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Journal of the British Interplanetary Society, Vol. 26, pp. 153-166, 1973.

Data Conditioning System of the Prospero Satellite

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This paper describes the Data Conditioning System that was developed for use on-board the Prospero Spacecraft that was successfully launched in October 1971 as part of the British National Space Technology Programme. Prospero used a new Pulse Code Modulated telemetry system to meet this programme requirements and its orbital performance has proved the mission's objective. A modular concept was adopted where standardized modules were interconnected for this mission and which could be developed for future programmes, for example, the X4 and UK5 spacecrafts.

1. INTRODUCTION

ONE OF THE mission objectives of the Prospero Spacecraft was to prove in orbit a new Pulse Code Modulated (PCM) telemetry system, which had been developed to meet the requirements of the British National Space Technology Programme. The Data Conditioning System (hereafter referred to as the system) which this paper describes forms part of the telemetry system complex. The system had been designed to operate at variable bit rates to a maximum of 50 k bits per second, with a data transmission accuracy of 1% of full scale. Compatibility also had to be established with the ESRO and NASA ground station requirements.

The system collects and arranges all on-board data into a logical sequence prior to modulating the transmitter and subsequent transmission to the ground. It has been designed using a modular concept where the emphasis has been flexibility coupled with low power consumption and high reliability. To offset system complexity with its inherent weight penalty, extensive use has been made of readily available integrated circuits in standardized modules. A standard module measures approximately 100 x 63 x 7.5 mm and consists of components welded either to a nickel cross-wire or nickel-mylar interconnection matrix. The module is then wire-trapped into an overall interconnection panel which allows ease of removal should a fault occur. When welding components to the interconnection matrix the weld was made in such a position that, should a component fail, the faulty device could be removed and a replacement inserted without significantly degrading system reliability. Facilities were provided within a module which enabled at least three welds to be made, that is, the initial assembly plus two repairs.

Throughout the system design every effort was made to build in reliability by purchasing components to detailed specifications. These were written with a view to eliminating rogue devices; particularly transistors and integrated circuits. Previous experience [1,2] had shown that the majority of semi-conductor failures were due to poor quality control during manufacture. Thus, wherever possible, all active devices have been purchased to 'in house'

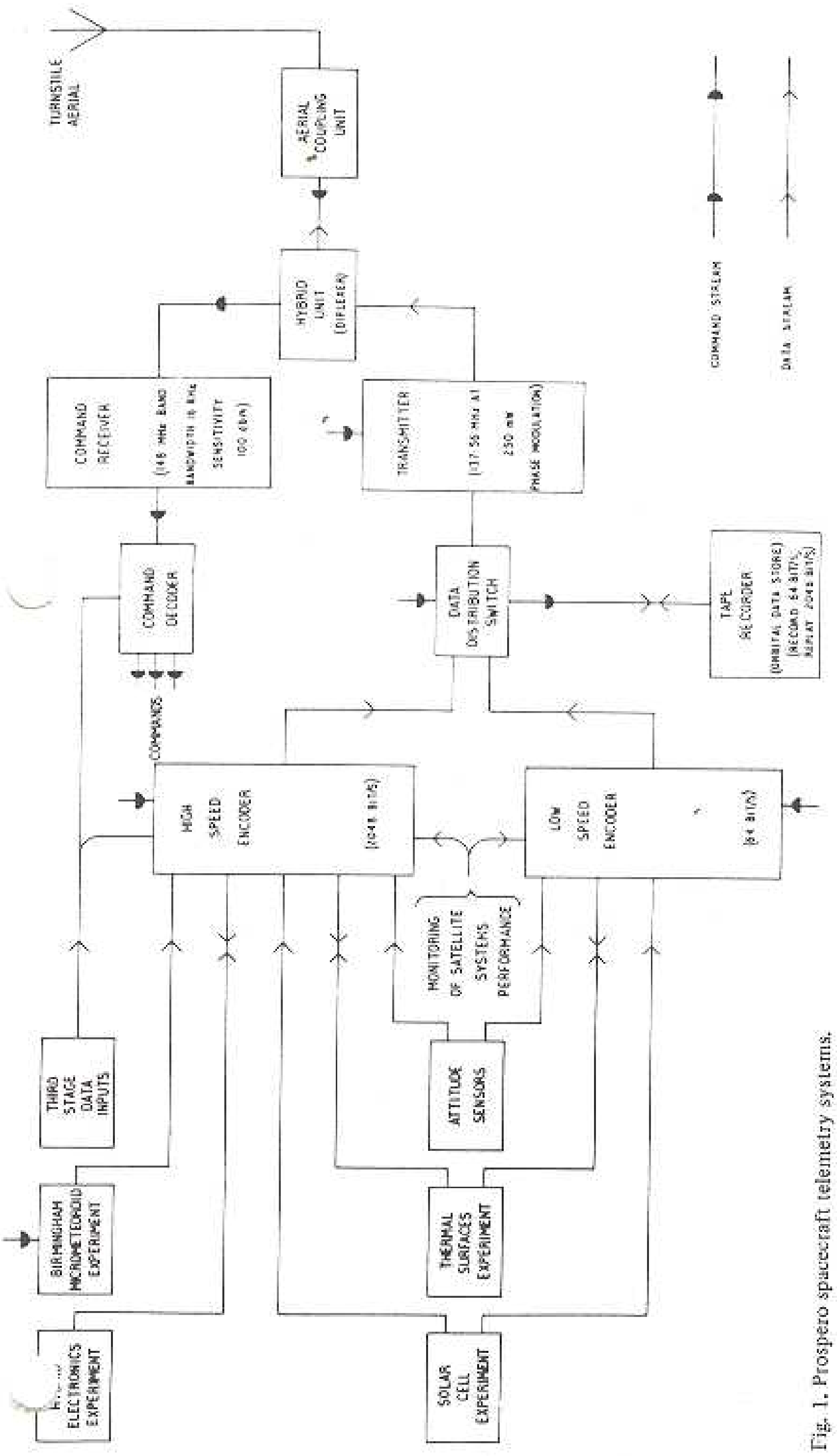

Fig. 1. Prospero spacecraft telemetry systems.

