Thermo Fisher
SCIENTIFIC

The world leader in serving science

Research and Development Efforts at CIDTEC Cameras & Imagers

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Director of Engineering
11-Mar-2011

Agenda

- Introduction to Thermo Fisher Scientific
- CIDTEC Cameras & Imagers
  - Organizational History
  - Mission
  - Revenue by Application
- R&D Process
- CID Pixel Architectures
- Key Products & Applications
- New Products
- Conclusion

The World Leader in Serving Science

We are the leading provider of analytical instruments, equipment, reagents and consumables, software and services for research, analysis, discovery and diagnostics.

Thermo SCIENTIFIC

Leading Brands

Fisher Scientific

Size and Scale

- $10.8 billion in revenue
- 37,200 employees in 40 countries
- 350,000 customers in 150 countries
- Fortune 300 company

Unmatched Capabilities

- Complete portfolio
- World-class technologies
- Commercial and service strength

An Important Mission

Enabling our customers to make the world…

Healthier ***Cleaner*** ***Safer***

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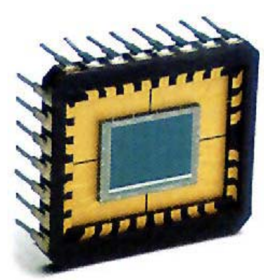
CIDTEC Cameras & Imagers - Organizational History

- CIDTEC founded in 1987
  - Management buy-out of a General Electric (GE) imaging business
  - Licensed to use GE's Charge Injection Device (CID) patents
- CID architecture protected from infringement by:
  - Patents (pending)
  - Internally developed technology & processes

From	To	
1987	1994	Privately owned company.
1994	Nov. 2006	Part of Thermo Electron Corp. Even though other technologies were divested over this period, CIDTEC product line technology was retained as a strategic asset.
Nov. 2006	---	Thermo Electron purchases Fisher Scientific to form Thermo Fisher Scientific.
Nov. 2006	Present	CIDTEC organized under Thermo Fisher Scientific's Scientific Instrument Division (SID).



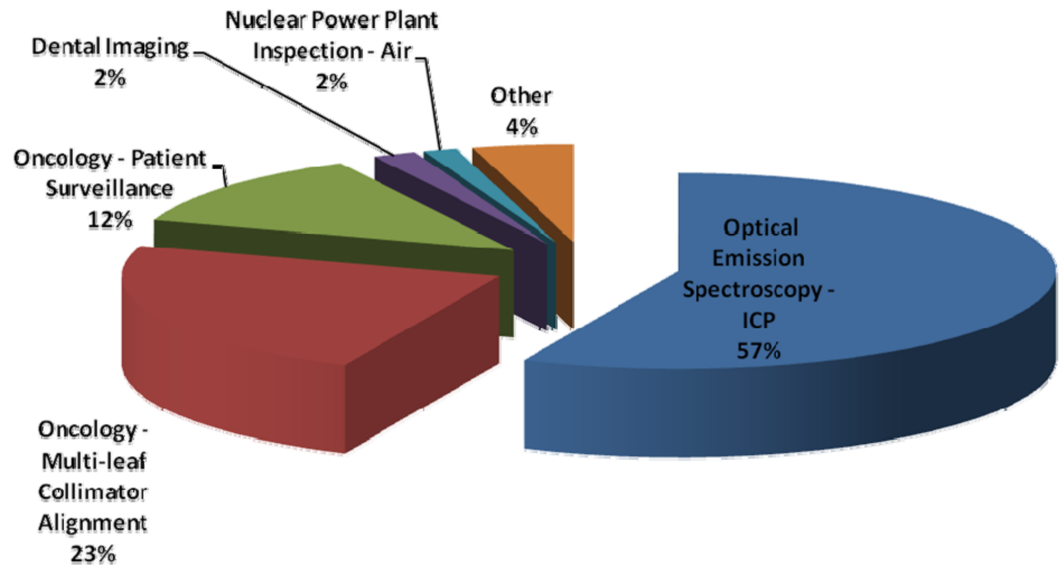
CID11 sensor from early '80's

Our Mission

- Rapidly grow revenue and profitability
  - Revenue growth rate target is greater than 20% per year
  - Pre-tax profit (EBITA) of 30%
- By developing and manufacturing high quality solid-state imaging products for applications such as:
  - Scientific imaging & instrumentation
    - Extreme dynamic range (10^7 to 10^8) scientific cameras
  - Radiation hardened video applications
    - Extreme radiation hardness (beyond 5 Mega-rad total dose) in both monochrome and color
  - Medical Imaging
  - Machine Vision

2010 Revenue by Application

- Highly focused on 2 applications
  - ICP optical emission spectroscopy (OEM customers)
  - Radiation oncology (OEM customers)
- Working to expand to:
  - Portable spark OES (future OEM's)
  - Nuclear power plant inspection and surveillance (End Users and Systems Integrators)



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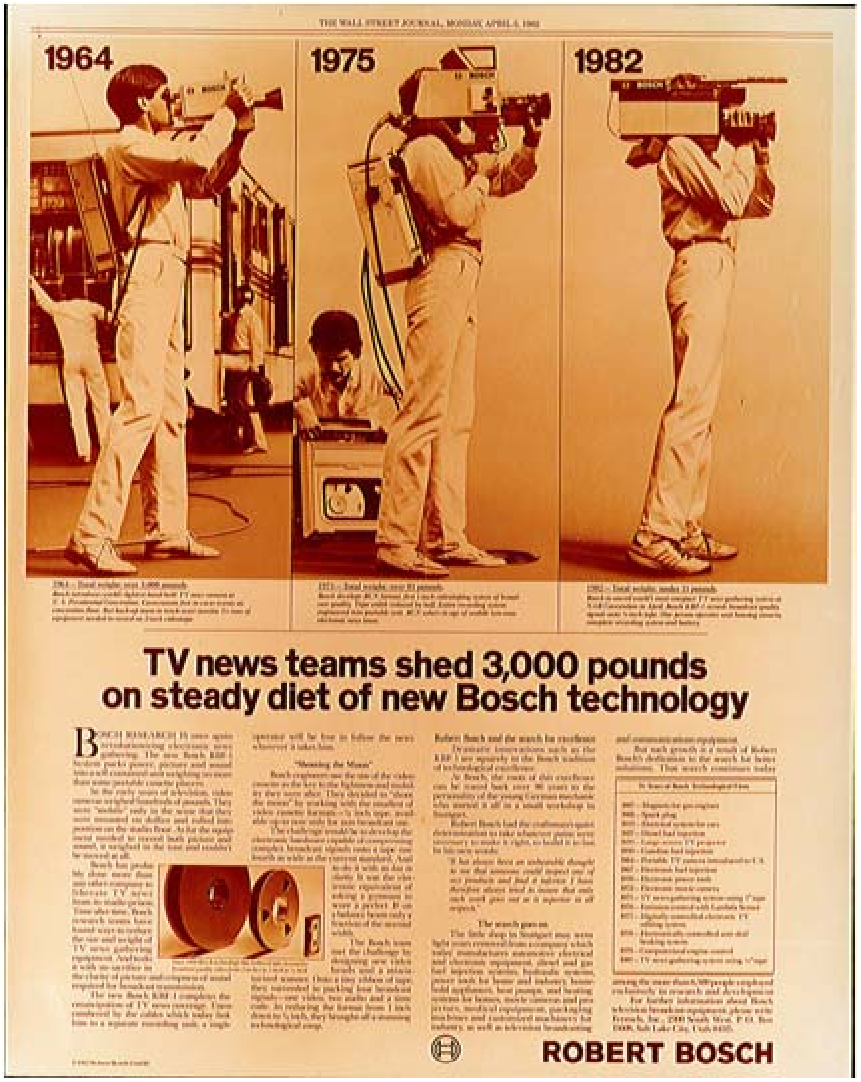
A Walk Down Memory Lane…..


