CACTμS:
a Compact Array of CdTe μ-Spectrometers

(a balloon-borne small CdTe detector prototype to evaluate applications in hard X-ray Astronomy)

E. Caroli, A. Donati, G. Landini,
J. B. Stephen, G. F. Taiocchi, G. Ventura

Internal Report N. 313
Te.S.R.E.-May 2001

Istituto Te.S.R.E./CNR
Via Gobetti, 101-40129 Bologna

parva iuvant humilesque myricae

Abstract

This internal report describes an experiment based on a small array of CdTe micro-spectrometers to be flown as a piggy back payload on a stratospheric balloon from the ASI base in Milo (TP). This experiment will be used to to measure the background level and to evaluate the overall performance and of a CdTe array at balloon altitudes These informations will help in defining the feasibility and the design of a Hard X and Soft Gamma ray telescope based on a thick CdTe large array detector for imaging and polarimetry in the 10-1000 keV range.

Table of contents

1. Introduction and objectives

To date the study of compact X and γ-ray sources has been limited to their spectral characteristics and timing variability, however further observational parameters are required to determine the precise emission mechanisms and physical conditions within the emitting astronomical objects. Polarization is one of these additional parameters as almost all mechanisms that generate high energy emission from astrophysical sources involve strong magnetic fields and lead to the production of polarised photons. Even if polarization measurements in lower energy bands have been extremely useful [1] and although telescopes such as the COMPTEL instrument on the Compton Gamma Ray Observatory were theoretically able to perform polarization measurements, their sensitivity was such that no actual measurements have been performed at energies greater than about 10 keV [2].

For several years our group has studied the development of compact telescopes suitable for hard X- and soft γ-ray astronomy based on the use of thick Cadmium Telluride position sensitive spectrometers [3]. The design concept of these instruments, with their low energy threshold (10 keV) and high pixellation (a few mm^2/pixel) allows their operation both as a spectroscopic imager and as a high energy polarimeter above 100 keV with good performances. In the last two years our collaboration has focused in particular, on the design of a small payload (CIPHER: Coded Imager and Polarimeter for High Energy Radiation) suitable for use as a stratospheric balloon borne imager and polarimeter experiment.

The CIPHER instrument is a coded mask telescope based on a CdTe position sensitive detector operating in the 10-1000 keV energy range. CIPHER is conceived as a balloon borne payload primarily intended to perform measurements of the polarisation level of strong hard X- and soft γ-ray astrophysical sources (the target of the first flight would be the Crab pulsar) and secondarily to assess and verify the performance of such an instrumental concept for a small/medium size satellite high energy survey mission [4]. CIPHER shall be operated in photon by photon mode, requiring a star sensor in order to have real time reconstruction of the telescope pointing direction, while the field of view allows the use of a low cost and weight platform with only moderate pointing stability (~10’) and coarse pointing accuracy (~1°).

The position sensitive detector (PSD) comprises four identical modules of 32×32 Cadmium Telluride micro-spectrometers. The basic sensitive unit is a crystal of 2×2×10 mm^3. These units are used in the configuration in which the optical axis is orthogonal to the charge collecting field, and are assembled on thin ceramic plates in linear modules that contain 32 units with their integrated analogue readout electronics and bias circuits. These linear modules are packed together to form a 32×32 matrix module inside an Aluminium case. Below the linear module, there are two layers containing the hybrid front-end electronics (FEE) with multiplexer and ADCs for the 1024 channels. The matrix module is therefore a complete and independent detector that can be tested and calibrated separately. Finally, the matrix modules are assembled together (for a total sensitive area of 164 cm^2 with 4096 pixels) and supported by a metallic (Al) or carbon fibre grid that also provides the mechanical interface for the active veto shield. This instrument concept has already been presented and discussed by our collaboration at several international conferences during the last year [5,6,7].

The small experiment described in this internal report shall be considered within this perspective. In fact, with the framework of the proposal to construct a Compact Array of

CdTe Micro Spectrometers (CACTμS) for a balloon borne experiment (refer to the following section for a technical description) we intend to verify the feasibility of using this kind of position sensitive detector for hard X and soft gamma ray spectroscopic imaging and polarimetry. In particular the objectives of the present project are:

1. A study of the instrumental background in a balloon environment over the 10-1000 keV energy range with particular respect to the spectrum and the distribution of Compton scattered events that trigger two pixel (double) events. The analysis of double events and of the effect of the active shield on their distribution and rate will give information which will be necessary in order to decide whether a veto system in a polarimeter operating at above 100 keV is required.

2. An evaluation of the efficiency and the reliability of an off line numerical method for signal compensation using the amplitudes obtained by a readout electronics with double shaping filter stage on CdTe flight data

3. A feasibility study of a balloon borne coded mask telescope for spectroscopic imaging and polarimetry (CIPHER) dedicated for the first flight to polarisation measurement of the emission form the Crab Pulsar. At the end of this study a more precise evaluation of both cost and time needed for the realisation of such an experiment shall be possible. Furthermore, we expect to consolidate the international collaboration of the groups (from Spain, France, United Kingdom) that have already expressed their interest including the share of responsibility and relevant costs.

2. The experimental set-up

The CACTμS in flight configuration block diagram is shown in **Fig. 1**. The main subsystems, which will be described in some detail below, are the following:

1. Primary detector Housing (CdTe detectors) with associated front-end electronics (High Voltage supplies, temperature sensors, Charge Sensitive Preamps, CSPs);
2. Anticoincidence detector Housing (Plastic Scintillator and photomultipliers-PMs) with associated Electronics (High Voltage supply, Amplifiers, Shapers, temperature sensors);
3. Analog scientific signal processor and Analog-to-Digital conversion with digital Electronics (MPAna-EL);
4. Service Electronics (SE) including the Power Supplies (DC-DC Converters, the power lines distribution, the Discrete Telecommand-TLC-handling module), the Analog Housekeeping data conditioning and the PCM synchronization units;
5. The Pulse Code Modulation Unit (PCM Enc) collecting the scientific data from the experiment and generating the code for the Telemetry data transmission. During the flight the PCM Enc is connected to the Telemetry Package which produces the modulated radio signal for the physical data transmission to ground;
6. Telecommand Unit (TLC Package) used for the ON-OFF remote actions during the flight. Since the TLC equipment is a facility under the responsibility of the flight team, which is strictly not a CACTμS subsystem, during the on-ground integration and tests a TLC simulator has been used.