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3. DATA CONDITIO

3. 1 General informatio

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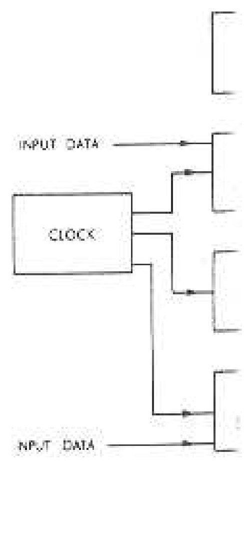

Fig. 2. Block diagram of Pros

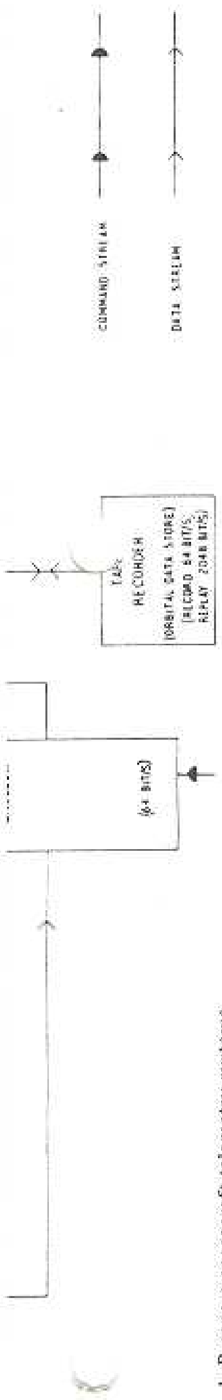

Fig. 1. Prospero spacecraft telemetry systems.

specifications which call for 100% inspection at all stages of manufacture, assembly and test.

To further enhance reliability, standby redundant equipment was provided in those areas where a single component failure could cause a total mission failure. Normally, only the operational equipment is powered, but in the event of a malfunction power is transferred to the redundant equipment by a COMMAND. This is transmitted and executed by a Tone Digital Command System.

2. PROSPERO SPACECRAFT SYSTEM

A block diagram of the Prospero spacecraft (telemetry) system is shown in Fig. 1. Data from the various experiments is fed into the High Speed (Direct) Encoder for real time transmission, whilst the Low Speed (Record) Encoder records data in the tape recorder prior to transmission when over a ground station. Both encoders use similar functional blocks and operate in a similar manner save that the Low Speed Encoder operates at a rate commensurate with the characteristics of the Tape Recorder.

3. DATA CONDITIONING SYSTEM

3. 1 General information

The system is shown in Fig. 2 which highlights the selected modes of operation. The Rocket mode was particular to the Launch Phase when information regarding the launch vehicle was transmitted, all satellite data being inhibited. On separation of Prospero from the third stage, the Rocket mode became inoperative and the system reverted to the Normal Mode Direct; when real time transmission of data encoded by the High Speed Encoder occurred at a bit rate of 2048 bits per second.

During this time data encoded by the Low Speed Encoder, which itself has two modes of operation; namely, Solar Cell mode and Thermal Surfaces mode is stored in the Tape Recorder. One receipt of the Playback COMMAND, the High Speed Encoder data is inhibited and the contents of the Tape Recorder are transmitted. After transmission of Tape Recorder data the system reverts

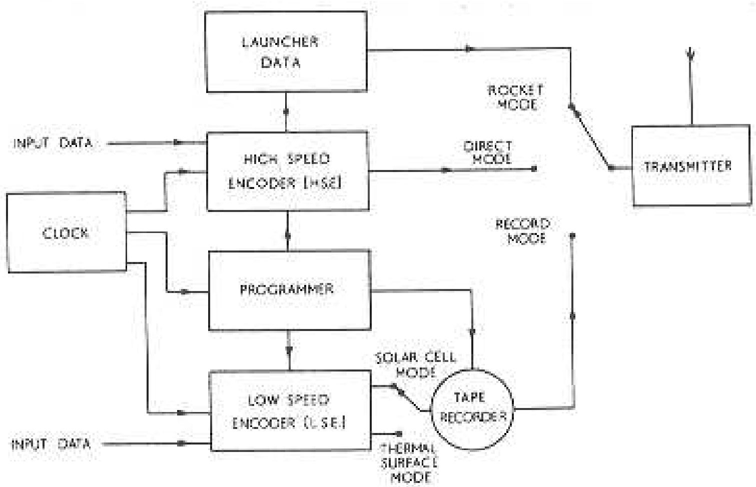

Fig. 2. Block diagram of Prospero spacecraft data system.

to its Normal Direct mode either by COMMAND or automatically after a period of four minutes.

3. 2 High speed encoder

A block diagram of the High Speed Encoder is shown in Fig. 3. An 'AT' cut crystal clock operating at a frequency of 2.097152 MHz provides the master time reference from which all control and logic operations are derived. The clock output feeds a binary divider and the outputs of the divider, both true and complement, are available for use both within the system and by on-board experiments. In this latter event isolation resistors prevent damage to the divider should a malfunction occur at an experimenter's interface.

