

# In-situ Sensing and Post-production Inspection for Additive Metal Parts Using Eddy Current Arrays

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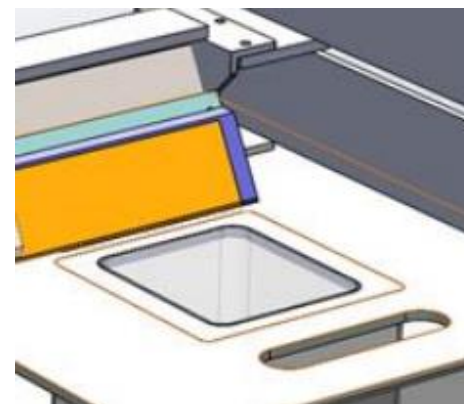
[Andrew.Washabaugh@jenteksensors.com](mailto:Andrew.Washabaugh@jenteksensors.com)

**JENTEK Sensors, Inc.**

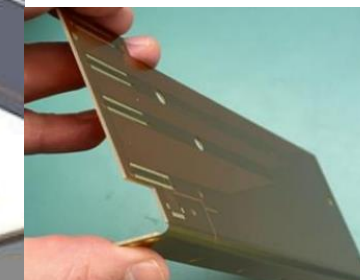
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[www.jenteksensors.com](http://www.jenteksensors.com)



NDE Technologies for LPBF



NDE Technologies for EB-DED Ti

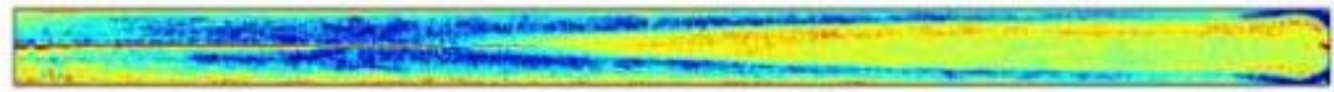
JENTEK Sensors

Non-contact Eddy Current Array



- JENTEK Friction Stir Weld (FSW) inspection
  - FSW history
  - Additive Friction Stir Deposition (AFSD) in-situ sensing potential
- JENTEK in-situ sensing technology for AM
- JENTEK post-process NDT for AM
  - Machined surface inspection (holes and surfaces)
  - Metallurgical assessment
  - Volumetric crack detection for thin walls (surface and subsurface)

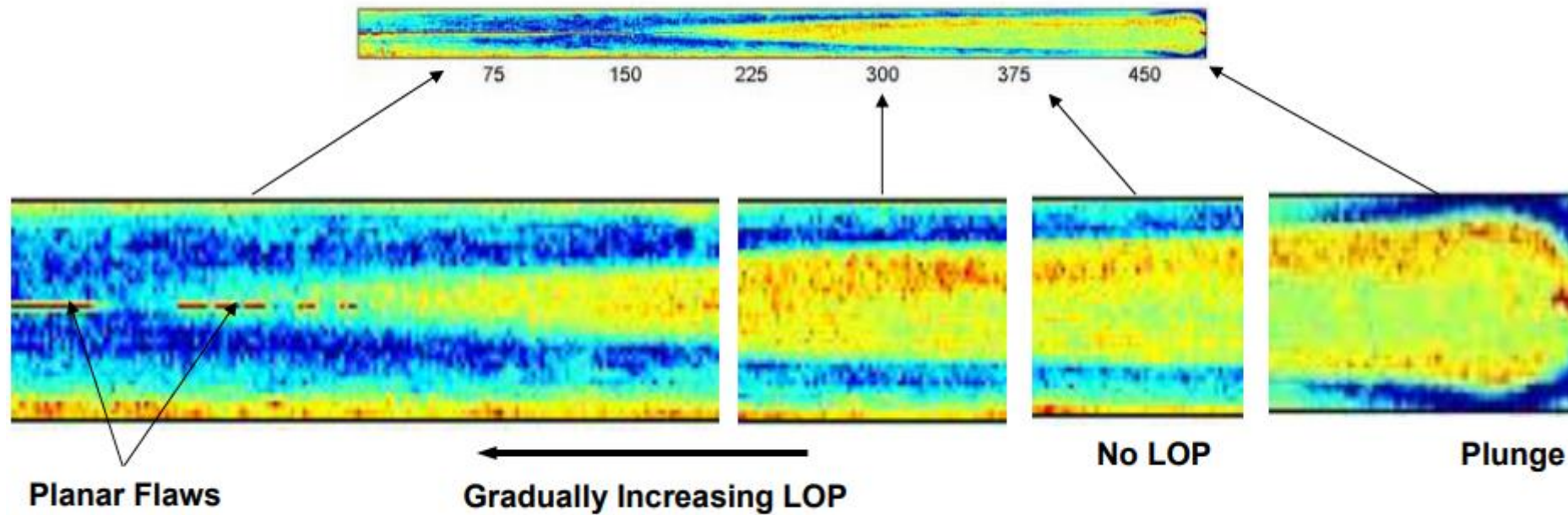
**JENTEK has completed three integrated demonstrations on EB-DED, and LPBF SLM 125 machines with a 79-channel MWM-Array for full width layer-by-layer in-situ sensing.**



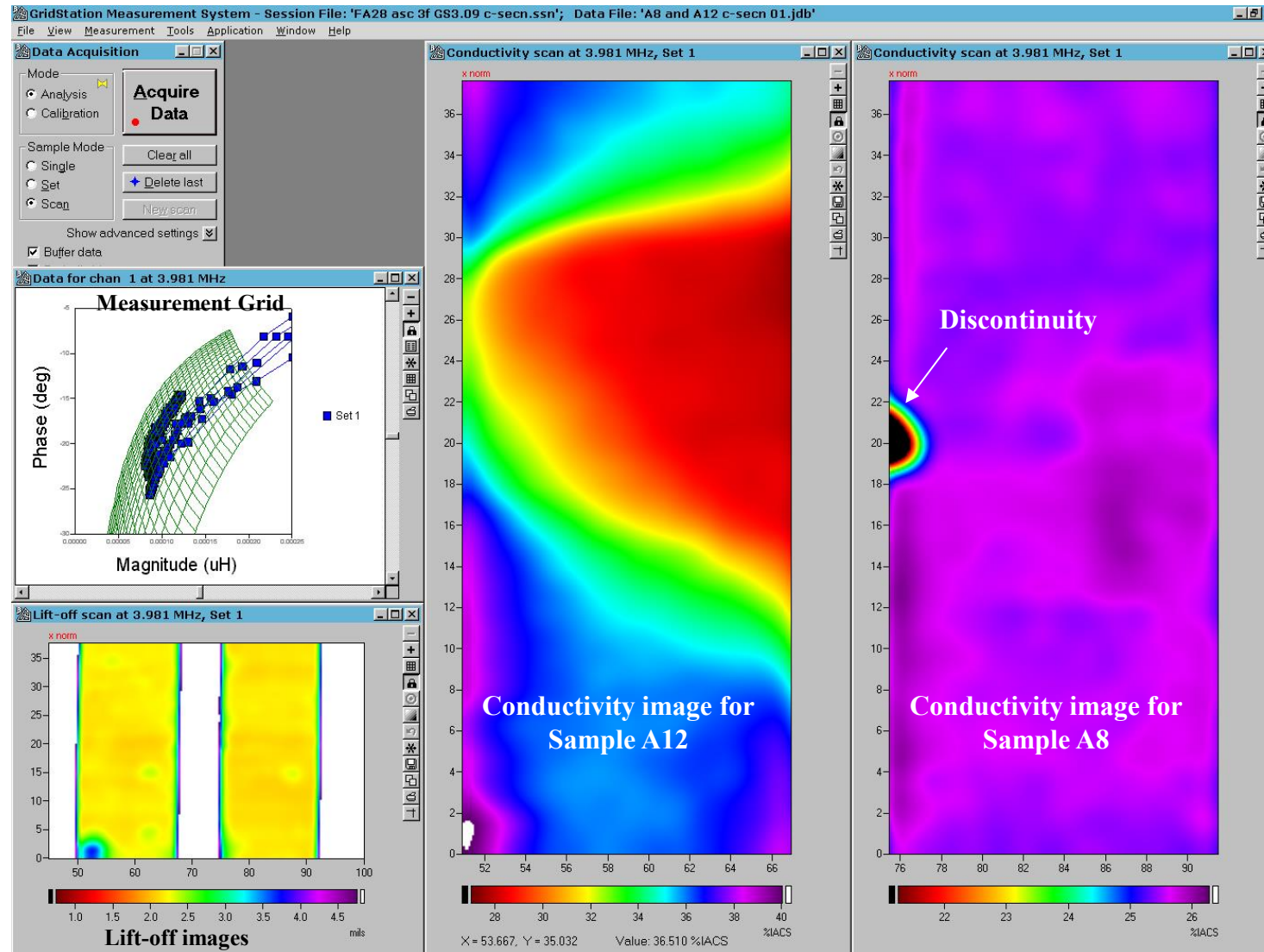
- Non-contact Eddy Current Array
  - Low frequency to penetrate as process surface layer
  - Material property images built from weld conductivity imaging
  - Defects, geometry, and material properties
- Leading and trailing value add
  - Leading can provide path-tracking information and non-contact temperatures measurement
  - Trailing can provide defect, geometry, and property data for quality assessment
  - Trailing can also provide real-time feedback for process control
- JENTEK has not demonstrated the above for AFSD, but anticipates opportunities for such demonstrations in the near future

