CMOS X-Ray Detectors
for Industrial NDT & Inspection

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Teledyne Rad-icon Imaging

TELEDYNE DALSA
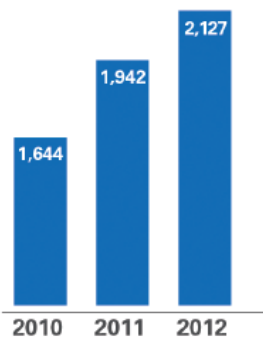Everywhere**you**look™

Teledyne Technologies

- Technology for a challenging world
  - Defense communications
  - Offshore exploration and production
  - Infrared imaging
  - Environmental monitoring
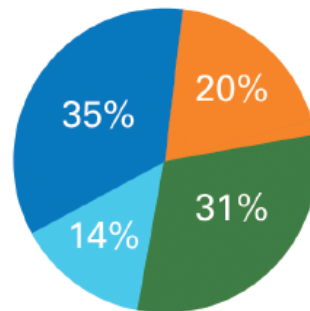 - Missile defense engineering
  - Commercial aviation

Sales Growth
$ in millions

2010	2011	2012
1,644	1,942	2,127

2012 Sales

- 35%
- 20%
- 31%
- 14%

Segment Overview

- **Instrumentation**
  Test and measurement, monitoring and control instrumentation, and power and communications connectivity devices for marine, environmental, electronics and other applications

- **Digital Imaging**
  High performance sensors, cameras and systems within the visible, infrared and X-ray spectra, used in industrial, government and medical applications

- **Aerospace and Defense Electronics**
  Sophisticated electronic components, subsystems and communications products, including defense electronics, commercial avionics, and harsh environment interconnects

- **Engineered Systems**
  Innovative systems engineering, manufacturing and specialized products for government, energy and industrial customers

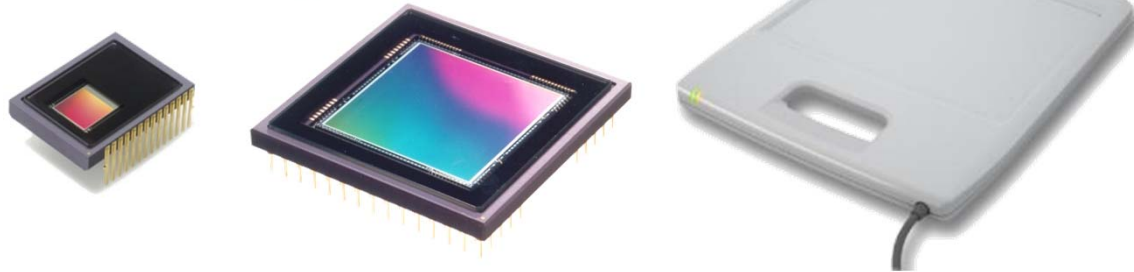**TELEDYNE DALSA**
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Teledyne DALSA's History

- 30 Years in Imaging as DALSA, a Canadian Public Company

- Focus on Image Sensor and Datapath Innovation

- Consistently Profitable

- Organic Growth + Acquisition Growth

- Legacy of Technology Leadership
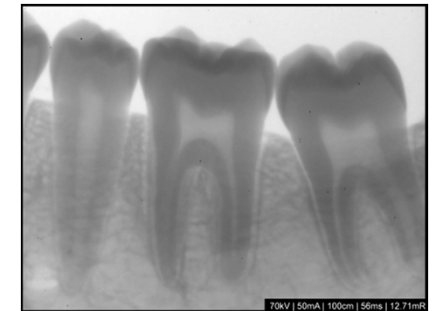
- Acquired in February 2011 by Teledyne Inc
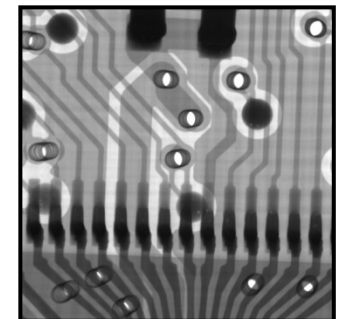
X-Ray Sensor/Detector Highlights

