JENTEK Sensors

A Hand-Held Instrument for both Eddy Current Arrays (ET) and Magnetoresistive (MR) Arrays

AA&S

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***jET*®**
for ET Arrays

& MR Arrays

What is next for Eddy Current Testing of Structures?

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- More ***accessible*** ET array tech
- More ***portable*** handhelds for arrays
- More ***adaptable*** by operators
- More ***predictable*** performance
- Plus
  - Reduced false indication rates
  - Less training requirements
  - Inspection through paint and other coatings
  - Reliable 2nd layer crack and corrosion detection
  - On-aircraft inspection in difficult to access areas
  - Support for complementary installed sensors
  - Reliable inspection of cold worked holes
  - Improved manufacturing and sustainment inspections for Alcad coatings, cold work quality, and additive manufactured part inspection for porosity, metallurgical condition, geometric feature dimensions, and cracks.

Challenges that must be met

Presentation Outline for Hand-Held jET® Applications

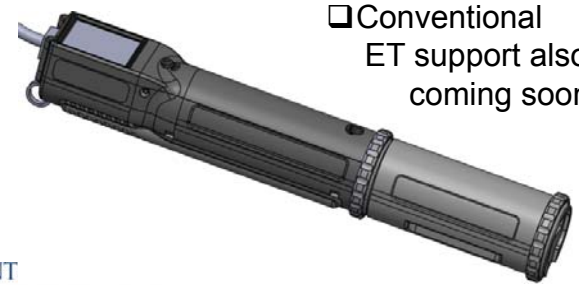
jET MR-Array Module Not Yet Available Unanticipated Delay

- Hand-held jET with ET and MR MWM-Arrays ►
  - jET configurations and end-effectors
  - MWM-Array sensors for jET
  - DOP Charts for varied drive-sense gap
  - Kits and methods for easy adaptation to new applications
  - **Introducing jAI (JENTEK A.I.)**
- Surface breaking crack detection (see PS&S Presentation)
  - Rescaling of crack response with variable liftoff, Grid Methods
  - Air calibration and Reference Calibration (per ASTM E2884)
  - Shaped filters used for improved POD and false indication performance
- Hidden corrosion imaging (first and second layer)
- Subsurface crack
  - 2-D and 3-D Modeling
  - HyperLattice Multivariate Inverse Method (MIM).
  - Landing gear inspection thru coatings
- SHM (permanently installed eddy current sensors)

Hand-Held Instrument for both ET and MR Arrays

jET

- ❑ < 1 pound (without laptop)
- ❑ 3 frequencies simultaneously
- ❑ 7 Parallel Channels
- ❑ 10x improved Signal-to-noise
- ❑ >1000 samples per second per channel
- ❑ Support for MWM-Array ET
  - ❑ MR-Array support soon
  - ❑ Conventional ET support also coming soon



Introducing jAI (JENTEK Artificial Intelligence)

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Modeled Deterministic Part

- Sensor design for predictable response using iterative model-based optimization
- Precomputed sensor response databases for model based Multi-variate Inverse Methods (MIMs)
- Instruments, such as the jET, designed to deliver data that is suitable for MIMs:
  - Simultaneous frequencies
  - Simultaneous Real and Imaginary transimpedance parts
  - Parallel channels
  - Accurate transimpedance with very low signal to noise
  - High data rates for rapid scanning
- Very rapid data analysis

Unmodeled Deterministic &Stochastic Part

- After removal of deterministic part (using model based MIMs), remaining data can be more appropriately processed using traditional AI pattern recognition or filtering methods.
- Shape filters (like wavelet analysis)
- Libraries of signatures for selective shape filtering based on apriori or logically determined metadata/information.
- Other pattern recognition, that takes advantage of
  - Simultaneous frequencies
  - Simultaneous Real and Imaginary transimpedance parts
  - Parallel channels
- **User AI guidance for new apps (in early development)**

Sensor Kits for adaptation to new applications

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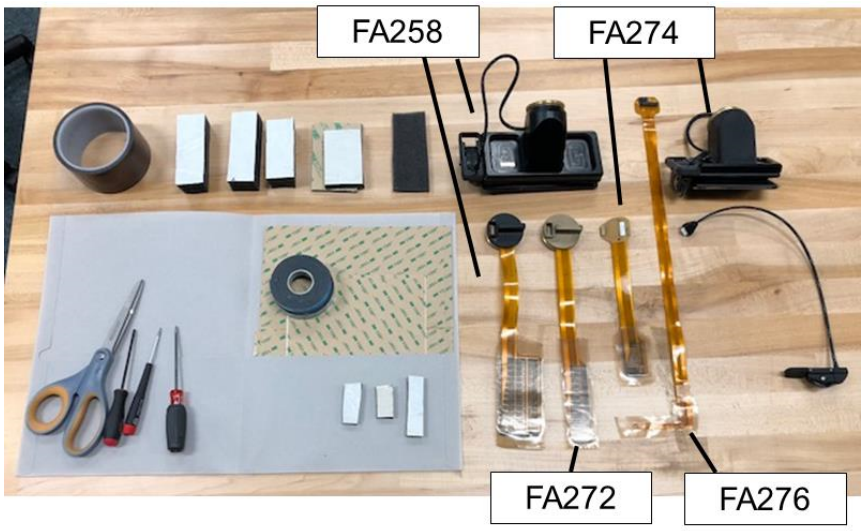

Depth of penetration comparison

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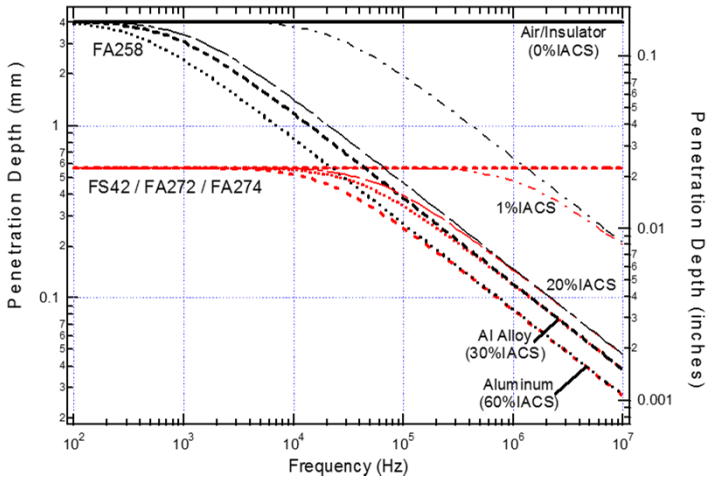
FA258 at lower frequencies (~100 kHz) can provide improved sensitivity to subsurface flaws in the Ti-6Al-4V alloys compared to FA272/FA274 due to larger drive sense gap.



