U.S. ARMY COMBAT CAPABILITIES DEVELOPMENT COMMAND – GROUND VEHICLE SYSTEMS CENTER

Corrosion Detection Under Coatings – FY17 CTMA Project

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WHY NEEDED?

- Predict the rate of corrosion and residual service life on Ground Vehicle Systems

- Early field detection of corrosion, enabling:
  - optimized maintenance scheduling
  - reduced maintenance costs
  - prolonged life of assets

- Determine the amount of corrosion on test panels or test vehicles without coating removal or destructive evaluation

DESIRED RESULTS

Identify, evaluate, develop and implement multiple Non-Destructive Examination (NDE) techniques that can aid in the detection /characterization of corrosion under coatings and benchmark their performance with respect to detection limits and resolution.

Identify coating formulation techniques that might enhance sensitivity of NDE techniques

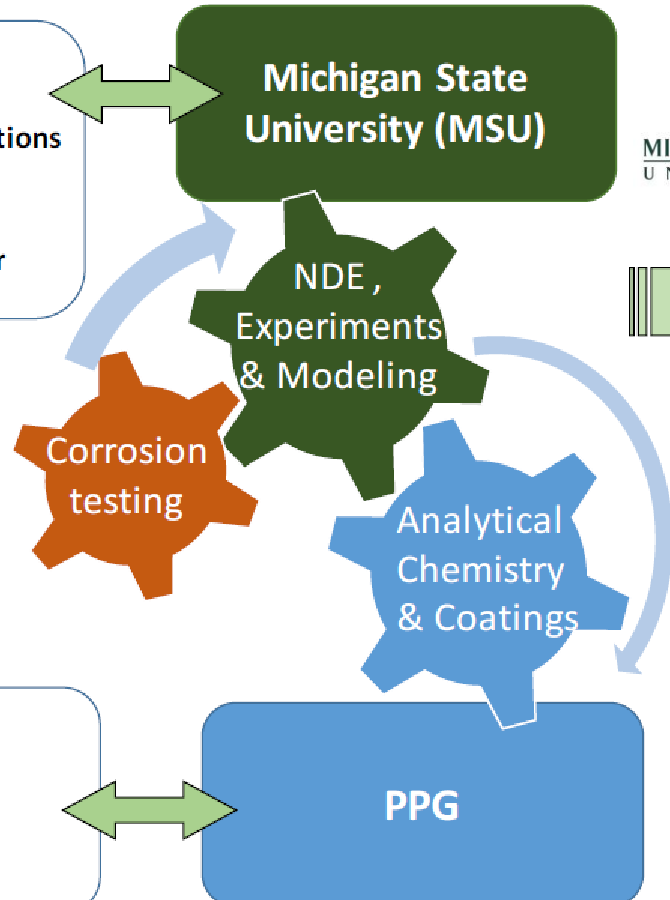
Ultimately, develop a field-deployable NDE tool to detect and monitor corrosion under coatings.

SCOPE

NCMS – TARDEC Contract

MSU and PPG subcontracted to NCMS

- Multiple NDE Techniques
- Robust Signal Processing
- Integrated Experiments and Simulations
- Prognosis and Residual Life
- Novel Technique Developments
- Path for Prototype development for possible field-deployment



- Advanced / Tailored Coatings
- Sample Preparation
- Accelerated Corrosion
- Coating Interpretations

OUTCOMES

- New Analytical tools
- Accelerated Development
- Path for field deployable NDE
- Dissemination of Results

SCOPE

<u>Project Objectives</u>:

- Objective 1: Evaluation of existing NDE techniques and computational tools for corrosion detection and assessment with respect to their **effectiveness, limitations, strengths and applicability** with an aim to identifying the optimal methodology.

- Objective 2: **Design of experiments** to take into account the types of substrates, coatings, resulting components (joints for galvanic corrosion) and level/degree of corrosion growth.

- Objective 3: Narrow down **constraints** such as accessibility, sample/component geometry, sensor sizes, resolution expected, measuring environment, etc.

- Objective 4: Develop **computational models** for conducting parametric studies that will aid in the sensor development and signal interpretation.

- Objective 5: Develop **signal processing algorithms** for diagnosis and prognosis.

