

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

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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

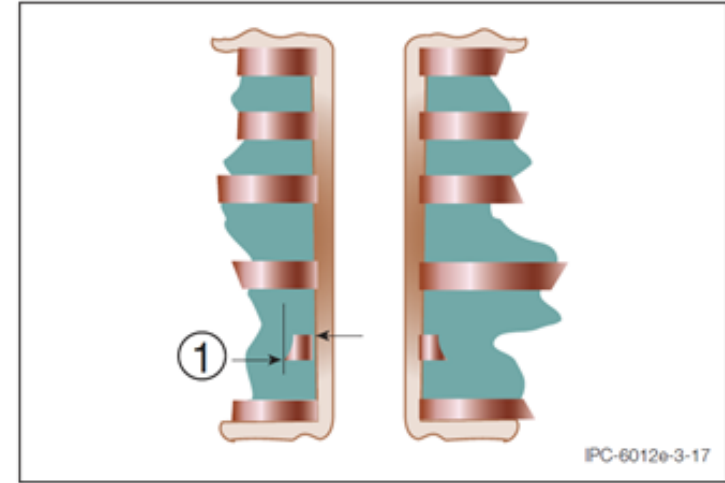
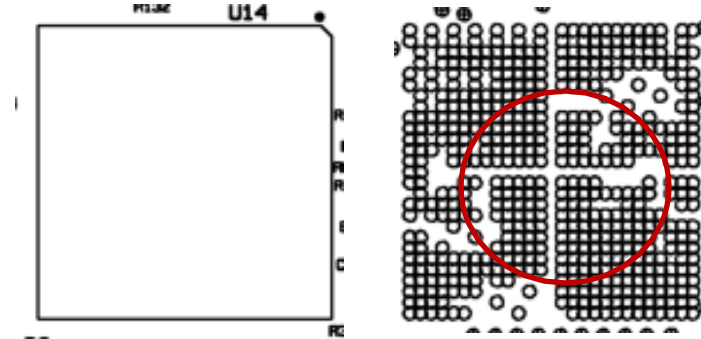


Figure 3-17 Annular Ring Measurement (Internal)

Note 1. Measurement of internal annular ring.



PCB Analysis

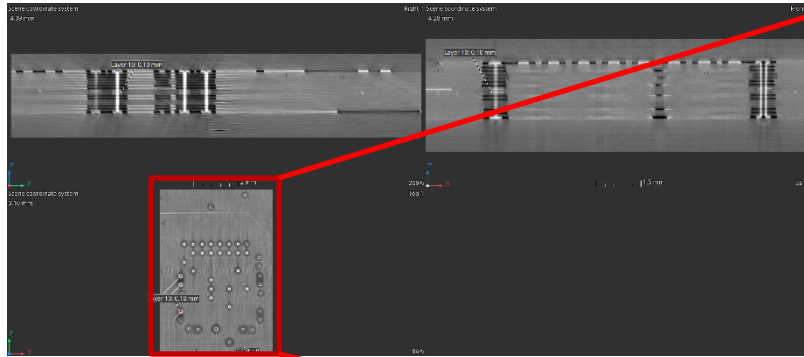


FPGA is the region of interest

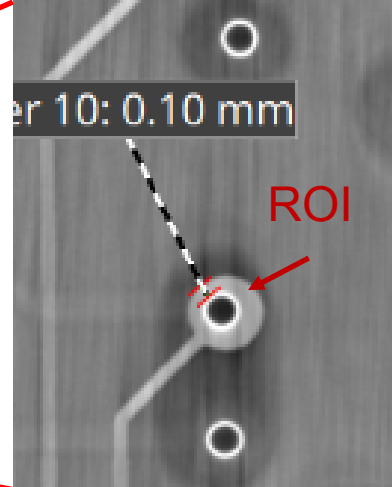
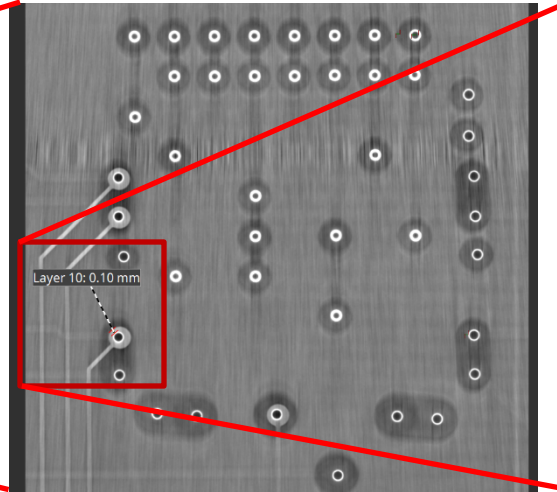
High density drilled via's through the board provide details on annular ring information for Class 3 PCB inspection.

