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Course Information
Scientific imaging in the Visible and Near infra-red

SCIENTIFIC IMAGING IN THE VISIBLE AND NEAR INFRA-RED

Teacher: Dr. Simon Tulloch (smt@qucam.com). Has worked for 15 years in the fields of instrumentation and operations at astronomical observatories both in the UK and Spain. For 8 years he was the head of the detector group at the Isaac Newton Group of Telescopes in La Palma, Canarias. He has recently completed his Ph.D. at the University of Sheffield. The subject of his thesis was "Astronomical Spectroscopy with Electron Multiplying CCDs".

Course Summary: The course begins with an introduction to the solid-state physics underlying the operation of modern scientific visible and near infra-red detectors. The basic principles of photo-diodes, CMOS and CCD detectors are then outlined. The course continues with a explanation of how CCD detectors have been progressively improved over the last 40 years and how their performance is now closely approaching that of an ideal detector. The current state of alternative CMOS design detectors and how they compare to CCDs is also described. Finally, the optimisation, characterisation and operation of practical camera systems are discussed. The course as a whole is very much biased towards CCD technology. CMOS detectors are discussed, but mainly in order to contrast the performance of the two competing technologies.

At whom the course is oriented: The course is oriented at physicists, engineers and astronomers that have worked or are working in instrumental projects that involve the use of CCDs, who feel that that they would benefit from a more in-depth knowledge of the detectors that play such a central role in the performance of their instruments. The course would also be a valuable introduction for those wishing to become scientific detector specialists.

Previous grounding: A basic grounding in physics is required. Some knowledge of electronics would be desirable but is not essential. The course contains very little mathematics.

At the end, the attendances will get:

- To gain an in-depth knowledge of the physics underlying modern scientific visible and near infra-red detectors.
- An appreciation of the current advanced level of detector technology and the likely paths that further development will take in the near future.
- To be in a position to identify a suitable detector technology for their particular engineering application and to understand the various performance parameters described in manufacturers data sheets.
- A knowledge of the techniques of detector characterisation in practical camera systems.

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CONTENTS (DRAFT ISSUE)

Module 1: Introduction to solid-state detectors

Summary: *This module is devoted to introducing the basic physical and engineering principles common to all scientific camera technologies.*

- **1.1. Ideal vs real-world detectors**
  - Poisson Statistics
  - Read Noise
  - Other noise sources
  - Signal-to-Noise ratio
  - Detective Quantum Efficiency

- **1.2 Semiconductor physics**
  - Periodic table
  - Semiconductor structure
  - Photo-electric effect
  - The PN junction
  - The electromagnetic spectrum
  - Silicon absorption depth
  - Other semiconductors
  - Traps

- **1.3 The photo-diode**
  - Structure
  - Standard modes of operation
  - Integration mode
  - Concept of QE
  - Avalanche photo-diodes (APDs)
  - Photo-diode arrays
  - Charge-coupled photo-diode arrays

- **1.4 The charge-coupled device (CCD)**
  - Bucket brigade structure
  - Buried channel
  - Charge transfer
  - Frame transfer/interline transfer/full-frame readout
  - Output amplifier structure and read noise (ktC, Johnson,1/f)
  - Correlated double sampling
  - Full well
  - Dark current
  - Cryogenic performance
  - Cosmic rays/radioactive materials in camera
  - Cosmetic defects
  - Radiation damage in Space applications

- **1.5 Scientific camera systems**
  - Thermal design and control
  - Cooling options (Peltier, LN2, CCC)
  - Vacuum systems and materials
  - Controller electronics

Module 2: Approaching the Ideal Detector

Summary: *This module is devoted to explaining the evolutionary changes that have steadily improved optical detector technologies over the last 40 year.*

- **2.1 CCDs: Boosting performance of the basic design**
  - Backside Illumination
  - Thinning
  - Backside passivation
  - Anti-reflective coatings
  - Deep Depletion CCDs
  - Hi-Rho CCDs
  - Anti-fringing process
  - Design driver: AO (an astronomical aside)
  - Low-noise amplifiers
  - Hi-speed through multiple amplifiers
  - Mosaicing
  - Orthogonal transfer CCDs and AO
  - Multiple non-destructive read (DEPFET)

- **2.2 The electron multiplying CCD (EMCCD)**
  - History
  - Structure
  - Multiplication noise
  - Clock-induced charge
  - Output signal distribution
  - Modes of operation
  - Photon-counting
  - Application: Adaptive optics (ESO CCD219)
  - Application: Astronomical spectroscopy (astronomical aside)

- **2.3 CMOS detectors: Boosting performance of the basic design**
    - Hybridised detectors
    - 4T and 5T designs
    - Use of microlenses
    - Back-thinned CMOS

- **2.4 Ultimate-performance future detectors**
    - Silicon APD arrays for photon counting in the visible
    - HgCdTe APD arrays for photon counting in the NIR
    - CMOS vs CCD

Module 3: Detector Characterisation

Summary: *This module is devoted to explaining the process of characterization of a practical scientific camera system.*

- **3.1 Characterisation and Optimisation**
    - Photon transfer method
    - Gain and Noise measurement
    - QE measurement in diode mode: light sources, monochromators etc..
    - Precautions when measuring dark current
    - Defect mapping using flat fields
    - CTE using Fe55 X-rays and the EPER
    - Video amplifier bandwidth using Fe-55 X-rays
    - Linearity and full-well
    - Channel cross-talk