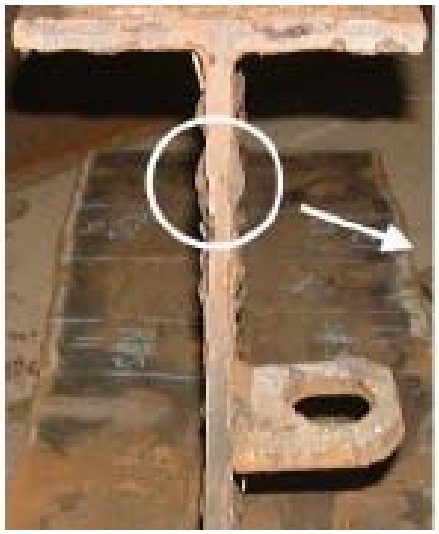
Structural Integrity Monitoring using Guided Ultrasonic Waves



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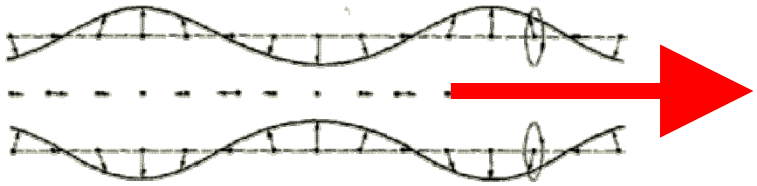
Overview

- Guided Ultrasonic Waves
- Large Area Structural Integrity Monitoring (SIM)
- Distributed Ultrasonic Sensors Array
- Defect Detection at a Stiffener
- Calculation of Scattering at Defect
- Defect Sensitivity Prediction
- Conclusions

Guided Ultrasonics

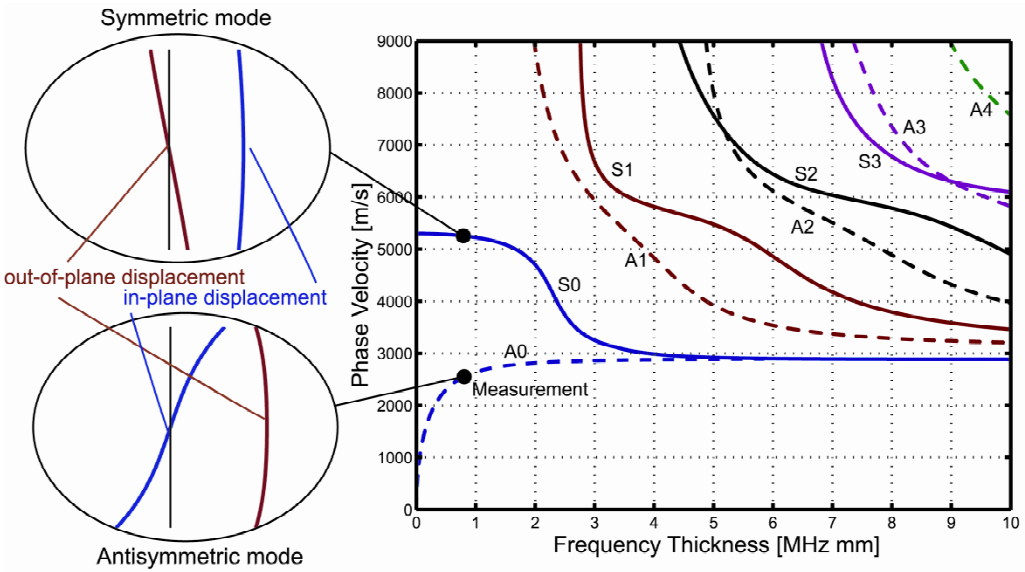
Guided Ultrasonic Wave Testing:

- Thin structure or layer
- Wave mode through thickness
- Propagation along plate
- Large area coverage



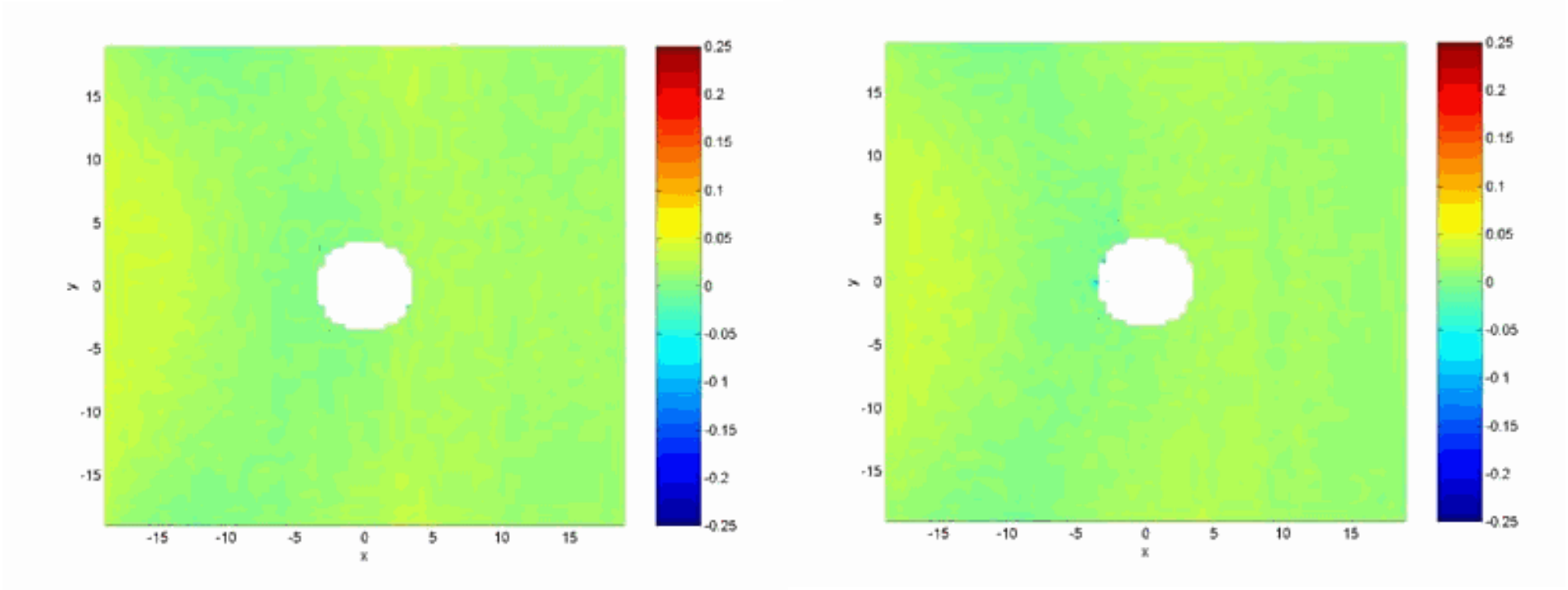
Propagation Direction

- A_0 Lamb Wave Mode
- Bending (Flexural) Wave
- Excitation using small Piezoelectric Transducer



