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University of Strathclyde Glasgow

Laser Induced Phased Array Element Localisation for Accurate 2D and 3D Ultrasonic Imaging

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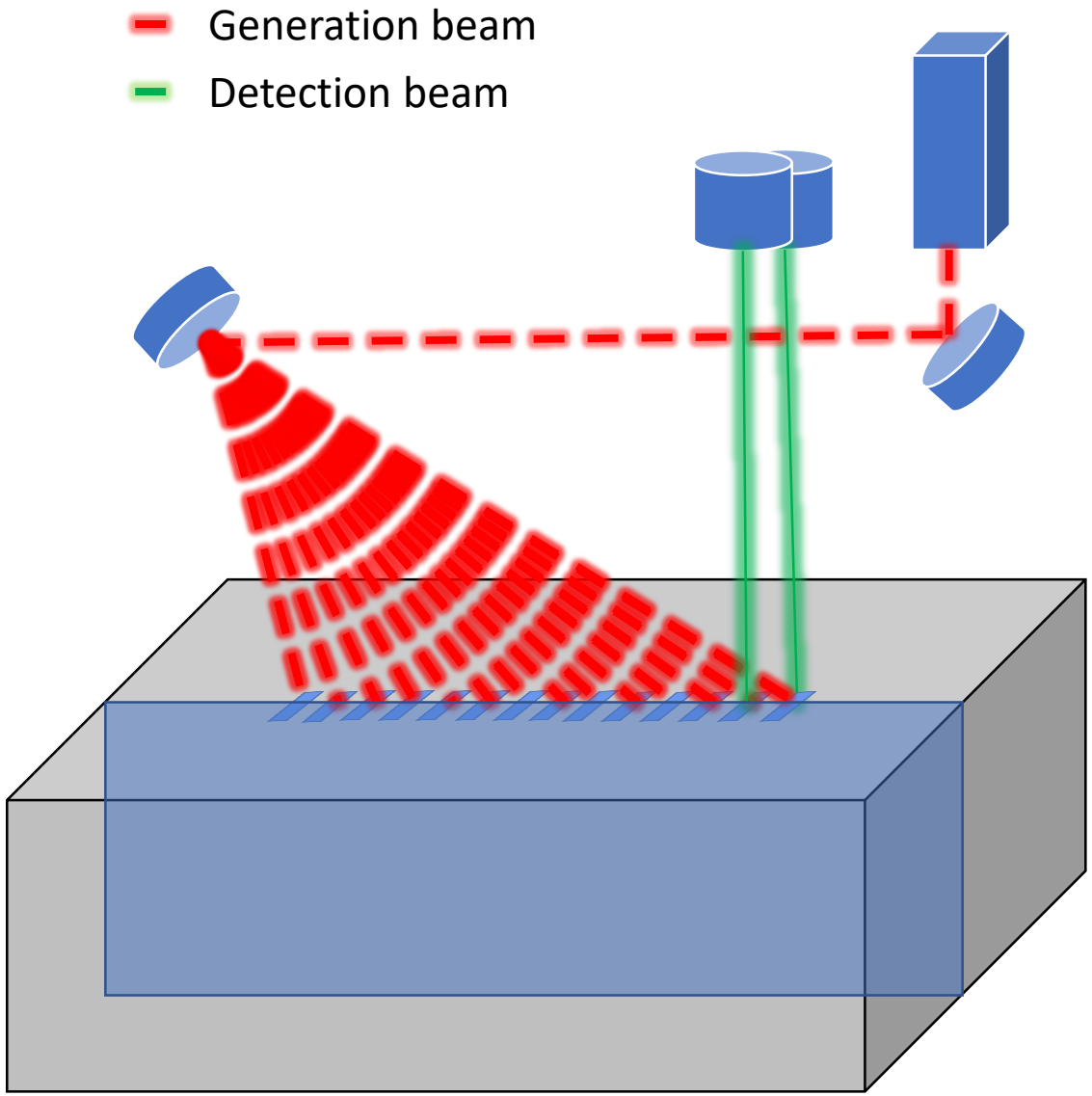
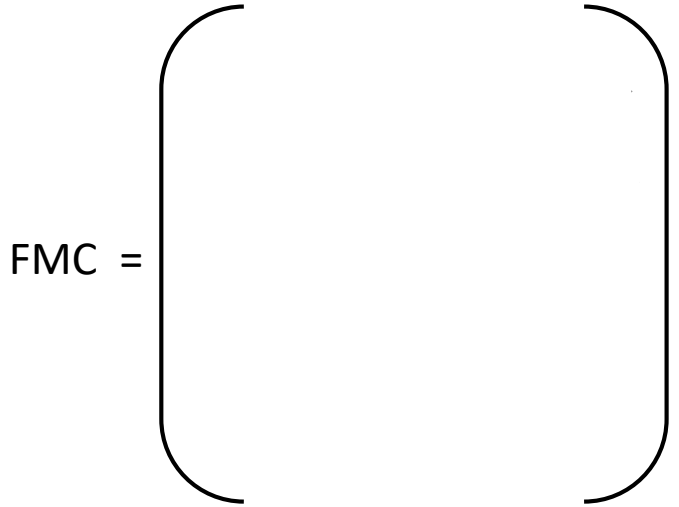
Laser Induced Phased Array (LIPA)