SCOPE

Task #	Task Description	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8
1	Survey of available and emerging NDE across academia, business and government organizations. A survey of available and emerging NDE across academia, business and government organizations will be evaluated with respect to resolution and sensitivity of a given technique against commonly encountered coating and corrosion related defects.		*						
2	Evaluation of electromagnetic NDE techniques and computational tools for corrosion detection and assessment with respect to their effectiveness, limitations, strengths and applicability.				*				
3	Evaluation of ultrasonic NDE techniques and computational tools for corrosion detection and assessment with respect to their effectiveness, limitations, strengths and applicability.					*			
4	Evaluation of thermographic NDE techniques and computational tools for corrosion detection and assessment with respect to their effectiveness, limitations, strengths and applicability.					*			
5	Evaluation of optical NDE techniques and computational tools for corrosion detection and assessment with respect to their effectiveness, limitations, strengths and applicability.						*		
6	Evaluation of NDE techniques on types of substrates, coatings, resulting components (joints for galvanic corrosion) and level/degree of corrosion growth.								
7	Develop and validate numerical models for use in parametric studies and training data generation.								
8	Signal processing algorithms for diagnosis and prognosis.								
9	Lab-scale demonstrations to allow assessment of technique utility in a given environment and ease of operation/interpretation.								
10	Recommendations for path forward to building a prototype system that could be field deployable.								*

* Milestone

CURRENT STATUS

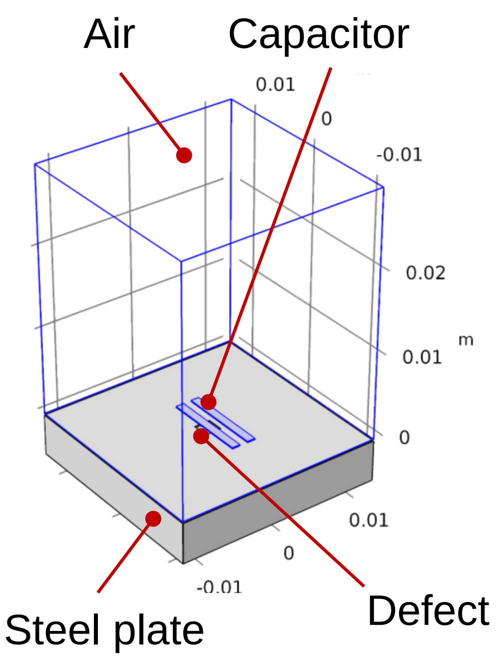
NDE Method	Eddy Current (EC)	Microwave	Speckle Pattern Interferometry	Infrared Thermography	Contact/Immerse Ultrasound
Resolution	Depends on sensor size (~mm^2 area)	Depends on waveguide size (~mm^2)	<mm^2	~mm^2	~mm^2
Lift-off distance	Small (~mm-cm)	Varies by post-processing: mm-cm or cm-m	~cm-m	~cm-m	Contact
Detection depth	~50μm-3cm+ depending on defect size	Near-surface <100μm	Near-surface (~50μm-	Near-surface	Large (~mm-10cm+)
Scan time	Can scan 1m/10s (depends on resolution and sensor type)(5 sensor array will speed up x5)	Same/Slower than EC (array sensors are possible but harder to fabricate)	~1min for 1m^2 Much faster than EC (5x-20x faster)	5-15min for 1m^2 depends on thermal conductivity of sample	Similar to EC (multi-element arrays can be used)
Portability	Portability possible – small/medium setup size	Portability possible – medium setup size	Portability possible – small setup size	Portability possible – medium setup size	Portability possible only in phased array (non-immersion) setups. medium size
Ease of use	Simple	Simple/moderate	Algorithms can simplify UI	Moderate	Moderate
Price	Low	Medium/high	Medium	Medium	Medium/high

