MWM-Array and MR-MWM-Array Eddy Current Testing for Piping and Vessels

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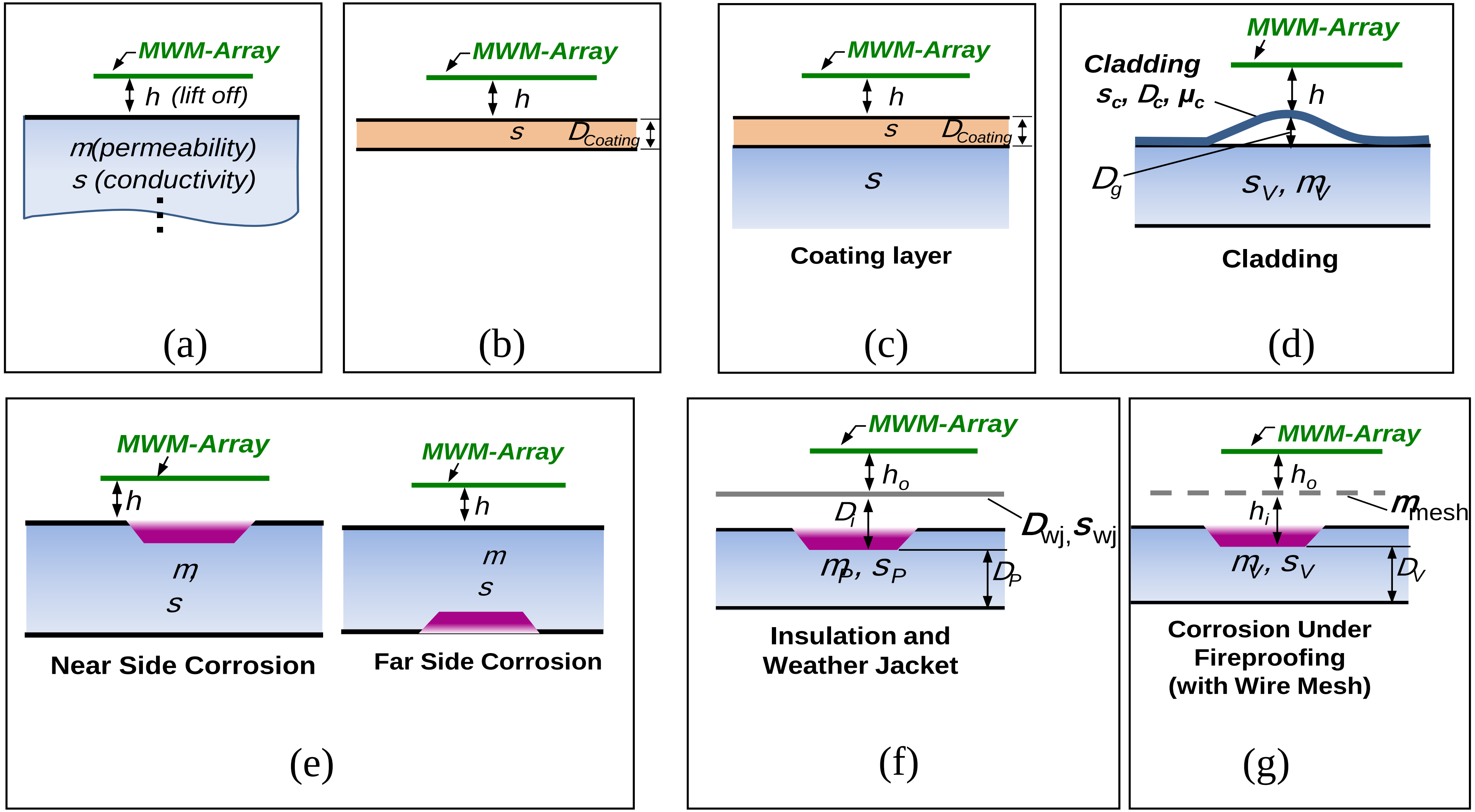
Example Problems: From Simple to Complex



Example Problems: From Simple to Complex

2-Unknowns
Conductivity and Liftoff (σ and h); or Permeability and Liftoff (μ and h)

(a)

3-Unknowns
Conductivity, thickness and Liftoff (σ, Δ_c and h)

(b)

4-Unknowns
Coating conductivity, coating thickness, substrate conductivity, and Liftoff (σ_c, Δ_c, σ_s and h)

(c)

3 or 4-Unknowns
Cladding thickness, gap thickness, and Liftoff, add substrate magnetic permeability (to detect substrate cracks also) (Δ_c, Δ_g, h and μ_s)

(d)

3-Unknowns
permeability, thickness and Liftoff (μ, Δ_c and h) assume conductivity value

(e)

4 or 5-Unknowns
Weather jacket thickness (assume w/ conductivity), insulation thickness, pipe thickness, and Liftoff and pipe permeability (or estimate μ_p at nominal Δ_p (Δ_{wj}, $\Delta_{i,}$ Δ_p, h, + μ_p)

(f)

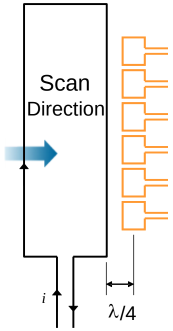
5-Unknowns
Concrete thickness (ho+hj), wire mesh permeability, vessel permeability, lift-off ho (= distance to mesh) (Δ_c, μ_m , μ_s , Δ_s h_o)

(g)

Three elements of the solution

1. Sensors: MWM®-Arrays & MR-MWM-Arrays

- Paradigm shift in sensor design (first priority is predictable response based on physics-based modeling)



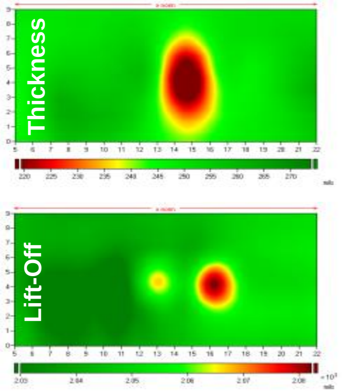
2. Parallel Instrumentation

- **3 frequencies simultaneously**
- **All channels simultaneously**
- **Wide bandwidth, accurate impedance**

