Quantitative Ultrasound Computed Tomography using phase-insensitive pyroelectric detectors

Bajram Zeqiri
Acoustics & Ionising Radiation Division
National Physical Laboratory, UK

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- PI detectors
- UCT System design
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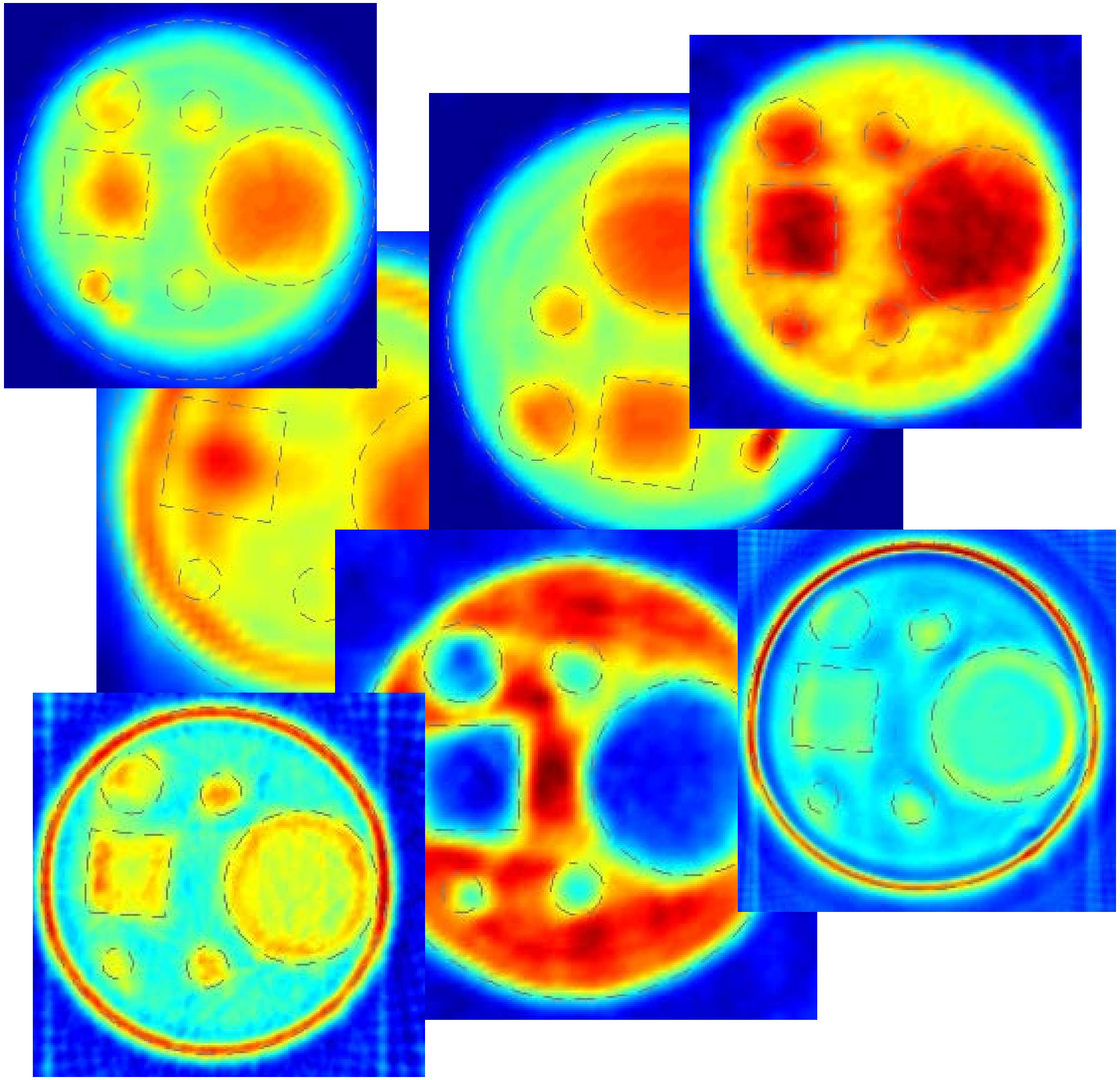
- Summary



Motivation

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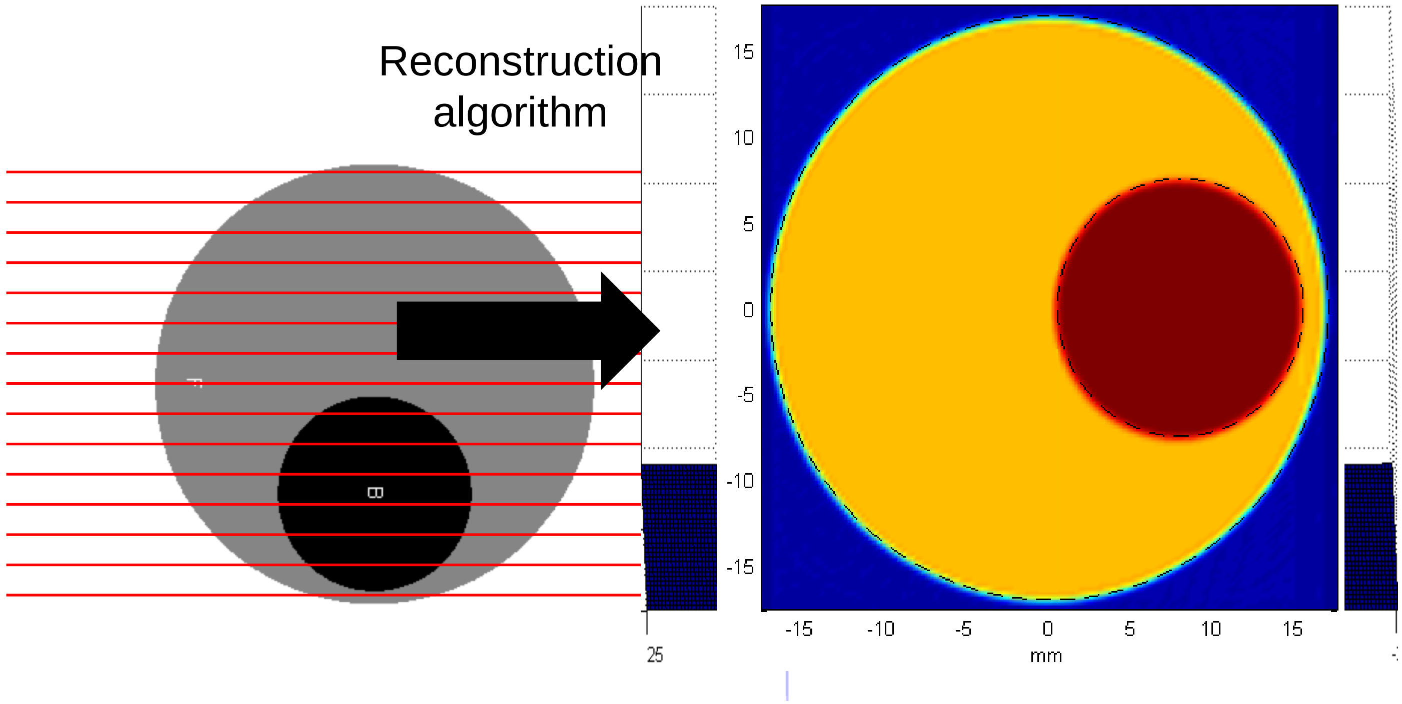
- Ultrasonic Computed Tomography (UCT) is being investigated for whole breast applications;
- Reconstructions are strongly affected by artefacts, particularly when based on ultrasound attenuation of tissue;
- These artefacts arise due to the nature of the detectors used, in particular that they are ***phase-sensitive***;
- In the 1980's, ***phase-insensitive*** detectors based on Cadmium Sulphide acoustoelectric sensors (1980s) seemed to show promise, but were too insensitive;
- This presentation describes ***phase-insensitive*** detectors that exploit the pyroelectric effect in a thin polymer and their application to UCT.

Computed Tomography (CT)

Projections

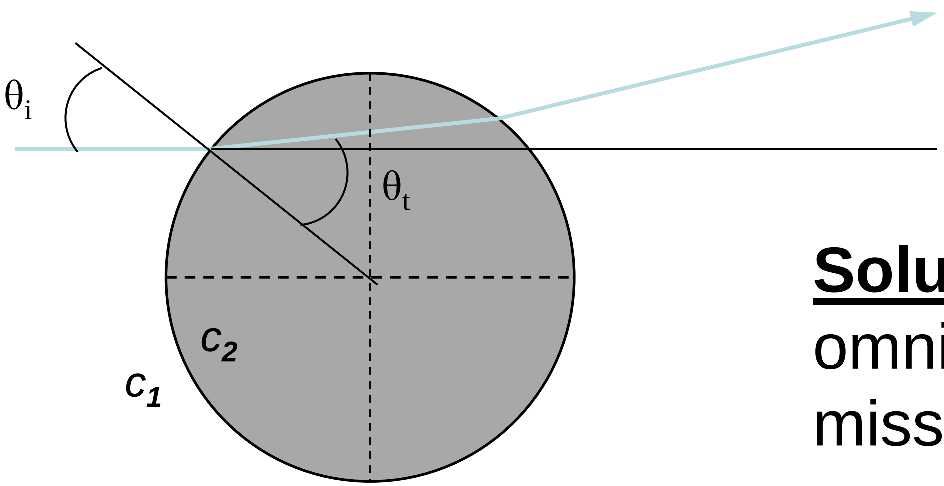
2-dimensional image



- Characteristic properties of biological tissues

Speed of sound [m/s]	***Fat***	***Breat fibroglandular tissue***	***Fibroadenoma***	***Carcinoma***	***Cyst***
Wiskins *et al. 2011*	1430 -1460	1550 -1575	1550 -1585	1585 -1630	1520-1540