- *Medical **Diagnostics***

- *Dental Imaging*

- *Non-Destructive Testing*

X-Ray Detector (Manufacturing) Locations

Headquarter + Manufacturing   Manufacturing   Sales & Customer Support

CMOS Technology Advantages
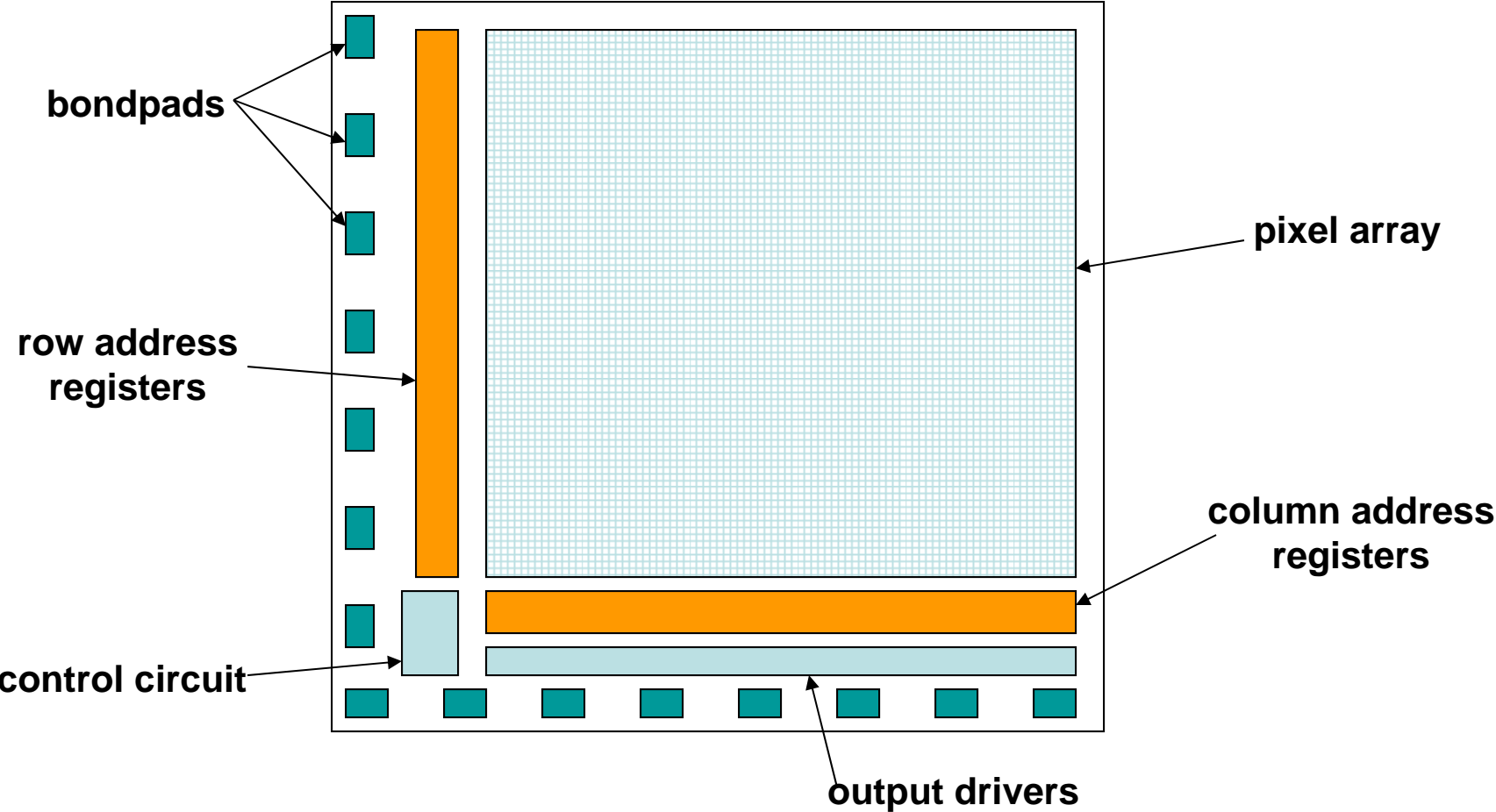
CMOS Technology Advantages
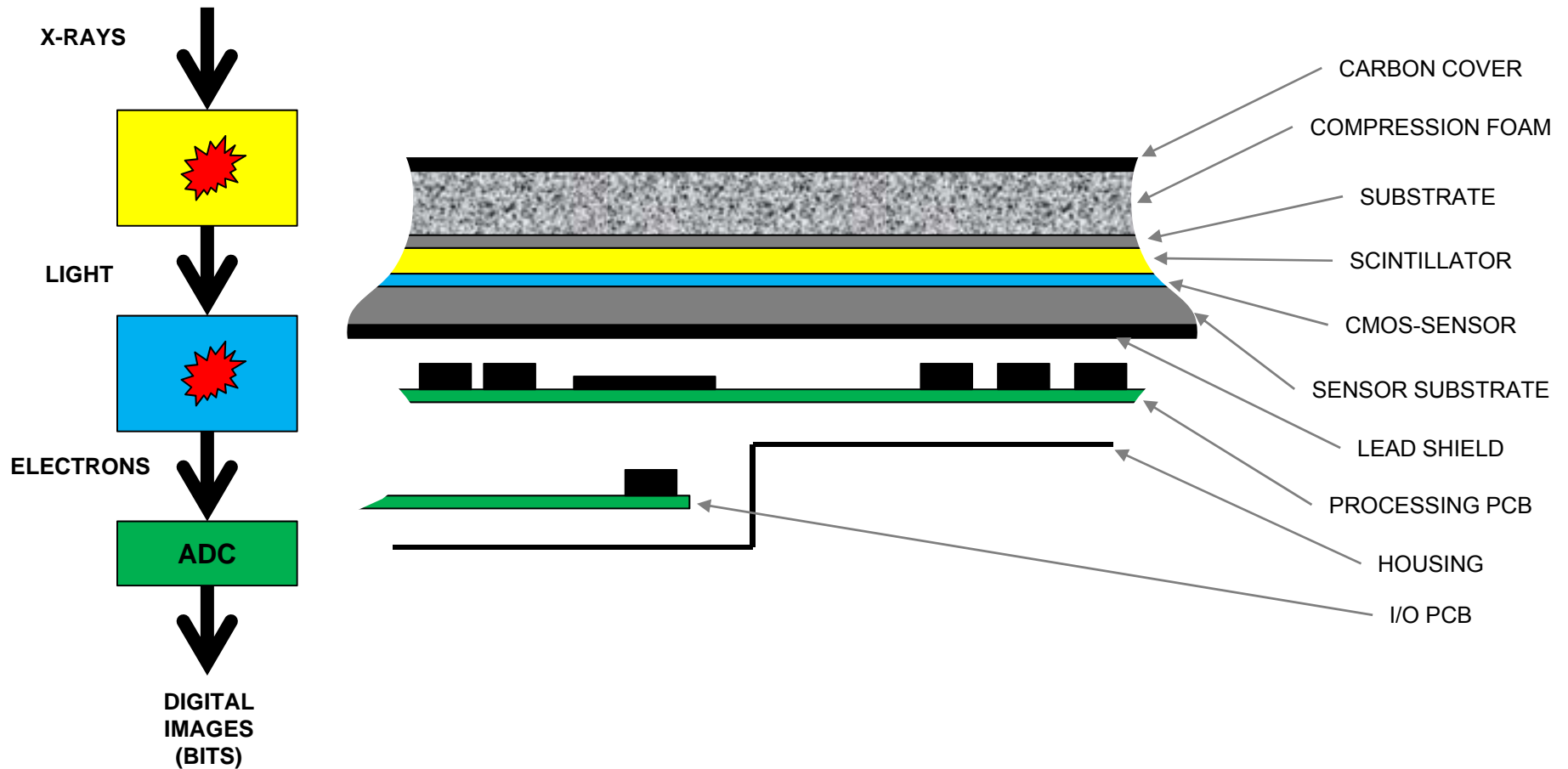
Leading Real-Time Imaging at Low X-Ray Dose

- Real-time ($\geq$30fps) imaging at full resolution
  - Enabled by high speed integrated circuits
- High diagnostic image quality (DQE) at low X-ray dose
  - Enabled by low noise CMOS
  - Up to ten times more sensitive (less noise) than amorphous silicon
- Increased resolving power (MTF)
  - Small CMOS pixel sizes with high fill factor, sensitivity
- Absence of image lag, ghosting and other artifacts
 - Enabled by high electron mobility and quality of CMOS process

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Integrated CMOS Image Sensor

bondpads

pixel array

row address registers

column address registers

control circuit

output drivers

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CMOS X-Ray Detector Architecture

X-RAYS

LIGHT

ELECTRONS

ADC

DIGITAL IMAGES (BITS)

