RT-2 Experiment Onboard the "CORONAS-PHOTON" Satellite

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***Abstract*. Low energy gamma-ray spectrometer/telescope RT-2 is a part of the "CORONAS-PHOTON" satellite that was launched from cosmodrome "Plesetsk" on January 30, 2009 into a low-Earth, low eccentricity, high-inclination orbit (altitude about 550 km, inclination 82.5°). "CORONAS-PHOTON" is a 3-axis stabilized, Sun-pointing out spacecraft. RT-2 experiment designed and developed for the study of solar gamma-rays/X-rays in the energy range of 15 keV to 150 keV, extendable up to 1 MeV. This experiment consists of three detectors (two phoswich detectors RT-2/S, RT-2/G, one solid state imaging detector RT-2/CZT) and one processing electronic device (RT-2/E). In this paper we briefly describe the on-board performance of RT-2 instrument since its launch and summary of the first observational results.**

***Keywords*: CORONAS-PHOTON, solar flares, gamma-ray spectrometer**

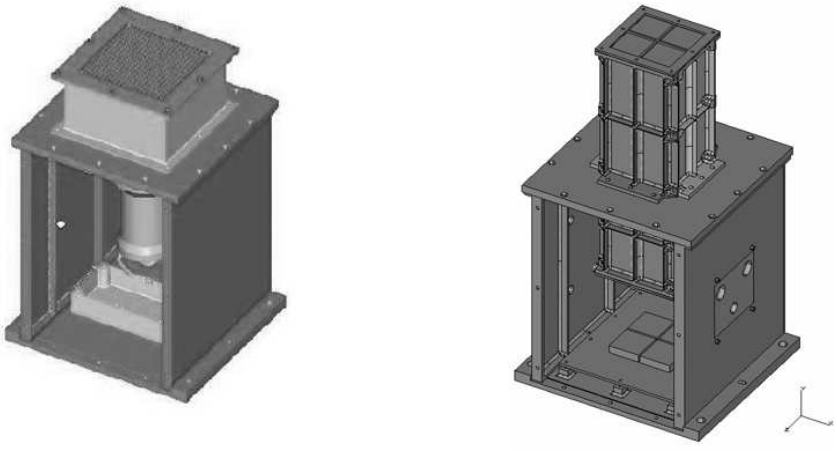
I. INTRODUCTION

RT-2 experiment is a gamma-ray/X-ray instrument which is developed as a part of "CORONAS-PHOTON" [1], [2] mission for the study of Sun in the wide-energy band of electromagnetic spectrum from ultraviolet to high energy gamma-rays. The main scientific tasks of the experiment are the study of the solar electromagnetic radiation in the wide energy range from 15 keV to 1 MeV, registration of the temporal profiles (TP) from solar and galactic X-ray radiation in the energy range of 15-150 keV and hard X-ray imaging of solar flares using pixelated CdZnTe and CMOS detectors in composition with collimators. The RT-2 experiment is comprised of three detector blocks RT-2/S, RT-2/G (both scintillator/phoswich detectors), RT-2/CZT (solid state detector) and one processing electronics block RT-2/E. The phoswich detector assembly houses the low energy gamma-ray/hard X-ray detector system and front end electronics. The RT-2/S and RT-2/G detectors consist of NaI(Tl)/CsI(Na) scintillator in phoswich assembly viewed by a single photomultiplier tube (PMT). This entire assembly is procured from M/S Scionix Holland BV, The Netherlands. Both the detectors sit behind a mechanical slat collimator surrounded by a uniform shield of tantalum material and having different viewing angles of 4°×4° (RT-2/S) and 6°×6° (RT-2/G). RT-2/S works in the energy range of 15-150 keV, extendable up to 1 MeV (spectrometric mode for full signal from both scintillators), whereas aluminium filter is used to cut-off low energy photons (<20 keV) for RT-2/G. The RT-2/CZT consists of three CdZnTe (CZT) detector modules (OMS40G256, procured from Orbotech-medical, Israel) and one CMOS detector (RadEye-1, procured from Rad-icon Imaging Corporation, USA) arranged in a 2×2 array. Each CZT detector module consists of 256 individual detectors (pixel dimension of 2.5 mm×2.5 mm, 5 mm thick), which are controlled by 2 ASIC, and CMOS detector consists of matrix of 512×512 pixels (pixel dimension of 48 μm×48 μm) situated in optical contact with Gd_2O_2S scintillator 25 mm×50 mm and 3 mm thick. The entire CZT-CMOS detector assembly sits behind a collimator with two different types of coding devices: coded aperture mask (CAM, 0.5 mm of tantalum) for two CZT detectors and Fresnel zone plate (FZP, 1 mm of tungsten) for one CZT and CMOS detectors, surrounded by a uniform shield of tantalum and has a viewing angle of 8°×8°. The detector characteristics are given in the Table I.