Dispersion Diagram and Mode Shapes at 0.8 MHz mm

Guided Ultrasonics



a) no defect b) with defect

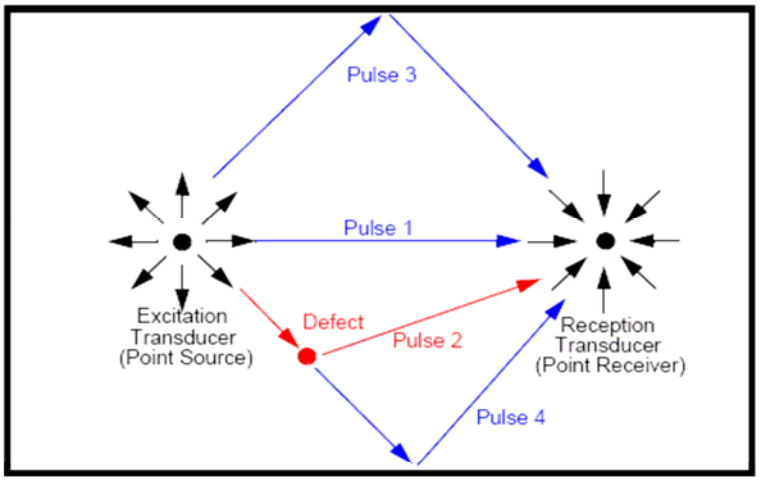
Measurement at tensile specimen with circular fastener hole

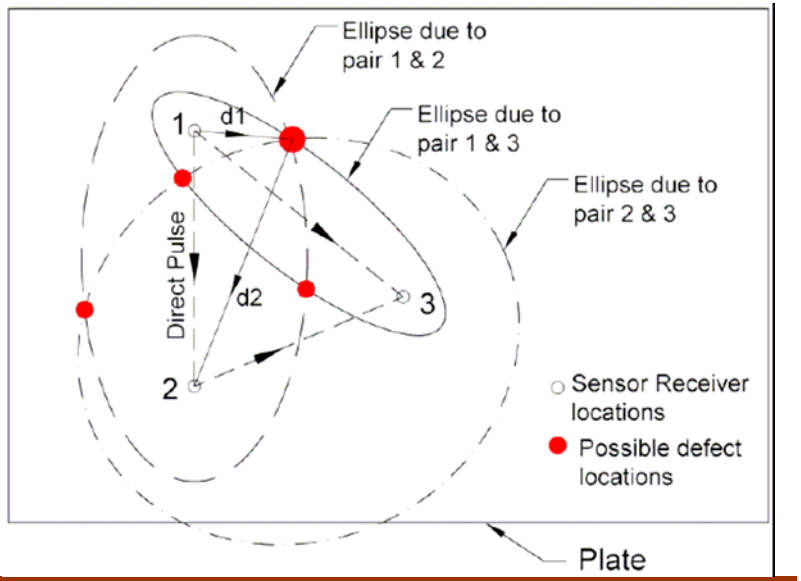
incident wave from left

f_0 = 40 kHz, λ = 26 mm, r_0 = 3.25 mm, h = 3.17 mm

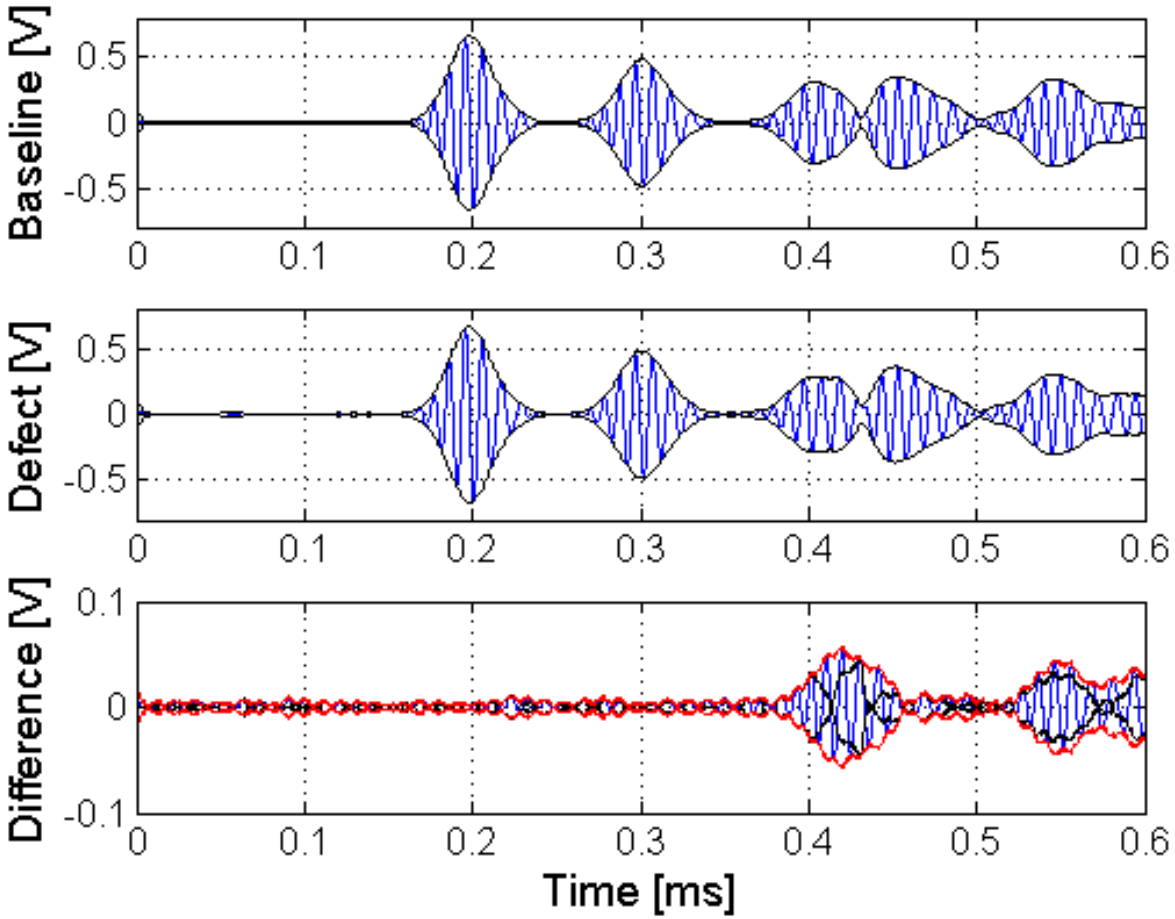
Distributed Sensors Array

- Distributed Sensors on Structure
- Point Source / Receiver
  for guided wave mode
- Propagation along plate
- Large area coverage
- Complexity of 'Baseline'
  - Multiple reflections
  - Edges and structural features
- Damage localization concept for SIM