# Friction Stir Weld Surface Image: Lack of Fusion, Weld Width DXZ Imaging

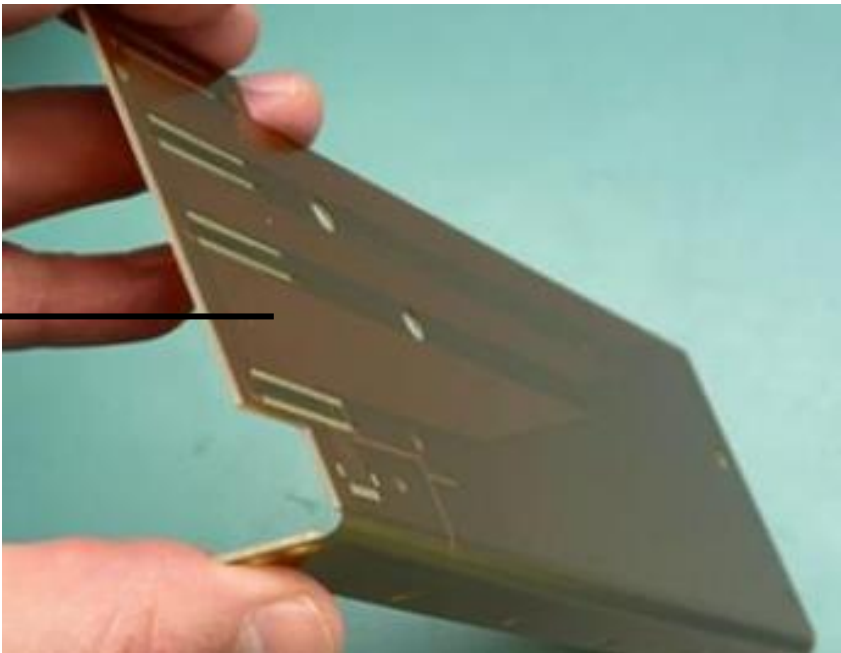
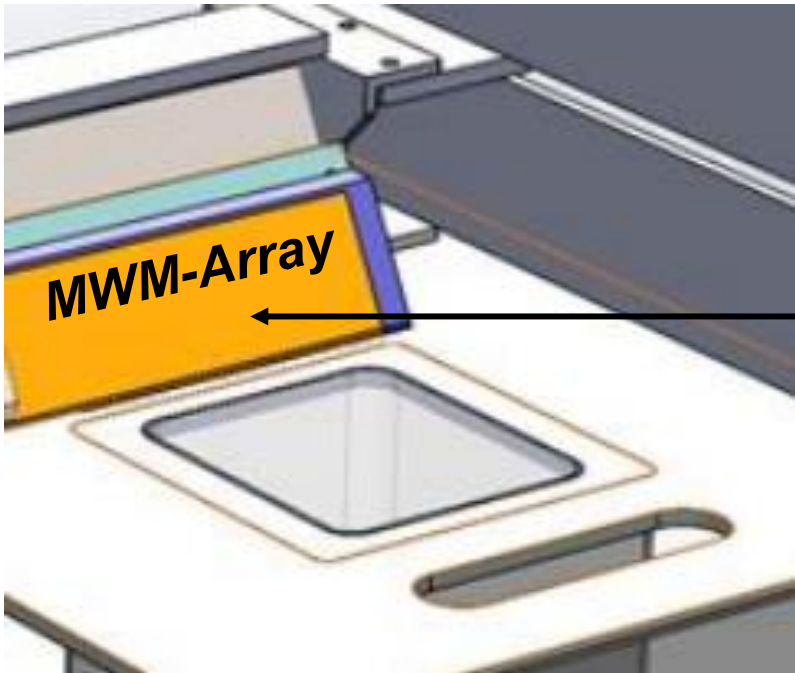
## MWM-Array conductivity image of FSW in blind test panel B01A



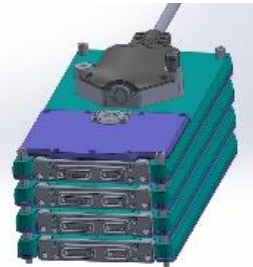
# Friction Stir Weld Cross Section Image: Metallurgical Imaging



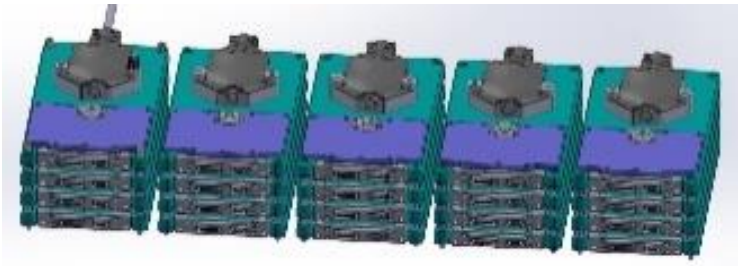
# JENTEK Approach for Laser Powder Bed Fusion (LPBF)



***GS9000 fully parallel instrument***

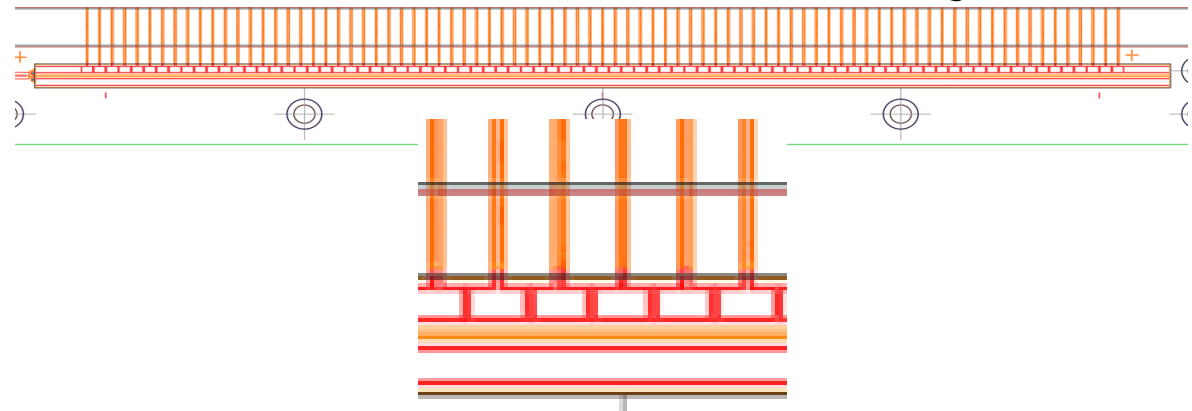


**79-channel**



**395-channel**

**79-channel MWM-Array**



# JENTEK Project for Electron Beam Direct Energy Deposition (EB-DED)

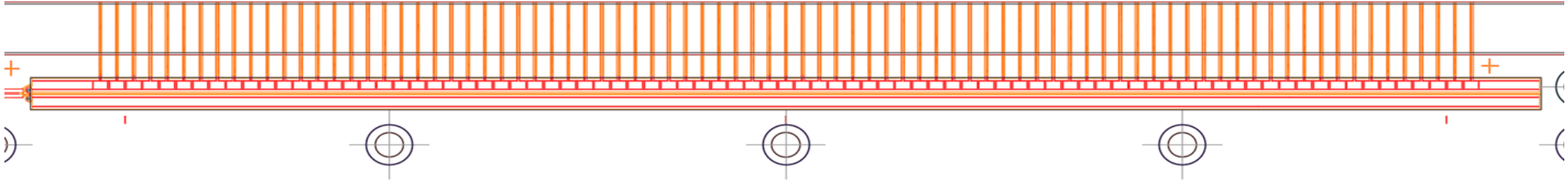


*Slide from public Lockheed Martin presentation (left images)*

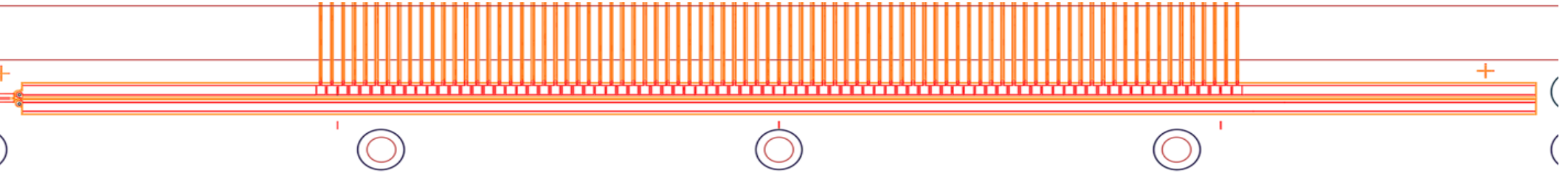
Lockheed Martin & JENTEK Sensors Proprietary

# MWM-Array LPBF Sensing Element Width Study

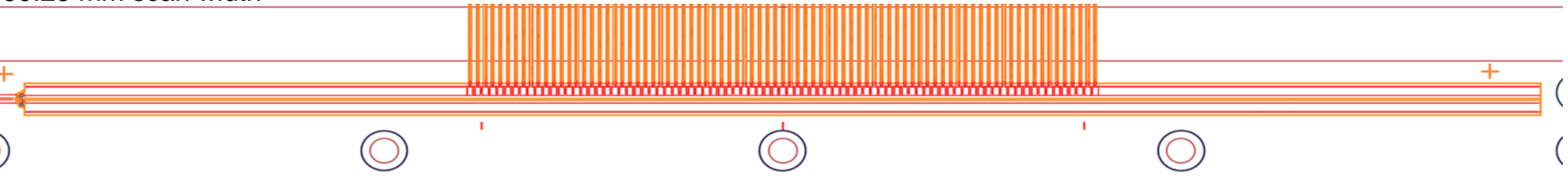
FA332 (for comparison)  
**1.65 mm** sense element spacing  
130.0 mm scan width



