HiFFUT – A New Class of Transducer

Kick-Off Meeting

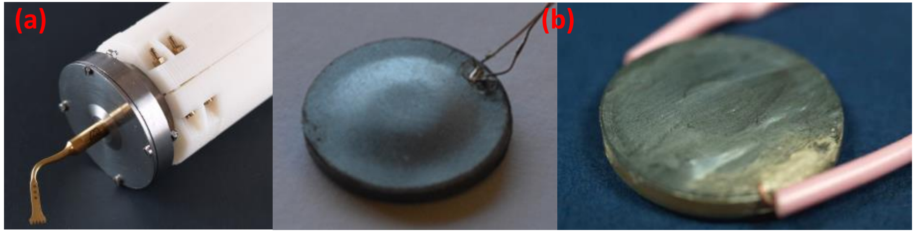
Dr Andrew Feeney, Postdoctoral Research Fellow

My Background

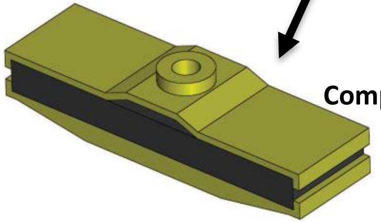
- I obtained a Master’s degree in Mechanical Engineering from the University of Glasgow in 2010
- I received my PhD from the same institution in December 2014, with a thesis titled *“Nitinol cymbal transducers for tuneable ultrasonic devices”*
- I am a Chartered Mechanical Engineer of the Institution of Mechanical Engineers (MIMechE, 2015)
- I have experience working or collaborating with a range of organisations:

My Research Career

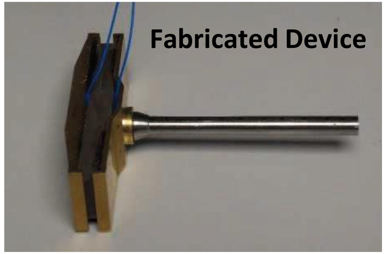
Novel Miniaturised Ultrasonic Transducers and Devices

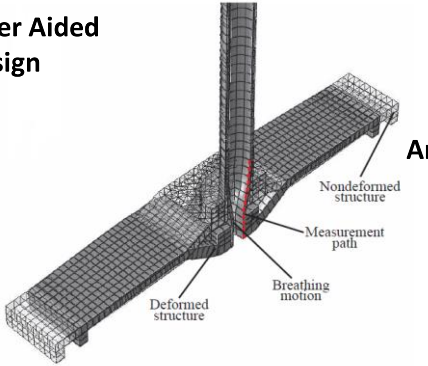


Cymbal-type transducers and devices, for (a) surgery, and (b) tuneable-frequency applications, utilising shape memory alloys



