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# Printed Wiring Assemblies (PWA) and Counterfeit Detection using Non-Destructive X-ray CT Analysis

Christopher Walker

Sandia National Labs/Computer Science R&D

cwalke@sandia.gov

(505)284-7708

U.S. DEPARTMENT OF ENERGY NNSA

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# Purpose

- Non-destructive evaluation of printed wiring boards/assemblies (PCB) has many challenges when it comes to determining whether a product is suspect/counterfeit or plagued by poor workmanship.
  - Complexity of the circuitry (trace width, laser drilled via's, etc.)
  - Populated vs. unpopulated (mixed material density)
  - Gerber overlay and Gerber optimization for production (Impact of this?)
- From a hardware assurance perspective, the fundamental difference between these can have profound impact to delivery time and cost.
- Having a Gold Standard for comparison of CT X-ray images improves the fidelity of incoming inspection, reduces the time spent evaluating each article, and increases confidence on fielding quality hardware.
- Evaluating each inner board layer is difficult, but necessary as we find out.

# Outline

- Introduction
- Background
- Data collection approach
- Data processing pipeline
  - Turquoise and Laserbeak
- Results
  - Layer to Layer Comparison
  - Layer to Gerber
- Image Artifacts on populated boards
- Future Work
- Conclusions

# Introduction

- Supply chain validation and verification is crucial in the digital age.
- Once the design file has left custody, the “Digital” wild west is all that remains.
- How does one quickly and reproducibly verify if a multi-layer printed circuit board is authentic to design?
- How does one separate out low quality/poor workmanship from suspect/counterfeit?

# Background

Exemplar PCB – 16 Layer Class 3 Printed Wiring Board

- IPC for Class 3 calls out
  - Outer Layer– annular ring – 50 micron
  - Inner Layer – annular ring – 25 micron
- Turquoise - an SNL developed software, paired with Laserbeak – an SNL software package
- A Golden Copy X-ray image and Gerber files can be compared on a layer to layer basis through differential imagery analysis to view the specific changes.
- Size of the board: 11” (W) X 16” (L) – 0.080”(H)
- Where to start?:
  - Dense via./plating areas.
  - FPGA - good start.
  - Others locations include a memory and processor

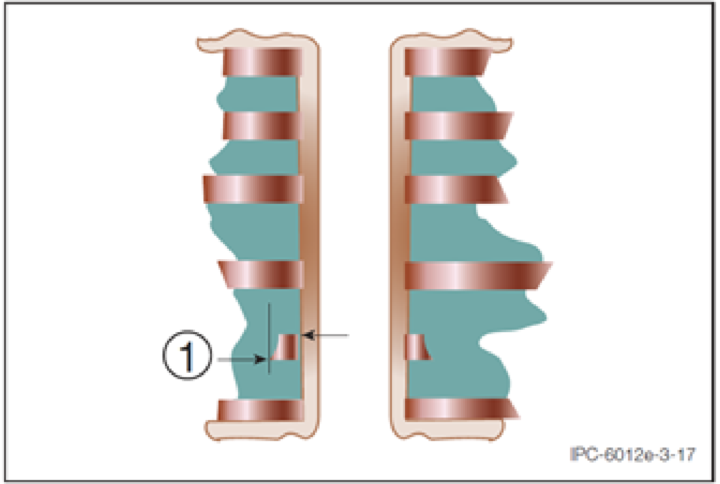
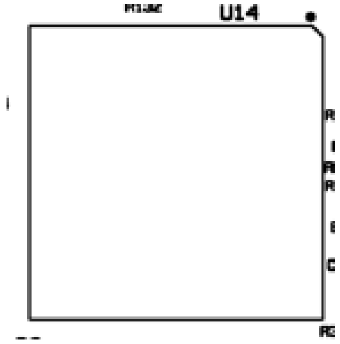
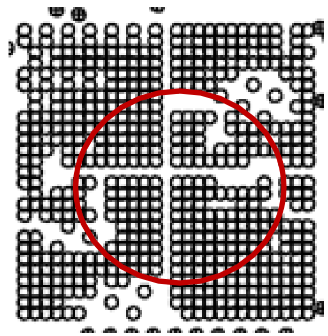


