

# Inspection Using Model-Based Eddy Current Sensors and Analysis

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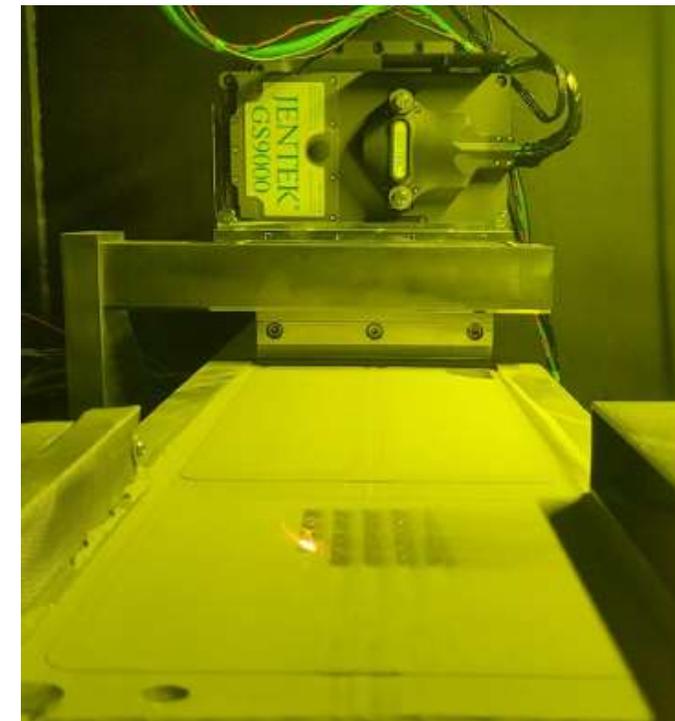
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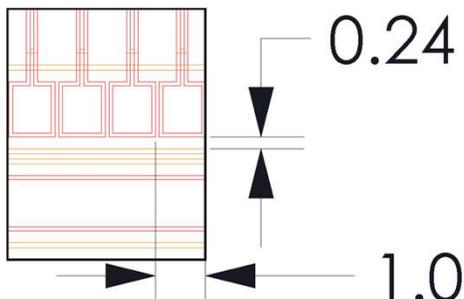
*Patents issued and pending*

# JENTEK Technology Description

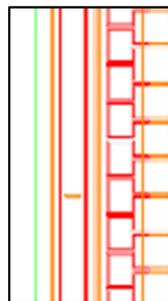
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## 1. Model-Based Sensors: MWM<sup>®</sup>-Arrays

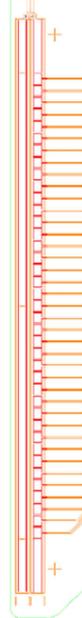
- Design the sensors to match the physics



1 mm  
FA354



1.5 mm  
FA358



## 2. Accurate Electronics: GS9000 and jET<sup>™</sup> Instrumentation

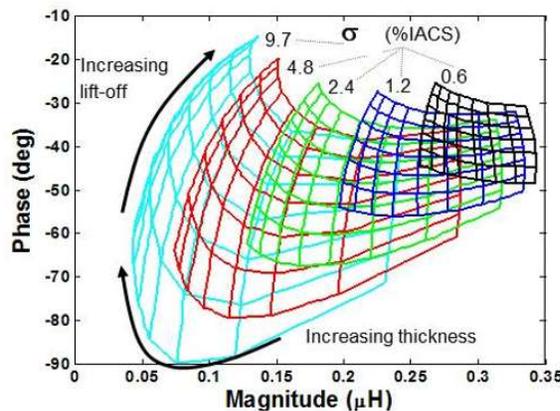
- True Impedance Measurement



## 3. Real Property Analysis: GridStation Software using Model-Based Multivariate Inverse Methods

- Rapid conversion of sensor data into real material properties

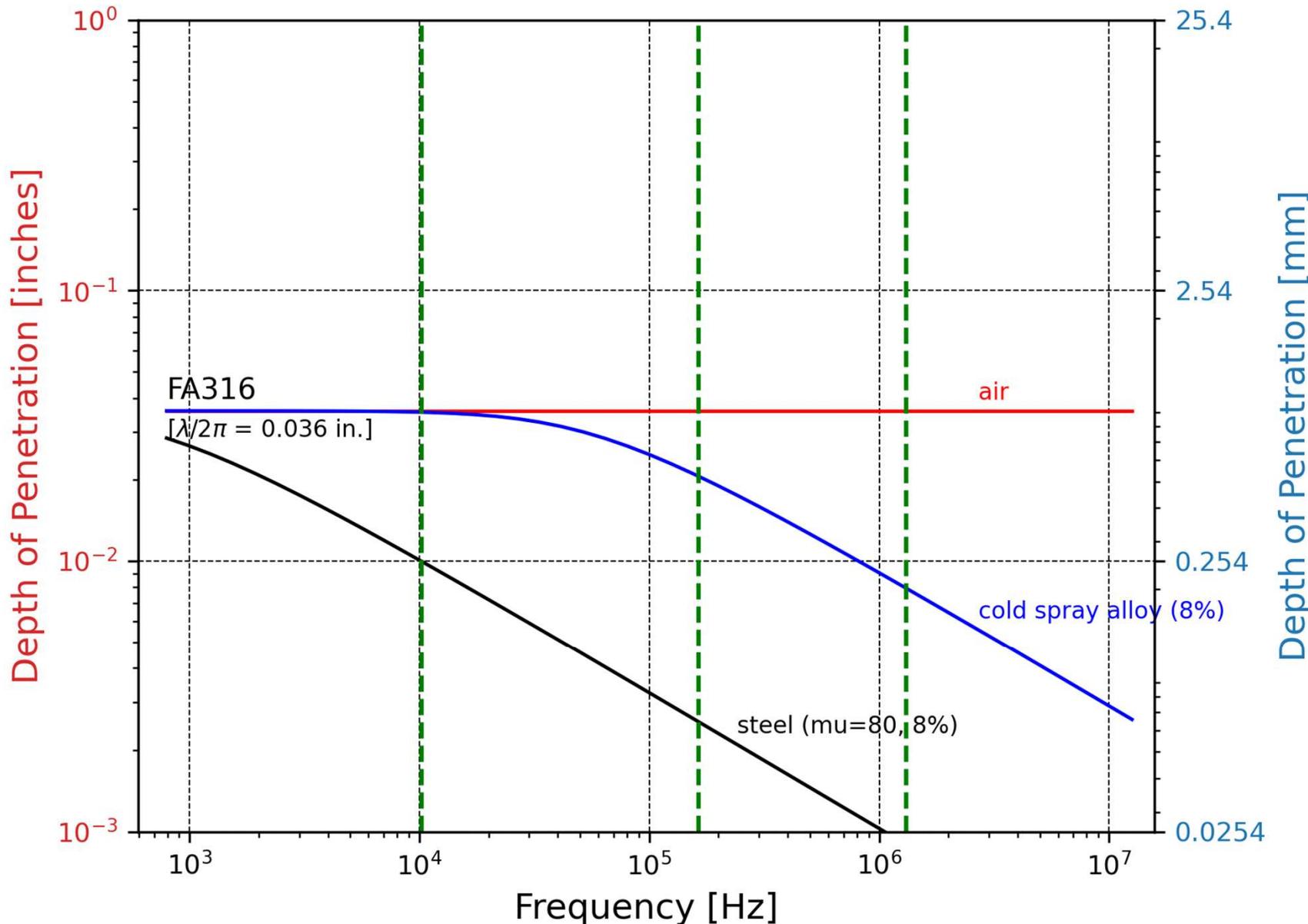
- Electrical conductivity
- Magnetic Permeability
- Thickness



## 4. Ease of Use

- Air Calibration – No Ref. Std.
- C-Scan, B-Scan Visualizations
- Data export at all analysis levels
- Decision support using intelligent filtering
- Rapid data analytics

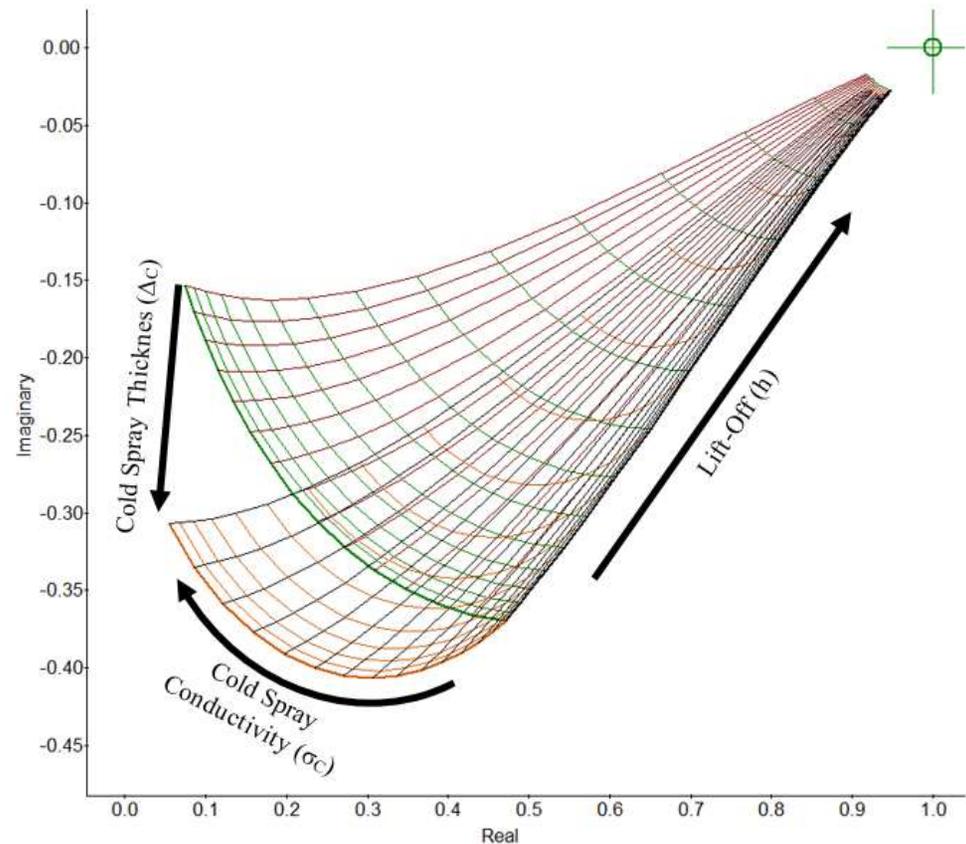
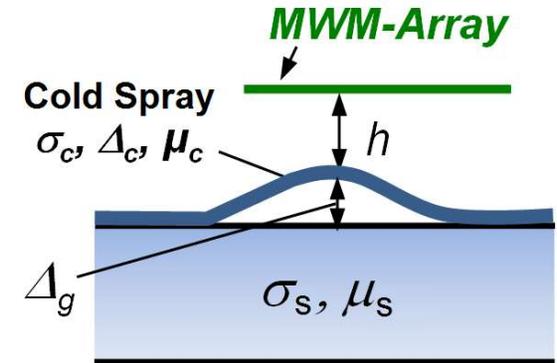
# Depth of Penetration for Cold Spray



