Wide-Angle Ultrasonic Backscatter: Concept for Enhanced Array-Based Inspection of Composite Materials

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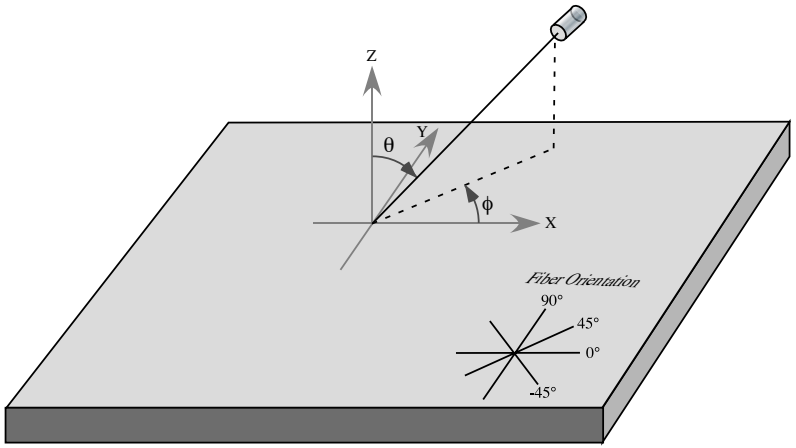
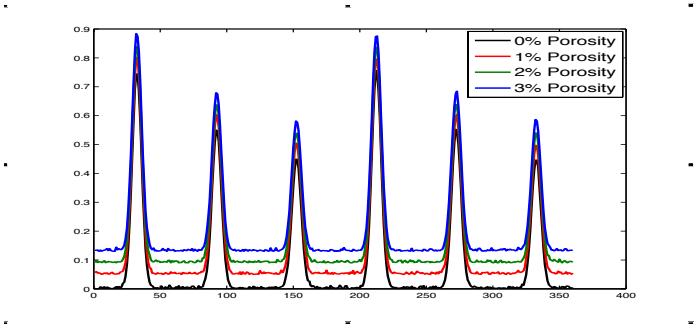
ASNT EVENTS

Introduction

- Beginning early in the 1980s, non-normal-incidence ultrasonic backscatter (polar backscatter) was shown as an effective method for measurement of fiber direction in composite laminates

- Polar backscatter did not catch on because:
  - Mechanical scanning of a probe at each point was not practical for large specimens
  - Array methods, instruments, array probes were not yet affordable for such applications

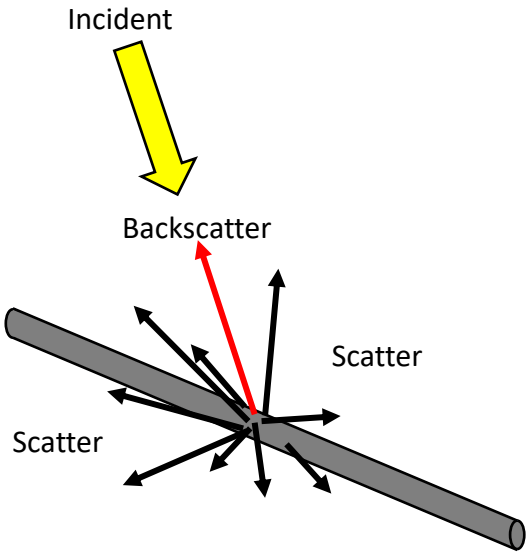




(Schematic data, after Bar Cohen and Crane, 1982, and others)

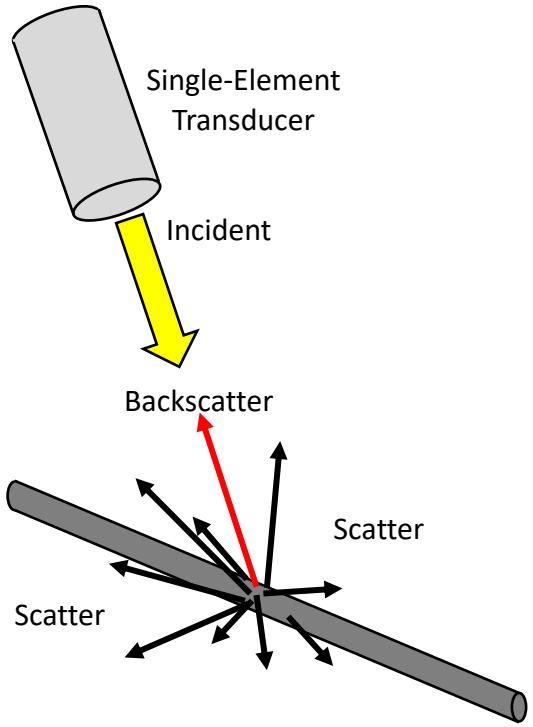
Introduction (continued)