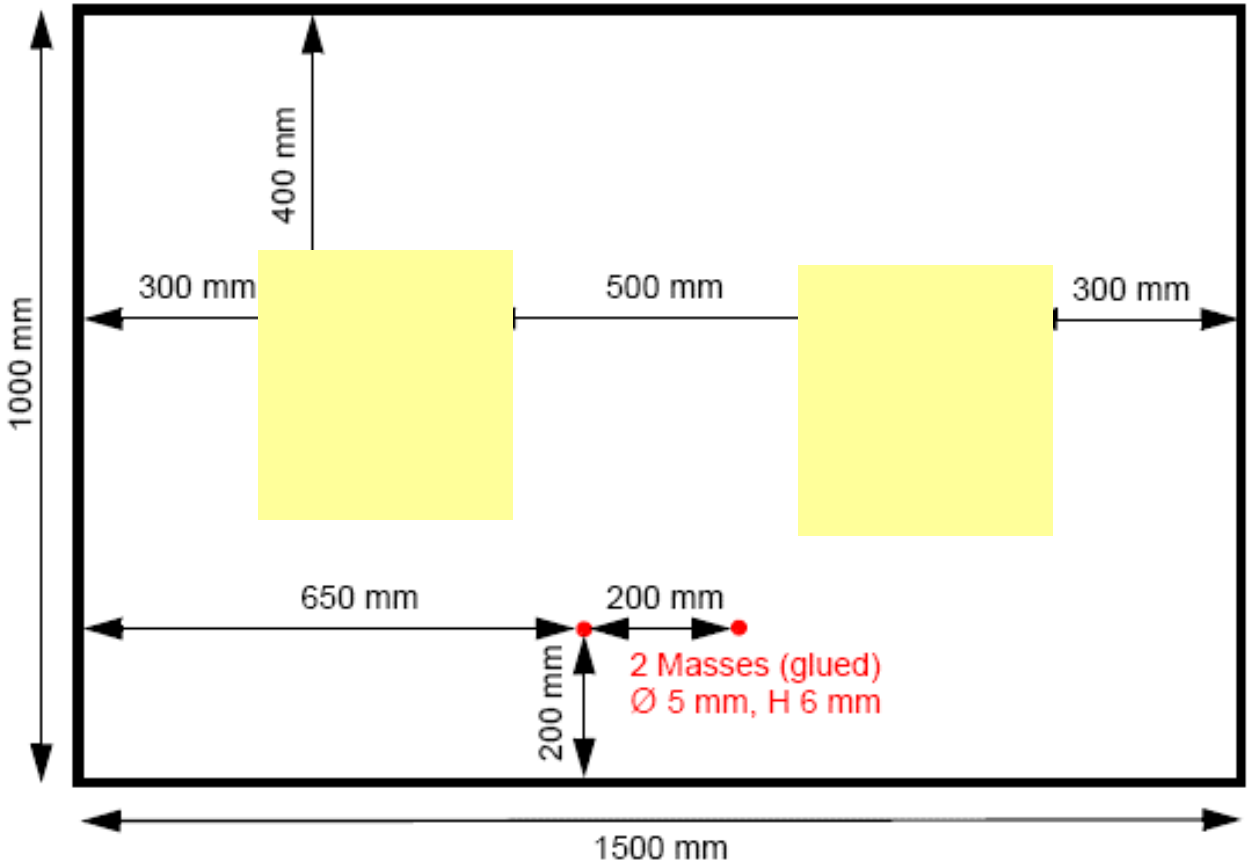
Distributed Sensors Array



Experimental time traces, plate with part-through slot
Top: no defect; Center: defect; Bottom: difference signal

- Baseline Measurement
- 'Defect' Measurement
- Baseline Subtraction
- Removal of reflections at structural features
- Reduction of signal complexity
- Temperature Compensation
- Difference of Envelope
- Difference of Signal

Plate - Experiment

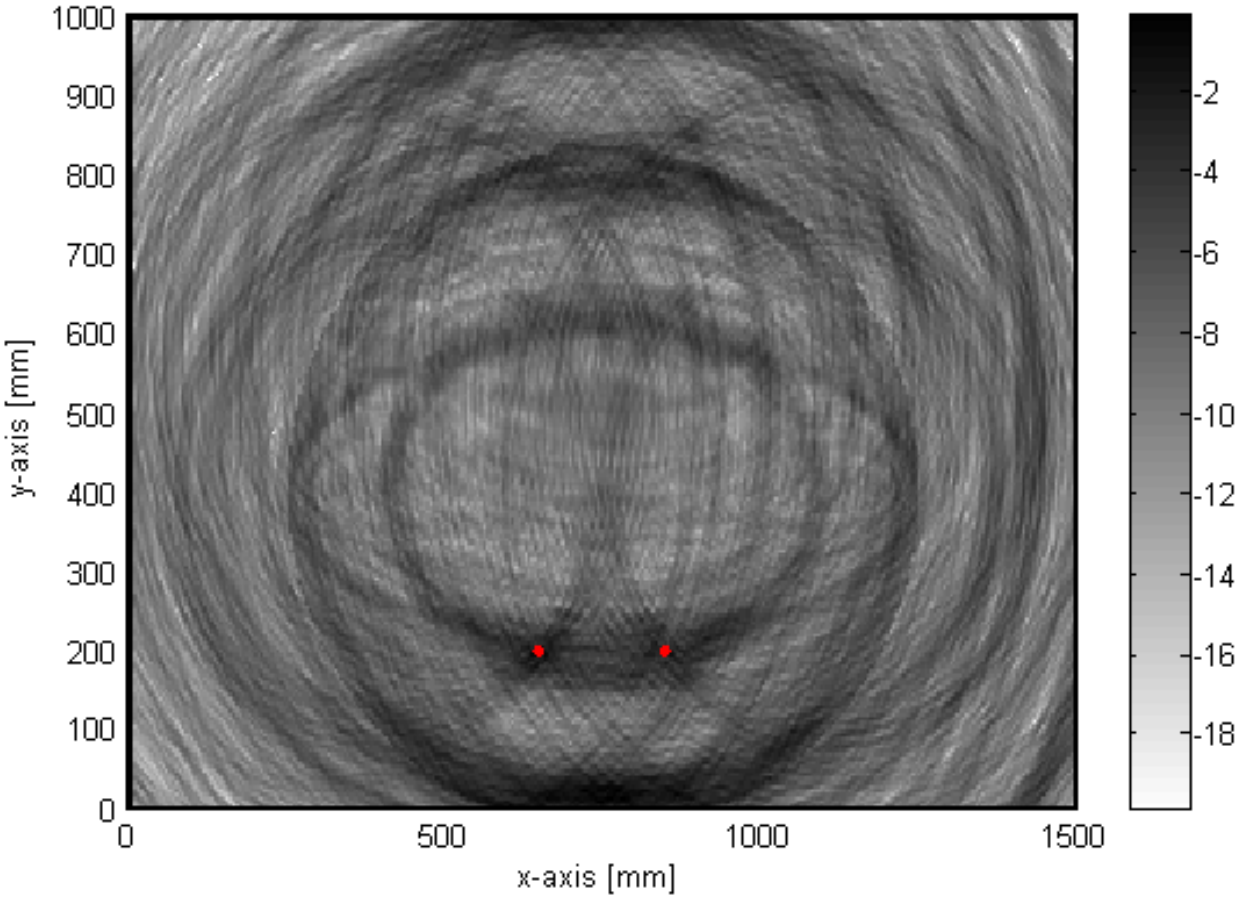


Schematic of aluminium plate (1.5m x 1m x 5 mm)

2 x 4 transducers, 28 pitch-catch time traces, 2 masses (glued)

