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Letter to the Editor

The Ibis-Picsit detector onboard Integral

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Abstract. PICsIT is the high-energy detector layer of the IBIS Imager, composed of 4096 CsI(Tl) scintillator detectors $8.4 \times 8.4 \times 300$ mm in size with PhotoDiode readout. The detector operates in the 175 keV−20.4 MeV range and its data generation modes make it possible to collect information from single events and multiple coincident events. PICsIT is surrounded by the active BGO VETO and is located about 3 metres below the coded mask. The entire PICsIT plane is physically divided into 8 modules and logically divided into smaller units. The overall performance of the plane is directly related to the behaviour of each individual pixel, including its electronics, the system interconnection logic, and interaction with the other sub-systems. Pixels and electronic parameters were monitored constantly during instrument assembly. The following report describes PICsIT design and contains a summary of on-ground test results.

Key words. IBIS – PICsIT – scintillators – detectors

1. Introduction

The use of a detector plane composed of scintillator detectors tightly packaged to form a position-sensitive instrument was envisaged right from the early project phases in the design of the Imager for INTEGRAL.

The Imager design (Ubertini et al. 2003; Lebrun et al. 2003) includes a high-energy detector plane PICsIT (Pixellated Imaging Caesium Iodide Telescope).

Several different advanced technologies were applied during the construction of PICsIT. In this context, it is of interest to note that the level of development reached in the miniaturisation of low power, low noise electronics has had a revitalising effect on the well-consolidated technology of scintillators.

PICsIT design (Labanti et al. 1996, 2002) consists of an array of 4096 scintillator crystals with a Photodiode readout.

Overall, PICsIT is a detector with an active area of 2890 cm^2 having an energy range span from 175 keV to 20.4 MeV. Events leaving one energy deposit in just one crystal can be detected up to approximately 6.8 MeV of energy release while multiple events are recognised and handled by the system electronics. It should be noted that due to the IBIS on board data handling unit, only multiple events up to 13.6 MeV will be transmitted to ground.

2. Picsit detector description

The IBIS high-energy detector plane (PICsIT) is composed of 4096 tightly packaged individual detectors arranged both mechanically and electronically utilising modular architecture in order to operate as a unit.

The basic elements of PICsIT are pixels (see Fig. 1) composed of a 3 cm long CsI(Tl) scintillator crystal with a square cross section of 8.4×8.4 mm. A custom-made PIN photodiode (PD), with an active area covering 84% of the crystal cross section, is glued with a transparent material on one of the two square sides. On all other sides the crystal is wrapped in a thin film of white paper acting as light diffuser and then in a layer of adhesive-aluminised Mylar, with a final conformal passivation coating.

In each pixel the scintillation light collected in the PD is transformed into an electrical charge and sent to the input of an Application Specific Integrated Circuit: the Icarus ASIC (see Fig. 2). ASIC topology was designed to serve a small array of 4×4 pixels. The ICARUS ASIC (Labanti et al. 1999) includes 16 independent channels each composed of the following circuits:

– charge preamplifier,
– shaping amplifier,
– self-triggering circuit,
– peak detector with analogue storage of peak level,
– prompt anticoincidence circuit controlled by an external veto signal arriving from IBIS VETO.

Moreover, the ASIC includes an analog multiplexer with sparse read-out logic and other functions such as threshold setting, killing of noisy channels and baseline auto-calibration operation.

The ASIC is the core of the analogue analysis of PD signals and its noise characteristic determines the performance of

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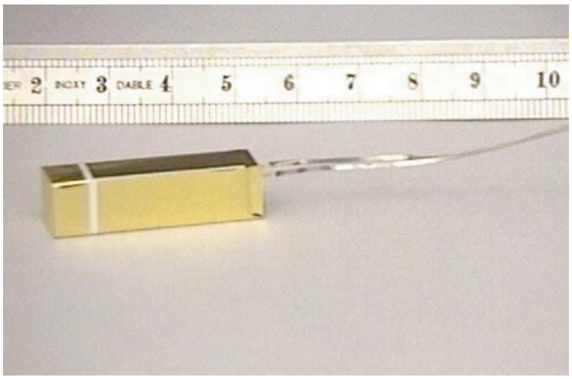

Fig. 1. PICsIT' s Pixel. The scintillator crystal is glued to a Photodiode, wrapped with light diffusive material and with protective Mylar.

