S-Parameter Extraction of Bond Wires Based on EM Field Simulations of Computed-Tomography-Generated 3D CAD Models

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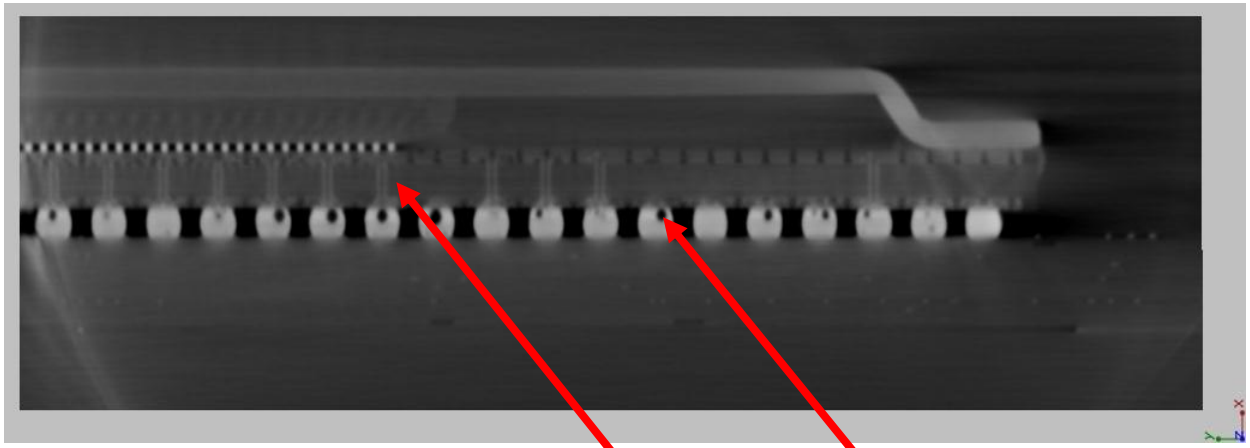
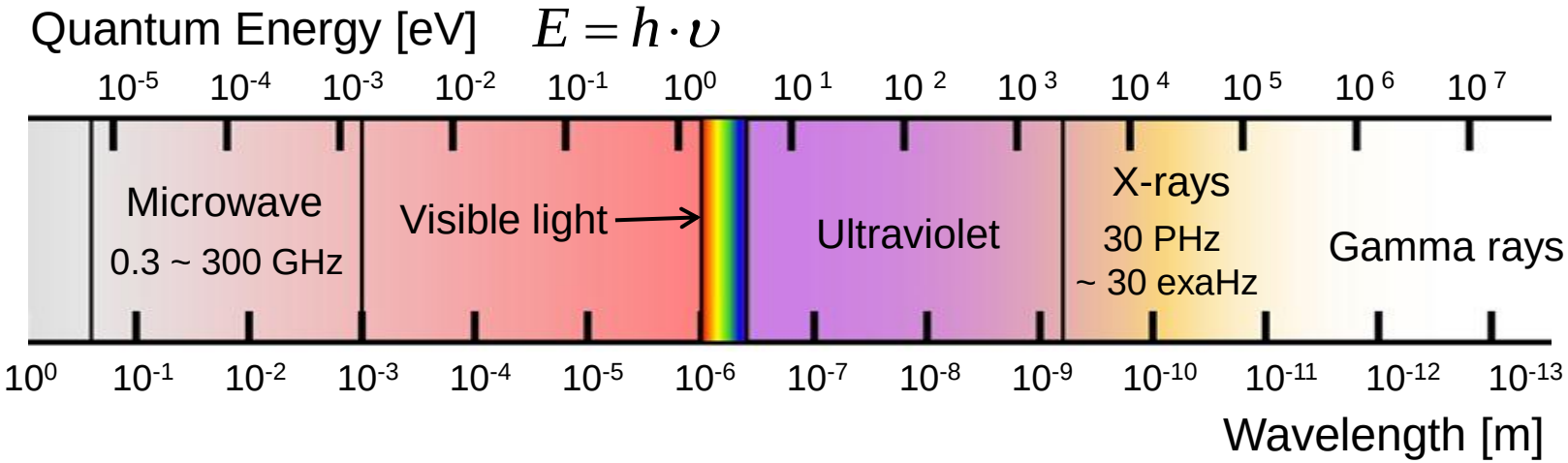
Outline

1. Introduction: X-ray images and computed tomography
2. Method to extract S-parameters from CT-data
3. Reconstruction of CAD models using CT-scans
4. Reconstruction technique for thin bond-wires and characterization with S-parameters
5. Comparison of CT-generated S-parameteres with electrical measurements
6. Conclusion

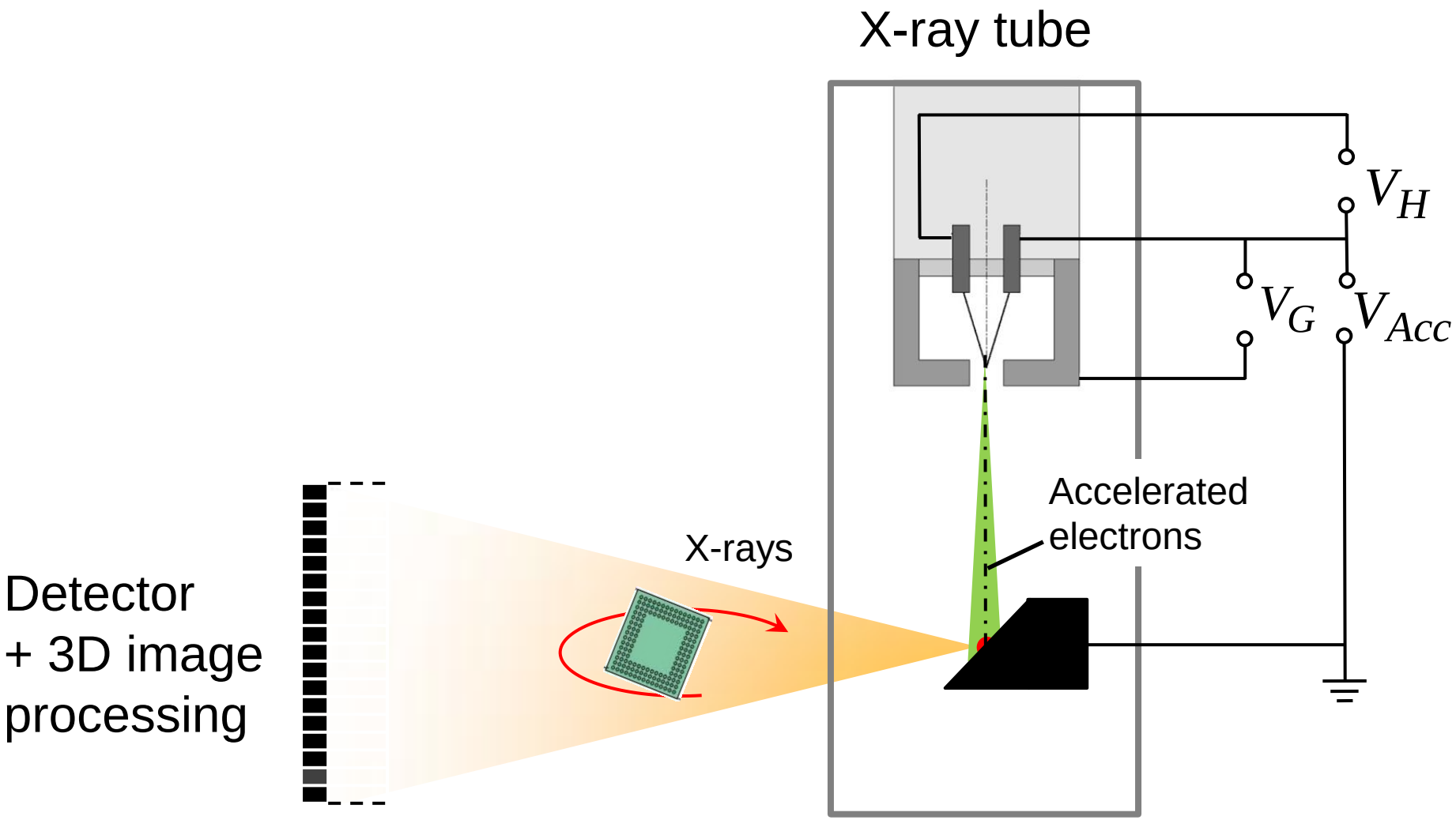
Introduction – X-Ray Solder Joint Inspection