1964 1975 1982

TV news teams shed 3,000 pounds on steady diet of new Bosch technology

ROBERT BOSCH

The Wall Street Journal, Monday, April 5, 1982

- Our R&D philosophy dates back to “GE days”
  - The Optoelectronic group at GE (CID group) developed the full chipset that included color signal processor and CID image sensor
    - Partnered with Bosch, who developed the TV camera
    - Chipset used in the Optomation systems that resulted in revenues of >$50M/year

R & D Capability - Resources

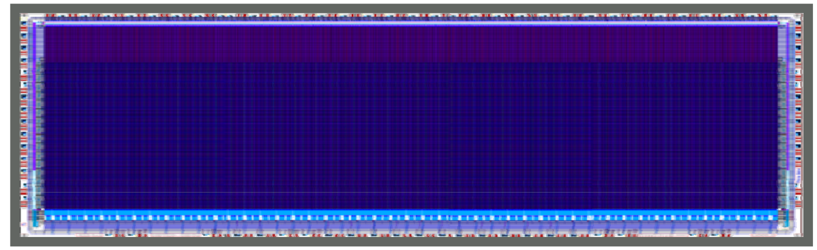
- Extensive in-house development capability
  - Over 135 years of combined experience in developing custom imaging solutions
  - State of the art design tools
    - Solid Works for mechanical and thermal management modeling
    - Mentor Graphics tools for printed circuit board design
    - Tanner EDA tools
    - Silvaco TCAD tools

R & D Capability - Resources

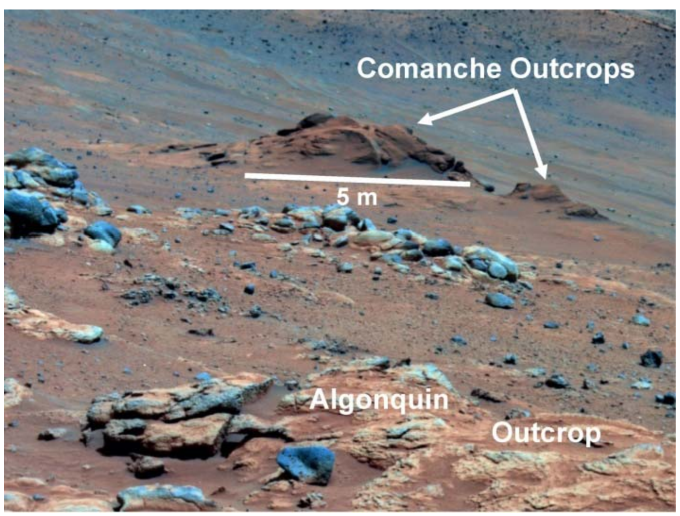
- Established partnerships with world-class semiconductor foundries
  - CMOS-CID processes on 2.0 μm, 1.2 μm, 0.8 μm, 0.6 μm and 0.18 μm
  - 6” and 8” wafers
- Upstate-NY region has great access to high-tech talent and colleges for collaboration

R & D Capability – Image Sensor Design

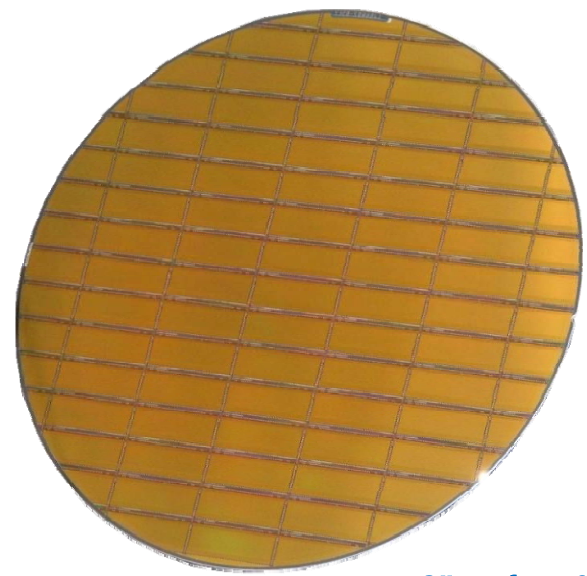
- Image sensor is our core technology!
  - All image sensors are designed in-house by world-class designers based upon CID architecture
  - Highly skilled process engineers on staff
    - Intimate partnership with our silicon foundries
  - Investing significant R&D funds in shuttle runs and prototype designs



4k CID51 Linear



A member of our team designed the imagers employed on the Mars Rovers (Spirit & Opportunity) when he worked for JPL.



8” wafer , 0.18μm

Research and Development Evolution

Problem Identification & Conceptualization
- Customer partnership
- Internal from product iteration / development path

Concept Evaluation & Market Analysis
- Analyze potential markets
- Competition

Initiate Design & Development (D&D)
- Program planning
- Return on Investment (ROI) model
- Generate specification of work (SOW)

D&D Inputs, Outputs & Review
- Update program plan
- Refine the specifications and update SOW
- Update ROI model

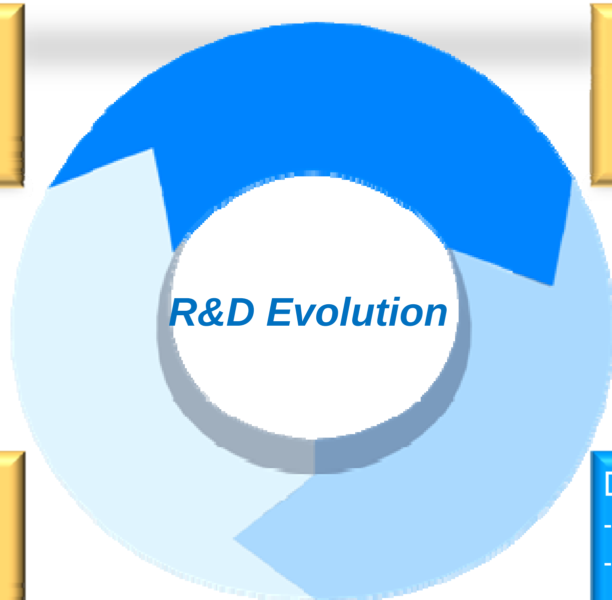
Prototype Evaluation & Viability Review
- Customer evaluation (Alpha testing)
- Update program plan and SOW as needed
- Set product value

Design Verification & Validation (V&V)
- Product tested against design spec's
- Customer's role in validation
- Roll-in design changes if required

Beta Systems
- Beta testing at customer's sites
- Limited production quantities

Production Launch
- Release to manufacturing
- Scale up for volume production

Market Research
- Continuous product improvement
- New iterations / Innovation



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What is a CID?

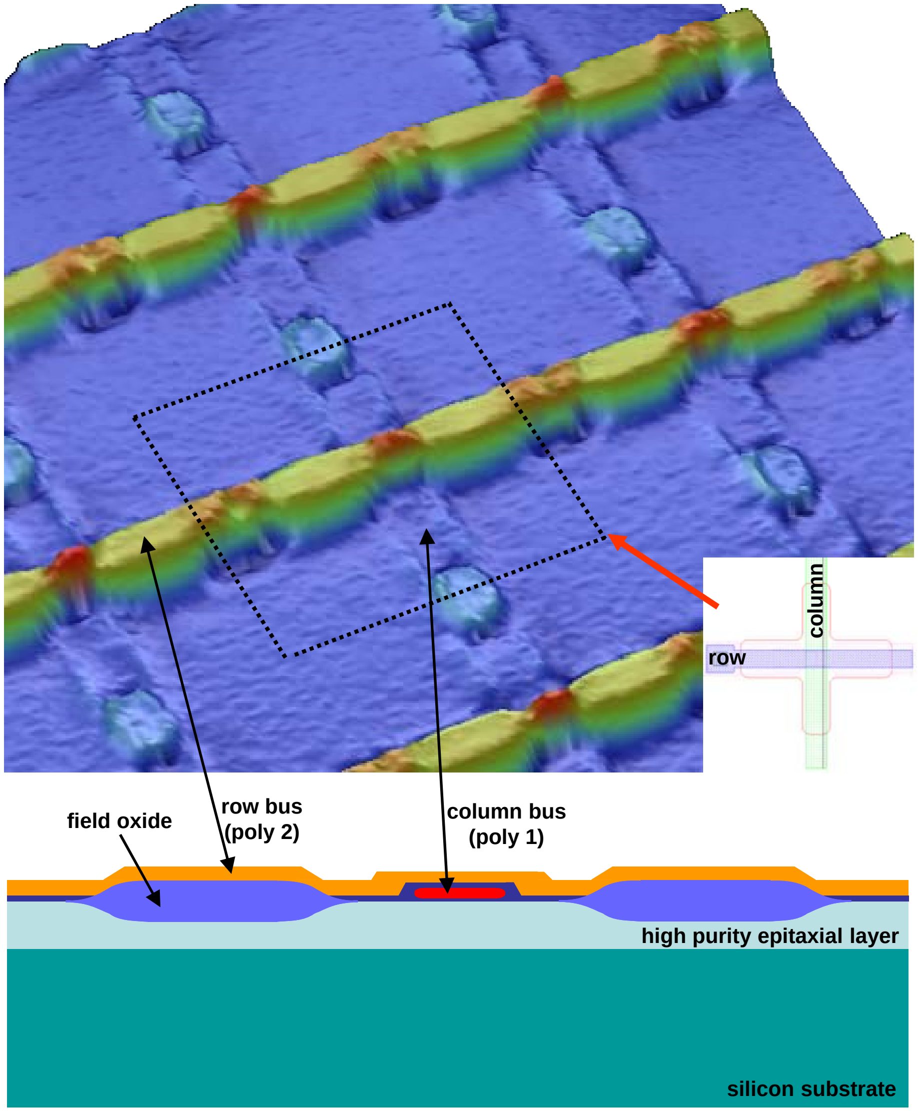
- CID is a silicon MOS device
  - A CID pixel is built on low-doped epitaxial material
    - EPI resides on top of heavily doped silicon substrate
  - A surface-channel charge transfer device
- CID converts photons to an electrical charge – done intra-pixel, unlike CCDs
  - Each pixel has two photogates and a means of transferring charge between them.
    - Storage gate for charge integration and Sense gate for sensing the charge
  - Sense node of a CID is a “floating gate” vs. “floating diffusion” of a CCD
- Unique ability to clear individual pixel sites by injecting its charge directly at the pixel site