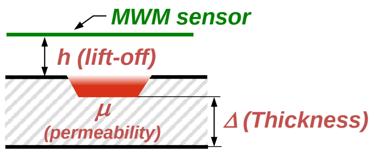
3. Multivariate Inverse Methods (MIMs)

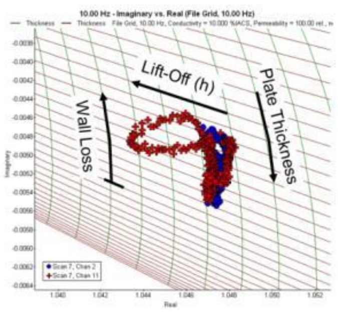
- **Rapid, autonomous data analysis Performs multivariate inverse method (MIM) using precomputed databases**
  - **Defect Images**
  - **Performance Diagnostics**
  - **Noise Suppression**

Images



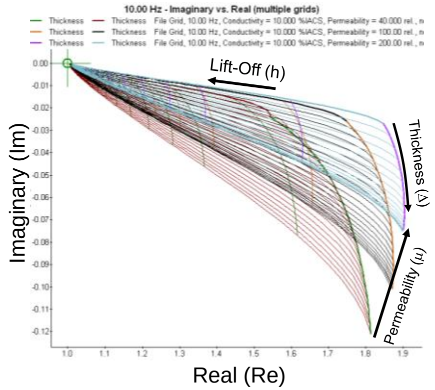
Analysis





Solve Multiple Unknown Problems

MIM



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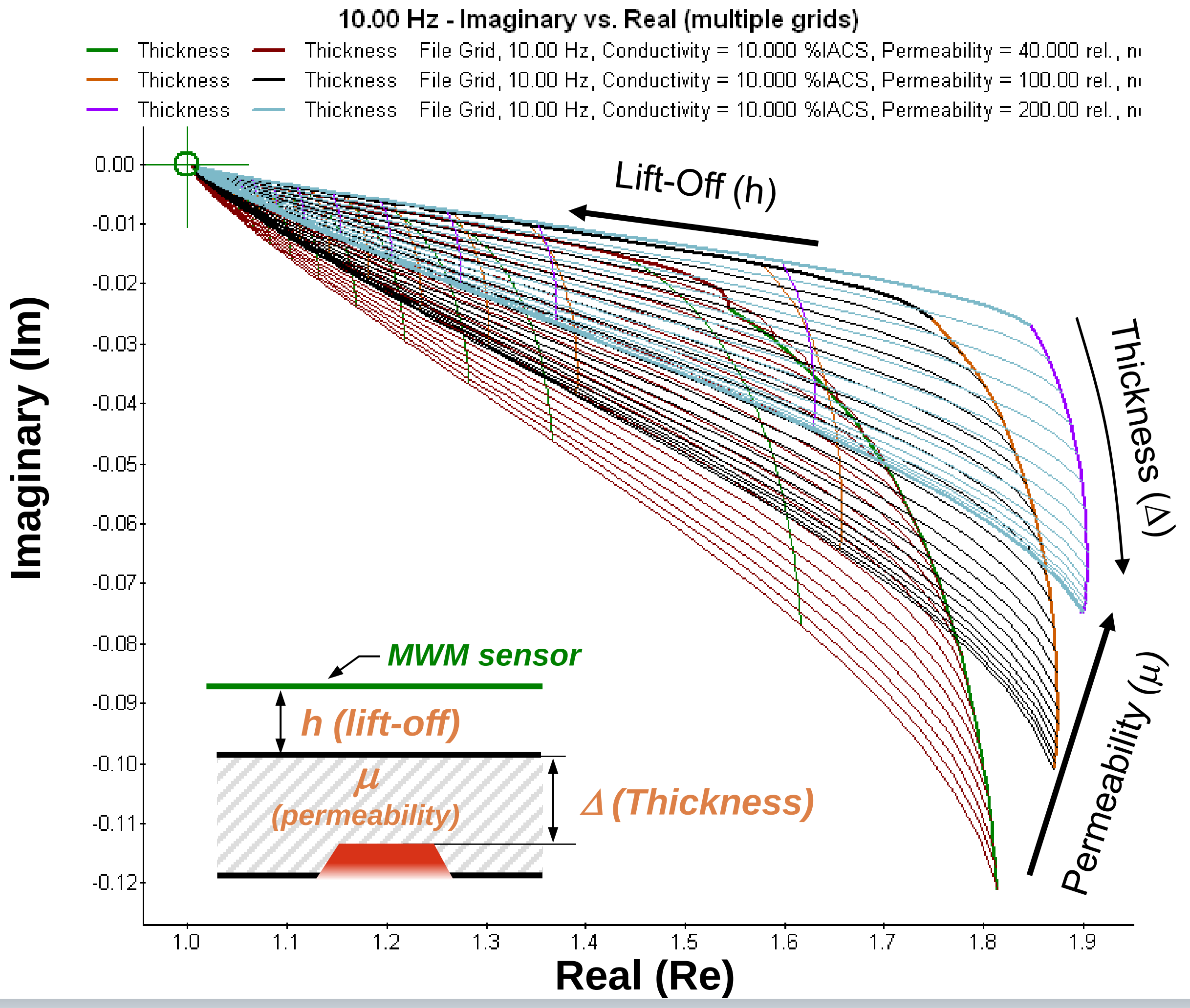
Definition of Real and Imaginary Parts of the complex Transimpedance Z=v/jωi