# Grid Methods: Lattices and Hyperlattices

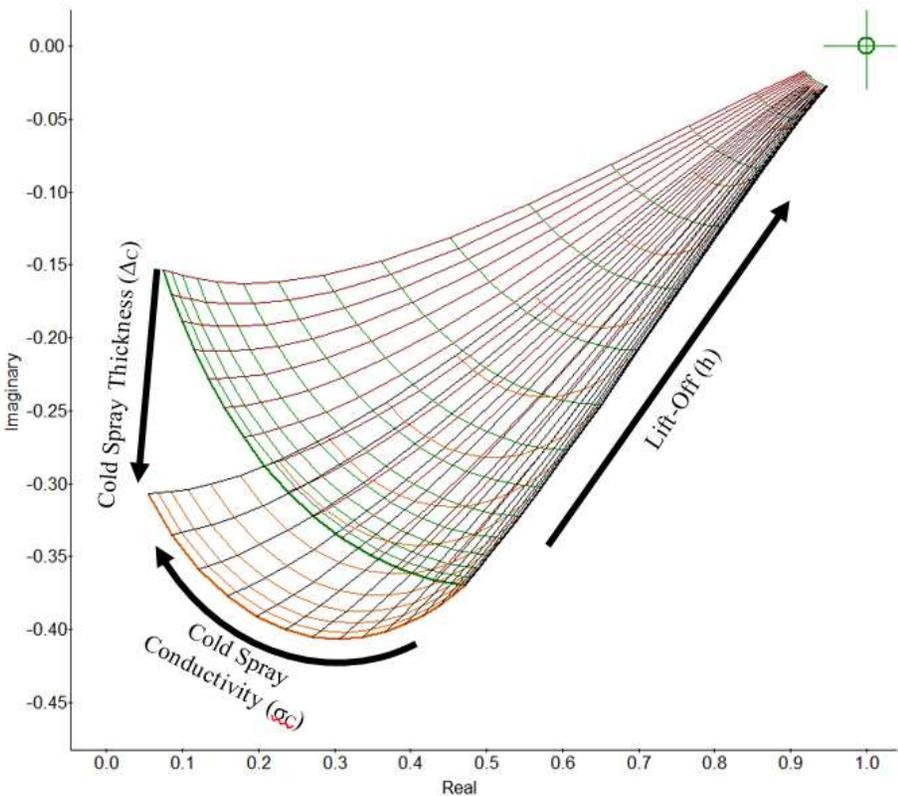
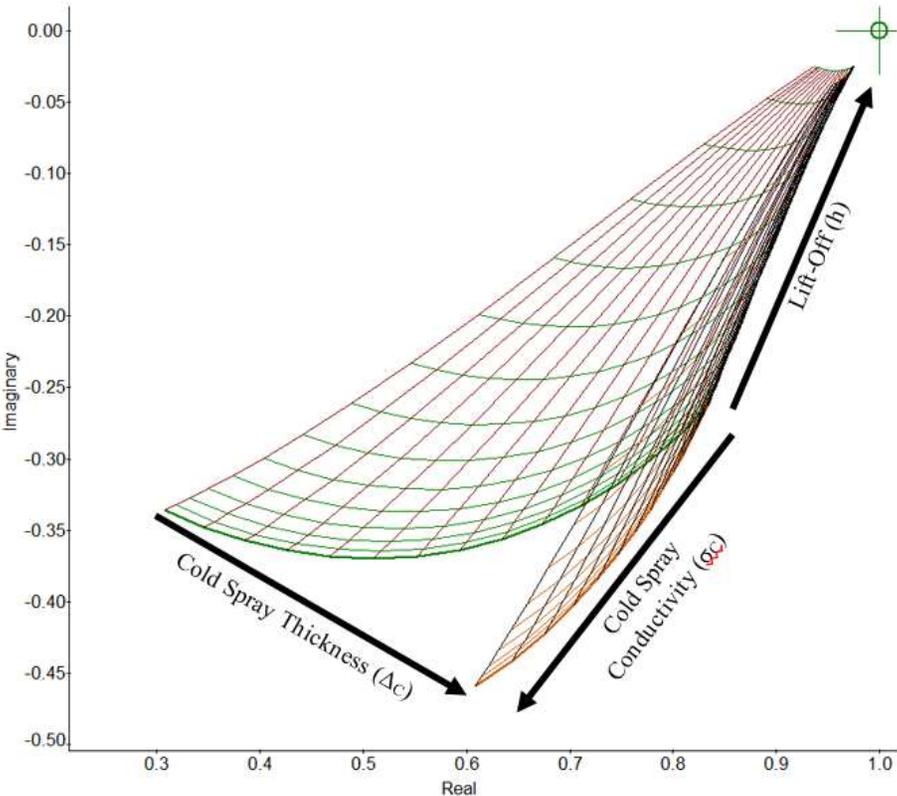
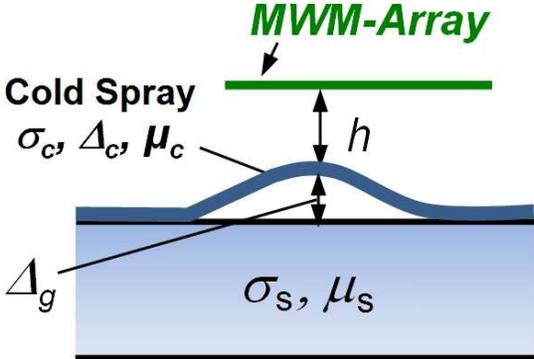
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- A single frequency can be used to estimate two properties
  - Conductivity / Lift-off
  - Permeability / Lift-off
- Multiple frequencies are required to estimate three or more properties
  - Typical properties:
    - Substrate conductivity
    - Cold spray conductivity
    - Cold spray thickness
    - Lift-off
  - Other properties:
    - Substrate permeability
    - Substrate thickness
    - Gap
    - Cold spray permeability



# Aluminum Cold Spray on Aluminum

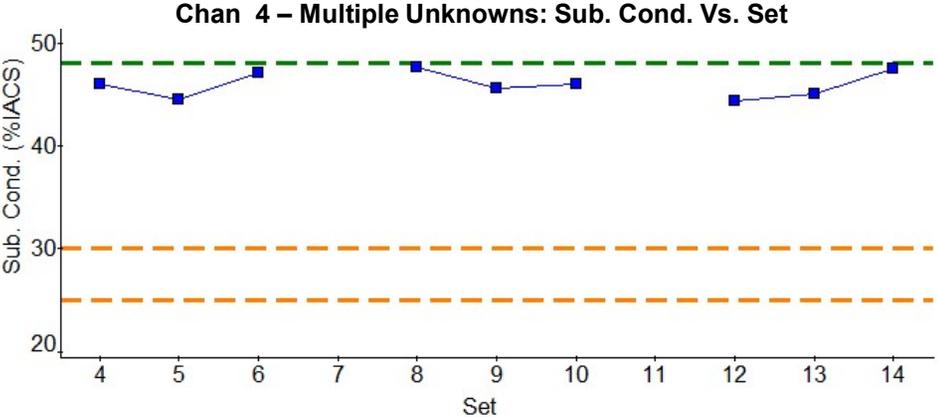
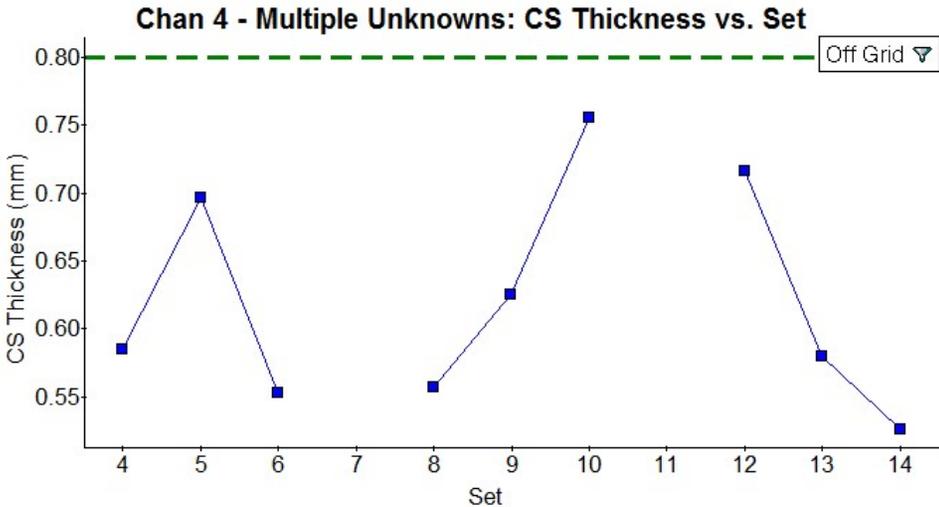
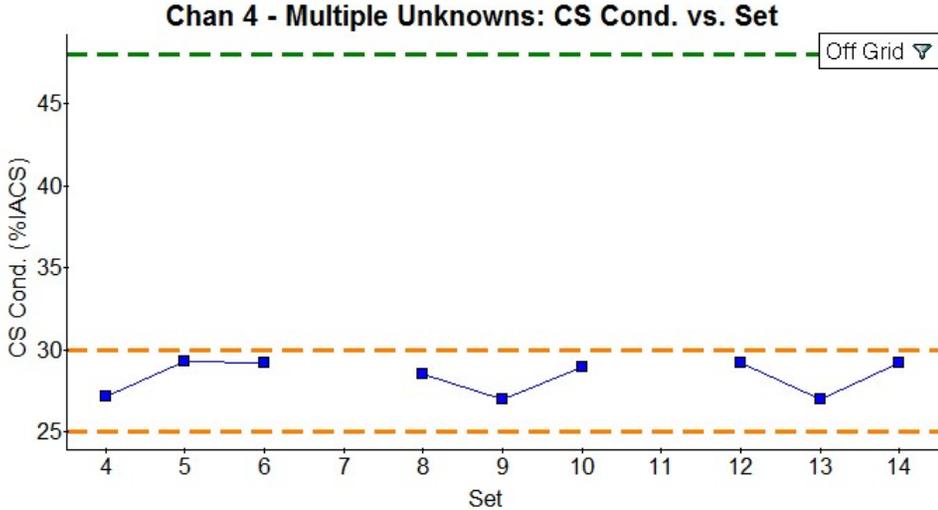
- Three frequency method to estimate:
  - Substrate conductivity
  - Cold spray conductivity
  - Cold spray thickness
  - Lift-off



