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Numerous Embedded Inductive and Capacitive Sensors for Corrosion & Fatigue

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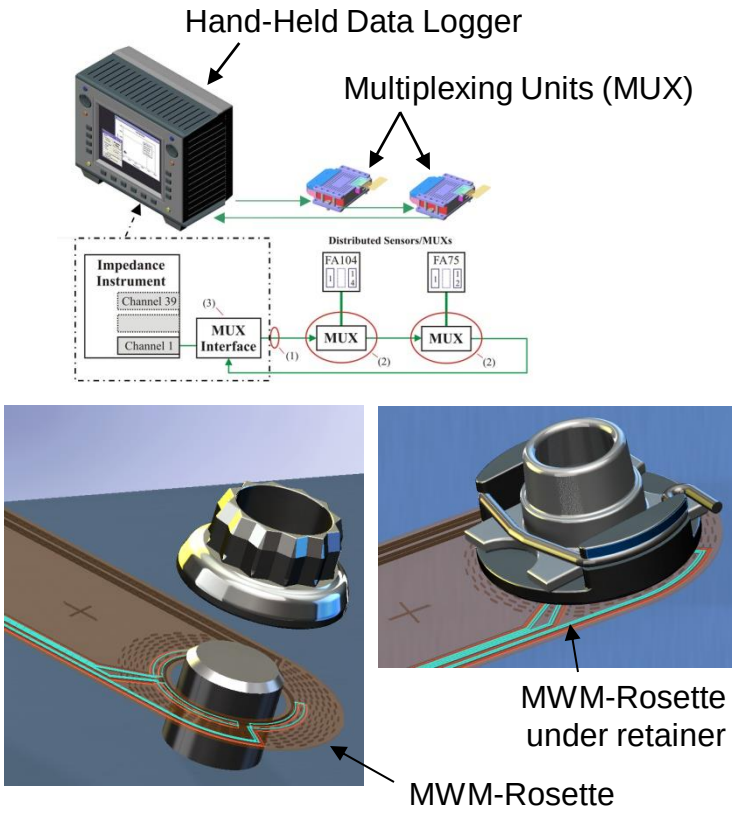


MWM sensors and MWM-Arrays covered by issued and pending patents, including, but not limited to:
5,793,206; 5,966,011; 6,144,206; 6,188,218 B1; 6,198,279 B1; 6,727,691 B2; 6,995,557 B2; 6,992,482 B2; 6,952,095 B1; 6,798,198 B2; 6,784,662 B2; 6,781,387 B2; 7,188,532 B2; 7,183,764 B2; 7,161,351 B2; 7,161,350 B2; 7,106,055 B2; 7,095,224, B2; 7,049,811 B2; 6,657,429 B1; 6,486,673 B1; 6,420,876; 6,380,747 B1; 6,377,039; 6,351,120 B1; RE39,206 E.

Need Addressed

Need/Problem:

Inspect for cracks at

- Numerous local and distributed features
- In difficult-to-access locations
- Without disassembly for inspection

Solutions:

1) **Portable Data Logger**
   - Embedded MWM-Arrays and MWM-Rosettes (eddy current sensors) and
   - Light weight cabling with
   - Distributed multiplexing (MUX) units
   - NDT data acquisition from easy access locations
2) **Embedded Data Logger** for continual in-flight or only ground-based NDT

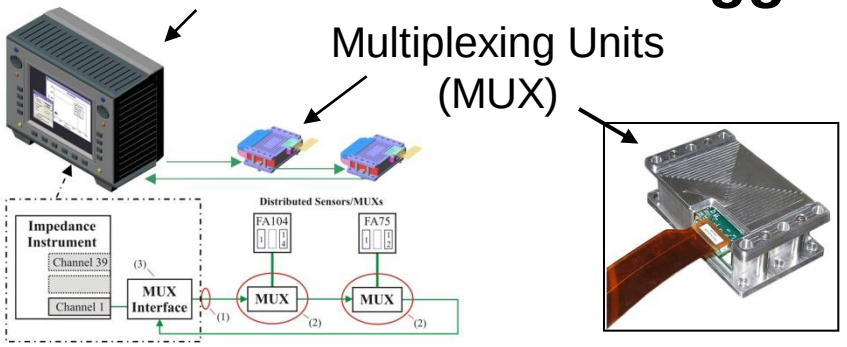
POD (Probability of Detection) for Embedded Sensors

- **New Phase II SBIR Awarded to JENTEK by Air Force**
  - Develop MWM-Rosettes for target applications
  - Develop low-cost POD curve generation method for embedded sensors
    - Use coupons monitored with embedded sensors to generate ahat *vs* a data
    - Generate POD curves using Military Standard-1823 like process
  - Perform environmental and durability testing for target applications
- **Obstacles for Transition to Fleet Use**
  - POD/performance validation
  - Durability
  - Costs
  - Flight test funding for target applications

Sensing Modes Supported

- **Eddy Current Testing**, for High Frequency and Low Frequency
  Using ***Linear MWM®-Arrays and MWM-Rosettes***
  - Enhanced Durability under fastener heads and between layers
  - Curved surface monitoring
  - Crack detection, surface and buried (first, second or third layer)
  - Corrosion monitoring through protective coatings/gaskets/metals/composites
  - Moderate area coverage (several inches)
- **Capacitive Sensing,** Using ***IDED™*** *(interdigitated electrode dielectrometer, and Segmented Field Dielectrometer Arrays (**SFD-Arrays**)*
  - Sealant, CPC age degradation monitoring
  - Moisture ingress detection through protective layers
  - Corrosion product detection
  - Environmental monitoiring (humidity, etc.)

Hand-Held Data Logger

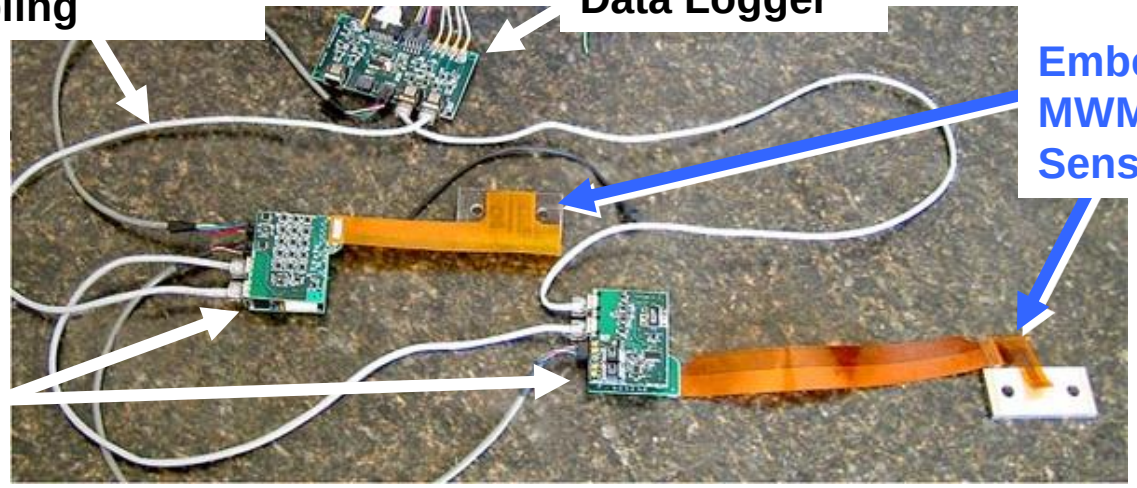


Light Weight Reconfigurable Cabling

MUX Interface for Hand-Held Data Logger

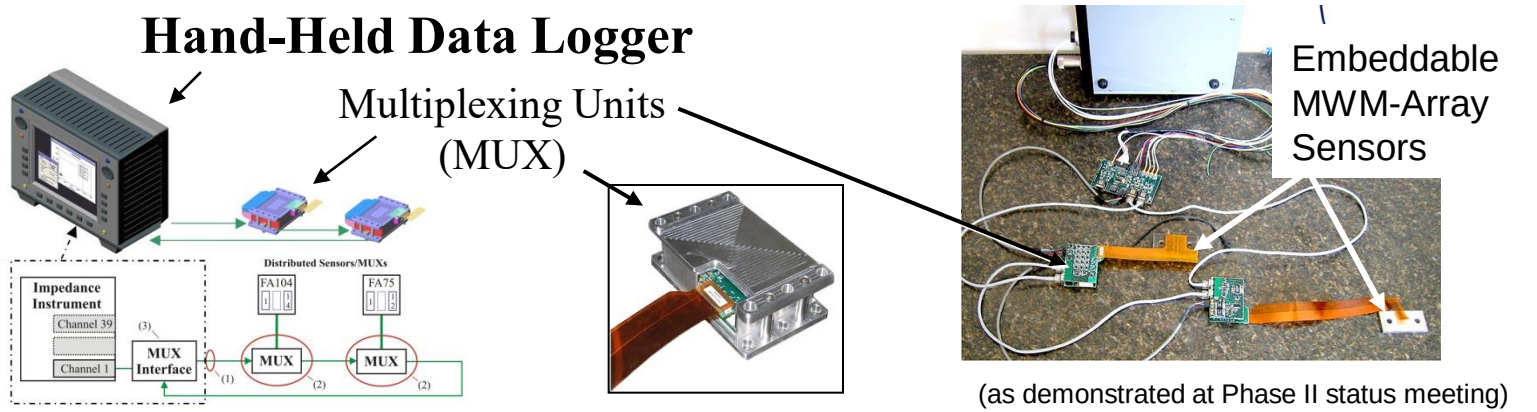
Two Different

Embeddable MWM-Array Sensors



Distributed MUX Units

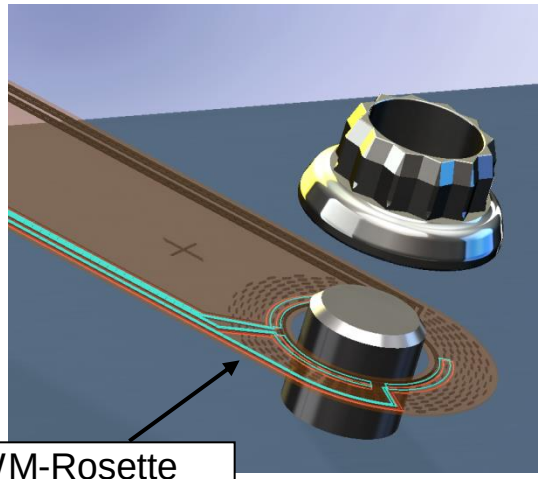
(as demonstrated at Phase II status meeting)

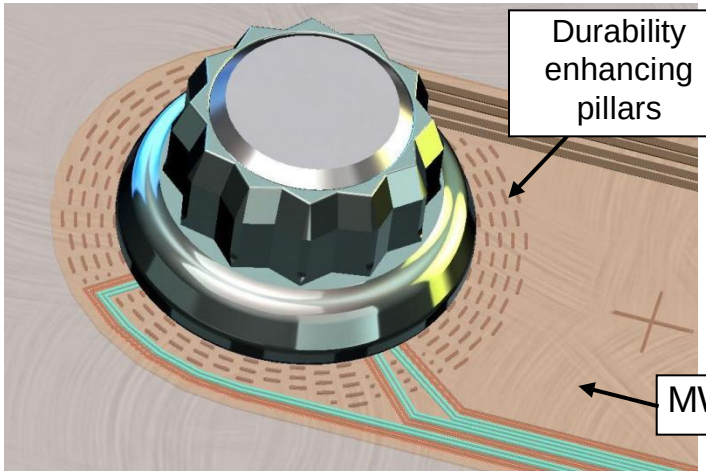


(as demonstrated at Phase II status meeting)

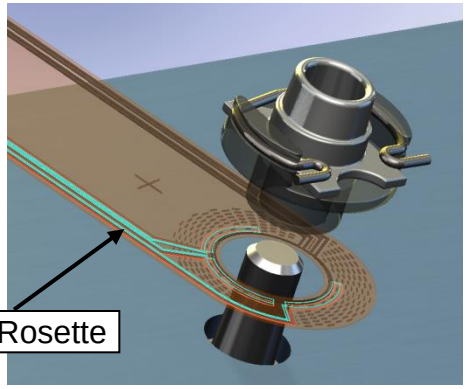
Features	Advantages	Benefits
Hand-Held Data Logger	Adds to the existing JENTEK high-end product line, providing a low cost field implementation and adds the support of multiplexed sensor networks to monitor numerous corrosion and fatigue sensors	• Low cost, field hardened • Supports MWM-Array fatigue and corrosion monitoring • Remote NDT without disassembly in difficult-to-access locations • Supports scanning MWM-Array NDT, e.g., bolt-hole ET
MWM-Array	Embeddable in difficult to access locations, light weight, conformable, durable, and can monitor corrosion and fatigue, without disassembly or collateral damage	• Corrosion and fatigue detection • Higher reliability than ET, LPI • Works thru paint and coatings • Enables frequent low cost inspection to detect damage early, from easy access locations
IDED-Array	Embeddable for moisture detection, corrosion product detection, and monitoring sealant aging	• Inspect thru coatings and sealants • Embeddable under sealant • Thin • Conformable
MUX	Multiplexing networks for numerous sensors, for MWM-Arrays and IDED-Arrays, with support for other sensors, e.g., temperature, strain.	• Light weight cabling • Low cost • Reconfigurable • Supports temperature, strain and other sensing
Calibration and data processing	Reduction of drift and noise for MWM-Arrays. Provides reliable crack detection and metal loss monitoring	• Needed to provide practical long term fatigue and corrosion monitoring • Simplifies installation and data processing