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FA258 Depth of Penetration

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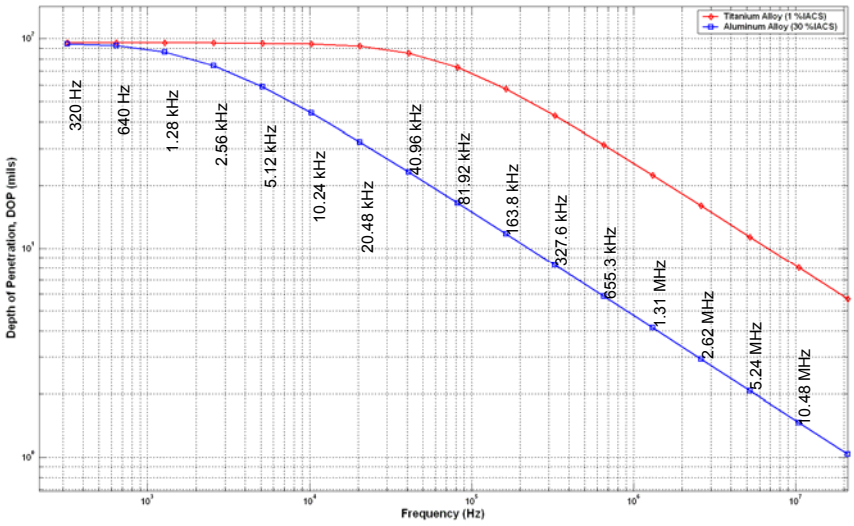

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Historical Data: 2002 Hidden Corrosion Imaging on Flight Deck Chine Plate
(older 7000 series GridStation system, using MWM-Array with 0.1 in. sense elements)

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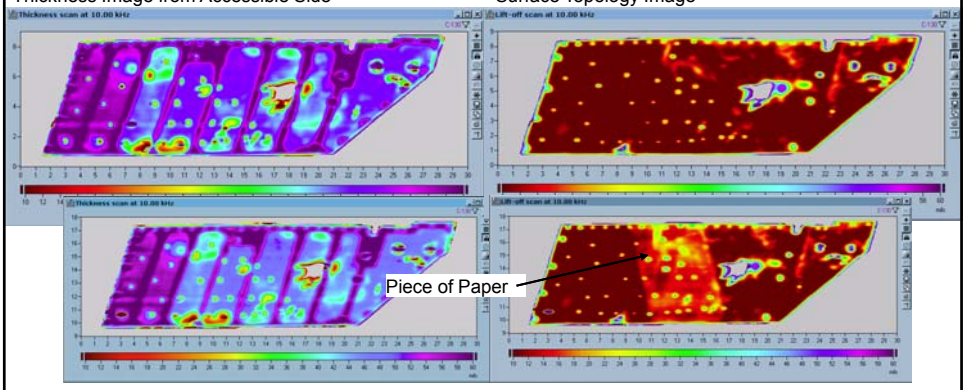
Inaccessible Side

Accessible

Thickness Image from Accessible Side

Surface Topology Image



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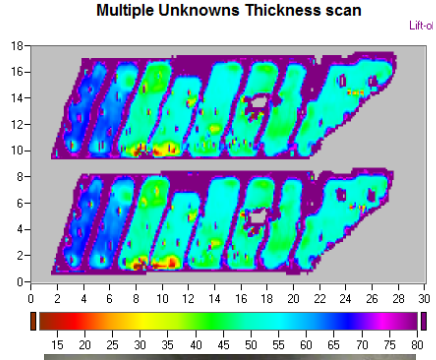
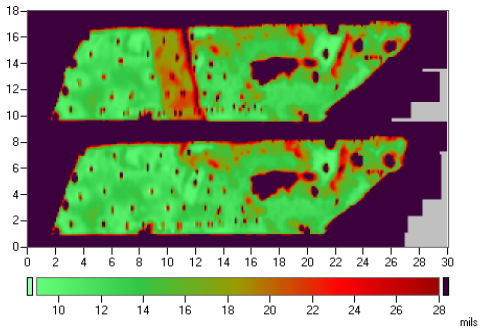
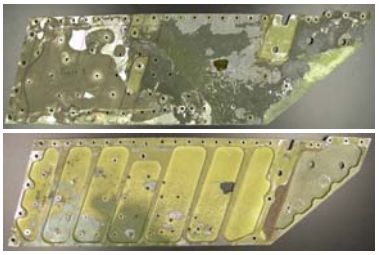
New 2018: Corrosion Imaging with jET (using FA258 MWM-Array with 0.25 inch sensing elements, much faster with improved signal to noise)

Multiple Unknowns Thickness scan



Multiple Unknowns Lift-off scan





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2018 Data: Corrosion Imaging with jET (faster, improved signal to noise)

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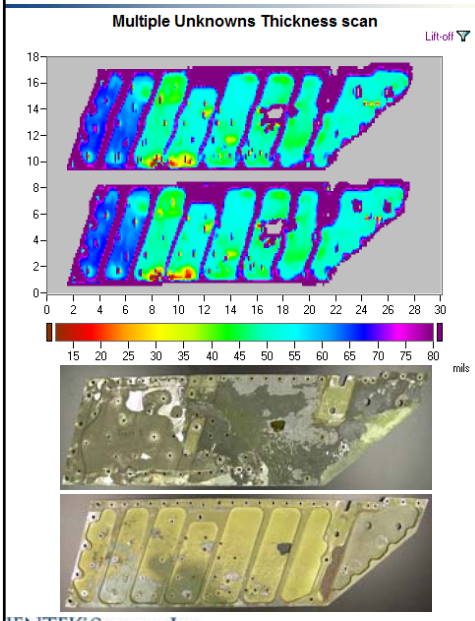

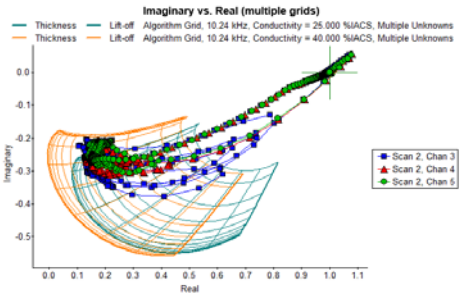

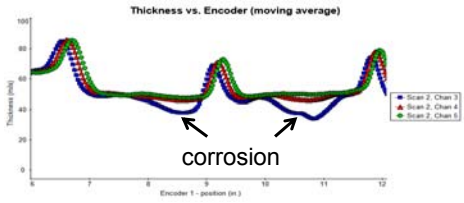

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Historical 2002 Data: Buried Corrosion in Lap Joints (7000 Series System), jET expected to deliver same results with 3 frequency, perhaps

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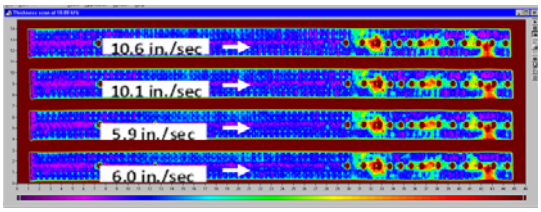
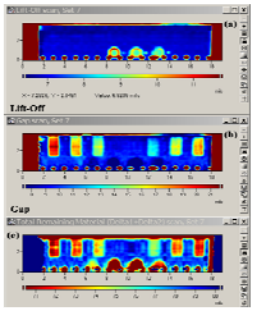
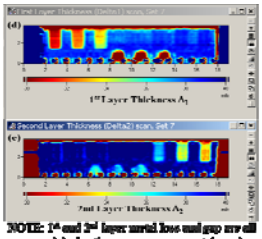
2-unknowns, single frequency with 7000 series

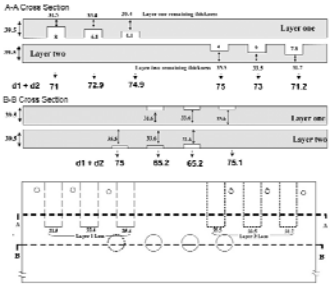


4-unknowns, 6 frequency, with 7000 series





NOTE: 1st and 2nd layer metal loss and gap are all measured during the same scan, accurately and independently, using a six frequency MWM-Array excited at 0.5 in./sec. scan speed with a 3.7 in. wide scan path. This capability is not offered by any other system.



