

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 ($150 \text{ keV} < E < 1 \text{ MeV}$) 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 $10^\circ \times 10^\circ$ field of view arranged so that a $180^\circ \times 10^\circ$ 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 charac-

24 terize the response of the FSH to the higher energy range ($150 \text{ keV} < E < 1$
 25 MeV) of particles it will encounter on orbit.

26 The final beam calibration was performed, and during this test, a ma-
 27 jor problem with the biasing of the detector guard ring was discovered and
 28 corrected.

29 2. Sensor Configuration

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

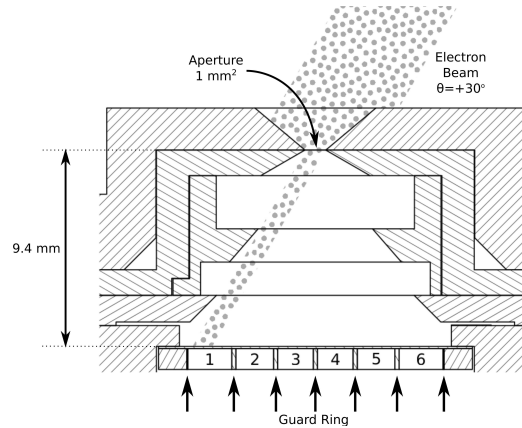


Figure 1: A cross-section of the FSH telescope illustrating the geometrical relationship between the sensor and the rest of the telescope housing. A collimated electron beam is shown entering the telescope as an example of the geometry of the detector illumination during the beam calibration.

34 The 6-pixel, $1000 \mu\text{m}$ thick, Si detector was produced by Micron Semicon-
 35 ductor of Brighton, UK. A diagram of the detector illustrating its primary

36 features is shown in Figure 2. The area of the pixels increases towards the
 37 outside to compensate for the geometric shadowing effect when installed in
 38 the FSH telescope.

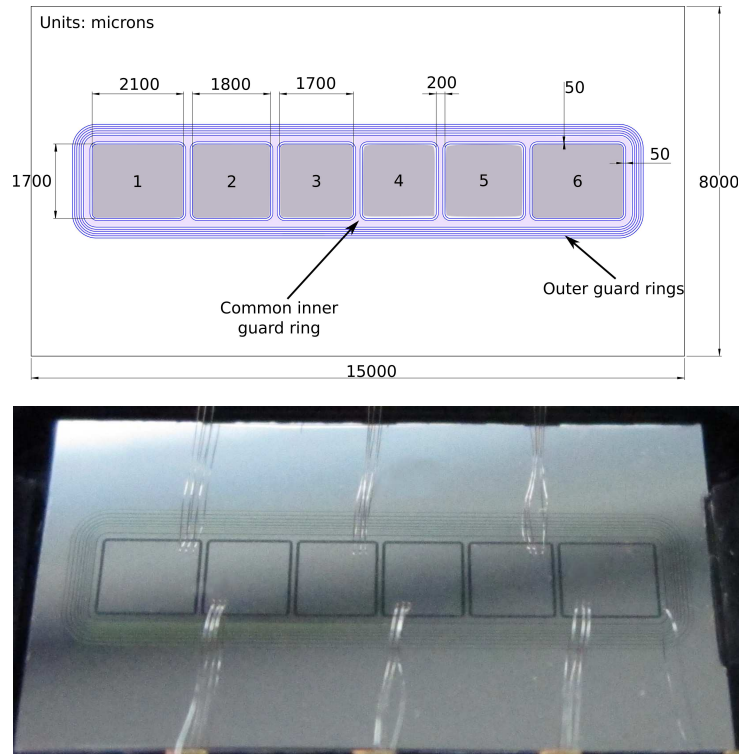


Figure 2: CAD drawing and photograph of the pixel detectors. The dark inclined stripe through the center is a shadow from the environment in which the image was taken.

39 Each of the six pixels is surrounded by a common guard ring separated
 40 from the active area of the pixel by $50\text{ }\mu\text{m}$ as well as a series of concentric
 41 guard rings that surround the entire group of pixels. Between the pixels, the
 42 guard ring is $100\text{ }\mu\text{m}$ wide.

43 Guard rings are a common noise reduction device used in the design of
 44 analog printed circuit boards and integrated circuits. Similar to a Faraday

45 cage, a guard ring is a ring of conductive material that surrounds a sensitive
46 electronic node. By biasing the guard ring correctly, noise from stray electro-
47 magnetic radiation can be channeled away from the sensitive node resulting
48 in better noise performance of the system.