# Aluminum-on-Aluminum Cold Spray (CSAT 2021)

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- Conductivity of the substrate (~49% IACS) is significantly different from the conductivity of the cold spray coating (25% - 30% IACS). This difference enables independent measurement.
- 6061 cold spray on a 6061 substrate
- Thickness was measured to be 0.8mm by the vendor
- Samples produced by Solvus Global; Access to samples provided by Mississippi State

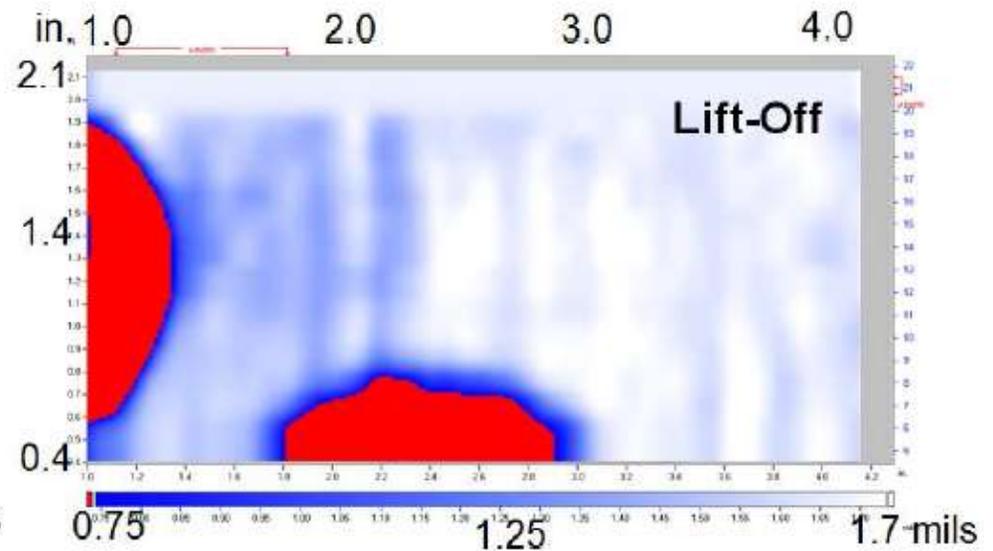
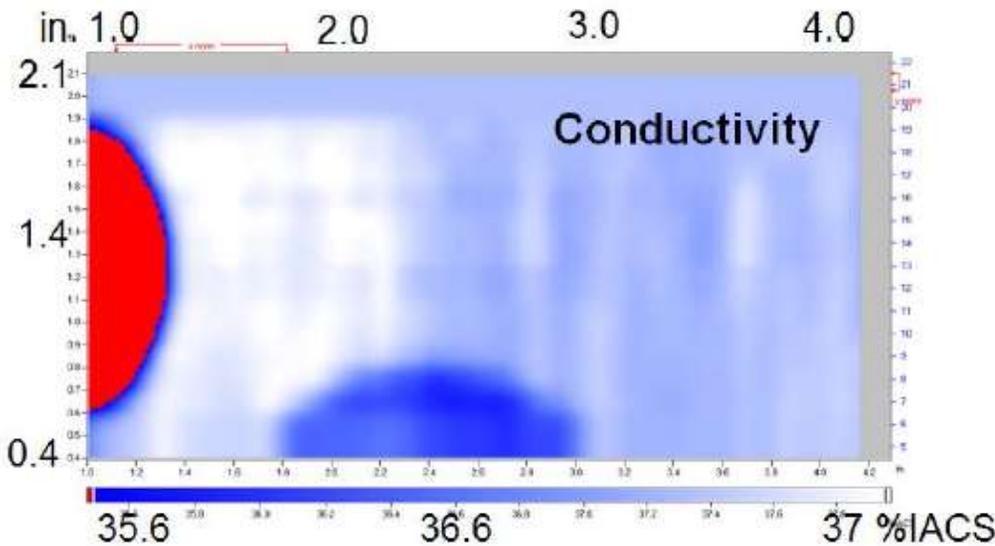


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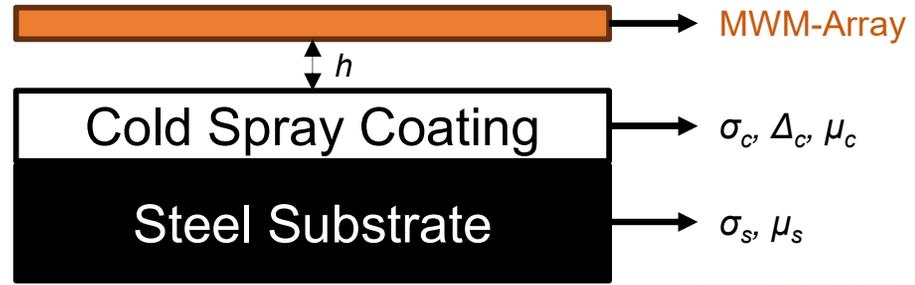
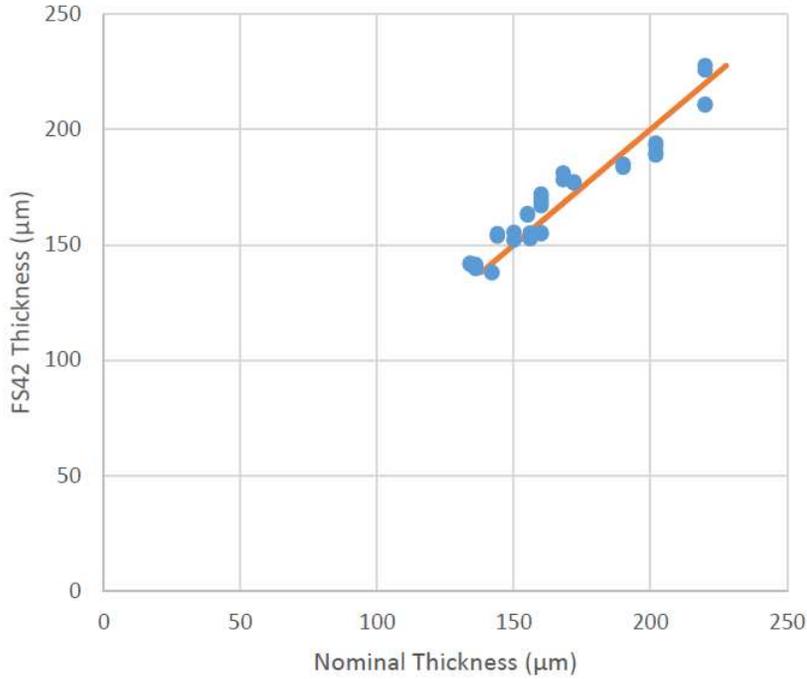
# Disbonds

- Shows sensitivity to simulated disbonds
- Note: In this case, material was removed to simulate the disbond. Tight disbonds with no gap will be difficult to detect.

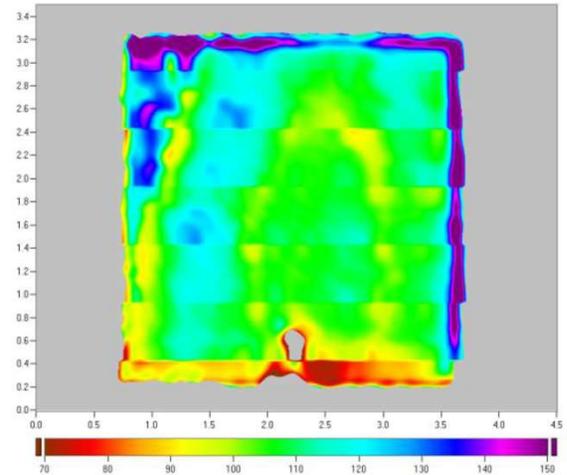


# Non-ferrous Metal Cold Spray on Steel (CSAT 2021)

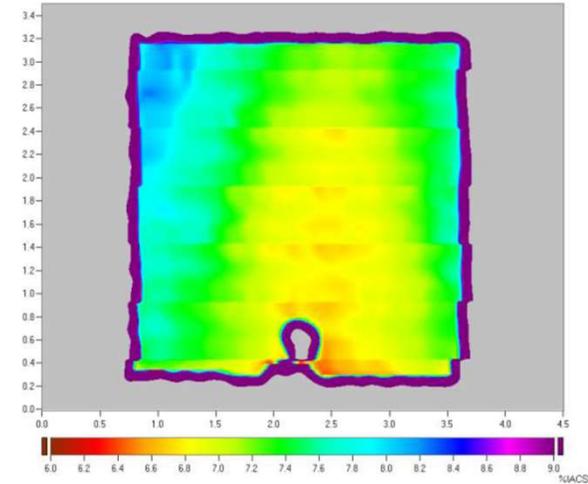
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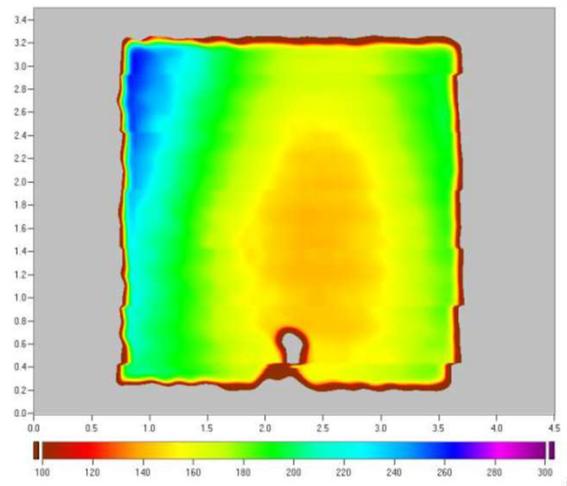
Multiple Unknowns Permeability scan