$\omega = 2\pi f$

- GridStation Lattices for MR-MWM-Array **wall loss imaging**
- Used for **external and internal** wall loss imaging

|Z| = Magnitude

θ = Phase

$$|Z| = \sqrt{Re^2 + Im^2}$$

$$\theta = \arctan(Im/Re)$$

$$Re = |Z|\sin(\theta)$$

$$Im = |Z|\cos(\theta)$$

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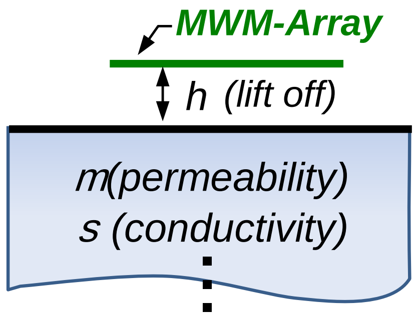
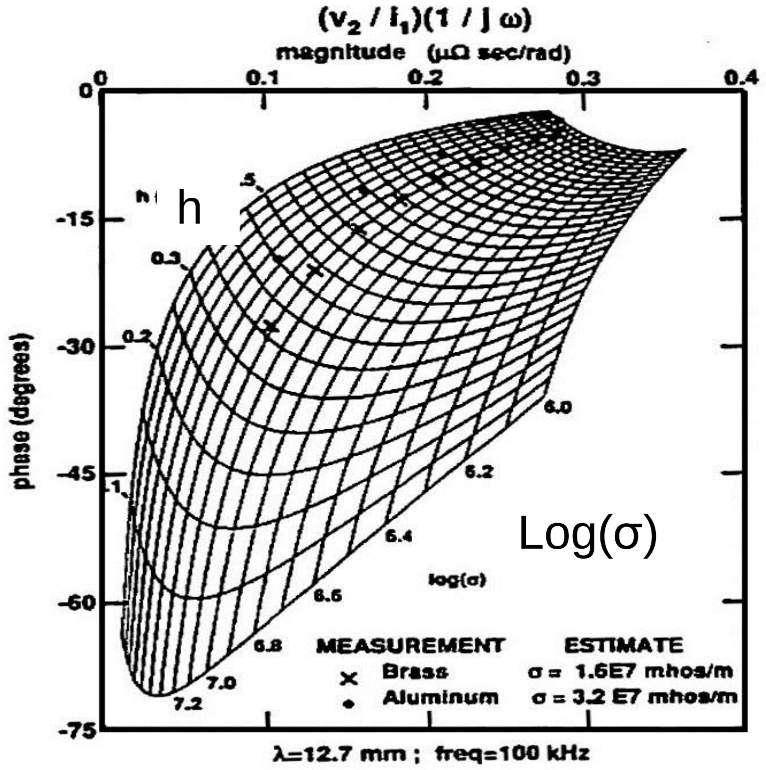
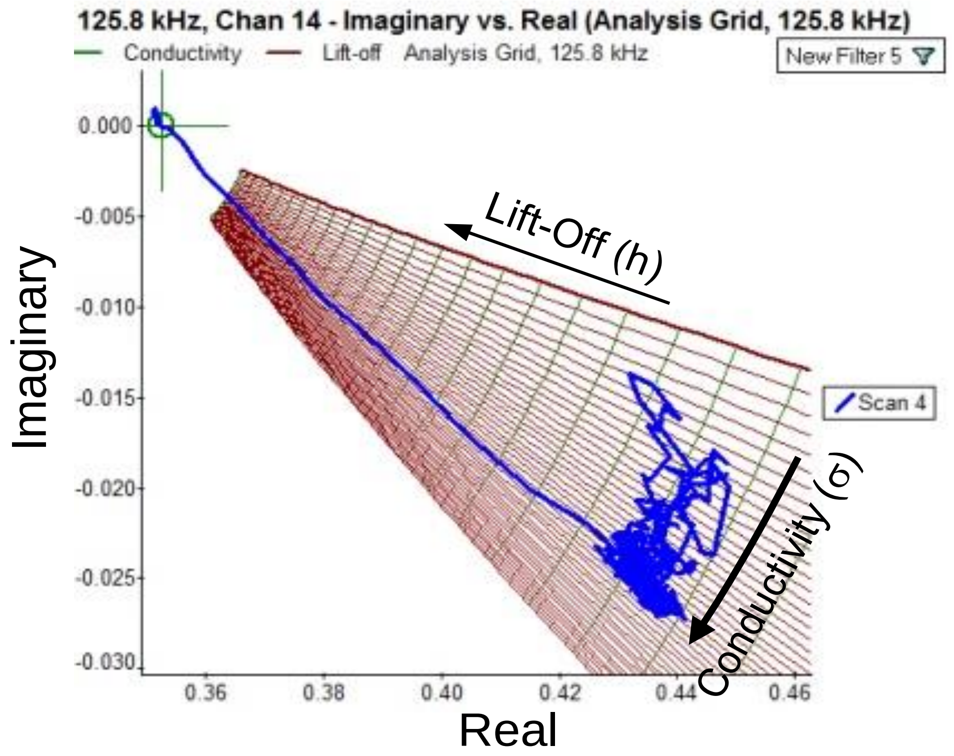
HyperLattices (precomputed response databases)

a) 2- Unknowns: conductivity (σ) and lift-off (h), with magnetic permeability (μ) assumed constant