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

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

61 **3. Beam Testing**

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

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

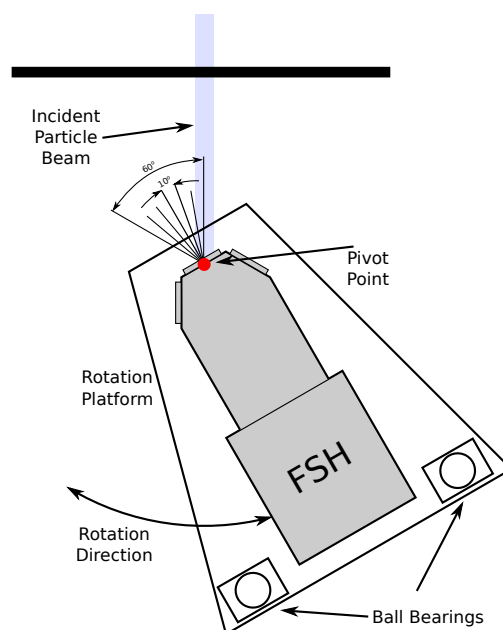


Figure 3: Beam testing setup used in the Goddard Space Flight Center beam tests. A shaft enters the beam chamber and is fixed to the rotation platform from directly underneath the pivot point and provides the torque to rotate the platform.

76 The configuration of the Goddard beam calibration tests is shown in Fig-
 77 ure 3. The FSH is placed on a rotating platform with a pivot point directly
 78 underneath the opening of the center telescope's aperture. A mono-energetic,

79 collimated electron beam enters the beam chamber and the FSH is rotated
80 through $\approx \pm 30^\circ$ with respect to the direction of the beam. The telescope
81 aperture is smaller than the pixels, so each pixel can be individually illumi-
82 nated while the other pixels are dark. By rotating the FSH through the beam
83 at a constant, known angular speed, the angular response of the telescope
84 can be obtained by observing the counting rate of the instrument over time.
85 At Hanscom, the beam chamber was large enough that the FSH could be ro-
86 tated through $\approx \pm 55^\circ$ allowing the mechanical cutoff of the telescope to be
87 observed. At the GSFC, a smaller chamber restricted the rotation to $\approx \pm 28^\circ$
88 so that only the very edge of the mechanical cutoff could be observed.

89 *3.1. Goddard Space Flight Center June 2009 Beam Test*

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

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

100 *3.2. Hanscom Air Force Base Beam Tests*

101 After the initial beam test at the GSFC, several beam tests were per-
102 formed using the MUMBO chamber at HAFB. In November of 2009, the

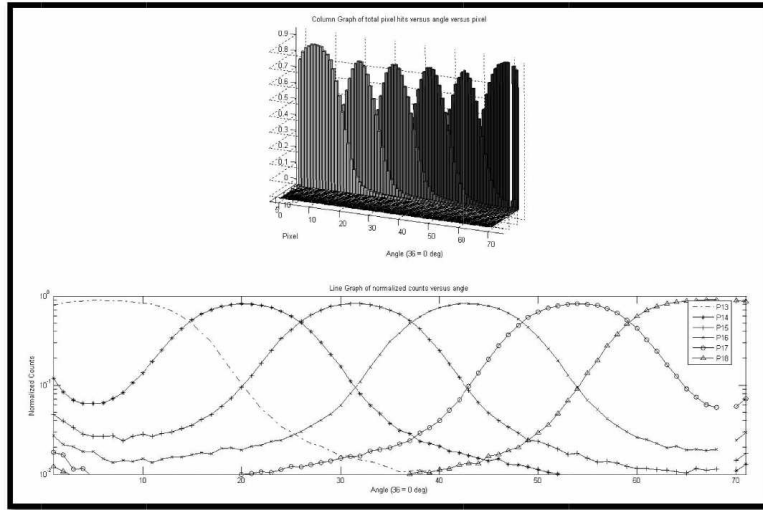


Figure 4: FSH response to the Goddard beam in 2009[1].