CARBON COVER

COMPRESSION FOAM

SUBSTRATE

SCINTILLATOR

CMOS-SENSOR

SENSOR SUBSTRATE

LEAD SHIELD

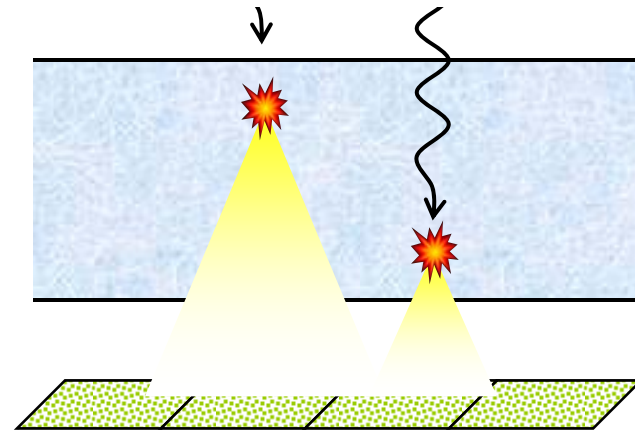PROCESSING PCB

HOUSING

I/O PCB

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Scintillators

- Converts x-ray energy to visible light
- Available as crystals, liquids, powders etc.
- Examples are $CaWO_4$, CsI and Gd_2O_2S
- Critical characteristics are conversion efficiency, absorption efficiency, and resolution
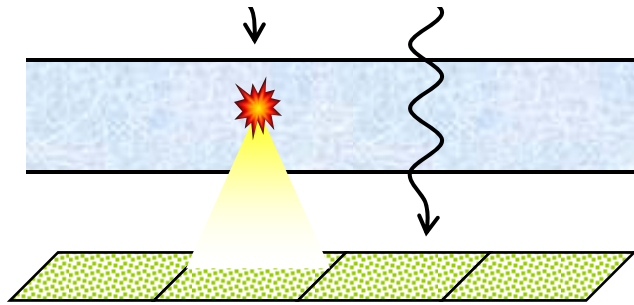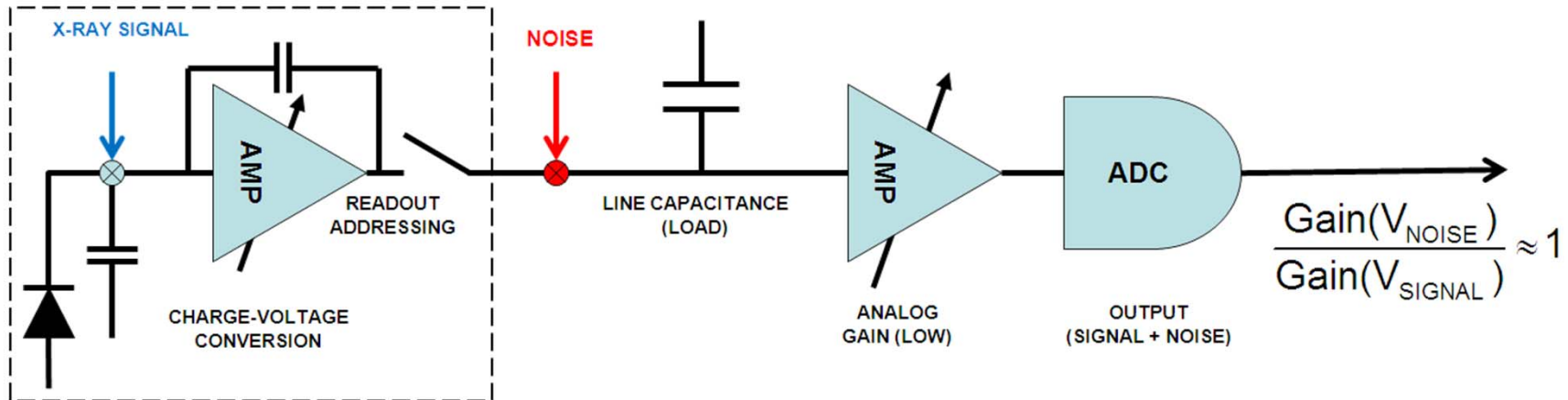
Thin Scintillator:
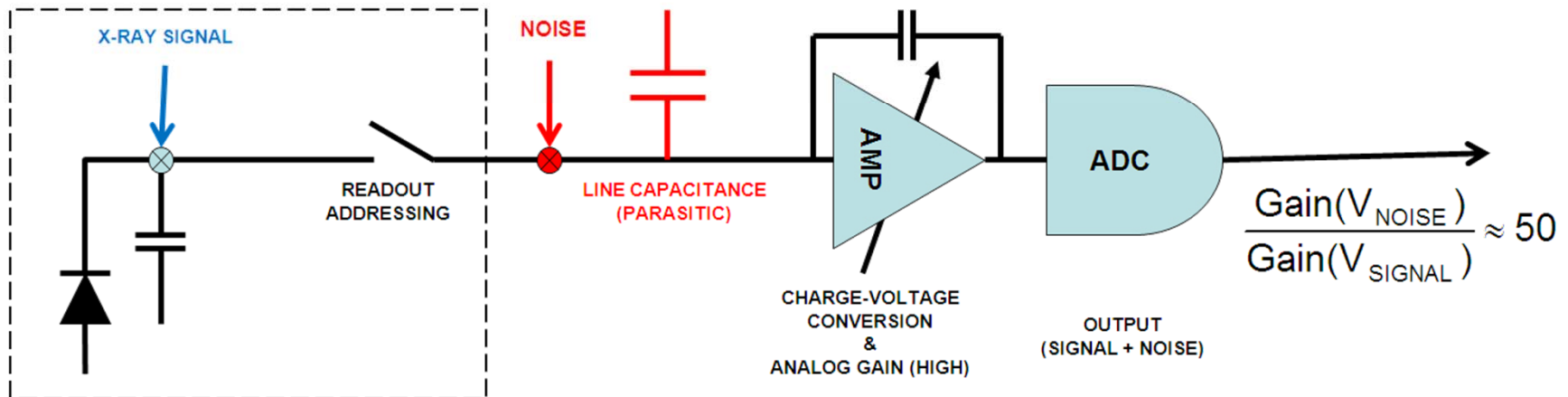- high resolution
- low sensitivity

Thick Scintillator:
- low resolution
- high sensitivity

Low Readout Noise

CMOS ACTIVE PIXEL

X-RAY SIGNAL

NOISE

AMP

READOUT ADDRESSING

CHARGE-VOLTAGE CONVERSION

LINE CAPACITANCE (LOAD)

AMP

ANALOG GAIN (LOW)

ADC

OUTPUT (SIGNAL + NOISE)

$$\frac{Gain(V_{NOISE})}{Gain(V_{SIGNAL})} \approx 1$$

AMORPHOUS PASSIVE PIXEL

X-RAY SIGNAL

NOISE

READOUT ADDRESSING

LINE CAPACITANCE (PARASITIC)

AMP

CHARGE-VOLTAGE CONVERSION & ANALOG GAIN (HIGH)

ADC

OUTPUT (SIGNAL + NOISE)

$$\frac{Gain(V_{NOISE})}{Gain(V_{SIGNAL})} \approx 50$$
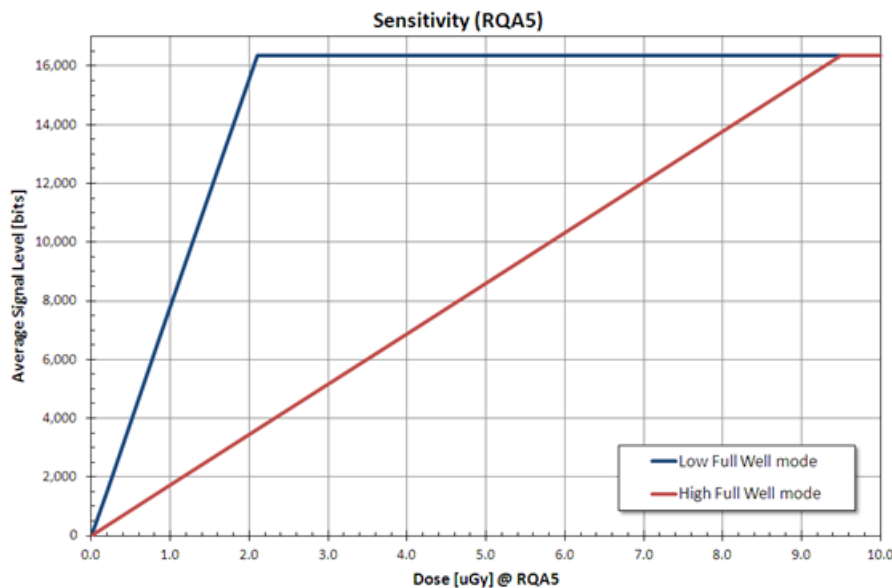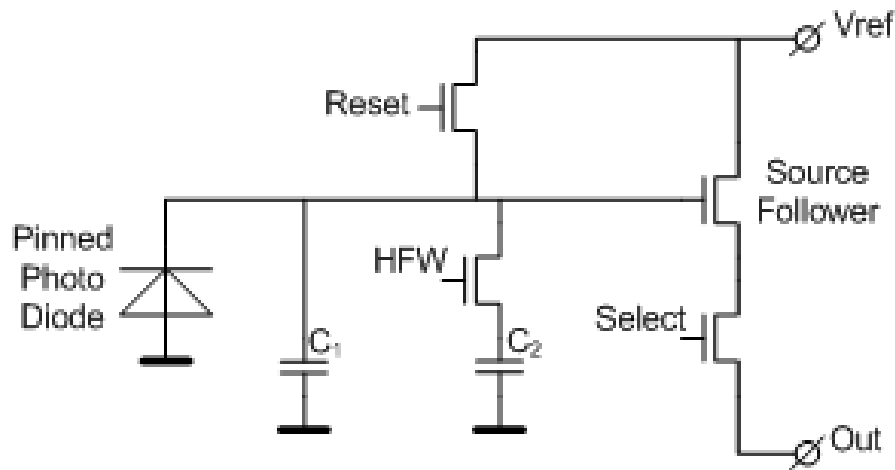
Detective Quantum Efficiency