FA364  
**1.10 mm** sense element spacing  
86.9 mm scan width

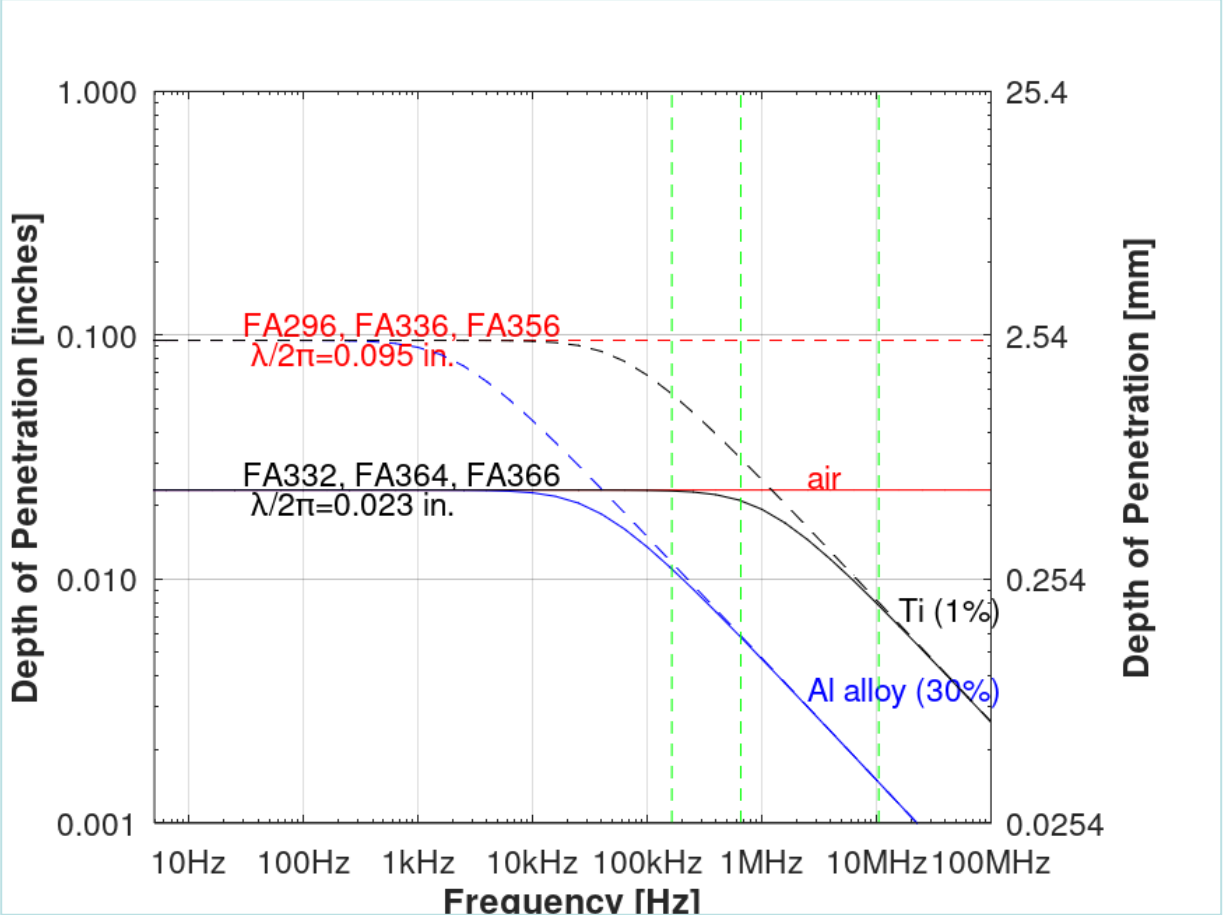


FA366  
**0.75 mm** sense element spacing  
59.25 mm scan width



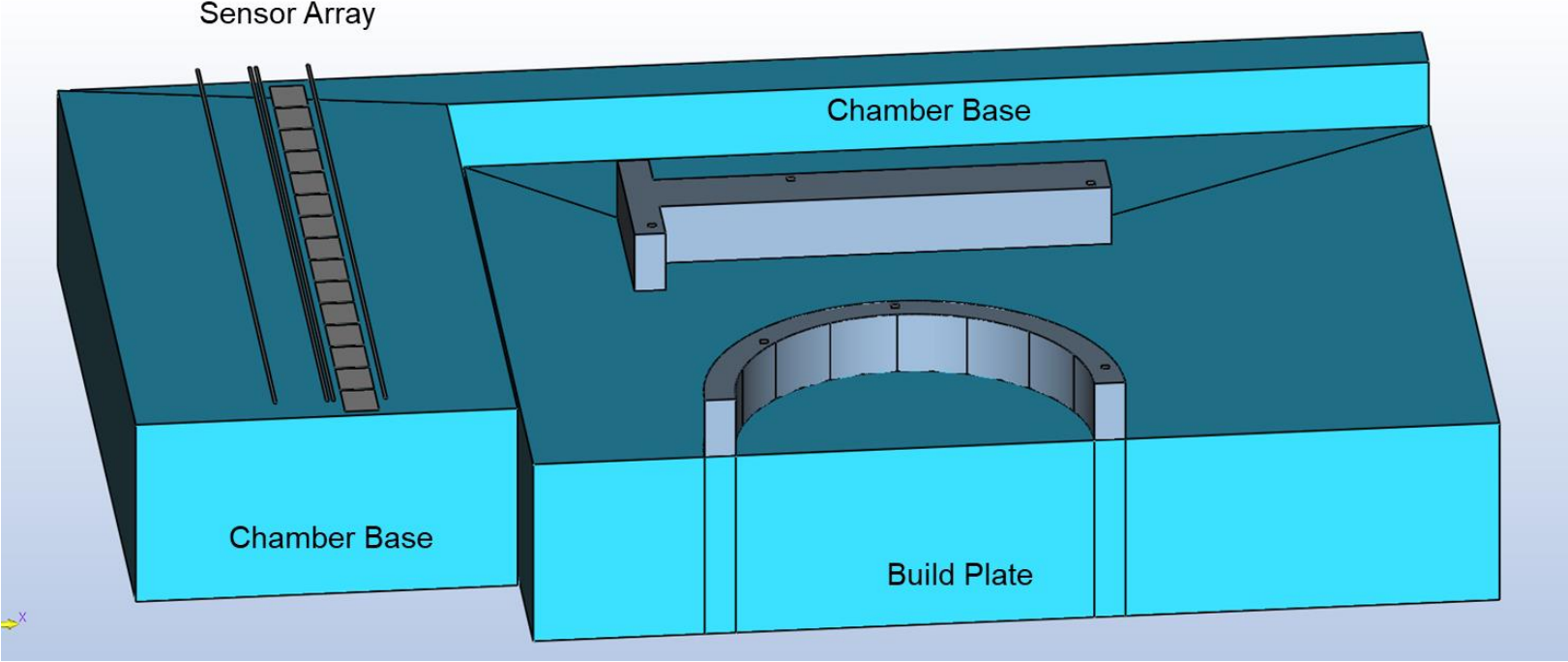


# 3-D Volumetric MWM-Array Imaging at Three Frequencies

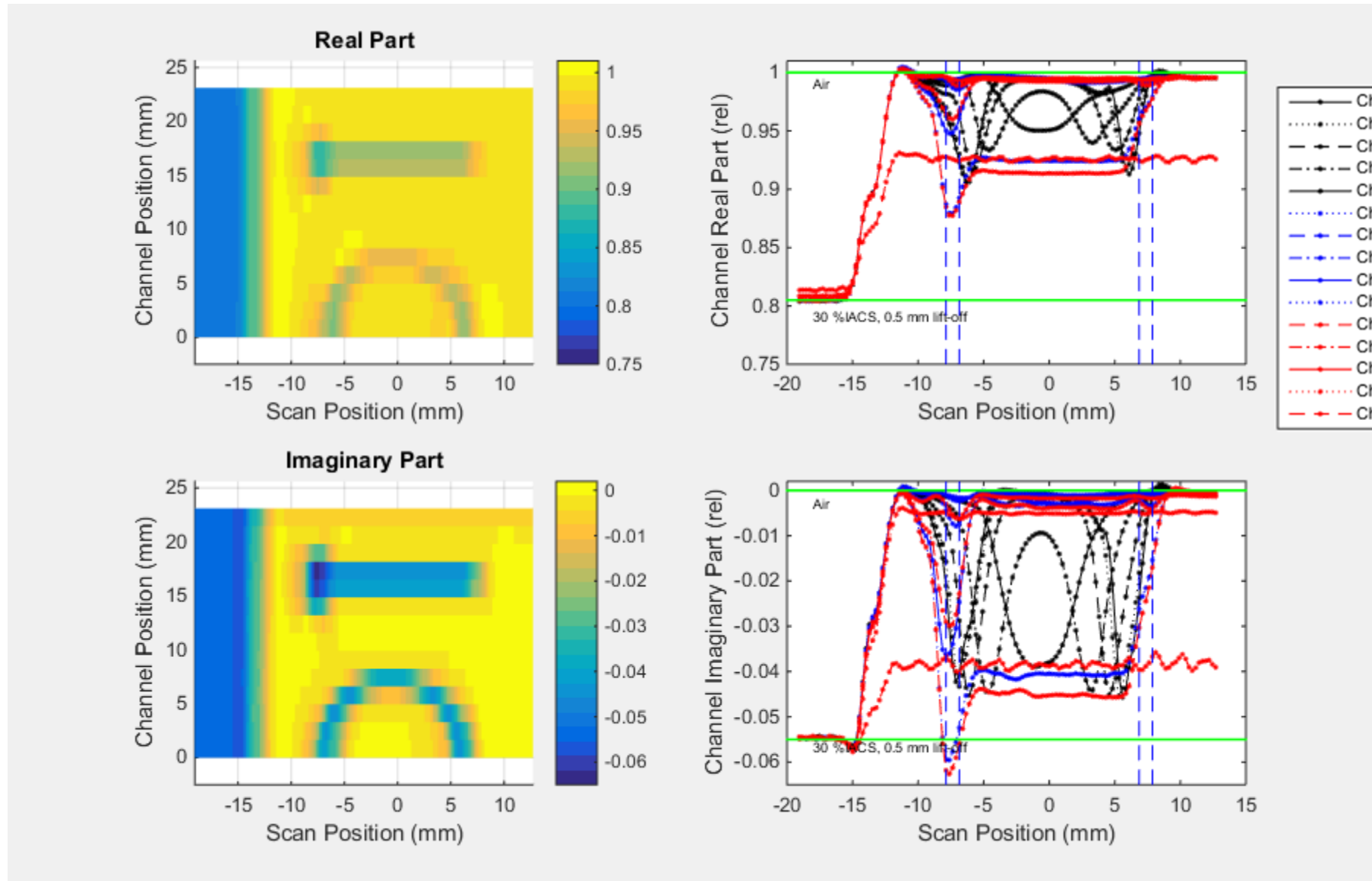


- Detect surface and sub-surface defects
- Sense three to five printed layers below the current process layer
- Full powder bed width imaging
- 0.75 to 2mm sensing element size
- Fully parallel data taken simultaneously at all channels at three frequencies