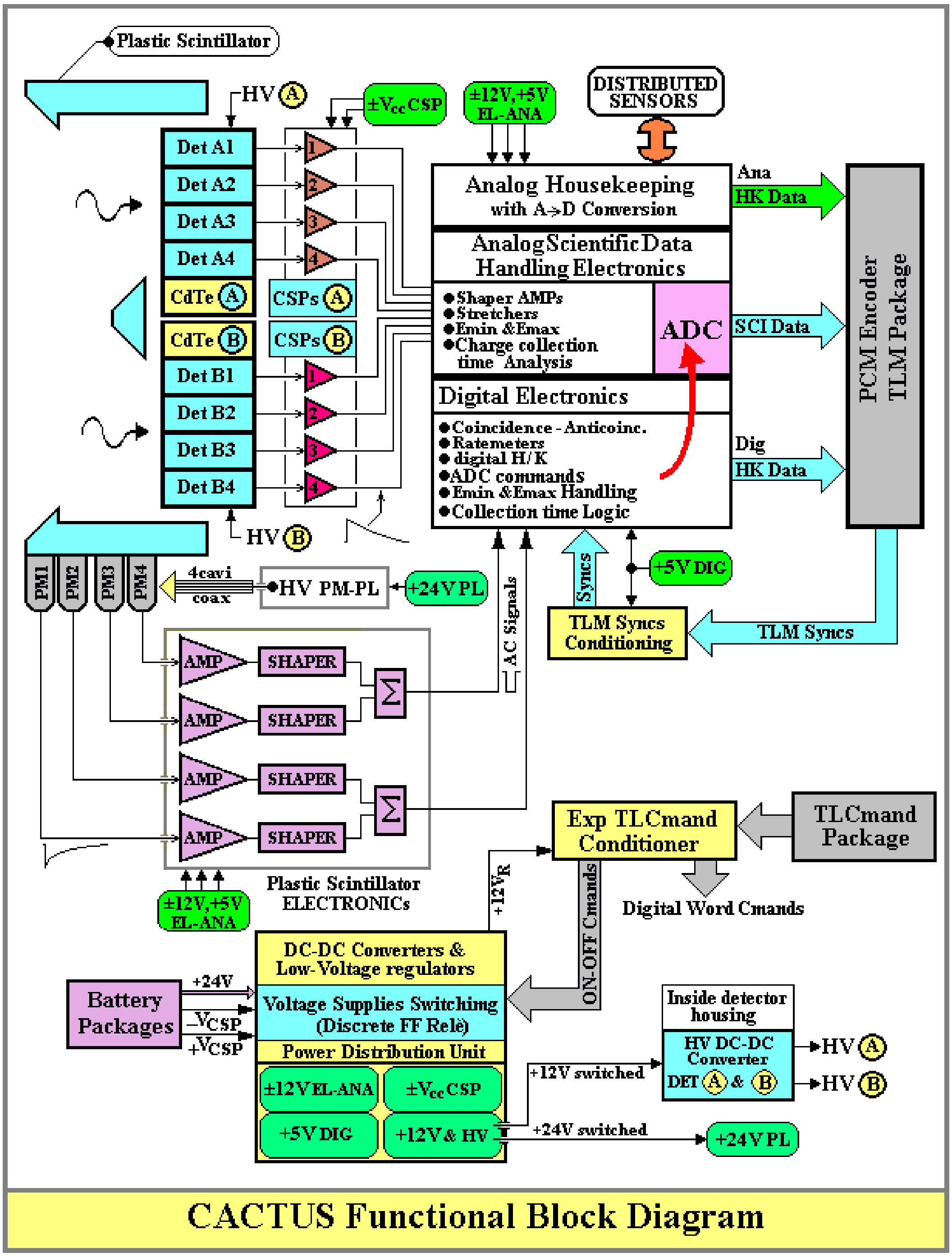

Figure 1. The Cactμs functional block diagram. All the experiment subsystems with their functional links are shown.

2.1 The detection system

The primary detection system consists of two CdTe solid state detector arrays each comprising four independent channels (pixels) operating at room temperature. The two units are mounted back-to-back and housed in a hermetically sealed container together with the front-end electronics, the high voltage supplies, the low voltage suppies and the housekeeping sensors for the remote monitoring.

As depicted in the schematic sectional view of **Fig. 2**, in the main detector housing the CdTe detectors are grouped in two units (Det "A" and Det "B": only one unit is shown in **Fig. 2**) wired Back-to-Back onto two PCBs (P0A & P0B). Each detector group consists of a single CdTe crystal divided electrically by a set of four metallic strips deposited on one face, while on the opposite face there is a common electrode connected to ground. Each strip is a positive biased independent electrode (nominally +120V) on which the charge delivered by an X-ray event is collected and amplified by a conventional Charge Sensitive Preamplifier (CSP) Clear Pulse CS-511 with a JFET as active input stage device and AC coupled with the detector channel.

The pitch distance between the strip centre is 2 mm (1.8 mm wide metallic strip plus a 0.2 mm gap). In this way each CdTe detector is equivalent to 4 bar shaped units having a base of 2 mm $\times$ 2 mm faced to the optical axis and a height of 10 mm. The total active area of the detection system is 32 mm^2 and the effective total sensitive volume is 320 mm^3.

On the PCBs P01 and P02 shown in **Fig. 2** are wired the low-voltage power supplies regulators for the CSPs, two independent low-noise High Voltage regulators to separately bias the detector groups "A" and "B" and the analog electronics for the monitoring of the detection system (voltage supplies checks and temperature monitors).