$$DQE = \left(\frac{SNR_{out}}{SNR_{in}} \right)^2$$


X-Ray Detector DQE(0) @ RQA5
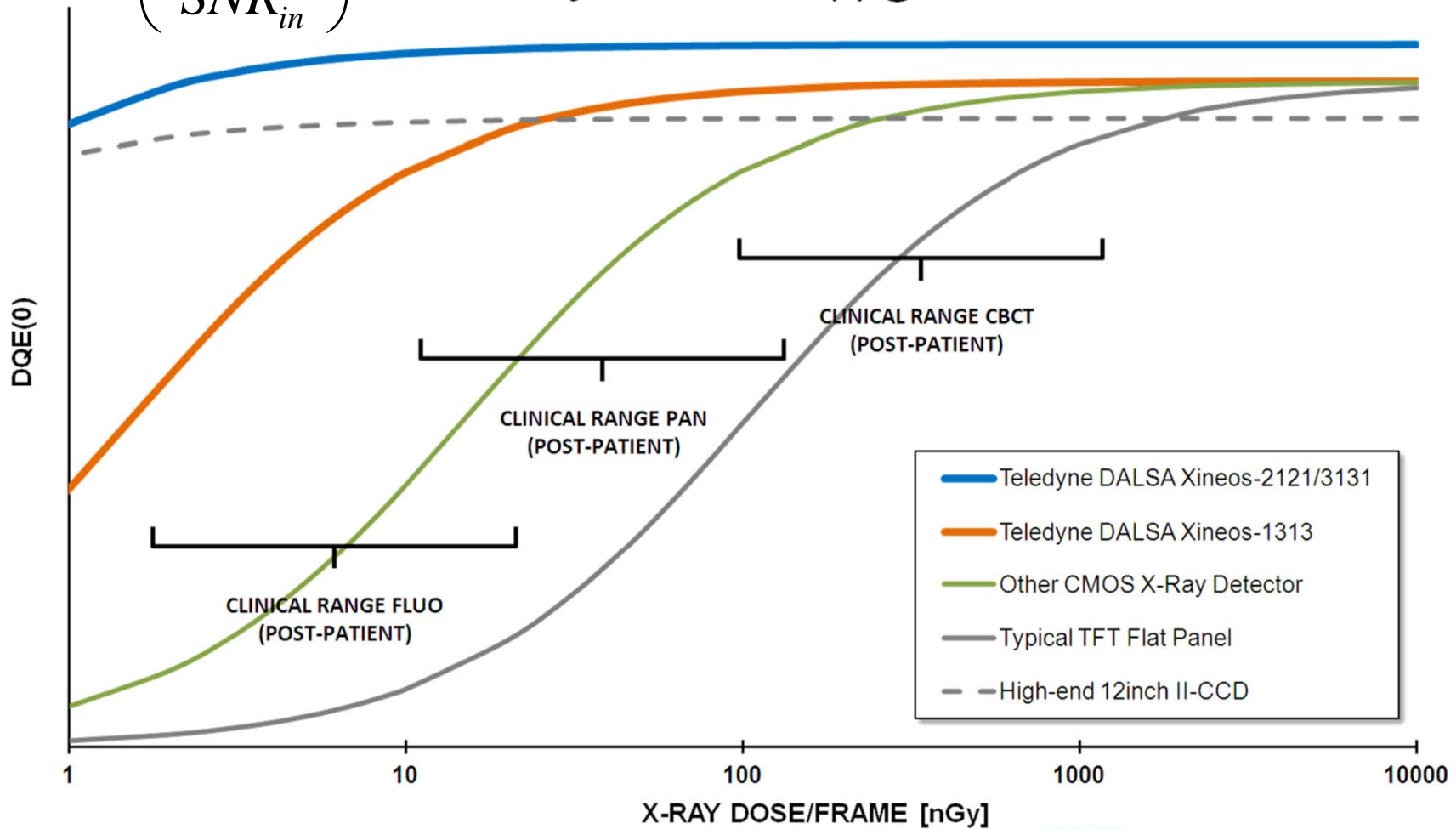
In-Pixel Switchable Sensitivity

- Pinned Photo Diode serves only as light sensitive element

- The connected capacitance defines the pixel sensitivity

- A switchable pixel sensitivity enables optimized performance for detector low and high dose operation