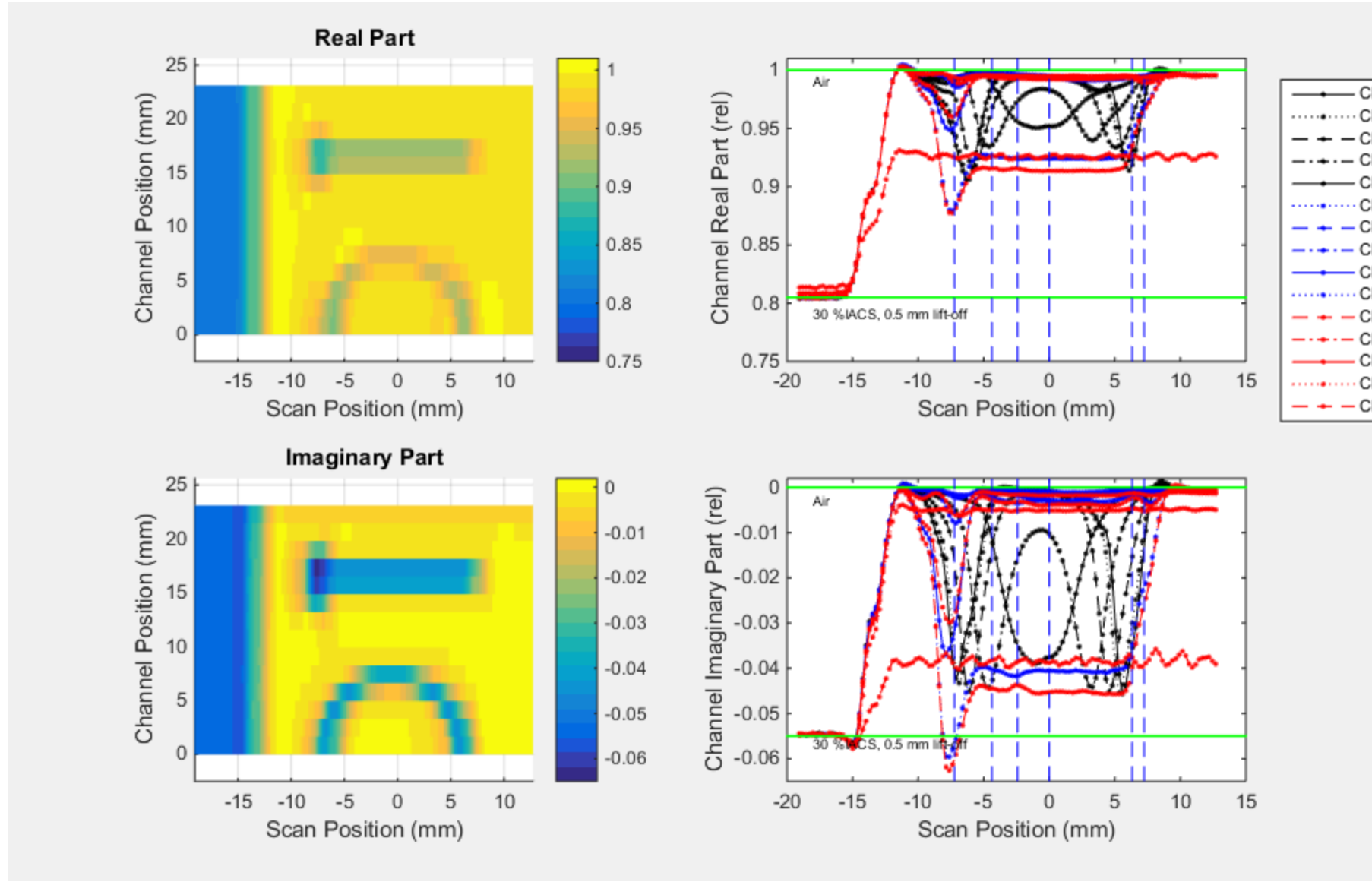
# Simulated response geometry



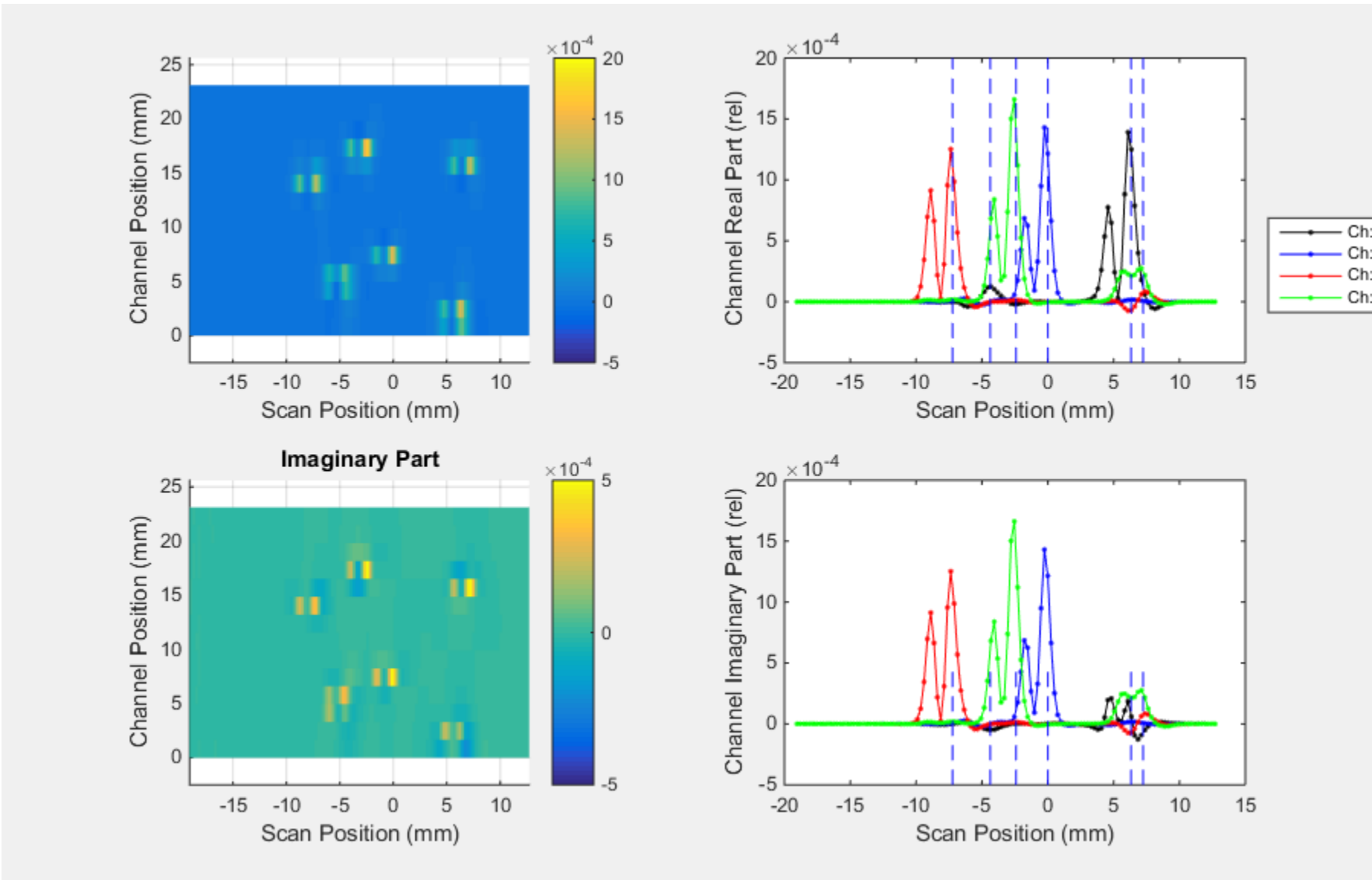
# Simulated response – No Flaws



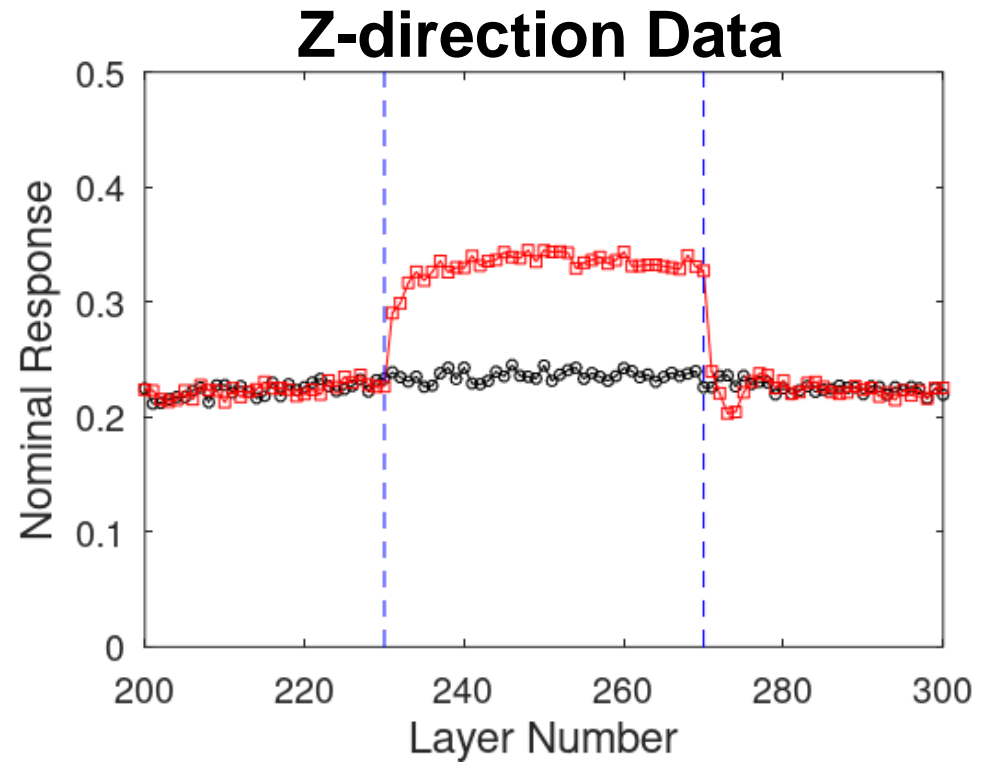
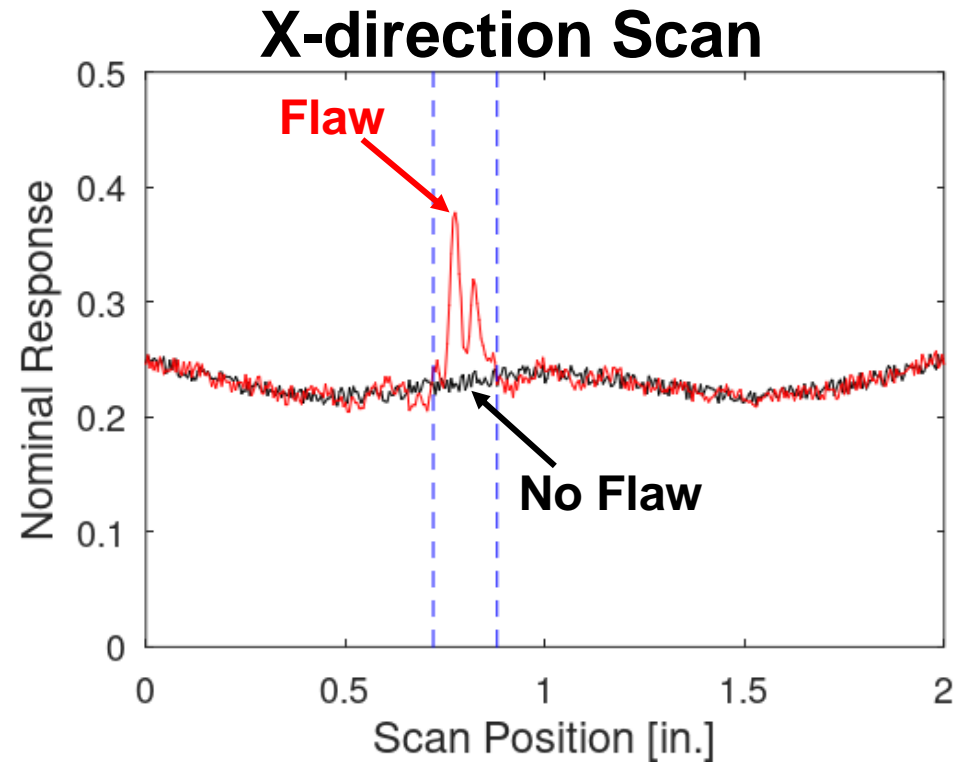
# Simulated response – Multiple 0.010 in. Flaws



# Simulated Response, Baseline Subtracted



# Simulated z-Directed Filtering for 2mm tall cylindrical flaw



Typical dual-rectangle drive flaw response.