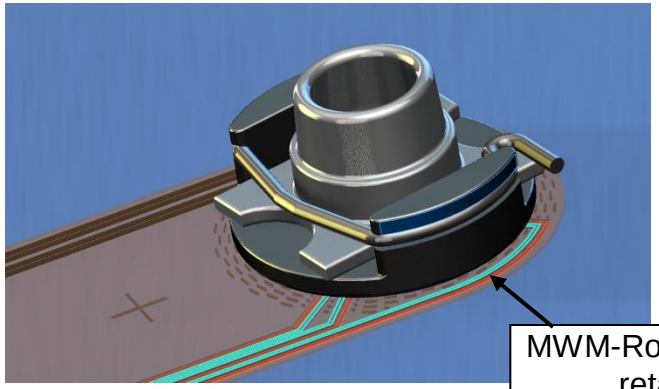
New Enhanced Durability MWM-Rosettes





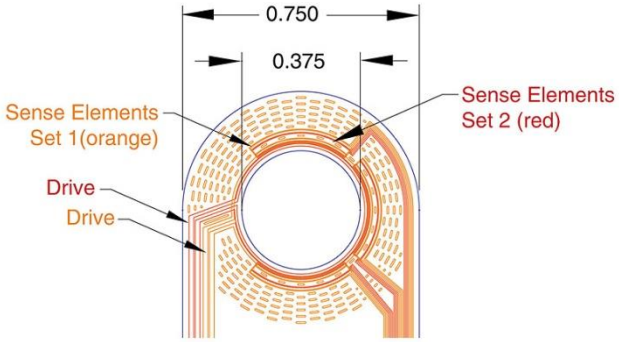
PATENTS ISSUED AND PENDING

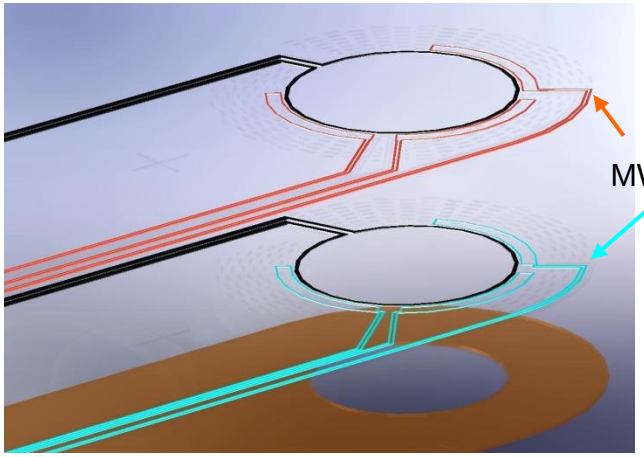


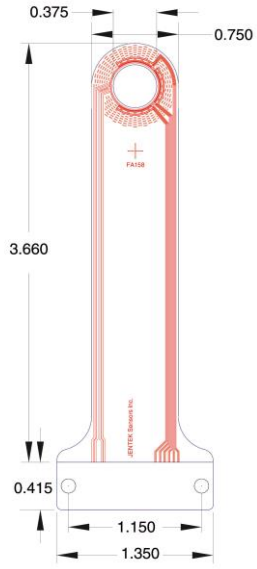


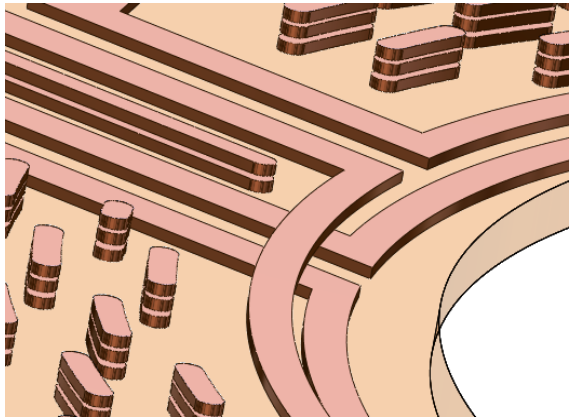
Redundant Drives and Durability Enhancing Pillars

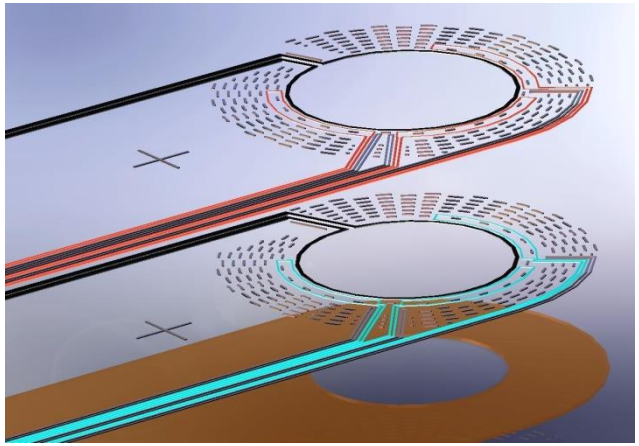
FA158 MWM-Rosette





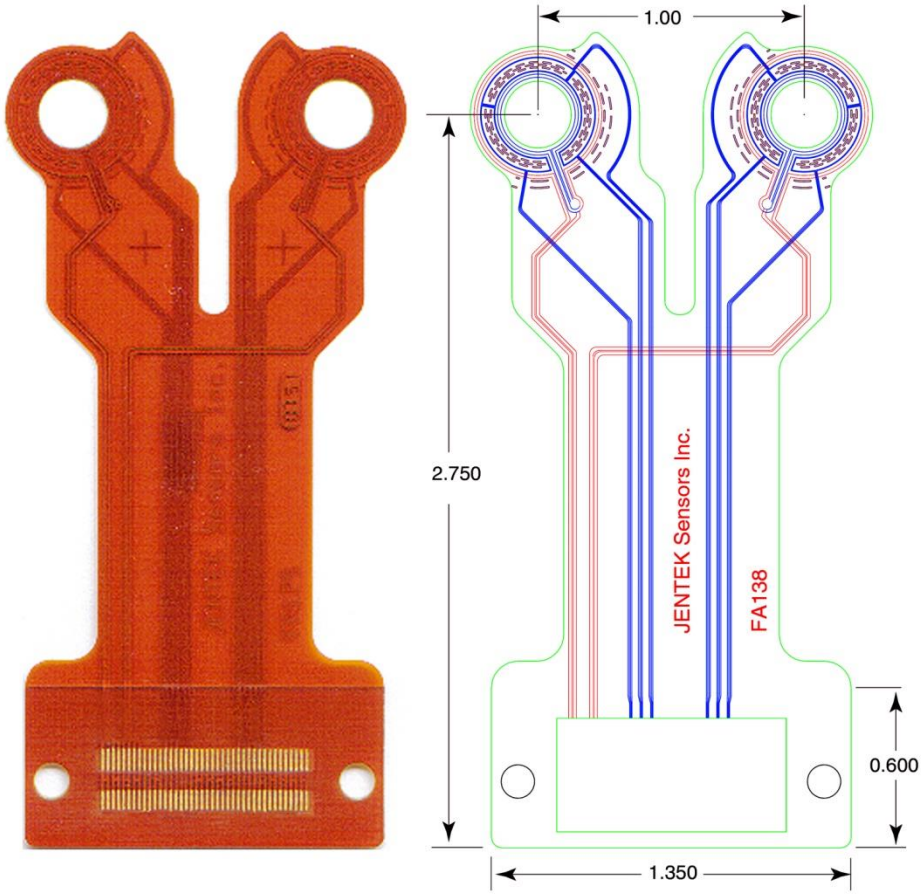


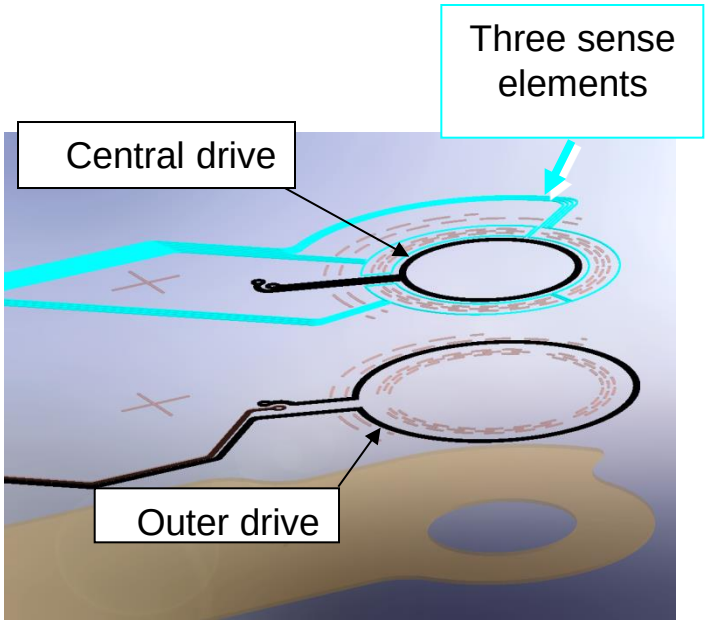




PATENTS ISSUED AND PENDING

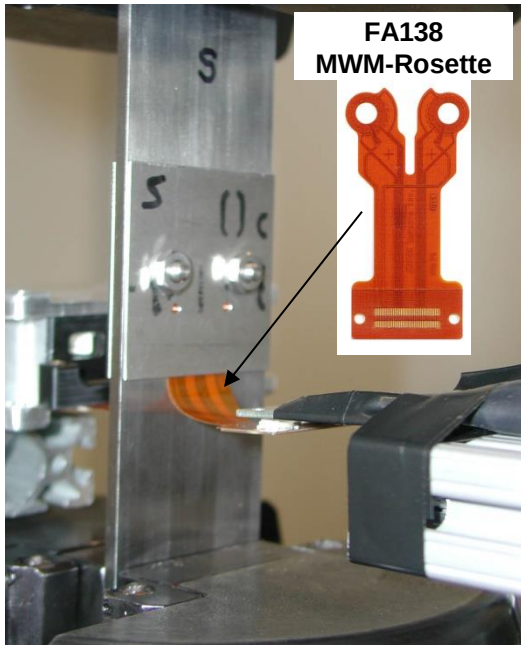
Low Frequency Dual Drive MWM-Array FA138



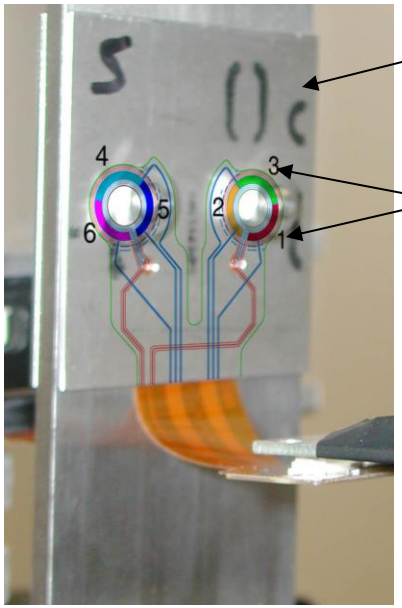


PATENTS ISSUED AND PENDING

Fatigue Specimen Setup

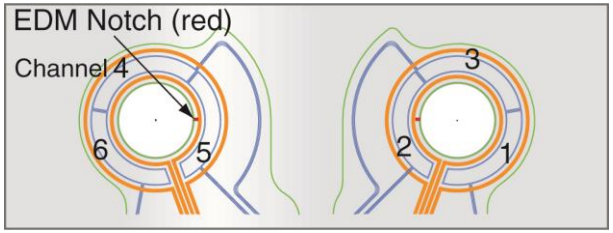


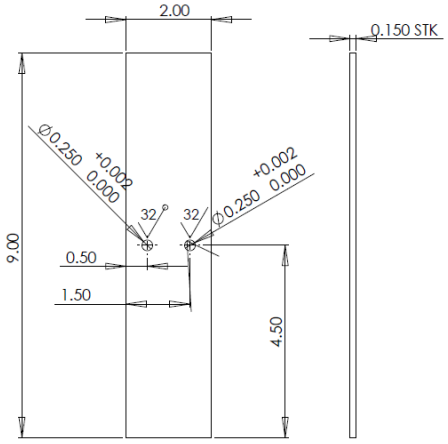
Fatigue test coupon

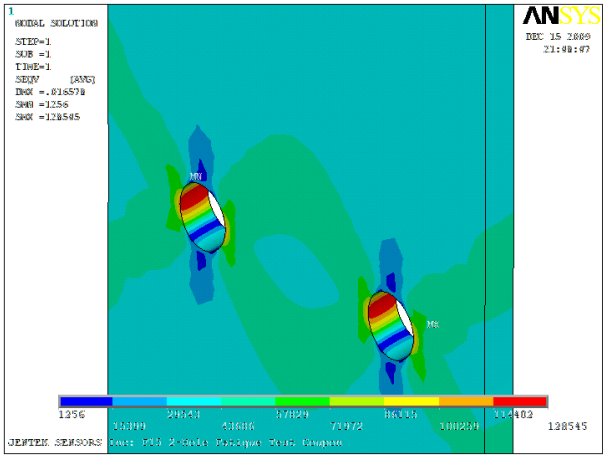


0.04-in. thick protective cover plates

Schematic overlay - location of the individual sensing elements

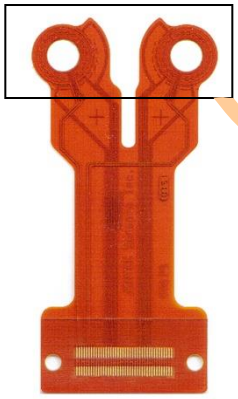




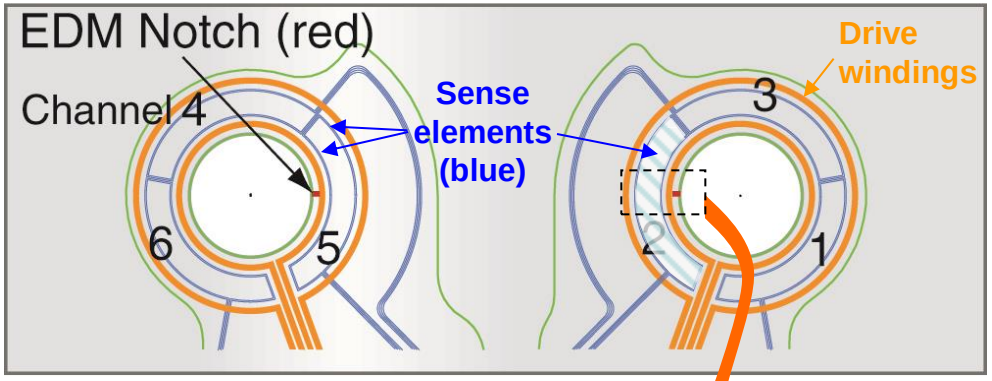


von Mises stress distribution determined by FEA of the geometry

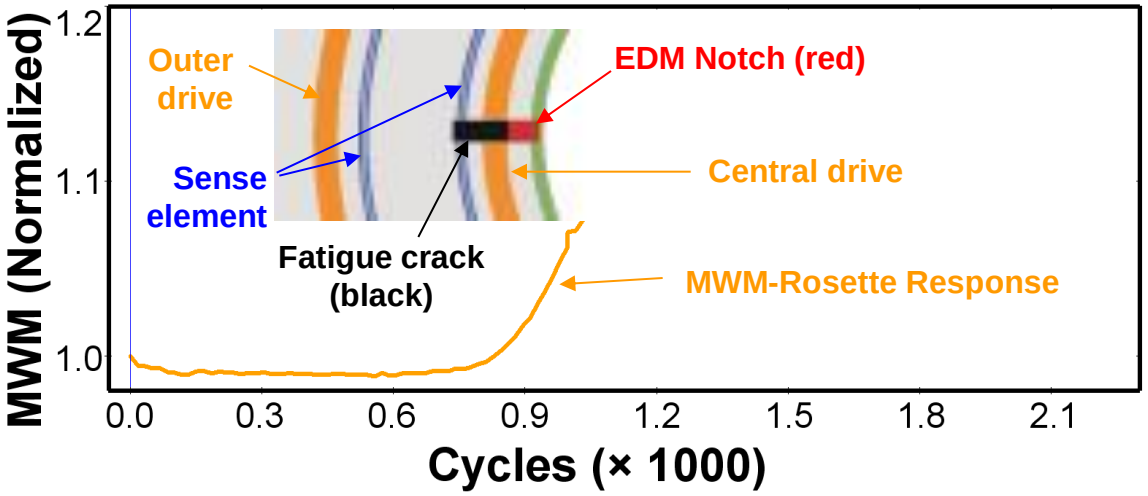
The FEA assured the specimen could be loaded sufficiently given the limits of the servohydraulic fatigue machine.