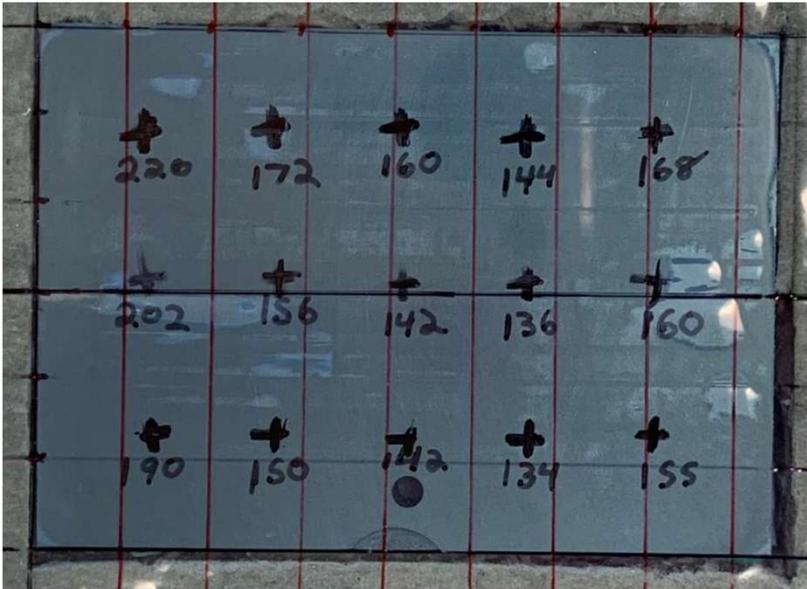
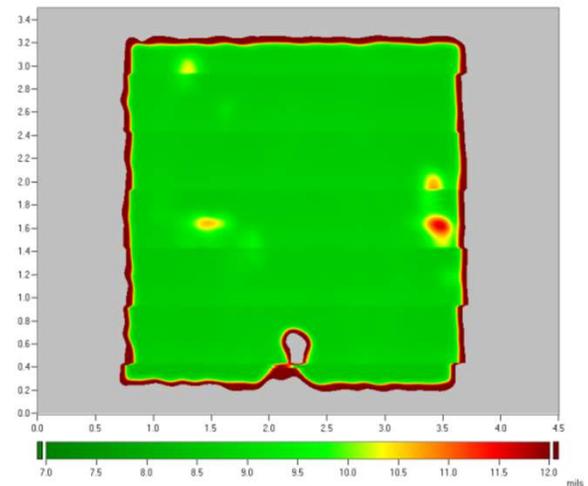
Multiple Unknowns Conductivity scan



Multiple Unknowns Thickness scan

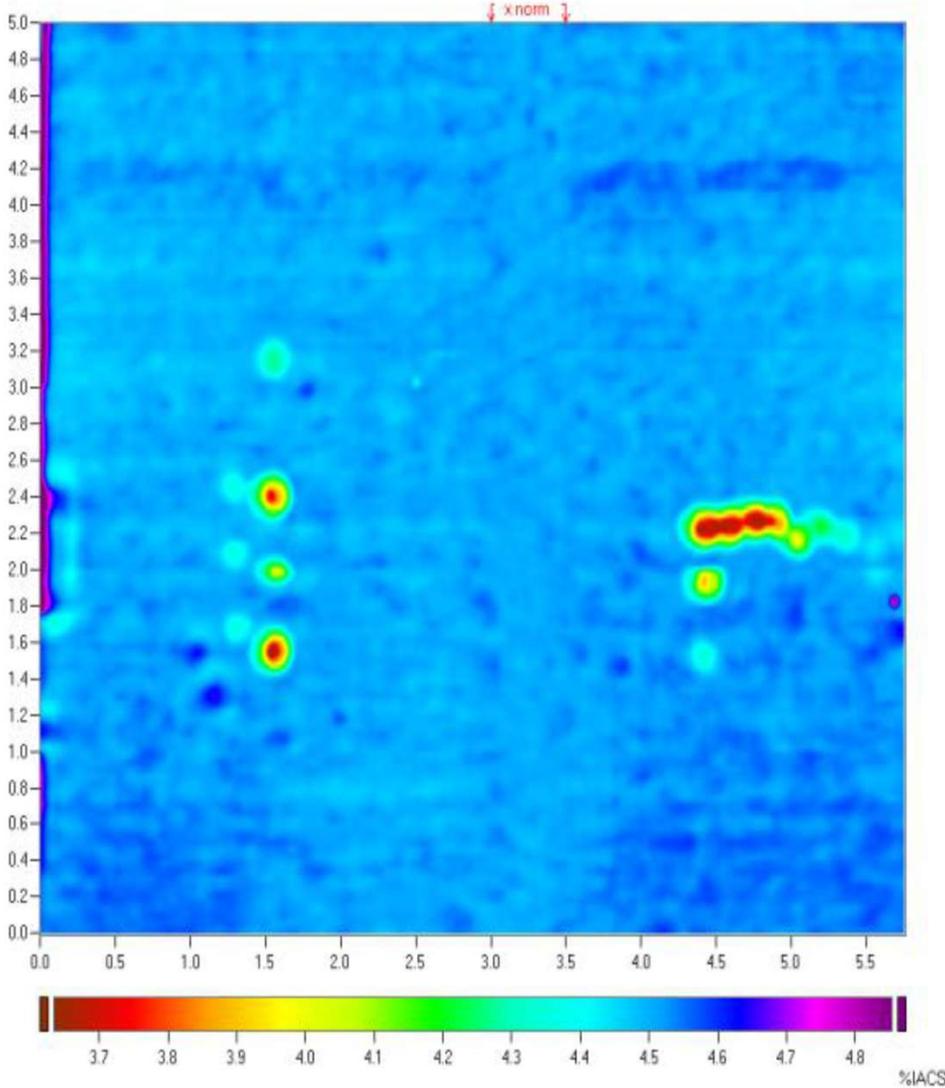
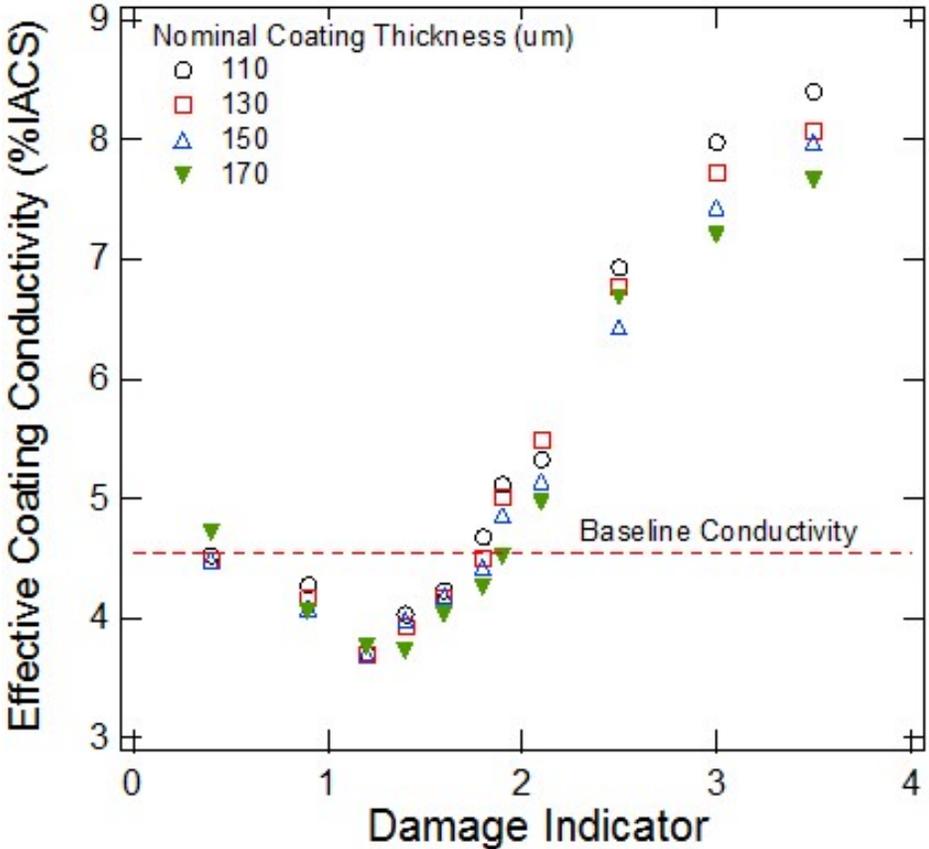


Multiple Unknowns Lift-off scan

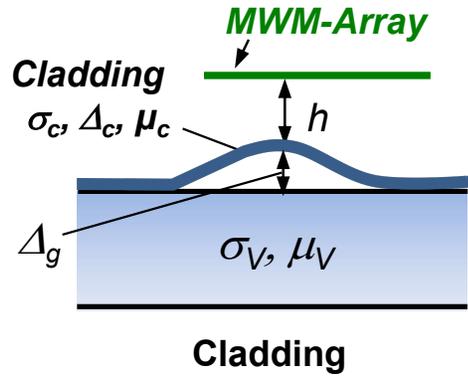


# Damaged in Cold Spray Layers (CSAT 2021)

- Properties such as cold spray conductivity can be correlated with damage conditions



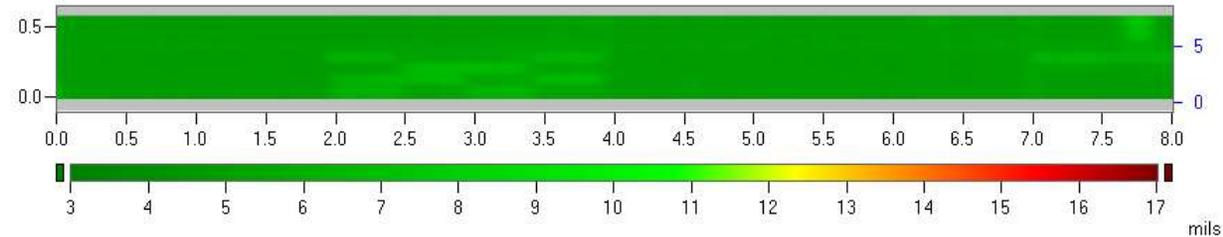
# Inspection through Cold Spray: Cracks



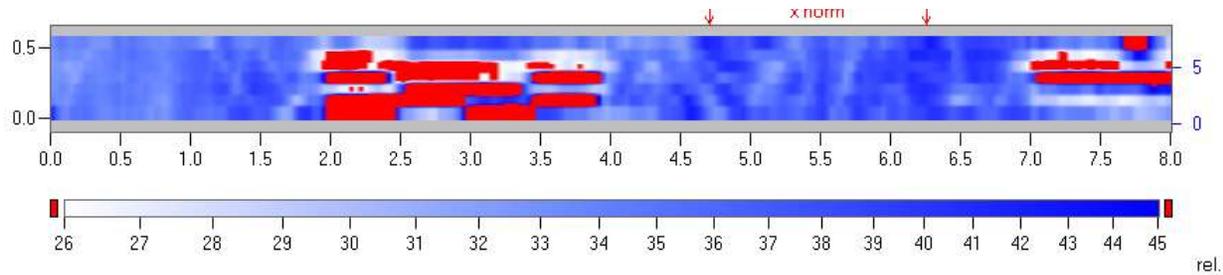
1 Shim



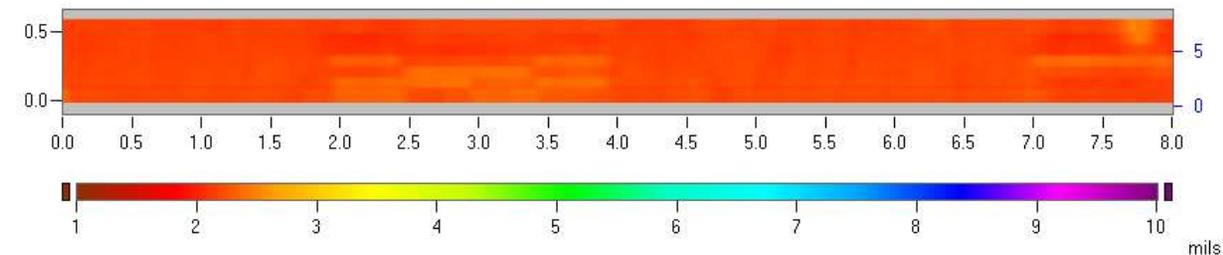
Lift-off



Permeability (rel)