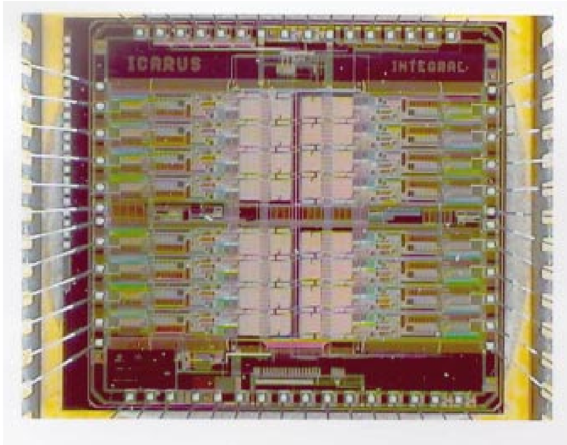

Fig. 2. The ICARUS ASIC chip on a package with the top removed. The die, about 17 × 17 mm, is mounted in a ceramic package. The pixel's PDs are directly connected to the 16 input on the left and right sides. ASIC input – output commands are done via the pins on the bottom and top sides.

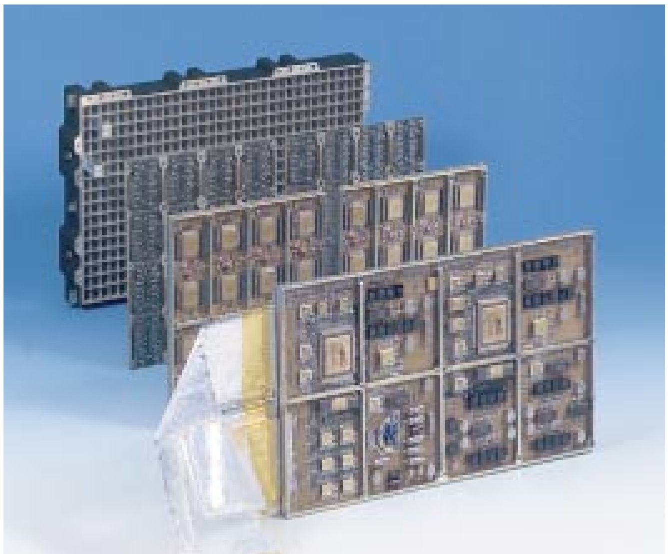

Fig. 3. PICsIT module. A mechanical structure (on the back) contains and positions the pixels. Three electronics boards are stacked below the module; to the first one are connected the pixel's PDs, in the second one are mounted the ICARUS ASICs and the third one is the Digital Front End. All the information came out from the module in digital words (Courtesy LABEN).

the whole instrument in terms of energy threshold, energy resolution and time tagging precision of events. The occurrence of an event is autodetected inside the ASIC and notified to the downstream digital electronics.

A group of 16 ASICs (256 pixels) refers to a single Digital Front End Electronics subsystem (DFEE). When this circuit detects one or more ASIC signals indicating that an event has occurred in one or more pixel, it performs time marking of the event, active pixels identification, and analogue to digital conversion of the pixel signals level.

A further logic in the DFEE manages the criteria for rejection of data when, for example, an external anticoincidence occurs. In the case of non-vetoed events, the DFEE generates the data words, temporarily stores them inside FIFO memories and subsequently forwards them to the overall PICsIT controller. Finally, the preparation and transmission of Housekeeping data such as ratemeters, temperature, and voltage monitoring data, is handled by the DFEE.

All PICsIT detector plane DFEE units are interfaced with the rest of the IBIS system by means of two PICsIT Electronics Boxes (PEB1 and PEB2) that incorporate a FIFO memory for data de-randomisation and a High Bit Rate (HBR) serial link to the IBIS Data Handling system. Another important task accomplished at this level is the temporal ordering of pixel data arriving from all modules. The PEBs contain the power supply units for the modules and Micro controller Boards responsible for detector management and command.

The PICsIT software loaded in the PEB performs full command handling, acquires and formats housekeeping data, handles the table that contains all relevant detector information (threshold levels, map of killed pixels, etc.), monitors PICsIT vital parameters, changes operating mode, and generates messages in the event of alarm situations.

In mechanical terms the PICsIT detector plane is designed with a high degree of modularity. The plane is divided into eight independent modules (see Fig. 3) each containing 512 detectors and related electronics; also the power supply of each module is independent from that of its neighbours.

The module is supported by an aluminium "egg-crate" structure designed to ensure high precision pixel positioning. The egg-crate has 512 positioning holes separated by an 0.2 mm aluminium wall, the mechanical precision of each hole is better than 0.05 mm over the entire module area.

There are three Printed Circuit Boards stacked below the egg-crate and mechanically connected to its external frame. The first board receives all the PD signals and routes them in an appropriate manner to the second board, which accommodates the ASICs. The third board includes two identical DFEE processing chains and all interfaces with the PEBs.

