Modeling of Ultrasonic Guided Waves in Metal and Composite Materials

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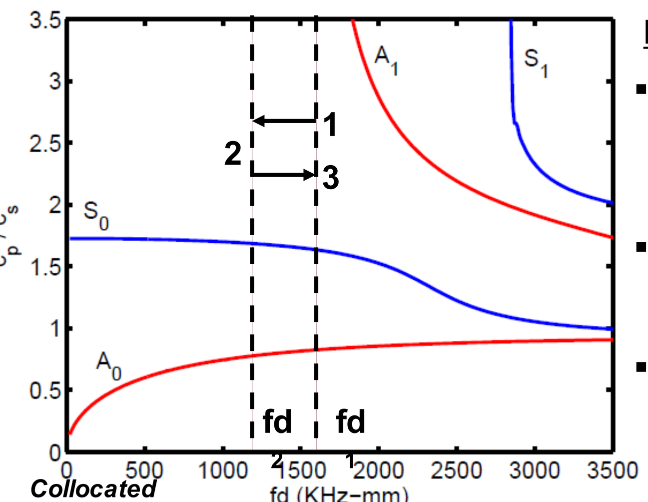
Objectives:

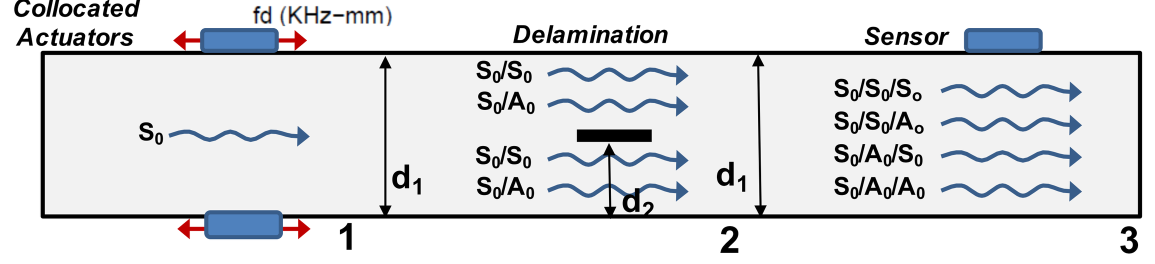
- **Study wave propagation behaviour in complex metallic and composite structures**
- **Evaluate the dispersion curves and attenuation trends for different layups and material properties**
- **Investigate wave interaction with damages for development of SHM methodology for structural damage detection and quantification**

Guided Waves



Mode conversion analysis

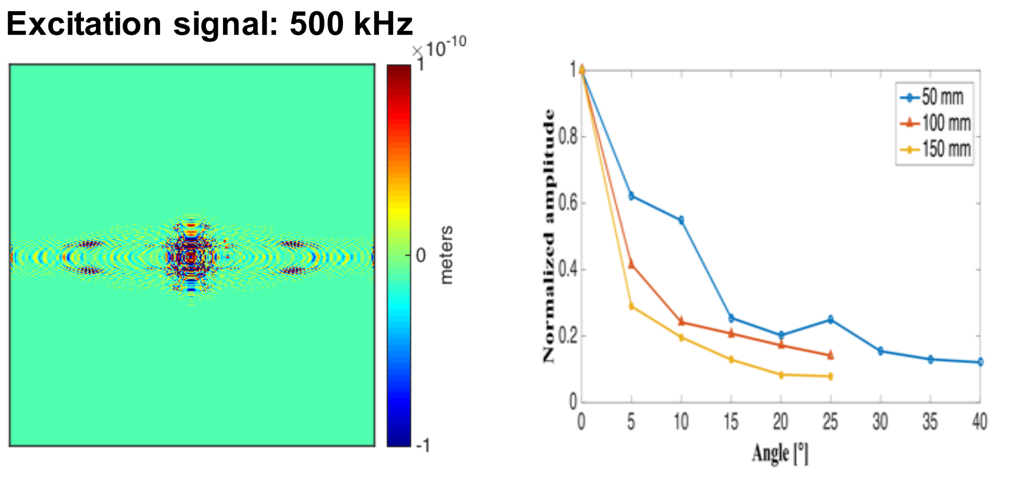
- Thickness change caused by damage acts as source of mode conversion
- Detecting mode converted waves → damage detection
- TOF information of mode converted waves → damage localization