X-ray wavelength < 1 nm

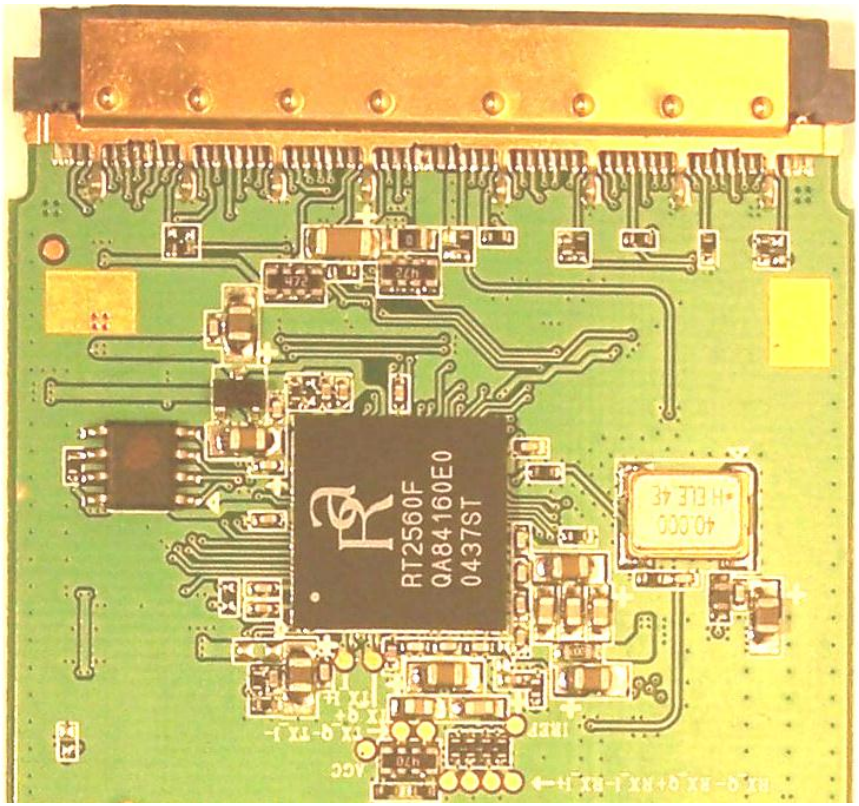


Introduction – Computed Tomography

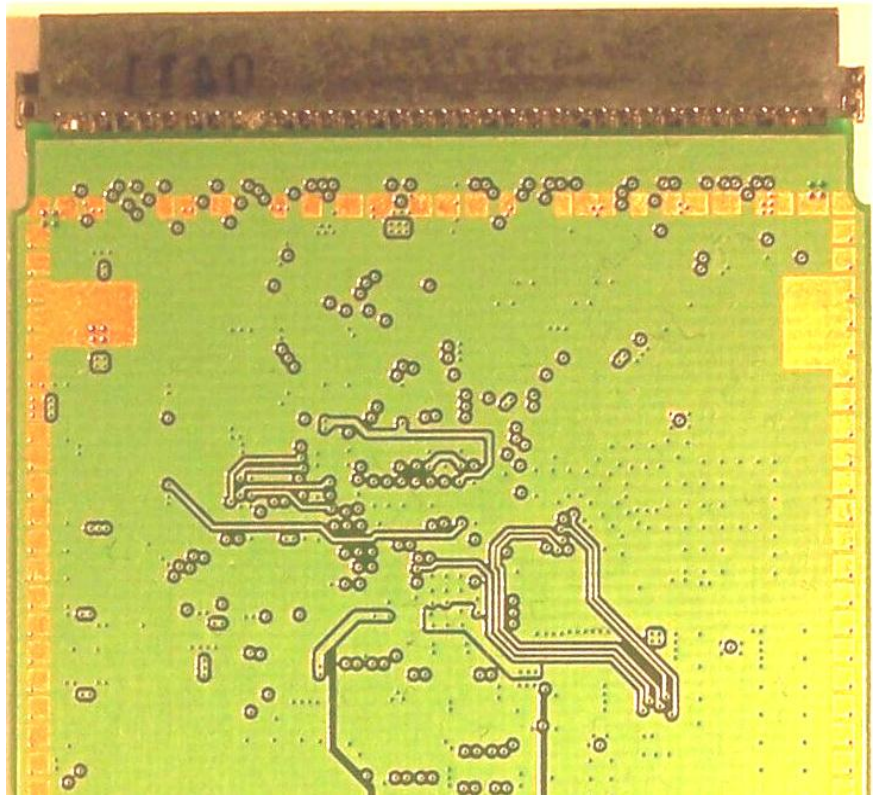


Introduction - Computed Tomography - Example

Top view

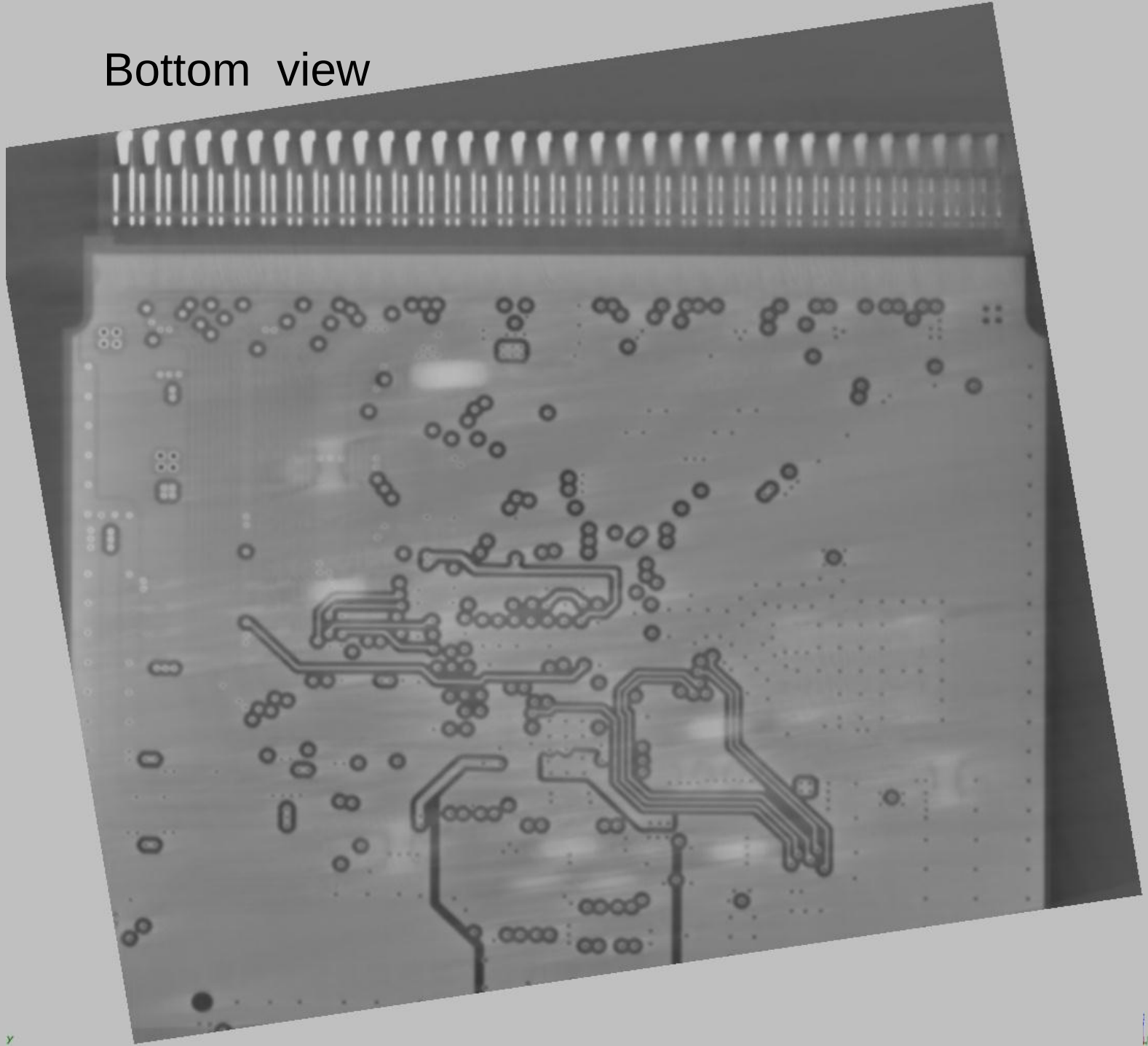


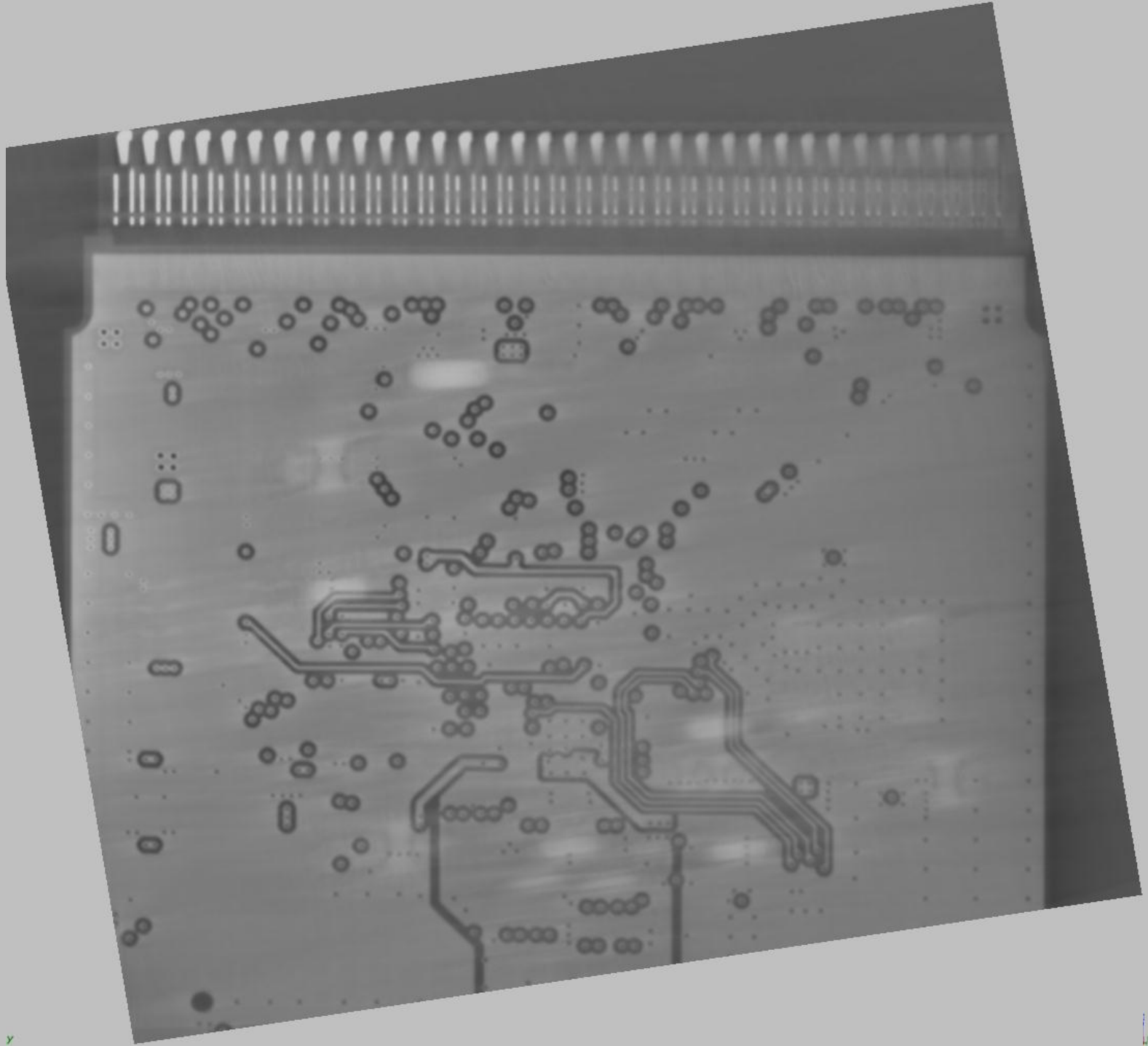
Bottom view

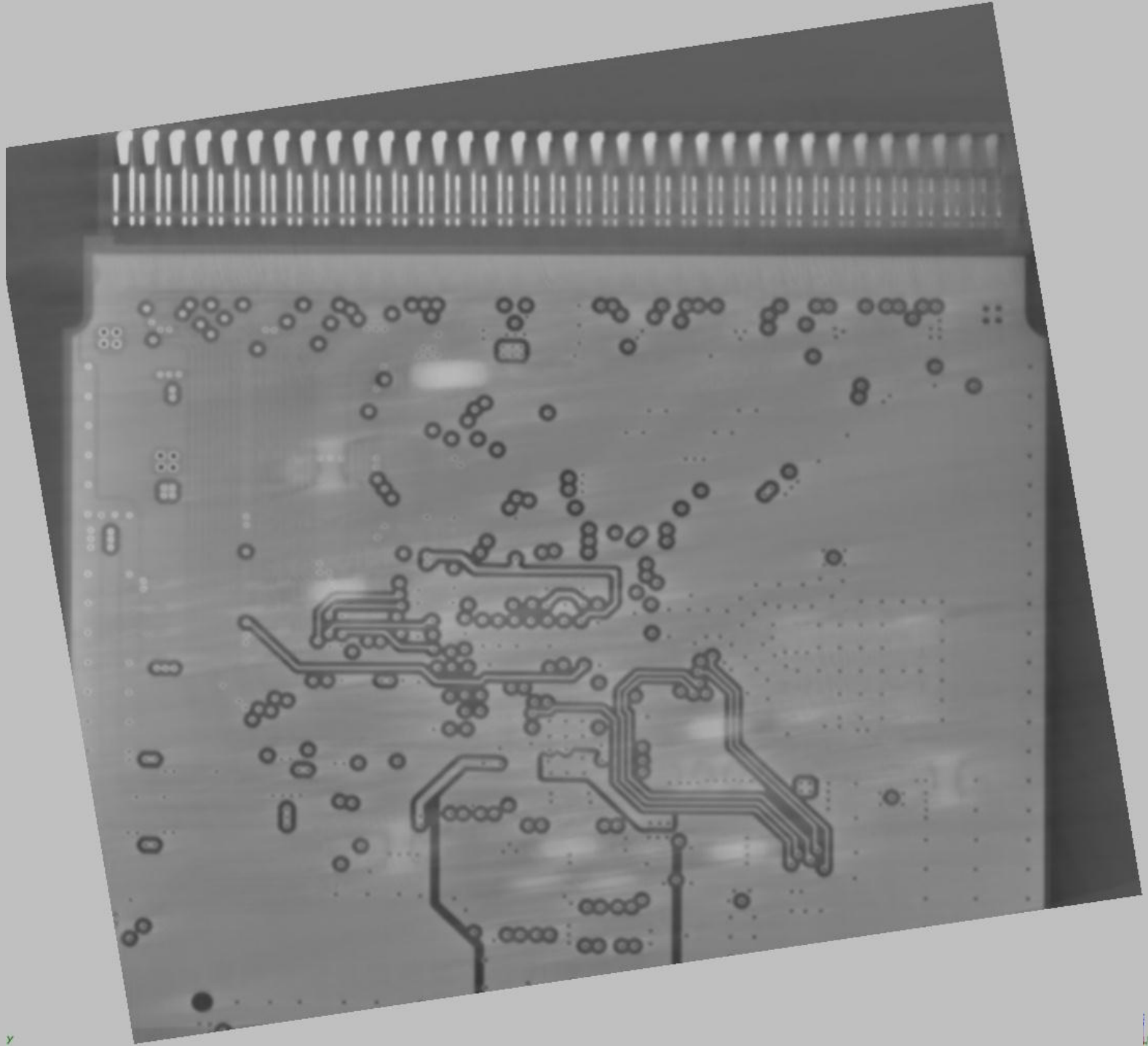


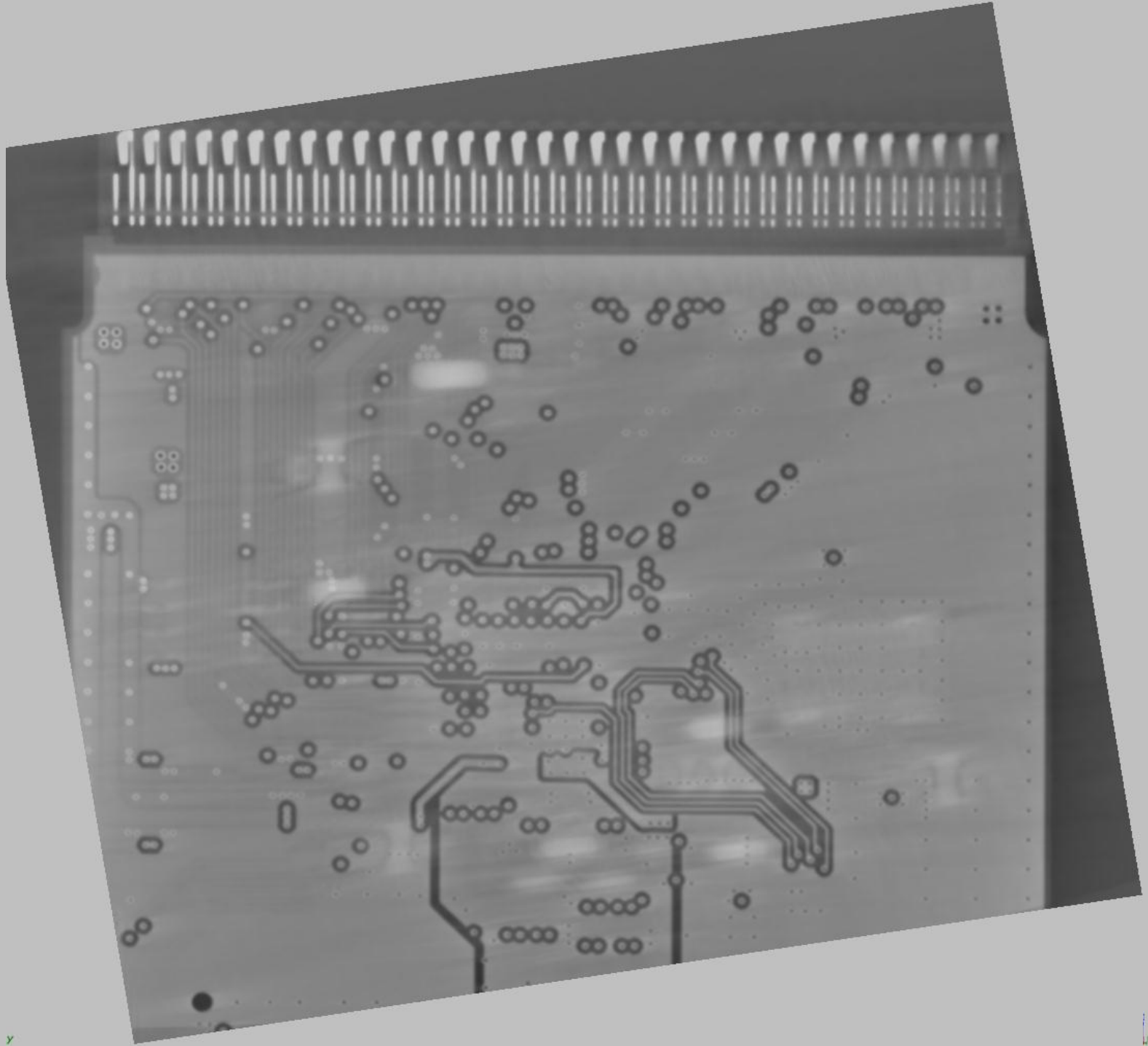
