A course sequence in Detector Array Theory, Camera Building, and System Testing.

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Center for Imaging Science

An interdisciplinary University Research and Education Center, dedicated to pushing the frontiers of imaging in all its forms and uses. The Center has existed since 1985 and offers BS, MS, and PhD degrees.

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Research Areas

- Algorithms
- Medical Imaging
- Color Science
- Nanoimaging
- Materials
- Printers & Displays
- Remote Sensing
- Sensors and Imaging Systems

Rochester Institute of Technology
Munsell Color Science Laboratory
Created in 1983 through a gift from the Munsell Foundation.

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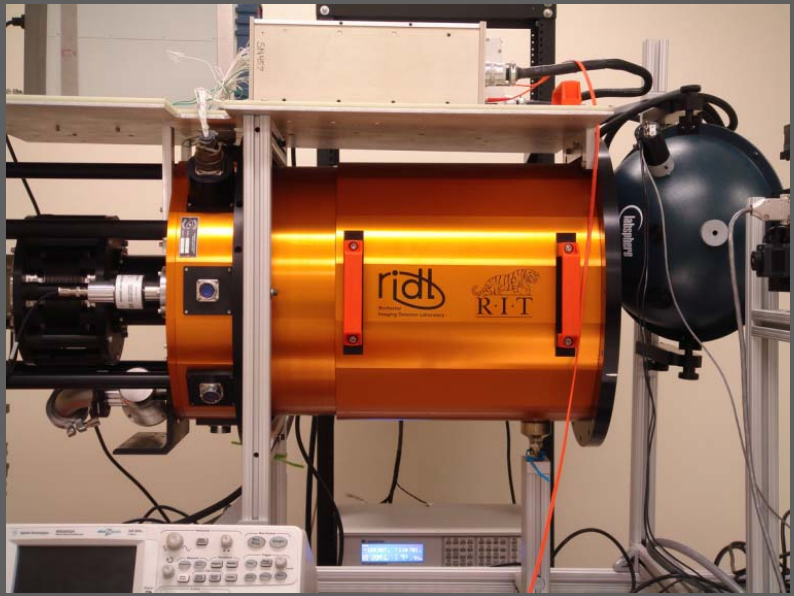
Center for Detectors (Don Figer, Director)

Center for Detectors



- The Center for Detectors enables
  - scientific discovery
  - national security
  - better living
  - commercial innovation

- CfD designs and develops advanced photon detectors & technology

- CfD collaborates with students, scientists, engineers, and business partners, at academic, industrial, and national research institutions.

- Founded in 2006

- NSF funded series of talks streamed on-line at http://ridl.cis.rit.edu/ under DVW (Detector Virtual Workshop).

Three course “Detectors” sequence

- background theory (class 1)
  - Principles of Solid State Imaging Arrays (SIMG 739)
  - Fall

- building a camera (class 2)
  - Fabrication of a CCD camera (SIMG 528/728)
  - Winter

- testing a camera (class 3)
  - Testing of a CCD Camera (SIMG 742)
  - Spring

Rational for the sequence :
"To learn one detector system well"

- detectors are very often the "tall pole" in high performance optical sensing systems. Our students frequently become the systems integrators for such systems.

- industry and government labs need people who have this background.

- graduate students can start on instrumentation projects sooner with such preparation

Class 1 : Principles of Solid State Imaging Arrays (SIMG 739)

- The class meets for 4 lecture hours per week for the duration of the Fall quarter (*i.e.* September through November for 10 weeks).
- The presentation format is two lectures a week with each lecture of two hours duration.
- Problems sessions once a week.

Selected topics covered in class 1

- energy levels, band gap, diffusion theory, and carrier lifetimes.
- Field Effect Transistors (FET), JFET & MOSFET construction, sources of MOSFET noise, and use of FETs in a source follower circuit.
- an overview of filtering theory, and an understanding of the correlated double sampling circuit.
- FETs as switches and how to use them to build a multiplexer.
- combining all of the above knowledge to design, conceptually, a CMOS imaging array.
- hybridized imaging arrays and some examples of such devices.
- CMOS image sensors.

Class 2 : Fabrication of a CCD camera (SIMG 528/728)

- 1.5 hour-a-week formal class
- a 10 hour-a-week laboratory over the ten weeks of winter quarter (*i.e.* December through February).

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Selected topics covered in lectures in class 2

The class material covers topics relating to one particular type of focal plane array, the Charge Coupled Device (CCD). Selected topics include ;

- a review of the principle of a MOS capacitor
- means and implementation of charge transfer
- channel stops
- buried channel CCD
- MPP operation
- Enhancing CCD sensitivity (e.g. back and front illumination, phosphor coating for the UV and X-ray)
- interline and frame transfer CCDs,
- 1-phase 2 phase 2 phase 4 phase operation,
- deep depletion CCDs.

Class 2 Lab Camera - Audine

- students are organized in groups of three,
- tasked with assembling a cooled CCD camera system.
- final camera is a rectangular box that measurers 80 X 80 mm X 95.25 mm, weight is 654 grams.
- use a Kodak KAF 0402, pixel size of 9 microns square, a format of 768 (H) x 512 (V) pixels
- the CCD camera also utlizes a shutter from Draco.
- a peltier cooler + fan regulates temperature.
- the camera is controlled via a PC parallel port.
- Acquisition software controls the camera from the PC. As of this time we use the PISCO

(http://www.astrosurf.com/audine/English/index_en.htm)

