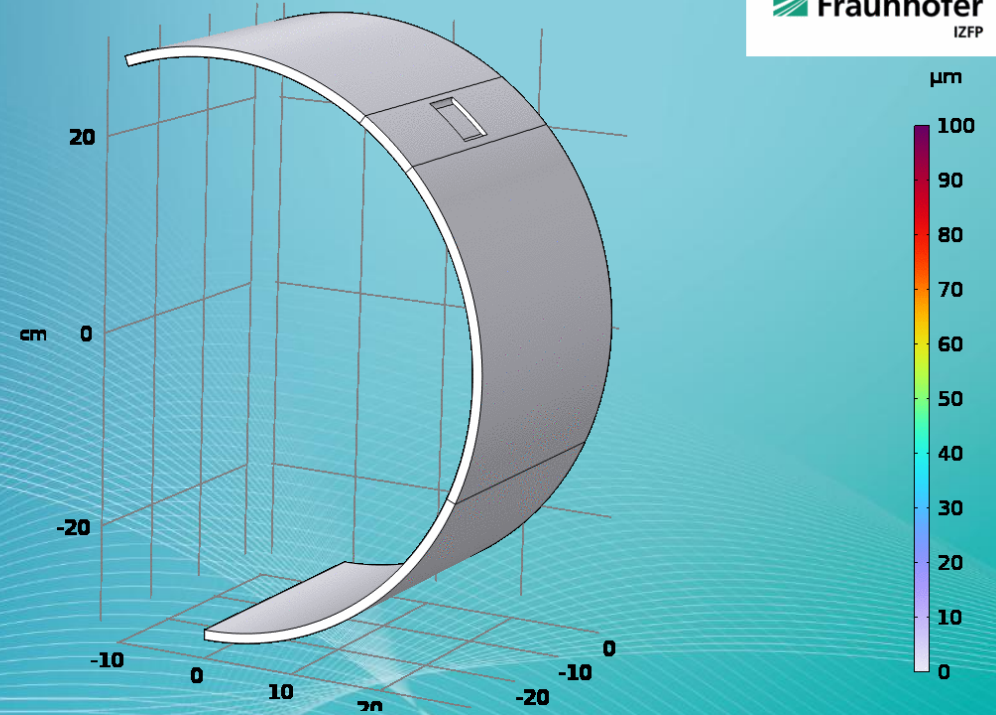


Speaker: Dr. Sascha Thieltges

Physics-based digital twin framework for rapid inverse characterization of corrosion defects using surrogate-assisted optimization

Time=0 s



Motivation and Current Challenges

Current Practice

- Guided Wave Testing (GWT) established for long-range pipeline screening
- Reliable detection of corrosion-related anomalies
- Efficient inspection of inaccessible assets
- Large-scale deployment in oil & gas industry

Current Limitations

- Signal interpretation often expert-dependent
- Limited quantitative defect characterization
- Defect sizing remains challenging
- Multiple defect geometries can produce similar signal responses
- High uncertainty in remaining wall thickness estimation

Digital Approaches

- Rule-based signal evaluation
- Data-driven machine learning models
- Full-scale finite element simulations
- Physics-based digital twins

Physics-based digital twin framework for rapid inverse characterization of corrosion defects using surrogate-assisted optimization

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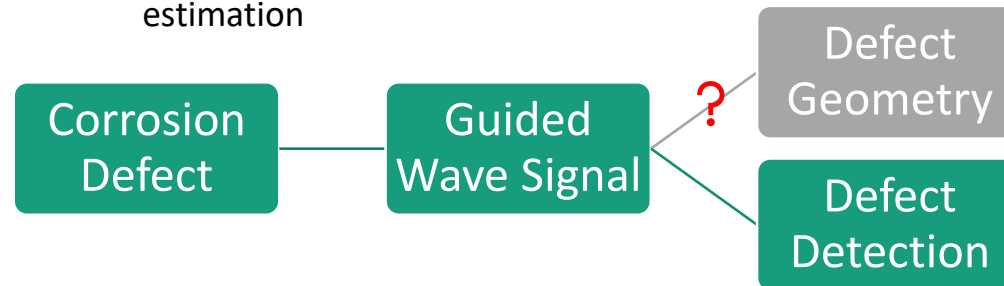
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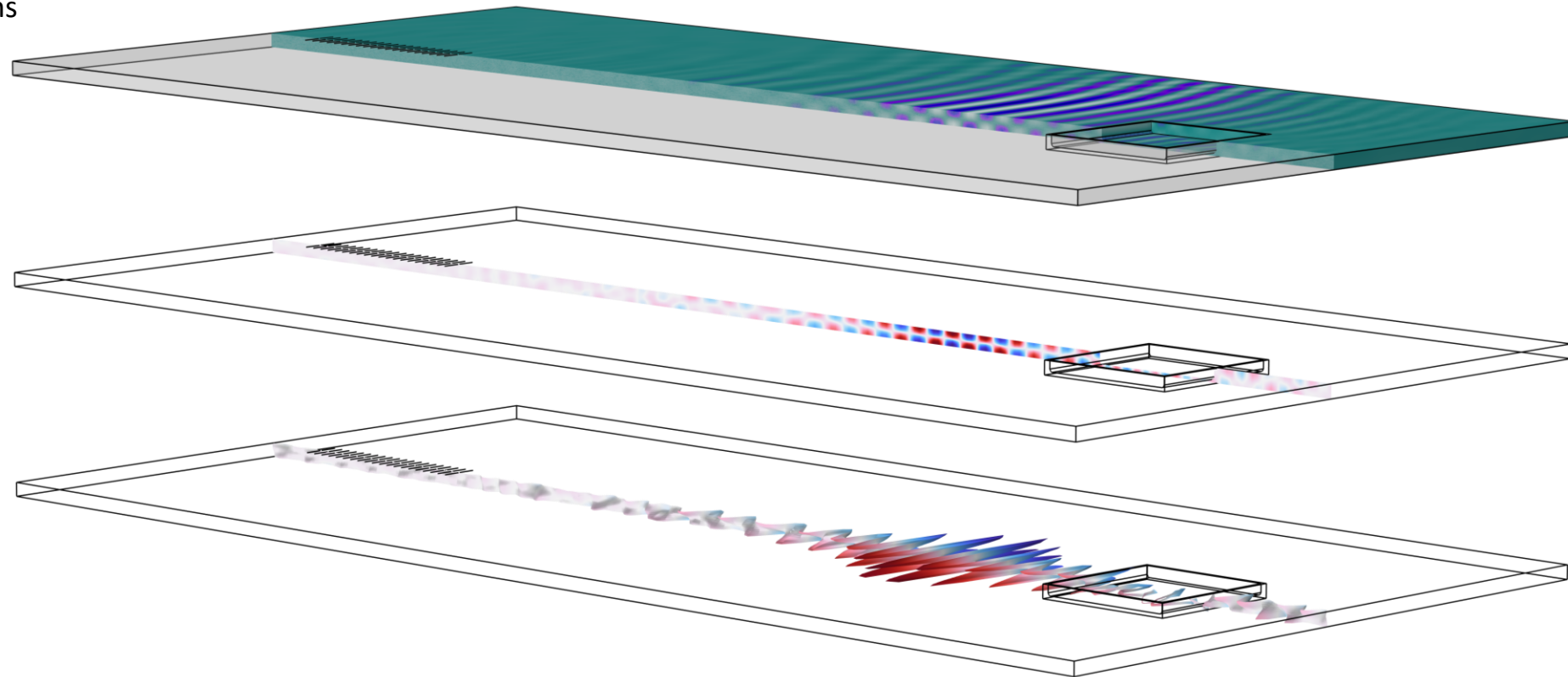