Lamb waves have ability to travel long distances in plate-like structures & are sensitive to multiple damage types

Directional Attenuation in Unidirectional Composites

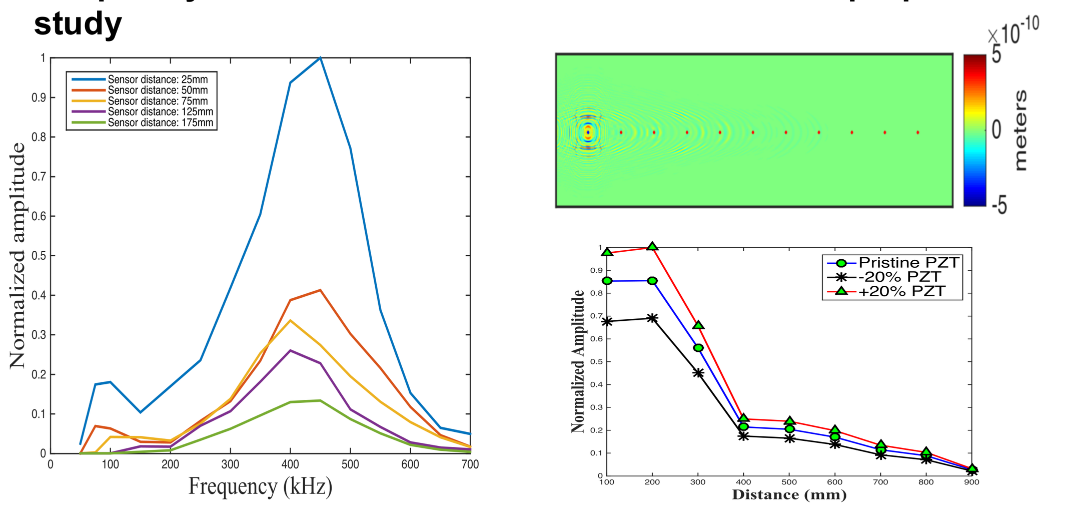
- S0 mode propagation; Layup: $[0^o]_{8s}$
- Plate dimension: 1000 mm x 1000 mm x 16 mm
- Sensor distance: 50 mm,100 mm and 150 mm
- Angle: 0º - 45º
- Propagation time: 100 μs
- Excitation signal: 500 kHz



Signal amplitude decreases with increasing angle

Frequency and PZT Property Dependence on Attenuation

- Layup: $[0]_{8s}$
- Sensor distance varied between 25 mm and 175 mm for frequency dependence
- Frequency: 50 kHz to 500 kHz. And 500 kHz for PZT properties study



- Optimum frequency can be selected based on the functional relation with amplitude
- Increasing PZT properties leads to higher wave amplitude

Matching Pursuit Decomposition (MPD)

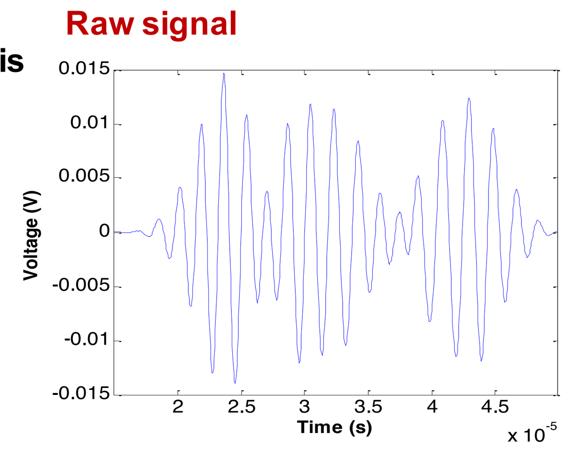
- Decomposes signal into weighted linear expansion of elementary basis function (atoms)

