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ELECTRON AND PROTON BEAM TESTING OF PIXELATED SOLID STATE DETECTORS (POSTPRINT)

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Electron and Proton Beam Testing of Pixelated Solid State Detectors

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Abstract

The importance of using beam testing to measure the angular response of particle instruments is illustrated through the development cycle of the Fixed Sensor Head (FSH) instrument that will be flown on the US Air Force's Demonstration and Science eXperiment (DSX) mission. During its construction, the FSH was tested using particle beams many times and each test yielded an important result that contributed to the design of the instrument before being delivered in Aug. 2010.

After several lower energy (<30 keV) beam calibration tests at Hanscom Air Force Base demonstrated that the FSH was performing very well, a final, higher energy (150 keV < E < 1 MeV) beam test at the Goddard Space Flight Center was almost skipped due to budget and scheduling constraints. This final test illuminated a major problem with the biasing of a detector guard ring that would have been difficult if not impossible to track down on orbit. The problem was easily fixed, but serves to highlight the necessity of testing instruments across the entire range of possible stimuli that they may encounter.

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Keywords: Charged particle detectors, solid state detectors, biasing

1. Introduction

The Fixed Sensor Head (FSH) [1][2] is an imaging electron spectrometer with 18 pixels each with a $10° \times 10°$ field of view arranged so that a $180° \times 10°$ region of the sky can be observed simultaneously. The instrument uses three silicon solid-state detectors with 6 pixels each to detect energetic charged particles and measure their energy. The FSH will fly as part of the Loss Cone Imager package on the US Air Force's Demonstration and Science eXperiment mission.

As the FSH was developed, it was tested on many occasions using particle beams at either the Goddard Space Flight Center's (GSFC) Radiation Effects Facility or at Hanscom Air Force Base (HAFB) in the MUMBO chamber. Each test provided valuable engineering data that was used to refine the design of the instrument. These refinements included modifications such as biasing the detector's guard ring, modifying the mechanical configuration of an electron trap, and removing a aluminized mylar foil that proved to be unnecessary for light-tightness and was detrimental to the angular response of the instrument.

In a very successful penultimate beam test of the flight telescope using low-energy (<30 keV) electrons at HAFB, the FSH demonstrated a noise width of less than 6-10 keV and an angular cutoff of nearly three orders of magnitude. The excellent performance of the FSH coupled with scheduling and budget constraints brought into question the necessity of a final beam calibration test at GSFC. The final beam calibration would serve to characterize the response of the FSH to the higher energy range (150 keV $<$ E $<$ 1 MeV) of particles it will encounter on orbit.

The final beam calibration was performed, and during this test, a major problem with the biasing of the detector guard ring was discovered and corrected.

2. Sensor Configuration

The detector is mounted in a telescope geometry as shown in Figure 1. The FSH telescope has a total field-of-view of 70° with 62° being viewable by the active pixel areas. The opening aperture of the telescope is $1\,\mathrm{mm}^2$. Each pixel as has a geometrical factor of $\approx 0.00025\mathrm{cm}^2\mathrm{sr}$.

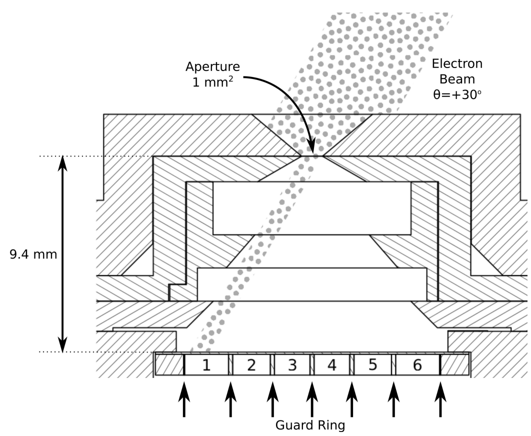

Figure 1: A cross-section of the FSH telescope illustrating the geometrical relationship between the sensor and the rest of the telescope housing. A collimated electron beam is shown entering the telescope as an example of the geometry of the detector illumination during the beam calibration.