Guided Waves for Pipeline Inspection

Characteristics

- Ultrasonic waves guided by boundaries
- Propagation over several meters
- Sensitivity to wall-thickness variations

$$\text{Pipe} = \text{Plate} \rightarrow \frac{ID}{OD} \geq 0.93$$

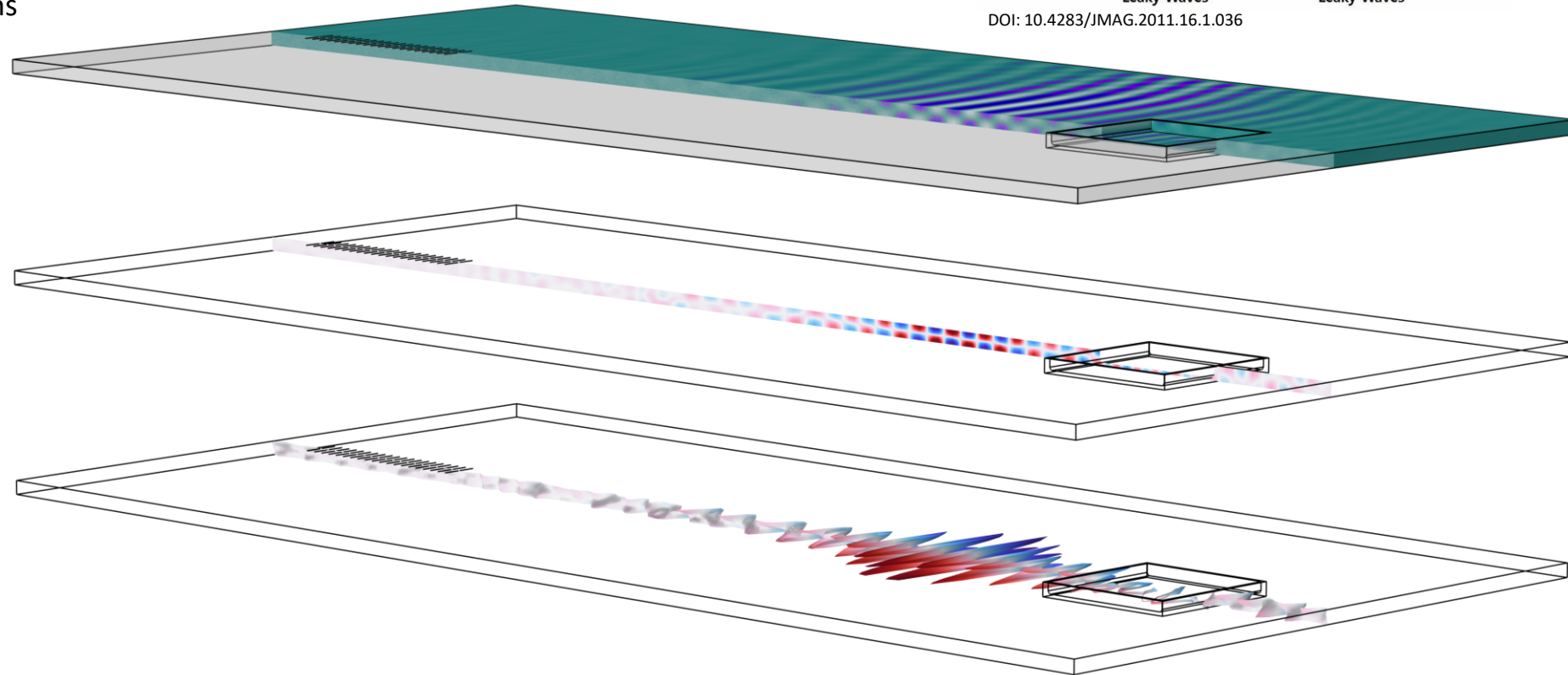
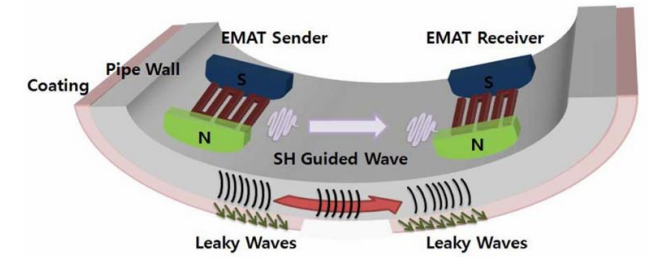


