Aircraft Structures NDT with ET Arrays

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N. Goldfine, A. Washabaugh, T. Dunford, Z. Thomas,
K. Walrath, M. Windoloski, S. Chaplan, K. Diaz, J. Nelms

JENTEK Sensors, Inc., 121 Bartlett Street Marlborough, MA 01752

Jenteksensors.com

Types of Eddy Current Arrays

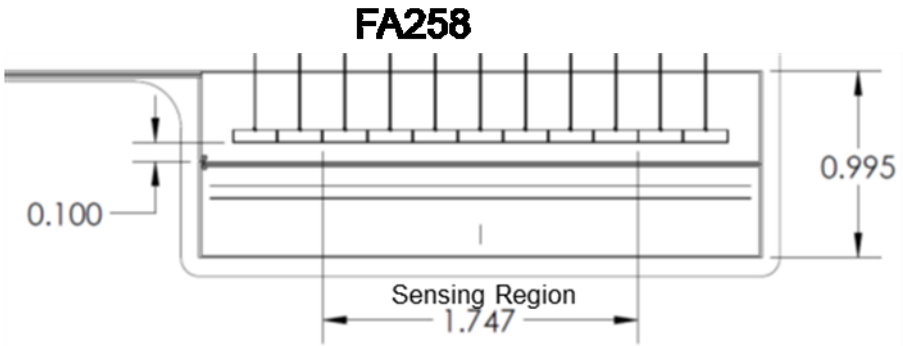
1. **Compilations of single eddy current testing (ET) coils**
   - Used independently (either in parallel or multiplexed)
   - Mounted on a shuttle that is rigid and shaped similar to the part
   - Challenges include: rigidity, cross talk for parallel operation, variability channel to channel, response variation across array, etc.
2. **Arrays of flat spiral coils** or multiple layered coils that can act as both drive and sense elements
   - Multiplexed in groups of channels (typically 4 or 8 at a time)
   - Must avoid exciting neighboring coils due to cross talk
   - Challenges include: variable channel performance, crack response variations across array, variable directional sensitivity across array, curvature effects and rigidity due to complex cabling issues.
3. **Single rectangular drive with linear array of square sense elements MWM-Arrays**
   - Fully parallel data acquisition from all channels
   - No significant cross talk
   - Designed for physics model-based analysis methods
   - Challenges include: larger cables for many channels, culture change is a hurdle for some customers

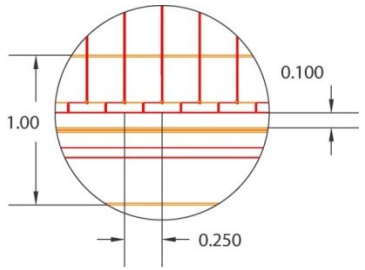
jET with MWM-Array Technology (larger channel count systems called GS8200 use same technology)

jET®

- 3 frequencies simultaneously
- 7 channels simultaneously
- Up to 1000 measurements/sec per channel

MWM®-Array





MWM-Array

- Designed for model based methods
- Drive sense gap determines depth of penetration

Fully Parallel Digital electronics, with MWM-Array Advantages

1. **Sensor: Designed for model-based multivariate inverse methods (MIMs)**
   - Designed with simple linear drives and square sensing elements
   - No significant cross talk between elements.
   - Enables more robust results, such as **rescaling of the crack response** for variable liftoff when scanning a curved surface.

2. **Electronics: Simultaneous data acquisition at up to 3 frequencies**
   - Needed to measure multiple properties, such as independent 1st and 2nd layer corrosion imaging independent of gap between layers.
   - Both complex impedance components simultaneously to retain data integrity and support model based methods

3. **Electronics & Sensor: Enable fully parallel (simultaneous) acquisition from 7 sensing elements**
   - Needed to reliably detect and size cracks
   - Needed to reliably detect cracks at edges
   - Needed to ensure consistent coverage of the inspection surface
   - Needed to rescale crack response for position within the array

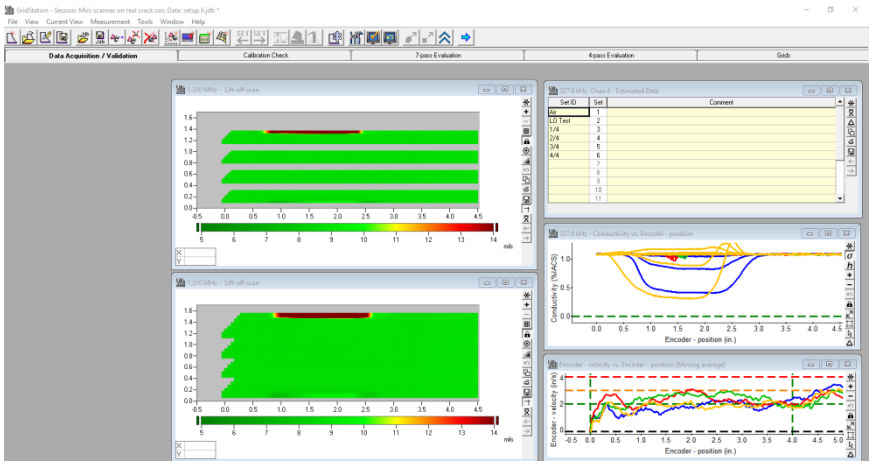
Probability of Inspection (POI)

1. **Actual POD = POD Study POD x POI**
2. **Need: Easy way for Inspector to determine that**

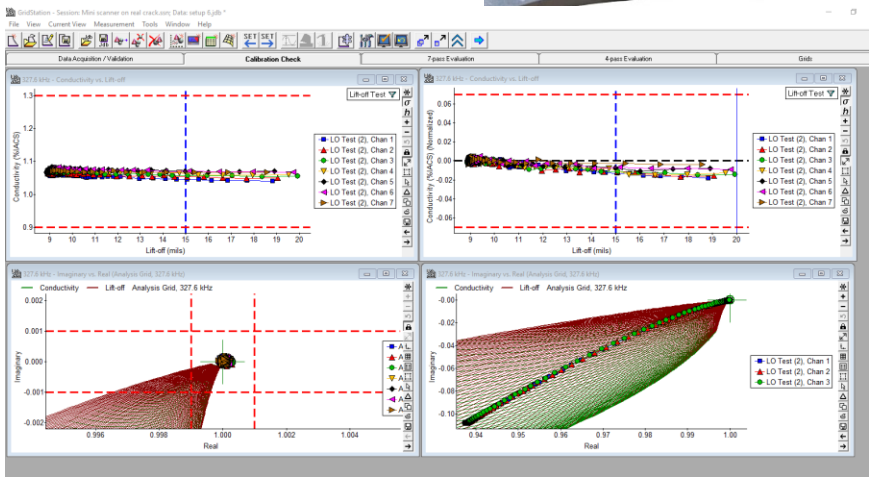
"POI is essentially 100%"

3. **Solution: Model-Based Data Analysis and Visualization**
   - Model-Based Inverse Methods (MIMs)
   - Calibration verification
   - C-Scan and B-Scan visualization
   - Rescaling of defect responses for other variables such as
     - Lift-off
     - Position within Array
     - Position relative to edges

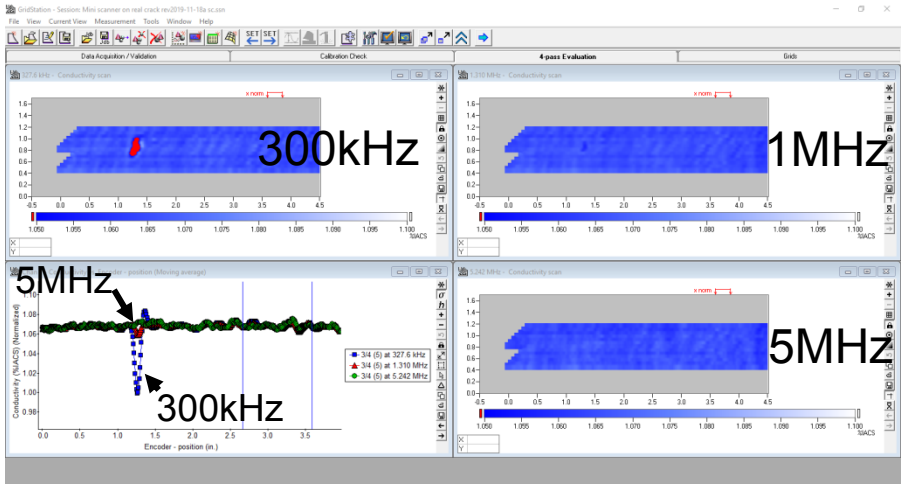
Software “Tabs” for window groups, for easy data analysis and POI Determination



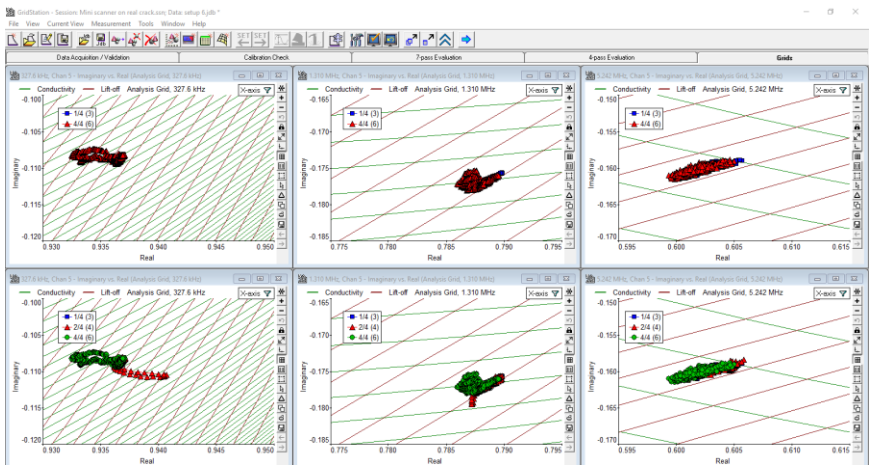
Liftoff and coverage verification



Air Calibration & Cal Check (Air and liftoff)



Crack detection

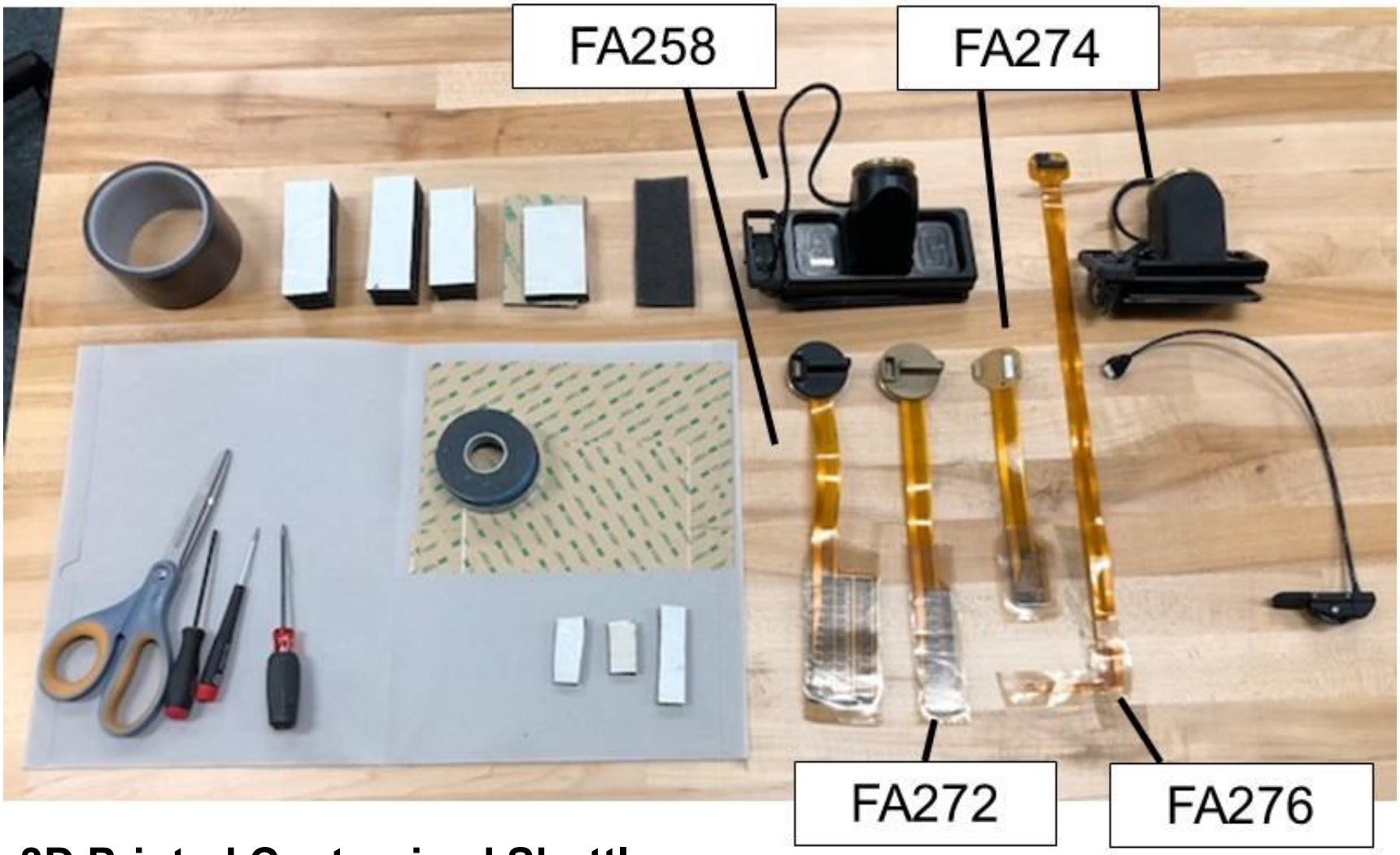


Model-Based visualization

Example Aircraft Structures NDT Applications for MWM-Arrays

1. **Corrosion imaging**
2. **Buried crack detection**
3. **Bolt hole inspection**
4. **Surface crack detection**
5. **Coating characterization**
6. Detection of cracks in steel through coatings
7. Friction Stir Weld (FSW) and other weld inspection
8. Detection of 1st and 2nd layer cracks at fasteners
9. Layer-by-Layer in process additive manufactured (AM) metal part inspection and post process NDT
10. Residual stress/stress monitoring, and cold work assessment for various but not all alloys

