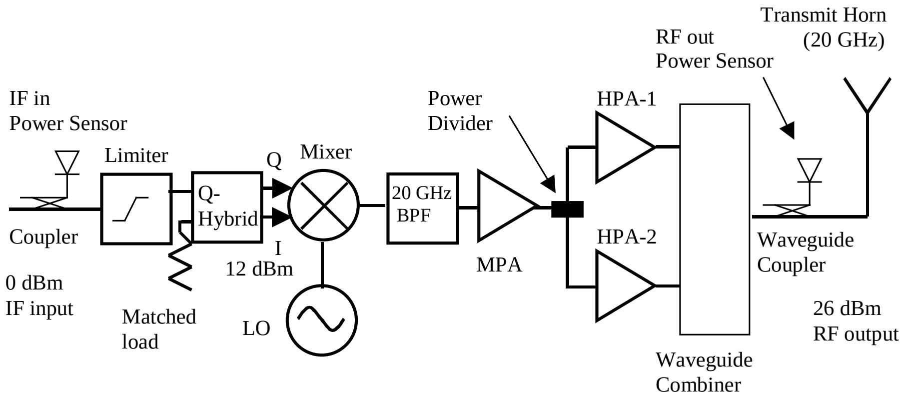

Figure 3 Ka-band transmitter

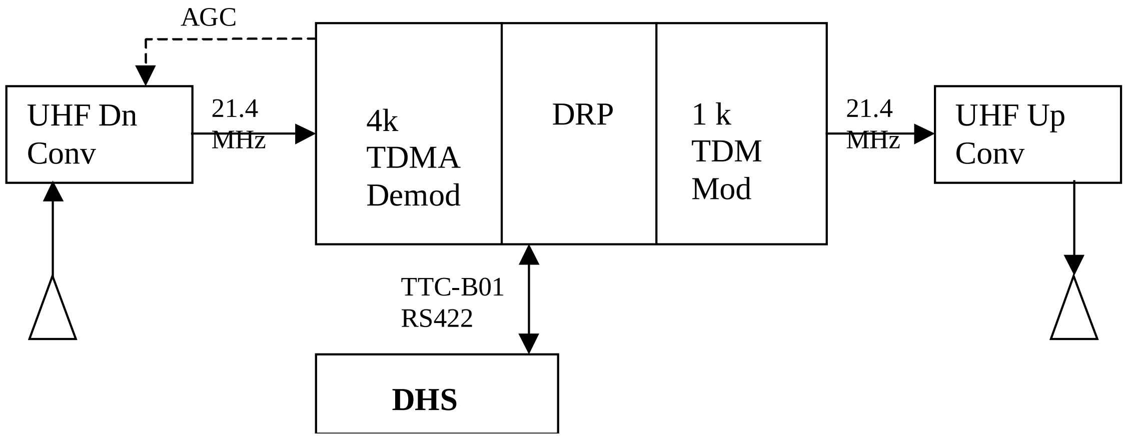

Figure 4 UHF ADAM payload in store & forward mode

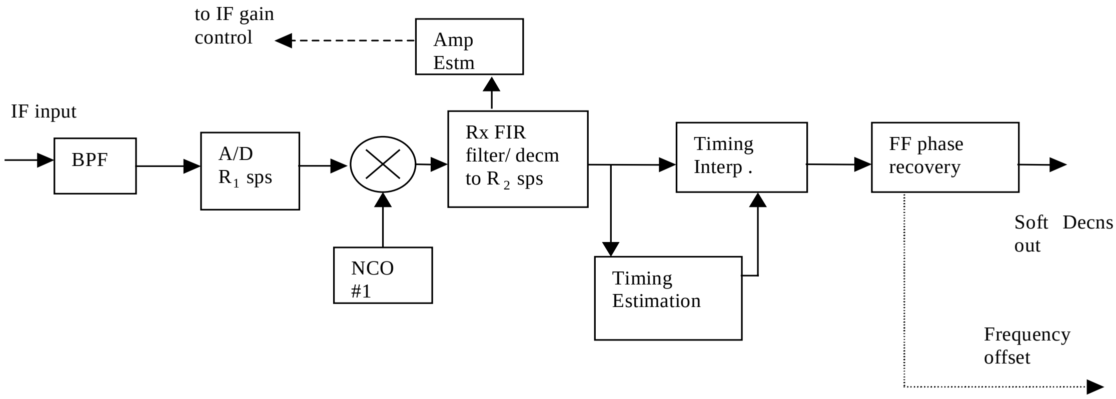

Figure 5 Demodulation processing

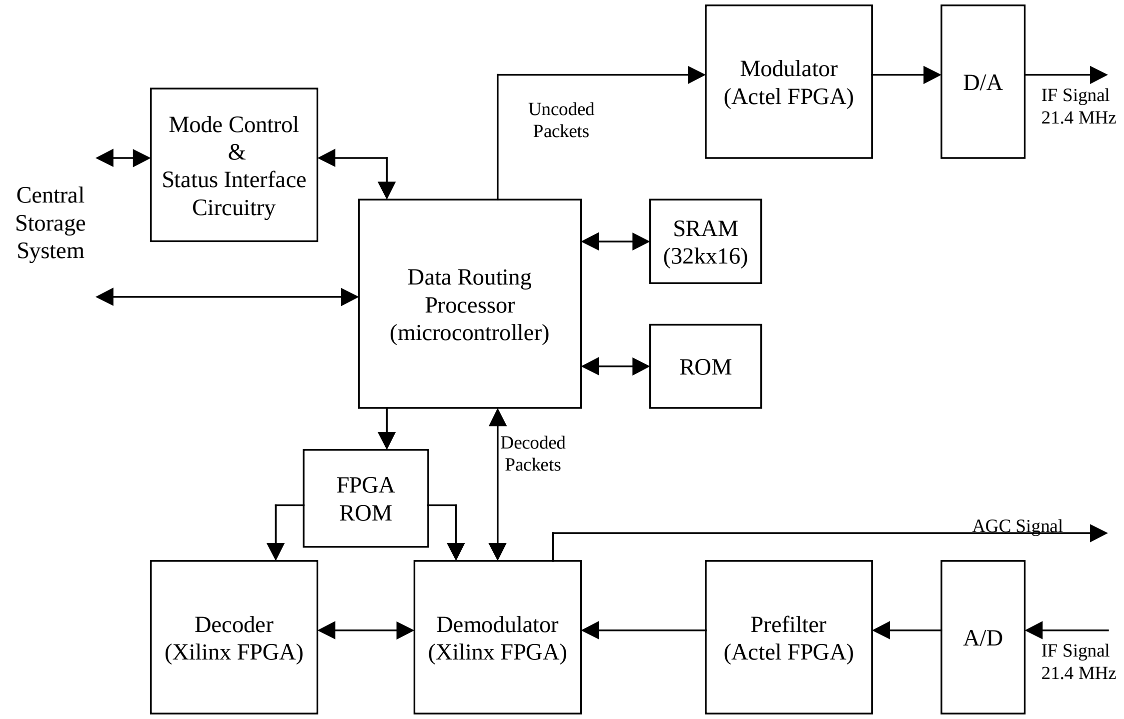

Figure 6 Baseband processor architecture