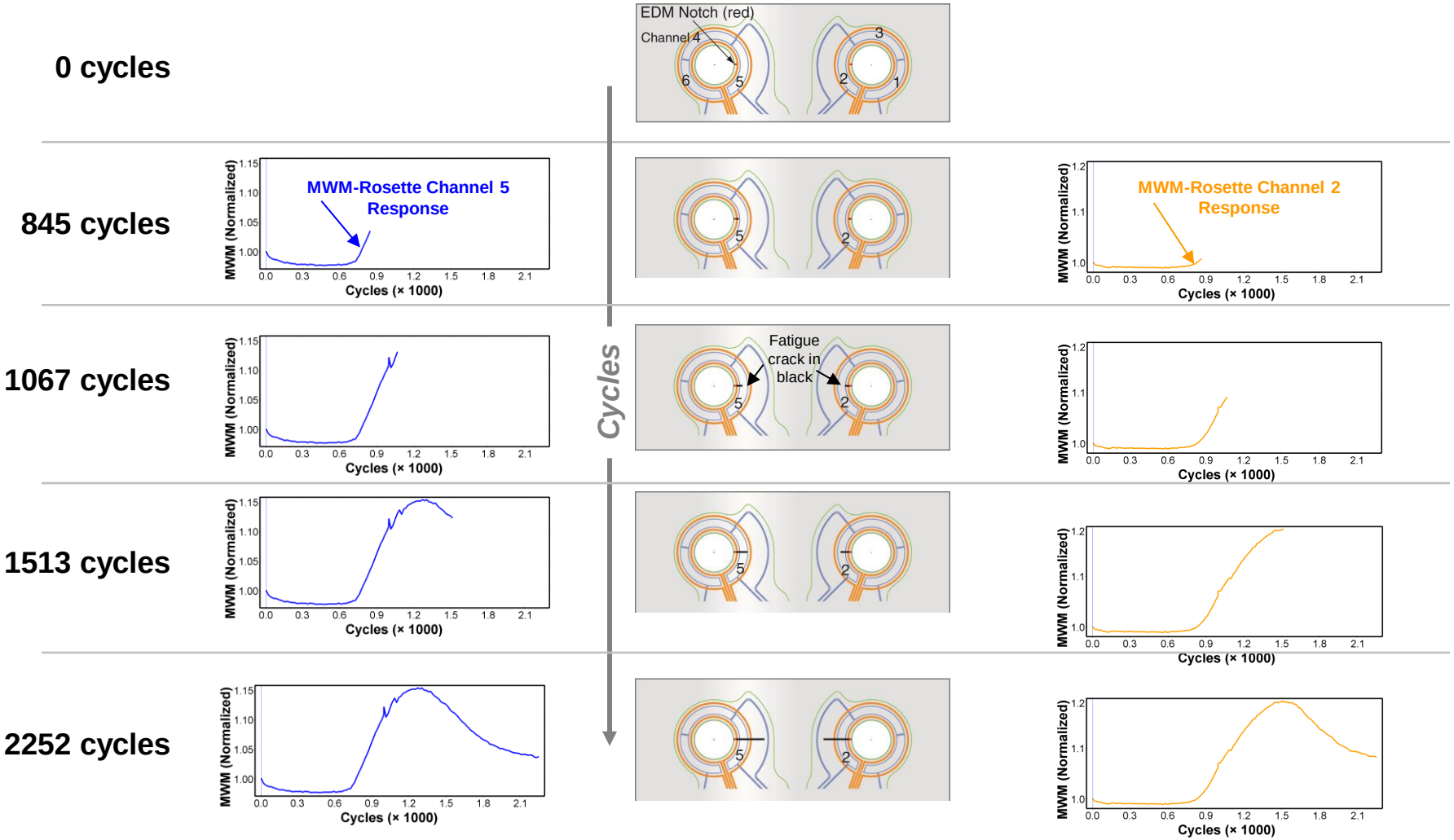
FA138
MWM-Rosette



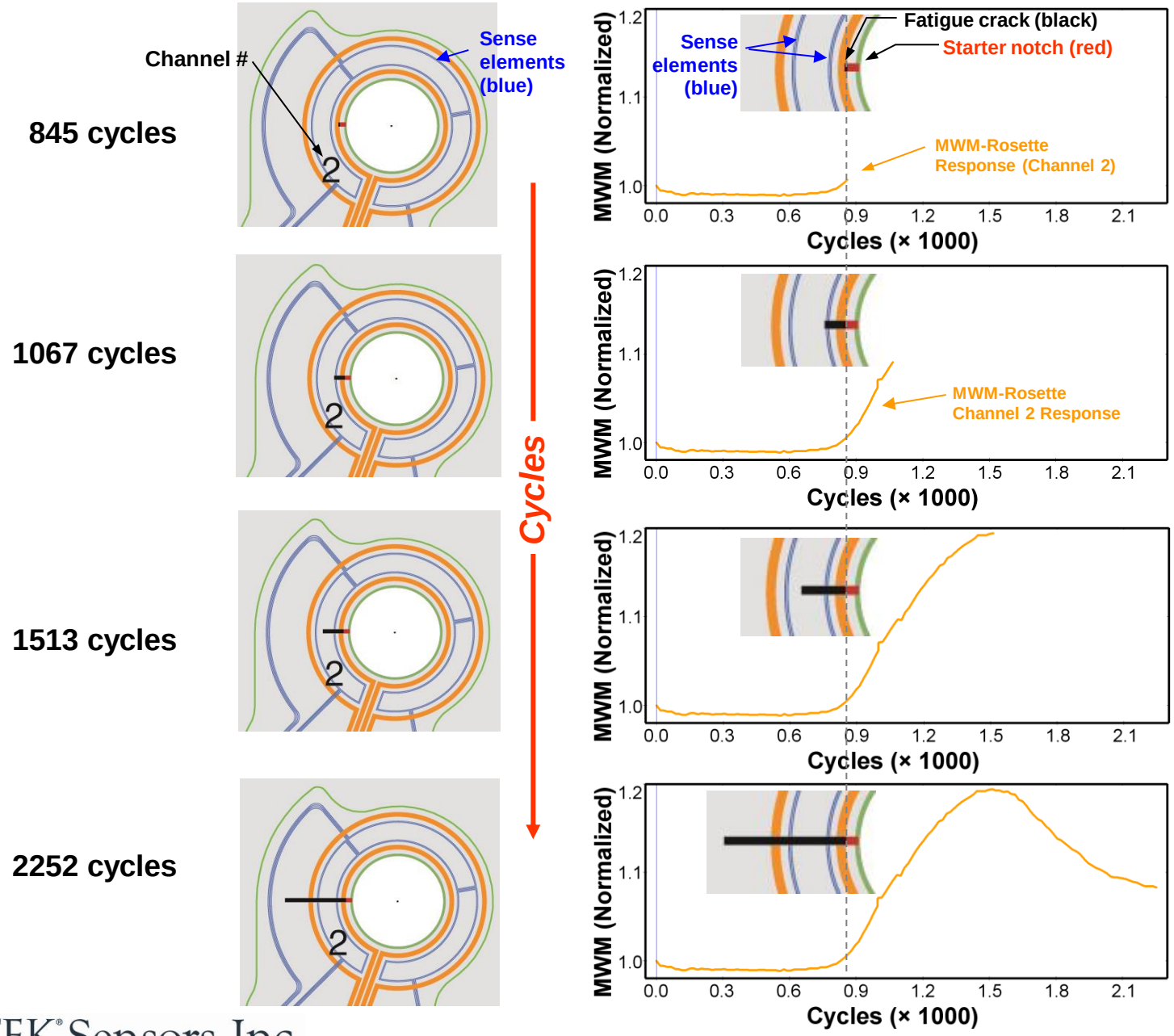
Example shown is Channel 2, at 1067 cycles



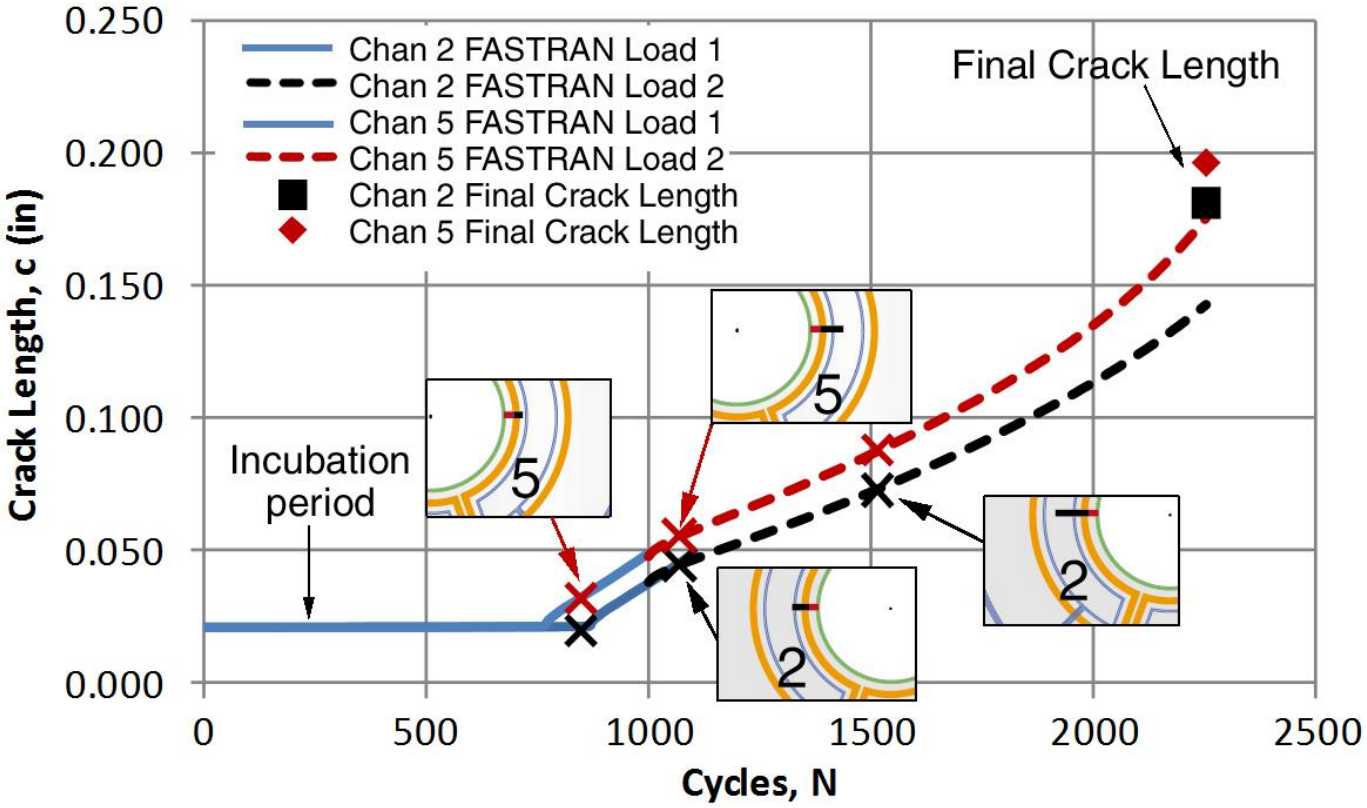
FA138 MWM-Rosette Responses During the Fatigue Test of a Two-Hole Coupon



Expanded view of FA138 MWM-Rosette Responses for Channel 2



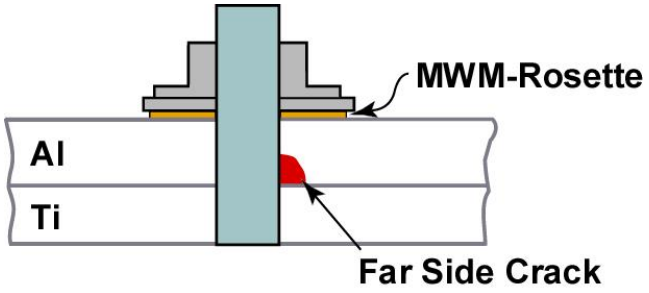
Crack Growth Monitoring Capability

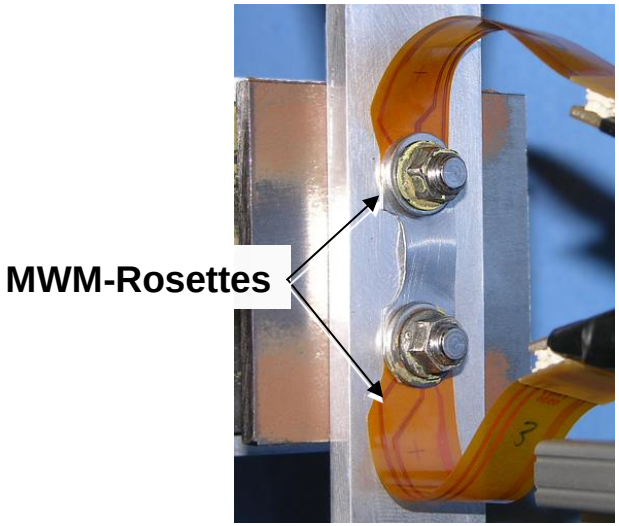


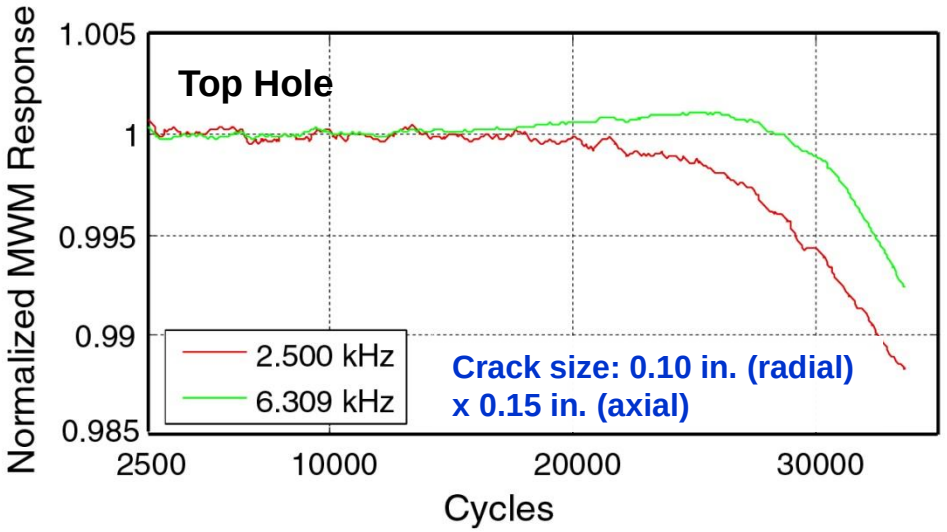
FASTRAN response with illustrations of MWM-Rosettes to show crack size relative to central drive and sense elements