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.

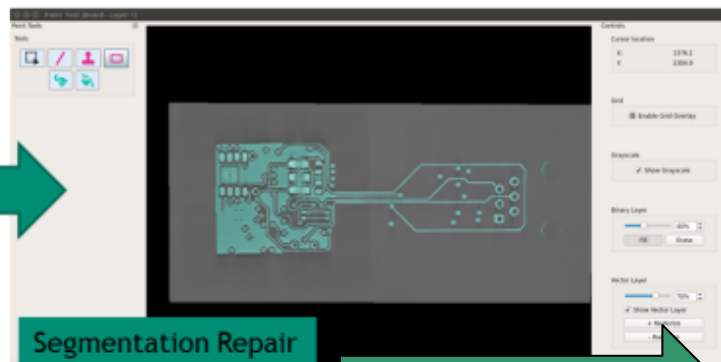
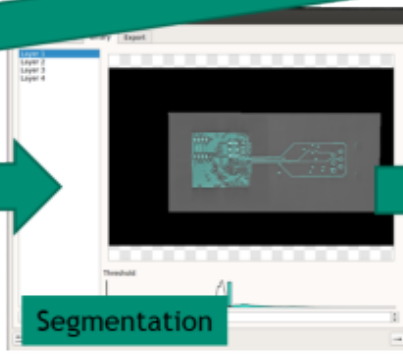
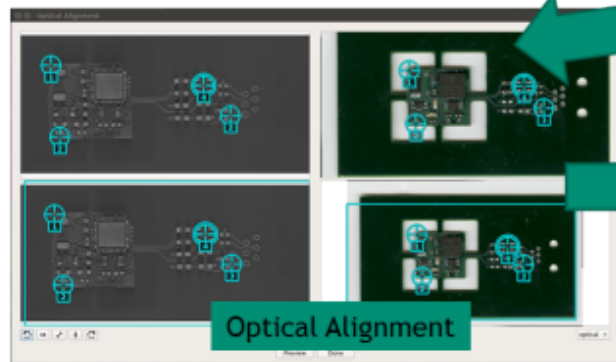
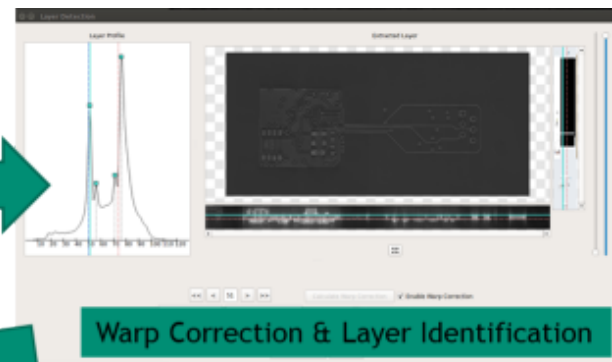
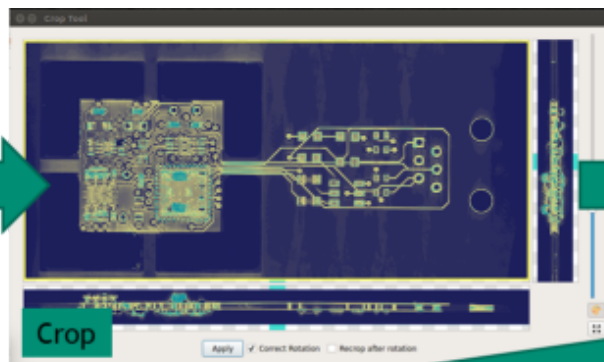
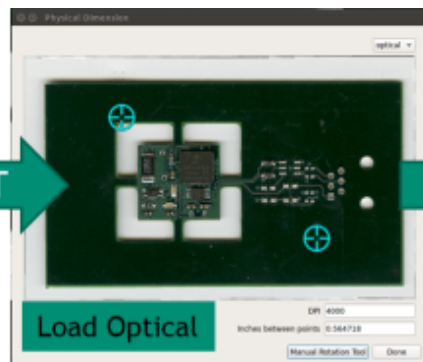


