Electrochemical Impedance Sensors to Detect Corrosion, Coating Degradation, and Moisture Intrusion into Composites and Adhesive Bonds

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In-situ Corrosion Sensors

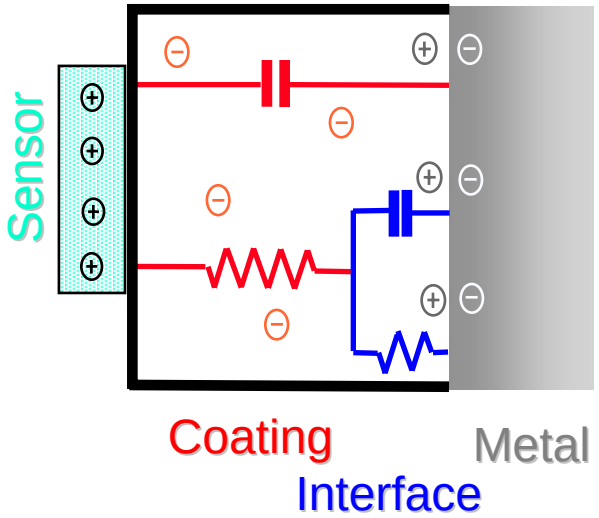
DSI

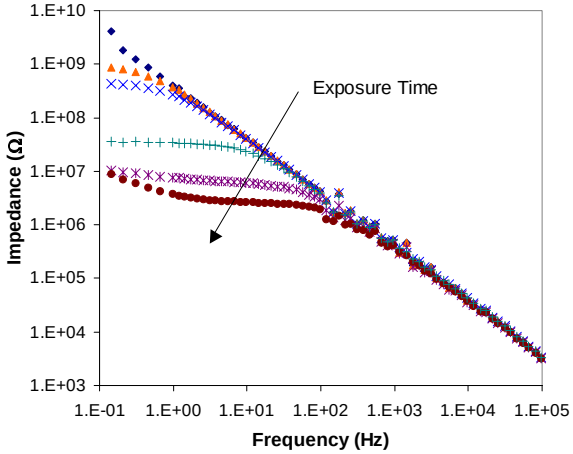
- Patented *In-Situ* Corrosion Sensors
  - Coating screening
  - Laboratory accelerated test validation
  - Health monitoring/Prognosis
    - » Coatings
    - » Adhesive bonds
    - » Composites
- Based on Electrochemical Impedance Spectroscopy (EIS)
  - Extends laboratory technique to field
- Detect degradation of structure/material of interest, not of sensor or witness material like corrosivity sensors
- Suitable for use with any commercial potentiostat

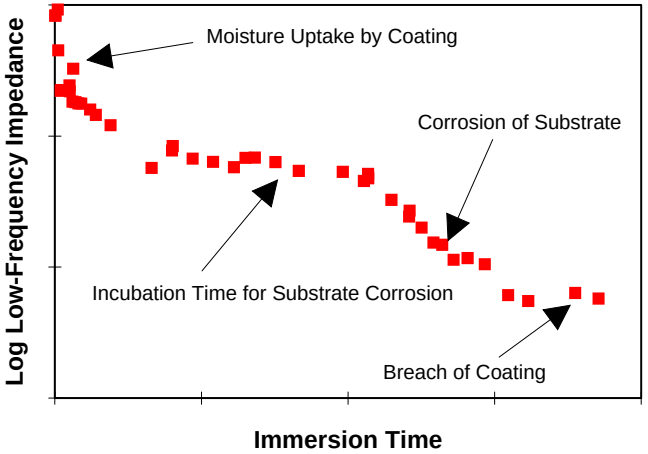
In-Situ Sensor Monitors Corrosion with Electrochemistry

DSI

- Sensor uses Electrochemical Impedance Spectroscopy (EIS) to monitor corrosion and paint degradation of actual structures
- A small ac voltage is applied to the coated metal. The response can be modeled as an electric circuit
- Impedance of coated structure gives early measure of deterioration before visual indications and can predict performance