WLAN printed circuit board

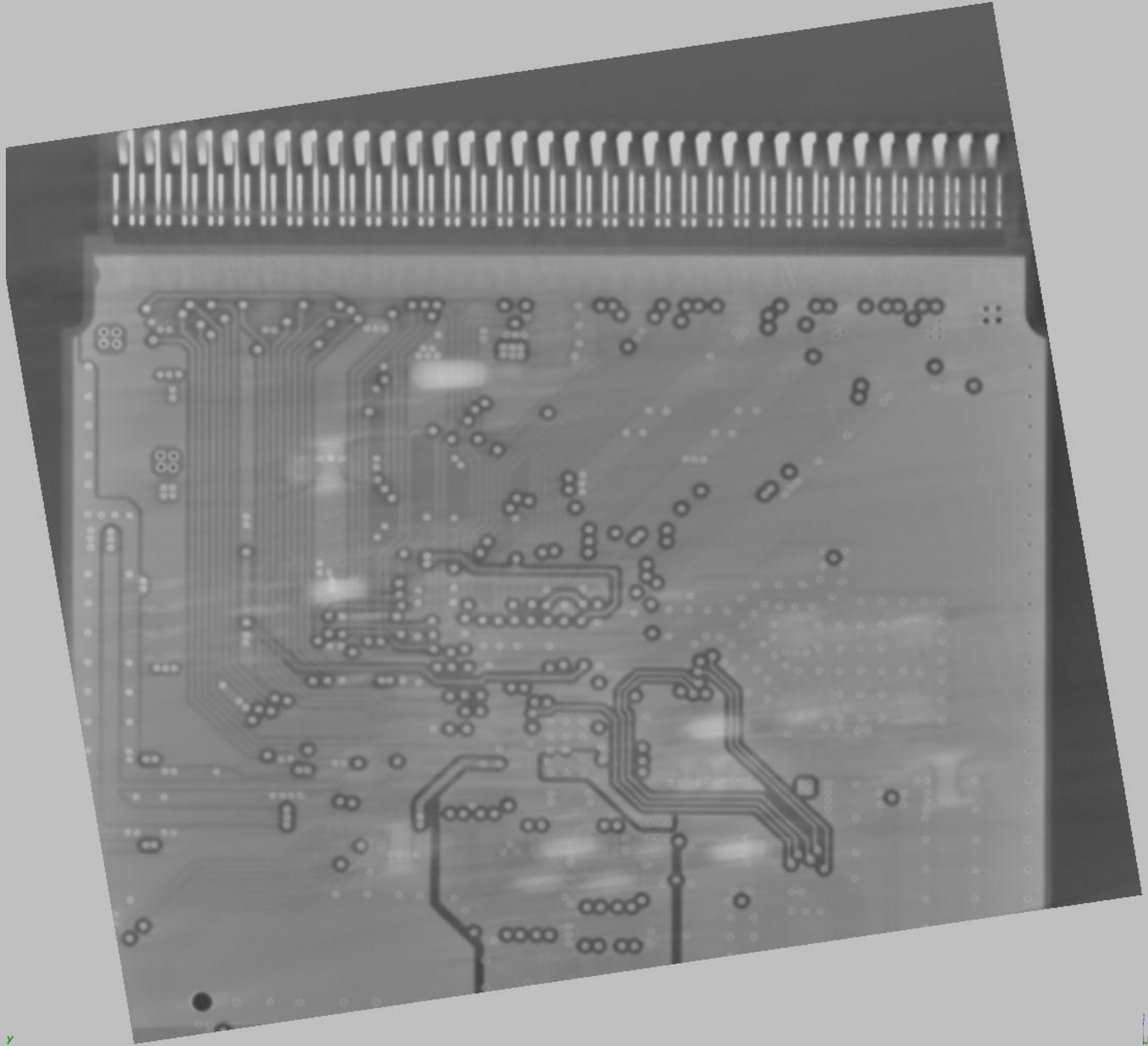
Bottom view

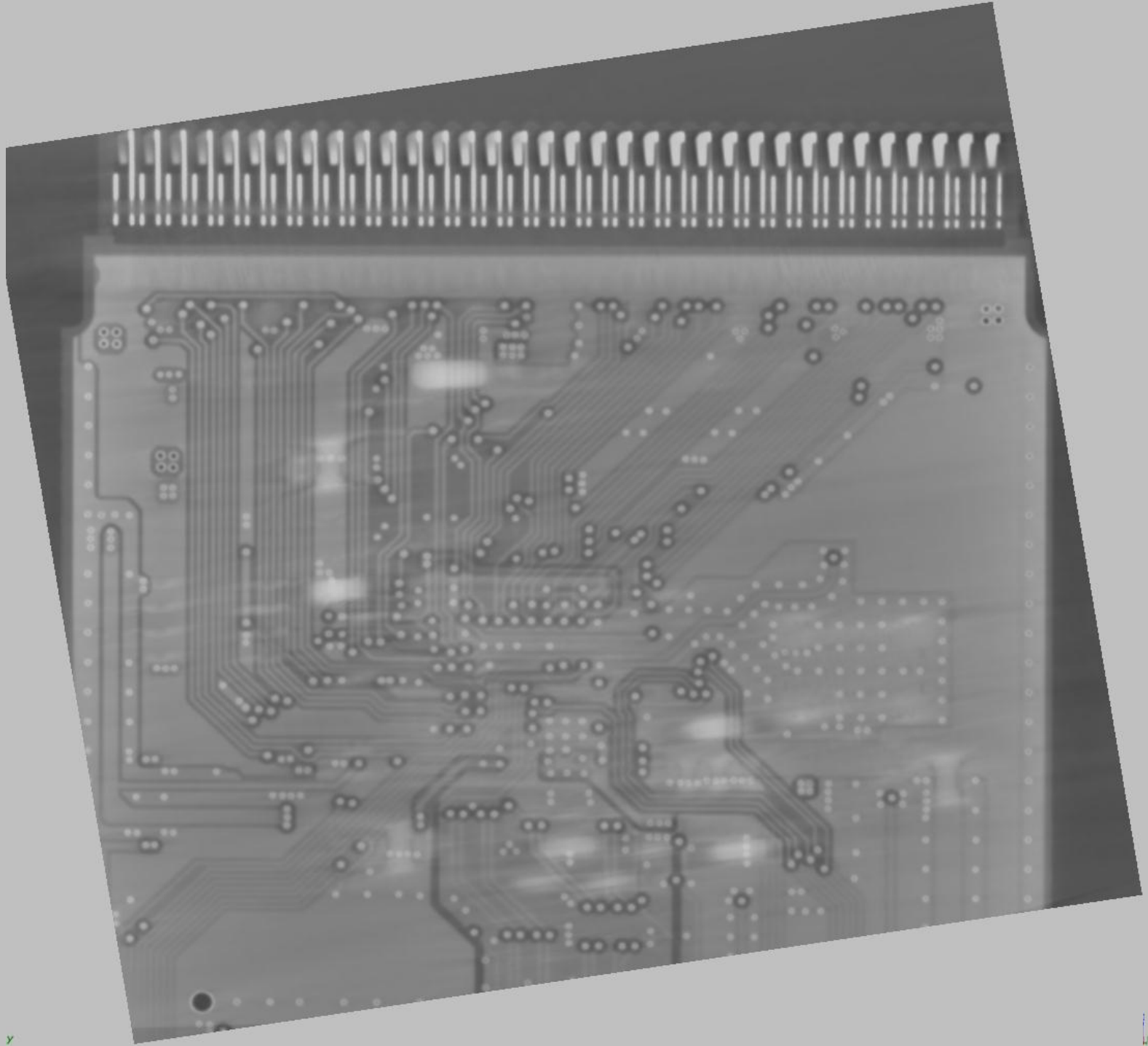


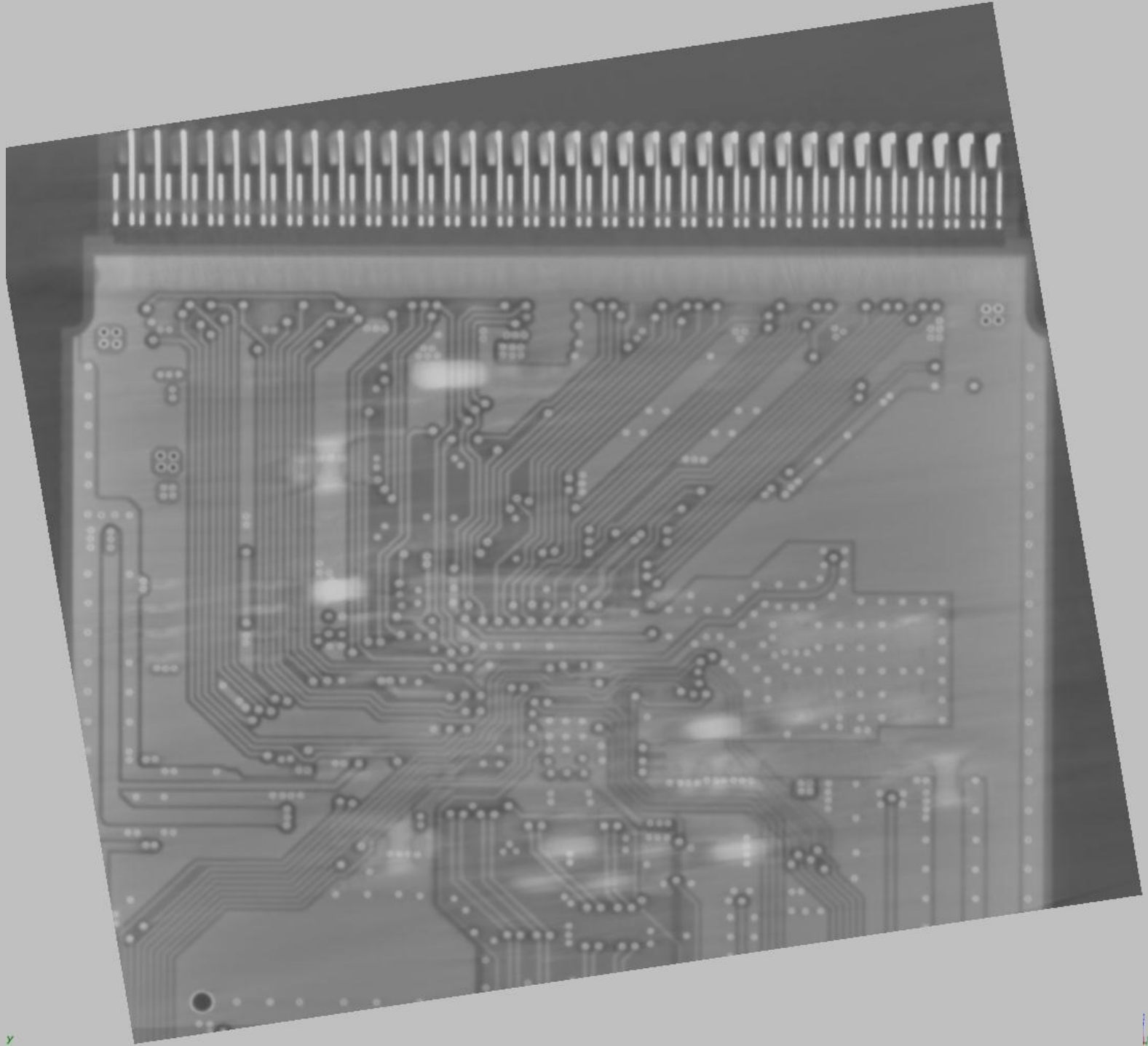


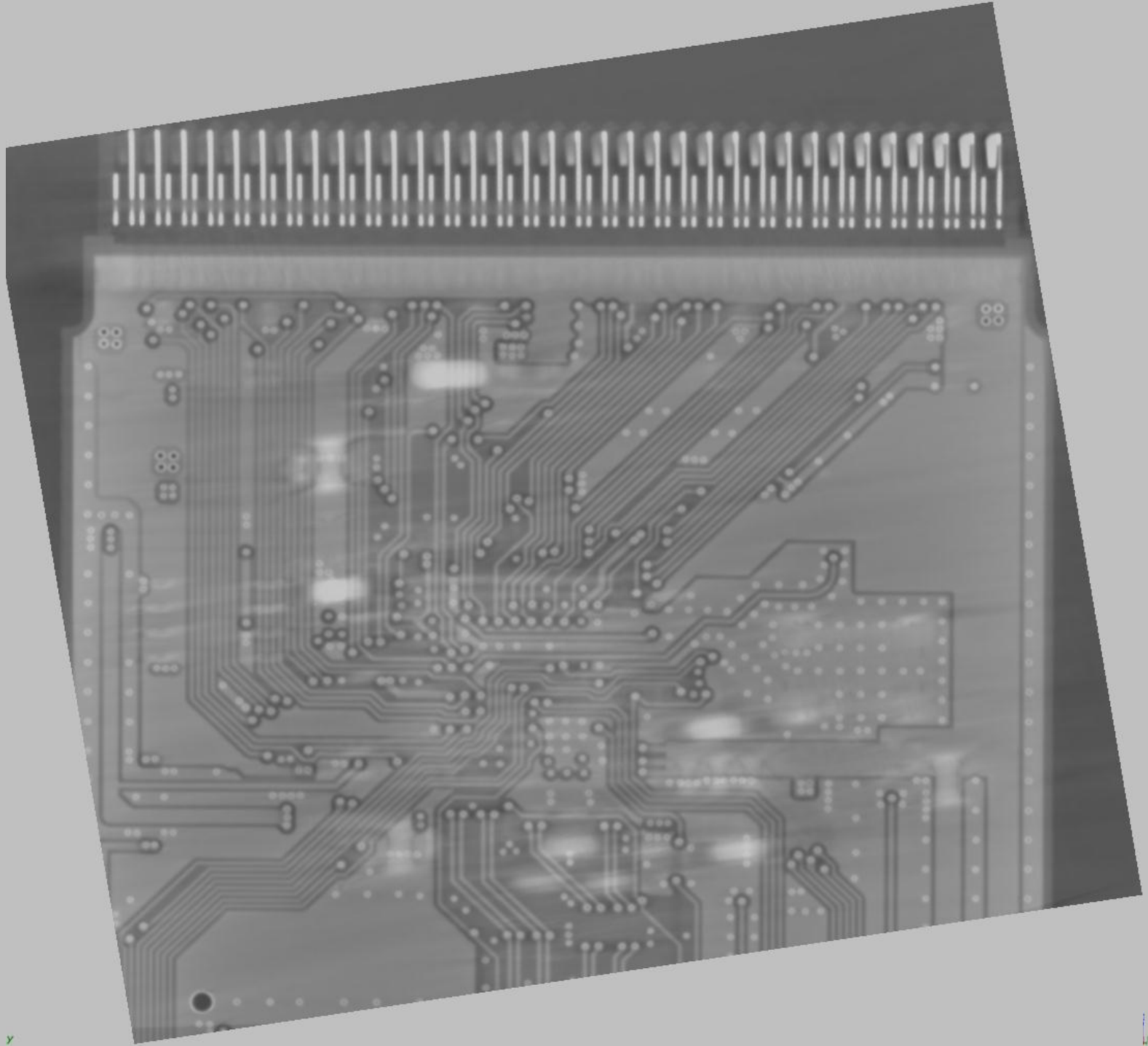


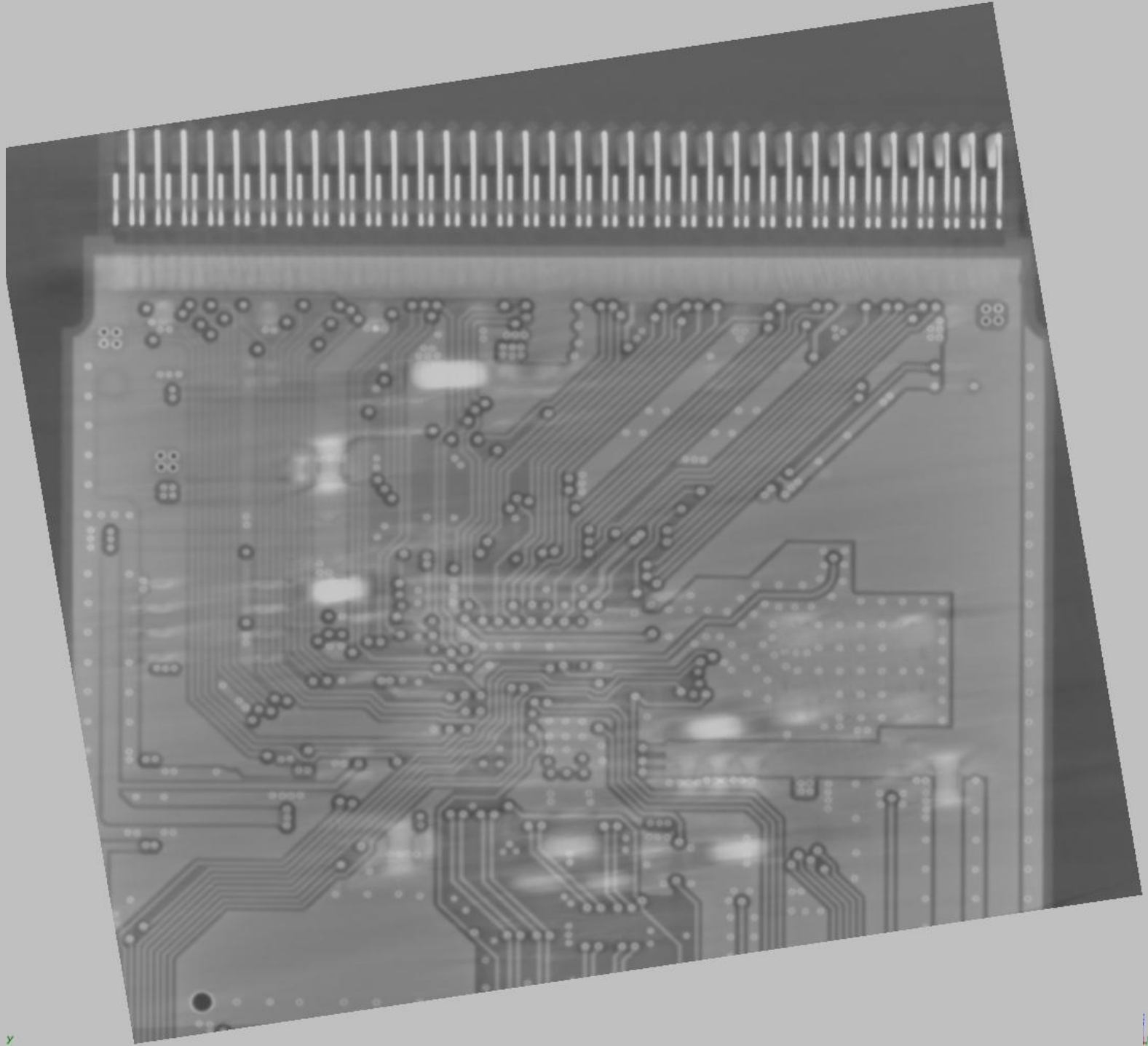


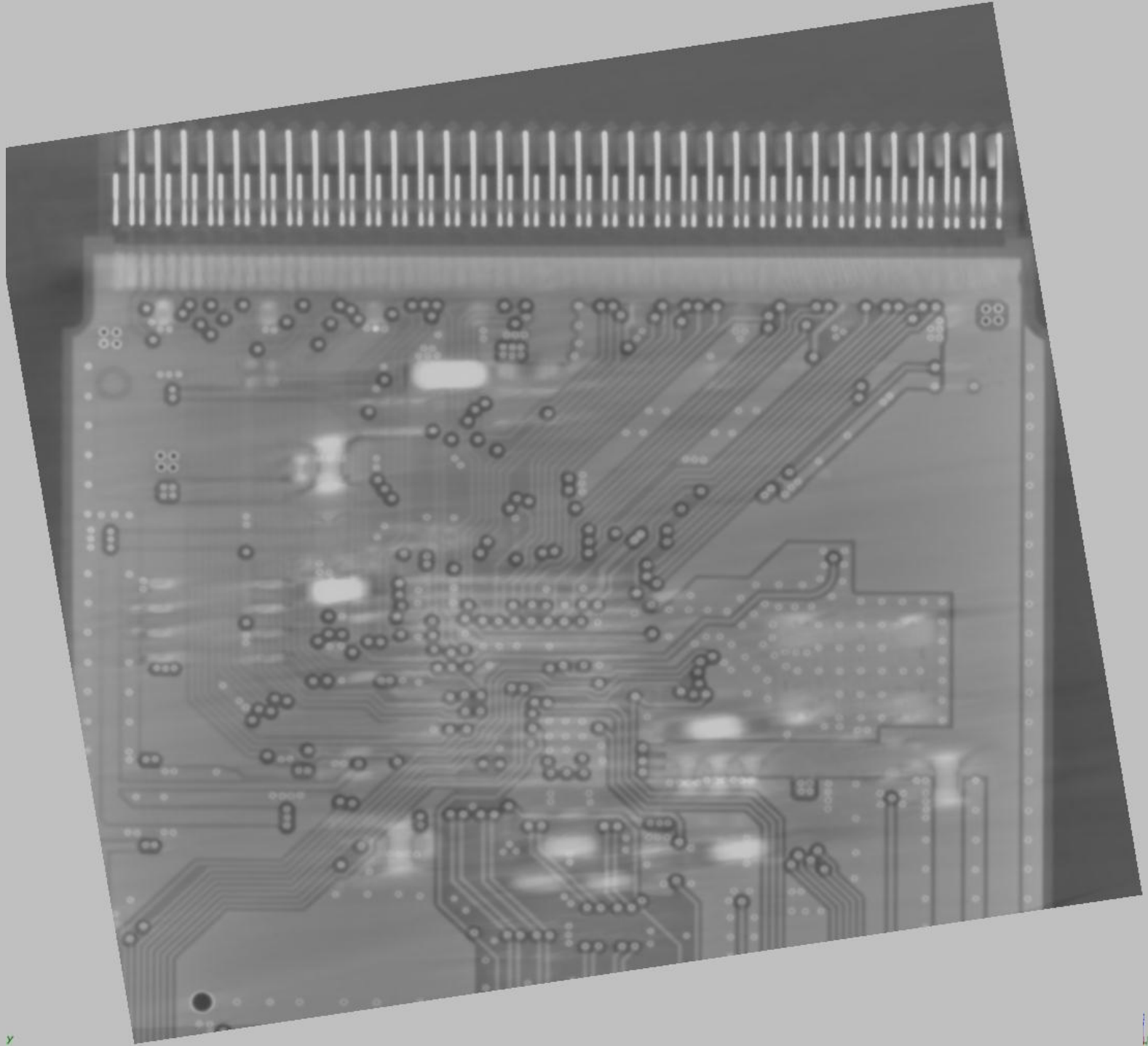


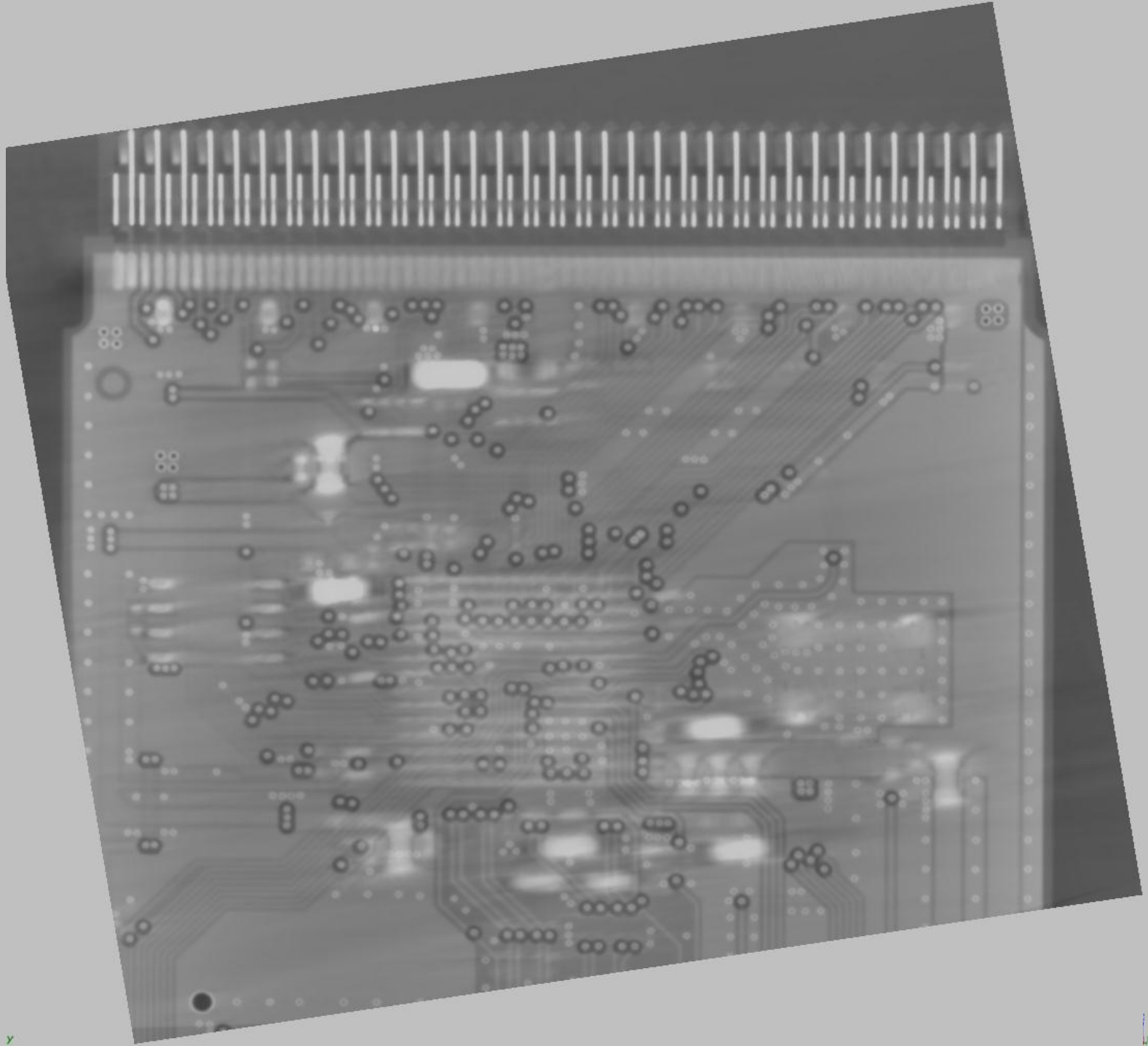


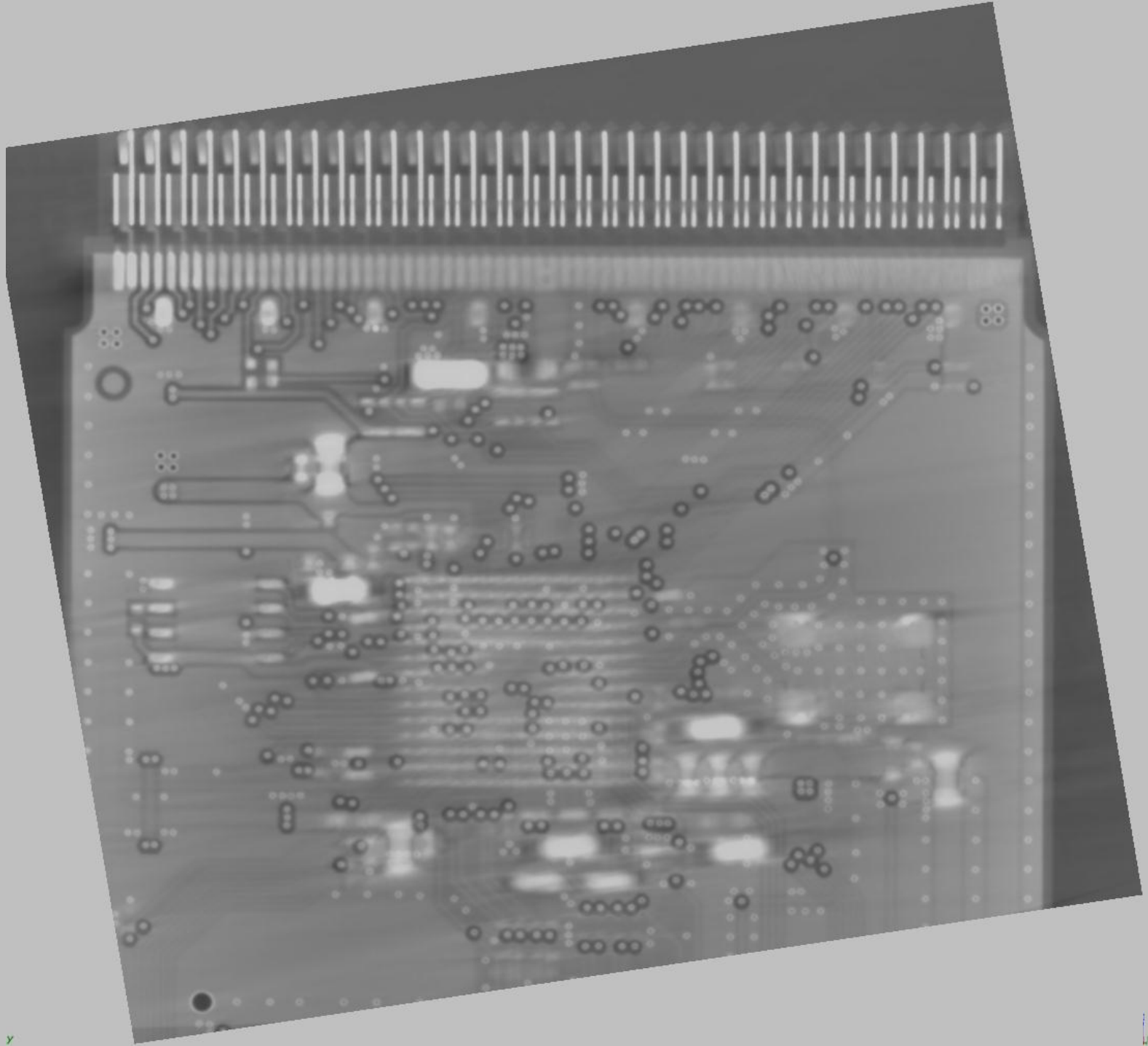