The 6-pixel, 1000 μm thick, Si detector was produced by Micron Semiconductor of Brighton, UK. A diagram of the detector illustrating its primary features is shown in Figure 2. The area of the pixels increases towards the outside to compensate for the geometric shadowing effect when installed in the FSH telescope.

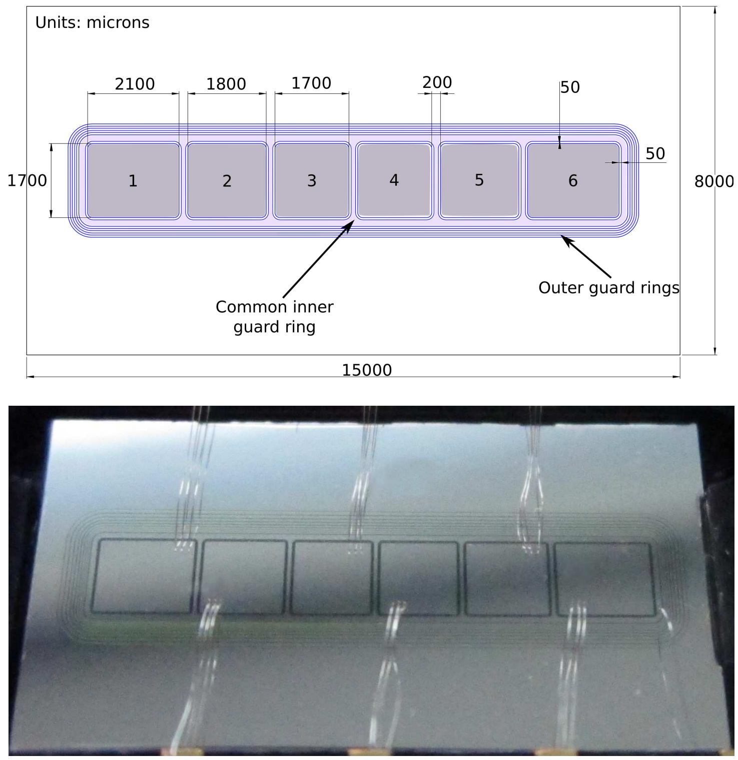

Figure 2: CAD drawing and photograph of the pixel detectors. The dark inclined stripe through the center is a shadow from the environment in which the image was taken.

Each of the six pixels is surrounded by a common guard ring separated from the active area of the pixel by 50 μm as well as a series of concentric guard rings that surround the entire group of pixels. Between the pixels, the guard ring is 100 μm wide.

Guard rings are a common noise reduction device used in the design of analog printed circuit boards and integrated circuits. Similar to a Faraday cage, a guard ring is a ring of conductive material that surrounds a sensitive electronic node. By biasing the guard ring correctly, noise from stray electromagnetic radiation can be channeled away from the sensitive node resulting in better noise performance of the system.

The pulse signals from each pixel of the detector are processed using an application specific integrated circuit called the Readout Electronics for Nuclear Applications (RENA) chip designed by NOVA R&D. The RENA chip contains 35 amplifier chains including charge sensitive preamplifiers and pulse-shaping amplifiers, triggering circuits, and peak and hold circuits. The detectors signals are processed and the peak voltage of each signal is digitized to 8-bits using an ADC before being read-out by the digital processing unit.

Each channel of the RENA chip is independent and highly configurable. Some configuration options include gain, pulse shaping time constant, and trigger threshold. The trigger threshold sets the minimum height of the detected pulse. This threshold is set by an 8-bit DAC to one of 256 values with higher DAC values corresponding to lower energies.

3. Beam Testing

The general method for all of the beam tests was to place the FSH on an articulating platform and rotate it through a uniform, mono-energetic, collimated particle beam that fills the entrance aperture. The response of the FSH is recorded as it is rotated and correlated with knowledge of the platform angle providing a measurement of the instrument's angular response to the beam. This response is measured for electron beams and proton beams at multiple energies since it is dependent on both parameters.