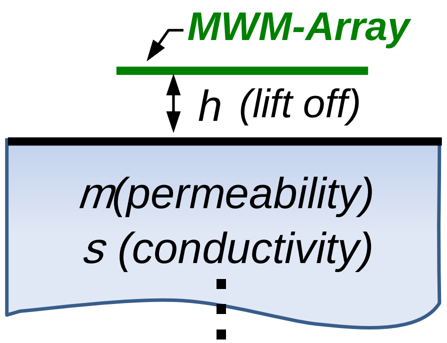


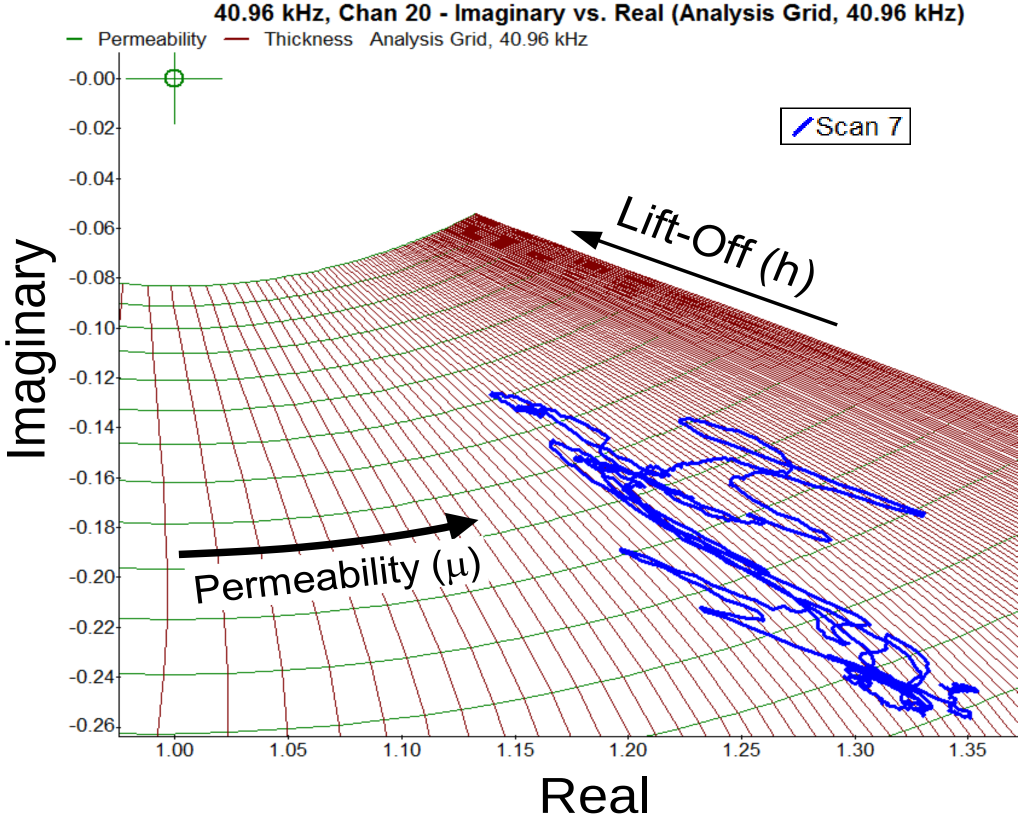


ASNT EVENTS

HyperLattices (precomputed response databases)

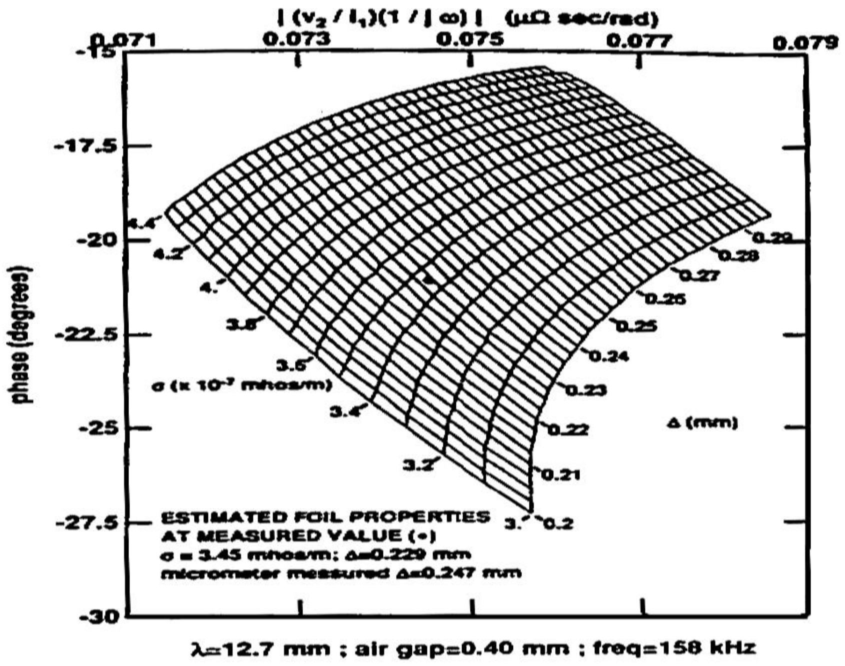
a) 2- Unknowns: magnetic permeability (μ) and lift-off (h), with conductivity (σ) assumed constant

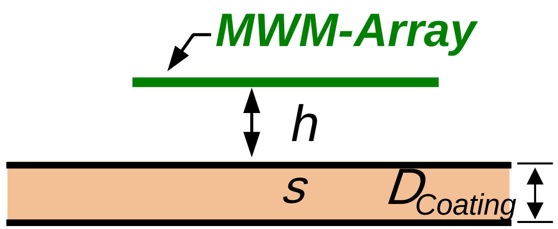




HyperLattices (precomputed response databases)

b) 3- Unknowns: coating conductivity, coating thickness, and lift-off, using hierarchical method.
Grid is for conductivity and thickness of the coating.
The lift-off is determined at a higher frequency, taken simultaneously.





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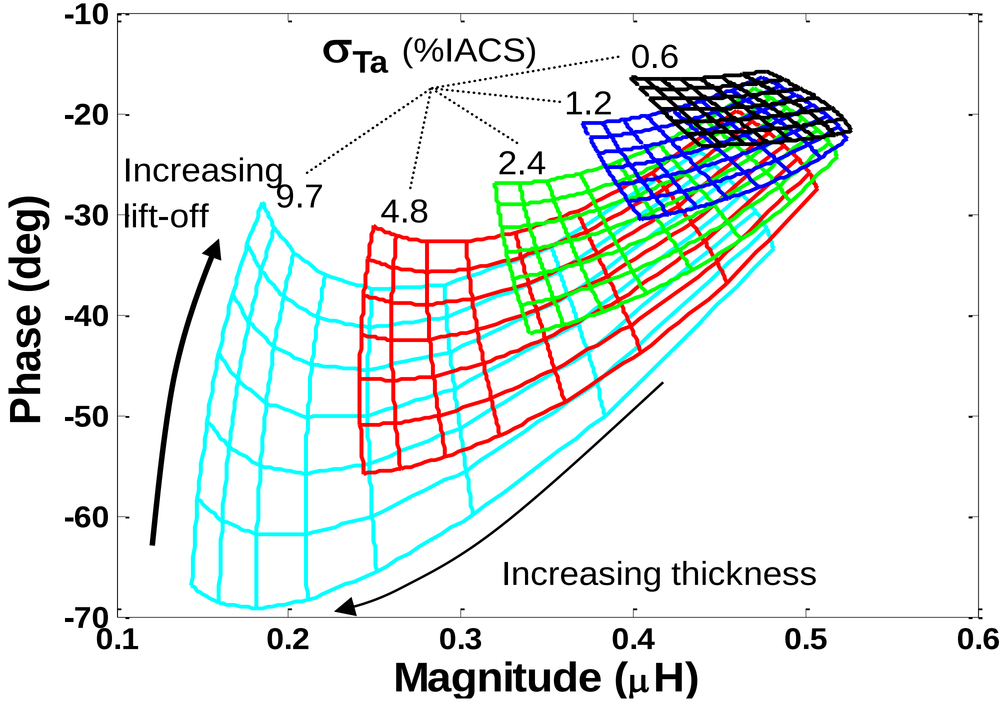
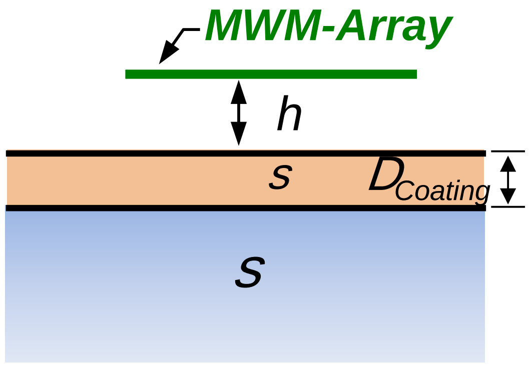
HyperLattices (precomputed response databases)