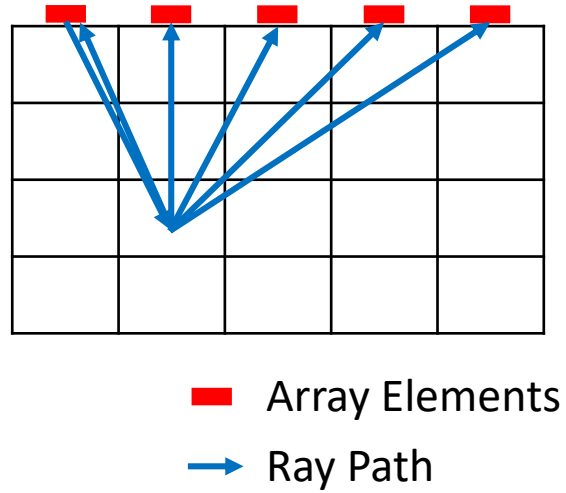


Full Matrix Capture

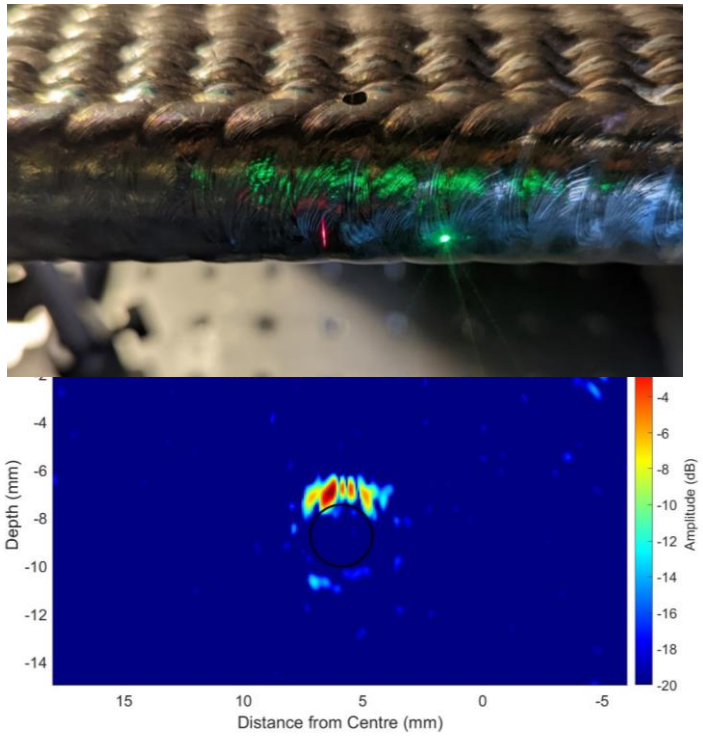
FMC =



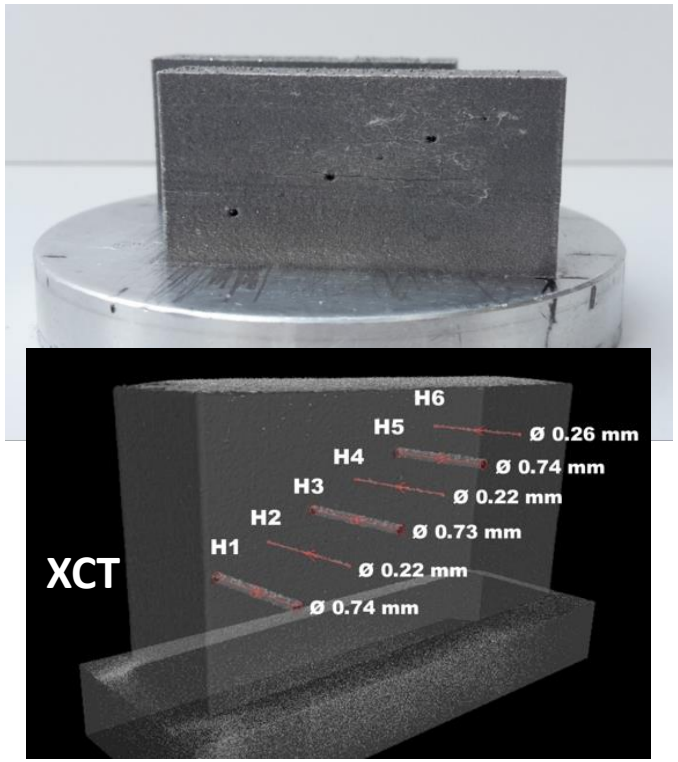
Total Focusing Method

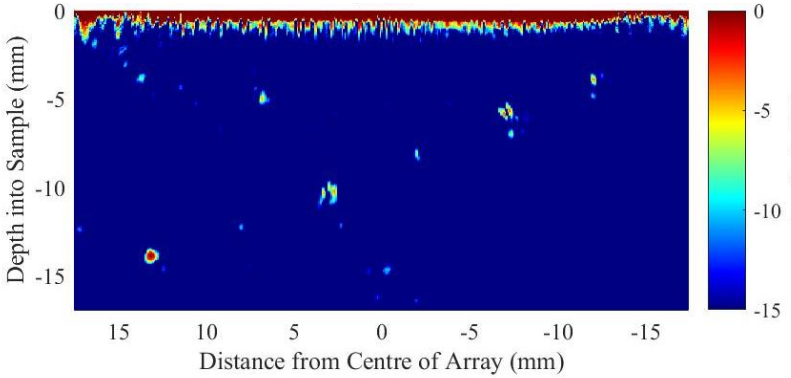


Evolution of LIPAs

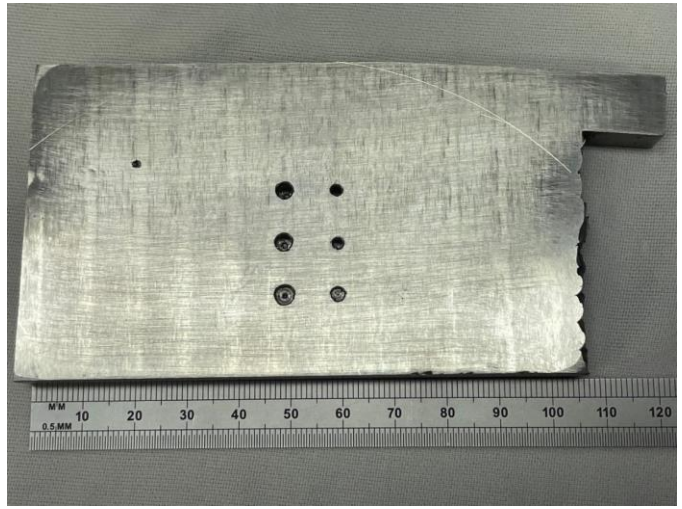


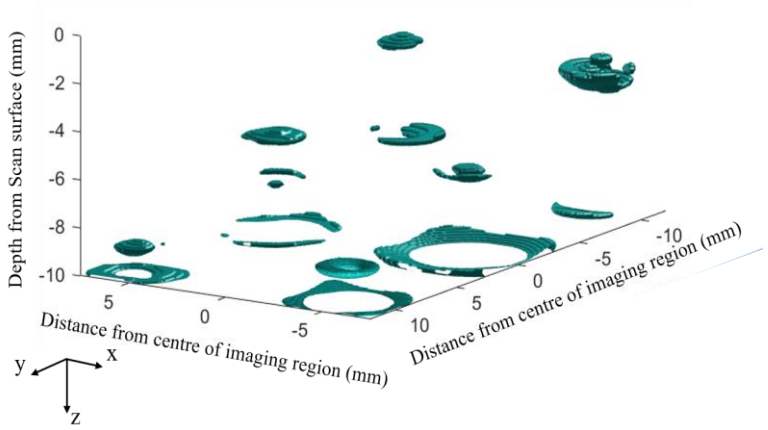
WAAM Ti-6Al-4V





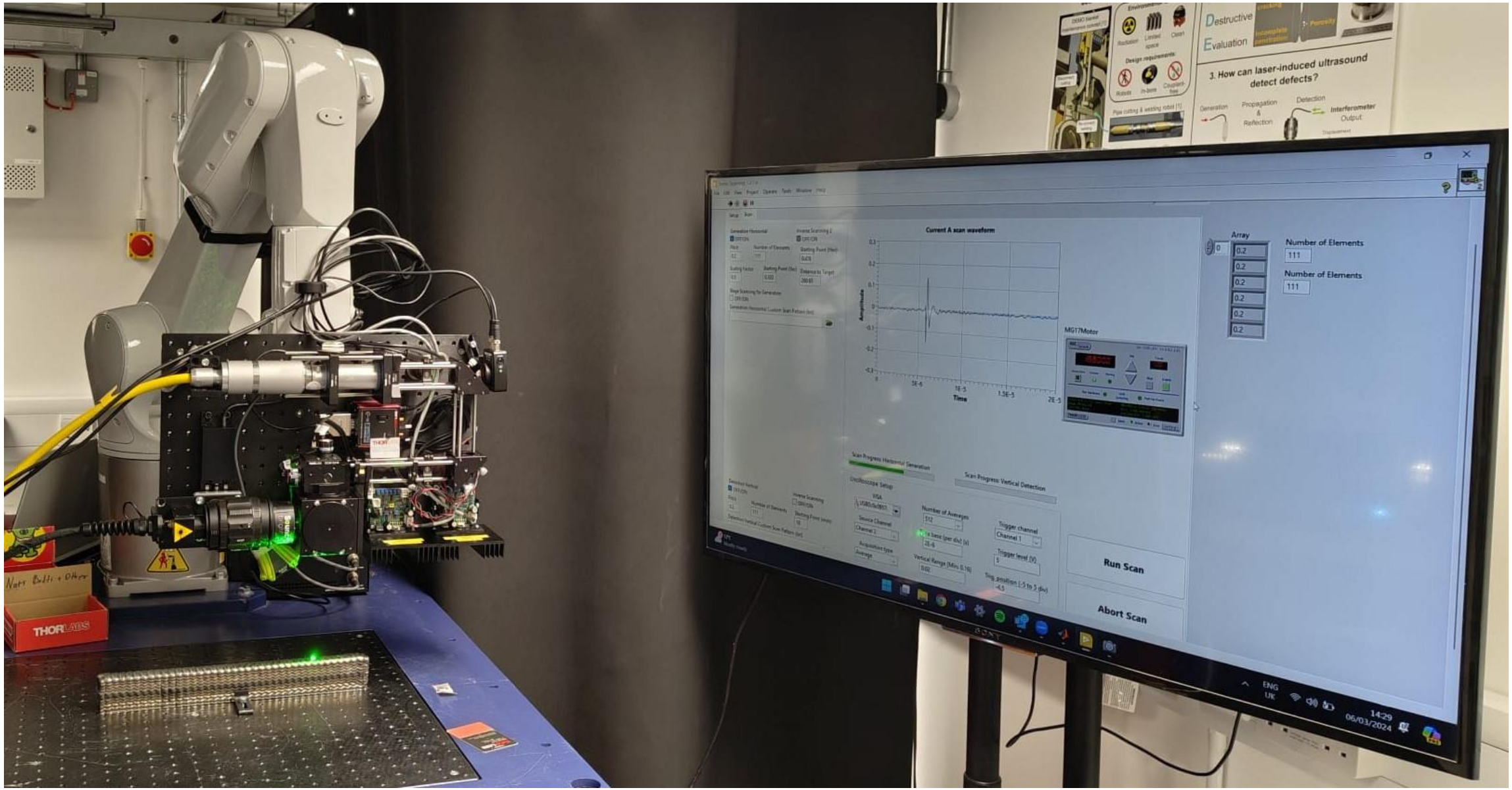
SLM Aluminium





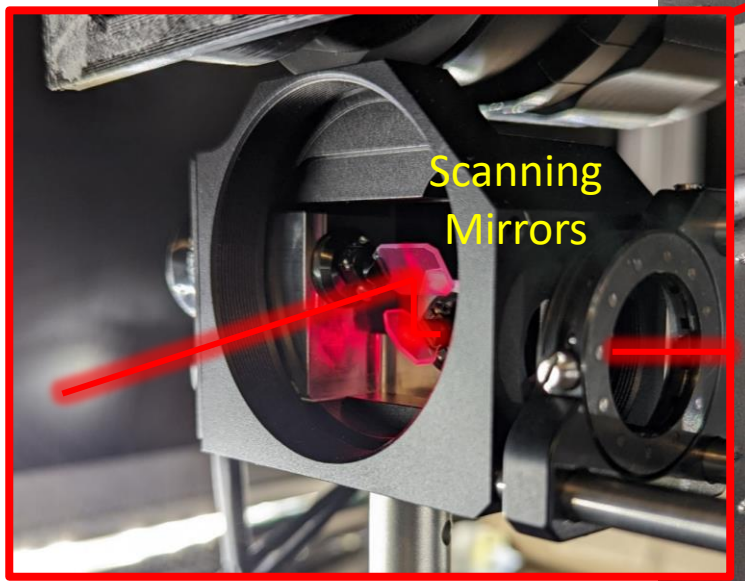
WAAM Steel

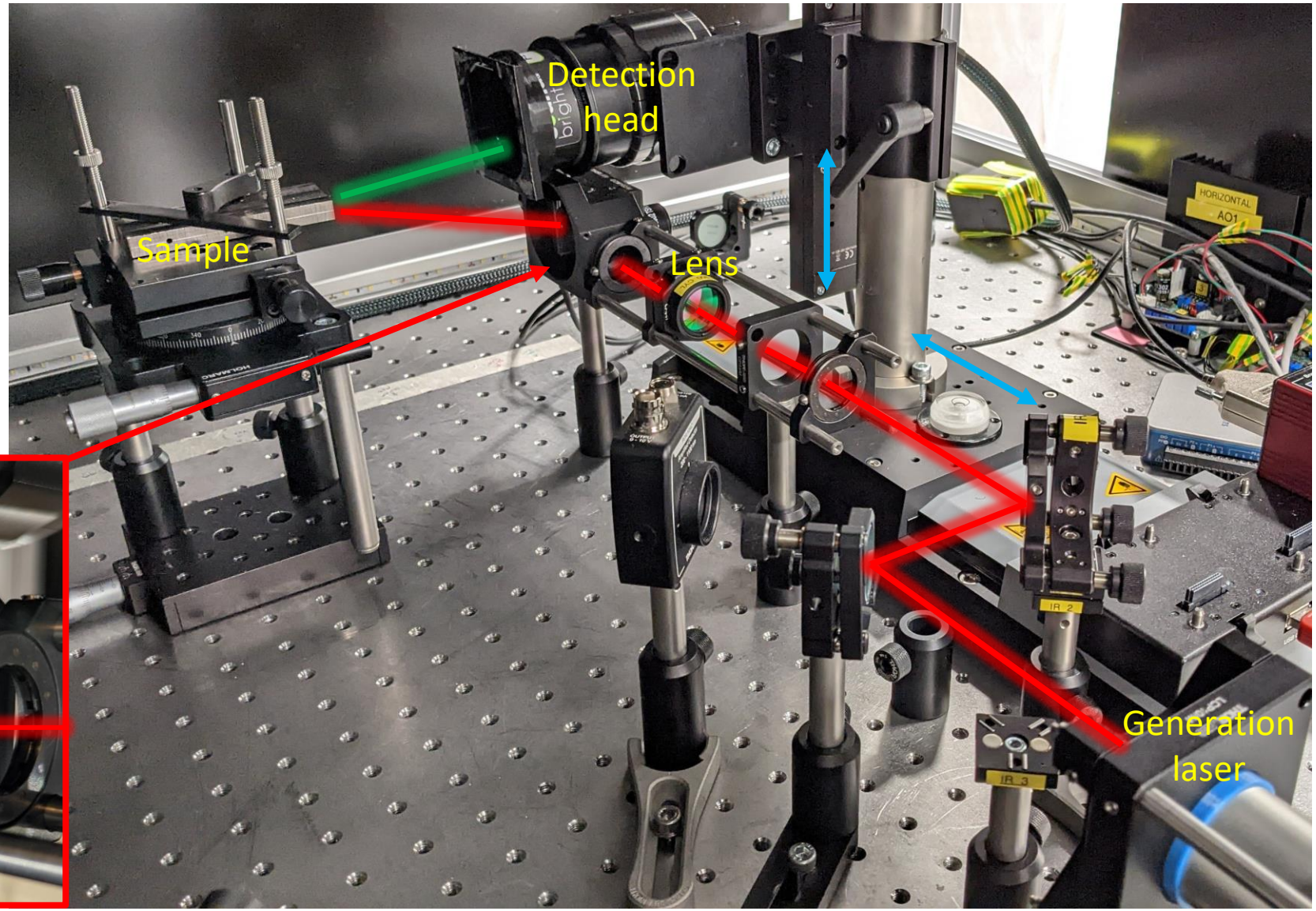