As the FSH is rotated through a beam that fills its aperture, individual pixels will be illuminated. Every pixel is larger than the aperture of the instrument, so there are regions in data in which the response remains approximately constant as the angle is varied. These regions alternate with regions in which the beam is transitioning from illuminating one pixel to illuminating a neighboring pixel. In these regions, counts are observed in both pixels.

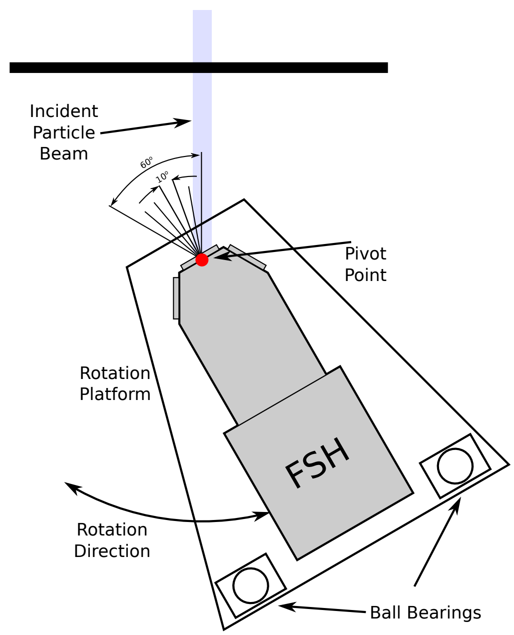

Figure 3: Beam testing setup used in the Goddard Space Flight Center beam tests. A shaft enters the beam chamber and is fixed to the rotation platform from directly underneath the pivot point and provides the torque to rotate the platform.

The configuration of the Goddard beam calibration tests is shown in Figure 3. The FSH is placed on a rotating platform with a pivot point directly underneath the opening of the center telescope's aperture. A mono-energetic, collimated electron beam enters the beam chamber and the FSH is rotated through $\approx \pm 30°$ with respect to the direction of the beam. The telescope aperture is smaller than the pixels, so each pixel can be individually illuminated while the other pixels are dark. By rotating the FSH through the beam at a constant, known angular speed, the angular response of the telescope can be obtained by observing the counting rate of the instrument over time. At Hanscom, the beam chamber was large enough that the FSH could be rotated through $\approx \pm 55°$ allowing the mechanical cutoff of the telescope to be observed. At the GSFC, a smaller chamber restricted the rotation to $\approx \pm 28°$ so that only the very edge of the mechanical cutoff could be observed.

3.1. Goddard Space Flight Center June 2009 Beam Test

A plot of the response of the FSH from the first beam test at the GSFC is shown in Figure 4. The response shows pixels that at best provided a cutoff of 10^{-2} at $+20$ deg from the central angle of the pixel, extending well into the next pixel on either side.

The cutoff at large angles provided by the mechanical configuration of the telescope also proved to be very poor. At both ends of the angular response, it can be seen that the counts in dark pixels (pixels not directly illuminated by the electron beam) began to rise. This was the result of scattering off of the interior structure of the FSH telescope. After this test, the telescope was modified to the configuration shown in Figure 1.

3.2. Hanscom Air Force Base Beam Tests

After the initial beam test at the GSFC, several beam tests were performed using the MUMBO chamber at HAFB. In November of 2009, the

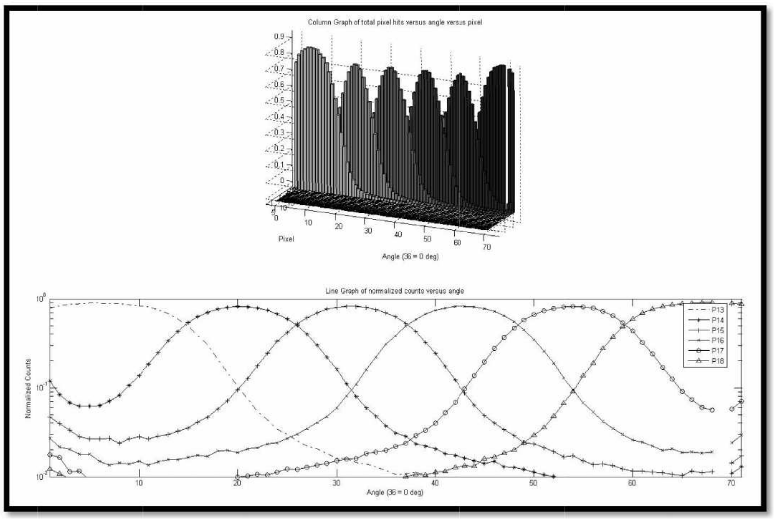

Figure 4: FSH response to the Goddard beam in 2009[1].