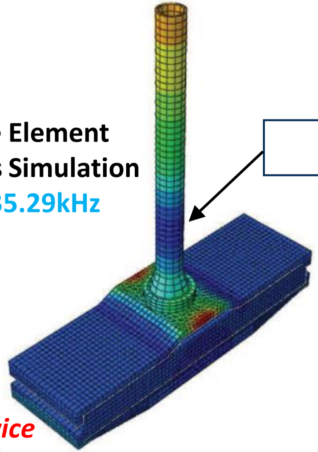
Computer Aided Design



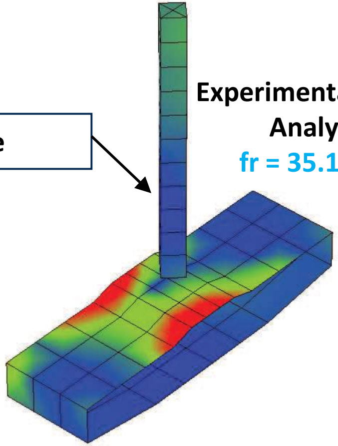


Class IV flextensional-type biopsy needle device

Finite Element Analysis Simulation
fr = 35.29kHz



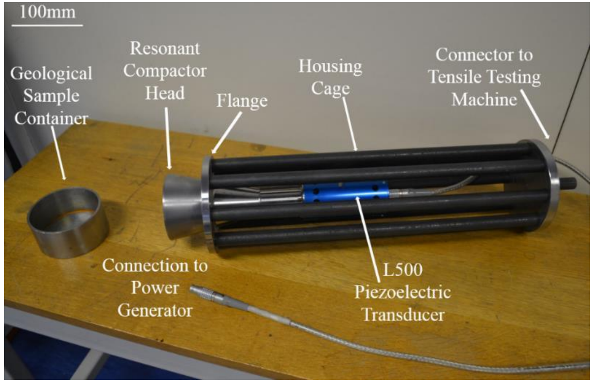
Node

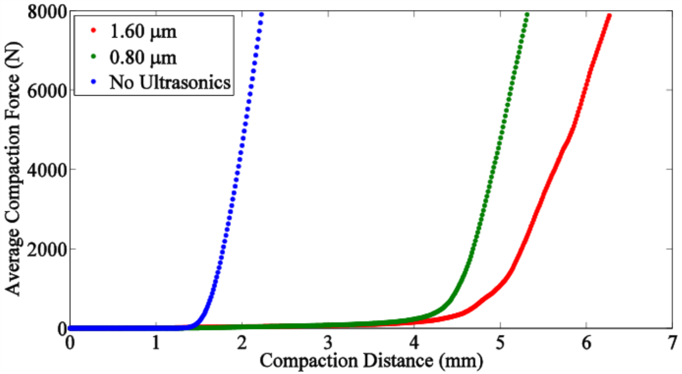


Experimental Modal Analysis
fr = 35.13kHz

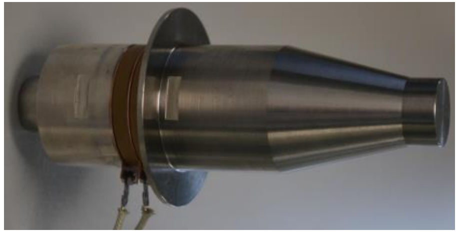
My Research Career

Ultrasonic Transducers and Devices for Sub-Sea and Hostile Environments

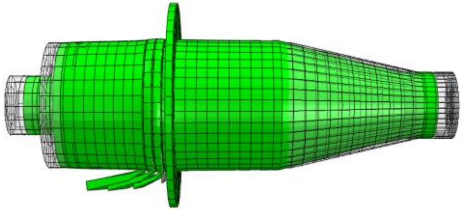




Fabricated Device



Finite Element Analysis Simulation
fr = 19.72kHz

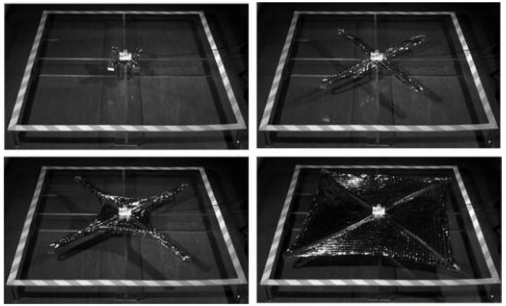


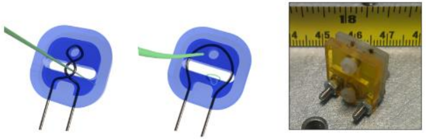
Experimental Modal Analysis
fr = 19.73kHz

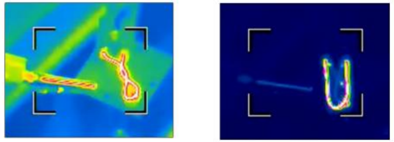
My Research Career

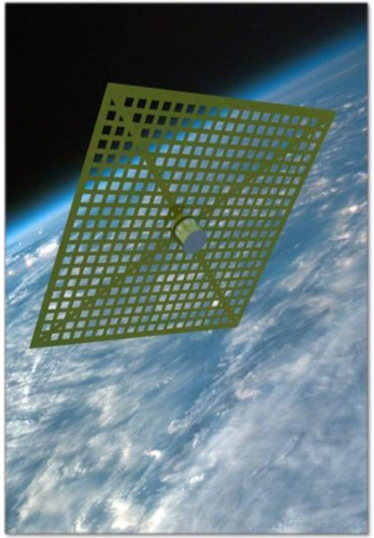
Compact and Deployable Space Structures

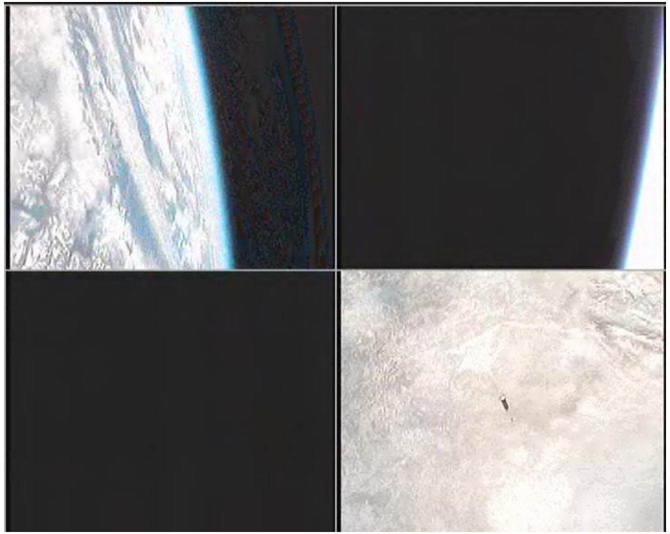
- Research conducted with University of Glasgow academics and small satellite specialists, Clyde Space Ltd
- The purpose of the research was to develop a deorbit mechanism for small satellites. My major contribution was to use Nitinol shape memory alloy as part of the space-web deployment system









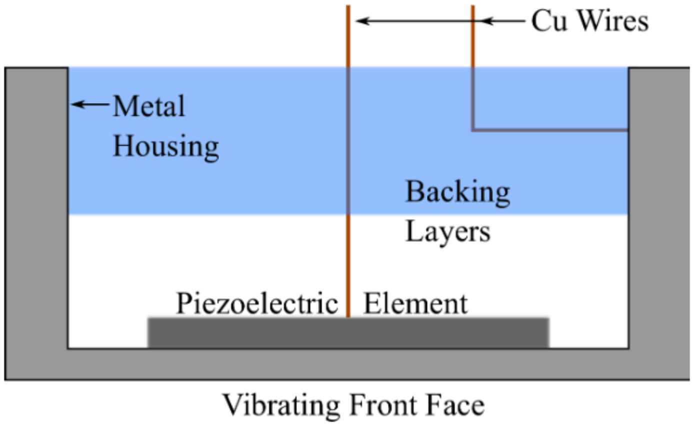


HiFFUT – A New Class of Transducer

- EPSRC Grant EP/N025393/1
- Funding: £1,194,109
- Project Period: 1st July 2016 – 30th June 2021