Radiation-Hard Sensor Design

- Sensor design optimized for constant detector performance over product lifetime
  - Response linearity
  - No additional pixel/row/column defects
  - Readout noise
- Very gradual changes over product lifetime
  - Sensitivity (scintillator)
  - Dark current (sensor)
- Dark current variations are intrinsically corrected by standard dark frame subtraction methods
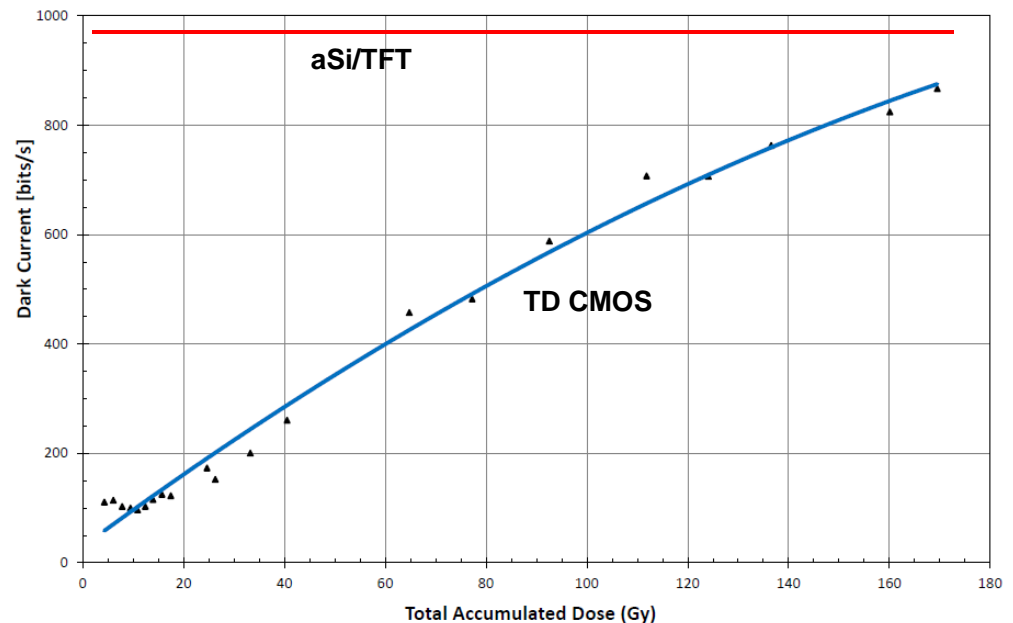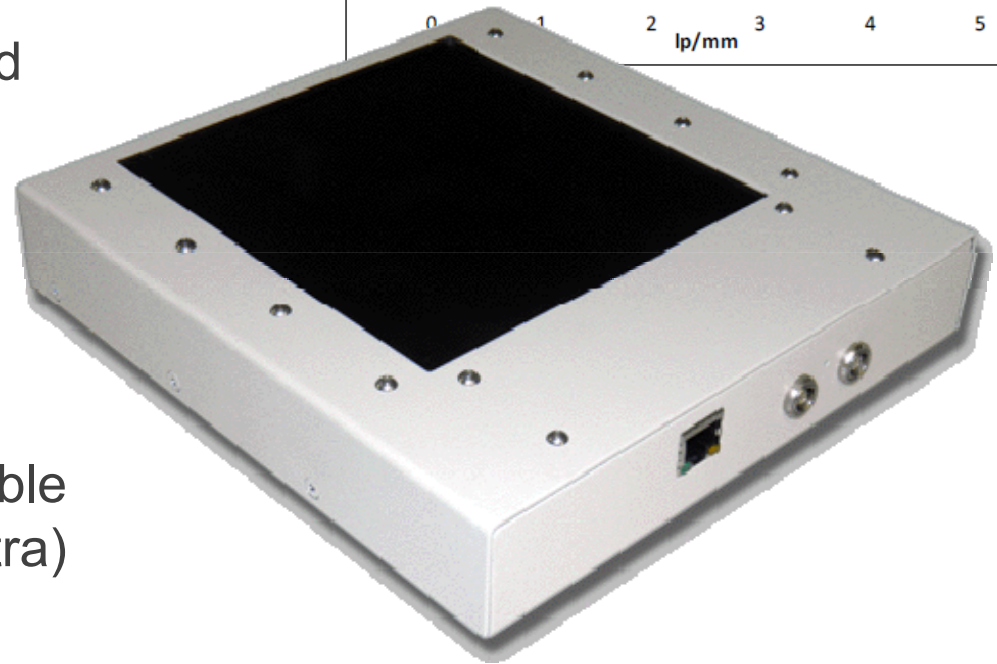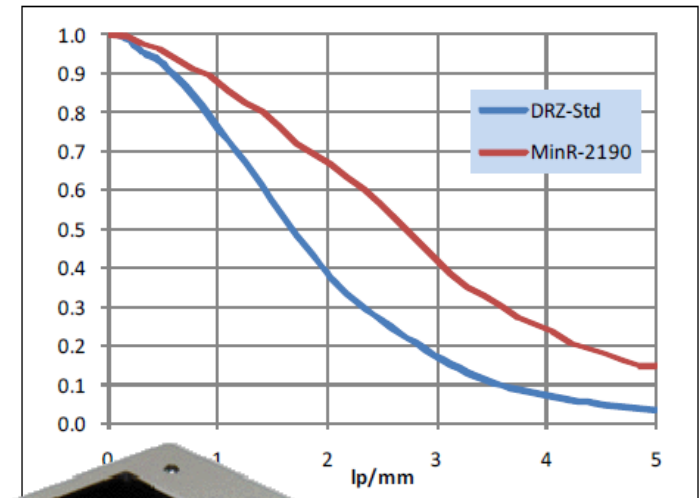
CMOS Detectors & Applications

Shad-o-Box 1280 HS

- Large active area of 12.8x12.8cm (5x5in)

- 5 lp/mm (100μm) resolution

- Real-time 30fps GigE interface
  - CameraLink option (OEM only)

- 14-bit digitization

- Radiation-hard up to 1 MRad at 225kVp

- Sensitivity as high as 15 LSB/μR (80kVp)

- Ready-to-run software, SDK, sample code

- Power supply & Ethernet cable included (trigger cable is extra)
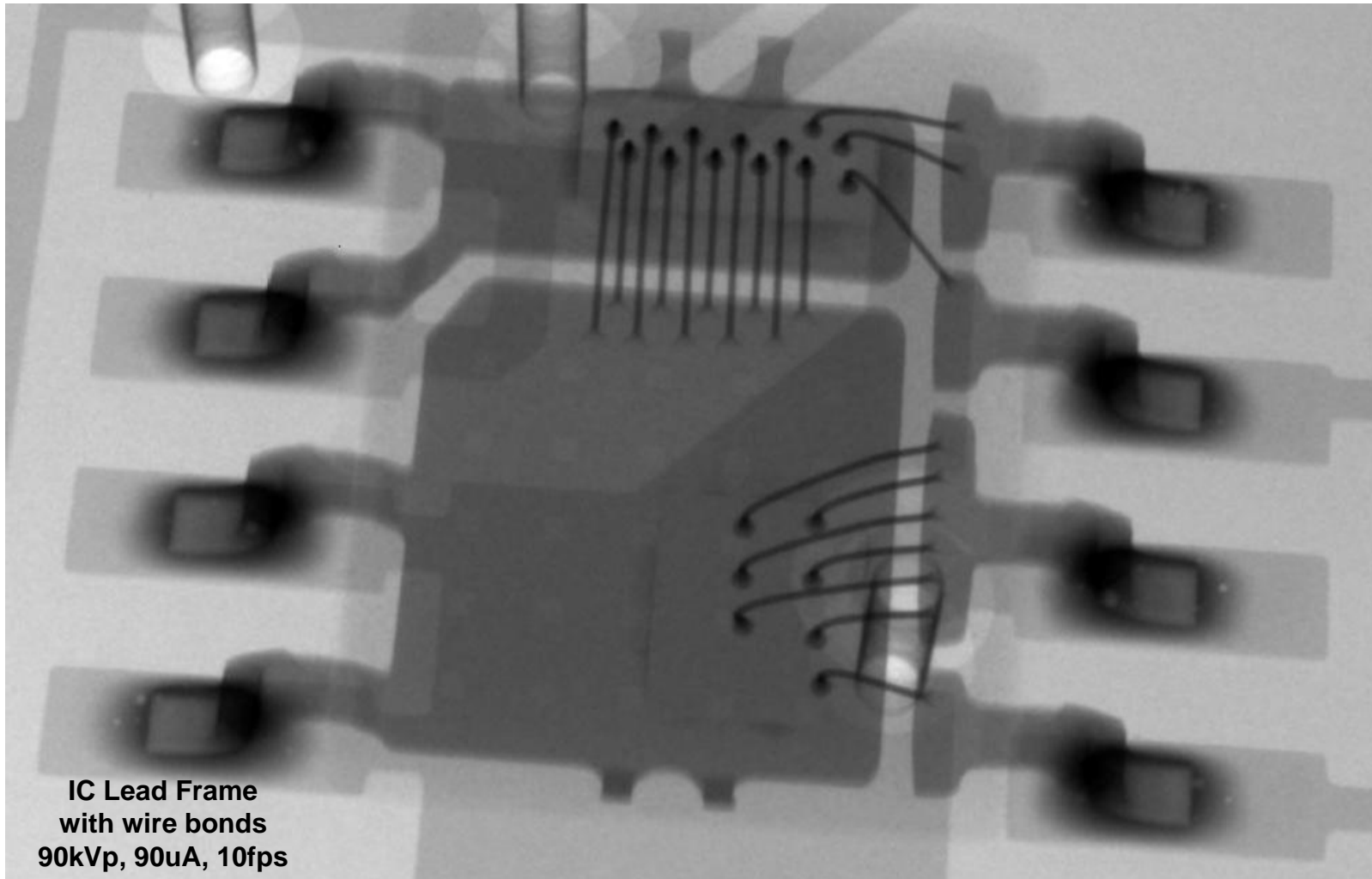
Cabinet X-Ray