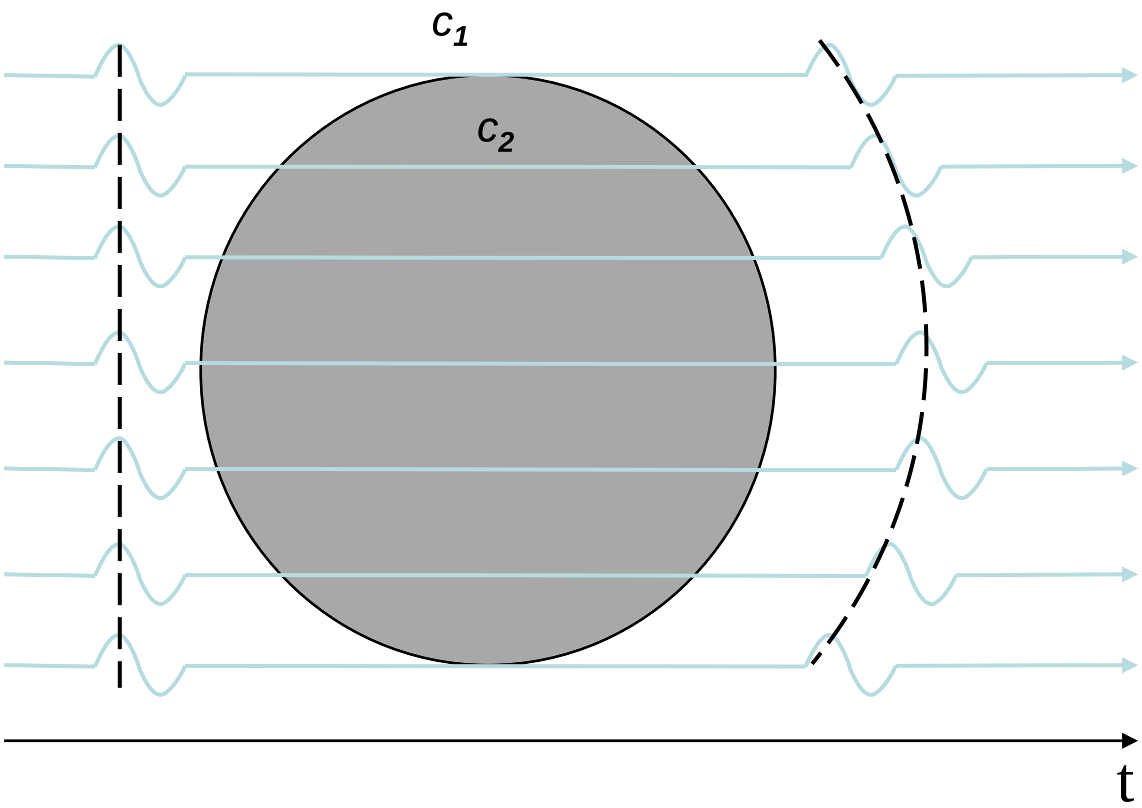
- Refraction of ultrasonic wave-fronts



Snell's law

<u>**Solution**</u>: need a large omnidirectional sensor to avoid missing refracted radiation

- Distortion of travelling acoustic wave-fronts



Acoustic plane-waves

$C_2 > C_1$

Solution: need a phase-insensitive (PI) detector

Biological tissue	α (dB cm^{-1}) 1 MHz	α (dB cm^{-1}) 2.5 MHz	Speed of sound (ms^{-1})
Subcutaneous fat	0.89	1.71	1470
Internal fat	0.92	1.8	1470
High attenuation tumour	0.92	3.2	1549
Cyst	0.06	0.38	1569
Glandular parenchyma	1.02	2.94	1515

Duric et al. Development of ultrasound tomography for breast imaging, Medical Physics, 32 (5), 2005.

Phase-insensitive (PI) detectors

Pyroelectric Detection

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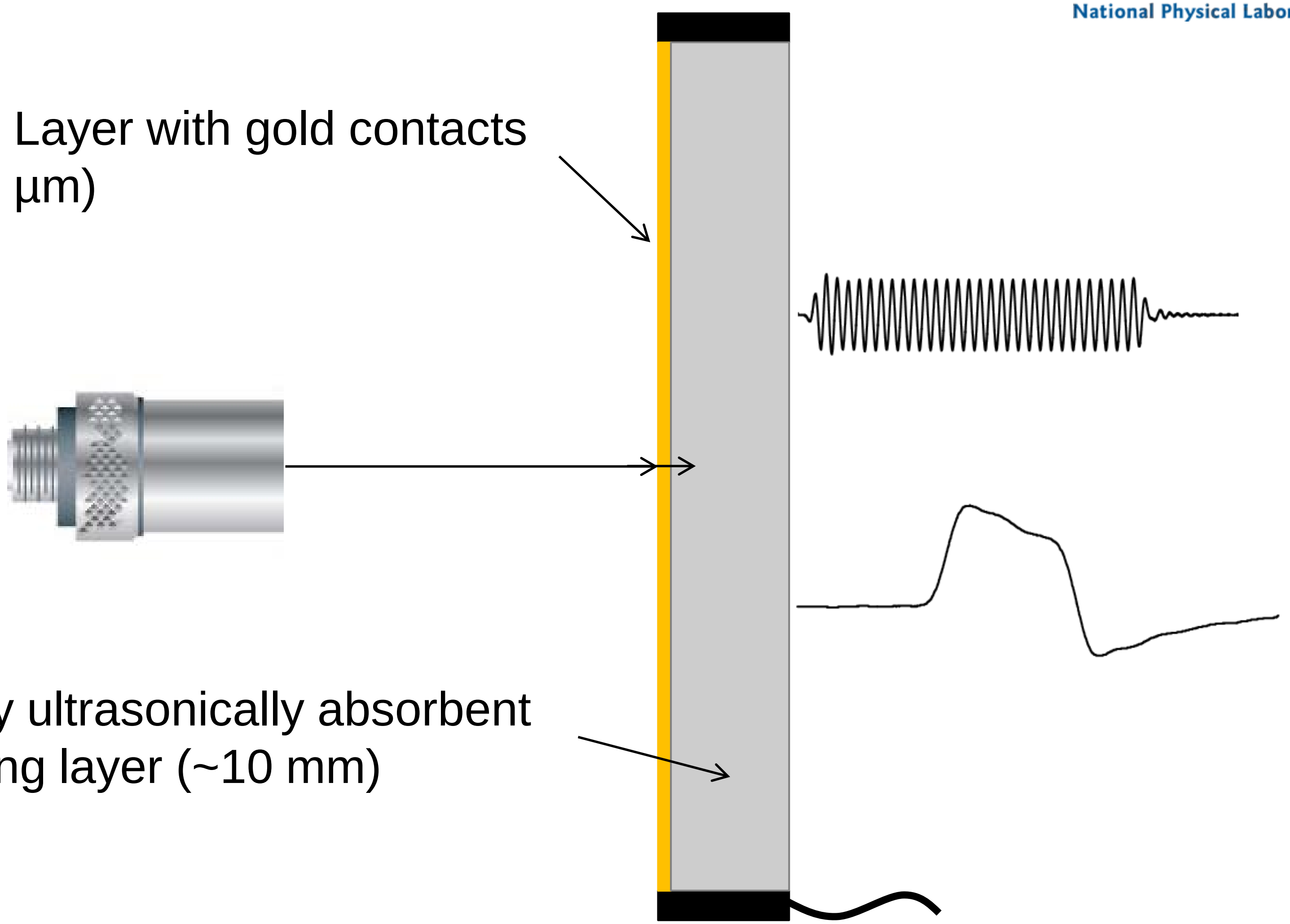
PVdF Layer with gold contacts (~110 µm)

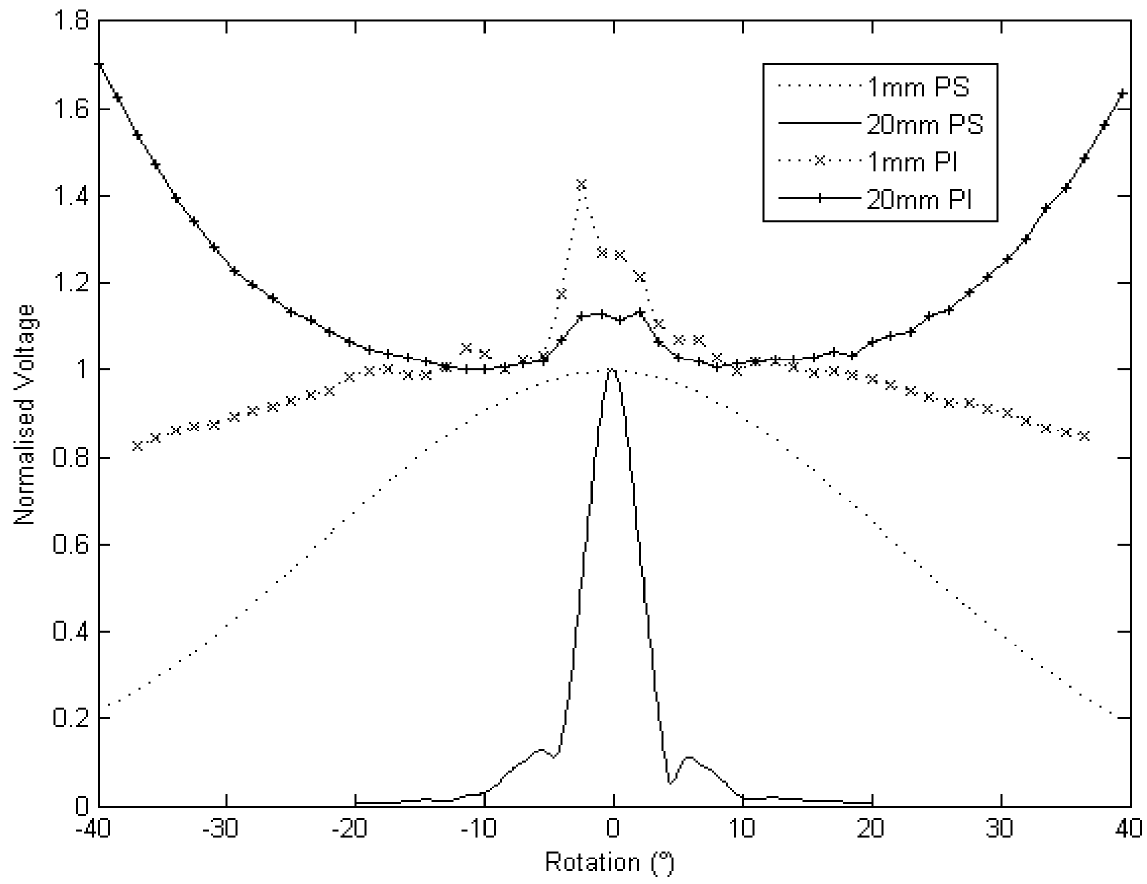


Highly ultrasonically absorbent backing layer (~10 mm)