Cross section of 16 layer PCB
In Volume Graphics.



25 micron or greater.

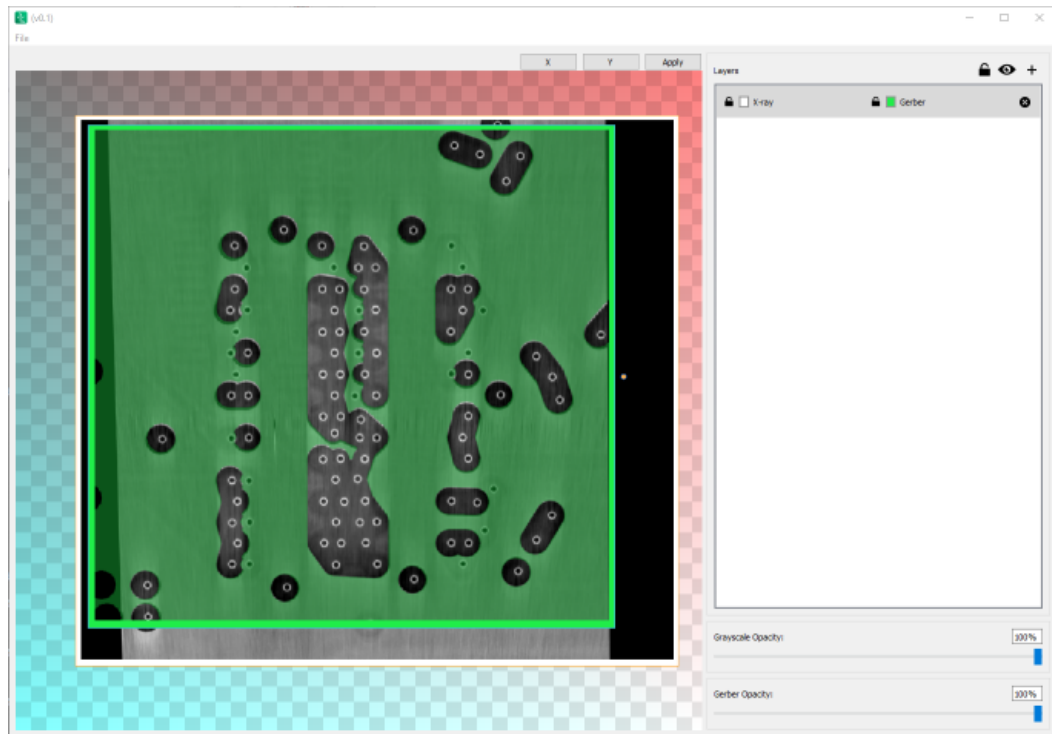
Turquoise Processing Pipeline



LaserBeak

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

The image shows the Laserbeak Analyst interface, a software tool for analyzing laser data. The main window displays a large heatmap of a device, with a red box highlighting a specific region. To the left, a sidebar contains several panels: 'Configure Grid' at the top, 'Evaluation Sets' below it, a 'Colormap' selection menu, and a 'Top/Bottom image selection' dropdown. The 'Colormap' menu is open, showing options like 'Twilight', 'Grayscale', 'BrBG', 'Gist Stern', 'HSV', 'Jet', 'Ocean', and 'Terrain'. The 'Top/Bottom image selection' dropdown is also open, showing 'eval' and 'diff' options. Below these are sliders for 'Top Opacity %' and 'Bottom Opacity %', and a 'Toggle Top Image' button. At the bottom of the sidebar is a 'Save Comparison Images' button. To the right of the main heatmap, there is a 'Streamlined mosaic building tool' window, which shows a grid of images and a 'Streamlined mosaic building tool' button. Below this is a 'Panel-by-panel comparison tool' window, which shows three panels: 'Difference View', 'Evaluation View', and 'Evaluation View'. Each panel has its own scaling and colormap settings.