CID Sensor Pixel Architectures

- Two primary approaches:
  - Passive Pixel CID
    - High fill factor
    - Excellent tolerance to very high radiation flux rates
  - Active Pixel CID
    - Low noise performance
    - Improved sensitivity
    - Significant effort of R&D resources applied

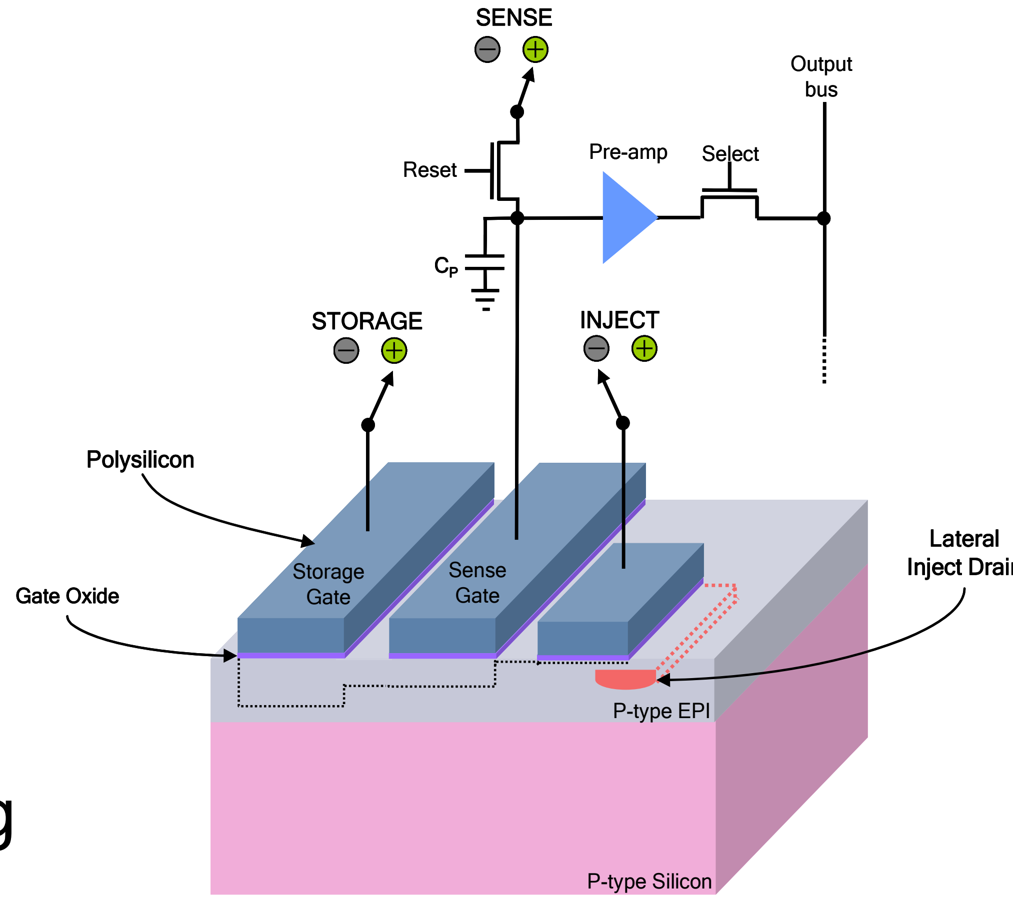
Passive Pixel Design

- The “crossed-cell” design is common in most passive pixel CIDs
  - All the photogates in the respective axis are electrically connected
    - Large Sense node capacitance = low conversion gain
  - Large FW
    - 100k - 2M electrons



Active Pixel CID

- 3 transistor design
- Three photogates
  - Storage
    - Non destructive readout feature maintained
  - Sense
    - Small sense node capacitance = high conversion gain
  - Inject gate
    - Also used to 'Skim' charge
- Lateral drain for removing photo-generated charge



Performance of Active Pixel CID versus CMOS Sensor

	APCID	CMOS	Comments
Full Well*	High	Low	FW of photogates can be controlled with applied bias. Size of photodiode typically determined FW.
Fill Factor*	High	Low	Fill factor for both approaches are lower, but given that FW can be controlled by applied bias, fill factor for AP CID's is higher
Conversion Gain	Low	High	CMOS uses floating diffusion for charge to voltage conversion, which has much lower capacitance than floating gate (AP CID)
Signal-to-Noise Ratio Performance	Low	High	Due to high signal output and low noise from a CMOS pixel, SNR performance is better than AP CID.
TID Radiation Tolerance	High	Low	Dark current of CMOS photodiode increases exponentially versus accumulated dose. AP CID has the advantage here.
Radiation Flux Rate Toleration	High	Low	Due to increased sensitivity, CMOS structure is sensitive to radiation scintillation noise. AP CID has the advantage here.

**Comparison for same pixel pitch*

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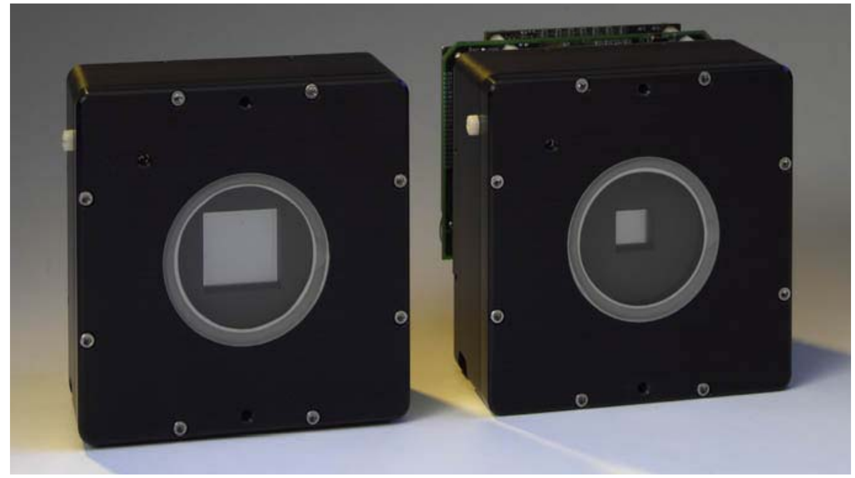
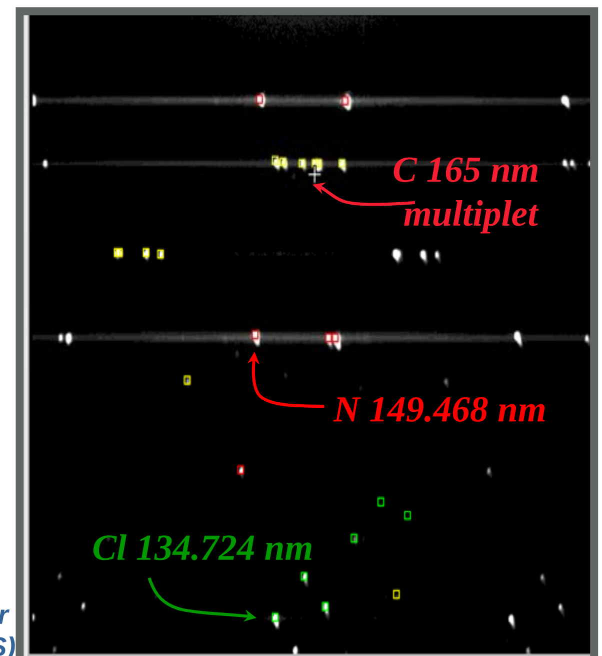
Key Products - Scientific Cameras