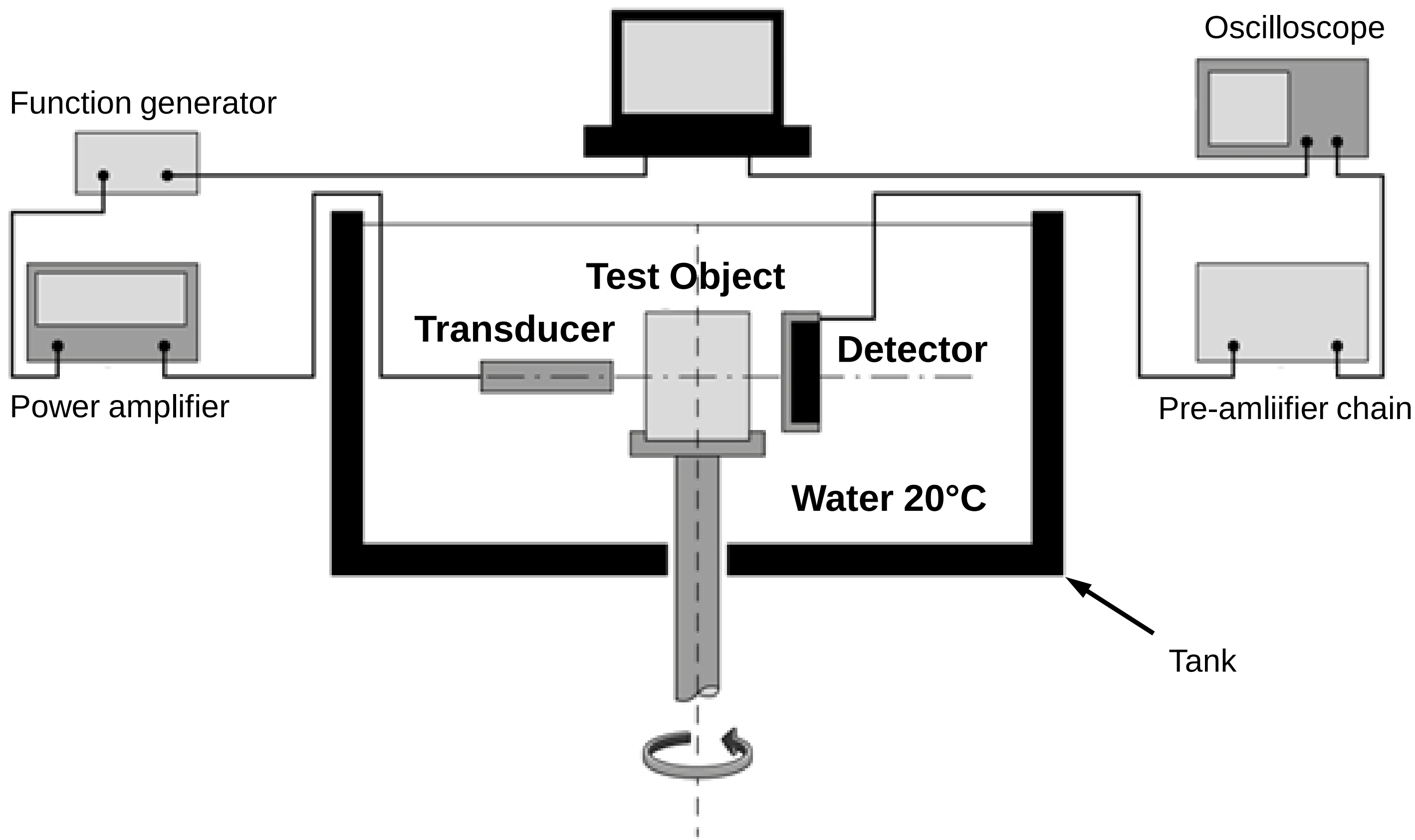
B. Zeqiri, P. N. Gélat, J. Barrie and C.J. Bickley. “A Novel Pyroelectric Method of Determining Ultrasonic Transducer Output Power: Device Concept, Modelling and Preliminary Studies”, IEEE Trans. Ultrason., Ferroelectr., Freq. Contr., Vol. 54, No. 11, 2318-2330, 2007.

Directional Response

PI, PS comparison for two detector apertures



UCT scanning platform



Pyroelectric UCT System

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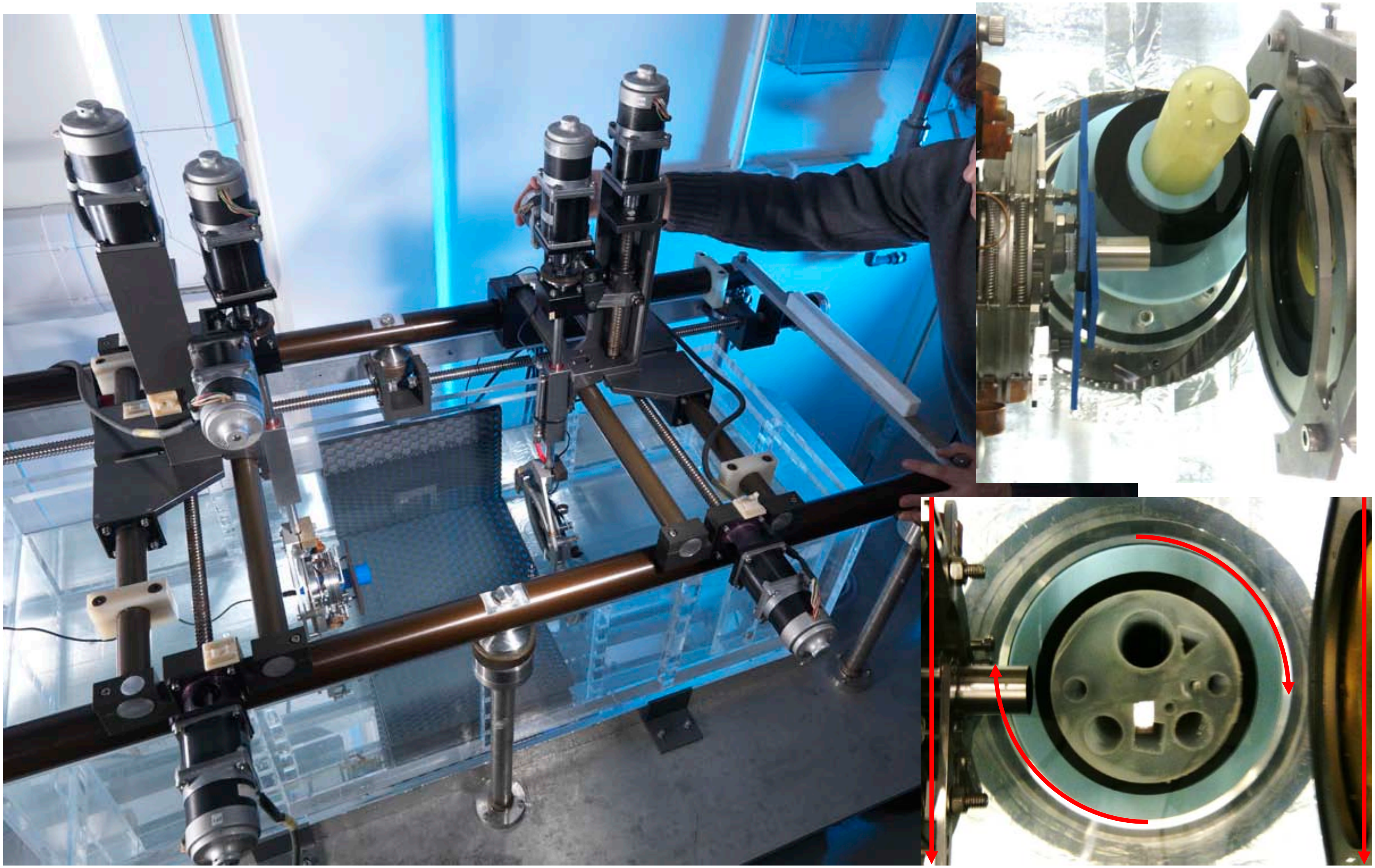
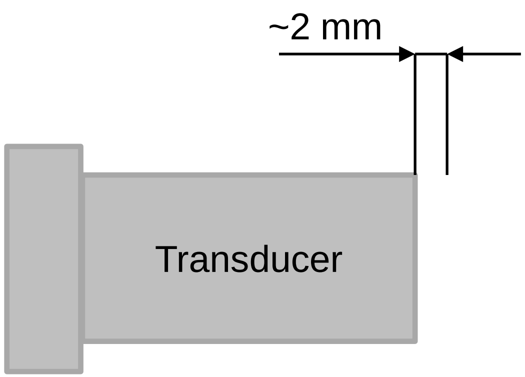
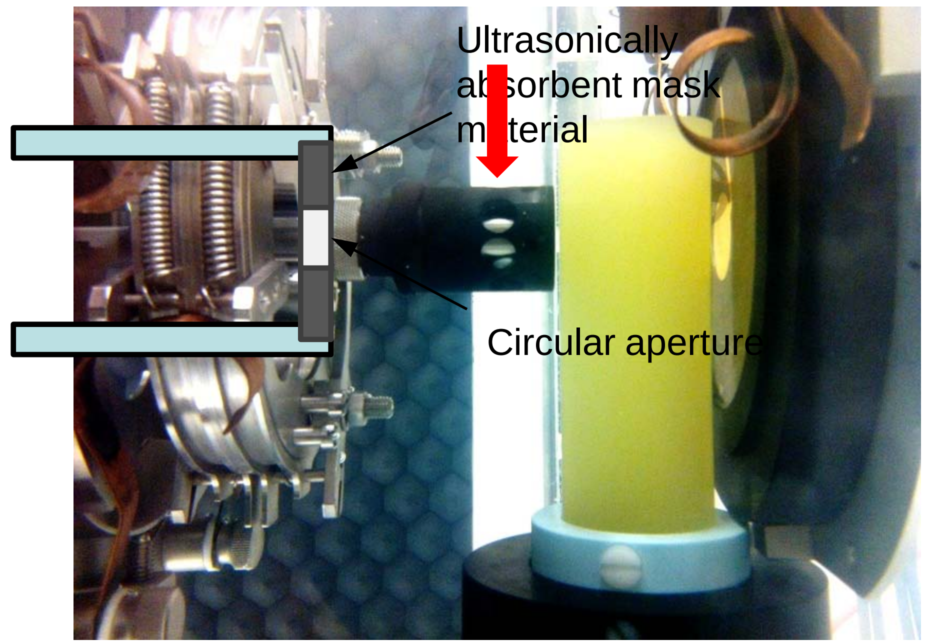


