Gamma-Ray Burst Monitor (CGBM) for the CALET Mission on board the ISS(II) – Current Development Status –

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Abstract

The CALorimetric Electron Telescope (CALET) is the experiment to observe high energy cosmic electrons and gamma rays. The CALET is a second period mission for "kibo" Exposed Facility of the International Space Station. It will be launched by HTV and set on the ISS. We are developing the CALET Gamma-ray Burst Monitor (CGBM). Three detectors out of the four employs $LaBr_3$(Ce) crystal and the other is a phoswitch detector which utilizes BGO crystal and plastic scintillator. Now, we are investigating detector's performance in the space environment. We irradiated it with gamma-rays and proton beams to study its endurance to radiations. We will present the development status and the result of the experiment.

Key words: ISS: GRB: CALET

1. CALET

The CALorimetric Electron Telescope (CALET) is an experiment which observes high energy electrons (1 GeV – 10 TeV), gamma-rays (10 GeV – 10 TeV), protons and heavy nucleus components (several 10 GeV – 1000 TeV). It is aimed to give us a clue for the universal picture of high energy space through various observation probes. The main scientific objectives of the CALET are to 1) clarify the origin of TeV electrons and 2) search for signals from dark matters. The CALET is one of the missions which are selected as the second period utilization of the platform of the Japanese Experiment Module "Kibo" on the International Space Station (ISS). The CALET is an international mission among Japan, U.S.A., and Italy. It is planned for launch by the H-IIB Transfer Vehicle (HTV) in summer of 2013.

The overview of the CALET payload is shown in Fig. 1. The CALET has two scientific instruments: Calorimeter (CAL) and Gamma-ray Burst Monitor (CGBM). The CAL mainly observes high energy electrons and gamma-rays in the GeV-TeV range, and CGBM observes gamma-ray bursts (GRB) in the 7 keV – 20 MeV X and gamma-ray range. The CAL has a wide field of view of 45 degrees from the zenith and an effective area of 0.2 m^2. It can also observe a gamma-ray burst with almost the same sensitivity to the EGRET aboard Compton Gamma-ray Observatory (CGRO). Some support sensors such as the GPS receiver (GPSR) for an accurate absolute timing required in pulsar and GRB observations, and Advanced Star Camera (ASC) for an accurate position determination of gamma-ray sources are installed to this payload.

The CAL is pair-conversion tracking system which is similar to Fermi-LAT. It consists of CHarged Detector (CHD), IMaging Calorimeter (IMC) and Total Absorption Calorimeter (TASC) from top to bottom. The CHD is an array of the plastic scintillator to measure the electric charge for atomic nucleus. The IMC is a multi-layered scintillation-fiber and tungsten, which can convert particles into showers, and track the showers with 1 mm position accuracy. The TASC is located under the IMC and it consists of an array of inorganic scintillators (PWO) readout by a Si avalanche and PIN photodiode.

The TASC can absorb and measure total energy of showers passing through the IMC in the wide dynamic range.

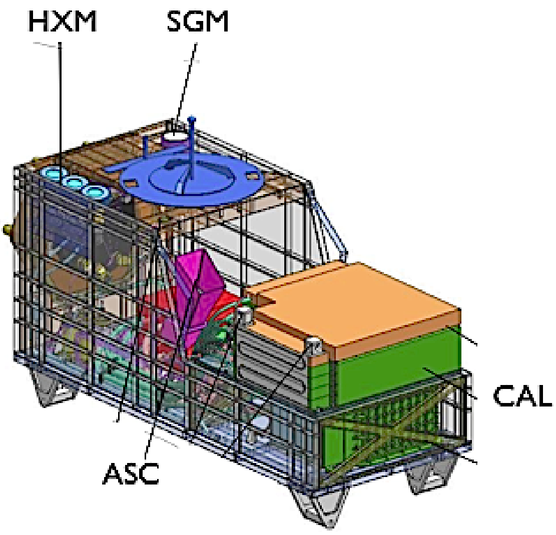

Fig. 1. An overall structure of CALET. The HXM and SGM are installed on the side panel having the FOV toward the zenith.