Plate - Experiment

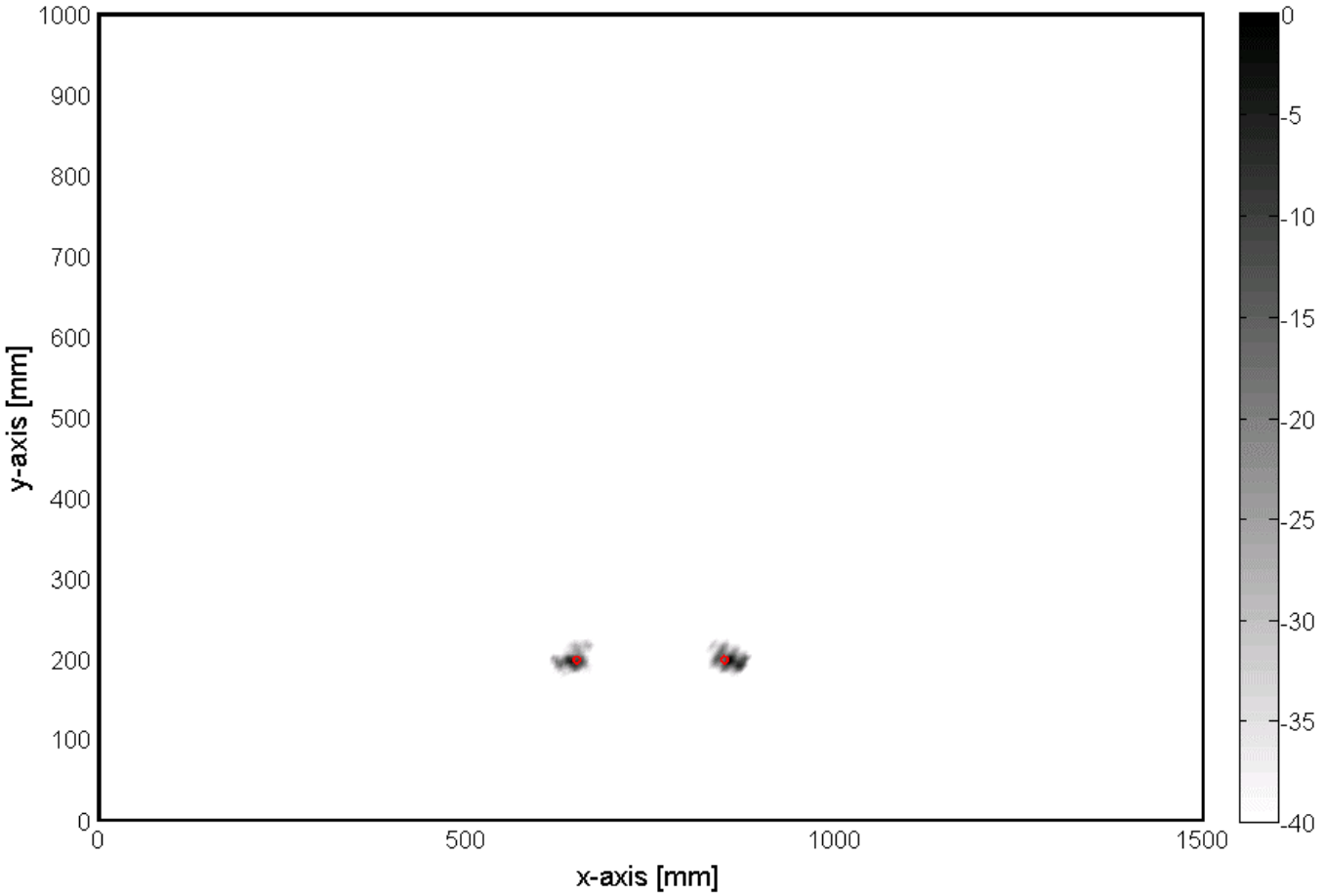
28 Signals



Damage map for 2 masses (glued), 20 dB scale, 2 pulses

Addition of monitored signals - ‘Probability of damage location’

Plate - Experiment

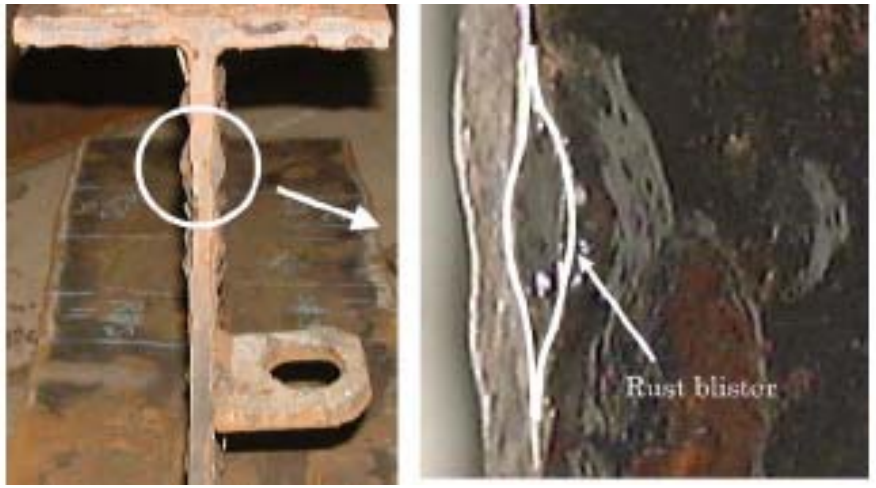


Damage map for 2 masses (glued), 40 dB scale, 2 pulses

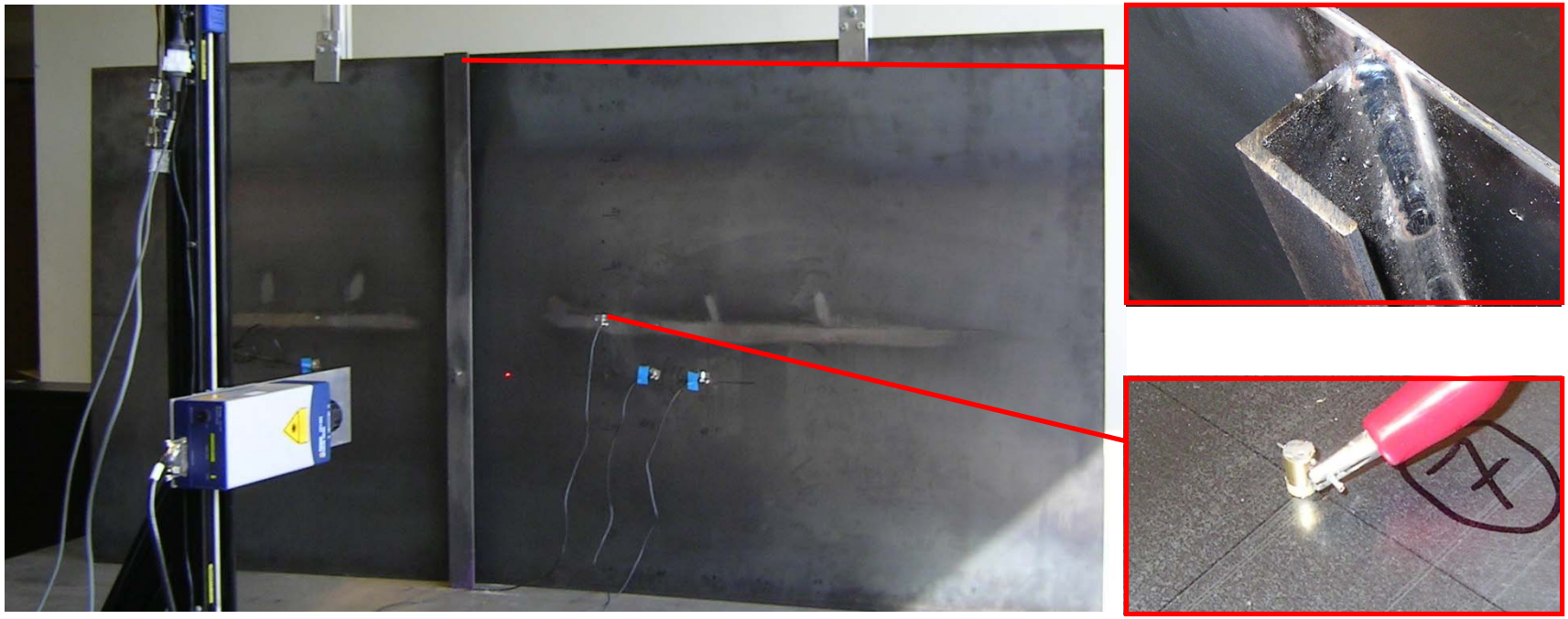
Multiplication of monitored signals - ‘Exclusion of damage location’