Collimating the acoustic field

Collimating mask





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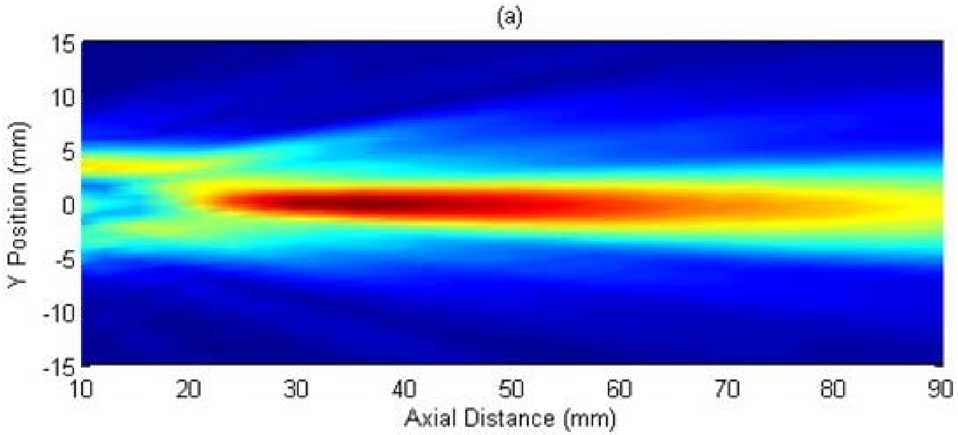
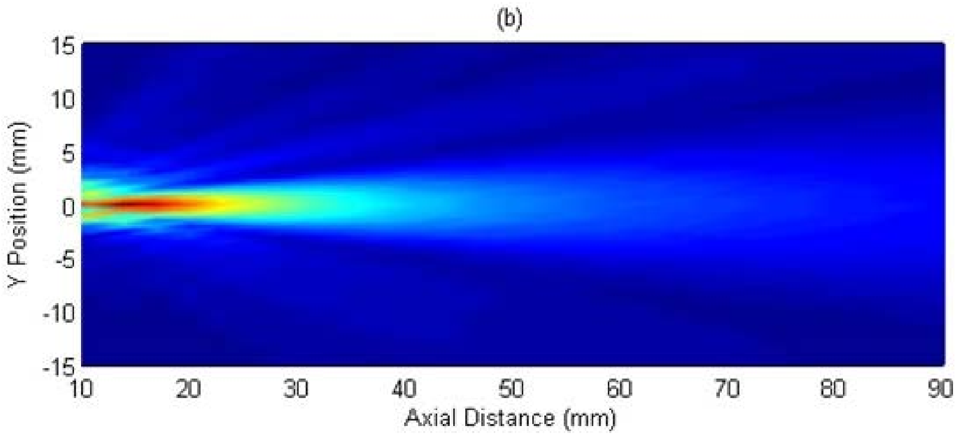
Measurement of the acoustic pressure distribution



