The flexural ultrasonic transducer

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Presented by Steve Dixon, Department of Physics, University of Warwick

CIU
Centre for Industrial Ultrasonics

ULTRASOUND GROUP
DEPARTMENT OF PHYSICS

The CIU overview

www.ciu.ac.uk

PHYSICS

Steve Dixon   Rachel Edwards

EMATs & EMAT arrays
Ultrasonic transducers (piezo)
Air coupled ultrasound– esp. flexural
Ultrasonic flow measurement
Eddy current (high frequency)
Robotic NDT
Laser ultrasound
Electromagnetic / magnetic
Thermography
Resonance testing (no-contact & contact)
Liquid crystal ultrasonic sensors

SCHOOL OF ENGINEERING

Dave Hutchins   Duncan Billson

Metamaterials / biomedical
Acoustics
Air coupled esp. micro-machined
Thermosonics
Near Infra-red
Capacitive sensors for NDE

CIU
Centre for Industrial
Ultrasonics

EPSRC
Engineering and Physical Sciences
Research Council

RCNDE
UK Research Centre in NDE

Flexural Ultrasonic Transducers
(and operation at "high" frequencies)

How did the work start at Warwick ?

https://warwick.ac.uk/fac/sci/physics/research/ultra/research/hiffut/

or google " Warwick + HiFFUT"

Flexural ultrasonic transducers

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hermetically sealed
(in a metal case)

open structure

Acknowledgements

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EPSRC
Engineering and Physical Sciences
Research Council

elster
Honeywell

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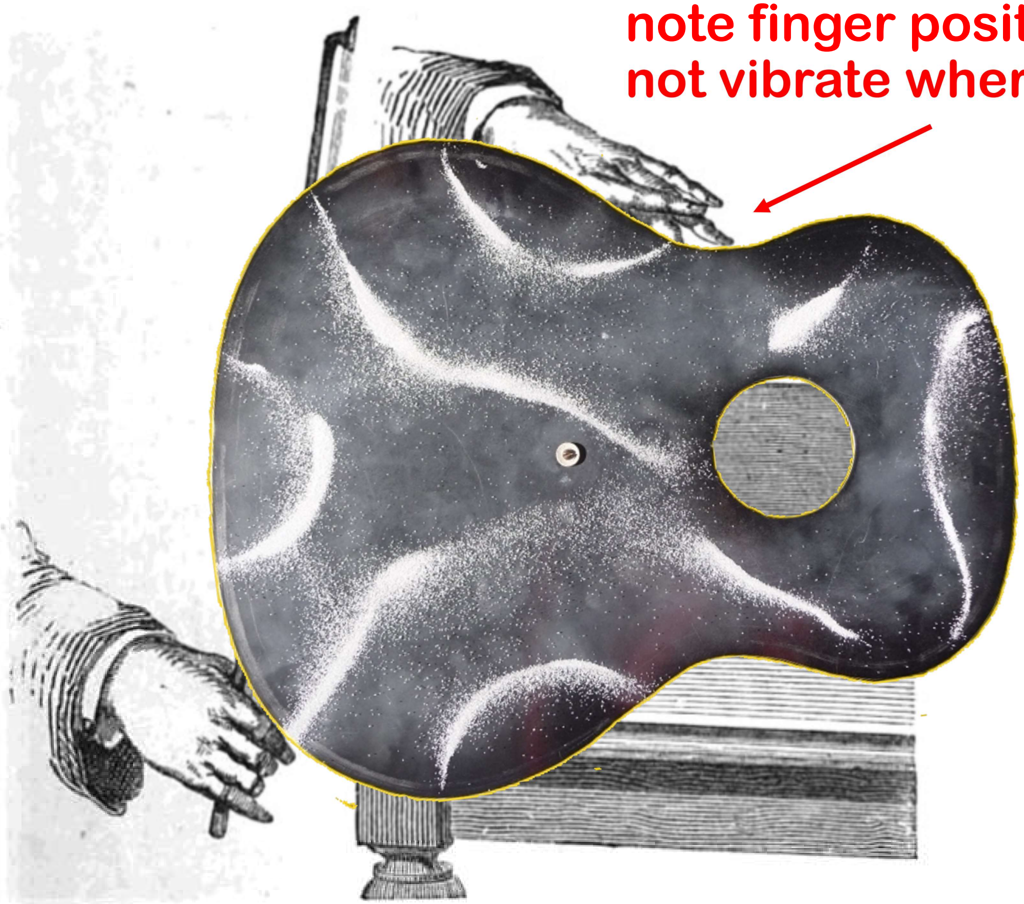
note finger position – plate will not vibrate where it is touched.



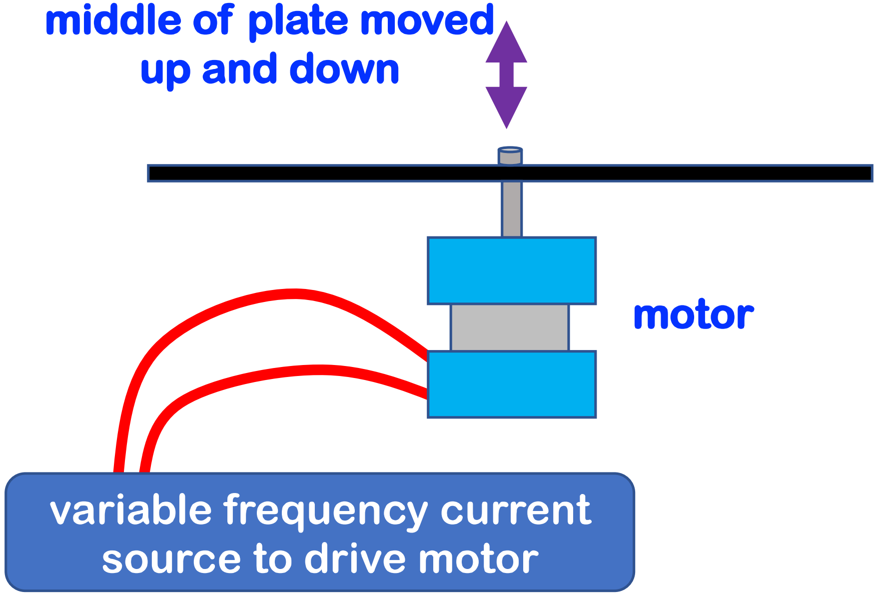
The Chladni plate

Ernst Chladni
1756-1827

The Chladni plate

aluminium plate
(painted black)