c) 3-Unknowns: coating thickness, coating conductivity, and lift-off. Two frequencies are needed.

Each frequency provides two equations to solve for up to two unknowns. Two frequencies is enough for 3 or 4 unknowns.

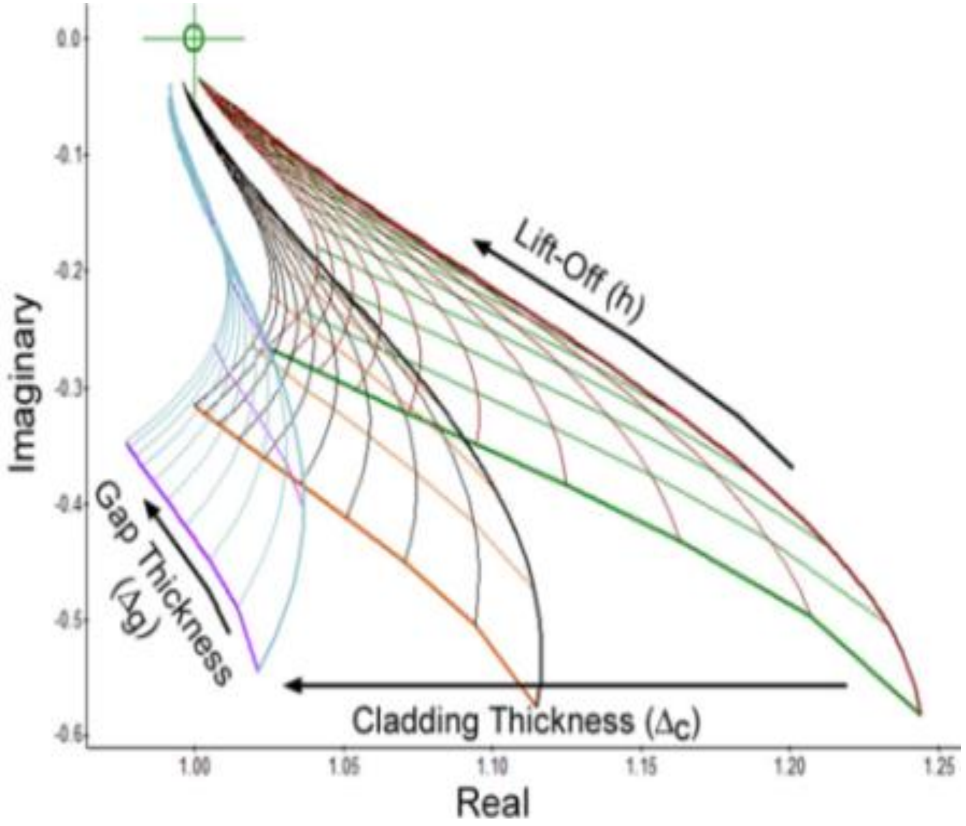


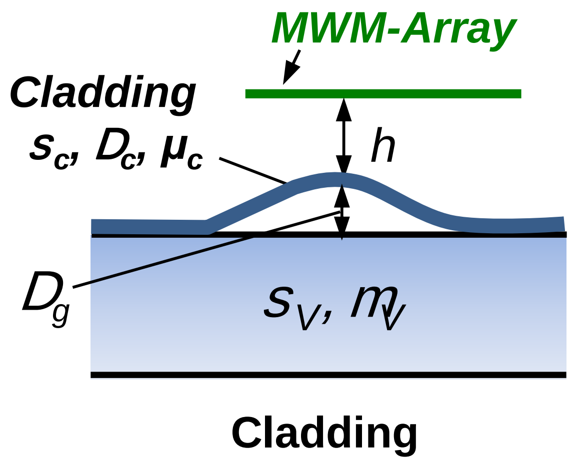


Coating layer

HyperLattices (precomputed response databases)