- Transducer alone Φ = 12.7mm;
- **-6 dB Beam-width ≈ 8 mm**

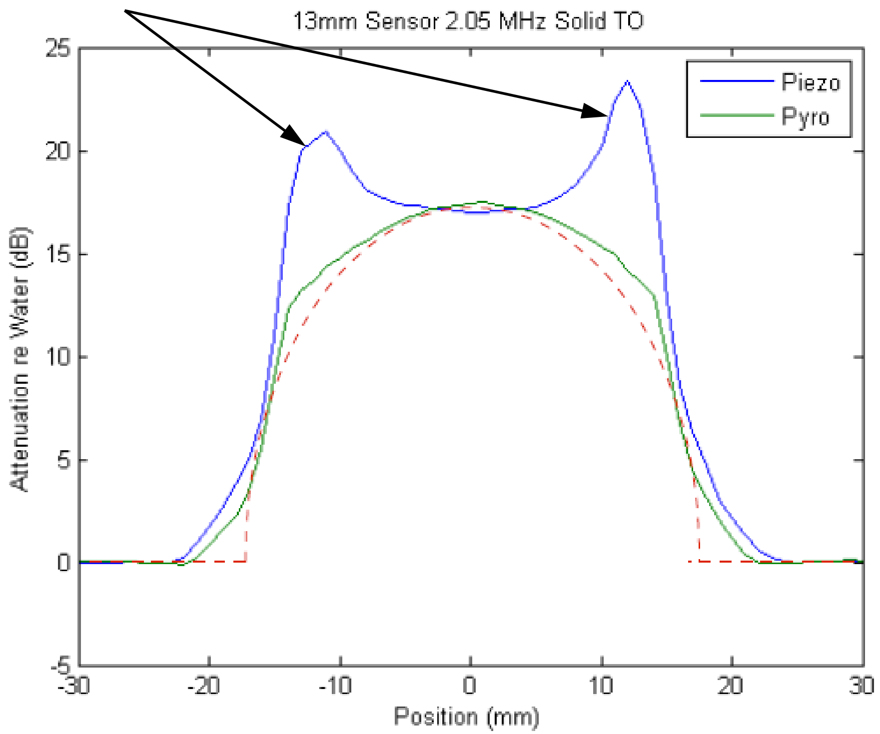


- Masked transducer - mask, Φ = 6 mm;
- **-6 dB Beam-width ≈ 3 mm**

Results: projections

PS vs PI detector responses

Phase cancellation



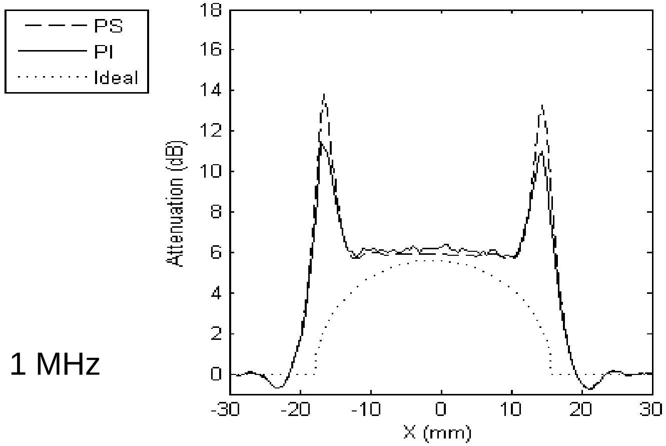
Experimentally derived projection

Homogeneous Test Object

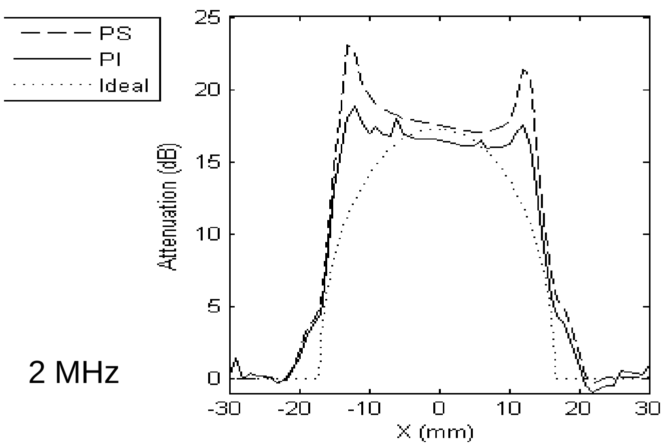
Results – homogeneous Test Object

4 mm Sensor

1 MHz



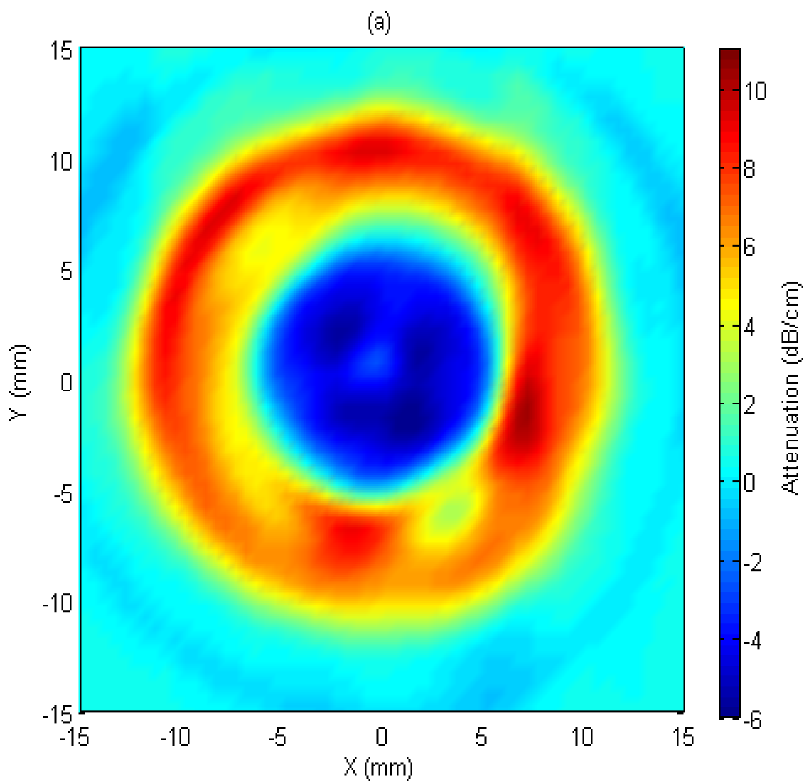
2 MHz



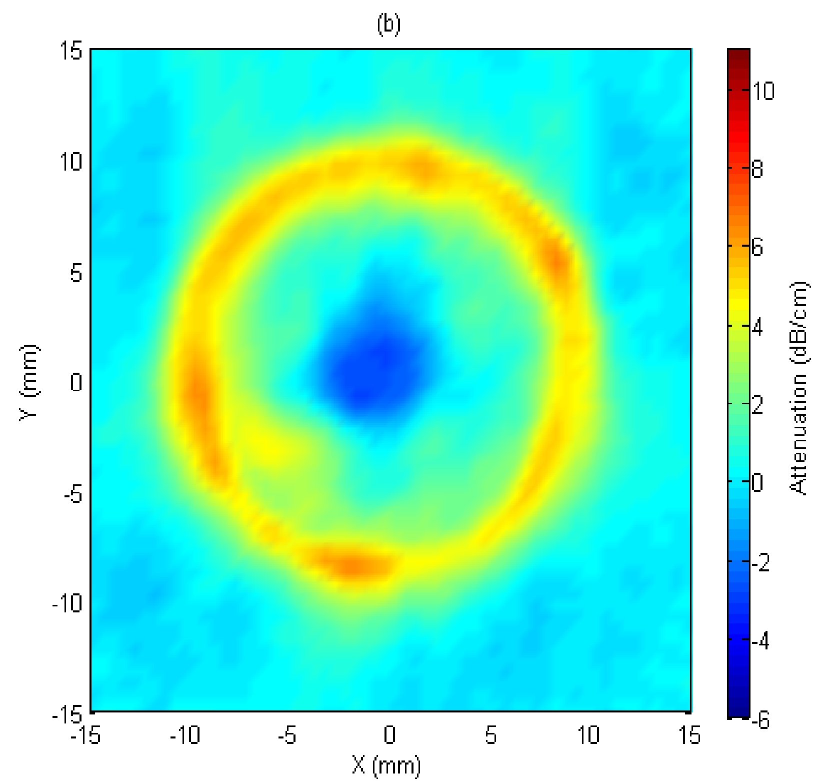
Results: UCT reconstructions

Water-filled, thin-walled tube (PETG – 0.38 mm and O/D 20.68 mm).

PS



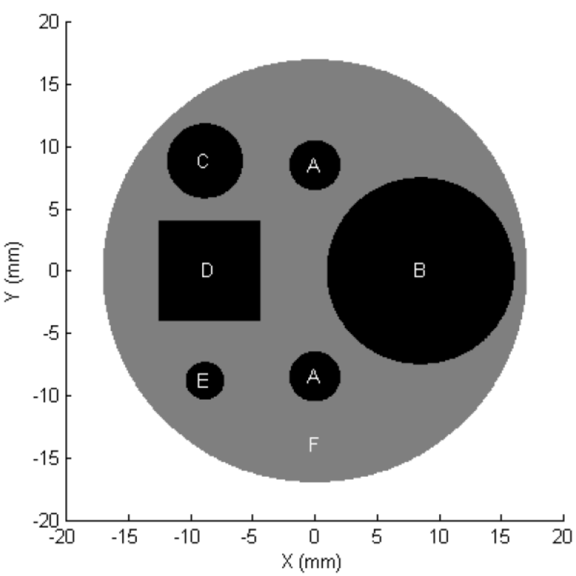
PI



Experimental conditions

- Plane-piston transducer Φ = 12.7mm, @ 2.05 MHz;
- Detector diameter: 13mm;
- Test Object – Detector: 18mm;
- Two-phase polyurethane Test Object:

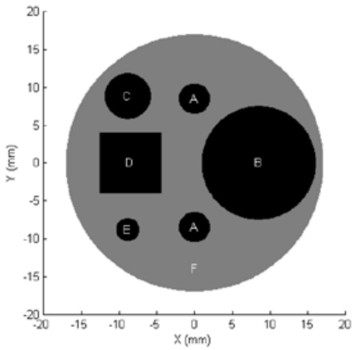
Test Object



Polyurethane properties

Material type	Component of TO	Sound speed (m/s)	Attenuation coefficient (dB/cm)
Shore A=35	Background matrix	1538*	5.1 (@ 2.05 MHz)
Shore A=55	Inserts	1567*	7.5 (@ 2.05 MHz)

* Speed of sound in water at 20 °C is 1482.4 m/s



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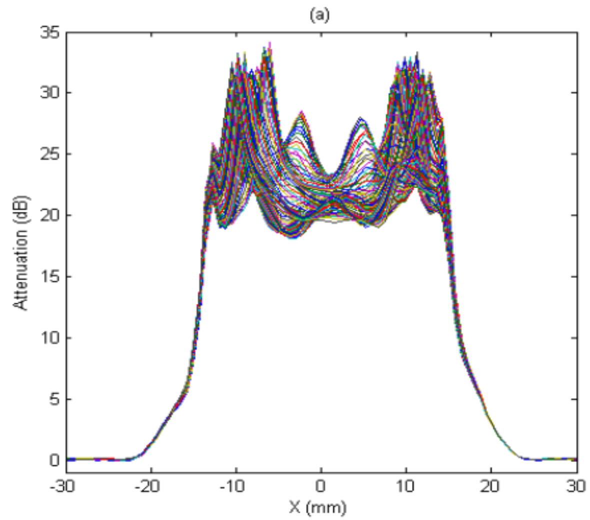
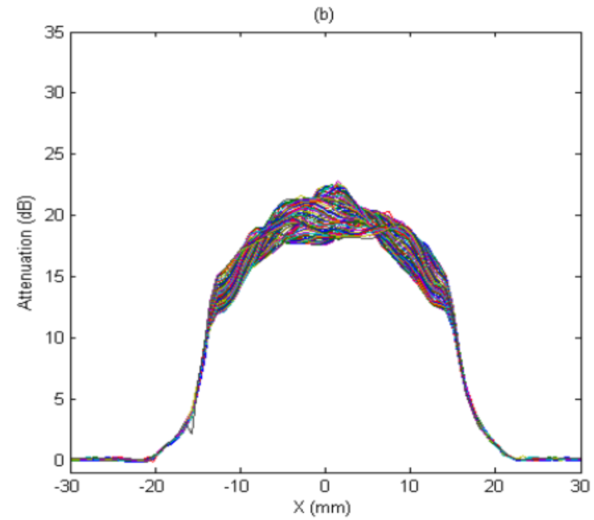
Piezoelectric - PS