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Sensor is Major Improvement Over Conventional EIS

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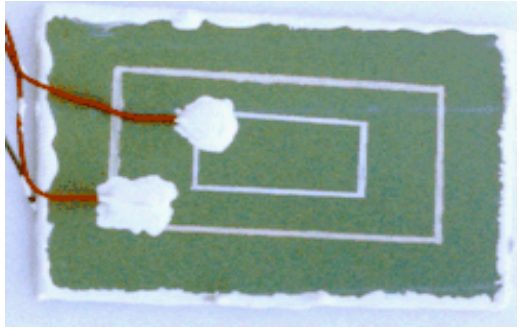
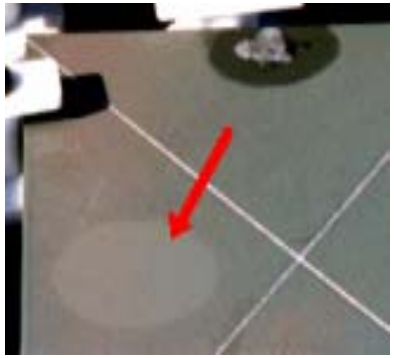
- DSI Corrosion Sensor
  - Field or test chamber or immersion
  - Permanent electrode for inaccessible regions or portable electrode for convenient areas
  - Arbitrary structure configuration
  - Detection area can be large
- Conventional EIS
  - Requires immersion or clamp-on liquid cell
  - Cell requires accessible, flat, horizontal area and messy electrolyte
  - Coating is monitored only where exposed to electrolyte
  - Coating can suffer artifactual damage





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Different Sensor Versions Meet Different Needs

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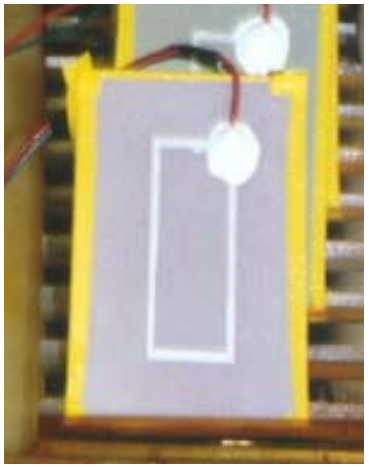
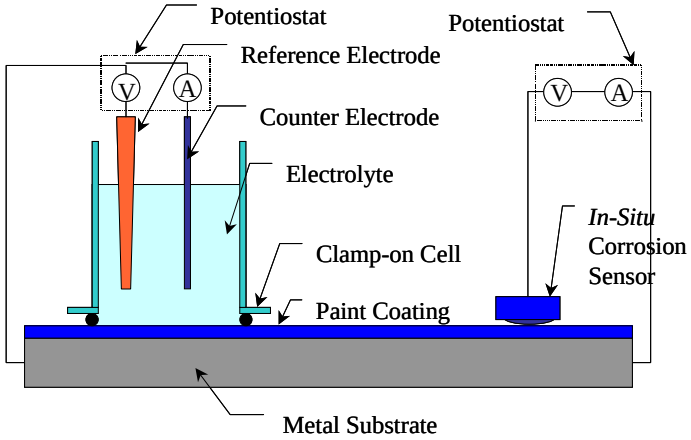
- Permanent
- Handheld/portable
- Semipermanent (tape)





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Advantages of *In-Situ* Sensor

