

Conceptual Design of Data Acquisition System for CALET on the ISS

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Abstract. We have been developing CALET (CALorimetric Electron Telescope) to make observations of high energy electrons, gamma-rays, and nuclei on the International Space Station (ISS). CALET consists of an imaging calorimeter (IMC), a total absorption calorimeter (TASC), a silicon array (SIA), and an anti coincidence detector (ACD). Triggers to start data acquisition of CAL are generated by combining information on tracks in IMC, partial shower energies in TASC, and traverse of charged particles through ACD. Three trigger conditions can be used simultaneously. The first one is for high energy cosmic rays over 10 GeV. The second one is for low energy electrons and protons affected by solar activities between 1 GeV and 10 GeV. The third one is for low energy gamma-rays from 20 MeV to 10 GeV. CALET can detect gamma-ray bursts (GRBs) in a wide energy range with a gamma-ray burst monitor (GBM) and CAL. Data of sum of energy deposit in TASC and event time are stored in ring memory for a certain period even if the low energy gamma-ray trigger is off.

Keywords: Electron, CALET, ISS

I. INTRODUCTION

We observed electrons from 10 GeV to 100 GeV with BETS (Balloon-borne Electron Telescope with Scintillating fibers) in 1996 and 1997 [1]. BETS was upgraded to PPB-BETS (Polar Patrol Balloon-BETS) to have capability to detect electrons up to 1 TeV. Then, we carried out an electron observation with PPB-BETS in Antarctica in 2004 [2], [3].

The flux of electrons is lower in higher energy range. Therefore, an observation in space is necessary to study electrons over 1 TeV. We have proposed to observe high energy electrons, gamma-rays, and nuclei with CALET (CALorimetric Electron Telescope) on the International Space Station (ISS). The detailed scientific objectives are described elsewhere [4].

In 2007, CALET was selected as one of next mission candidates to utilize the Japanese Experiment Module

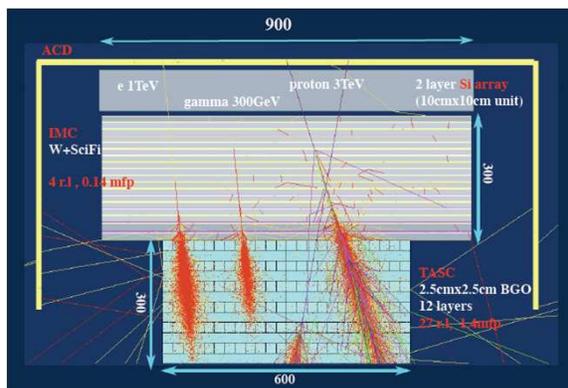


Fig. 1. Schematic drawing of the configuration of CAL composed of IMC, TASC, SIA, and ACD. Examples of simulated shower induced by an electron of 1 TeV, a gamma-ray of 300 GeV, and protons of 3 TeV are shown.

Exposed Facility (JEM-EF). We are carrying out conceptual design study in phase A. Next decision to select one mission to proceed to a development phase will be made in 2009. If CALET is approved as the mission, it will be launched with HTV in 2013.

II. INSTRUMENTATION

A main instrument of CALET is composed of an imaging calorimeter (IMC) and a total absorption calorimeter (TASC). IMC to take images of shower tracks is followed by TASC to measure deposited shower energy precisely. SIA is settled at the top of IMC to determine charges of incident particles [5]. SIA, IMC, and TASC is covered by ACD to reject charged particles in detection of low energy gamma-rays. The configuration of the main calorimeter (CAL) composed of those four detectors (SIA, IMC, TASC, ACD) is shown in Fig. 1. A gamma-ray burst monitor (GBM) is placed aside CAL.