Original CCD Cookbook Camera

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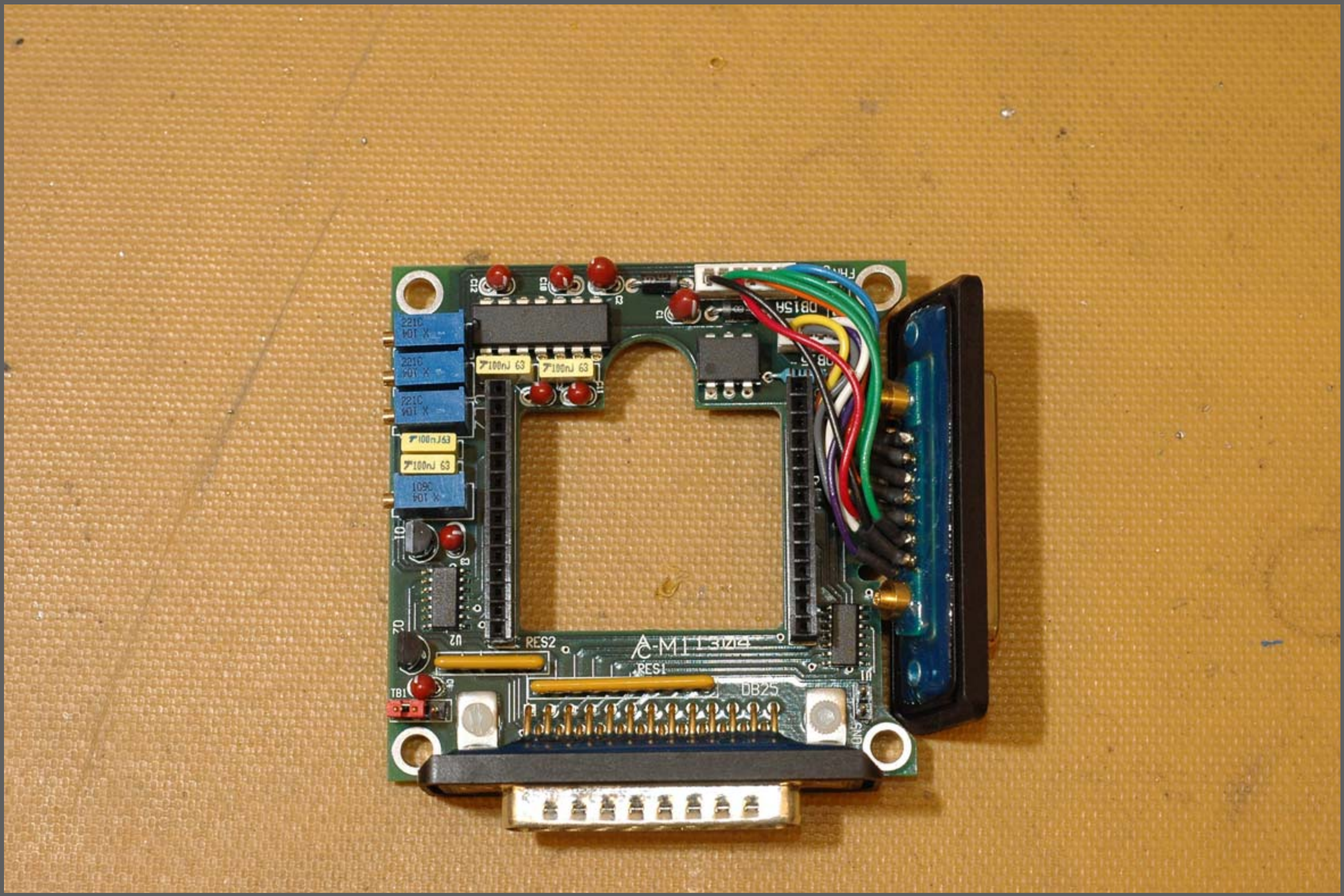
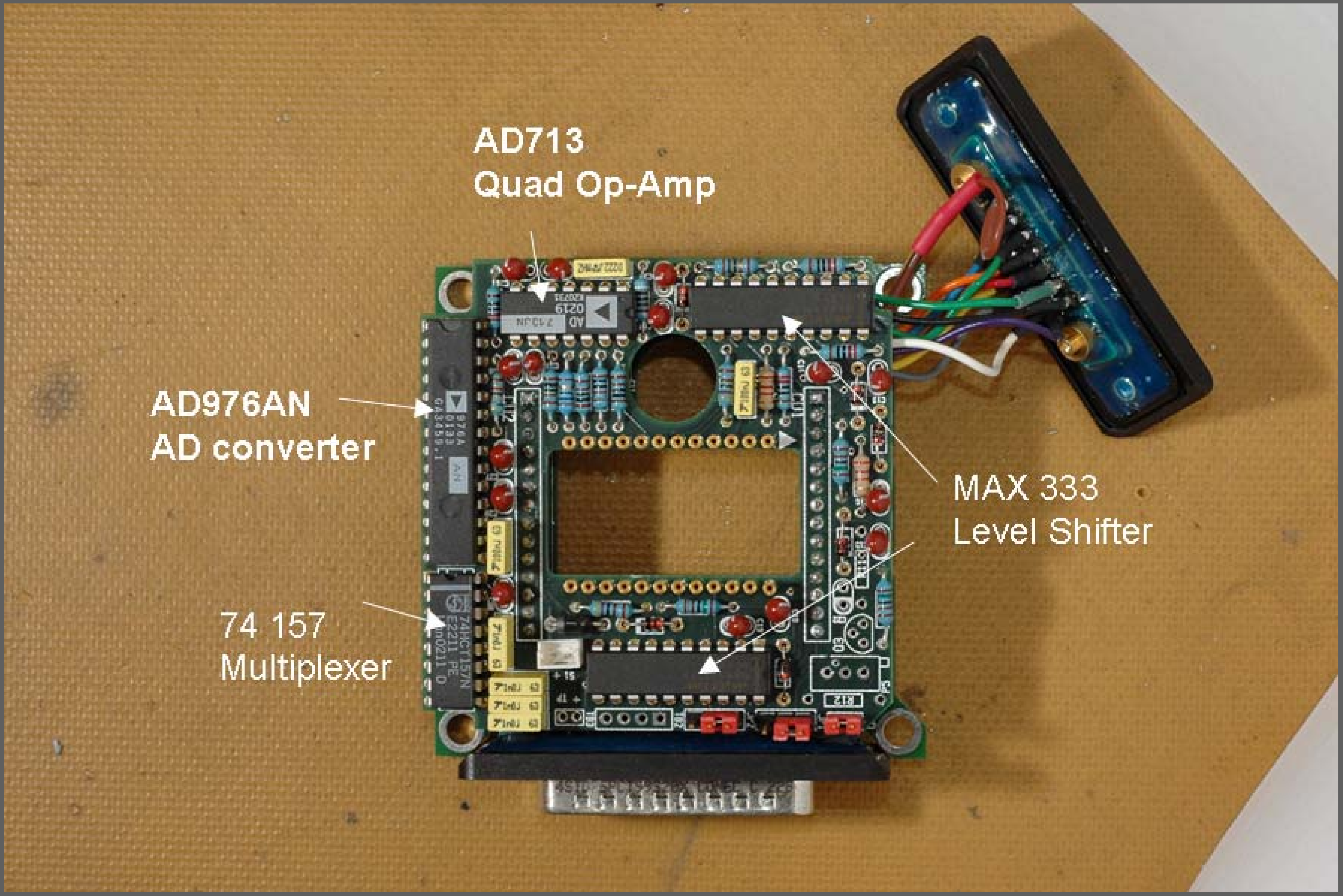
Lower Board