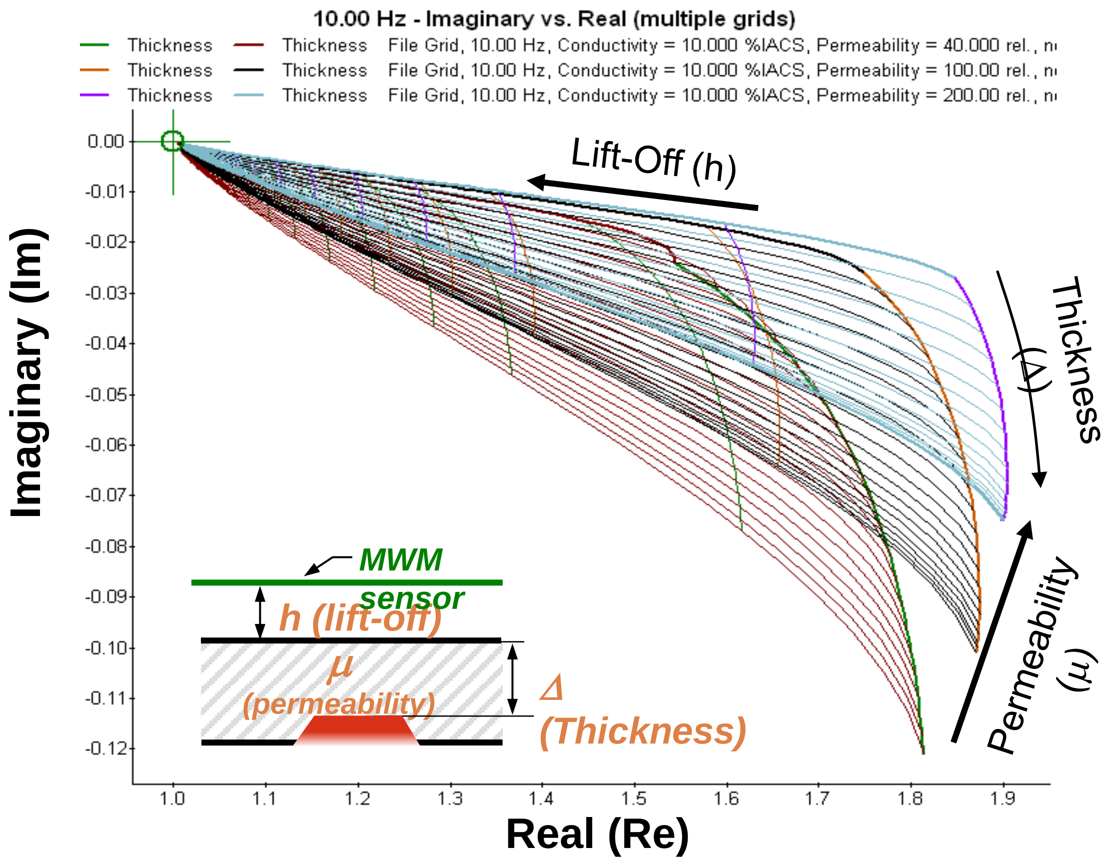
d) 3- Unknowns: cladding thickness, blister gap, and lift-off

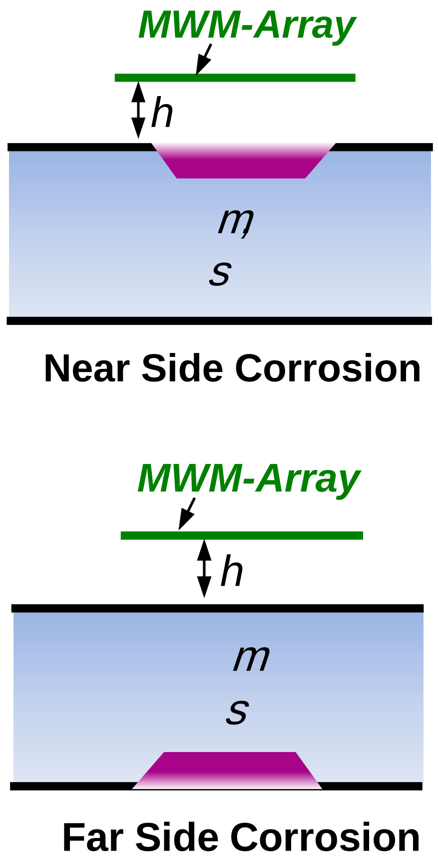




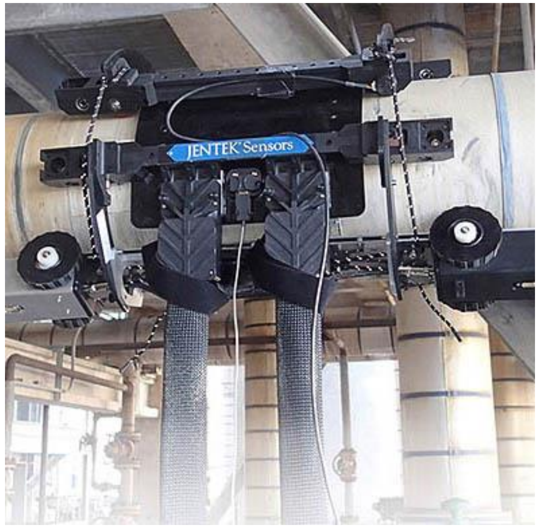
HyperLattices (precomputed response databases)

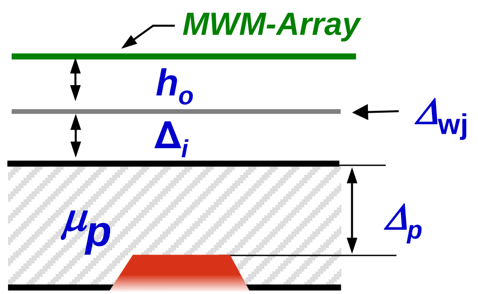
e) 3- Unknowns: pipe wall permeability, pipe wall thickness, and lift-off





Scanners and Implementation in the plant





$$h, \Delta_{wj}, \Delta_i, \Delta_p, \mu_p$$

h_o = distance between sensor & external surface of weather jacket

Δ_{wj} = weather jacket thickness

Δ_i = insulation thickness + external metal loss

Δ_p = remaining pipe wall thickness

μ_p = pipe magnetic permeability

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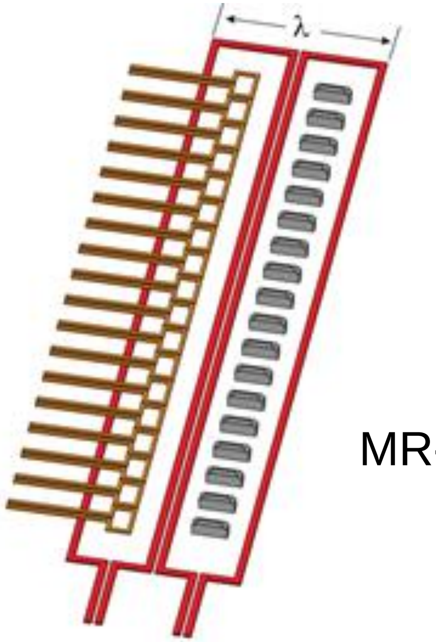
Sensor Selection

