A Design and Feasibility Study for the Detector Assembly of the *Experiment for X-ray Characterization and Timing (EXACT)* CubeSat Project

Jeffrey Chaffin, L Glesener, D Gebre-Egziabher, G Manda, A Nightingale, T Kukowski, H Weiher, R Vogt, M Yurs, K Bergstedt, T Knuth

University of Minnesota
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University of Minnesota EXACT CubeSat Program

Mission Overview and Instrumentation Requirements

The Experiment for X-ray Characterization and Timing (EXACT) mission will be a 3U CubeSat based hard X-ray spectrometer used for viewing solar flares with high time precision.

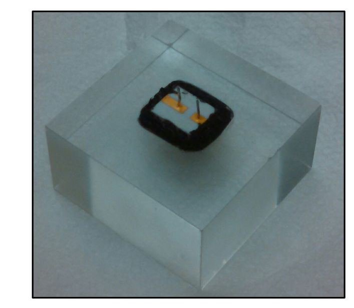
EXACT is a three-axis-stabilized, 3U CubeSat that makes use of an existing University of Minnesota Aerospace Department designed Gamma Ray Burst sensor that is intended for studies in deep space navigation using Gamma-ray burst timing for relative ranging of spacecraft. The high timing resolution of the gamma ray burst sensor, as well as the heritage of the pulse-read-out circuitry, makes it a good candidate for use on *EXACT* if it can be shown to suit the energy range and resolution requirements in the HXR regime.

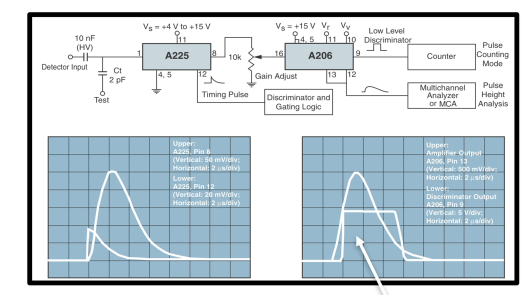
The GRB detector design incorporates square scintillators of Thallium-doped Cesium Iodide (CsI(Tl)), each connected to one Avalanche Photodiode (APD) for read-out to pulse processing circuitry. A laboratory evaluation of that design, and recommendations were made for modifications to the current design in order to fulfill the instrumentation requirements of *EXACT*.

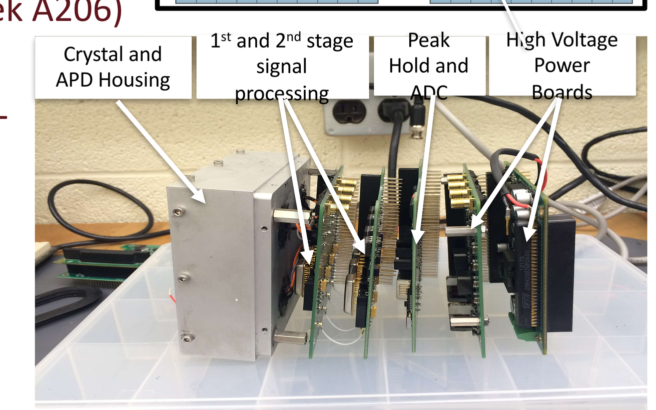
Property	Goal	Justification
Energy range	~4-100 keV	Measure to nonthermal energies
Energy resolution	~3 keV	Differentiate Maxwellian and power-law spectra
Effective area	20-60 cm^2	Comparable to *RHESSI* (~50 cm^2)
Timing information	1 µs timestamp	Precision timing for flare time profiles
Temperatures	No active cooling	Limited volume/power

Gamma Ray Incident Detector Initial Design (GRID)