Load & analyze multiple evaluation datasets

Colormap selection

Top/Bottom image selection

Toggle foreground and background images enabling quick difference identification

Save mosaics & comparison images to standard image formats. Save preserves colormap & scaling settings.

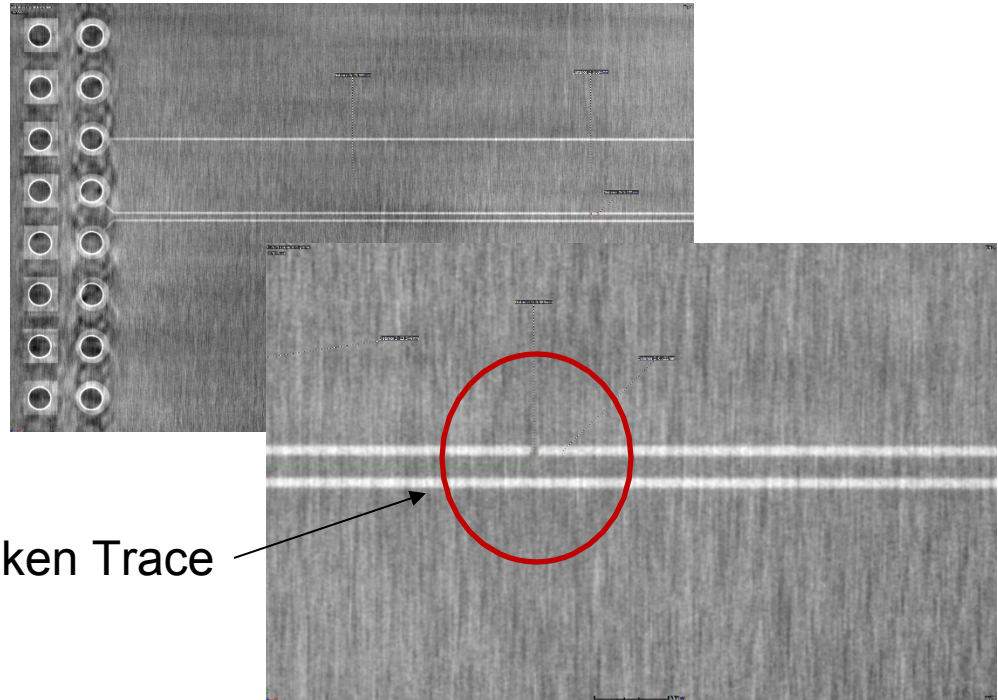
Streamlined mosaic building tool simplifies tiling multiple images covering one device.

Panel-by-panel comparison tool with linked displays, each with their own scaling and colormap settings.