response of the instrument was evaluated with different foils placed over the detectors to make them light tight. Three cases were examined: no foil, a foil from the IES on the CLUSTER RAPID [3] experiment, and a new foil designed for the current FSH. Figure 5 shows the response of the FSH in each of these cases.

The FSH demonstrated a very sharp angular cutoff in the pixels with no foil (P13, P14, and P15). In the other pixels much of the angular resolution is lost by scattering in the foils. It is easily seen that the foils also attenuate the particle flux significantly at this energy (25 keV). These results prompted further testing of the detector response to light sources, and it was ultimately determined that the metallic contacts on the detectors provided sufficient shielding from light and that the foils were unnecessary.

In a Jan 2010 beam test of the flight unit at HAFB the FSH showed excellent performance. Figure 6 shows a sharp, nearly ideal, angular cutoff of

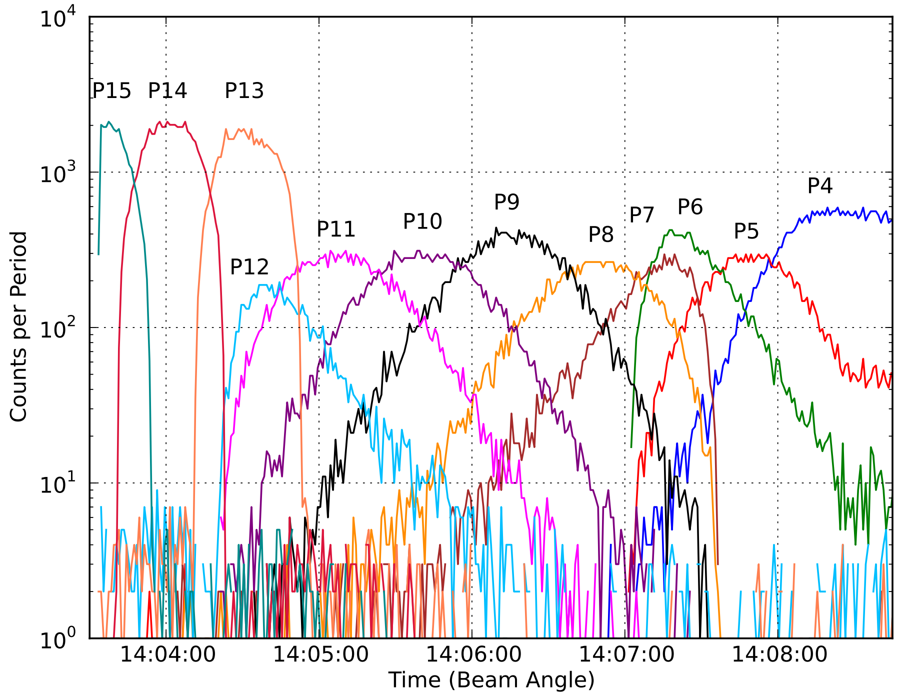

Figure 5: Comparison of the angular cutoff for two different Mylar windows and no mylar window. The data was taken using a 25 keV electron beam.

nearly 3 orders of magnitude. The overlap between pixels is what is expected as the beam transitions from illuminating one pixel to the next. It can be seen that the response of each pixel has completely stopped as the nearly flat region of the next pixel begins.