Flexural Transducers

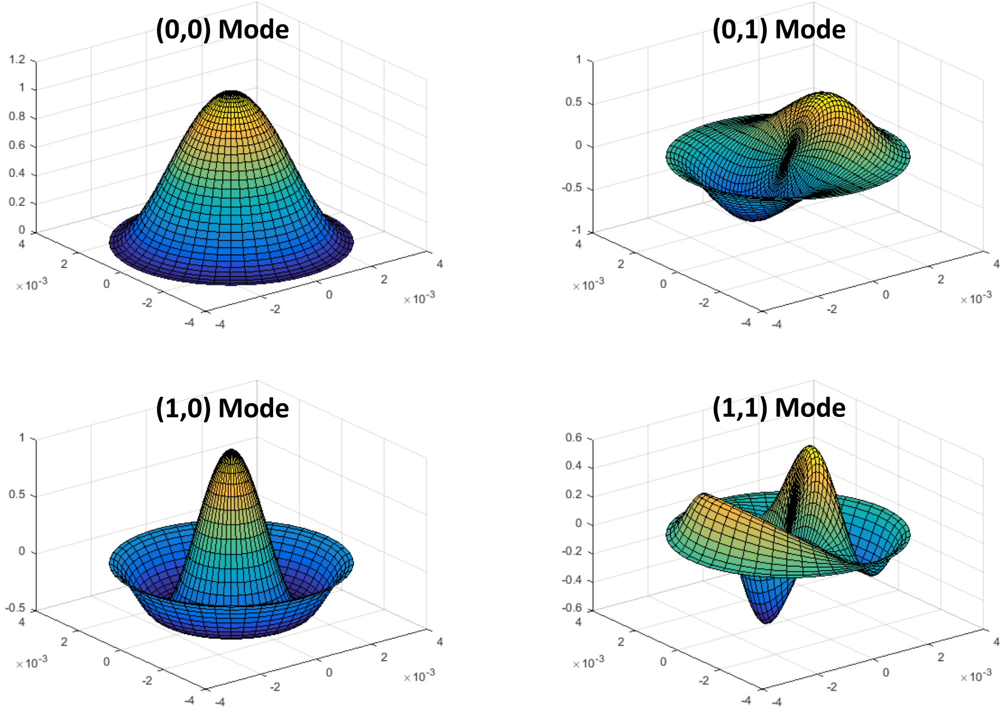
- The flexural transducer is a unimorph device, with a piezoelectric driver bonded to a metal cap.
- The vibration of the piezoelectric element causes bending of the metal cap, with significant vibration amplification.
- A notable advantage of flexural transducers compared to standard ultrasonic transducers is that the transducer couples efficiently to low-impedance media, operating with lower input voltage.
- Flexural transducers have been exploited for a range of applications, including for non-destructive evaluation, and as car-parking sensors.



- T.J.R. Eriksson, S.N. Ramadas, and S.M. Dixon, "Experimental and simulation characterisation of flexural vibration modes in unimorph ultrasound transducers," *Ultrasonics*, vol. 65, pp. 242-248, 2016.
- T.J.R. Eriksson, S.M. Dixon, and S.N. Ramadas, "Metal cap flexural transducers for air-coupled ultrasonics," *In 41st Annual Review of Progress in Quantitative Nondestructive Evaluation: Volume 34*, AIP Publishing, vol. 1650, no. 1, pp. 1287-1291, 2015.
- T.J.R. Eriksson, S.M. Dixon, and S.N. Ramadas, "Flexural mode metal cap transducer design for specific frequency air coupled ultrasound generation," *In 2013 IEEE International Ultrasonics Symposium (IUS)*, pp. 1602-1605, 2013.

Modes of Vibration

- The modes of vibration of a flexural transducer can be considered in terms of plate vibration modes
- Flexural transducers are commonly driven in the (0,0) and (1,0) fundamental axisymmetric modes



Principal Objectives

- Currently, flexural transducers are manufactured and driven in ambient atmospheric conditions, up to approximately 50kHz. Flexural transducers which can operate effectively at higher frequencies are desirable, since at frequencies around 50kHz, the associated signal wavelengths are relatively long, thereby decreasing measurement resolution. These new transducers are also desired to endure high pressures (around 200 bar) and temperatures of the hostile environments of many industrial applications. The new transducer class is termed HiFFUT (High Frequency Flexural Ultrasonic Transducer)
- Exploration of different driving mechanisms for HiFFUTs, including using a range of different piezoelectric elements, and through electromagnetic excitation
- Development of hardware and software algorithms for ultrasonic beam steering with flexural arrays, after which demonstrator technology can be produced
- For this research investigation, four work packages have been proposed:

    1. **Calculation and subsequent publishing of a parameter matrix for HiFFUT design**
    2. **The electromagnetic driving of flexural transducers**
    3. **Evaluation of transducer performance in hostile environments**
    4. **Development of demonstrator applications, focusing on outreach and engagement**

Staffing and Resources

Research Team

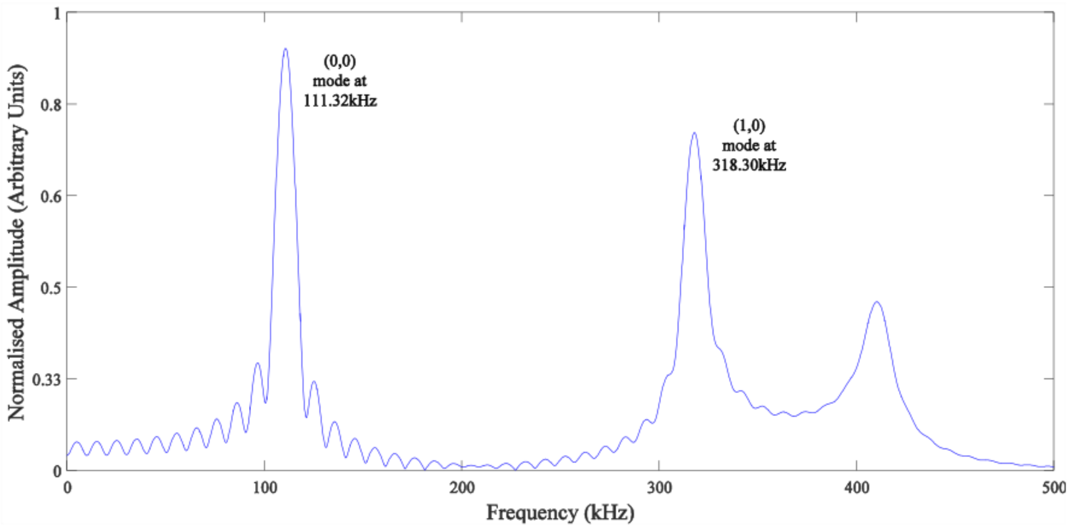
- Two postdoctoral researchers – one employed for four years, and a second employed for three years, upon completion of Work Package 1.
- A skilled technician, Jonathan Harrington, recently joined the Department of Physics
- Two postgraduate research students will be involved during the course of the fellowship
- Undergraduate project students will contribute to the research through dissertation-level research projects