- Electronics Inspection: cabinet systems for bare PCBs (alignment) or complete assemblies (solder joints, BGA, wirebonds etc.)

- Industrial CT: 3D analysis of parts ranging from micro-assemblies to engine blocks
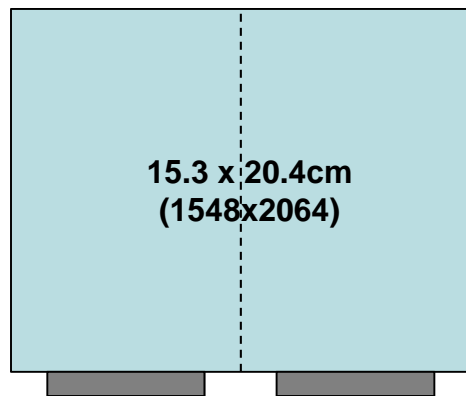
Micro-focus X-Ray

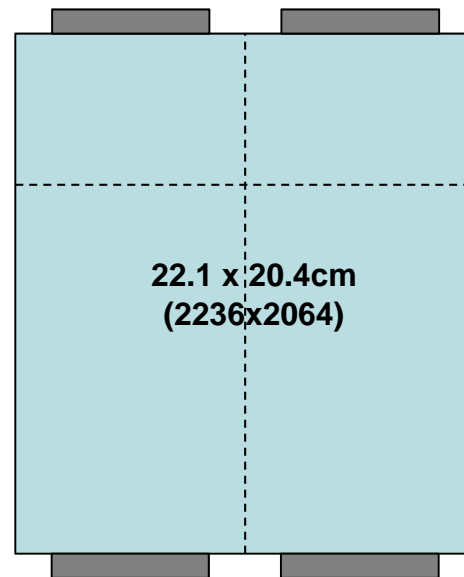

**IC Lead Frame
with wire bonds
90kVp, 90uA, 10fps**
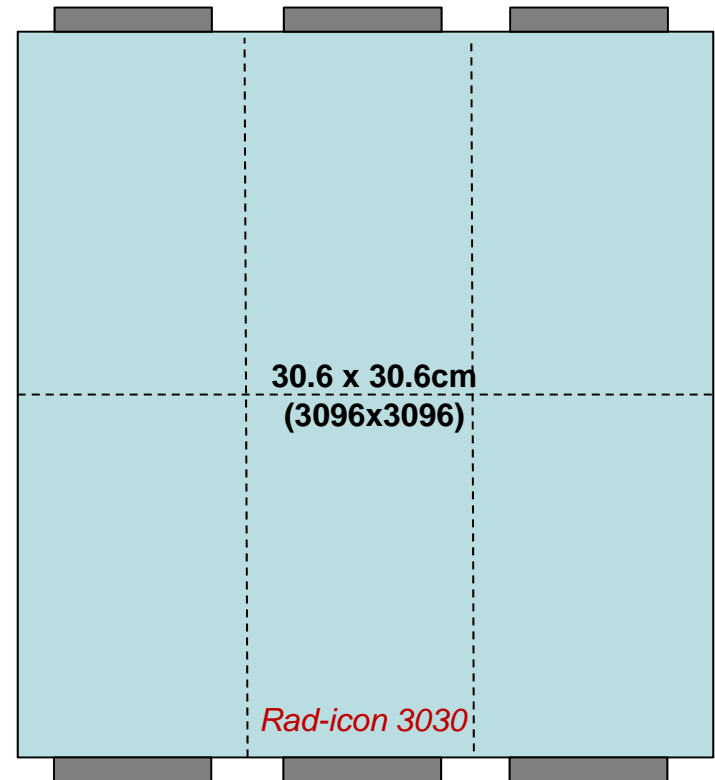
Multi-tile Detectors

Multi-tile, large-area cameras

- Based on Shad-o-Box HS 99 µm architecture
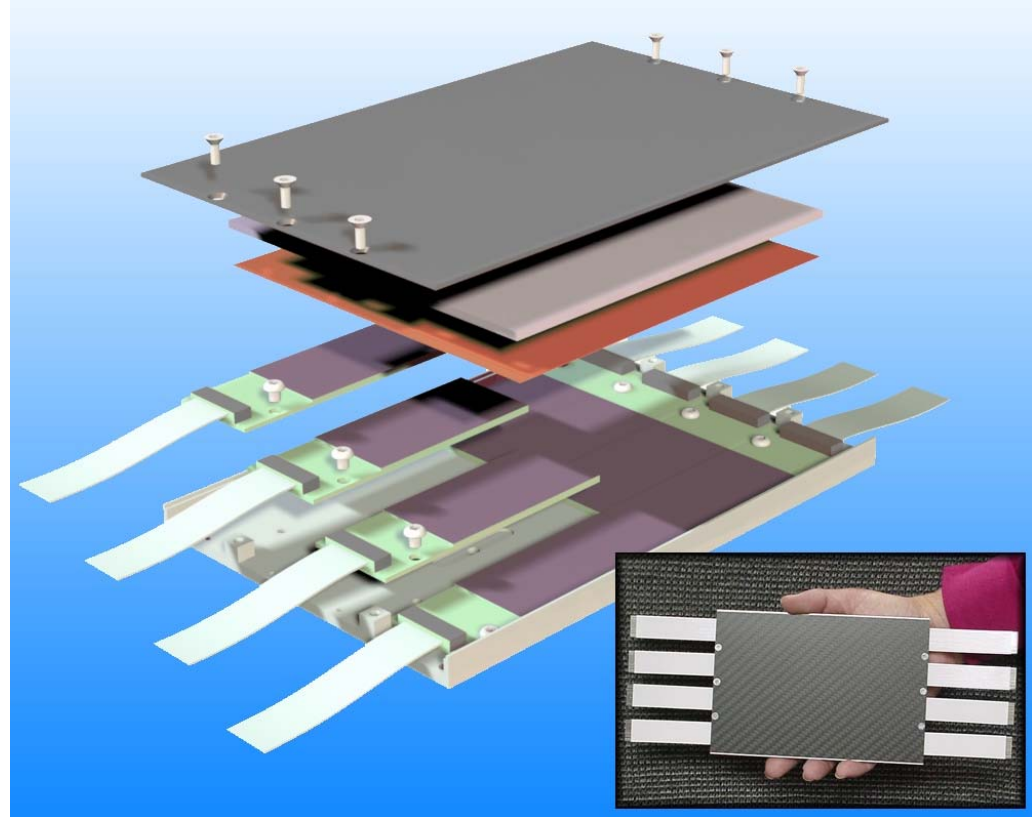- Real-time performance, radiation hard