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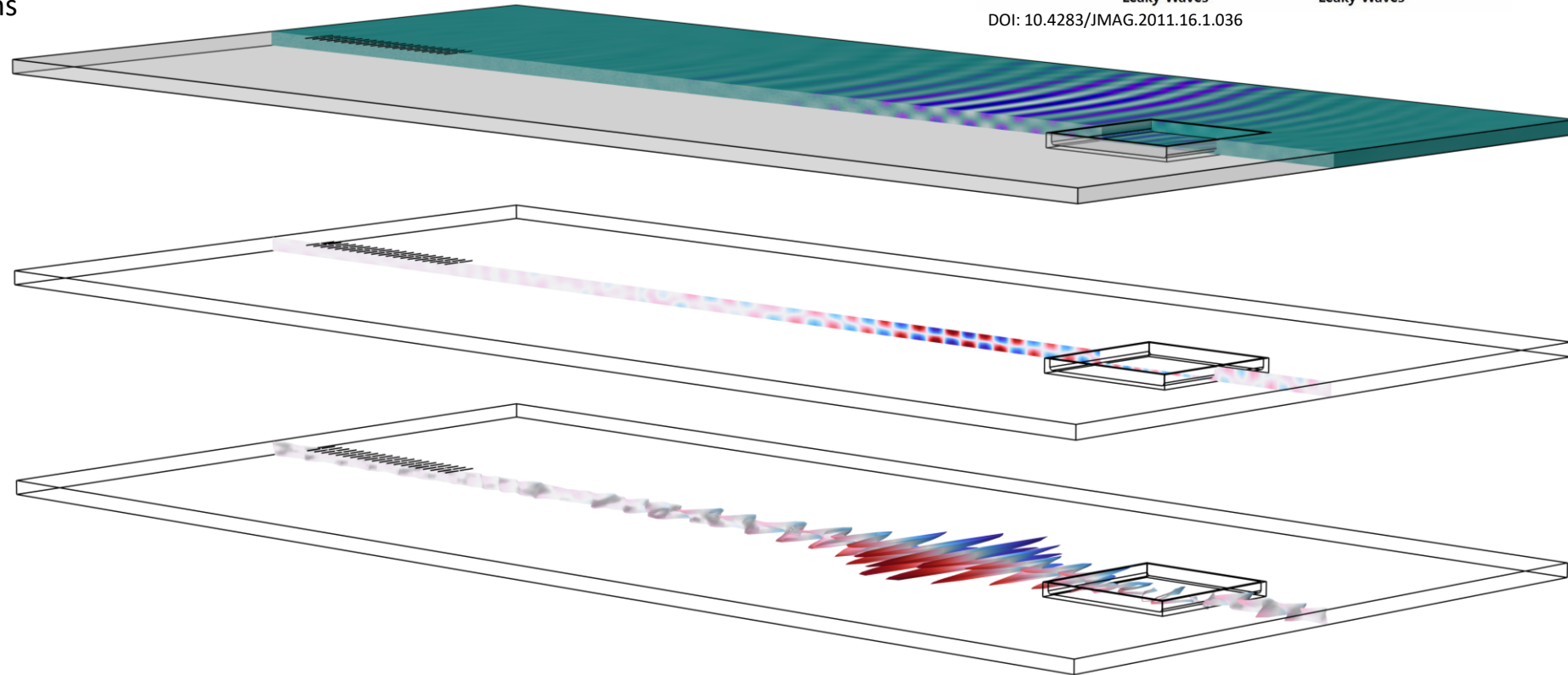
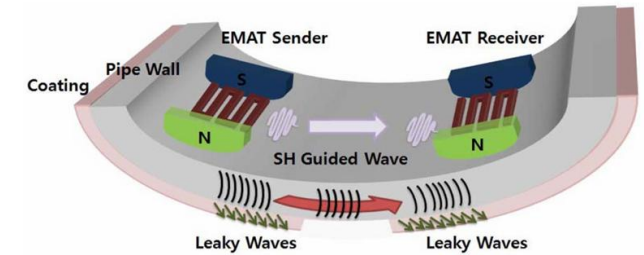
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Guided waves do not distinguish between whether the defect is located on the inner or outer surface of a pipe

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Guided Waves for Pipeline Inspection

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Advantages

- Large inspection coverage
- Screening of inaccessible regions
- Reduced inspection time
- Suitable for buried and insulated pipelines



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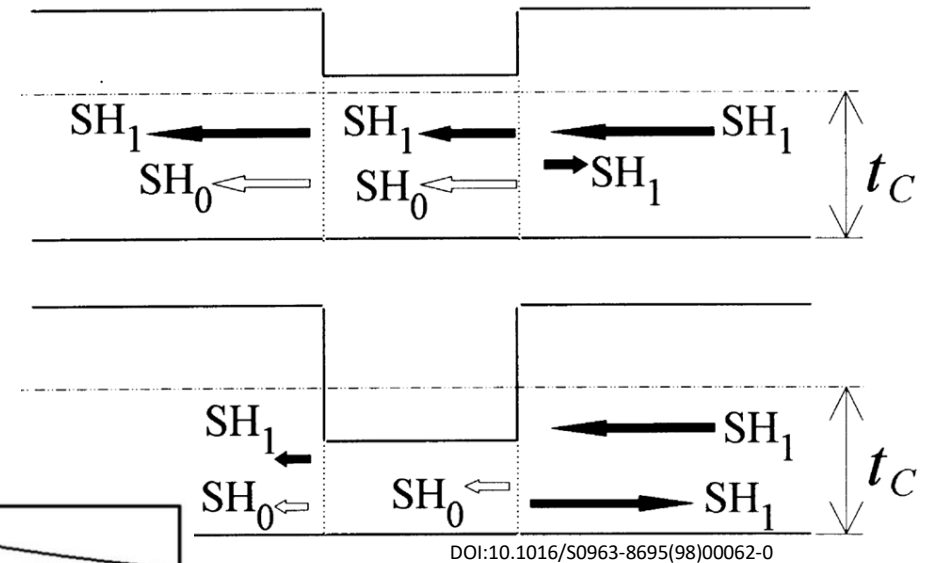
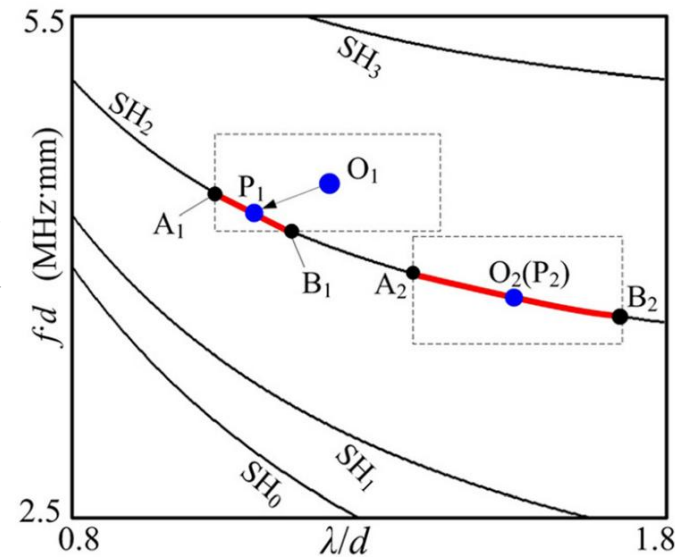
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Principle

