



Surface acoustic wave suppression for ultrasonic imaging of near-surface defects using laser induced phased arrays

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EPSRC

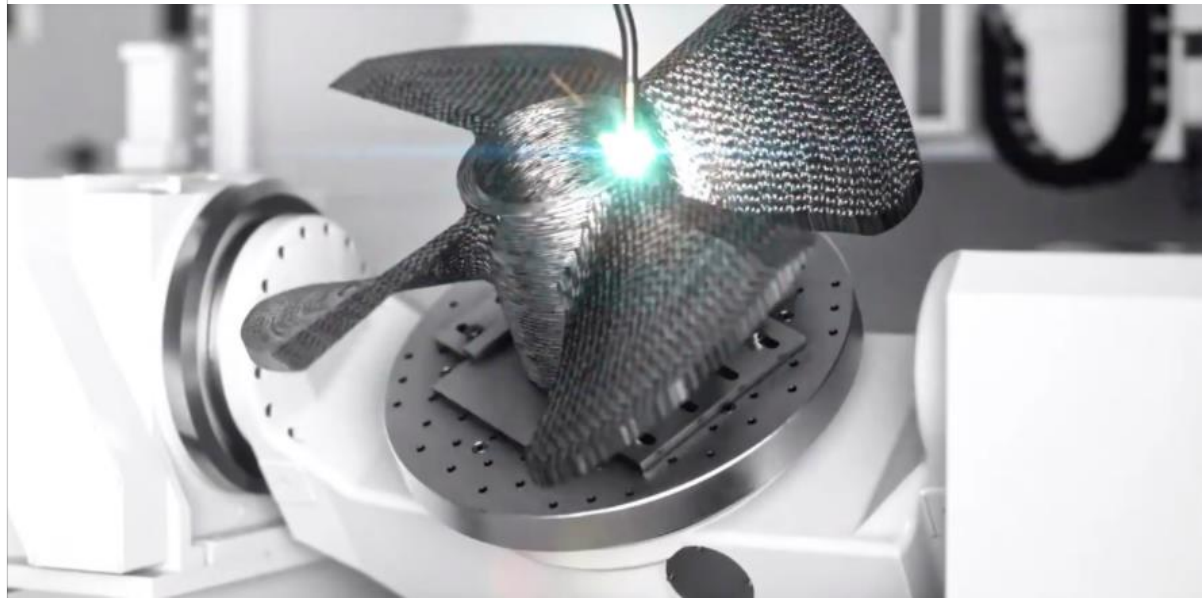
Engineering and Physical Sciences
Research Council

Outline

- Motivation
- Laser Ultrasonics
 - ❑ Laser Induced Phased Arrays & the Full Matrix Capture
 - ❑ Total Focusing Method and SAW Crosstalk
- Methodology
 - ❑ Amplitude Thresholding
 - ❑ Phase Coherence Imaging
 - ❑ Frequency-Wavenumber Filtering
 - ❑ Experimental Setup and Target Sample
- Results
- Conclusion and Future Work

Motivation

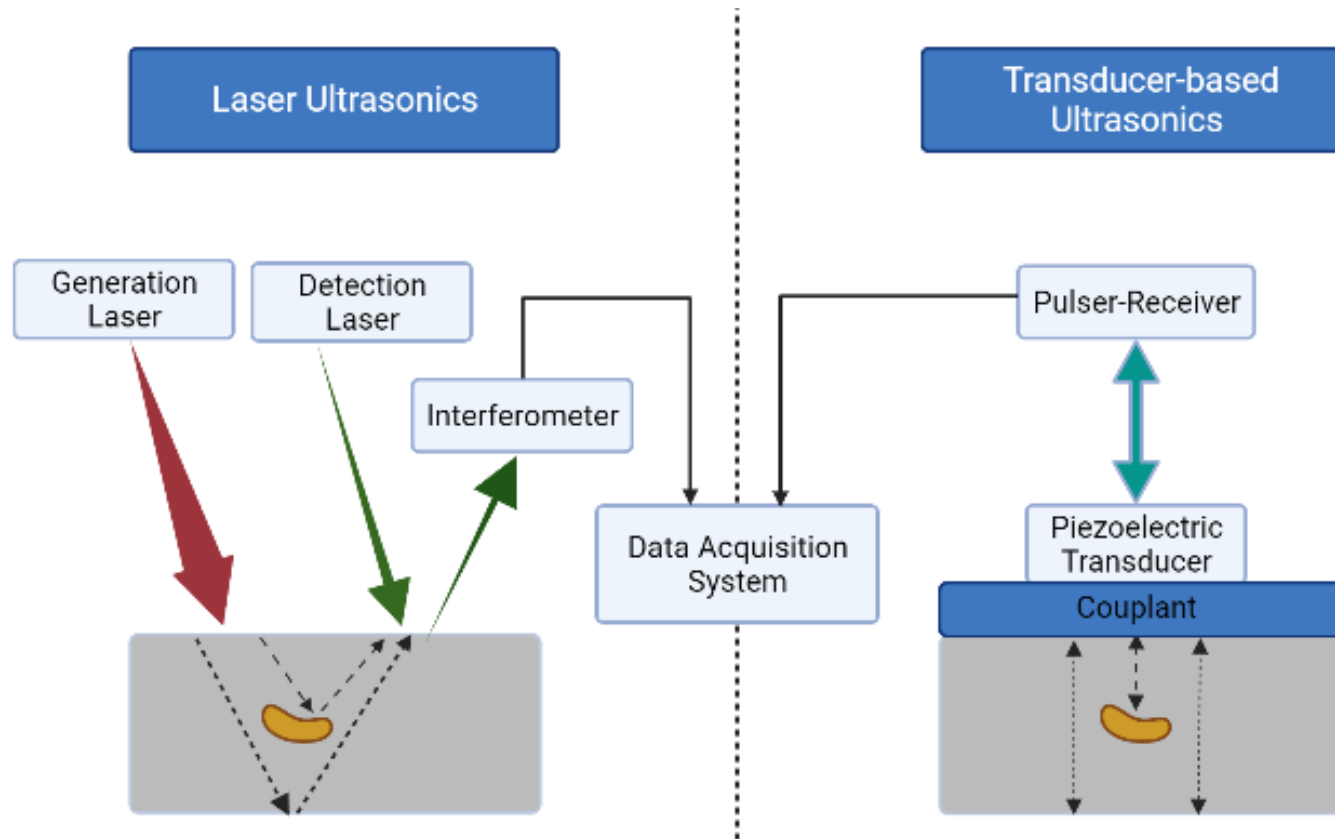
Enable automated imaging of the near surface during metal 3d printing inspection



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Laser Ultrasonics



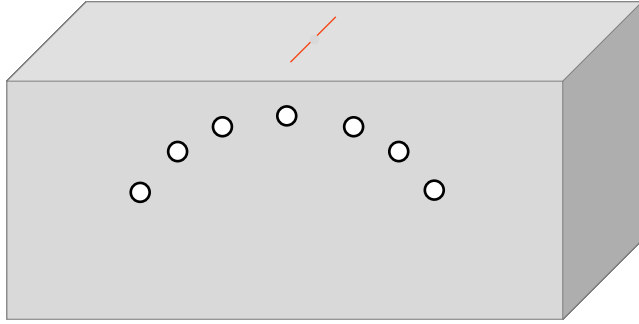
Advantages of LU:

- Non-contact/Remote
- Couplant-free
- Broadband
- Simultaneous generation of all ultrasonic modes
- Flexibility
- Suitable for:
 - Complex geometries
 - Hostile environments
 - Places of restricted access

Disadvantage:

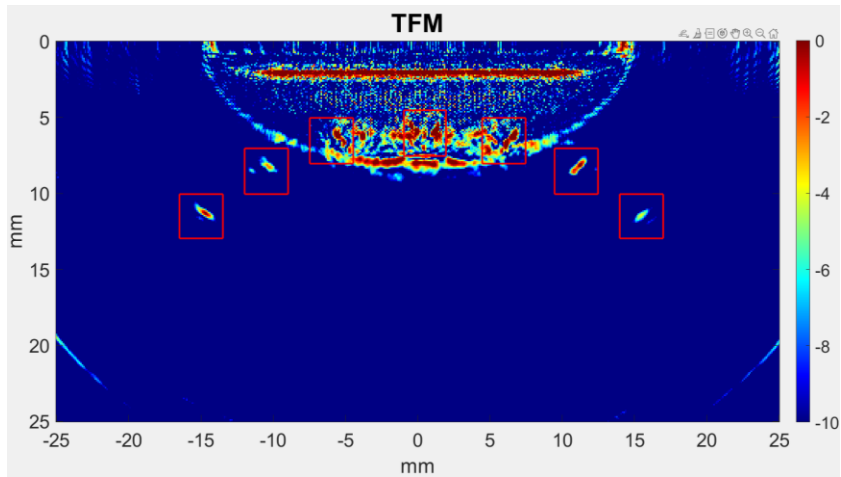
Low SNR

Laser Induced Phased Arrays & Full Matrix Capture



Full Matrix Capture =

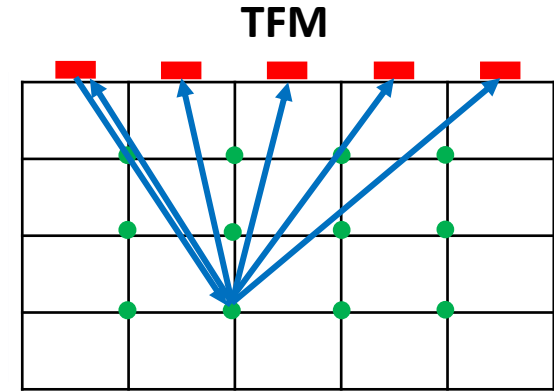
$$\begin{bmatrix} S_{11} & S_{12} & S_{13} & S_{14} \\ S_{21} & S_{22} & S_{23} & S_{24} \\ S_{31} & S_{32} & S_{33} & S_{34} \\ S_{41} & S_{42} & S_{43} & S_{44} \end{bmatrix}$$



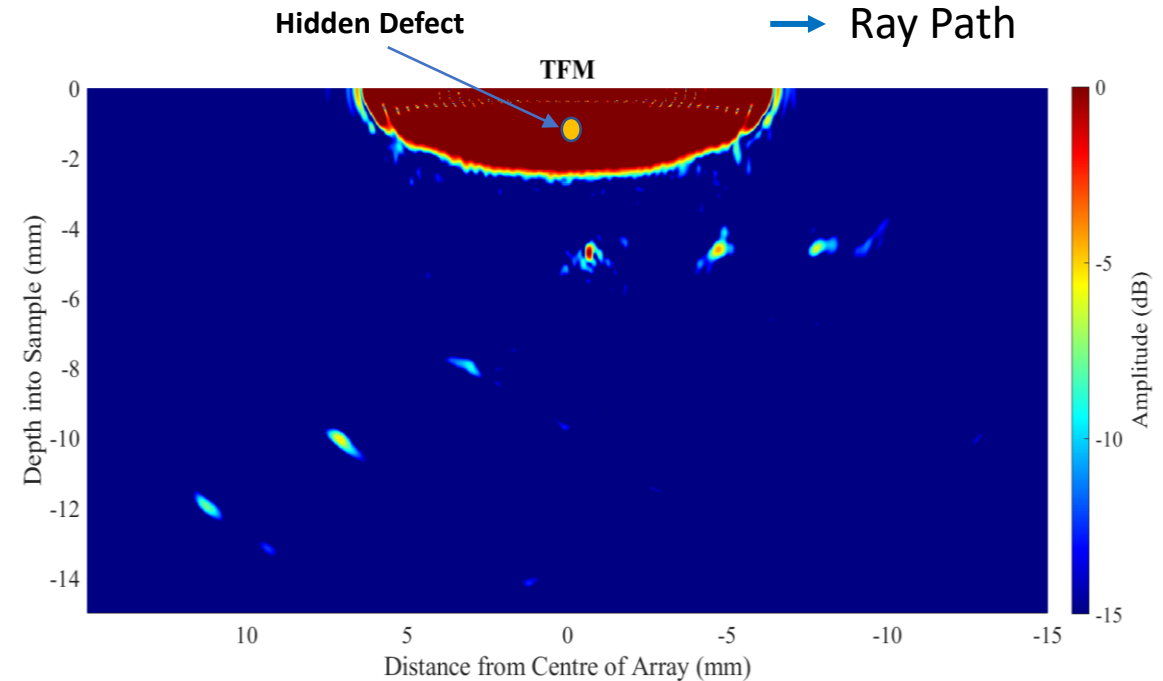
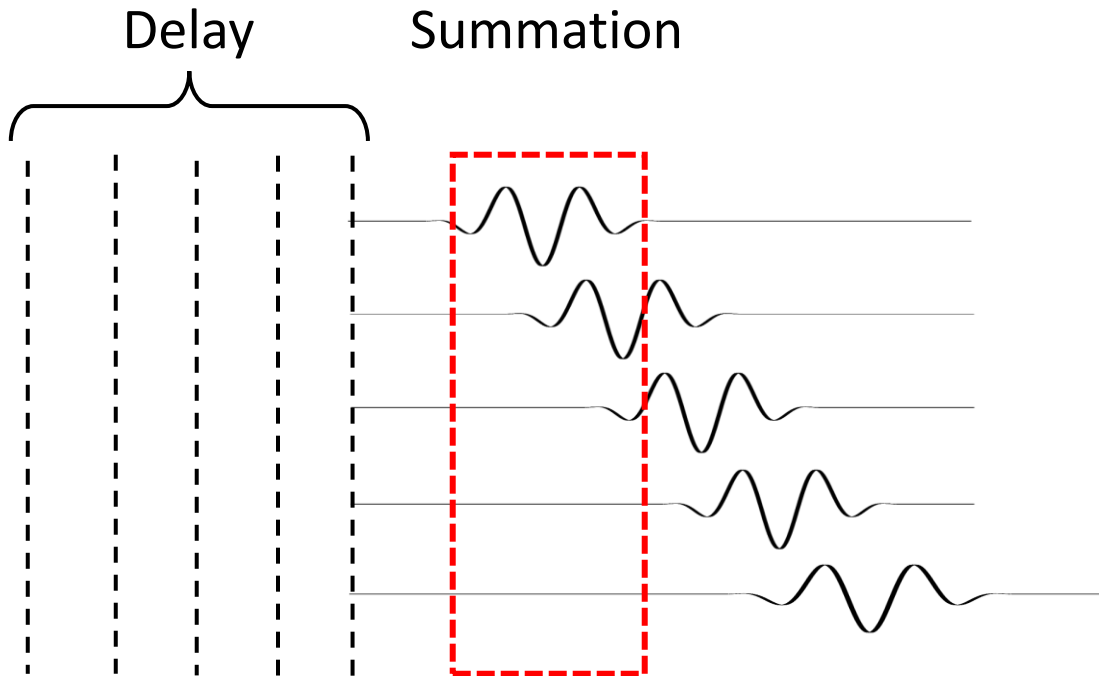
Total Focusing Method and SAW Crosstalk

- Discretising the target region into a grid
- The signals from every possible combination of array elements are summed to synthesise a focus at every point in the grid

$$\text{FMC} = \begin{pmatrix} S_{11} & S_{12} & S_{13} & S_{14} & S_{15} \\ S_{21} & S_{22} & S_{23} & S_{24} & S_{25} \\ S_{31} & S_{32} & S_{33} & S_{34} & S_{35} \\ S_{41} & S_{42} & S_{43} & S_{44} & S_{45} \\ S_{51} & S_{52} & S_{53} & S_{54} & S_{55} \end{pmatrix}$$