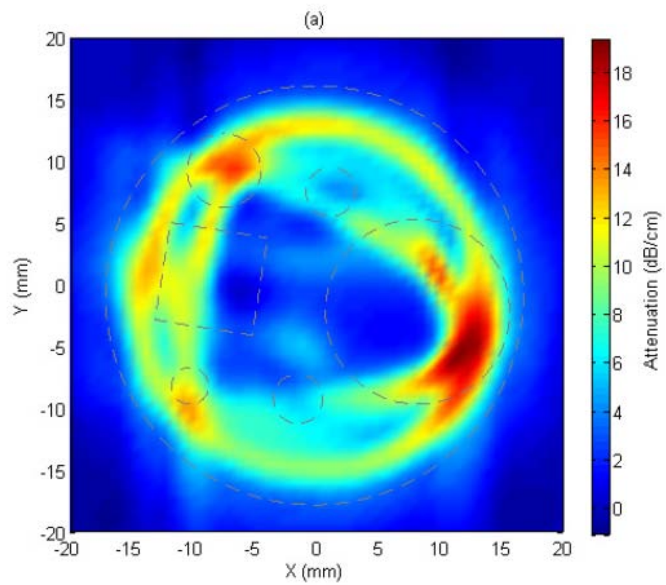
Pyroelectric - PI

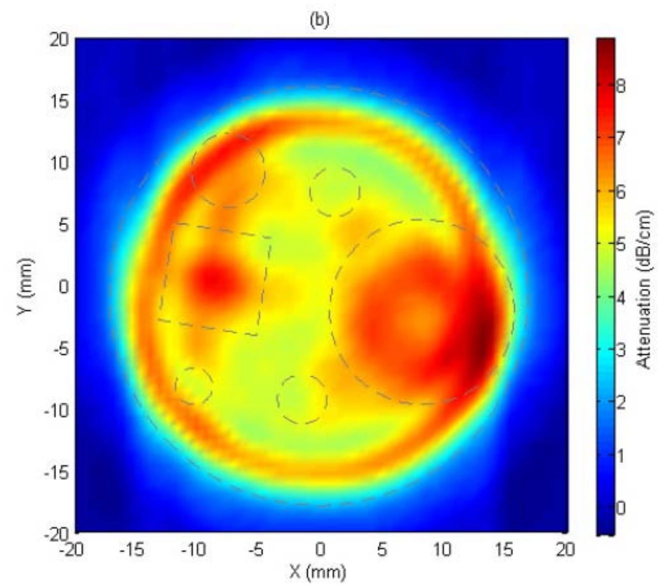
Projections

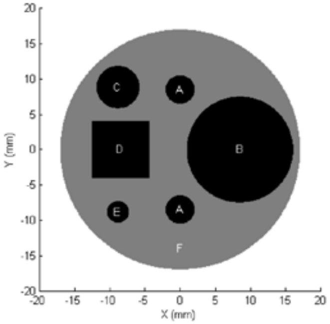




UCT Reconstructions







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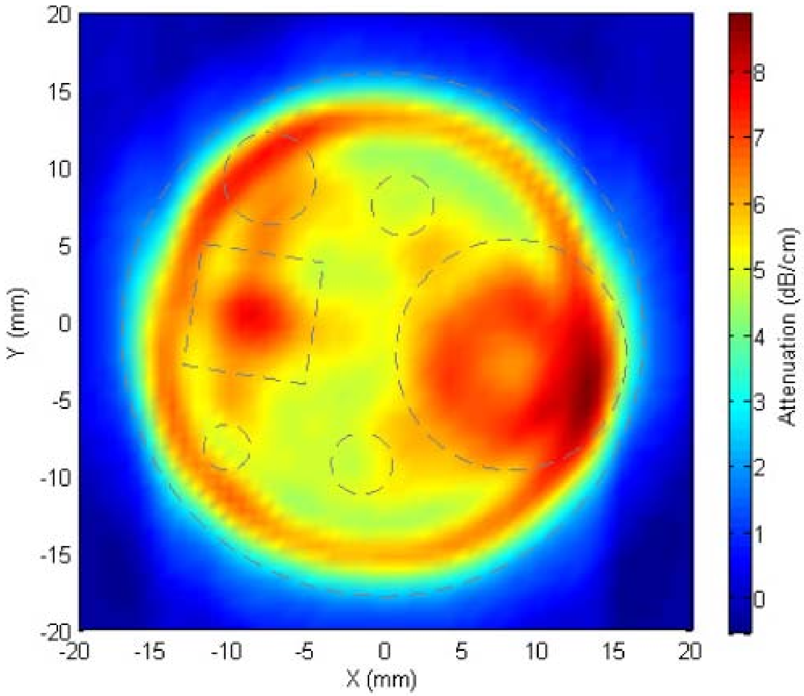
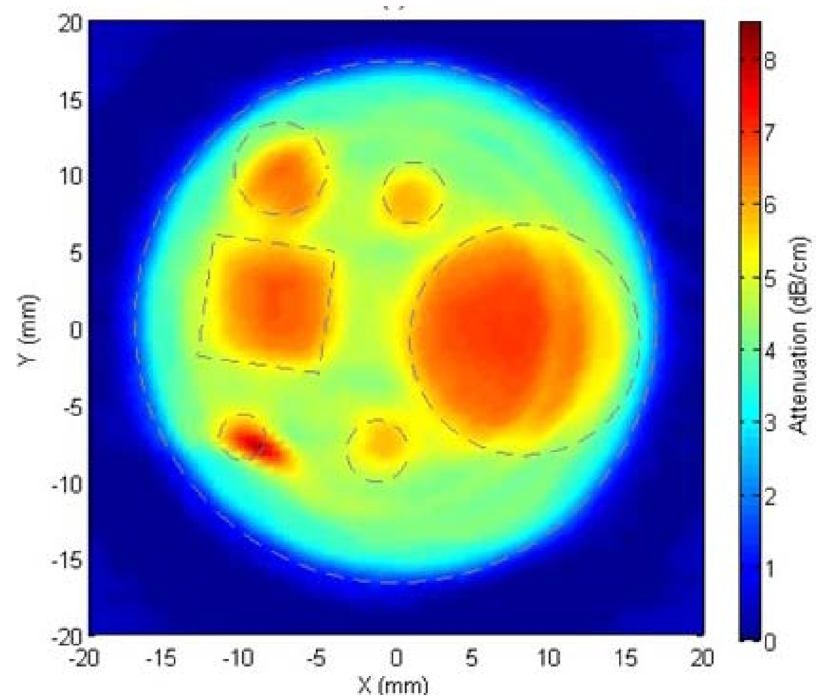
NO MASK - PI

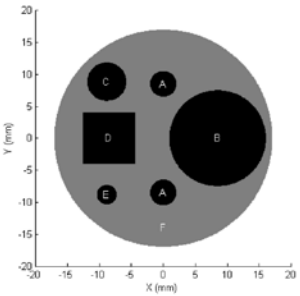


- Transducer Φ = 12.7 mm;
- Sensor Φ = 13 mm

MASK - PI



- Transducer + 6 mm Φ mask;
- Sensor Φ = 20 mm



Water-filled Test Object

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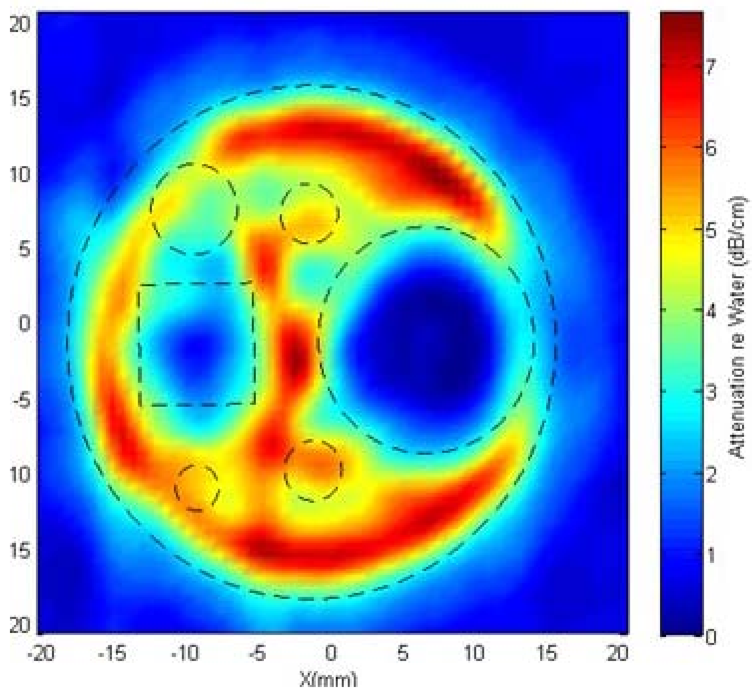
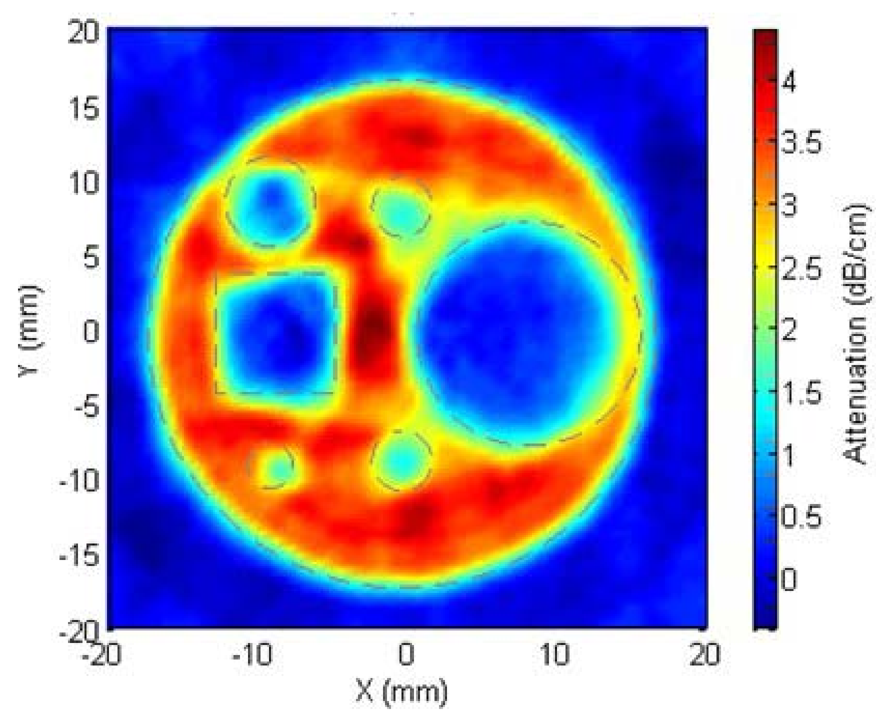
NO MASK - PI