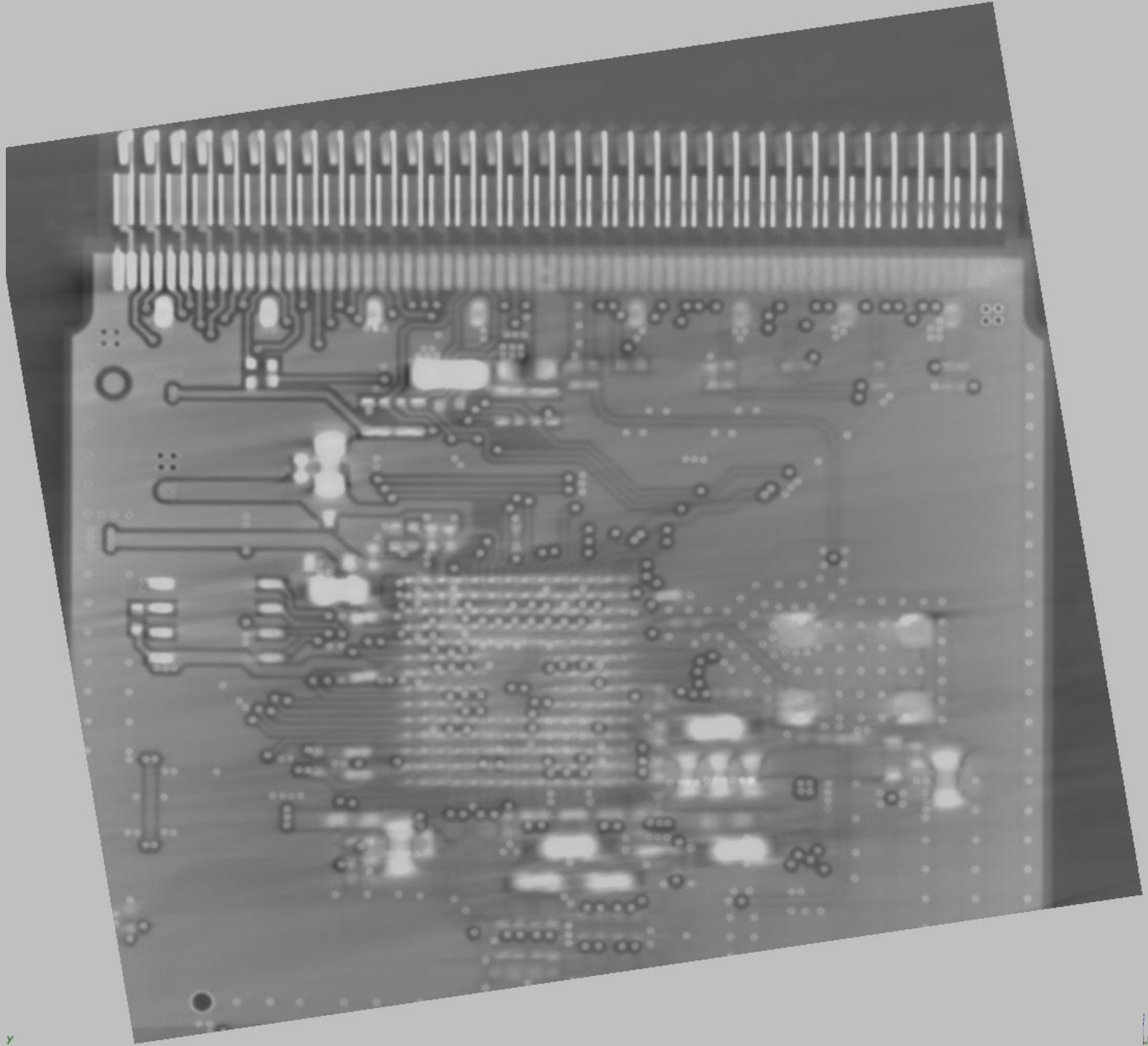


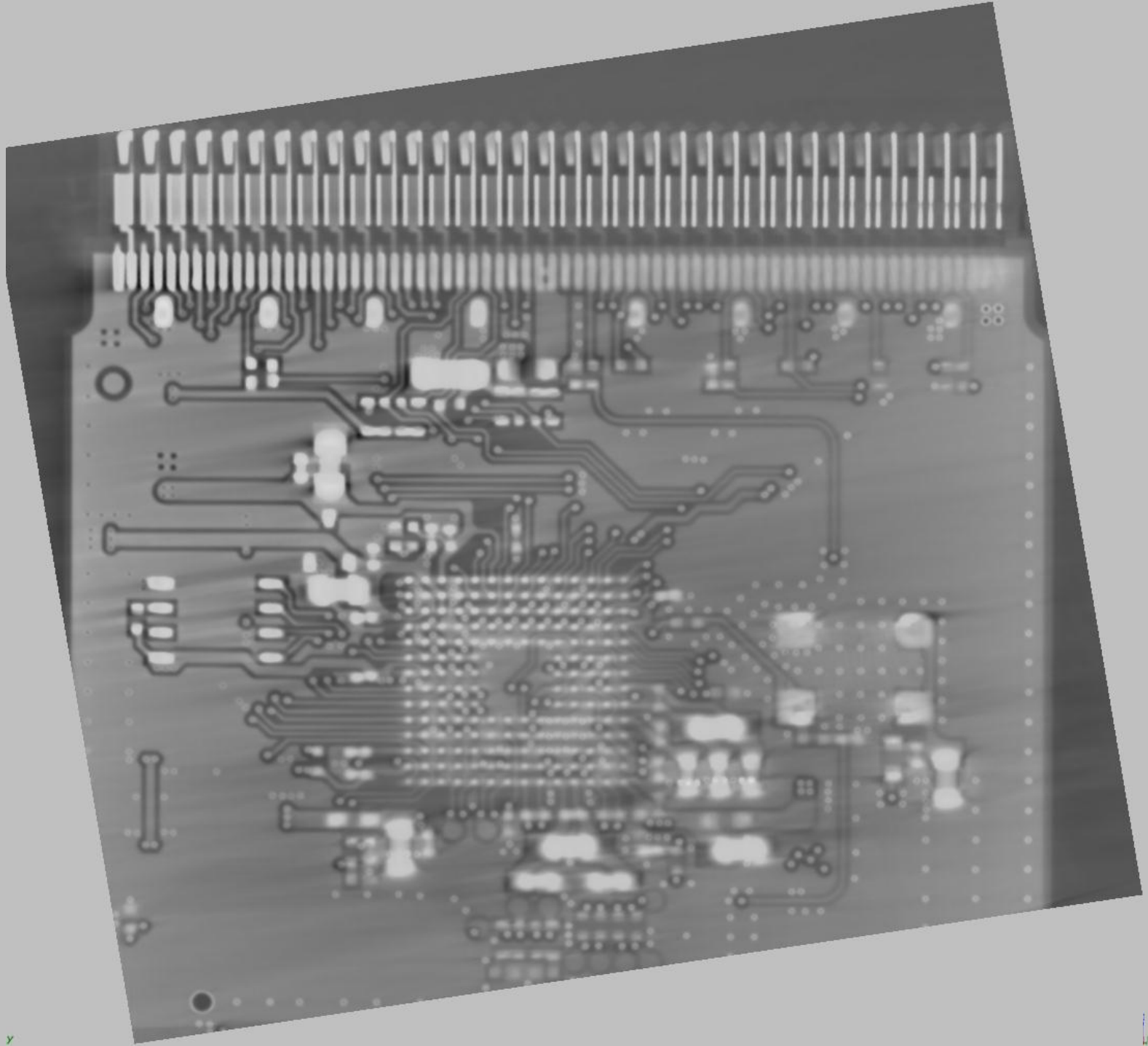


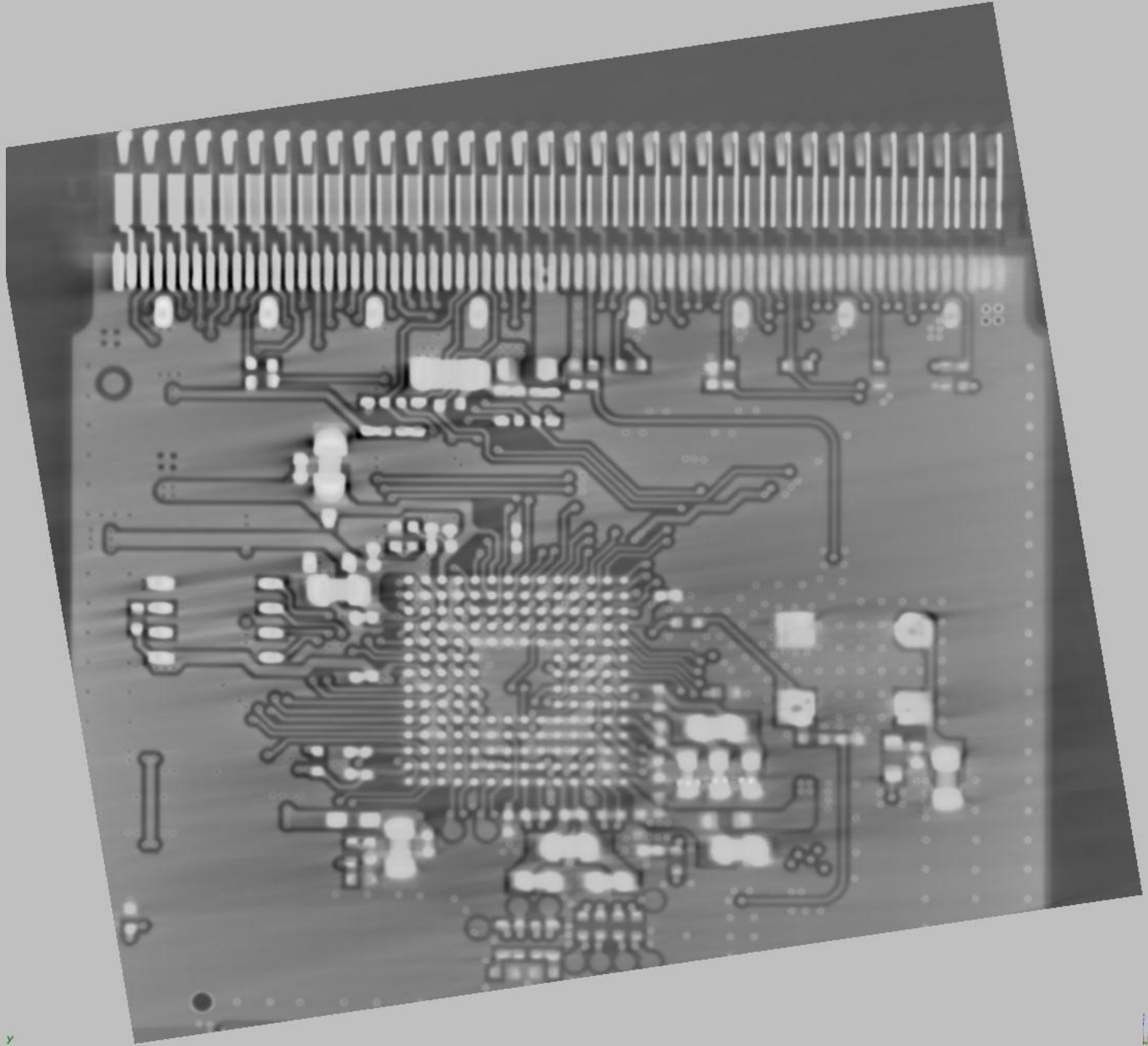


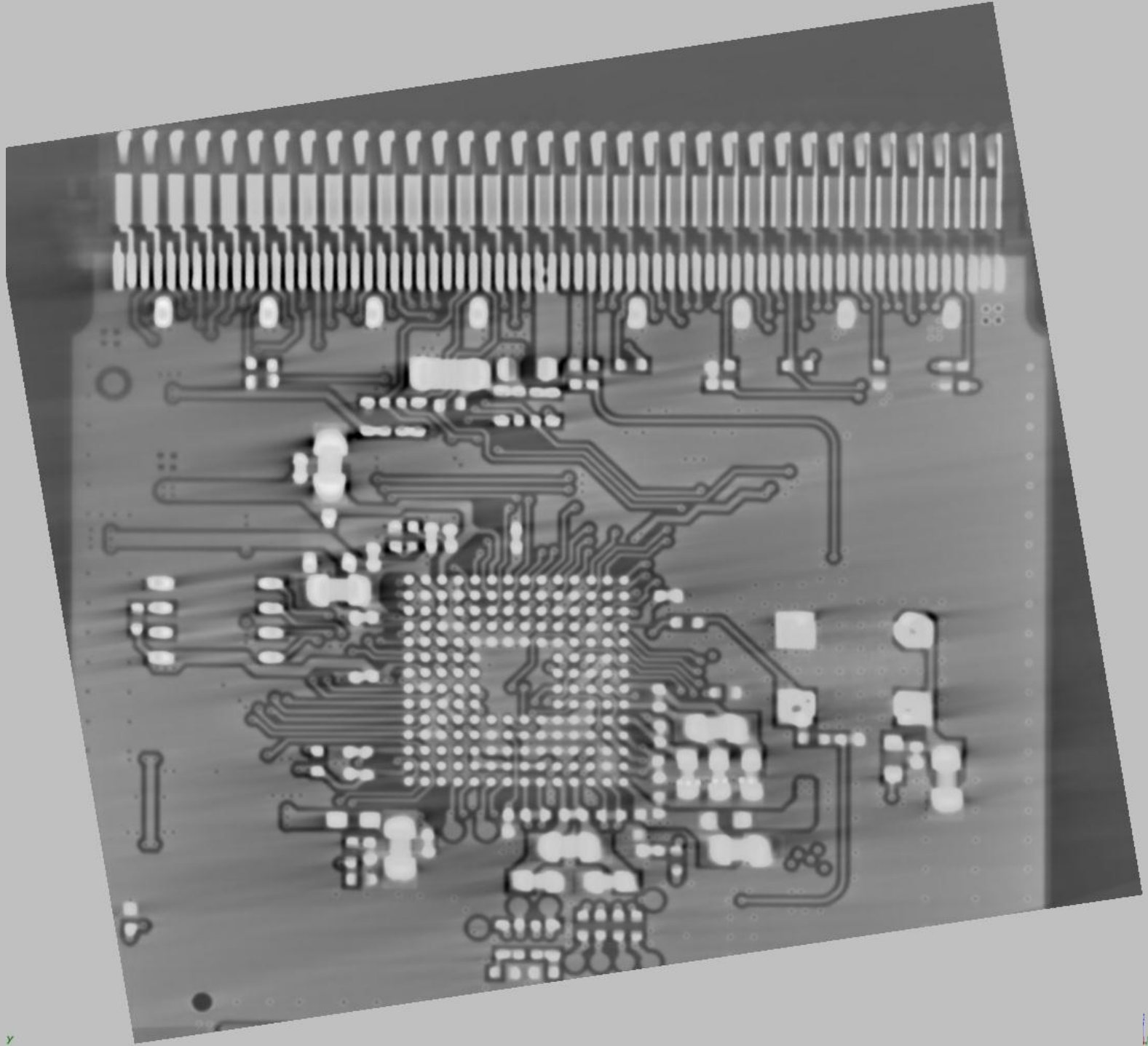


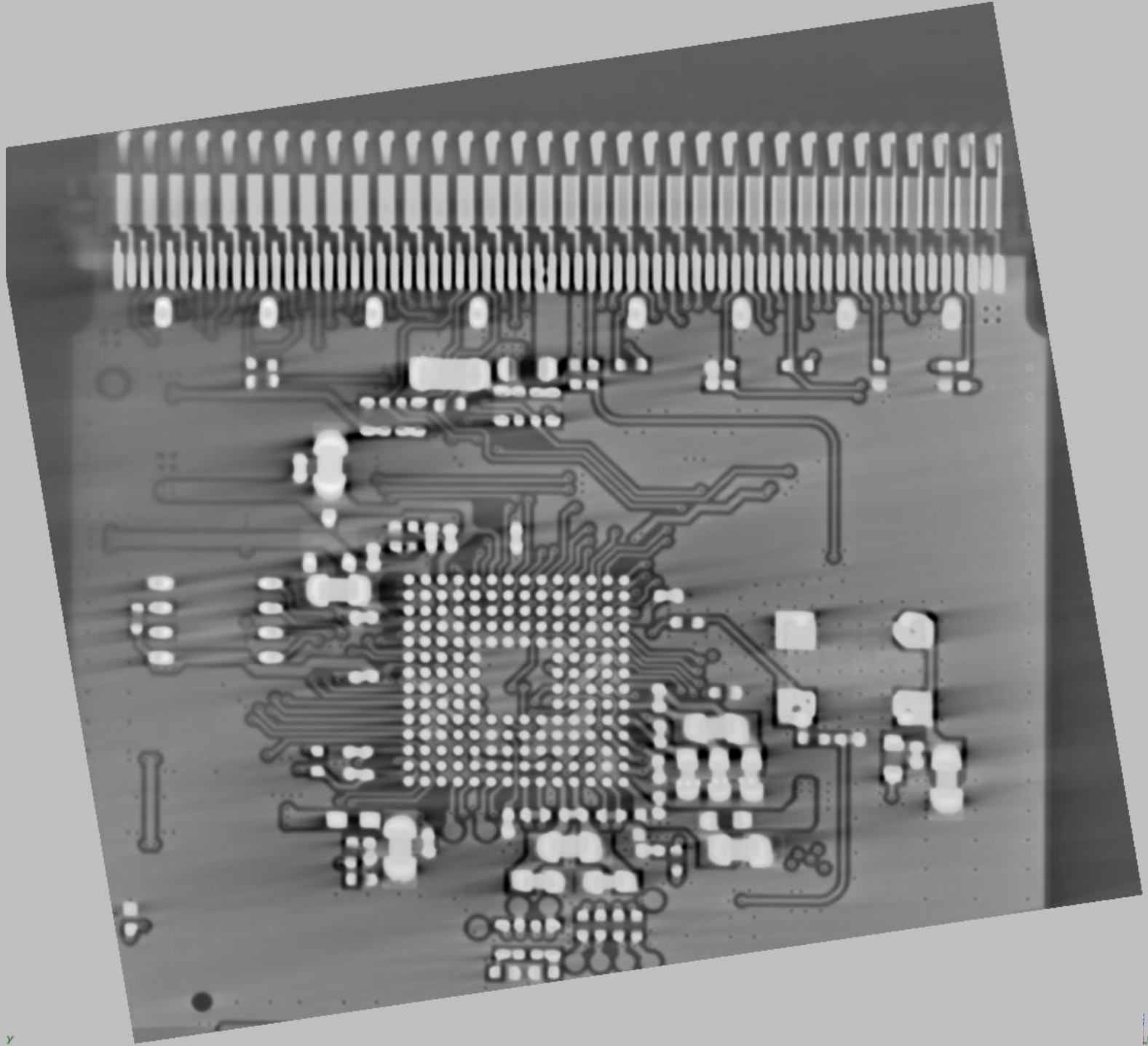


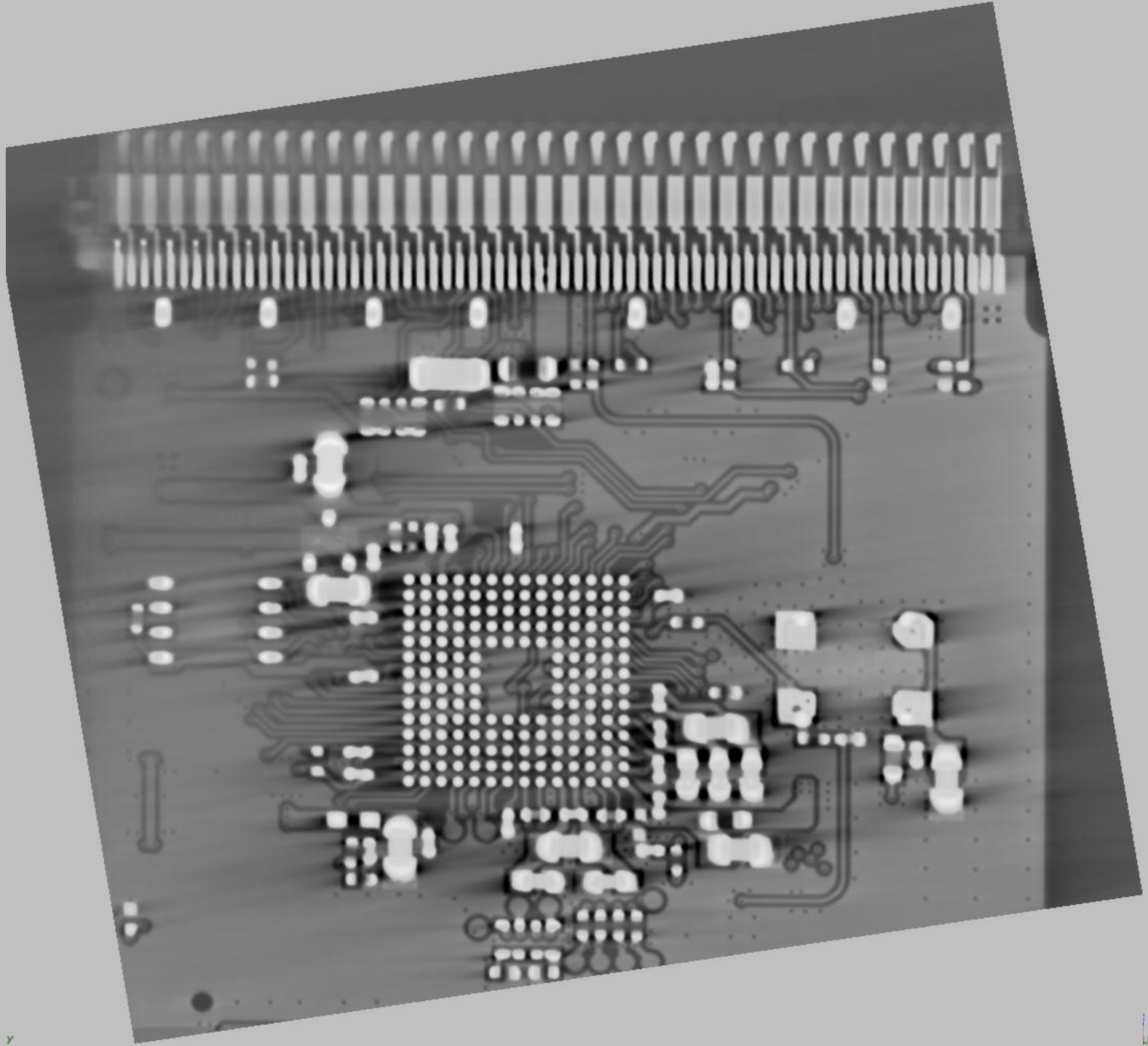


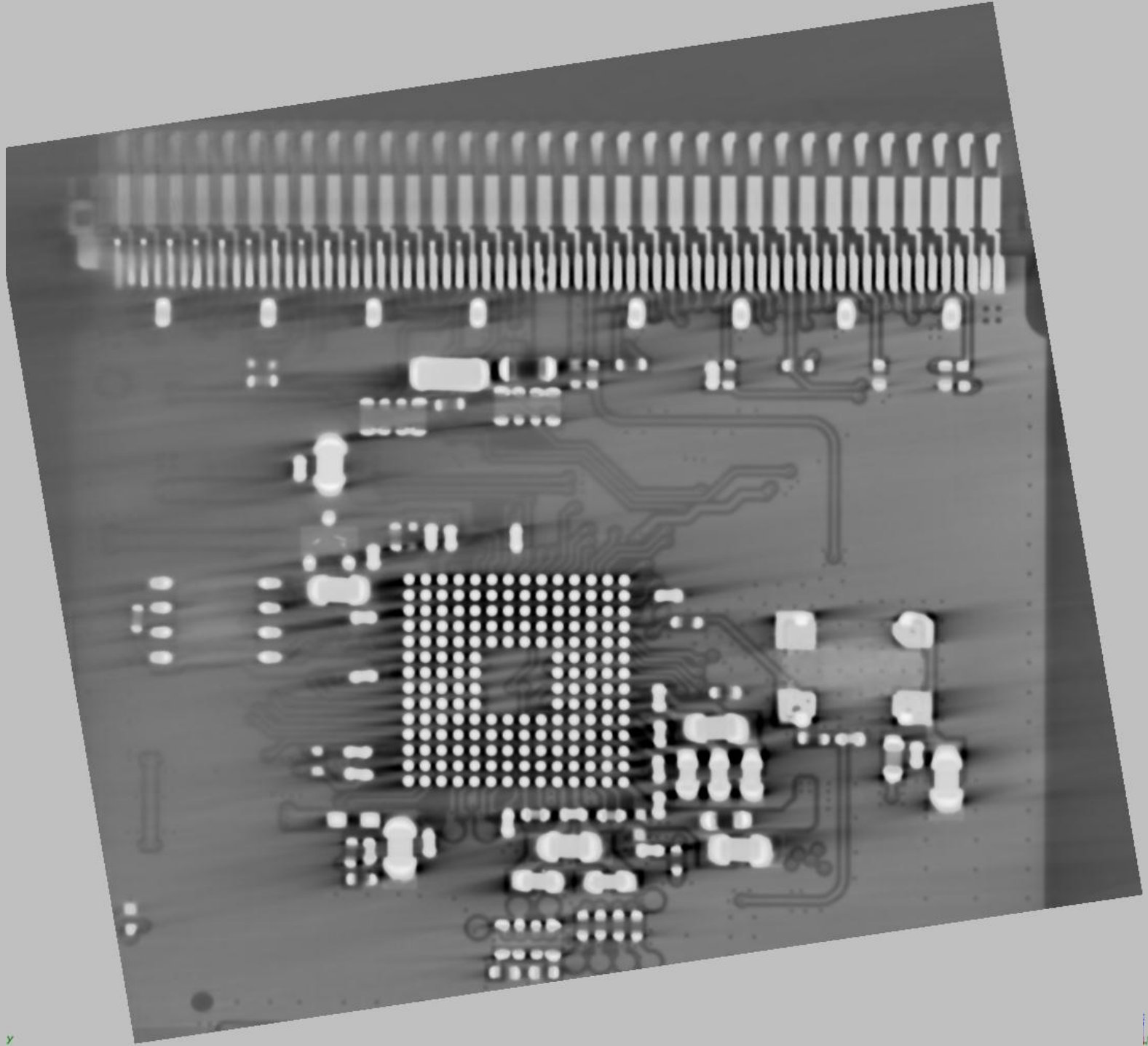


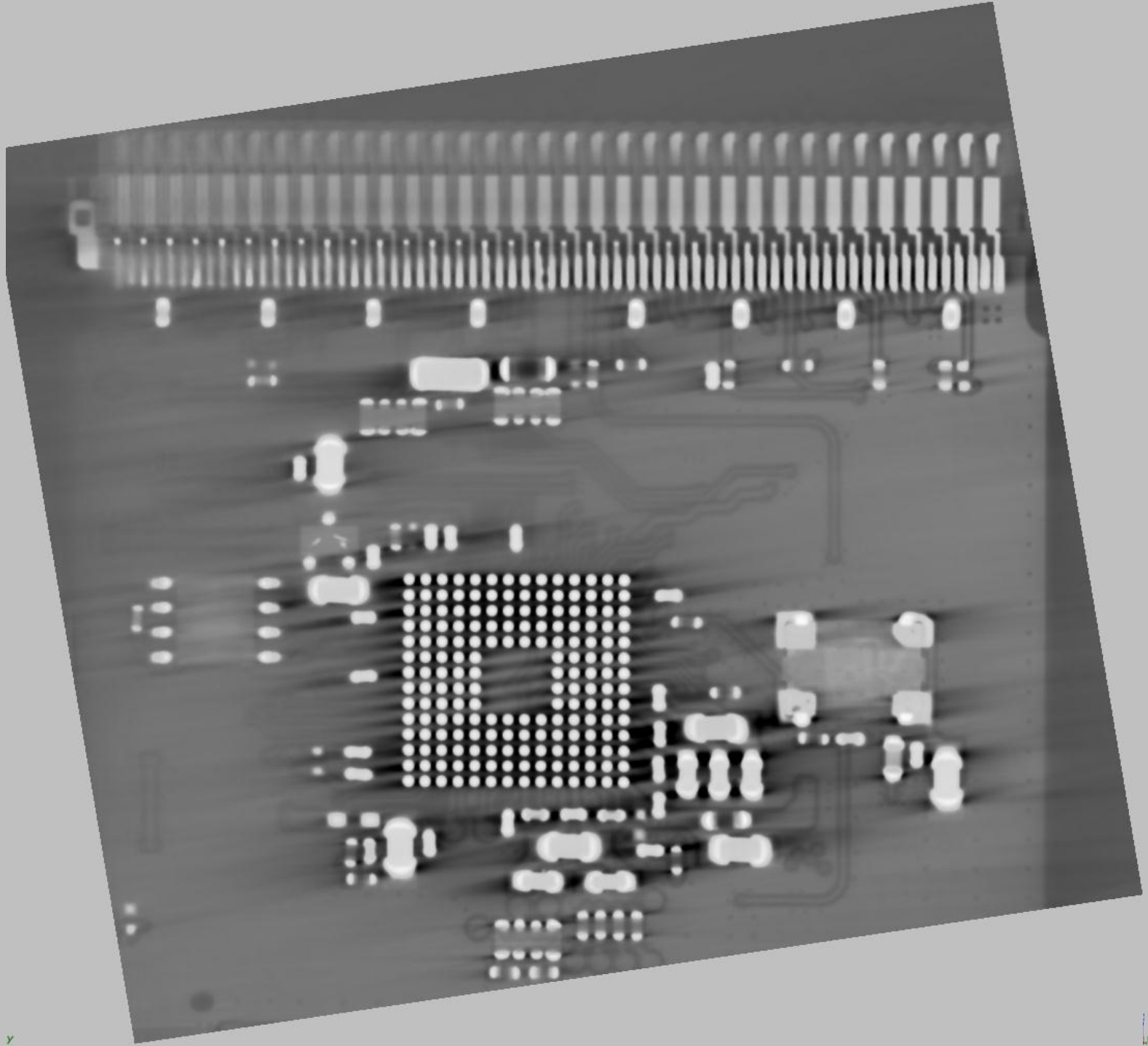


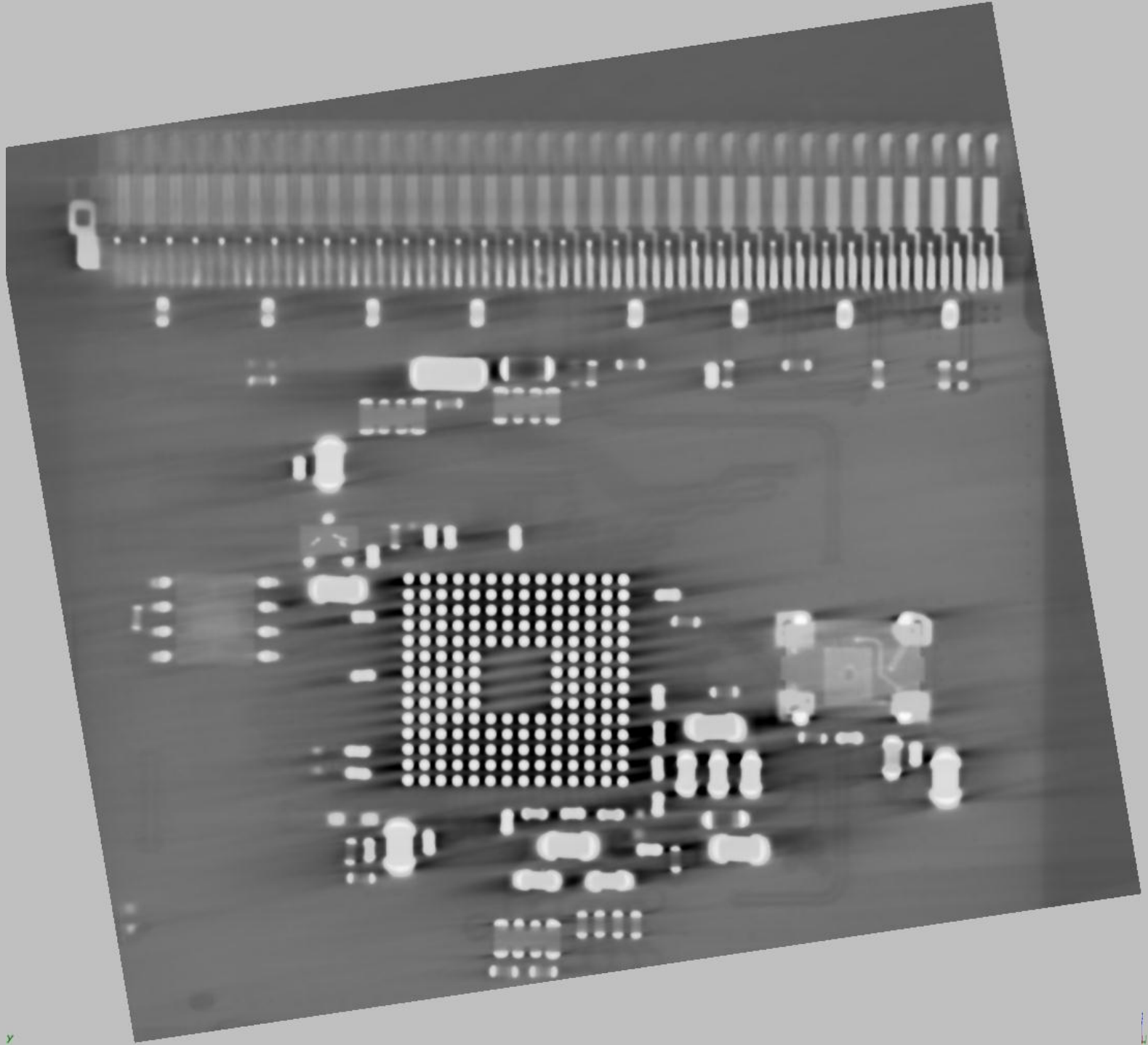