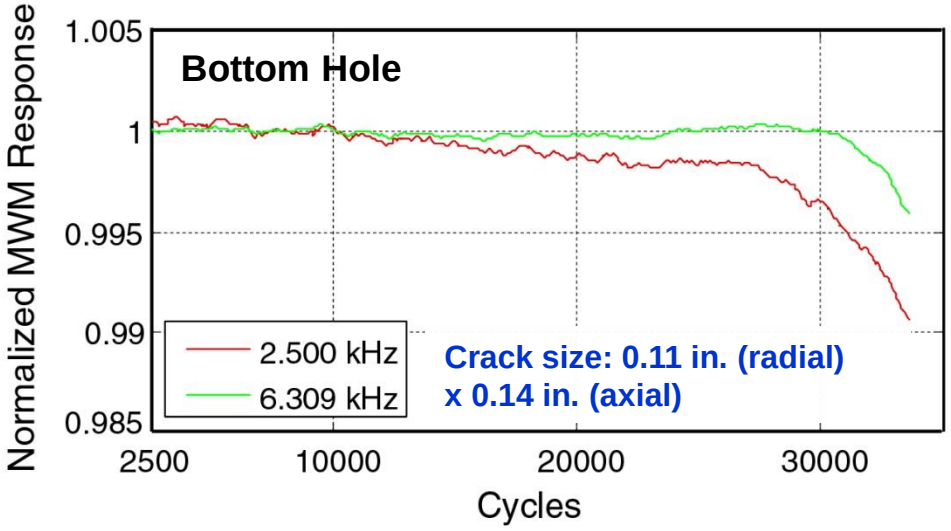
Buried Crack Detection with MWM-Rosettes

"Smart Washer"





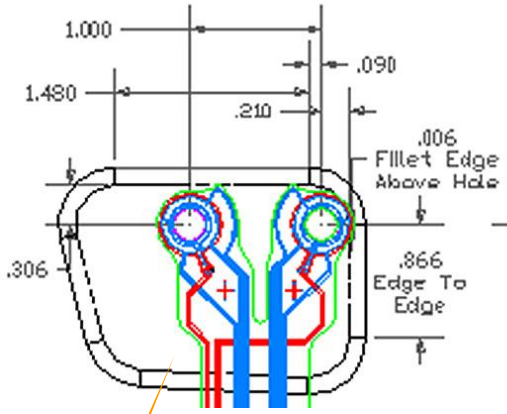


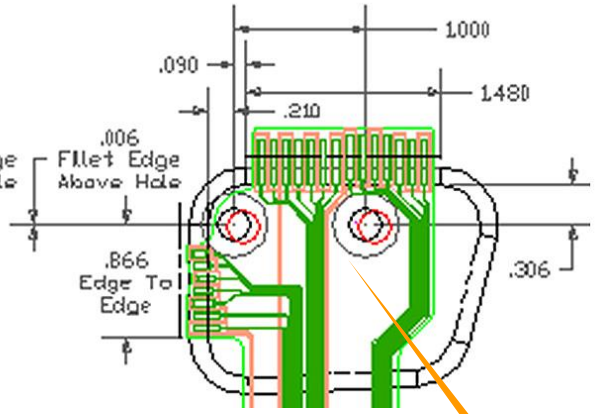


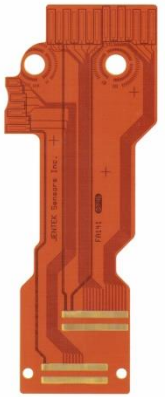
Durability:
Both MWM-Rosettes operable after 90,000 fatigue cycles, in two separate tests

Stackable Low and High Frequency Solutions

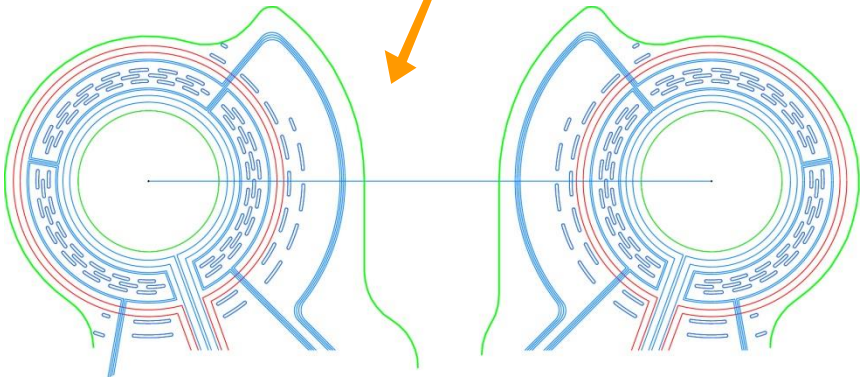
MWM-Array
FA138

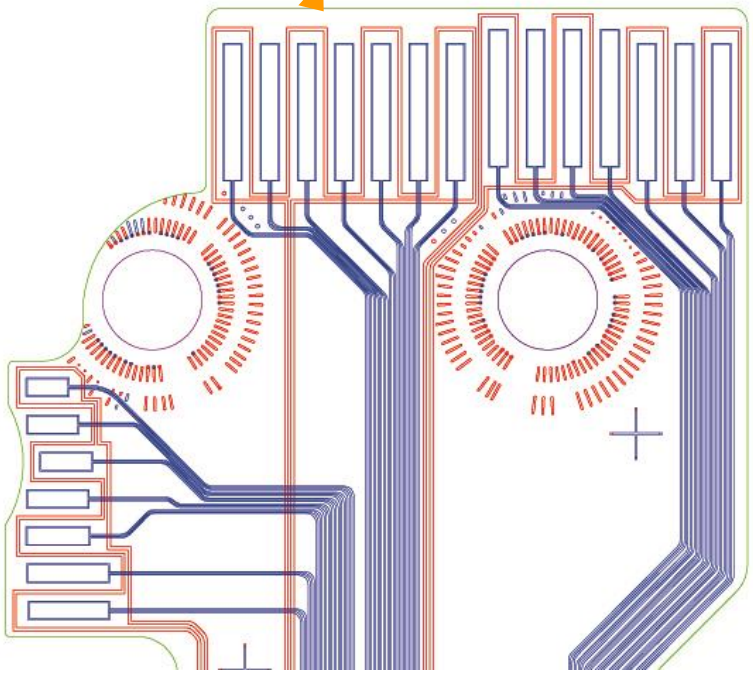




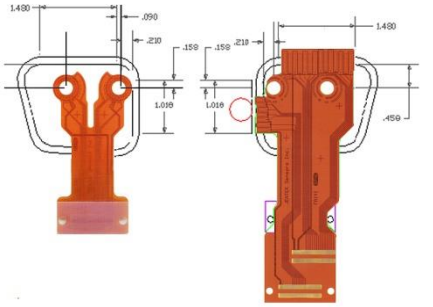


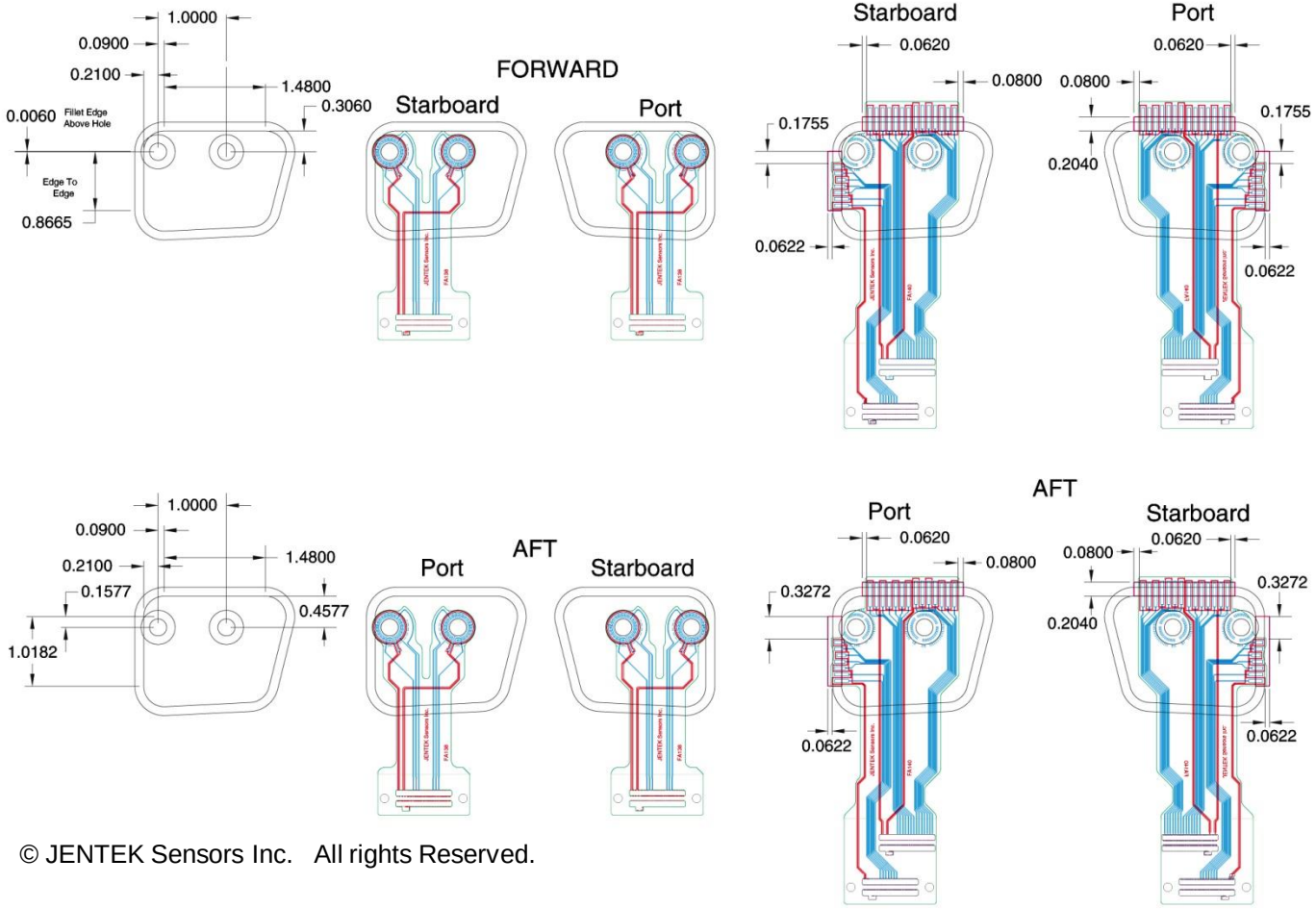
MWM-Array
FA140

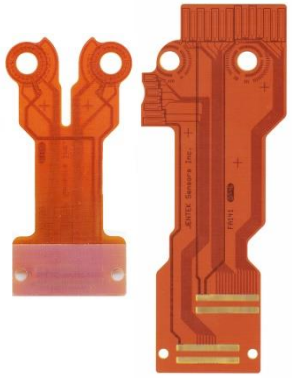




Fatigue Sensor Network

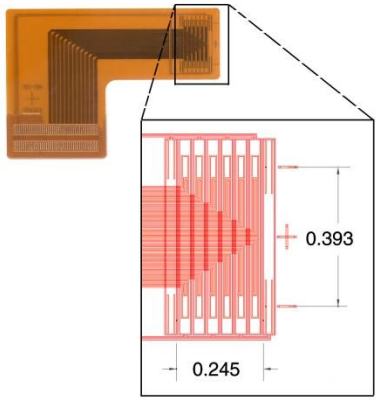


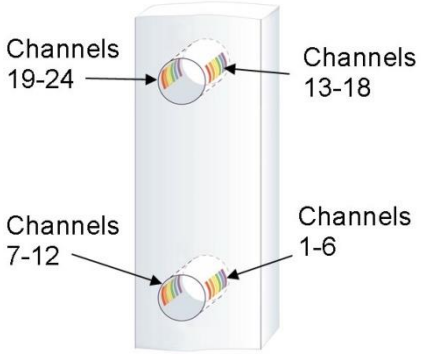


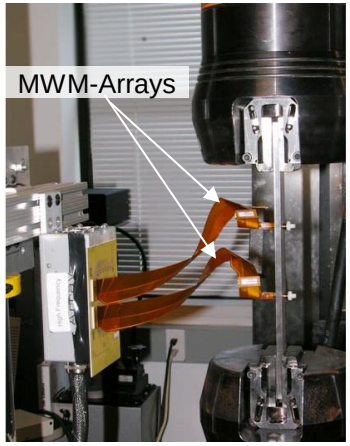


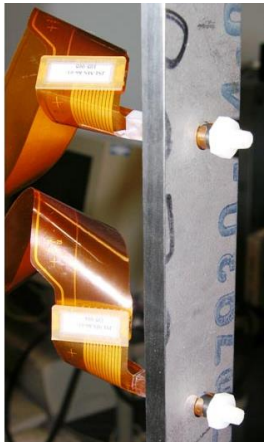
Fatigue Monitoring with Linear MWM-Arrays in Bolt Holes Suitable for "Smart Bolt" Development