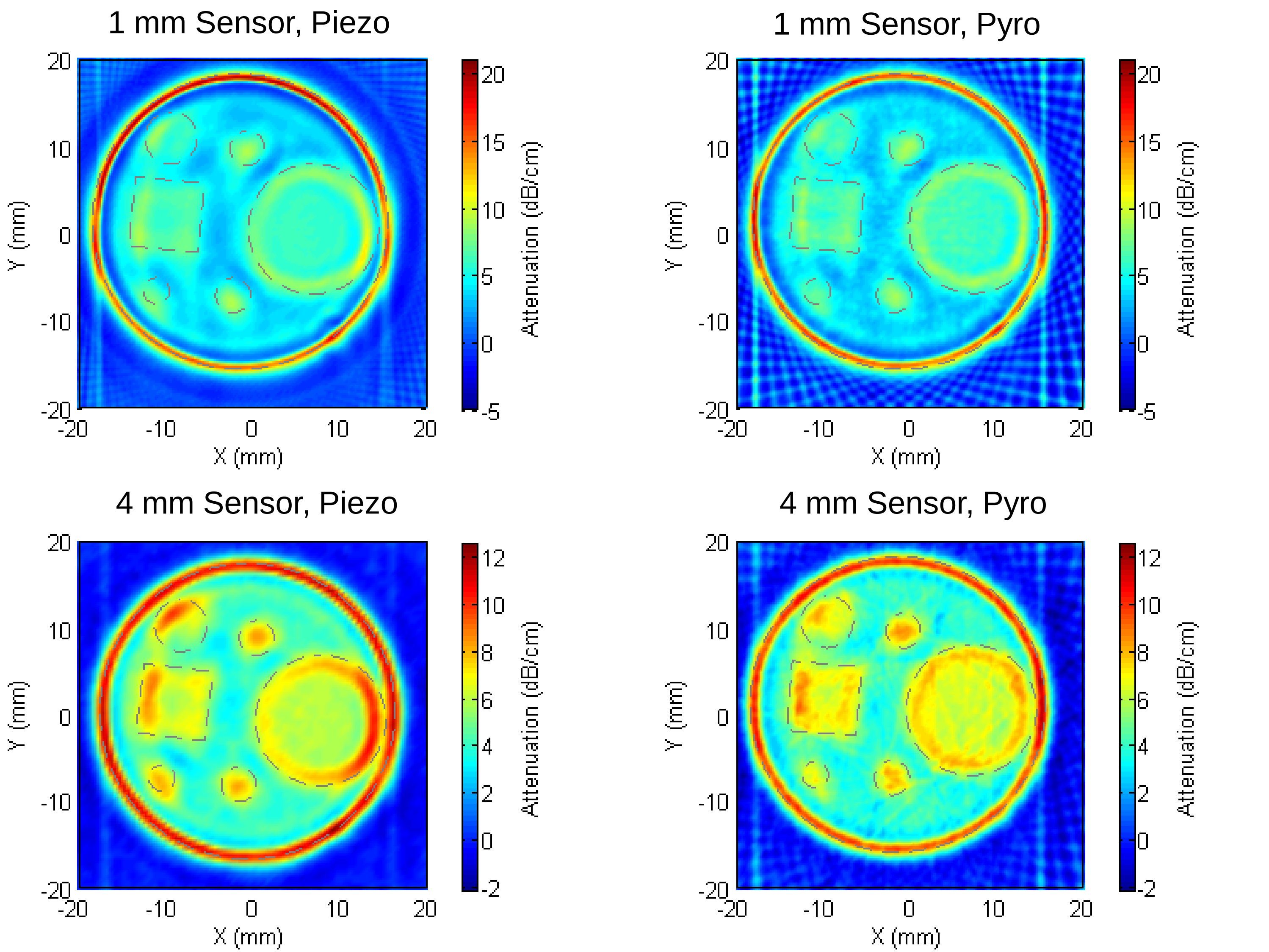
- Transducer Φ = 12.7 mm;
- Detector Φ = 13 mm

MASK - PI



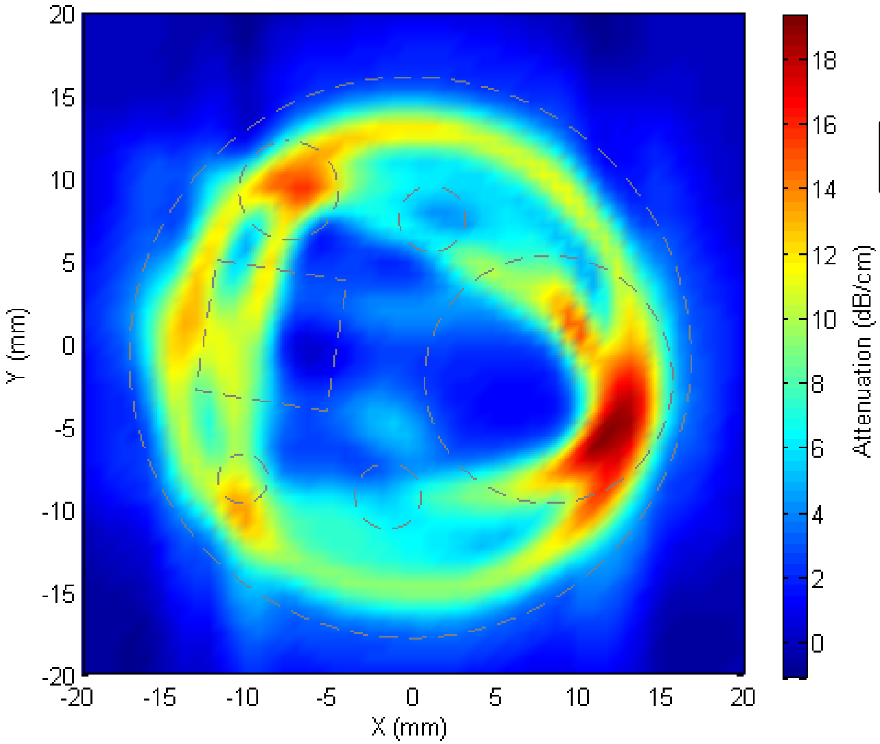
- Transducer + Mask, 6 mm Φ;
- Detector Φ = 20 mm

Small area detectors: masked transducer

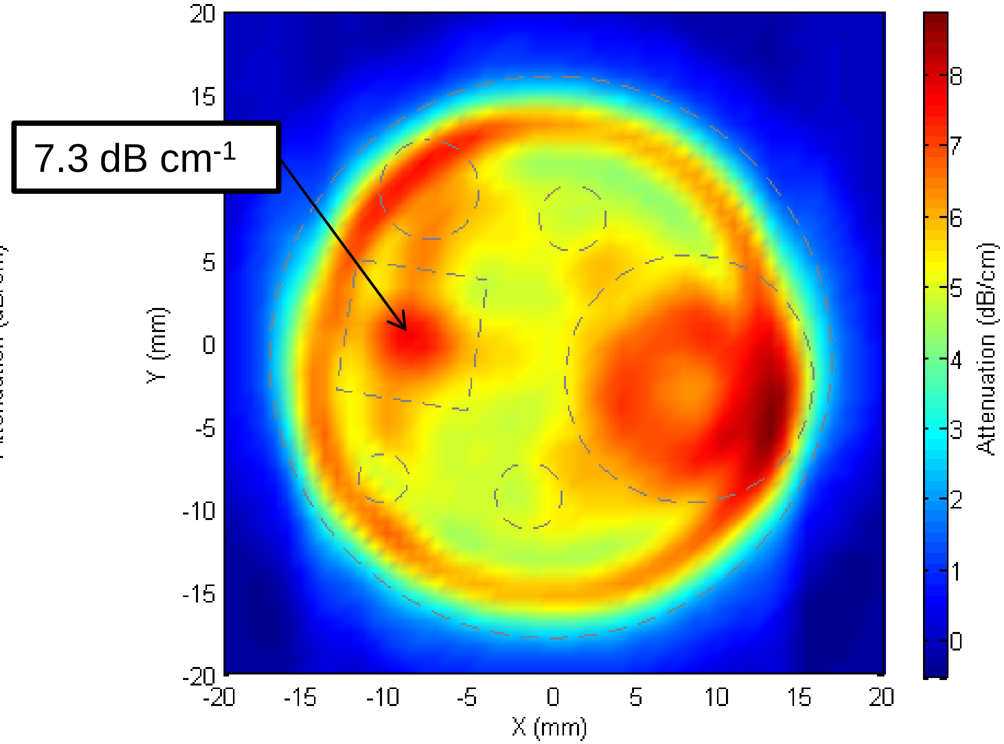


Quantitative analysis

Piezo (PS)



Pyro (PI)