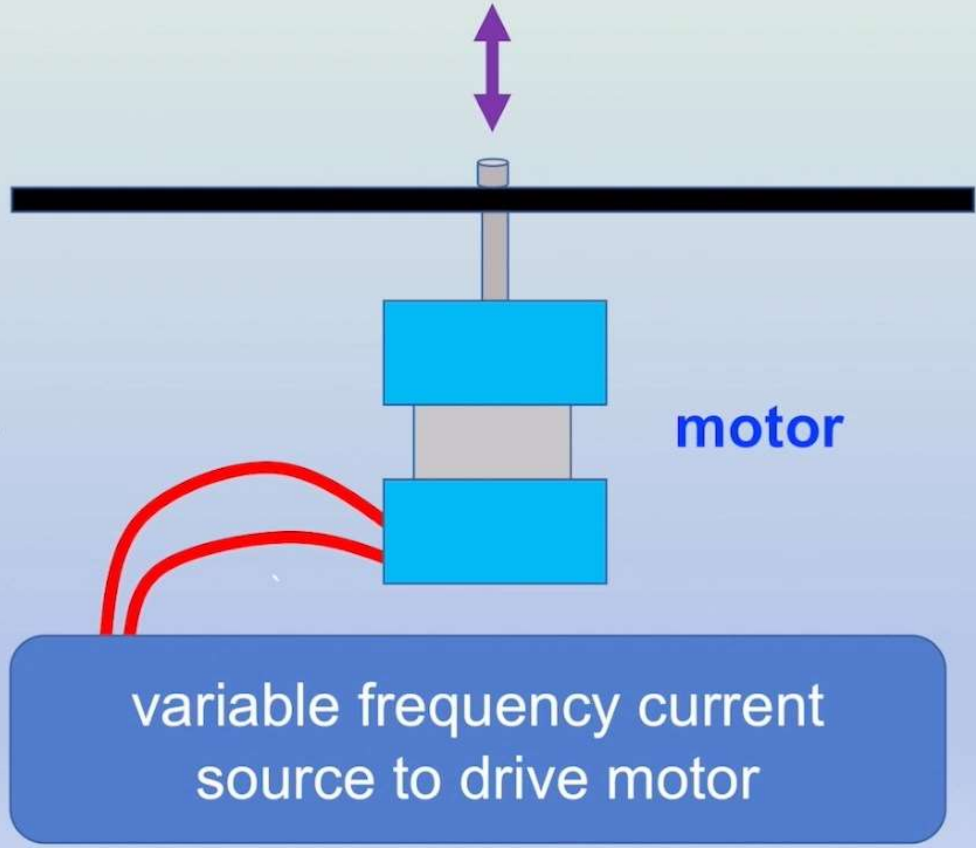
covered in table salt



middle of plate moved up and down

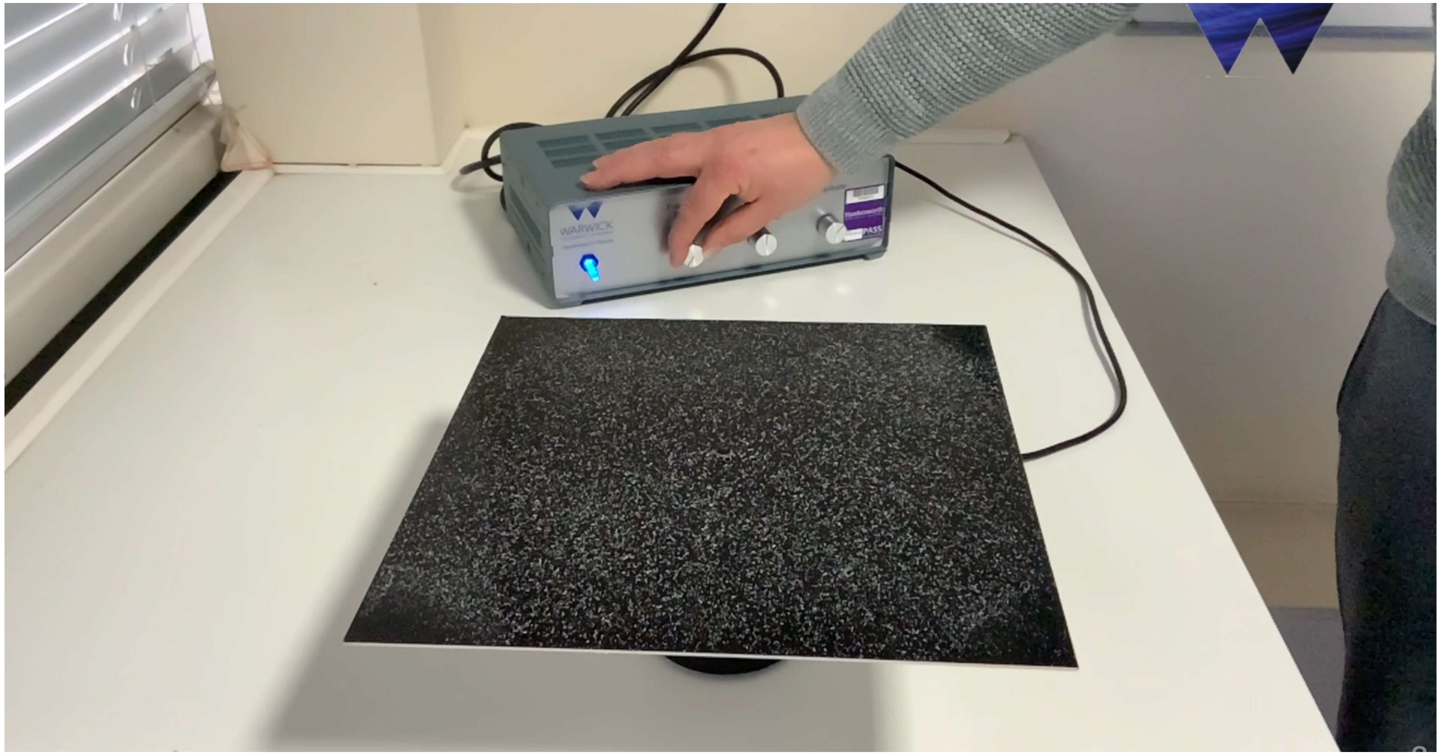
aluminium plate (painted black)

covered in table salt

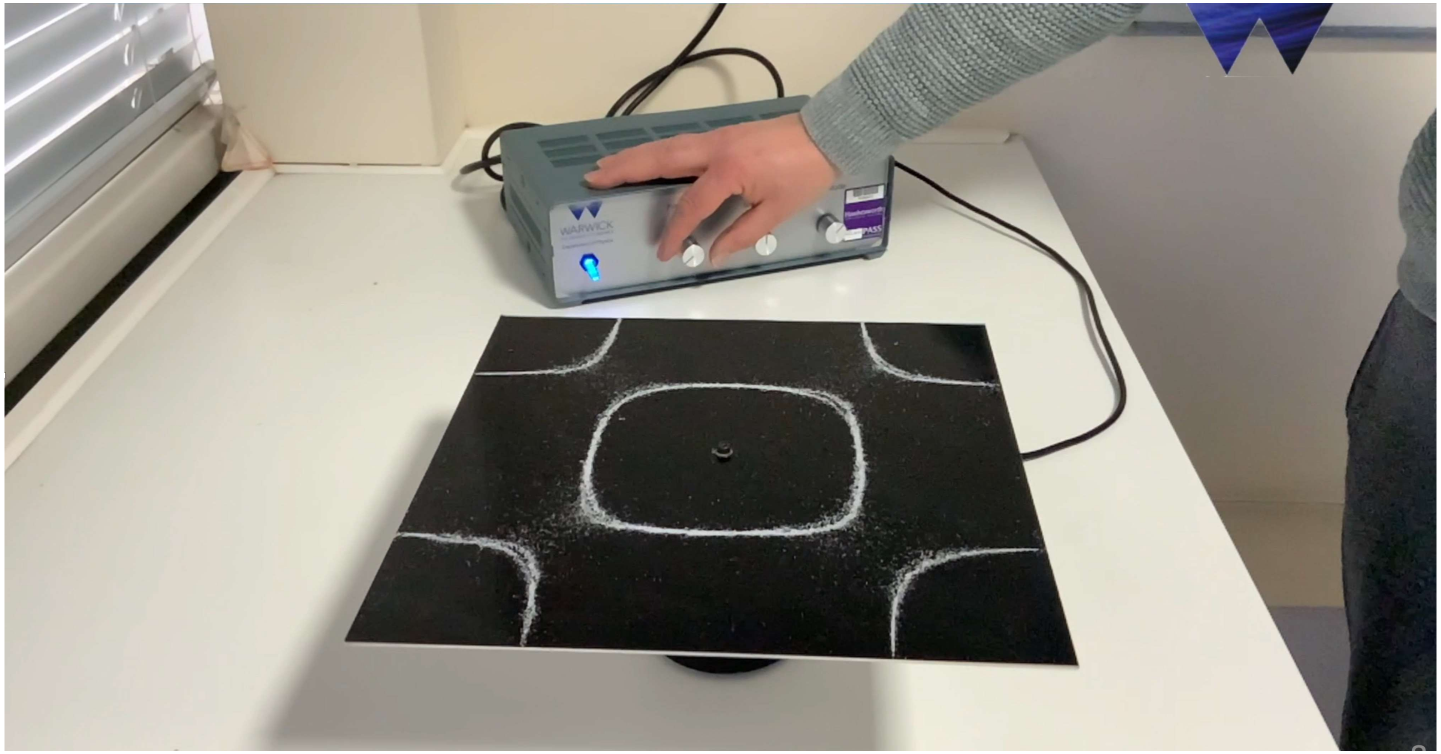


The Chladni plate

- Salt sprinkled on the plate and then the frequency is swept, causing the plate to have large vibrations when it hits a resonance.