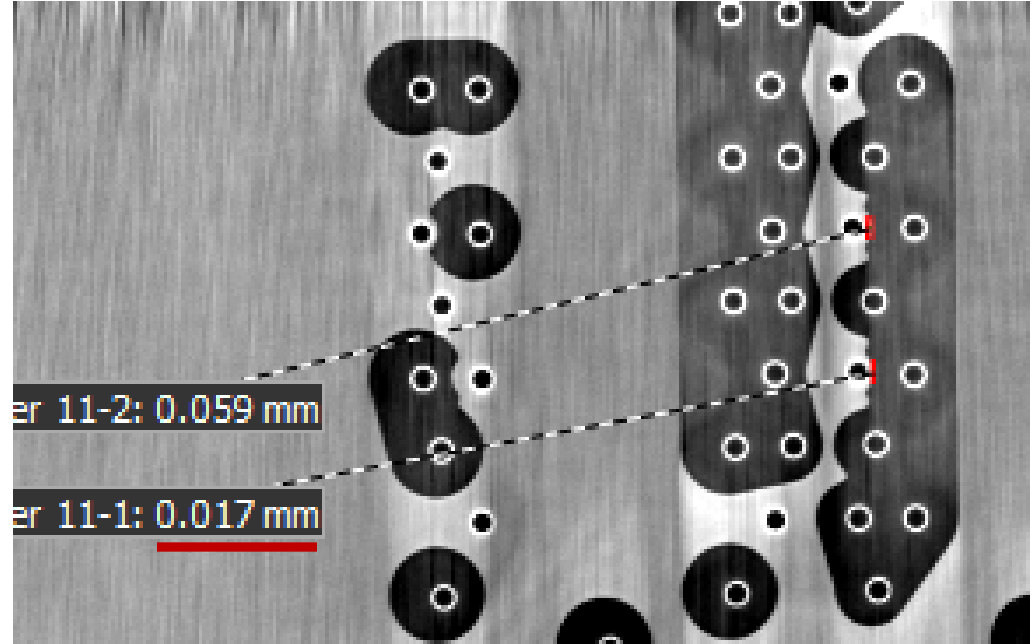
Test Coupon and PCB Layer Analysis

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

Figure 1 shows a completed coupon form. The coupon is divided into several sections. At the top, there are fields for 'COUPON POSITION', 'PANEL NUMBER', 'ARRAY NUMBER', and 'DATE CODE'. Below these are sections for recording component values, including 'XRF PAD' and 'LYR' (Layer) values with their respective ohmages. The coupon is filled out with handwritten data, and a red circle highlights the 'LYR 12 100 OHM' entry.