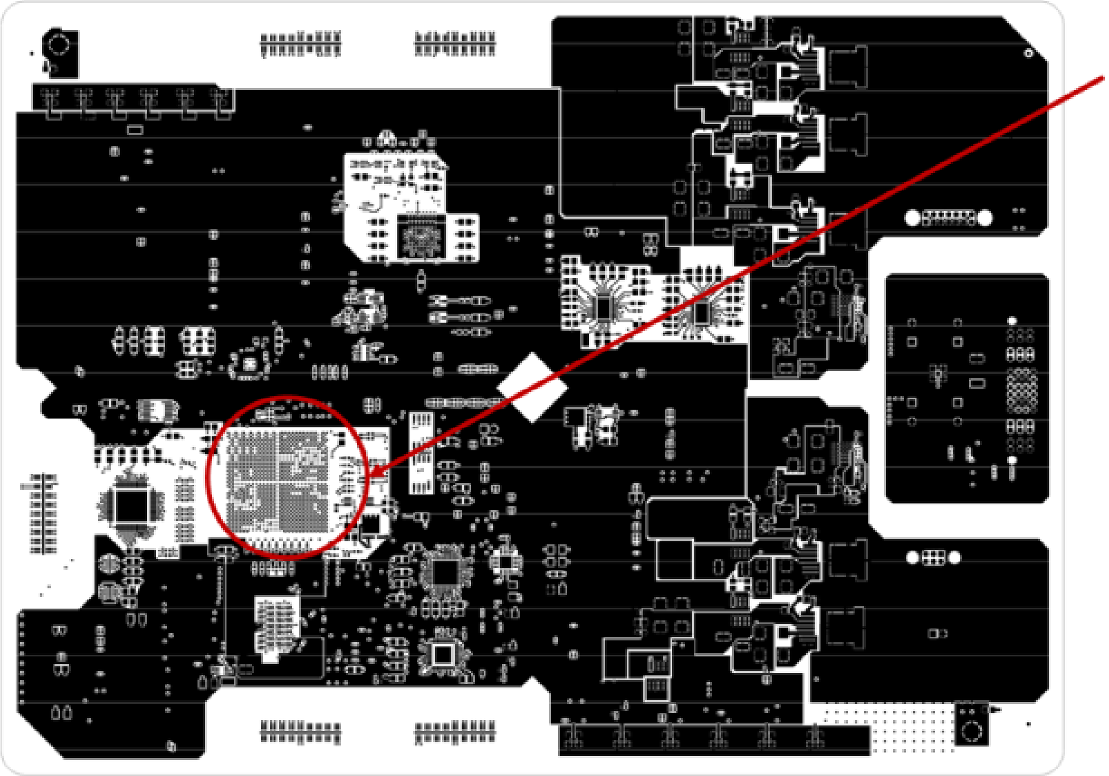

**Figure 3-17 Annular Ring Measurement (Internal)**

Note 1. Measurement of internal annular ring.



# PCB Analysis

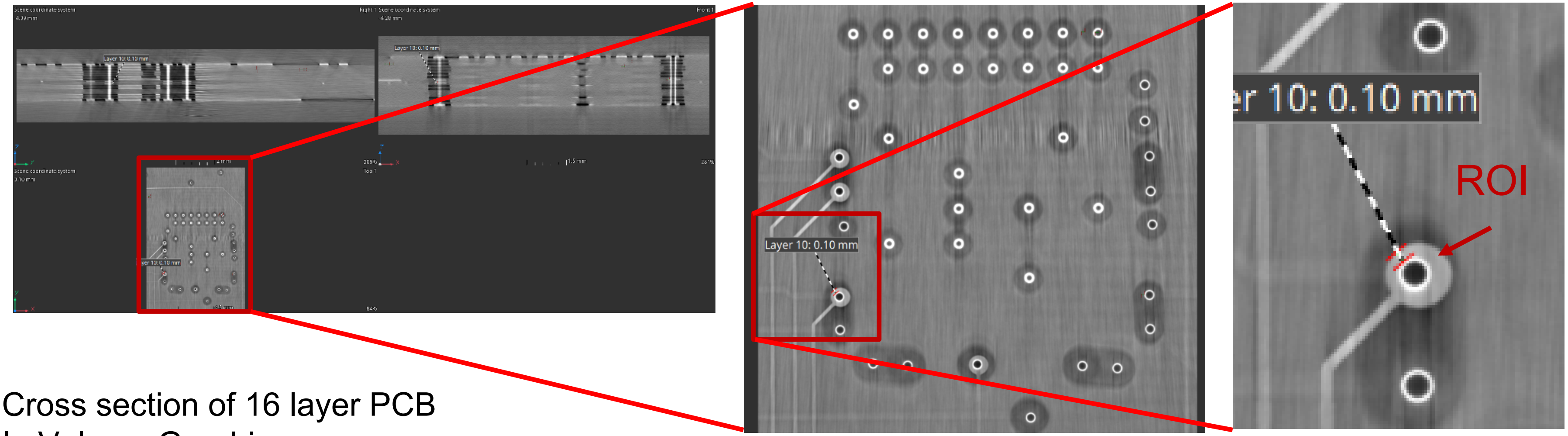


FPGA is the region of interest

High density drilled via's through the board provide details on annular ring information for Class 3 PCB inspection.