- 4 (4cm x 4cm x 2cm) CsI(Tl) Scintillation Crystals
  - 54 photons per Kev of incident energy
  - Peak wavelength emission 550nm
  - Primary decay time 1 microsecond
- Each Crystal is backed with a single 5mm x 5mm Hamamatsu Avalanche Photo Diode
  - Peak photosensitivity at a wavelength of 600 nm
  - Requires a Reverse Bias Potential on the order of ~350V
- Signal Processing Circuitry
  - 1st stage Charge Sensitive Pre-amplifier and Shaper with a shaping time of 2.5 microseconds (Amtek A225)
  - 2nd stage 10x amplification and discrimination (Amtek A206)
- Peak Hold and Analog to Digital Conversion for Pulse Height Analysis
  - Micro-controller peak hold logic triggered by a 5v TTL signal from A206 discrimination
  - 12 Bit ADC
- High Voltage Power Supply
  - From a 12 v supply the potential is stepped up to 370v to be applied as a reverse potential to the APD

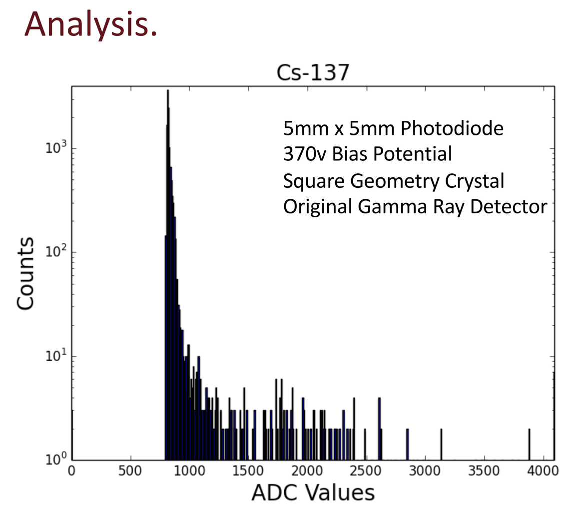


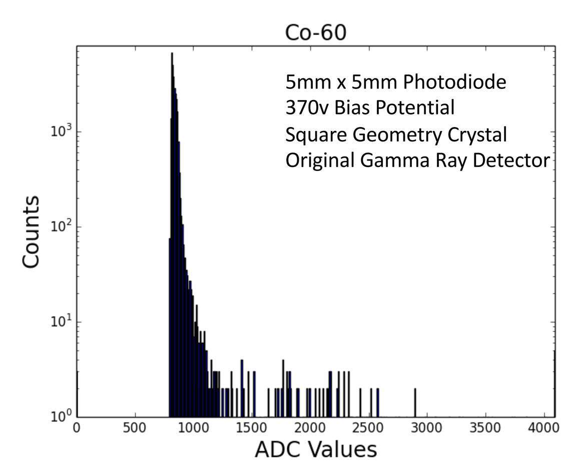


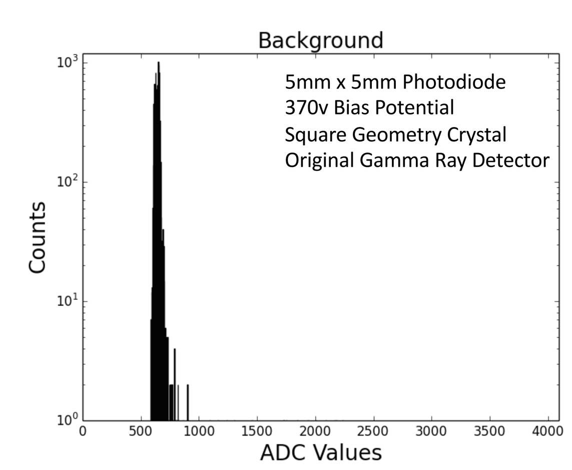


Preliminary tests: It doesn't work. Now what?

After testing with multiple sealed radiation sources it was determined that the original detector design had several flaws preventing discernable detection of incident radiation and any subsequent Pulse Height Analysis.







Though the detector responded to the presence of lab radiation sources with an increased count rate and noise profile no distinct peaks were seen that could be correlated to the energy profile of the known sources.