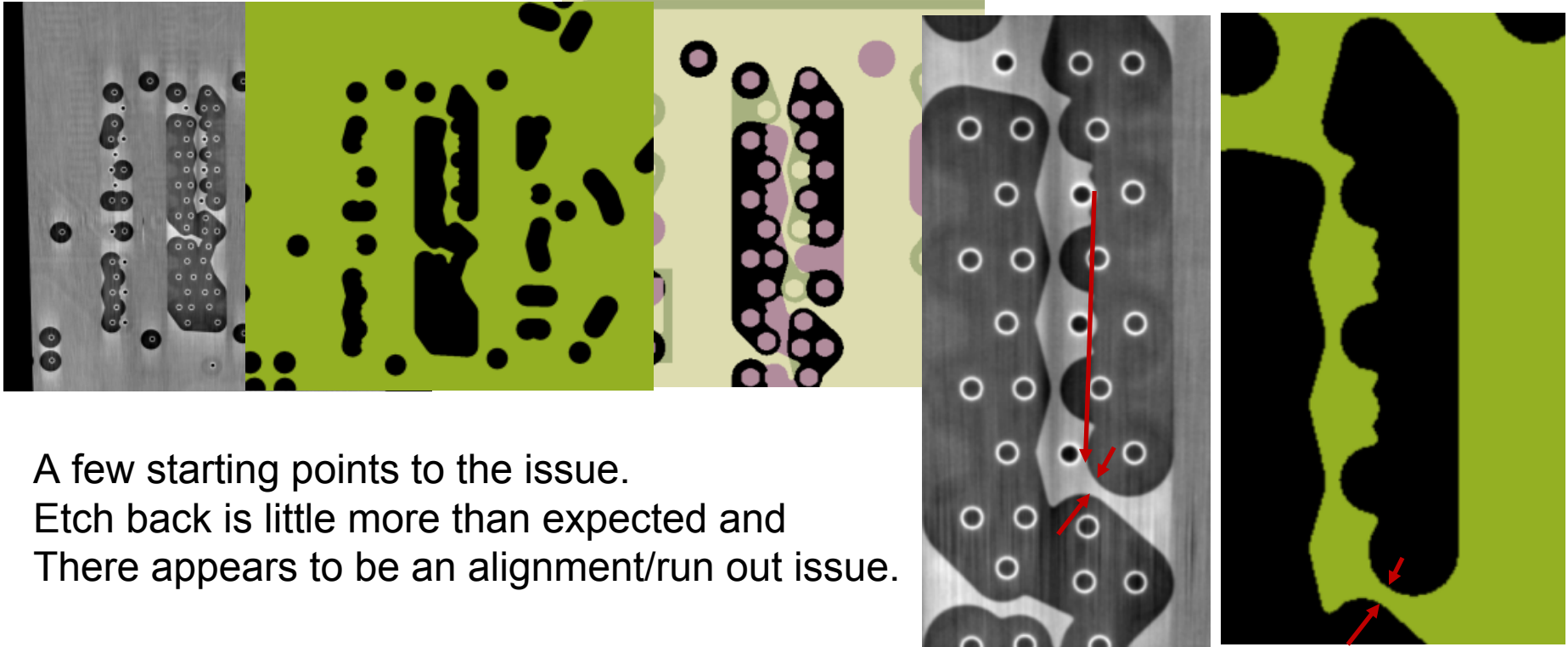


Layer and Annular Ring Measurements

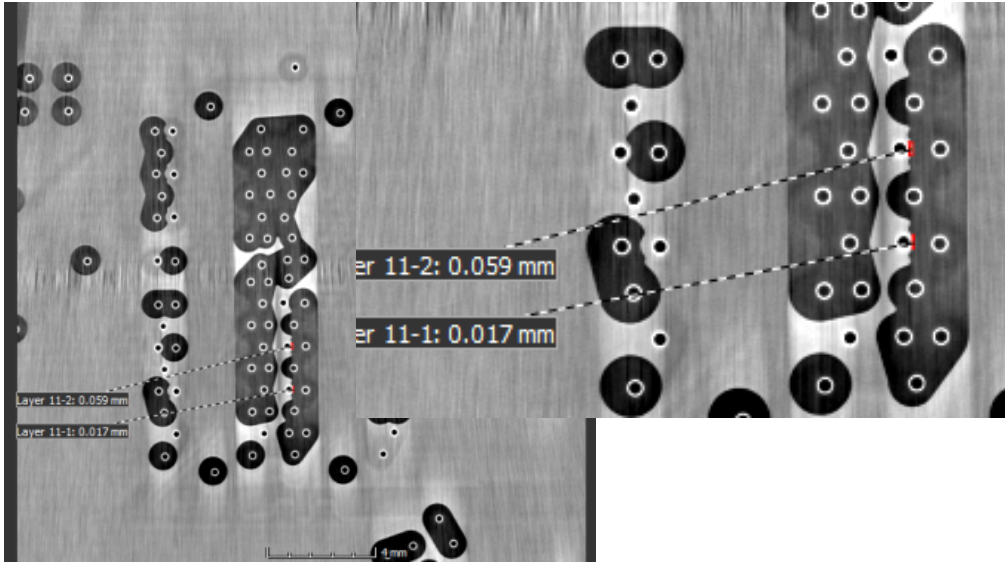


Issue location identified – less than 25 micron.