# Data Collection Approach

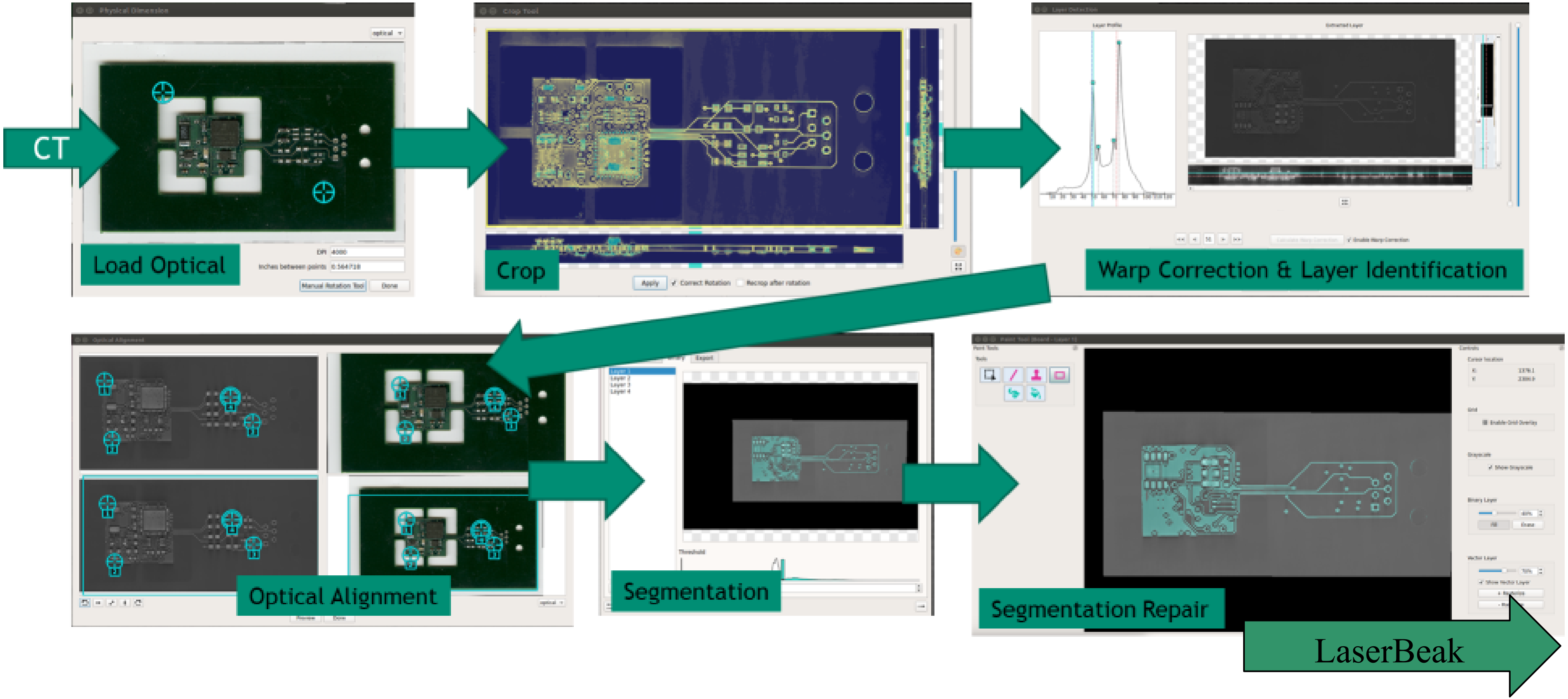
- X5000 CT –X-ray setup
- Need at least 12-16 micron resolution to determine issue of 25 micron plated via. (annular ring) for the region of interest (region in red for measurements and inner layer evaluation)
- Beam hardening required due to the asymmetry of the hardware
- Cannot swing the board a full 360 degrees due to resolution. - ~ 275 degrees Partial Scan and Reconstruction.




Cross section of 16 layer PCB
In Volume Graphics.

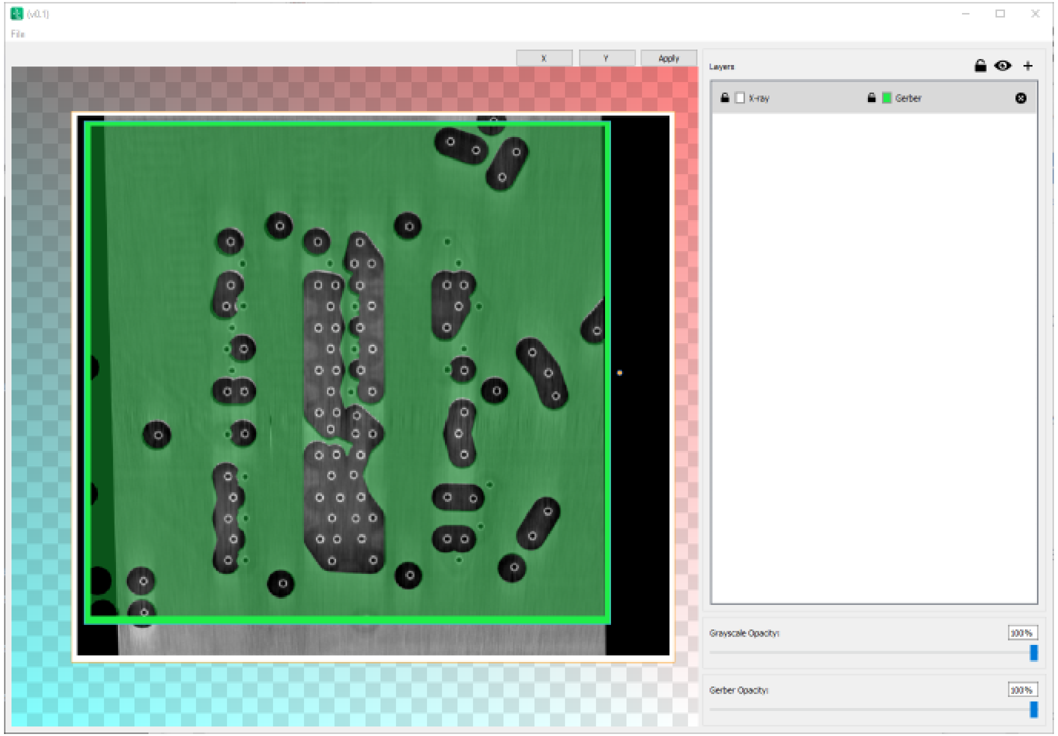
25 micron or greater.