The Chladni plate



The Chladni plate

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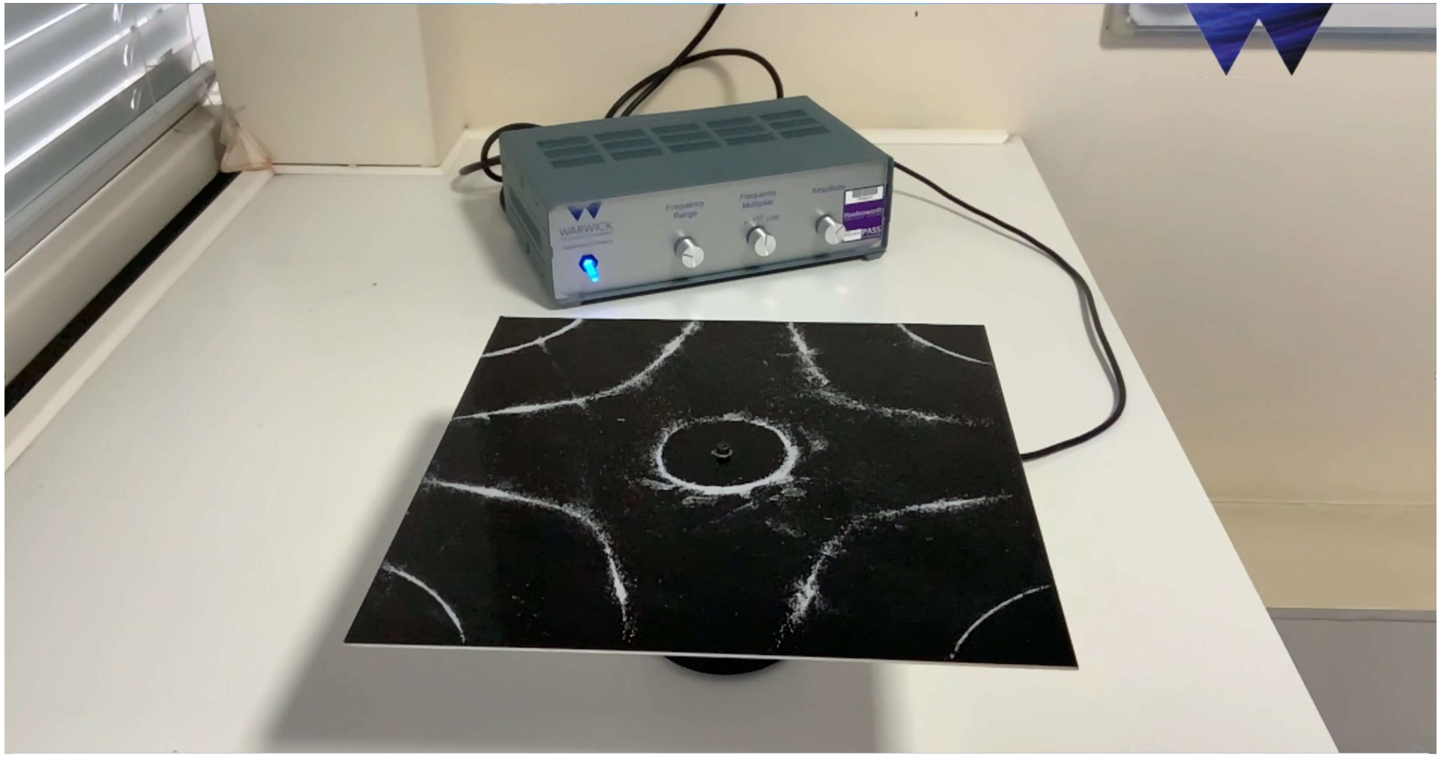

Flexural ultrasonic transducers

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hermetically sealed
(in a metal case)

open structure

Piezoelectrically Actuated Metal Cap

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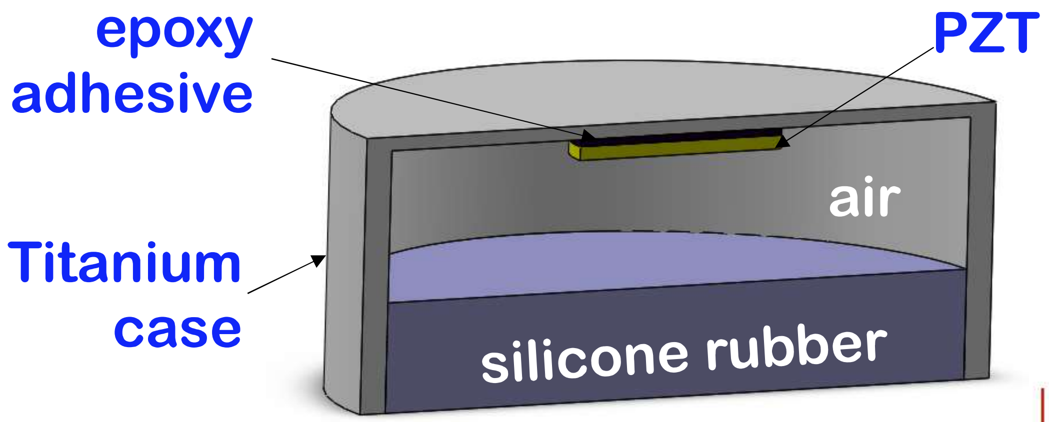
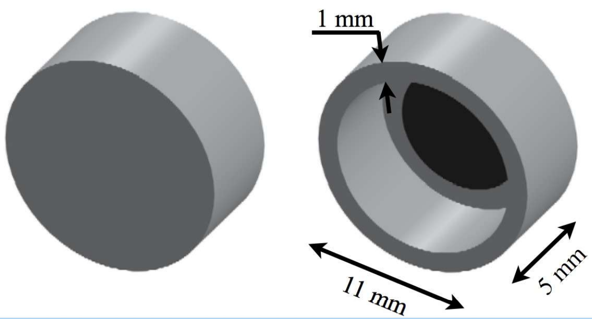
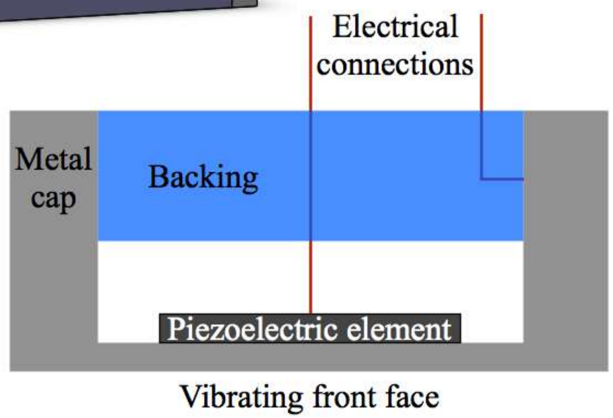
- Piezoceramic disk inside cap bonded to front plate – usually PZT.
- Cap provides inherent protection.

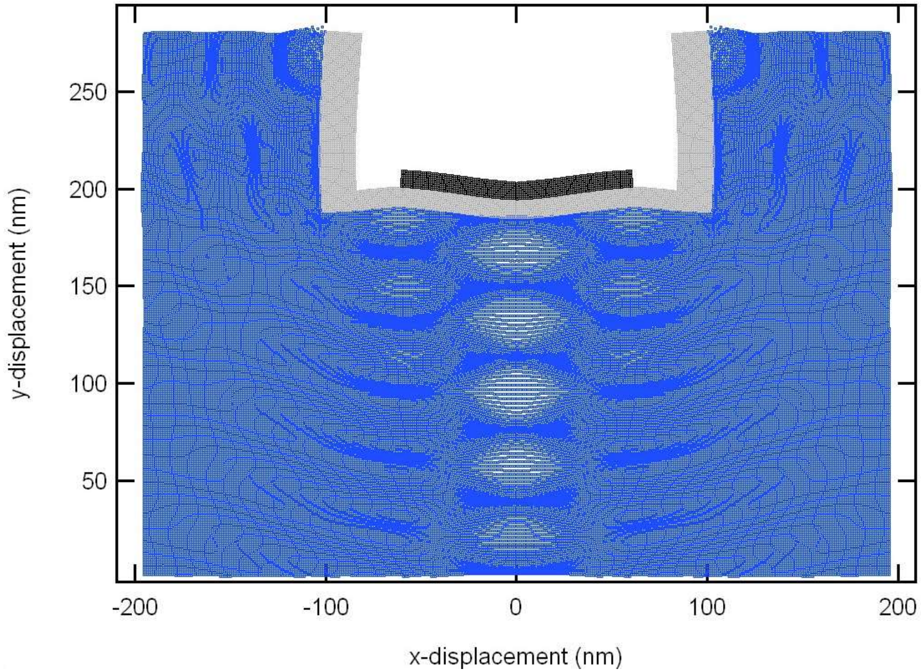






Finite Element Model (FEM)

- FEM used to predict transducer behaviour.
- Effective for fine tuning output, and optimising the design.