PCB Layer to Gerber Analysis



Overlay of X-ray to Gerber



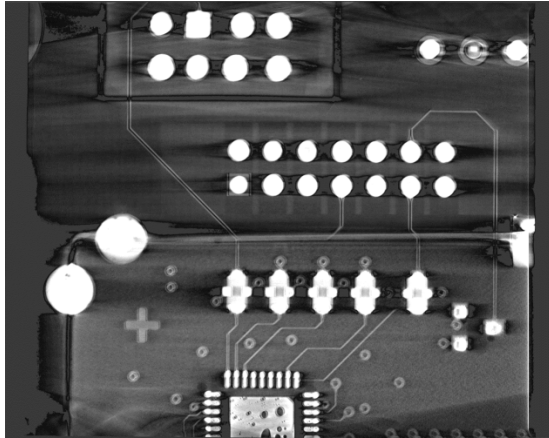
***Note: Image is flipped**

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

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



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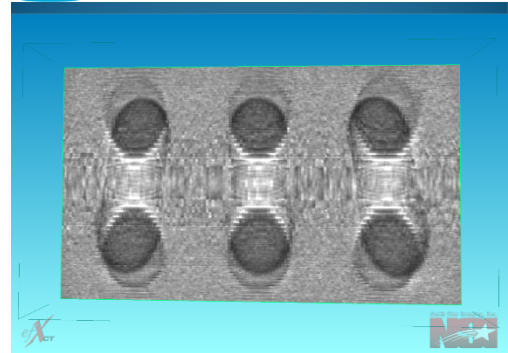
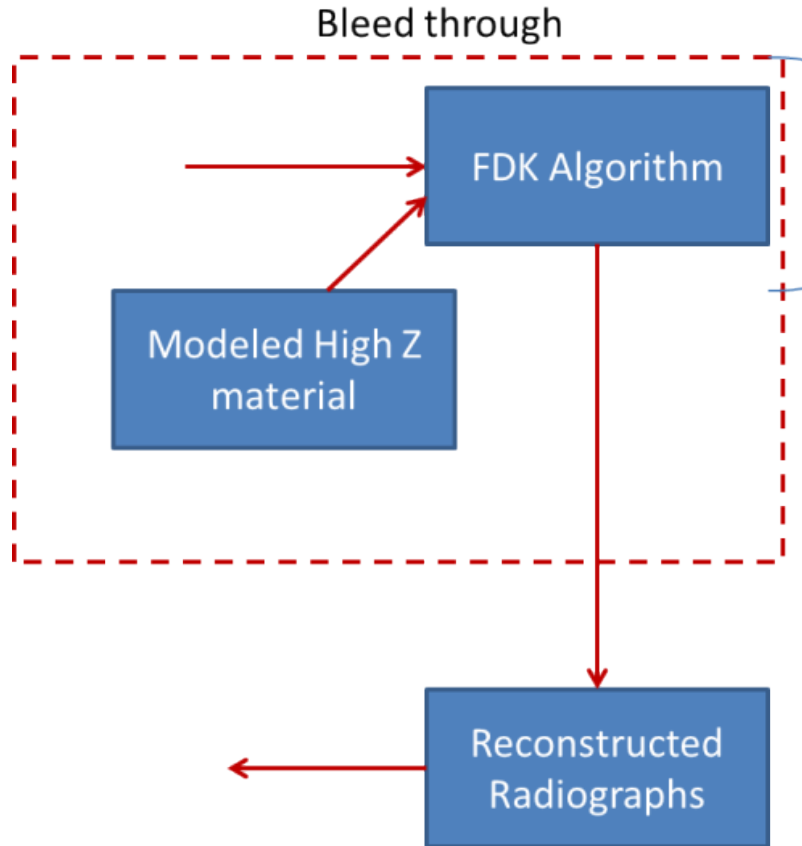
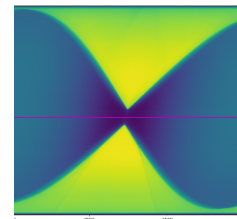


Image Artifacts

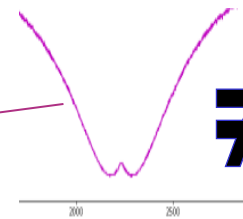


FDK Algorithm

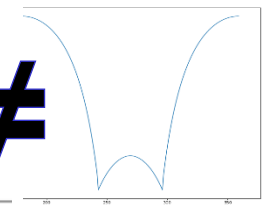
- Correlates 2D picture with theta and vertical motions.
- Makes 3D Volume.
- Cylinder assumptions are commonly made for the algorithm.
- Calibration hardware moves in a circle (known geometries on hardware)
- Algorithm likes to have data inside it's linear range (0-255 gray scale)