Sensor Kits for adaptation to new applications



3D Printed Customized Shuttles

Picking the Right MWM-Array Sensor
(Depth of Penetration is NOT Depth of Sensitivity)

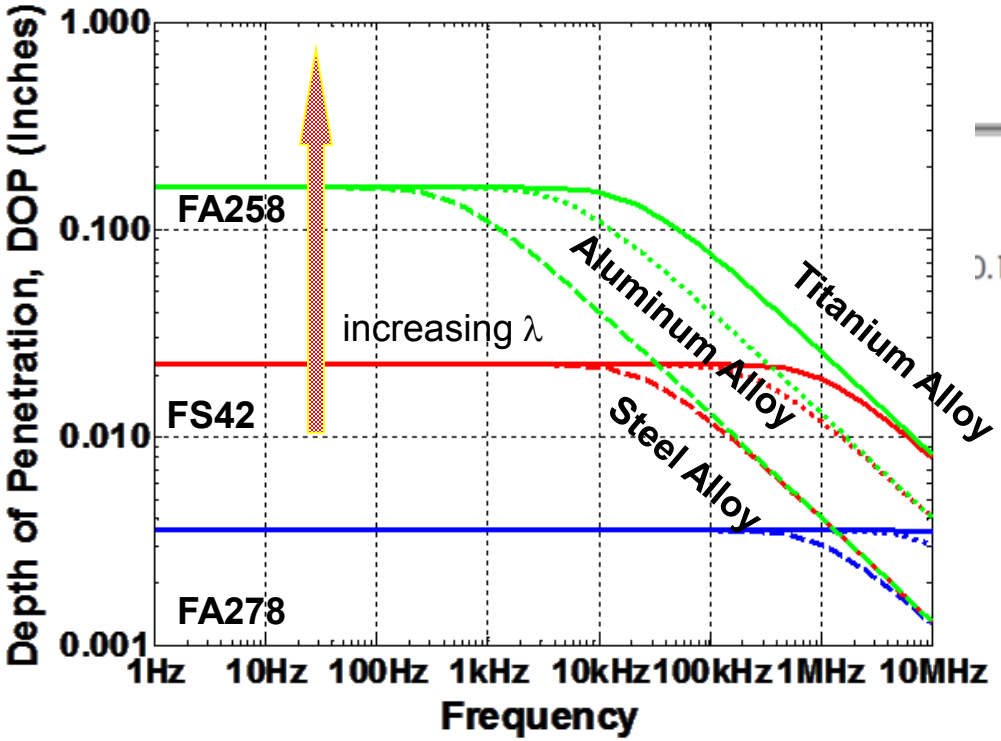
Field Variation with Depth ≈ $e^{-\Gamma_n z}$

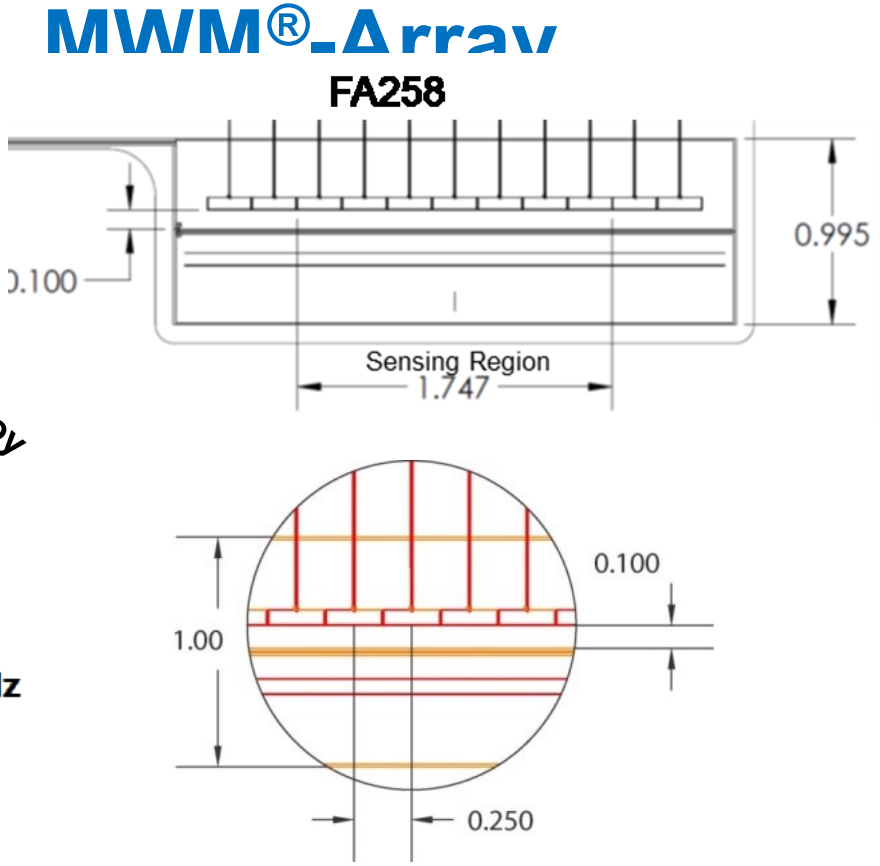
$$\Gamma_n = \sqrt{(2\pi n/\lambda)^2 + j2/\delta^2}$$

Spatial Fourier Mode Depth of Penetration = $1/\mathrm{Re}(G_n)$

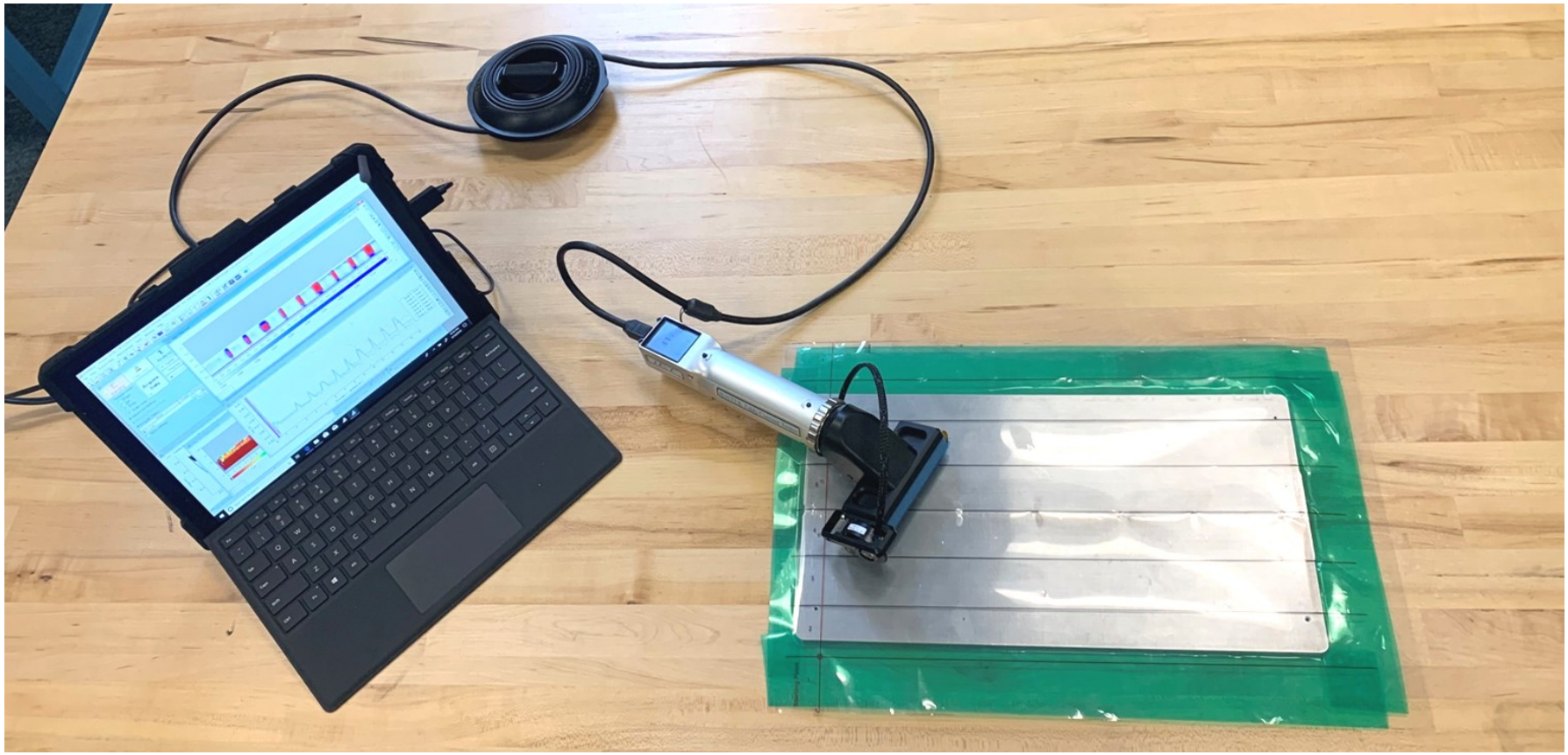
Low frequency asymptote = $\lambda/2\pi$

Skin depth: $\delta = \sqrt{\frac{1}{\pi f \mu \sigma}}$

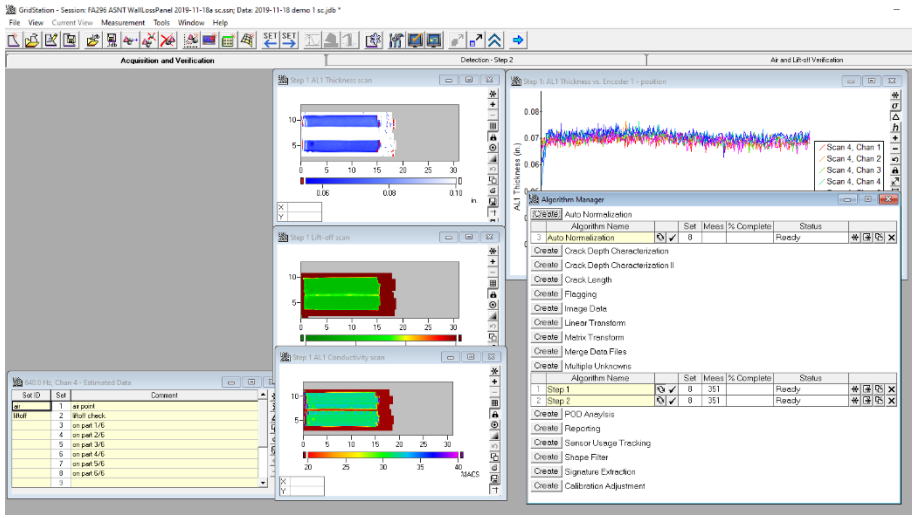




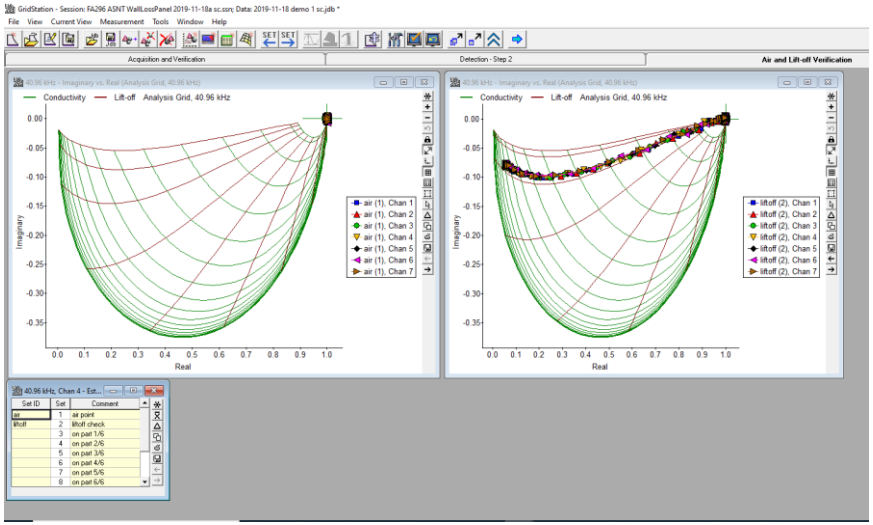
Corrosion Imaging Performance Study Ongoing



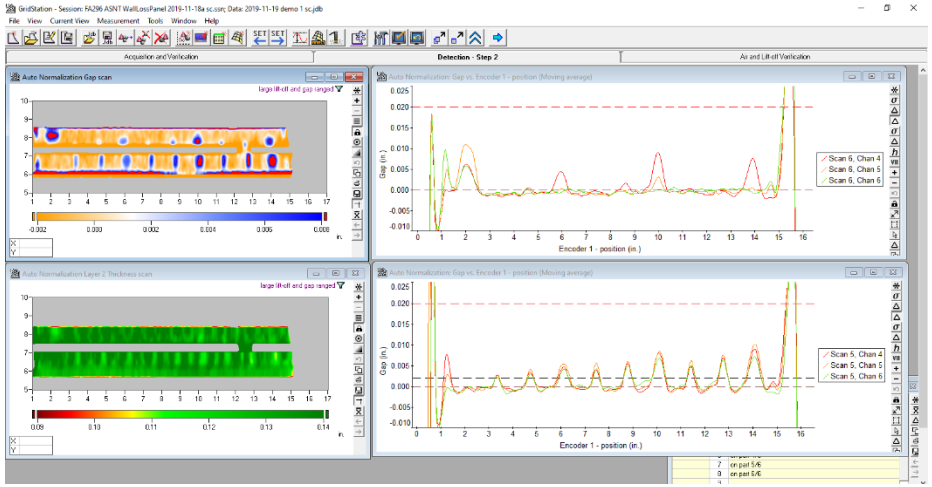
Corrosion Loss Imaging and POI Verification



