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Ultra-fast X-ray Imager

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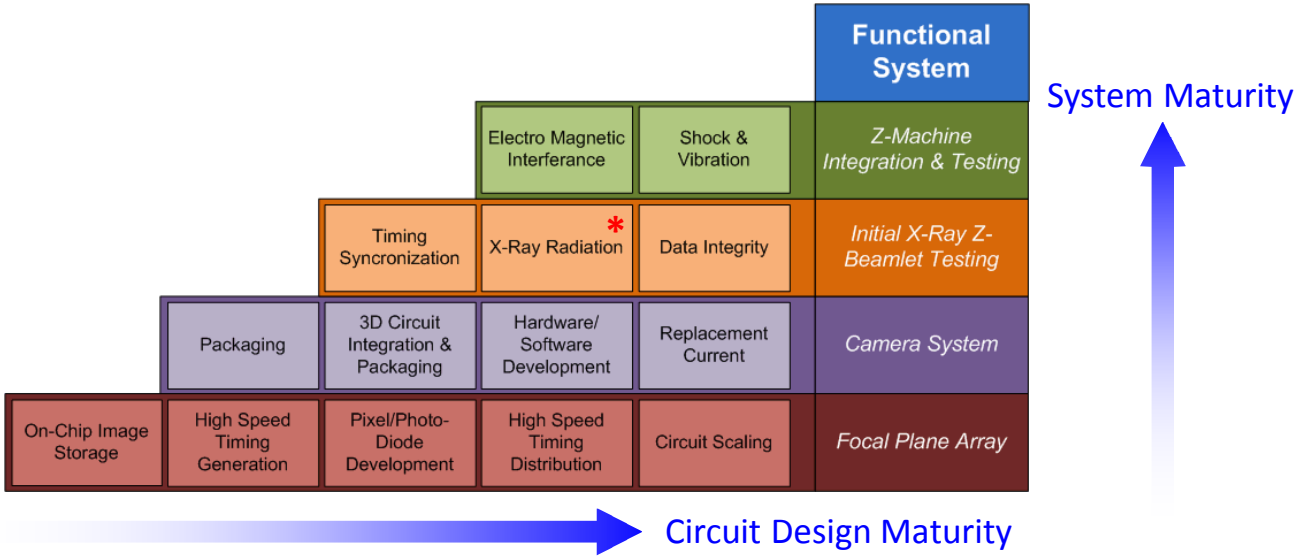
Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

Program Description

- Primary Goal
  - Develop a high speed, multi-frame, radiation hardened digital X-Ray imaging system for the Sandia National Laboratories Z-Machine
- Development Approach
  - Multi-year program with intermediate milestones that build off of successful proof of concept designs and cycles of learning