Each detector group can be powered ON and OFF by independent remote

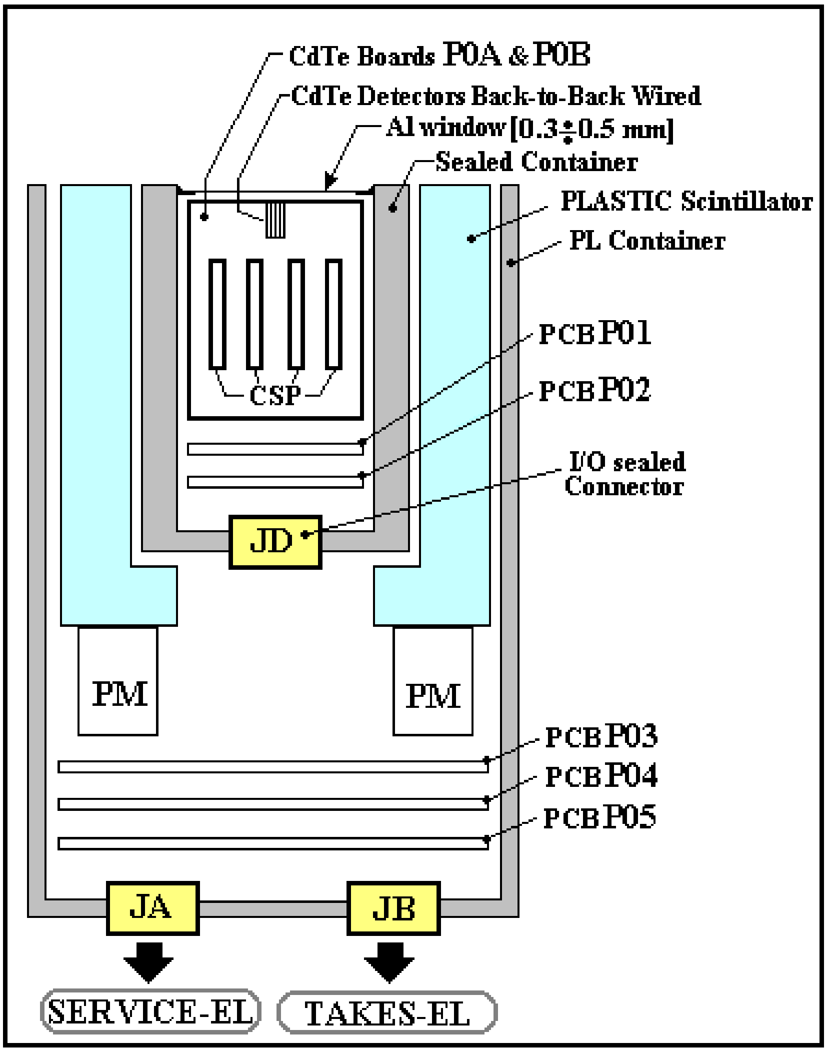

Figure 2. The scheme of the Cactμs detector

commands.

The gain and offset of each amplification channel will be periodically checked during in-flight operations by sending to the eight CSP “Test Inputs” double valued voltage signals in order to electrically calibrate any amplification channel gain and offset within ≈ ± 2%.

The detector is actively shielded by an anticoincidence plastic scintillator (PL) surrounding the CdTe Detector Housing. The PL, placed in an unsealed container, is read by four independent half-inch diameter PM’s and will have thickness of about 1 cm.

The printed circuit boards P03, P04, P05 house the PM Summing Amplifiers and the shaping devices required to trigger the anticoincidence Multiparametric Analog electronics (MP-AnaEL) logic, the HV DC-DC Converter for the PMs and the analog electronics for the subsystem monitoring (voltage and temperature monitors).

2.2 The scientific data handling system: the MultiParametric Analog Electronics

Each analog signals from the CdTe sensitive units is separately preamplified by a CSP (§2.1) so as to give information on an X-ray interaction in the range ~15 keV÷1MeV. The eight analog outputs from the CdTe detector channels are connected to the MPAna-EL through the connector J_B shown in **Fig. 2** to be conditioned, converted to digital form and loaded into the PCM Encoder for TLM data trasmission. Four main blocks can be identified in MPAna-EL, each corresponding to a dedicated function, even if this description does not correspond to a physical subdivision in the electrical implementation.

- ***Analog conditioning of the 8 CdTe channels or Front-end “analog” card.***

  Any CdTe channel (electrical signal output from the relative CSP) is first amplified in order to adapt the signal voltage to the range of the A-to-D converter. Amplifer coarse regulation (voltage gain ≈ 50-100) is possible by by means of potentiometers, but accurate adjustment and matching of the gains of the eight channels is performed by periodically issuing test stimulations to the detector CSPs (§ 2.1 and below) and automatically correcting for offsets and gain drifts. Test data are also inserted in the TLM data stream to allow a ground off-line accurate correction of the gain differences and the offset drifts.

  After the “initial” amplification each channel is shaped by two parallel analog filter paths: in the first the signal is shaped with a “short” time constant (0.35 μsec), while the other uses a “long” (3 μsec)shaping time. This will permit a measurement of the overall energy deposit (“slow” signal) due to both electrons and hole collection toghether with the fast component of the signal due only to electrons. Since the slow component of the signal represents the integrated charge collected at the detector (i.e. it is proportional to the energy of the event), while the fast gives informations on the position of the event with respect to the collecting electrode (i.e. it is proportional to the derivative of the charge collected), by off-line analysis on both these analog components it will be possible to recover information on the loss of charge signal due to the charge recombination in the detector crystal [8] and to reconstruct the “effective” energy of the primary photon.

  The fast and the slow components of any channel are analogically memorized by two separate pulse stretchers, whose action is sustained if no signal is detected from the anticoincidence Plastic Scintillator detector (AC-PL).

A typical waweform diagram in absence of a "*veto*" signal from the AC detector is depicted in **Fig. 3**. With no-AC veto signal, post stretching actions are issued by the decision logic and the linear gates connected to the outputs of the stretchers are enabled in sequence to be faced to the A/D Converter through a 16-channel Analog Multiplexer.

The threshold voltage $\mathbf{V_{Min}}$, which sets the minimum detectable energy (i.e. $\mathbf{V_{Min} \propto E_{Min} \approx 15}$ **keV**), is common to all the channels, ensuring the application of the same $\mathbf{E_{min}}$ reference to any channels. This prevents non uniformities and mismatching between analog detector chains, and will add the same noise contribution to each energy signal channel. Any signal which overcomes the $\mathbf{V_{Min}}$ voltage always triggers the "Rise Time Protection (RTP)" circuit for about 6 µsec. This is the time during which the pulse stretchers are qualified to operate and to pre-memorize both the signal components, i.e. the "slow"-"fast" amplitudes.