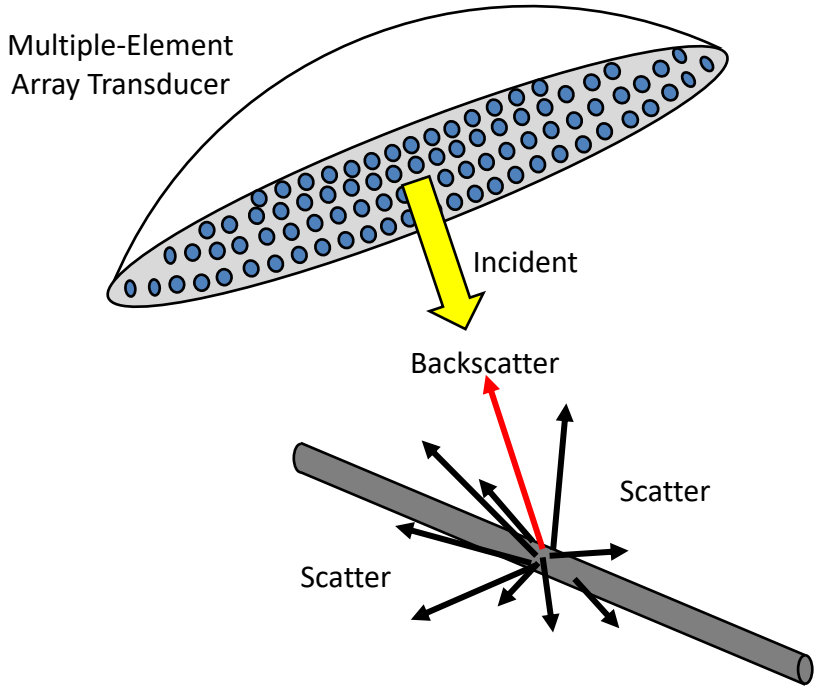
- Stemming from research in polar backscatter, the author reasoned:
  - Ultrasound scattered from fibers would likely have measurable magnitude over a wide range of angles, including the backscatter direction
  - The scattered field would likely have angular structure related to the fiber geometry
  - Scattered field from multiple plies with different fiber orientations may then have angular structure relatable to the fiber architecture



Introduction (continued)

- Much of the angular scattering would not be detected by a standard transducer in backscatter measurement
  - Envisioned large-aperture 2-dimensional array to measure the angular distribution of scattered sound
  - Examine the structure of angular distribution to infer the local fiber orientations
  - Called this concept Wide-Angle Backscattering





Introduction (continued)

- The **Advanced Composites Project (ACP)**
  - Project under the NASA Advanced Air Vehicles Program
  - Partnership between NASA and a number of industry partners
  - Goal is increasing the efficiency of development and introduction of composite components into service
  - Fiber waviness arising during layup or cure has been identified by industry partners as one of a number of issues requiring improved detection and characterization

- Advances in RF electronics, transducer manufacturing, computational capability, phased array instrumentation, and 3-D printing raise the potential for practical array-based methods

- ACP provided an opportunity to exploit these advances to develop array-based measurements of local fiber orientation
  - Explore the concept of Wide-Angle Backscattering

Approach

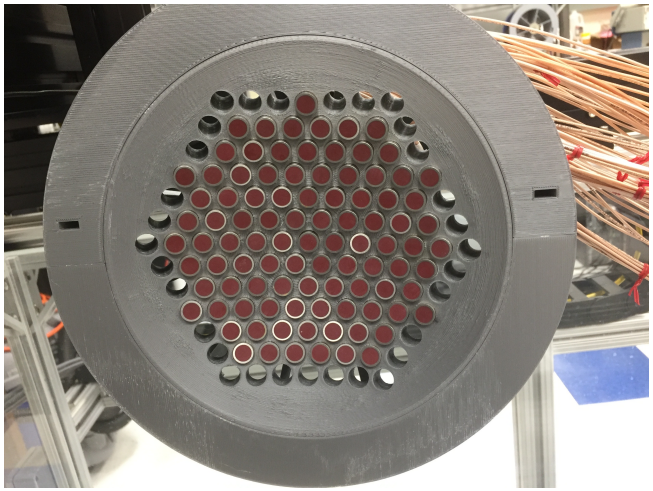
- Procure research-capable array instrument
  - Verasonics 256-channel system
- Fabricate 2-dimensional arrays which sample a relatively wide range of scattering angles
  - Use 3-D printer technology for mounting fixtures
  - Array comprises assembly of commercial immersion transducers
  - Multiple frequencies to explore frequency-dependence
- Measure angular distribution of scattering from a composite laminate

Wide-Angle Backscatter Array

- Wide-Angle Backscatter Array
  - Array fixture 3-D printed of polylactic acid (PLA) plastic
  - 96 planar immersion transducers (0.25-inch diameter, 2.25 MHz)
  - Transducers on a spherical surface of radius 7 inches
  - Hexagonal pattern with 3.6° minimum angular spacing
  - Cone of half angle just under 19°