Upper board



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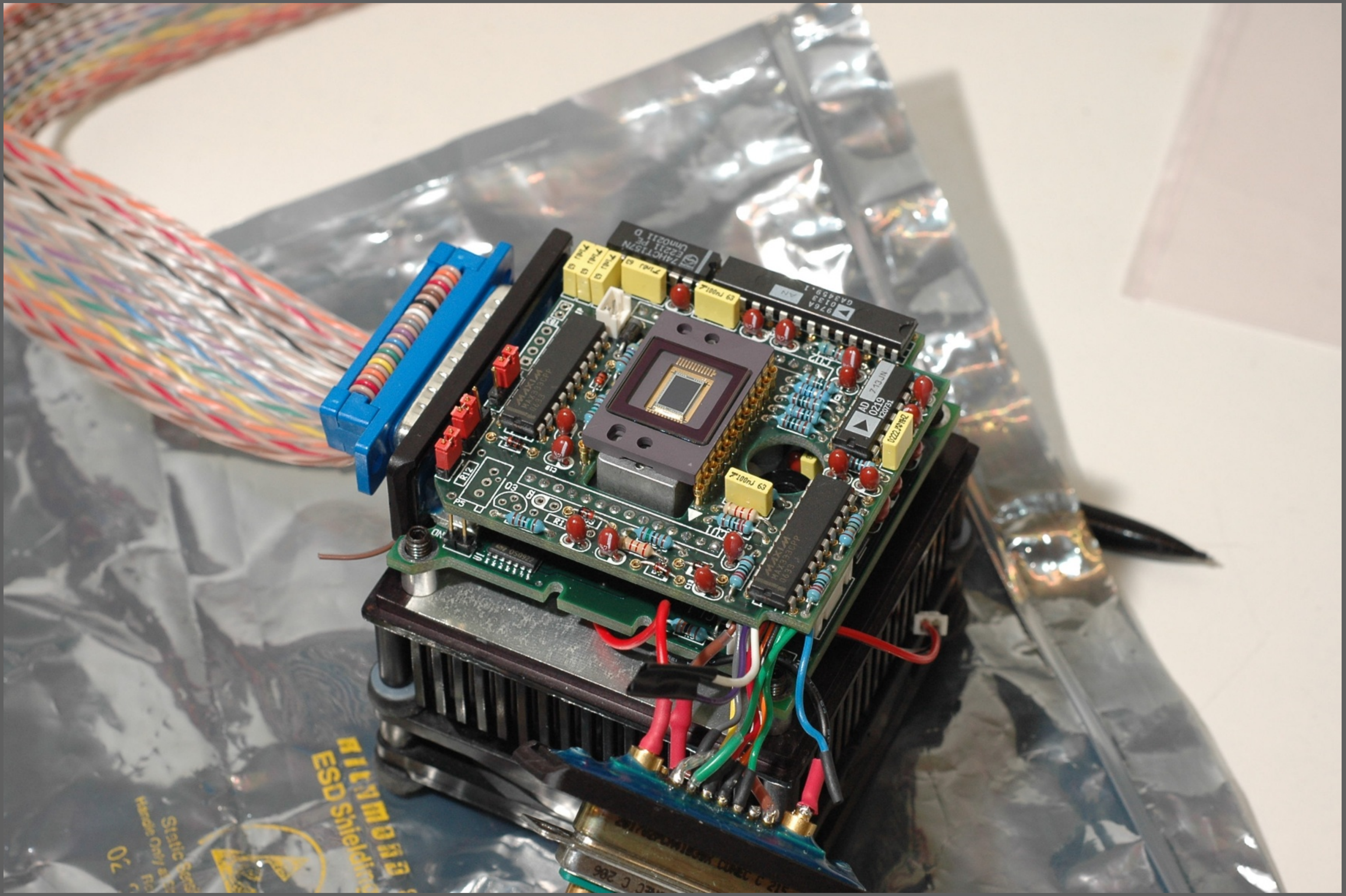
Assembled Camera