TABLE I: RT-2 detectors characteristics

Assembly	RT-2/S and RT-2/G	RT-2/CZT
Detector Type	NaI(Tl) + CsI(Na)	CZT + CMOS
Thickness (mm)	3+25	5+3
Size (mm)	⌀116	40×40, 24×24
Readout	PMT	Pixels
Effective area (cm2)	100	48, 4.5
Energy resolution	18% (60 keV)	8% (60 keV)
Energy range	15-150 keV (S) 20-150 keV (G)	20-100 keV
Time Resolution	1 s TP+100 s spectra 0.1 s TP+10 s spectra 10 ms TP+1 s spectra	1 s TP 100 s Image

All three detectors would be calibrated in flight using Co^{57} (122 keV) source of strength 100 nCu (maximum). A pellet of this source is embedded into one of the slats of the collimators. Measured angular resolution for CZT composition is 30 angular minutes. Resolution may be increased till 2 angular minutes for powerful flares. According to laboratory testing



(a) RT-2/S(G) (b) RT-2/CZT

Fig. 1: Isometric view of RT-2/S (Phoswich detector) and RT-2/CZT (Solid-state detector). The different parts of the assembly (eg. collimator, HV box, PMT, CZT-CMOS mounting plate etc.) are seen in the drawing

for the most powerful flares with simple structure the angular resolution of CMOS detector may be up to $\sim$10 angular seconds. All three detector systems (RT-2/S, RT-2/G and RT-2/CZT) are interfaced with the satellite onboard systems and data acquisition and registration of scientific information system (SSRNI) through electronic processing block (RT-2/E). RT-2/E receives necessary commands from the satellite system and passes it to the individual detector system for proper functionary of the detector units and acquires data from the detector system and stored in its memory for further processing. The schematic diagram of RT-2/S (RT-2/G) and RT-2/CZT are shown in Fig. 1. All three detectors are placed outside the hermetically sealed module of the satellite and mounted with instrument axis parallel to the Sun pointing out axis of the satellite.

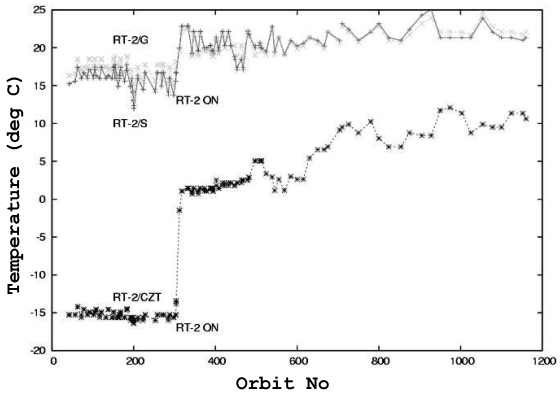


Fig. 2: RT-2 instruments temperature profile onboard "CORONAS-PHOTON" mission

II. Overall performance

RT-2 instrument onboard "CORONAS-PHOTON" mission was switched on 20 February 2009. Before that, orbit temperatures of the detectors were maintained at around 16°C for RT-2/S and RT-2/G and 15°C for RT-2/CZT. After switching on, detectors temperature variations were noticed to be in comfortable range of 18°C to 25°C for RT-2/S and RT-2/G and 2°C to 11°C for RT-2/CZT. The orbit-temperature profile is shown in Fig. 2. The fluctuations in the temperature profile are due to the temperature change in each orbital conditions.