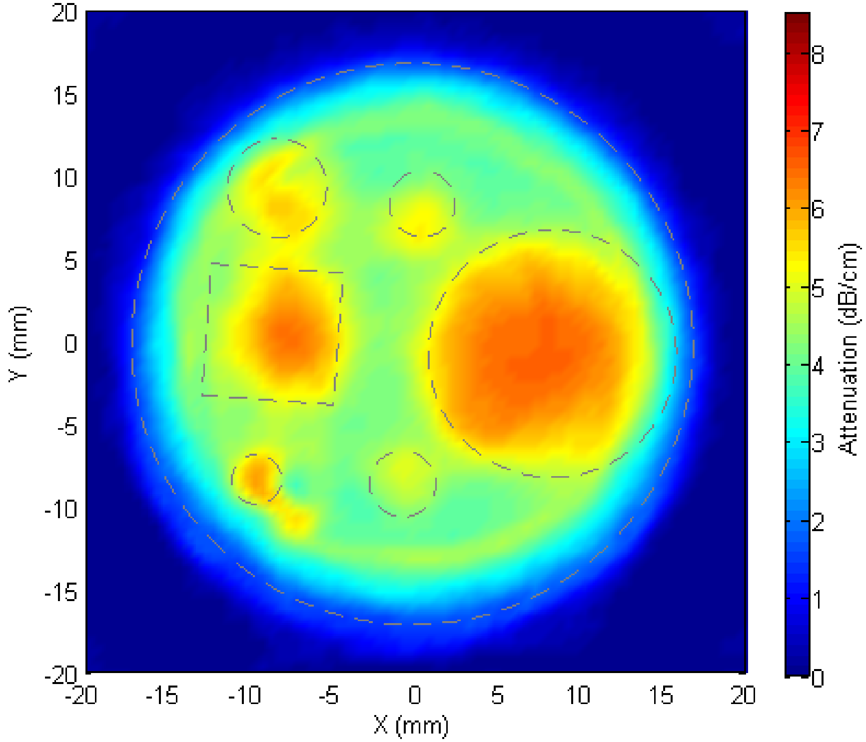


2.05 MHz 12.7 mm transducer
13 mm sensor

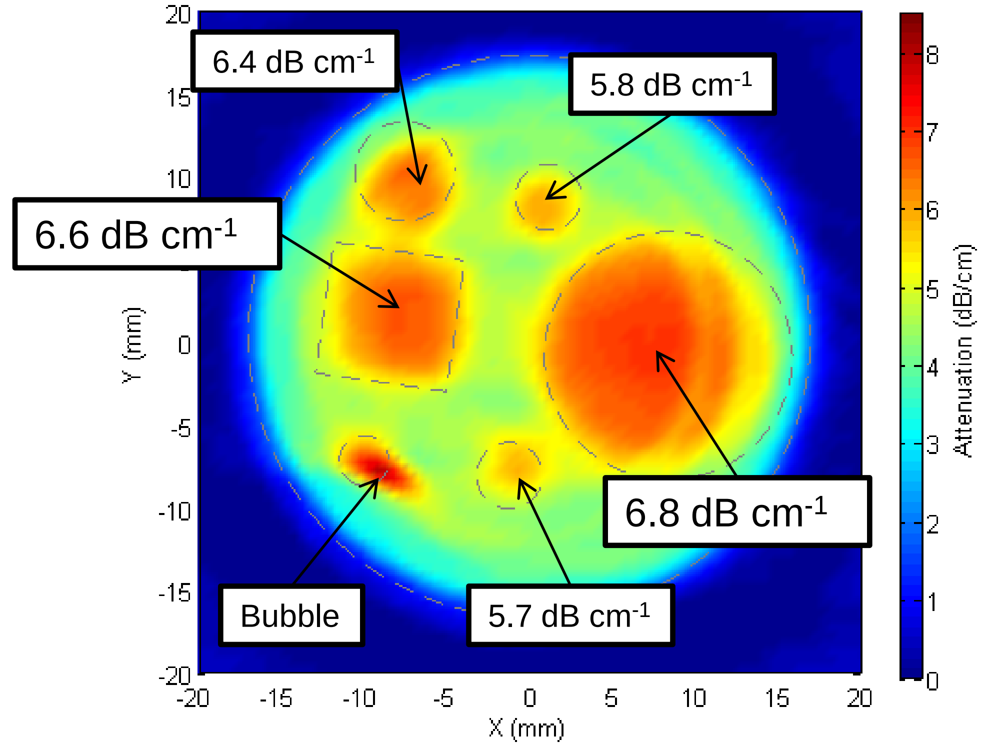
Rest of inserts: between 5.8 and 6.6 dB cm^{-1}
Actual attenuation = 7.5 dB cm^{-1}

Masked transducer

8 mm Mask, Pyro



6 mm Mask, Pyro

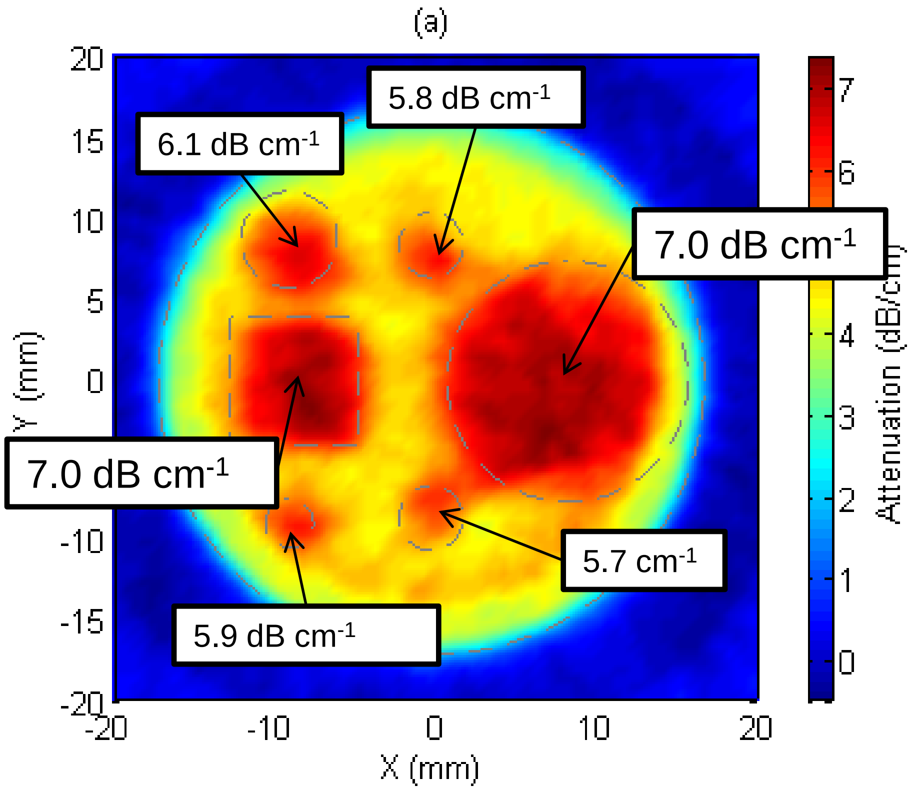


2.03 MHz 12.7 mm transducer
20 mm detector

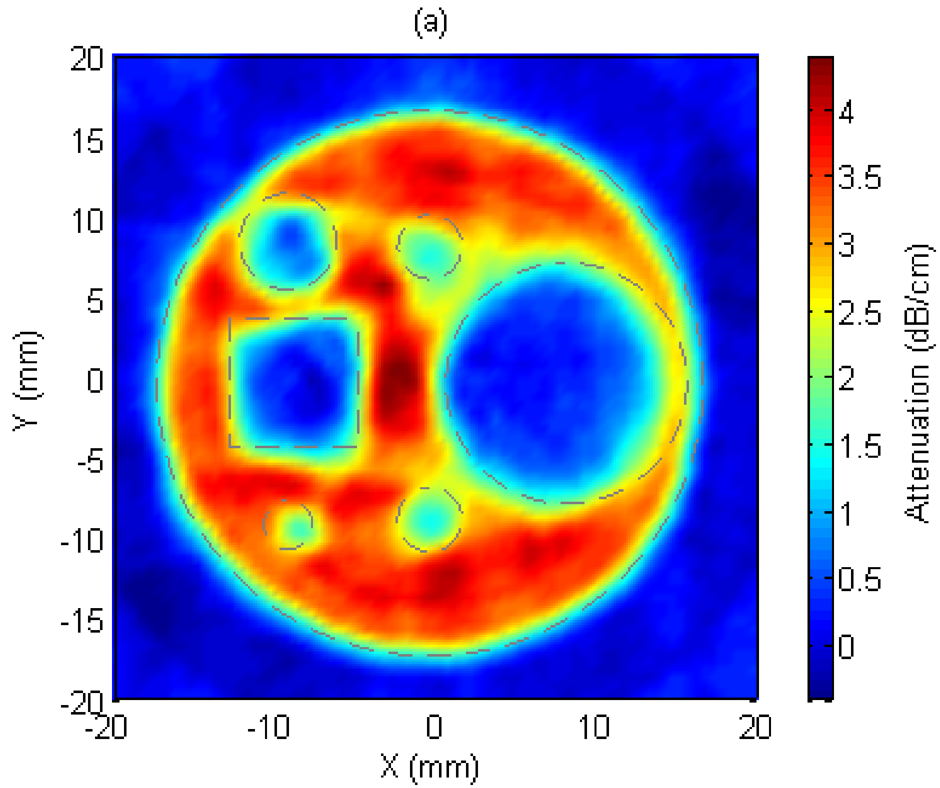
Actual attenuation = 7.5 dB cm^{-1}

6 mm mask, 20 mm sensor

Two-phase Test Object



Water-filled



Actual attenuation = 7.5 dB cm^{-1}

Summary

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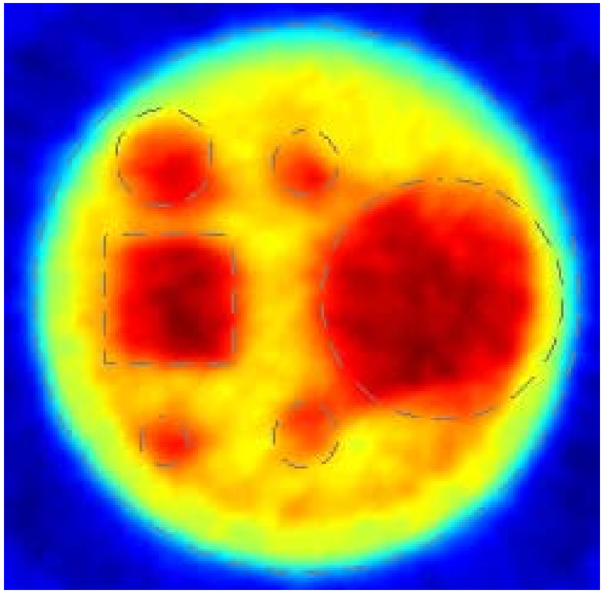
- Phase-insensitive (PI) sensors exploiting the pyroelectric effect have been used to reduce UCT artefacts;
- Artefacts arise due to refraction and phase-cancellation;
- PI sensor response is weakly dependent on direction;
- The need for large area PI receivers has been confirmed, the required spatial resolution being produced through the applied acoustic field;
- The PI sensors are non-optimized - changes in sensor design will be needed to boost sensitivity and to improve sensor response time;
- The research has been submitted for publication within **Phys. Med. Biol.,** "*Quantitative ultrasonic computed tomography using phase-insensitive pyroelectric detectors*".

Summary



bajram.zeqiri@npl.co.uk

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