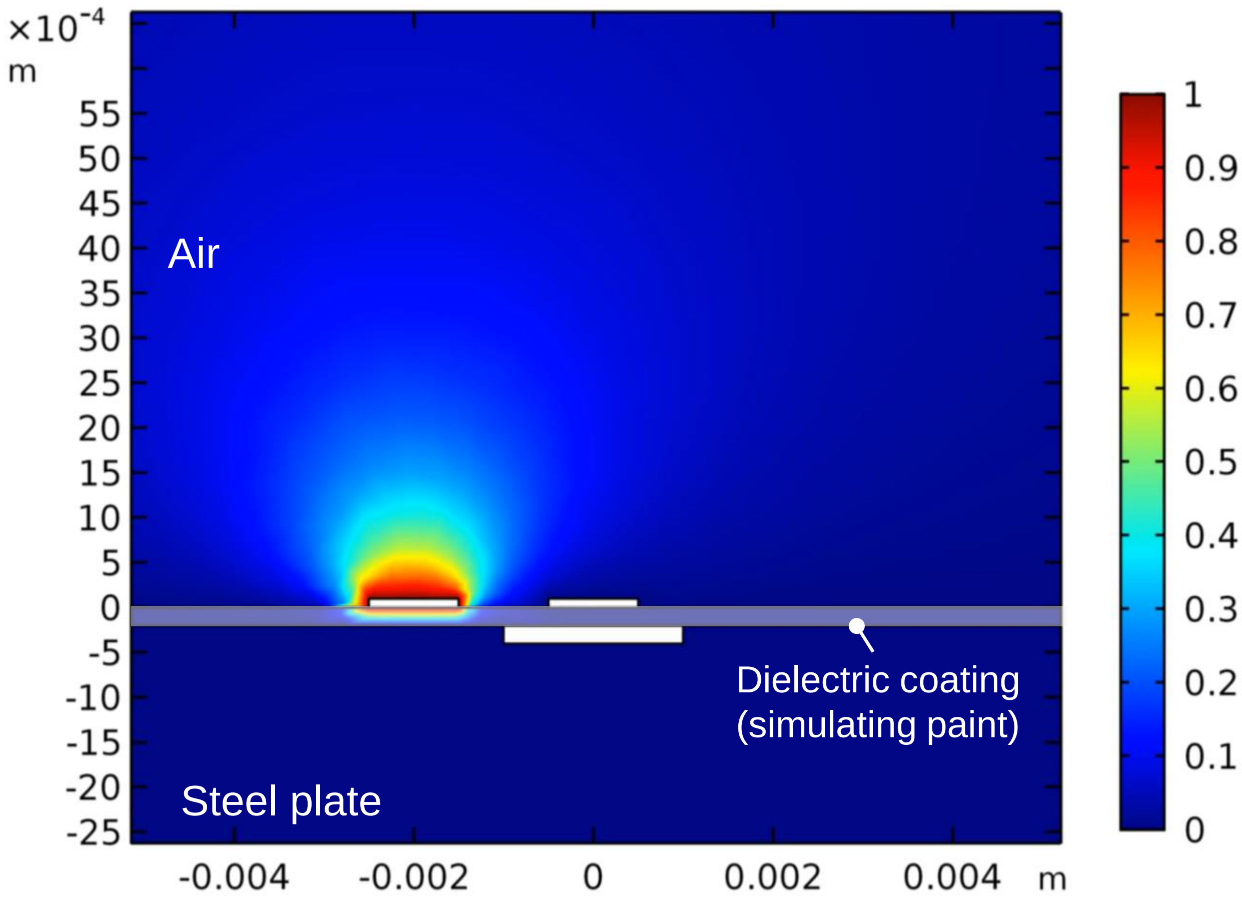
Technology Readiness Level (TRL) is generally low ~2-3

CURRENT STATUS

Capacitive Sensing – FE Modeling

- Capacitive sensor behaves as an electric dipole
- Most of the electric field is focused in the gap between the electrodes
- Electric field contours also fringe downwards and upwards from electrodes, this field is used for sensing