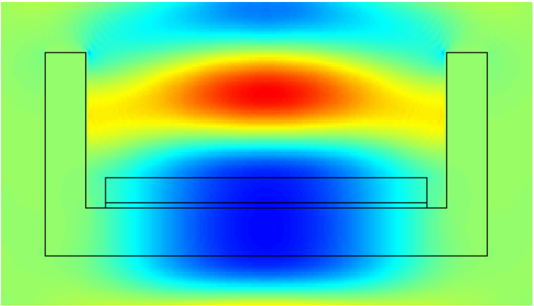
Key Resources and CIU Facilities

- Transducer fabrication capability, including piezoelectric ceramics
- Optical test equipment, including a Laser Doppler Vibrometer (Polytec) for measuring the modal vibration of transducers, Interferometers for accurate displacement measurement, and thermal imaging equipment
- Ultrasonic pulsers and amplifiers for driving piezoelectric devices and EMATs (Electromagnetic Acoustic Transducers)
- Rapid Prototyping, with two 3-D printers available for fast production of laboratory components
- Project web-page: http://www2.warwick.ac.uk/fac/sci/physics/research/ultra/research/hiffut/

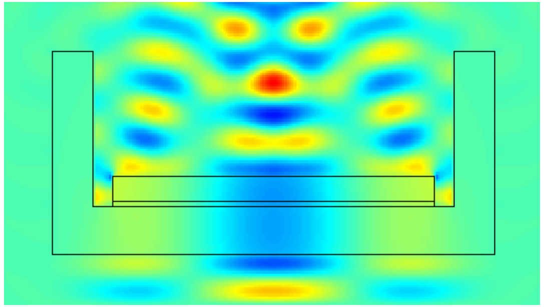
Current Research Contributions

- Finite element analysis software, PZFlex®, has been used to design a prototype titanium HiFFUT, in the form of a 2-D axisymmetric model
- The dimensions of the HiFFUT have been set to ensure the frequencies of the (0,0) and (1,0) modes exist between 100-500kHz



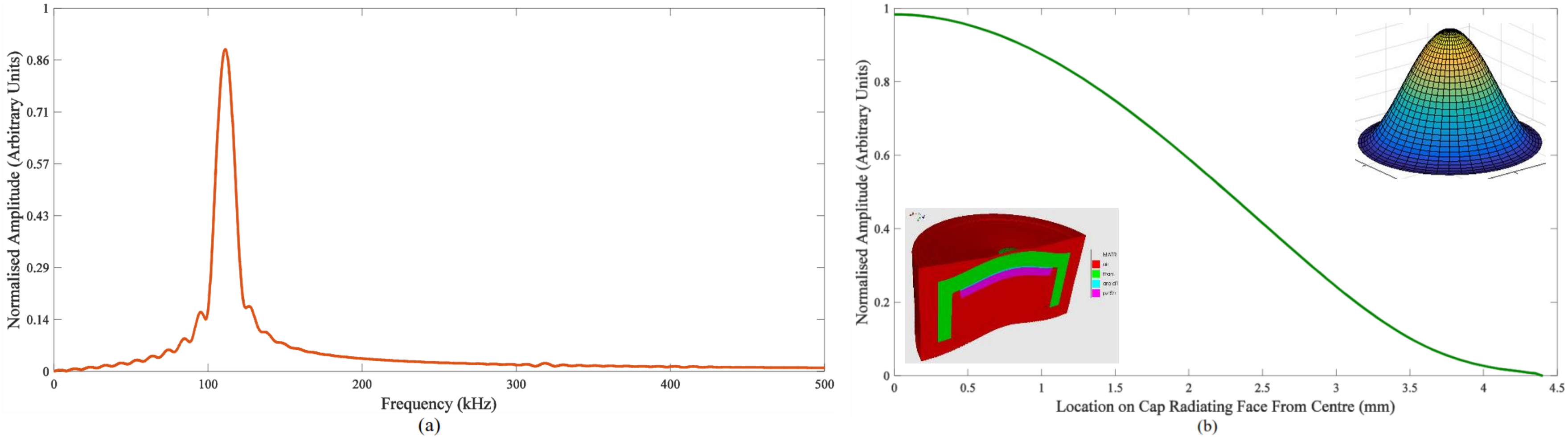


Simulated radiation pattern of the (0,0) mode



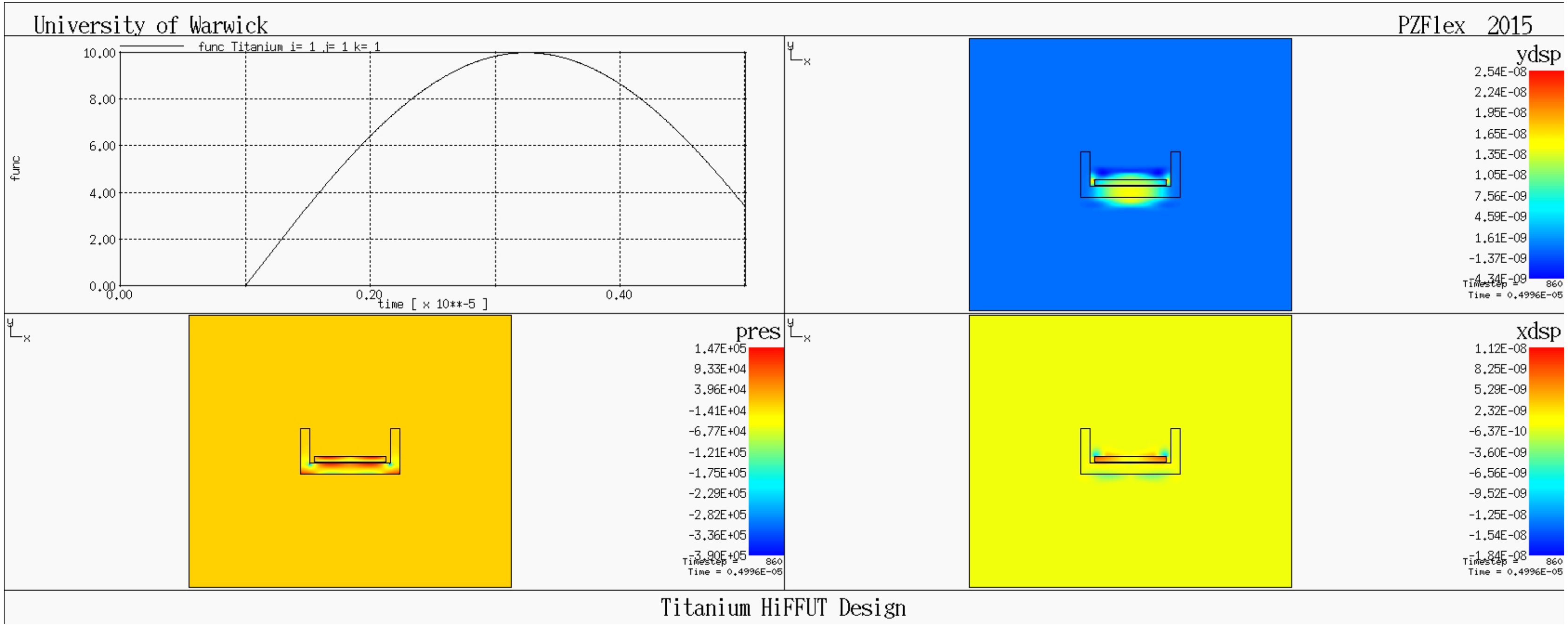
Simulated radiation pattern of the (1,0) mode