Liftoff & coverage verification

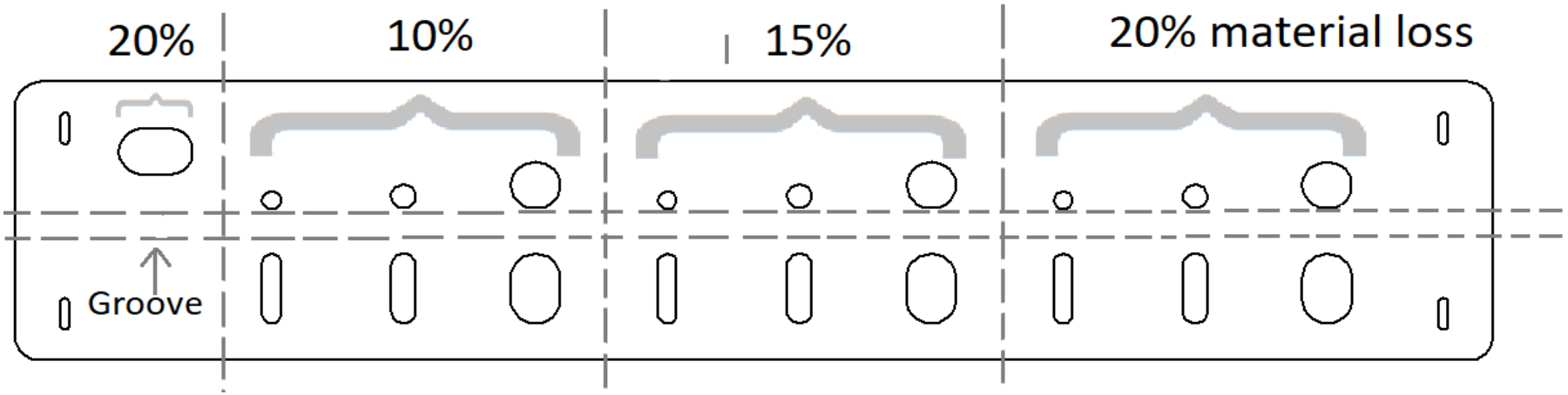


Air Calibration & Cal Check (Air and liftoff)

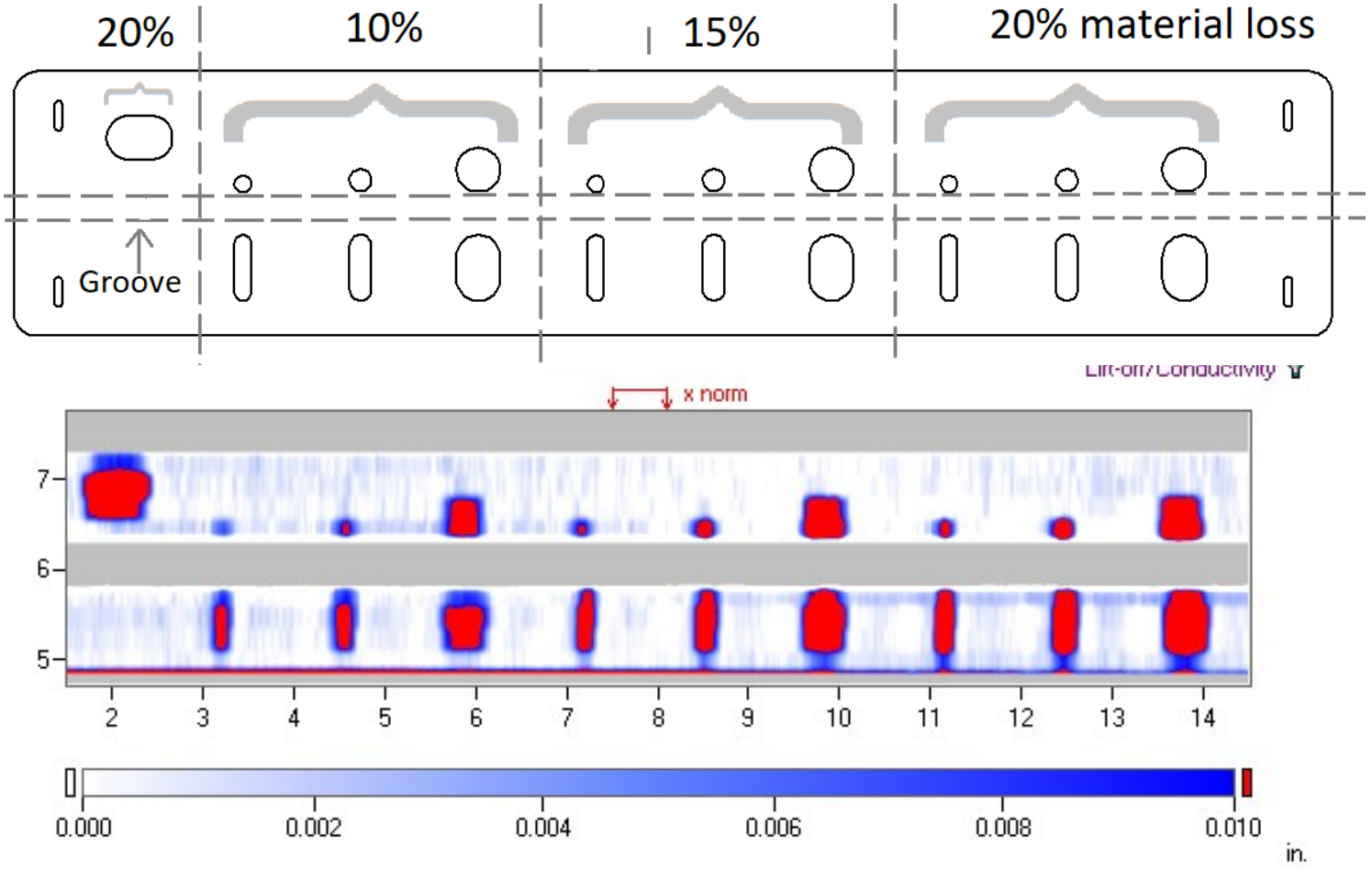


C-Scan and B-Scan data visualizations

15 inch Corrosion Loss Sample

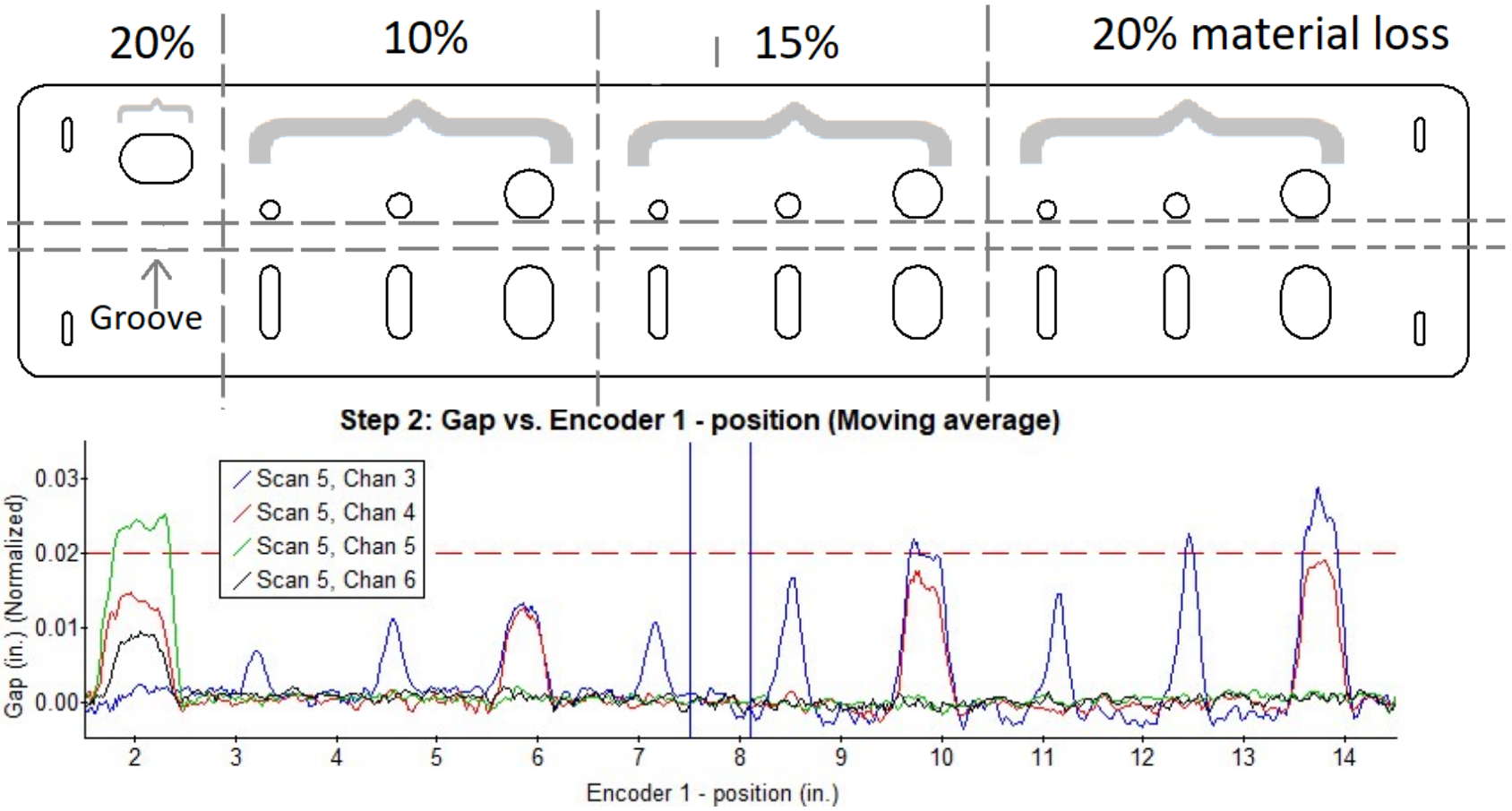


FA296: 15 inch Corrosion Loss Sample (1)



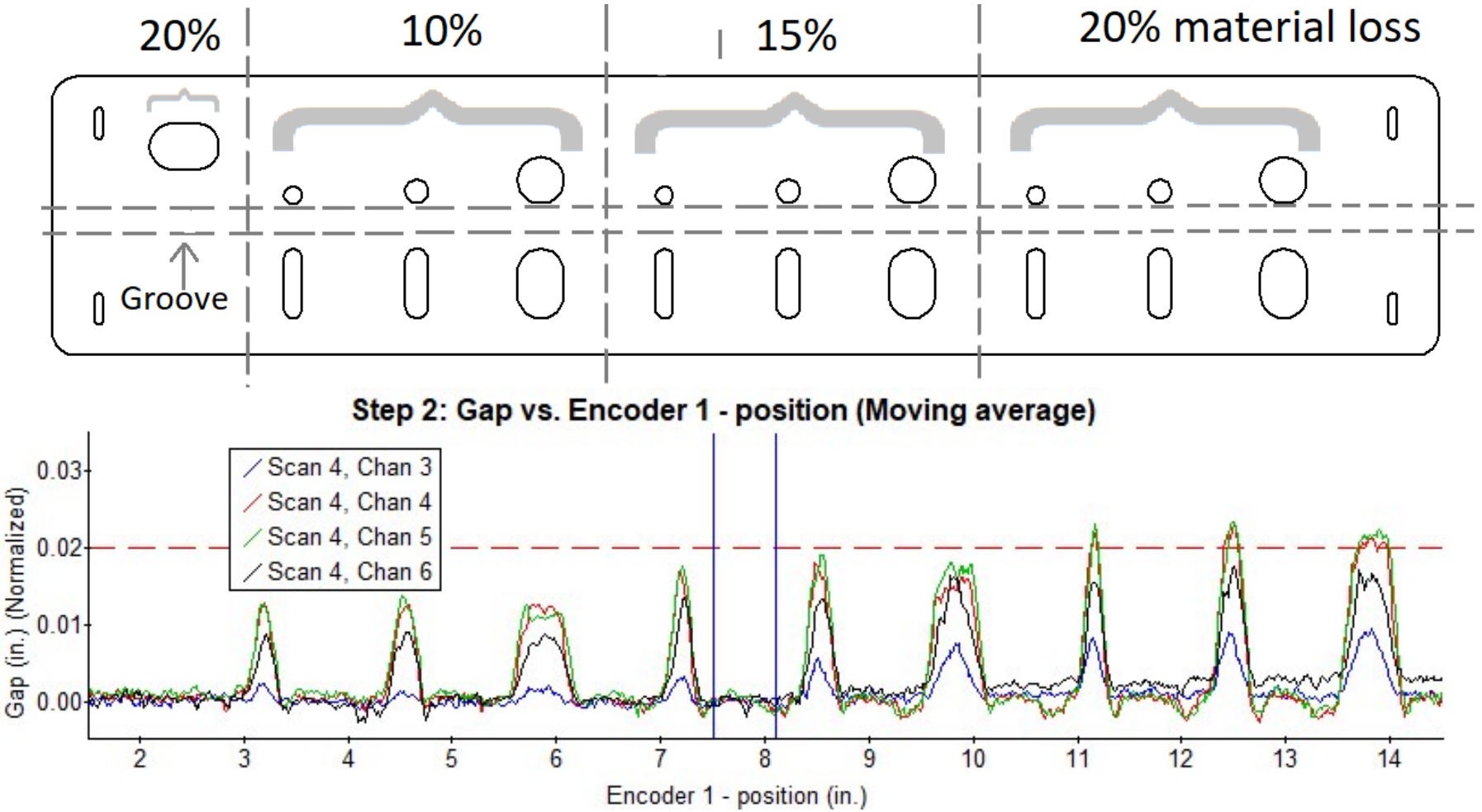
Filtered and normalized C-scan of Gap data across the corrosion defect locations.