- ***Digital Electronics or Front-End Logic (DE)***
  A CdTe voltage signal $\mathbf{V_i}$ will be analyzed, i.e. coded into binary form, if it is in the energy range [$\mathbf{V_{Min} < V_i < V_{Max}}$] and if there is no "veto" signal from the AC-PL

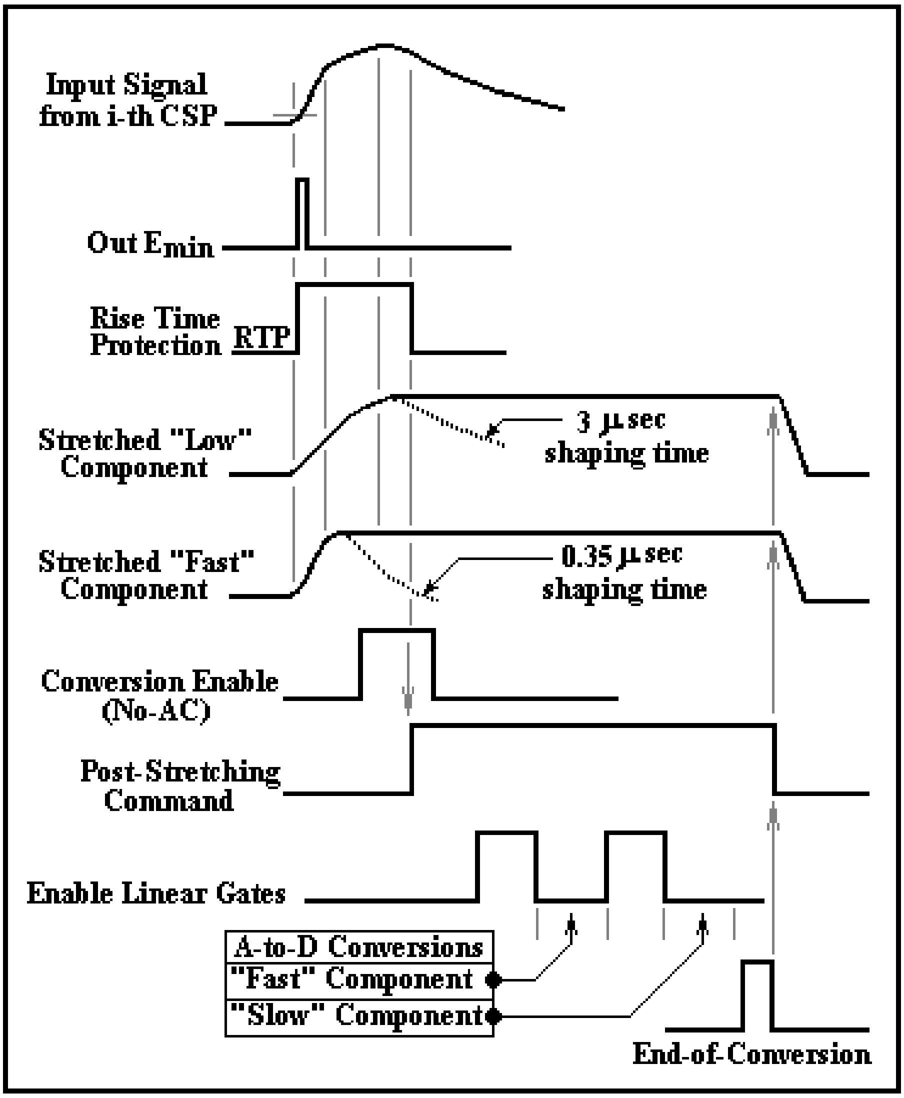

Figure 3. Typical waveform diagram with no veto signals.

detector. At the end of the RTP pre-stretching command (**Fig. 3**), the logic enables the post-stretching action if there is no AC pulse and if the signal is in energy range. During the conditioning of the actual pulse, any further data handling is inhibited.
This logic examines the RTP bus and sets the identification data to also spot out the channel which is under conditioning. After that, the logic issues a post-stretching action on the excited channel and prevents any other channel to be analysed and converted.
The logic also generates the command to start the A-to-D conversions (two per channel, i.e. slow and fast components) and, after, the resetting of the analog lines and the enabling of the system to acquire new data.
The DE is also designed to supply the TLM with digital "Housekeeping informations" (Dig H/K) in the form of ratemeters, i.e. integrated counts for the time base units fixed by the TLM timings. The main Dig H/K data transferred to the PCM Enc are:

- Integral AC counts;
- Integral counts in the useful energy window from the detectors of the "A" group;
- Integral counts in the useful energy window from the detectors of the "B" group

- ***ADC Data formatting and I/F to the PCM Enc***

Because of the low x-ray conting rate which are expected at balloon altitudes on our small volume detector (see section 2.1), it was decided to use a unique A-to-D converter (ADC) coupled to an analog MUX at its input. The ADC is a "flash-type" unit with a resolution of 12 bit in 3.5 μsec. This means that a complete conversion of a signal (2 parameters: slow and fast amplitudes) takes about 10 μsec including the recovery and dead times required to store the converted data. The output binary code for any component is transferred with a resolution of 10 bit (the most significative ones from the ADC), 1 LSB corresponding to an energy resolution of about 0.8 keV.
As pointed out by **Table I**, scientific coded data are also provided with 6 bits, giving added information on the event, i.e. 1 bit specifying if the data is relative to a slow or a fast component, 3 bits for the channel address (one-of-eight detectors), 1 bit indicating the Test/Cal phase or normal operation, and finally 1 bit marking a single event (one detector) or multiple event (more than one detector).

Table I
Event identification code field in TLM

	Event Identification Field			
Scientific Data	**CH Address**	**F/S**	**Test/Cal**	**S/M**
10 bit	3 bit	1 bit	1 bit	1 bit

F/S= Fast or Slow component
Test/Cal = Test/Calibration procedure or normal operation
S/M = x-ray event from single or multiple detectors

Converted scientific data together with the identification field bits for a total of 16 bit are stored in a 4kb by 32 bit FIFO memory in order do "derandomize" the data acquisition with respect to the data transfer to the in flight PCM Encoder. Sync signals from the PCM Encoder buffered by the Service Electronics (SE) are used by the MP-AnaEL to insert the data stream into the TLM format reserved words [9].

- ***Automatic correction for offset and gain***

  As previously stated, most of the scientific data reliability depends on the equalization of the amplifier chains. Since CACTμS does not have an in-flight radioactive sources calibration system, it was decided to periodically stimulate the amplifier chains (including the detector front-end CSPs) by electical test pulses.