- Transmit with one element and receive with all elements in parallel
  - Provides angular sampling of the scattering from fibers in specimen

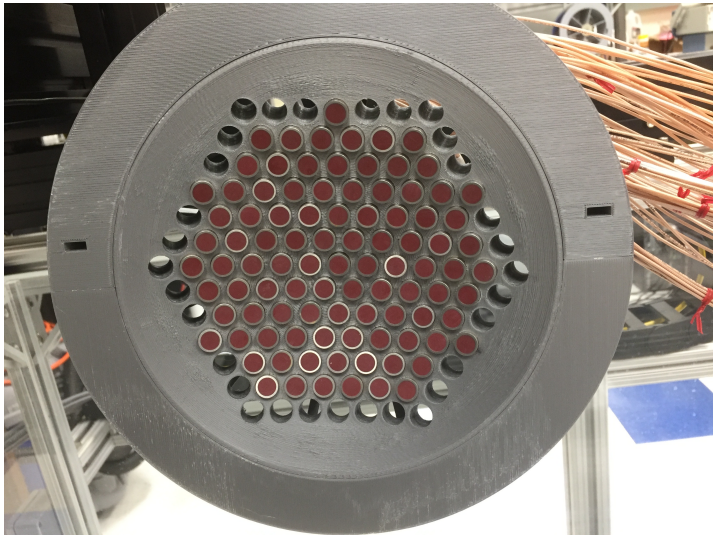
Back View



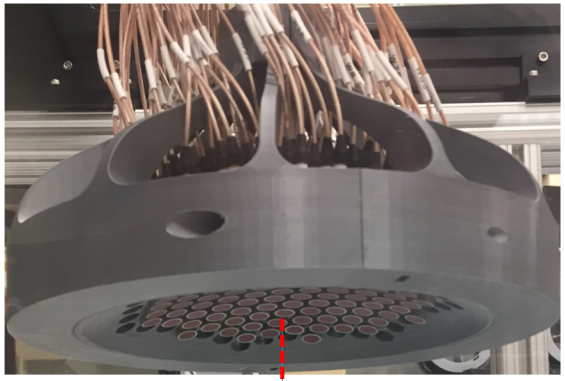
Front View

Wide-Angle Backscatter Array Measurements

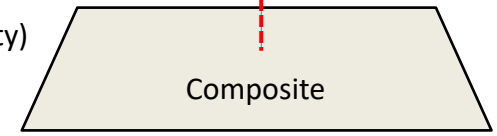
Front View



Side View



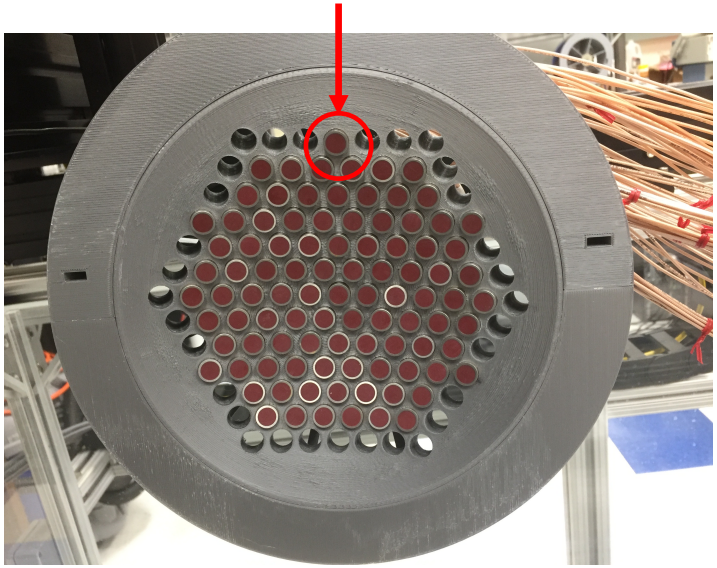
Array is Used Normal to Composite (angled for visibility)