- Focus Points
- Array Elements
- ➔ Ray Path

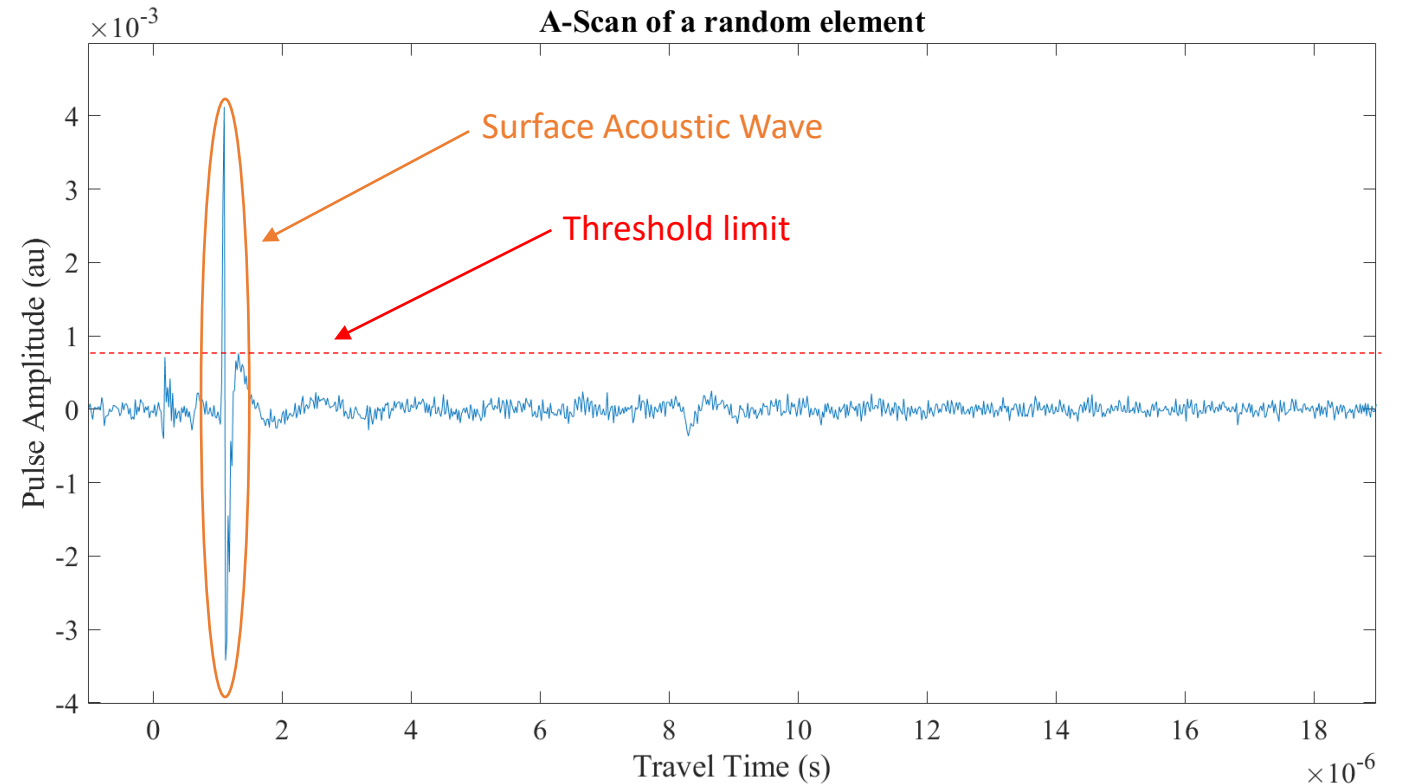


Outline

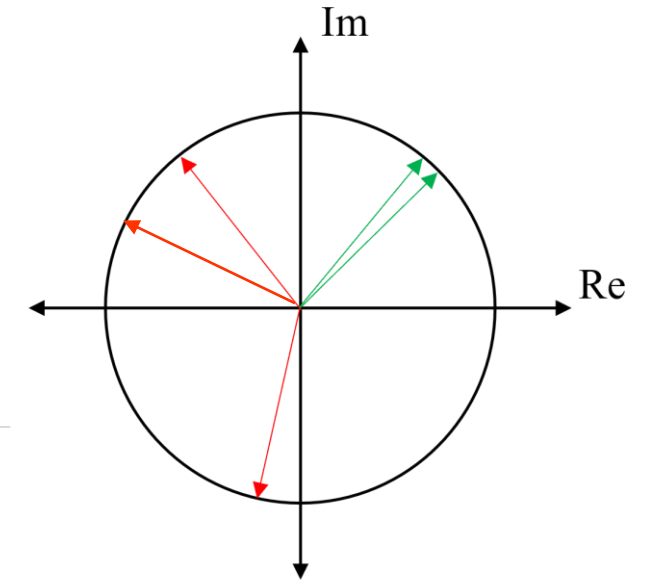
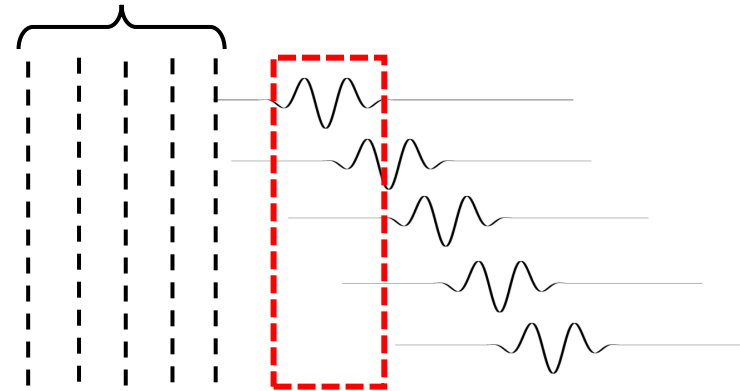
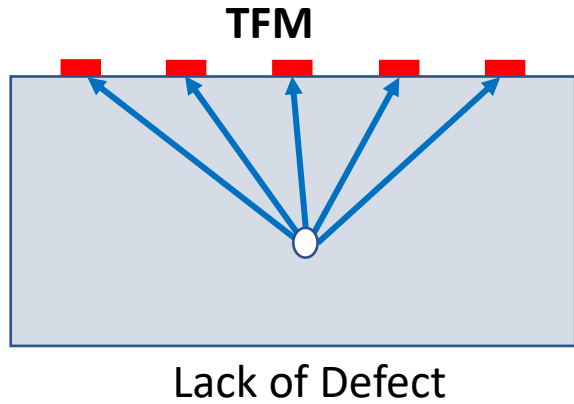
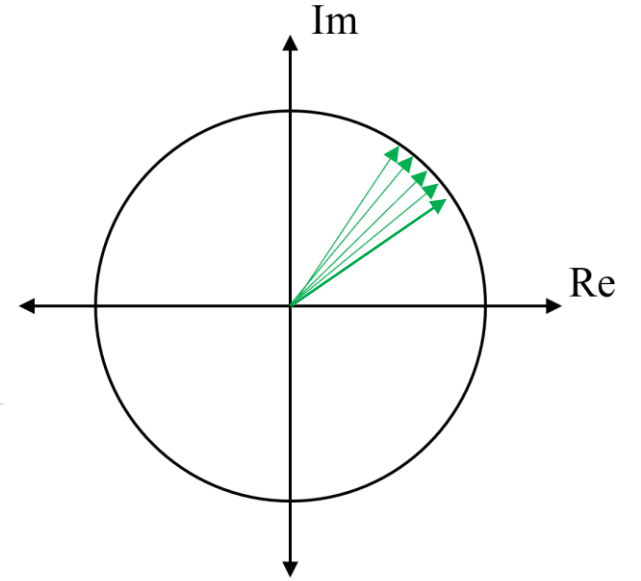
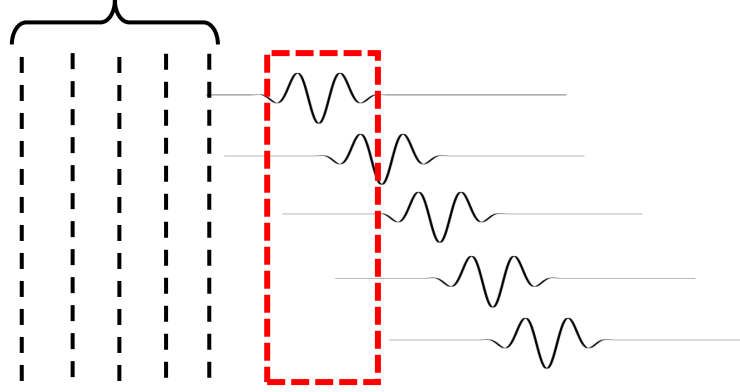
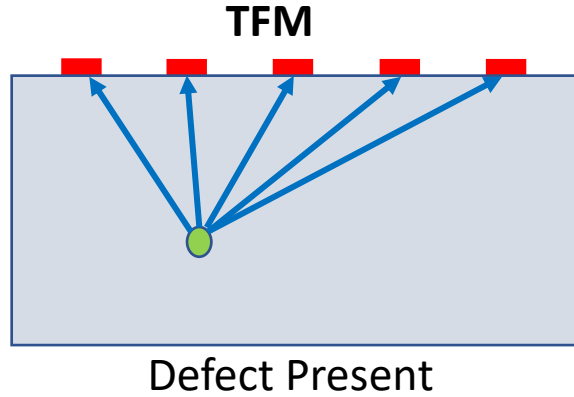
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Amplitude Thresholding

- The amplitude of the SAW is much larger compared to the rest of the signal
- A threshold can be applied to eliminate any signal which exceeds this limit