3.3. Goddard Space Flight Center Aug 2010 Beam Test

Time and budget constraints coupled with the excellent performance of the FSH in the Jan 2010 Hanscom test raised the question of whether the final beam test was necessary or could be skipped as an opportunity to save

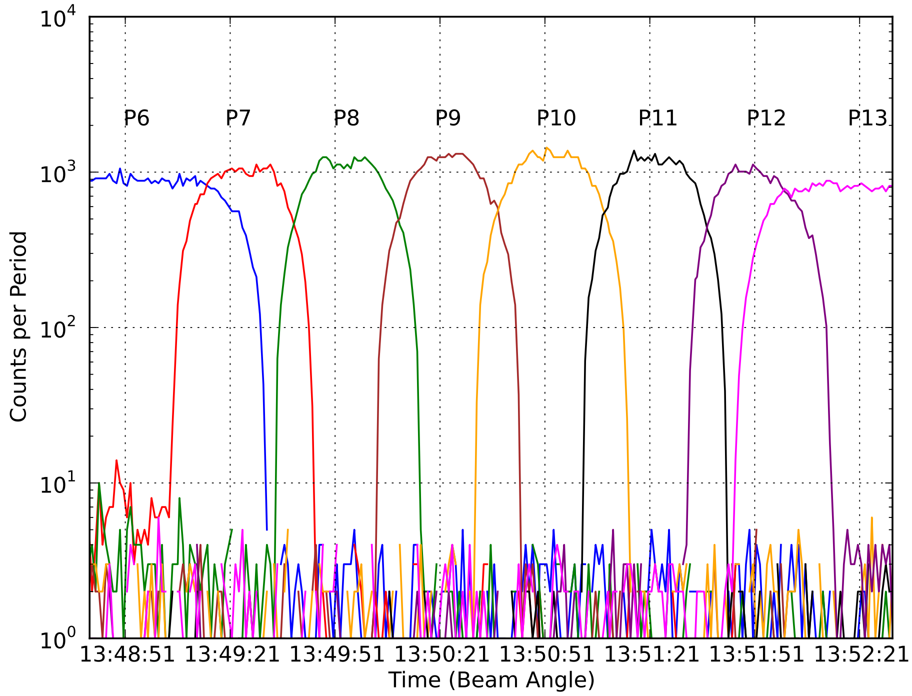

Figure 6: FSH response to the Hanscom beam in Jan 2010.

both money and schedule. After much debate, the FSH was taken to the GSFC a second time for a test with higher energy particles (>30 keV) before it was delivered to the Air Force.

Upon placing the FSH in the beam at the GSFC, the response in the top panel of Figure 7 was observed. A previously unobserved feature is the presence of counts in all pixels as the beam transitions from illuminating one pixel to the next. These counts were initially suspected to be the result of charge building up on a test input port for a pulser that had been left floating. The telescope was removed from the beam chamber and modified by one of the staff at the GSFC to short this input to the detector bias supply, effectively tying the input to an AC ground. After reinstalling the telescope, the response in the middle panel of Figure 7 was observed. In comparing the top panel with the middle panel, it is important to note that the triggering threshold of the pixel was reduced from ≈ 40 keV to ≈ 15 keV resulting in a slightly broader response.