Wide-Angle Backscatter Array Measurements

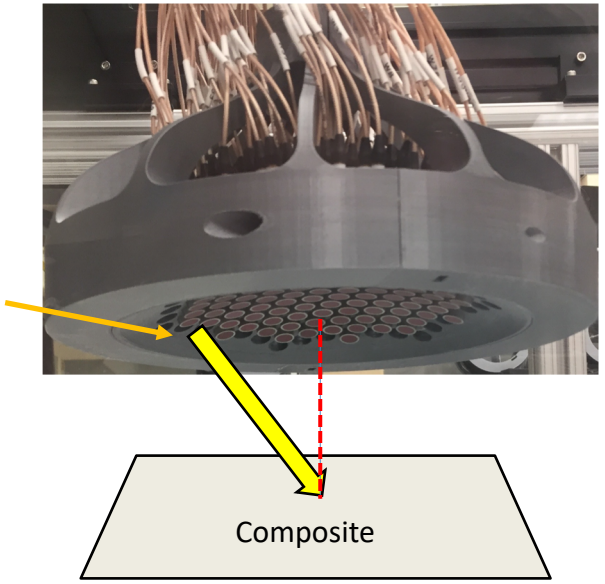
Front View

Transmitting Element



Side View

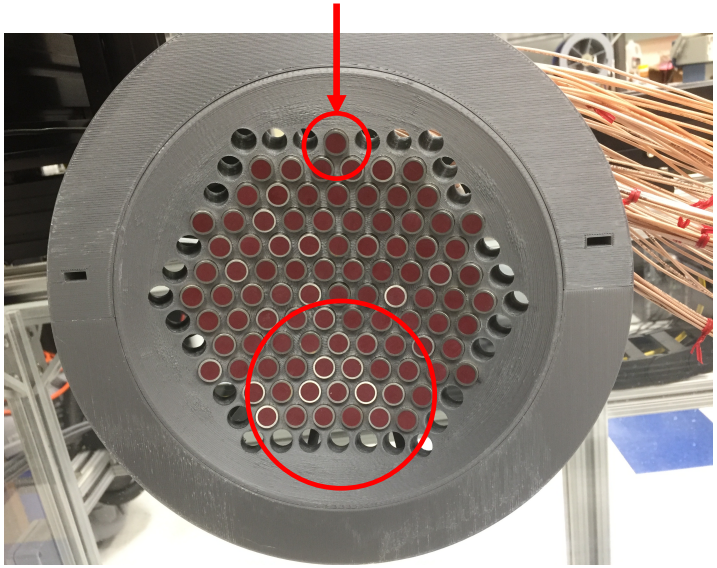
1 Element Transmits



Wide-Angle Backscatter Array Measurements

Front View

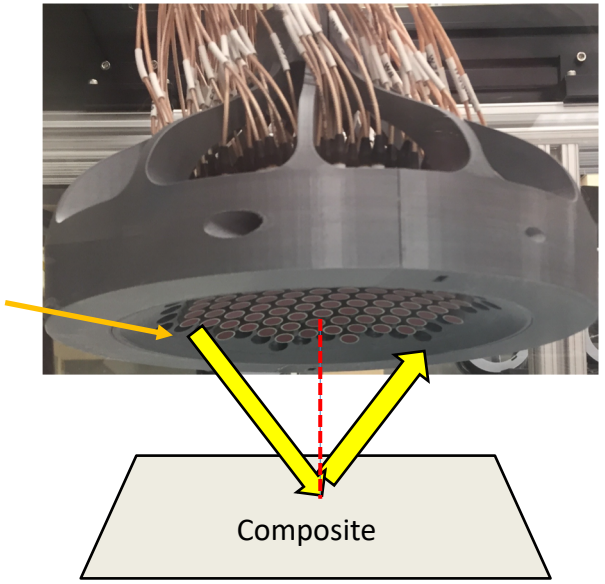