$$x(t)=\sum_{i=0}^{Z-1}\alpha_i g_i(t)+r_Z(t)$$

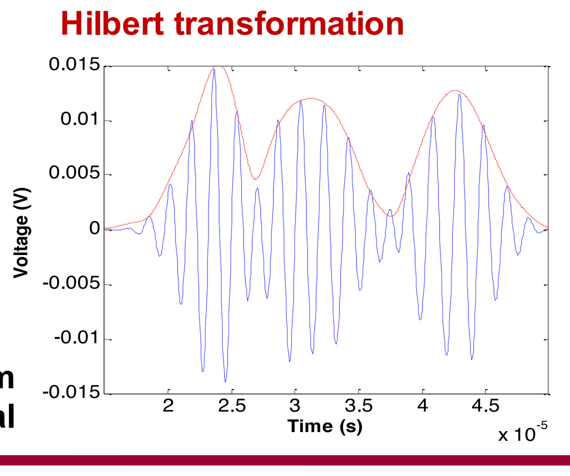
where,
$x(t)$ – input signal
α_i – expansion coefficient
$g_i(t)$ – basis function
$r_Z(t)$ – residual energy after Z iterations

- Iterative algorithm sorts decomposition by magnitude of α_i (highest energy)
- Basis function chosen to resemble signal and reduce computational complexity
- Number of peaks in Hilbert transform estimates number of modes in signal