15.3 x 20.4cm
(1548x2064)

Rad-icon 1520

22.1 x 20.4cm
(2236x2064)

Rad-icon 2022

30.6 x 30.6cm
(3096x3096)

Rad-icon 3030

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Large-Area Tiled Sensors

- Mulitple sensors tiled in *2 x N* array

- Active area up to 30x40cm (12x16")

- 100-200µm pixels

- Up to 225kV x-ray energy range
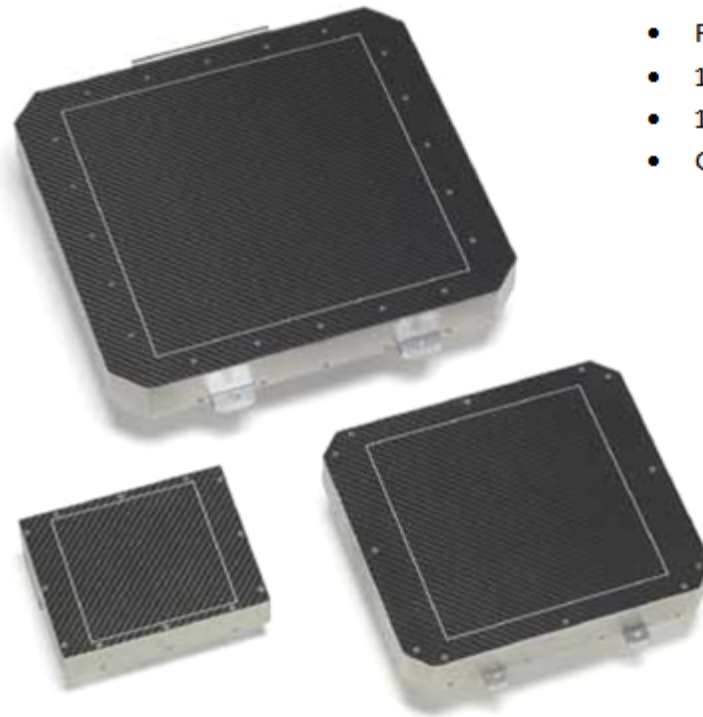
Shad-o-Box 3028 HS

- First large-area, tiled, real-time CMOS x-ray detector
- Active area of 30x28 cm (12" x 11")
- 8.3 Mpixel resolution at 100 µm pixel size
- 30 fps real-time video
- Dual CameraLink I/F
- 14-bit digital image quality
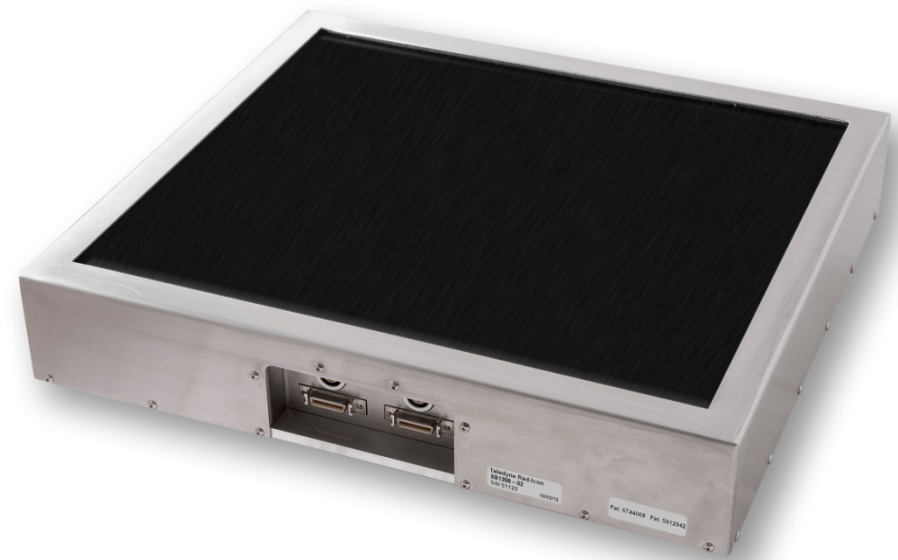
"Rad-icon" Large-Area Detector Family

Utilizing Teledyne DALSA's proprietary CMOS active pixel technology, the Rad-icon family of real-time CMOS x-ray detectors is the industry's first to exceed the low-dose performance of Image Intensified detectors, setting new industry benchmarks in DQE, low power dissipation and radiation lifetime.

- Real-time frame rates up to 30 fps
- 100 µm pixel size (5 lp/mm)
- 14-bit digitization
- GigE interface

Rad-icon 3030
Large-format detector designed to replace 12 inch II cameras.

available Oct.'14

Rad-icon 2022*
Medium-format detector with approx. 8x10 inch active area.

available Dec.'14

Rad-icon 1520*
Cost-effective dual-tile detector with 6x8 inch format.

available now

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Industrial Inspection / NDT

- Portable Inspection: Compact, portable x-ray panels for bomb detection, pipelines, infrastructure

- High Energy: Applications require up to 450kVp of x-ray energy to penetrate thick steel objects (compared to 70-120kVp for medical apps)