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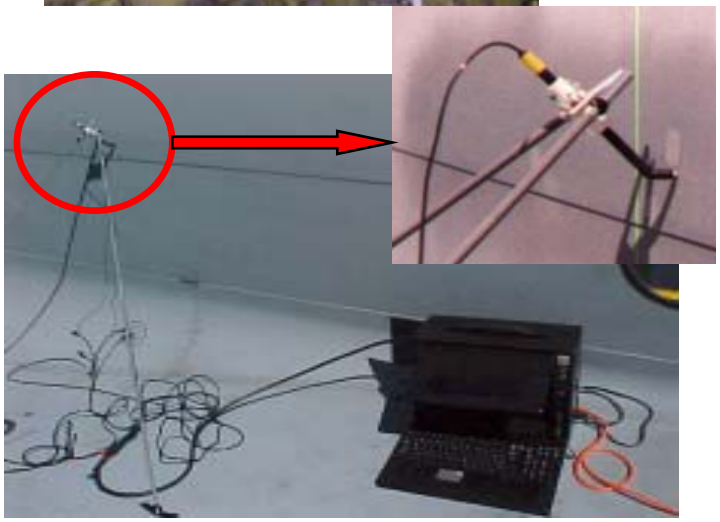
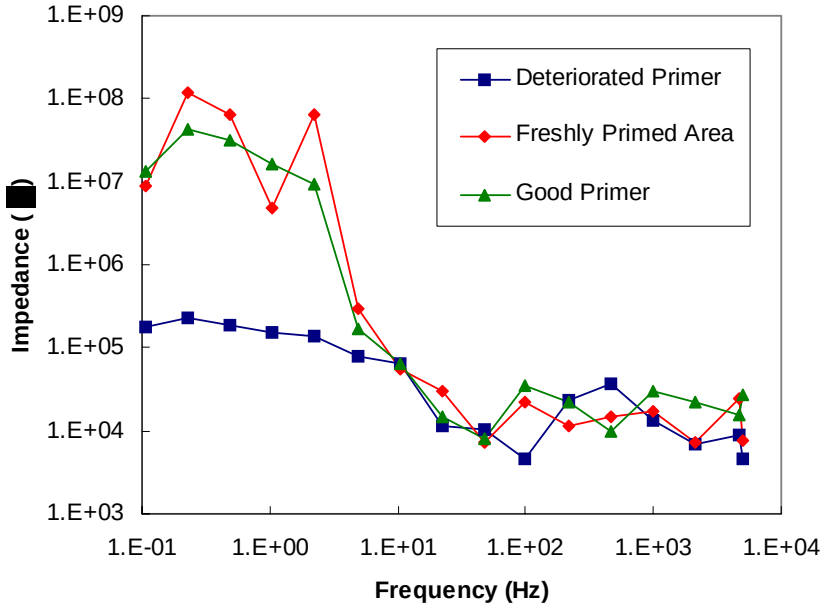
- Sensor directly measures coating degradation and substrate corrosion on the structure of interest
- Sensor detects early stages of degradation before serious damage
- Sensor is suitable for one-time measurement (Sensor does not have to be left in place to allow it to degrade)
- Sensor is suitable for a wide range of environments, including ambient service and accelerated testing
- Painted sensor can be mounted
  - in inaccessible areas of a structure
  - inside test chamber for true *in-situ* measurements
- Handheld sensor is pressed against surface for short time only
- Range of detection is controllable
- Sensor can also detect moisture in composites and adhesive bonds

Inspection of Aircraft

- Inspection of C-135 / KC-135 aircraft at Tinker and Hickam AFB distinguished between good and deteriorated coatings





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Predictive Assessment of Accelerated Laboratory Tests