- SpectraCAM Scientific Camera
  - Available with 1024(H) x 1024(V), or 540(H) x 540(V)
    - 27 µm x 27 µm pixels
    - Full Well 500 ke-
    - Read noise 100 e- to 200 e-
    - Supports Collective Read (Binning)
  - Signal processing
    - 200 kHz pixel rate
    - Nondestructive read
    - Windowing
    - True random access
  - Run-time SW/firmware licenses
    - Random access integration
  - 3-stage TE cooled to -45 C
  - Hermetically Sealed or purged

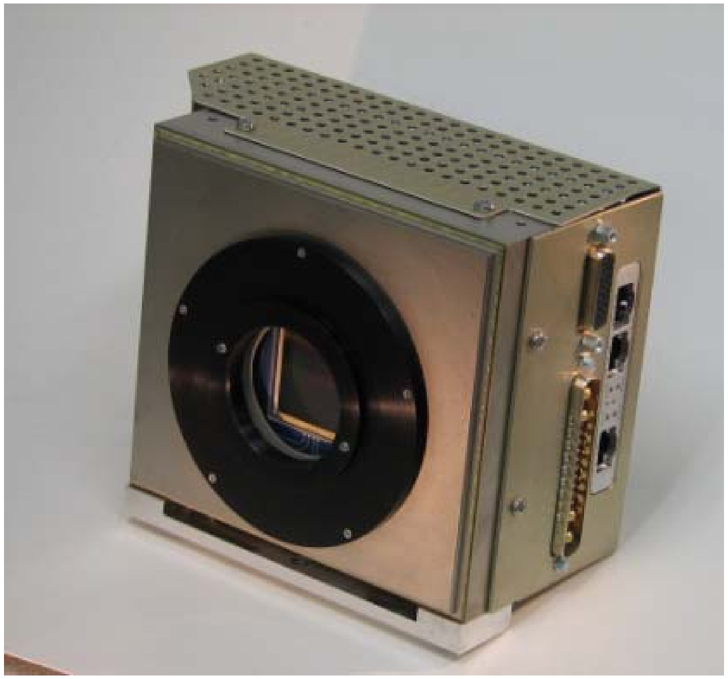




SpectraCAM system used for Optical Emission Spectroscopy (OES)

Key Products - Scientific Cameras (Contd.)

- SpectraCAM XDR
  - CID sensor with preamplifier per pixel
    - 2048 h x 2048 v format
    - 12 μm x 12 μm pixels
    - 24.6 mm x 24.6 mm photoactive area
    - Raw Dynamic Range = 80 dB
  - Signal processing
    - 2.1 MHz pixel rate
    - Nondestructive read
    - Windowing
    - True random access
  - Run-time SW/firmware licenses
    - Extreme DR ($10^6 – 10^8$)
    - Random access integration
    - Time resolved spectroscopy
  - TE-cooled (-45C)
  - Hermetically sealed or purged

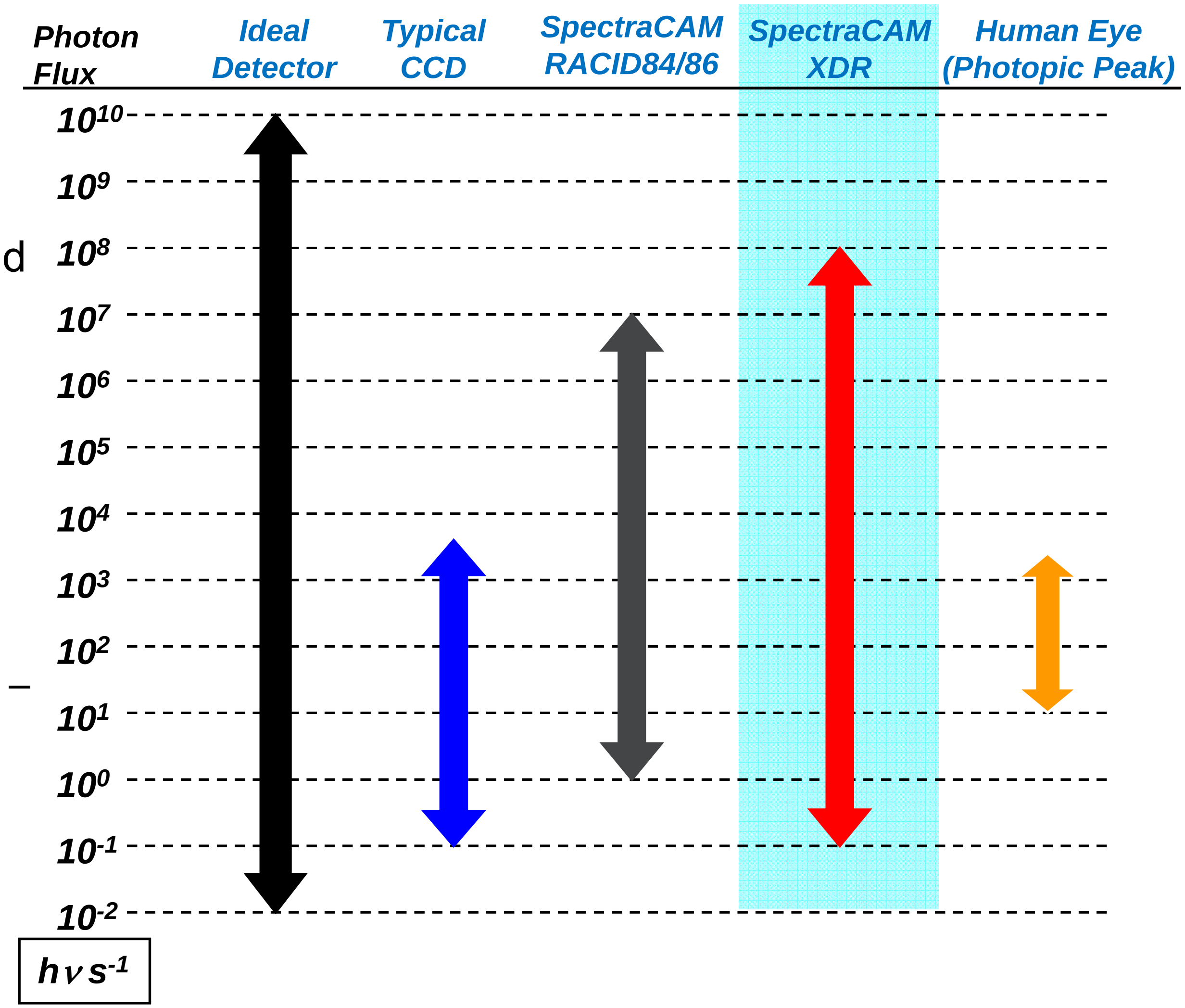


What Does ‘Dynamic Range’ Mean?