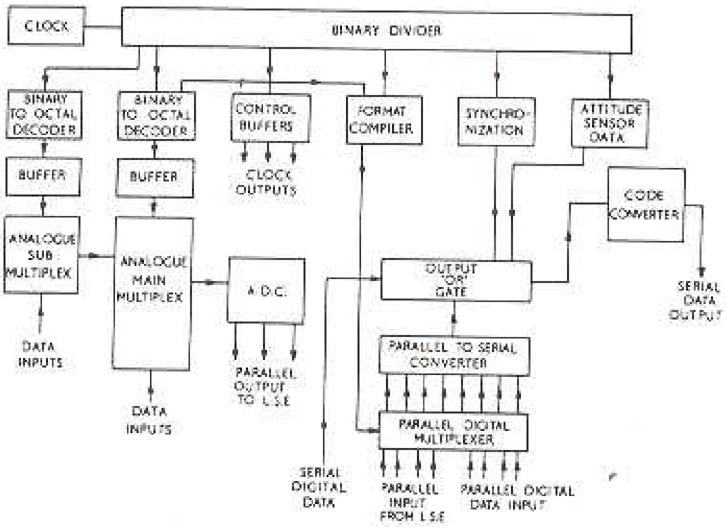

Fig. 3. Block diagram of high speed encoder.

Analogue data outputs in the range of ±5 volt are sampled by the analogue multiplexer. The multiplexer uses 'N' channel junction FET's as the switching element in a 'pyramid' configuration Fig. 4. The switches are connected in parallel groups of eight, two groups being assembled in one module. Circuit operation is such that elements 'a' to 'h' within groups 1S,2S etc. operate sequentially, all corresponding switches of similar groups being 'ON' at the same time. However, to ensure that only one data point is sampled at any instant, switches within group S1 etc. are also operated sequentially.

The multiplexer operates at a sampling rate of 256 samples per second although it is capable of operating at much higher rates. A total of 64 channels are provided at the basic sampling rate, with one channel being sub-multiplexed to provide a further 8 channels. These have a sampling rate of 32 samples per second. If rates greater than 256 samples per second are required then a data source can be connected to two or more switch points.

The output of the analogue multiplexer feeds an 8 bit, Analogue to Digital Converter (ADC) [3] which operates at a bit rate of 32 k bits per second yielding a conversion time of approximately 250 micro-seconds.

To allow for the insertion of data already in parallel digital form, within the data stream the analogue switches can be inhibited either individually or in blocks of eight.

Fig. 4. Analogue multiplexer

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3. 3 Low speed encoder

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3. 4 Programmer

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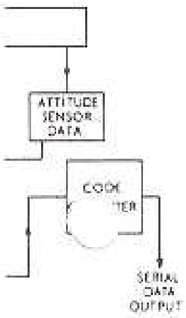

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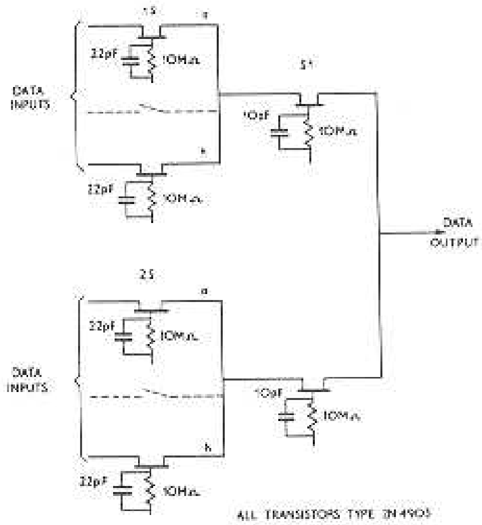

Fig. 4. Analogue multiplexer configuration.

This digital data exists as single bit or multiples of bits. These are assembled as 8 bit parallel words within the Parallel Digital Multiplexer. The output is fed to the Parallel to Serial Converter where it is combined with ADC data. The serial data output is then fed to the 'OR' gate together with existing serial digital data, sychronization and identification data.

3. 3 Low speed encoder

The Low Speed Encoder is similar to the High Speed Encoder. The multiplexer, however, operates at a rate of 8 samples per second which results in data being stored in the Tape Recorder at a rate of 64 bits per second. The recorder has a RECORD/PLAYBACK ratio of 1:32, hence data is played back at 2048, bits per second, that is, a rate identical to the High Speed Encoder transmission.

3. 4 Programmer

The functions of the Programmer are to:

(a) Initiate the Automatic RECORD/PLAYBACK sequence
(b) Control the various modes of operation
(c) Provide the switches for supplying power to the standby systems
(d) Decode all received COMMANDS and initiate appropriate action.

The command system is designed to ensure, as far as possible, that all commands sent to the spacecraft are received and actioned correctly and that no accidental operation can occur; for example by transmission intended for other spacecraft.

The command format consists of five words, an address word unique to a given spacecraft, transmitted twice, and an execute word transmitted three times plus a blank and synchronization word. The reception of one correct address plus one correct execute is sifficient to execute a command. An address code consists of two logic 1's and six 0's, or two 0's and six 1's, whilst an execute word consists of a combination of four 1's and four 0's enabling a total of 70 commands to be transmitted.