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

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

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

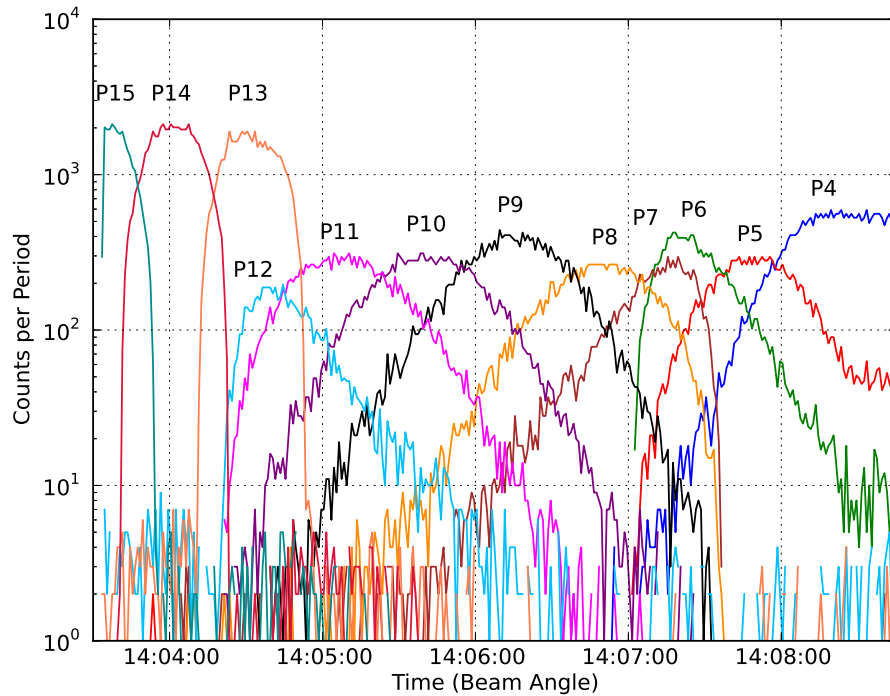


Figure 5: Comparison of the angular cutoff for two different Mylar windows and no mylar window. The data was taken using a 25 keV electron beam.

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

121 3.3. Goddard Space Flight Center Aug 2010 Beam Test

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

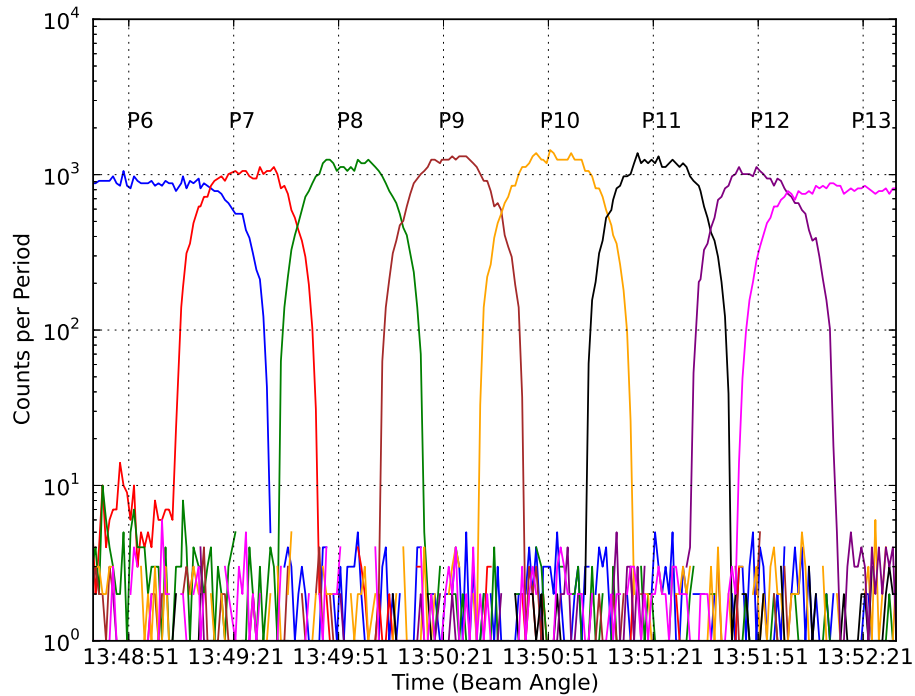


Figure 6: FSH response to the Hanscom beam in Jan 2010.

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

128 Upon placing the FSH in the beam at the GSFC, the response in the
 129 top panel of Figure 7 was observed. A previously unobserved feature is the
 130 presence of counts in all pixels as the beam transitions from illuminating
 131 one pixel to the next. These counts were initially suspected to be the result
 132 of charge building up on a test input port for a pulser that had been left
 133 floating. The telescope was removed from the beam chamber and modified

134 by one of the staff at the GSFC to short this input to the detector bias supply,
 135 effectively tying the input to an AC ground. After reinstalling the telescope,
 136 the response in the middle panel of Figure 7 was observed. In comparing the
 137 top panel with the middle panel, it is important to note that the triggering
 138 threshold of the pixel was reduced from ≈ 40 keV to ≈ 15 keV resulting in
 139 a slightly broader response.