3. Picsit data generation

Because of the nature of the specific PICsIT architecture, the data generated display several characteristic features.

The ASIC detects one or more events in the group of pixels it serves, at which point, if no coincident Veto signal occurs, the address and maximum signal level of each activated pixel are independently stored by the ASIC in its registers and analogue memories. Meanwhile, a Look At Me (LAM) signal, which contains no information regarding the number of pixels fired, is sent to the DFEE unit.

When an ASIC triggers, the DFEE unit opens a 1 μsec width time window; all triggers arriving within this window are considered coincident and marked with the same time. At the end of the coincidence window all the ASICs managed by the DFEE unit are frozen and the read-out sequence begins.

The DFEE processes the contents of the ASIC registers and analogue memories and deals with up to three pixels. If more than three pixels in one or more ASICs are found to be coincident, the whole event is flagged; in this case it will just be counted and discarded later in the PEB.

For a typical gamma-ray photon that interacts with two pixels of a module the processing time is less than 30 μsec. The data word contains the event time, several dedicated flags, and the address and pulse amplitude for each pixel fired.

Events occurring in coincidence with an IBIS-Veto signal are rejected at ASIC level, while events coincident with an IBIS-Calibration signal are flagged and analysed; these latter will be recognised as *Calibration* events in the IBIS Data Handling unit.

Data are processed in a DFEE unit by time of arrival and they display a constantly incremental trend through time. The depth of the FIFO memory used to de-randomise the data makes it possible to store a maximum of 85 pulse-related words in the DFEE unit.

One of the PEBs of PICsIT collects the event data from all the DFEE units and orders them using the event time marking having a size of 250 nsec bin. Events having the same time mark i.e. coincident between different DFEE units, are rejected.

PICsIT data are then supplied to the IBIS Data Handling system for packet generation. In order to equalise pixel response on board, PICsIT data are corrected in all modes with a linear function whose parameters are pixel-dependent.

4. Picsit parameters tested during assembly

Numerous detector parameters were evaluated and used for selection of components or monitoring of the assembly process (Di Cocco et al. 2002). These parameters were measured with different test equipment and methods depending on the PICsIT integration status. They can be roughly grouped and described as:

– *pixel sensitivity* in e$^-$/keV i.e. the magnitude of the charge delivered by the PD of a pixel struck by a gamma ray of known energy. Due to the characteristics of CsI(Tl) crystals this value is temperature-dependent. This parameter was evaluated considering the pixels as stand-alone detectors before their integration in the modules and using reference low noise electronics. *Pixel sensitivity* distribution on the 4096 detectors has an average value of 29.1 e$^-$/keV.

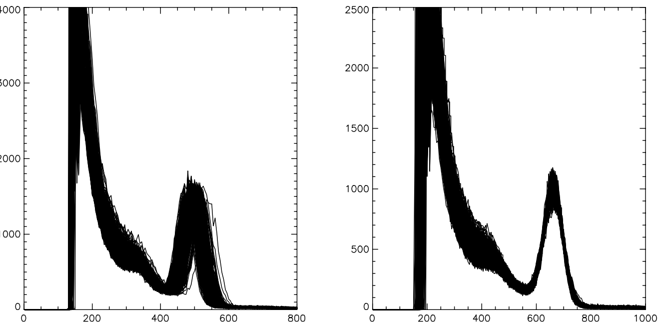

Fig. 4. Cs137 single events spectra. On *X* axis are channels (arbitrary units) and in *Y* axis are counts. Left: data from all the pixels are superimposed before calibration Right: data from all the pixel are equalised after calibration and superimposed.

Table 1. Resolutions % FWHM at the 661 keV for the Flight Modules (FMx).

Module	Res	Thr
FM1	12.5	175
FM2	12.0	180
FM3	12.6	180
FM4	12.0	180
FM5	12.3	180
FM6	12.0	170
FM7	12.4	170
FM8	12.2	180

– *electronic parameters* of the amplifying chains of each pixel such as noise, gain, and time jitter. These are strictly related to the behaviour of the ASIC. In general, they are highly uniform. For example, gains of all channels do not differ from each other by more than a few percentage points, while channel electronic noise is always around 950 e$^-$ rms.

– *peak parameters* i.e. peak position (in ADC channel) and resolution for the photopeaks induced by radio-actives sources as Cs-137 (662 keV), Na-22 (511 and 1275 keV) and Y-88 (898 and 1836 keV).

The spread in pixel parameters, mainly in *pixel sensitivity*, results in a spread in pixel response, e.g. in the position of peaks detected when a module is exposed to a gamma radiation source. These inconsistencies are corrected on board by the IBIS Data Handling unit (see Fig. 4).