Current Research Contributions



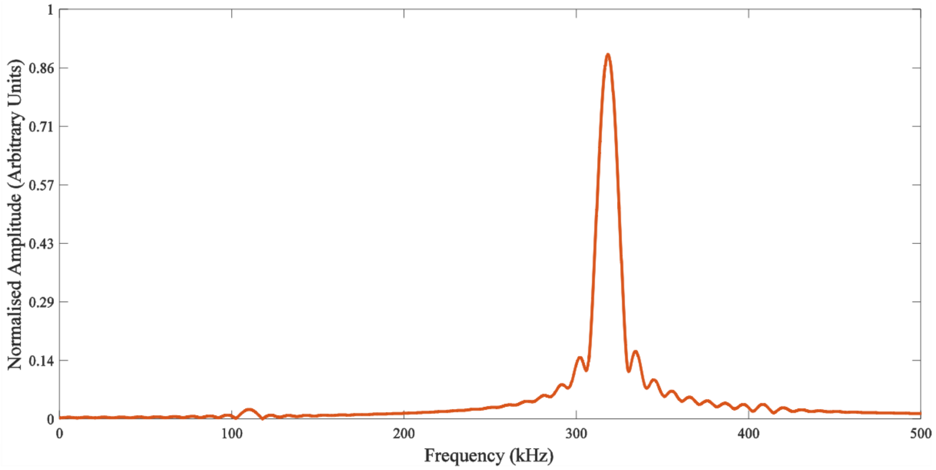
Simulation results for the HiFFUT operating in the (0,0) mode, showing (a) the normalised amplitude profile as a function of frequency at the centre of the cap output face, and (b) the calculated mode shape. Note that a symmetric boundary condition is placed in the finite element model