Flexural ultrasonic transducers

painted black to
help with contrast

40 kHz
transducer

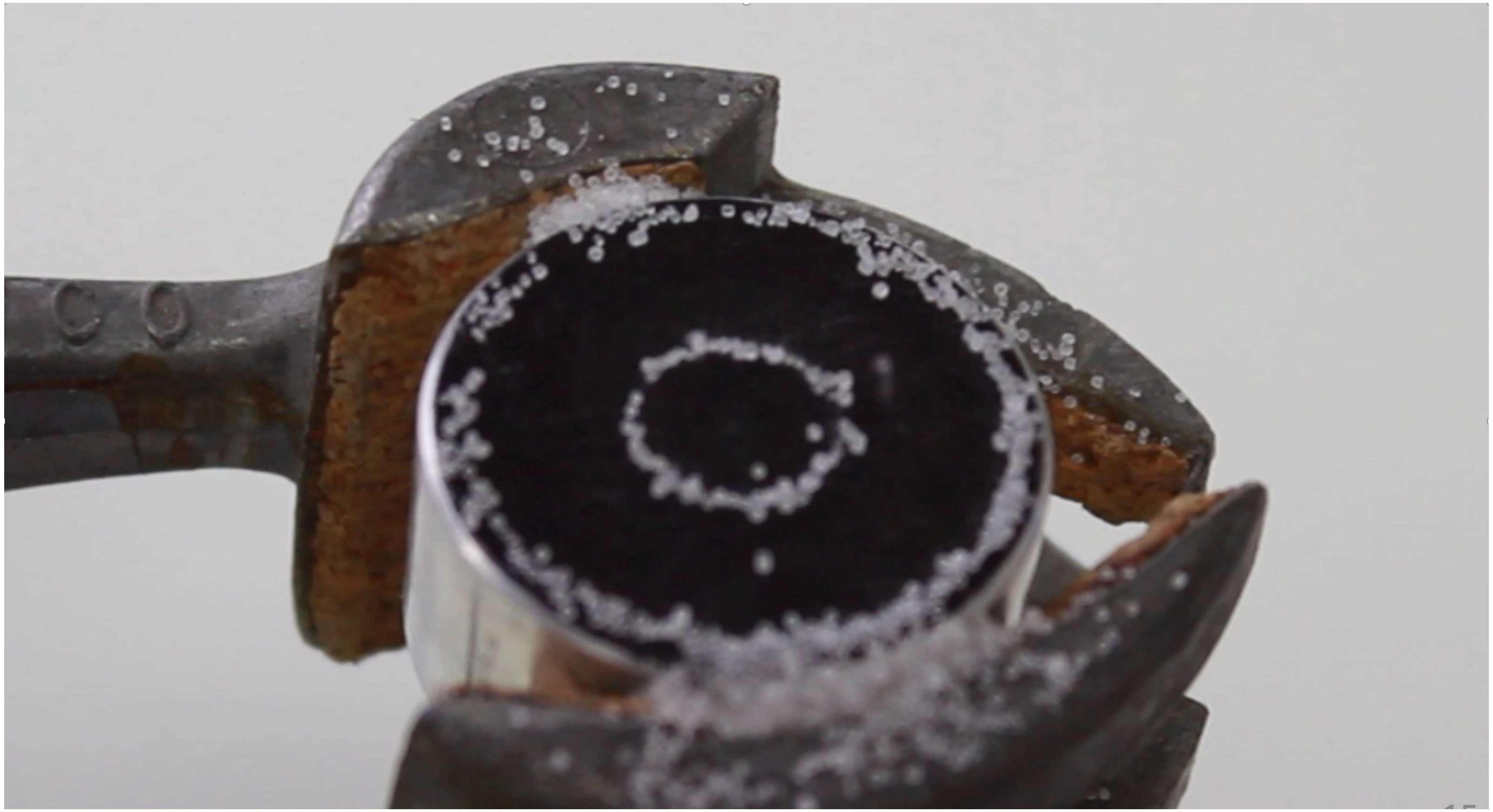
Flexural ultrasonic transducers

Sprinkle salt over the face of the transducer when it's not vibrating – then turn it on.

It should act like a "mini' Chladni plate.

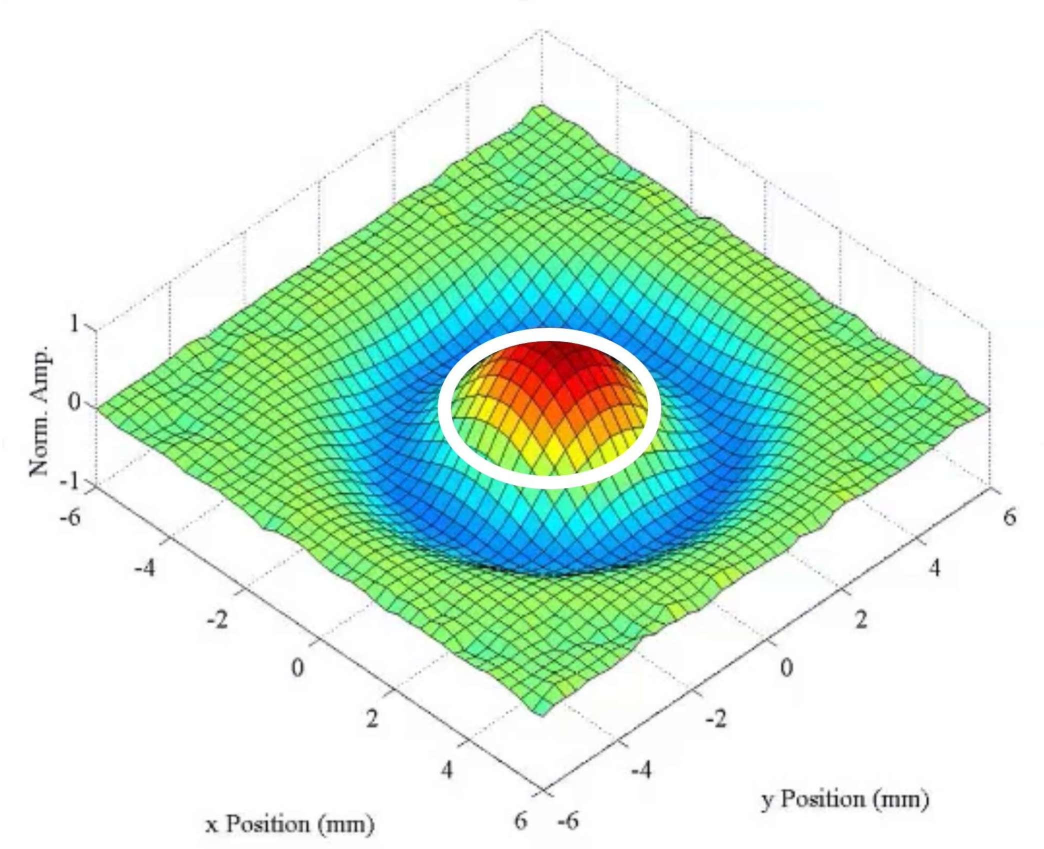
Flexural ultrasonic transducers

mode (1,0) is excitied in this case – it has a ring where of salt where the transducer is no vibrating.

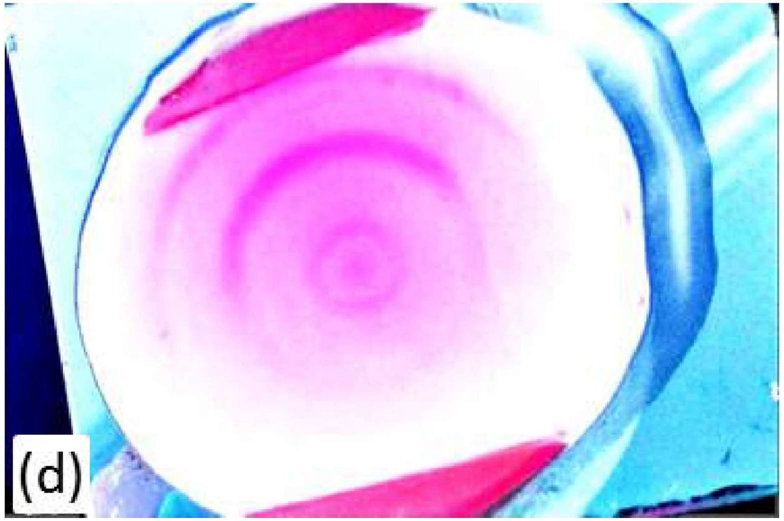


The flexural modes of vibration

This is that same mode (1,0) measured using a laser vibrometer.