During initial phase of operation RT-2 instrument was kept throughout at lower high voltage (HV) till all issues related GOOD/BAD command operation (corresponded to low/high background regions) was settled. In this conditions, the maximum variations of counts as registered by the RT-2 detectors (25 counts/sec for RT-2/S and 57 counts/sec for RT-2/G), while passing through the high background region (South Polar Cap (SC), North Polar Cap (NC) and South Atlantic Anomaly (SAA)) show a normal behaviour of characteristics in SC and NC. Both the detectors also registered huge counts while passing through the SAA region. RT-2/CZT detector modules also registered the particle events with maximum rate of 2 counts/sec. During this observation all health parameters of the instruments were normal.

The operational aspects of both RT-2/S and RT-2/G are identical and they operate with 27^{+7}_{-3} V with total power consumption about 4.5 Wt for each block. The input power is converted to +15 V and +5 V with the help of a low voltage MDI DC-DC converter for the necessary requirement to drive different components of the individual detector blocks. The +15 V is also converted separately through a voltage regulator circuit to high voltage ($\sim$700 V) needed for biasing the PMT. The PMT is operable in the range of 400-900 V and change in HV is commandable in $\sim$5 V increments. The Pulse Shape Discrimination (PSD) from two crystals (NaI(Tl) and CsI(Na)) and Lower Level Discrimination (LLD)

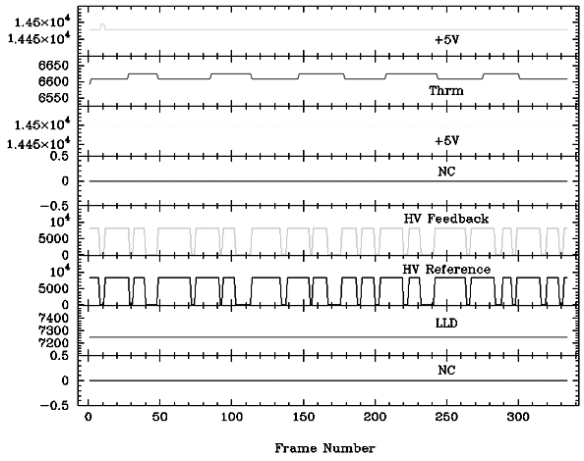


Fig. 3: Health parameters plot of RT-2/S on April 16, 2009

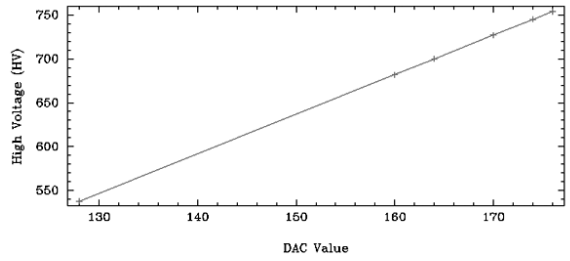


Fig. 4: Linearity calibration of HV operation of RT-2/S detector

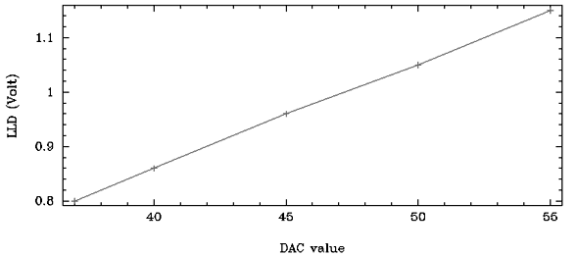


Fig. 5: Linearity calibration of LLD operation of RT-2/S detector

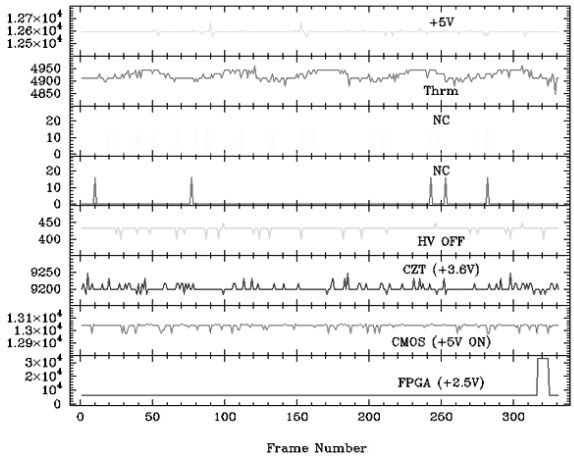


Fig. 6: Health parameters plot of RT-2/CZT on April 16, 2009

for two amplifiers (G1 and G2) are also commandable. Voltage Control Oscillator (VCO) is used to monitor the instrument health parameter, such as +5 V supply, temperature variation, HV and LLD control. Till now, the RT-2/S and RT-2/G detectors are working normally. The sample of health parameters of RT-2/S detector on April 16, 2009 is given in Fig. 3.