Phase Coherence Imaging

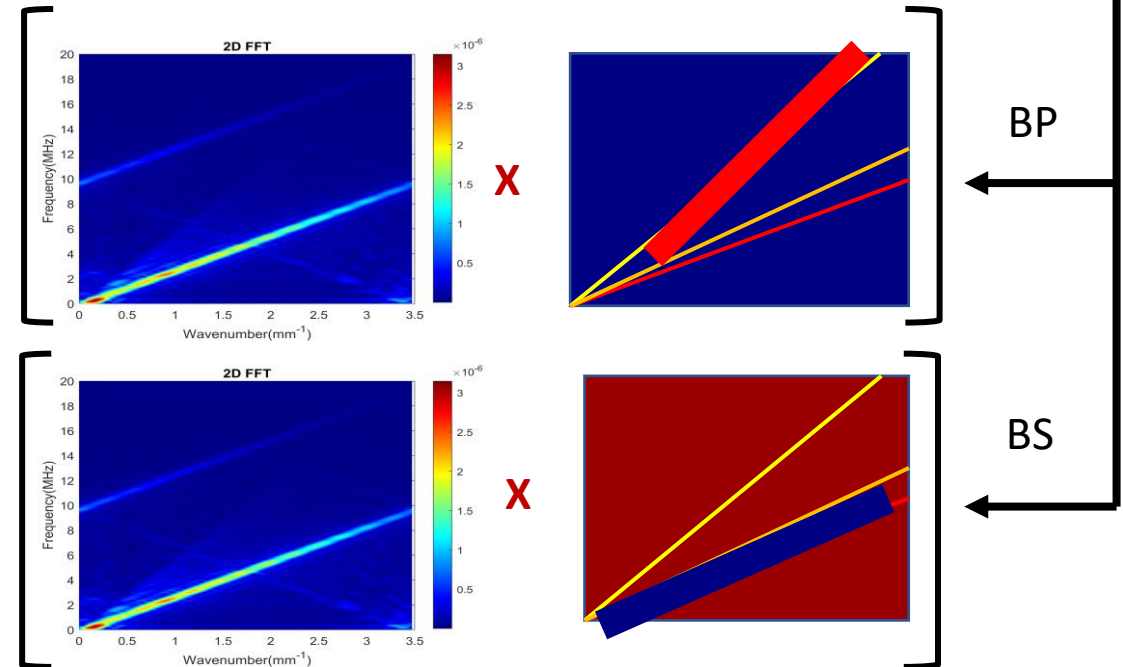
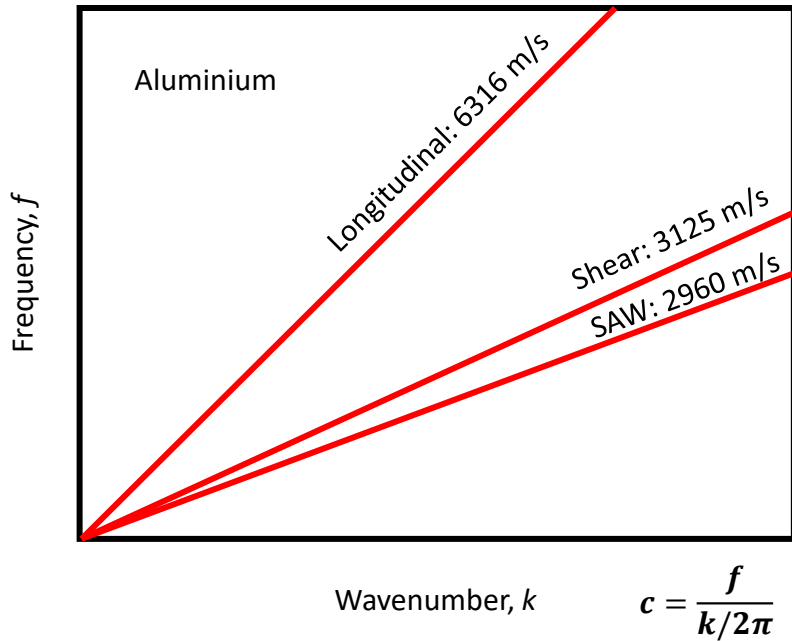
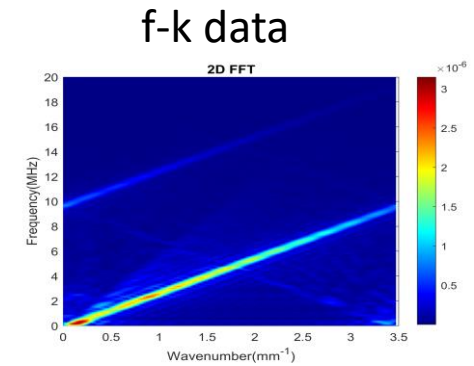