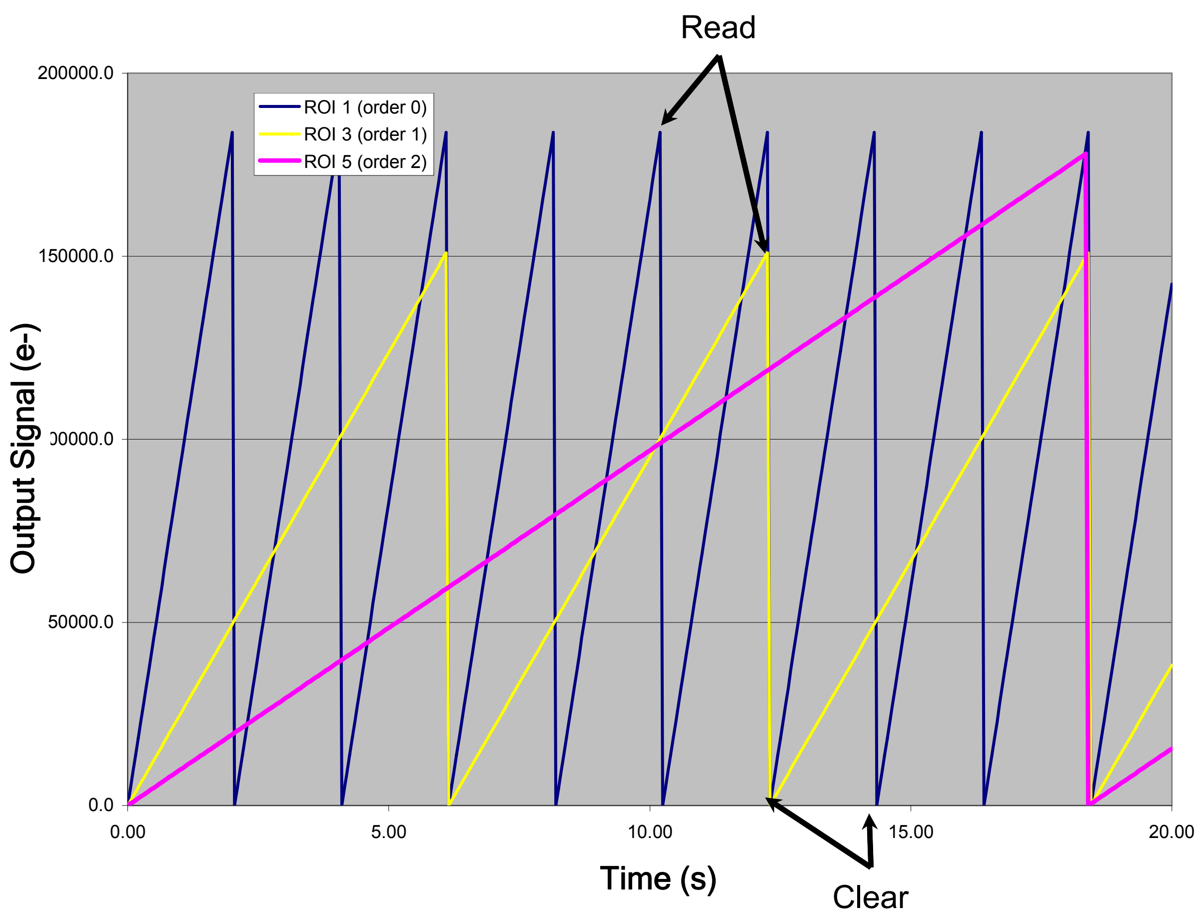
Ratio of maximum detectable value of a parameter to the minimum detectable value of that parameter

The Dynamic Range Advantage

- CCDs - very sensitive, but limited in upper end range
- CID based scientific cameras have the advantage
  - SpectraCAM™, RACID84/86 ideally suited to ICP-OES
  - SpectraCAM™ XDR – unprecedented dynamic range



Extreme DR™ Driver Readout Mode



- Intensely illuminated regions of interest (ROI) read and cleared
  - Cycle frequency defined by experimentally observed photon flux
- Dynamic range is **NOT** limited by full well capacity
- …But, dynamic range **is** limited by the speed at which the ROI may be cycled

Non Destructive Read in ICP-OES Application

Application for Shaping a Laser Beam

Image from CCD-based Camera

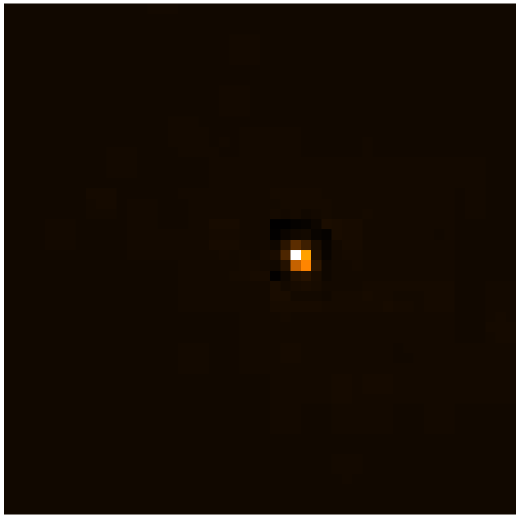
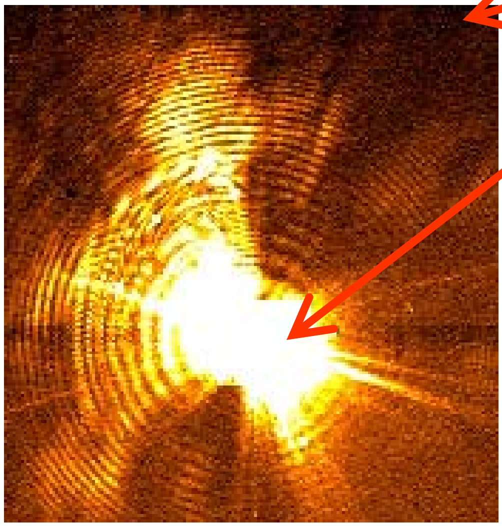
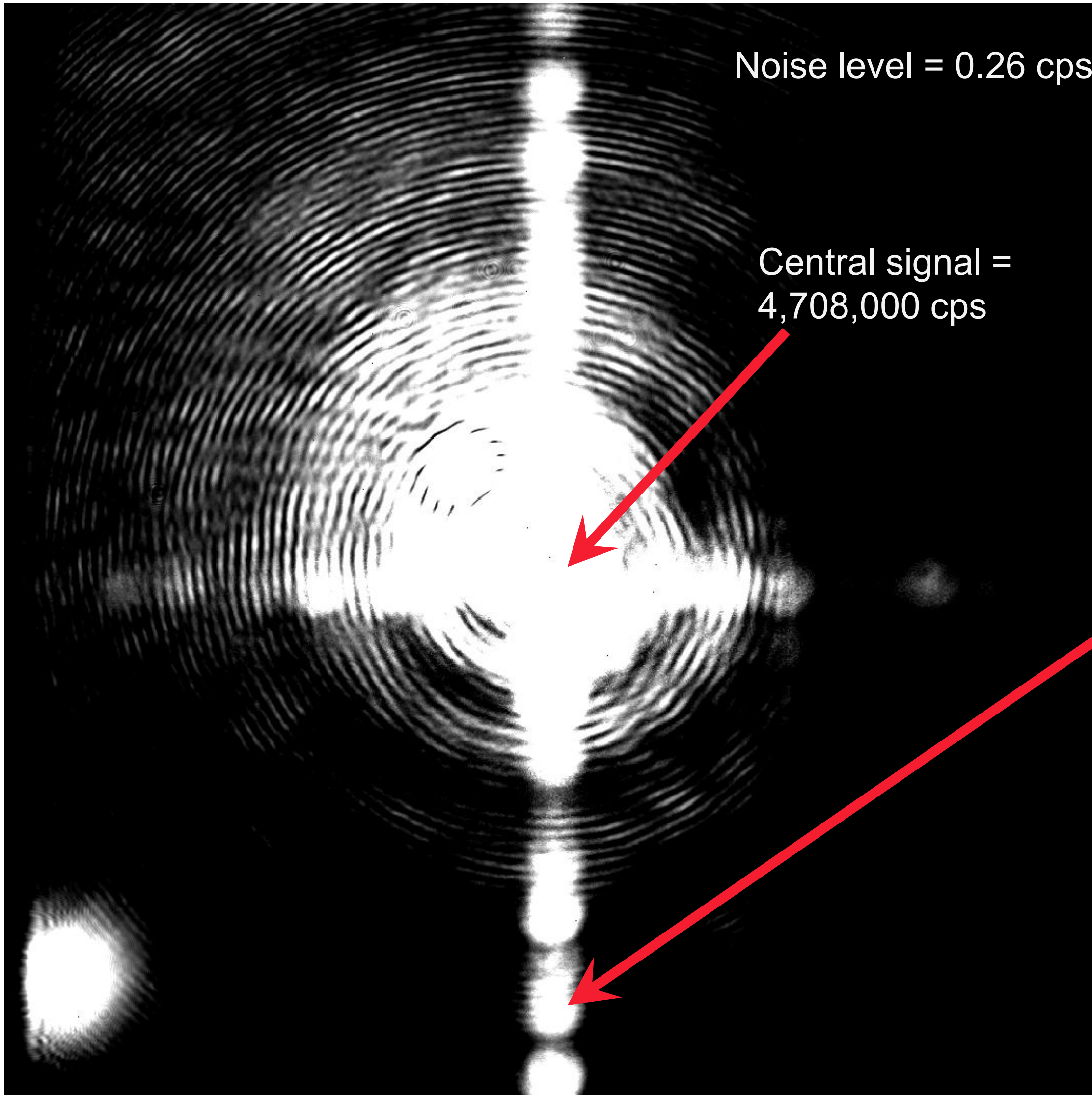


Image from SpectraCAM84 Camera



- Experimental setup
  - High-power HeNe laser
  - Collimator
  - Neutral density filters
  - Focused on SpectraCAM™84
- Dynamic range
  - Smax = 990,000 cps
  - Smin = σ = 0.176 cps
  - Resulting DR = 6.75 orders of magnitude
- CCD
  - One view OR
  - The other view
  - But not both at the same time
  - Also potential blooming

Application: Beam Profiling Using SpectraCAM XDR



- CERN – Particle accelerator alignment
- Dynamic range = $10^{6.3}$
- True simultaneous data acquisition for all 4.2 million pixels
- Lens flare or internal reflections?