Sensitivity to the last three to six layers.

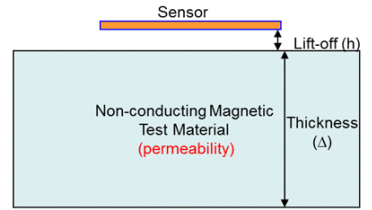
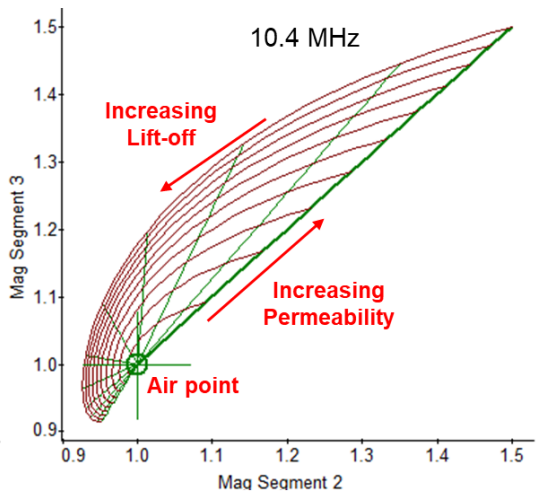
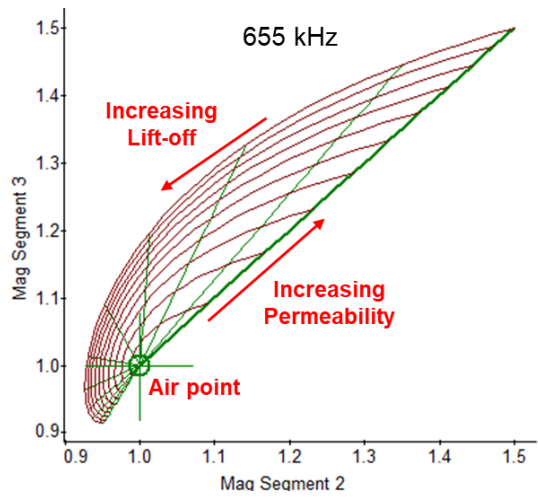
# Ferrous (magnetic) Material Representation (Permeability & Lift-off)

Segmented sensor grids for estimation of permeability and lift-off

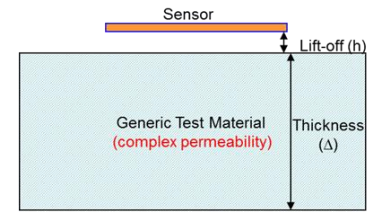
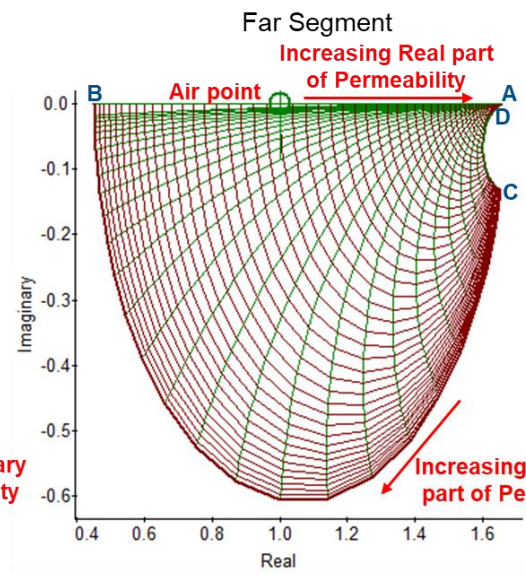
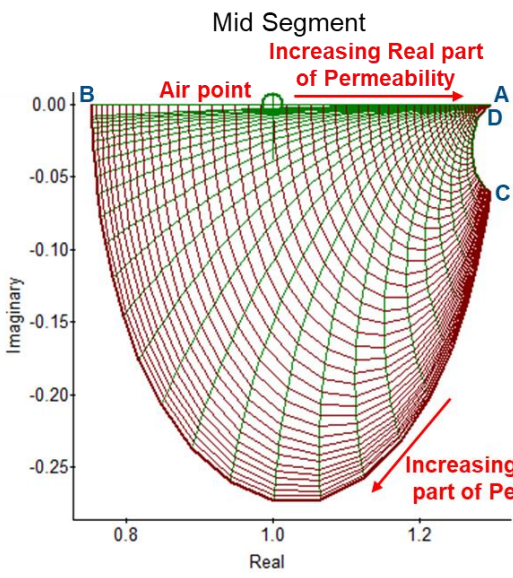
JENTEK uses:

1. Pre-computed databases (grids) to provide rapid solutions for physics-based models.

2. Intelligent filtering/AI to enhance defect responses and correct for geometric variations.



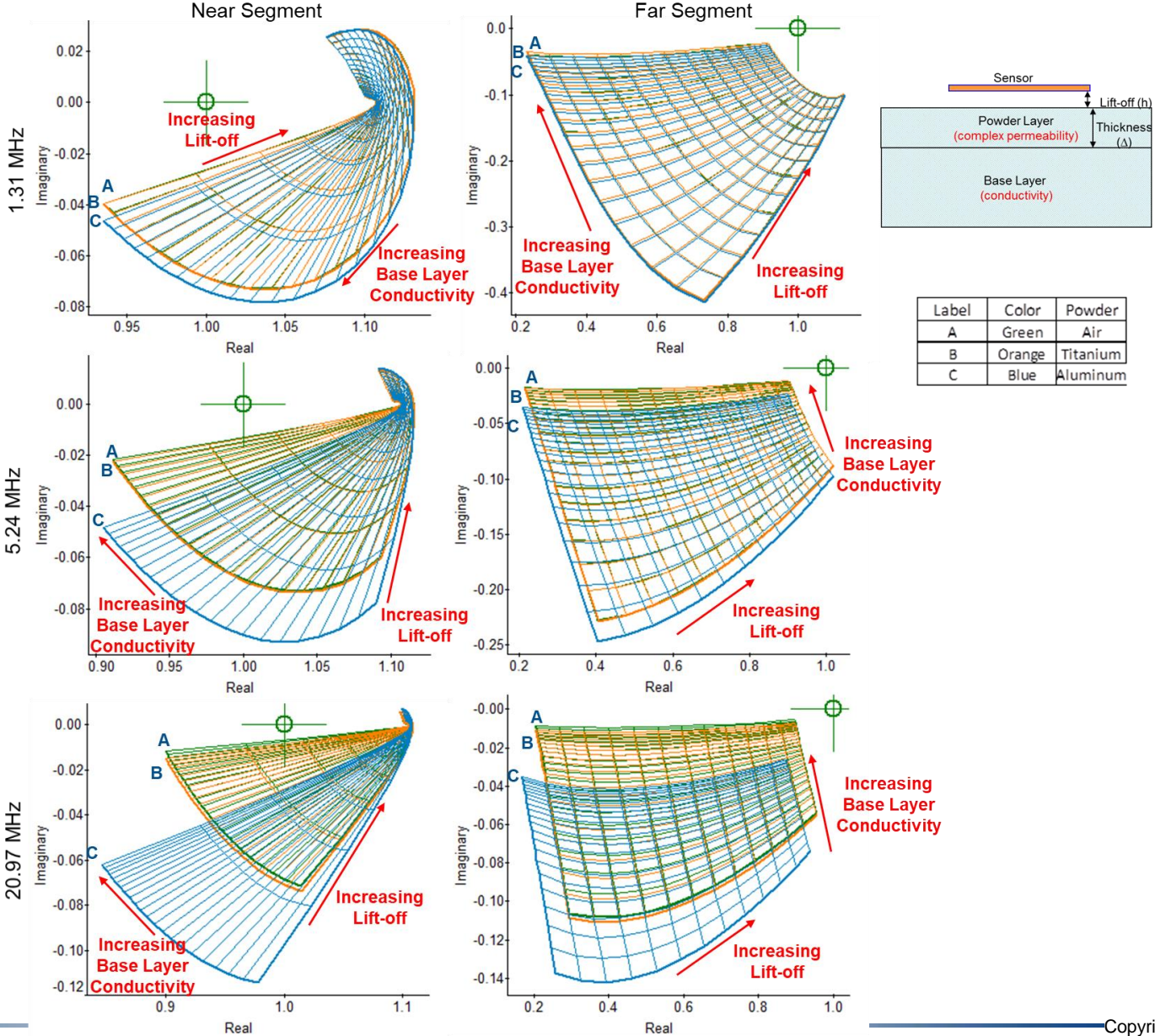
Complex mu – halfspace, 0.020 in. lift-off, FA294



Label	$\mu_{real}$	$\mu_{imag}$
A	1000	0
B	0.1	0
C	0.1	-10
D	1000	-10

# Measurement Grid Methods (Nonferrous)

Sensitivity to most recent process layer and prior three to six layers.





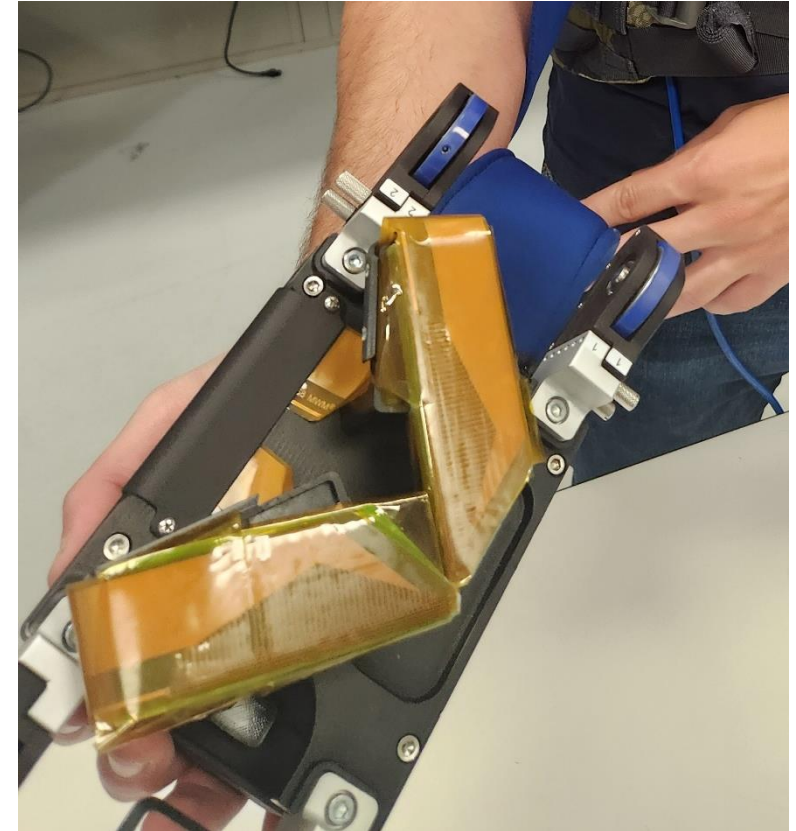
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# Post-process NDT for Relatively Rough Surfaces