  Voltage pulse trains of two pre-definite amplitudes are generated under the digital control of independent DACs and sent to the CSP test inputs. The first amplitude V_G, is used to test/calibrate any channel voltage gain, while the second ($V_{OF} \approx V_G/k$, k~50) is used to test the offset.

  This test/calibration procedure should produce two energy peaks in a multichannel pulse height analysis of the type represented qualitatively in **Fig. 4**. By evaluating the integral counts and the centroid of the peaks defined by the two energy bands $E_a<E<E_b$ and $E_c<E<E_d$, it is possible to operate a correction for offset drifts and gain changes, respectively in order to maintain differences between channels at some percent level.

  Neglecting most of the details of the implementation, the "actual" coded calibration data for the offset-gain test are stored in a memory (CAL Mem) with the window energy data E_a, E_b, E_c, E_d. The Data obtained by the CAL/TEST procedure are compared with the reference ones stored the CAL Mem and used to correct the offset by adding or subtracting to any event signal a voltage amount proportional to the measured drift. The correction for gain changes are compensated by issuing an increase or a decrease of the reference voltage of the ADC proportional to the gain shift detected in the CAL/TEST procedure. Calibration data extracted in the last CAL/TEST procedure are updated in the CAL Mem.

The auto-calibration facilities can be H/W enabled or disabled depending on the

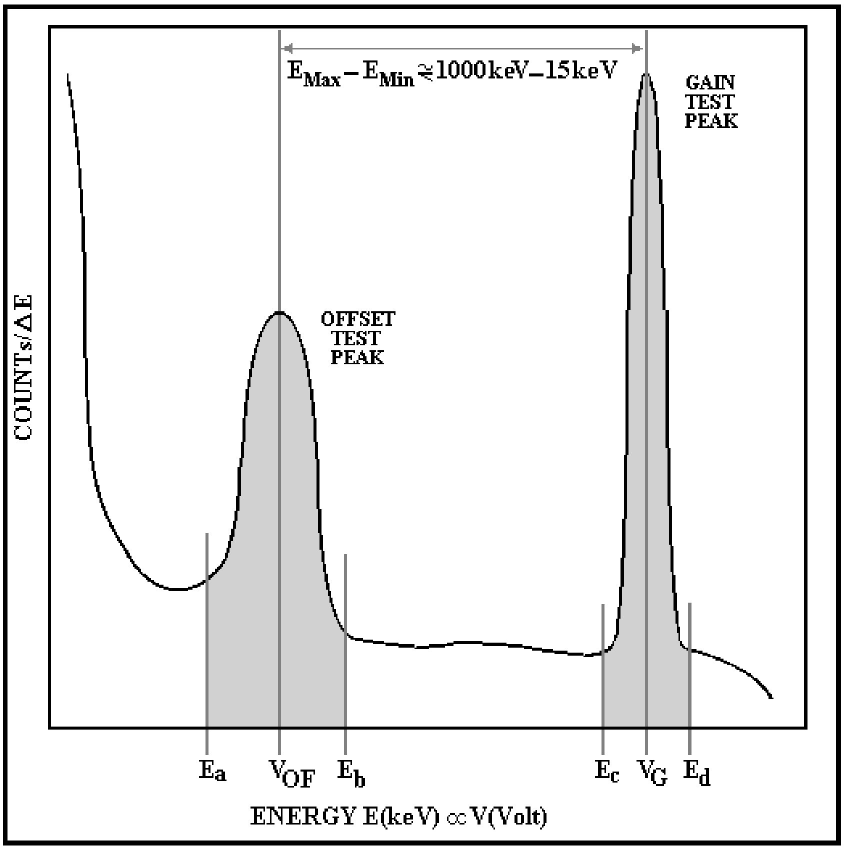

Figure 4. Self Test and calibration procedure on FE electronics

confidence of the automatic correction algorithm rather than in the off-line correction procedure. Autocorrection performances are to be empirically evaluated, but it seem reasonable to anticipate correction efficiencies on both gain and offset within some % units.

2.3 The Service Electronics (SE)

The SE includes:

- the batteries: two main packages are provided, one for the ± $\mathbf{V_{CSP}}$ supplying the working voltages to the CdTe detector CSPs, and the other supplying the voltage + 24 V for the remaining electronics;
- the DC-DC Converters and the voltage switching actions;
- the Discrete Telecommands conditioner connected to the TLC flight package or, during the on-ground tests, to the TLC simulator;
- the Analog Housekeeping module (Ana H/K) which collects the data from the sensors distributed over the experiment to monitor the working ststus of the various subsystems during the flight (temperature, power supplies operating voltages);
- the Sync Module which receives the synchronization signals from the PCM Encoder (Bit, Word, Minor Frame, Major Frame or Format) required to load the scientific data in the desired position of the TLM format.

The implementation of the SE is described in detail, including the electrical drawings, in the Technical Note 314 [9].

2.4 The Telemetry format (TLM Format) and the tele-commanding system (TLC)

The TLM format is generated by a PCM Encoder (PCM Enc) Metraplex 760 system based on a µP which permits the TLM format programming depending on the user request. The TLM format structure, which is permanently stored in the system Electrically Alterable ROM (EAROM), can be varied by a simple RS232 link connected to an external PC.

Beside the TLM format length and dimensions, the user has the possibility to also program the working bit rate and the output data encoding (NRZ, Biϕ, etc).

The PCM Enc, which was successfully tested in several balloon flights, has the following hardware configuration:

- 760µP card performing the functions of controller, sequencer and programmer;
- four 760BM1 card (Digital MUX), anyone of which permitting the transfer of three-bytes digital data for a total of 12-by-8 bit digital words;
- two or three 760AM1 card (High Level Analog MUX), anyone accepting 16 single-ended analog signals in the range 0÷+5V for the analog-to-digital 8-bit conversion. Digitized data are inserted in the TLM format depending on the program of the user's format;
- 760AT1 card (PCM Output Code) feeding the serial code to the radio transmitter link. The programmed serial output code is actively filtered before the transmission in order to mainly reduce the 1/f noise.

Since CACTμS is supposed to be hosted by another payload, the PCM Enc could be used by both the experiments, so as to optimise the radio link and the TLM Format utilization .

