TEAMSAT's Data-Handling Systems

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Twenty-five weeks from project approval to the delivery of two working, flightworthy spacecraft data-handling systems did not, during the feasibility study, seem possible to fulfil. However, due to staff dedication combined with some calculated risk-taking and the availability of the ESA Telemetry and Telecommand chipset, a working data-handling system including ground segment was already available six weeks prior to TEAMSAT's shipment to Kourou.

Introduction

The highly restricted budget dictated the use of old flight spares and engineering models wherever possible. Thus, for the RF link, we used transponders from Olympus and Eureca. However, size and lack of adaptability of other parts such as a Central Data Management Units made them unsuitable, so we opted to design a new system from scratch. Not only did the system have to be much smaller, but it also had to accept the event-driven, asynchronous experiment data outputs 'as is', since there was no time to adapt the experiments or their existing test and development systems.

Fortunately, we had a small stock of Application Specific Integrated Circuits (ASICs) for building on-board telemetry and telecommand core systems compliant with the ESA subset of the recommendations of the Consultative Committee for Space Data Systems (CCSDS). These standards support asynchronous data delivery. The availability of this chipset and the fact that the system built from it did not involve a processor or software made the otherwise impossible task feasible.

Another advantage the telemetry/telecommand (TM/TC) chipset conferred was the 'Very high speed integrated circuit Hardware Description Language' (VHDL) models that came with it. The use of VHDL enables devices and whole systems to be designed and simulated down to very fine detail. Models of other components were already available, including the whole ground segment, in sufficient detail to exercise all the TM and TC protocols at an early development stage. This was instrumental in our successfully flying the data-handling system 'straight off the drawing board' without a prototype and with debugging restricted to relatively minor user interface issues.

Another essential element was an in house Field Programmable Gate Array (FPGA) design facility. There were two FPGAs in each spacecraft, supporting TM and TC functions respectively. They also controlled house-keeping packet generation (including control of the analogue subsystem) and provided programmed delays for command pulses. The FPGA design process also produced VHDL models.

Data-handling system design features

Our requirement to accept user interfaces and data structures 'as is' meant we had to provide a 'byte stream' rather than a packet service for both up- and down-links. In effect, the data-handling system provided a transparent path between experiments and their respective test and monitoring equipment. However, ESA/CCSDS packet structures were used to send the main power switching and configuration commands, and carry the platform housekeeping data. With no recognisable packets, delimiting between users was done by allocating different Virtual Channels (VCs) and Multiplexer Access Points (MAPs) on the TM and TC links, respectively. This is not necessarily a strategy we would advocate in other circumstances since VCs and MAPs are intended to primarily delimit different levels of service and/or address redundant paths in the transport layer. A given VC or MAP may then carry packets with different sources and destinations, as identified by the packet Application IDs, but with compatible requirements for bandwidth and latency. The ESA TM chipset was designed to support simultaneous byte stream and packet modes on different VCs.

We decided to include all the central power switching and housekeeping functions in the On-Board Data-Handling (OBDH) box, thereby creating one self-contained service unit for

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each spacecraft with the following characteristics:

Dimensions	310 x 170 x 110 mm^3
Weight	3.2 kg
Power	7 watts

The boxes were designed and manufactured in the ESTEC Workshops and contained one TM board and one TC board, each weighing about 450 g. They also contained relays, power regulators modulation filters, thermistor matching networks, etc. The housekeeping system provided 32 single-bit digital channels and 16 analogue channels with 8-bit resolution. Configuration switching telecommands were decoded by the Packet Telemetry Decoder (PTD) and, after amplification, used to operate the power-switching relays.

Self-adapting, asynchronous TM service

TM systems of earlier designs obliged users to adapt their data production to a lock-step regime imposed by the fixed-format TM transfer frame. Although the frame generated by the VCM/VCA chipset has a fixed size, its internal format adapts itself dynamically to user activity. This met the requirement to accept user data as randomly occurring squirts of various sizes or as fully asynchronous individual bytes. The useful bandwidth available on the TM link was 28 259 bits/sec (overheads removed). The system shared this among individual users such that each got a guaranteed share (which could be re-specified in flight), but any bandwidth not taken up by one user would be offered to other users in proportion to their guaranteed share. If users failed to exploit all the bandwidth offered, the generator itself completed frames with filler.