Using liquid crystal layers to sense ultrasound

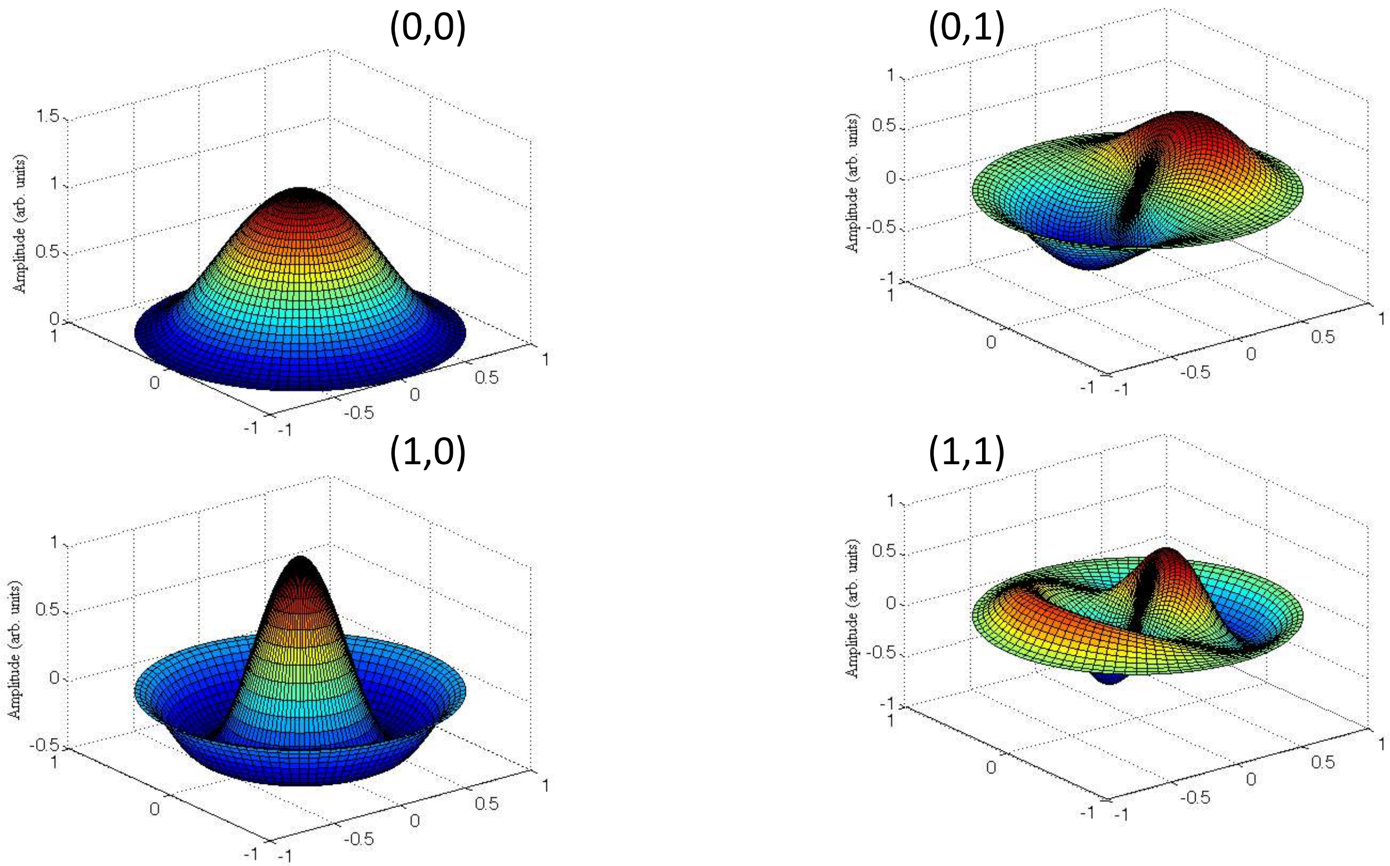


mode 11:0 - 690 kHz

Trushkevych, Oksana et al (2015). Applied Physics Letters, 107 (5). 054102

Theory of Vibrations in Plates

- Theory gives mode shape, for a frequencies for a plate.
- This gives a good starting point for transducer design.



Estimation of mode frequency

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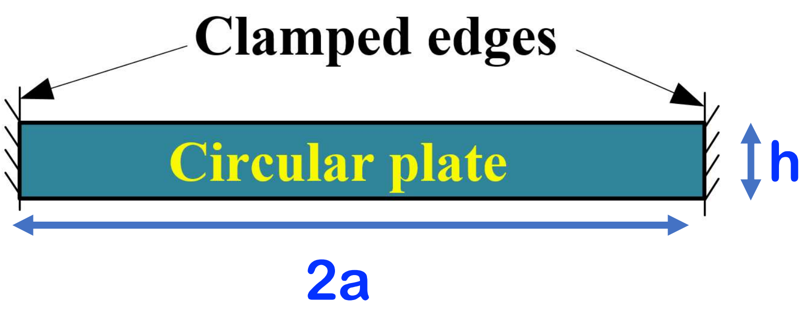


$$\frac{Eh^3}{12(1-\nu^2)} \times \nabla^4 w + \rho \frac{\partial^2 w}{\partial t^2} = 0$$ governing equation

$$f_{m,n} = \frac{\lambda_{m,n}^2}{2\pi a^2}\sqrt{\frac{Eh^3}{12(1-\nu^2)\rho}}$$ mode frequency

$$W_{m,n}(r,\theta) = \left[A_n I_n\left(\frac{\lambda_{m,n} r}{a}\right) + B_n J_n\left(\frac{\lambda_{m,n} r}{a}\right)\right]\cos(n\theta)$$ displacement

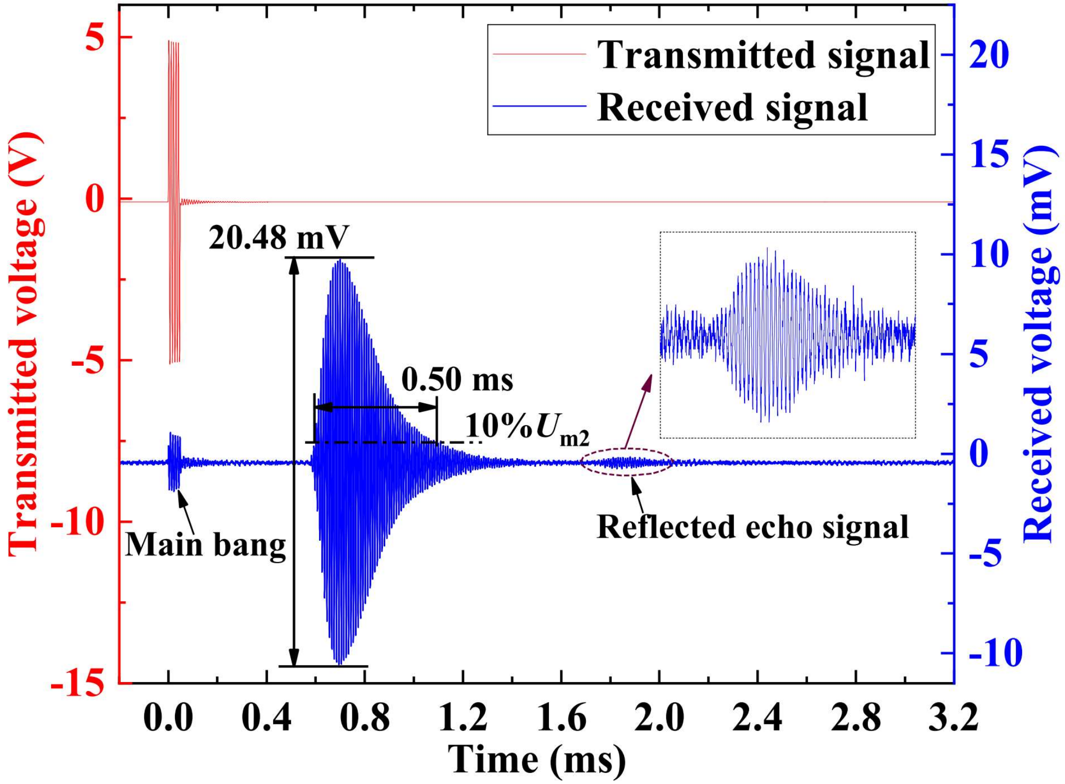
A.W. Leissa, Vibration of Plates (U.S. Government Press, Washington, 1969), pp. 1–8.

High frequency flexural modes

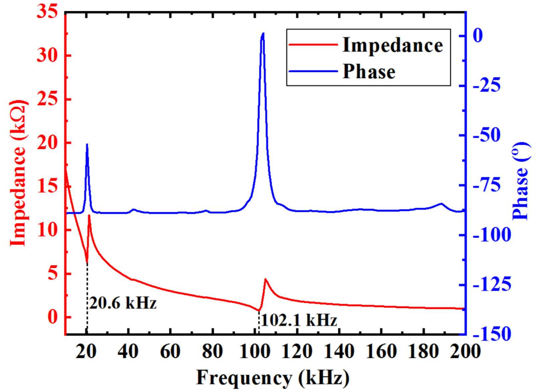
"At frequencies above 70 kHz, conventional bending oscillators cannot deliver practical characteristics."