Evolution of LIPAs



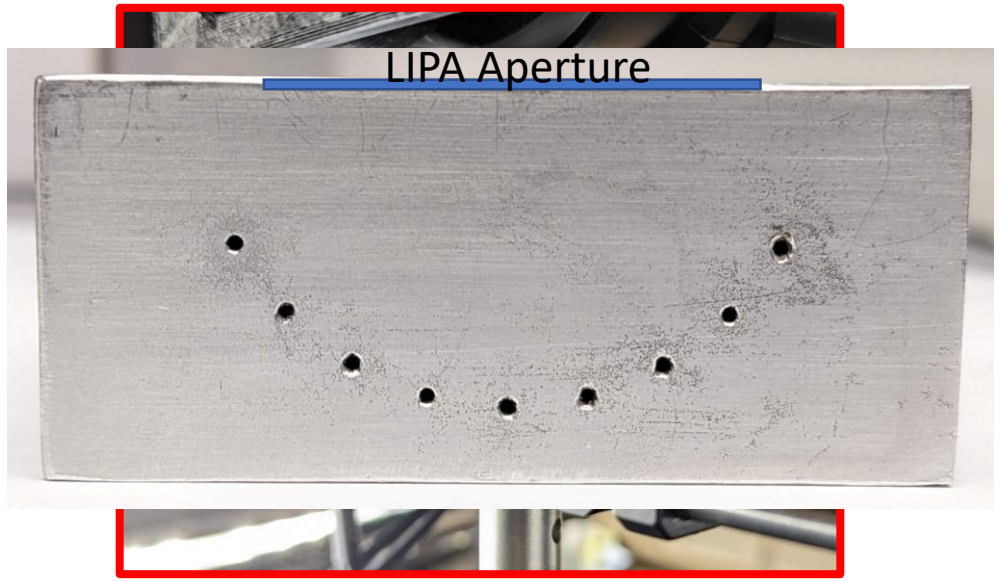
Experimental Setup

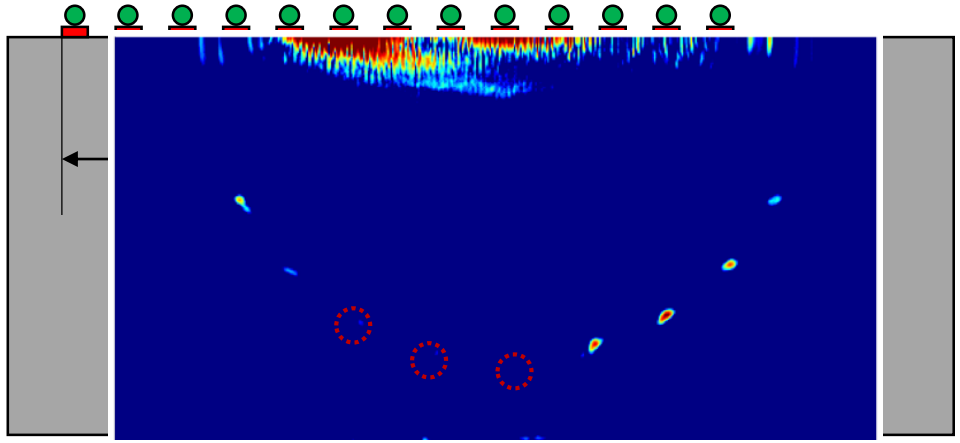
- 0.37mJ IR generation laser
  - ✓ 23ns Pulse duration
  - ✓ 5kHz Repetition rate
- 1W Green detection laser
- Receiver
  - ✓ Bandwidth: 1-66 MHz

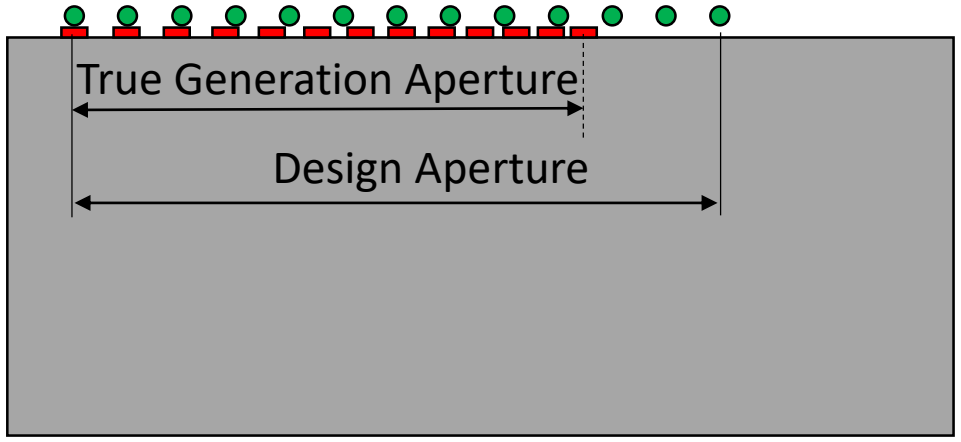


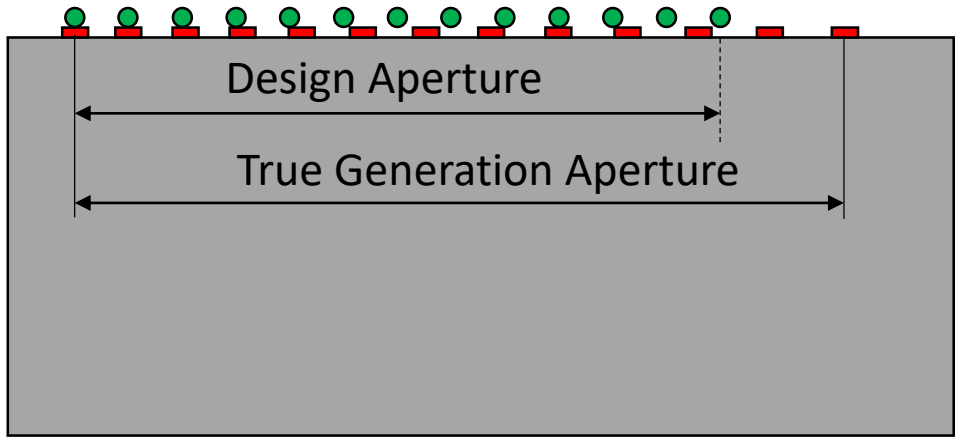


The Research Problem (1D LIPA)

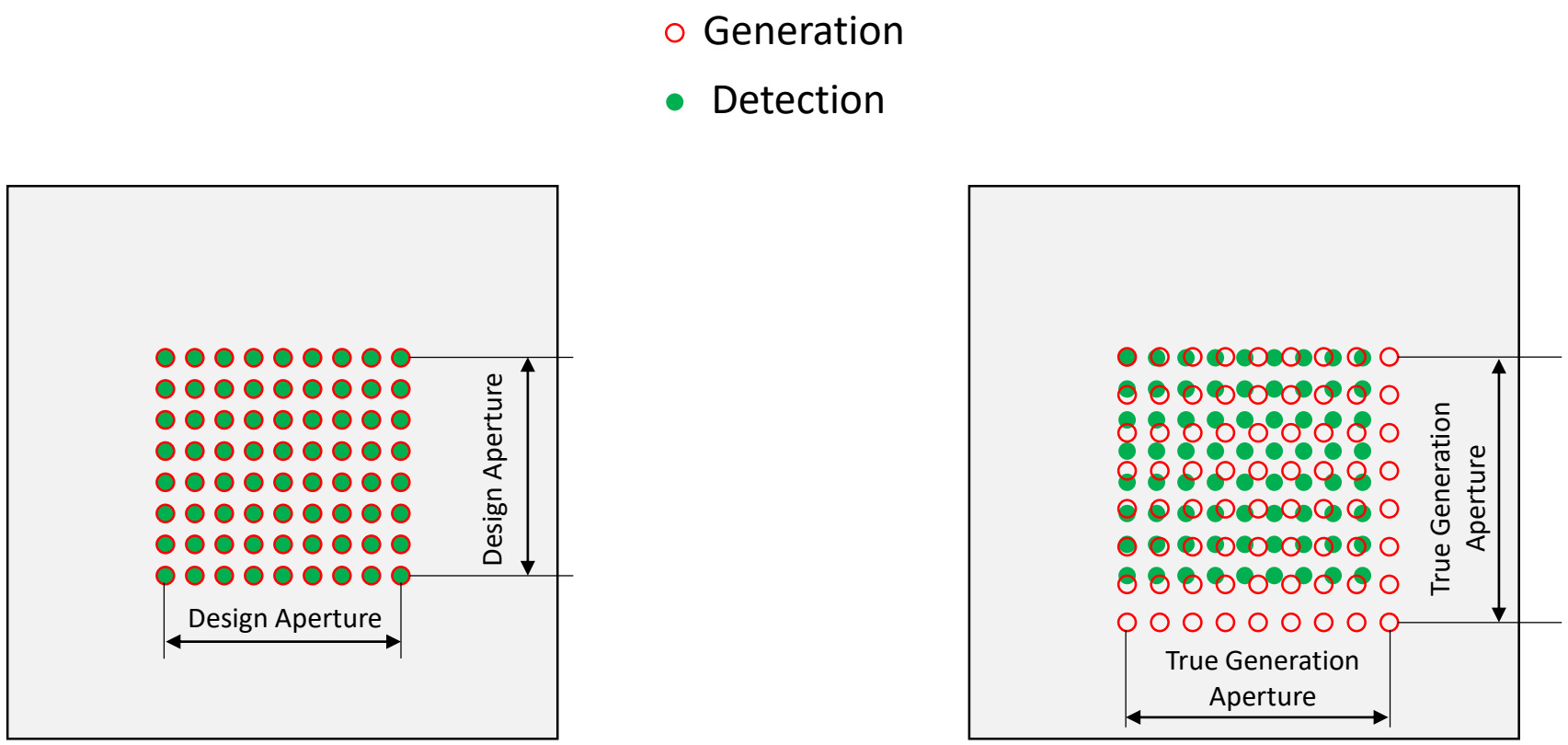








The Research Problem (2D LIPA)