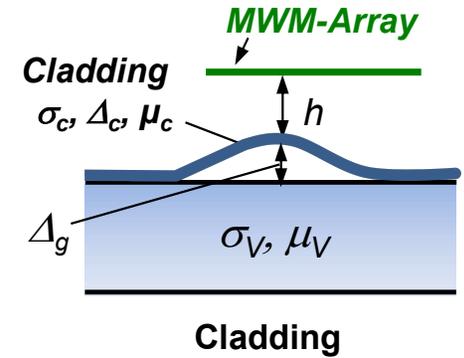
Thickness (mil)



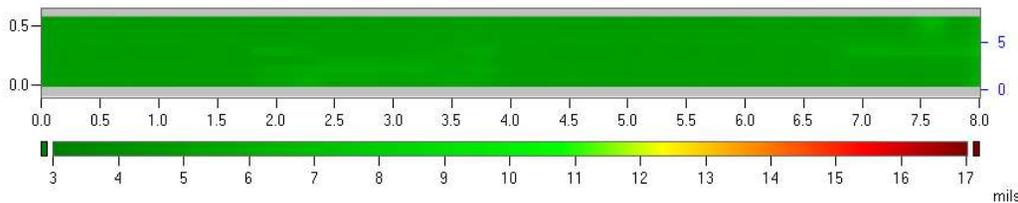
# Multiple Properties: Cracks through Metal Coating

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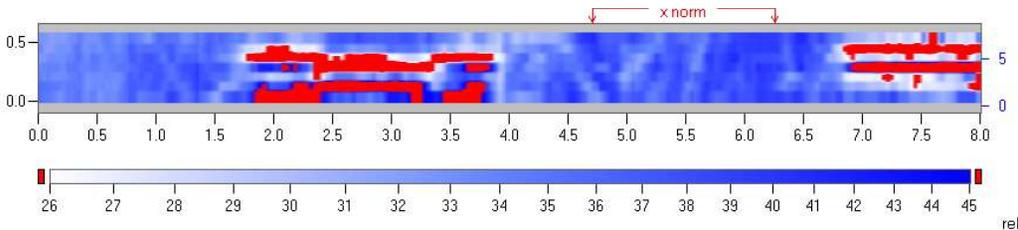
- Varying coating thickness yields similar steel substrate permeability damage



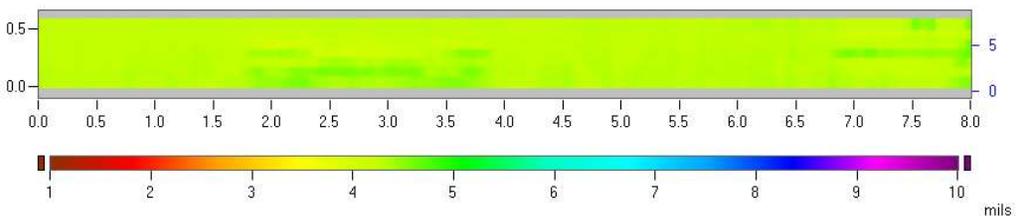
Lift-off



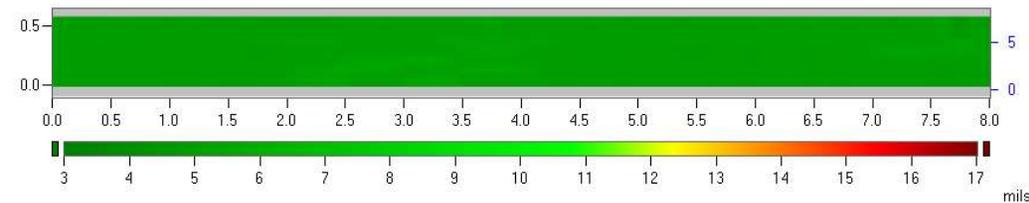
Permeability (rel)



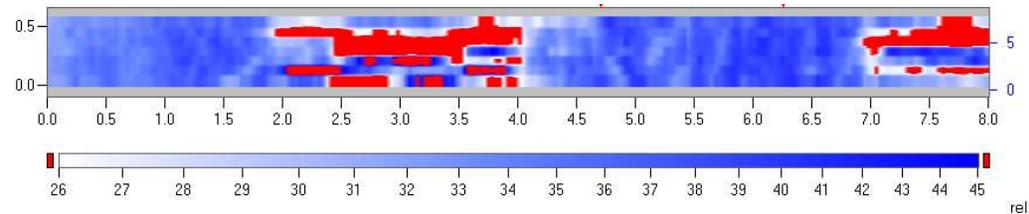
Thickness (mil)



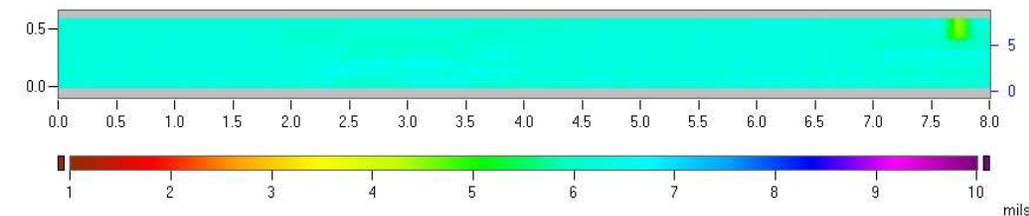
Lift-off



Permeability (rel)

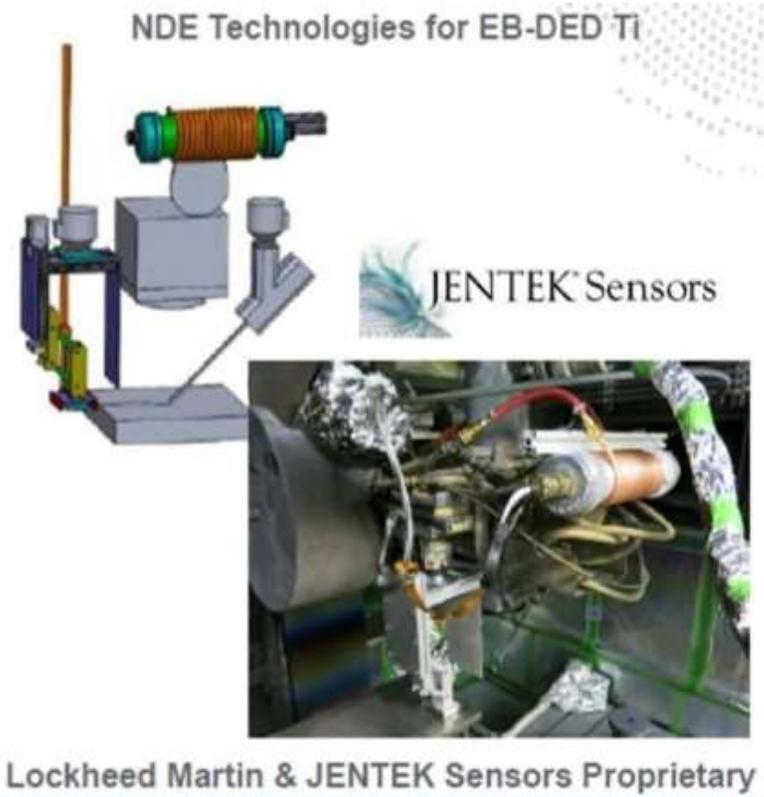


Thickness (mil)



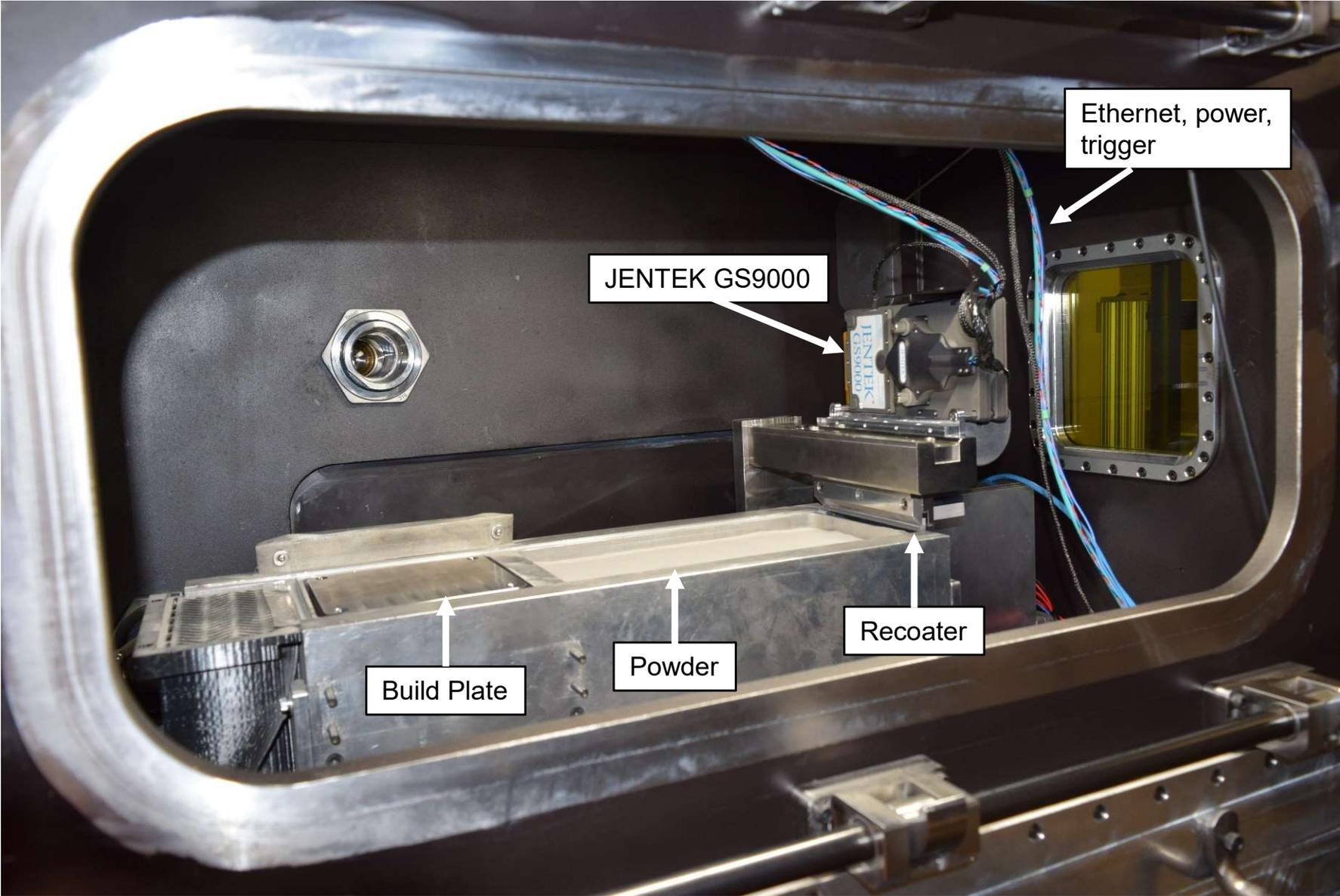
# In-Situ EC Array Sensing for EB-DED

- JENTEK Project for Electron Beam Direct Energy Deposition (EB-DED)
- Slide from public Lockheed Martin presentation