Transmitting Element



Opposite Elements
Receive Surface
Reflections

Side View

1 Element
Transmits

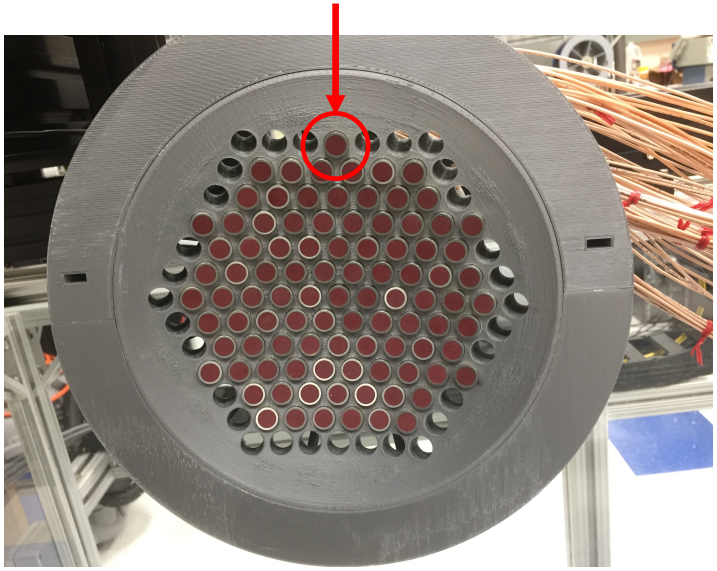


Opposite Elements
Receive Surface
Reflections

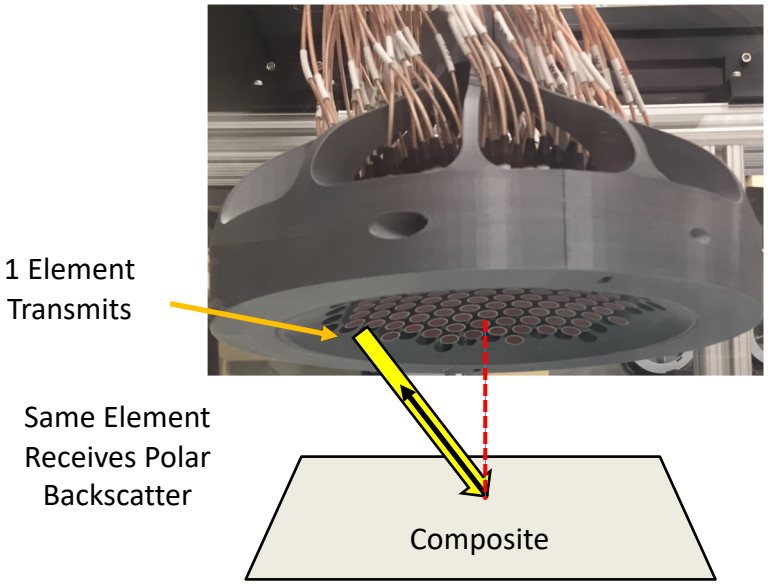
Wide-Angle Backscatter Array Measurements