CURRENT STATUS

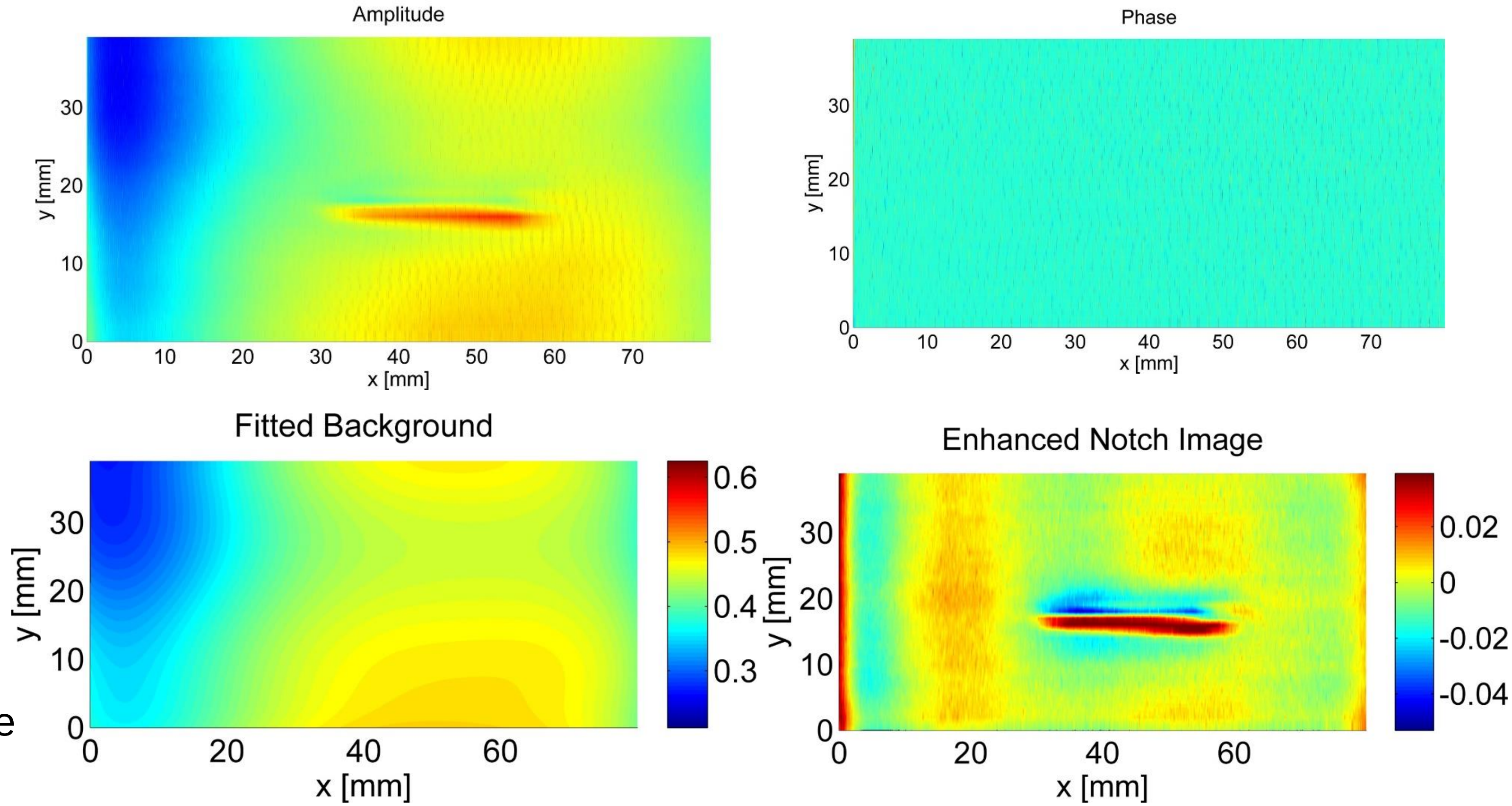
Capacitive Imaging - Initial Experimental Results

- Cap sensor consists of two electrodes printed on the opposite sides of a 2-mm thick plastic plate

Cap Sensor

Steel plate

Machined defect (20x2x0.25 mm)