# Turquoise Processing Pipeline

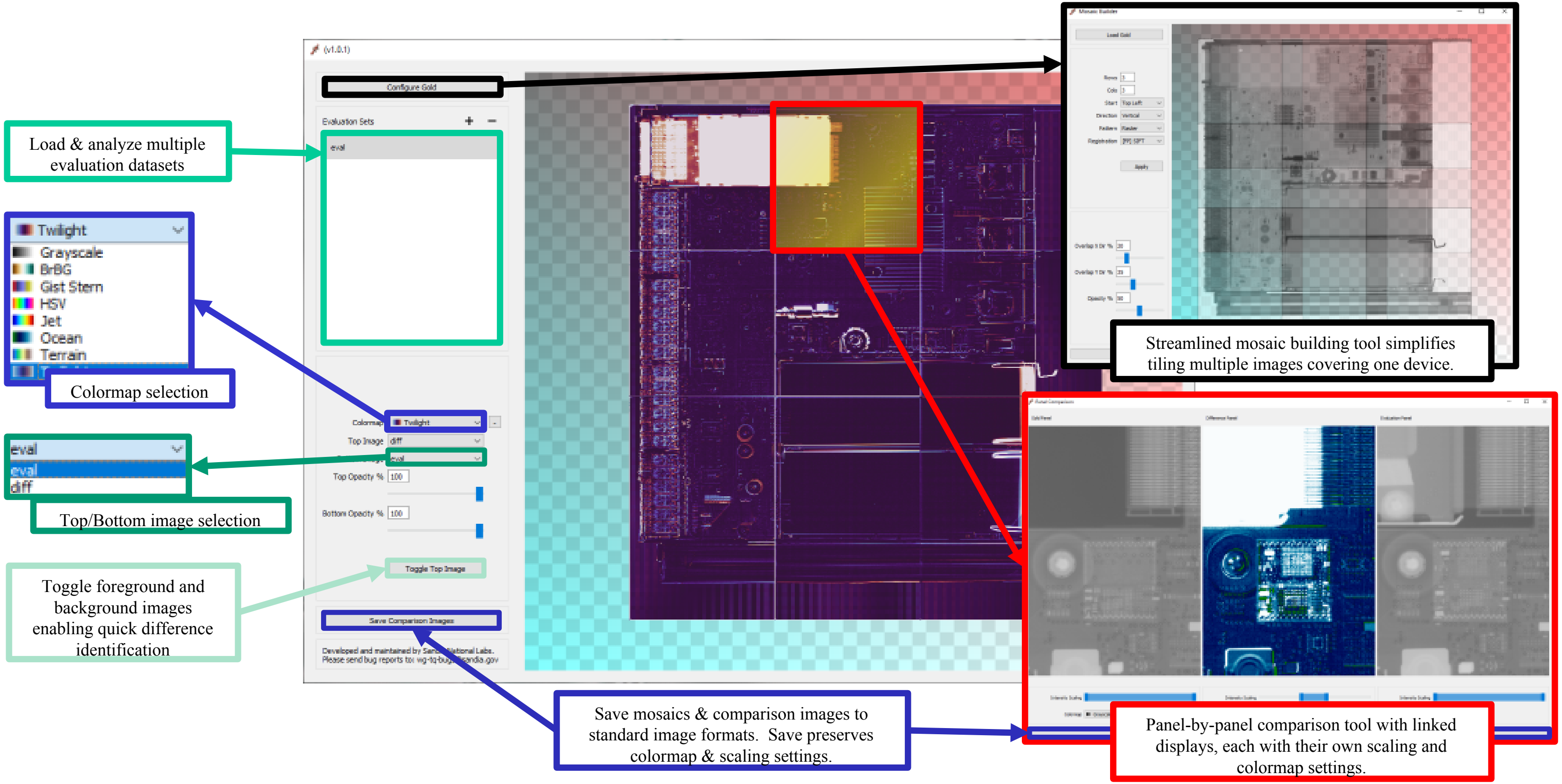


# Laserbeak Gerber Pipeline

- Laserbeak was originally developed to register and overlay x-ray radiographs
- Adding support for PCB/IC design files (grb/gds2)
  - Currently allows user to read, render and overlay gerber files
  - Supports full or partial regions
  - Manual alignment (current)
    - Rotation
    - Translation
    - Scaling
  - Measurement tools