weighting coherence factor * TFM data at every pixel

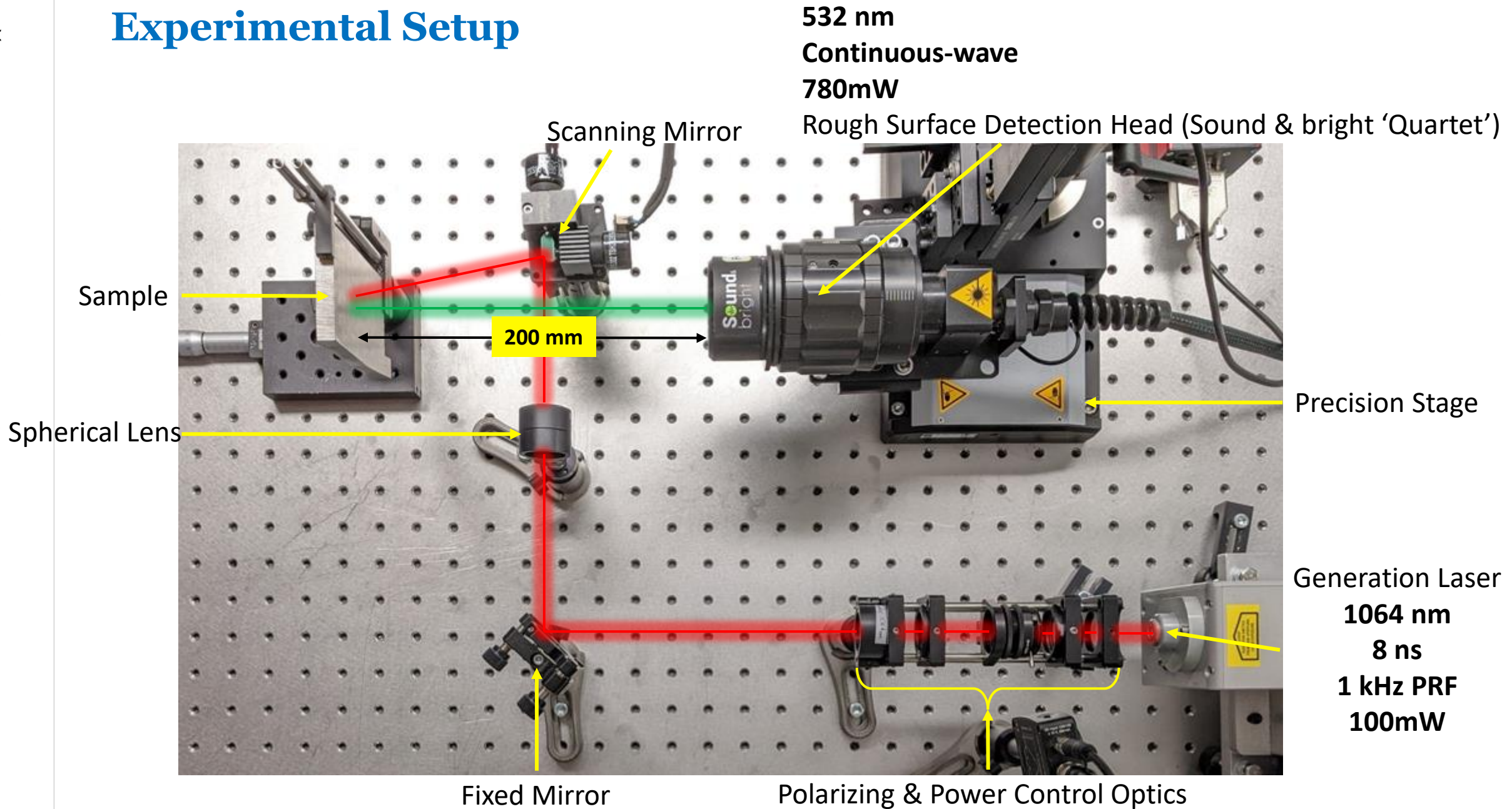
Wavenumber-Frequency Filtering

- Wavenumber-Frequency Filtering

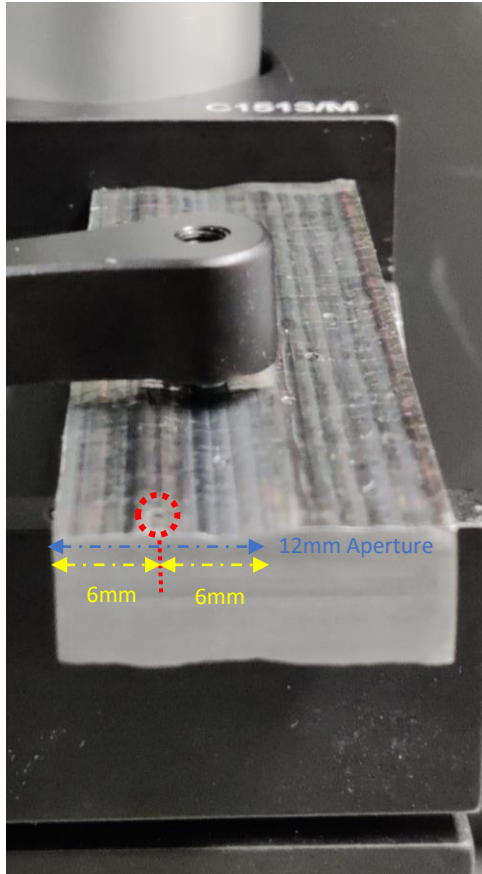
Full Matrix Capture =
$$\begin{bmatrix} S_{11} & S_{12} & S_{13} & S_{14} & \dots & S_{1n} \\ S_{21} & S_{22} & S_{23} & S_{24} & \dots & S_{2n} \\ S_{31} & S_{32} & S_{33} & S_{34} & \dots & S_{3n} \\ S_{41} & S_{42} & S_{43} & S_{44} & \dots & S_{4n} \\ \vdots & \vdots & \vdots & \vdots & \ddots & \vdots \\ S_{n1} & S_{n2} & S_{n3} & S_{n4} & \dots & S_{nn} \end{bmatrix} \xrightarrow{2d\text{ FFT}}$$



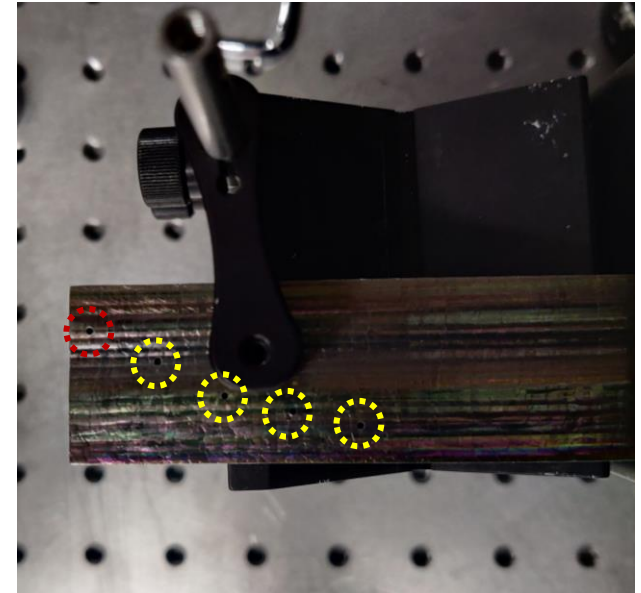
Experimental Setup



Target Sample



- **Sample material:** Titanium alloy (Ti-6Al-4V)
- **Fabrication Method:** Wire-Arc Additive Manufacturing (WAAM)
- **Target defect:** Side drilled hole 1mm \varnothing , 5mm deep, 3 mm from the scanning surface
- **Array Aperture:** 12mm
- **Number of Elements:** 80
- **Pitch:** 0.15mm
- **Averages:** 64
- **Bandpass Filter:** 5MHz c.f
- **Shear Mode Velocity:** 3250m/s
- **Scan Time:** 2 h 34 m 18s