2. Gamma-ray Burst Monitor(CGBM)

The CGBM is an instrument which provides a function of GRB observations by the primary instrument CAL. It observes a lower energy range which the CAL can not cover and is aimed to obtain GRB spectra over a wide range of X-rays to gamma-rays. It is composed of sensors and electronics-BOX (E-BOX) which processes the signal of sensors. The outputted data from the E-BOX are formatted by Mission Data Controller (MDC), and sent as a telemetry to the ground station at NASA. We will describe details of sensors and E-BOX in the following subsections.

2.1. Sensors

Two types of detectors, Hard X-ray Monitor (HXM) and Soft Gamma-ray Monitor (SGM), are used for CGBM to cover a wide energy range of 7 keV to 20 MeV by its combination. As for the HXM, we utilize a novel scintillator $LaBr_3$(Ce) with an excellent performance in terms of light yield, energy resolution, time response, and density in comparison with those of NaI(Tl). However, it is not used in space yet. Hence, we have been verifying the performance through various tests. The thin beryllium window with 410 μm thickness is used for soft X-ray detections (< 10 keV). For the SGM, we utilize the phoswich detector consisting of BGO and plastic scintillator. The BGO has a high stopping power for gamma-rays due to its large density(ρ = 7.13 g/cm^3) and effective atomic number($Z_{\rm eff}$ = 74). The size of the BGO is 4 inch diameter and 3 inch thickness. To reduce the particle background effectively, we plan to cover the BGO crystal by the plastic scintillators with a thickness of 5 mm, and read out the signals with one photo-multiplier tube(PMT).

Table 1. Performance of CAL for gamma-rays

	CAL
energy range (nominal)	10 GeV - a few TeV
energy range (GRB trigger)	1 GeV - a few TeV
Field-of-View (FOV)	$\sim$2 str
effective area	1000 cm^2

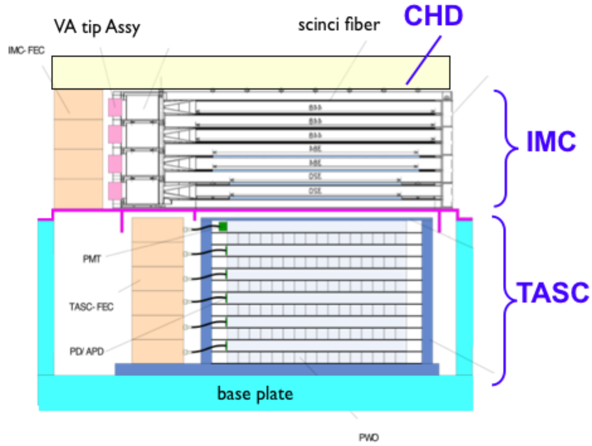

Fig. 2. Cross section of CALorimeter.

The CGBM sensors are in total four detectors, three identical HXMs and one SGM. Each detector mainly consists of a scintillation crystal, a photo-multiplier tube, a high voltage divider, and a charge-sensitive preamplifier (CSA).(See figure**??** for SGM.) The vibration tight model of Hamamatsu PMT R6232 and R6233 will be used for HXM and SGM, respectively. Newly developped hybrid ICs are used for the CSA. All the components are encaptured as one package in the Aluminum housing.

2.2. Electronics-BOX(E-BOX)

The E-box processes four signals from pre-amplifiers of the four sensors. It is installed apart from both MDC and sensors. The block diagram of the SGM signal processing in the E-box is shown in Fig. 4. The SGM and HXM signal processing are very similar, except for classification of signals from BGO and plastic sensors in the SGM. To ensure the wide dynamic range, the signals from preamplifiers are divided into amplifiers with two different gains, which are independently read out by different sample-hold ADCs. The signals are bipolar-shaped with a CR-RC^2-CR filter whose time constant (τ)