- Defect-free region → undisturbed propagation
- Corrosion defect → reflection, transmission and mode conversion
- Defect information encoded in received waveforms

Guofu Zhai et al.; Wavelength measurement of guided waves in plates with electromagnetic acoustic transducers. *J. Acoust. Soc. Am.* 1 April 2012; 131



DOI:10.1016/S0963-8695(98)00062-0

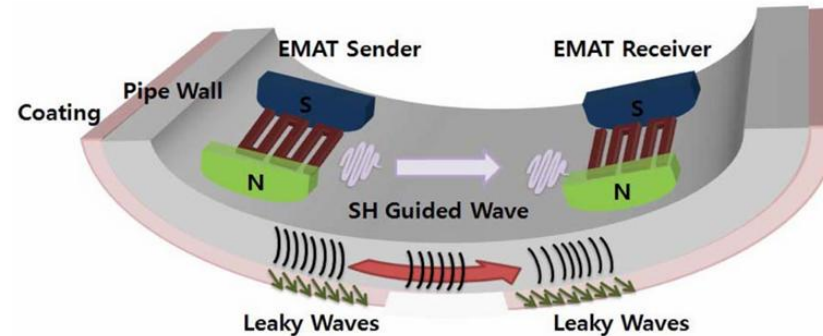
Electromagnetic Acoustic Transducers (EMAT)

Principle

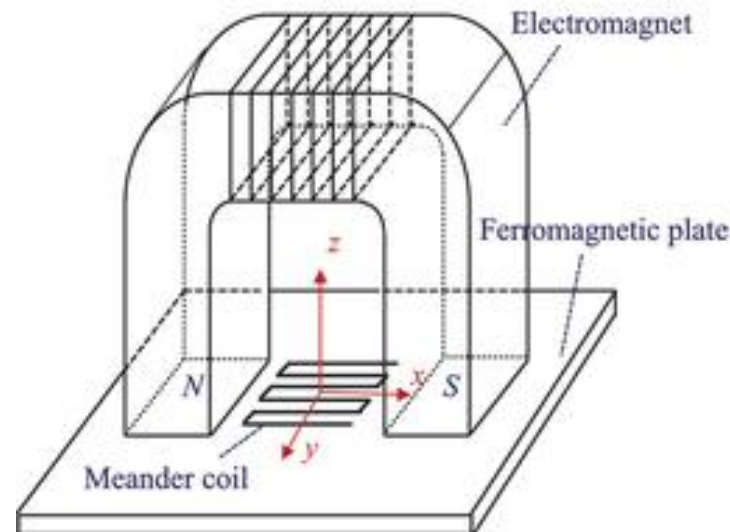
- Contactless ultrasonic excitation
- Dynamic + static magnetic field
- Magnetostrictive and Lorentz-force mechanisms

Benefits

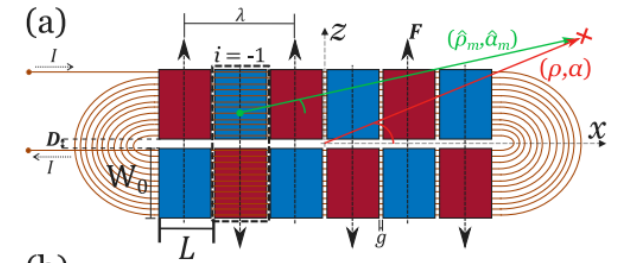
- No couplant required
- Suitable for hot surfaces
- Robust operation in harsh environments
- Compatible with automated inspection systems



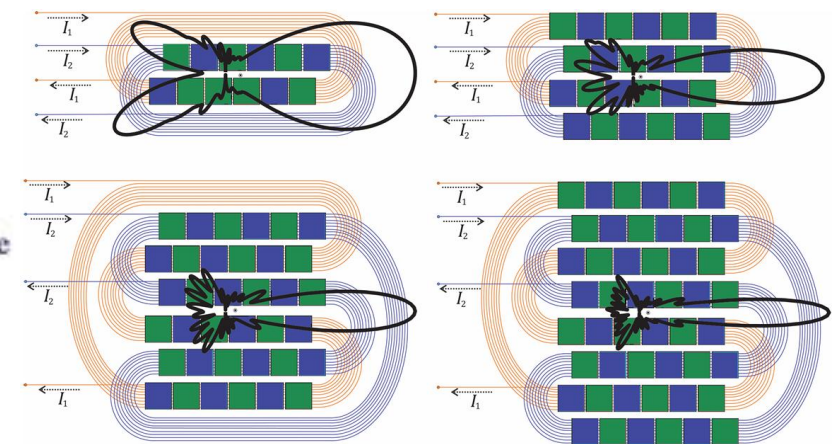
DOI: 10.4283/JMAG.2011.16.1.036



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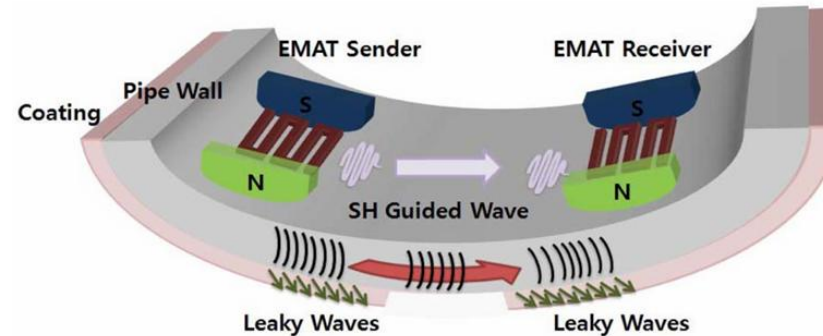
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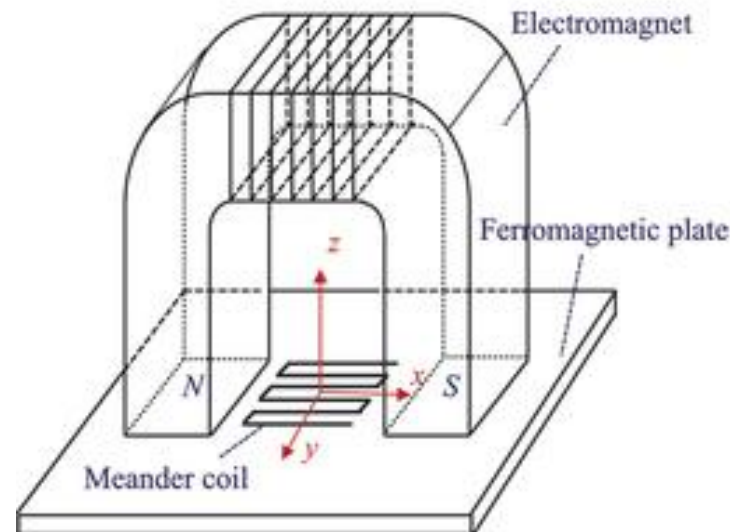
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Output