Pixel population was subsequently performed in PICsIT modules by grouping detectors having similar *sensitivity* and connecting them to the same DFEE unit; pixels with greater *sensitivity* were placed in the central areas of the PICsIT plane.

Once the pixels were assembled in the modules, each was calibrated individually with a linear calibration function evaluated with data obtained by exposing the whole module to multiple calibration radioactive sources. For example, Fig. 5 shows the map of the pixel *gain* parameter in keV/ch, which is complementary to the *pixel sensitivity* map. For each module acting as a whole detector the minimum threshold and resolution at different energies was evaluated as shown in Table 1 which

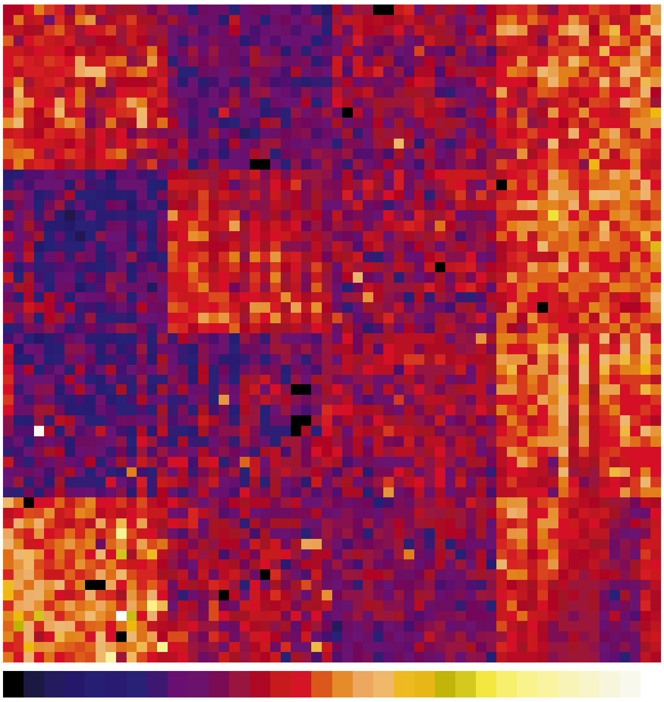

Fig. 5. Map of the gain in keV/ch. On the colour scale the minimum at left is 6 keV/ch and the maximum is 8. The average value on the plane is 6.7 KeV/ch.

considers resolution % FWHM at the 661 keV of Cs-137 line; the values were assessed considering only single events in pixels at room temperature. For multiple reconstructed events the overall resolution behaves like the situation illustrated in Table 2 for module FM2.

5. Conclusions

At the end of the entire integration process of PICsIT modules in IBIS about 35 of the 4096 pixels showed excess noise and had to be killed; 15 additional pixels in the immediate vicinity of this group of 35 were also switched off because of their sensitivity to their noisy neighbours. Overall about 1% of the pixels were switched off.

During the initial commissioning phase PICsIT proved to be a relatively robust instrument, with performance that remained unvaried with respect to the performance features evaluated in on-ground conditions (Di Cocco et al. 2003).

From an engineering point of view we encountered several surprising situations during initial operations. For example, the map showing distribution of saturated events in the whole plane had the same footprint as Fig. 5; this can be expected because saturated events cannot be corrected by the IBIS data handling unit; indeed, it is a positive indication that launch stress had no effect on the instrument.

Table 2. Resolution % FWHM for various energies and various kind of events for FM2.

E (keV)	Source	Single	Double	Triple
511	Na-22	15.5	22.4	–
661	Cs-137	12.0	16.1	18.0
898	Y-88	9.7	12.2	15.4
1275	Na-22	7.3	8.9	9.9
1836	Y-88	5.3	6.6	8.1

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References

Di Cocco, G., Caroli, E., Celesti, E., et al. 2003, A&A, 411, L189

Di Cocco, G., Labanti, C., Malaguti, G., et al. 2002, Nuclear Instruments and Methods in Physics Research Section A, 477(1-3), 556

Labanti, C., Di Cocco, G., Malaguti, G., et al. 1996, Proc SPIE 2806, ed. B. D. Ramsey, & T. A. Parnell, 269

Labanti, C., Rossi, E., Mauri, A., et al. 1999, IEEE Trans. Nuclear Science, 46 (3), 144

Labanti, C., Di Cocco, G., Malaguti, G., et al. 2002, Nuclear Instruments and Methods in Physics Research Section A, 477(1-3), 561

Lebrun, F., Leray, J. P., Lavocat, P., et al. 2003, A&A, 411, L141

Ubertini, P., Lebrun, F., Di Cocco, G., et al. 2003, A&A, 411, L131