XT H 450

HIGH POWER
450KV MICRO CT

Portable Valve Inspection System

- Teledyne to develop a portable pipe valve x-ray inspection system consisting of:
  - High-voltage x-ray generator (200-300kV)
  - CMOS real-time x-ray detector
  - Laptop with software
- Estimated selling price $75-100K
- Ability to "see" in real time the motion of internal components
- Portable x-ray generator can be switched on only when needed
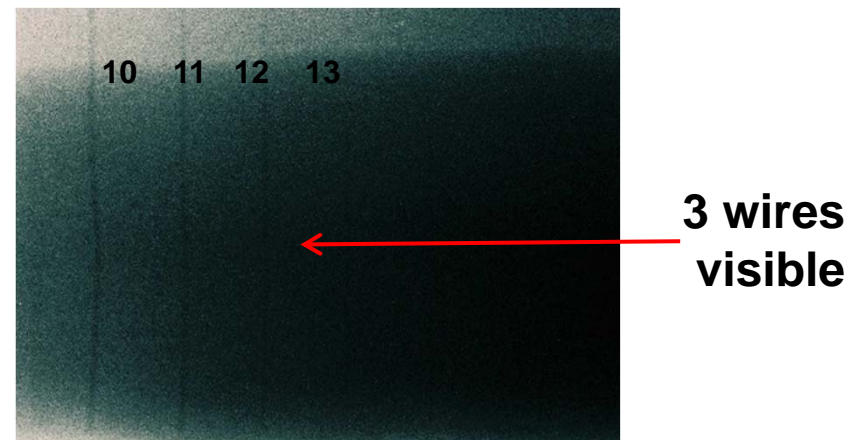- Live demo (world premiere!) tomorrow
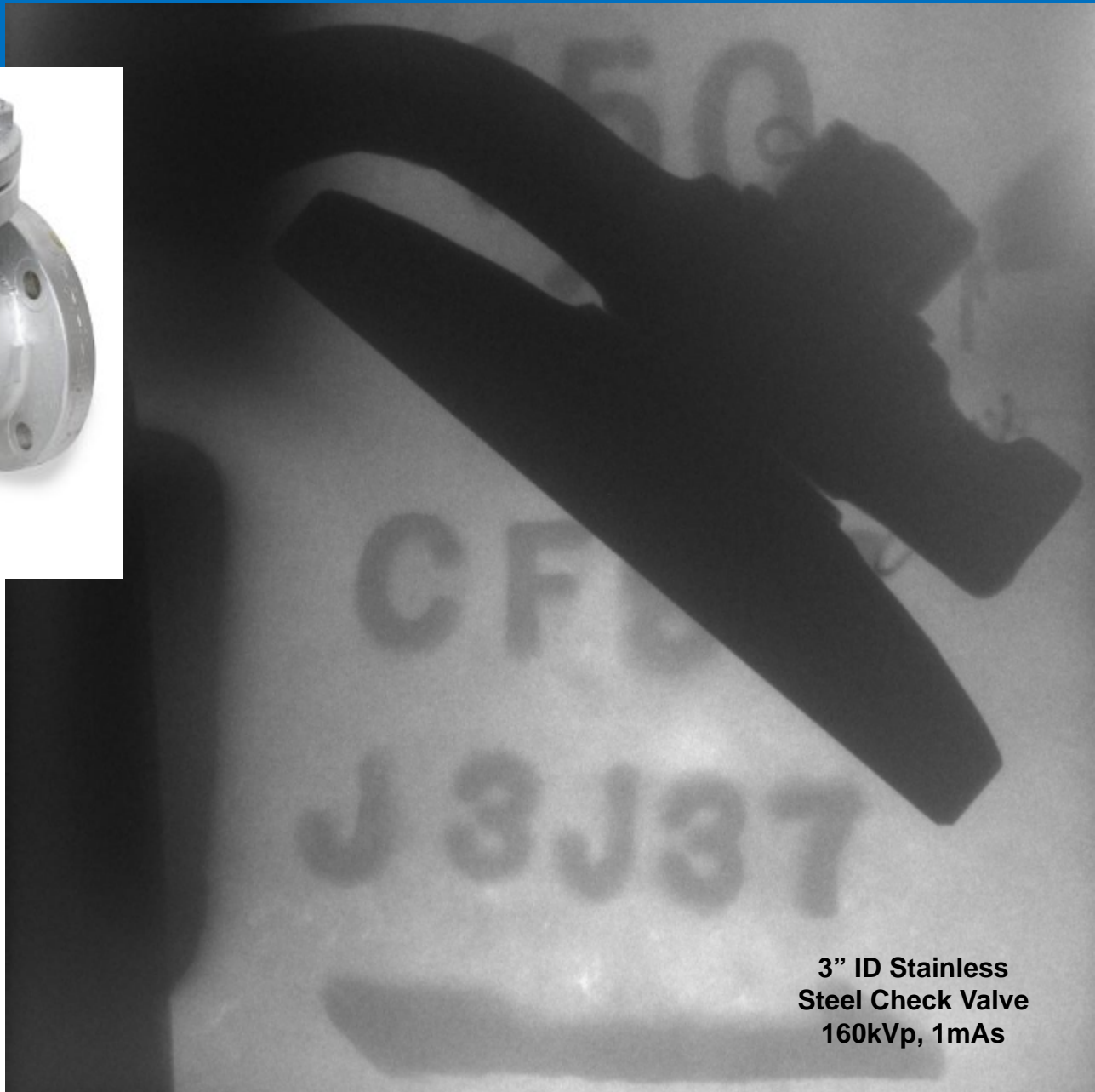
3" ID Stainless
Steel Check Valve
160kVp, 1mAs

Weld Inspection

- Teledyne DALSA CMOS Detector (99µm pixel size, 30x30cm area)

- ICM CP200 X-Ray Generator (200kV, 4.5mA, const. potential)

- EN 462-1 standard for 15mm steel plate: requirement is to observe D13 (Ø200µm) wire in IQI (Image Quality Indicator)

10   11   12   13

4 wires visible

CMOS, 10 sec Exposure

10   11   12   13
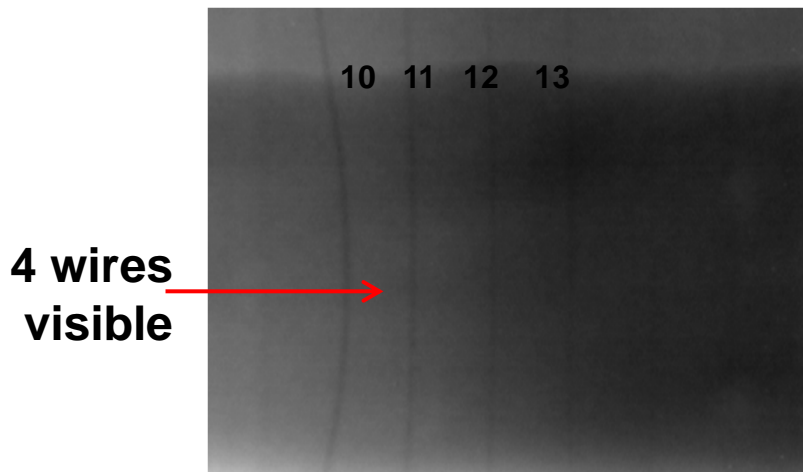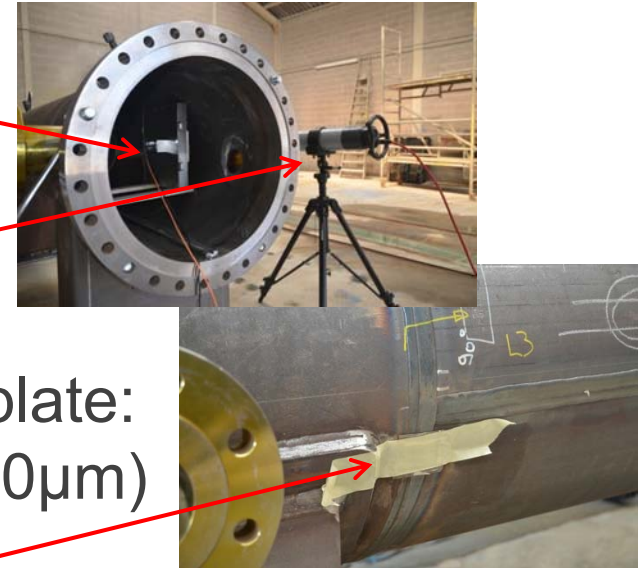
3 wires visible

Film, 2 min Exposure

Thank You!