Example: Ship Hull

- Single or Double Hull
- Hull Plating (Mild Steel)
- Corrosive Environment
  - Seawater
  - Crude Oil (Sulphur)
- Depending on Treatment
  - General Corrosion
  - Corrosion Pitting
- Fatigue Cracks
- Often at Structural Features
  - Stiffeners
  - Web Frames



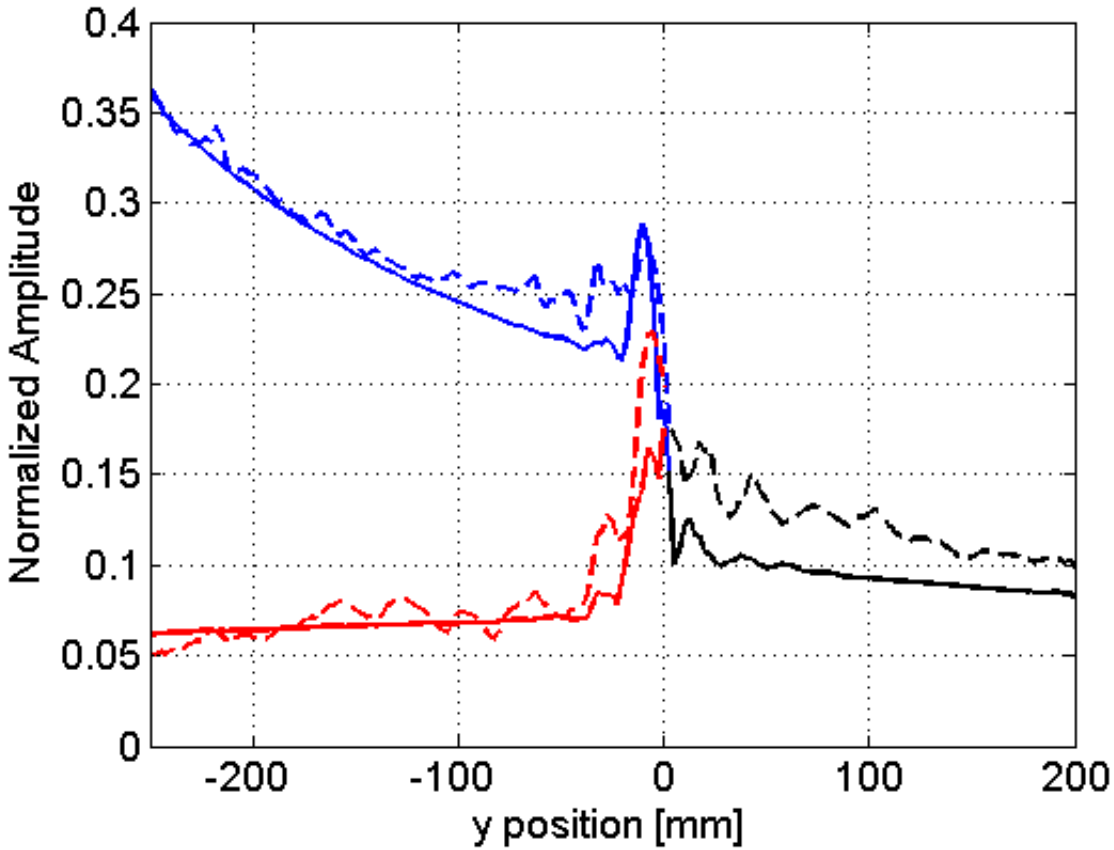
Stiffened Steel Plate



Steel Plate (mild steel): 2 m x 1 m x 5 mm
Stiffener: 50 mm x 50 mm x 5 mm

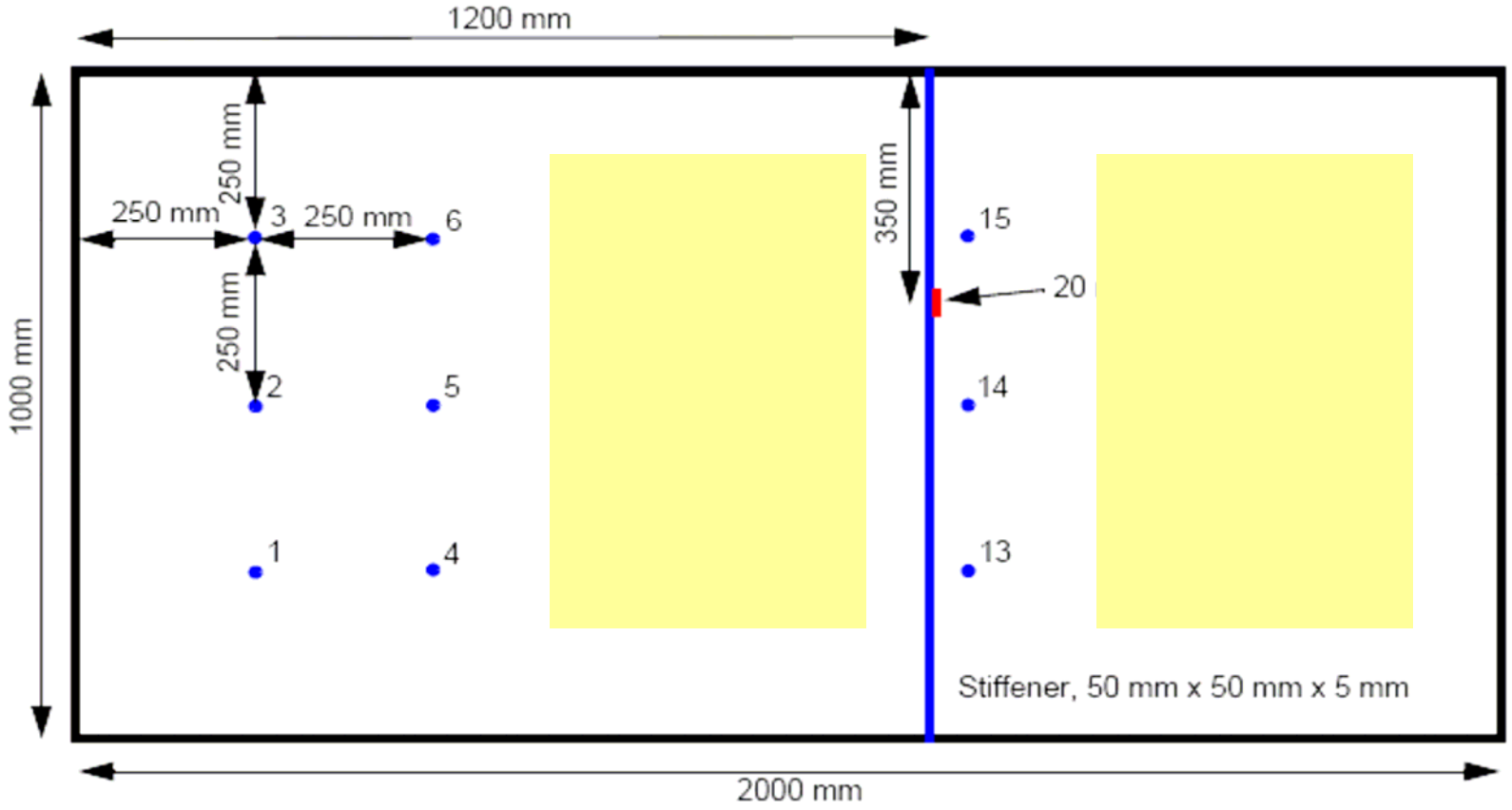
Excitation: Transducer (Pz27, brass backing, D = 5 mm)
Measurement: Polytec Laser Vibrometer