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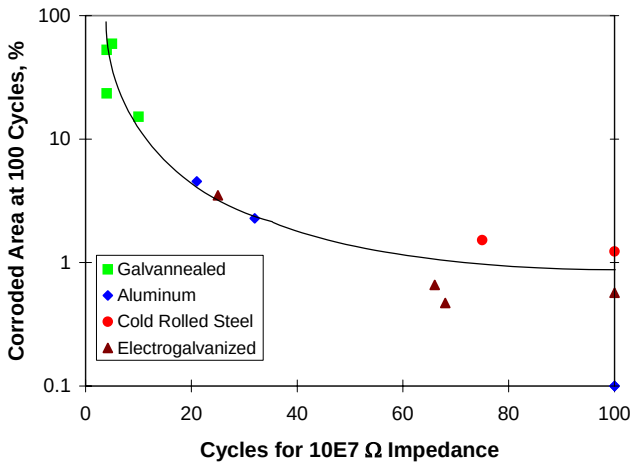
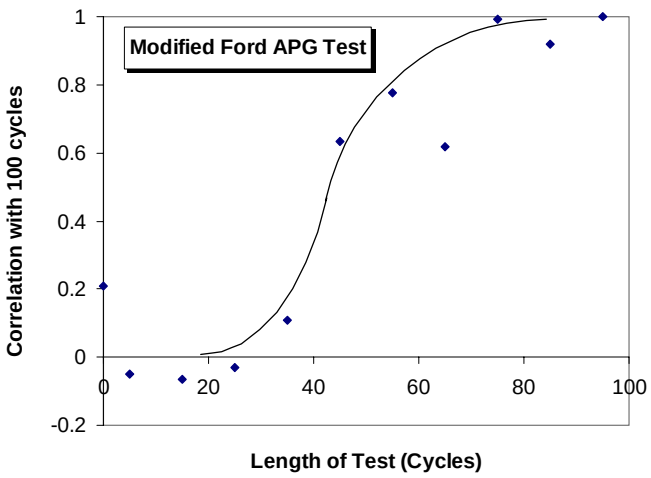
- Cyclic accelerated corrosion test correlates with field performance but is 100 cycles (days) long
- Sensor measurements during test predict amount of corrosion after 100 days
- Excellent correlation is seen between intermediate times (>50 days) suggesting that the test could be shortened.





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Sensor Allows Comparison of Lab Tests and Field Exposures

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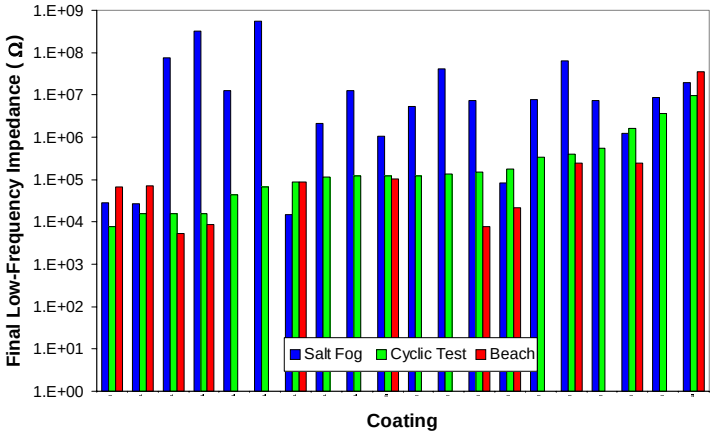
- Cyclic automotive test correlates with beach exposure at KSC
- Salt fog, immersion, and humidity tests give poor simulation to field exposure



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Competing Sensor Technologies

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- Corrosivity Sensors
  - Measure corrosion of a sensor component, not of the structure being inspected
    - » Galvanic couple
    - » EIS of sensor electrodes on chip
    - » Fiber optic coating
    - » Piezoelectric oscillator
  - Require elapsed time; not suitable for one time measurement
  - Measure environmental conditions
    - » Time of wetness
    - » pH, T, Cl^-, etc.
  - Not suitable for materials evaluation/screening