* Current program state

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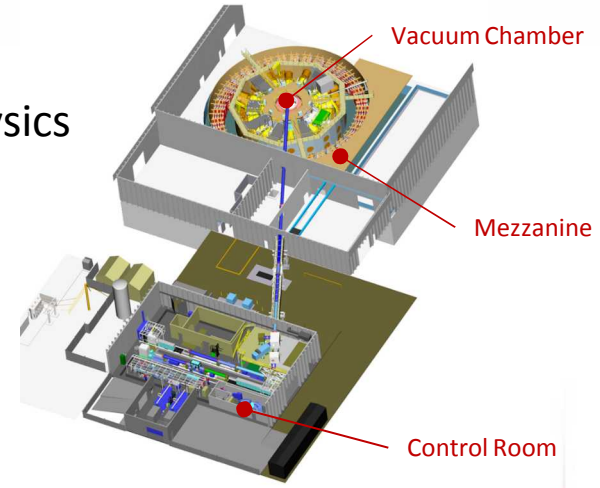
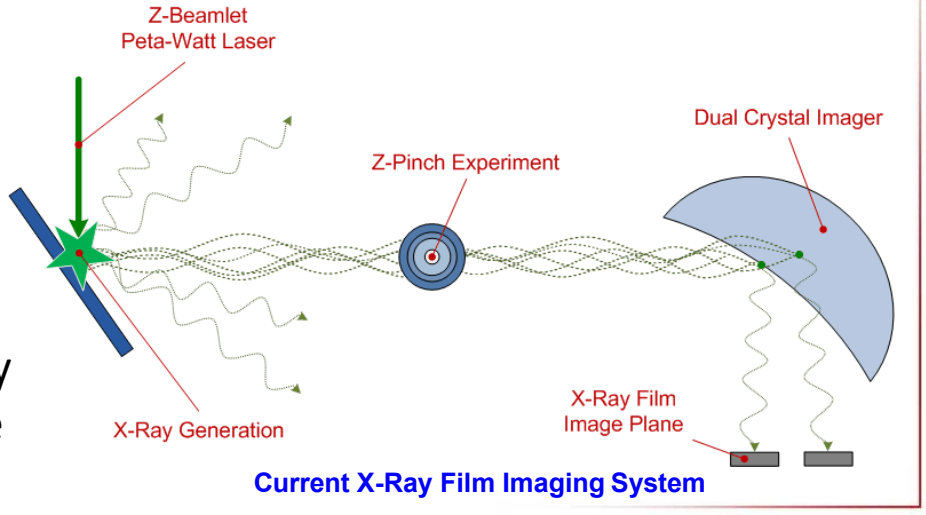
Application Space

- Sandia Z-Machine
  - Used for inertial confinement fusion and weapon physics experiments in support of the Stockpile Stewardship Program
  - Magnetic fields are used to implode BB sized targets
    - Implosion collisions occur along Z-axis; “Z-Pinch”



Z-Beamlet and Z-Machine Facilities

- Z-Pinch Imaging
  - Z-Beamlet (ZBL) is a laser used to generate 6KeV X-rays that act as a “flash bulb” in order to image the Z-Pinch
  - Dual crystal imager system splits the X-Rays spatially and temporally thus allowing for two images to be captured



Current X-Ray Film Imaging System

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Program Benefits

- Impact
  - Cost
    - An experimental data set (8-10 images) could be collected in a single Z-machine shot for ~$100,000, a cost reduction of $900,000

Estimated yearly savings of $5,400,000

  - Z-Machine Operation Time
    - A digital imaging system with multi-frame imaging would save ~ 2 weeks of operating time for each experiment (10 weeks/year)

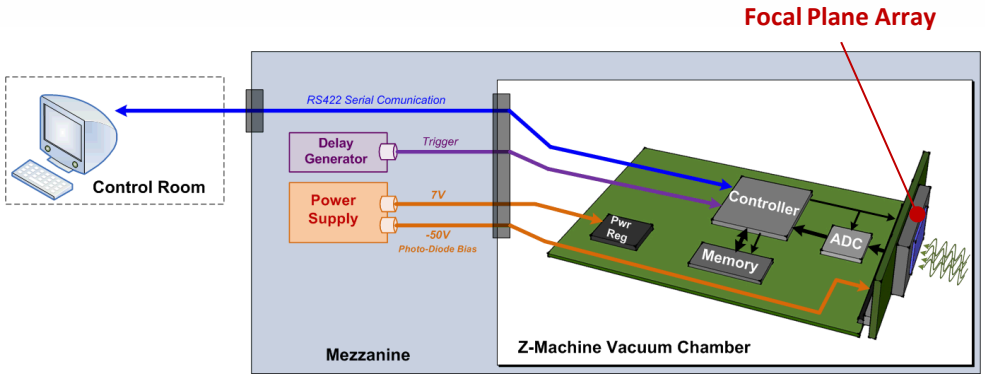
20% more Z-Machine time available for new experiments
(current demand for experiment time greater than availability)

  - Data Set Accuracy and Fidelity
    - Images would have reduced integrated background noise and would be created from a single Z-shot, eliminating timing jitter, target non-uniformities, and Z-machine dynamics that exist when a data set is created from multiple Z-machine shots