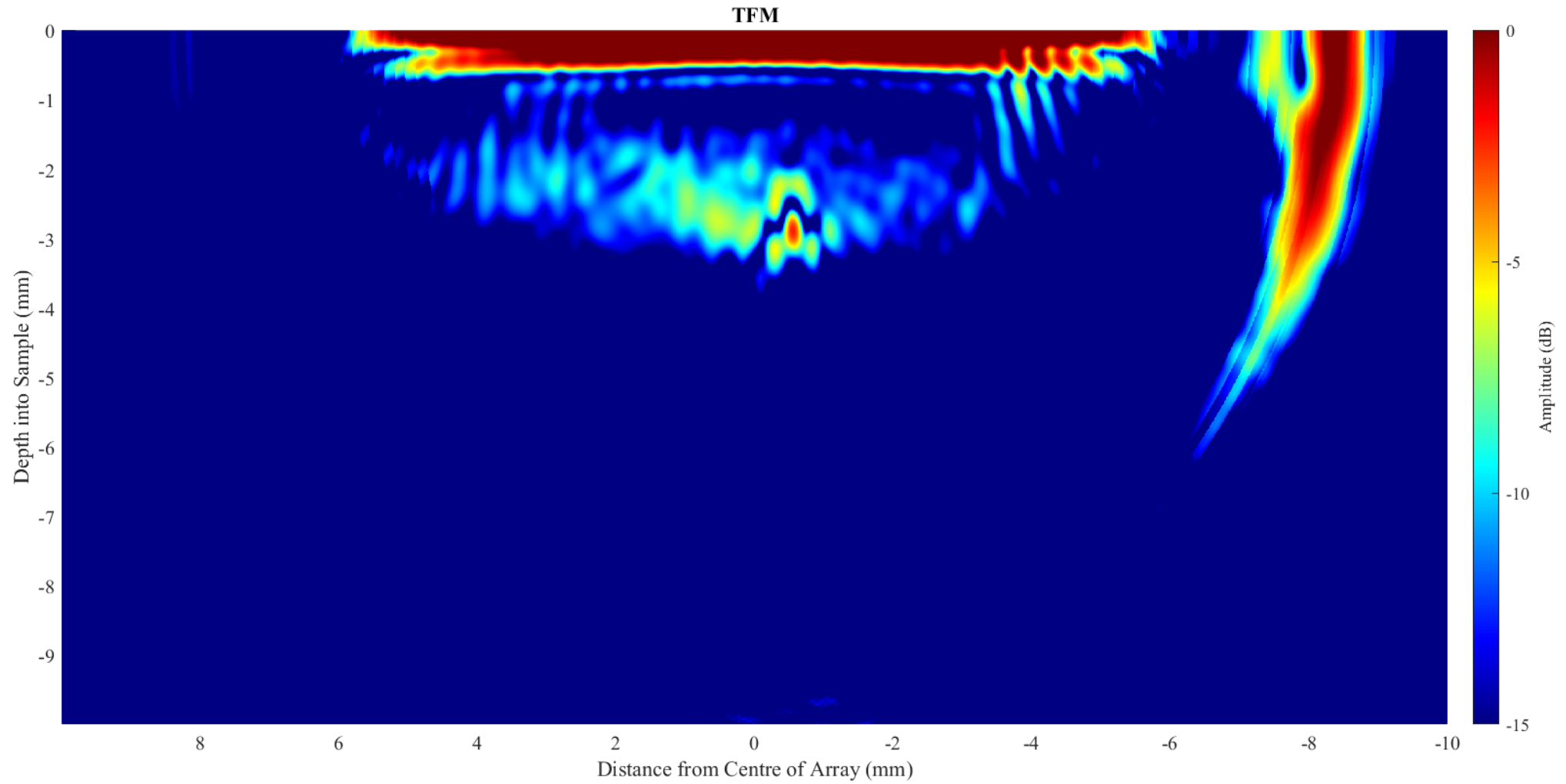


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Results

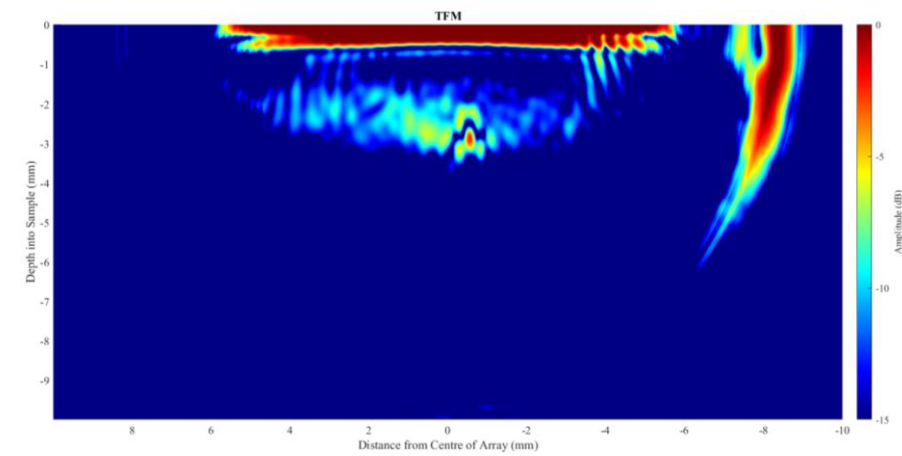
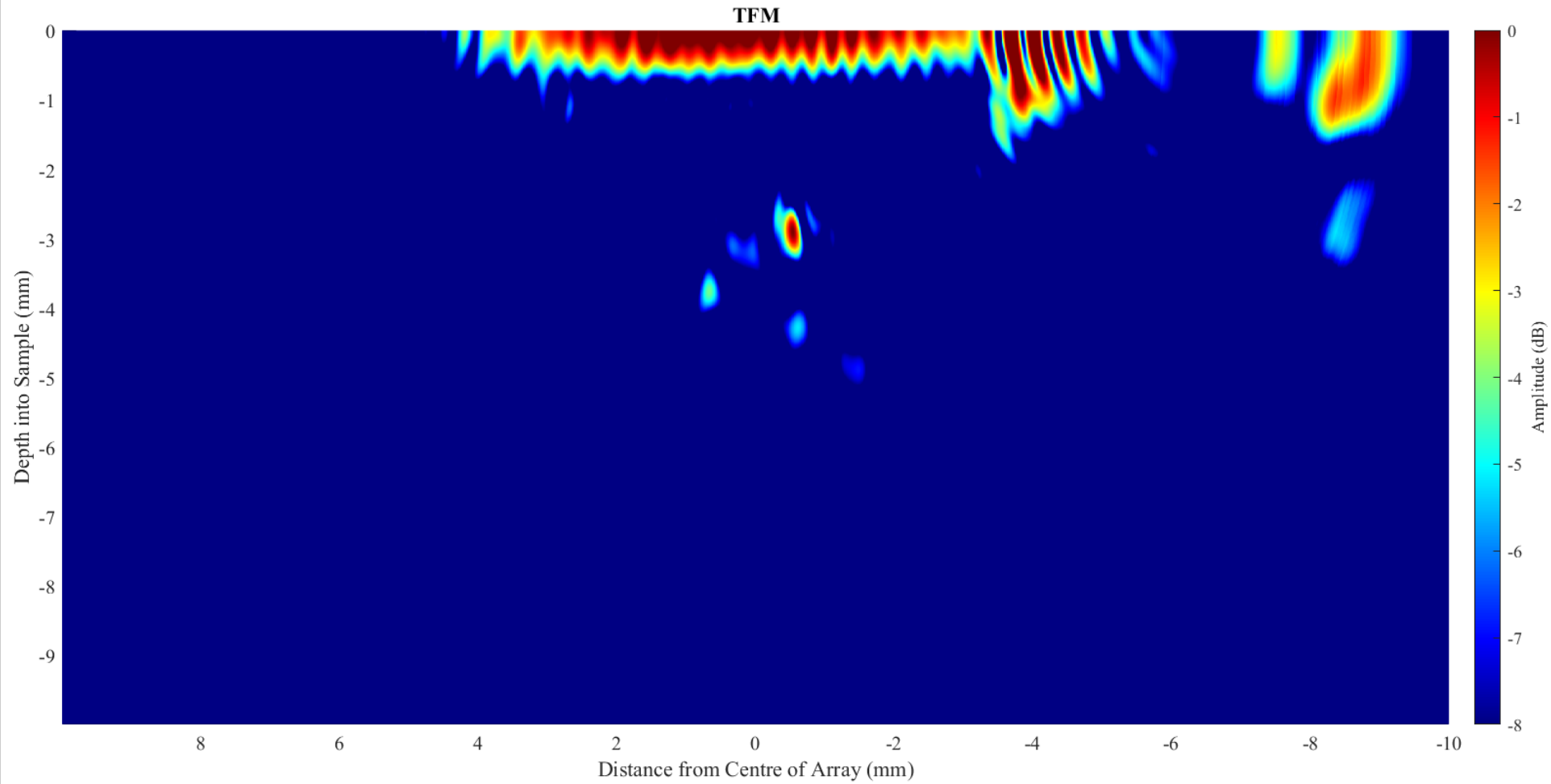
- Original TFM Image



Results

- Amplitude Thresholding

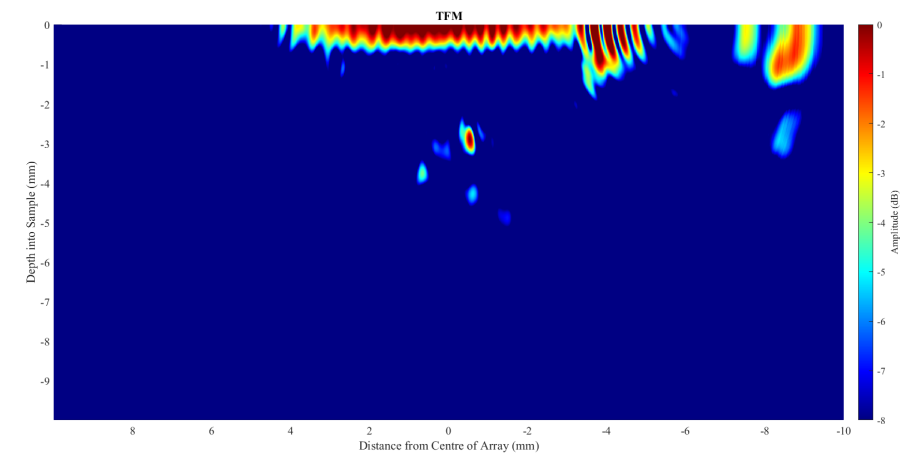
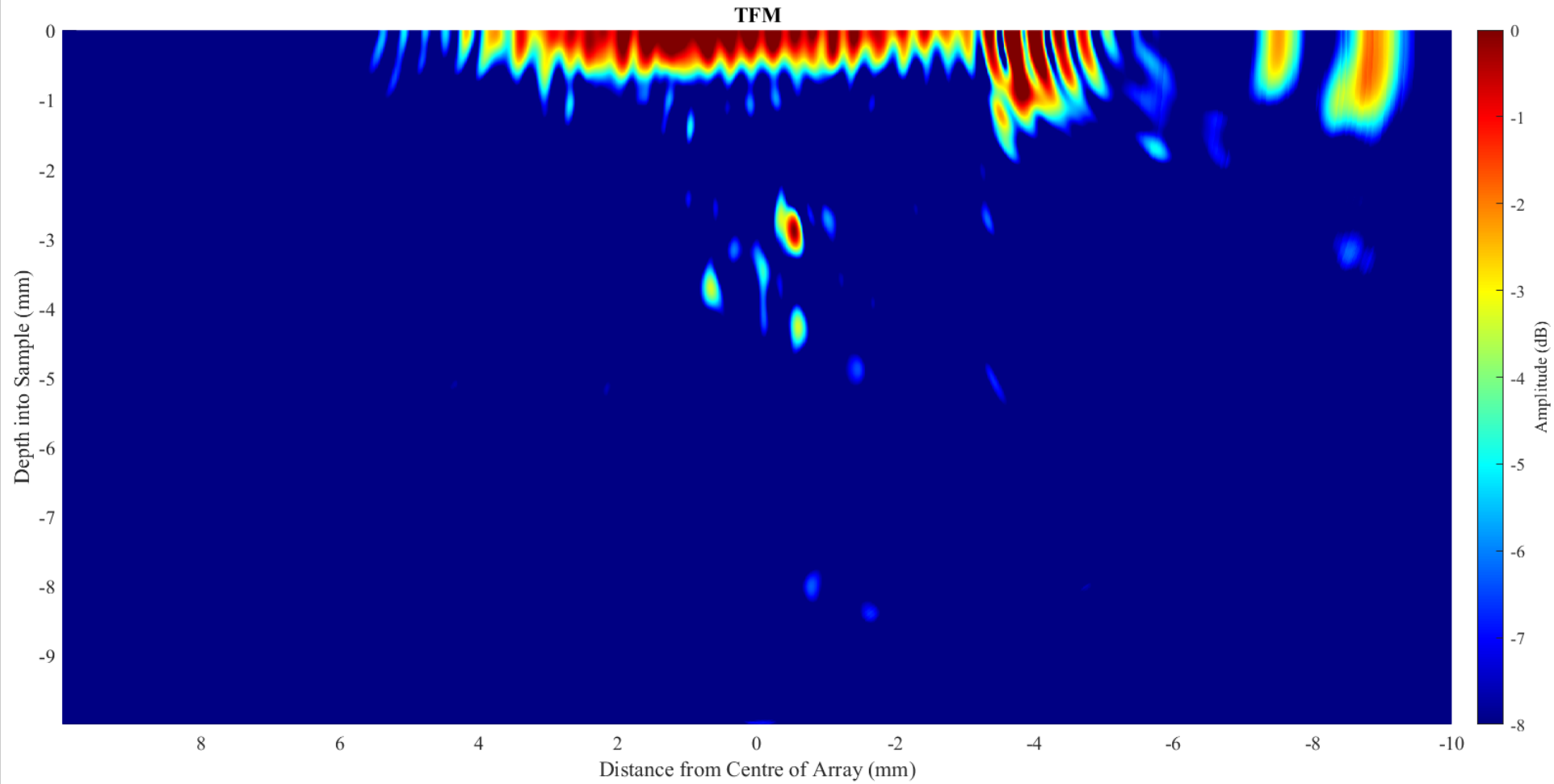
Threshold > 0.75 mV