The AVS star-finder experiment on TEAM is a good example of a sporadic data producer. In quiescent mode, it produced a small squirt of housekeeping data from time to time, but when an image was taken a more prolonged squirt would be produced. The experiment had no flow control, so the TM system had to accept the data as it was produced at 19.2 kbaud from its PC-type asynchronous serial interface. It was guaranteed a share of the TM bandwidth matching this peak requirement, but this was only taken up occasionally due to the nature of experiment operations. The FIPEX experiment, also on board TEAM, was somewhat similar in its data-production characteristics.

The third TEAM experiment, the Visual Telemetry System (VTS), produced small amounts of housekeeping as a background activity, but it also had a 128 Mbyte buffer for video information. Its output interface was flow-

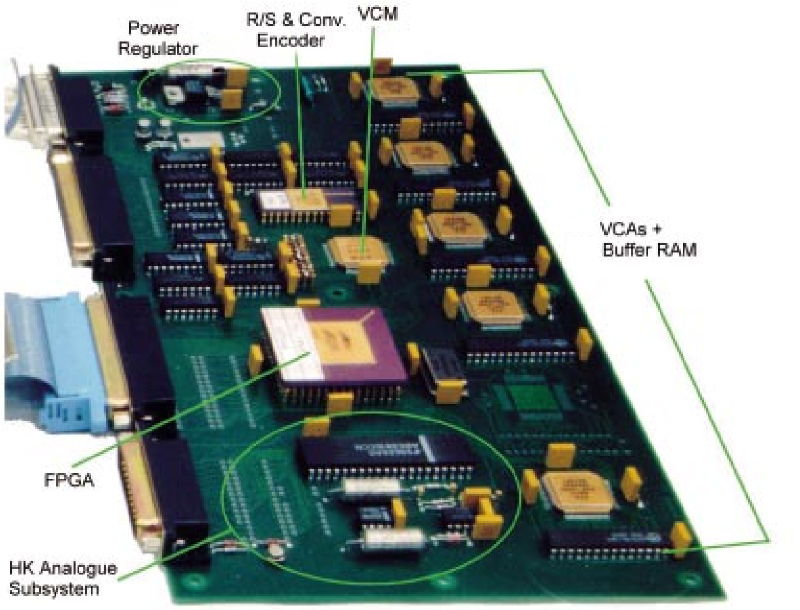

Figure 1. TEAM telemetry board

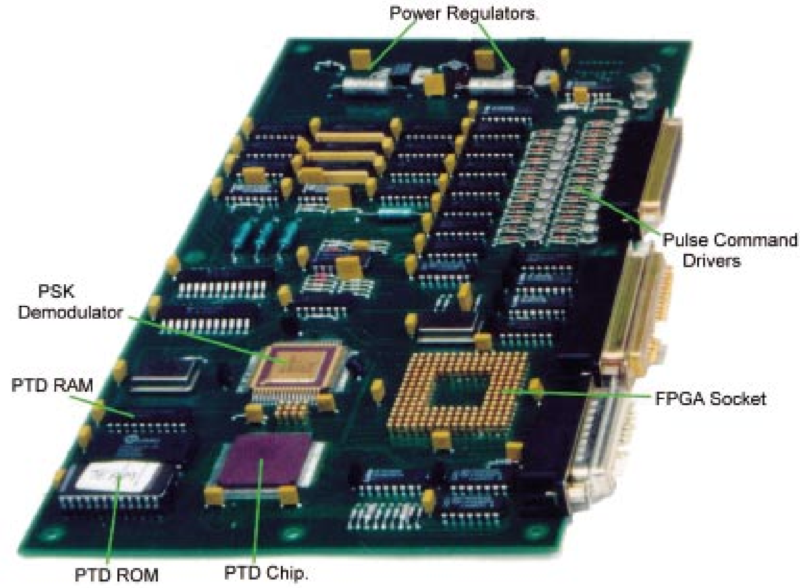

Figure 2. TEAM telecommand board

controlled so the VCA only accepted data when there was space in the transfer frame. This made it an ideal companion for AVS and FIPEX, since it could soak up the substantial bandwidths allocated to them but not used most of the time. In effect, the flow control applied by the TM system emptied the VTS buffer as fast as the total link bandwidth and current activities of the other users would allow.

In addition, we had platform housekeeping data being produced in ESA/CCSDS packets of fixed size and format every 4 sec. In that case, bandwidth was used consistently because of the constant data production rate.