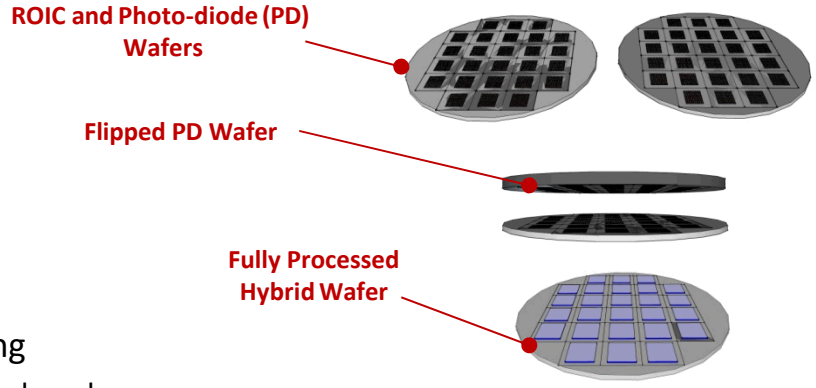
A UXI Imaging System would enable the collection of higher quality data, resulting in improved weapon/fusion modeling and research

UXI Imaging System Overview

- Targeted System Concept
  - System Software
  - Control/Support Electronics
    - Control chip (FPGA/Custom I.C.)
    - Analog to digital converter
    - Memory
    - Power conditioning
  - Focal Plane Array
    - 128x256 active pixels
    - High speed/adjustable image capture
      - 1-5 ns integration time, 2-25 ns frame rate
    - On-chip front end pixel test circuitry
    - ZIPTRONIX DBI© Hybridization
    - CMOS7 .35um radiation hardened processing
      - Metal-Insulator-Metal (MIM) capacitors developed



Imaging System Concept



Wafer to Wafer Bonding

Sandia is extending it's manufacturing capabilities, partnering with industry, and developing custom mixed signal circuitry in order to realize a 1GHz imaging system

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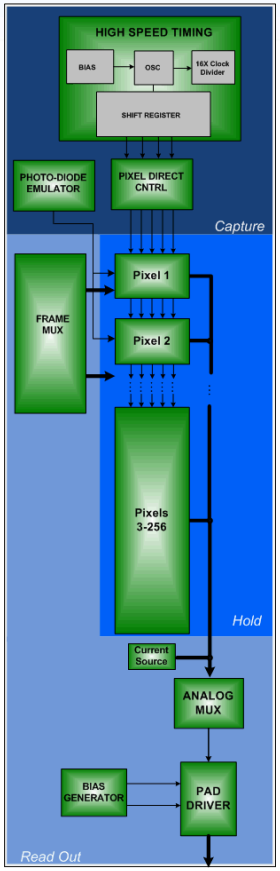
UXI Imaging System Overview (continued)

- Primary Technical Challenges
  - System Software
    - Maintaining data integrity across communication link
  - Control/Support Electronics
    - EMI/Radiation upsets
    - Data integrity of image data stored in memory
    - The minimization of noise injection on image data
  - Focal Plane Array
    - EMI noise
    - ~ 16A of replacement current (assuming full fluence on all pixels)
    - Minimizing the skew of high speed timing signals across the pixel array
    - Analog storage of image data prior to read-off
    - Generating repeatable high speed timing signals
    - 1ns response of photo-diode array

Progress

- FY09 Focus
  - Develop, fabricate, and test; pixel, high speed timing, and readout circuits for a single column
- FY09 Results
  - PHOENIX Read Off Integrated Circuit (ROIC)
    - Single column; 2 active/254 dummy pixels (to supply realistic parasitics)
    - On chip photo diode emulator that stimulates photo-diode response
    - Three separate read-off architectures implemented to determine best performance
  - Achieved targeted high speed capture, hold, and read-off of 2 active pixels for all three read-off architectures implemented