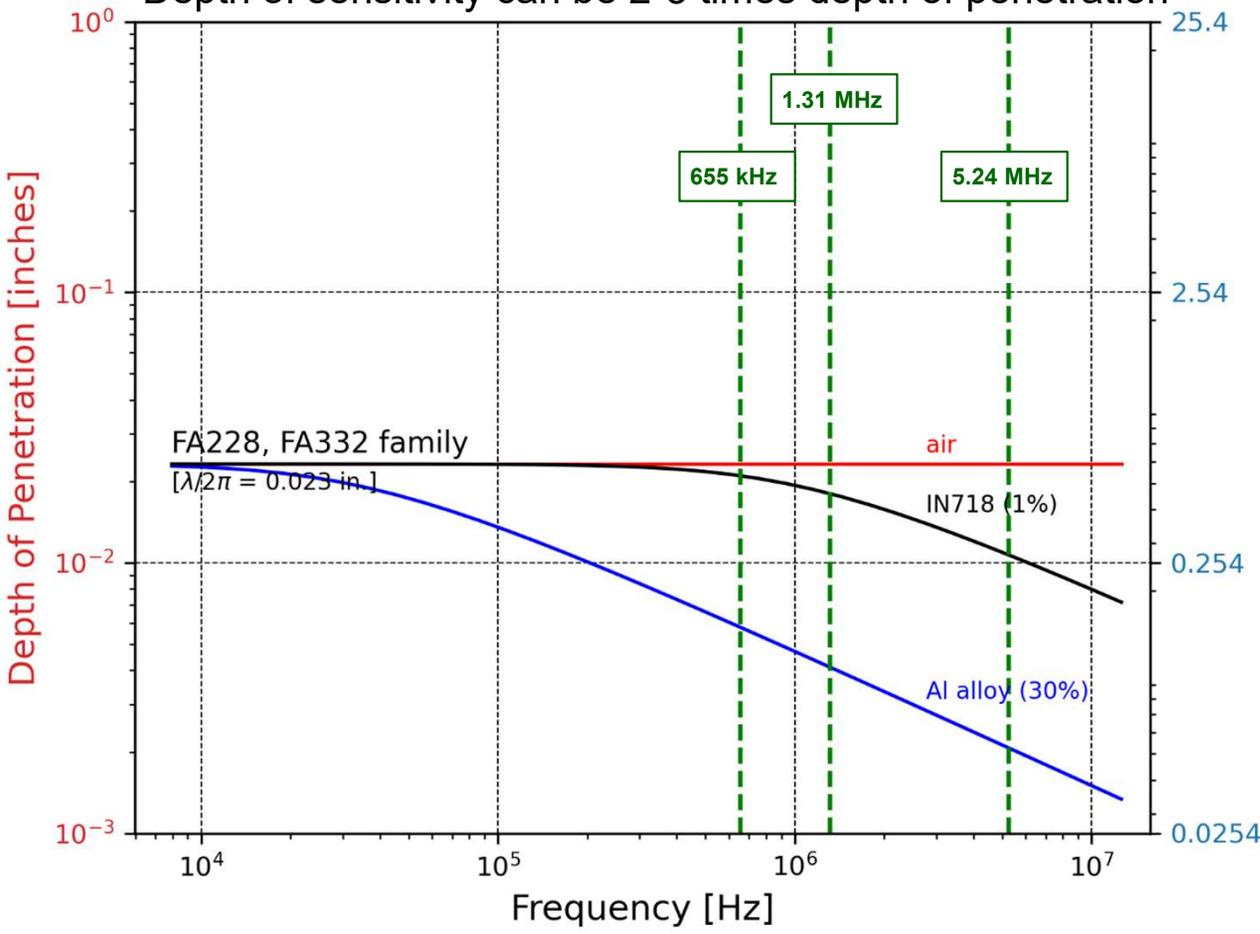
# DART 2 System with GS9000 Installation

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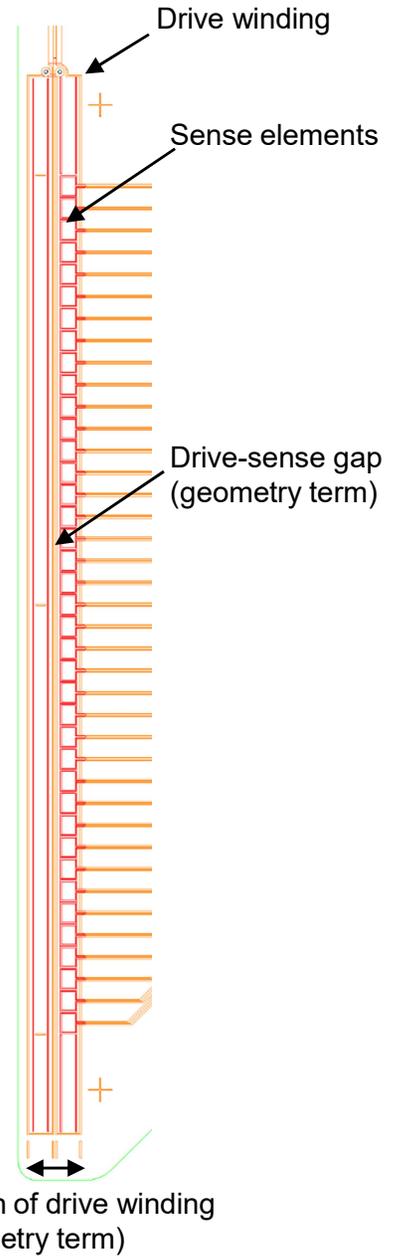
# Depth of Penetration (Build Frequencies)

- Magnetic field decay ~ exponentially with distance away from drive winding
- Decay rate in material determined by material properties and sensor geometry
- Depth of sensitivity can be 2-3 times depth of penetration



**Geometry limited**  
Affects the lift-off that can be tolerated

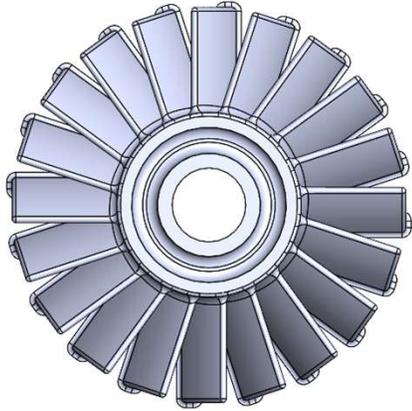
**Skin depth limited**  
Primary factor affecting field penetration into the metallic material under test



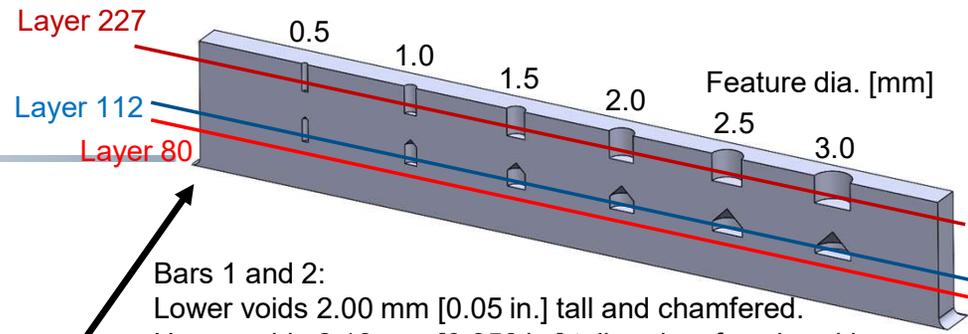
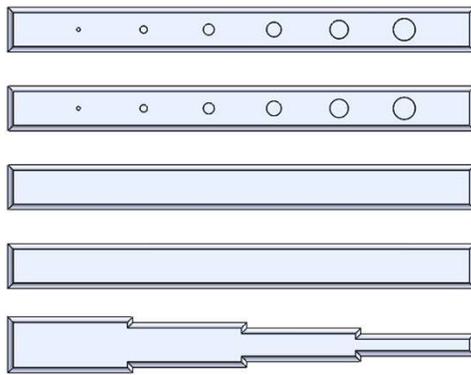
# Build Geometry Model Details

249-layer build of Inconel 718.  
Bars are 10 mm [0.394 in.] tall.