Raw signal

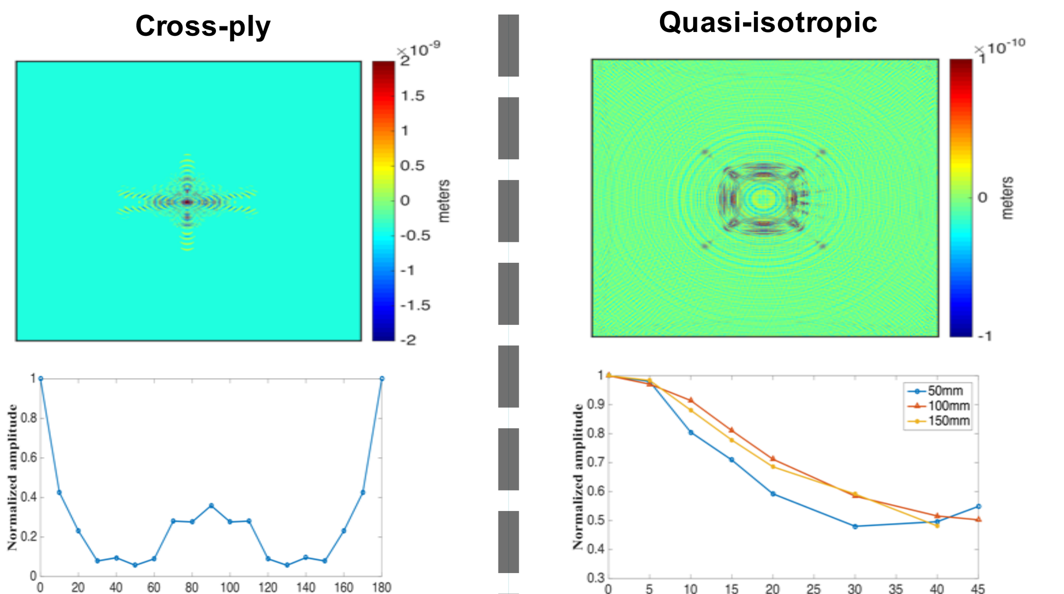


Hilbert transformation



Directional Attenuation in Cross-ply and Quasi-isotropic Composites

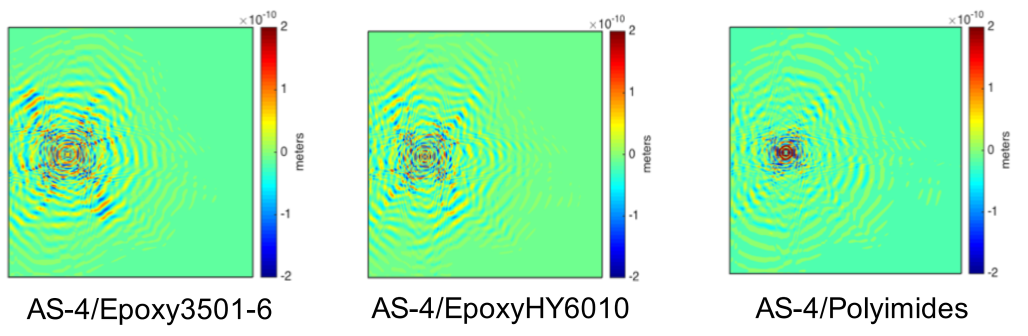
- S0 mode propagation; Excitation signal: 500 kHz
- Plate dimension: 1000 mm x 1000 mm x 16 mm



- Highly symmetric wave propagation behavior can be found in cross-ply composites
- Amplitude decreases as wave leaves fiber orientations

Composite Material Property Dependence on Attenuation

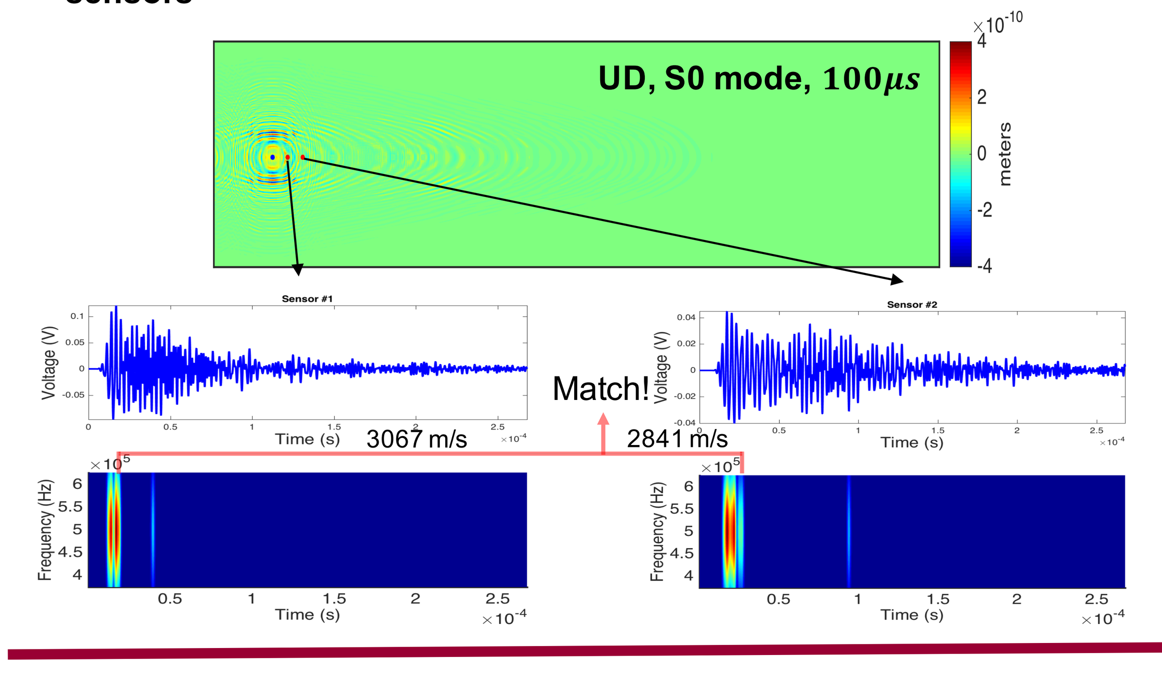
- Layup: $[0^o/45^o/\text{-}45^o/90^o]_{2s}$, 400 mm x 400 mm x 16 mm
- Sensor distance varied between 50 mm and 200 mm
- Polymer materials: Epoxy 3501-6, Epoxy HY6010 and polyimides
- Fiber materials: AS-4 carbon fiber, E-glass fiber and Kevlar 49
- Case 1: same fiber (AS-4) with different polymer materials
- Case 2: same polymer (Epoxy 3501-6) with different fiber materials
- Propagation time: 45μs