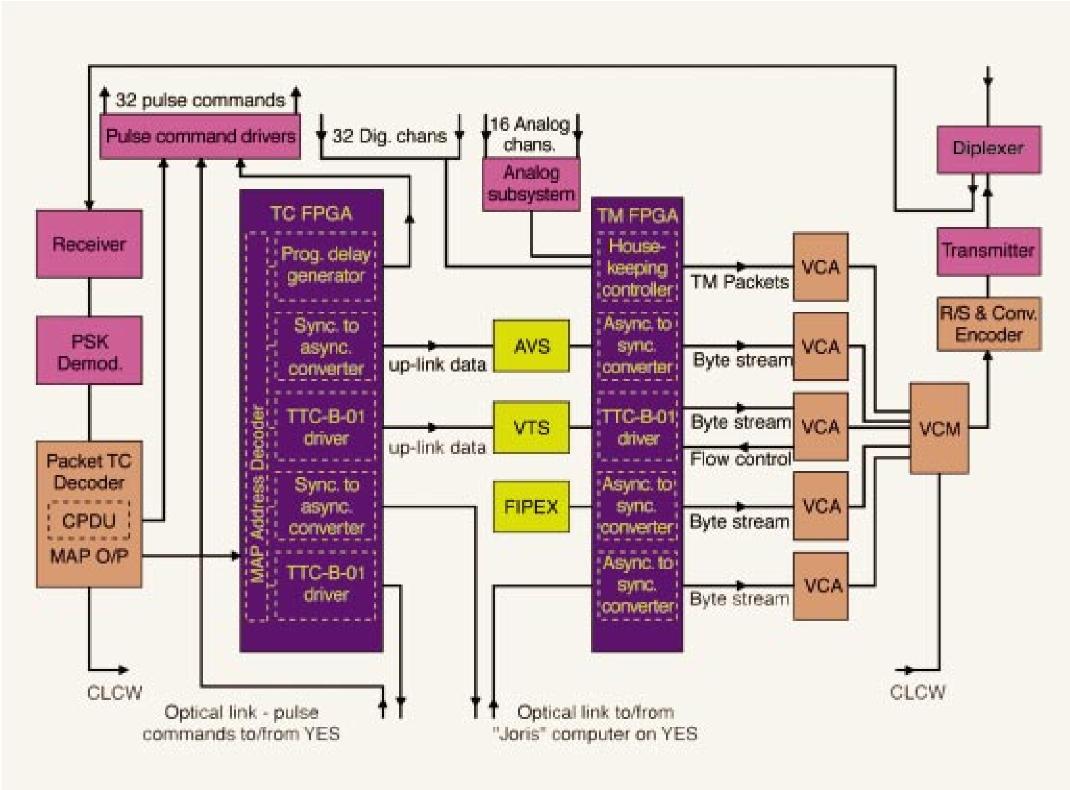

Figure 3. The TEAM On-Board Data-Handling System (OBDH)

The housekeeping system was similar to a classical ESA fixed-format approach. It made very inefficient use of the bandwidth it occupied (constant values reported in successive packets, etc.). However, the bandwidth in question was only a small proportion of the total, so the inefficiency could be tolerated in the interests of simplicity.

The ground segment

The ground segment had to be ready in time to support spacecraft integration and testing. Additionally, everything concerned with terrestrial- and space-link compatibility and procedures had to be resolved with ESOC during this period.

The transparent TC and TM links reduced the work required to implement the ground segment by ensuring that existing PC-based experiment development sets and software could be used for experiment control and processing during testing and flight. In this way, a comprehensive experiment control centre was created at very low cost.

System performance and conclusions

TEAMSAT is the first ESA spacecraft to be flown with TM and TC systems both fully compatible with ESA/CCSDS standards, and the first spacecraft to exploit the adaptive asynchronous TM capabilities they support. The performance and ease of use delighted everybody. There is also no doubt that the short, relatively trouble-free design and construction phases resulted from the use of the TM and TC ASICs, which implemented all of the tricky core functions and protocols.

The failure of the YES TM transmitter to command on after a routine short battery-saving hibernation period towards the end of the mission was the only blemish on an otherwise faultless performance. The YES transponder was an ex-Olympus engineering model that was over 16 years old. Its use was one of the many calculated risks we had to take.