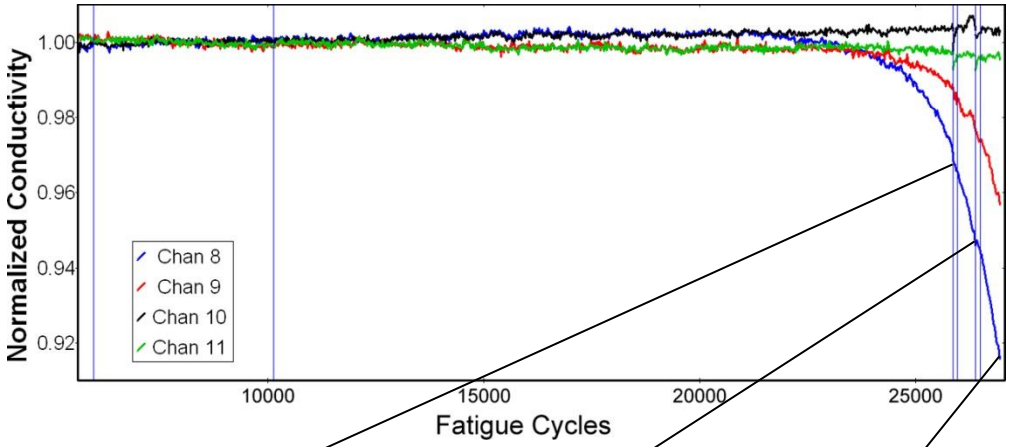
MWM-Array FA75

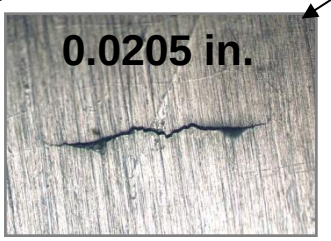






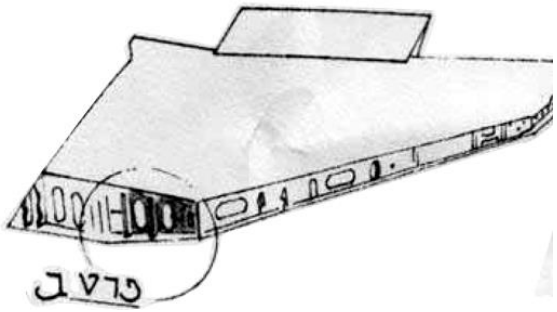




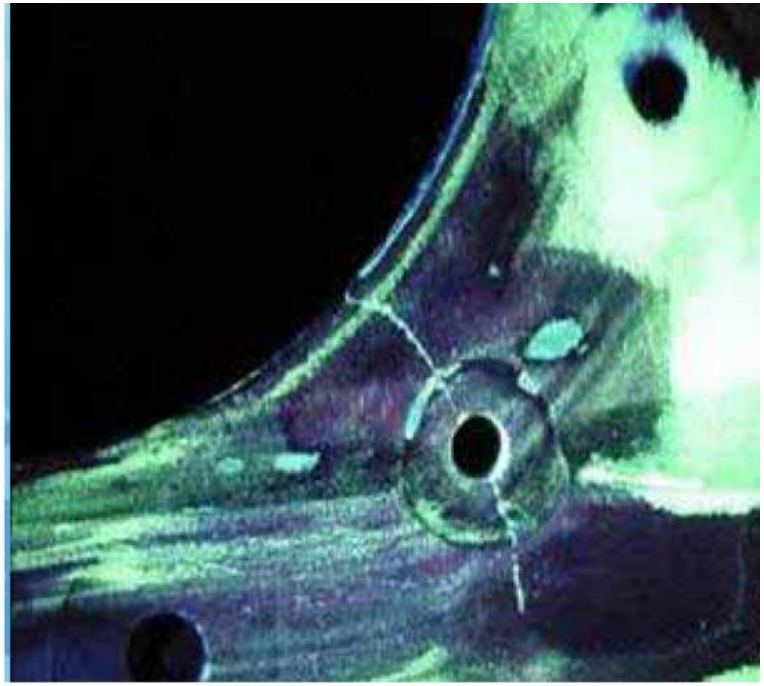


A-4 Application

MWM-Array Sensors to be installed under repair with access to connector

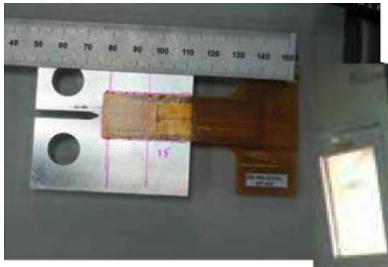


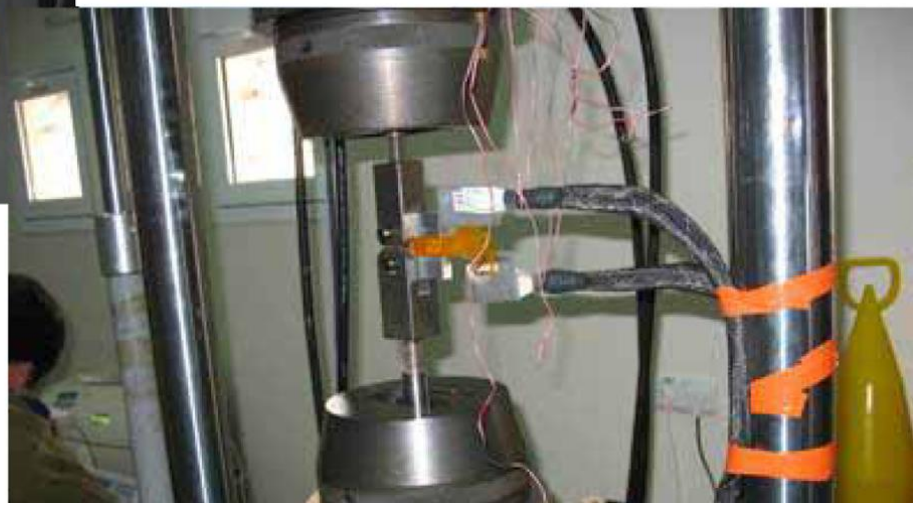
A-4 front spar cracking



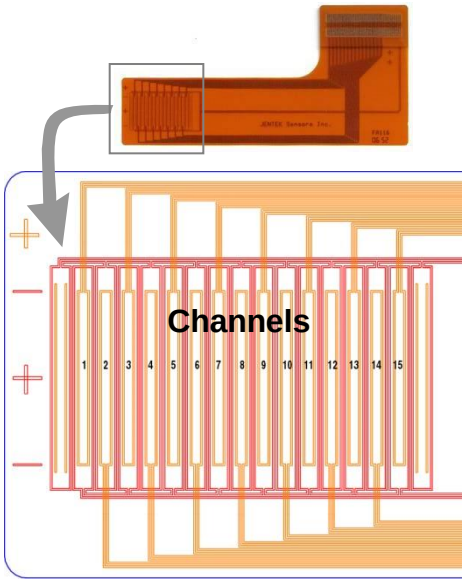
Photographs provided by IAF

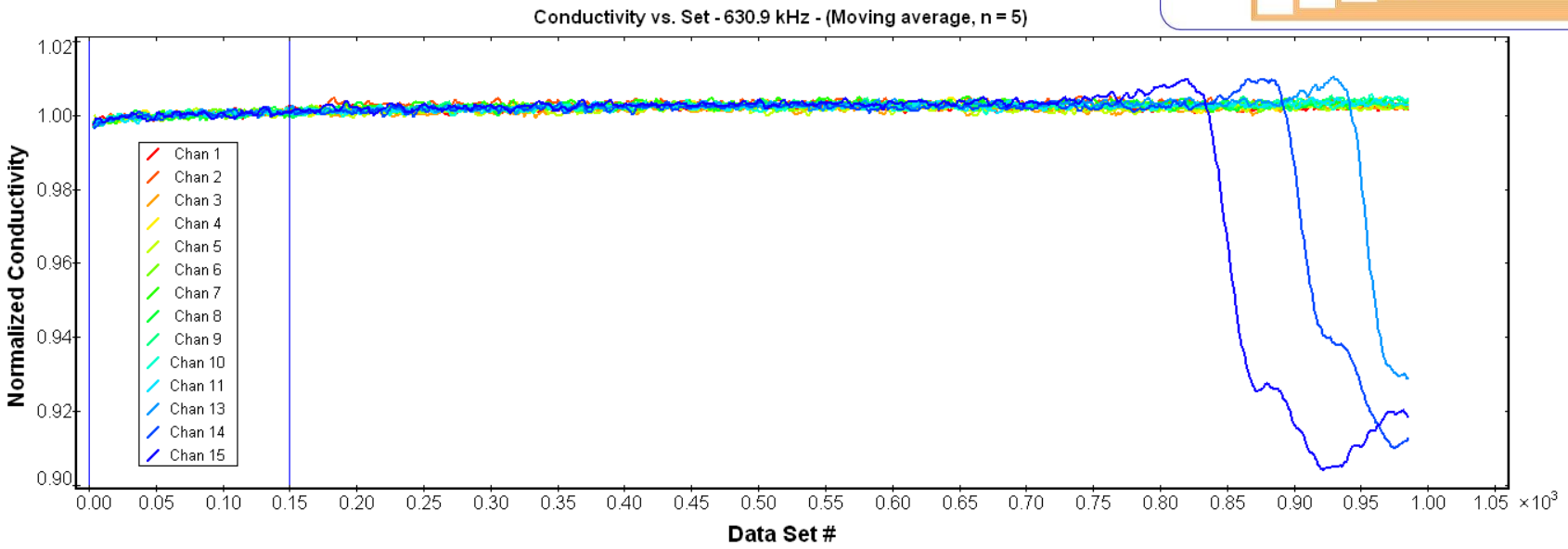
JENTEK/IAF Fatigue Test Results



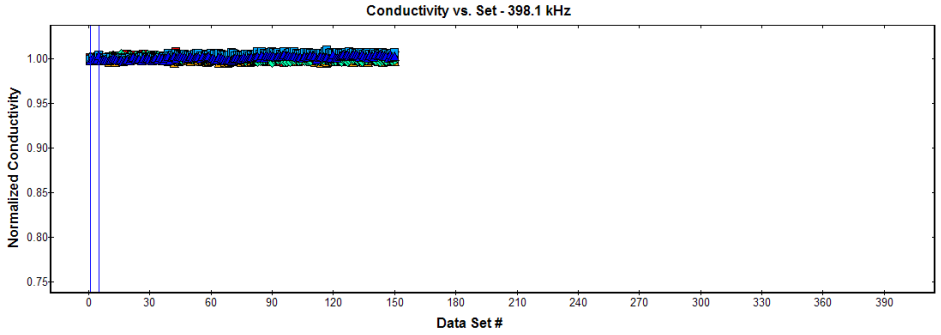


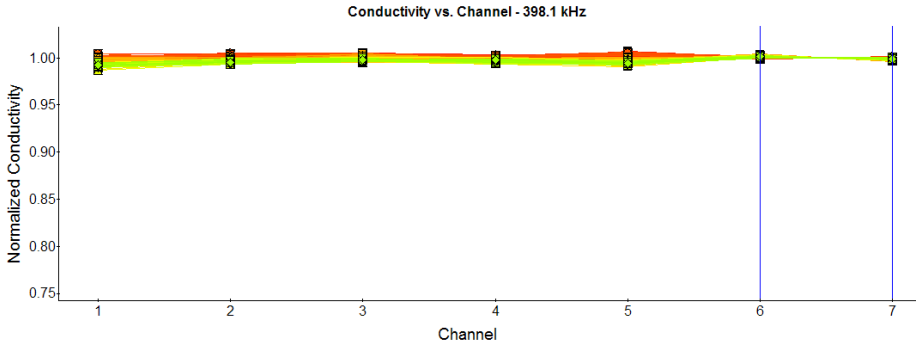
MWM-Array FA116

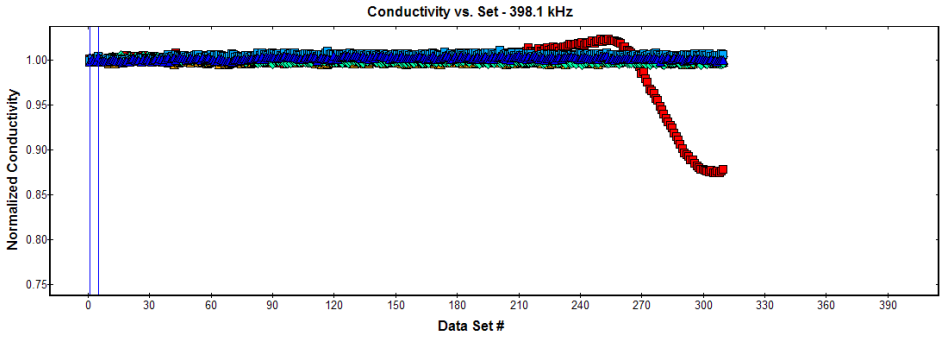