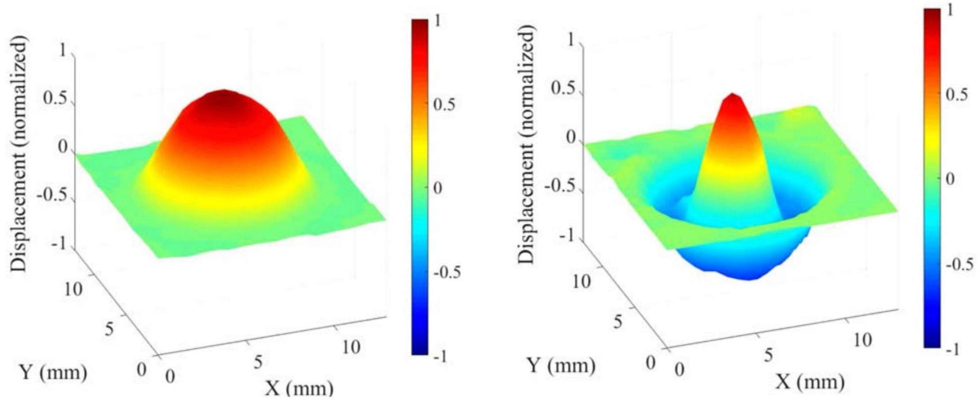
Murata.com

High frequency flexural modes



102 kHz SNR > 20dB

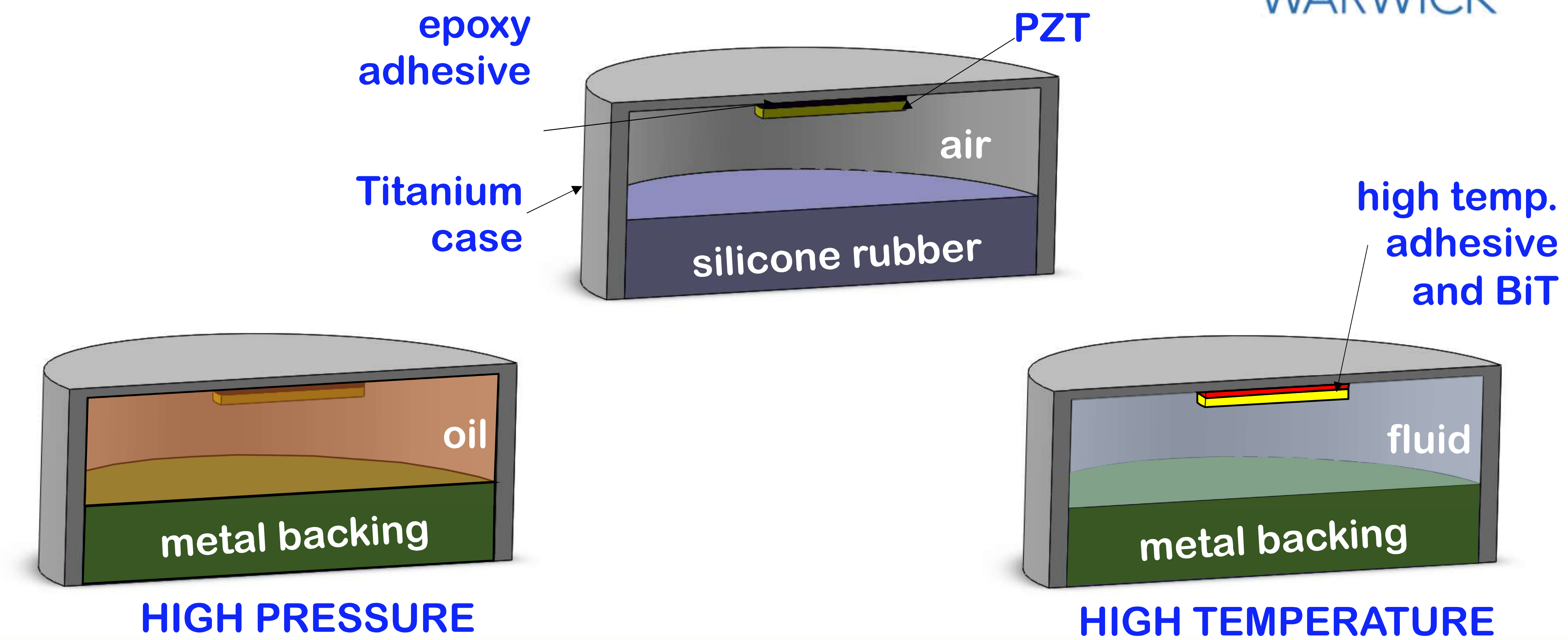




20 kHz (0,0) mode

102 kHz (1,0) mode

Hostile environments



Hostile environments – elevated pressure

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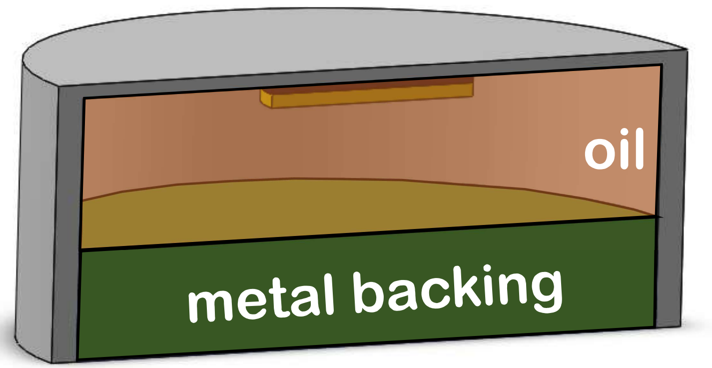
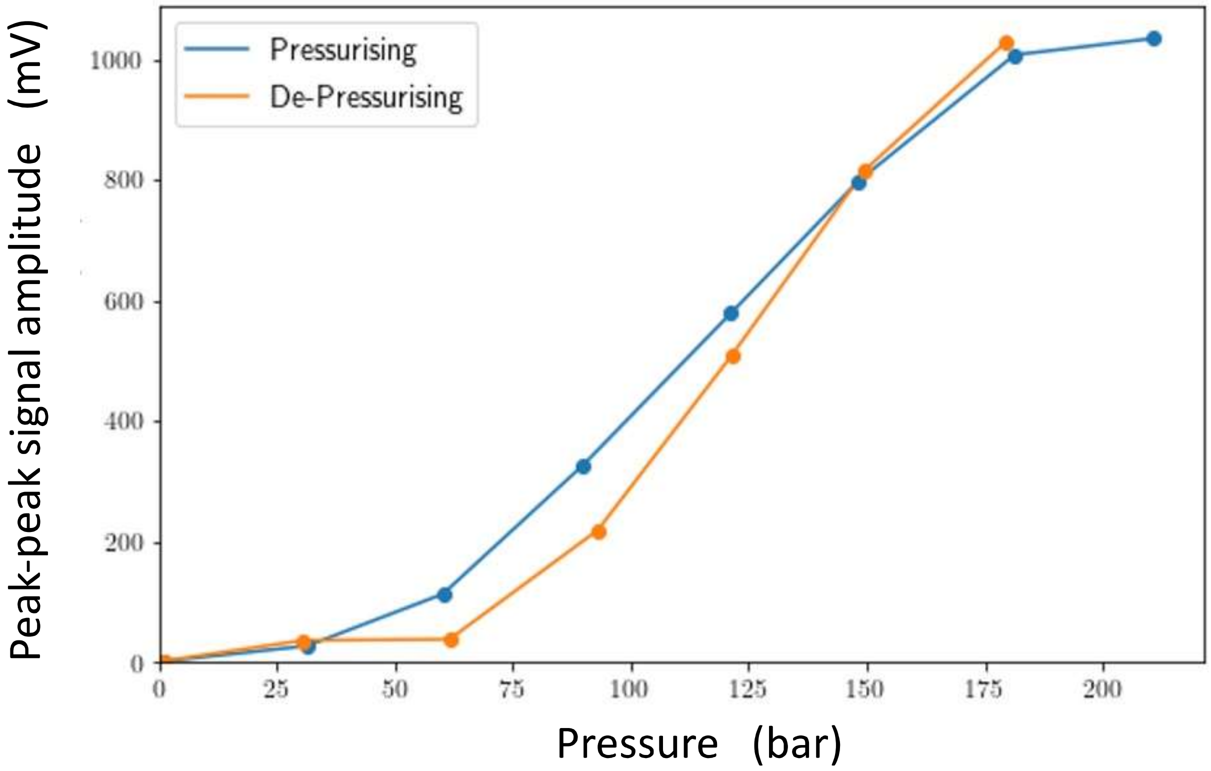
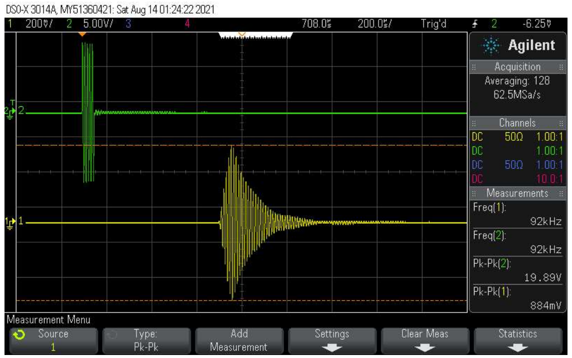