Possible explanations for poor performance listed by each step in GRID's detection and signal processing chain

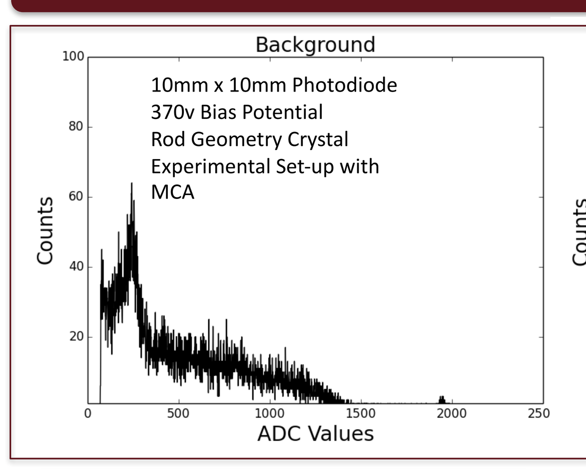
- Scintillation Crystal and APD
  - Insufficient photon flux incident on the avalanche photodiode (APD) photosensitive window. Possibly as a result of either degradation of the crystal scintillation properties or the photosensitive area of the APD being mismatched to the geometry of the crystal and not able to collect sufficient photons within the decay time of the scintillated light.
- Signal Processing: charge collection, shaping and amplification
  - Insufficient electromagnetic shielding of the APD and 1st stage charge sensitive pre-amplification and shaping. Charge sensitive amplifiers are highly sensitive to electromagnetic interference that can increase trigger noise degrading the signal to noise ratio.
- Peak Hold Circuitry and ADC
  - Peak Hold logic/circuitry not functioning correctly.
  - ADC speed is insufficient to maintain sufficient live-time in recording the pulses for analysis resulting in pile-up and loss of significant data.
- High Voltage Power Supply
  - Significant source of electromagnetic noise from the step-up transformers in conjunction with insufficient shielding resulting in an increased noise profile and degraded signal to noise ratio.
  - High voltage supply fixed at 370v not allowing for an increase in bias-voltage to increase the gain of the APD.

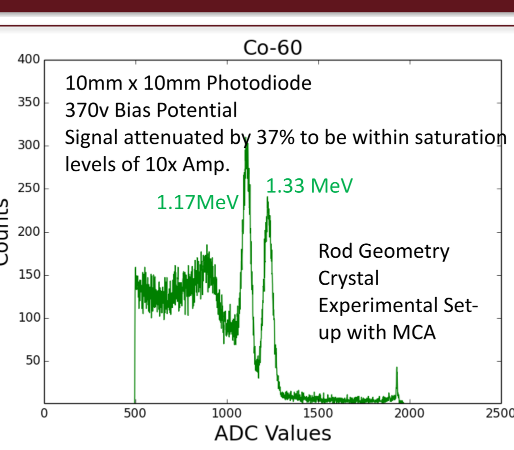
An experimental testing setup was designed to fulfill the following requirements

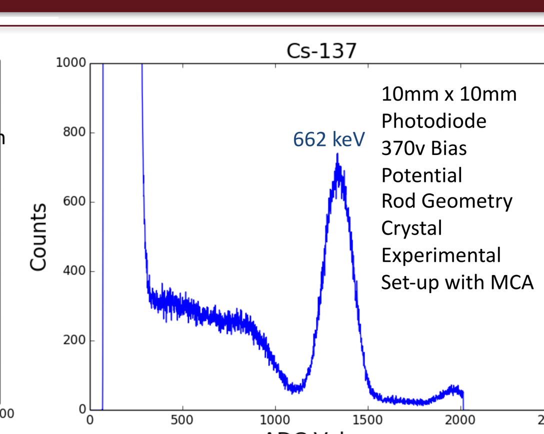
- Light Proof.
- EM Shielding of APD and 1st stage charge sensitive pre-amp.
- Size: should be able to fit inside a reasonably priced and sized environmental chamber.
- Ability to adjust attenuation, discrimination and high voltage supply, and measure the associated voltages without compromising light tightness in real time data acquisition.
- Use of existing GRID electronics for signal processing.
- Easy BNC access to all points in the signal processing chain.
- Incorporate off the shelf Multi-Channel Analyzer to be used to circumvent the GRID signal processing at key points in the chain.
- Structures specifically designed to support different geometries of scintillation crystals while allowing for variable distance options of radiation sources.
- Inputs for both the currently used 5mm X 5mm APD and a new larger 10mm X 10mm APD from Hamamatsu.