- Decay rate determined by skin depth at high frequency and sensor dimensions at low frequency
- Large dimensions needed for thick coatings/insulation
- Low frequencies needed to penetrate through steel pipe wall



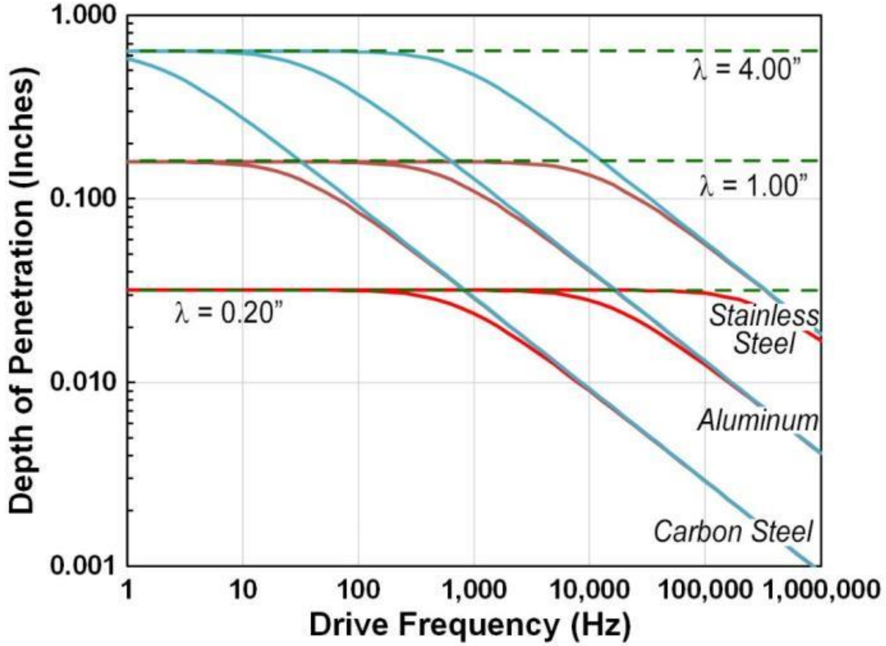
MR-MWM-Array

Depth of Penetration = $1/\mathrm{Re}(\Gamma_n)$

Low Frequency Limit = $\frac{\lambda}{2\pi}$

$$\Gamma_n = \sqrt{(2\pi n/\lambda)^2 + j2/\delta^2}$$

Skin depth: $\delta = \sqrt{\frac{1}{\pi f \mu \sigma}}$



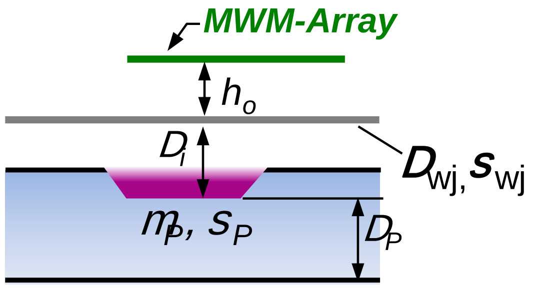
1 inch = 25.4 mm

HyperLattices (precomputed response databases)

(f, left) 5- Unknowns:

1. pipe wall permeability,
2. pipe wall thickness,
3. weather jacket thickness (assume conductivity)
4. insulation thickness
5. lift-off (distance to weather jacket)

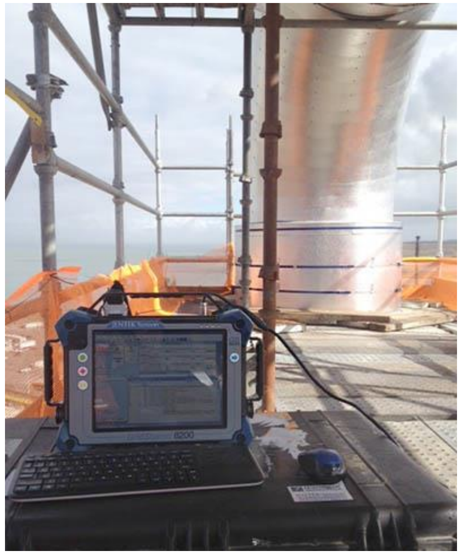
Can’t visualize easily



Insulation and Weather Jacket

Example: Corrosion Imaging on Refinery Piping

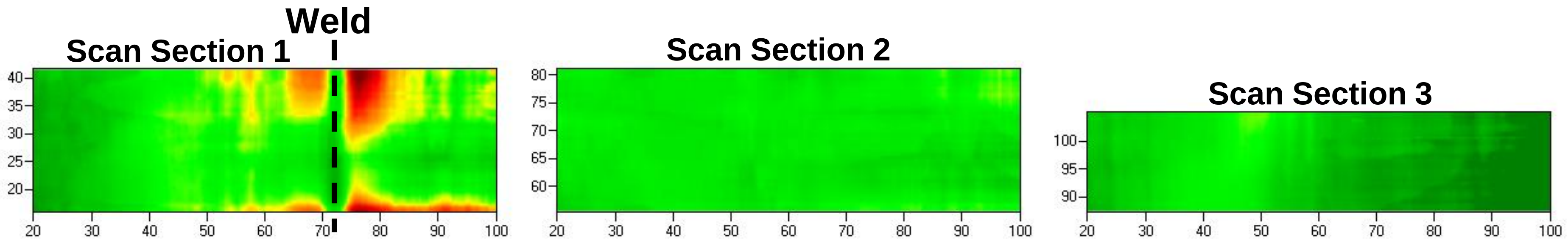
Inspection was performed with the pipe in production at high temperature



CUI Performance Evaluation Results (July 2013)