Current Research Contributions

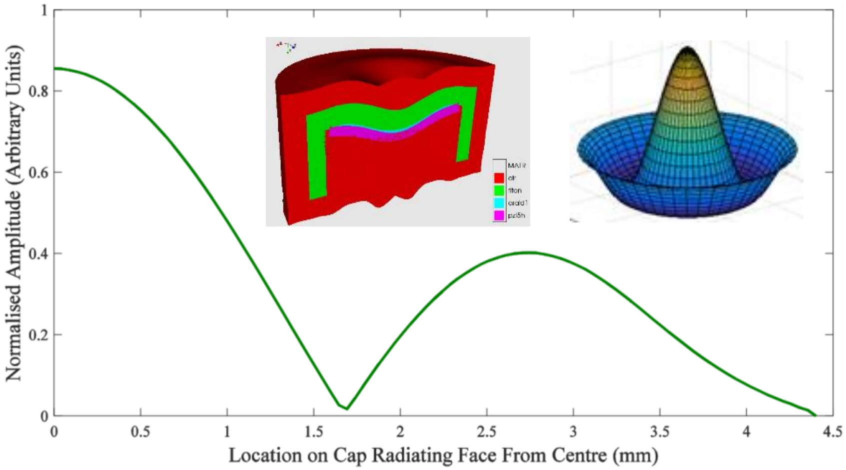


Prototype Design – (0,0) Mode

Current Research Contributions



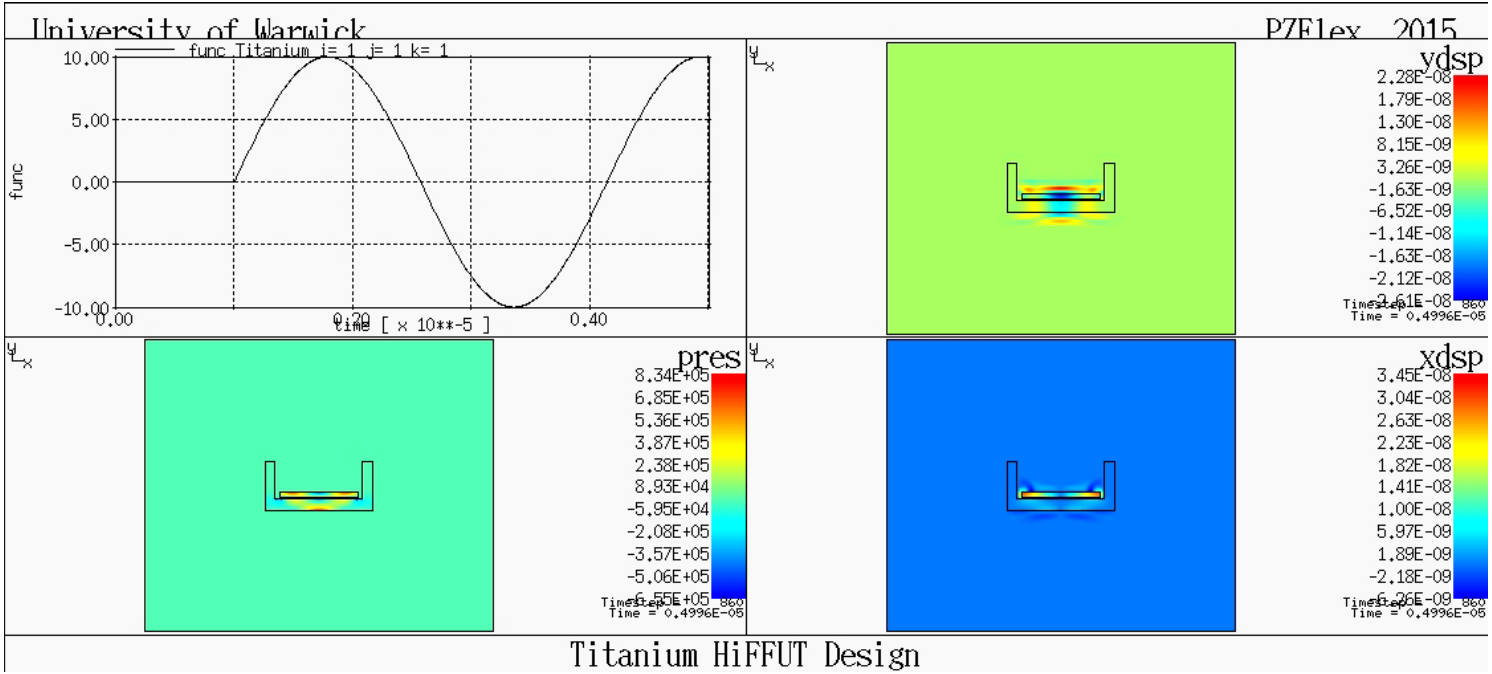
(a)



(b)

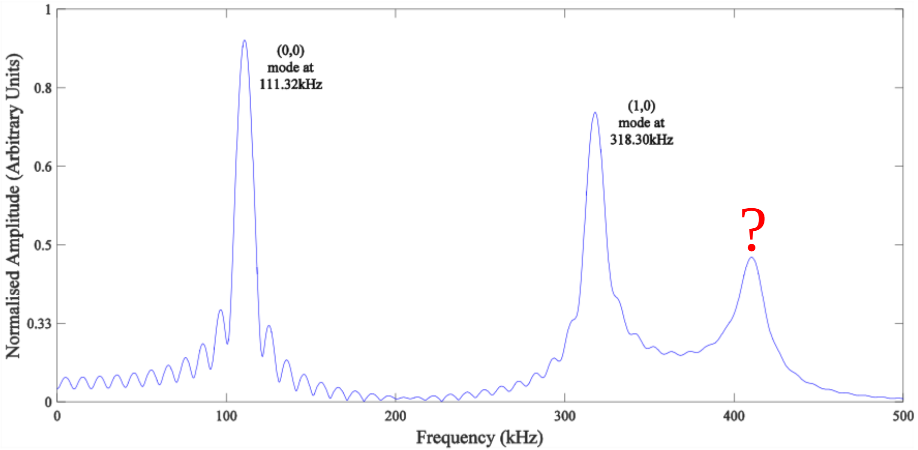
Simulation results for the HiFFUT operating in the (1,0) mode, showing (a) the normalised amplitude profile as a function of frequency at the centre of the cap output face, and (b) the calculated mode shape. Note that a symmetric boundary condition is placed in the finite element model