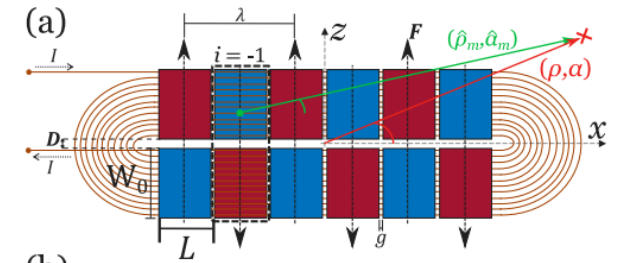
- Controlled excitation of guided wave modes
- Reflection and transmission signals



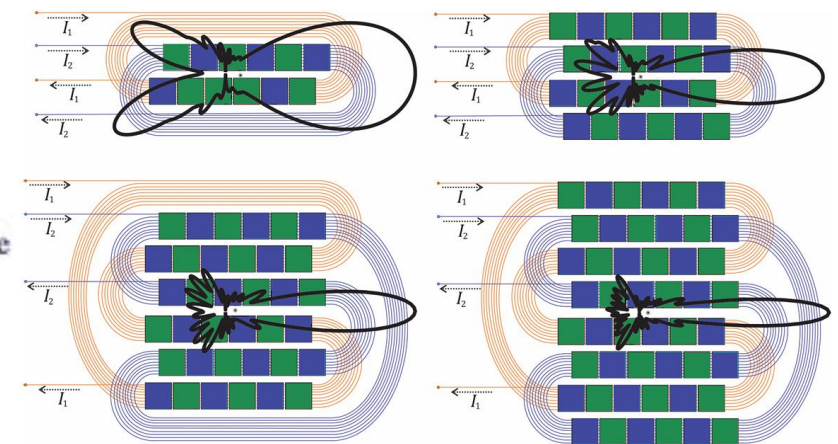
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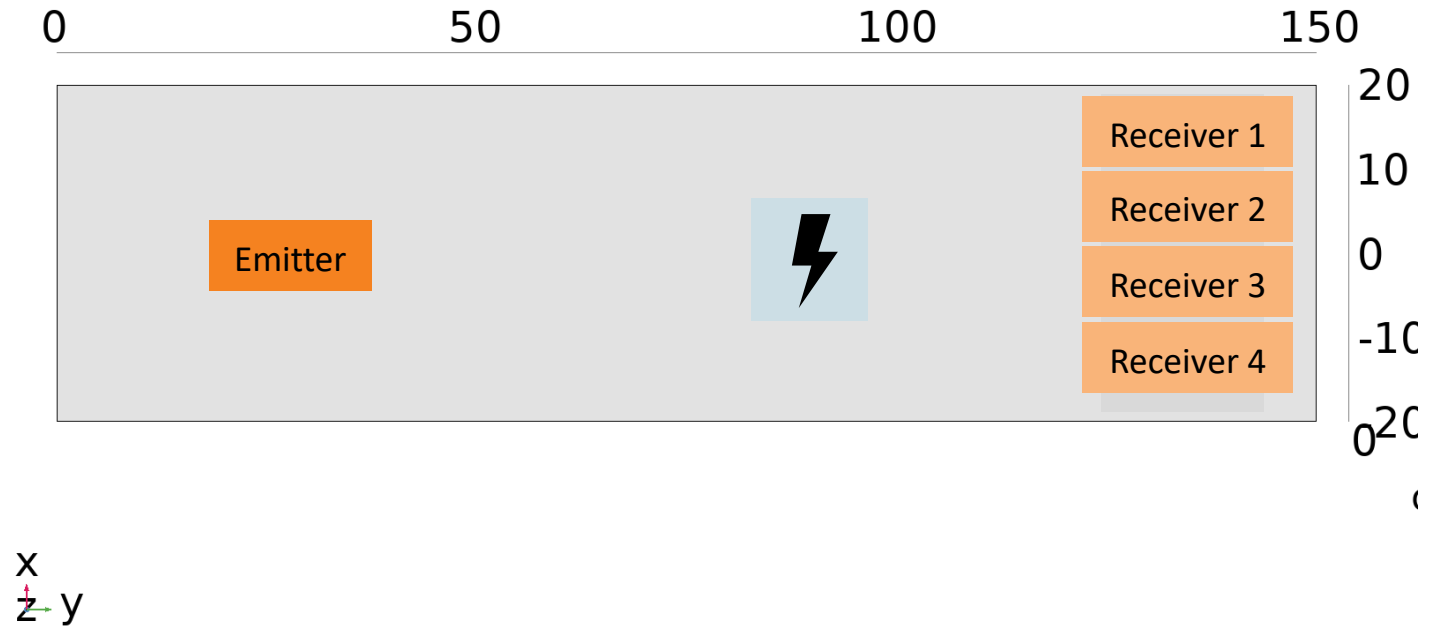
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From Detection to Defect Characterization

Physics-Based Digital Twin and Optimization via Differential Evolution

Current Situation

- Guided waves enable reliable defect detection
- Reflections indicate the presence of wall-loss defects
- Defect location can be estimated accurately