Air Force material loss calibration standards as configured for previous MWM-Array demonstrations; dimensions in mils (1 mil = 0.001 in.).

The rectangular milled-out regions show up in the correct layers (1st or 2nd), the circular regions also show up in the correct layers.

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Subsurface crack modeling option

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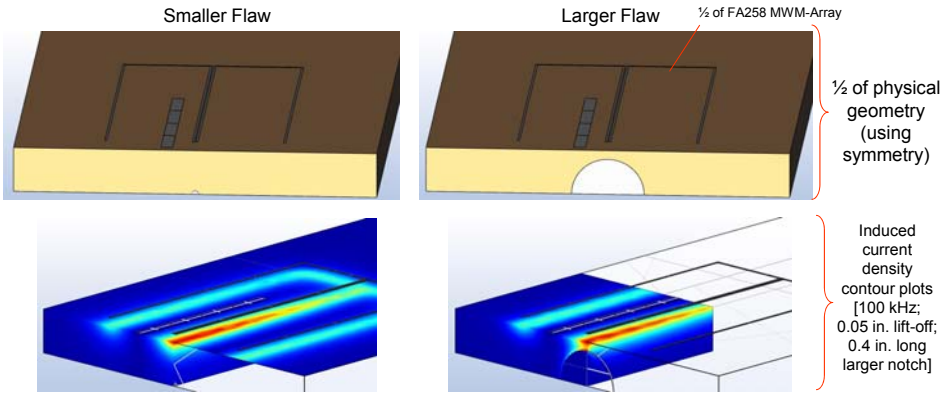
- Standard 2D models for sensor response
  - Use JENTEK Grid Methods to obtain conductivity values for several frequencies
  - Higher frequencies will provide a measure of near surface region conductivity
  - Lower frequencies provide higher sensitivity to subsurface cracks
- 3D models to better correlate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



HyperLattice Multivariate Inverse Methods (MIMs)

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- Surface breaking flaws – Two unknown Grid Method for conductivity/liftoff at single frequency
  - Rescaling of crack response with variable liftoff
  - Enables air calibration
  - Modified reference calibration used to tune air-cal for improved crack detection and surface anomaly suppression
  - Shaped filters used for improved POD performance and false alarm suppression
- Subsurface crack detection – HyperLattice Multivariate Inverse Method (MIM). Need Lattices for three unknown method to correct for variable layer thickness.

Rescaling of Conductivity Response *(not shape filtered)*

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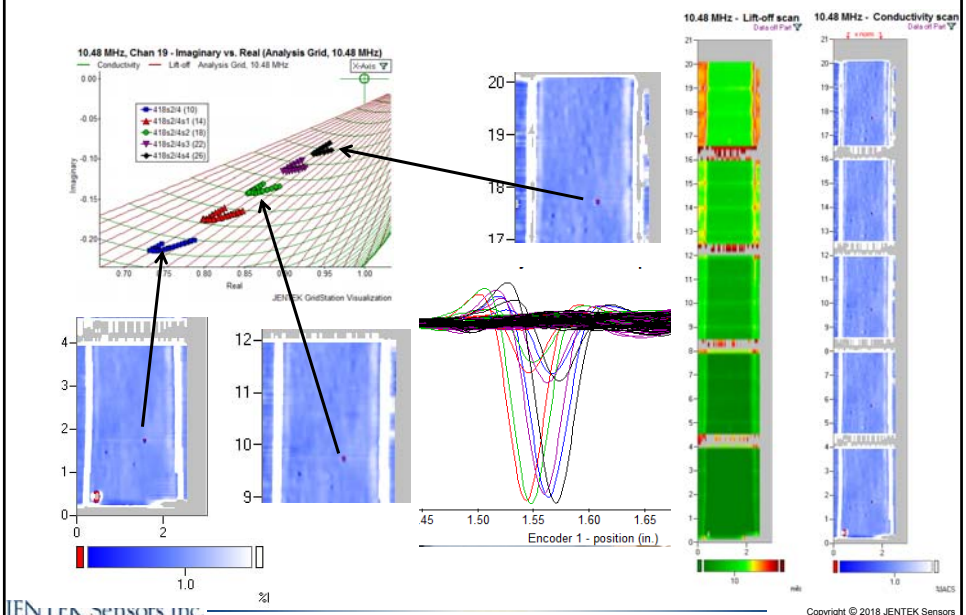

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Rescaling of Conductivity Response *(not shape filtered)*

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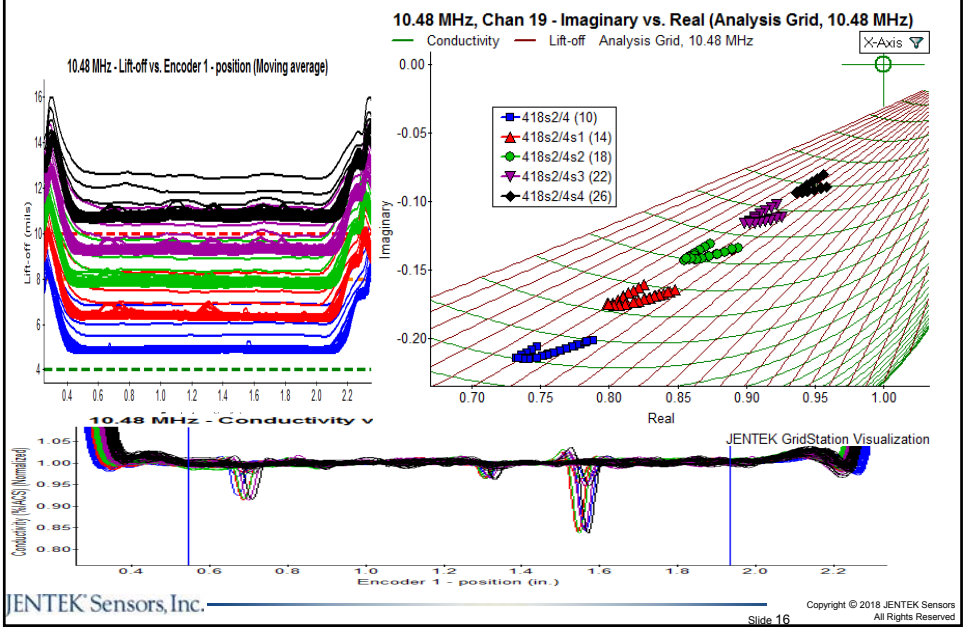

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Titanium and Aluminum Alloy Inspection after Air Calibration, Using GridStation Software

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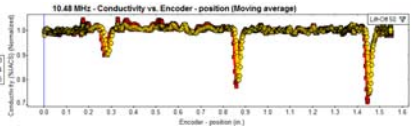
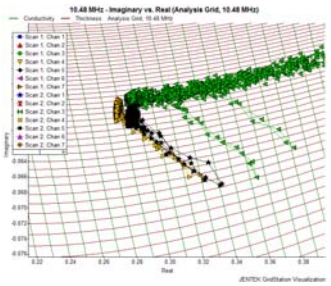
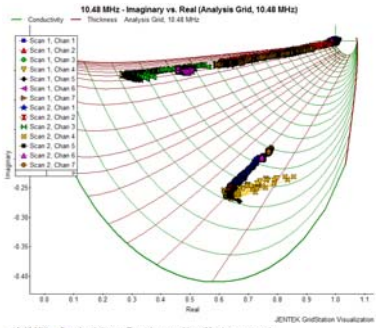
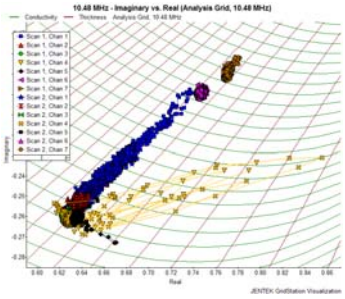
Aluminum Alloy Standard