IMC is a sampling calorimeter made of 18 layers of scintillating fiber (SCIFI) belts inserted between tungsten plates of 4 radiation length (r.l.) in total. Ten tungsten plates in the upper layers have each thickness of 0.1 r.l., five plates in the middle layers have each thickness of 0.2 r.l., and two plates in the lower layers

have each thickness of 1 r.l. or 3.5 mm. The SCIFI belt is assembled with 896 SCIFIs of 1 mm square in cross section. Two SCIFI belts laid in right angle form one layer and are set between tungsten plates. Incoming cosmic rays induce shower particles one after another in IMC. The shower particles are detected with the SCIFIs, and shower images projected into two directions are taken. Basic technologies on IMC were developed and verified through the balloon experiments, BETS and PPB-BETS, and beam tests at CERN-SPS [6]. We use multi-anode photo multiplier tubes (MAPMTs) to read out the fluorescence from the SCIFIs. Each SCIFI corresponding to one anode is read out channel by channel. As the MAPMT has 64 anodes, the SCIFIs of 32256 channels are read out with 504 MAPMTs.

TASC has 12 layers composed of BGO scintillator logs of $25 \times 25 \text{ cm}^2$ in cross section and 30 cm in length. As the area of TASC is $60 \times 60 \text{ cm}^2$, two logs are needed in length and one layer is assembled with 48 logs. BGO logs of 576 are used for TASC in total. Each BGO log is read out with photo diodes (PDs) or a photo multiplier tube (PMT). In order to achieve a high rejection power against proton back grounds and a high energy resolution, the readout should cover a dynamic range from one minimum ionizing particle (MIP) to 10^6 MIPs. If we use the PD as the readout, two PDs of different sizes are attached to one BGO log to obtain such high dynamic range. If we use the PMT, readout from not only an anode but also a dynode is necessary to attain such high dynamic range. Detailed studies on the TASC readout is described in [7]

After incident positions at SIA are determined by following up shower axes with IMC and TASC data, precise measurements of incident charge are made with SIA data. SIA has two layers of silicon arrays. A pixel of the silicon array is about 1 cm square. A charge resolution of SIA is $0.1 e$ for protons and heliums, $0.2 e$ for carbons, nitrogen, and oxygen, and $0.35 e$ for irons. It will be developed by Italian collaborators [5].

In order to make an observation of low energy gamma-rays below 10 GeV, ACD is necessary to reject charged particle backgrounds. ACD is not available over 10 GeV, because it detects signals of back scattered particles from showers. It is segmented into several plastic scintillators to obtain rough positions of charged particles. Technical information on ACD will be obtained from collaborators in the U.S.A.

GBM detects gamma-ray bursts (GRBs) in the energy range between 7 keV and 20 MeV. An observation of GRBs in a wide energy range from 7 keV to several TeV is possible with a combination of GBM and CAL. Development of GBM and scientific objectives are described minutely in [8].

A visual star camera (VSC) and a GPS receiver (GPSR) are placed near CAL to support the observations. We calibrate the attitude of the CALET instrument to determine directions of incident cosmic rays precisely with VSC. GPSR is necessary to get accurate time stamp



Fig. 2. Left picture shows a FEC unit developed to read out MAPMT. One MAPMT is attached to the FEC in the right picture. The FEC unit contains 16 chips of VA32HDR14 to read out 8 MAPMTs. Analog signals of 512 channels from MAPMT are processed and digitized by 16 bits ADC.

to study timing features of light curves of pulsars and GRBs.

III. ELECTRONICS

A. Front-end circuit

We have developed a front-end circuit (FEC) to read out the MAPMTs of IMC as shown in Fig. 2. An analog ASIC was indispensable to read out a lot of channels of MAPMTs. We tried using a Viking chip which was developed originally to read out silicon detectors and manufactured by IDEAS in Norway. We modified it and developed a new chip VA32HDR14 for the MAPMT readout to obtain at least ten times higher dynamic range than that of an existent chip. VA32HDR14 has 32 sets of a pre-amplifier, a shaping amplifier, and a sample hold (SH) circuit and one analog multiplexer in it. A peaking time of the shaping amplifier is $1.85 \mu\text{s}$. Each peak level of 32 channels can be held to the SH by an external hold signal. They are read out in turn through the analog multiplexer. VA32HDR14 has a high dynamic range from a noise equivalent charge of 0.8 fC to a maximum input charge of around 20 pC . Although the noise level slightly increases to 1.3 fC when the chip is bonded