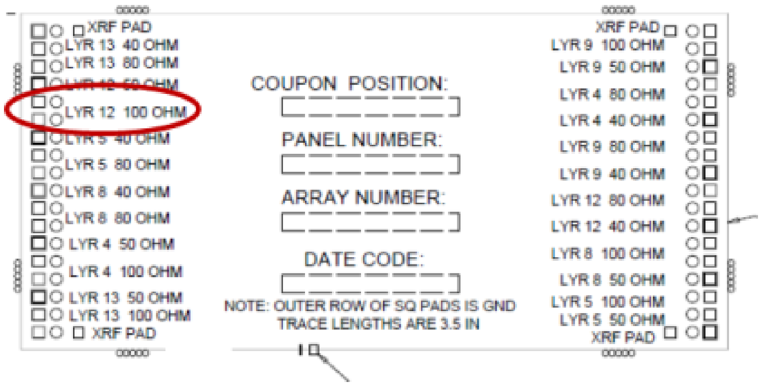


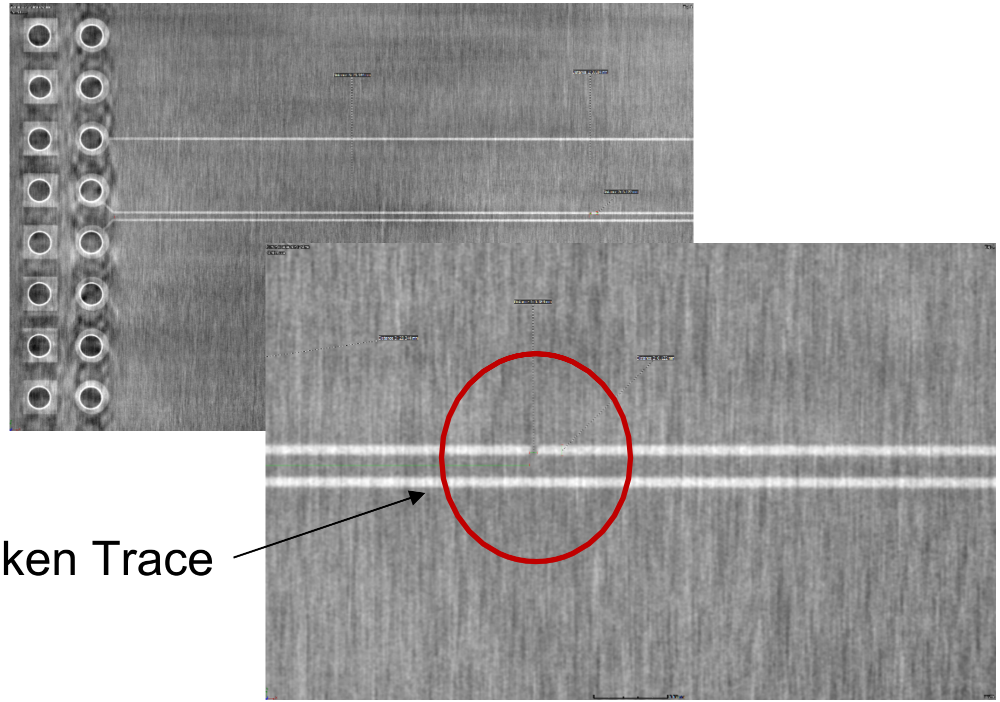
# Laserbeak Analysist Interface



# Test Coupon and PCB Layer Analysis

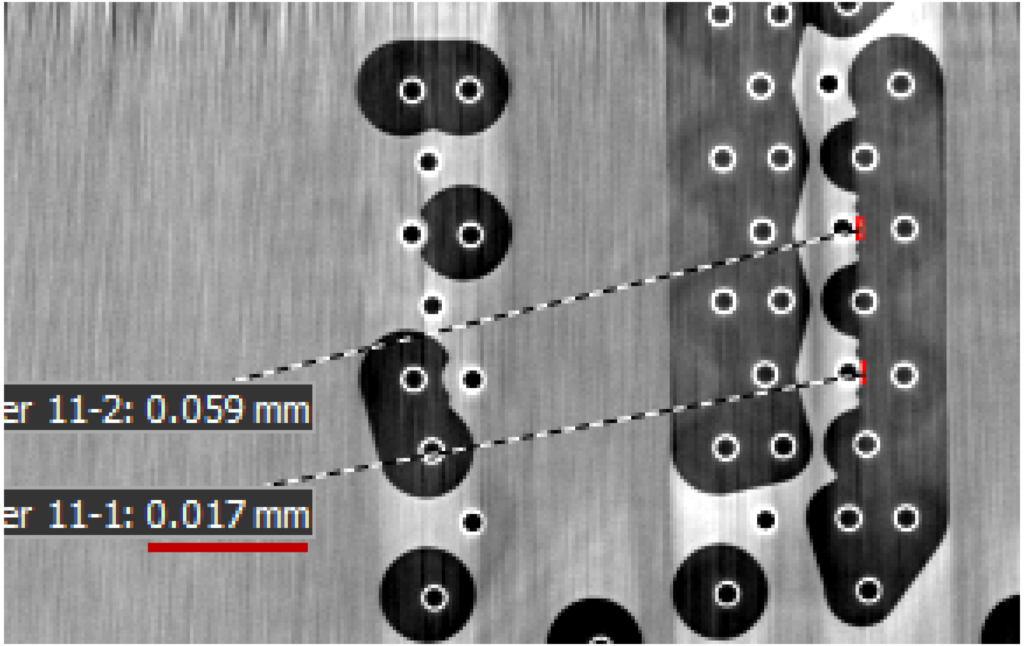
- Time Domain Reflectivity (TDR) coupon
- PCB is 16 Layers