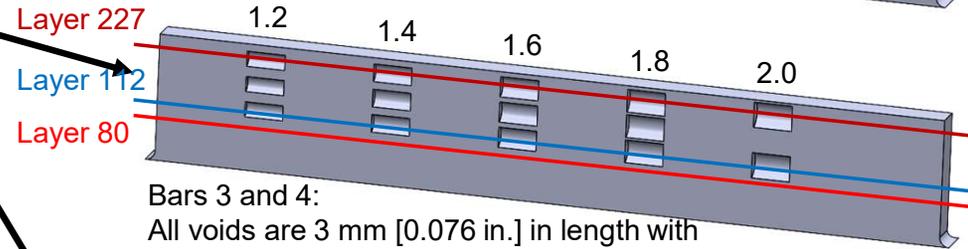
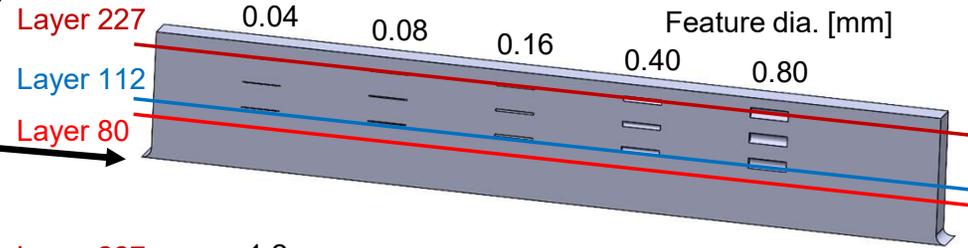
Example complex shaped part



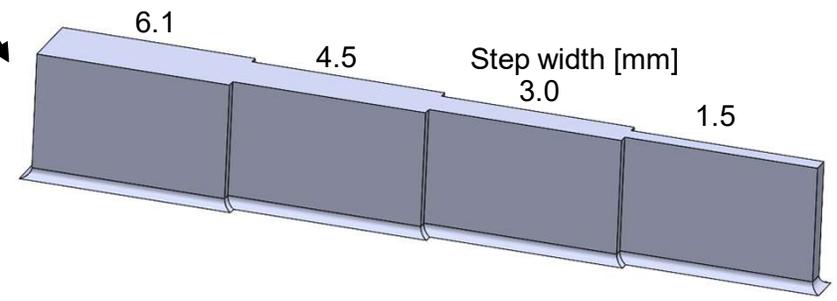
Each bar is 62 mm x 4.6 mm  
[2.44 in x 0.180 in.]



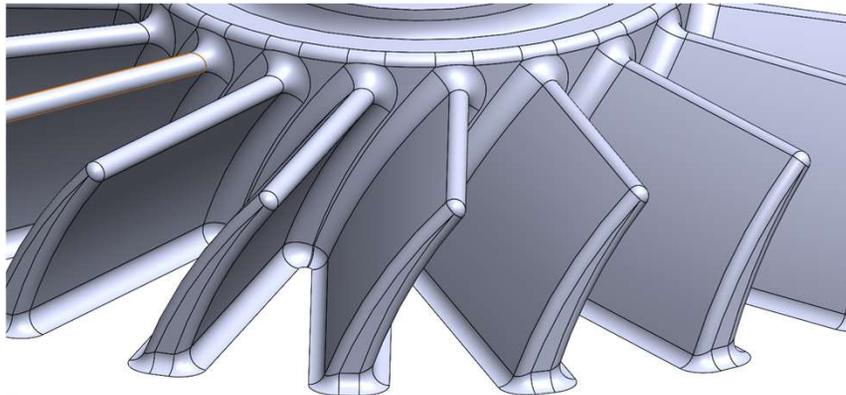
Bars 1 and 2:  
Lower voids 2.00 mm [0.05 in.] tall and chamfered.  
Upper voids 2.19 mm [0.056 in.] tall and surface breaking.  
2 mm [0.05 in.] solid metal between upper and lower voids.



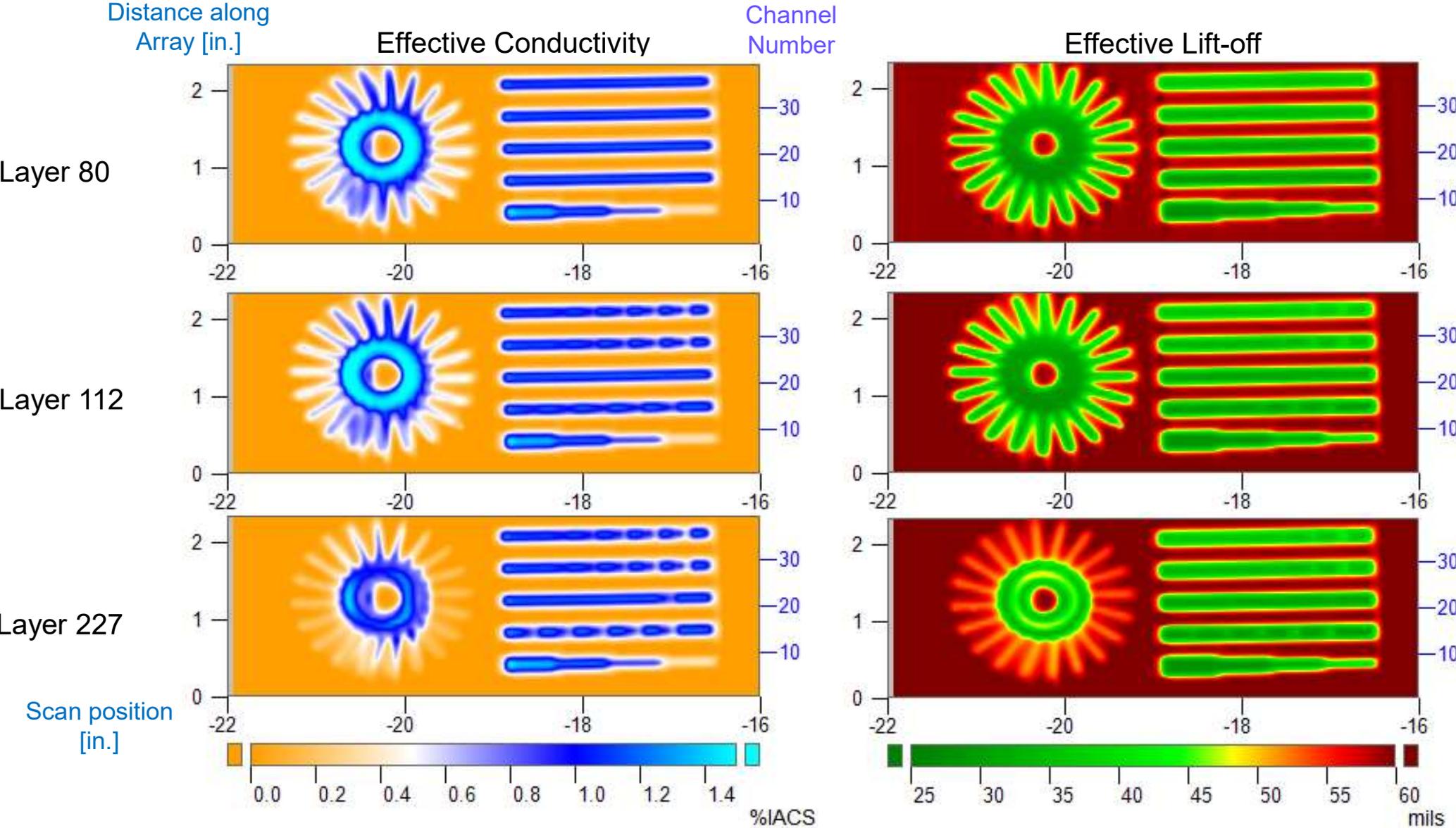
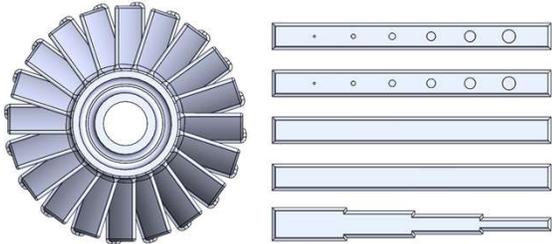
Bars 3 and 4:  
All voids are 3 mm [0.076 in.] in length with  
7 mm [0.180 in.] spacing.



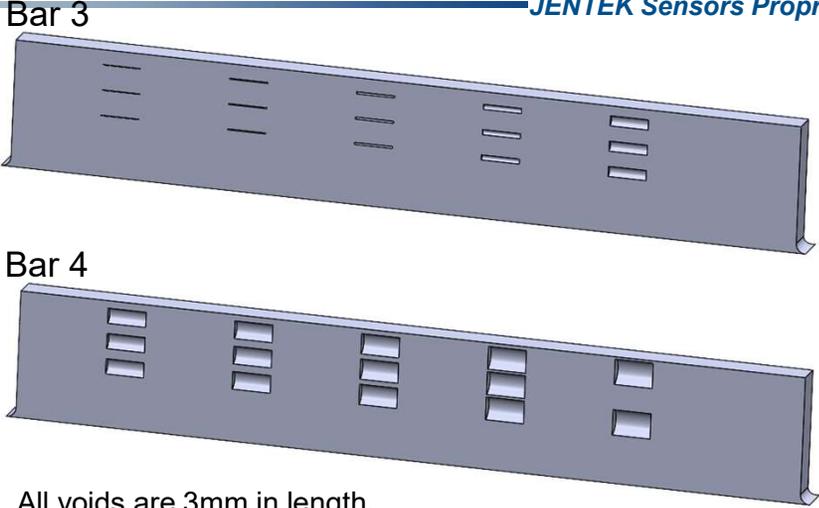
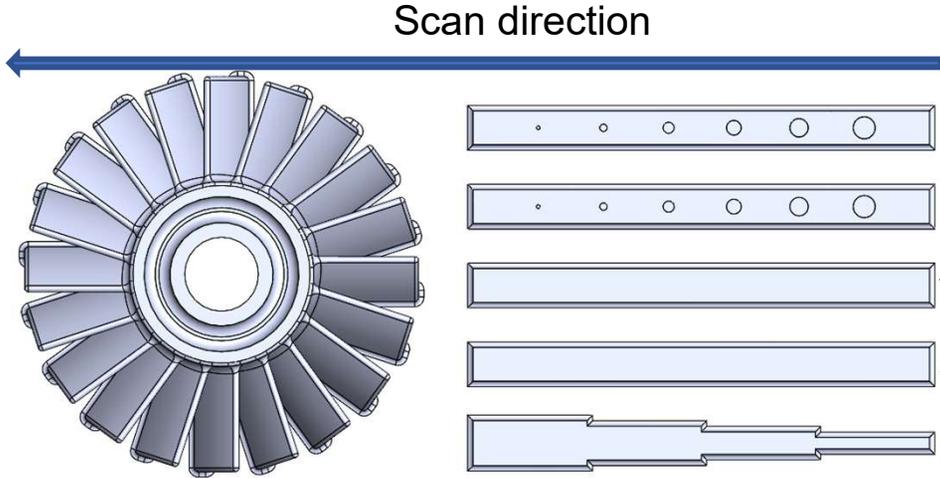
Bar 5: stepped taper. Each step is 15.5 mm [0.609 in.] long.