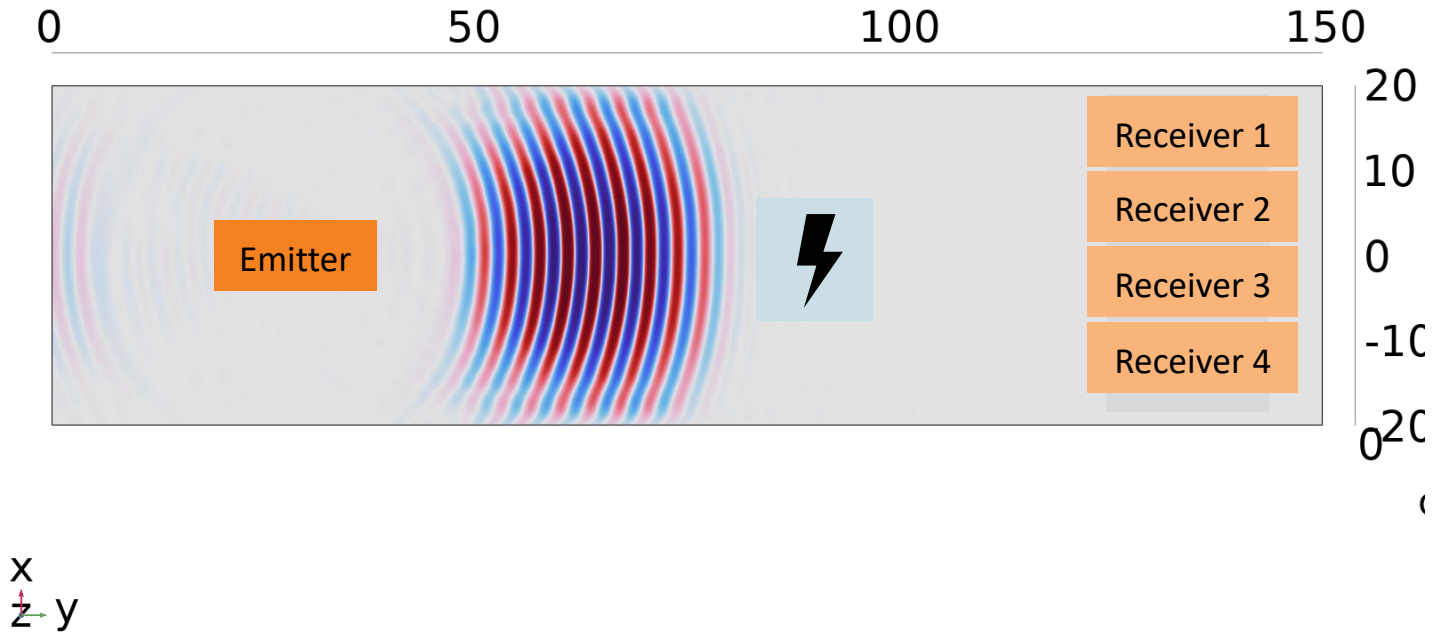


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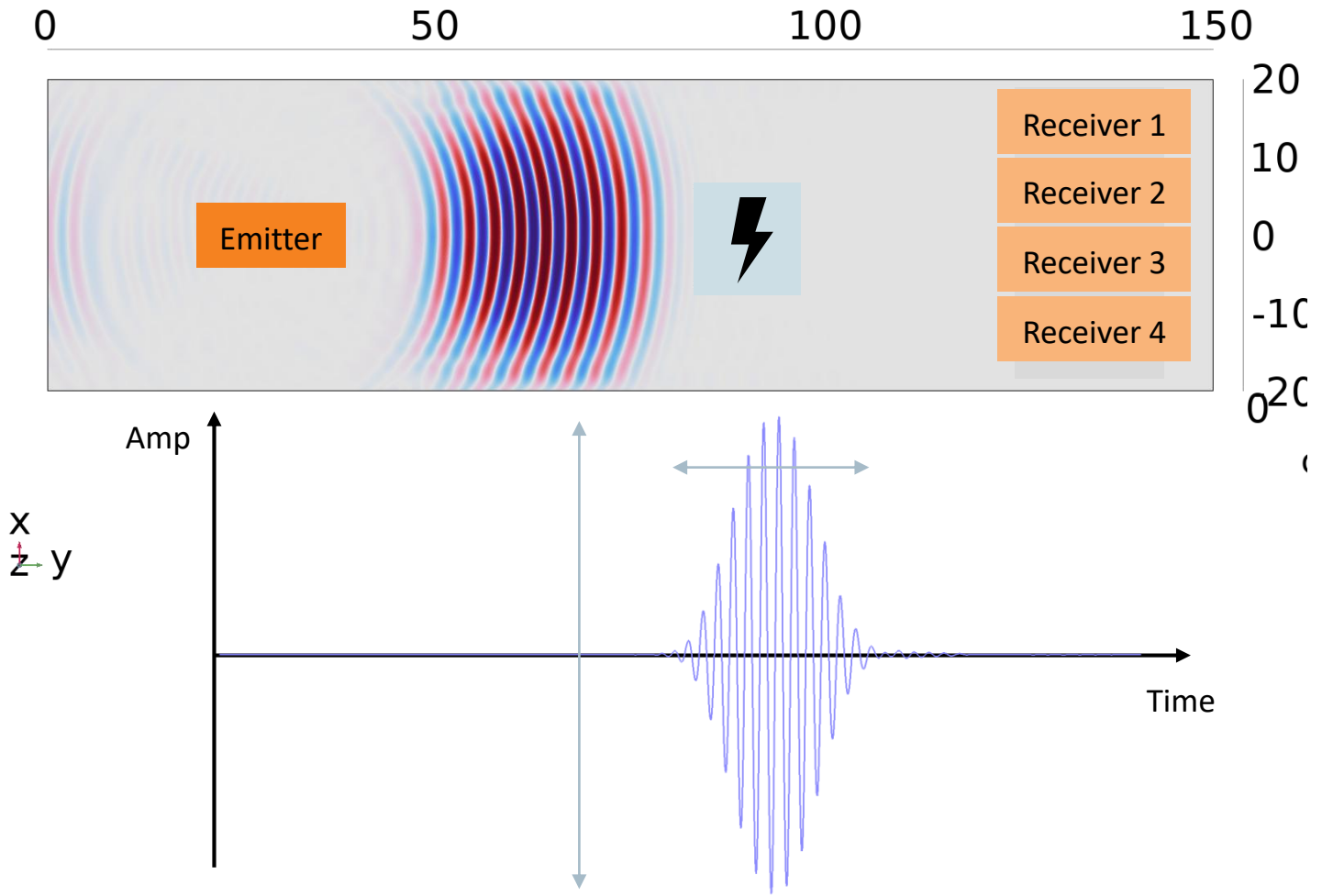
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