HIGH PRESSURE

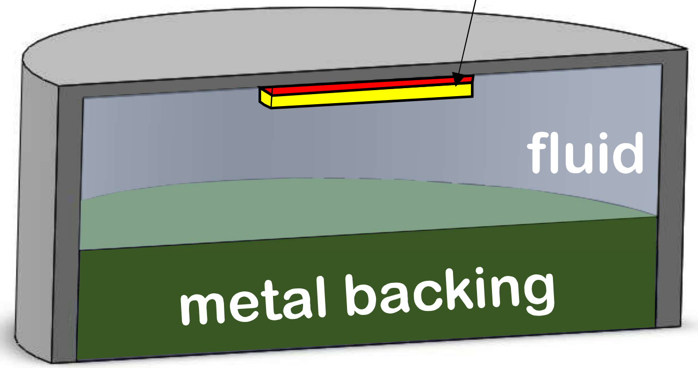


Hostile environments – elevated temperature

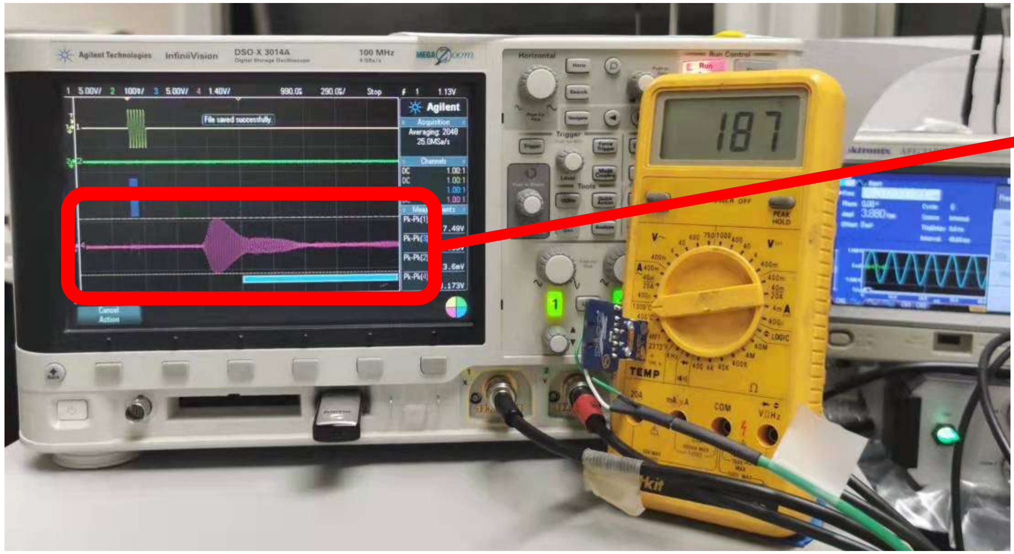


102 kHz @ room temp

high temp. adhesive and high T_C PZT

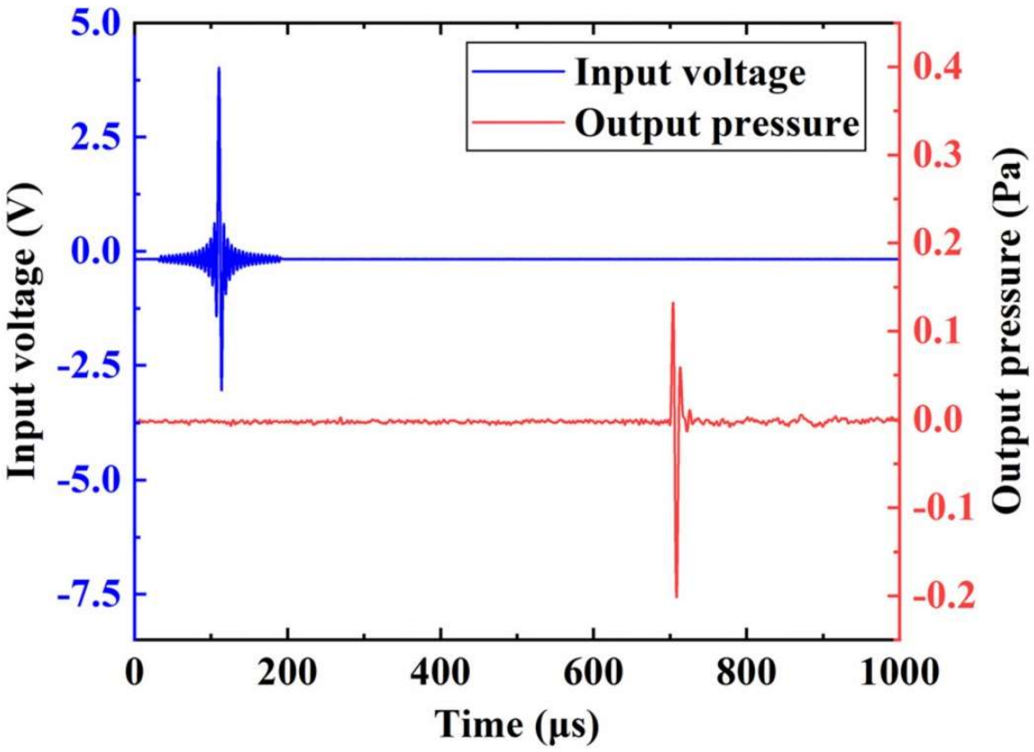


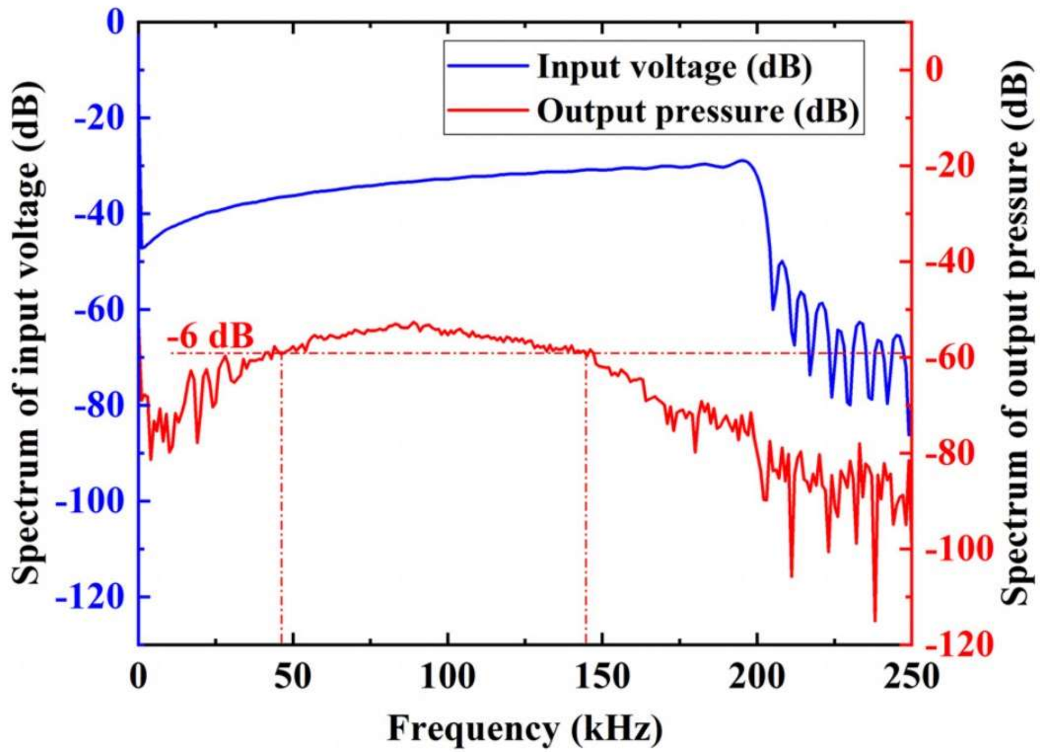
HIGH TEMPERATURE



@ 187 °C

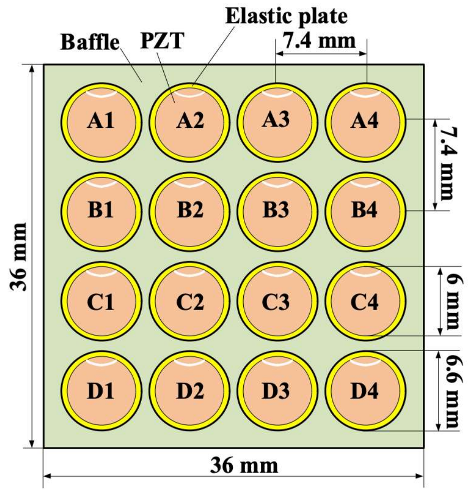
Wide bandwidth & Lorentz force driven

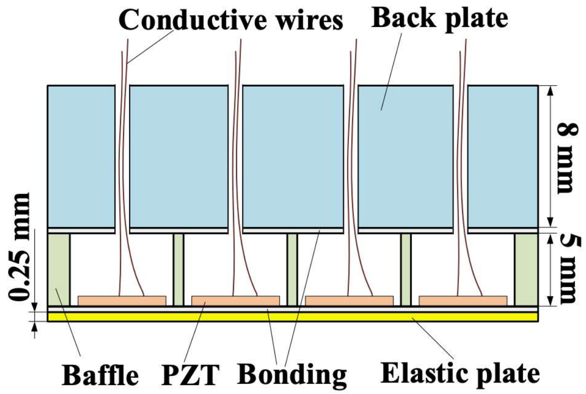


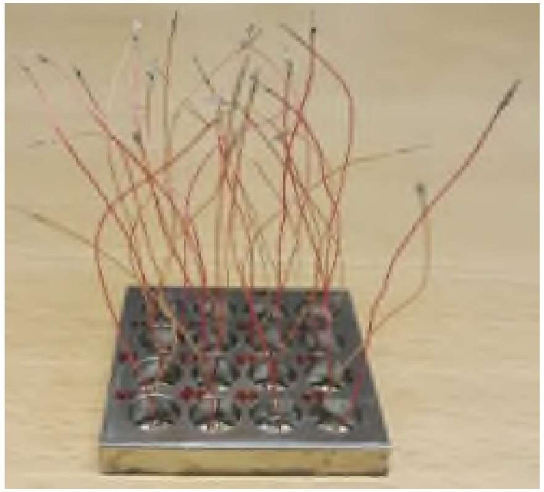


Arrays

4 x 4 array of ultrasonic transducers.







Flow measurement

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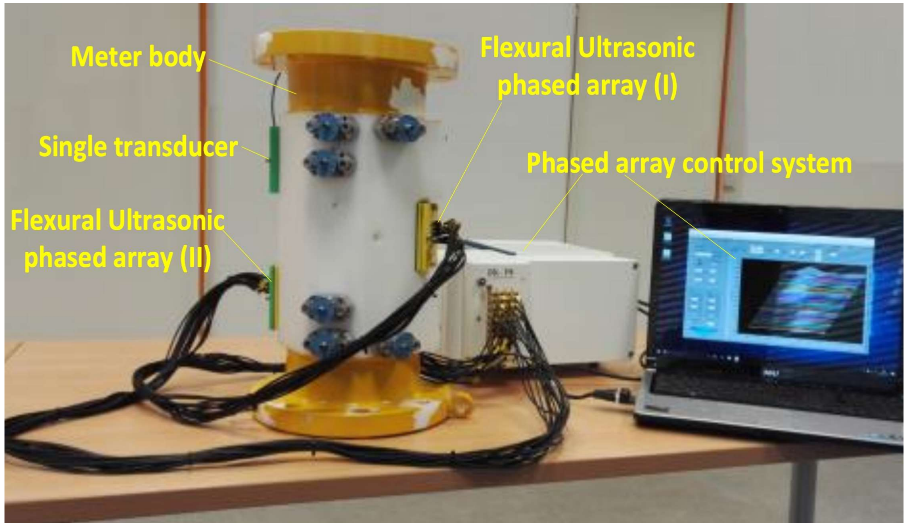
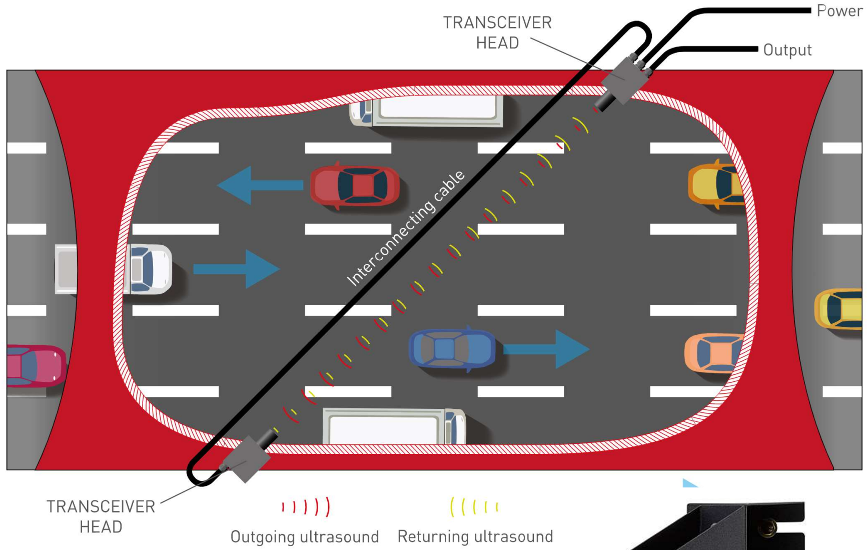
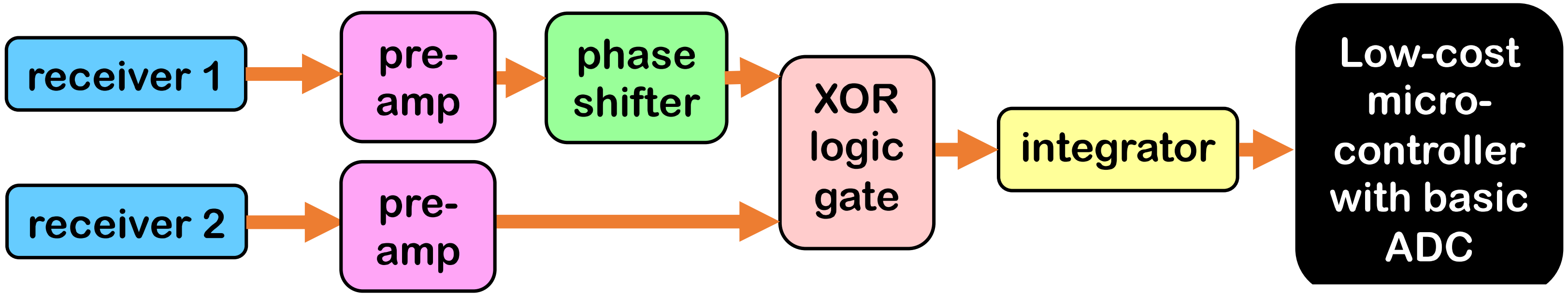


Gas flow in pipes – arrays can change the steering angle as flow rate changes, sending the ultrasound in the right direction.

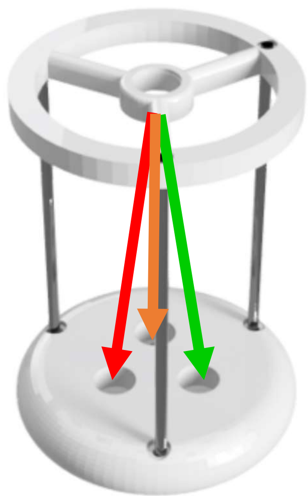