Optical links between the two spacecraft before separation enabled essential TC and TM of one to be routed via the RF links of the other to overcome the expected effect of antenna pattern holes. One such link providing a redundant TC path via TEAM to YES was discovered to be unreliable during testing and could corrupt the intended command. By that stage there was no time to correct it, so an extra safety interlock was placed on the path by removing such commands from the ESOC database. In any case, given the pre-launch official disabling of the Tether experiment, it was no longer required. As a last-resort 'nothing-to-lose' action, the safety interlock was deliberately removed to make a final attempt to switch on the YES transmitter towards the end of the mission. The command corruption on that occasion resulted in the premature ejection of YES. At that time, all other principal objectives having been achieved, this did not further degrade the mission in any way other than to deprive us of some pictures of the separation via VTS that we might otherwise have had.

The efficient, adaptive behaviour of the TM system in accepting asynchronous, event-driven inputs without involving a processor is of particular note. It is a mode of operation that, considering it too complex, project groups and industry have so far mostly avoided. If attempting to implement it in software, there is probably some justification in this point of view. However, in successfully flying such a system 'straight off the drawing board' after ultra-short design and construction phases, we have demonstrated that by using the TM ASICs such misgivings are unfounded.

There was no mission requirement for the authentication process supported on the TC chip, so it was not used. The only other ESA/CCSDS capability not demonstrated in flight was the COP-1 protocol. TEAMSAT was the first ESA spacecraft to support this capability, but there had been no time to verify ground-station compatibility. However, its functionality on board had already been verified during integration and testing and its effectiveness in flight had already been demonstrated in 1994 by the low cost STRV-1 A and B satellites built by DERA, UK. These used an earlier prototype telecommand decoder chip, very closely related to the one we used.

The TEAMSAT project has proved that a spacecraft data-handling system of high performance and guaranteed compliance with standards can be designed and built quickly and cheaply by using commercially available, space-quality ASICs and supporting VHDL models. These ASICs are mutually compatible, come with all the complex protocols frozen into their silicon, and so enable the radically new system capabilities and standards they support to be implemented with no risk. They are outputs of an on-going ESTEC development activity exploiting VLSI technology to reduce costs and improve performance within the framework of the new ESA/CCSDS standards. Currently, more than ten projects are already committed to using them.

Acknowledgements
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ASIC Descriptions

All ASICs used latch-up-free, Silicon-On-Sapphire (SOS) technology have a footprint of about 8 cm^2 and weigh about 15 g.

Telemetry ASICs

Virtual Channel Assembler (VCA): Assembles data into one of up to eight VCs on the TM link (one VCA per VC). Applies flow control (optionally) to match the data source production rate to the bandwidth available to that VC. Accepts data as ESA/CCSDS packets or byte stream.
TEAM used five VCAs and YES used four.

Virtual Channel Multiplexer (VCM): Multiplexes outputs of up to eight VCAs on to one TM link. An inflight-programmable Bandwidth Allocation Table guarantees minimum portions to each VC. The VCM completes the transfer frame header (spacecraft ID etc.). Also provides interfaces for the Command Link Control Word (CLCW) from the TC decoder chip, and to the Reed-Solomon and Convolutional Encoder chip.
Each spacecraft used one VCM.

Reed-Solomon Convolutional Encoder: The on-board segment of a forward error detection and correction system providing a coding gain of about 7dB on the link budget. Its use is optional, but a tight link budget for TEAMSAT made it mandatory.

A complete TM frame generator core comprises one VCM, one VCA for each VC and an optional Reed-Solomon and Convolutional Encoder chip. Power (5V) is typically about 30 mW per chip, but depends mostly on clock rate and output loading.

Telecommand ASICs

PSK Demodulator: Demodulates the noisy PSK subcarrier from the TC receiver and recovers the NRZ data, bit clock and a 'signal present' indicator when the signal-to-noise ratio exceeds a predetermined value. One chip was used on each of the two spacecraft. Belongs to the physical layer and is not strictly part of the data-handling chipset.

Packet Telecommand Decoder: On-board segment of an ESA/CCSDS compatible up-link providing error-free delivery of packets or arbitrary data structures via up to 62 addressable MAPs. Also hosts an authentication check (not used for TEAMSAT), and a Command Pulse Distribution Unit (CPDU) which decodes multiple bi-level commands delivered in a packet.

Power (5V) is typically about 30 mW per chip, but depends mostly on clock rate and output loading.

Sources for more information:

Data-Handling System: TEAMSAT Website
http://www.estec.esa.nl/teamsat/

ASICs: TOS-ES Microelectronics Website
http://www.estec.esa.nl/wsmwww/