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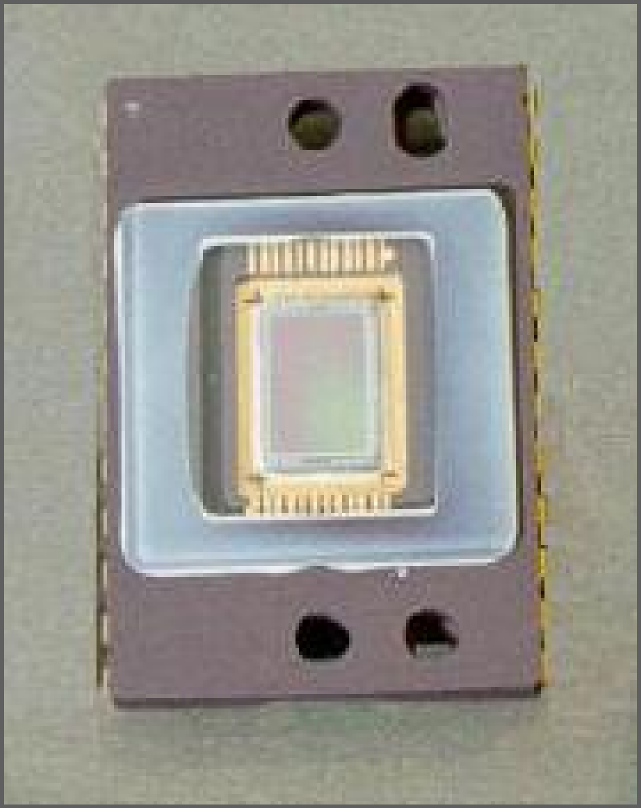
Completed Camera & Chip



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Completed Camera

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Class 3 : Testing of a CCD Camera (SIMG 742)

- a one hour-a-week class and problem session.

- a 10 hour-a-week laboratory.

- Both portions are presented over the ten weeks of the Spring Quarter (March through May).

Purpose

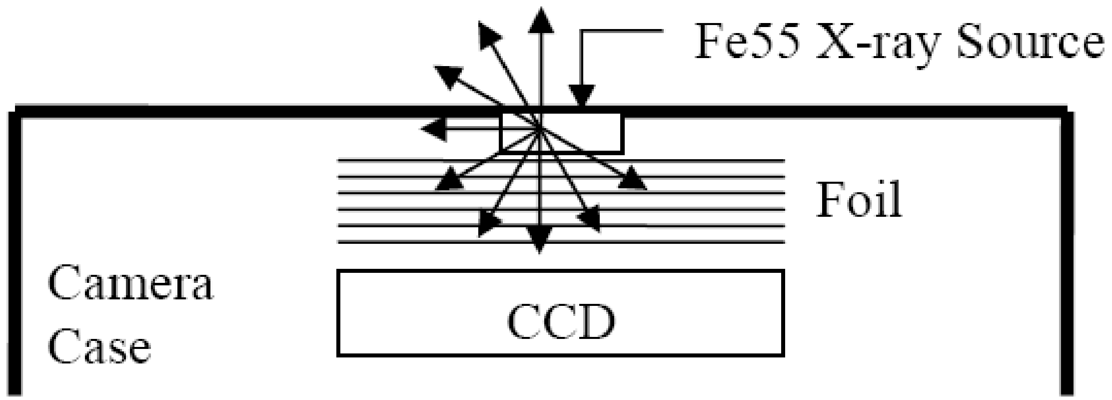
- Students are asked to conduct a series of calibration experiments similar to what they might be asked to do in a commercial, government or academic laboratory.

- Students generally use the camera fabricated in the prior quarter to conduct these fundamental testing experiments.

Experiments for class 3

- Measuring the gain (electrons per digital count out) using the photon transfer method.
- Measuring the noise, dark current and linearity.
- Determining the quantum efficiency of the CCD using a traceable NIST photodiode and spectrometer.
- Determining the modulation transfer efficiency (MTF) using a sine target.
- Determining the Charge Transfer Efficiency using a Fe-55 X-ray source.

Experimental setup



Experimental setup. The arrows indicate how the x-rays are emitted in all directions.

Two images (60 sec) with X-ray illumination

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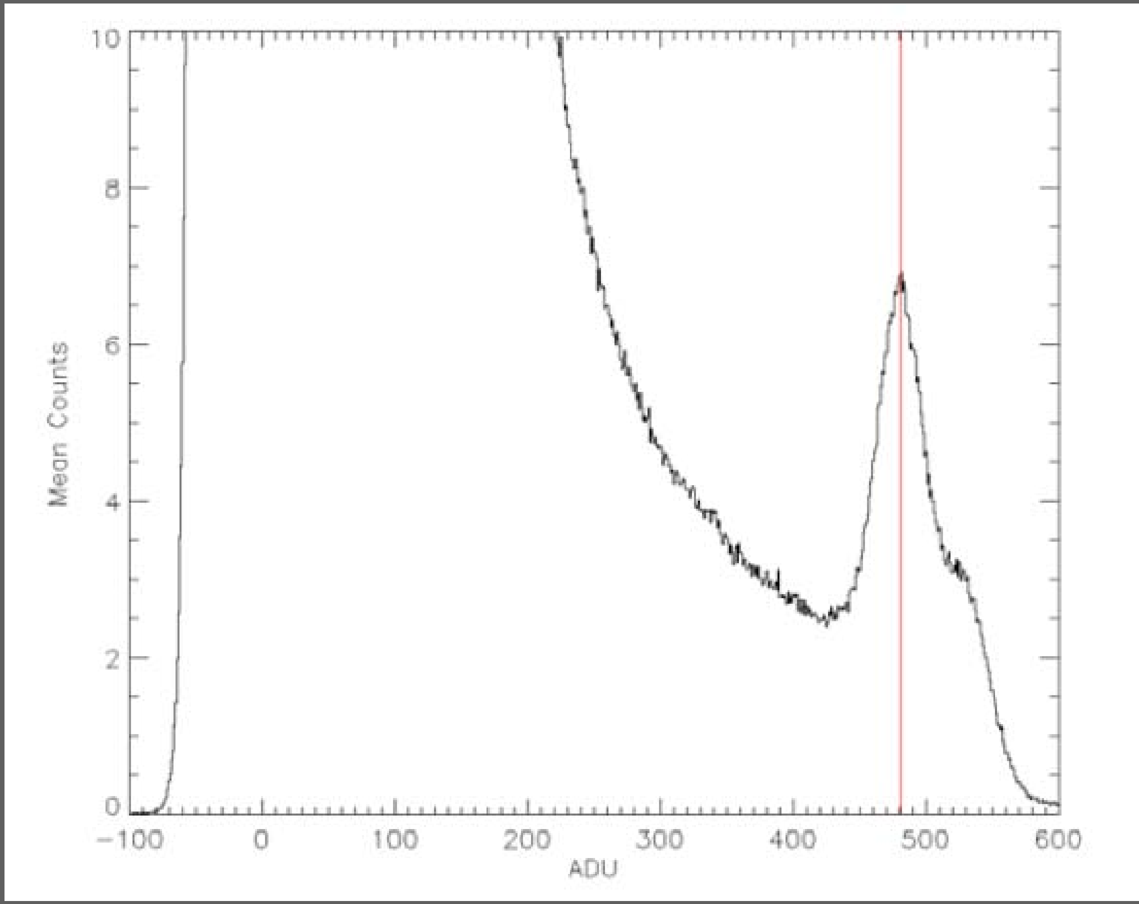
Fe-55 decay generates 5.9 KeV X-ray which produces 1620 e^- single pixel event.