FA296: 15 inch Corrosion Loss Sample Holes (2)



Normalized B-scan of Gap data across the flat bottom hole defect locations.

FA296: 15 inch Corrosion Loss Sample Slots (3)



Normalized B-scan of Gap data across the flat bottom slot defect locations.

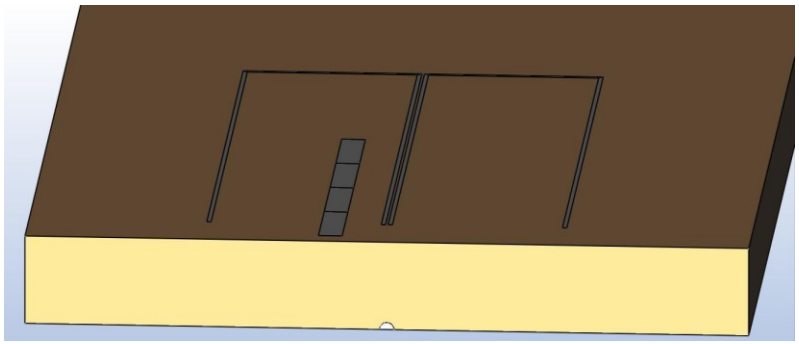
Subsurface crack modeling option

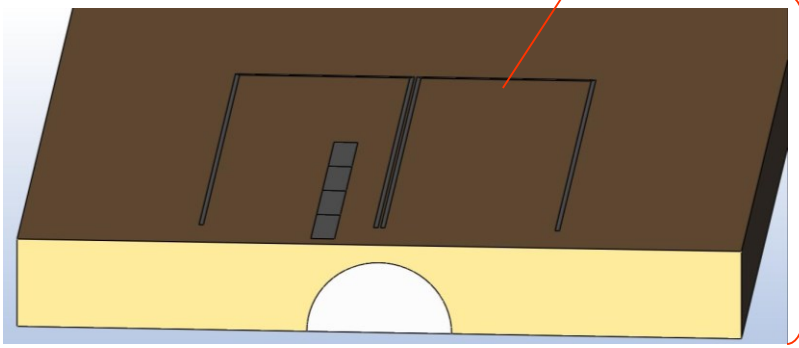
- Standard 2D models for sensor response
  - Use JENTEK Grid Methods to obtain conductivity values for several frequencies
  - Higher frequencies will provide a measure of near surface region conductivity
  - Lower frequencies provide higher sensitivity to subsurface cracks
- 3D models to better correlate scan information to crack dimensions
  - Example: FA258 over a 0.25 in. plate with small and large cracks (for 1%IACS)

Smaller Flaw

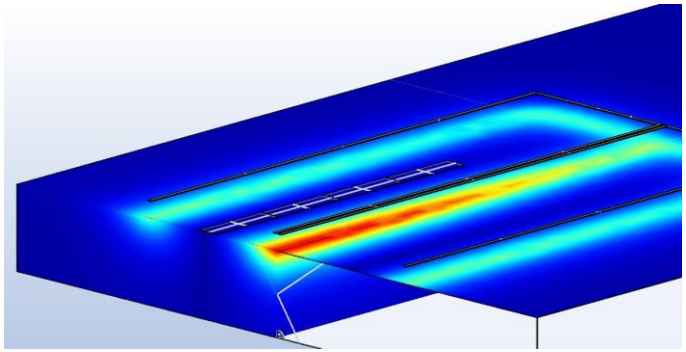
Larger Flaw

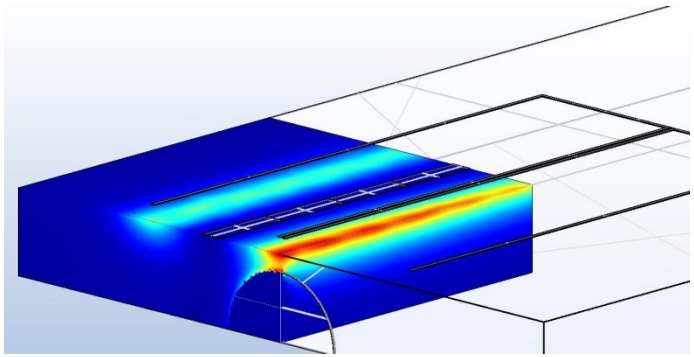
½ of FA258 MWM-Array





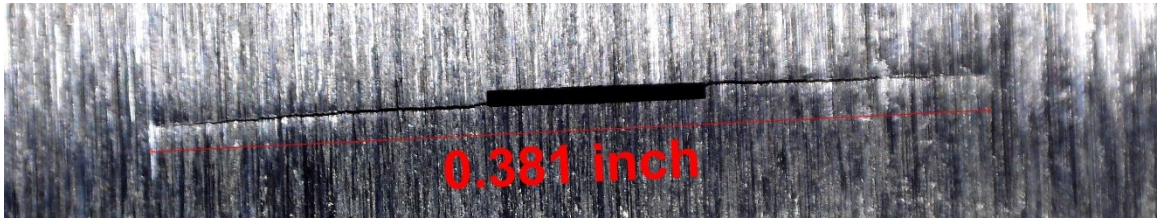
½ of physical geometry (using symmetry)

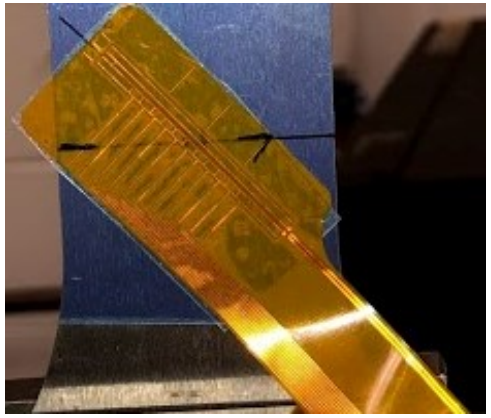


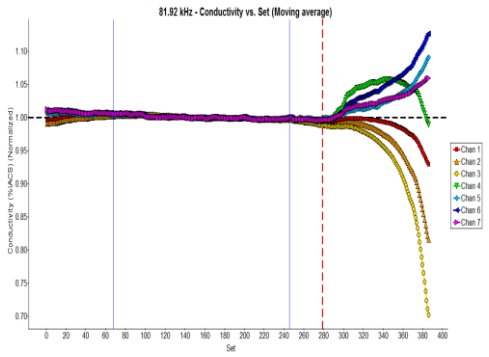


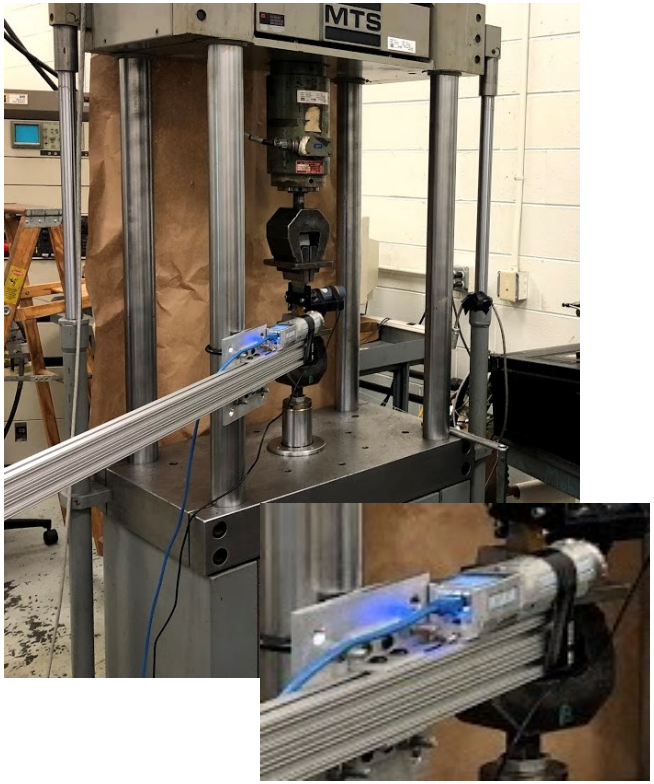
Induced current density contour plots [100 kHz; 0.05 in. lift-off; 0.4 in. long larger notch]