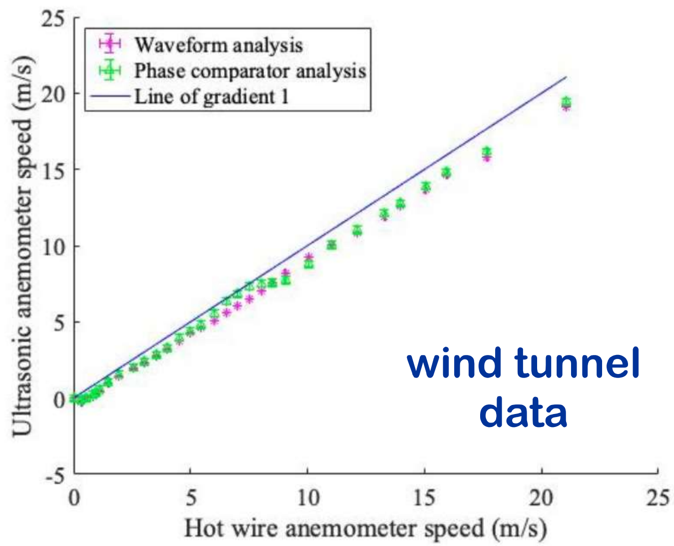
Measuring airflow in road tunnels.

Low cost, high accuracy ultrasonic anemometry



original prototype design





wind tunnel data

So what ?

This is the most common ultrasonic transducer in the world – and there was virtually nothing in the literature to explain how they work.

When we understand and then share knowledge of how something works – well that is when really interesting and useful new things can happen.

The take home messages

Just because something works – don't assume that we understand how it works.

There is a lot of excellent science done within companies and some real research expertise – but you won't always (usually) get to hear about it.

THANKS FOR YOUR ATTENTION

https://warwick.ac.uk/fac/sci/physics/research/ultra/research/hiffut/

or google " Warwick + HiFFUT"

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