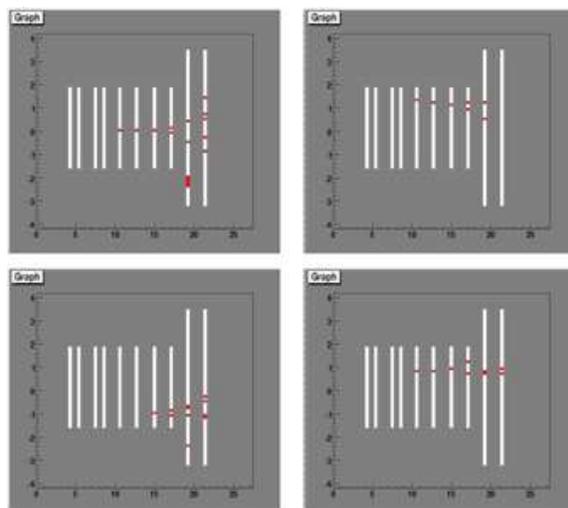


Fig. 3. Beam test of prototype IMC with gamma-rays at LNS in Tohoku University. Gamma-ray beams of 0.8 GeV were irradiated from left side and tracks of pair creation of electron and positron in IMC were obtained successfully.

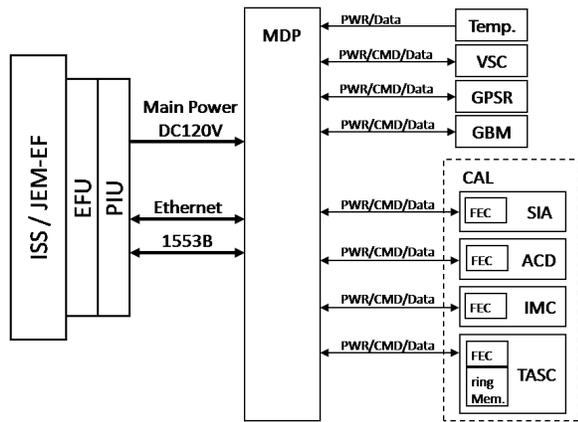


Fig. 4. Block diagram of CALET electronics.

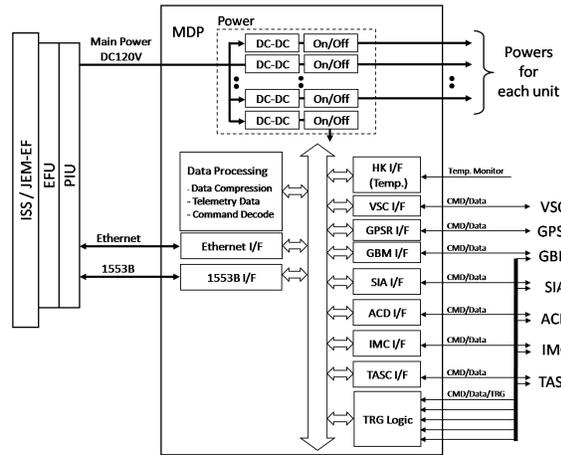


Fig. 5. Block diagram of the inside of MDP.

on an FEC board, a few thousands of dynamic range is achieved. We tested the FEC with heavy ion beams at HIMAC (Heavy Ion Medical Accelerator in Chiba) in National Institute of Radiological Science (NIRS) and with electron and proton beams at CERN-SPS.

We carried out a balloon experiment with a prototype of CALET. It was successfully done and results are described in [9]. We also made a test of a prototype IMC with sub-GeV gamma-ray beams at the Laboratory of Nuclear Science (LNS) in Tohoku University. Examples of electron and positron pair creation tracks induced by gamma-rays of 0.8 GeV are shown in Fig. 3.