Results

- Amplitude Thresholding

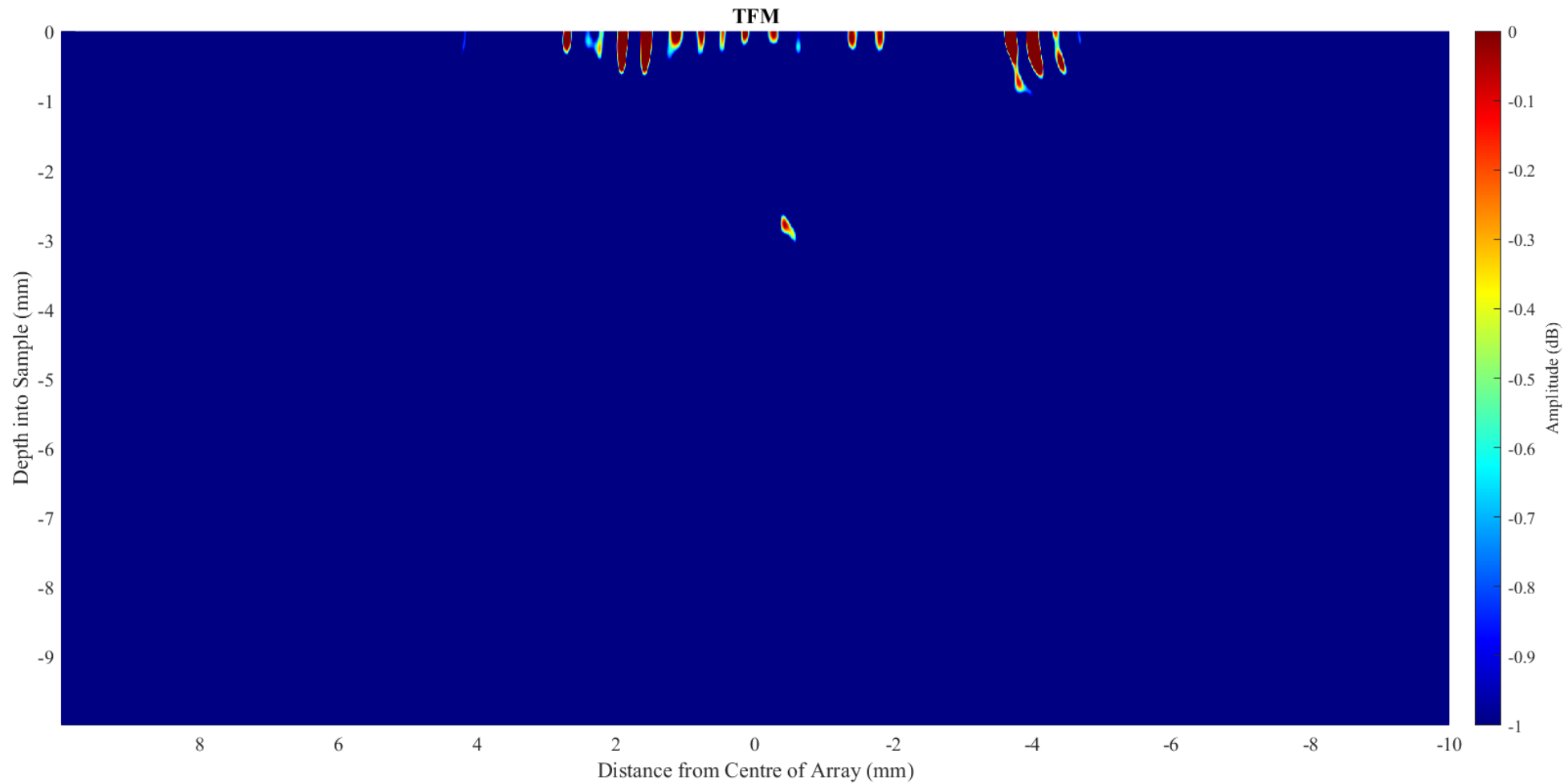
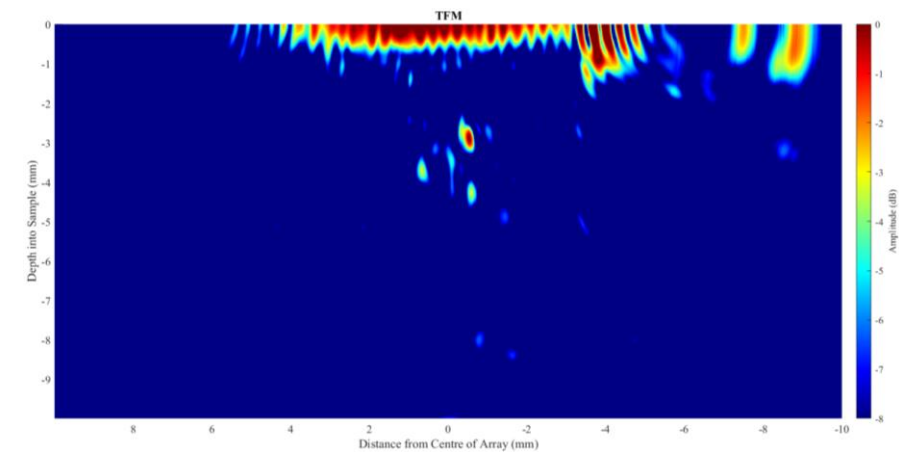
Threshold > 0.50 mV



Results

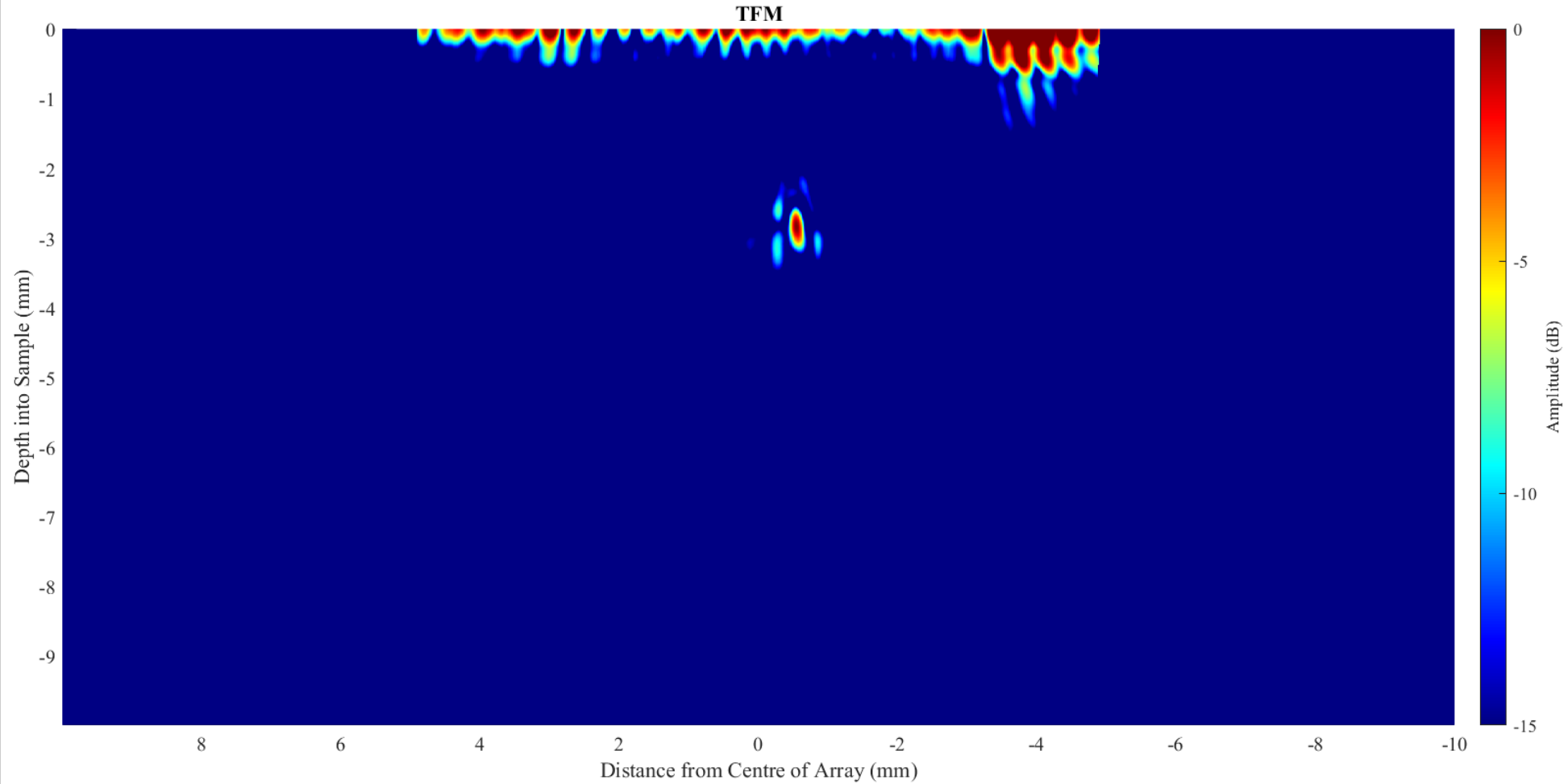
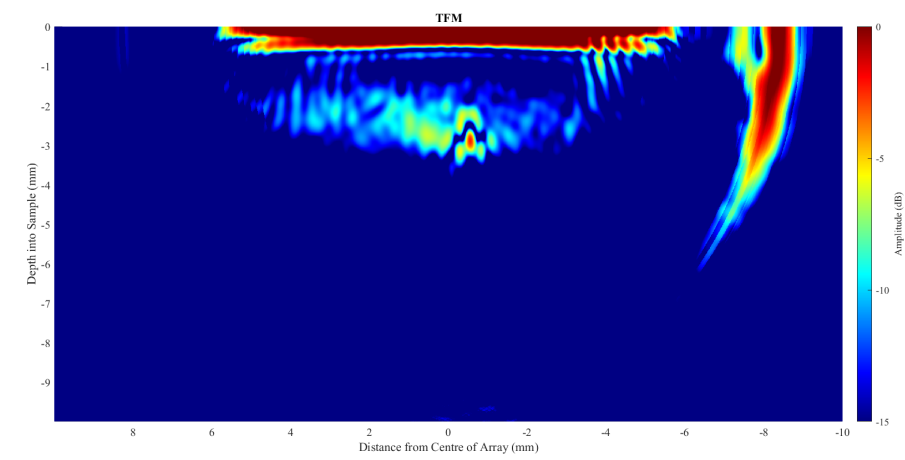
- Amplitude Thresholding