Real Crack Fabrication, Using MWM-Array Monitoring

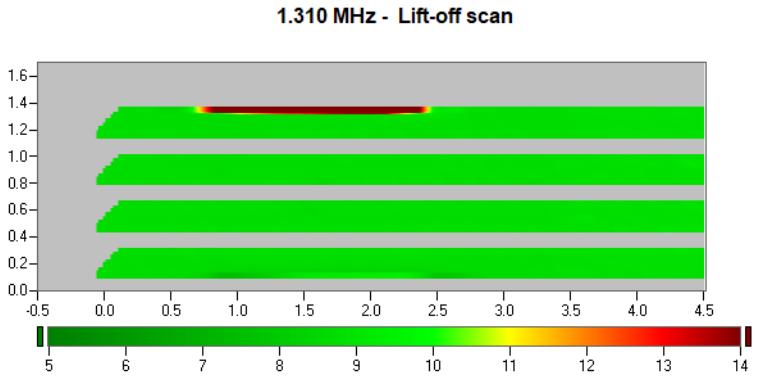


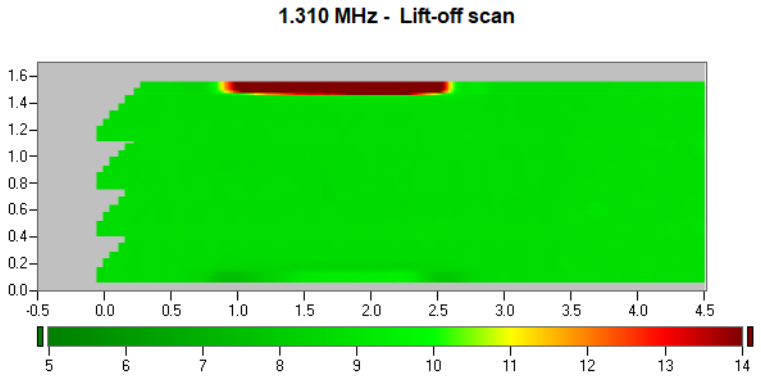


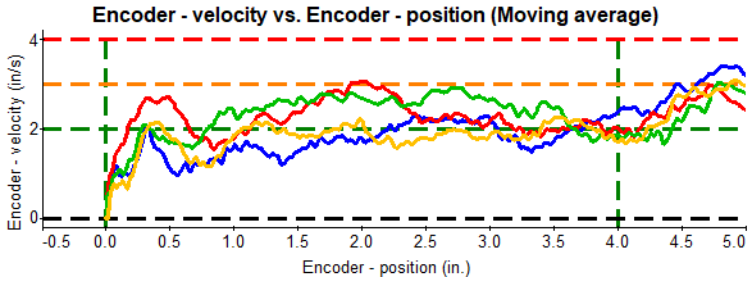




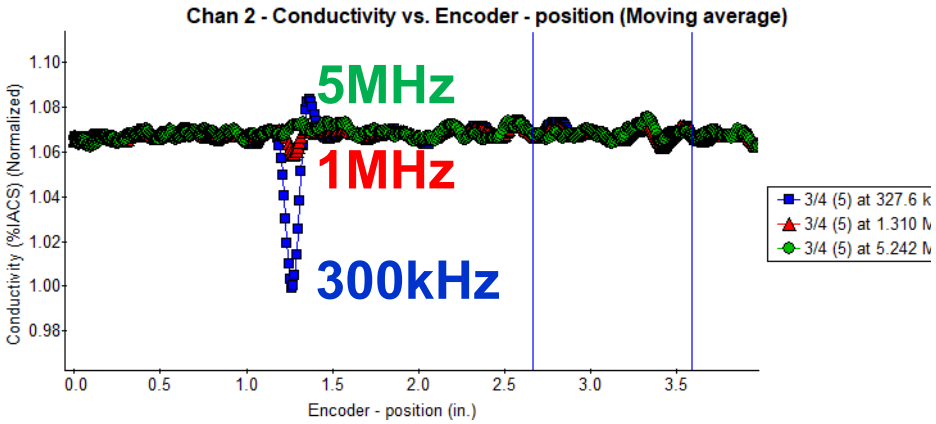
Data Validation and Inspector Feedback

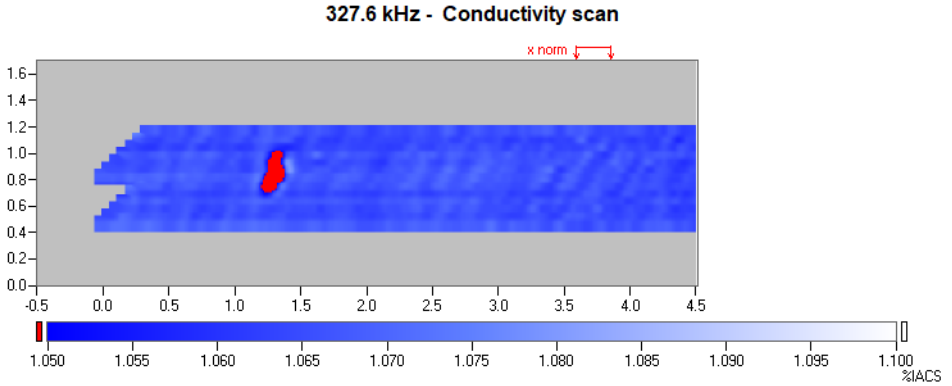


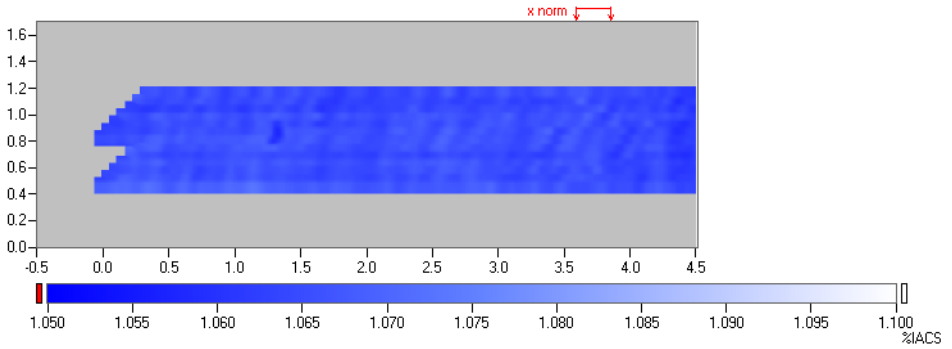


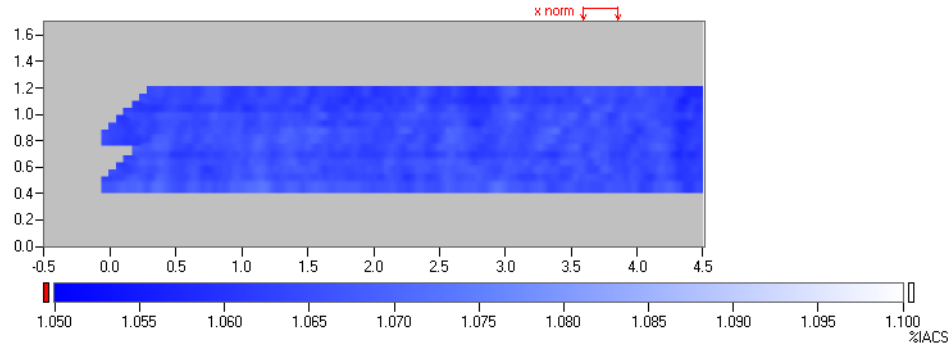


Subsurface Crack Detection – 3 Frequency



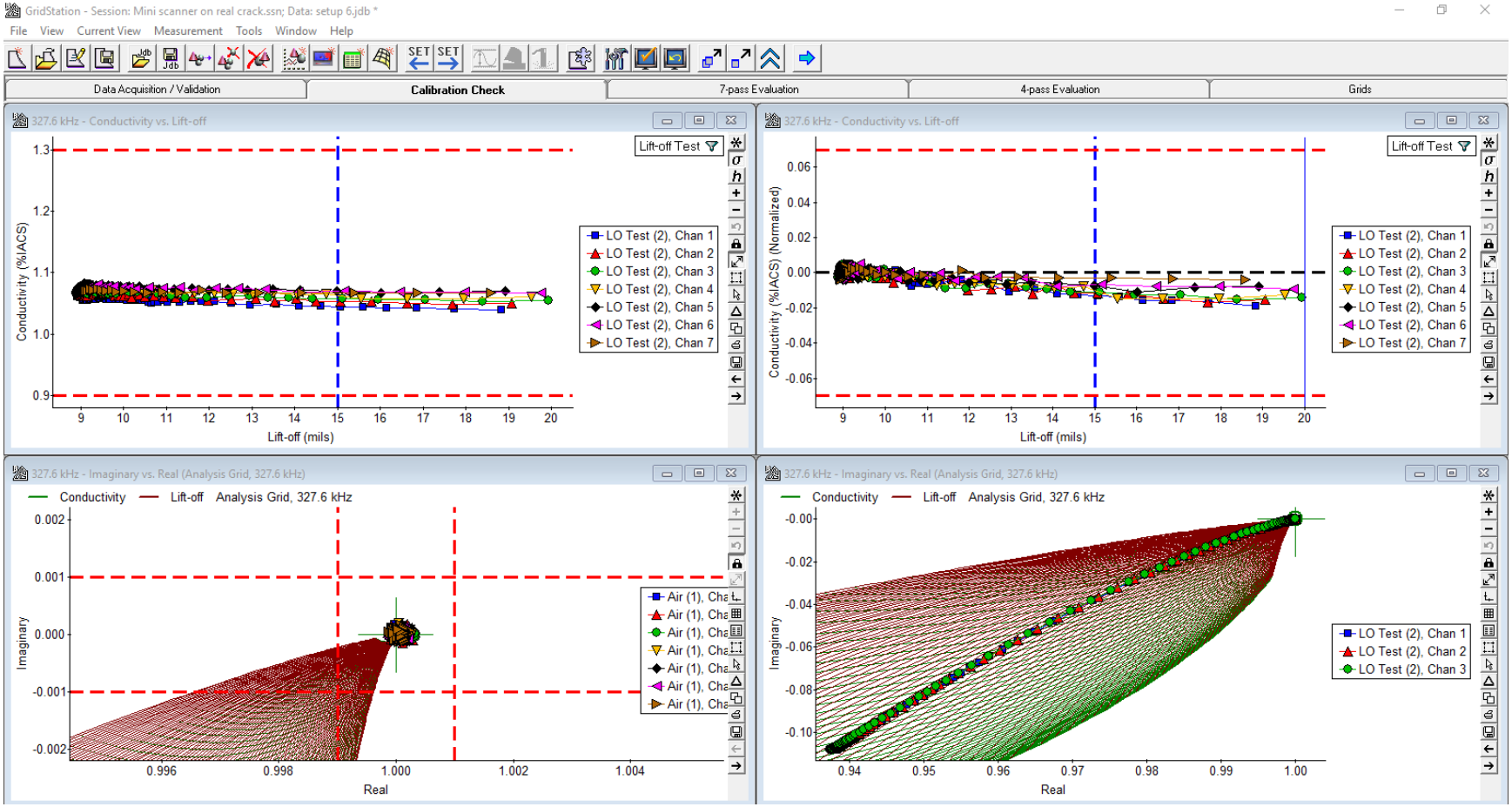




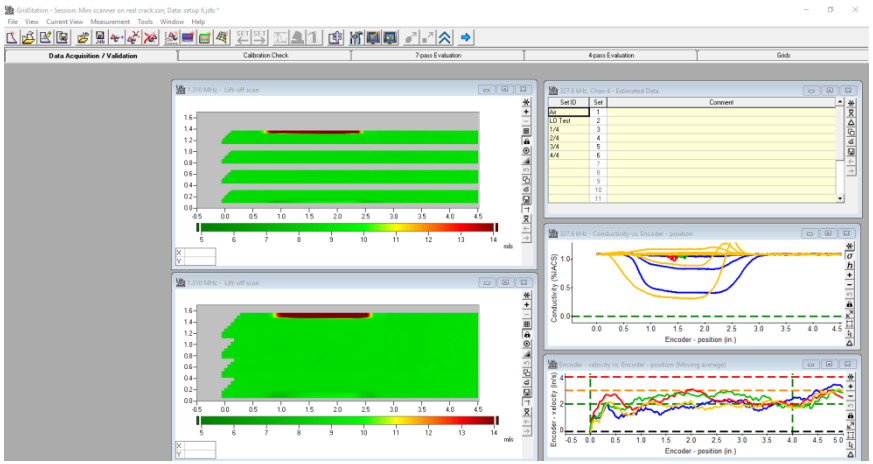


Calibration Verification (POD = Assumed POD x POI)

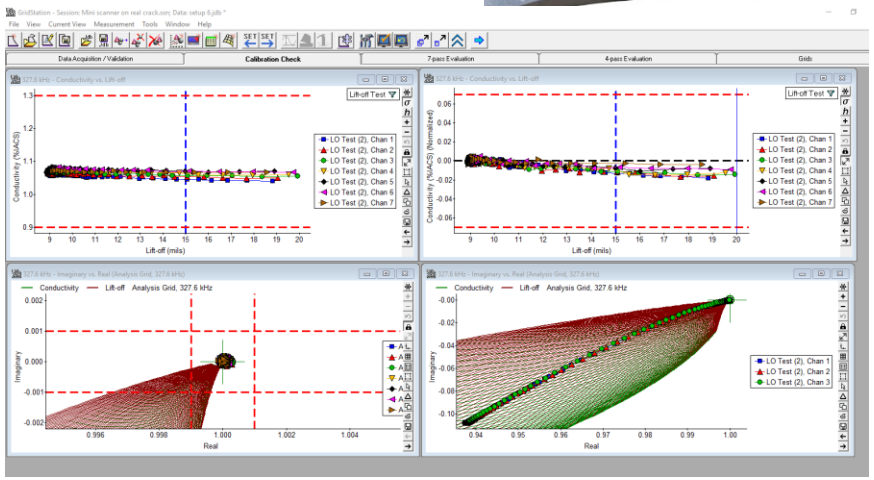
Inspectors must always verify that the POI (Probability of Inspection) is essentially 100%



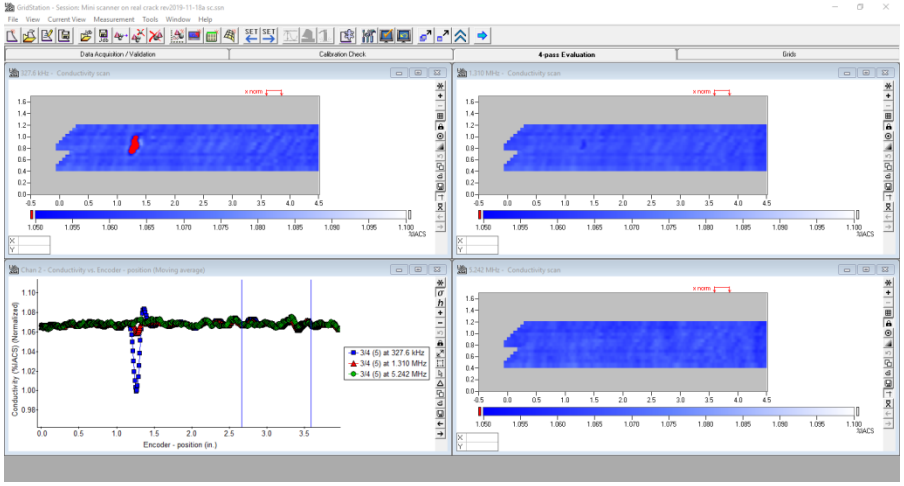
Software “Tabs” for window groups, for easy data analysis and POI Determination



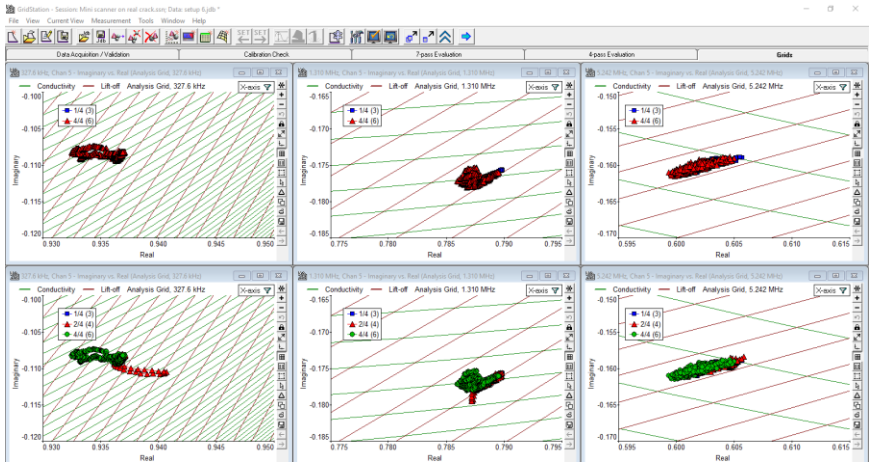
Liftoff and coverage verification



Calibration Check (Air and liftoff)