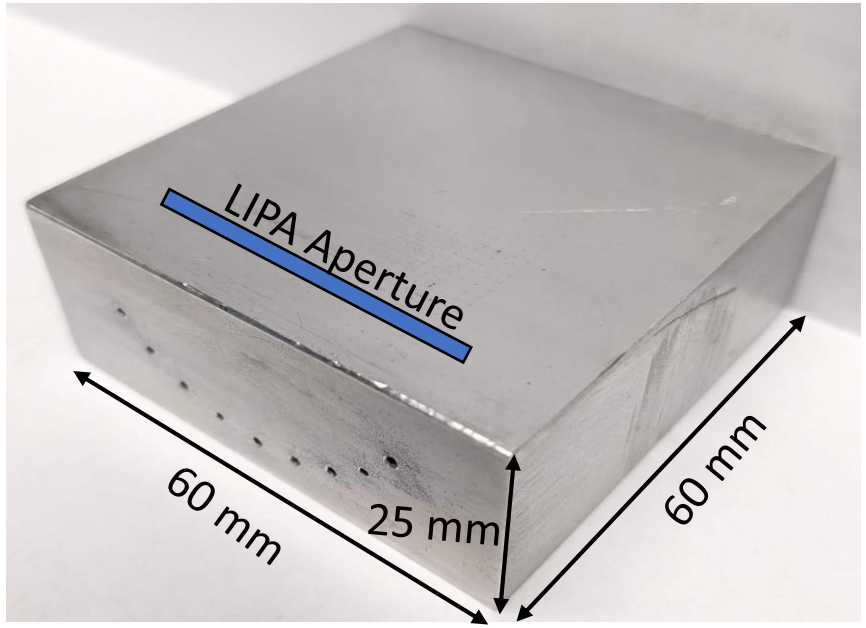


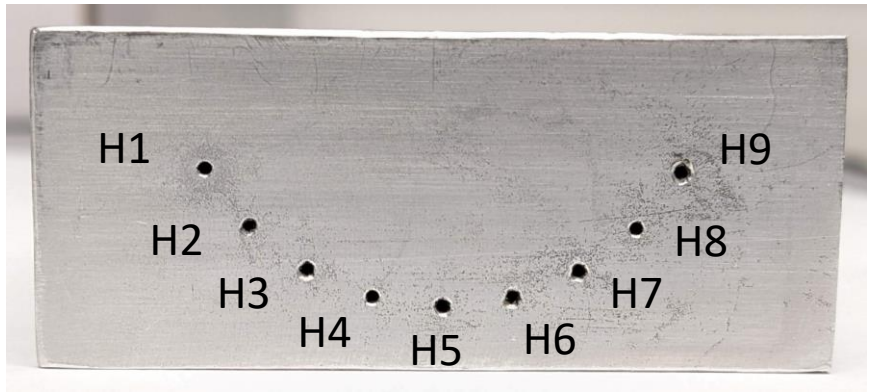
Samples

For 1D LIPA

Material: Aluminium

Features: 1 mm dia side-drilled holes

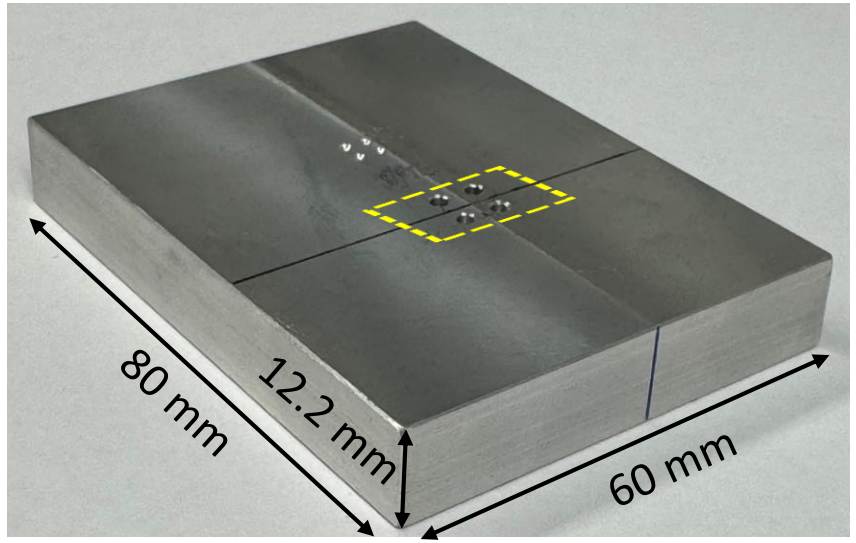


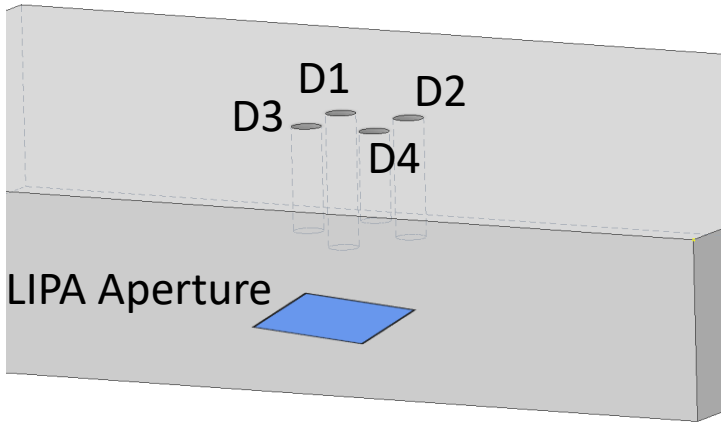


For 2D LIPA

Material: Aluminium

Features: 2mm dia bottom-drilled holes





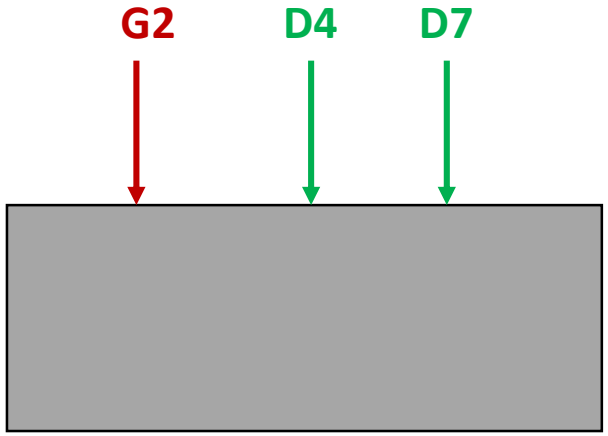
LIPA and TFM Imaging Parameters

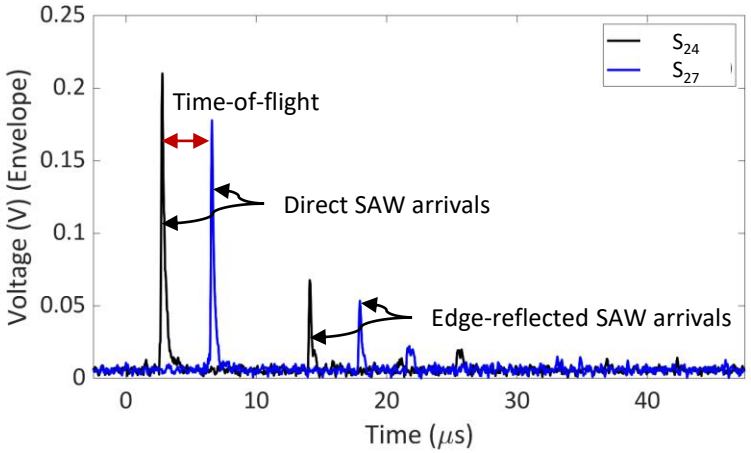
Parameter	Value (1D LIPA)	Value (2D LIPA)
Aperture (mm)	Unknown (Gen), 30 (Det)	10 x 10 (Gen), 8 x 8 (Det)
Number of elements	201	289
Pitch (mm)	Unknown (Gen), 0.15 (Det)	0.625 (Gen), 0.5 (Det)
Number of Signals	40401	83521

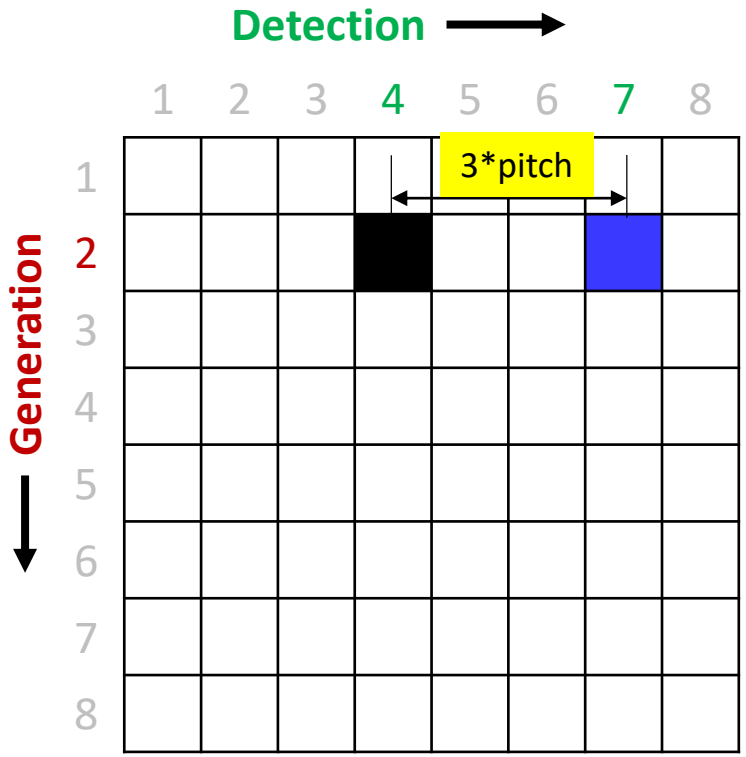
Method	Parameter	Value (1D)	Value (2D)
Digital frequency filtering	Filtering Method	Bandpass	Bandpass
	Filter Type	Gaussian	Gaussian
	Centre frequency (MHz)	5 (Transverse), 10 (Longitudinal)	5 (Transverse), 10 (Longitudinal)
	Bandwidth (%)	120	120
TFM imaging	Wave modes used	Transverse (shear), Longitudinal	Transverse (shear), Longitudinal
	Wave mode velocity (m/s)	Transverse: 3200 Longitudinal: 6300	Transverse: 3200 Longitudinal: 6300
	Pixel size (mm x mm)	0.1 x 0.1	0.25 x 0.25 x 0.25

Instrument	Parameter	Value (1D)	Value (2D)
Generation Laser	Energy per pulse (mJ)	0.31	0.27
	Pulse repetition frequency (kHz)	5	5
	FWHM pulse duration (ns)	23	23
Detection Laser	Power (W)	0.76	0.76
Oscilloscope	Averaging	64	128
	Sampling rate (MHz)	20	100
	Signal Length (μs)	50	10
	Number of sampling points	1000	1000