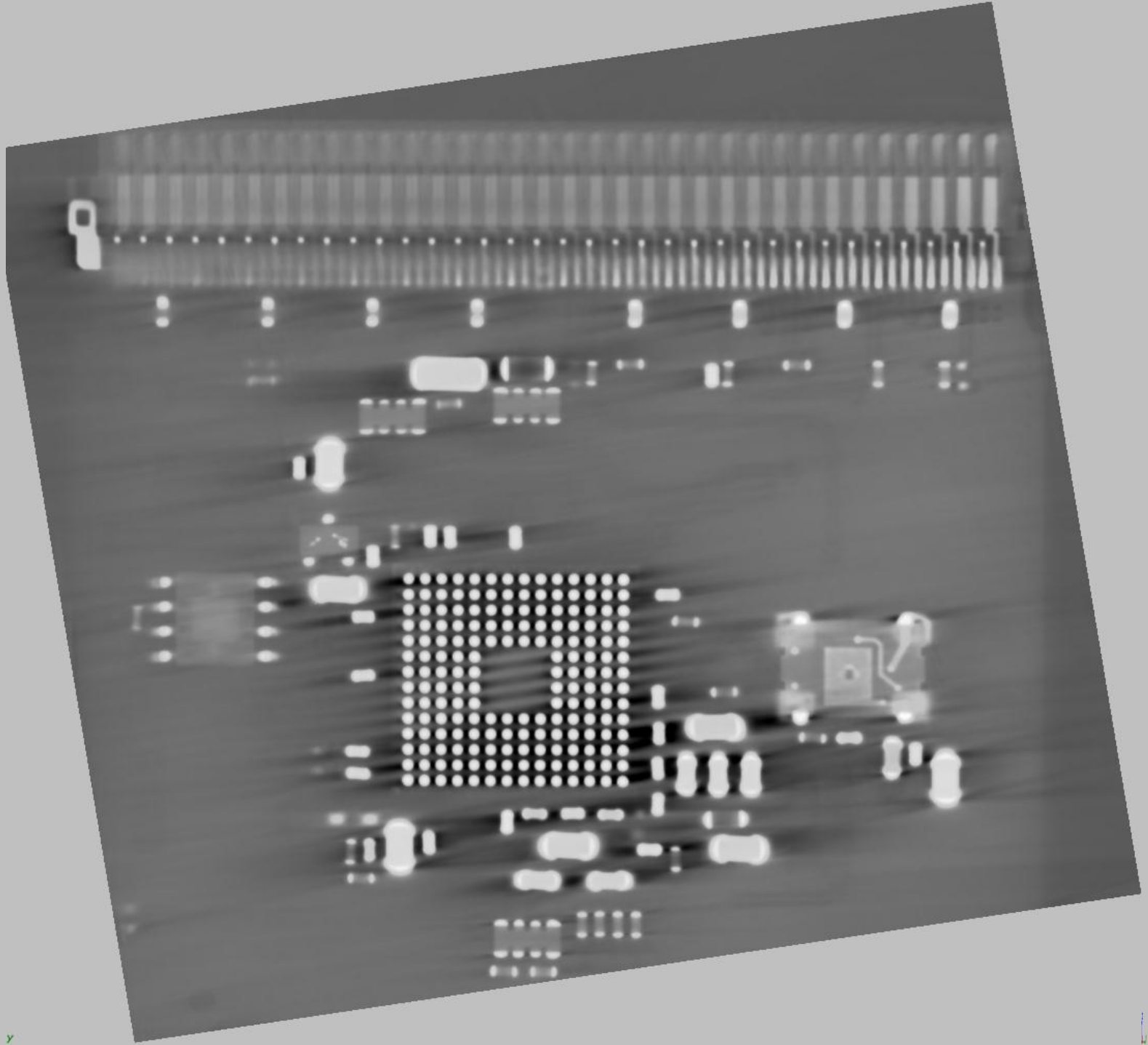


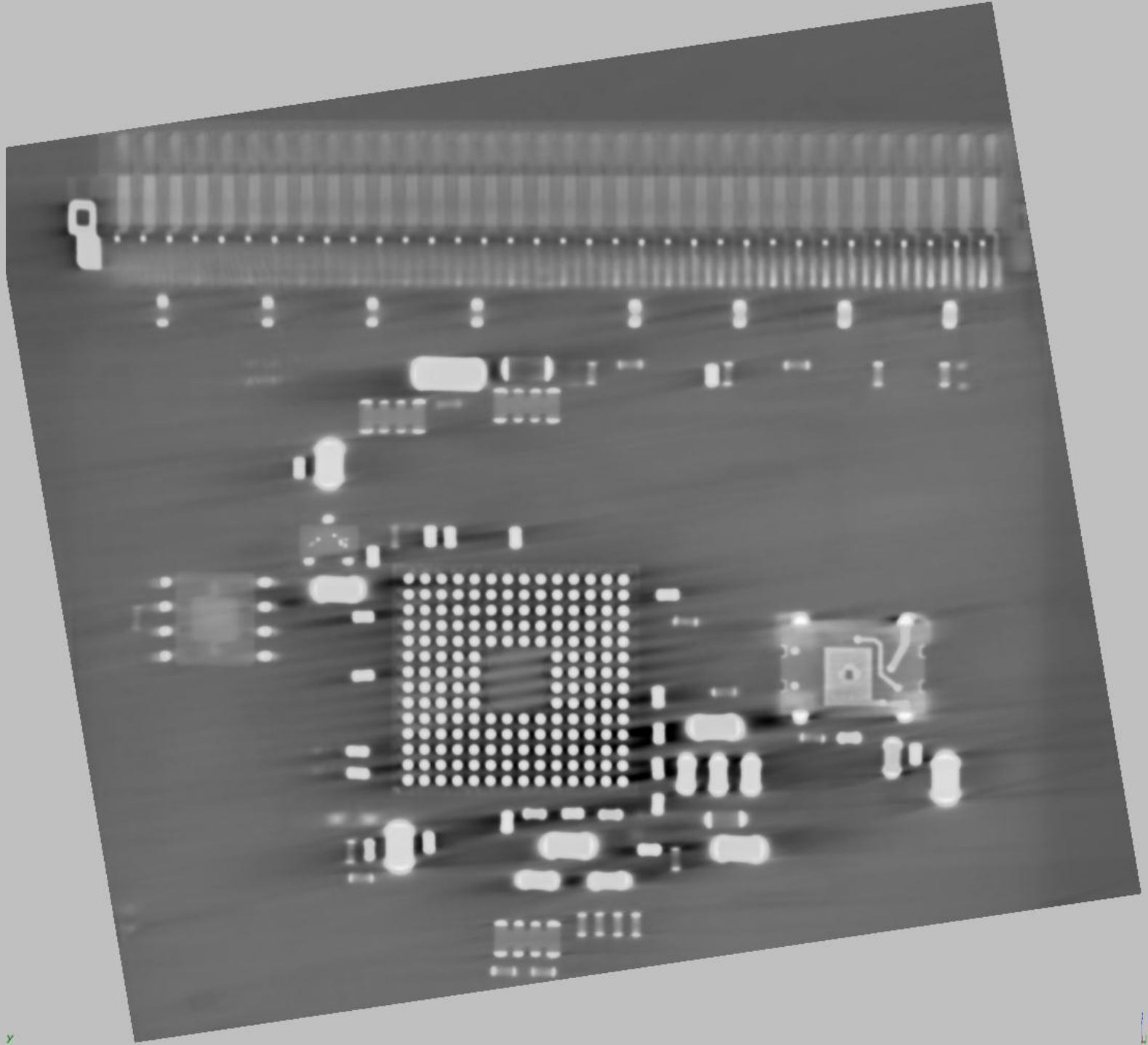


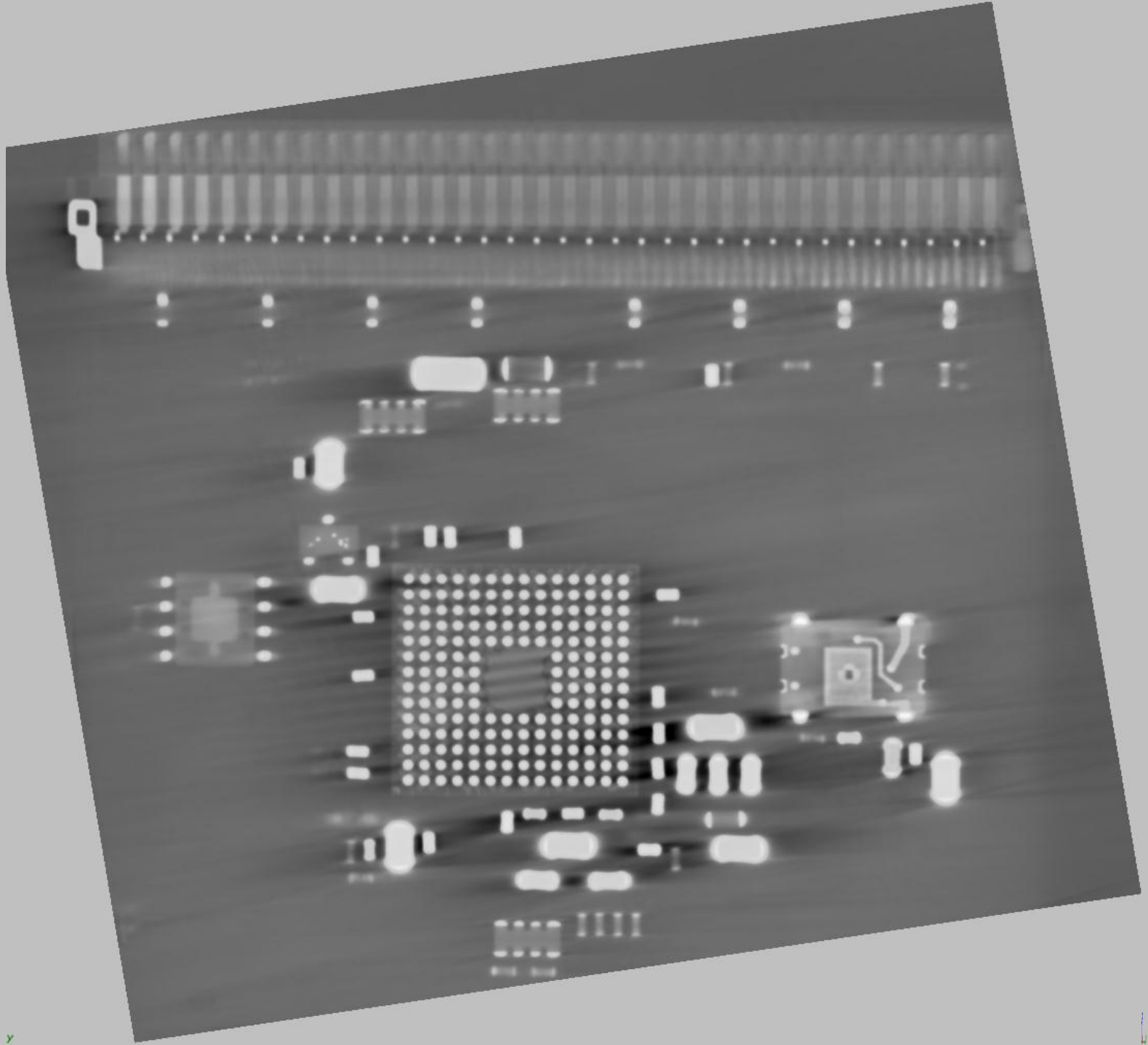


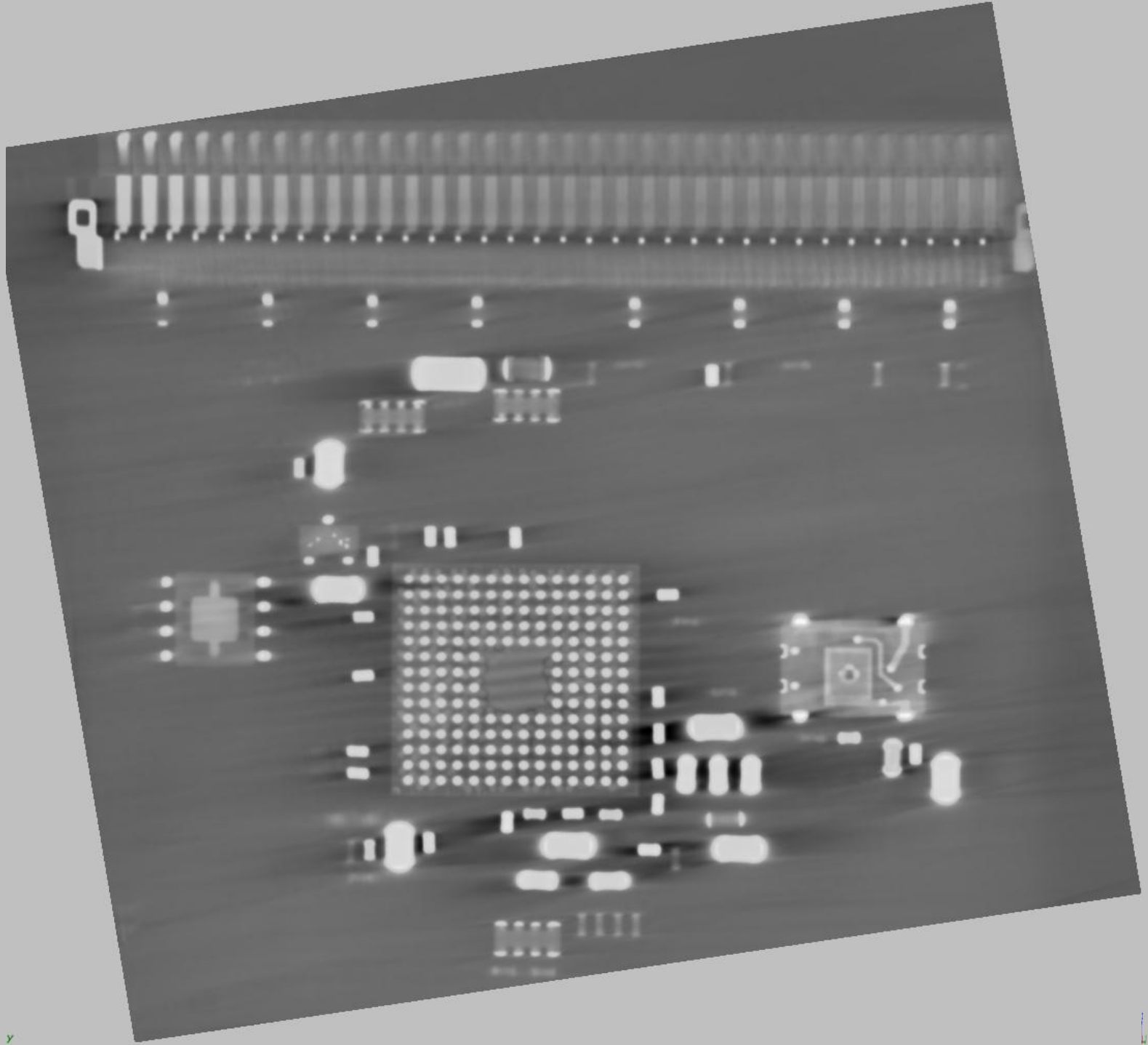


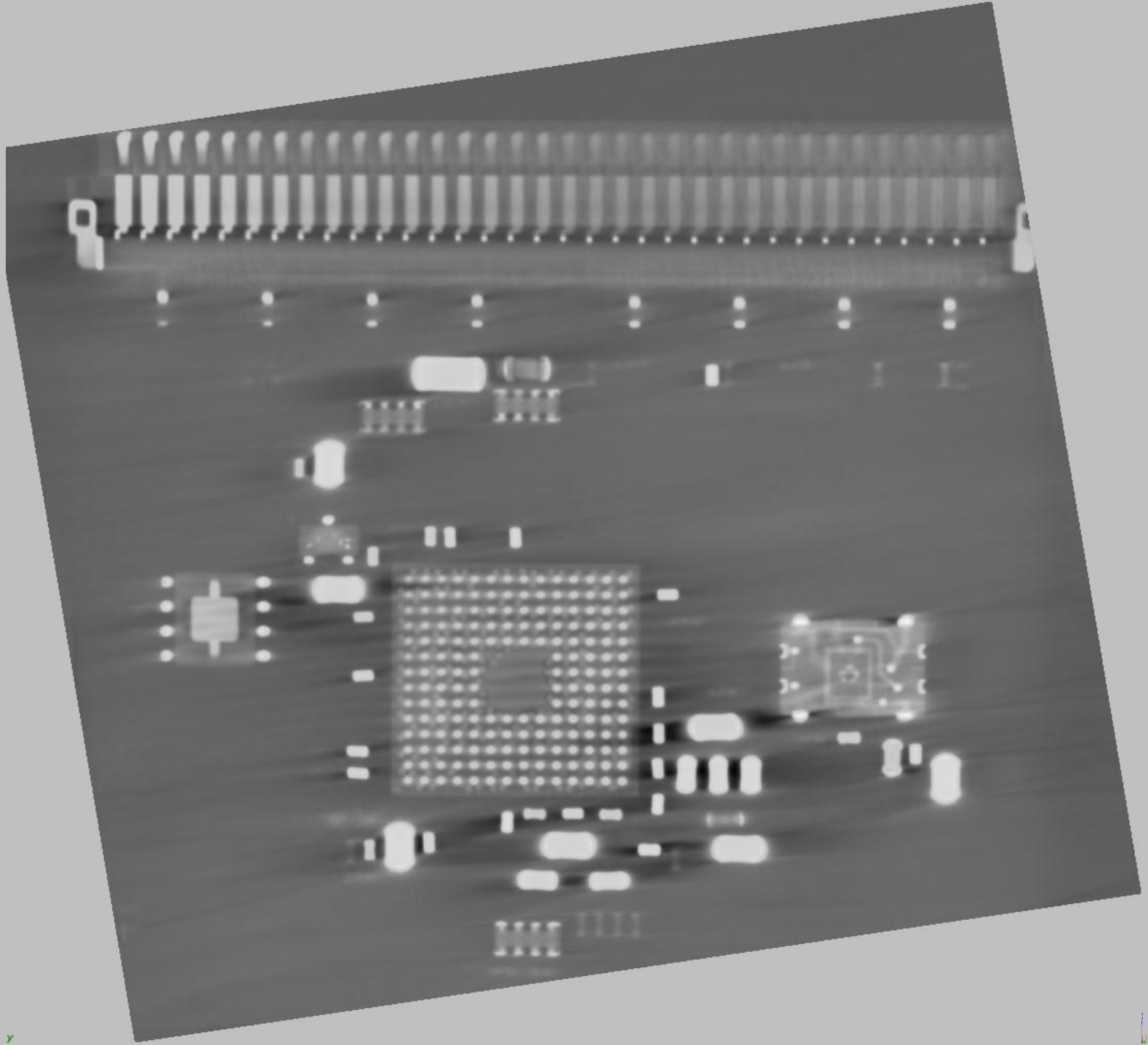


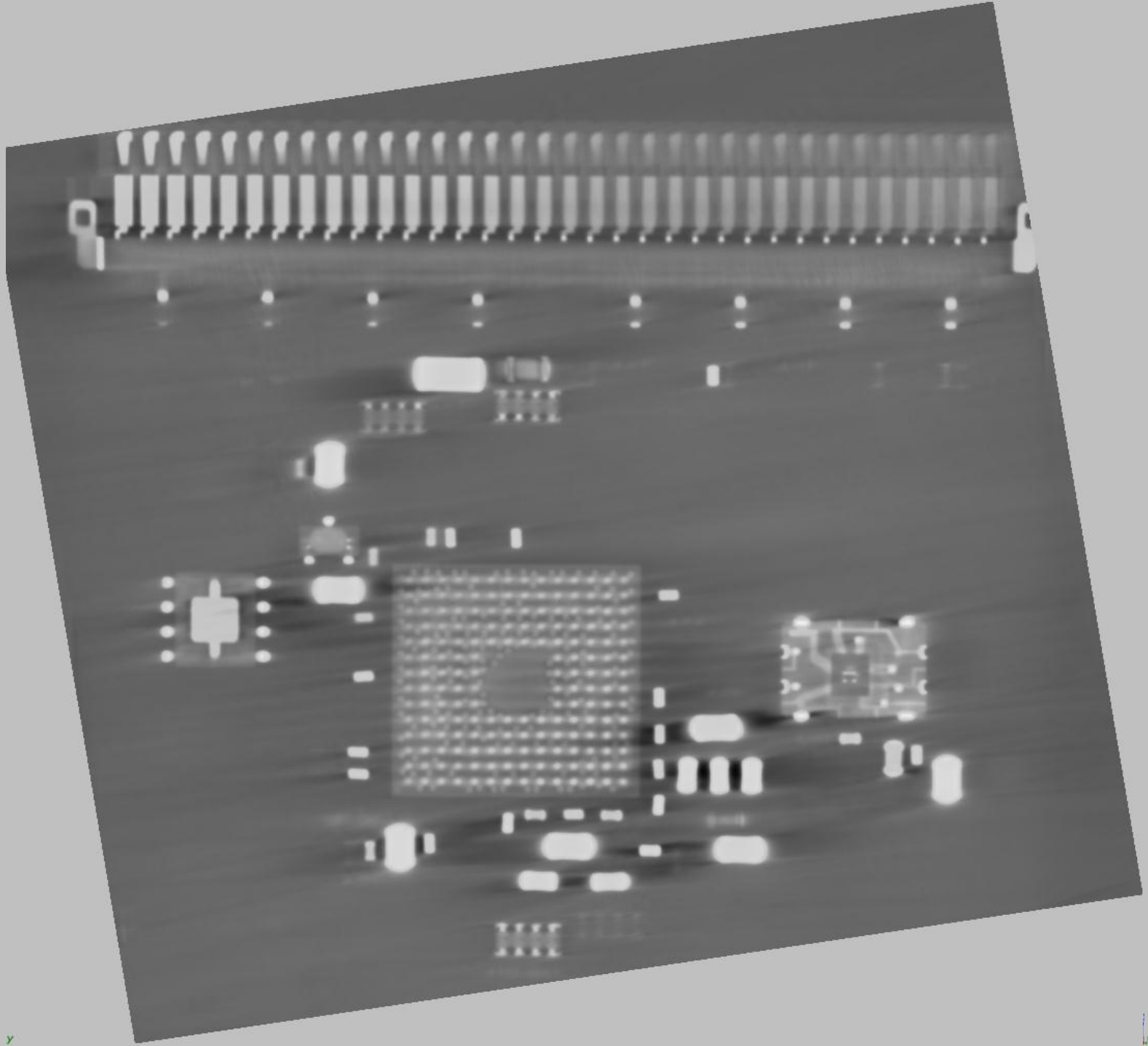


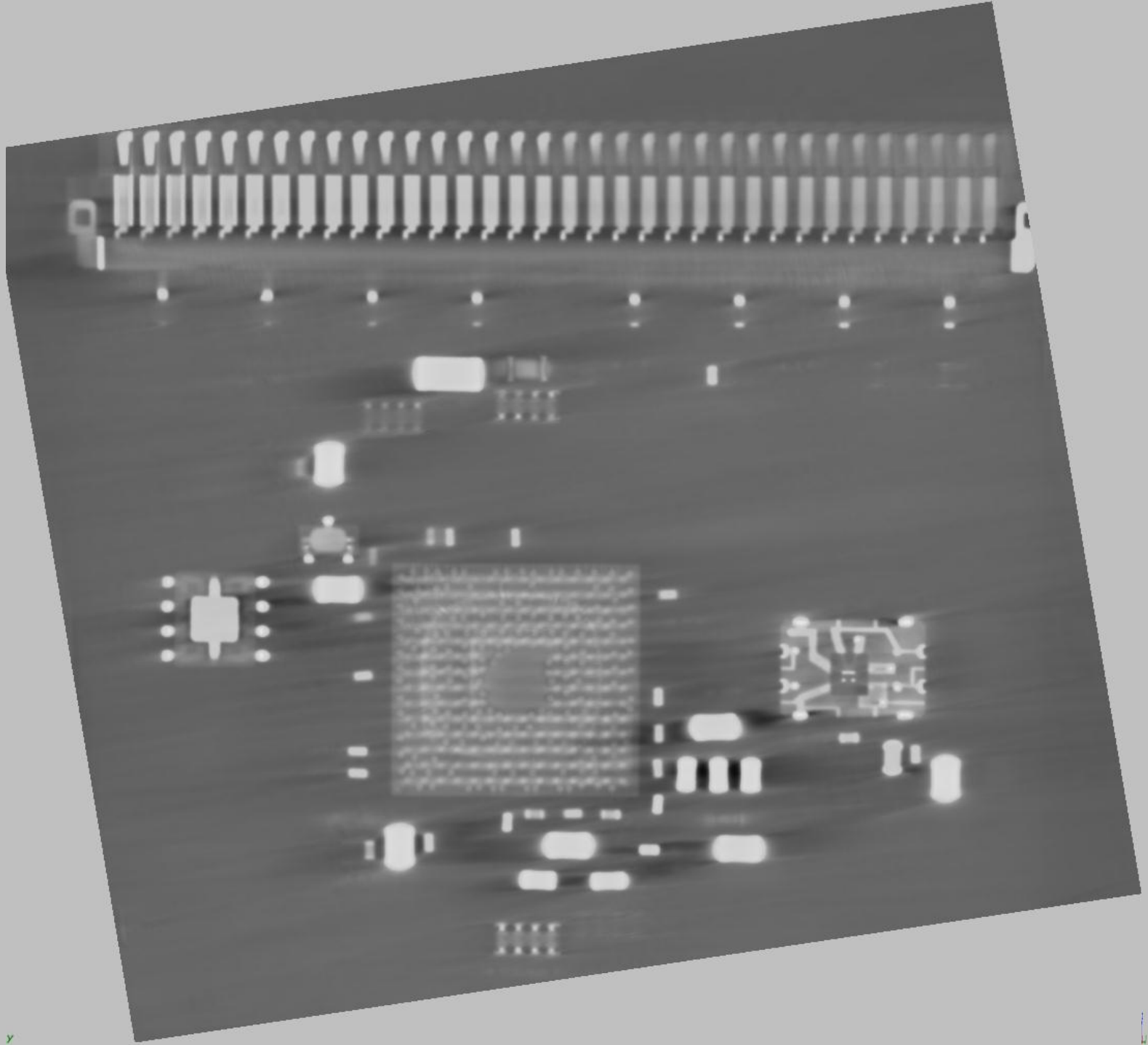


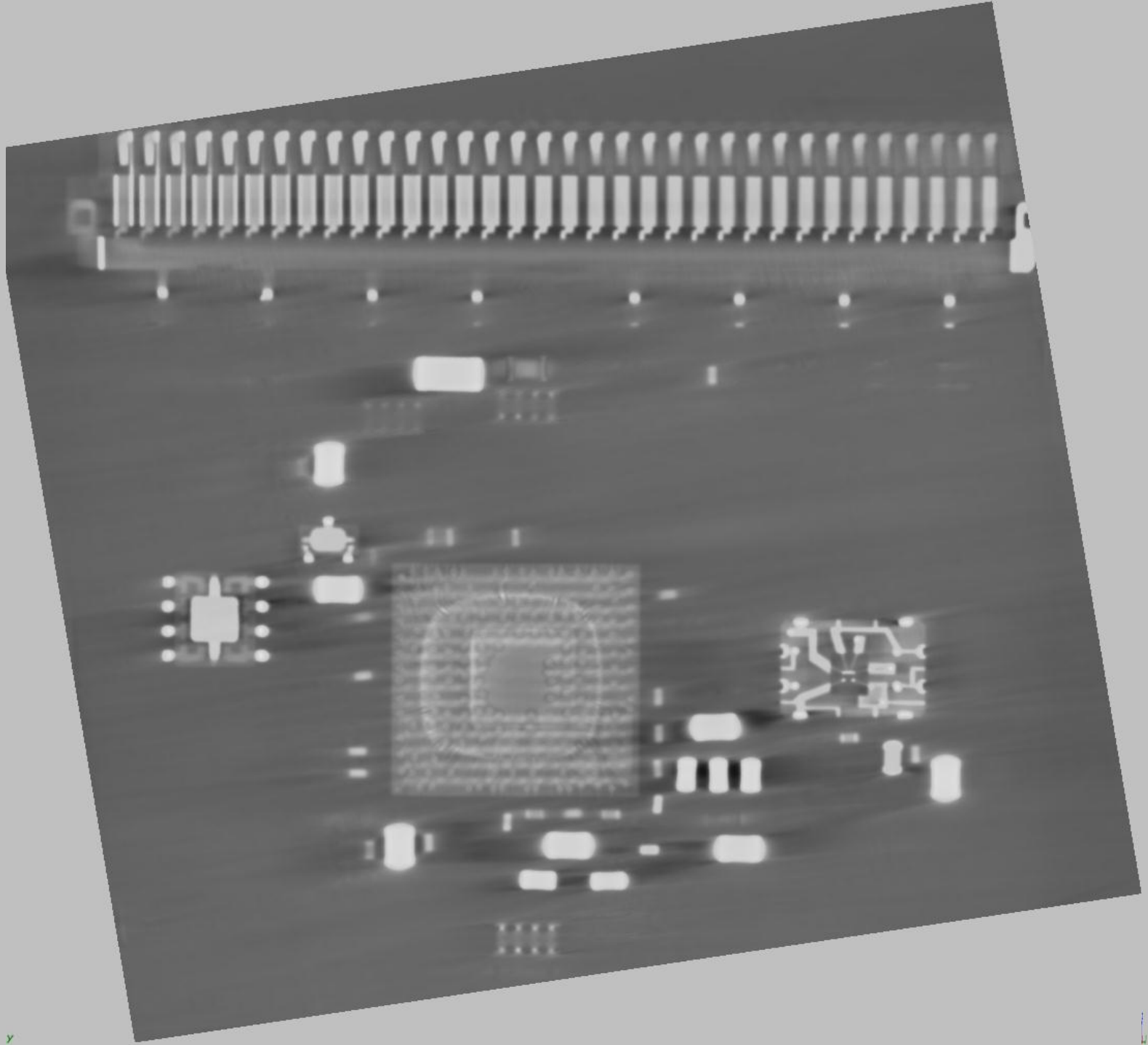


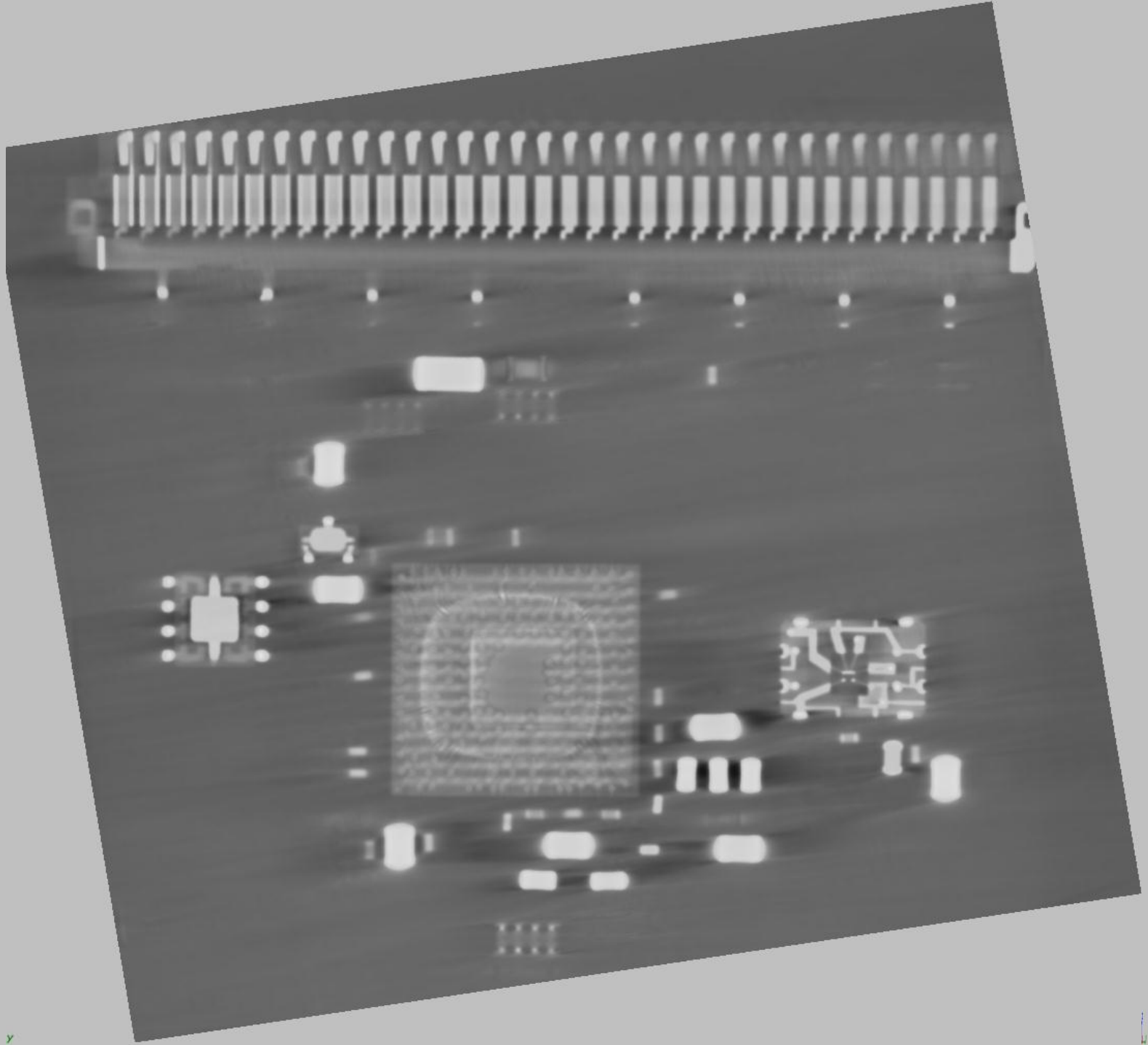