Presently the PCM Enc is programmed to operate at a Bit Rate of about 15.5 kbps with a basic word length of 8-bit. Depending on both the host and guest experiments, a reasonable Minor Frame length is composed of 16 words and the Major Frame (Format) is 32 Minor Frame long for a total Format Length of 512 Bytes but can be re-programmed upon users' request.

Since CACTμS is an experiment with "simple" design features the remote interaction with the experiment was limited to a reduced set of TLCs in order to have direct and immediate feedback on the behaviour of the flight subsystems.
Therefore, it was decided to use only Discrete Commands to operate ON/OFF switching action on the main subsystems. Any low voltage supply can be switched ON and OFF, as well as detector HV supplies (Det "A" & Det "B") can be switched indipendently. Furthermore, to detect the in-flight efficiency and amount of the anticoincidence contribution, it is possible to switch ON and OFF the HV supply of the PMs, in order to enable and disable the anticoincidence signals. Since the TLC package is under the responsibility of the launch team, during the test and integration phase a Discrete TLC Simulator will be used [9].

In any case the TLM format will be programmable in order to meet the requirements set by the foreseen in-flight count rate.

3. The Ground Support Equipment (GSE)

The GSE can be used both during the calibration-integration activity of the experiment and the flight to extensively test the scientific data reliability and the payload performance.

TLM data may be acquired in two possible modes with a PC-based GSE:

1. PCM encoded serial data by means of a PC compatible board performing the operations of "bit/format synchronizer".
2. Parallel data (byte-by-byte with a hardware acquisition flag) by means of a PC compatible parallel input card which requires an external bit synchronizer (e.g. a D-PAD).

The two arrangements, schematically shown in **Fig. 5**, are realistic and consistent with respect to the environments met in a laboratory and at the ground station during the flight.
Any PC-based system requires a hardware interface to recognize the TLM format Sync pattern such as a bit/frame synchronizer internal or external to the GSE itself. The GSE operating Software should perform the following tasks:

a. Data acquisition and temporary storage of reconstructed TLM formats. The acquisition software shall be fast and optimised in order to limit the load on the main CPU required by this task and to permit quick-look control on collected data.
b. Data selection upon user's command and pre-analysis for a quick-look monitoring and display. Multi window applications could permit a quasi-real time control on the in-flight scientific and house-keepings data.
c. Permanent data storage on a mass storage device for off-line data analysis.

d. TLC issuing (output operation via an RS232 link) for the remote ON/OFF control of the experiment subsystems.

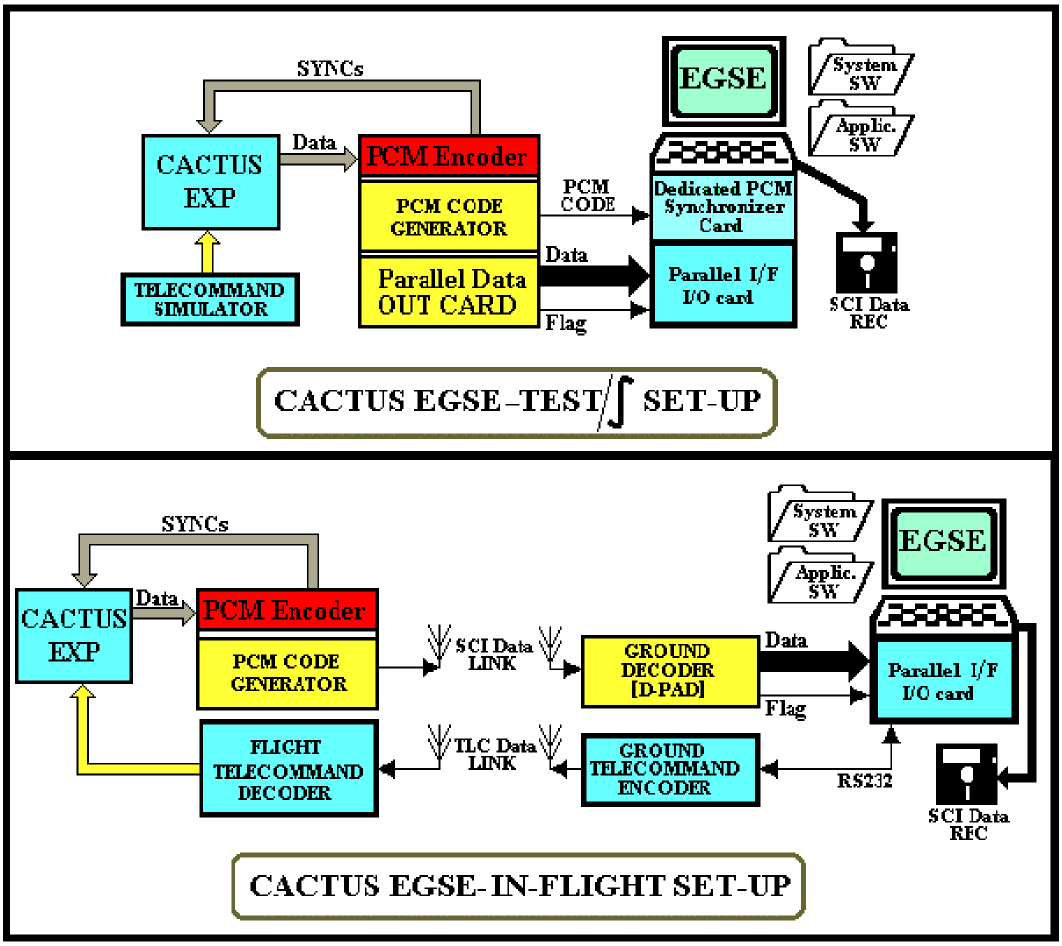

Figure 5. Two possible and equivalent configuration for the Cactμs experiment EGSE.

4. Expected in-flight counting rate

In order to evaluate the expected count rate at balloon altitudes we have scaled from the background data obtained during a flight from Alice Springs in October 1995 by the small experiment PoRTIA (Piggyback Room Temperature Instrument for Astronomy) [10]. The PoRTIA experiment have two room temperature semiconductor detectors (CZT and HgI_2) housed in a small pressure vessel. PoRTIA was flown on three balloon flights on top of the GRIS payload (a large Germanium experiment) with three different shielding configurations. In particular we have used the background data obtained by the 2.5 x 2.5 x 0.19 cm^3 CZT detector shown in Fig. 6a. To evaluate the Cactμs maximum count rate we have scaled the PoRTIA data taking into account the volume ratio (0.32/1.1875) and a field of view (FOV) for Cactμs detector of 4π. The result is shown in Fig. 6b. The integrated count rate over the 10-1000 keV energy range is about 11 c/s. This figure, that is almost a maximum value because of the smaller effective Cactμs FOV, will be used to adapt the final telemetry bit rate for the data downlink.