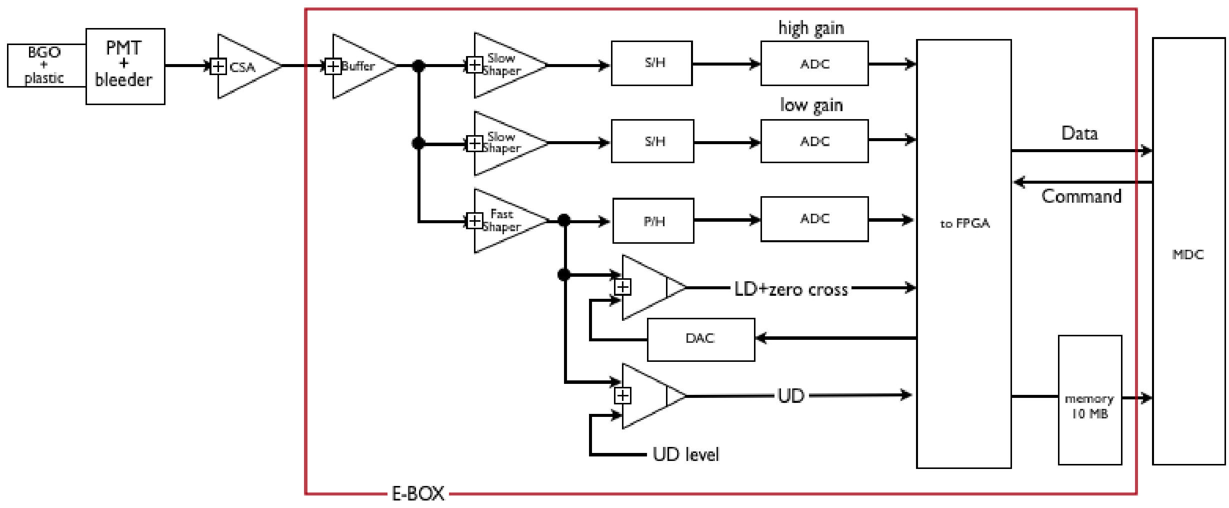

Fig. 4. Block diagram of signal processing for SGM. The red box indicates the E-box.

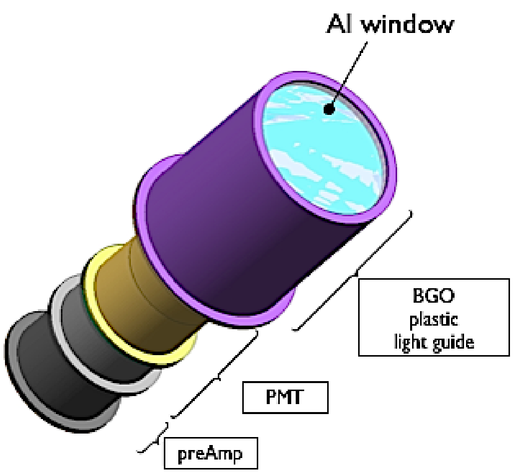

Fig. 3. The structure of the SGM sensor. There are scintillator(BGO+plastic), light guide, PMT, bleeders and pre-amplifiers.

is 2 μs. The ADC conversion timing is produced by the zero-crossing comparator after the fast shaping (τ=0.1 μs). The upper discriminator (UD) is also equipped to avoid malfunction in case of signals with a large energy deposit. In addition to the HXM analog circuit described above, the SGM is required to distinguish BGO signals from plastic signals. The BGO and the plastic signals have different decay time of 300 ns and 2 ns in the PMT output respectively, hence we can distinguish by comparing the output of two shaping amplifiers with a different time constant, so-called double integration method. We added the peak-hold circuit for the fast shaping output and prepared another ADC for this signal.

The digital output from ADCs and comparators are sent to Field Programmable Gate Array (FPGA). The FPGA realizes the scalers from the LDs and UDs, a GRB trigger logic, and soon.

The CGBM E-box produce two types of the data. One is monitor data which is always outputted independent of the GRB trigger status. The data are used for background monitors and analysis for untriggered GRBs. The other is an event data produced once a GRB triggers. The monitor data are composed of two histogram data: Time Heighit (TH) Data with a 1/8-sec time resolution and 4 energy channels, and Pulse History (PH) Data with a 4-sec time resolution and 512 energy channels. The event data has information of arrival time (1 msec time resolution) and energy (4096 energy channels) for each event.