Cu Bar Sinogram



Detector Response

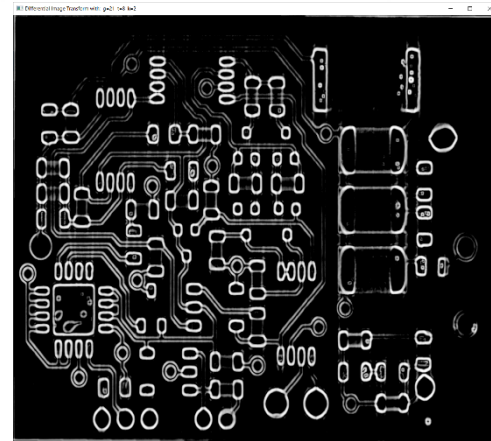
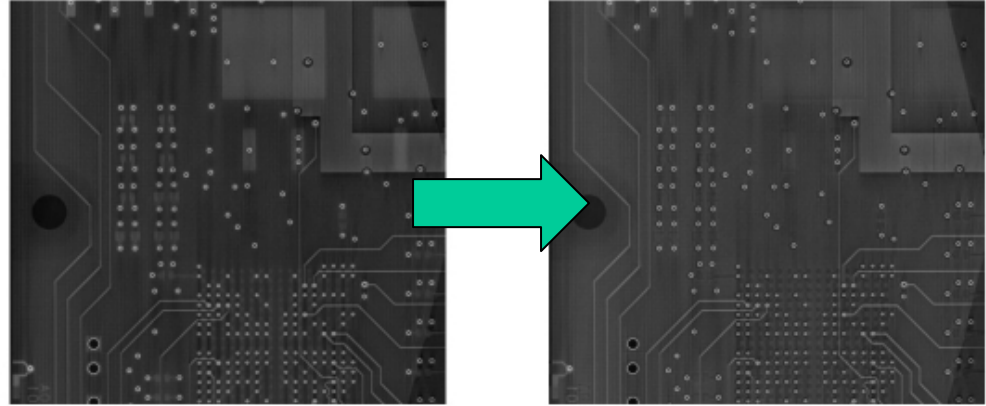


Cu Bar thickness

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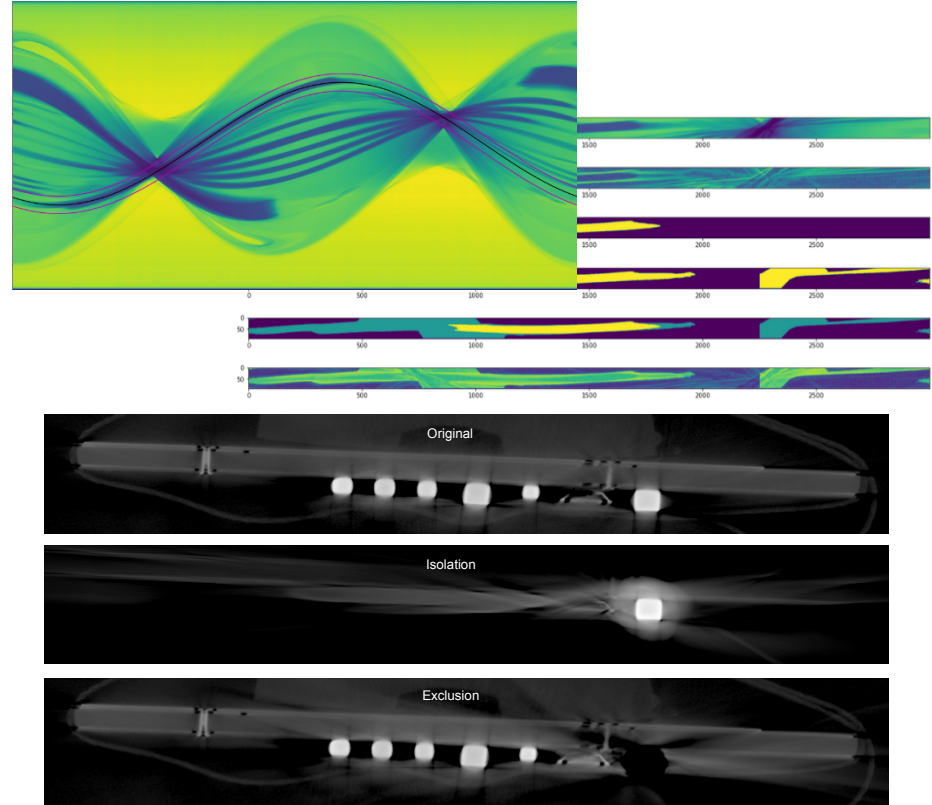
Image Artifacts: Future Efforts

- 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