As described in the previous section, we will use the PDs or the PMTs for the readout of the BGO scintillators of TASC. Whichever sensor we choose, at least two signals should be read out for each BGO. Furthermore, two systems of amplifier circuit with different gains are needed to cover the wide dynamic range of 10^6 . This study is described in [7].

B. Data acquisition system

Data acquisition of CALET is controlled by a mission data processor (MDP). MDP has connections to the JEM-EF and to the CALET payload units as shown in Fig. 4. MDP uses a power line of 120 V d.c. and communication lines of Ethernet and 1553B provided by the JEM-EF. These lines are connected to the JEM-EF through an attach point structure of a payload interface unit (PIU) and that of an exposed facility unit (EFU). MDP controls each payload unit of VSC, GPSR, GBM, SIA, ACD, IMC, and TASC. It supplies each unit with an appropriate power, sends commands to change conditions of each unit. It receives pre-data related to triggers from ACD, IMC, TASC, and GBM, and then decides whether it should issue a trigger to certain units. Once a trigger is asserted, it gathers event data from each detector. It collects house keeping data like temperatures and voltages to monitor every units periodically.

An inside of MDP are shown in Fig. 5. The main power of 120 V d.c. supplied from JEM-EF is divided and transformed to appropriate voltages with DC-DC

converters. MDP controls on-off conditions of power line connected to each unit. Triggers are judged immediately by hardware on the trigger logic board. Data are gathered through interfaces to the payload units. They are compressed and transferred to the JEM-EF through the communication lines.

We can utilize the other standard facilities of the JEM-EF. For example, an active thermal control system (ATCS) is also available. ATCS enables us to cool sensors and electronics efficiently with fluid. We estimate that CAL will be operated with temperatures less than 40 degrees Celsius by using ATCS.

IV. TRIGGER SYSTEM

A. Trigger conditions

1) *High energy shower trigger*: Triggers for showers induced by high energy incidents are generated with IMC and TASC. One trigger requirement is to detect hits in more than three consecutive layers in IMC. The other trigger requirement is for a sum of energy deposit in the top layer of TASC to exceed a threshold which 95 % electrons of 10 GeV clear. If the both requirements in IMC and TASC are satisfied, the trigger logic board in MDP will issue a trigger to IMC, TASC, SIA, and ACD to take event data.

The decision of trigger assertion is needed to be done within $1.85 \mu s$ which is the peaking time of VA32HDR14. Electrons, gamma-rays, and nuclei are triggered with this high energy shower trigger, and an average trigger rate is estimated about 38 Hz. Detailed study on percentages of incident cosmic rays to be triggered, and on the trigger rate depending on the orbit of the ISS is described in [10].

2) *Low energy shower trigger*: In order to observe electrons below 10 GeV, triggers for showers induced by low energy incidents are also generated with IMC and TASC. The requirement in IMC is the same as that for high energy shower trigger. The threshold for a sum of energy deposit in the top layer of TASC is just lowered. The threshold is cleared by 95 % electrons of 1 GeV.

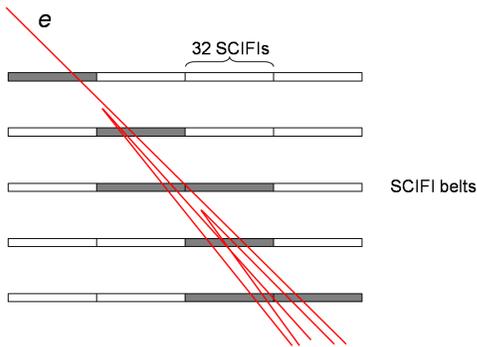


Fig. 6. SCIFIs of 32 channels are grouped into one segment. Hits of each segment can be detected with TA chips. Decision whether hits are detected in more than 3 consecutive layers is possible.