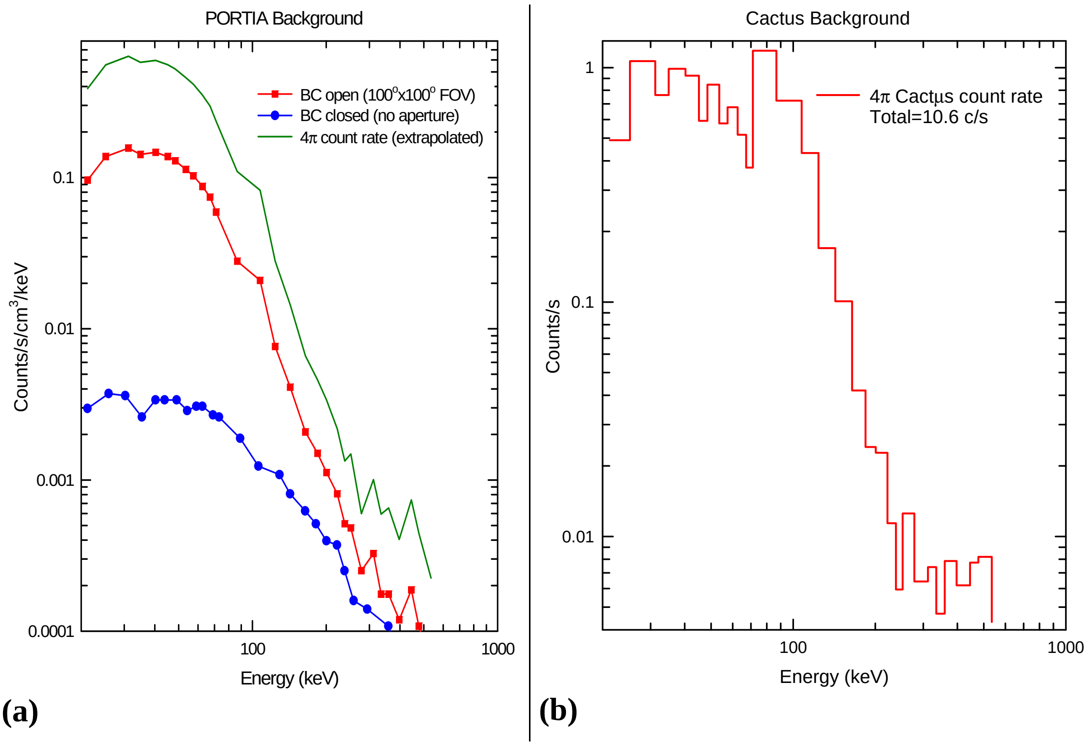

Figure 6. **(a)** The PoRTIA background measured during the Alice Spring flight in October 1995. The lines with circle and square symbols are the measured date with the detector window close and open, respectively (see reference [10]). The line without symbols is obtained by scaling the square symbol line data to a field of view; **(b)** The evaluated Cactμs background count rate spectrum obtained from the extrapolated 4π data in (a) with scaling for the detector volumes and integrating over a fixed number (30) of energy bins between 10 and ~550 keV .

5. References

[1] T. Velusamy, *Monthly Notices Roy. Astron. Soc.*, **212**, p. 359 (1985)

[2] F. Lei, A.J. Dean, and G.L. Hills, *Space Sci. Rev*., **82**, p. 309 (1997)

[3] E. Caroli, et al., Proceedings of the ESA Symposyum on *Photon Detectors for Space Instrumentation* (ESTEC, Nordwijk, 10-12 Nov. 1992, NH), ESA **SP-356**, p. 27 (December 1992).

[4] E. Caroli, et al., Presented at the SPIE's 44th Annual Meeting, Conference 3764 *EUV, "X-Ray, and Gamma-Ray Instrumentation for Astronomy X"*, SPIE Vol. 3765, p. 597 (1999)

[5] E. Caroli, et al., *The 5th Compton Symposium*, M.L. McConnell and J.M. Ryan eds., AIP Conference Proceedings **n. 510**, p. 809 (2000).

[6] E. Caroli, et al., Nuclear Instr. and Meth. in Physics Research, **A448**, p. 525 (2000).

[7] E. Caroli, et al., Spie Proceedings on "*X-ray and Gamma-ray instrumentation for Astronomy XI*", **Vol. 4140**, p. 573 (2000).

[8] J. Lund et al., IEEE Trans. Nucl. Sci., **NS-43**, p. 1411 (1996).

[9] A. Donati, G. Landini, G. Ventura, R.I. Istituto TESRE **n. 314**, May 2001

[10] A. M. Parsons, et al., Spie Proceedings on "*Gamma-Ray and Cosmic-Ray Detectors, Techniques, and Missions*", **Vol. 2806**, p. 432 (1996).

Appendix A

Photo 1. The Cactμs CdTe detection units from Acrorad (Japan): the cathode surface (left), the multistrip anode side (right).