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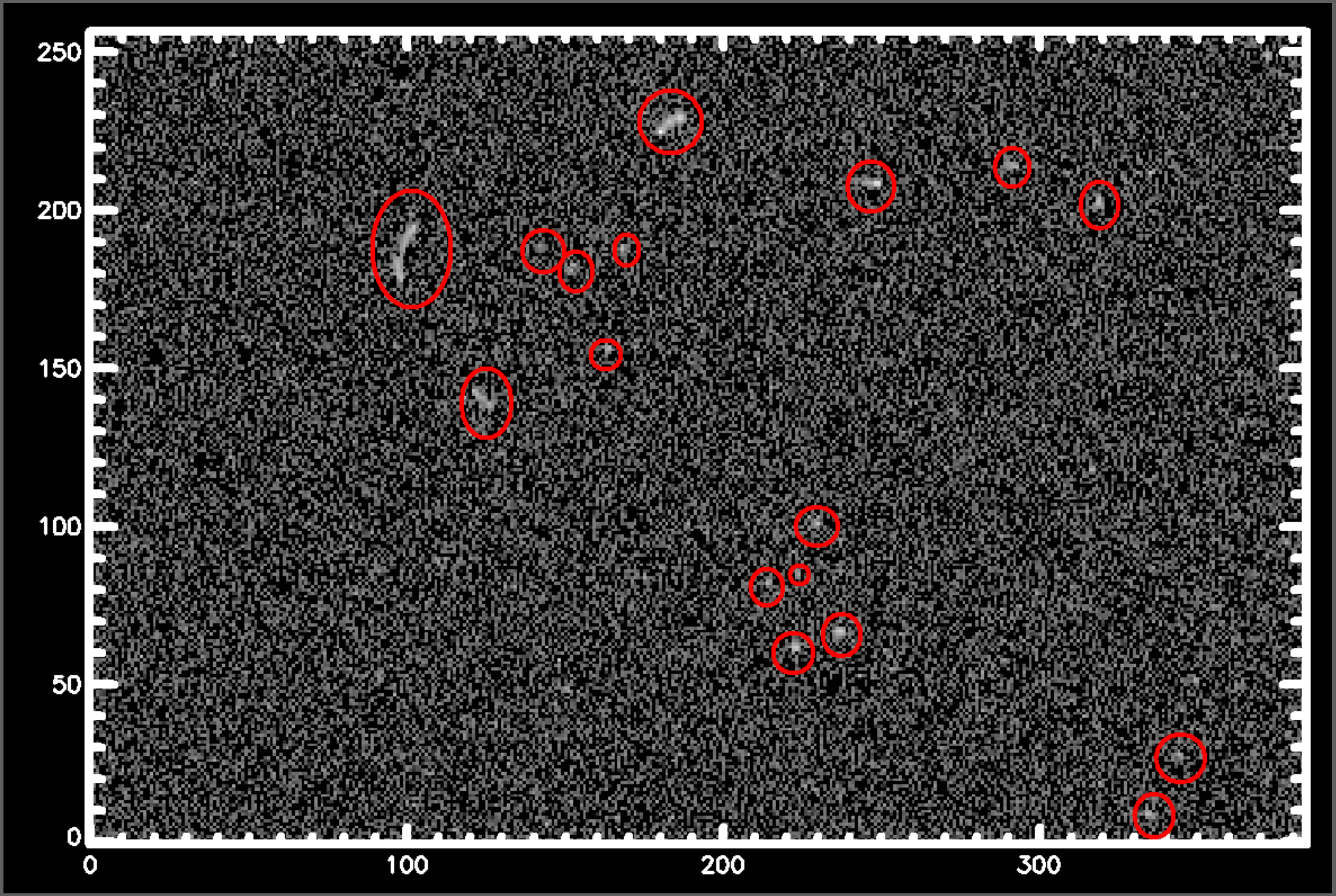
Subtracted image of two half an hour dark exposures. Suspected muon events are highlighted in red elipses.