Stiffened Steel Plate



Amplitude of incident, reflected, and transmitted waves:
FEM (solid), Experiment (dashed), line from excitation to stiffener
A_0 Excitation: Point Source at x = 0 mm, y = - 400 mm

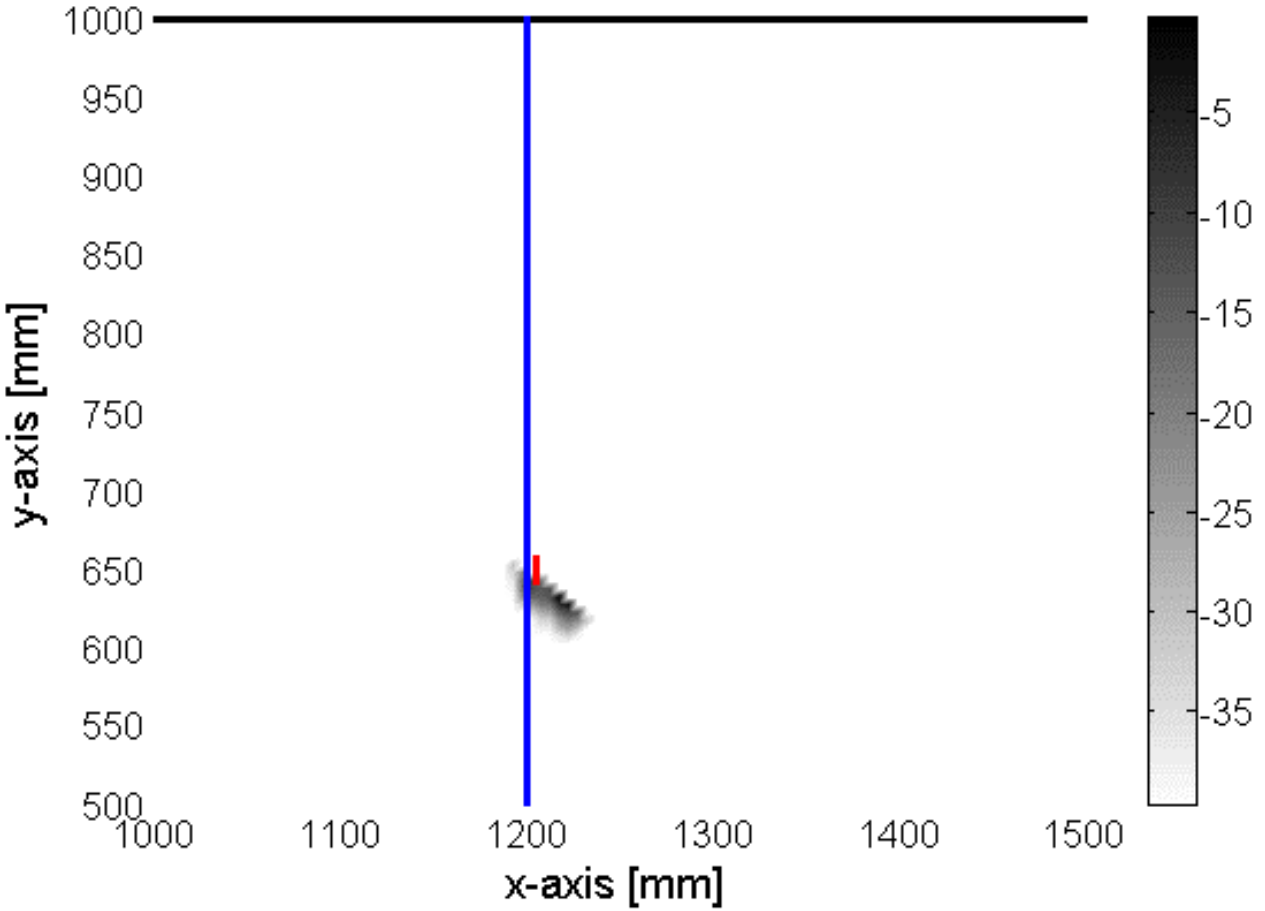
Stiffener - Measurement



Schematic of steel plate (2m x 1m x 5 mm) with stiffener

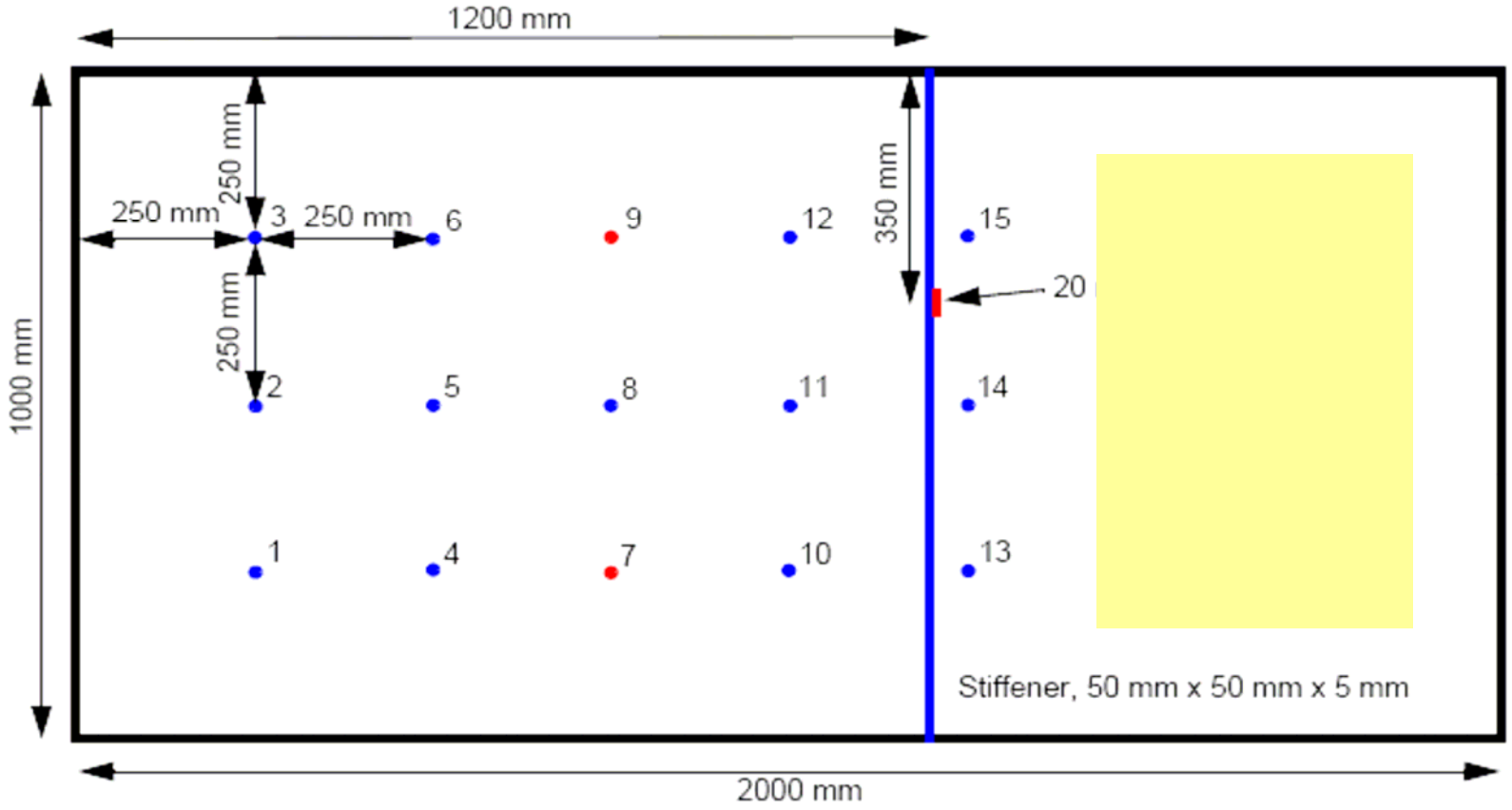
2 x 6 transducers each side of stiffener, 66 pitch-catch time traces