RADIATION HARDENED CAMERAS

Radiation and CID Sensors

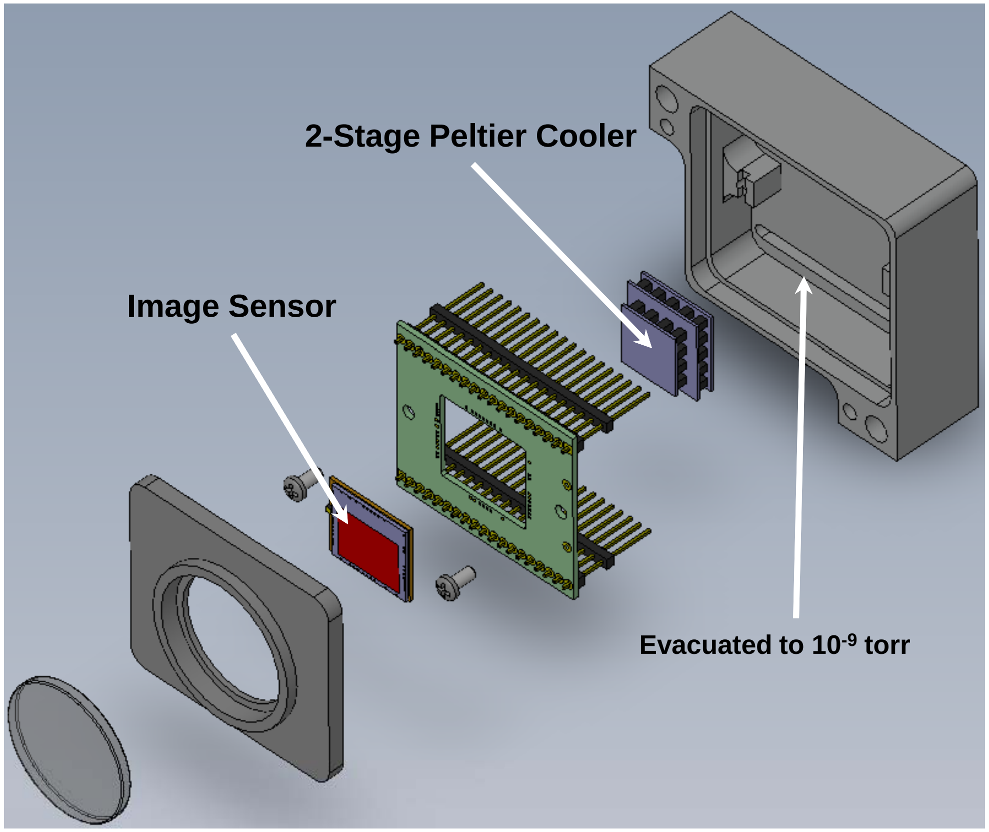
- CID sensors experience the same damaging effects as with any other solid state device
  - Long-term Effects
    - Ionizing Energy Loss
      - Primary cause of shift in MOS threshold voltage due to trapped charge in oxide
    - Non-Ionizing Energy Loss (NIEL)
      - Displacement of silicon atoms
  - Transient effects associated with dose rate
    - Observed as random noise in video - depends on pixel architecture employed
      - Passive pixel has the best performance in this case

How Do We Overcome Radiation Effects?

- CID Sensor
  - All-PMOS technology
    - NMOS devices become leaky after long-term exposure to radiation
    - PMOS will require more negative voltage to turn 'ON'
      - Use it to our advantage!
  - Follow radiation tolerant design methodology
    - Guard rings
    - Eliminate 90^o bends in active region of the photogate
    - Use proven design
  - Custom Process

How Do We Overcome Radiation Effects? (Contd.)

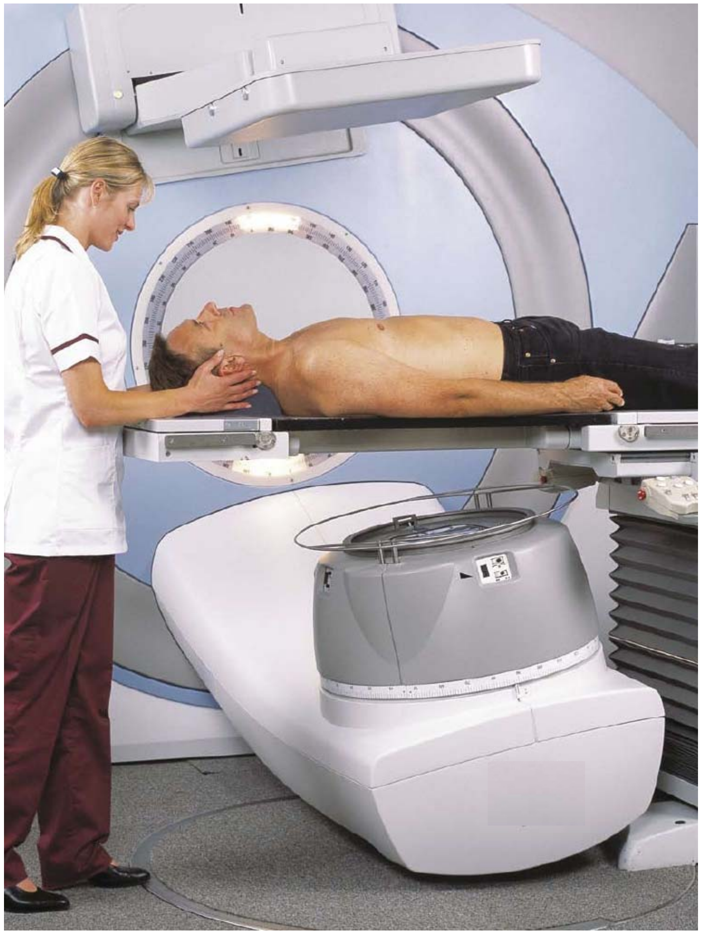
- Camera Electronics
  - Use radiation tolerant (commercially available) devices
    - BJT's and JFET's are inherently radiation hard
    - Rigorous radiation testing of off-the-shelf parts
  - Recycling of designs
  - All signal processing electronics to be located in a safe location
  - Cool the sensor to overcome damage from NIEL



Key Products – Radiation Hardened – MegaRAD1

- High tolerance to gamma, Neutron, Proton, high energy electrons
  - Radiation tolerant operation beyond 1 Mega-rads (10 kilo-gray) of total dose
  - Unpowered operation beyond 20 Mega-rads of total dose
  - Excellent imaging in flux greater than 750 kilo-rads/Hr
- RS-170, and CCIR monochrome video cameras
- Replaceable remote head
- Supports cable length of up to 30 meters