# Example 5.24 MHz, Property Data



# B-Scan type plots of responses

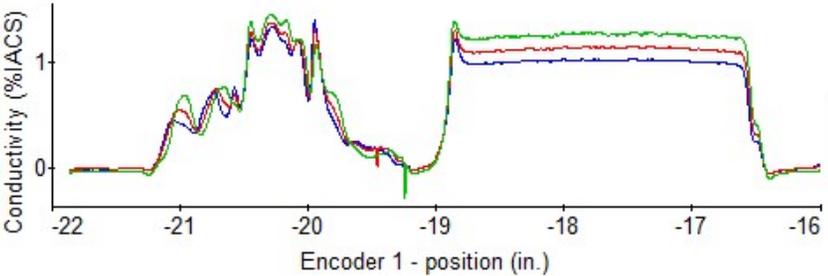
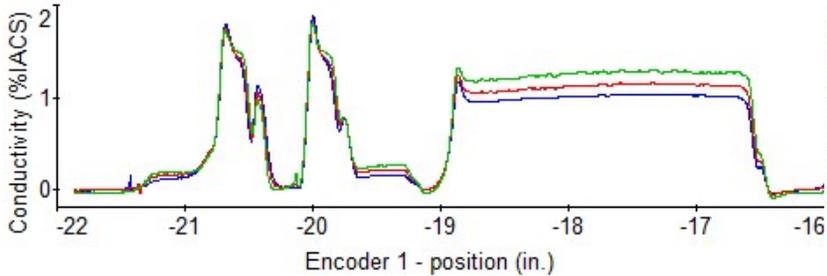


All voids are 3mm in length.  
 Feature diameters in microns:  
 800, 400, 160, 80, 40 for Bar 3  
 2000, 1800, 1600, 1400, 1200 for Bar 4

Bar 3: Channel 22

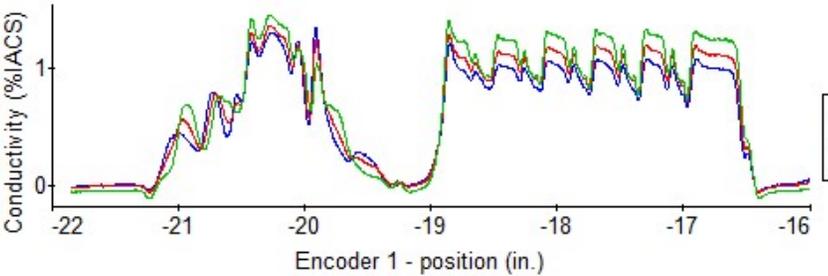
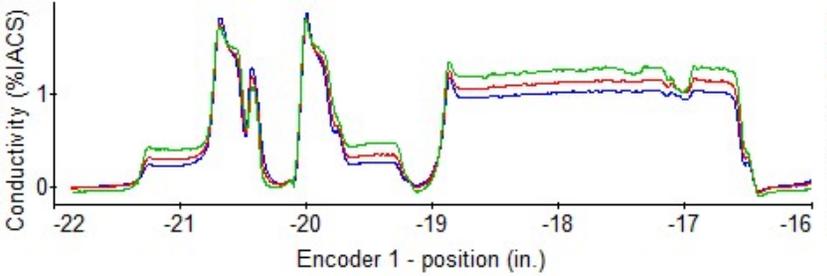
Bar 4: Channel 15

Layer 80



Scan 80 at 655.3 kHz  
 Scan 80 at 1.310 MHz  
 Scan 80 at 5.242 MHz

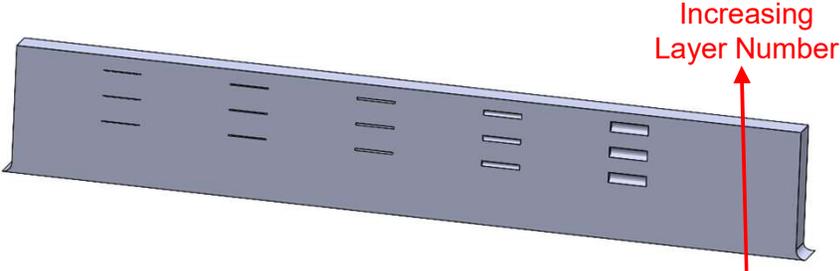
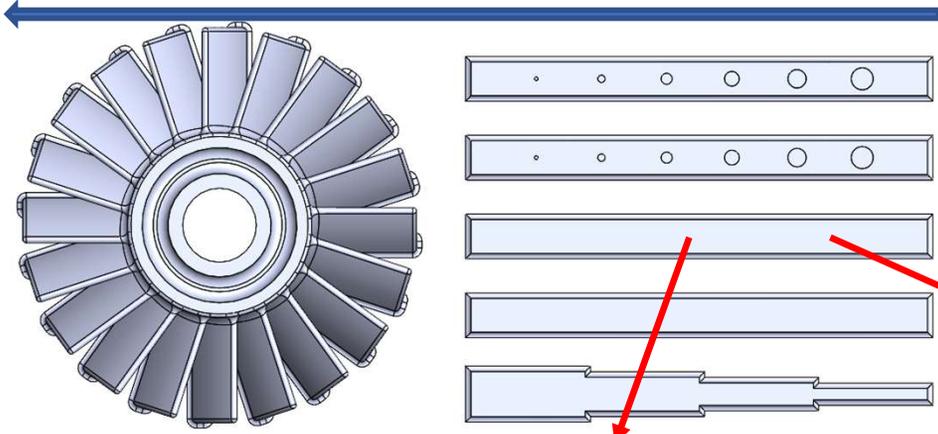
Layer 120



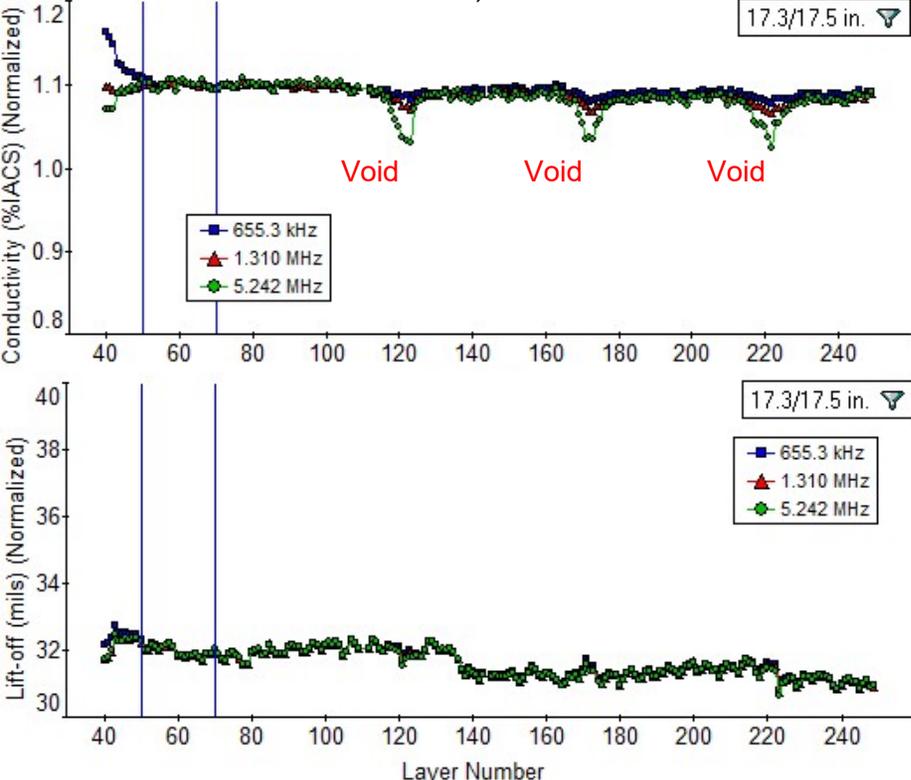
Scan 120 at 655.3 kHz  
 Scan 120 at 1.310 MHz  
 Scan 120 at 5.242 MHz

# B-Scan responses in z-direction

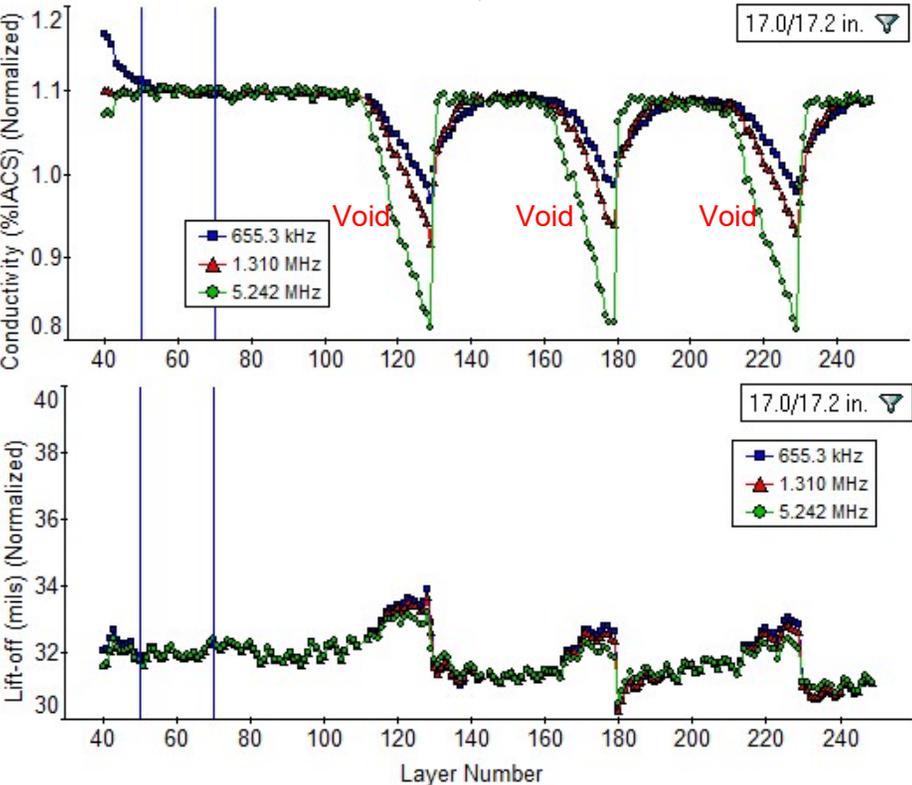
Scan direction



Bar 3: Channel 22, 0.4 mm dia. voids



Bar 3: Channel 22, 0.8 mm dia. voids



# Preliminary Example rendering of MWM-Array data

- Used MWM-Array conductivity estimates to create 3D rendering of components



Finished components (top) and MWM-Array rendering (bottom)



# Future Work

- Cold Spray
  - Implementations/automation for targeted customer assets
  - Increase available simultaneous frequency number from 3 to 5
  - Improve fieldable system durability
  - Expand capability for detection and identification of coating/substrate damage
- Laser Powder Bed Fusion
  - Larger channel count MWM-Arrays
  - Larger channel count impedance instrumentation
  - Improve ML/AI & preferred direction filtering support
  - Machine agnostic installation
  - Improve large data file handling
  - Rapid data analytics including multithreading
- Other AM Implementations
  - Electron Beam Directed Energy Deposition (EB-DED)
  - Blown Powder DED
  - Other wire DED (WAAM, laser)
  - Additive Friction Stir Deposition (AFSD)