On-board trigger system is installed in the FPGA of the E-box. The following equation is realized in the hardware logic.

$$S - \frac{Bg}{\Delta bg}\Delta t > \sigma\sqrt{\frac{Bg}{\Delta bg}\Delta t} \tag{1}$$

where S is the source plus background rate during the GRB judgment time (Δt), Bg is the background counts integrated over a fixd time (Δbg sec), and σ is the significance level. The represents the net GRB counts during the GRB judgment time (Δt). If it can exceed the Poisson fluctuation level ($\sqrt{\frac{Bg}{\Delta bg}\Delta t}$). The trigger level ($\sigma$), the sampling time ($\Delta$t), energy and the background

Table 3. The CGBM data types and contents.

	Monitor Data ¬ †		Event Data
	TH data	PH data	
energy channels	8 channels	512 channels	4096 channels
time resolution	1/8 sec	4 sec	1 ms
time coverage	any time		100 s before and 256 s after the trigger

integration time can be set by commands. This equation was also applied to the GRB trigger system in the Ginga/GBD and Suzaku/WAM.

Once the trigger system judges as a GRB, the event data are accumulated from 100 sec before to 256 sec after the trigger in the 10 Mbyte memory, and the E-box will also take the following action to the MDC.

1. send a GRB trigger and the MDC time latched by the trigger timing.

2. transfer the event data in the memory

3. request to make an energy threshold of CAL down to around 1 GeV.

4. request to take an optical image with ASC.

3. Development Status

3.1. Gamma-ray irradiation test

We developped the test model of the BGO and plastic phoswich detectors. This was made by OKEN Co Ltd. The BGO size is one inch diameter and one inch thickness, surrounded by plastic scintillators EJ 212 with 5 mm thickness. First we irradiated gamma-rays from the radio isotope ^{137}Cs to the test model at room tempareture. The output is read out by the double integration method with two different shaping amplifiers (τ=100 ns and 2 μs). Figure 5 shows the 2 dimensional histgram between fast shaper outputs and slow shaper outputs. We can clearly see two sepated branches. For plastic events, the pulse height ratio between the slow and fast shapers would be about unity because signals are fully integrated for both time constants. For BGO events, the pulse height of the fast shaper would be less than that of the slow shaper due to the slow time response of BGO. Figure 6 shows the BGO selected spectra for ^{137} Cs. We clearly see the photo-peak for 662 keV, and the FWHM energy resolution at 662 keV is 10.4±0.2 %, which is typical for BGO crystals. Thus, we found that we could clearly separate BGO events from plastic events for gamma-rays.

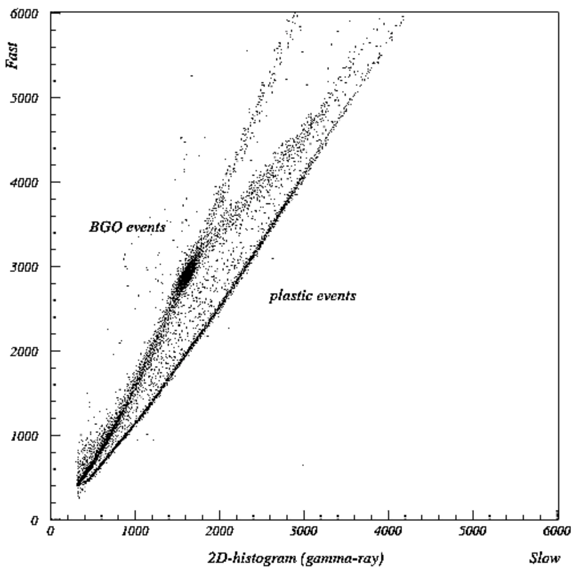

Fig. 5. Two dimensional histogram between fast-shaper outputs and slow-shaper outputs. The radio-isotope ^{137}Cs was irradiated to the SGM test model. We can clearly separate events interacted in two scintillators (plastic and BGO).