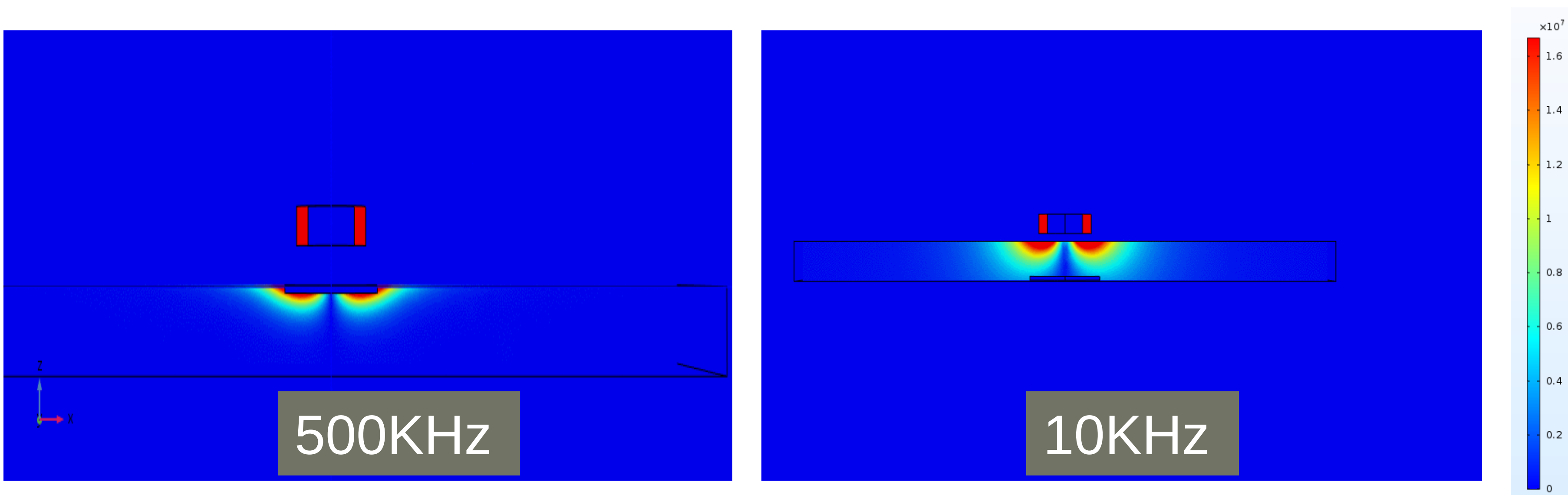
CURRENT STATUS

EC Corrosion Detection – Modeling

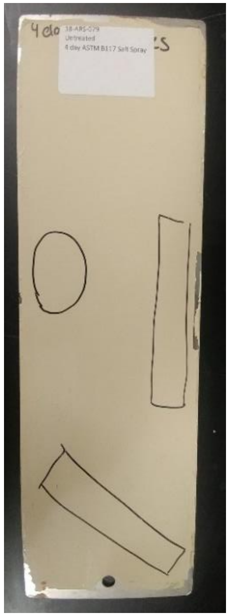
Sample: 2mm thick steel plate, 3cmx3cm area
Corrosion: 10% depth (.2mm) diameter 4mm
Coil: 3mm diameter, 2mm inner diameter, 1mm height

Simulations done with corrosion on surface and on bottom of 2mm plate

- Skin depth of signal (detection depth) increases as frequency decreases. The image shown on the right illustrates this effect.
- Surface corrosion is detected at high frequencies (~ MHz)
- Sub surface Corrosion - detected at lower frequencies (~KHz)