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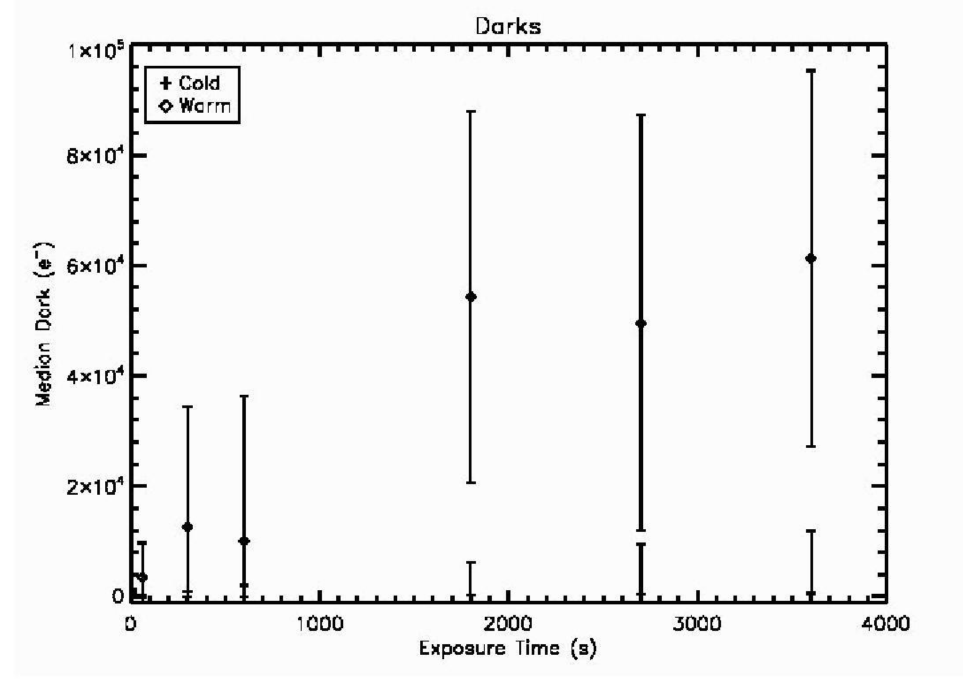
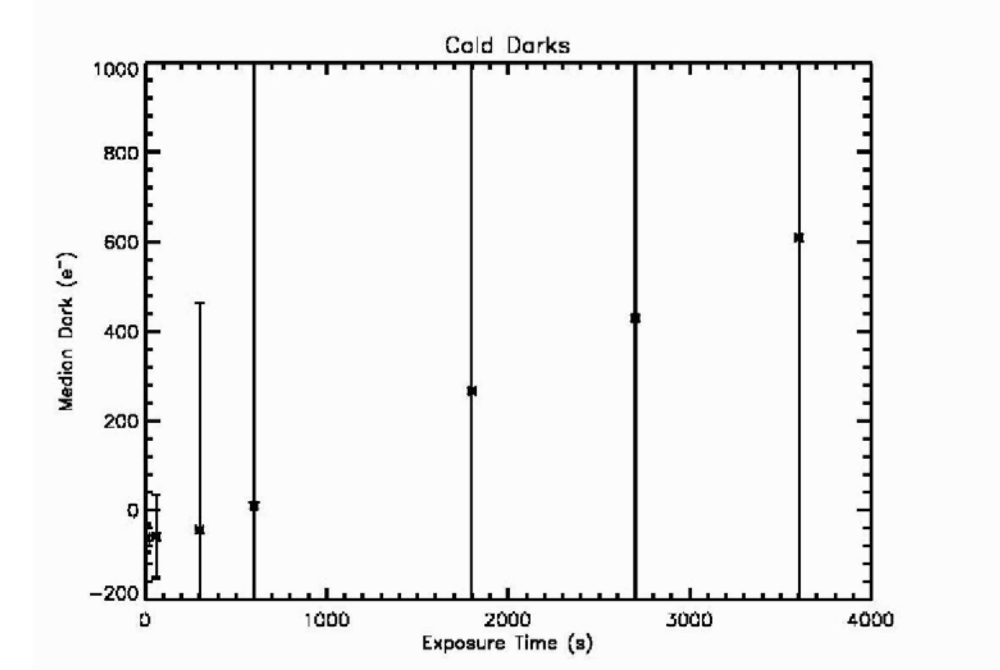
Dark Current as a function of Temperature