Activation to accept commands will only take place upon receipt of a carrier of correct frequency and within the command receiver bandwidth. Henceforth the command must conform to a strict format and format tolerances within the NASA tone digital command standards. It must satisfy three prime conditions:

(a) The sub-carrier must be an audio tone which is pulse-width modulated containing a synchronization bit followed by eight other bits and a blank.
(b) The code carried must address the spacecraft.
(c) The correct number of digits must be present, arranged in a word that has been previously recognised as a valid command, upon which the decoding matrix will act to provide an output pulse.

The Command decoder is designed to be switched on in sections, power being applied to each section as successive criteria of the command signal are satisfied. Once a command frame has been decoded, and the command recognised as one which the decoder is programmed to accept, the final part of the decoder is powered and an output is routed to the required part of the spacecraft.

Together the command receiver and decoder make an extremely sensitive system possessing built-in security. The system can operate continuously and reliably with received signal strengths as low as 100dBm and in the presence of noise more than twice tne intensity of the command signal. This is achieved by the high sensitivity of the receiver in conjunction with the narrow bandwidth of the audio filter which detects the command sub-carrier.

Two command decoders are included for redundancy purposes, both of which perform the same functions but each having its own address code. The two receivers are redundant only in that both are normally operating together to increase sensitivity and tolerance to aerial polar diagram irregularities.

3. 5 Tape recorder

The Tape Recorder Fig. 5 is a single track recorder using an endless loop of mylar tape which has a lubricating coating on its reverse side. The tape is contained on a tape capstan with the free ends spliced to form an endless loop. The tape feeds off the hub at the centre of the tape capstan and back on to the outside of the capstan as shown in Fig. 5.

The tape capstan and head assembly are mounted on the upper surface of a flat magnesium disc whilst the drive mechanism is located on the underside.

The drive mechanism between the motor and the drive capstan assemblies is by means of mylar belts. There are two drive paths and uni-directional clutches are arranged such that for one direction of motor rotation the capstan rotates at a RECORD speed of approximately 6.0 mm per second and during PLAYBACK in the opposite direction at 190 mm per second.

The Tape Recorder occupies a space approximately 190 mm in diameter by 125 mm height and has an approximate weight of 2.2kg. The power consumption is 0.5 watts when recording and increases to 0.65 watts in the PLAYBACK mode.

4. DATA FORMATS

4. 1 General information

The output of each encoder is a serial data stream in 8 bit groups termed

Fig. 5. Tape record

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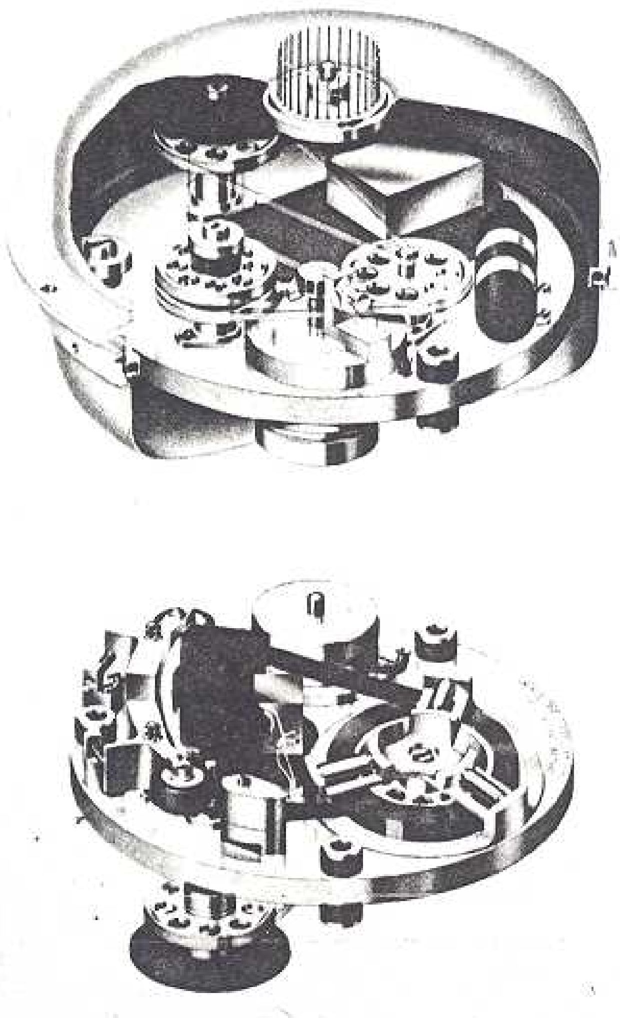

Fig. 5. Tape recorder

syllables, 64 of which (0 to 63) are sequenced to form a Minor Frame. Minor Frames are assembled successively (beginning with Minor Frame 0) to form a Major Frame which consitutes the Data Format. A Major Frame represents the total time to sample every data point as least once. In all cases data is presented with the Most Significant Bit appearing first.

To identify a particular syllable, mode of operation and Minor Frame within the Format, unique data was inserted at known points in each Minor Frame. Locations of the identification data for all four formats used on Prospero are shown in Fig. 6. The first three syllables of each Minor Frame contain the NASA 23 bit synchronization code plus a tape recorder status bit. In the fourth syllable the first 2 bits identify the mode of operation; the remaining 6 bits (in binary form) identify the Minor Frame. Data processing if faciliated by synchronizing the data formats from the two encoders at the commencement of syllable 0, Minor Frame. 0.