Changing matrix properties do not cause significant change in wave propagation behavior

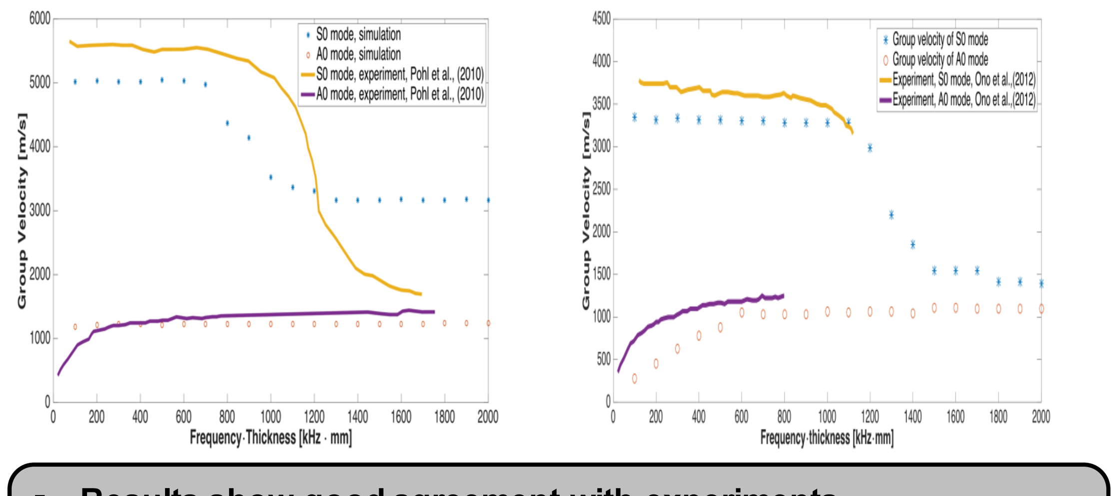
Time of Flight Analysis Using Supervised Learning Based MPD Algorithm

- For signal collected from each sensor, multiple modes found by MPD methodology
- Found the time of arrival (TOA) of each mode
- Calculated the group velocity for each mode
- Expected mode found by comparing the group velocities from all the sensors



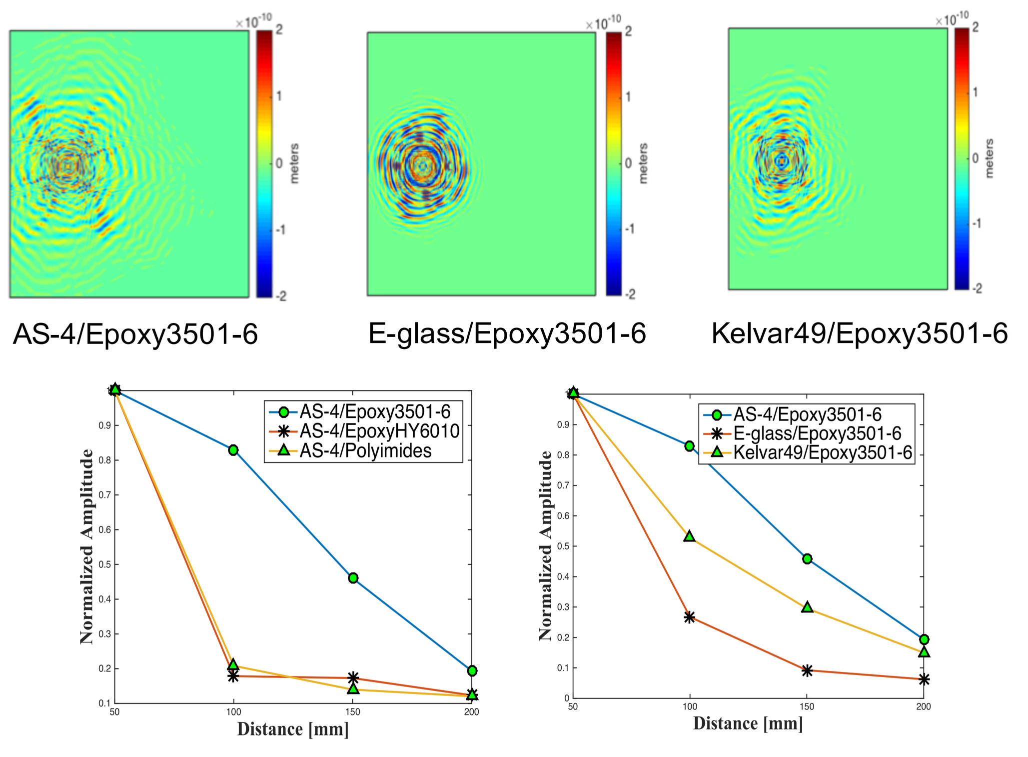
Dispersion Curve for Carbon/Glass Fiber Reinforced Polymer Composites