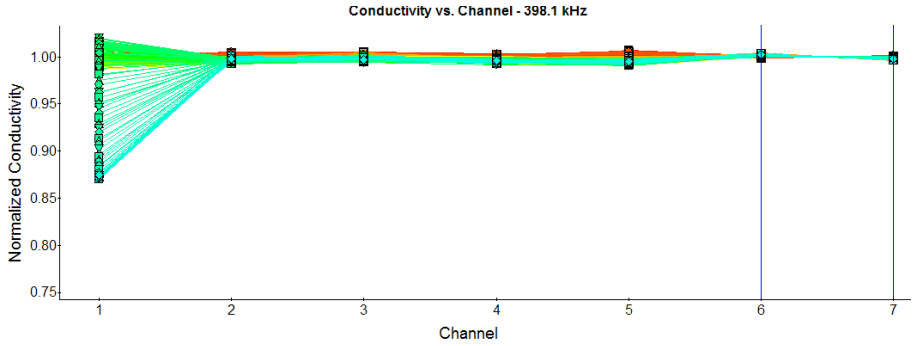


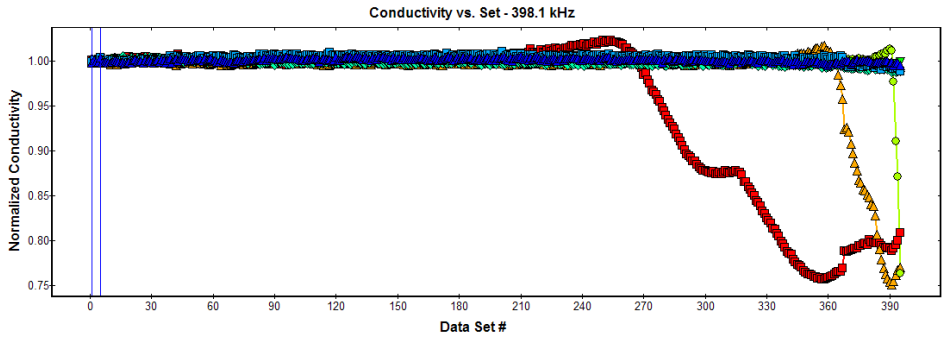
Continuous Monitoring: MWM-Array FA65

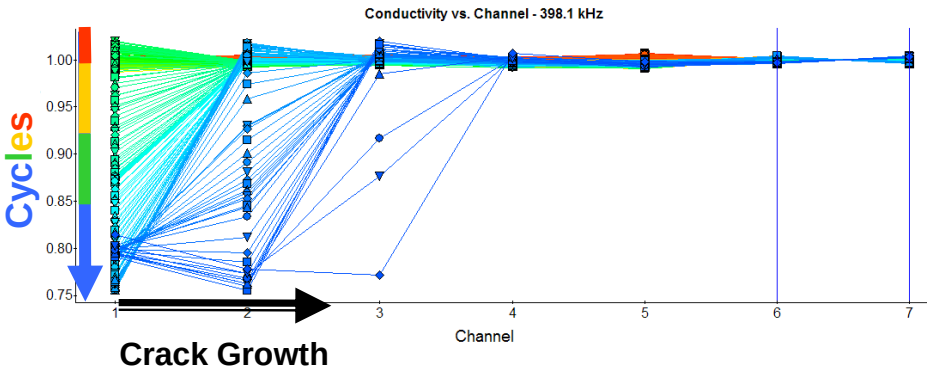






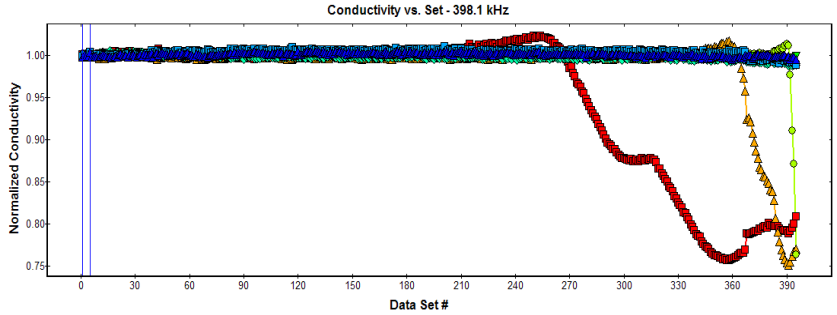


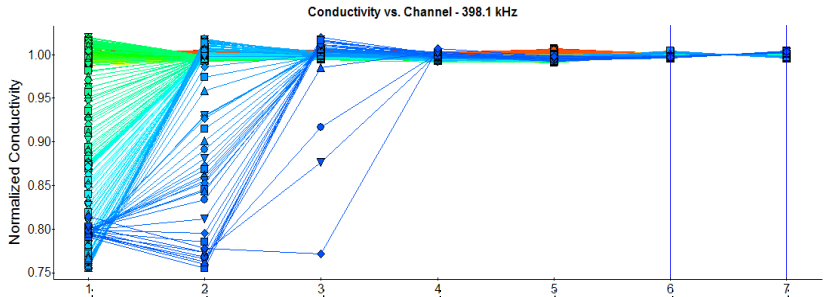


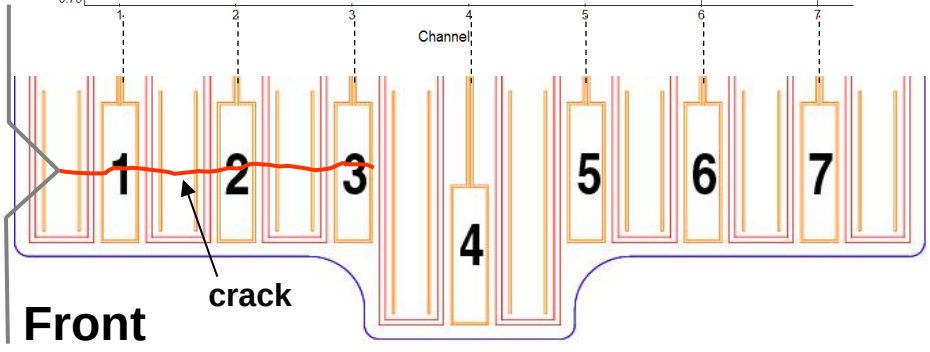


Recent IAF Fatigue Test
Compact Tension Specimen

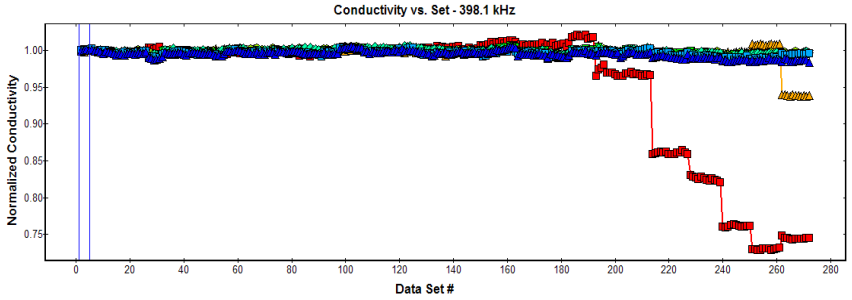
Continuous monitoring

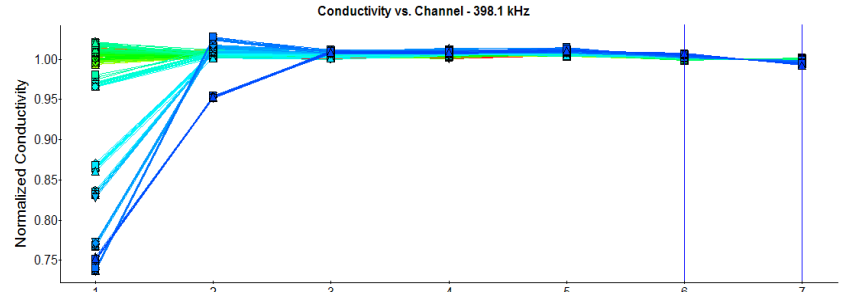


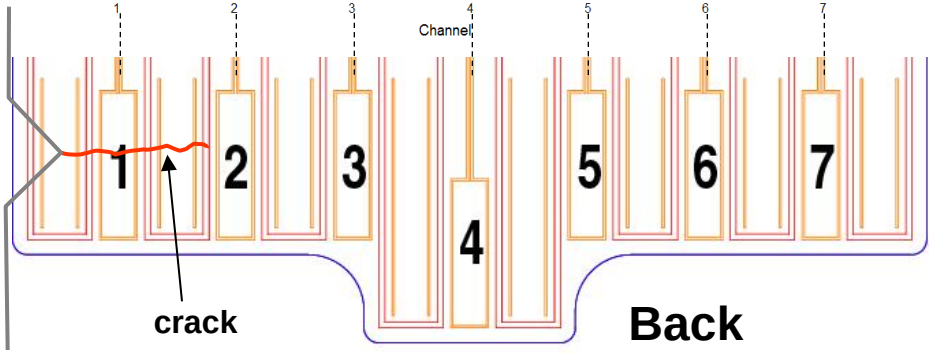




Scheduled inspections to simulate on-aircraft use

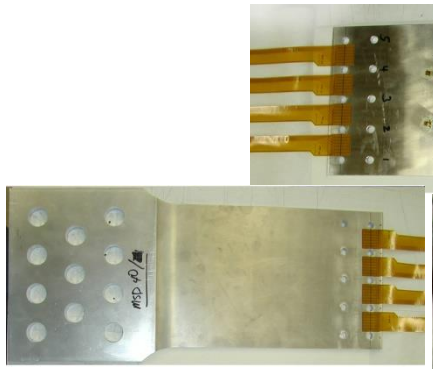






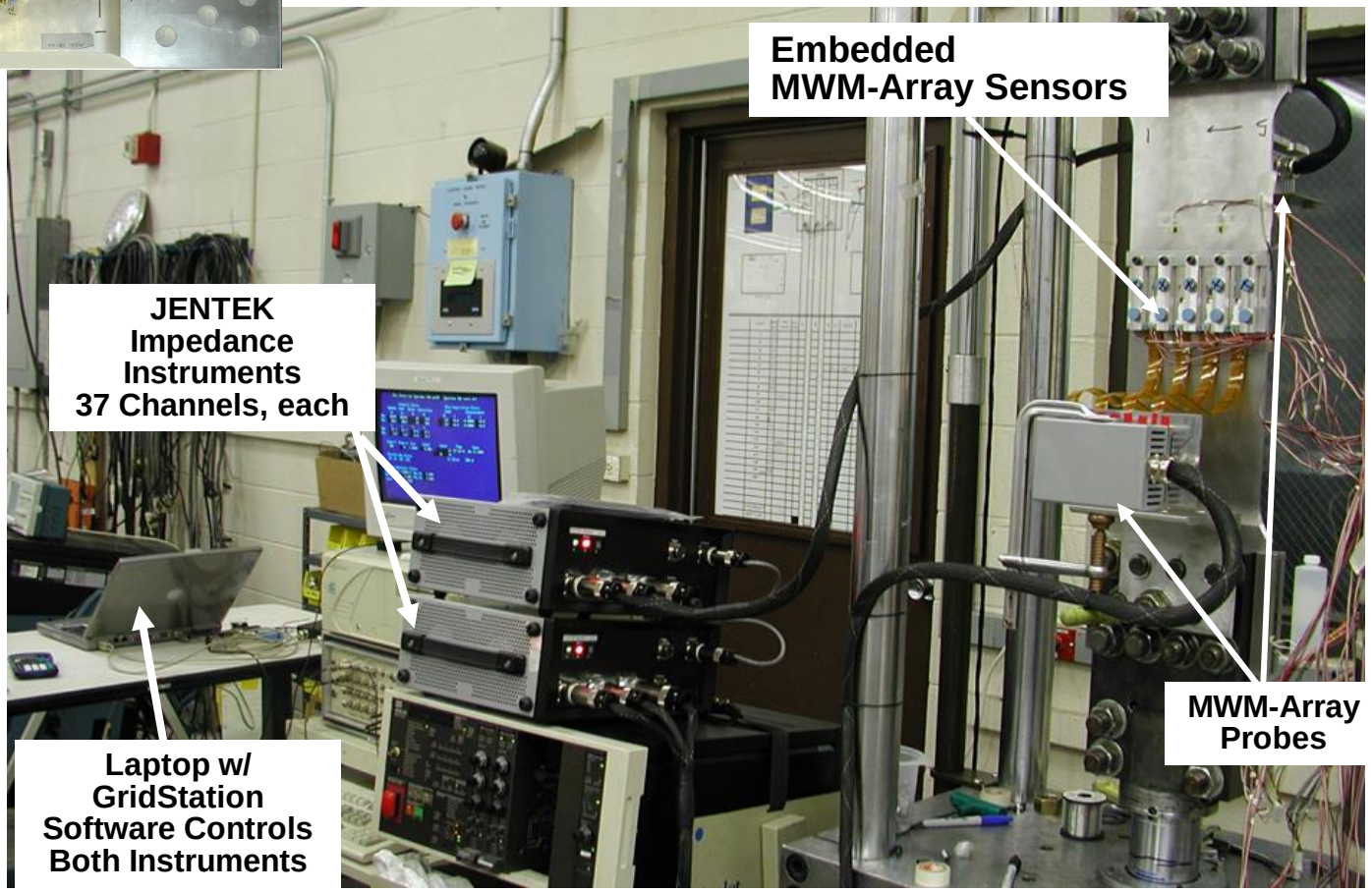
Previous Results for Multi-Site Fatigue Testing