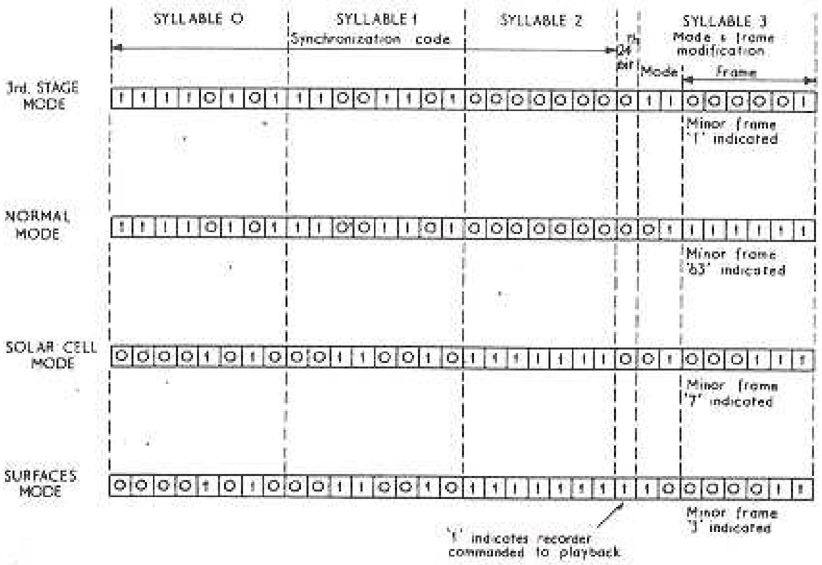

Fig. 6. Synchronization and identification syllable contents for the various operational modes.

4. 2 Direct formats

Two direct data formats have been used; 3rd Stage Mode Direct and Normal Mode Direct. These modes are as follows:

(a) *3rd Stage Mode Direct.* This format consisted of a single Minor Frame transmitted repetitively during the Launch Phase at a basic sampling rate for direct data of 256 samples per second. Thus each Minor Frame was transmitted in 250 milliseconds. This provided rapid transmission of rocket data to the launch area which enabled an instantaneous or real time record of data to be made. From this record, rocket performance was assessed and showed that the predicted orbit was likely to be achieved. This mode was terminated after Prospero's separation to be replaced by Normal Mode Direct.

(b) *Normal Mode Direct.* This format consisted of 64 Minor Frames to a Major Frame. At the basic sampling rate of 256 samples per second, a Major Frame was sampled once every 16 seconds. This mode is normally operative during orbit except for the period when the Tape Recorder is commanded to Playback.

In the 3rd Stage and Normal Mode Direct Formats the NASA synchronization code is in direct binary form Fig. 6. This illustration also shows the maximum Minor Frame count for the Normal mode.

3 Recorded formats

In a similar manner to the direct formats there are two recorded formats in use; Solar Cell Mode Recorded and Surfaces Mode Recorded. The difference here is that both modes are and have been available (by command) throughout the orbital life of Prospero.

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(b) *Surfaces Mode Reco*
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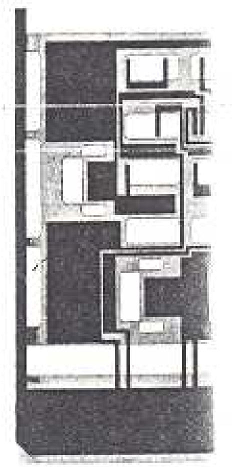

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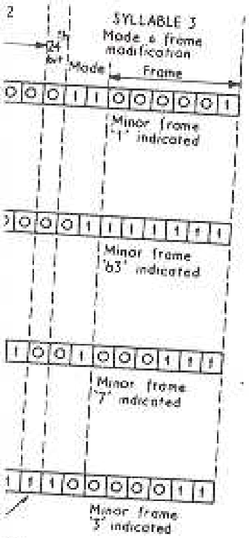

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(a) *Solar Cell Mode Recorded.* This format is the one in normal use. The Major Frame (comprising the format) consists of 8 Minor Frames. The sampling rate is 8 samples per second for compatibility with the Tape Recorder characteristics and time per orbit. Thus each Minor Frame occupies 8 seconds and a Major Frame is sampled every 64 seconds.

(b) *Surfaces Mode Recorded.* This format is similar to the Solar Cell Mode; the difference being that Thermal Surfaces data replaces Solar Cell data in the syllables allocated for this purpose. In all other respects the data rates are the same.

For recorded formats the NASA synchronization code is the binary complement of that for the direct formats. Reference to Fig. 6 shows this and also illustrates the maximum Minor Frame recorded binary count for Solar Cell Mode with the Tape Recorder commanded to Playback in Surfaces Mode.

5. MECHANICAL DESIGN

The design of modules, units and the data tray has incorporated techniques and materials of light weight commensurate with adequate strength.

A module consists of an interconnection matrix supported within a framework and having pins for external connection at its upper and lower edges; components are welded to the interconnection matrix. Where the components are predominantly integrated circuits, a nickel-mylar interconnection matrix is used.

Accurate design and manufacturing techniques have produced a 0.5 mm conductor track which terminates in tabs to which the components are welded. For external connection tabs on the outer edge of the film are welded to the pins on the upper and lower module edges as shown in Fig. 7.