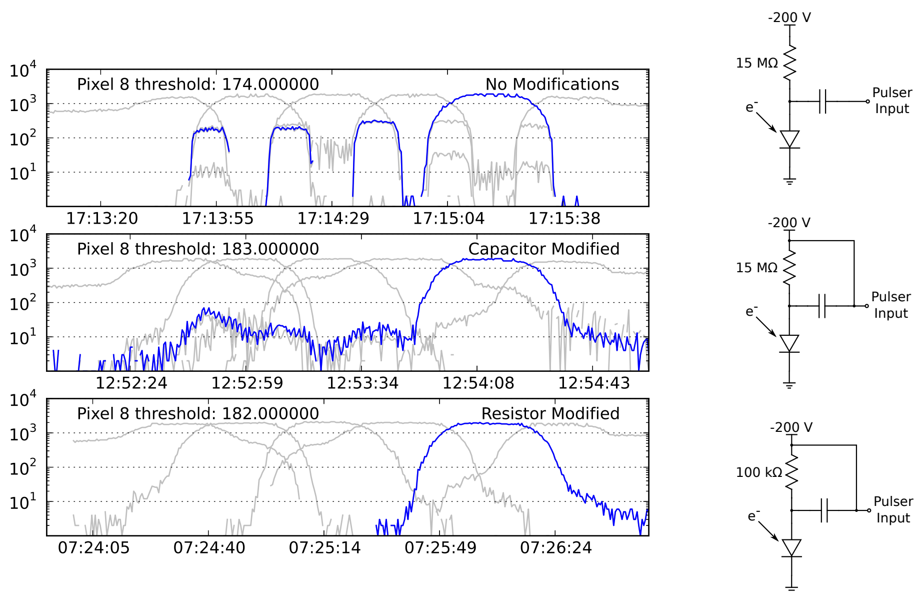

Figure 7: A comparison of the angular response of the detectors to 500 keV protons initially and after each of the modifications was made to the biasing circuit. Note that after the modifications, the thresholds are at *lower* energies than in the unmodified run. The runs have been approximately aligned for comparison. The time increment scale of each figure is the same. The circuits on the right show the biasing network for the guard ring for each case. The guard ring is represented as a diode in the same manor as a pixel.

The middle panel of Figure 7 shows marked improvement over the top panel, however a significant number of counts were still being observed in dark pixels. Figure 8 shows that the events responsible for these counts were coming in at low energies. This is also the case with the "wings" that can be seen in the response of the pixels in the background of the plot.

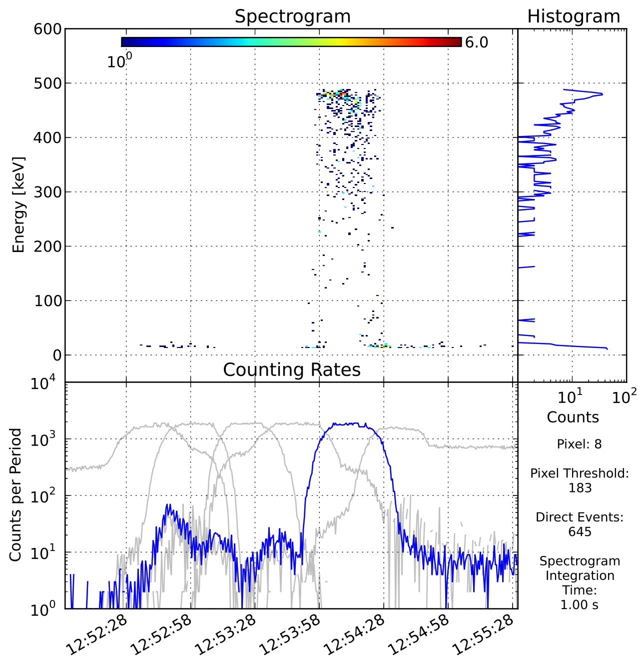

Figure 8: Spectrogram illustrating that the energies of the events responsible for counts in dark pixels are at low energies.

Further speculation on source of these counts led to the hypothesis that events were liberating charge on the guard ring and that charge was not being dissipated quickly enough causing a signal to capacitively couple into the pixels. This was tested by reducing the resistance between the guard ring and the biasing supply from 15 MΩ to 100 kΩ. The result was the bottom panel of Figure 7.

The resistor modification further improved the out-of-pixel response. The remaining out-of-pixel counts are measured at the noise edge and can be eliminated by slightly increasing the triggering threshold of each pixel.

The data presented in this sequence were all responses to 500 keV protons. Similar effects were observed in the response to 250 keV and greater electrons, and 350 keV and greater protons. The lowest energy tested at the GSFC was 150 keV for electron beams and 350 keV for proton beams.

4. Conclusions

Beam testing is an essential part of the development cycle for particle instruments. As the experience with this instrument shows, each beam test produced new information that allowed the performance of the instrument to be improved. The information obtained from these tests affected both the electrical and mechanical designs of the FSH in addition to providing the calibration and angular response information that is necessary for interpreting on-orbit data. The final beam calibration test underscores the importance of testing across the entire range of possible stimuli, even when a system is performing well and believed to be well understood.

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