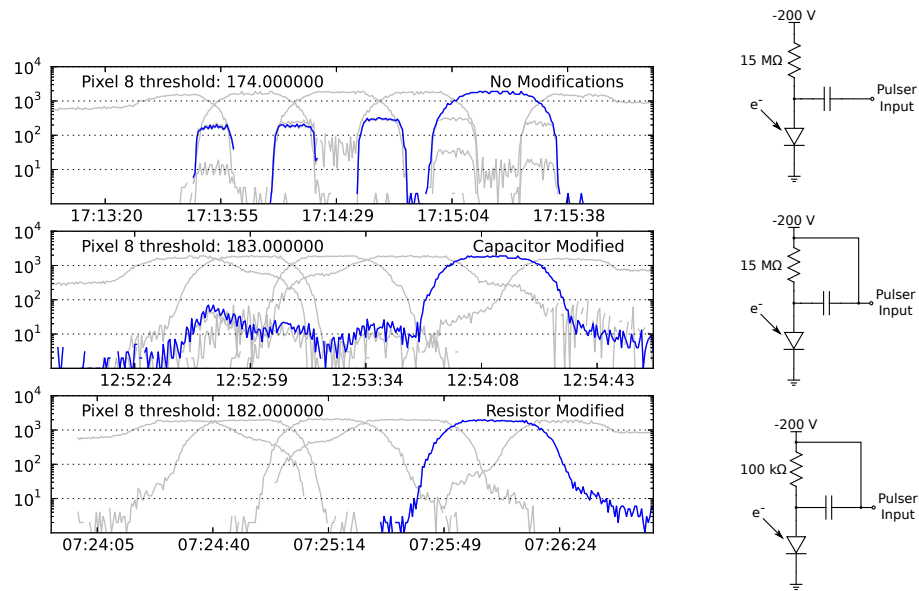


Figure 7: A comparison of the angular response of the detectors to 500 keV protons initially and after each of the modifications was made to the biasing circuit. Note that after the modifications, the thresholds are at *lower* energies than in the unmodified run. The runs have been approximately aligned 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.

140 The middle panel of Figure 7 shows marked improvement over the top
 141 panel, however a significant number of counts were still being observed in
 142 dark pixels. Figure 8 shows that the events responsible for these counts were

143 coming in at low energies. This is also the case with the “wings” that can
 144 be seen in the response of the pixels in the background of the plot.

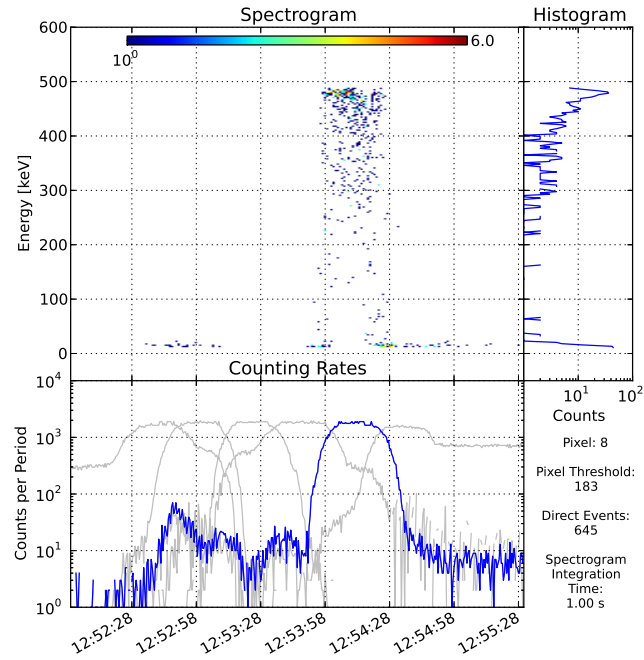


Figure 8: Spectrogram illustrating that the energies of the events responsible for counts in dark pixels are at low energies.

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

151 The resistor modification further improved the out-of-pixel response. The

152 remaining out-of-pixel counts are measured at the noise edge and can be
153 eliminated by slightly increasing the triggering threshold of each pixel.

154 The data presented in this sequence were all responses to 500 keV protons.
155 Similar effects were observed in the response to 250 keV and greater electrons,
156 and 350 keV and greater protons. The lowest energy tested at the GSFC was
157 150 keV for electron beams and 350 keV for proton beams.

158 **4. Conclusions**

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

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