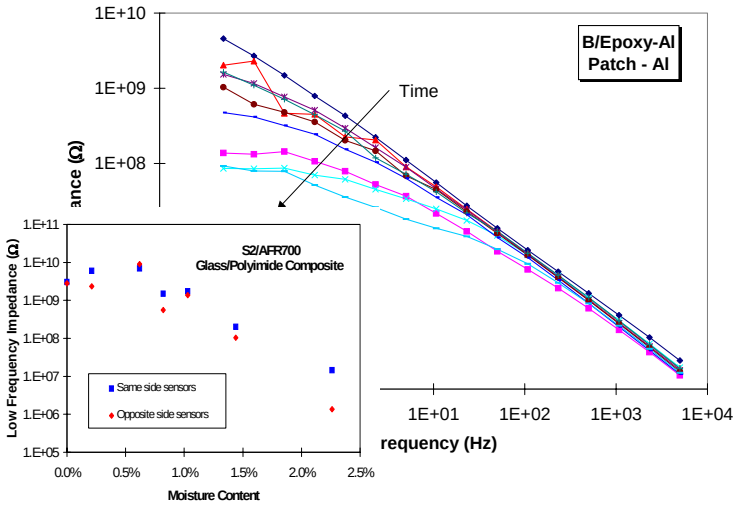
Competing Sensor Technologies

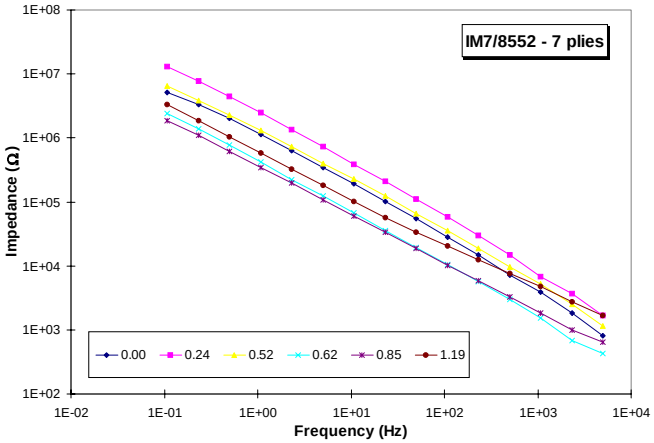
DSI

- Sensing Paint Systems
  - Fluorescent dyes in paint/primer detect pH changes or metal ions at interface
  - Measure actual corrosion, but require visual access: direct or embedded fiber optics
  - Limited to doped paint systems
- Traditional NDE techniques
  - Require significant material loss (>5%) or interfacial delamination
    - » Ultrasonics
    - » Thermography
    - » Metrology
    - » X-rays

Moisture in Composites

- GRP and BRP behave like coatings
  - Low-freq. impedance is a strong function of moisture
- CRP maintain capacitive behavior
  - Capacitance (CPE) is function of moisture
- Circuit modeling allows moisture levels to be calculated





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North Island Demonstration

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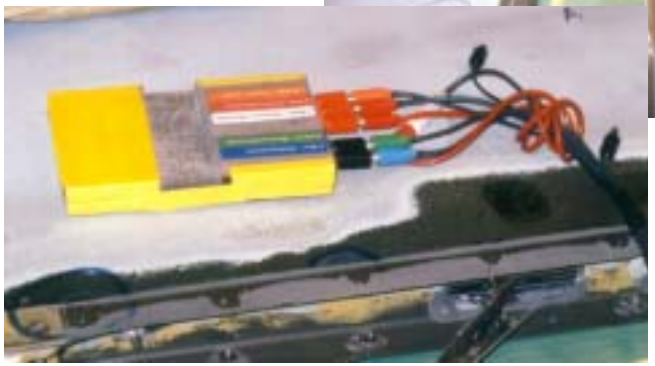
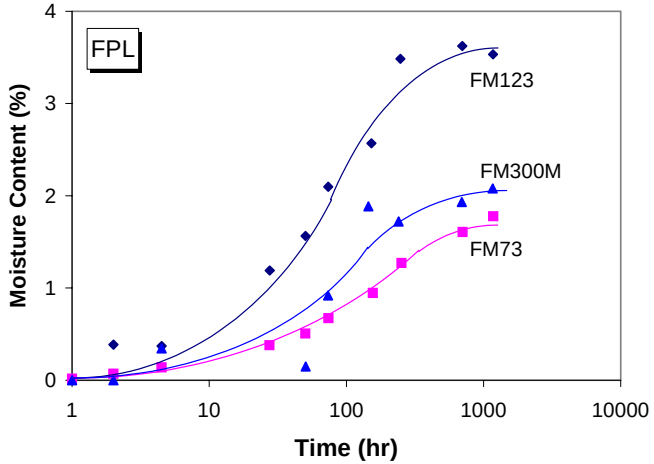
- Prototype sensor was used at North Island NADEP to inspect F/A-18 rudder.
- Sensor worked best on bare graphite/epoxy
  - 1.3% moisture detected based on laboratory honeycomb database