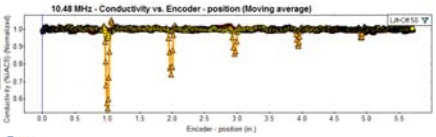








Titanium Alloy Fillet Sample



Titanium Alloy Unfiltered and Filtered Results

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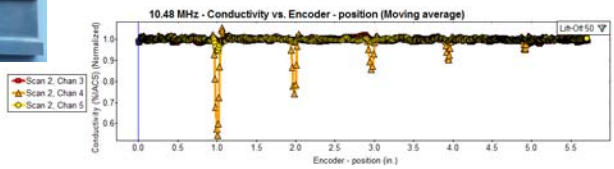
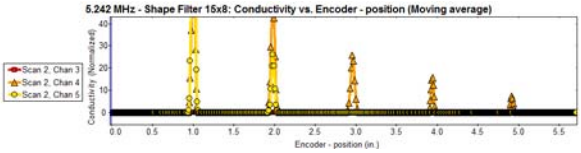
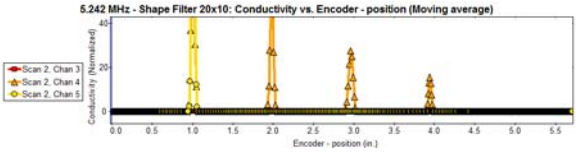
EDM Notch Sizes: length 0.06 0.04 0.03 0.02 0.015
depth x0.03 x0.02 x0.015 x0.01 x0.0075







Subsurface cracks (σ-Δ-h Lattices; Titanium Alloys)

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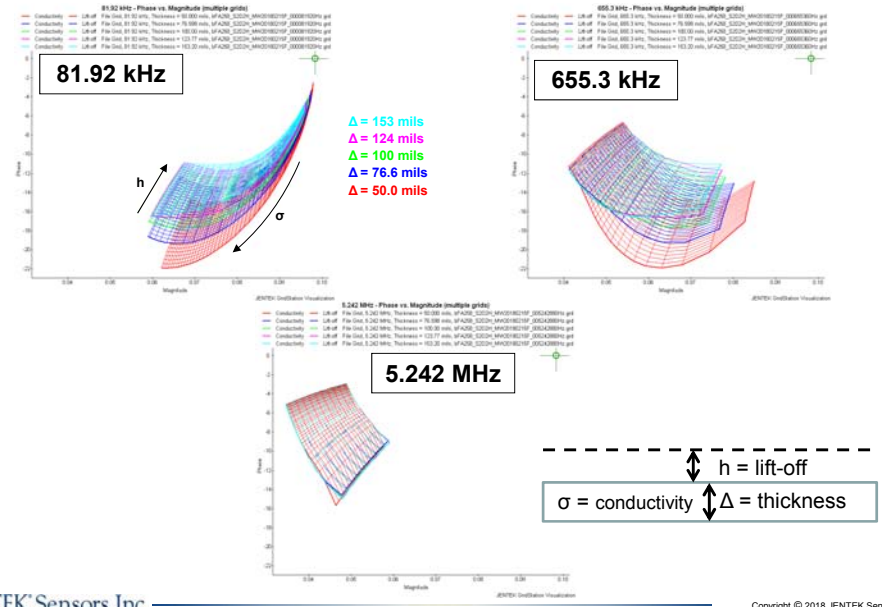

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Subsurface cracks (σ-Δ-h Lattices; Titanium Alloys)

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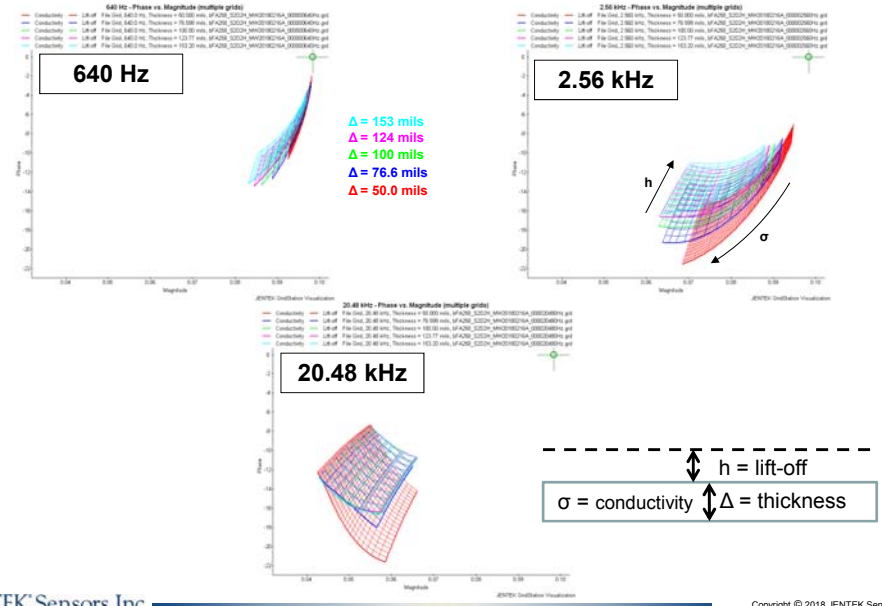

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Subsurface cracks (σ-Δ-h Lattices; Aluminum Alloys)

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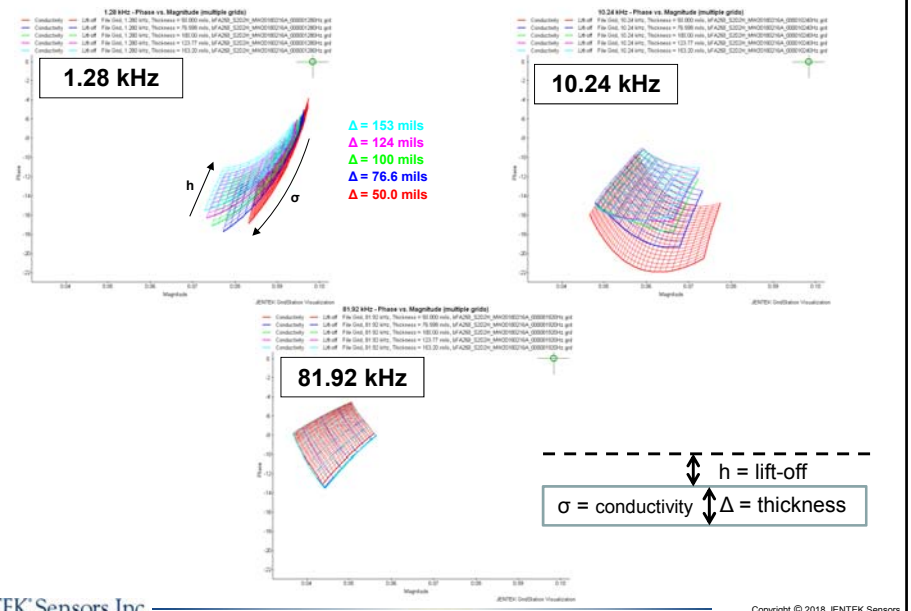
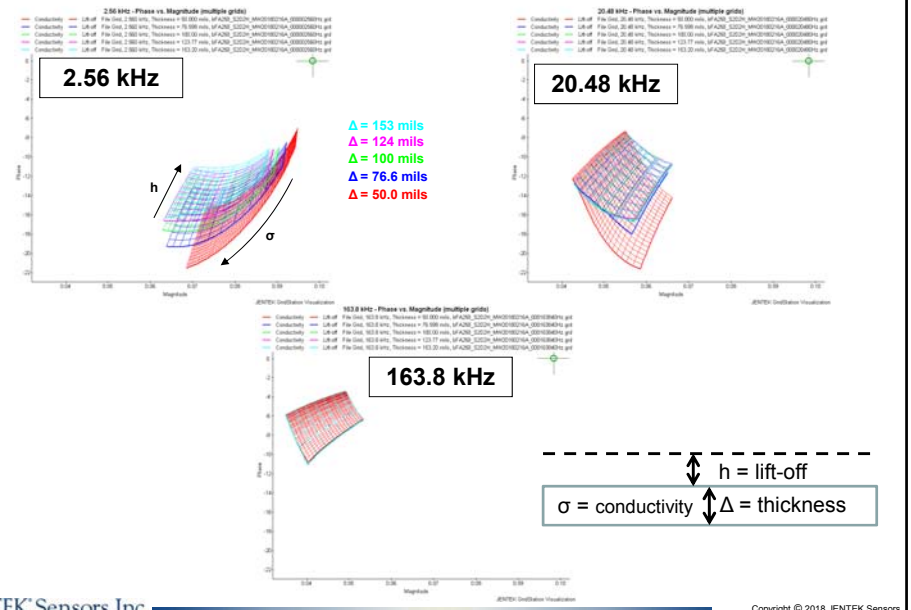