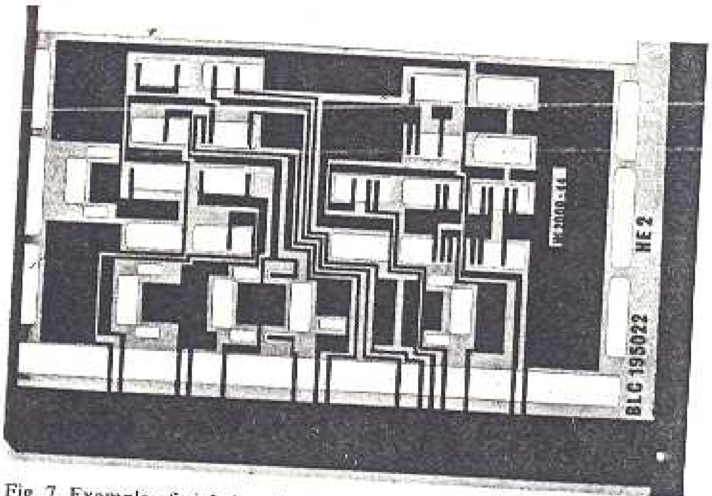

Fig. 7. Example of nickel-mylar film.

The circuit complexity of a number of modules requires four film layers which necessitates accurate indexing of each layer with respect to the others. To avoid undue stressing of the films during the encapsulation process they are mounted on a premoulded foam back panel which contains the exotherm stress to one direction only.

Where a module consists entirely of integrated circuits, their physical dimensions make it possible to construct two half modules within a standard thickness, interconnection being made between top pins on the module as shown on Fig. 8. Discrete components which are to be welded to a nickel-mylar film have the component leads presprigged with nickel tape as shown in Fig. 9.

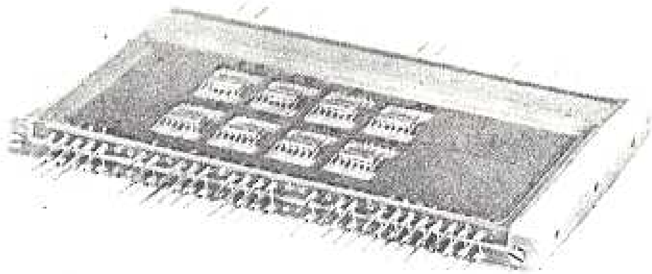

Fig. 8. Module containing only integrated circuits.

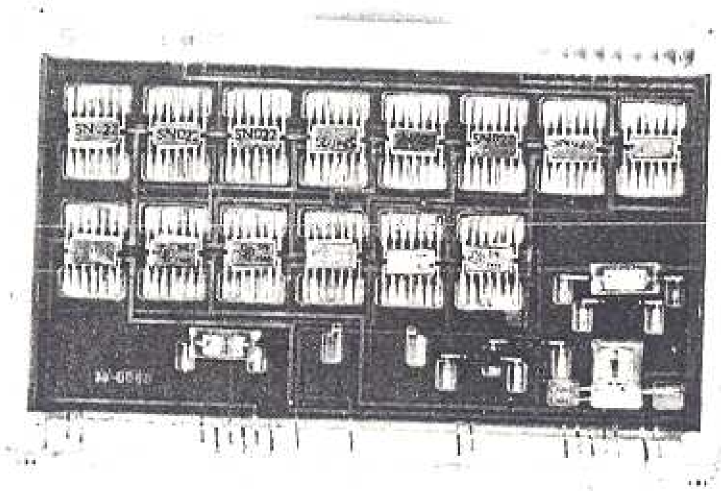

Fig. 9. Hybrid module on nickel-mylar film.

Modules containing only discrete components use nickel wire matrices supported by a thin polyester film, see Fig. 10.

To form a unit, modules are mounted side by side, held in position by r screws fitted to side plates and wire-wrapped into an interconnection rix. End plates, top cover and bottom cover complete the assembly. An encoder with top cover removed is shown in Fig. 11. Here the advantages of standard thickness module is demonstrated. Constant pitch interconnection pins enable modules to be positioned anywhere within a subsystem.

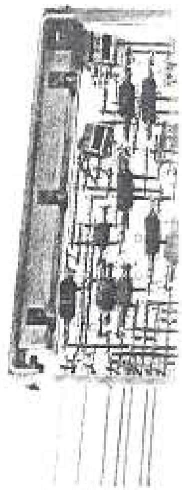

Fig. 10. Module con

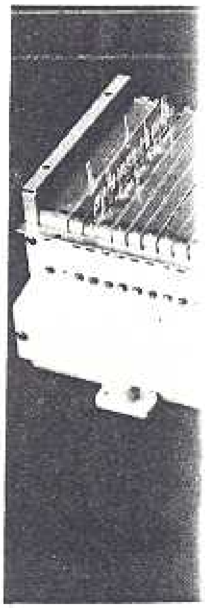

Fig. 11. Encoder with

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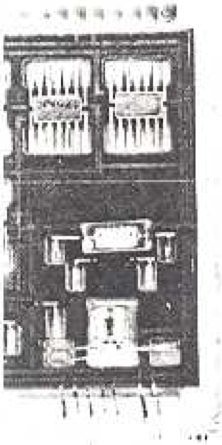

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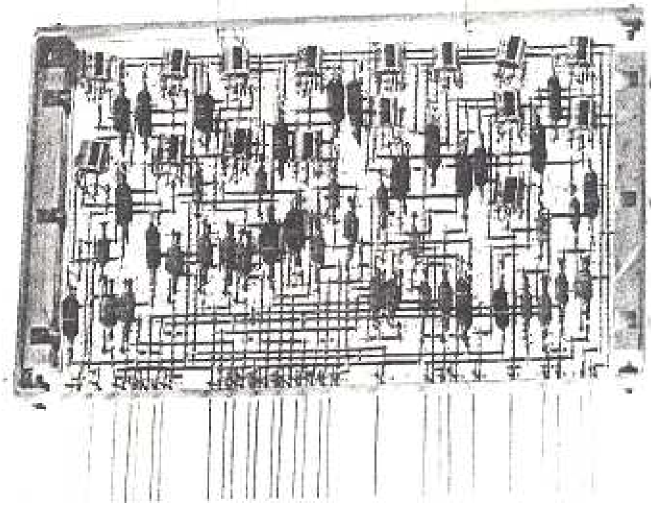

Fig. 10. Module containing only discrete components.