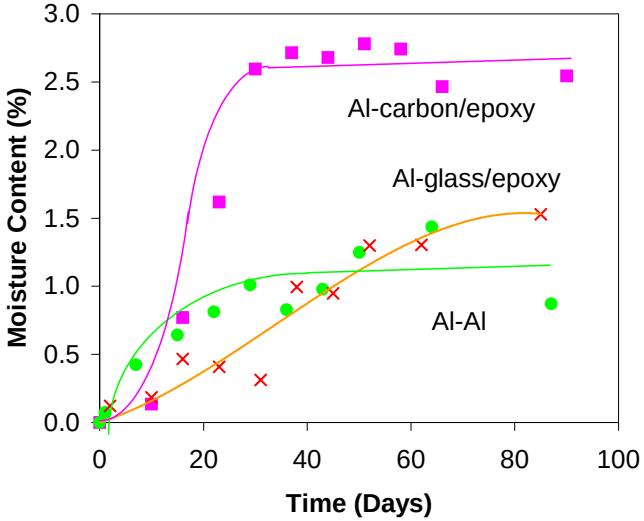


Sensor Detects Moisture Intrusion into Adhesive Bonds

DSI

- Moisture levels can be calculated from capacitance values
- Moisture uptake depends on adhesive and adherend material





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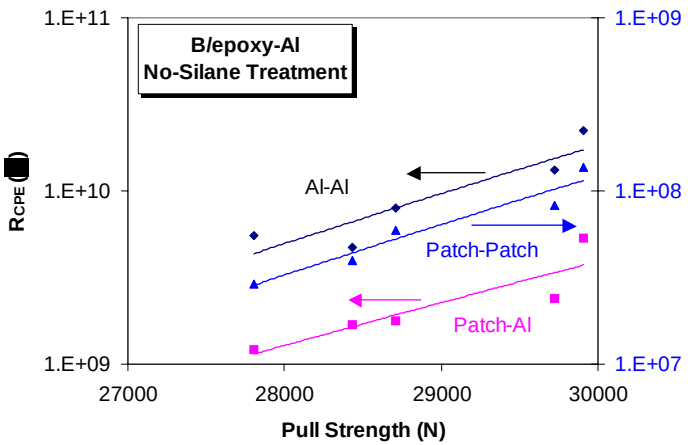
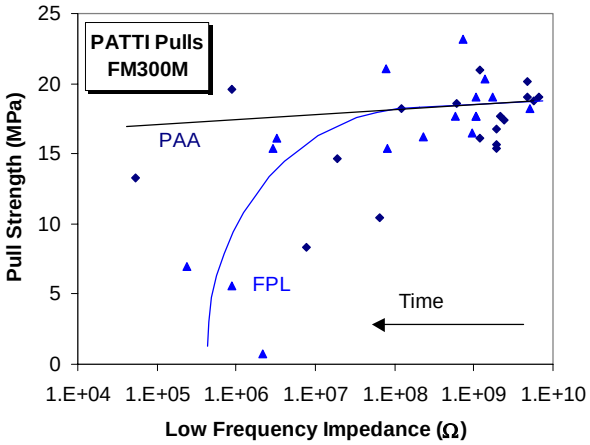
Bond Performance

- Different impedance spectra parameters correlate with bond performance
  - Plasticization of adhesive
  - Hydration/corrosion of adherend
- Ample warning given before serious bond degradation





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Marketing Opportunities

- DACCO SCI is interested in possible teaming, partnering, licensing opportunities
  - DARPA Prognosis BAA
  - Health monitoring
  - Materials screening