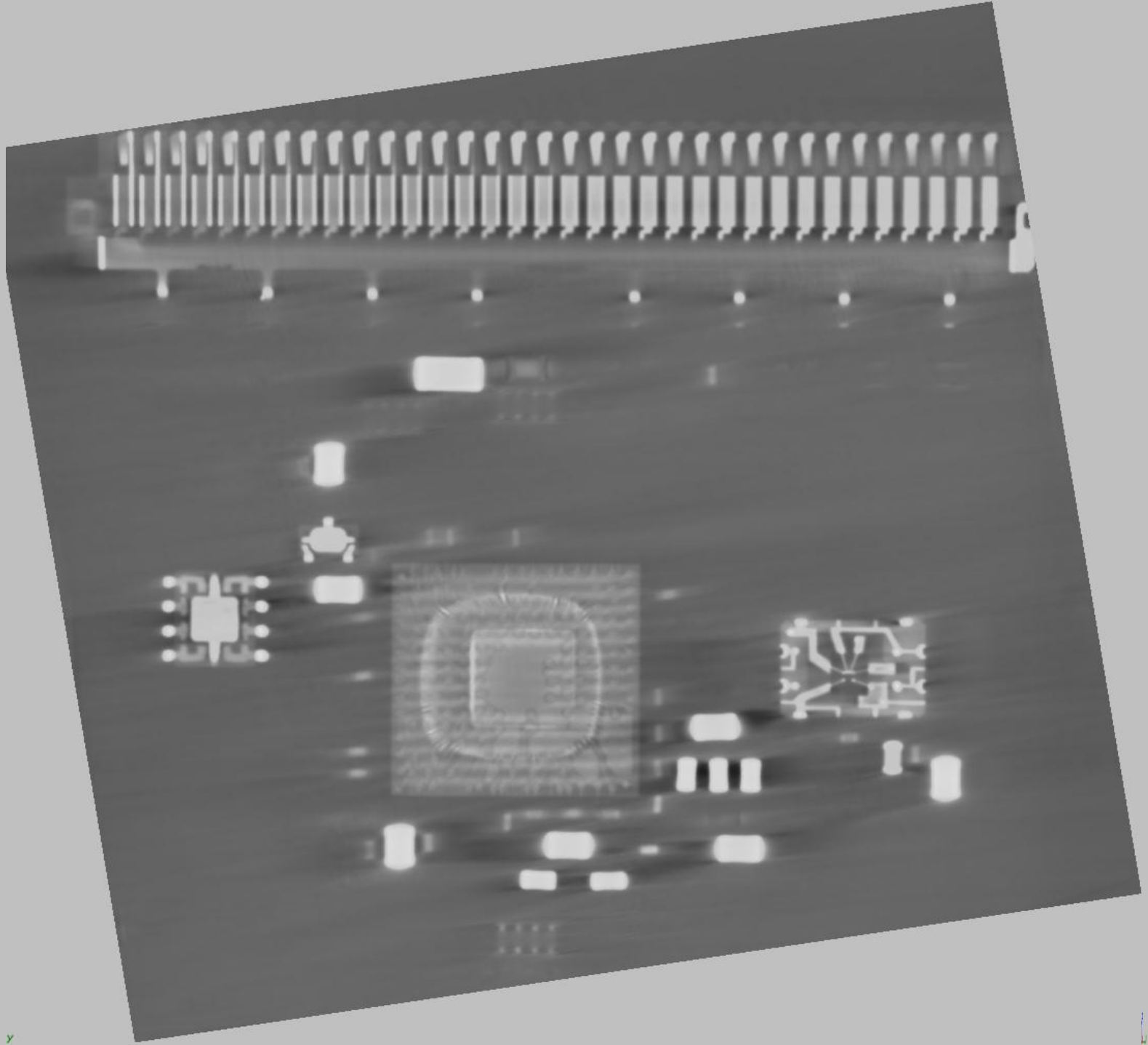


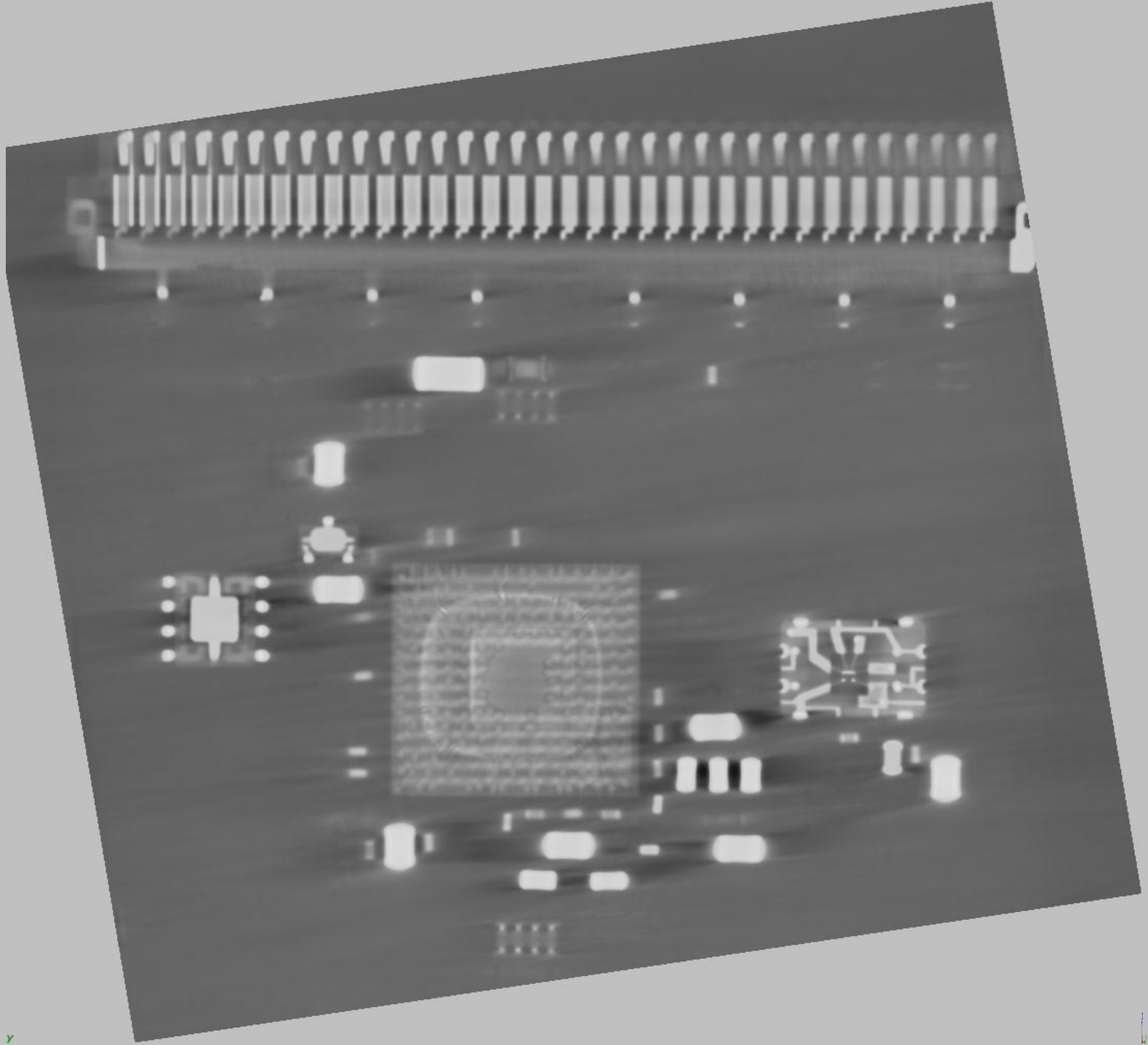


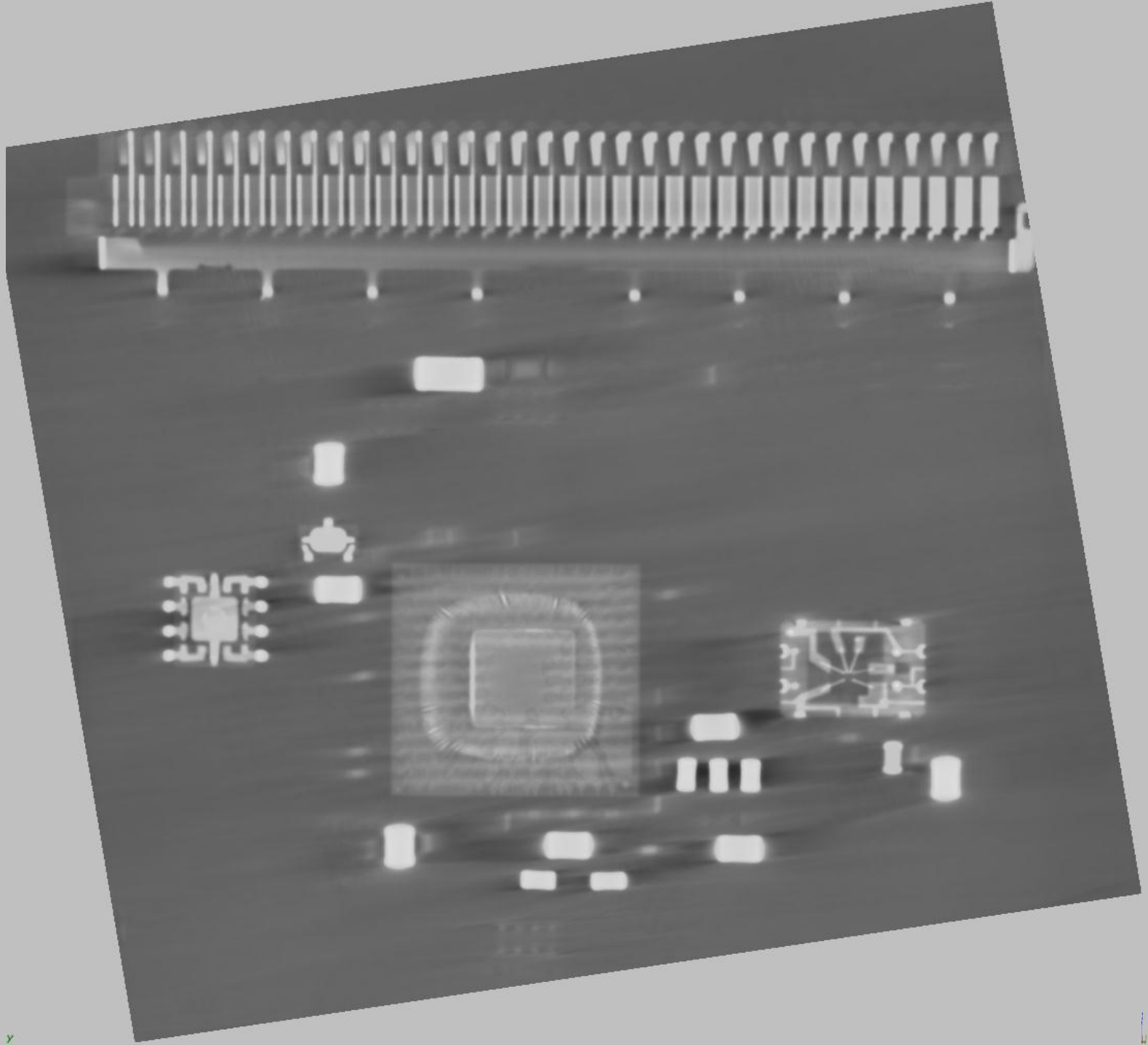




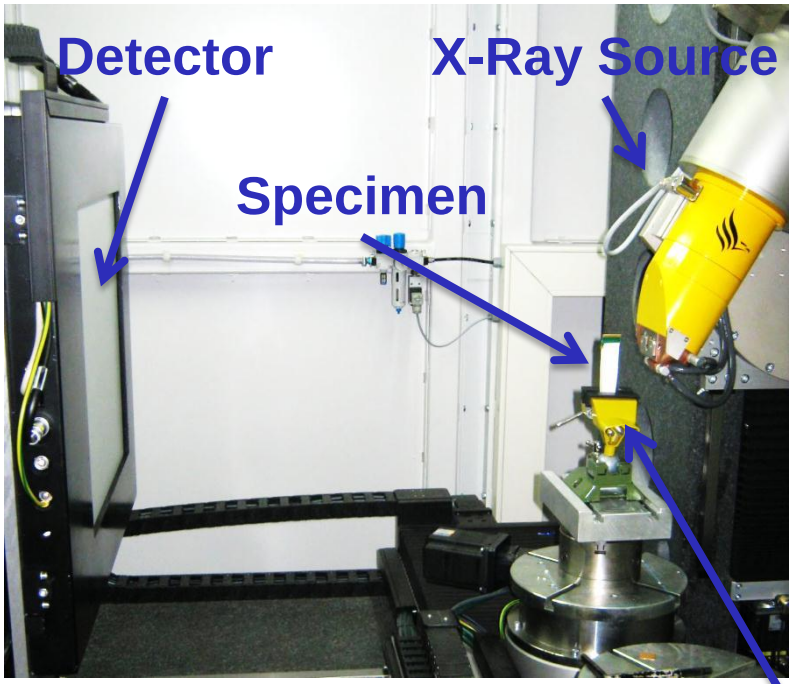


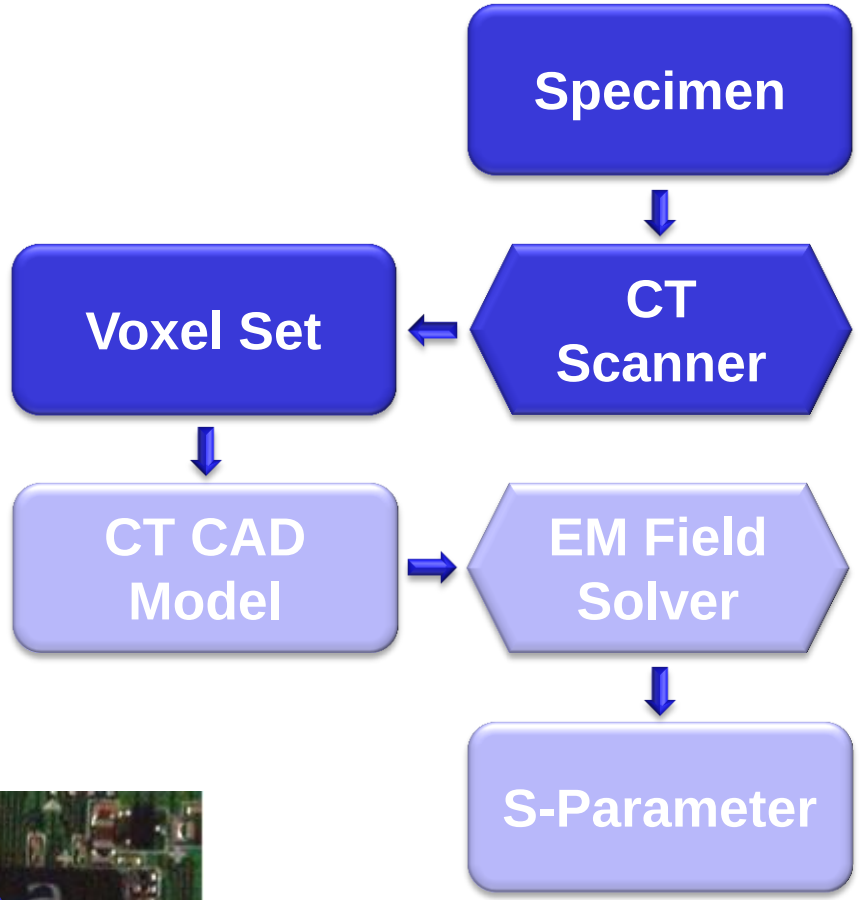






Using a CT-Scanner for Extracting S-Parameters





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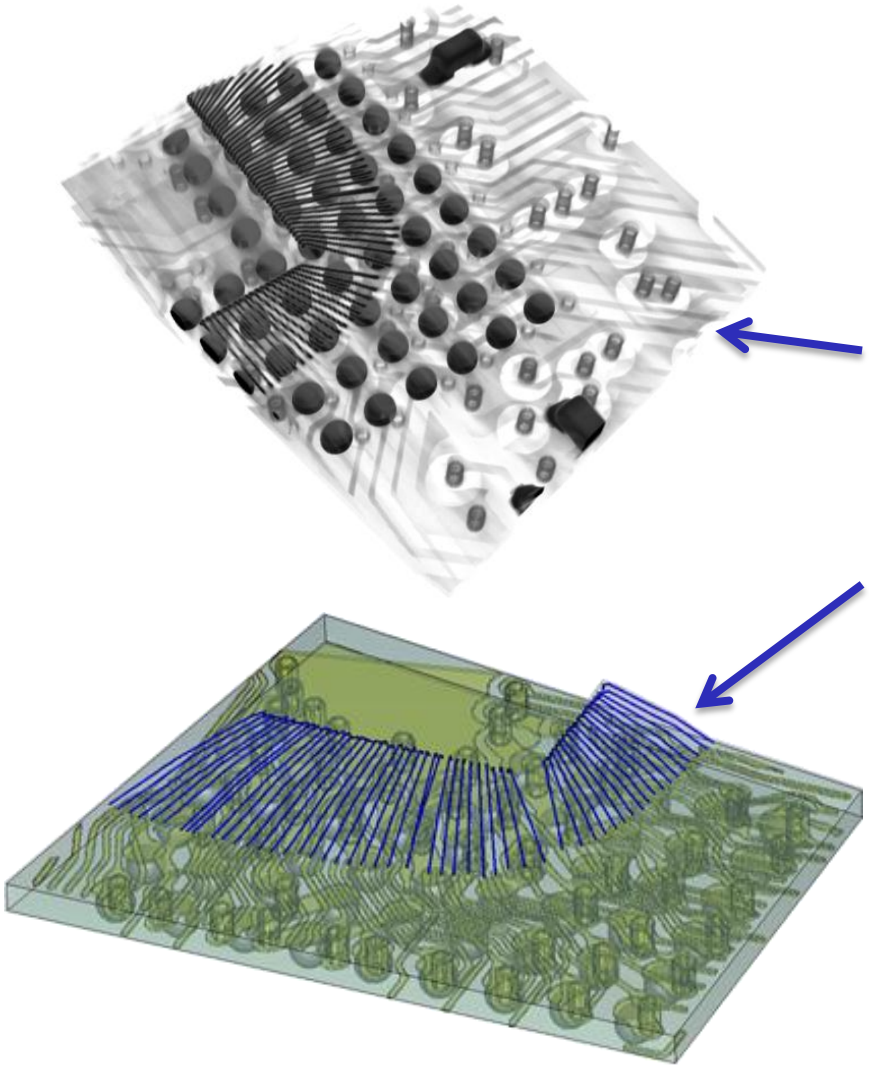