Front View

Transmitting Element



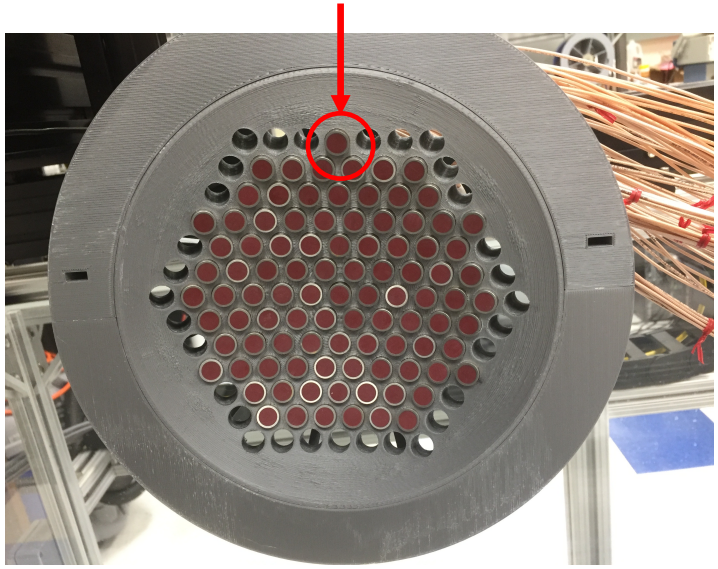
Side View



Wide-Angle Backscatter Array Measurements

Front View

Transmitting Element

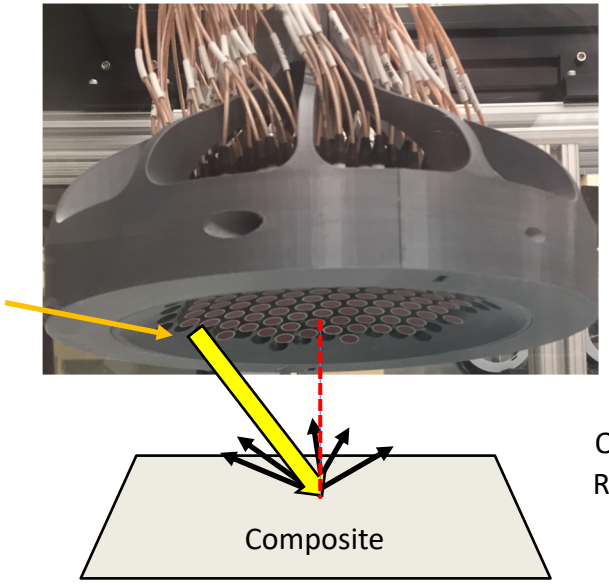


Receive with all elements

Angular Distribution
of Scattering

Side View

1 Element
Transmits

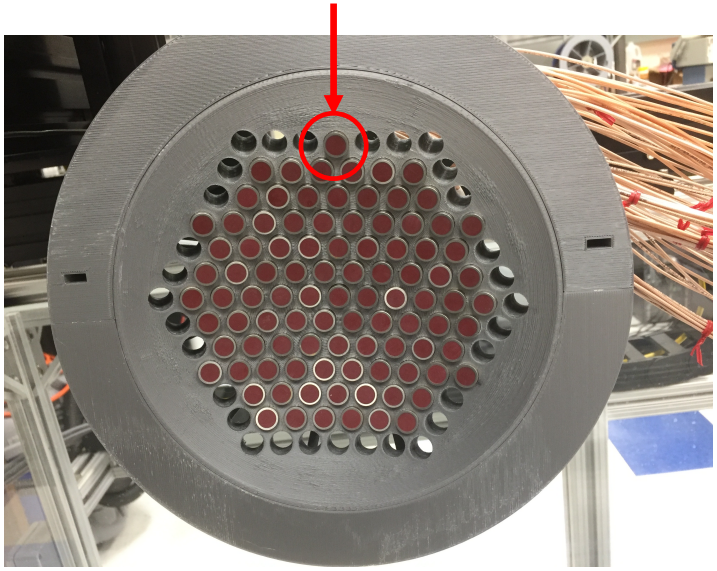


Other Elements
Receive Angular
Scattering

Wide-Angle Backscatter From Quasi-Isotropic Laminate

Front View

Transmitting Element



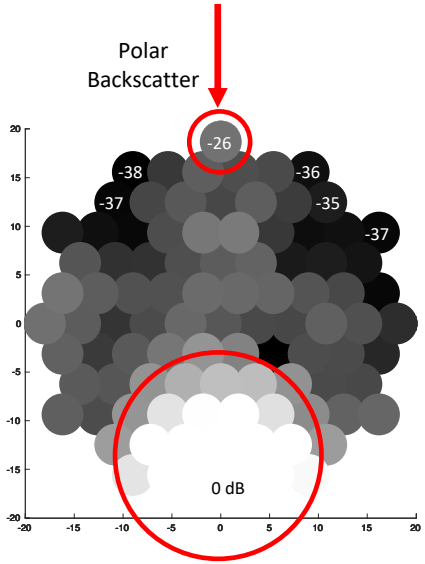
Receive with all elements

Angular Distribution
of Scattering

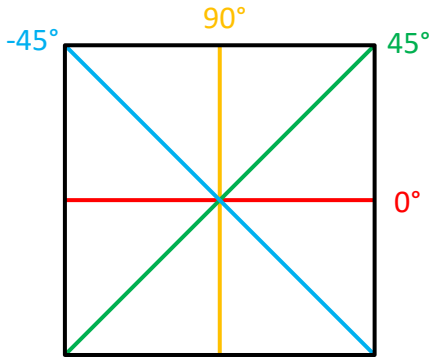
- Gray scale is RMS of received signal as dB relative to peak signal (surface reflection)

Signals outside the red circles represent scattering phenomena never before measured