Fatigue Test Monitoring: 10-Hole Specimen

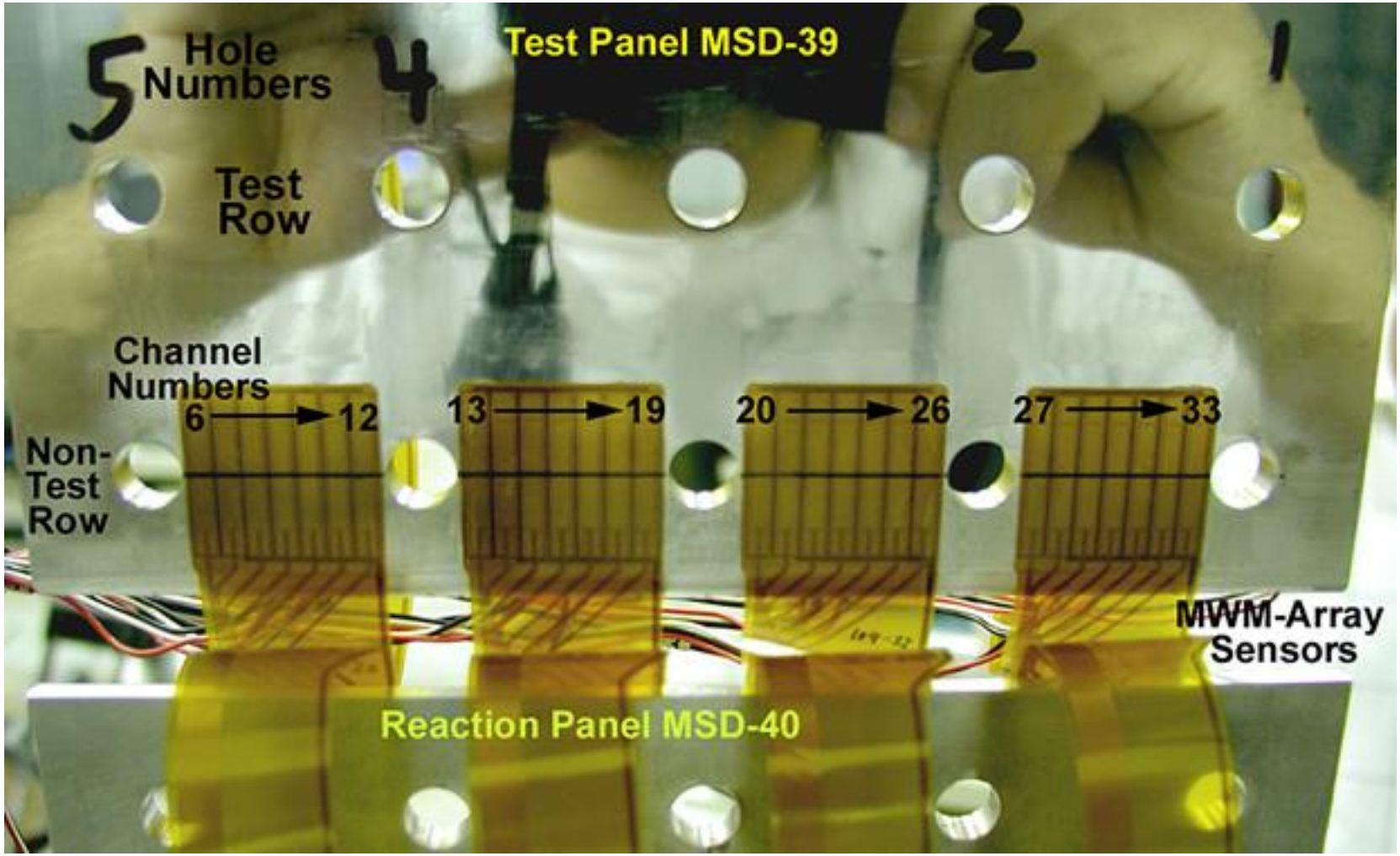


10-Hole Specimen with MWM-Array Networks

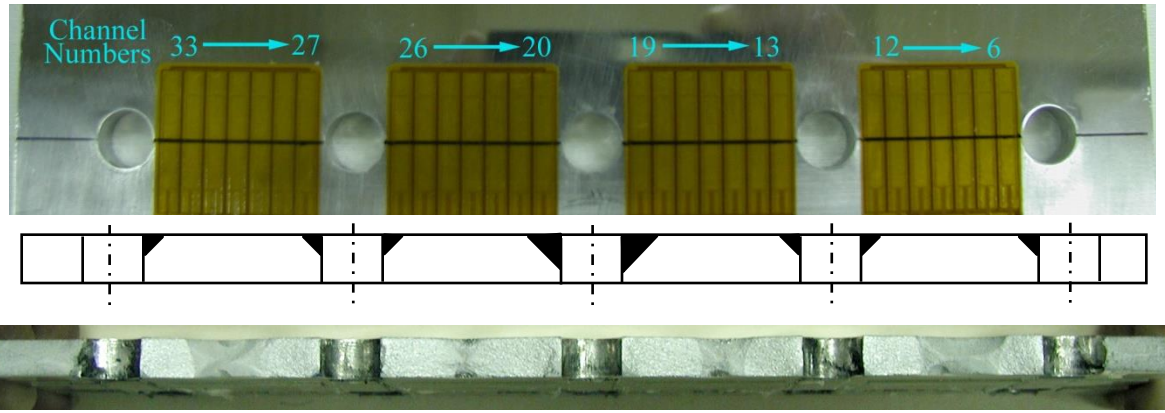
MWM-Array FA45

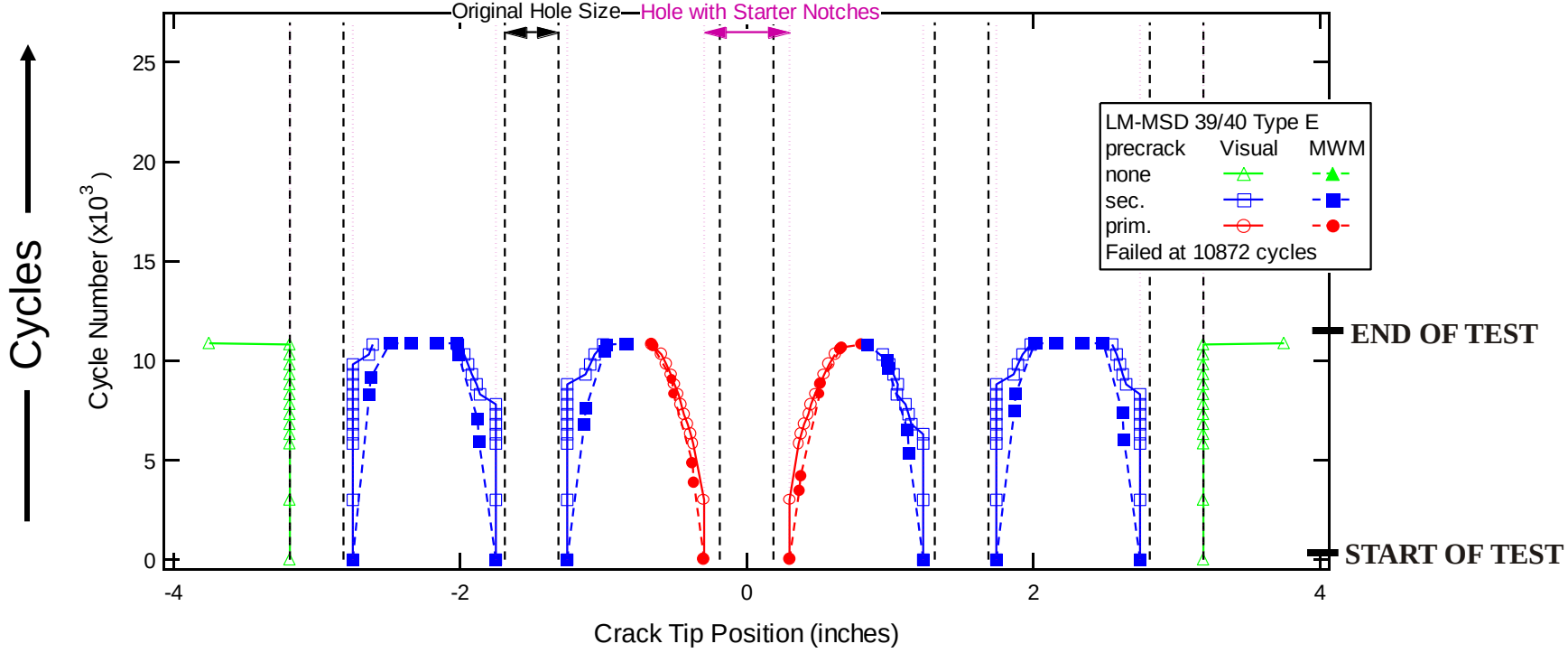


Four FA45 MWM-Arrays Mounted to Test Panel MSD-39

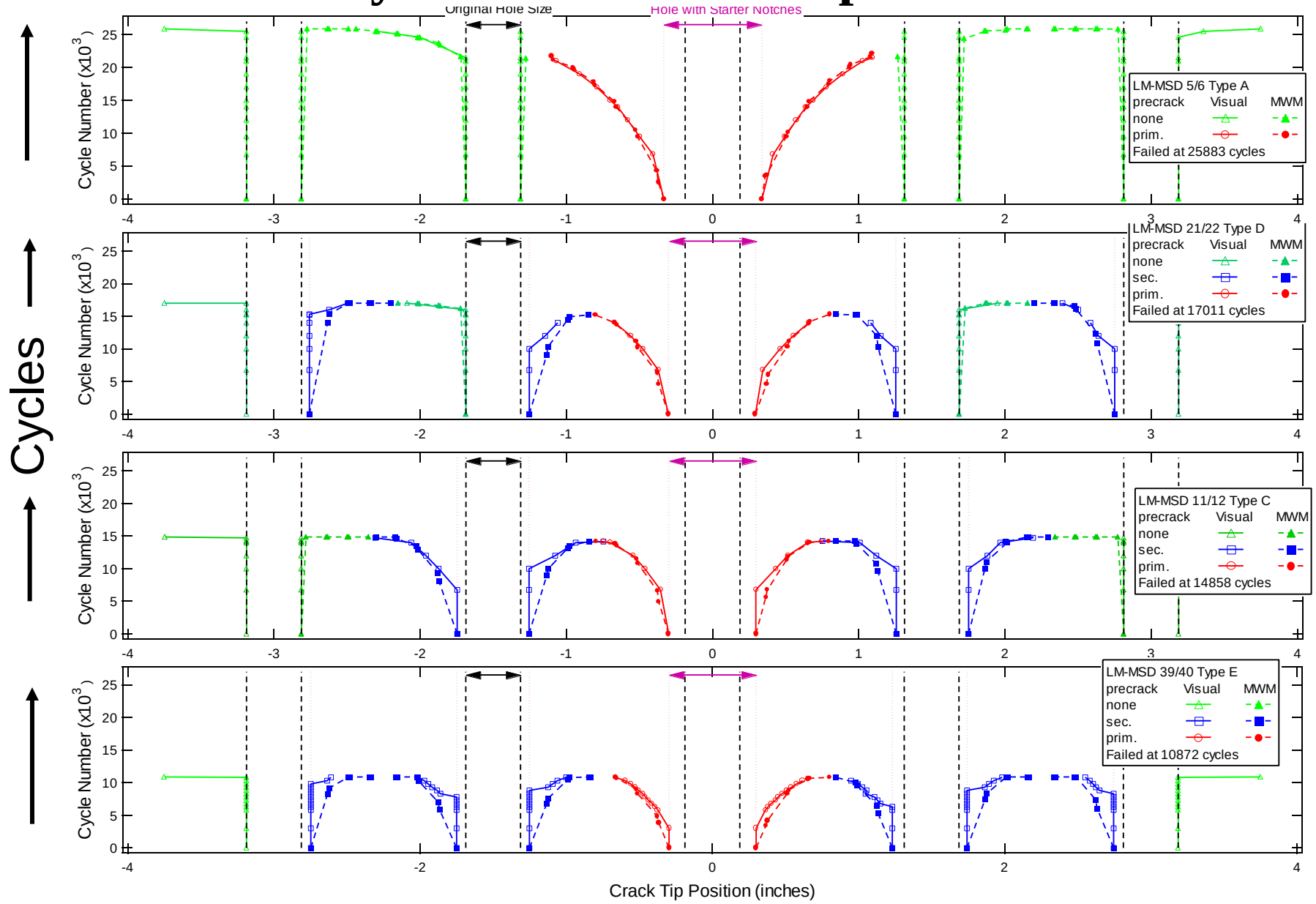


MWM-Array & Visual Crack Tip Position Results





MWM-Array & Visual Crack Tip Position Results

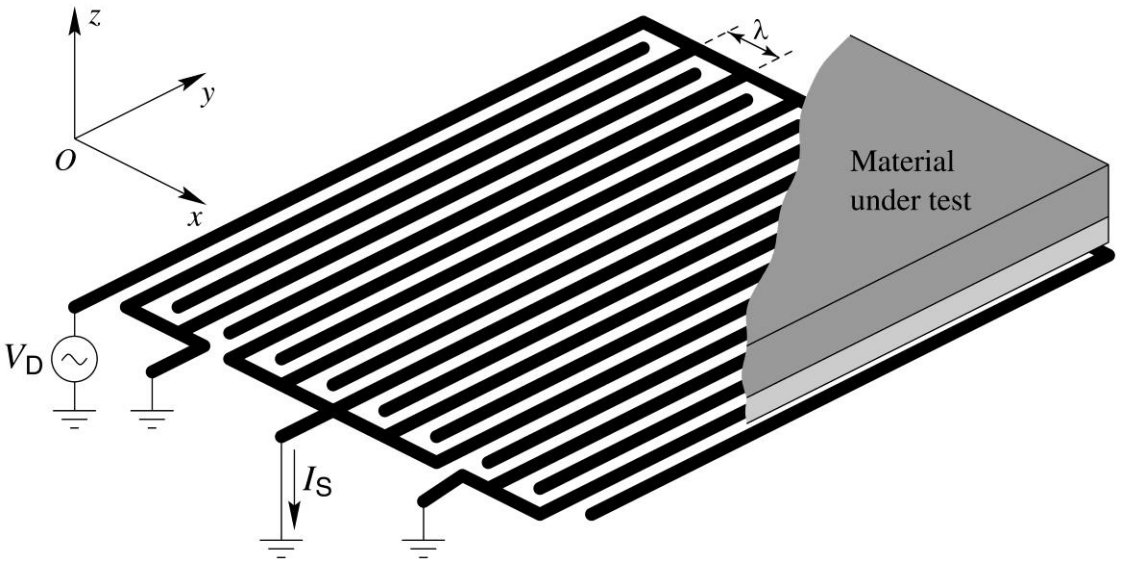


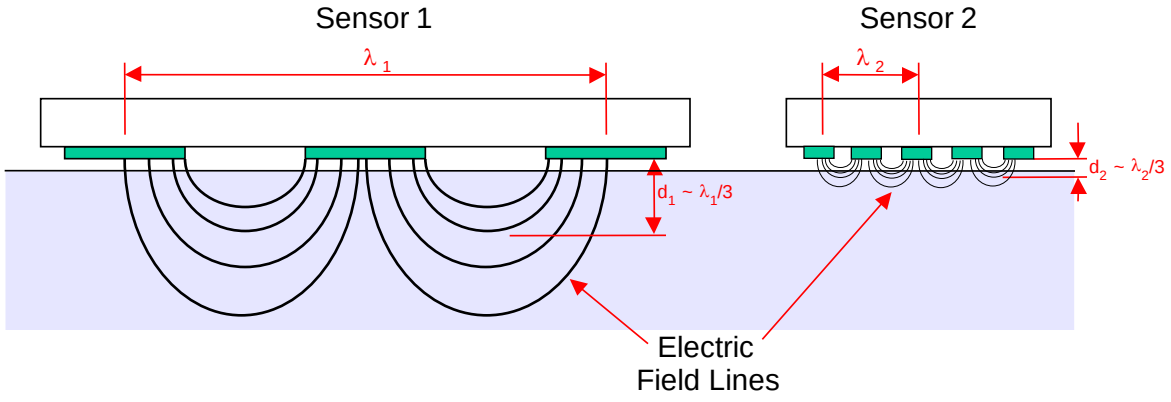
EQS: Interdigitated Electrode Dielectrometry (IDED®)

- Electric field based
- Material Properties:
  - Dielectric permittivity e, ohmic conductivity s

$$\varepsilon^* = \varepsilon' - j\varepsilon'' = \varepsilon' - j\frac{\sigma}{\omega}$$

  - Porosity, voids, delamination, etc. can affect these properties
- One-sided measurements
- Imposed spatial and temporal frequencies
  - longer wavelengths penetrate further
  - spatial profiling