- A0 and S0 modes propagation; Layup: $[(0/90)_f, 45,\text{-}45, (0/90)_f]_s$
- Plate dimension: 1300mm x 300 mm x 2 mm
- Sensing distance: 50 mm; Frequency: 50 kHz to 1000 kHz
- Composite materials: IM6/SCI081 and glass fiber composite
- Results are plotted along with published experiment data



- Results show good agreement with experiments
- The discrepancy of S0 mode in CFRP is due to the different material properties

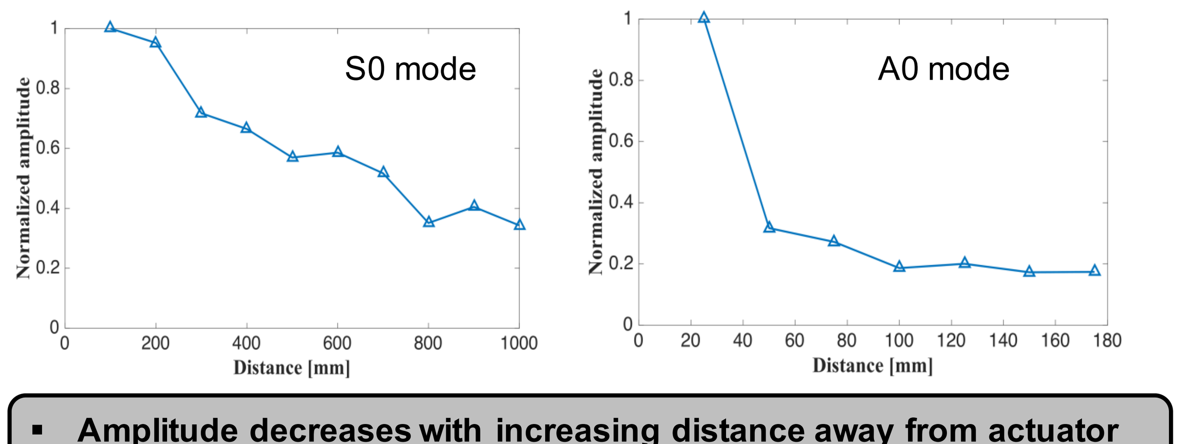
Composite Material Property Dependence on Attenuation