Subsurface cracks (σ-Δ-h Lattices; Aluminum Alloys)

JENTEK Sensors



Simultaneous Coating Thickness Measurement and Subsurface Flaw Detection with new jET

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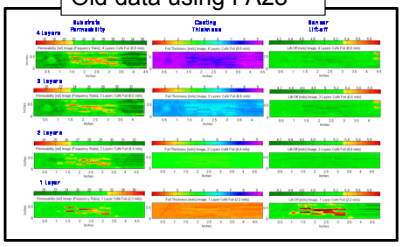
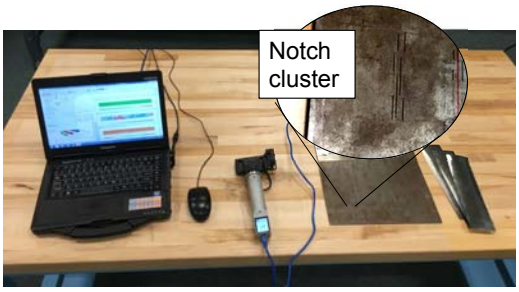
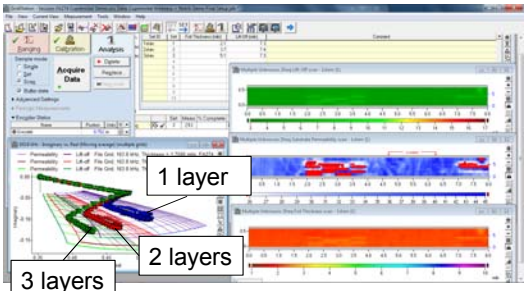
Old data using FA28





- FA274 MWM-Array
- 3 frequency approach
- EDM notch detection through cupronickel shims
- Simultaneous coating thickness measurement and EDM notch detection



MWM-Array Scanning

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2 Frequency, 3 Unknown Method

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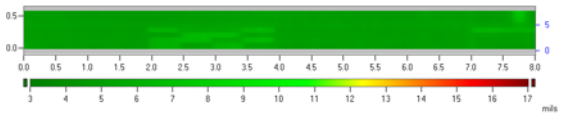
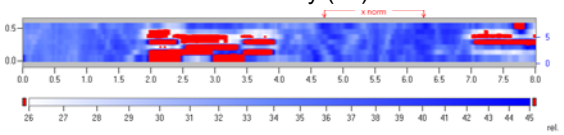
1 Shim

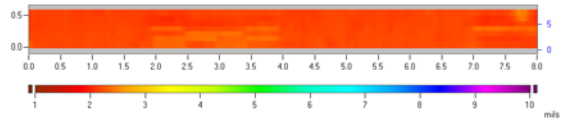
Lift-off



Permeability (rel)



Thickness (mil)



2 Frequency, 3 Unknown Method

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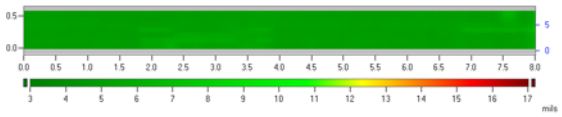
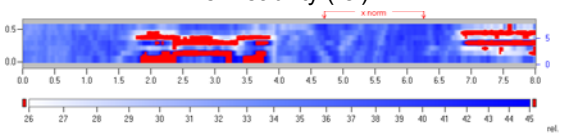
2 Shims

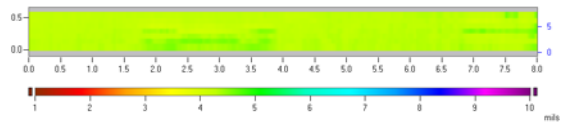
Lift-off



Permeability (rel)



Thickness (mil)



2 Frequency, 3 Unknown Method

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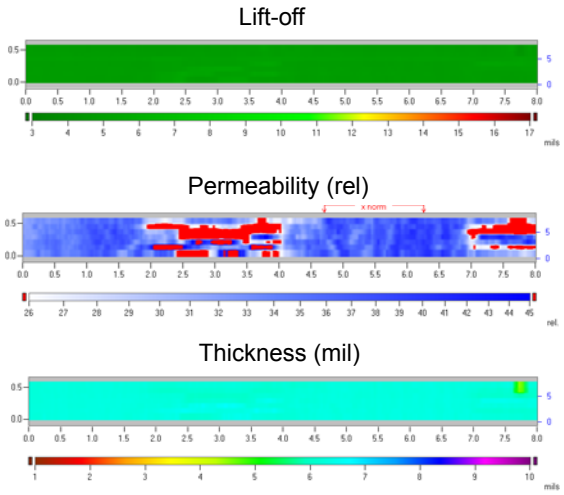

μ-Δ-h Lattices

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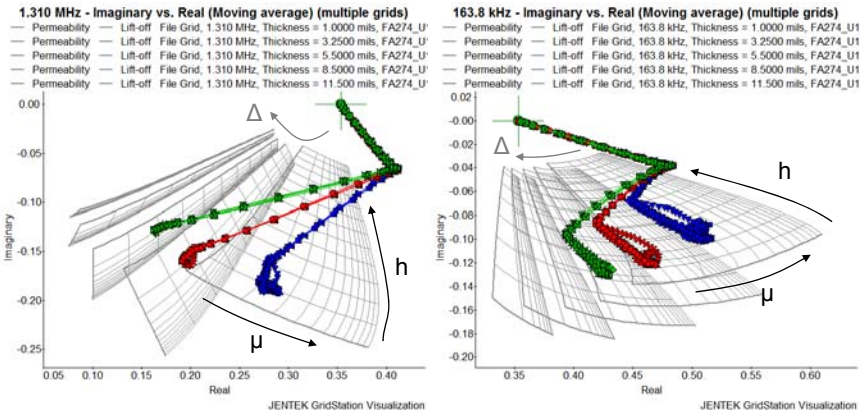