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Quantum Efficiency

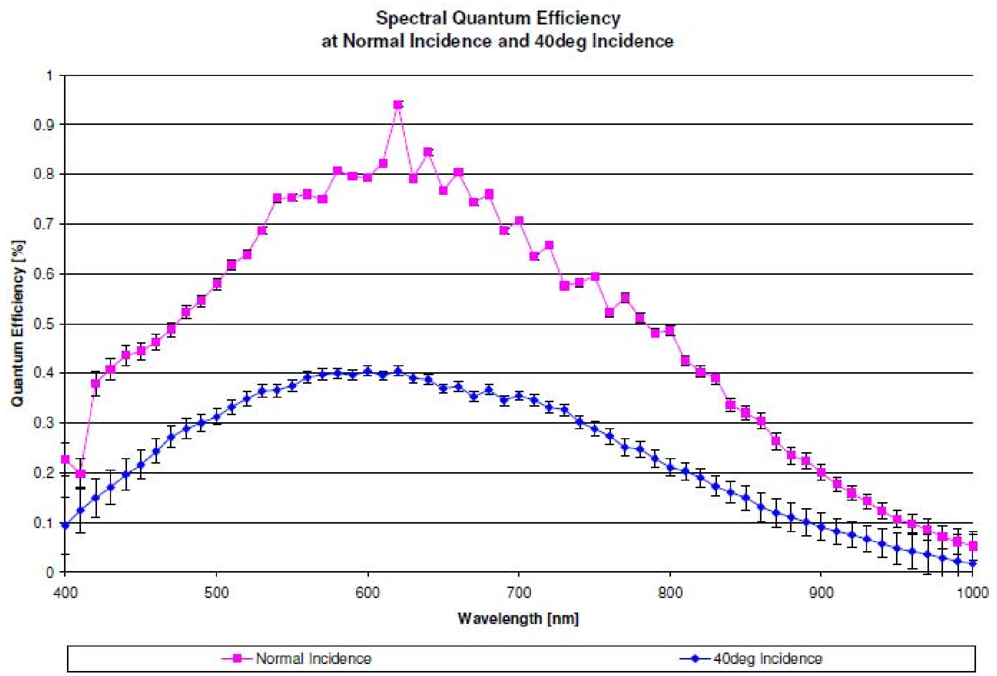
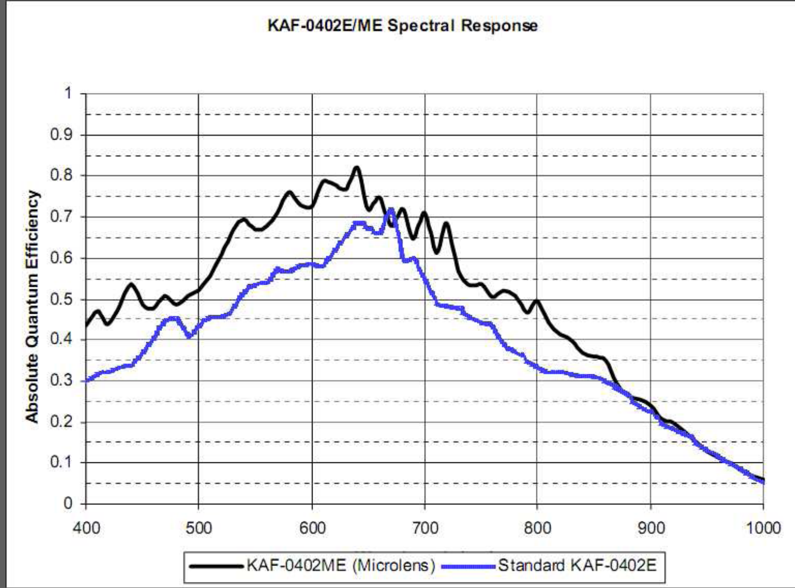


Figure 7, Spectral QE of CCD at Normal and 40° Incidence.



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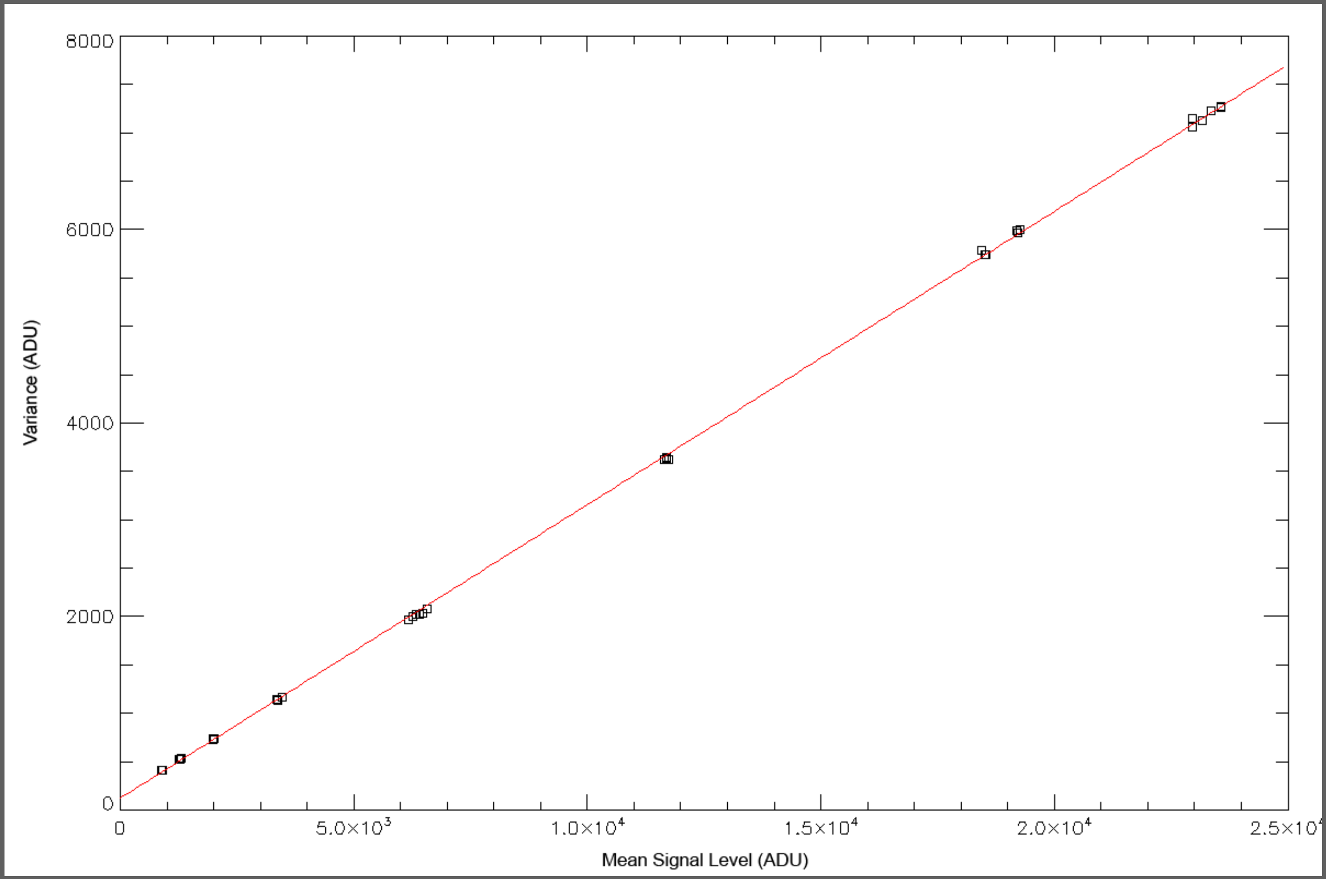
Photon Transfer Calibration