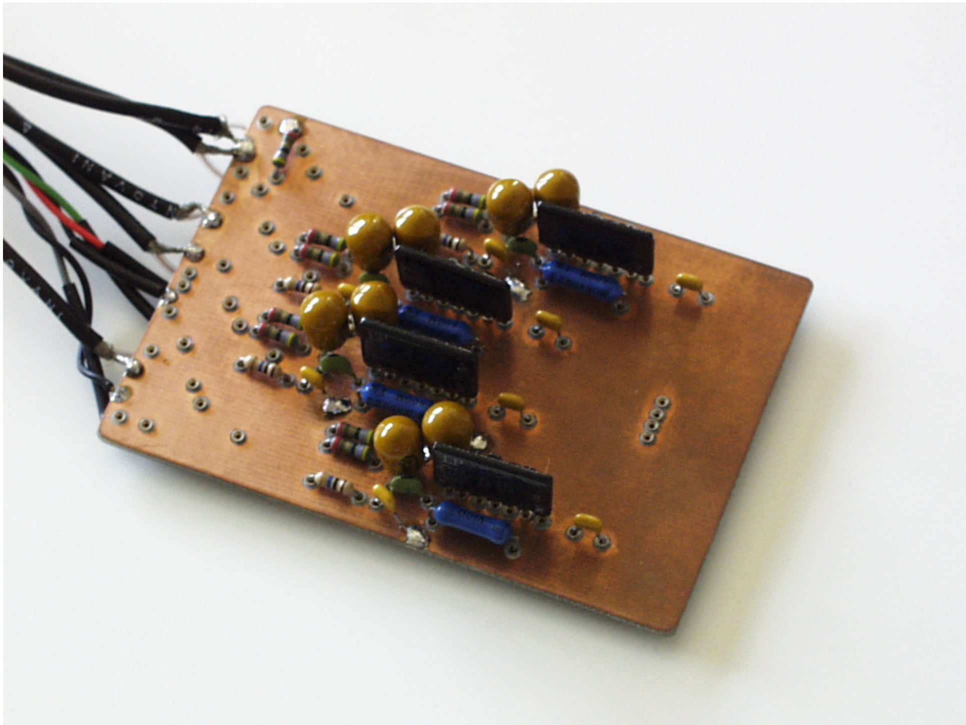

Photo 2. The front-end readout electronics board with the charge sensitive preamplifier (black elements) Clear Pulse CS-515 and the analogic filters for HV and low bias.

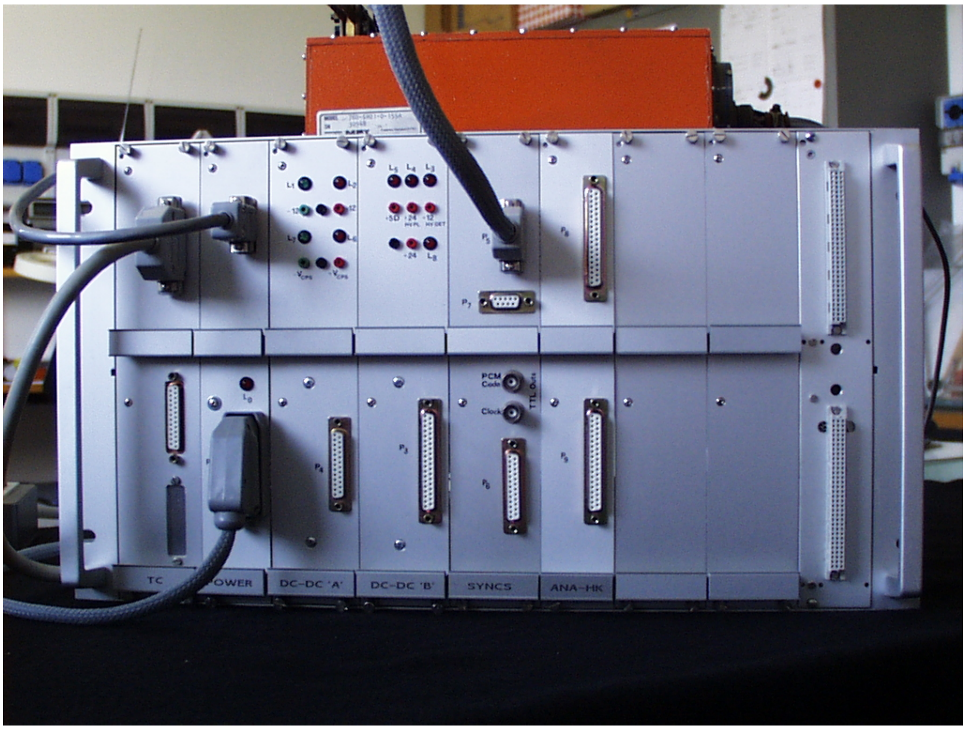

Photo 3. A front view of the Cactµs Service Electronics. The modules are from left to right: the Telecommand unit, the Power, DC-DC converters for CSP and electronics module, the DC-DC converters for CdTe detectors and Plastic HV and for digital electronics bias module,Syncronism unit and Analog House keeping module.

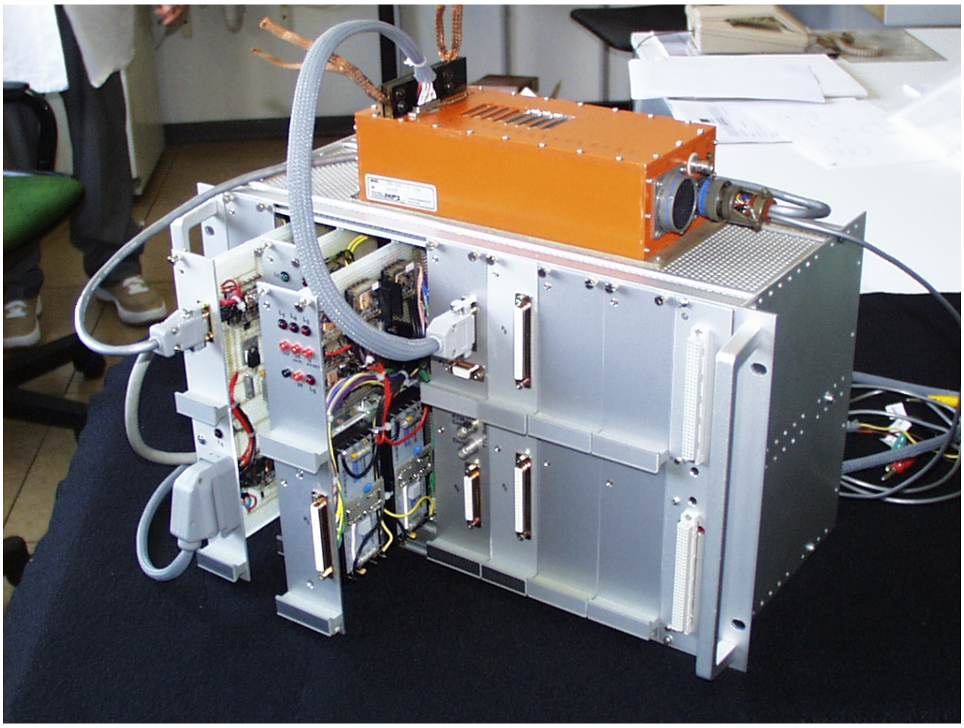

Photo 4. Another view of the Cactµs Service Electronics with the PCM Encoder (Metraplex 760) box above.