Specimen

CT Scanner

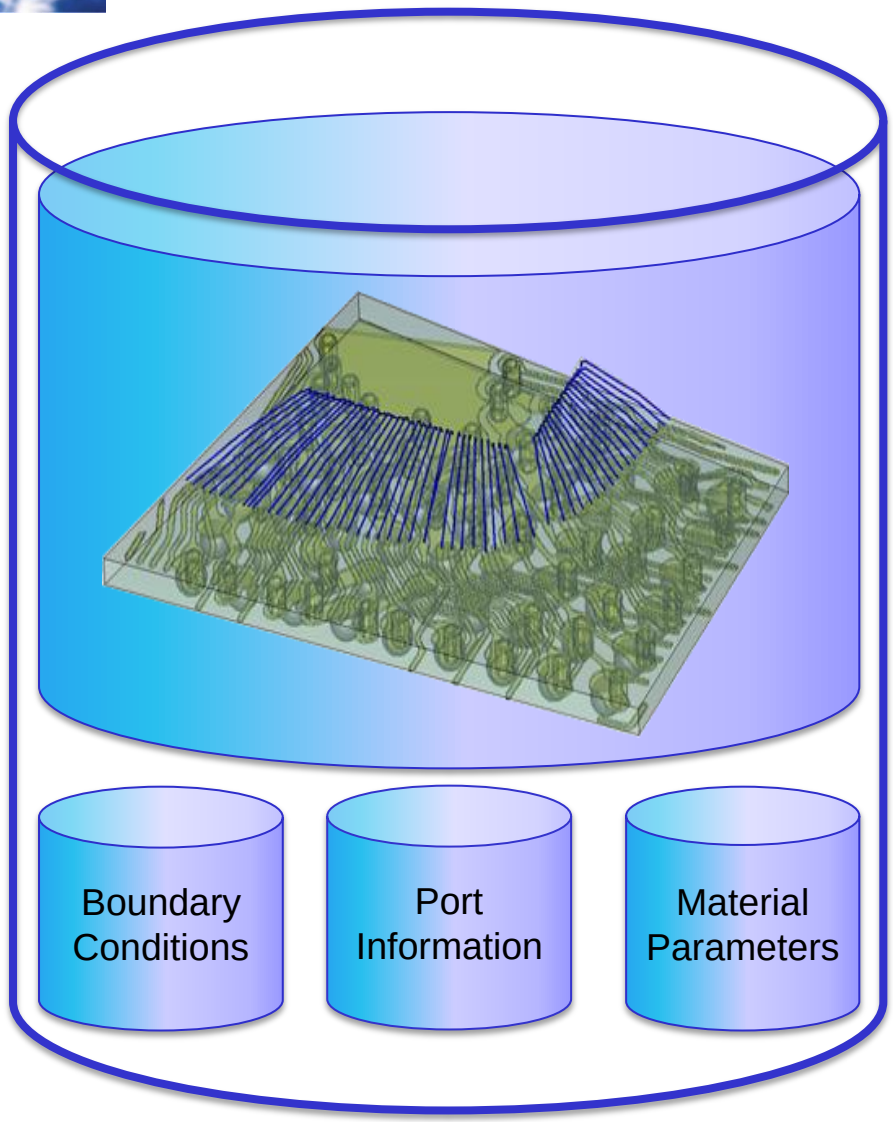
Voxel Set

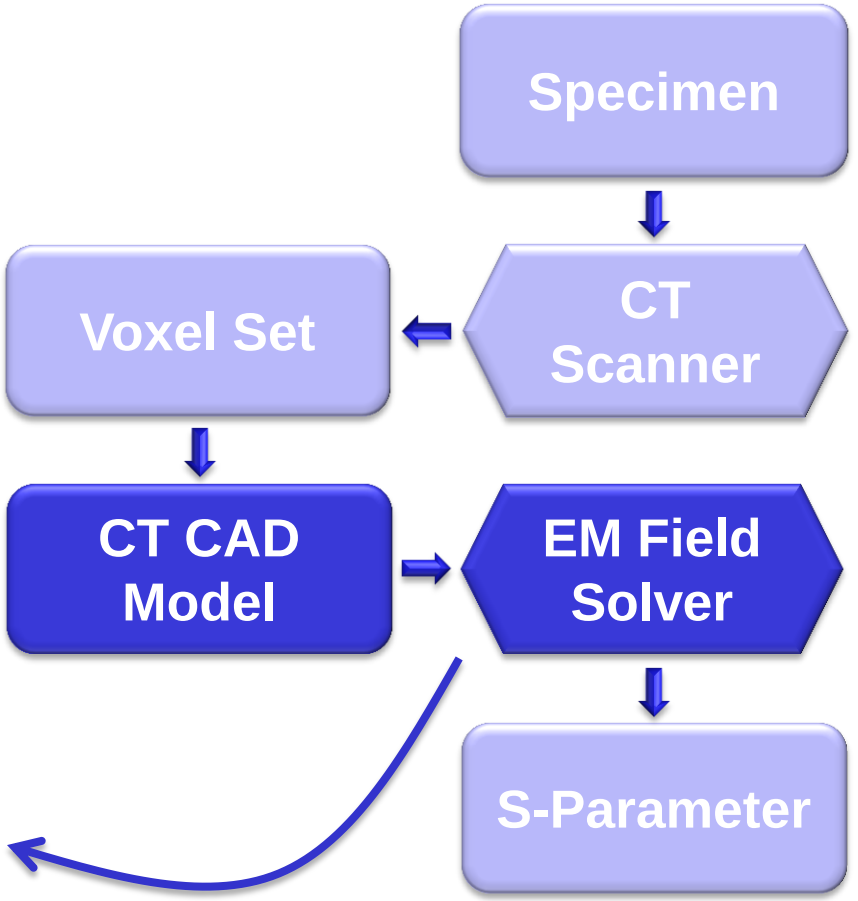
CT CAD Model

EM Field Solver

S-Parameter

Using a CT-Scanner for Extracting S-Parameters





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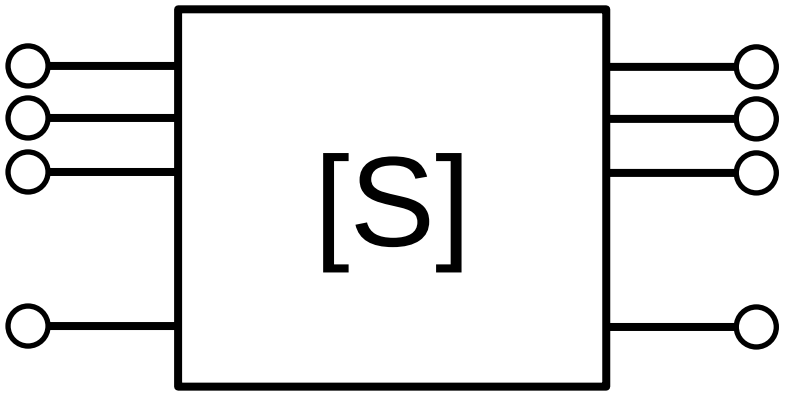
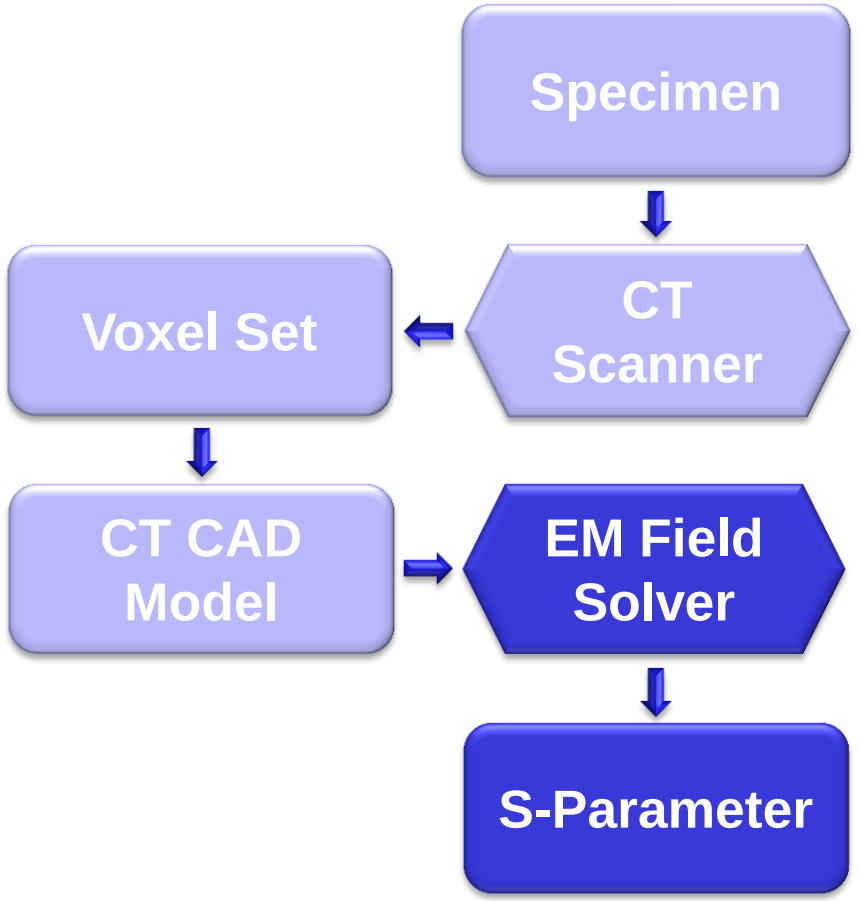




Using a CT-Scanner for Extracting S-Parameters

- Non-intrusive method to extract S-parameters of planar passive circuits.
- Reconstructed models include variations due to manufacturing.
- Method
  - avoids complex measurements, like de-embedding
    - embedded circuits can be virtually de-embedded by using CAD operations.
  - enables „cheap“ multiport measurements
    - number of measurement ports is just limited by storage and computation time.
  - gives visual and electrical information about faults in passive circuits
    - makes device testing easier.

Reconstructing CAD Models Using CT-Scans

- Package consist of different parts, with different sizes, e.g.:
  - transmission lines: width: 50…250µm, height: 17…35µm
  - solder balls: diameter: 400µm, spacing: 500…1000µm
  - bond wires: diameter: 25µm

- Problem for CAD model reconstruction is the resolution of the CT scanner

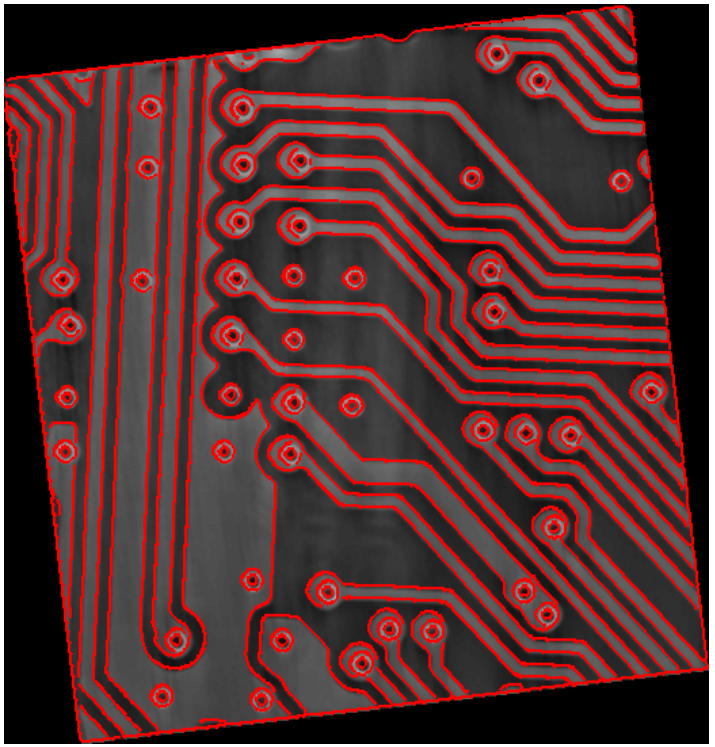
$\Delta s = \frac{w}{N}$, Δs: voxel size, w: scanned space, N: number of pixels (detector)

- **Example:**
  - Detector: image format of NxN=2048x2048 pixels.
  - IC-Package: size of approx. 20…40mm
  - ➢ Typically gives a minimal resolution of around 10…20µm

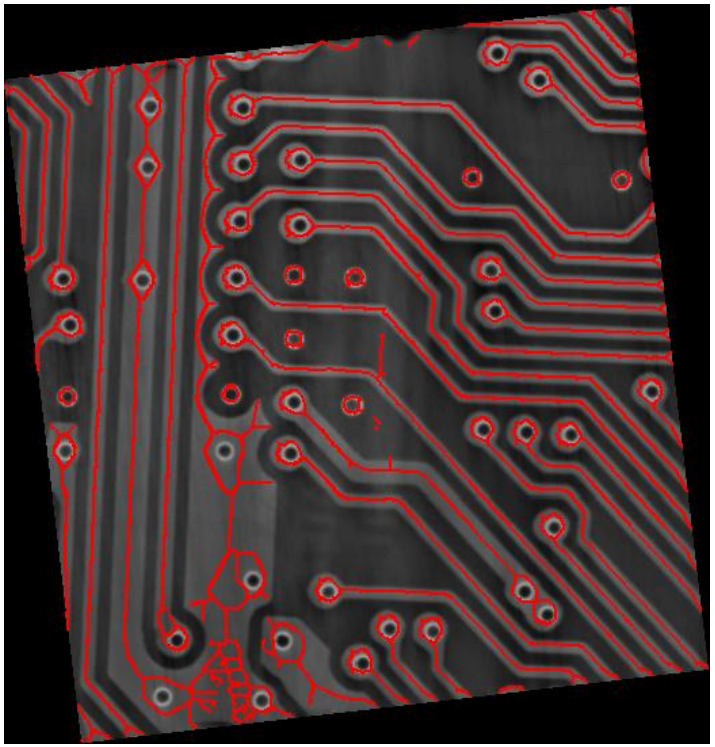
!!! size of bond wires is close to resolution provided by the chosen CT scanner !!!

Reconstructing CAD Models Using CT-Scans

- Use of different reconstruction techniques for different parts:
  - **Edge Detection:** transmission lines, planes, vias, solder balls
  - **Thinning:** thin transmission lines, bond wires



Edge Detection



Thinning

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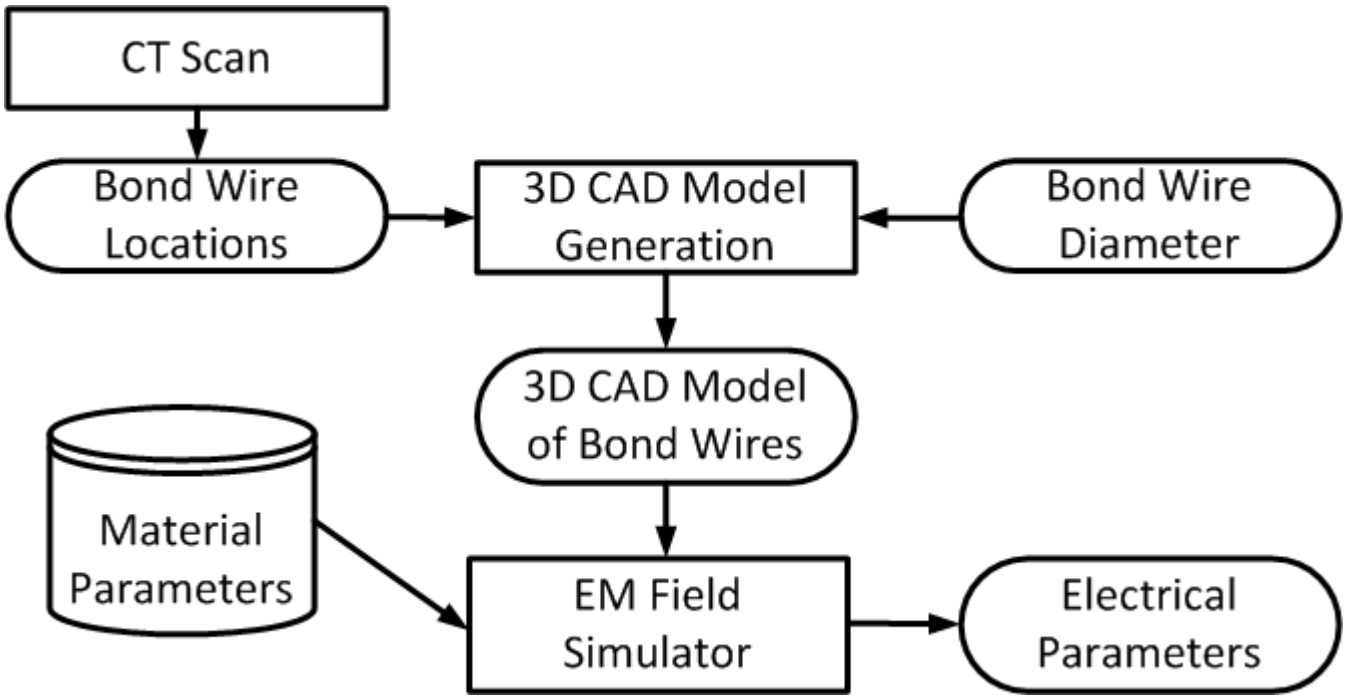
5. Comparison with electrical measurements
6. Conclusion

Reconstruction Technique for Thin Bond Wires

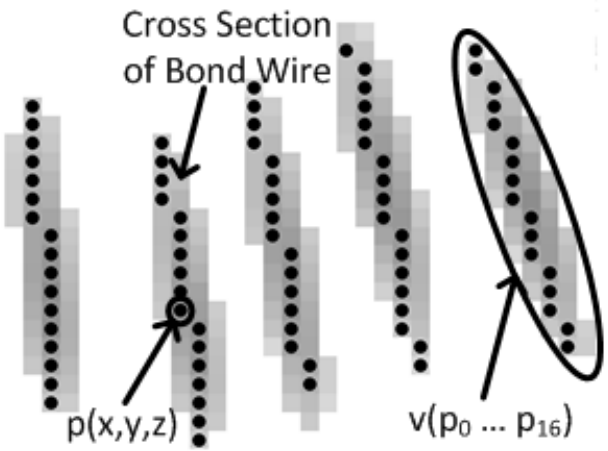
- Because the resolution is close to the diameter of thin bond wires,
  - just information about orientation and location of bond wires is taken from CT scans.
  - Diameter is applied to the model in a different way (X-ray scans or datasheet)

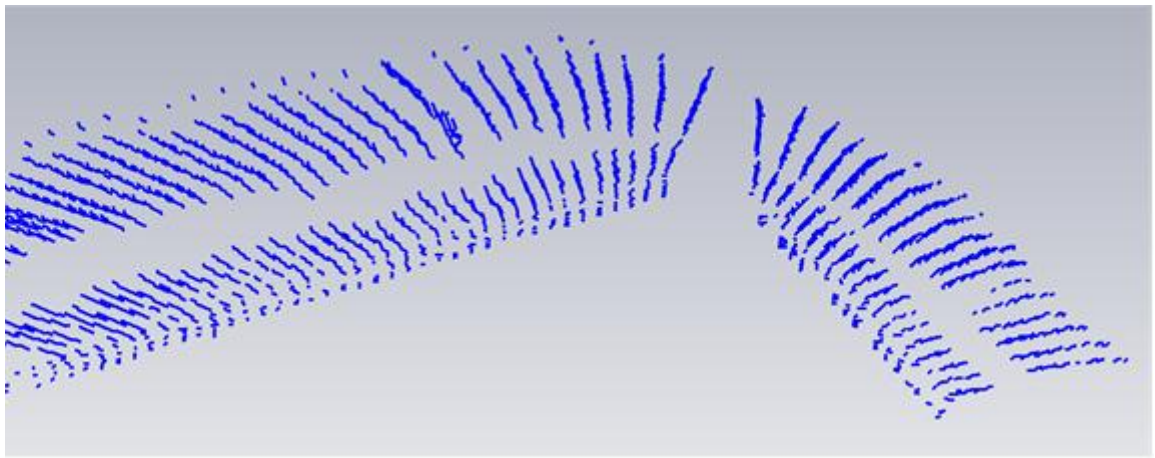


Reconstruction Technique for Thin Bond Wires

First step:

- Separating voxel volume into slices.
- Applying a thinng algorithm to the separated slices.
- Thinning returns vectors $v_i(p_m)$ with several points p_m, combined to a chain.
  - Each „chain“ is aligned along the major axis of the oval formed by the cross-section of a single bond wire.