Description	Value	Units
Gain	3.29747	e^-/ADU
Read Noise	11.0 ± 0.3	ADU
Read Noise	36.0 ± 1.0	e^-
Correlation R^2	0.999937	None
Frame Readout Time	15.9	sec

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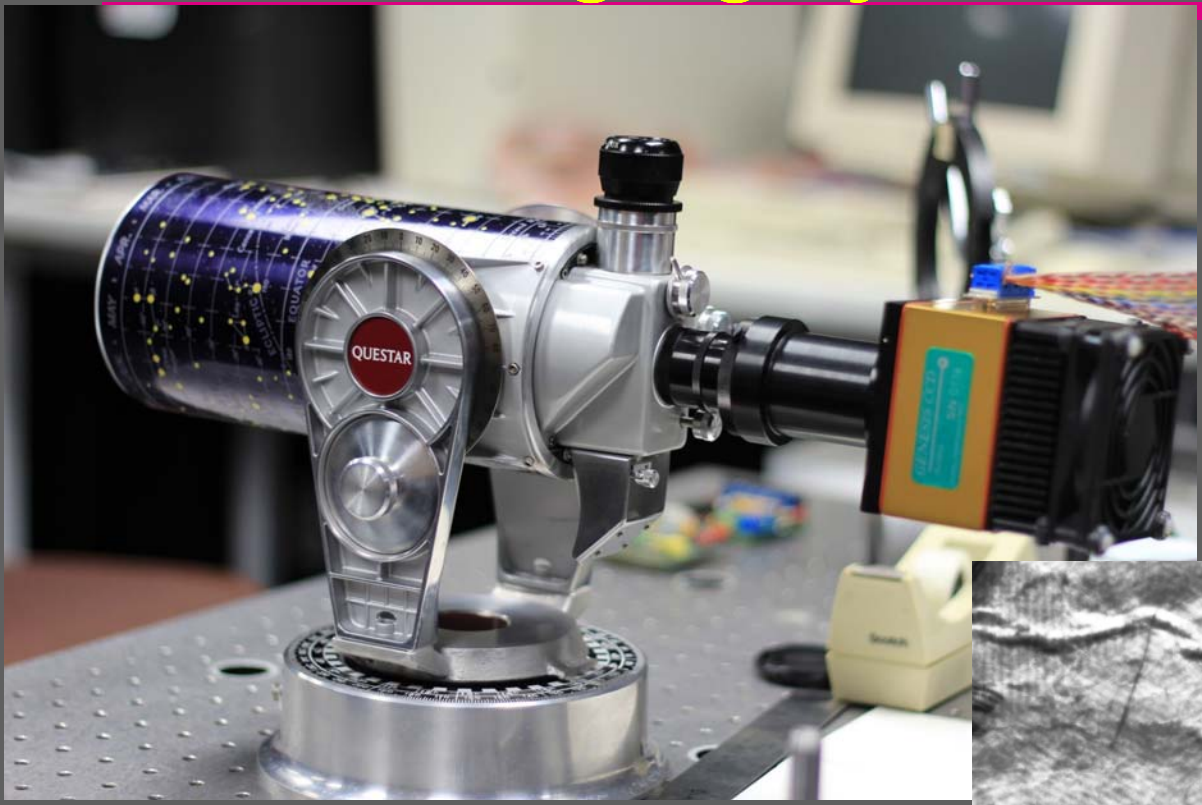
On an imaging system



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Enrollment

- students from the College of Science, the College of Engineering, the College of Information Technology and the College of Imaging Arts & Sciences.

- They rarely take a class together

- The students are organized into teams of three. As they progress in building the camera, they find that each student's background is of value.

- The elitist mentality (*i.e.* that one's own major is superior to others) that often results from being confined into increasingly siloed academic programs is seen not to be true when building a complex instrument like a CCD camera (*i.e.* students discover that other majors know things that they haven't learnt).

Assesment of "Principles of Solid State Imaging Arrays"

- series of homework problem sets utilizing MathCad/Matlab/Mathematica.

- a final examination

- a class presentation of fifteen minutes duration on a type of focal plane detector array that was not covered in class. Students are expected to utilize the electronic databases (e.g. INSPEC, SPIE Digital Library). The key element of their presentation must be an explanation of the underlying physics governing the operation of the device and a clear illustration (*i.e.* a figure) of how the detector works.

Assessment of "Fabrication of a CCD camera"

- a midterm exam
- a final exam
- maintaining an up-to-date group laboratory notebook
- a final oral exam

- the oral exam is often the first time the students have had to respond directly to questions about their work. They are put on the spot and for some the experience is stressful. However it also gives them a taste of what to expect after graduation.

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Assesment of “Testing of a CCD Camera”

- final exam
- detailed reports and conclusions on each of the laboratory tests the students complete.

- Since a commercial CCD sensor is used in the camera system the performance metrics determined by students as part of their laboratory can be compared to the specifications listed by the manufacturer.

Connections to Physics

- understanding the QE of a detectors (need to know about reflection, absorption length and diffusion etc).
- noise in a detector (photon statistics, FET operation)
- MTF of a detector system (diffraction limit, sampling theory)
- radiation interaction with a detector (muon etc interaction in silicon)
- dark current generation and latent images (solid state physics, materials)
- performance variations with temperature (thermal physics/cryogenics, material conductivity)

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Outcomes

- a sense of personal accomplishment
- an excellent understanding of the operation of many other instruments.
- hands-on, practical course desired by employers.
- “capstone” course where the years of conventional coursework is integrated into something meaningful and practical for students.

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