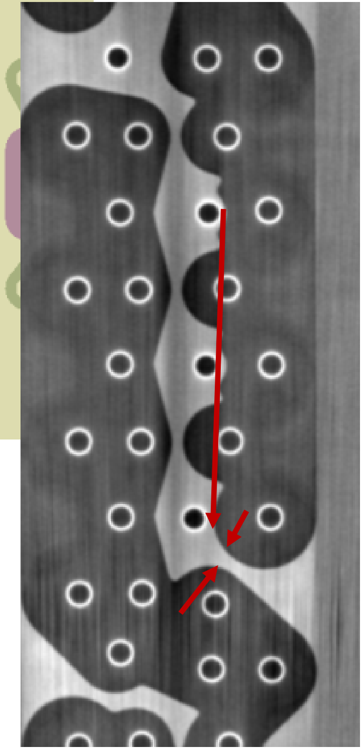
Broken Trace

# Layer and Annular Ring Measurements

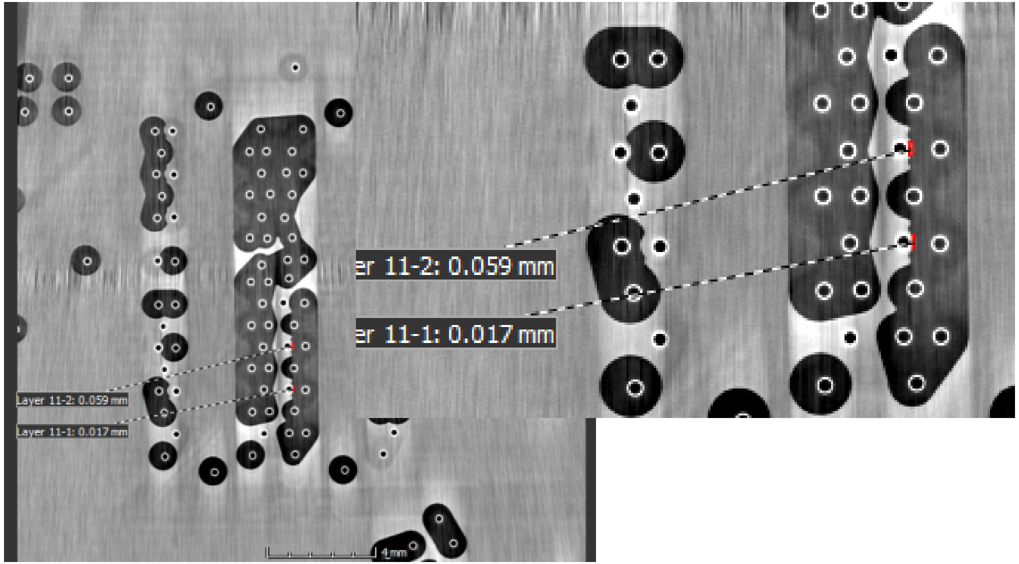

Issue location identified – less than 25 micron.

# PCB Layer to Gerber Analysis

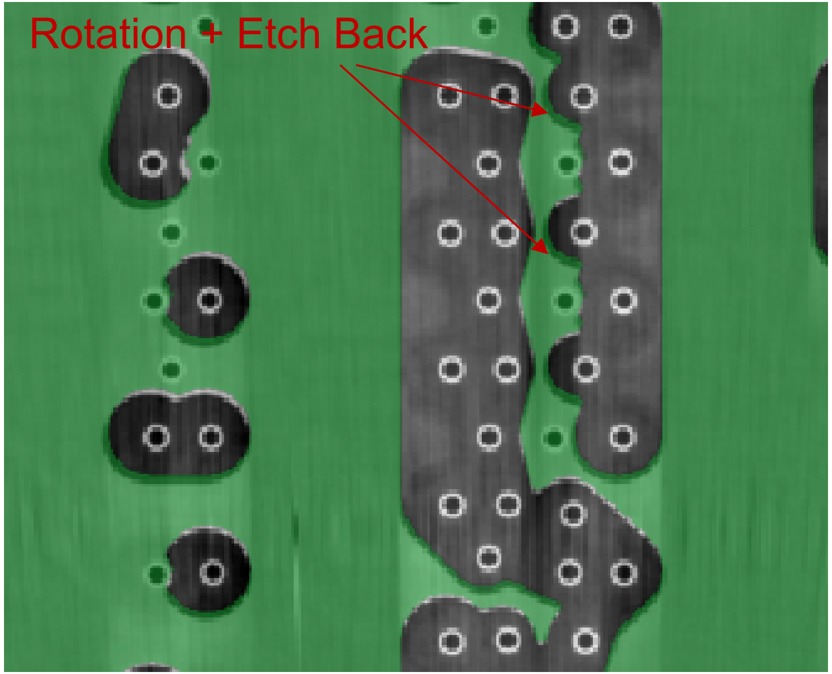


A few starting points to the issue.
Etch back is little more than expected and
There appears to be an alignment/run out issue.

# Overlay of X-ray to Gerber




Whether alignment or assembly issue,
we can start to deduce the production error.