Stiffener - Measurement



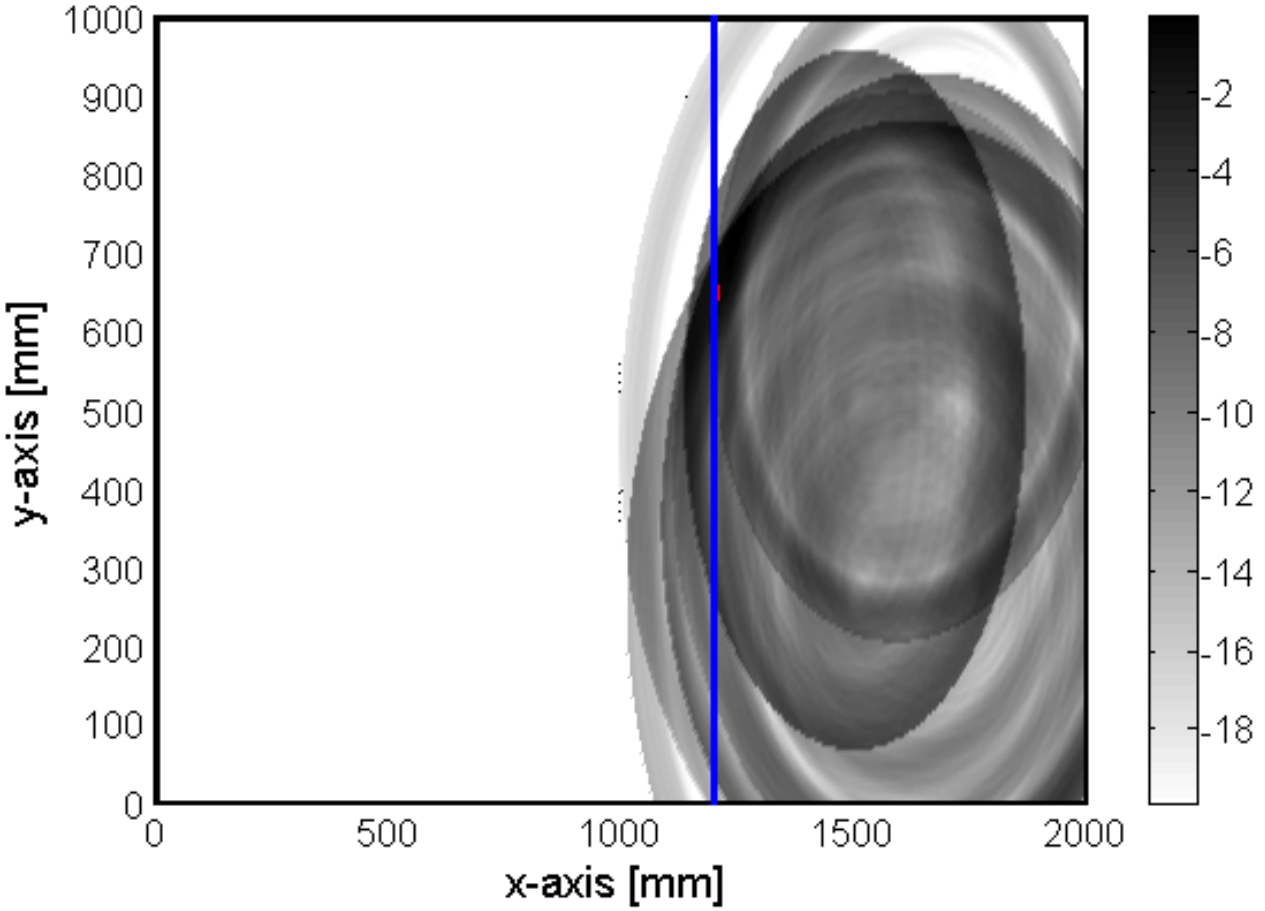
Damage map for through notch (20 mm long), 40 dB scale
Multiplication of measured signals on both sides of stiffener

Stiffener - Measurement



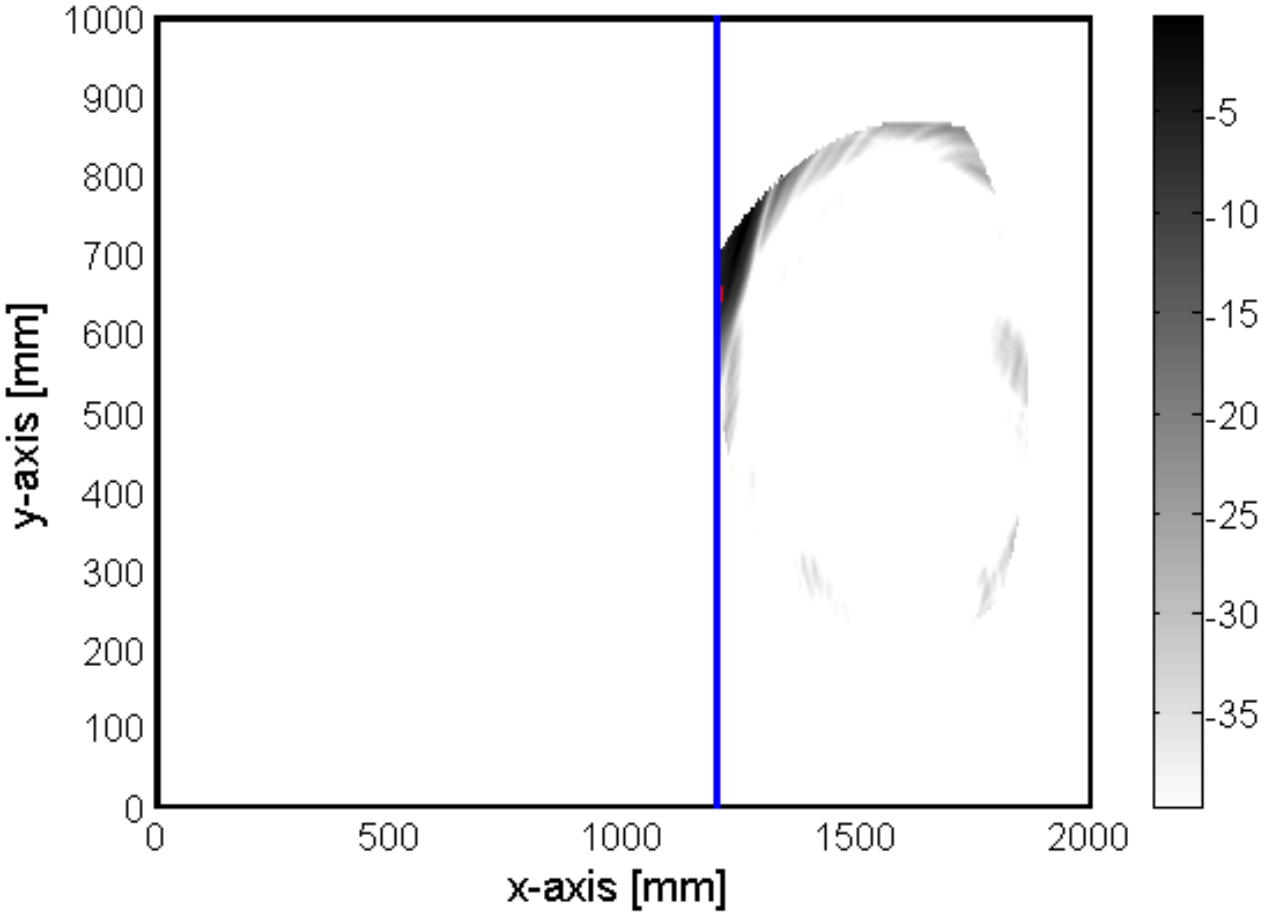
Schematic of steel plate (2m x 1m x 5 mm) with stiffener
6 transducers on right side of stiffener, 15 pitch-catch time traces