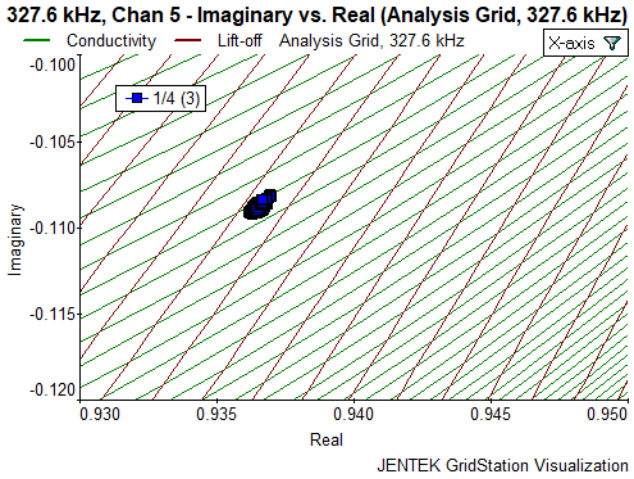
Crack detection

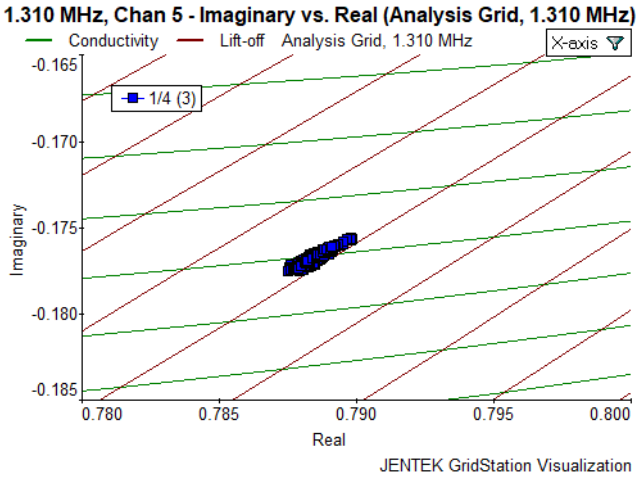


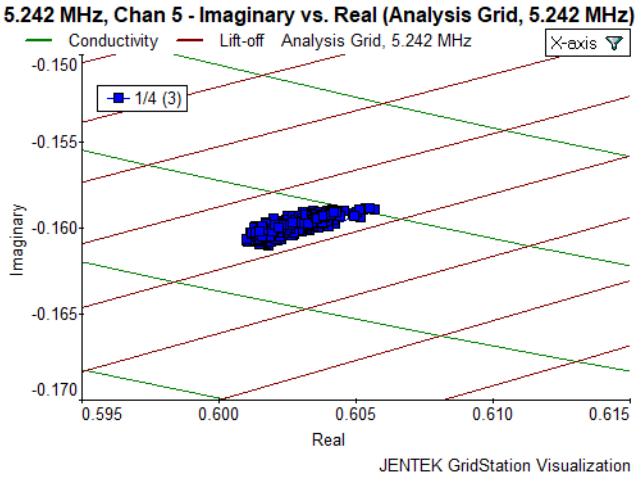
Model-Based visualization

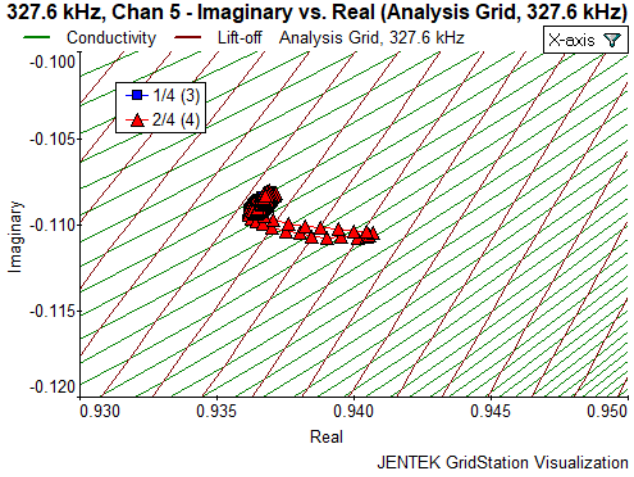
MIMs– 327 kHz, 1.3 MHz, 5.2 MHz

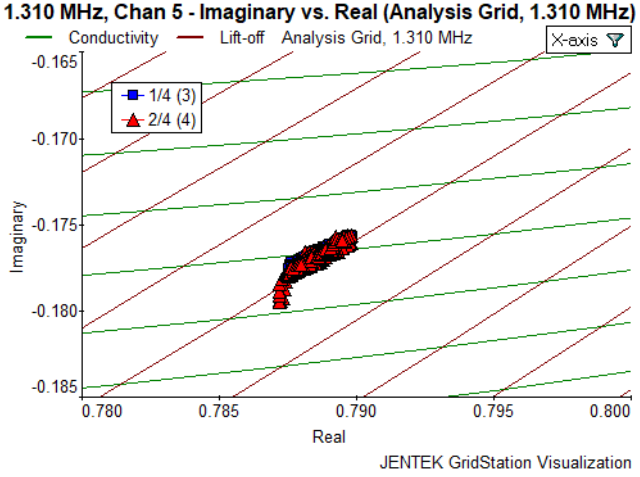
Model-Based visualization, for Multivariate Inverse Methods (MIM)

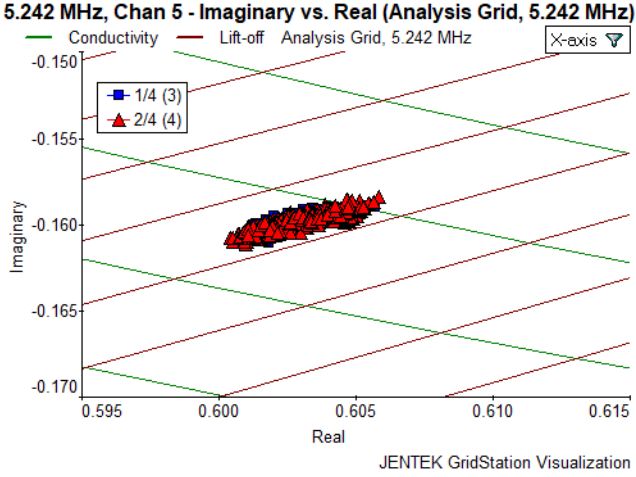




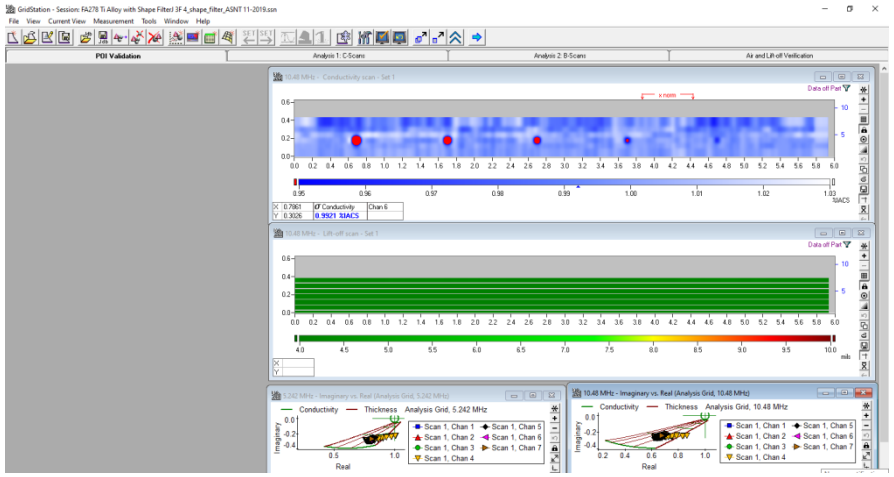




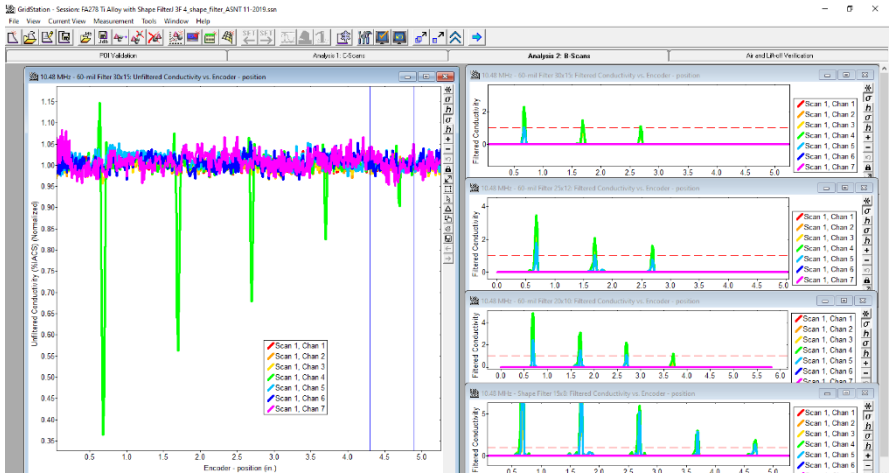




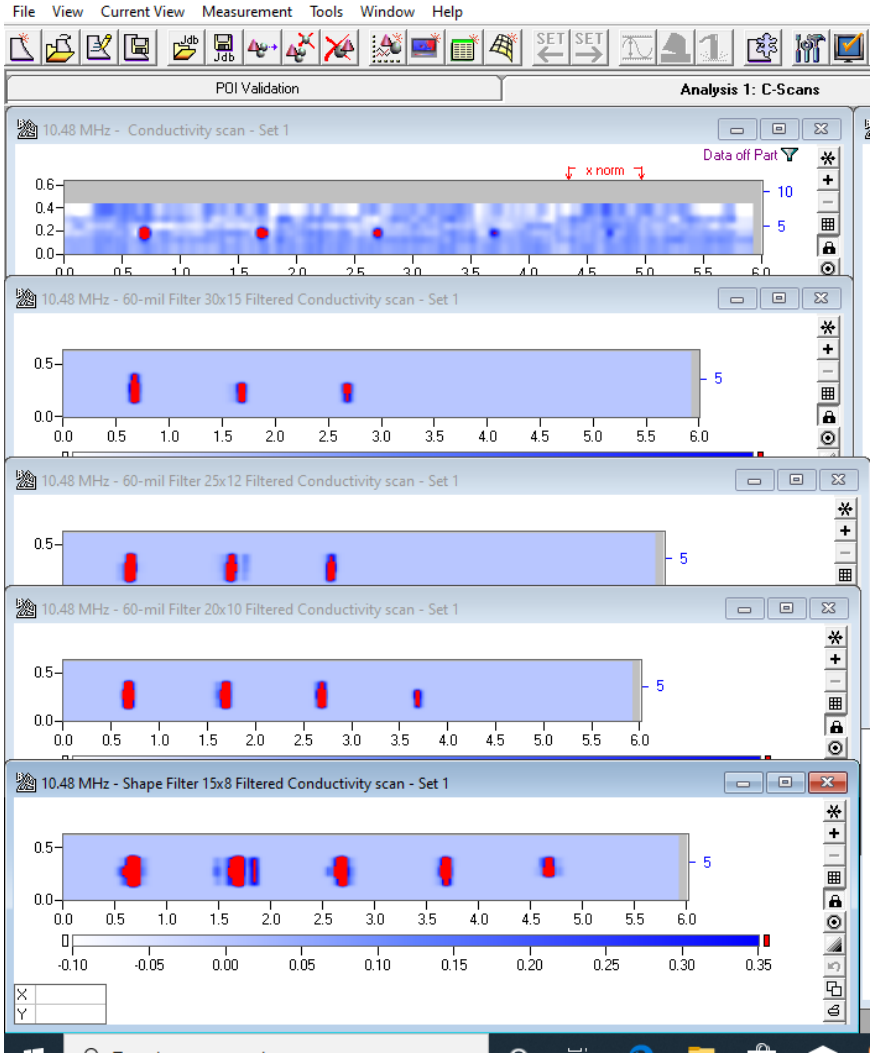
Surface Crack Detection Interface for POD verification and Inspection