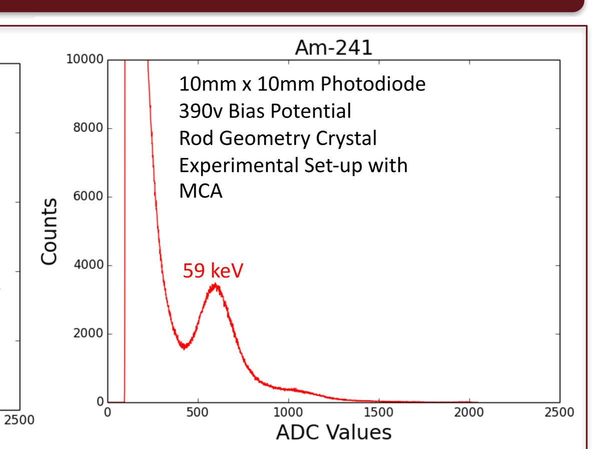
Laboratory Testing: Results and Recommendations

10mm x 10mm APD with rod shaped crystal to match effective area of APD

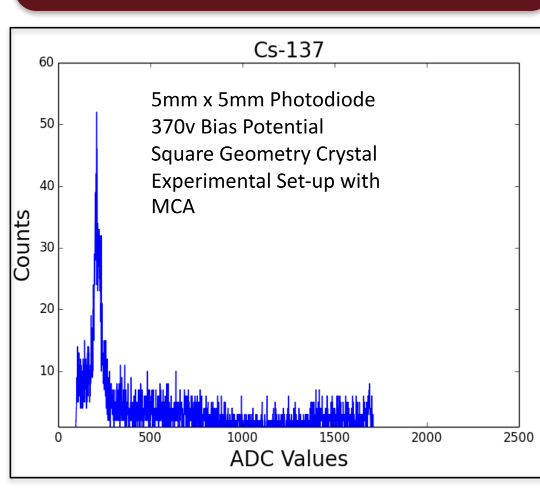


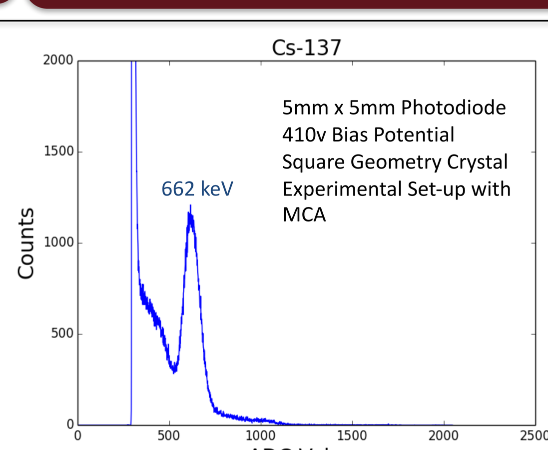


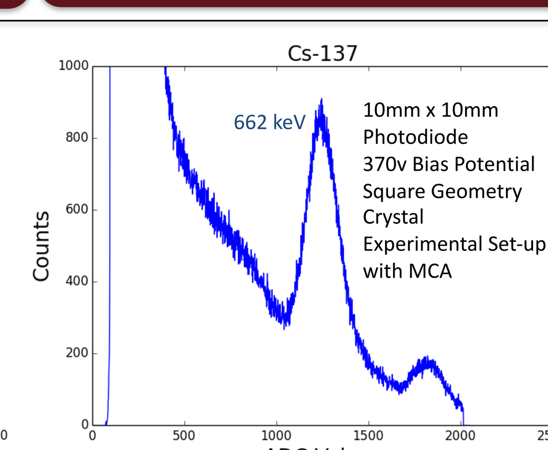


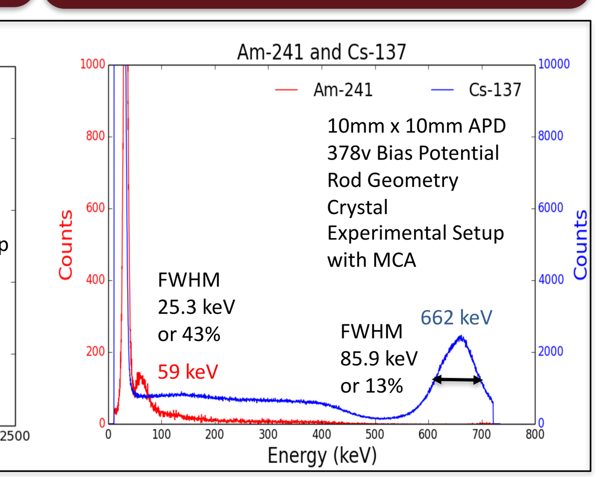


5mm x 5mm APD with paddle shaped crystal	5mm x 5mm APD with square shaped crystal and Bias voltage of 410v	10mm x 10mm APD with square shaped crystal used in GRID	Preliminary Calibrated Spectrum of Am-241 and Cs-137 10mm x 10mm APD with rod shaped crystal









Preliminary Conclusions

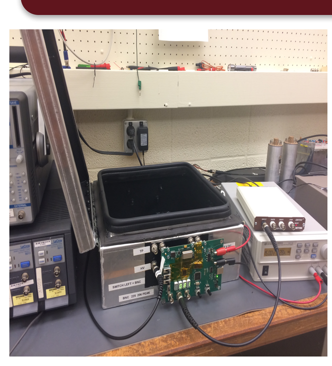
What worked

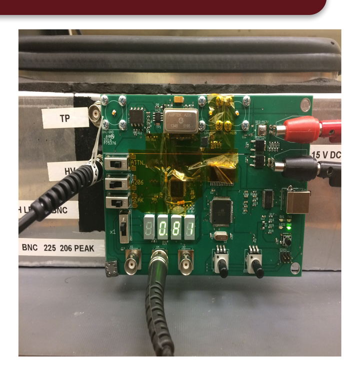
- Increased photon flux due to the larger photodiode and reduction of trigger noise from extraneous sources resulted in the successful detection and pulse height analysis of multiple known energy sources.
- With proper noise reduction and an increased bias voltage, tests of the smaller 5mm x 5mm APD and the GRID square crystals were successful.
- By having both the charge sensitive pre-amp and APD within the EM shielded box background trigger noise was greatly reduced.
- The Ortec MCA performed well with no pile up of data and sufficient live time.
