CMOS X-Ray Detectors for Industrial NDT & Inspection

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Teledyne Rad-icon Imaging
Teledyne Technologies

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

Sales Growth

<table>
<thead>
<tr>
<th>Year</th>
<th>Sales ($ millions)</th>
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</thead>
<tbody>
<tr>
<td>2010</td>
<td>1,644</td>
</tr>
<tr>
<td>2011</td>
<td>1,542</td>
</tr>
<tr>
<td>2012</td>
<td>2,127</td>
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2012 Sales

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’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

Leading Real-Time Imaging at Low X-Ray Dose

- Real-time ($\geq 30$fps) 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
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
Scintillators

- Converts x-ray energy to visible light
- Available as crystals, liquids, powders etc.
- Examples are CaWO$_4$, CsI and Gd$_2$O$_2$S
- 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

AMORPHOUS PASSIVE PIXEL

Gain($V_{NOISE}$) / Gain($V_{SIGNAL}$) ≈ 1

Gain($V_{NOISE}$) / Gain($V_{SIGNAL}$) ≈ 50
Detective Quantum Efficiency

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

X-Ray Detector DQE(0) @ RQA5

- Blue: Teledyne DALSA Xineos-2121/3131
- Orange: Teledyne DALSA Xineos-1313
- Green: Other CMOS X-Ray Detector
- Gray: Typical TFT Flat Panel
- Dashed: High-end 12inch II-CCD
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
Large-Area Tiled Sensors

- Multiple sensors tiled in $2 \times N$ 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.

Rad-icon 3030
Large-format detector designed to replace 12 inch II cameras.
available Oct.'14

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

Rad-icon 2022*
Medium-format detector with approx. 8x10 inch active area.
available Dec.'14

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

Film, 2 min Exposure

CMOS, 10 sec Exposure
Thank You!