Changes in fiber property lead to significant change in wave propagation

Attenuation in Unidirectional Composites

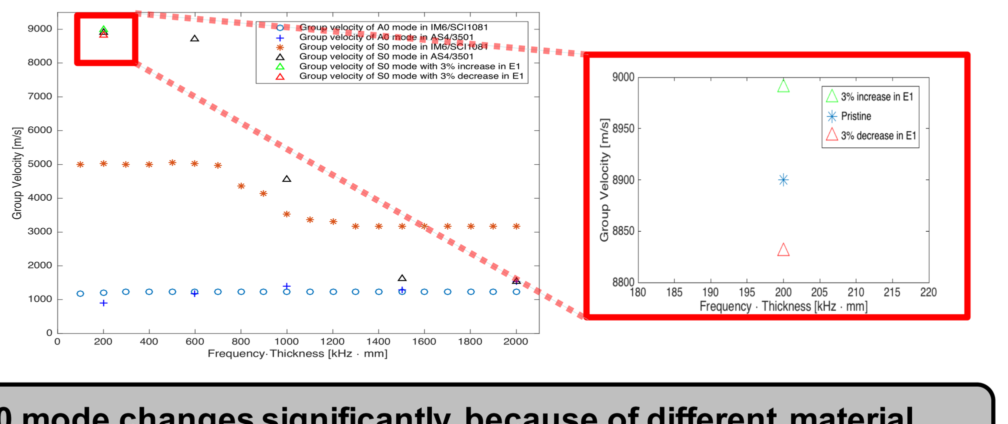
- Layup: $[0]_{8s}$
- Collocated actuators are used to generate S0 and A0 modes
- Frequency: 500 kHz
- Plate dimensions: 1200 mm x 300 mm x 16 mm
- Actuation signal: 5 cycle cosine tone burst



- Amplitude decreases with increasing distance away from actuator
- A0 mode has higher amplitude attenuation than S0 mode

Effect of Stiffness Components on Dispersion Curves

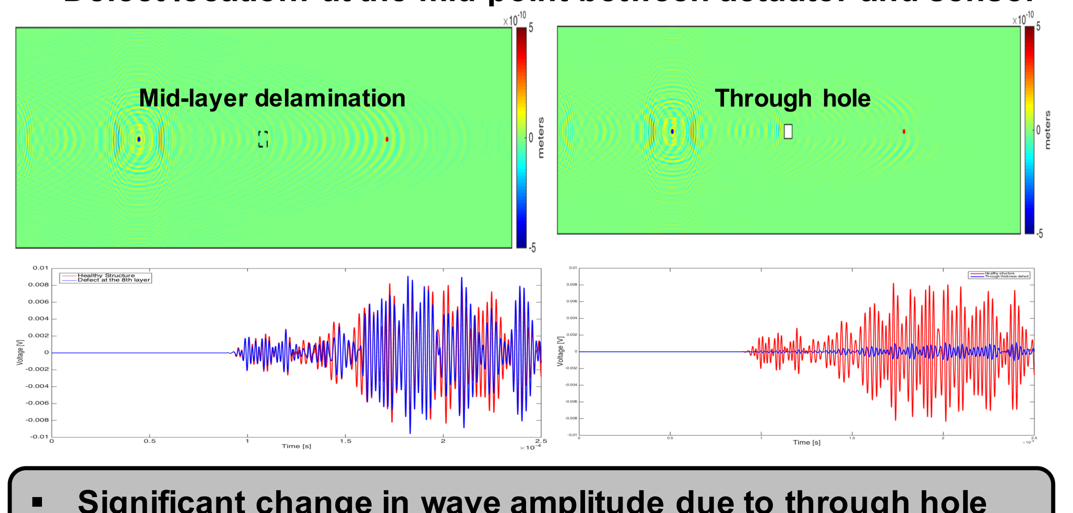
- A0 and S0 modes propagation
- Layup: Quasi-isotropic IM6/SCI081, $[(0/90)_f, 45,\text{-}45, (0/90)_f]_s$, and unidirectional AS-4/3501-6 plates, $[0^o]_{8s}$
- Sensing distance: 50 mm; Frequency: 50 kHz to 1000 kHz
- Small perturbations are introduced in the stiffness components



S0 mode changes significantly because of different material components and layups. A0 is not sensitive to these changes

Interaction With Delamination and Through Hole

- Layup: $[0]_{8s}$, sensor distance 600 mm
- Plate dimensions: 1200 mm x 300 mm x 16 mm
- Defect dimension: 20 mm x 20 mm
- Defect location: at the mid point between actuator and sensor



- Significant change in wave amplitude due to through hole
- Wave refection due to damage

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