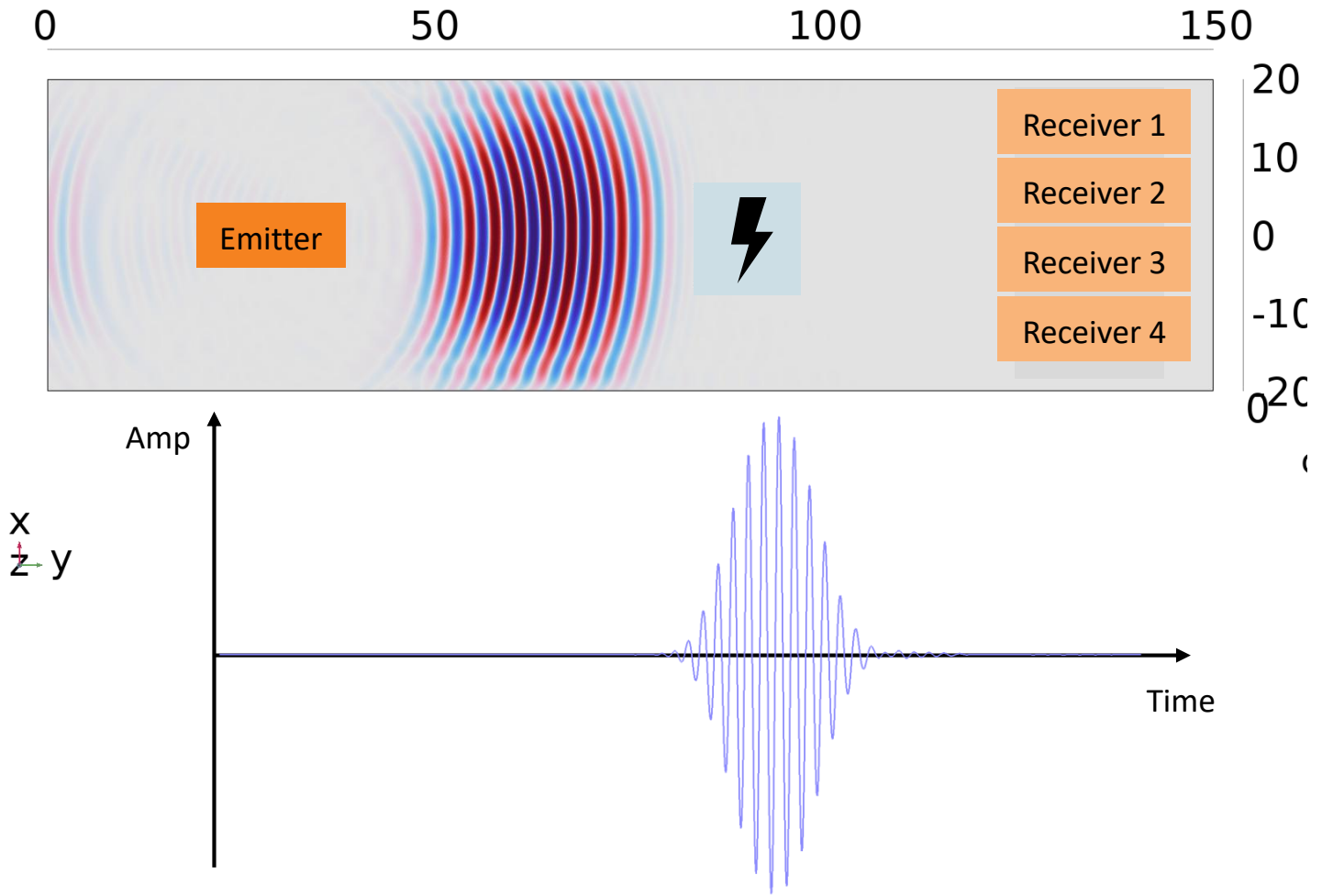
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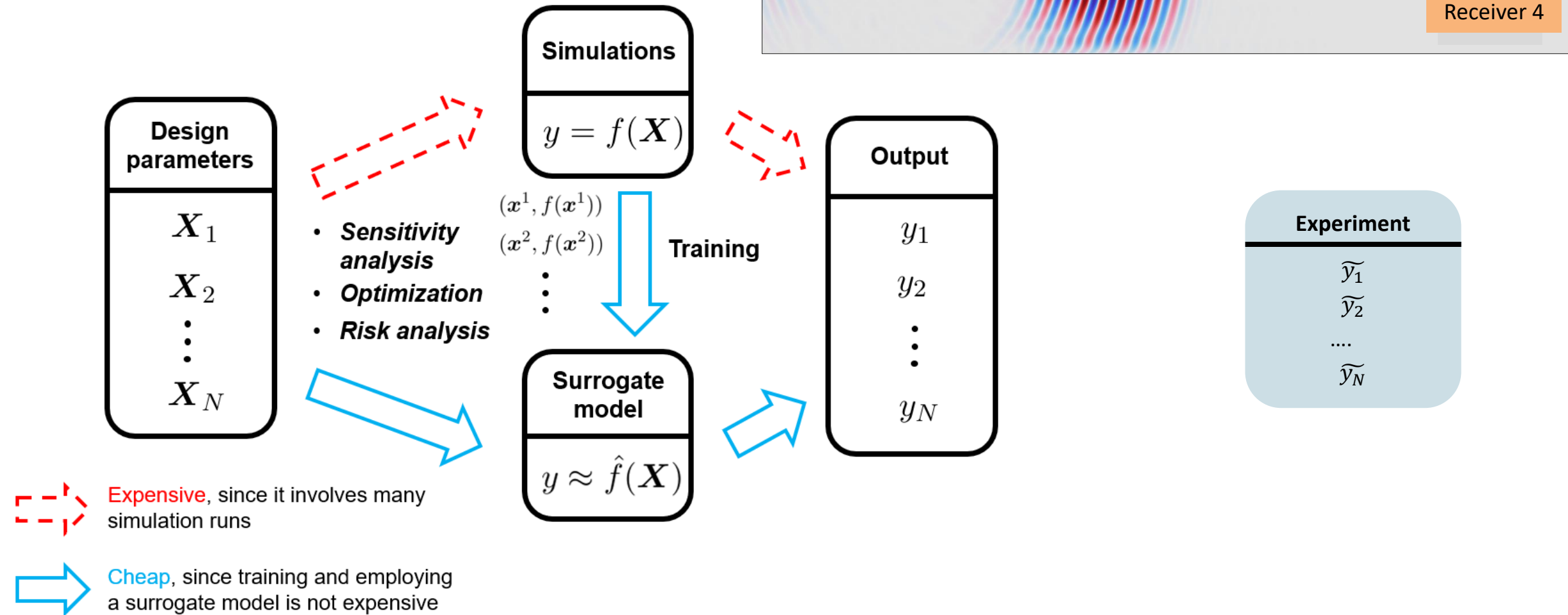
Proposed Solution