Application – Oncology Treatment with MegaRad1

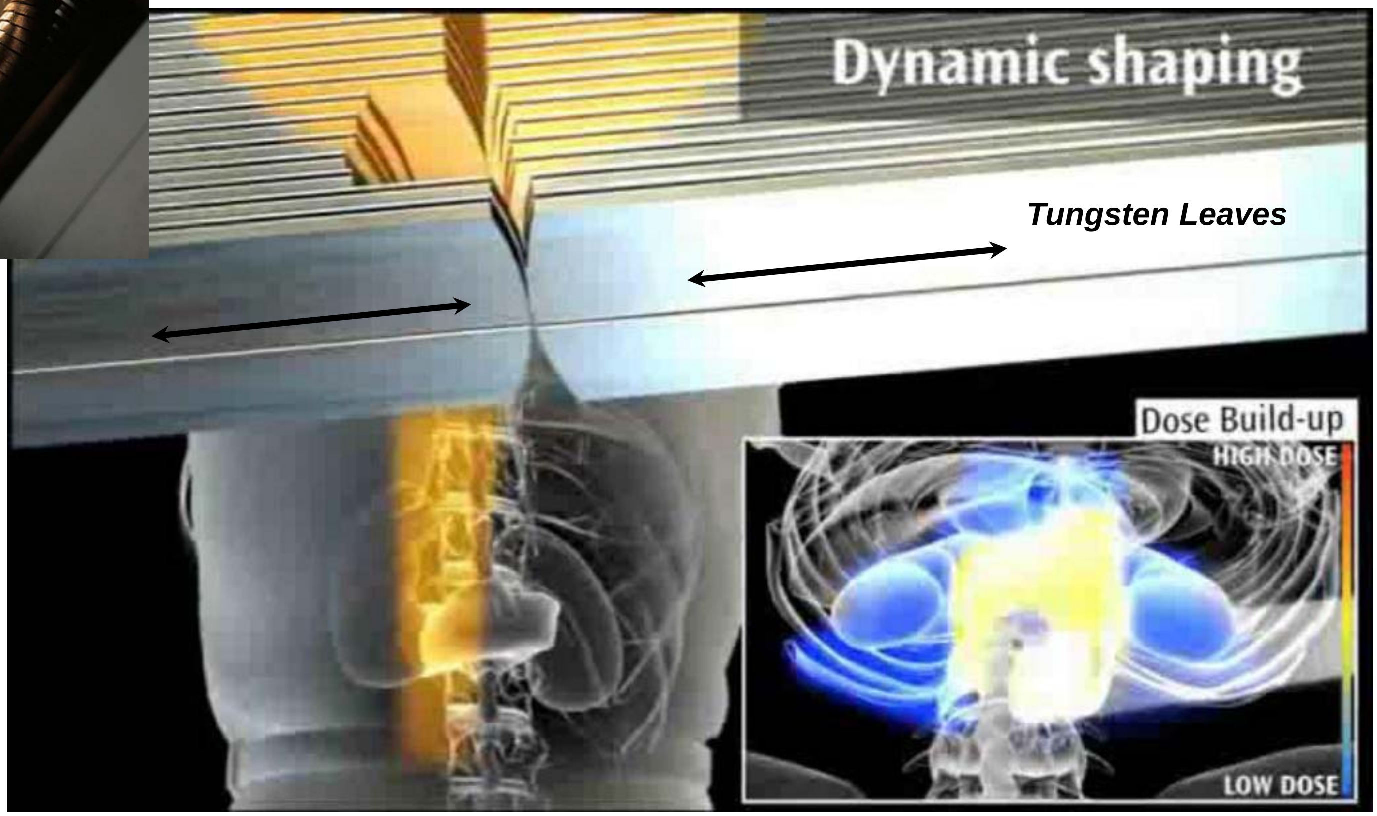


MegaRAD1 Camera is installed in the X-Ray Head

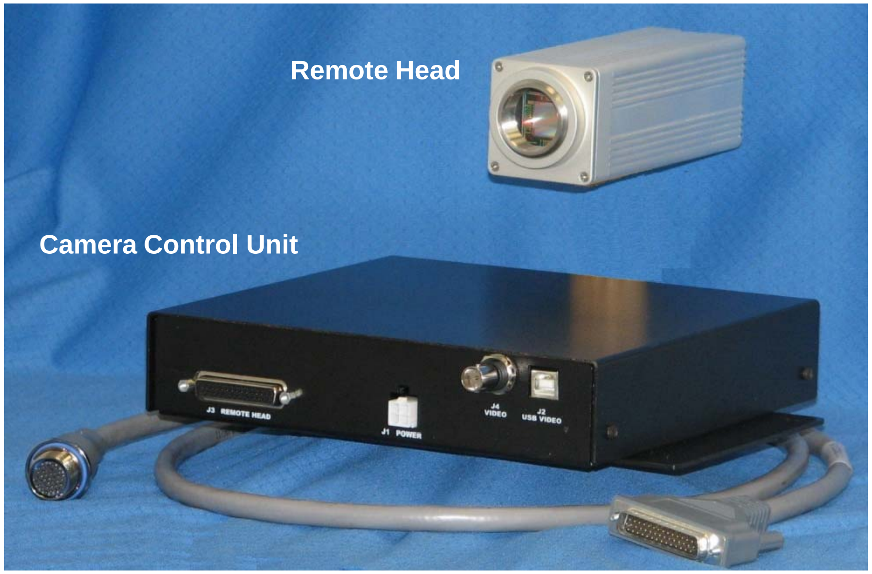
- The camera is critical to the operation of X-Ray radiation therapy equipment
  - The cameras are exposed to high levels of high energy X-ray radiation and >50C operating conditions
    - A CMOS or CCD camera installed in this application would cease to operate in a matter of hours

Application - Oncology Treatment (Cont'd)

The Tungsten leaves in the multi-leaf collimator system as seen by the CID sensor

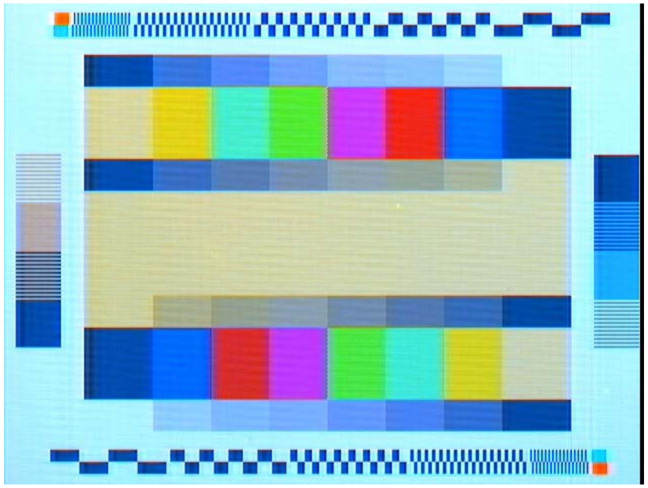


Key Products – Radiation Hardened – MegaRAD3

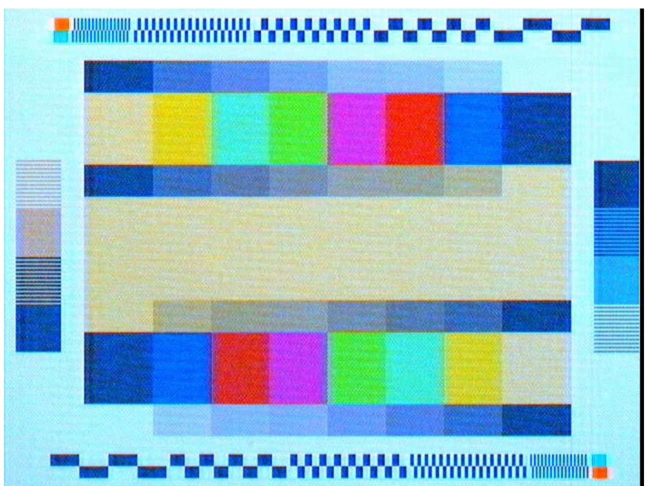


- World's only true commercially available rad-hard solid state color camera!
- NTSC or PAL format
- Radiation hardened to at least 3 Mega-rads (30 kilo-gray) with no degradation in performance
  - Has been tested to 14 Mega-rad (140 kilo-gray) with noticeable degradation in video image
- Digital USB2.0 output
- Replaceable remote head
- Supports cable length of up to 150 meters

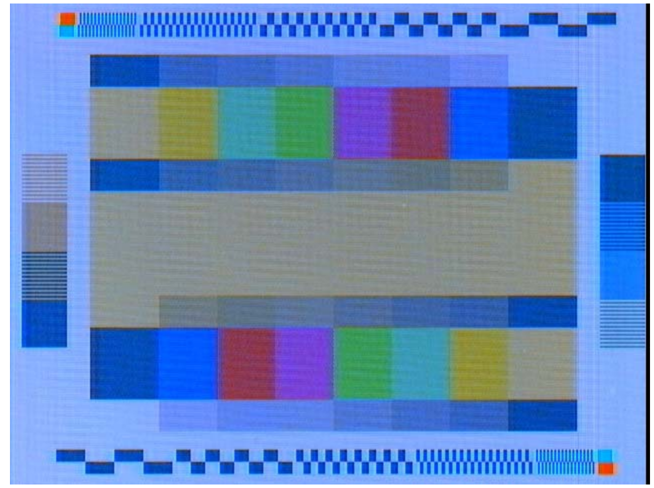
Performance of MegaRAD3 Camera in Radiation (^{60}Co Test)