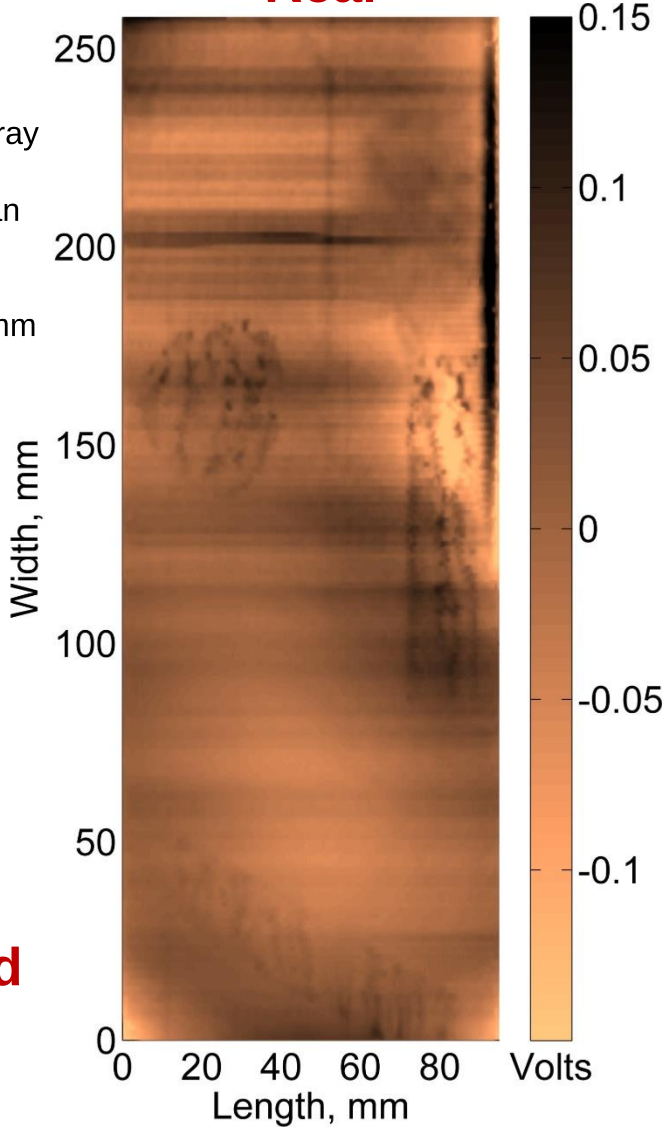
CURRENT STATUS

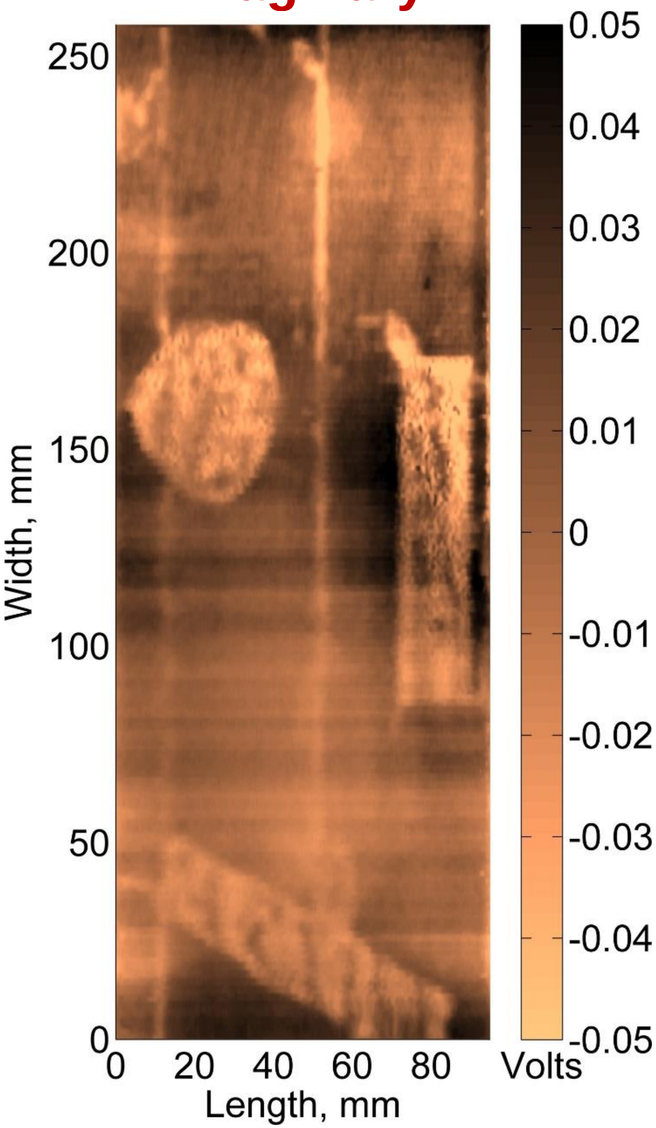


Differential Coil Sensor: Experimental Results
4 Day Salt Spray

Single coil scan speed:
80s for a 100mm x 80 mm panel

Scanned area





TRANSITION

- Project output: Recommendations for path forward to building a prototype system that could be field deployable.

- Phase II (conceptual): Take MSU results and develop:
  - Lab tool to assess test specimens – coating qualification testing
  - Field tool to access corrosion at Aberdeen Proving Ground during Army Corrosion Durability Test (ACDT)
  - Field tool for use during vehicle maintenance - not too complex to use.