Liftoff & coverage verification

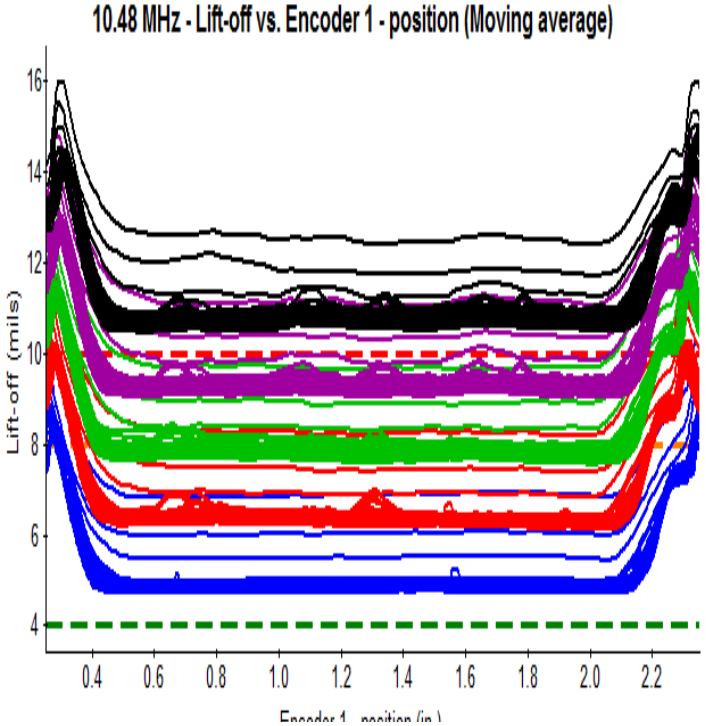


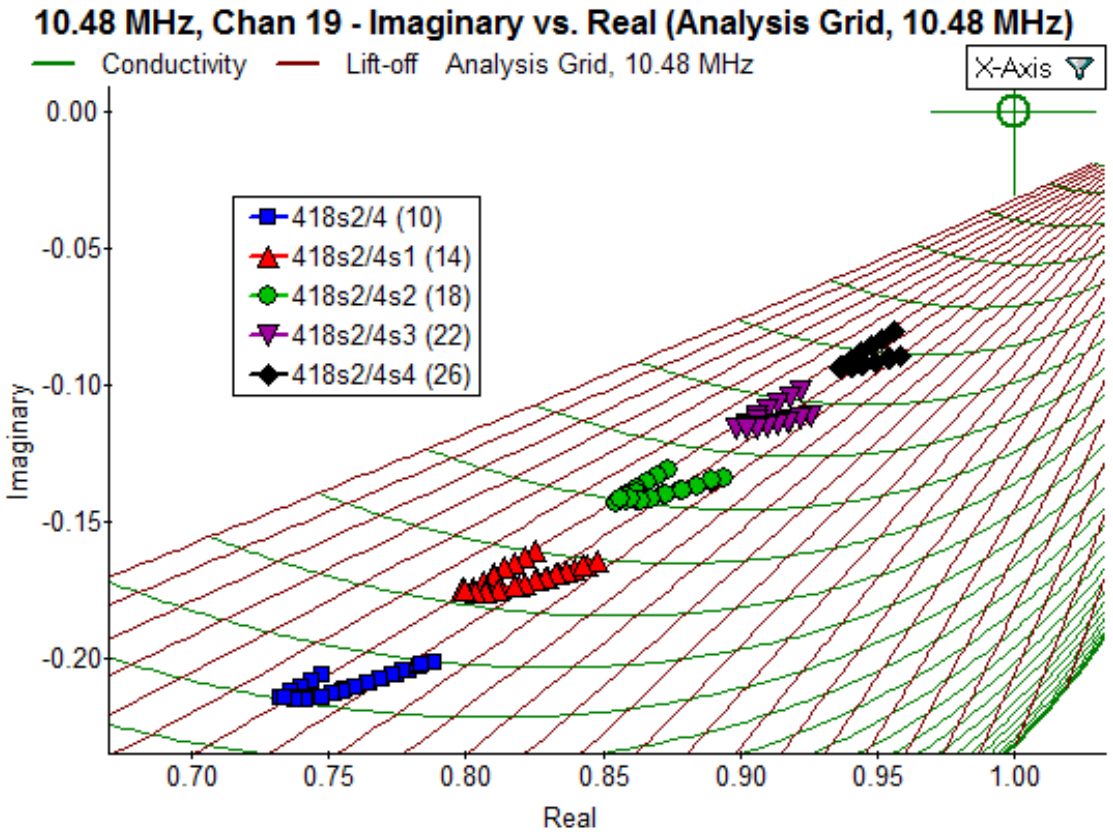
Unfiltered and Filtered B-Scans

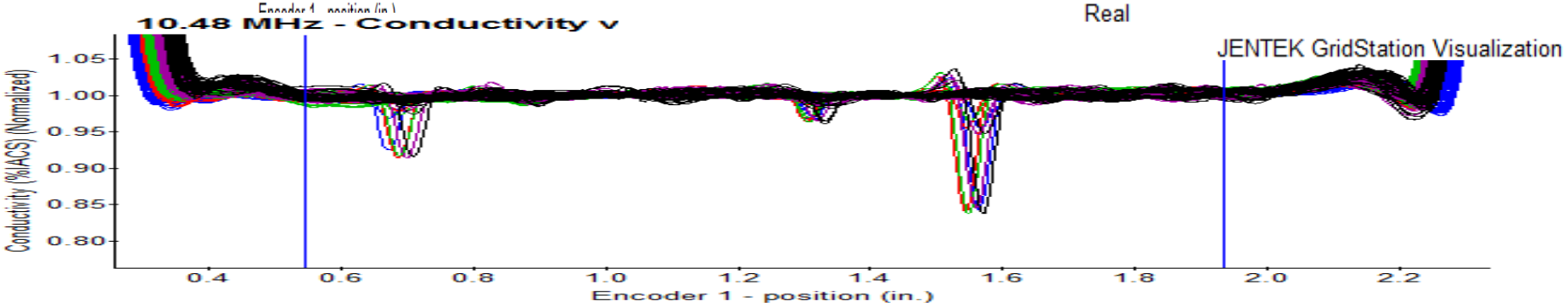


Unfiltered and Filtered C-Scans

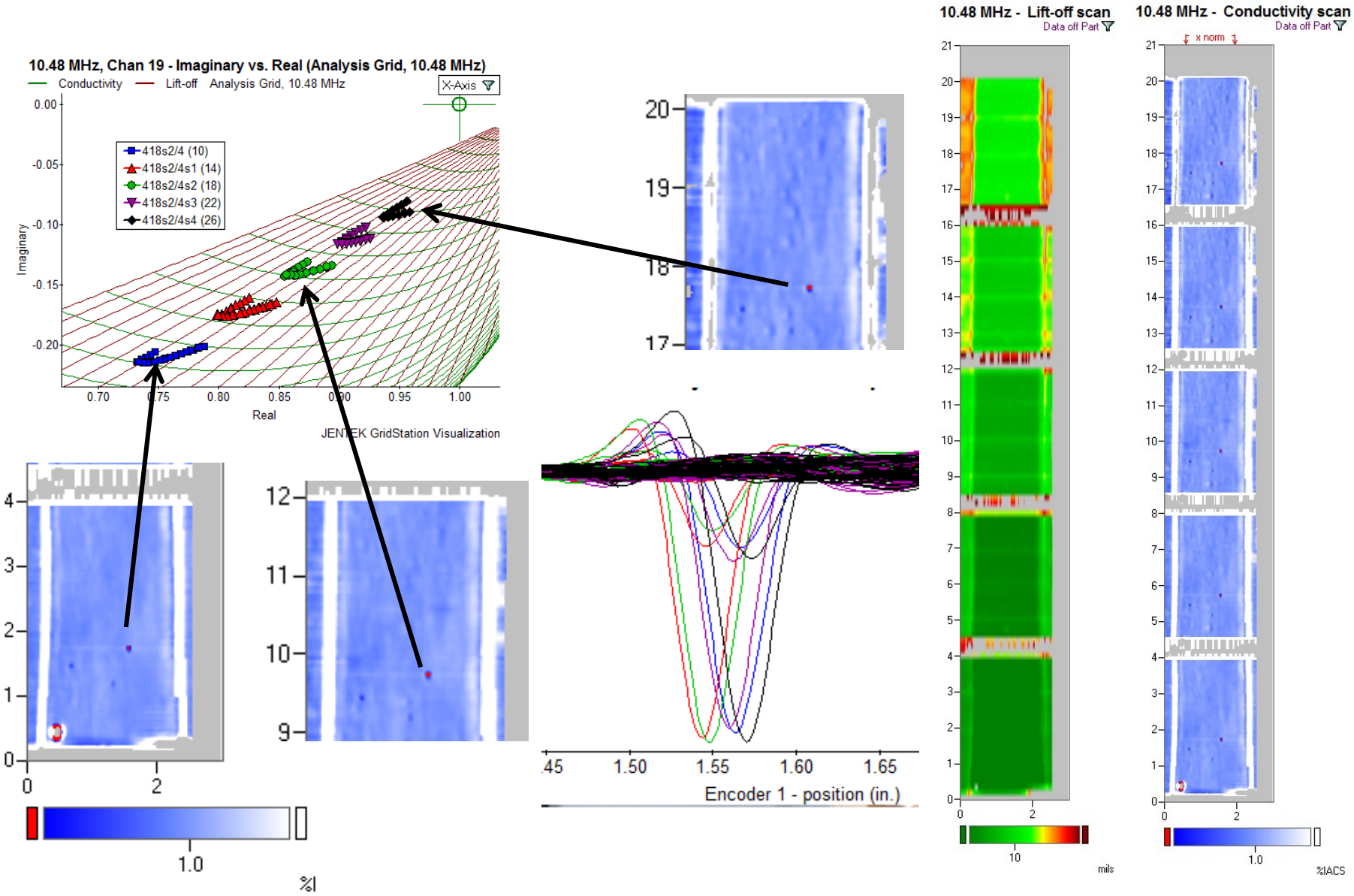
Surface Cracks: Rescaling of Conductivity Response (evolving jAI)





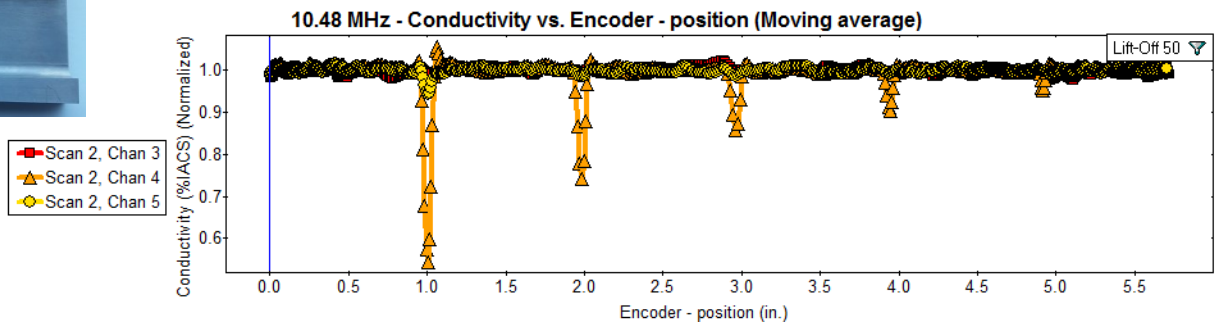


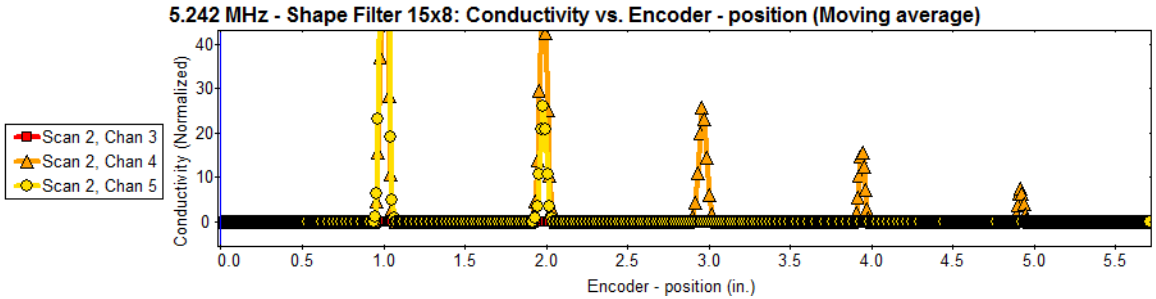
Surface Cracks: Rescaling of Conductivity Response (evolving jAI)

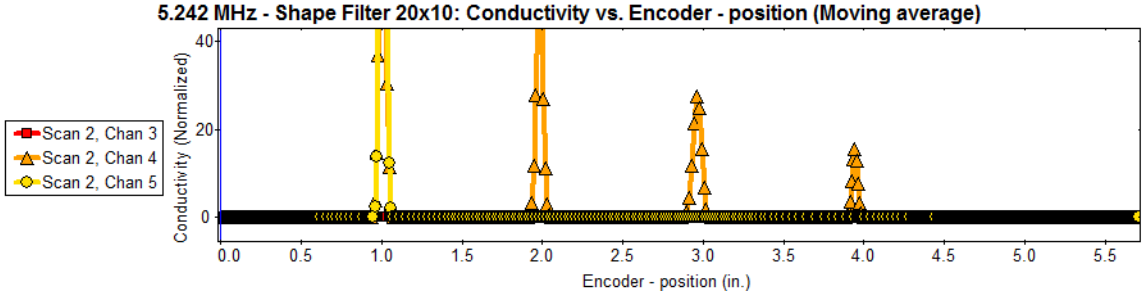


Titanium Alloy Unfiltered and Shape Filtered Results

EDM Notch Sizes:	length	0.06	0.04	0.03	0.02	0.015
	depth	x0.03	x0.02	x0.015	x0.01	x0.0075



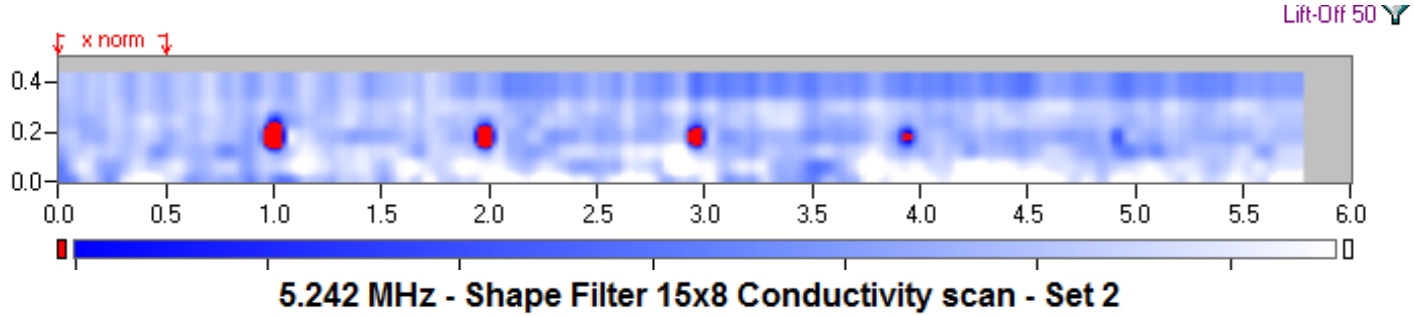




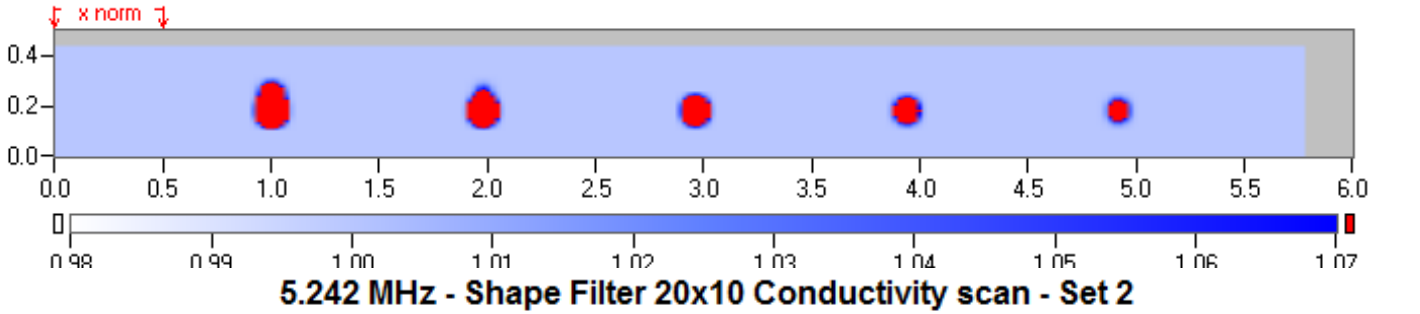
Titanium Alloy, air calibration, unfiltered and shape filtered results

EDM Notch Sizes:	length	0.06	0.04	0.03	0.02	0.015 in.
	depth	x0.03	x0.02	x0.015	x0.01	x0.0075 in.