Stiffener - Measurement



Damage map for through notch (20 mm long), 20 dB scale
Addition of measured signals on right side of stiffener

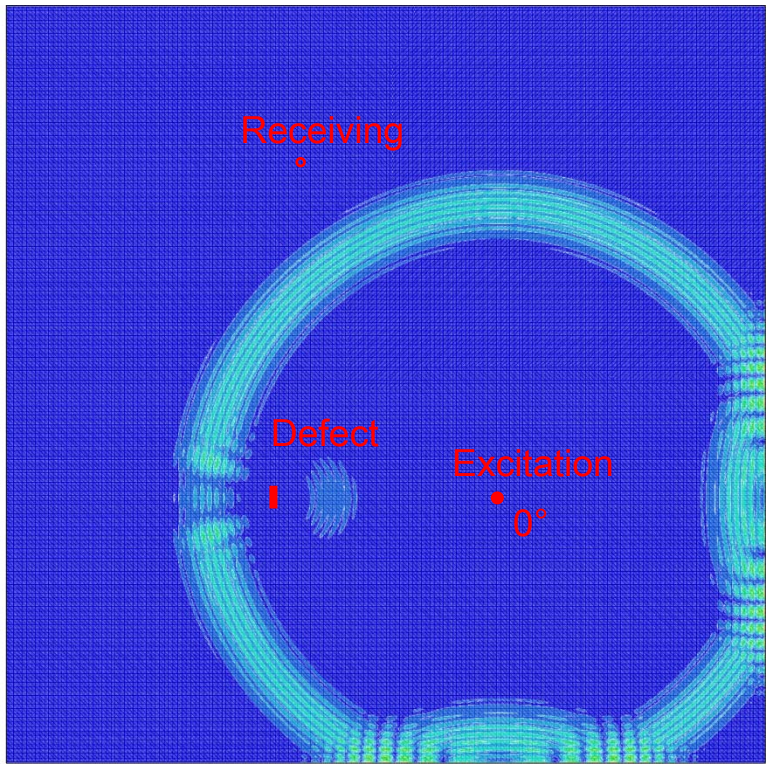
Stiffener - Measurement



Damage map for through notch (20 mm long), 40 dB scale
Multiplication of measured signals on right side of stiffener

Scattering Predictions

- Hybrid model to predict relative amplitudes of guided wave pulses
- Scattering amplitude and directivity from FE numerical calculation
- Verified from experiments

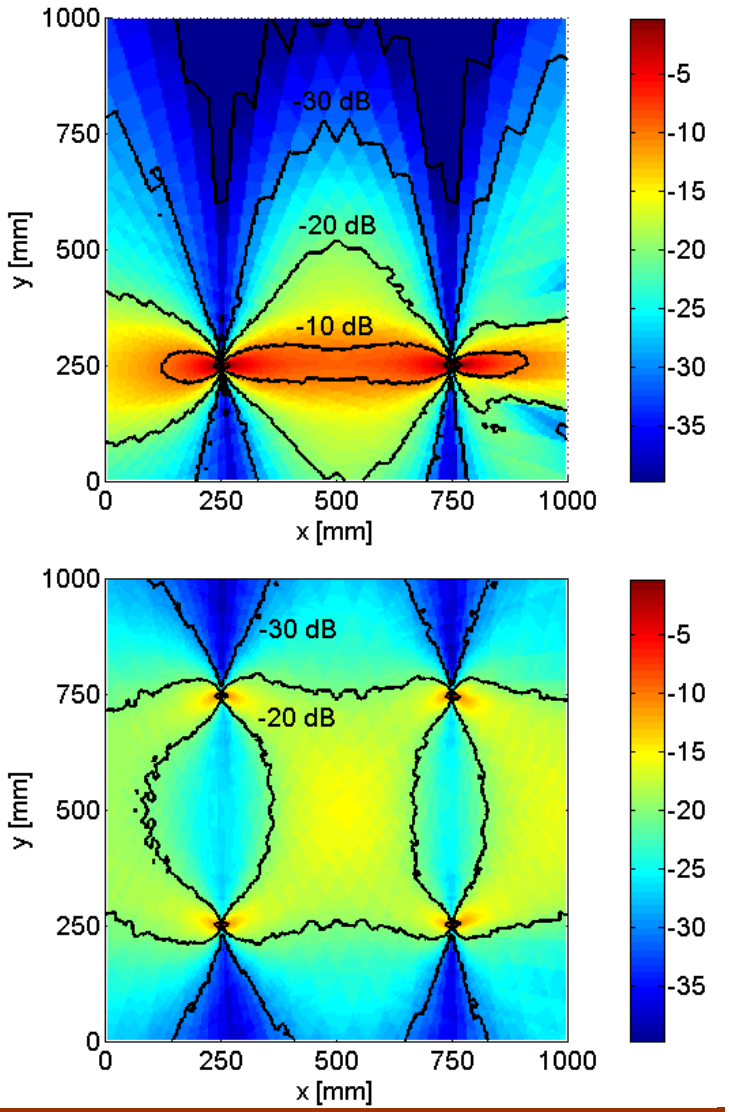


- Received defect pulse
  - Amplitude of incident wave at defect
  - Locally scattered amplitude from FE
  - Radial wave propagation
  - Amplitude decreases with $\approx 1/\sqrt{r}$

- Relative amplitude for distributed sensor array

Implications for SIM

- Distributed sensor array:
  - Assumption 20 mm long vertical through thickness crack
  - Calculate predicted defect pulse amplitude relative for sensor pair
  - For multiple sensors / pathways use algorithm for data fusion (e.g. addition)
  - Predicted amplitude ratio for 4 sensors
  - Comparison to array performance
  - Comparison to advance knowledge of stress state in structure (location & preferential direction of fatigue cracks)
  - Guidance for sensor placement



Conclusions

- Guided Ultrasonic Wave:
  - A_0 Lamb wave mode (low frequency)
  - Scattering at defects and structural features
  - FEM simulations and experiments
  - Variation defect size, location and orientation
  - Prediction of scattered wave amplitude & directivity

- Distributed arrays for Structural Integrity Monitoring:
  - Defects in large plate structures
  - Detection and localization
  - Prediction for minimum detectable crack size
  - Guidance for number and placement of sensors

Acknowledgments

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