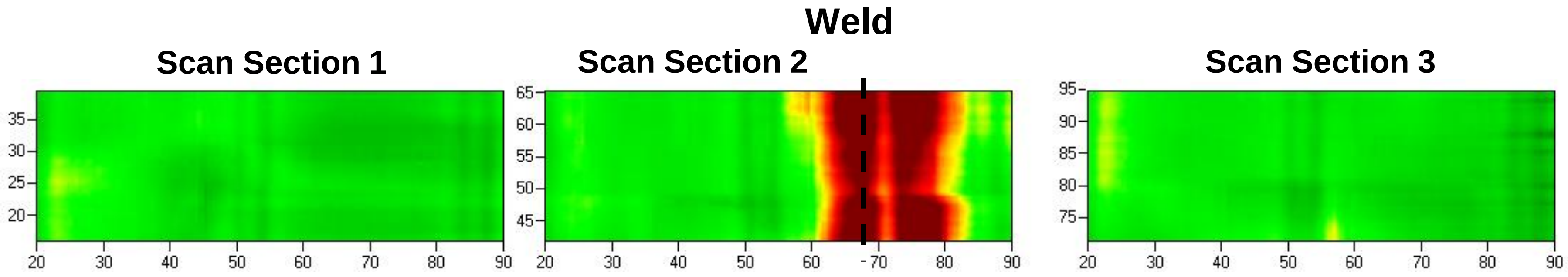
Internal Corrosion – Sample A

16” Schedule 80 (0.500” wall)
2” insulation with aluminum weather jacket
0.100” max wall loss (20%) over 20-25 inches (full circumference)



Internal Corrosion – Sample B

16” Schedule 80 (0.500” wall)
2” insulation with aluminum weather jacket
0.175” max wall loss (35%) over 20-25 inches (full circumference)

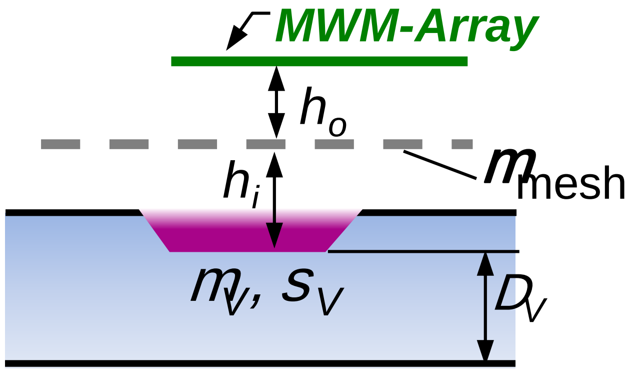


HyperLattices (precomputed response databases)

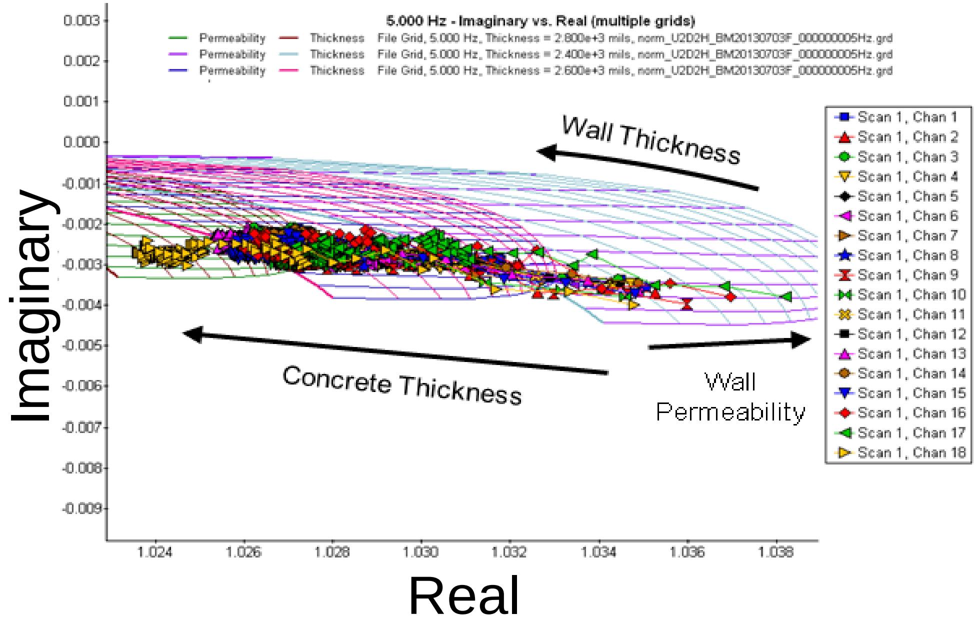
(f, right) 5- Unknowns:

1. vessel wall permeability,
2. vessel wall thickness,
3. , 4., permeability and position of wire mesh (simple layer)
5. vessel wall permeability

Can't visualize easily



Insulation and Weather Jacket



Summary of Elements of Solution and Example Capabilities

Elements of Solution

1. Sensor designed to match the modeled response

2. Parallel architecture impedance instrument, providing at least 3 simultaneous frequencies

3. Rapid Model-Based Multivariate Inverse Method (MIMs)

Example Capabilities

1. **Internal and external corrosion imaging through**
   - Insulation
   - Concrete with wire mesh (fireproofing, weight coat)
   - Other coatings

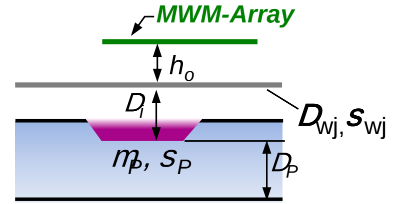
2. **Hydrogen blister imaging (through cladding overlay)**

3. **Buried crack detection**

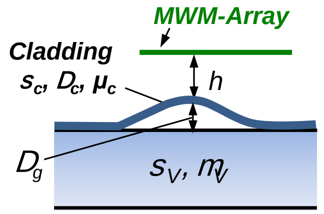
4. **Coating characterization**

5. **In-line inspection for surface and subsurface defects**

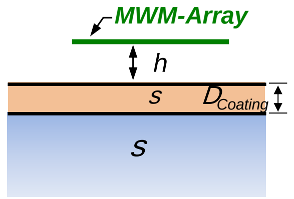
6. **Stress mapping from outside and inside pipelines, structures**



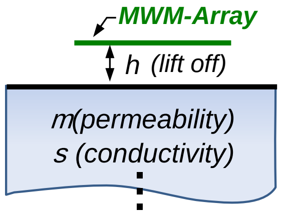
Insulation and Weather Jacket



Cladding



Coating layer



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