Methodology - SAW velocity measurement

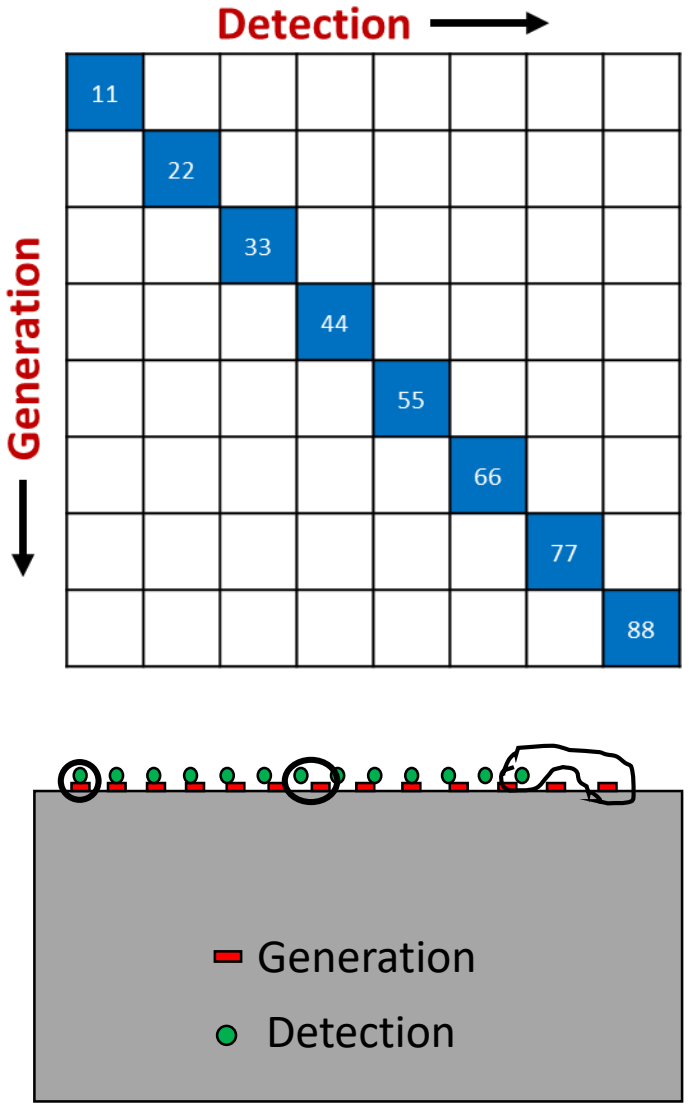


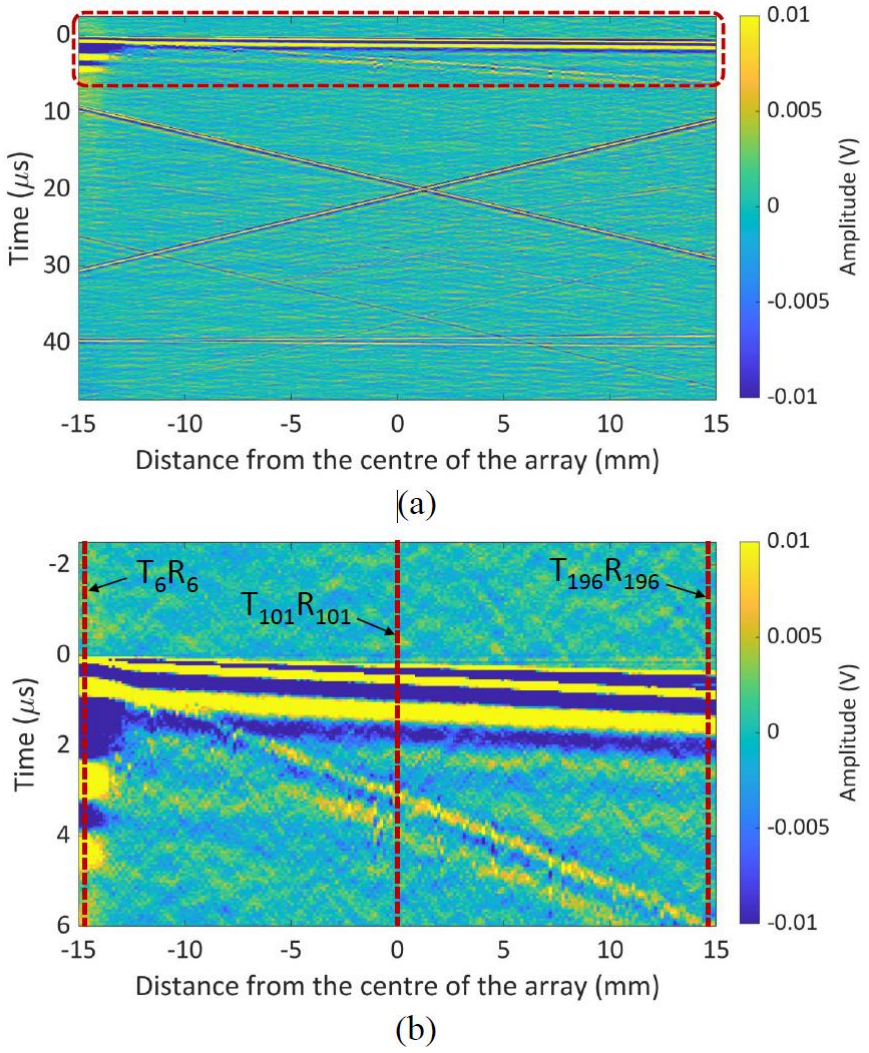


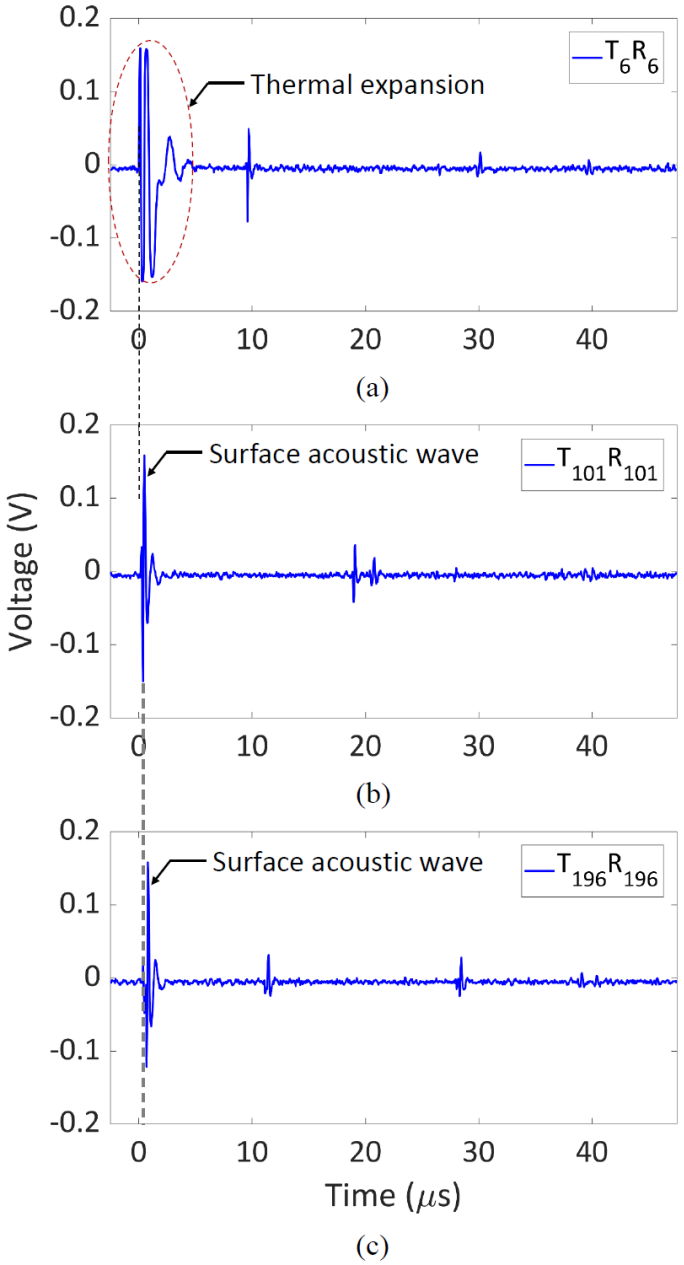


$$velocity = \frac{distance}{time}$$

Methodology (1D) - Estimation of true element locations



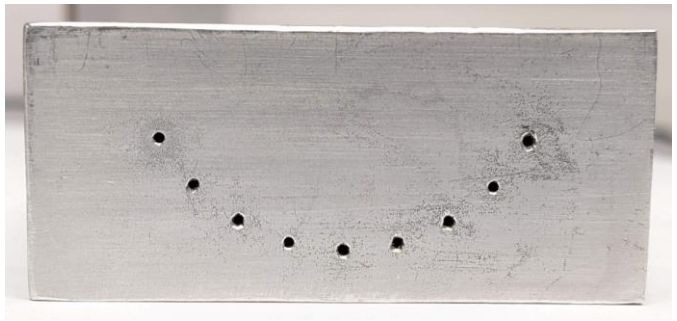




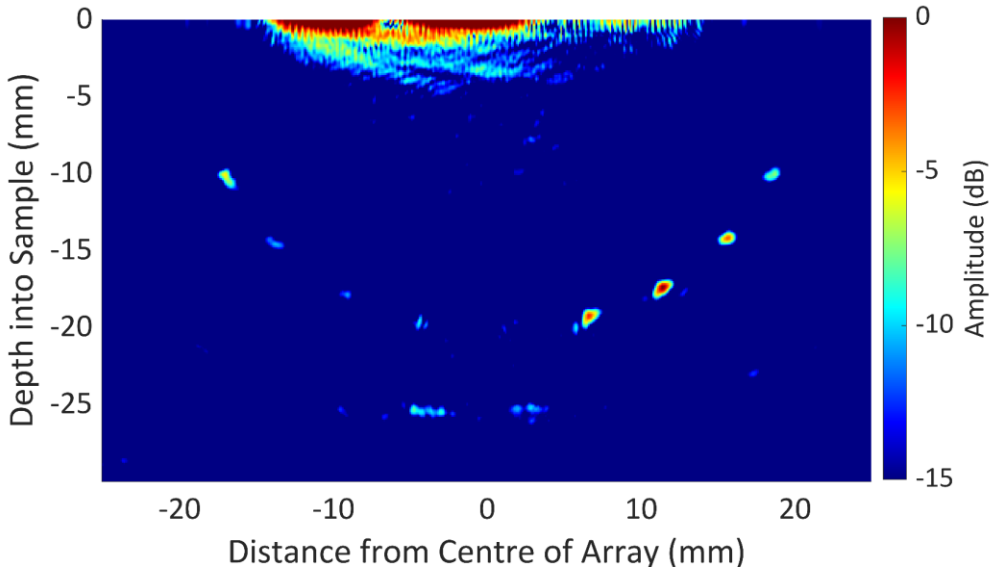
Results: 1D LIPA

Results: TFM Without Element Localisation

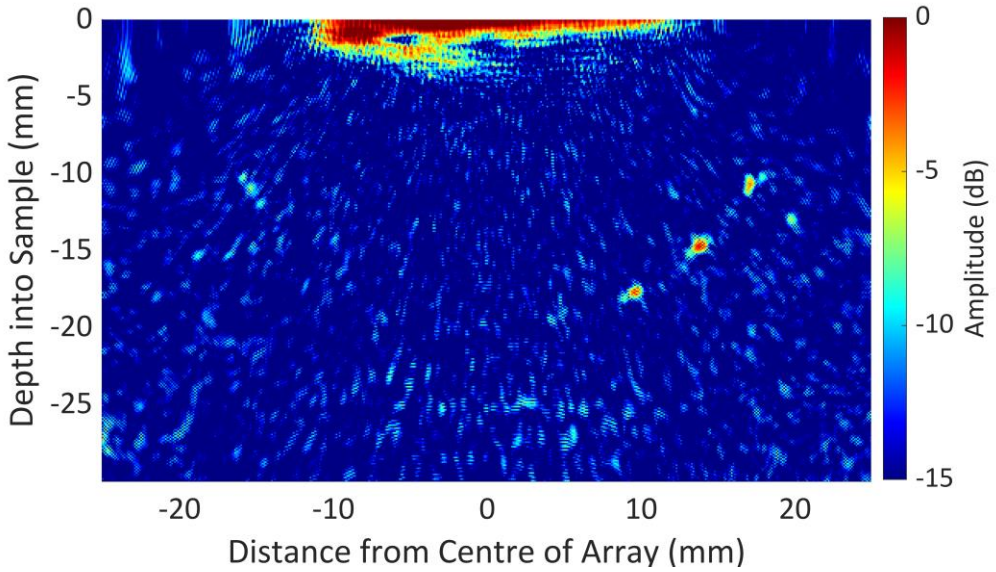
Detection aperture pitch: 0.15 mm (Constant)
Generation aperture pitch: Unknown (Nonlinear pitch)
Assumed generation aperture pitch: 0.15 mm (Constant)