PHOENIX ROIC Block Diagram

The fundamental design elements of the UXI focal plane array (high speed timing , pixel, and read-off circuitry) were developed to the targeted needs of the program

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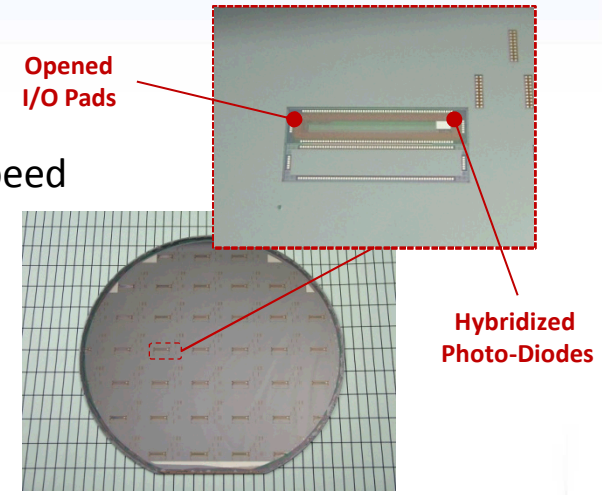
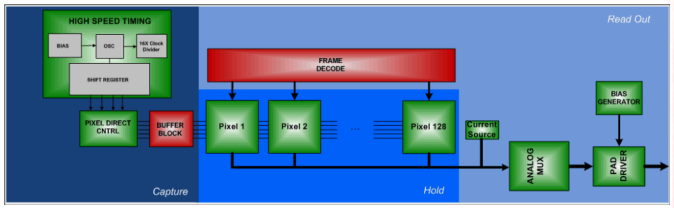
Progress (continued)

- FY10 Focus
  - 3D ROIC/Photo-diode hybridization
  - Develop ROIC circuitry that minimizes timing skew of high speed capture signals across 128 columns of pixels
  - 1st generation imaging system hardware/software



HARPI Bonded Wafer

- FY10 Results
  - HARPI ROIC/Photo-diode Hybrid – **2-pixel camera**
    - **Successful** hybridization of PHOENIX ROIC to photo-diode array
  - GRIFFIN ROIC:
    - 128 active pixels
    - Adjustable high speed timing and skew test circuits
    - 3D hybridization complete, packaging in progress



GRIFFIN ROIC Block Diagram

  - 1st Generation Imaging System
    - Control/support electronics and software developed
    - **Successful** initial testing of HARPI in Z-Beamlet using imaging system

The work performed this fiscal year culminated in the capture, storage, and read-off of Z-Beamlet X-Ray signals

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Progress (continued)

- FY11 Focus
  - Additional Z-Beamlet X-Ray testing of HARPI hybrid
  - Z-Beamlet testing of GRIFFIN hybrid
  - Development of 2nd generation imaging system hardware/software
    - Component and footprint reduction
    - Replace COTs parts with CMOS7 radiation hardened equivalents
  - Begin design of 256x128 ROIC and corresponding photo-diode array

The program is at a point where qualitative data can be taken and new information learned from the interaction of X-Rays on the UXI hybrid focal plane arrays. The knowledge gained shall be applied to the realization of a 256x128 pixel imaging system

Summary

- Imaging System Development
  - To date three ROIC iterations and a supporting hardware/software system have been realized with each targeting the implementation of a critical design requirement
    - 1GHz image capture timing signal generation
    - Storage and read-off of charge on new process MIM cap
    - 3D ROIC/Photo-diode array hybridization
  - The program is at a point where X-Ray data can be taken at the required speeds
- Path Forward
  - With additional X-ray testing the program will focus on the realization of 128x256 imaging system
  - Larger imagers (scaled or tiled 128x256) may be possible with the current architecture, however investigation is needed
  - Imaging system is of interest to other accelerators where high speed operation or hardness to radiation are fundamental needs