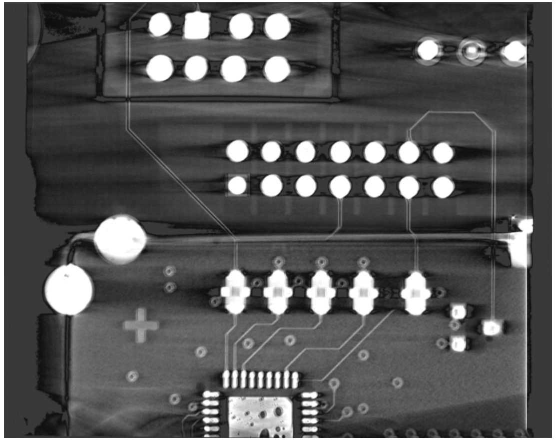


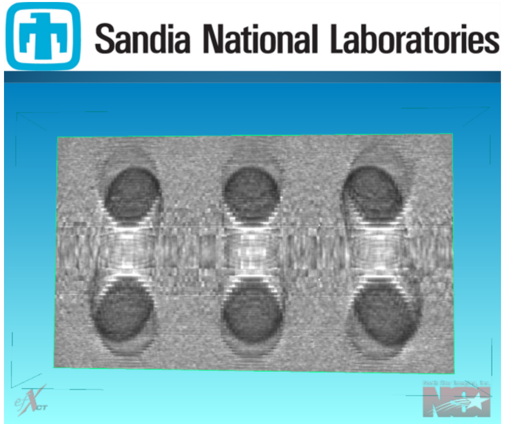

*<u>**Note: Image is flipped**</u>

From the rough estimate of translation – 0.5 degree rotation or greater in rotation error.
With an approximate 0.001” to 0.003” (inch) shift to the left.

# Image Artifacts

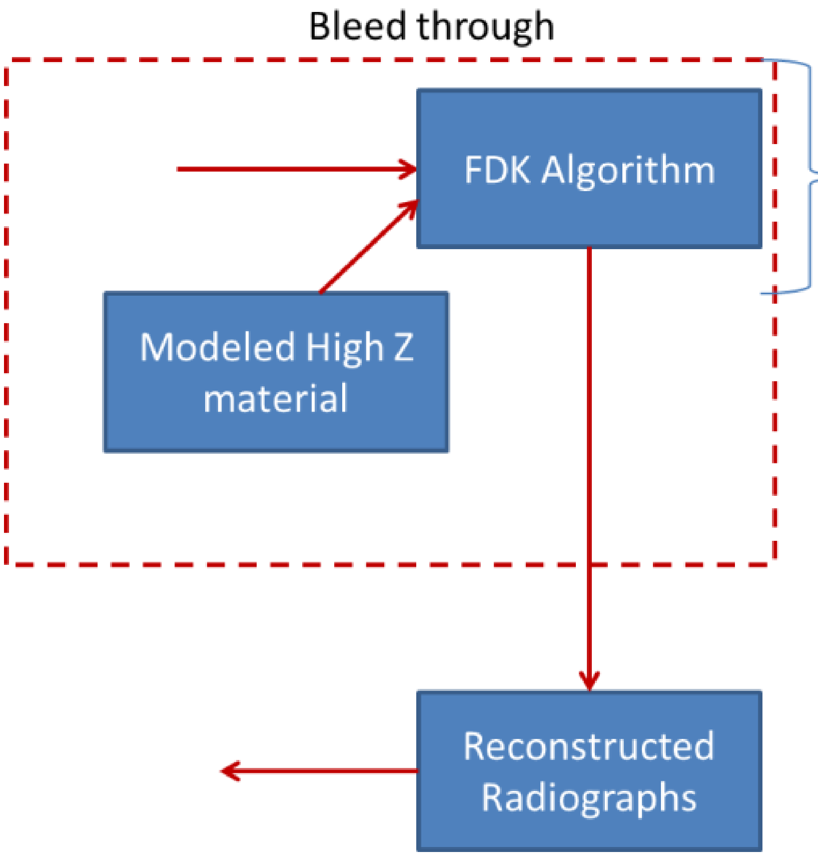
- Populated Boards pose challenges due to high Z-materials absorbing and scattering of X-rays.
  - Ghosting/Bleed Through/Smearing are few technical terms used to describe this challenge.
  - Issues come from assumption made by the Felder Kamp (FDK)