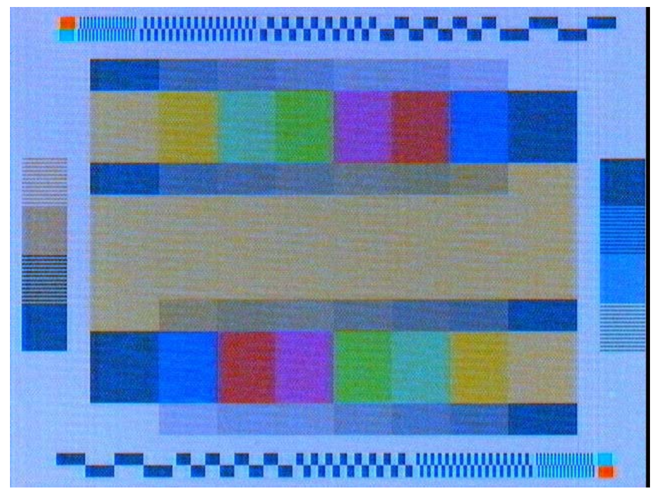
Start of the test (TID= 0rad, Flux = 0rad/hr)



TID= 0rad, Flux = ~36krad/hr



At the end of the test (TID= 3.9Mrad, Flux = 0rad/hr)
Note that the IR filter has browned resulting in reduced light transmission



TID= 3.9Mrad, Flux = ~55krad/hr
Note that the IR filter has browned resulting in reduced light transmission

Application: Patient Monitoring with MegaRad3

MegaRAD3 color camera used as a CCTV system

- The camera is used to used to monitor patient's comfort during radiation therapy
  - The cameras are exposed to various levels of X-ray radiation
    - Replaces CMOS cameras that were failing after months of use

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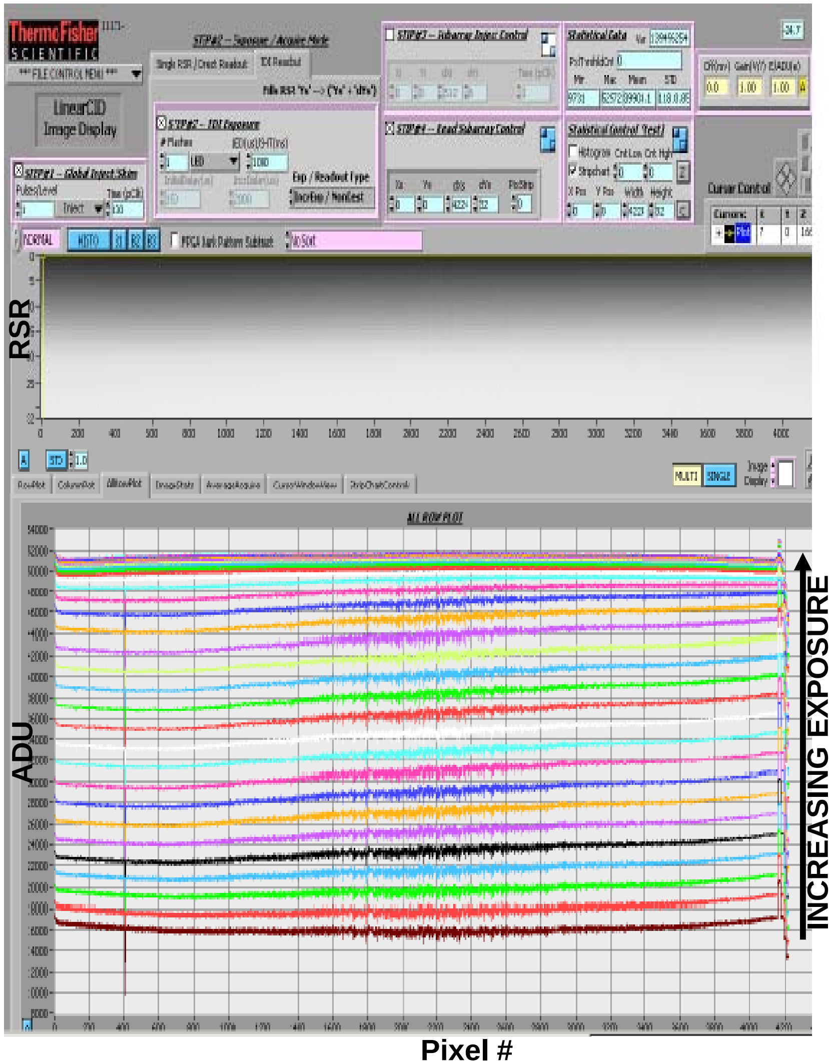
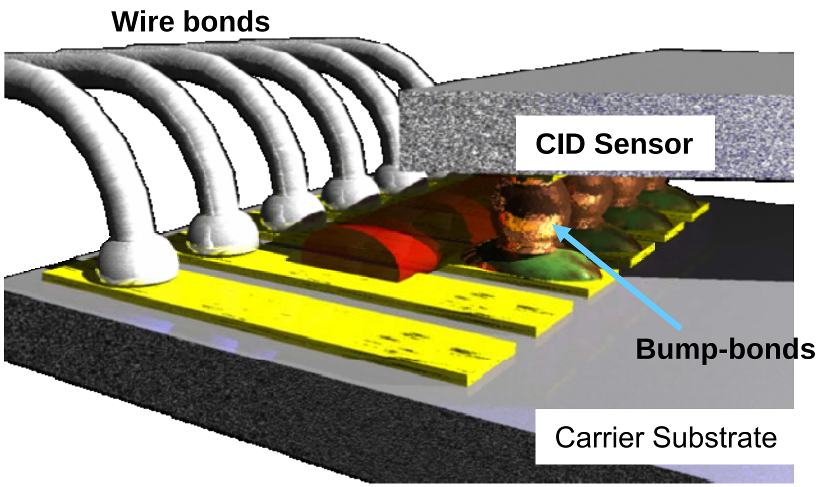
Linear CID System for Optical Emission Spectroscopy

- Developing a new Linear CID for OES
  - 4096 randomly addressable pixels
    - 14µm x 50µm tall pixels
      - Staggered arrangement resulting in 7µm pixel pitch
  - Features 32 Storage Registers
    - Allow for time-stamped storage of integrated charge
  - Designed to operate at pixel rates of 10MHz
  - Presently in evaluation stage



Improving the Quantum Efficiency of CID Sensors

- Back-thinning!
  - Goal is to back-thin the CID device to a few microns thickness
    - For enhancing blue (and UV) response
    - Will result in a commercially viable CID back-thinning process
- A custom process
  - Unique bump-bonding technique
  - Use of Magnetorheological Finishing (MRF)



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Conclusion

- Innovation is the lifeblood of the business
- R&D effort shall focus on enhancing the unique properties that CIDs offer in high-dynamic range scientific and radiation hardened applications
  - Develop camera systems that being high value to an OEM application
    - Improved sensor quantum efficiency
    - High speed scientific cameras
    - High resolution radiation hardened cameras systems
    - CID support chips

Thank you all your attention!

Extreme DR^{TM} Dynamic Range

$$R = \frac{E_f P_f P_2 Q}{m \sigma}$$

Where

- R = Extreme DR^{TM} Exposure dynamic range (full frame image)
- E_f = Ratio of full well capacity to lowest signal to be observed (typically 100 – 600)
- P_f = Ratio of user-specified exposure time to pre-exposure time (typically 100 – 300)
- P_2 = If two pre-exposures required, ratio of longer pre-exposure time to shorter pre-exposure time (typically 10)
- Q = Linear full well capacity
- m = Detection limit factor (2σ or 3σ)
- σ = Read noise

Extreme DR™ for an ICP-OES Application Using SpectraCAM™ XDR Camera

$$R = \frac{E_f P_f P_2 Q}{m\sigma} = \frac{275*150*10*275{,}000}{3*37} = 1.022\times 10^9$$

30-bits or 9 orders of magnitude!

Where

- E_f = 200. In order to maintain SNR, minimum signal should be 1000 photo-electrons. Maximum signal is full well (275,000 / 1000 = 275)
- P_f = 150. Typical exposure time is 60 seconds. Typical pre-exposure time is 0.4 seconds. (60 / 0.4 = 150)
- P_2 = 2nd pre-exposure can be about 0.04 seconds (0.4 / 0.04 = 10)
- Q = Linear full well capacity (~275,000 photo-electrons for CID820)
- m = Detection limit factor (3σ)
- σ = Read noise (37 electrons rms for SpectraCAM™ XDR system)