μ-Δ-h Lattices

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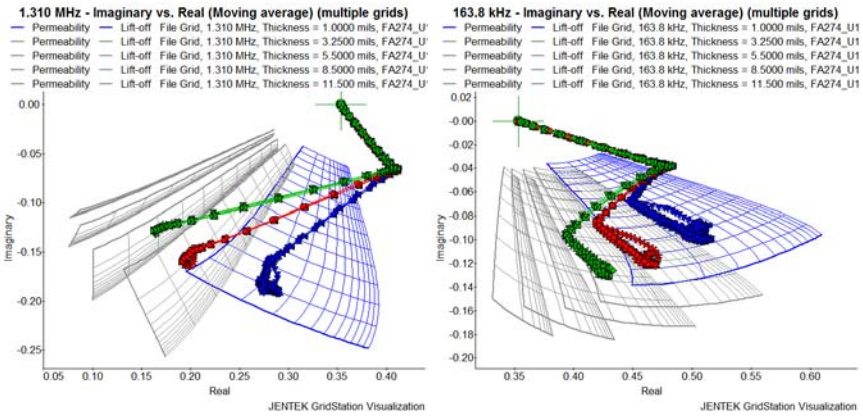

μ-Δ-h Lattices

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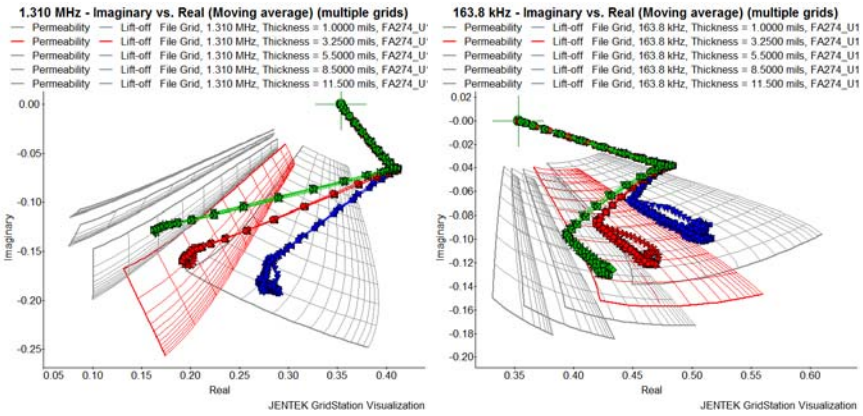

μ-Δ-h Lattices

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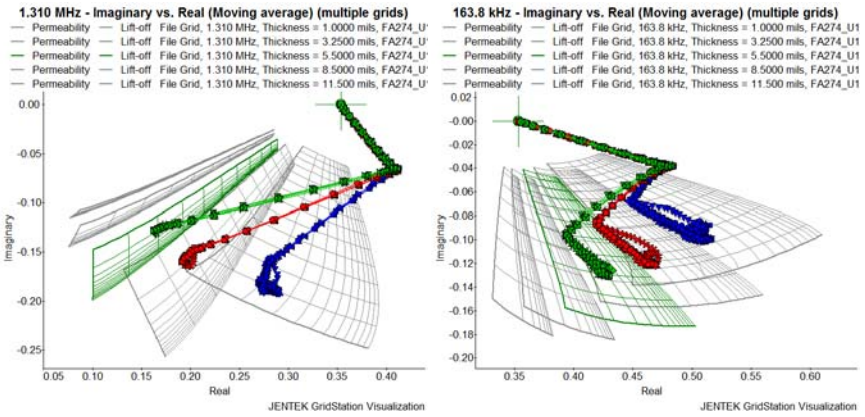
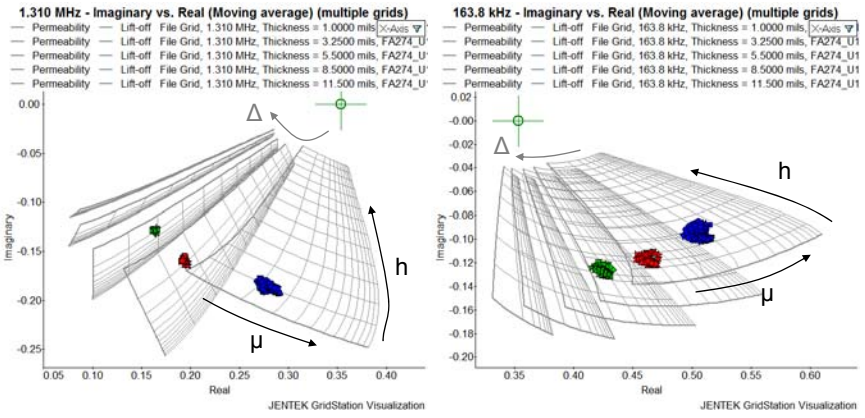