In flight condition, high voltage of both phoswich detectors was increased in steps to check the linearity of HV values with the VCO counts. Different HV commands were sent to the detectors and in each HV operation, the detector functionality and health parameters were verified. At present, RT-2/S and RT-2/G are operated with HV of 754 V and 727 V respectively. The linearity calibration of HV operation of RT-2/S is shown in Fig. 4.

To operate RT-2/S and RT-2/G with different energy thresholds and to check the LLD linearity, different LLD commands were sent to the detectors. In different LLD command operations, both phoswich detectors were working normally. At present, they were operated with 1.05 V. The linearity plot of LLD variation of RT-2/S is shown in Fig. 5.

RT-2/CZT also operates with 27^{+7}_{-3} V with the total power consumption about 7.5 Wt. The input power is converted to +15 V and +5 V with the help of a MDI DC-DC unit for the required supply of different components of the instrument. A non-controllable high voltage generator is used to bias the CZT detectors with fixed level of -600 V. An Analog-Digital Converter (ADC) instead of VCO is used to monitor the instrument health of RT-2/CZT. The ADC output monitors +5 V power supply, temperature variation, HV, CZT detectors supply and CMOS supply. Till now, the RT-2/CZT detector is working normally. The sample of health parameters on April 16, 2009 are given in Fig. 6. The channel spectra of NaI(Tl) and PSD spectra of both the detectors are stable throughout the present orbital operation. The channel spectra of RT-2/S and RT-2/G of NaI(Tl) and CsI(Na) crystals are shown in Fig. 7 and Fig. 8 respectively. PSD spectrum shows the separation between the NaI(Tl) and CsI(Na) events. The Pulse Shape parameter (PS) is applied at 26 channel (RT-2/S) and 28 channel (RT-2/G) to discriminate the NaI(Tl) and CsI(Na) events. The PH around 540 (RT-2/S) and 590 (RT-2/G) channels of NaI(Tl) spectrum is the signature of background peak due to the decay of activated I^{121} (58.5 keV). The Co^{57} (122 keV) line is clearly seen in G2 spectrum. Both the PS and PH are stable. A typical energy calibrated spectra of RT-2/G NaI(Tl) crystal is shown in Fig. 9. The background peak I^{121} is detected with energy resolution $\sim$30%. The decrease in energy resolution is due to the weakness of the source Co^{57}.

The sample of energy spectrum of CZT1 module is shown in Fig. 10. All 3 CZT modules have detected

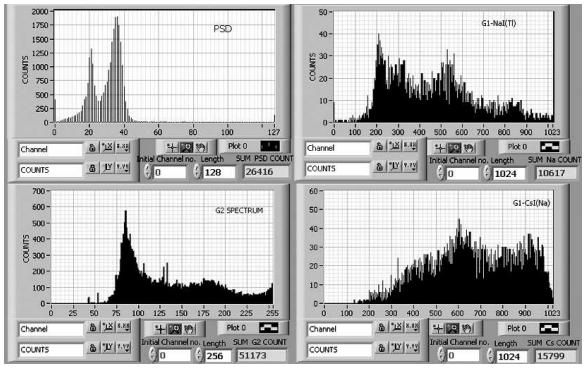


Fig. 7: Channel spectra (PSD, NaI(Tl), CsI(Na) and G2) of RT-2/S on April 16, 2009