Quasi-Isotropic
$[45,0,-45,90]_S$
Composite

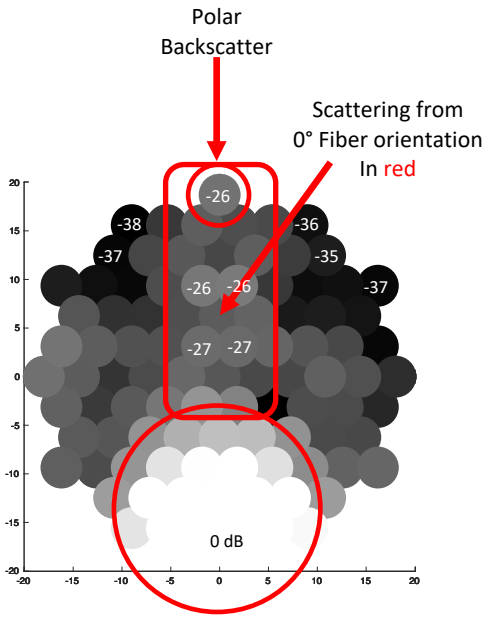


Signal Dominated
By Surface Reflection



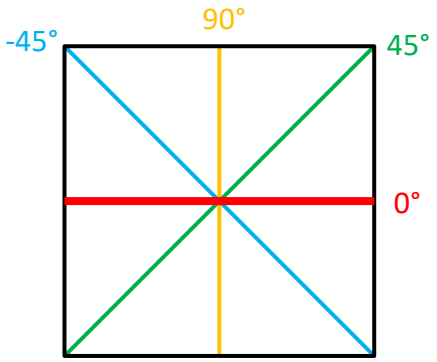
Rotation: 0°

Wide-Angle Backscatter From Quasi-Isotropic Laminate



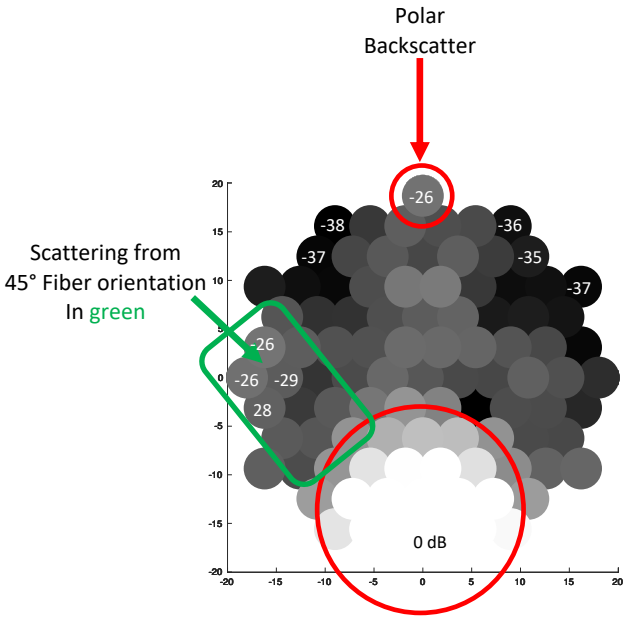
Signal Dominated
By Surface Reflection

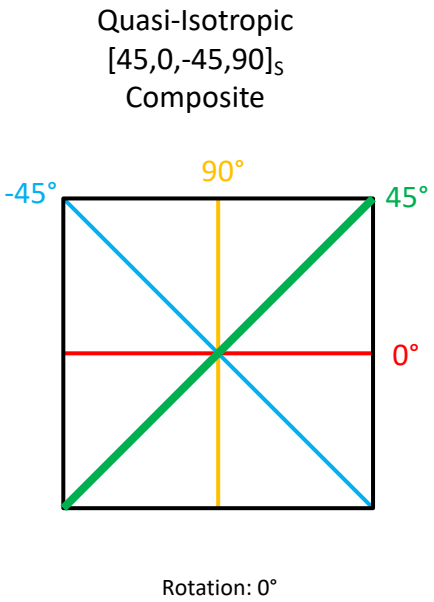
Quasi-Isotropic
$[45,0,-45,90]_S$
Composite



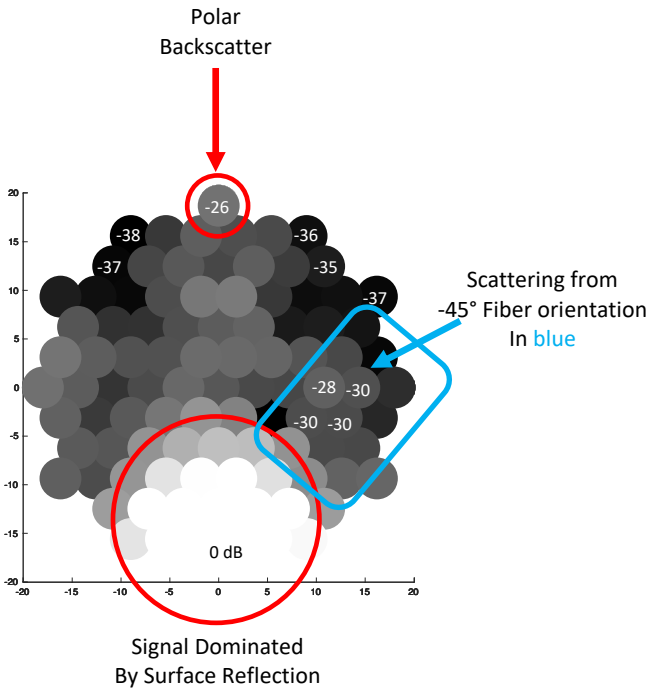
Rotation: 0°

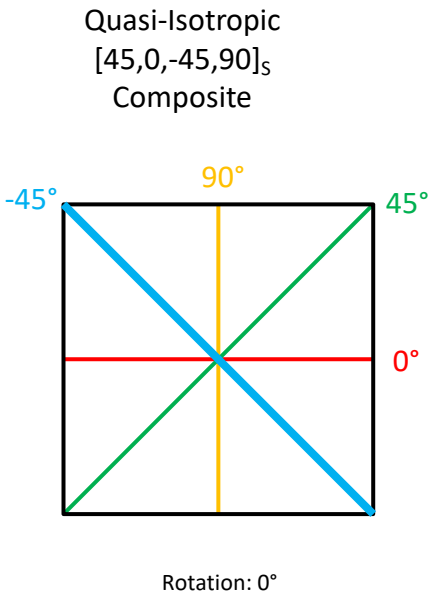
Wide-Angle Backscatter From Quasi-Isotropic Laminate