- Physics-based digital twin
- Surrogate-assisted optimization
- Quantitative reconstruction of corrosion geometry



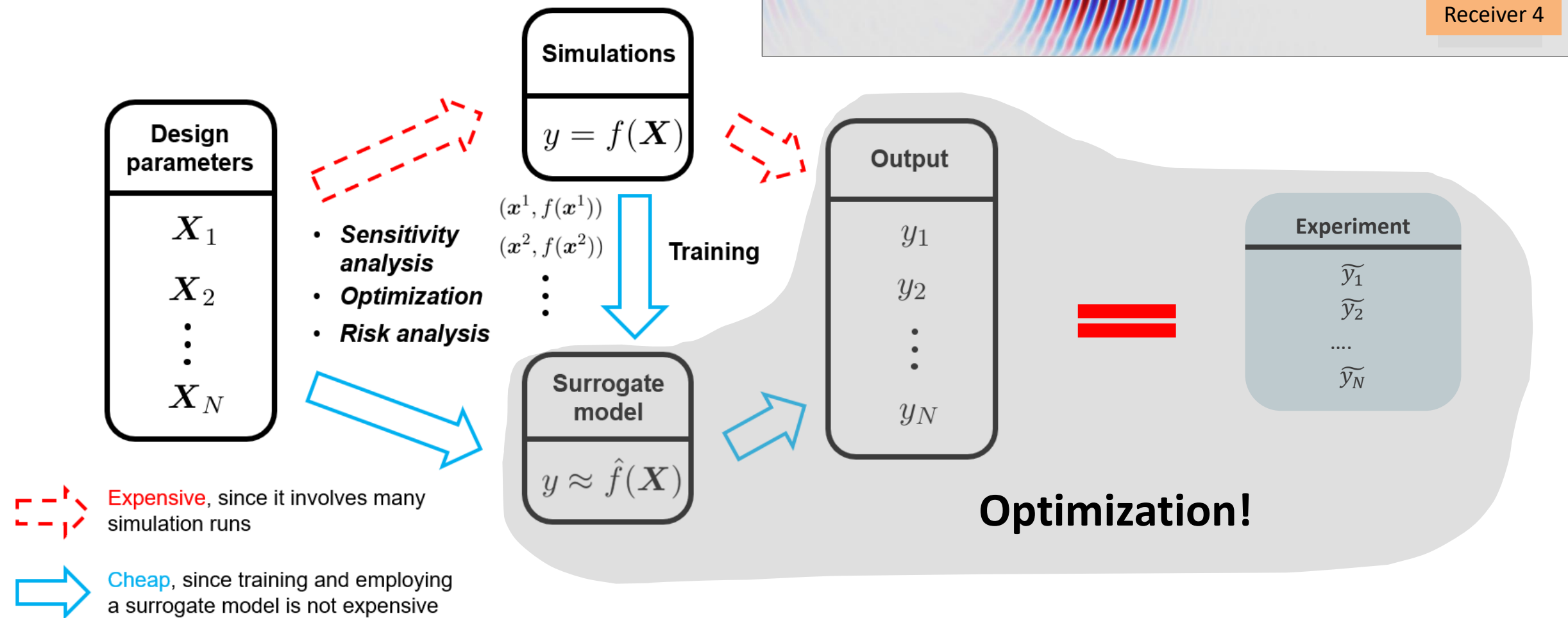
Physics-Based Digital Twin Framework

Surrogat Model & Optimization



Physics-Based Digital Twin Framework

Surrogat Model & Optimization



Case Study – Forward Model

Objective

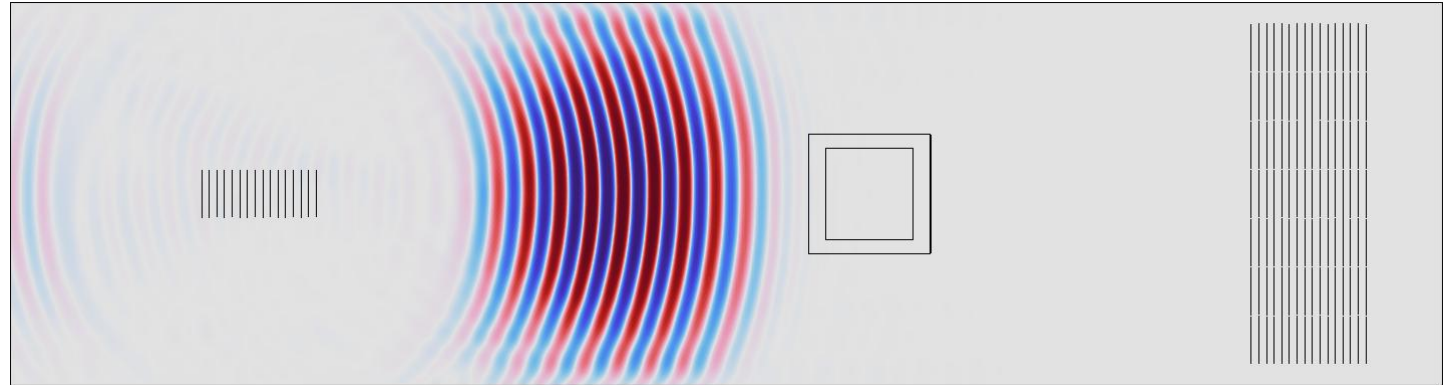
- Demonstrate inverse reconstruction workflow
- Controlled validation using synthetic data
- Known defect geometry used as reference

Corrosion Parameters

- Wall-loss depth: 1.00, 5.98 mm
- Axial length: 1.01, 9.99 cm
- Circumferential extent: 1.06, 9.94 cm

Output

- Synthetic GW signals (A-Scan)
- Used as virtual measurement data



- $d_0 = 8mm$

Case Study – Inverse Reconstruction

Optimization Variables

- Defect depth
- Defect length
- Circumferential extent

Objective Function

- Minimize deviation between:
 - Synthetic signal
 - Output signal of Surrogat model

Output

- Synthetic GW signals
- Used as virtual measurement data

Outlook and Collaboration Opportunities

Near-Term Development

- Experimental validation
- Multiple defect configurations
- Complex defect geometries
- Noise robustness
- Different pipe geometries
- Real inspection data
- Different GW modes

Long-Term Vision

- Real-time defect characterization
- Digital-twin-assisted asset integrity assessment
- Integration into inspection workflows
- Decision support for maintenance planning