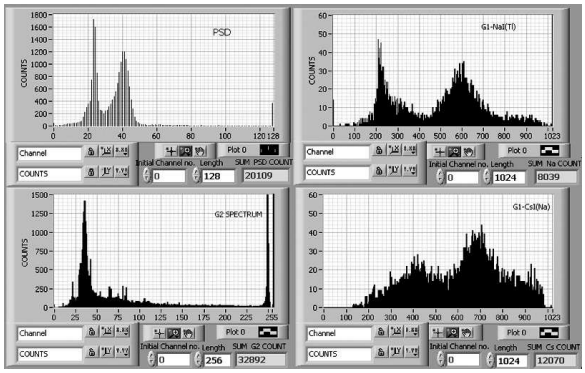


Fig. 8: Channel spectra (PSD, NaI(Tl), CsI(Na) and G2) of RT-2/G on April 16, 2009

the 122 keV Co^{57} calibration source peak with energy resolution 7.32% (127 keV), 5.6% (122 keV) and 5.97% (124 keV) respectively. The calibration source peak shift to the higher energy in CZT1 (127 keV) and CZT3 (124 keV) could be due to the resultant effect of the noisy pixels.

CMOS calibration is one of the major and important tasks to subtract the noise background. It was observed

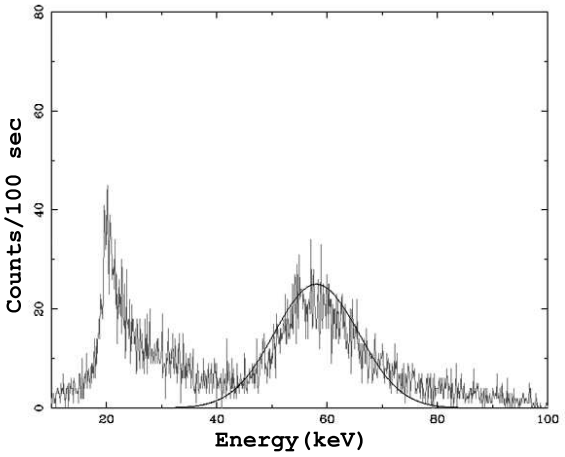


Fig. 9: A typical energy calibrated spectra of NaI(Tl) crystal (RT-2/G)

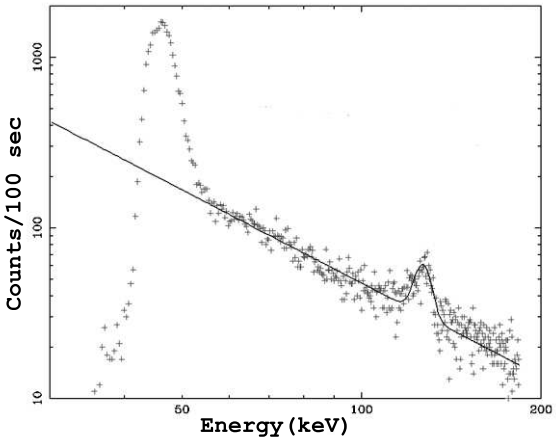


Fig. 10: Sample of CZT1 spectrum with calibration source peak of resolution 7.32% at 127 keV

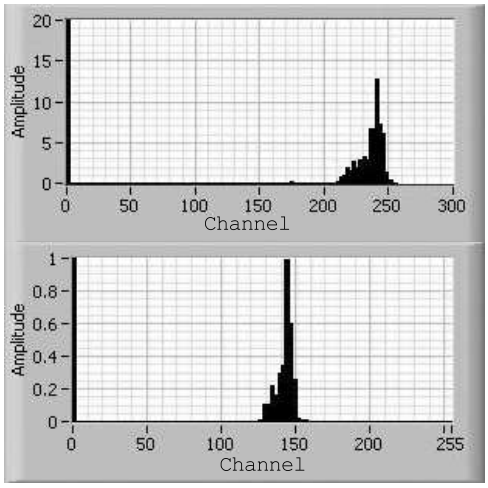


Fig. 11: The sample of CMOS calibration spectra observed in different parts of the orbit

that in different parts of the satellite orbit the CMOS constant values changes. The results of calibration are shown in Fig. 11. Once the CMOS constant will be fixed, then we have to do the actual CMOS calibration by subtracting the background threshold.

III. SUMMARY

At present both the phoswich detectors (RT-2/S and RT-2/G) are functionning properely in desired energy ranges. The pixels of CZT1 and CZT3 modules are still noisy. To understand this peculiar behaviour a very careful analysis is needed to understand the individual pixel behaviour. CMOS detector calibration is not yet complete. We have to do it in absolutely noise free (excluding the region of NC, SC and SAA) region.

REFERENCES

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