Shear wave

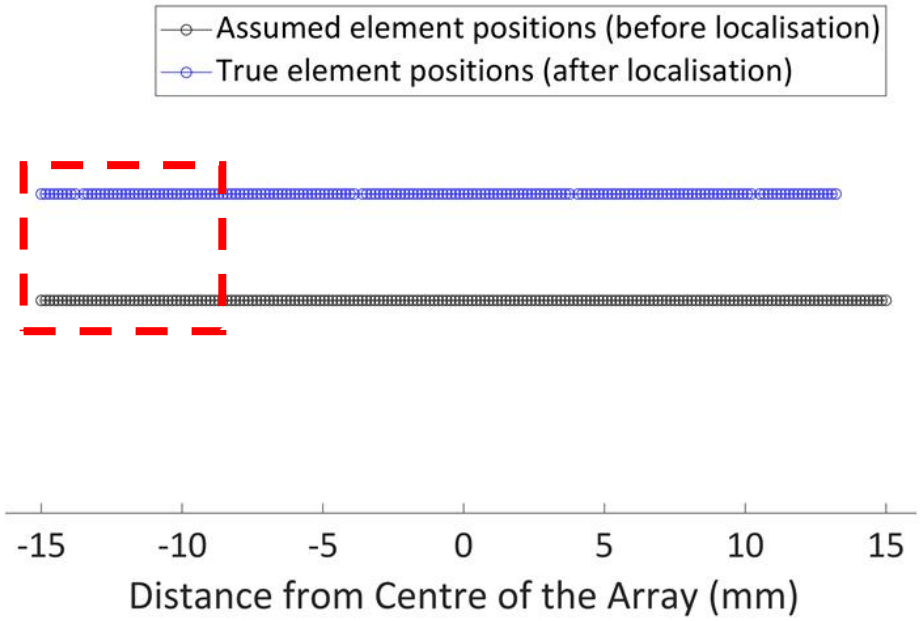


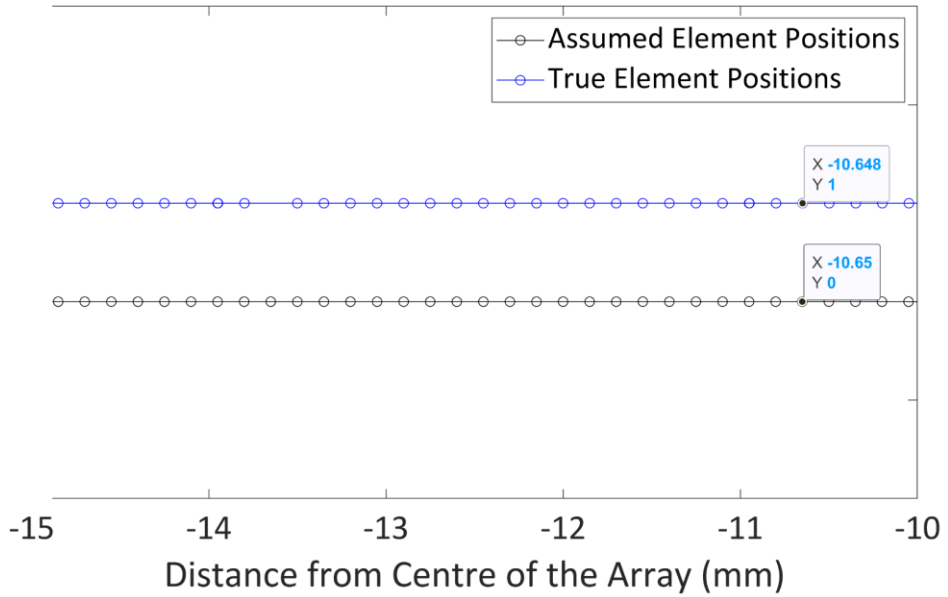
Longitudinal wave



Element Positions Before and After Localisation

Generation

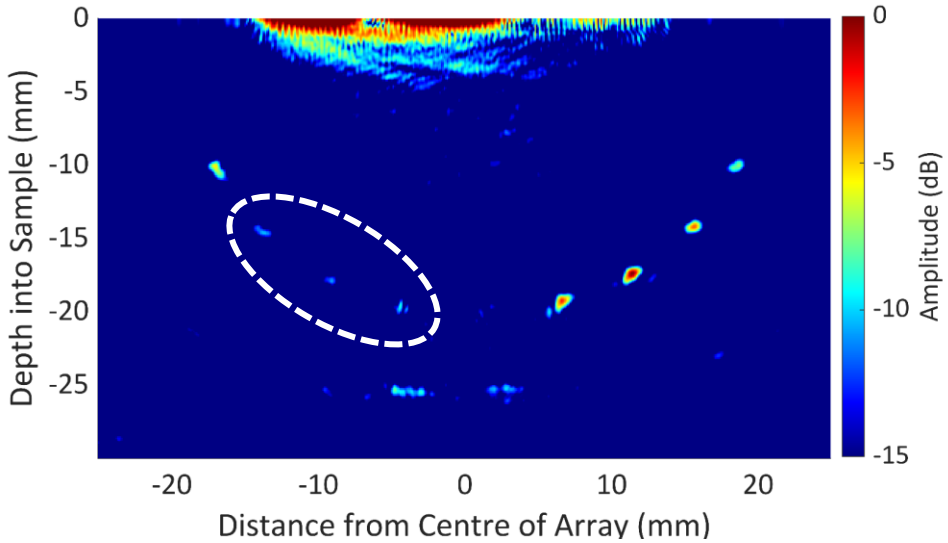


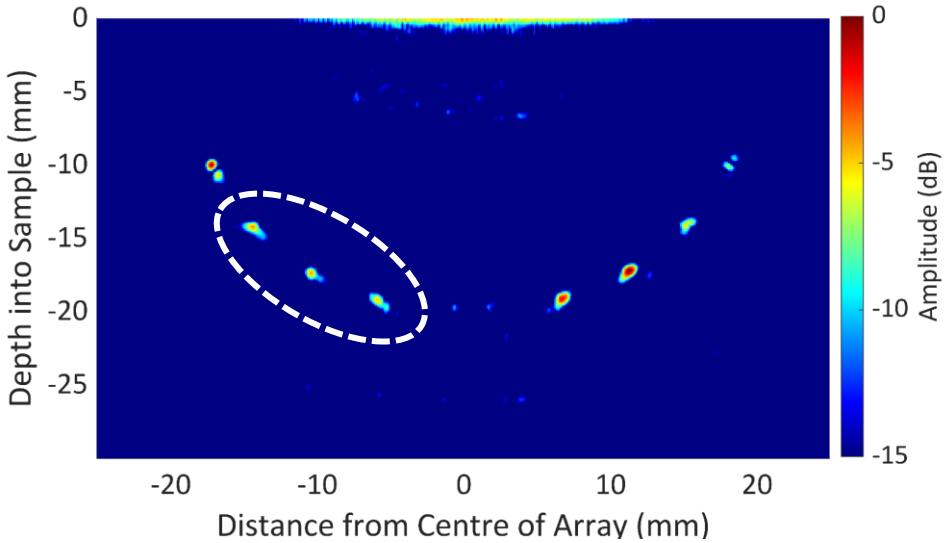


TFM Images Before and After Element Localisation

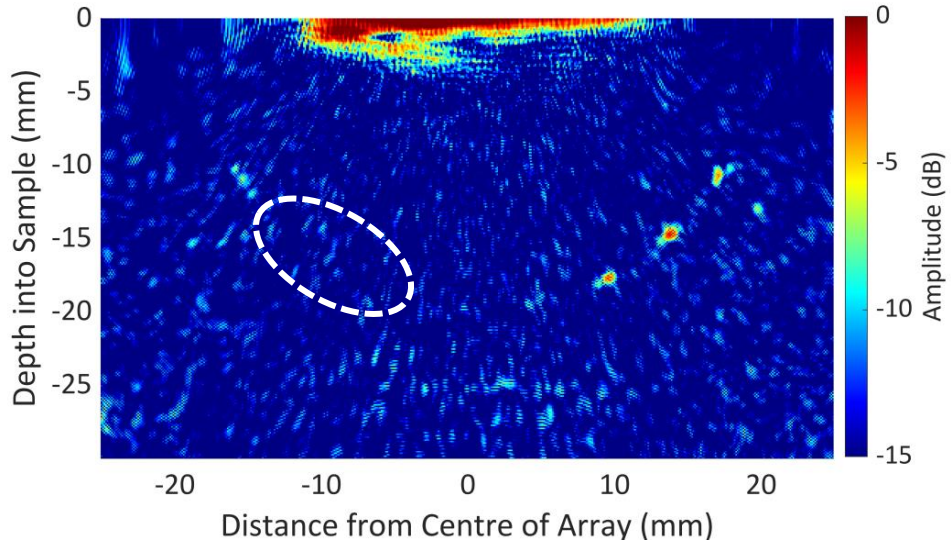
Before **After**

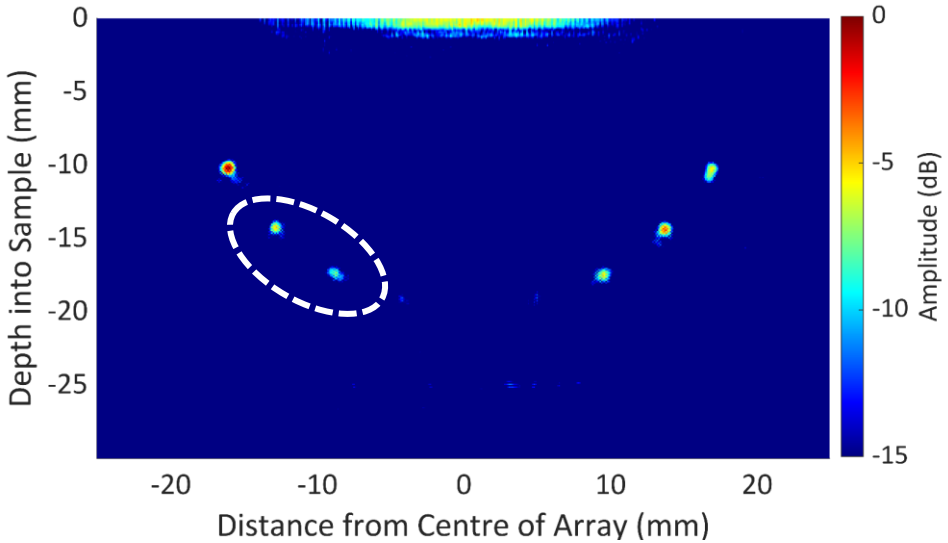
Shear



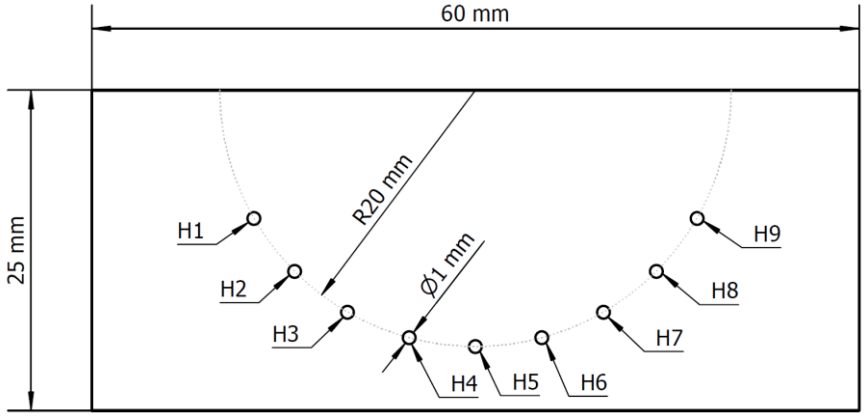


Longitudinal





Results



Shear

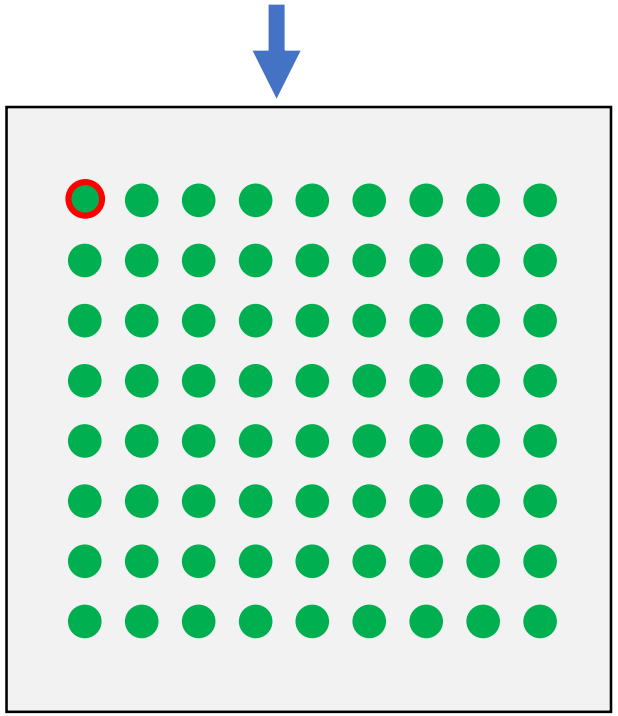
Defect identifier	H1	H2	H3	H4	H5	H6	H7	H8	H9
SNR before localisation (dB)	18.5	13.5	12.6	14.9	10.7	21.6	24.0	20.5	16.4
SNR after localisation (dB)	24.1	21.3	21.0	20.1	14.5	23.1	25.2	19.1	18.3
SNR Improvement (dB)	5.6	7.8	8.4	5.2	3.8	1.5	1.2	-1.4	1.9

Longitudinal

Defect identifier	H1	H2	H3	H4	H5	H6	H7	H8	H9