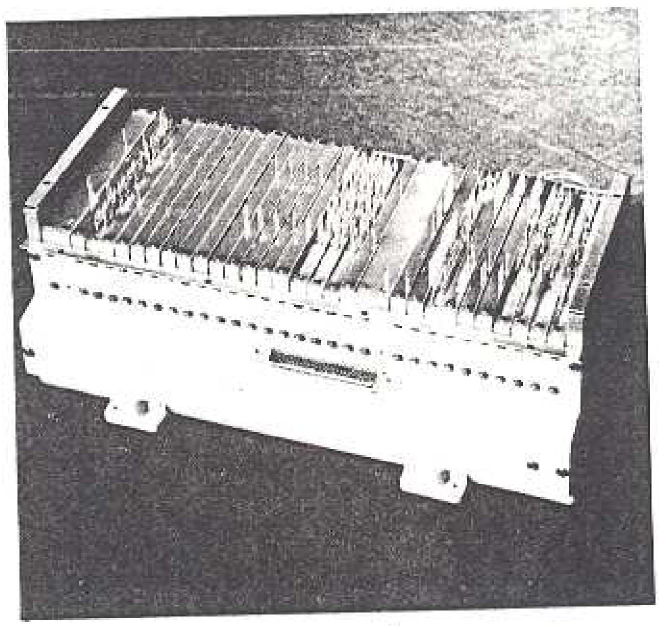

Fig. 11. Encoder with top cover removed.

The programmer unit uses a multilayer nickel-mylar film interconnection back panel mounted on a fibreglass board containing back panel pins. Where interconnection to a module is required, the nickel track terminates in a tab which is welded to a back panel pin. The module pin projects through the back panel and is wired-wrapped. Fig. 12 shows as example of this type of back panel.

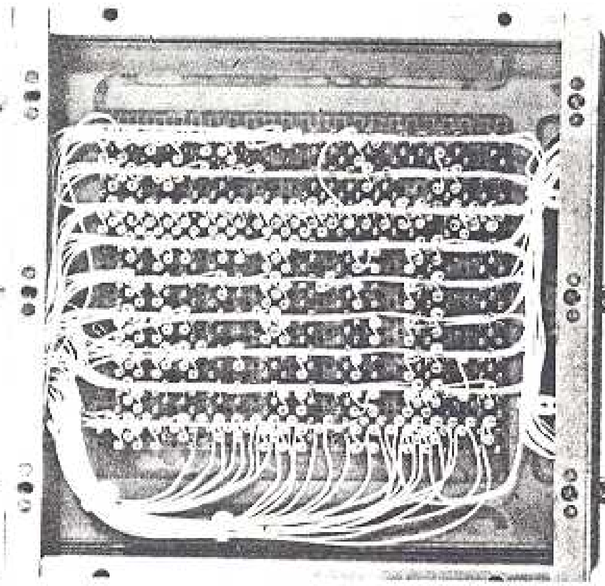

Fig. 12. Example of multi-layer nickel-mylar back panel.

For the two encoders the module pins are wire-wrapped to the back panel pins and point-to-point wiring interconnects the constituent modules.

All the units which constitute the telemetry system are mounted on a framework and the whole assembly is identified as the Data Tray. This enabled the telemetry system to be fully qualified prior to insertion within the spacecraft. Individual trays were fully interchangeable so that in the event of a failure, one could be readily interchanged with another without invalidating the spacecraft status. The complete tray assembly, is shown in Fig. 13

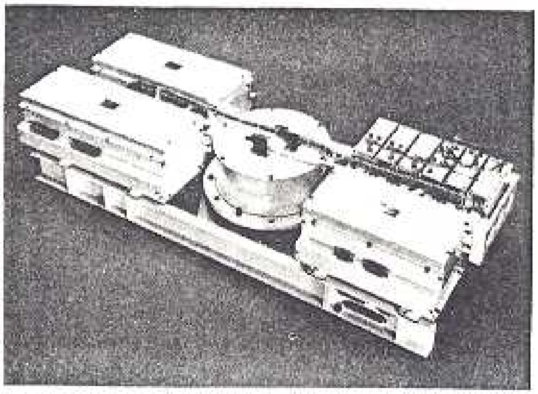

Fig. 13. Data tray

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6. SYSTEM QUALIF

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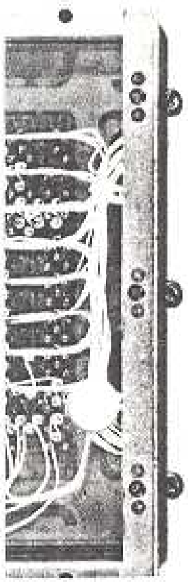

anel.

pped to the back panel
ituent modules.
are mounted on a
Data Tray. This enabled
:rtion within the space-
at in the event of a
r without invalidating
hown in Fig. 13

whilst a view of its position within the spacecraft is shown in Fig. 14.

Typical weight of an encapsulated module is 50gm, that of an encoder typically 2kg; and the complete tray assembly weighed approxiamtely 12kg.