Wide-Angle Backscatter From Quasi-Isotropic Laminate

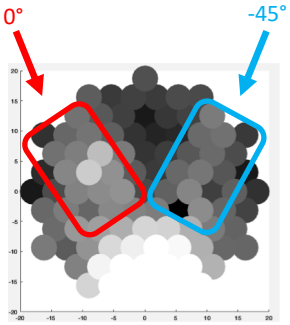


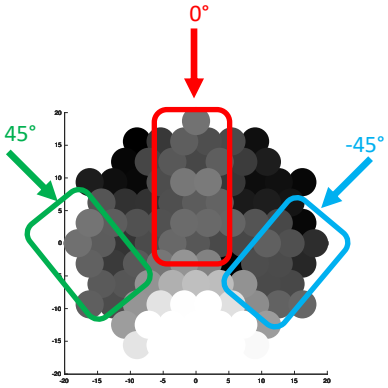


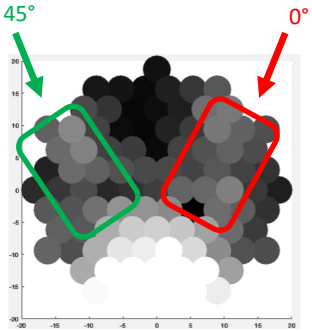
Wide-Angle Backscatter Rotates with Specimen

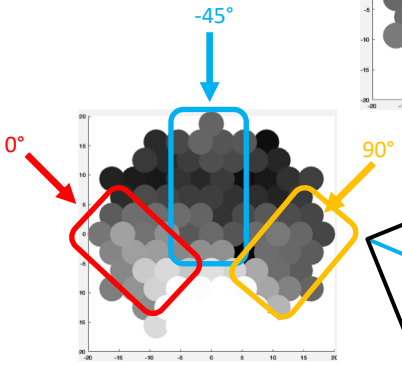
As the composite is rotated beneath the array, the scattered signals rotate around the array.

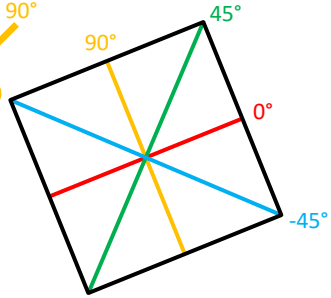
Colored arrows/boxes indicate the corresponding fiber orientation which is scattering



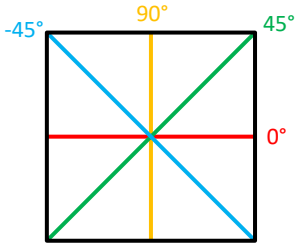




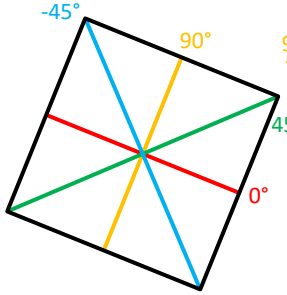




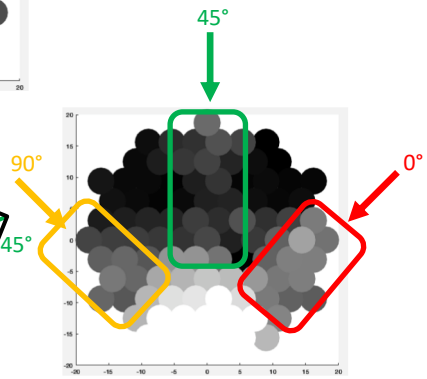
Rotation: -22.5°

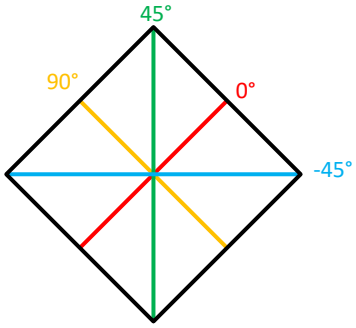


Rotation: 0°



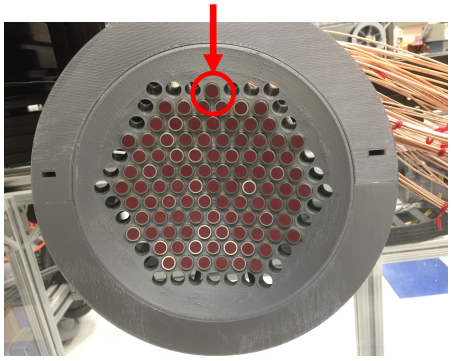
Rotation: 22.5°



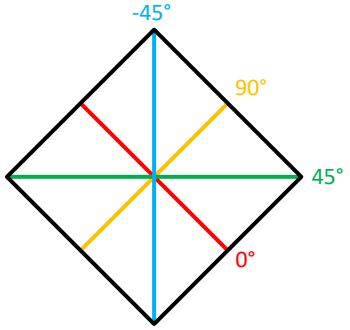


Rotation: -45°

Transmitting Element



Receive with all elements



Rotation: 45°

Conclusion

- Utilized a 2D angular scattering array system to measure the angular distribution of scattering from a quasi-isotropic composite laminate
- Observed an angularly-structured scattered field having a geometry reminiscent of the fiber architecture
- Observed the structured field to maintain its orientation with the composite when coupon rotated beneath array
- Observations support proposed concept of wide-angle backscatter as potential measure of fiber orientation