This low energy shower trigger is used to make observation of electrons from 1 GeV to 10 GeV at near the maximum latitude of the ISS orbit for 5 minutes every 2 orbits. Not only electrons but also nuclei and gamma-rays are triggered. The maximum rate is estimated to reach 1.2 kHz. The rate depends on the ISS orbit. Detailed study is also described in [10].

3) *Low energy gamma-ray trigger:* For gamma-ray observation over 20 MeV, a low energy gamma-ray trigger is generated with IMC and ACD. A track should be detected in IMC. Therefore, the trigger requirement in IMC is the same as the shower trigger described above. Because low energy gamma-rays lose their energy in IMC before they reach to TASC, any trigger condition in TASC is not required. As another trigger condition, ACD is required not to detect any charged particle traversing it. If the both trigger requirements in IMC and ACD is satisfied, the trigger logic board will assert a trigger to IMC, TASC, SIA, and ACD to gather event data.

Over 10 GeV, back scattered particles from a shower may hit ACD and such event is rejected by ACD. Hence, gamma-rays from 20 MeV to 10 GeV are triggered by this low energy gamma-ray trigger, and an estimated trigger rate is about 45 Hz. Gamma-rays over 10 GeV are triggered by the high energy shower trigger.

B. IMC Trigger with TA

The IMC trigger, the quick detection of tracks in IMC, is necessary for all trigger conditions mentioned above. We are considering to adopt a function of TA chip for that purpose. TA chips are also manufactured by IDEAS. It possesses a function of discriminator.

For example, TA32CG includes 32 sets of a fast shaping amplifier and a comparator. Outputs from the pre-amplifiers of VA32HDR14 can be connected to the fast shapers in TA32CG. The peaking time of the fast shaper is 75 ns. Each output from the fast shaper is fed to a comparator to generate a discrimination signal that indicates the fast shaper output exceeds a pre-settable threshold level. Finally, a logic sum of 32 discrimination signals is obtained as an output from TA32CG.

Hits of each segment which contains 32 SCIFIs can be detected with TA chips as shown in Fig. 6. Detection of hits in more than three consecutive layers in IMC is possible with the hit patterns. We are considering to develop a new VATA chip by combining VA32HDR14 with TA32CG in one chip.

C. TASC data taken with GRB triggers

We estimate that about five events in one day will be detected with GBM. If the low energy gamma-ray trigger of CAL is active, a wide band simultaneous GRB observation from 7 keV to 20 MeV with GBM and from 20 MeV to several TeV with CAL is possible. Data takings from CAL and GBM are done independently on-board, and we can confront the both data in offline to make analyses on GRBs.

Even though the low energy gamma-ray trigger of CAL is disabled, data of sum of energy deposit in TASC and event time are kept into a ring memory for a certain period. The data recording to the ring memory is triggered when the sum of energy deposit in TASC exceeds 100 MeV with no hit in ACD. A rate of such data storage is estimated to be about 1 kHz. Thus, the TASC data both before and after a GRB can be acquired from the ring memory according to a GRB trigger asserted by GBM.

V. SUMMARY

CALET is designed to observe cosmic-ray electrons, gamma-rays, and nuclei simultaneously. We have been considering the way to control CAL together with GBM. The shower trigger is generated with IMC and TASC to detect electrons, gamma-rays, and nuclei over 1 GeV or over 10 GeV. The low energy gamma-ray trigger is generated with IMC and ACD to detect gamma-rays from 20 MeV to 10 GeV. Those enable to make a wide range GRB observation together with GBM. Summed energies of TASC are stored in the ring memory and acquired according to the trigger from GBM even if the low energy gamma-ray trigger is disabled.

We have already started tests for such data acquisition system partially by a balloon flight and beam experiments at CERN-SPS and at LNS in Tohoku University. In a few years, we will carry out beam tests of the full-scale data acquisition system at CERN-SPS. This plan is supported by a Grant-in-Aid for Scientific Research B (No.21403004). The data acquisition system is also to be verified through balloon experiments with a scale model of CALET.

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