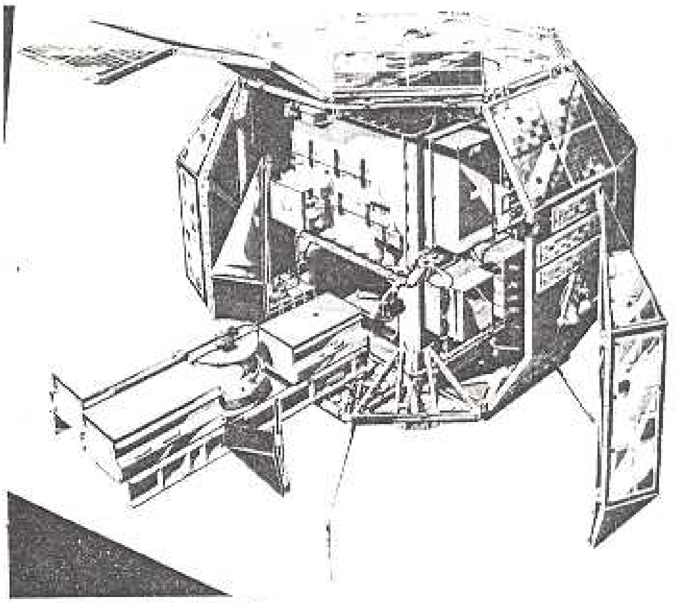

Fig. 14. Exploded view of Prospero.

6. SYSTEM QUALIFICATION

Qualification of the data system was performed at three levels: module, unit and system.

Modules were first assembled in the white state and subjected to detailed functional checks. After encapsulation performance was verified over the temperature range of -20°C to +50°C. Modules were then assembled to form units.

The Units were subjected to a high degree of testing using an automatic Data Tray Checkout Equipment (DTCE) based on a PDP8 computer. Fig. 15. Additional monitoring of unit performance was achieved by using test points which have been incorporated into the equipment design. Protection for each test point was provided by a series resistor.

On completion of unit tests, the data tray assembly, comprising the whole telemetry complex was subjected to exhaustive tests, again using the DTCE. The Tray was then subjected to an environmental test programme which simulated conditions likely to be experienced during launch and in the space environment.

7. ORBITAL BEHAVIOUR

The Prospero spacecraft has been in orbit for 11 months during which time there has been no apparent change in the data system's performance. Measurements of on-board calibration voltages show no change from the values obtained immediately prior to launch.

Most of the redundancy configurations have been commanded into operation with no degradation in system performance.

The Tape Recorder has excelled itself. Except for a very short initial orbital period of erratic behaviour (during which time recorded data *was* received and

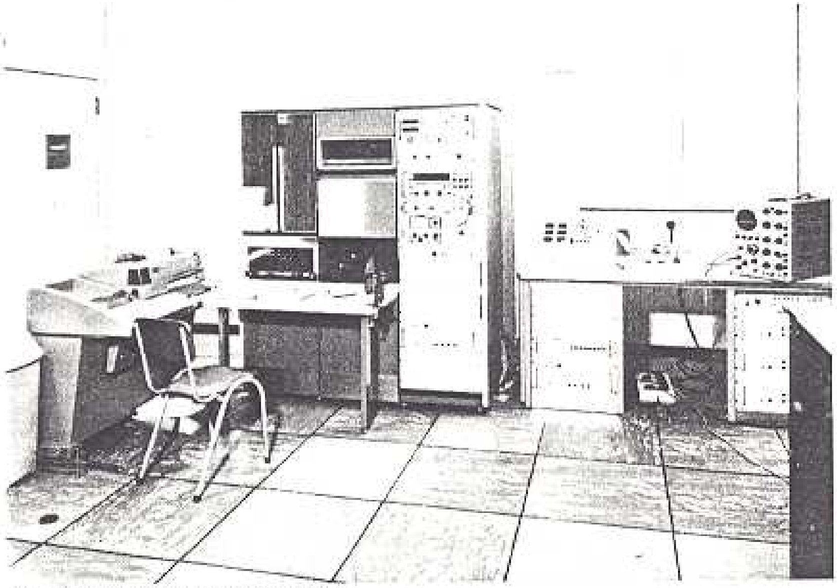

Fig. 15. Automatic checkout facility.

processed, albeit with difficulty) no change from its prelaunch performance is apparent. More than 700 RECORD/PLAYBACK sequences have been executed.

8. CONCLUSIONS

A highly successful performance over a period of 11 months in orbit has verified the soundness of the design, manufacturing techniques and system qualification. There is every confidence that this mission's definition of 1 year's useful life will be achieved. The orbital behaviour proved that the system adopted satisfies the requirements for the basis of the British National Space Technology Programme.

Currently the data conditioning systems for X4 and UK5 have been designed and are in course of manufacture; both of which use variants of the Prospero system design concept.

ACKNOWLEDGEMENTS

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Measurements of Sp

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1. INTRODUCTION

MOTIVATED BY PATR
to resolve telemetry an
mission from 1971-93 A
received at Kettering du
on 28 October 1971.

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to be imparted by the la
was expected to decay
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2. OBSERVING EQ

A block diagram of the

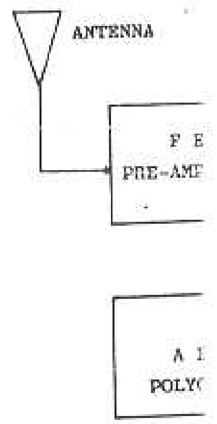

Fig. 1. Receiving and reco

The 6-element crossed
for the reception of au
logical satellites. The E
long loan from the Rad
detector is fed into the
amplifier and magnetic
from the Ferrograph is

* Senior Science Mast