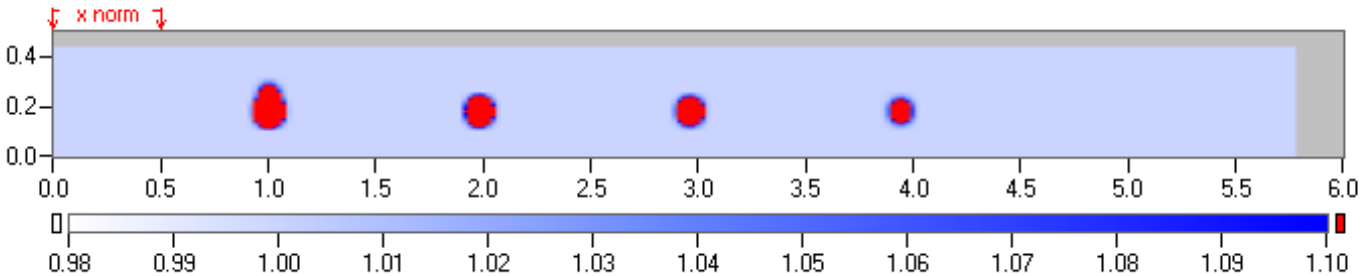
Unfiltered 5.2MHz Conductivity



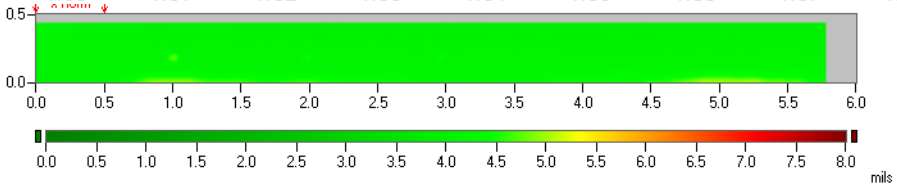
Shape Filtered 0.15 x 0.008



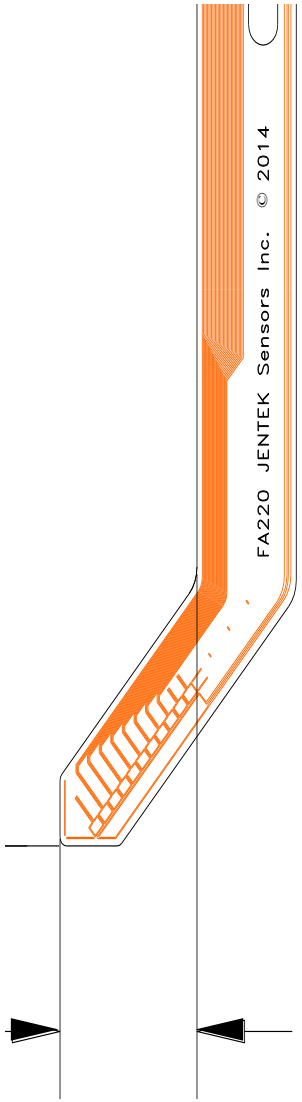
Shape Filtered 0.2 x 0.01

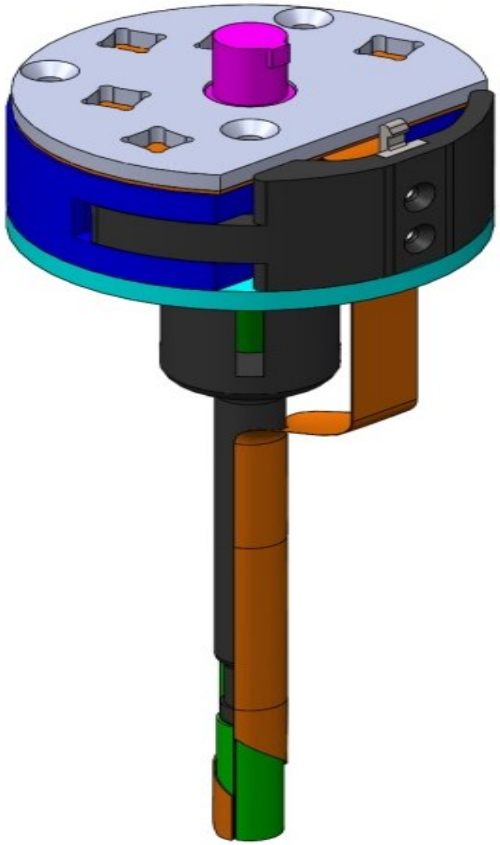


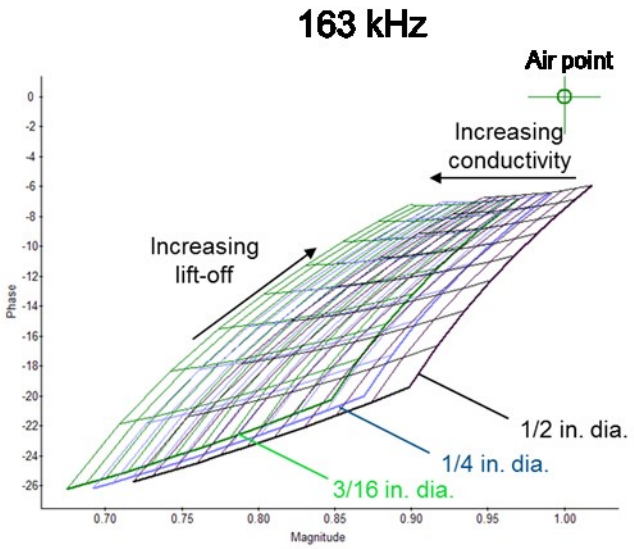
Lift-off Verification

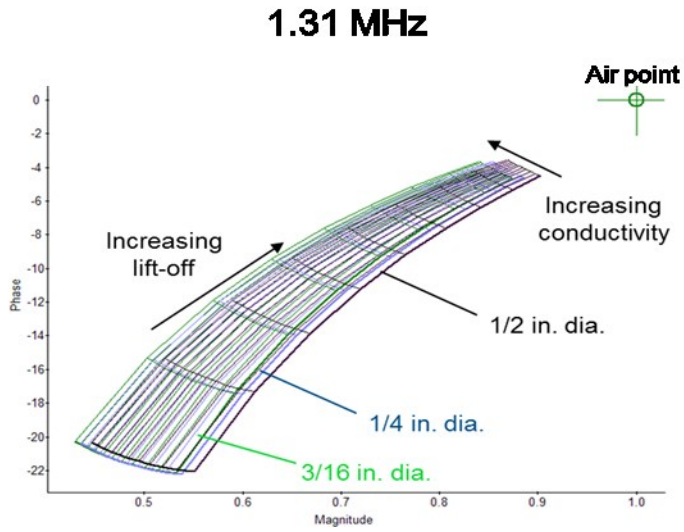


Bolt Hole Inspection – Hole Diameter Impact





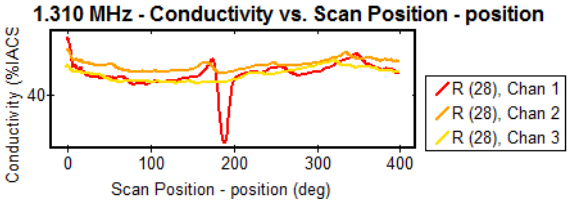


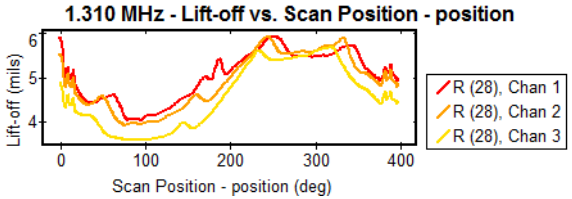


Bolt Hole Flaw Detection

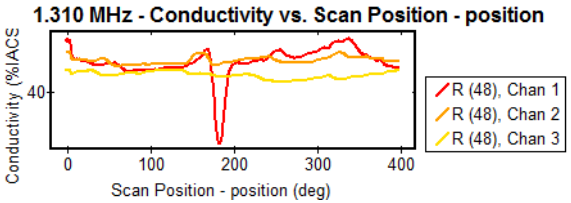
Automatic rescaling of crack response with varied liftoff

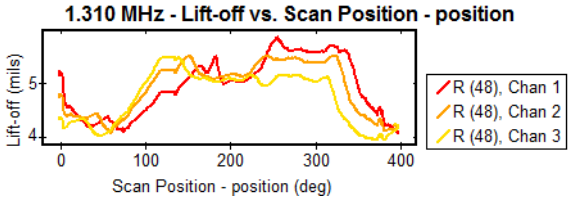
40 x 40 notch (0.001 in.)

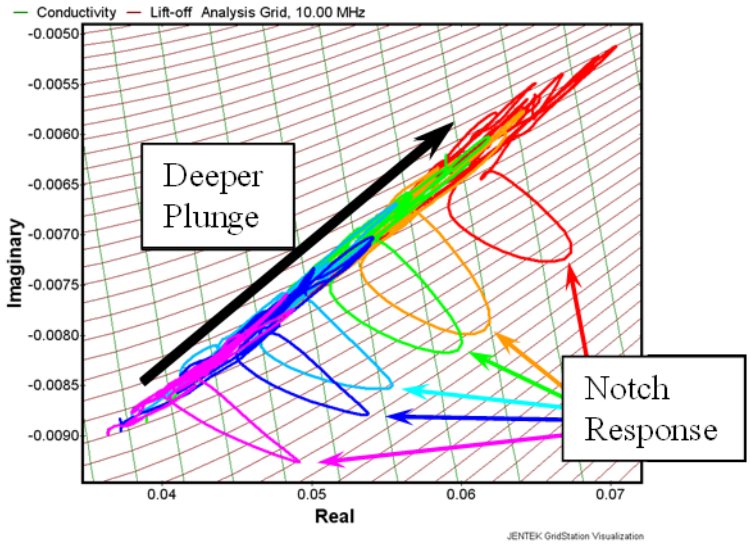


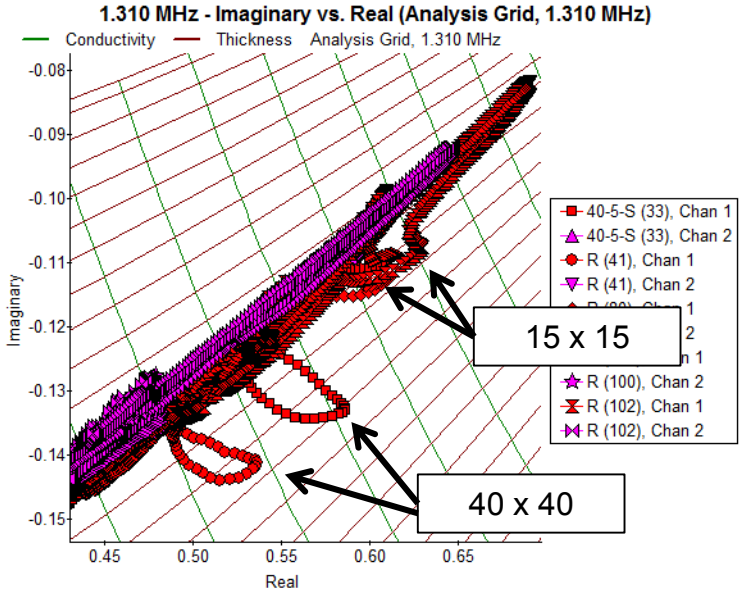


30 x 30 notch (0.001 in.)

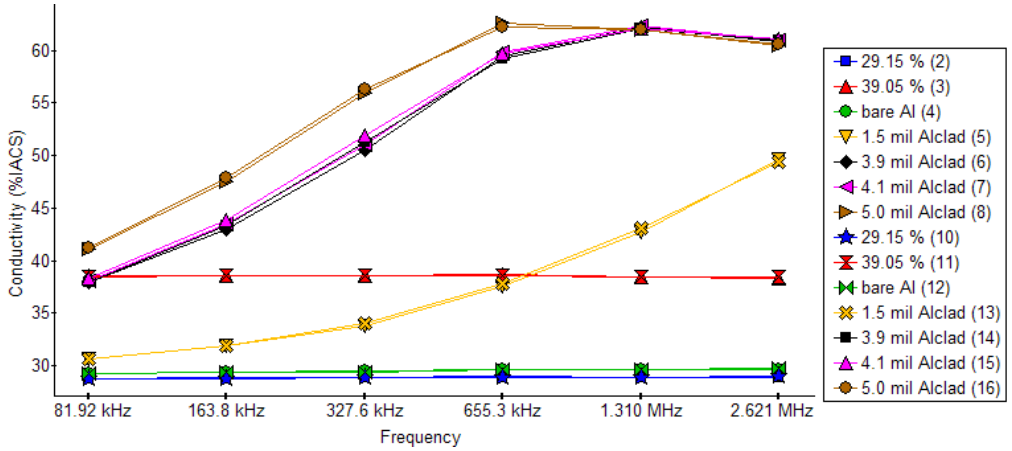








Aluminum Cladding Thickness Assessment

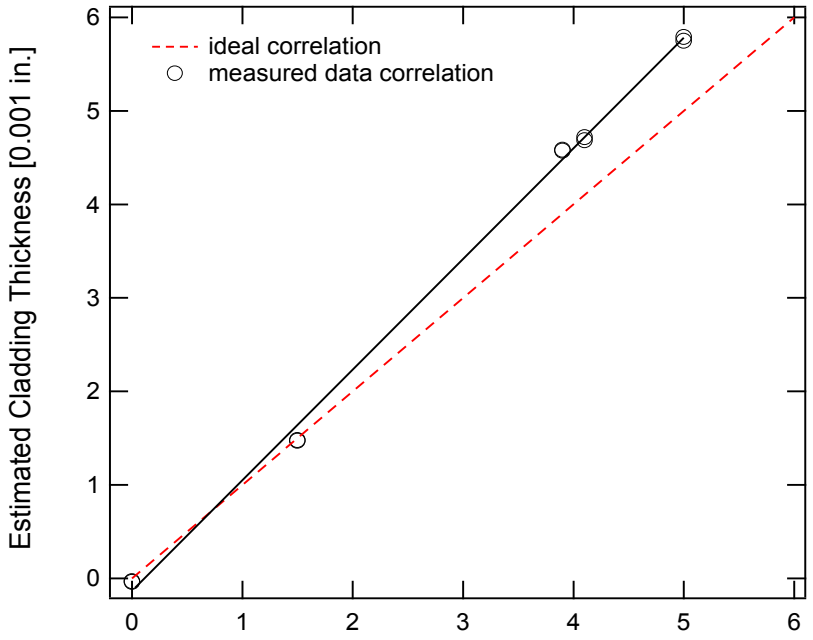


Needed for accurate corrosion imaging for aircraft structures.

More than 3 unknowns requires HyperLattice® databases.

- Effective conductivity values for FS42 measurements on clad test coupons and uncoated aluminum alloy samples.

MWM



Summary

Example Ongoing Performance Trials for Aircraft Structures NDT

- Corrosion imaging
- Subsurface crack detection
- Bolt-Hole Inspection

New Hand-held unit

- More modular and adaptable
- Sensor and accessory kits for easy adaptation

Tabs for grouping of windows

- Designed for next generation ET Arrays with Model-based methods with digital data archiving
- **POI validation** and operator visualization to aid interpretation