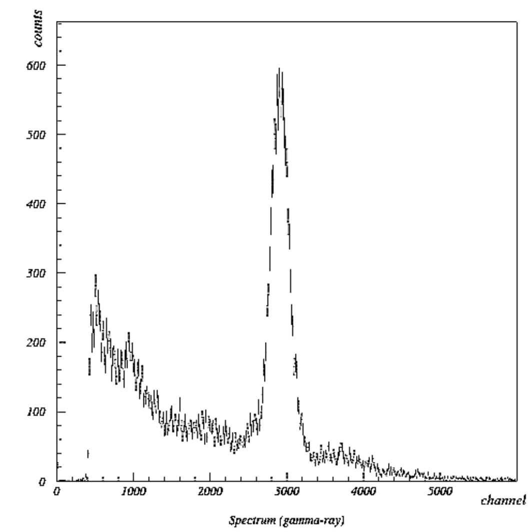

Fig. 6. BGO spectrum of the radio isotope 137Cs selected from Fig. 5. The 662 keV photo-peak is seen at 2900 channels.

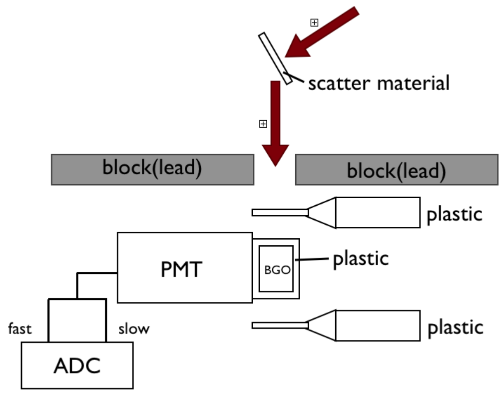

Fig. 7. Setup of the proton-beam irradiation test for the SGM test model.

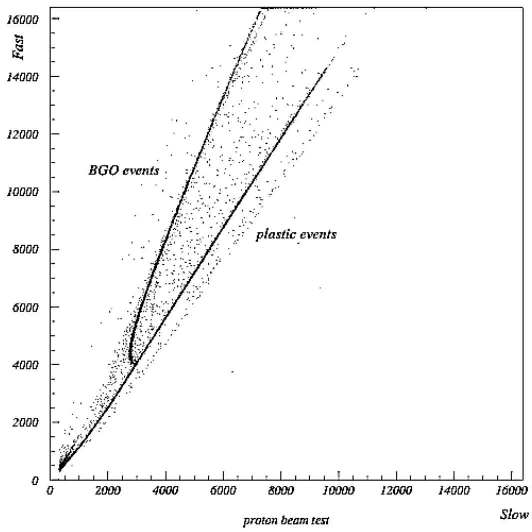

Fig. 8. Two dimensinal histrogram for proton irradiation tests. The proton beams are irradiated from the side of the SGM test model.

3.2. Proton beam irradiation test

To verify whether the test model can eliminate proton events effectively, we irradiated the proton beam with a kinetic energy of 200 MeV at the Wakasa-wan Energy Research Center (WERC) in August, 2010. To reduce the intensity of the beam, scattered proton beams in the 5 mm thickness polyethylene were used. Two plastic scintillators were put back and front of the test model to identify the charged particles. We regard "proton events" as events reacted in the three scintillators (front plastic, test model, and back plastic). All the detectors were covered by lead blocks to reduce the background.

Figure 8 shows two dimensional histogram for proton events. Two separated branches are seen in this figure, which is very similar to that of gamma-rays. We can also see a line with a curvature connected between pure BGO and plastic events. This indicates events whose energies are deposited in both BGO and plastic scintillators. When the protons are incoming to the side of the test model, the deposited energies smoothly changes due to the difference of the pass lengths for BGO and plastic viewed from the side. If we apply the same criteria as gamma-rays to the proton events, we found that about 26.5% of all the protons are confused in BGO events. Simulation studies for various energies and incident directions are under way. Now the bled-board model for the CALET CGBM is under testing, and the design of the CALET flight model to be finalized soon for its launch in summer of 2013.

Table 2. Performance of SGM and HXM

	HXM	SGM
crystal	$LaBr_3(Ce)$	BGO+Plastic
number	3	1
diameter	61 mm	4 inch
thickness	0.5 inch	3 inch
shape	cylindrical	cylindrical
energy range	7 keV – 1 MeV	100 keV – 20 MeV
energy resolution	$\sim$3 % @662 keV	$\sim$12 % @662 keV
field of view	$\sim$1.8 str ($\lesssim 30\,\mathrm{keV}$) $\sim \pi$ str ($\gtrsim 30\,\mathrm{keV}$)	$\sim 2\pi$ str