SNR before localisation (dB)	11.4	8.2	7.6	8.5	9.1	11.0	15.8	18.2	14.0
SNR after localisation (dB)	25.6	21.0	17.7	13.6	9.3	14.0	20.6	22.9	20.2
SNR Improvement (dB)	14.2	12.8	10.1	5.1	0.2	3	4.8	4.7	6.2

Methodology (2D) - Estimation of true element locations

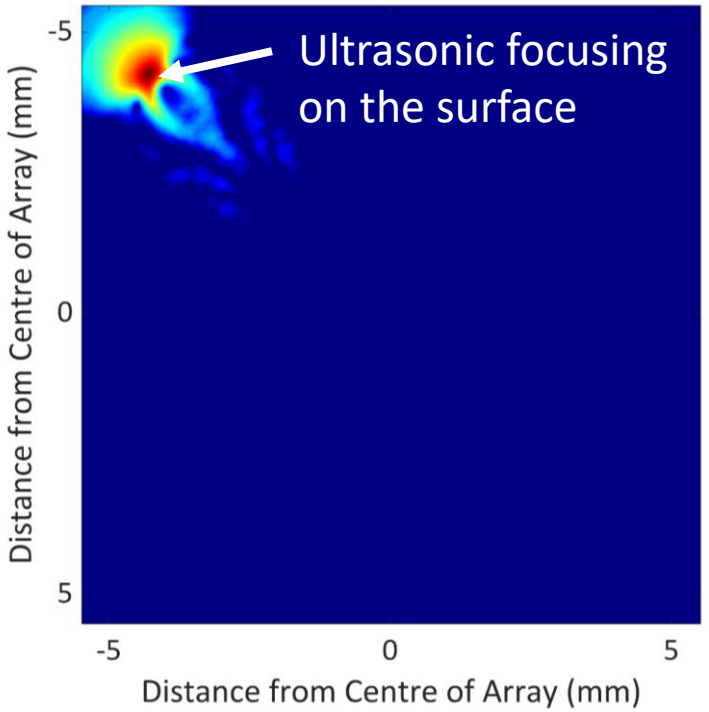
1. Consider ultrasonic signals for one generation and all detection.



Generation

Detection

2. TFM algorithm is applied to the ultrasonic signals (selected in step 1) using the SAW velocity.

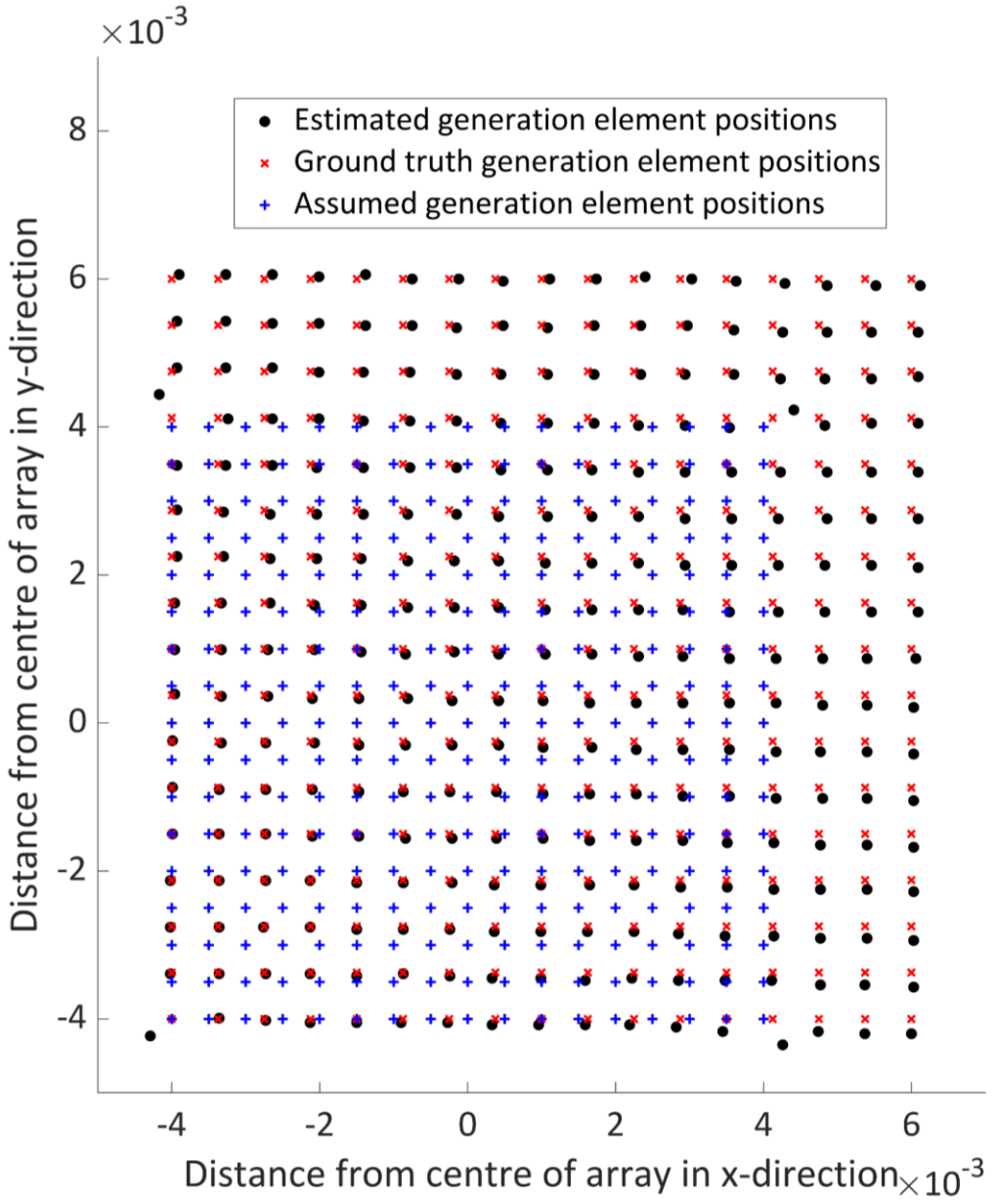


3. The coordinates corresponding to the peak intensity of the imaged ultrasonic source gives the true generation element location.

4. Repeat steps 1, 2 and 3 for each generation element position.

Results: 2D LIPA

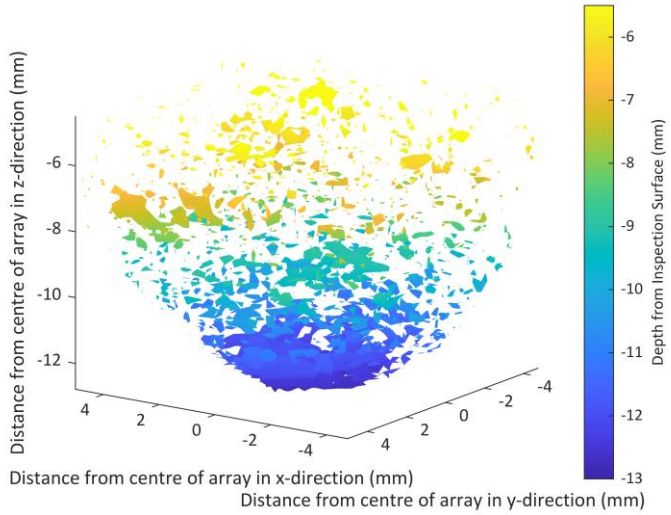
Element Positions Before and After Localisation (2D)