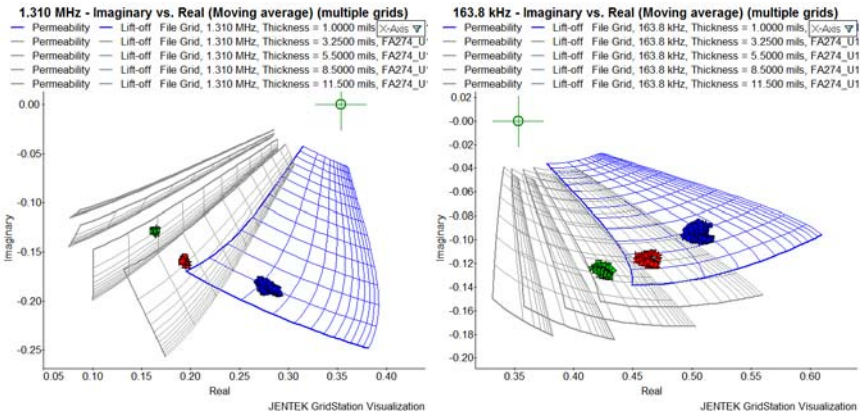
μ-Δ-h Lattices

JENTEK Sensors



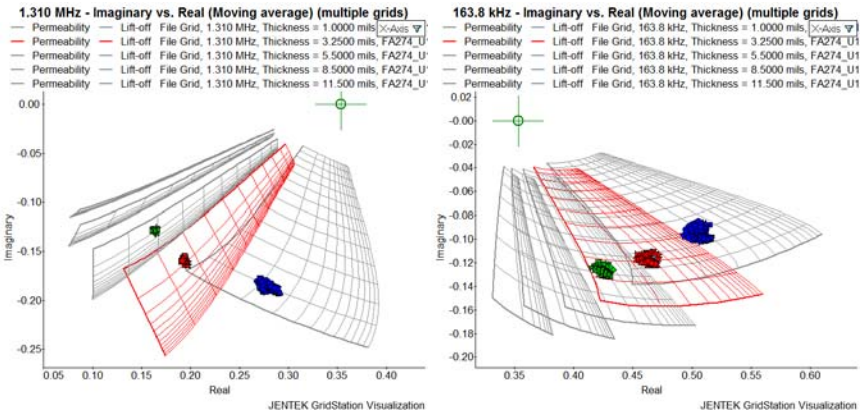
μ-Δ-h Lattices

JENTEK Sensors



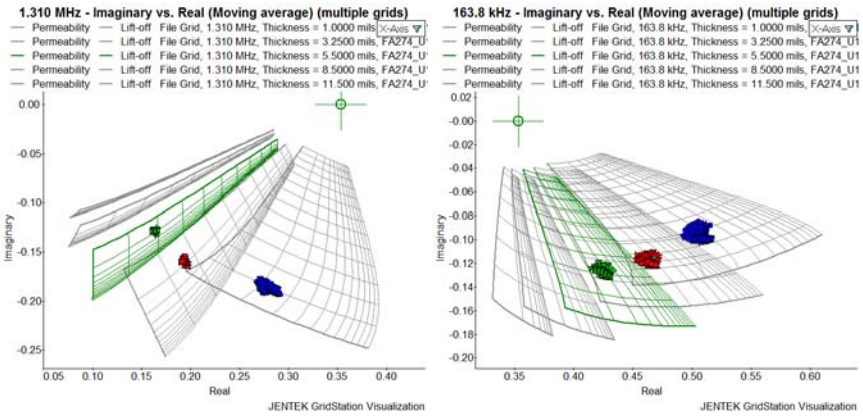
μ-Δ-h Lattices

JENTEK Sensors



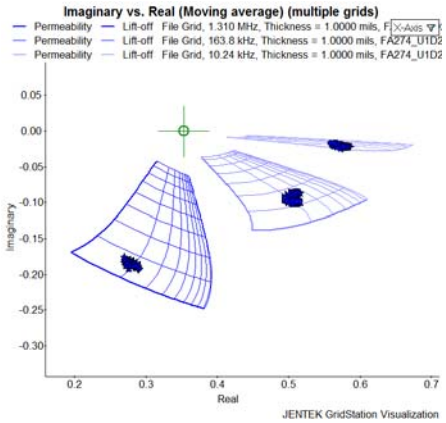
μ-Δ-h Lattices

JENTEK Sensors



1 Shim Data at 10.2kHz, 164kHz and, 1.31MHz

JENTEK Sensors

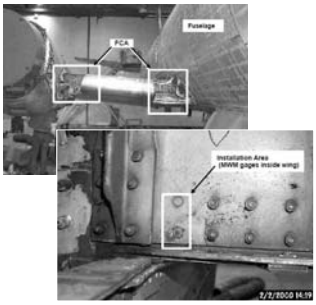


Permanently Installed MWM-Rosette Fatigue Gages

JENTEK Sensors

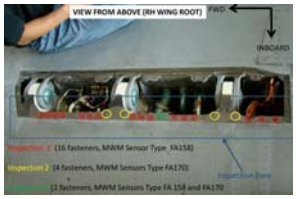
2000-2002 | 2006-2007 | 2013 - 2014

Lockheed Martin
P-3 Fatigue Critical Areas[1]



Northrop Grumman
Full-Scale Testing of EA-6B
Outer Wing Panels[2]

US Navy Fighter Aircraft



Now also installed on the Air Force Airframe digital twin (ADT) test article.
Note the new jET hand-held and improved cabling designs will substantially reduce implementation costs for laboratory and full-scale tests.

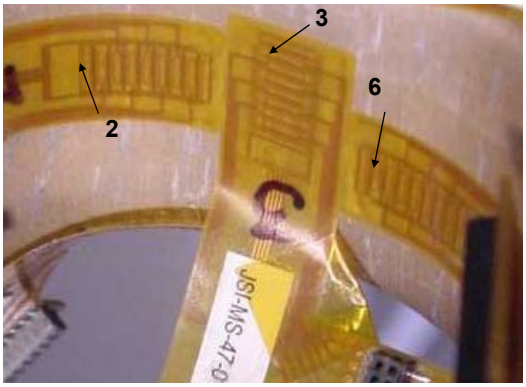
Sources:
[1]Neil J. Goldfine, et al, "Surface Mounted Periodic Field Current Sensors for Structural Health Monitoring," SPIE Conference: Smart Structures and Materials NDE for Health Monitoring and Diagnostics, Newport Beach, California; March 2001

[2]http://adt.larc.nasa.gov/files/2013/01/ADT_Sept2012_NorthGrum.pptx

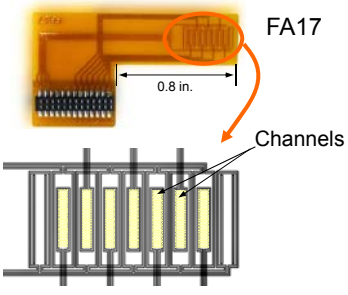
Historical data: Landing Gear Overload & Residual Stress Monitoring

JENTEK Sensors

Note this can be supported by jET with either
- permanently installed MWM-Arrays as shown or
- bidirectional MWM point measurements

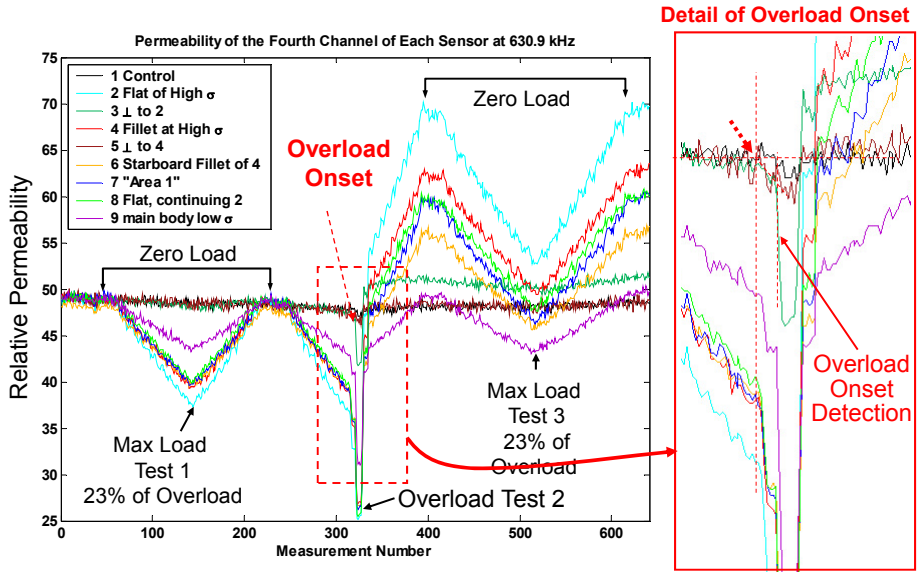


- Bi-directional permeability
- Detect onset of overload event
- Load/stress monitoring



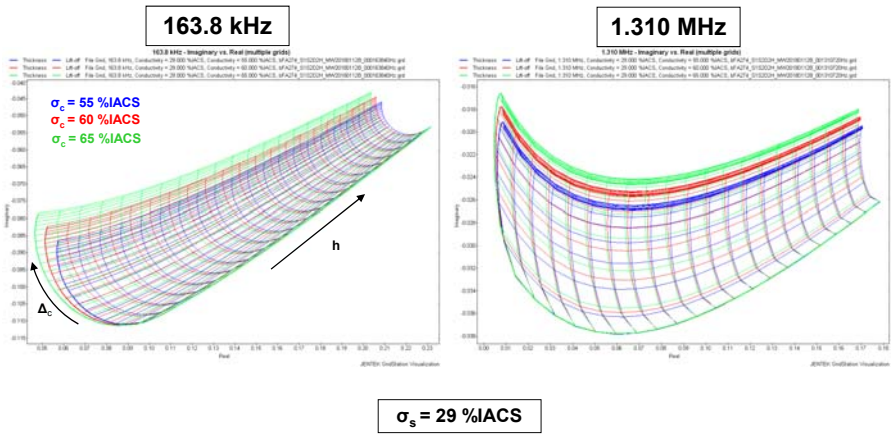
Historical Data: MWM-Array FA17 Channel 4 Permeability Response from all 9 Sensors During Strength Tests