- Adjustable Bias voltage proved paramount in attaining the lower energy source spectrums with the larger photodiode and when using the smaller diode for Cs-137. i.e. increasing the gain of the APD.

Further Challenges

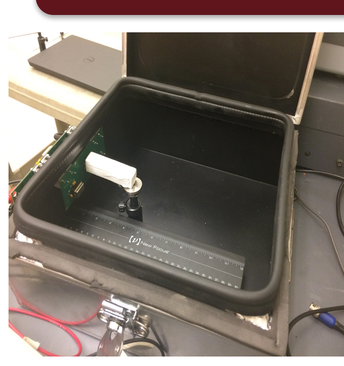
- The energy range and resolution requirements for EXACT's science goals have not yet been met.
- To achieve these goals further investigation is needed in methods to further reduce the noise pedestal and increase the signal to noise ratio.
- The bias voltage which controls the Gain of the APD has to be quite high, close to the breakdown voltage of the APD, to amplify the signal sufficiently to attain a spectrum. We suspect that this level of Gain is well above the value that minimizes both shot and thermal noise in the APD, resulting in poor signal to noise ratio and resolution.
- Our goal is to increase the signal sufficiently to allow for a smaller bias voltage and APD Gain to further minimize noise.
- We will also explore the option of using a CdTe semiconductor detector for better resolution and lower backgrounds.

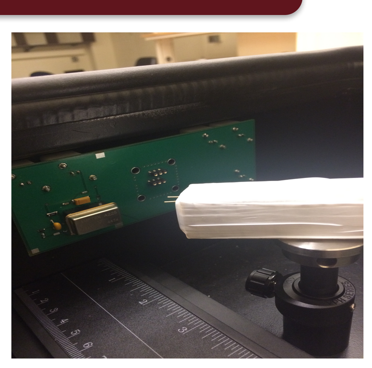
Experimental Set-up





Rod Shaped Crystal





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