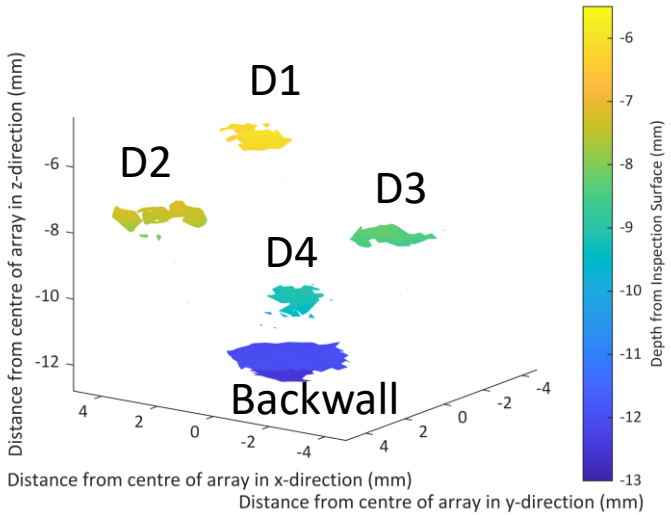


Volumetric TFM Images Before and After Element Localisation

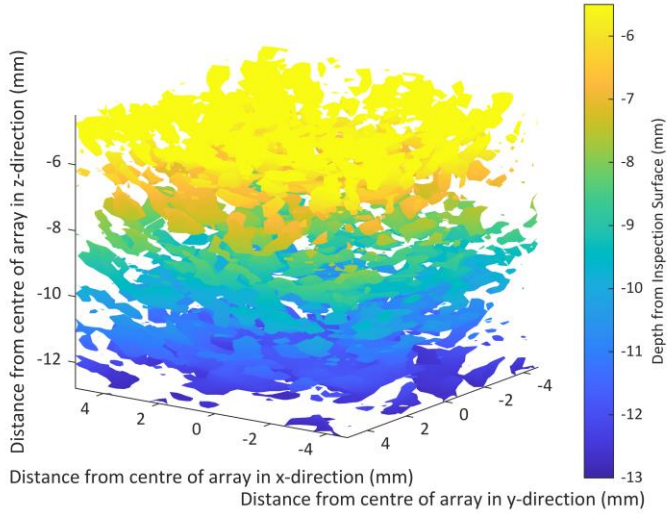
Before **After**

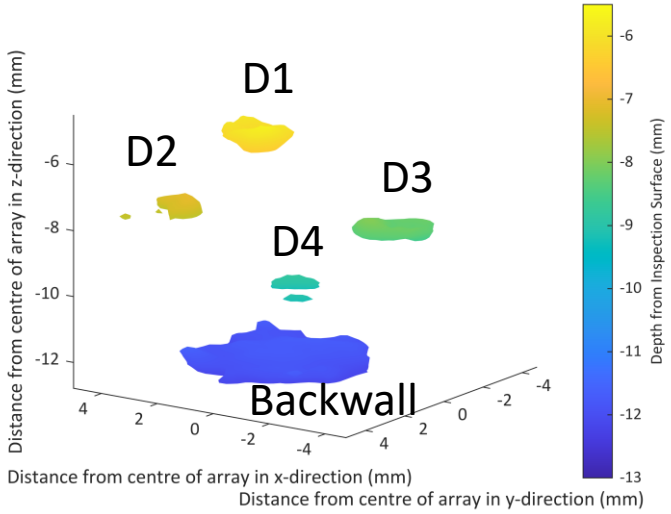
Shear

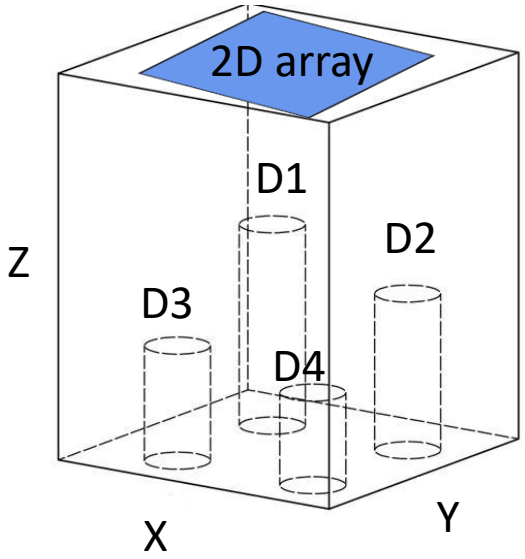




Longitudinal







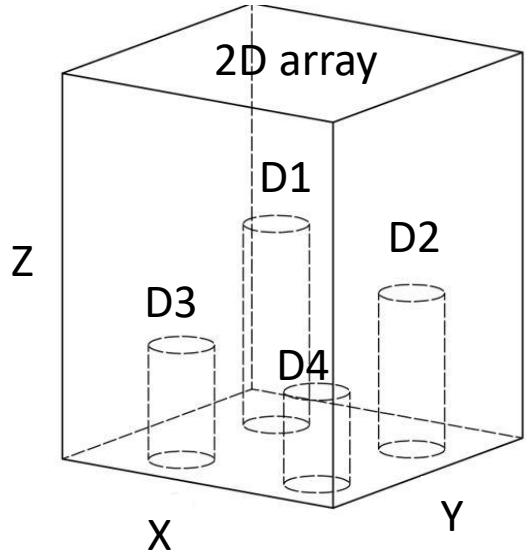
Results (Volumetric Imaging)

Shear

Defect identifier	D1	D2	D3	D4
SNR before localisation (dB)	33.3	26.4	24.2	27.5
SNR after localisation (dB)	41.7	39.8	31.9	36.3
SNR Improvement (dB)	8.4	13.4	7.7	8.8

Longitudinal

Defect identifier	H1	H2	H3	H4
SNR before localisation (dB)	28.9	26.5	23.0	23.7
SNR after localisation (dB)	40.8	46.5	38.0	42.1
SNR Improvement (dB)	11.9	20	15	18.4



Summary & Conclusions

- Optical phased arrays can be synthesized using the principles of laser ultrasonics for non-contact inspection.

- Scanning errors/sample displacment can cause the LIPA element positions to deviate from the designed positions. This can lead to
  - ✓ Poor focusing/low SNR
  - ✓ Missed defects
  - ✓ Inaccurate location of defects
  - ✓ Crosstalk and artefacts

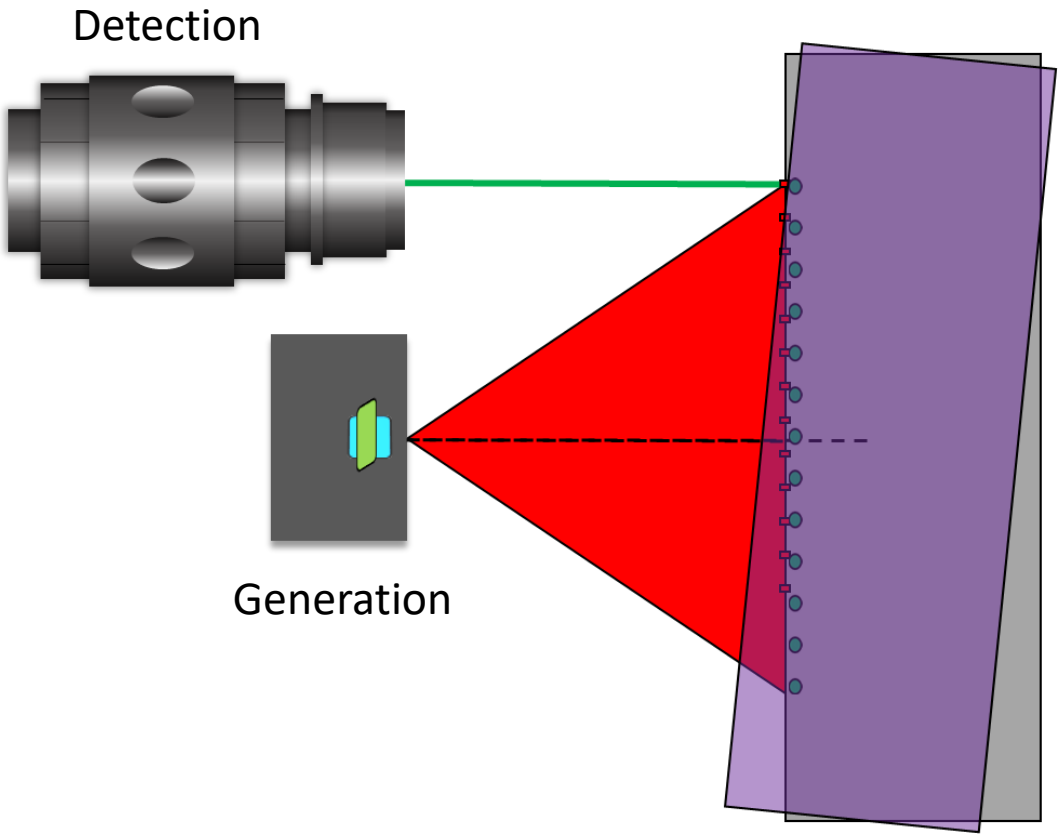
- An ultrasonic surface acoustic wave-based element localisation method is proposed and demonstrated.

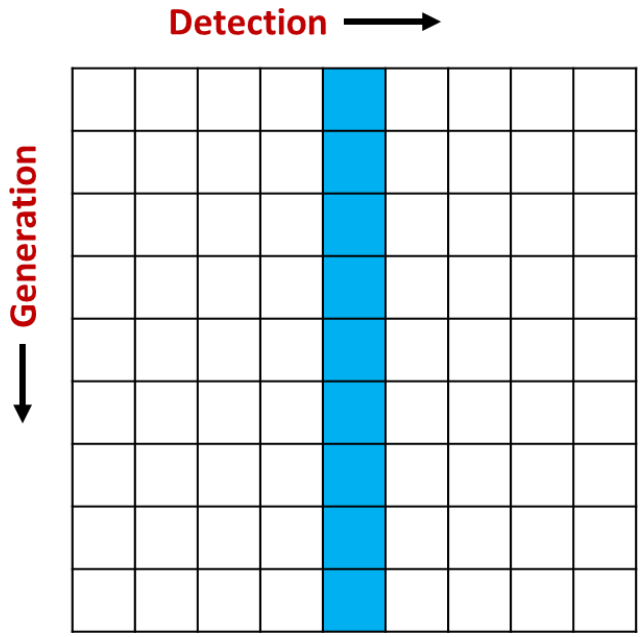
- For 1D element localisation:
  - Shear wave imaging: Max SNR improvement of 8.4 dB, mean = 3.8 dB, std = 3.3 dB
  - Longitudinal wave imaging: Max SNR improvement of 14.2 dB, mean = 6.8 dB, std = 4.6 dB

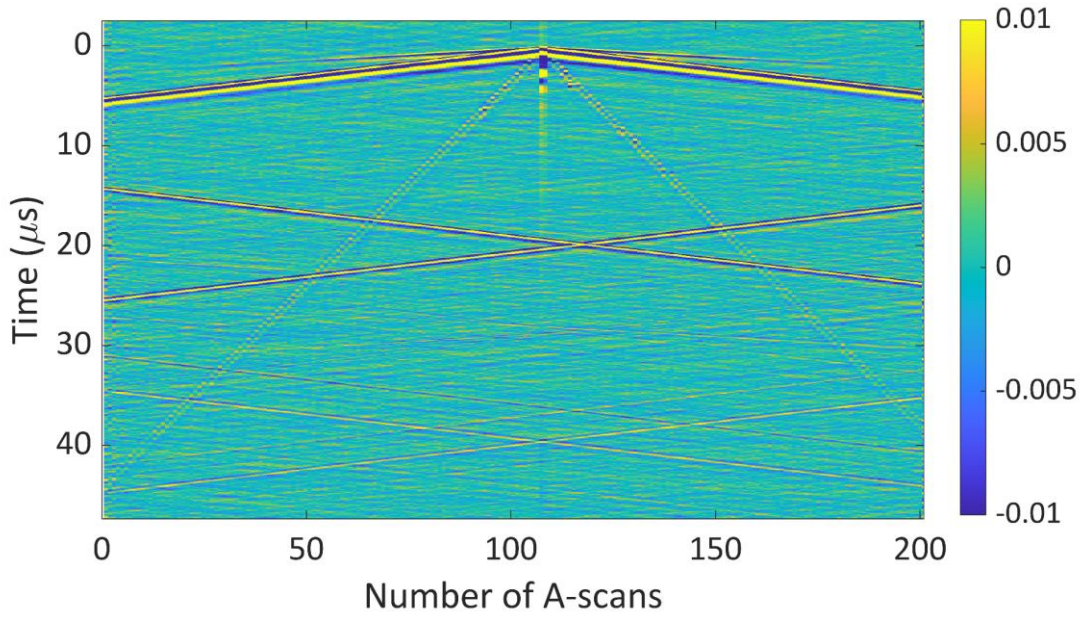
- For 2D element localisation:
  - Shear wave imaging: Max SNR improvement of 13.4 dB, mean = 9.6 dB, std = 2.6 dB
  - Longitudinal wave imaging: Max SNR improvement of 20 dB, mean = 16.3 dB, std = 3.6 dB

Future Scope

Automated Sample Alignment







Thank you

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