JENTEK Sensors



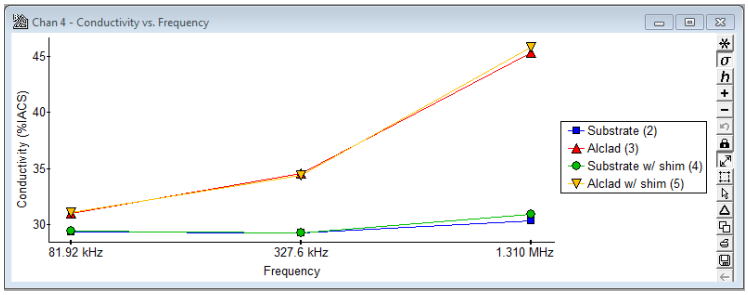
2018 Data: Alclad Thickness Point Measurement and Imaging (σ_c-Δ_c-h Lattices for 163.8 kHz and 1.310 MHz)

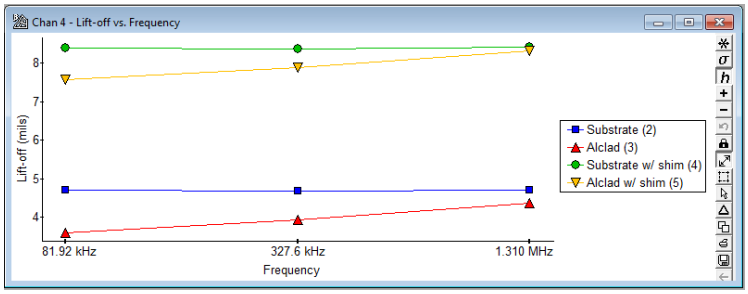
JENTEK Sensors



2018 Data: Frequency Set 1 – 81.92kHz, 327.6kHz, 1.310MHz

JENTEK Sensors





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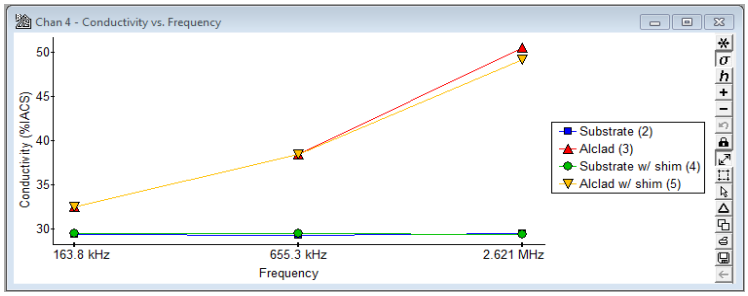
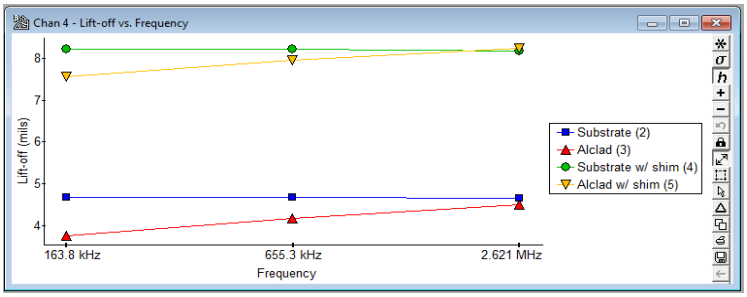
Slide 41

2018 Data: Frequency Set 2 – 163.8kHz, 655.3kHz, 20621MHz

JENTEK Sensors





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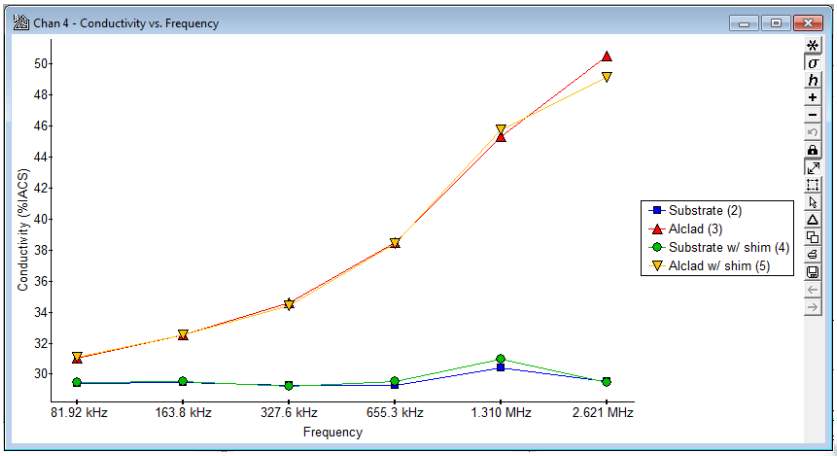
Slide 42

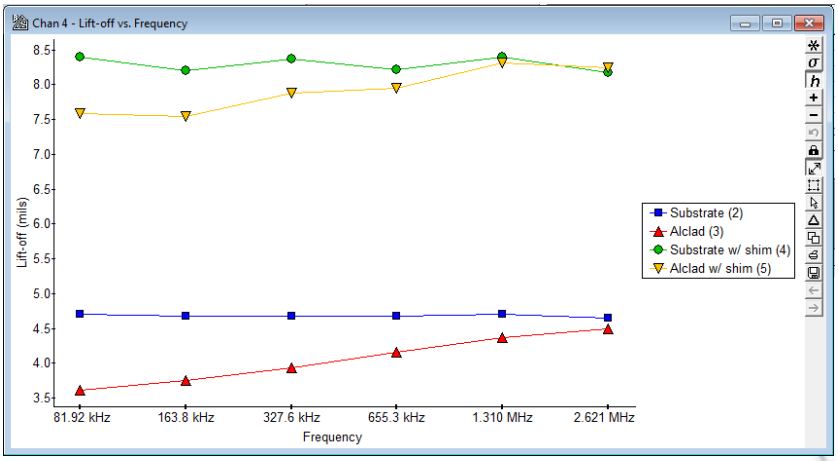
2018 Data: All Frequencies – Conductivity vs. Frequency

JENTEK Sensors



2018 Data: All Frequencies- Lift-off vs. Frequency

JENTEK Sensors



2018 Data: 4-Unknown Method (using 6 frequencies)

JENTEK Sensors

Chan 4 - Multiple Unknowns: Estimated Data

Set ID	Set	Conductivity (%IACS)	Conductivity (%IACS)	Thickness (mils)	Lift-off (mils)	Comment
	1					
Alclad	2	29.42	58.63	1.655	4.669	
Alclad w/ shim	3	29.61	58.06	1.575	8.491	
	4					
	5					
	6					
	7					
Average		29.52	58.35	1.615	6.580	

Summary and Future Work

JENTEK Sensors

jET with MWM-Array ET

- Surface crack detection demonstrated and available
- 1st and 2nd layer subsurface cracks development ongoing (Air Force and Navy funding)
- Subsurface corrosion development ongoing (U.S. Air Force and U.S. Navy funding)
- Coating characterization demonstrated and available
- Crack detection under coatings demonstrated and available (ongoing U.S. Army funding)
- Landing gear overload detection, demonstrated
- Permanently installed sensors for crack detection in difficult to access locations demonstrated (installed on Air Frame digital twin test article, now supportable with jET).

jET with MR-MWM-Arrays not yet available, development ongoing, delay due to unexpect electronics issue.