## Backpack Portable NDT Scanning System (GS9000 Version)



**$\pm 45$  degree scanner for crack detection and weld inspection**





***JET***



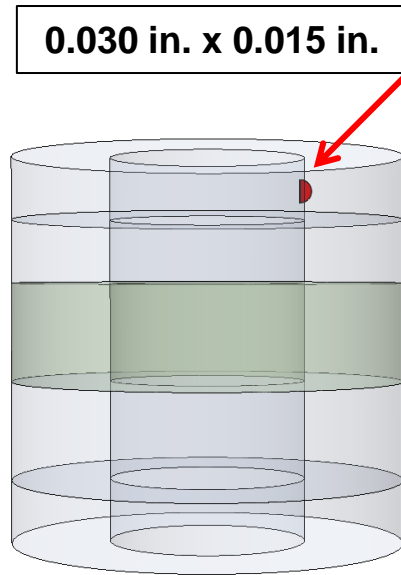
***JETi***



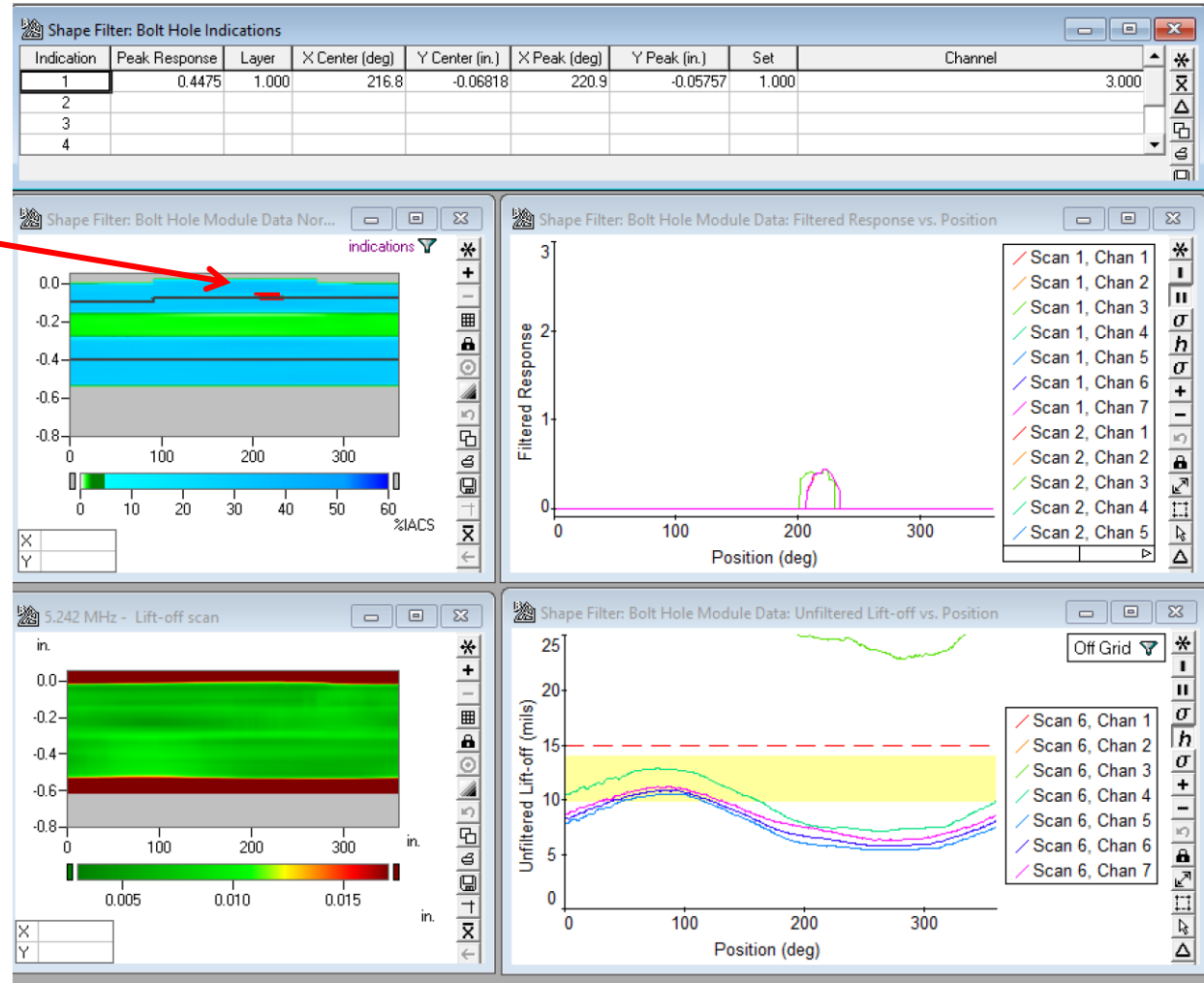
**GS9000 Backpack Portable**



# Bolt Hole NDT with jETi (30 x 15 mil; mid-wall flaw)



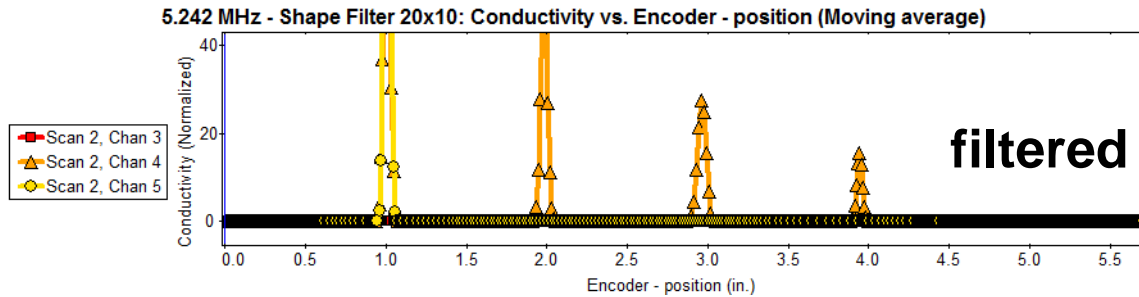
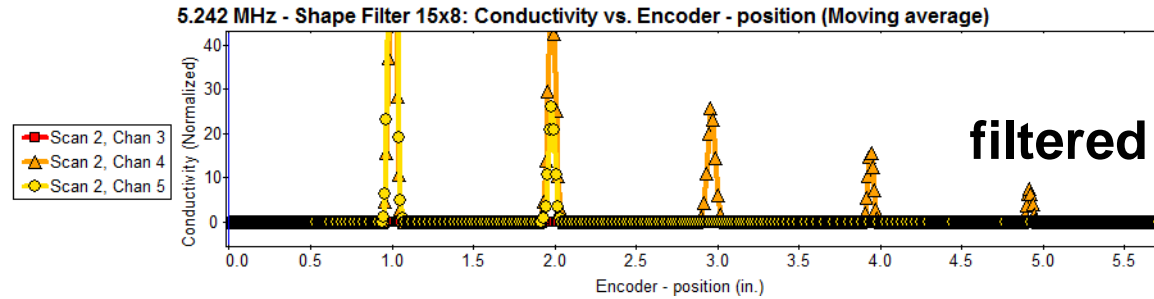
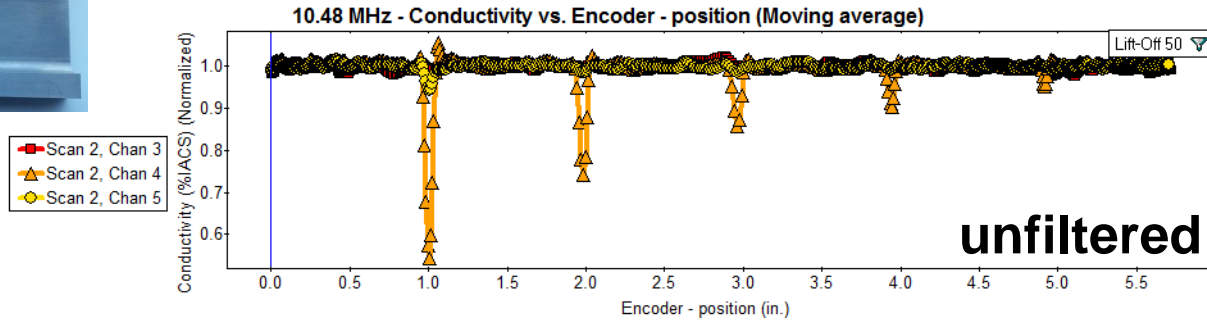
- Aluminum
- Aluminum
- Titanium
- Aluminum
- Aluminum



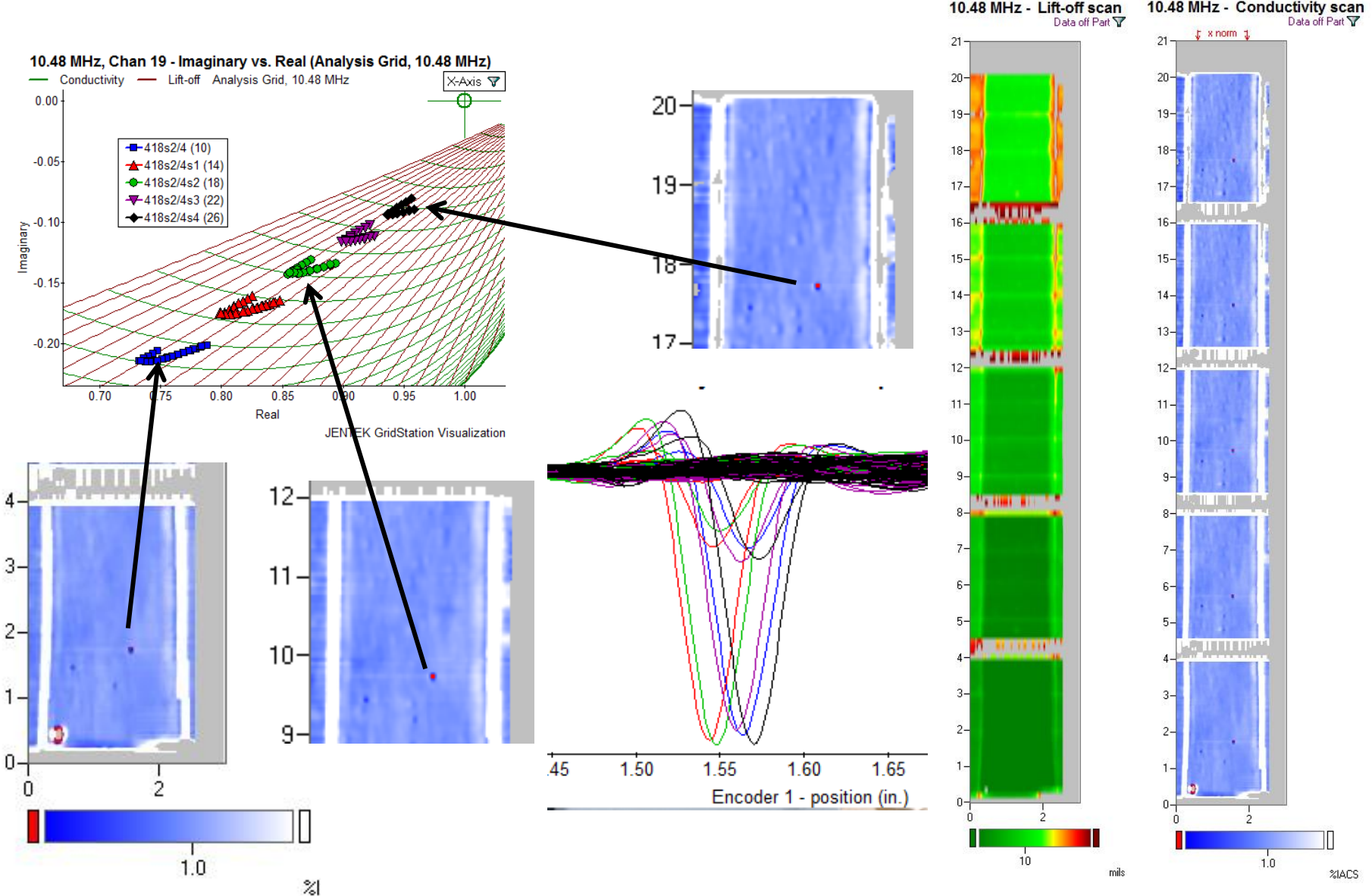
# Surface Cracks in Fillets (unfiltered and filtered response)