Threshold > 0.25 mV



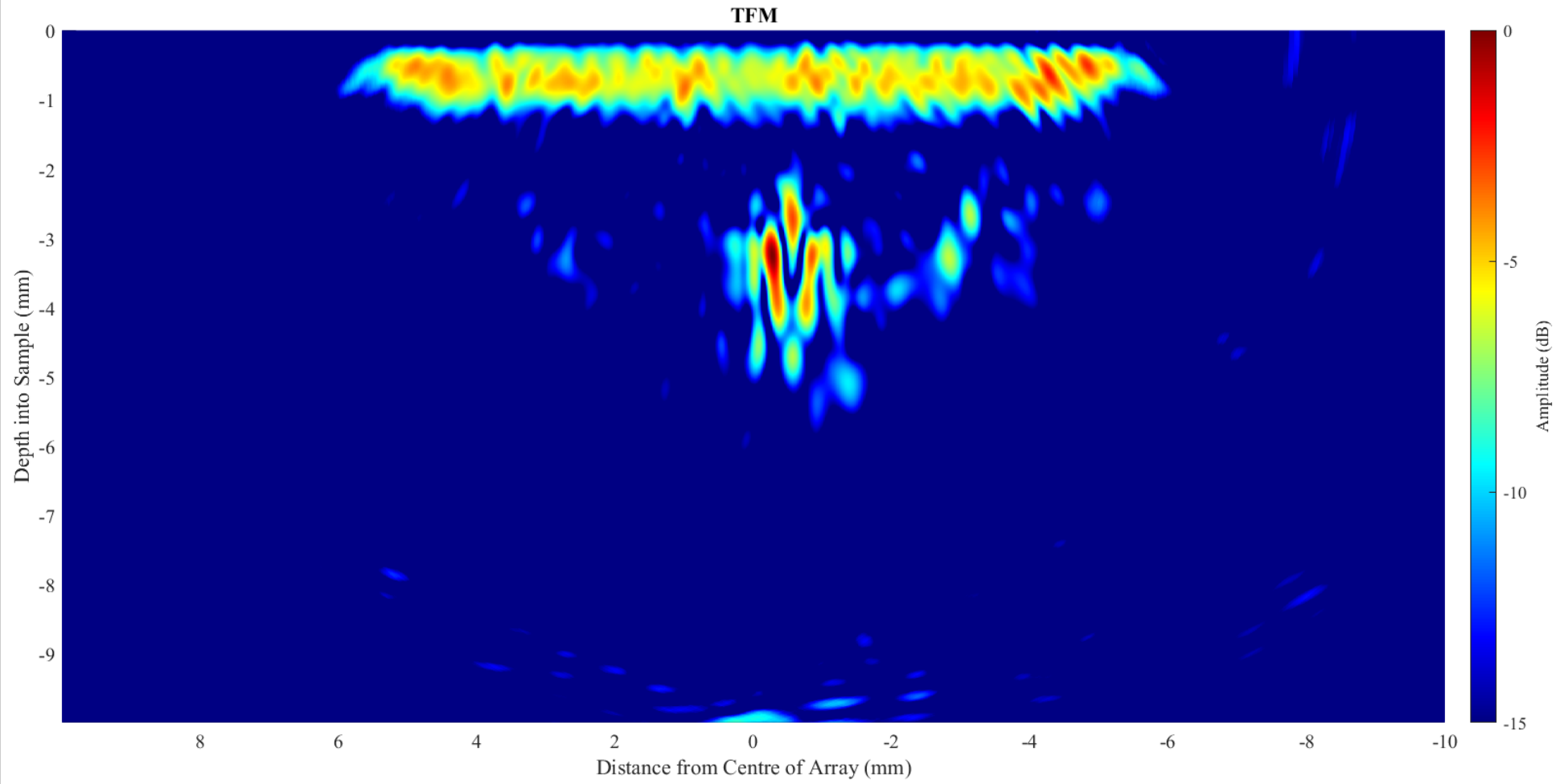
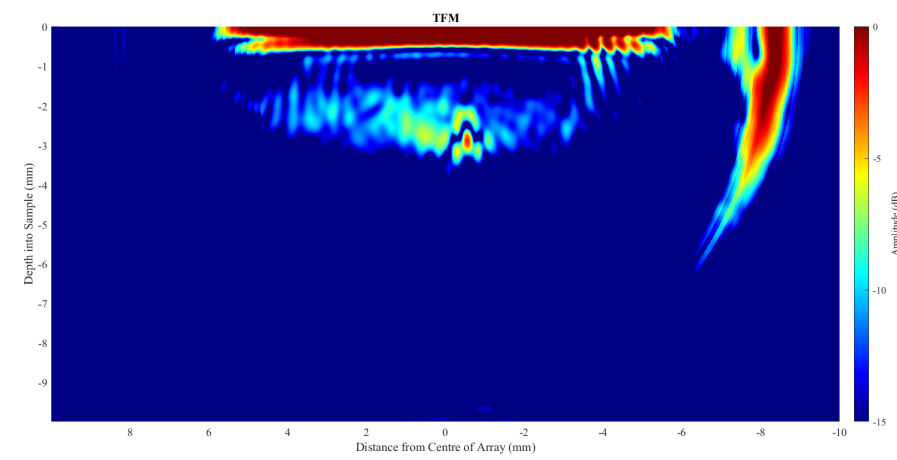
Results

- Phase Coherence Imaging



Results

- **Wavenumber-Frequency Filtering**



Results

- Using SNR and API metrics for method comparison

Signal-to-Noise Ratio (SNR): indicates the relationship between the defect signal and noise

$$SNR = 20 \log_{10} \left(\frac{I_{max}}{I_{avg}} \right)$$

Array Performance Indicator (API): quantifies the performance of the image reconstruction algorithm

$$API = \frac{A_{-6 dB}}{\lambda^2}$$

Results

	SNR	API
• Original TFM Image	24.5	3.1
• Amplitude Thresholding > 0.75 mV	30.2	2.1
• Phase Coherence Imaging (PCI)	31.2	0.2
• Frequency-Wavenumber Filtering	26.4	0.9

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Conclusion and Future Work

- **SAW crosstalk suppression is essential in TFM imaging**
- **Multiple methods can be used to achieve crosstalk suppression**
- **Caution is required when the SNR and API metrics are used**
- **In process inspection of metal AM components**
- **Comparison of SAW crosstalk methods in common defects**

Thank you