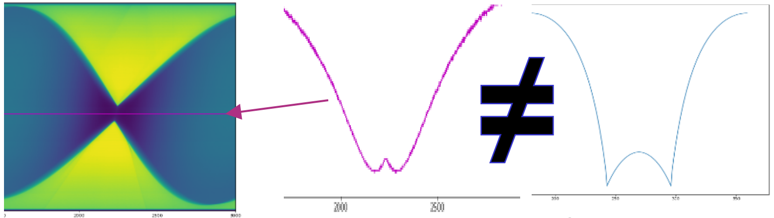

Example of artifacts present in traditional CT reconstructions

# Image Artifacts




FDK Algorithm

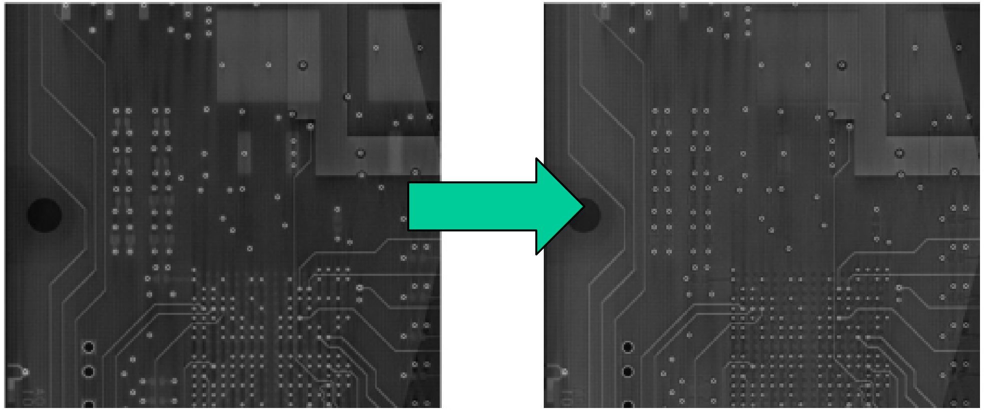
- Correlates 2D picture with theta and vertical motions.
- Makes 3D Volume.
- Cylinder assumptions are commonly made for the algorithm.
- Calibration hardware moves in a circle ( known geometries on hardware)
- Algorithm likes to have data inside it's linear range (0-255 gray scale)

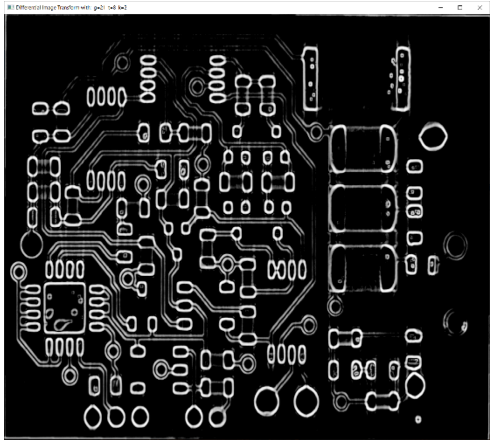



Cu Bar Sinogram Detector Response Cu Bar thickness

# Image Artifacts: Future Efforts

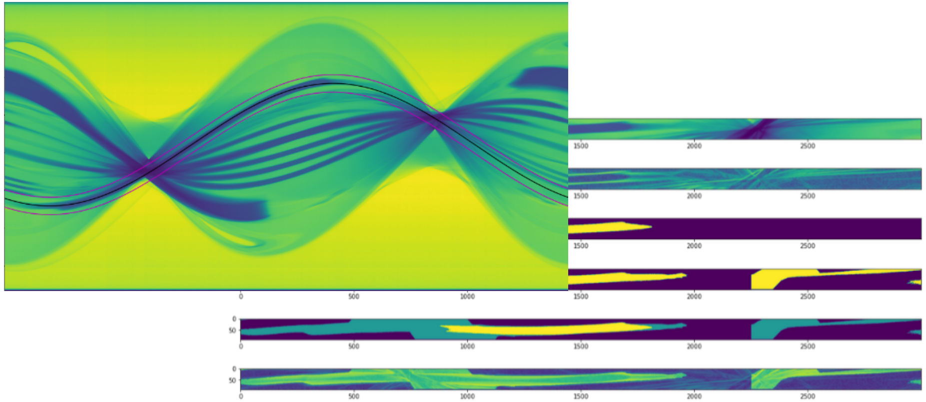
- Automated removal techniques being researched:
  - Gerber-based bleed-through characterization & correction
  - Advanced / custom edge detection
  - Further segmentation improvements.

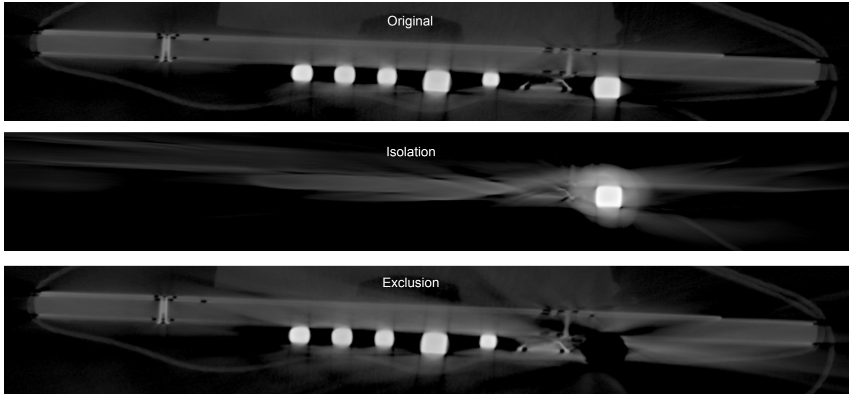




# Additional Future Efforts

- Sinogram segmentation
  - Identify and track high-z / high-aspect ratio through sinogram
  - Enables separate reconstruction and processing
- Automate CT/gerber registration





# Conclusions

- Incoming inspection of hardware needs to be quick and accurate.
  - Low false positives
  - Ability to understand the issue and report back to the production team/company the problem with confidence.
- Lead times for hardware are driving potential short cuts by production companies, sub-optimally trained personnel due to high turn over rates post-COVID.
- The previous example highlighted low quality/poor workmanship.
- However, one can easily connect the same example to suspect/counterfeit issues.
- Special Thanks to: John Cates, Eric Sorte, Edward Jimenez, Edward Graef, and Cody Washburn