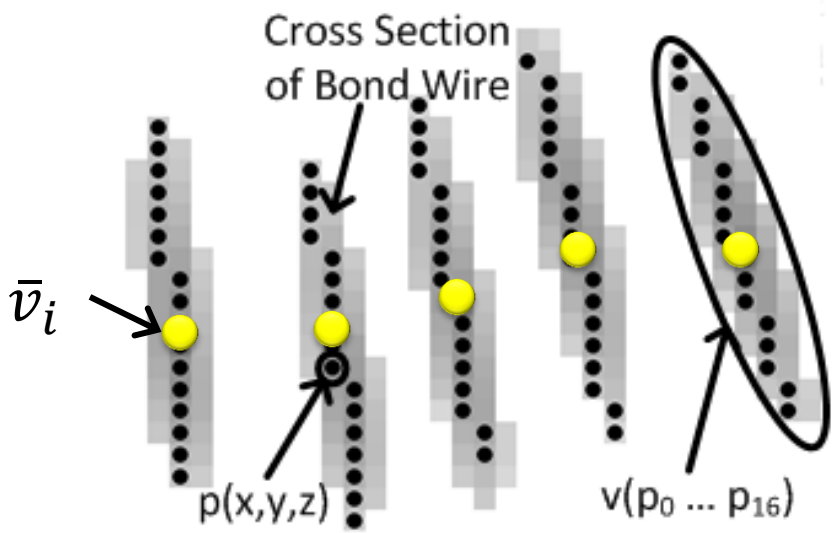


Reconstruction Technique for Thin Bond Wires

Second step:

- Assumption: Center point of each cross section is in the center of the detected points in the data vectors $v_i(p_m)$.
- Computation of center points for each cross section by

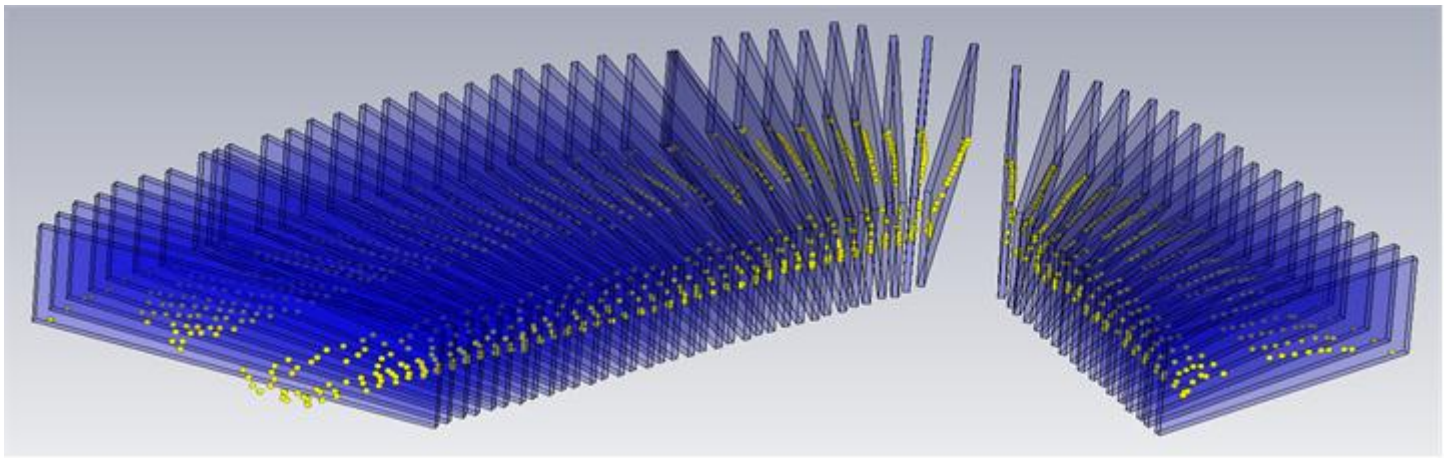
$$\bar{v}_i = \frac{1}{\dim(v_i)} \sum_{m=0}^{\dim(v_i)-1} v_i(p_m) \qquad for \quad 0 \le i \le dim(v) - 1$$



Reconstruction Technique for Thin Bond Wires

Third step:

- Assign center points to the corresponding bond wires
  - Start and end points for each bond wire detected by using markers
  - Construction of bounding boxes, aligned to detected start and end points for doing a collision test.

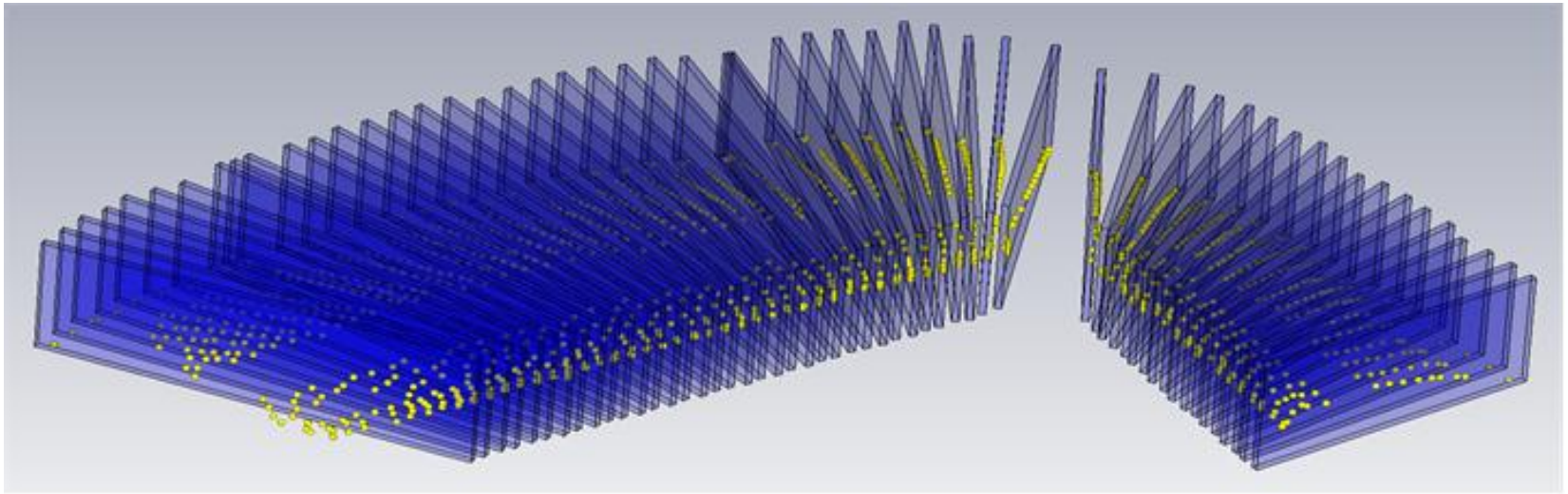


Reconstruction Technique for Thin Bond Wires

Third step:

- Collision test between each center point $\bar{v}_i$ and bounding box b_i.
- Gives vector $v_{BW,i}$ that consists of all corresponding center points $\bar{v}_i$ of a single bond wire.

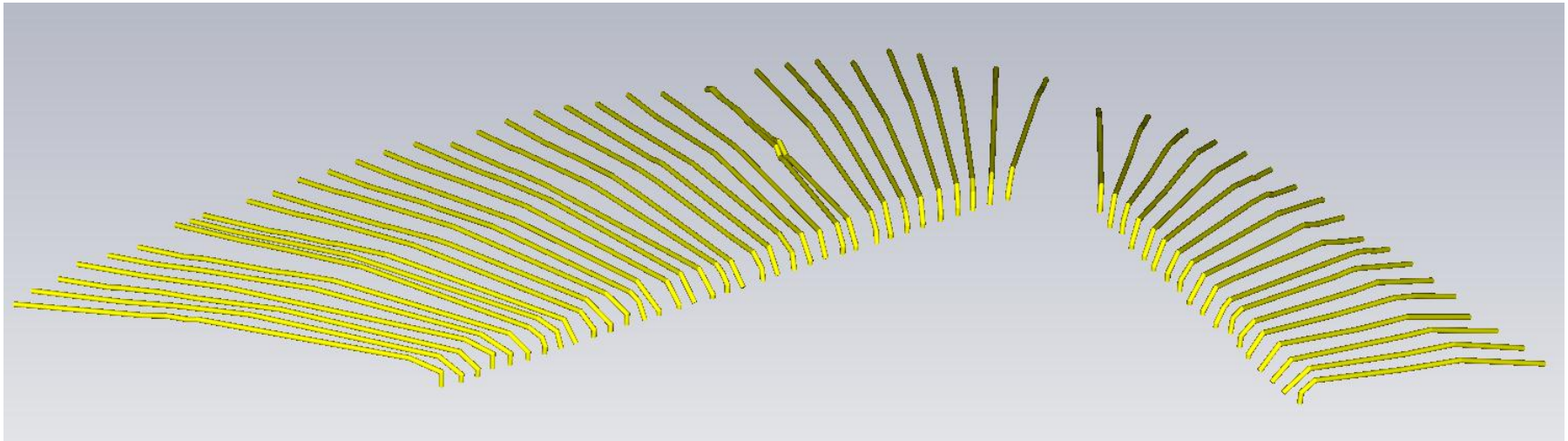
$$v_{BW,i} = b_i \cap \bar{v}$$



Reconstruction Technique for Thin Bond Wires

Fourth step:

- Creating bond wires by interpolation of all points in vector $v_{BW,i}$



Outline

1. Introduction
   - Using a CT-scanner for extracting S-parameters
   - Reconstructing CAD models using CT-scans

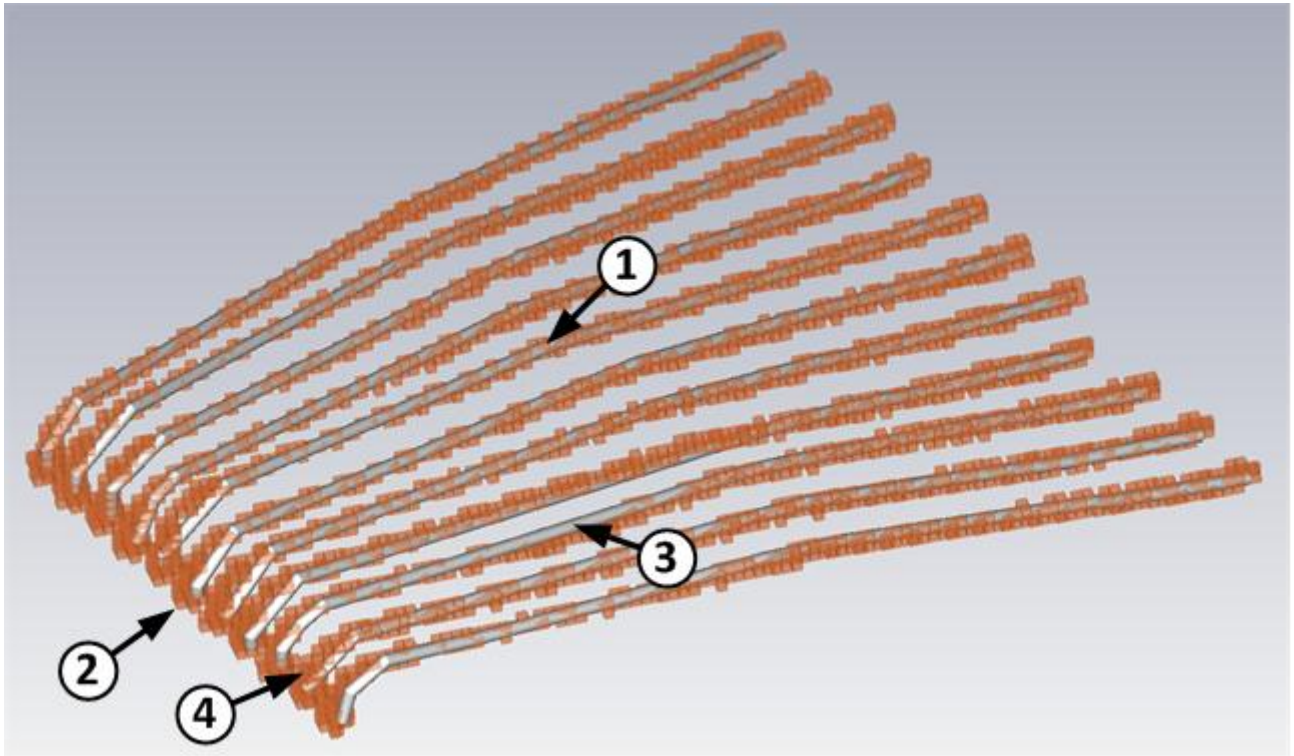
2. Reconstruction Technique for thin Bond-Wires

3. Comparison
   - Comparison of Geometrical Accuracy
   - Comparison of Electrical Accuracy

4. Conclusion

Verification of the Geometric Reconstruction

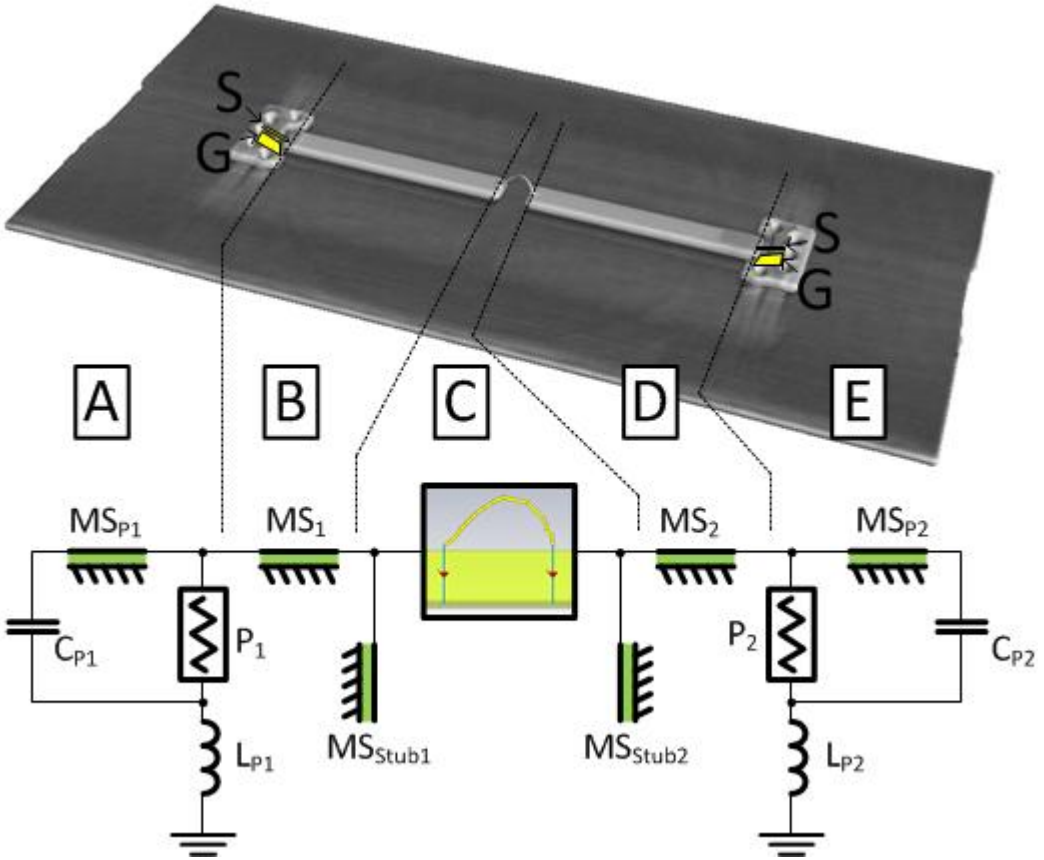
- CT image data overlaid with reconstructed bond wires

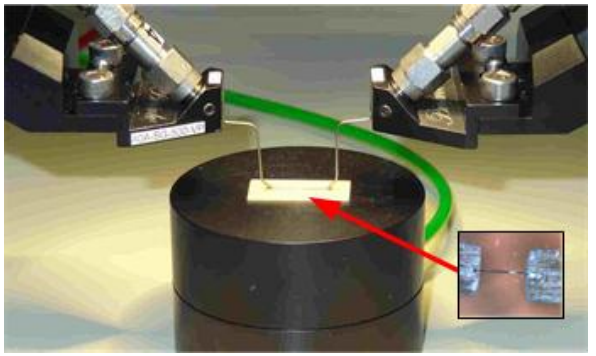


- Visible errors due to
  - omitted interpolation points (marker 1 and 2)
  - image filtering (marker 3 and 4)

Demonstration - Electrical Measurement of a Bond Wire

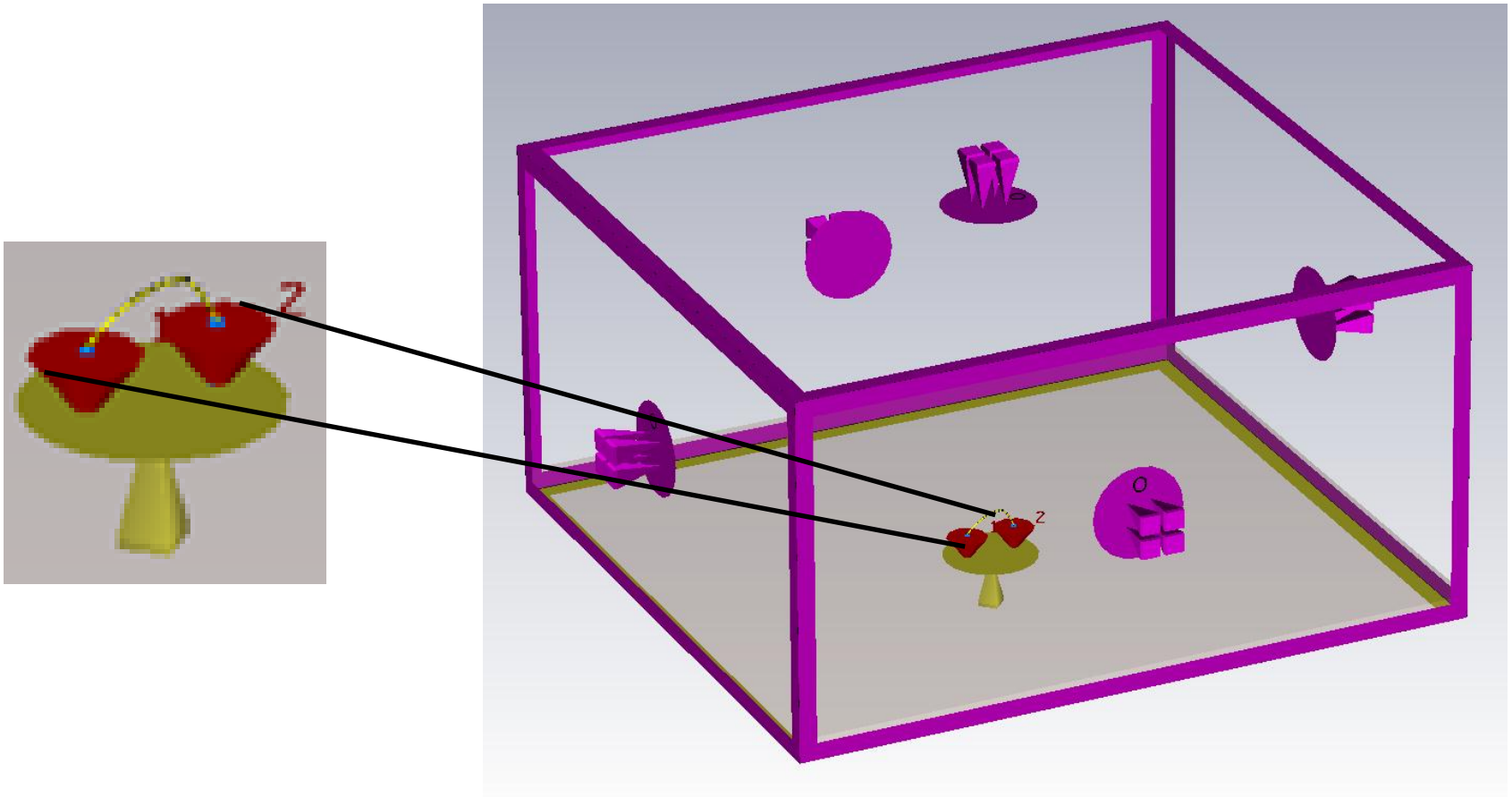
- Comparison of S-parameters obtained by hybrid simulation and VNA measurement





EM-Simulation of the Bond Wire for S-Parameter Characterization

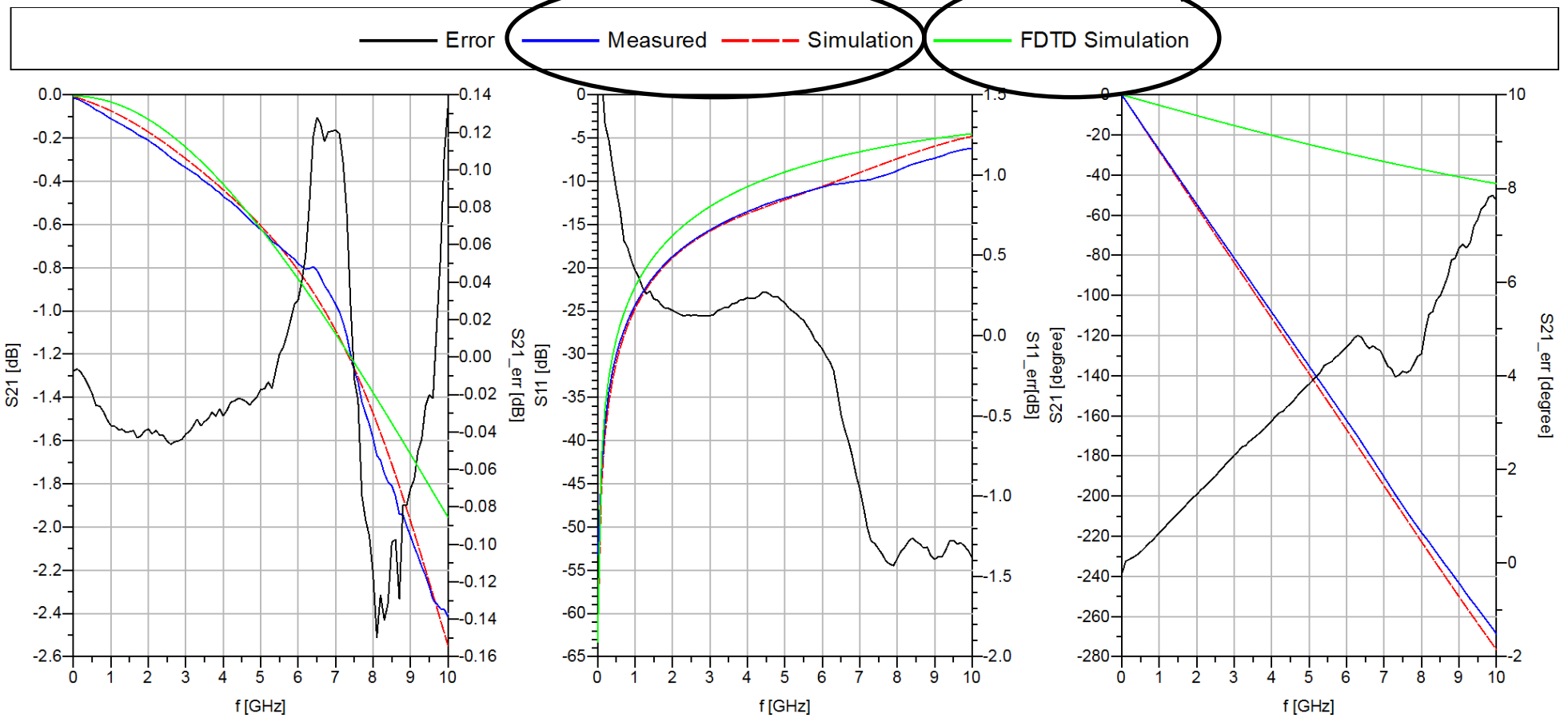
- S-Parameters of the bond wire for hybrid simulation are obtained by an FDTD simulation



Comparison of the Electrical Measurement and the EM-Simulation of the CT-Based Geometric Model

MS - Bond Wire - MS

Bond Wire Only



Conclusion

- Model extraction algorithm for thin bond wires inside IC packages.
  - Location and orientation of the bond wires is taken from CT scan.
  - Small diameters have to be assigned different either from
    - X-ray scans with higher resolution or
    - by using values from product datasheets.
- Model is suitable for use in an EM field simulator to extract the S-parameters
  - S-Parameters are can be used for further simulations.
  - E.g. hybrid simulation (as presented here)
    - Comupted S-parameters are in good agreement with measured S-Parameters
    - S21 < -0.05 @ 0…6GHz
    - S21 < ±0.15dB @ 6…10GHz

Thank you for your attention!