EDM Notch Sizes:

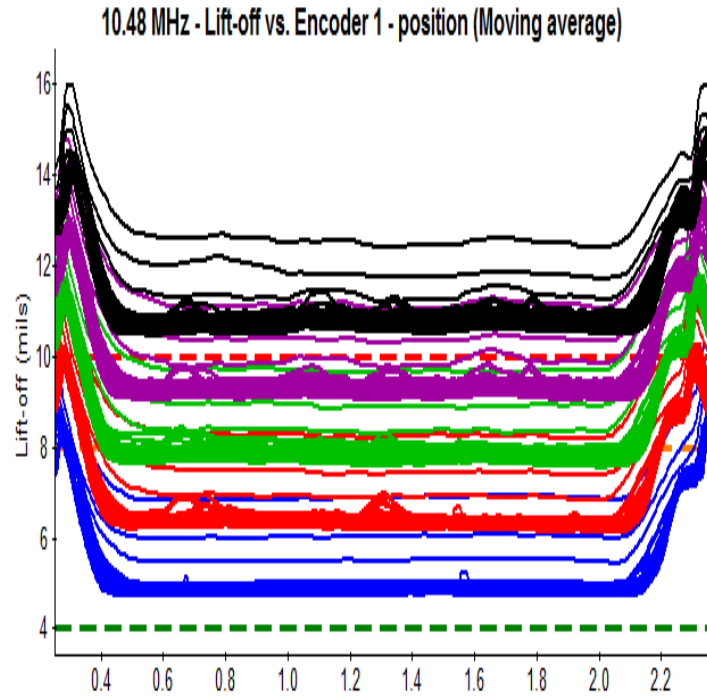
length	0.06	0.04	0.03	0.02	0.015
depth	x0.03	x0.02	x0.015	x0.01	x0.0075 in.



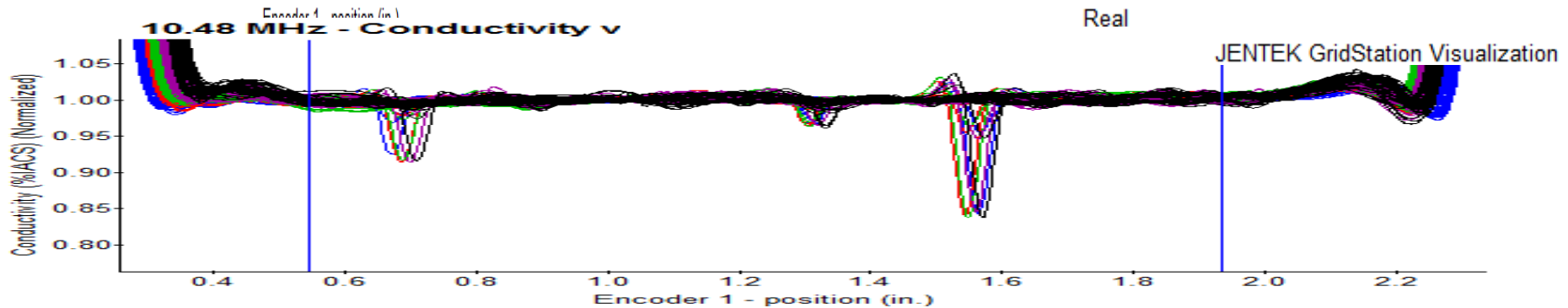
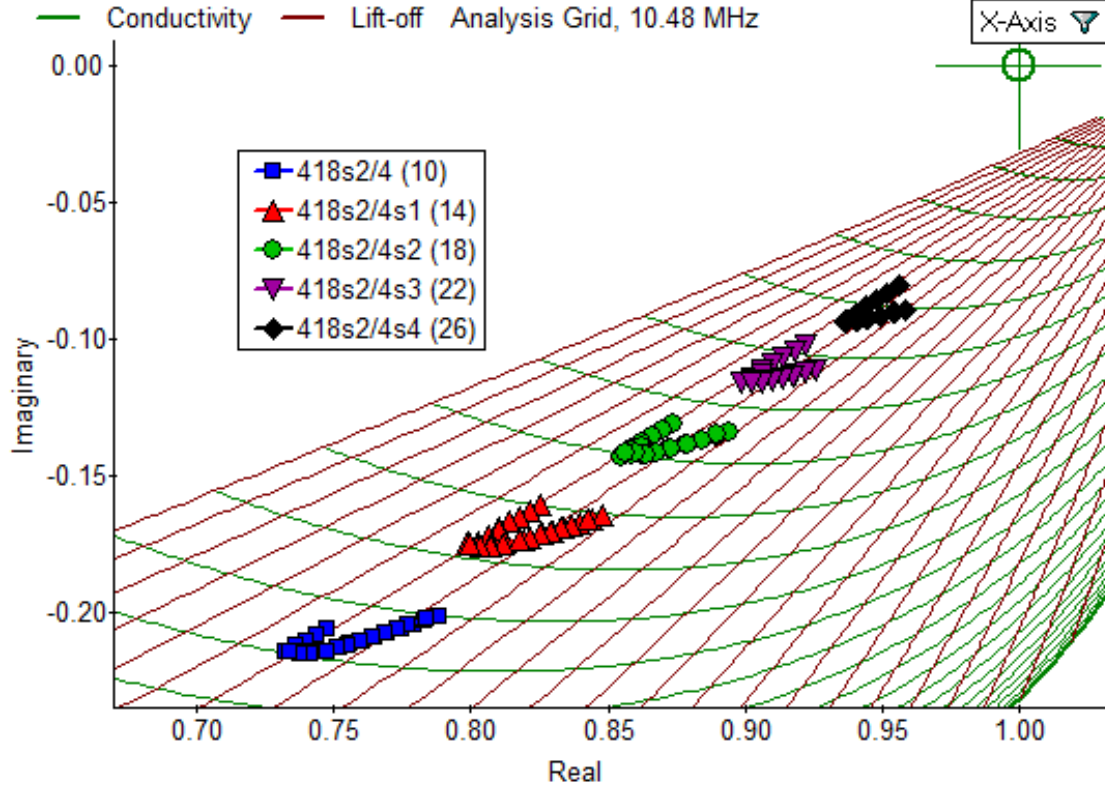
# Surface Cracks: Automatic Rescaling of Conductivity Response for Variable Ltoff



# Surface Cracks: Rescaling of Conductivity Response



10.48 MHz, Chan 19 - Imaginary vs. Real (Analysis Grid, 10.48 MHz)



# JENTEK Sensors, a history of delivering NDT solutions

Outstanding Paper Award,  
*ASNT Materials Evaluation Magazine*,  
 July 2003, Aerospace Health Monitoring



2004 Outstanding Phase III Transition Award, awarded by the Navy Transition Assistance Program



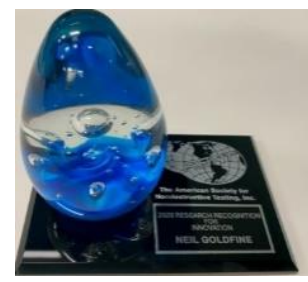
2006 National Tibbetts Award for outstanding contributions to the SBIR Program



2007 FAA/Air Transport Association 2007 "Better Way" Award for Engine Component Inspection Technology



2020 ASNT Innovation Award



Awards

Success Stories

- 2001-present; fighter aircraft engine blade inspection
- 2002-present; C-130 propeller inspection
- 2005-present; fighter aircraft disk slot inspection
- **2007-2011; space shuttle leading edge inspection**
- 2009; fighter aircraft blade dovetail inspection
- 2011-present; Rolls Royce AE engine inspection
- 2013-present; SCC crack detection for pipelines
- 2015-present; A380 pump hole inspection
- 2016-present; engine blade fir tree inspection
- 2018-present; additive manufactured part inspection
- 2019-present; conductivity mapping for AL plate
- 2020-present; friction stir weld inspection

Sticky solutions that produce a revenue stream over decades

New transitions with >10x revenue growth opportunities

- **Spacecraft weld inspection**
- **Additive manufacturing in-situ sensing**
- **Army asset quality and sustainment**
- NDT for aircraft
- Off-shore NDT
- NDT for automotive in-process

Targeted solutions, continual revenue

<https://jenteksensors.com/resourcecenter.php>



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