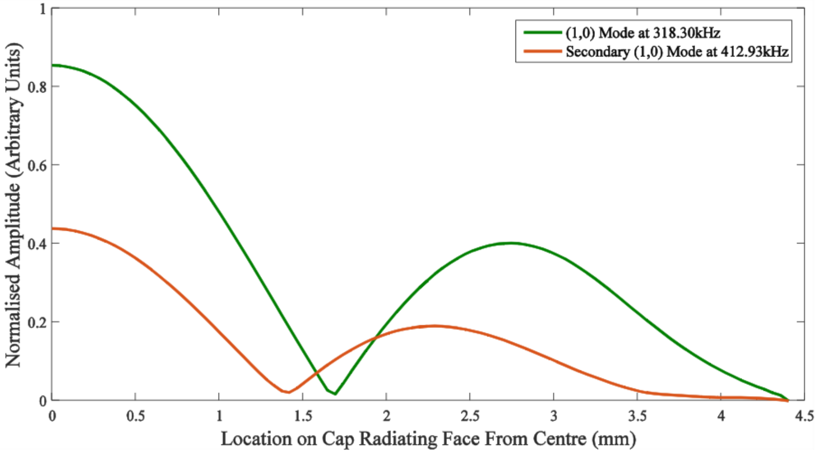
Current Research Contributions



Prototype HiFFUT Design – (1,0) Mode

Current Research Contributions



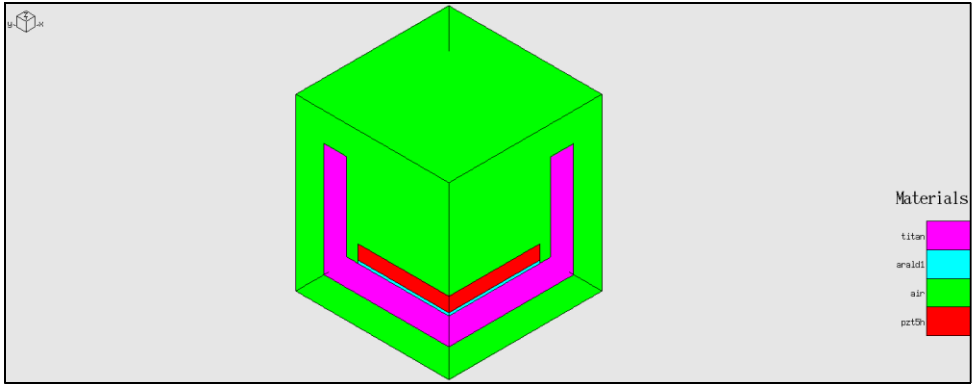


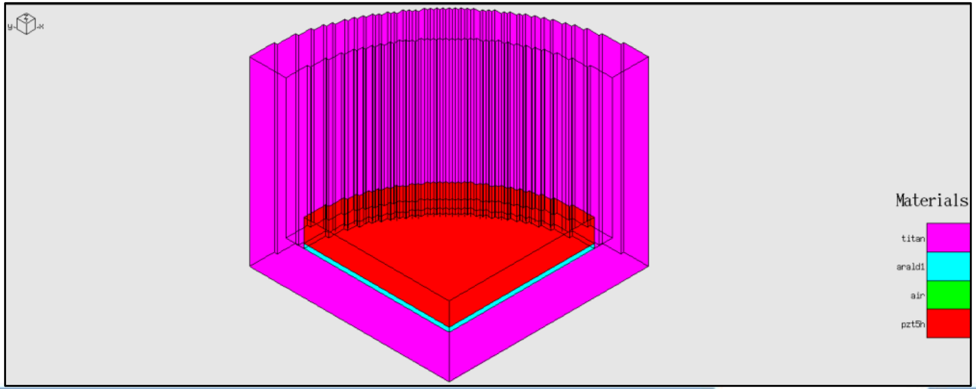
Determination of the modal response of the HiFFUT

- The mode around 400kHz cannot be closely correlated with the theoretical plate mode vibration prediction
- Finite element analysis was again used to drive the transducer at this mode to determine the mode shape
- It has been found to be a variation of the (1,0) mode, likely due to the influence of the cap side-wall

Current Research Contributions

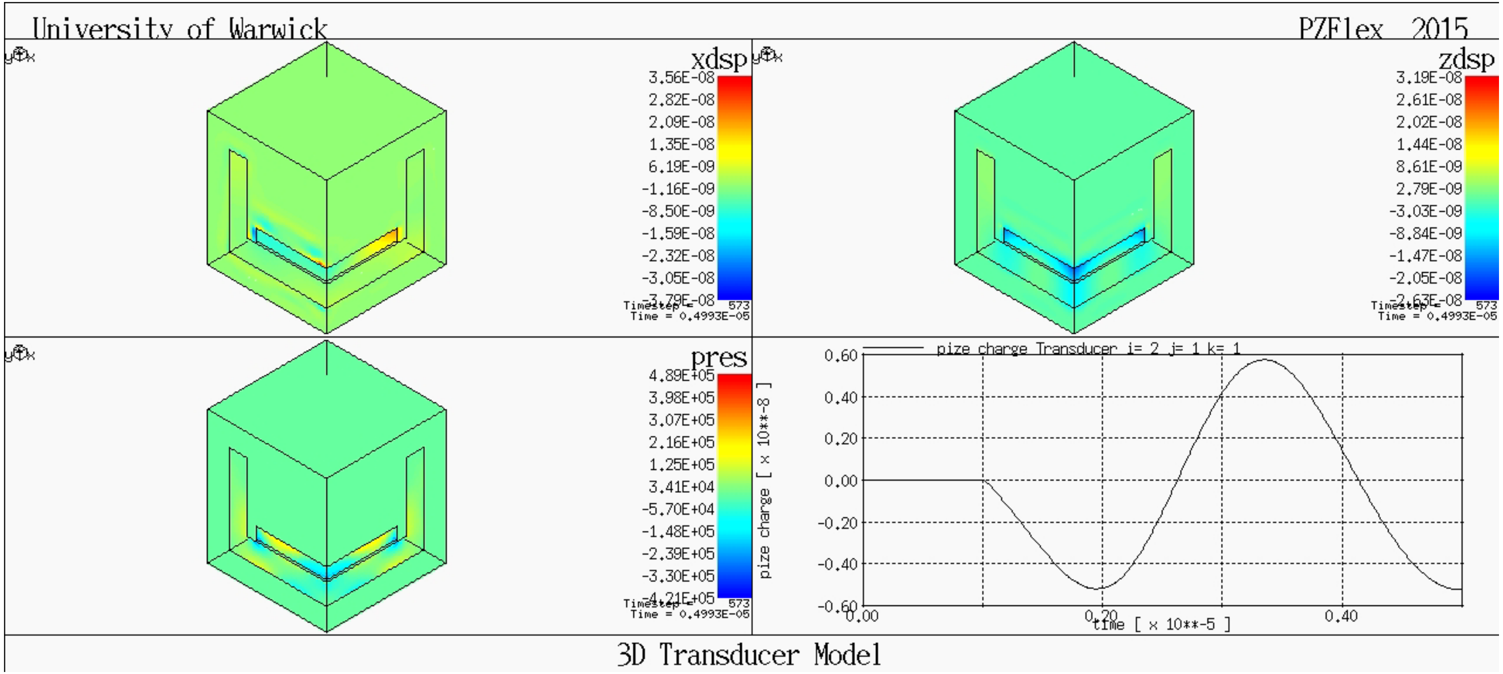
- A fully 3-D representation of a HiFFUT has been produced using PZFlex®, to enable the modelling of intricate transducer geometries or asymmetries into the design
- This model could be used to investigate imperfect transducer fabrication
- At present, a quarter-model of the HiFFUT has been modelled, in order to ensure both a sufficient level of model resolution and complexity, but for it to also run efficiently
- The 3-D model will provide the freedom to incorporate different features into the analysis procedure which are not possible with the 2-D axisymmetric model