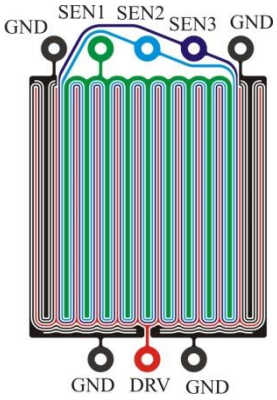




Three-Wavelength, IDED Constructs

Single-Sided Capacitive Monitoring and Imaging

- **Single Sensing Element**

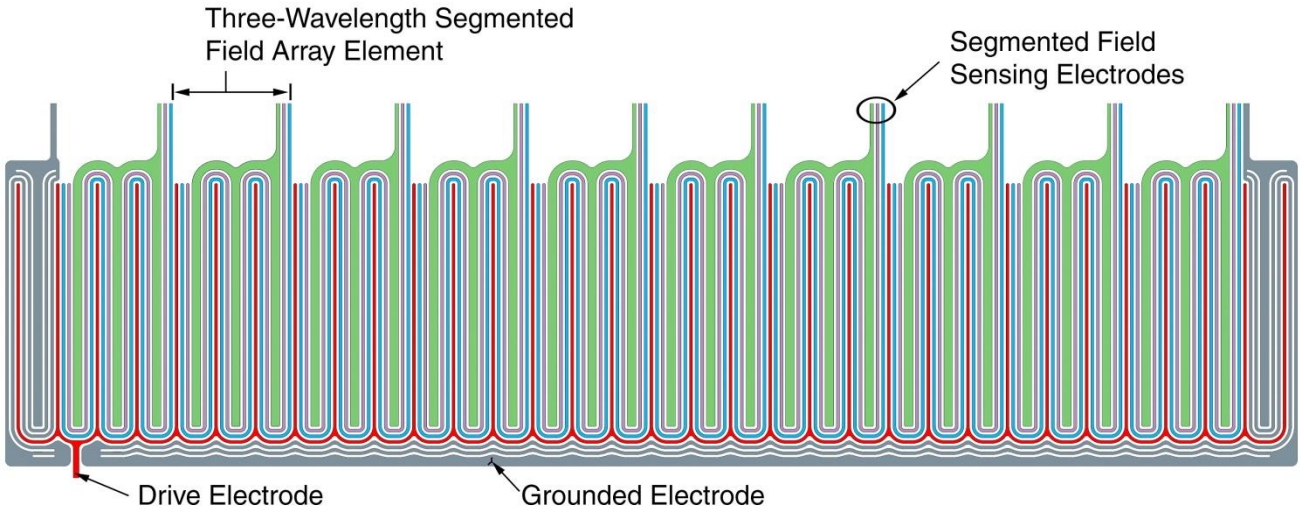


DS03

Flexible Dielectrometer

DS04

- **Array**



Embedded Sealant Monitoring

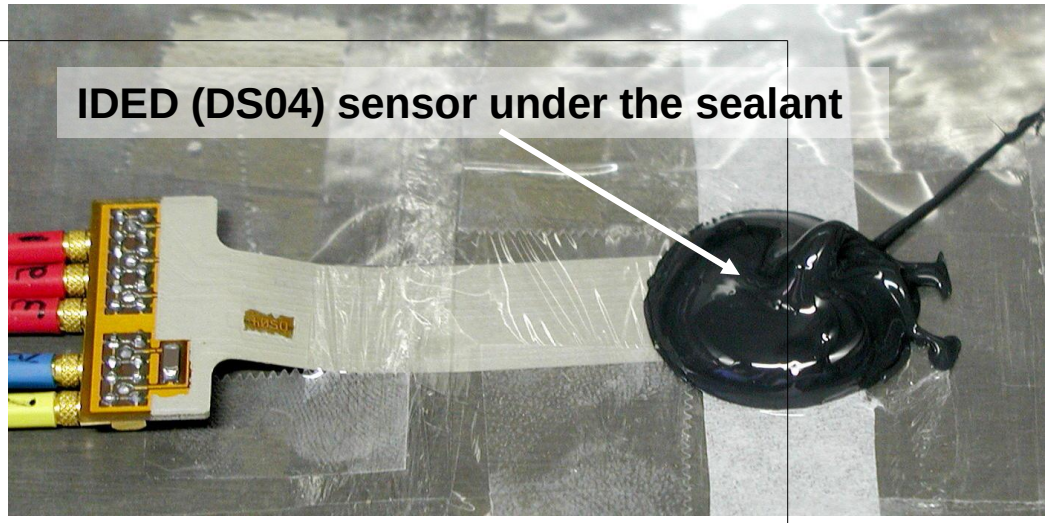
Components

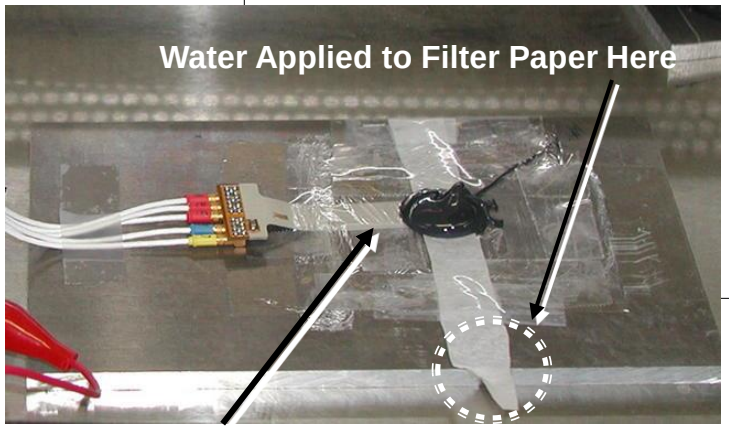
Sealant: PR 1826 Class B (DeSoto International) provided by Lockheed Martin. It is a 2-part, epoxy cured polythioether compound used for aircraft fuel tanks and structures.

Sensor: IDED dielectrometer DS04, three spatial wavelength sensor.

Metal: Aluminum alloy plate provided by Lockheed Martin.

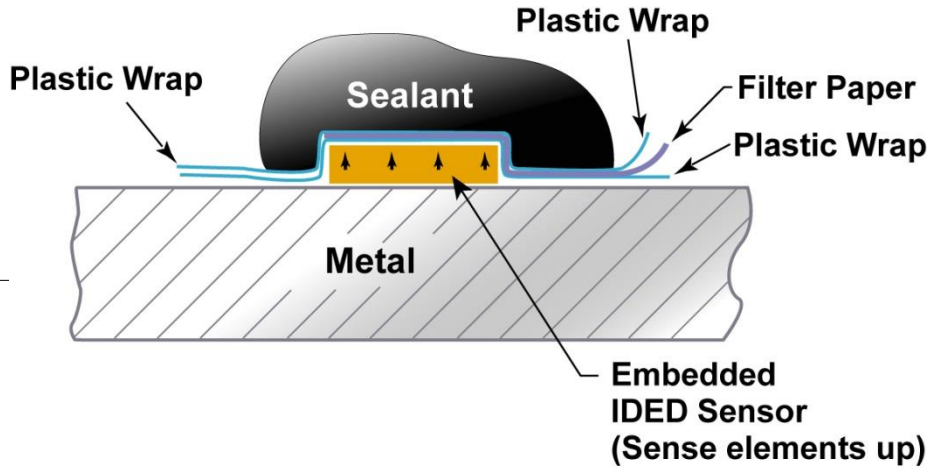
View of IDED Sensor Embedded Under Sealant





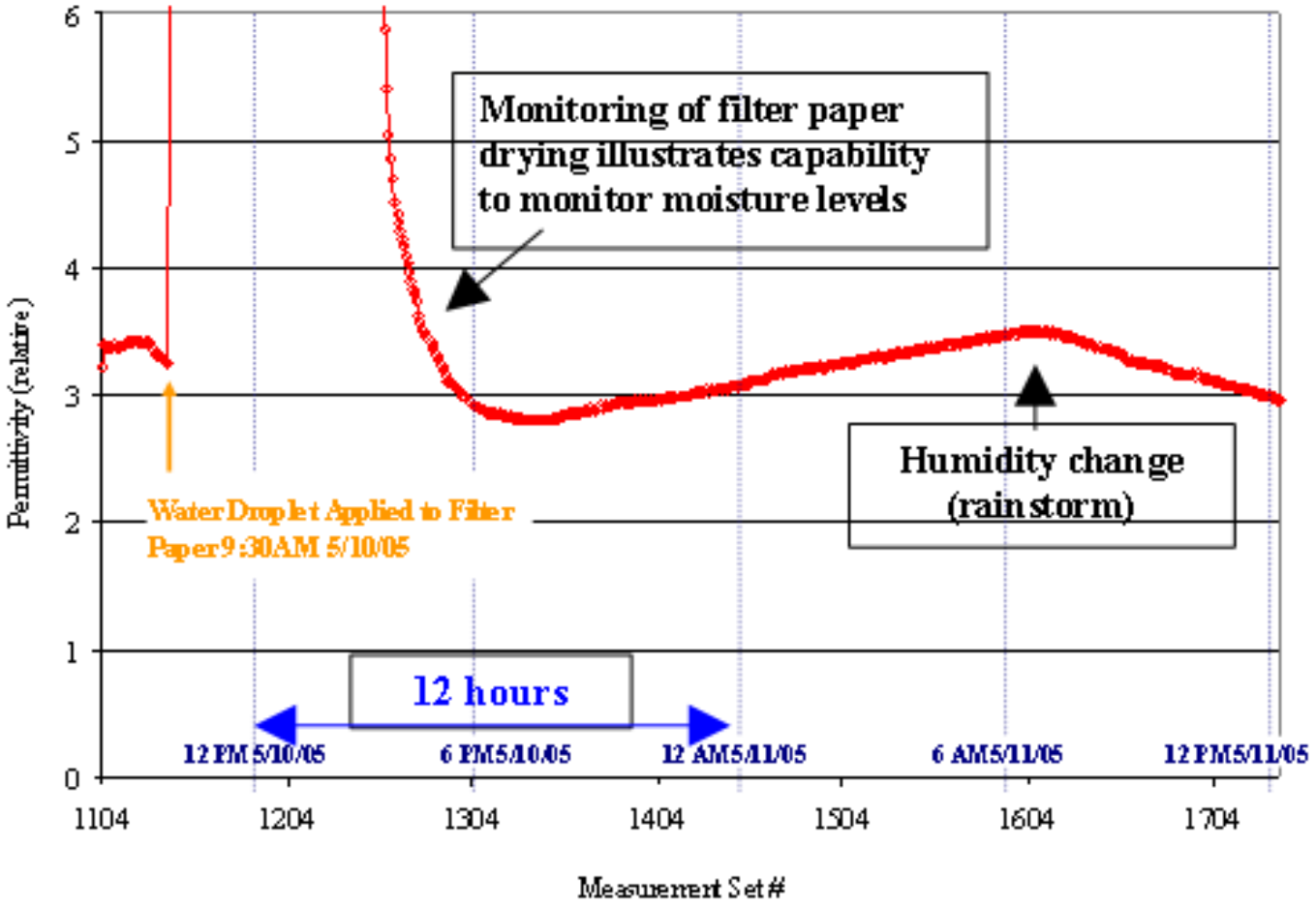
IDED (DS04) sensor

Cross Sectional Representation



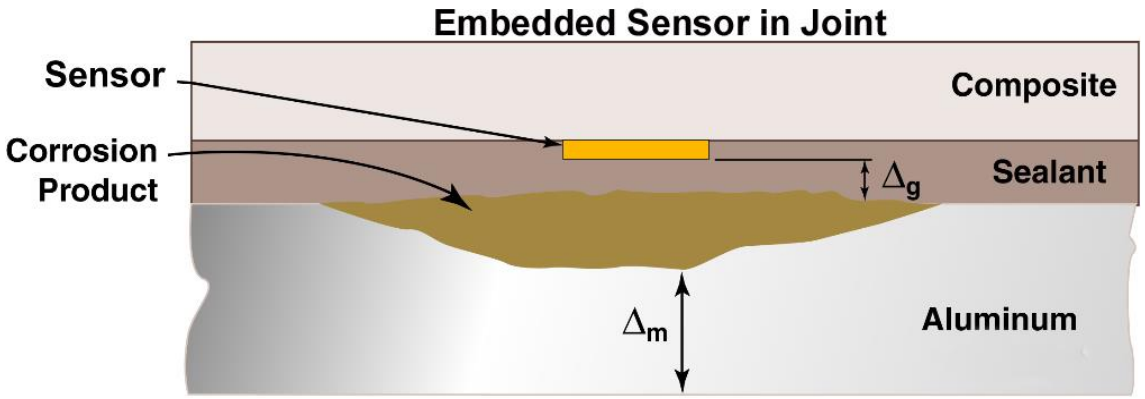
Real Time In-Process Monitoring

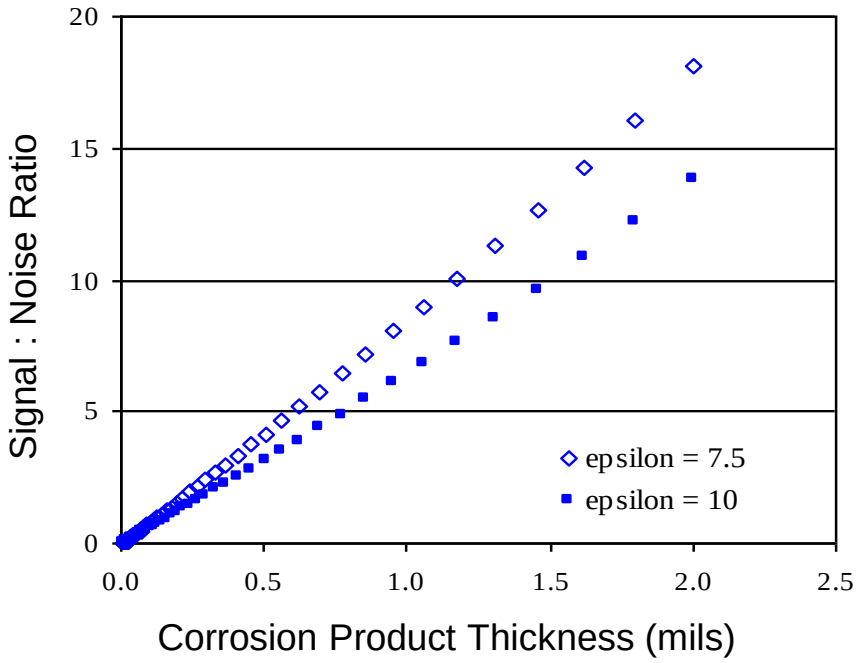
- Embedded IDED for monitoring moisture diffusion transient
  - Water added to filter paper to represent moisture change penetrating sealant



Corrosion Product Monitoring

- Simulated use of an IDED to monitor formation of corrosion products
- Assumed an aluminum surface with an IDED embedded at the top of the CPC
- The IDED responds to the thickness and dielectric constant difference between the CPC and the product layer





Need Addressed

Need/Problem:

Inspect for cracks at

- Numerous local and distributed features
- In difficult-to-access locations
- Without disassembly for inspection

Solutions:

1) **Portable Data Logger**
   - Embedded MWM-Arrays and MWM-Rosettes (eddy current sensors) and
   - Light weight cabling with
   - Distributed multiplexing (MUX) units
   - NDT data acquisition from easy access locations
2) **Embedded Data Logger** for continual in-flight or only ground-based NDT

Questions?