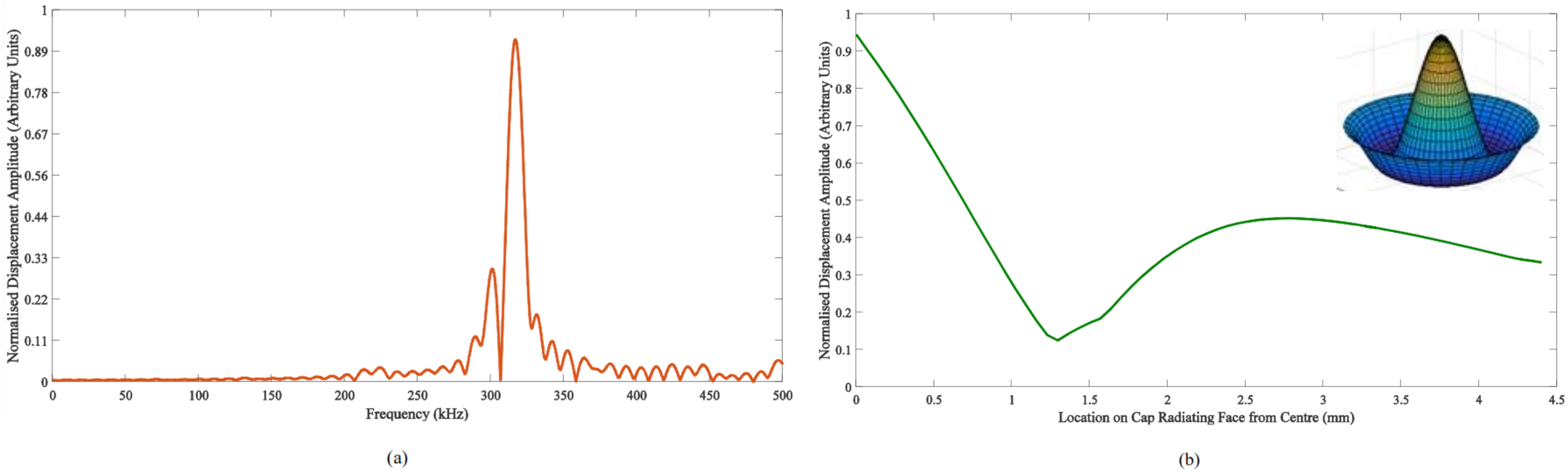
Prototype 3-D HiFFUT Design

Current Research Contributions



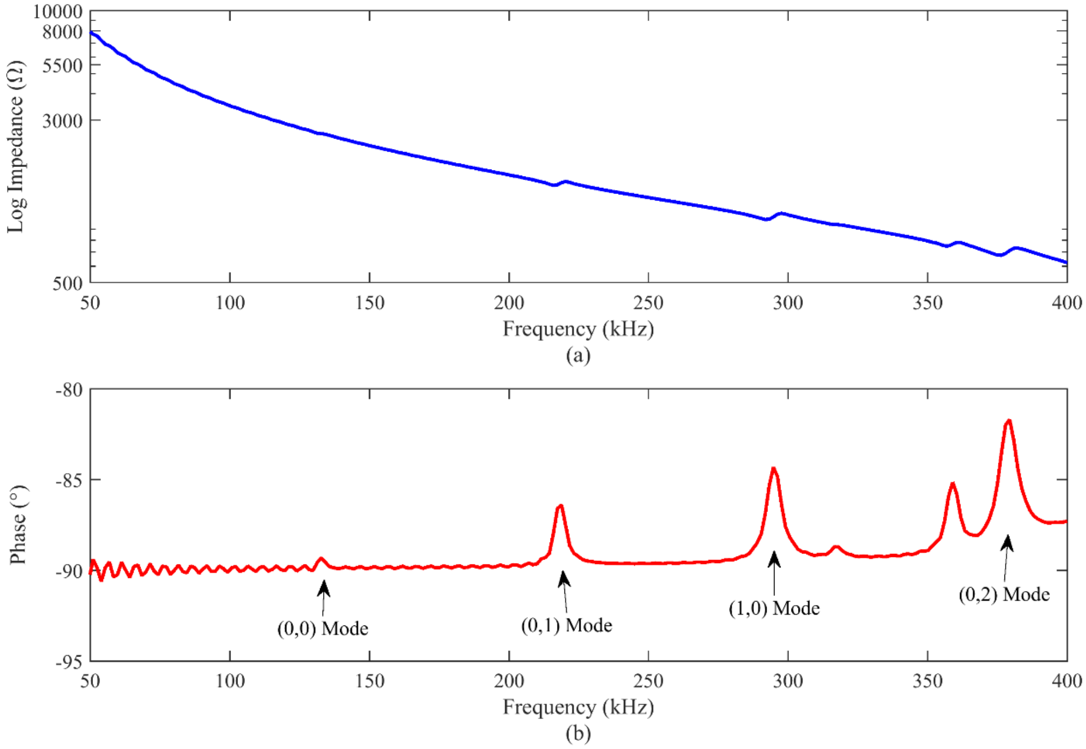
Prototype 3-D HiFFUT Design – (1,0) Mode

Current Research Contributions



Simulation results for the 3-D HiFFUT operating in the (1,0) mode, showing (a) the normalised amplitude profile as a function of frequency at the centre of the cap output face, and (b) the calculated mode shape. These results closely match the simulation output of the 2-D axisymmetric model

Current Research Contributions



Simulation results for the 3-D HiFFUT showing (a) the impedance-frequency and (b) the phase-frequency responses, modelled with free boundary conditions

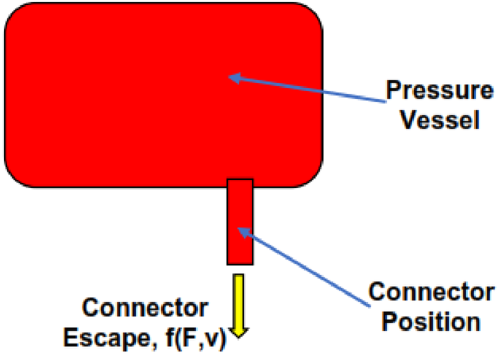
Current Research Contributions

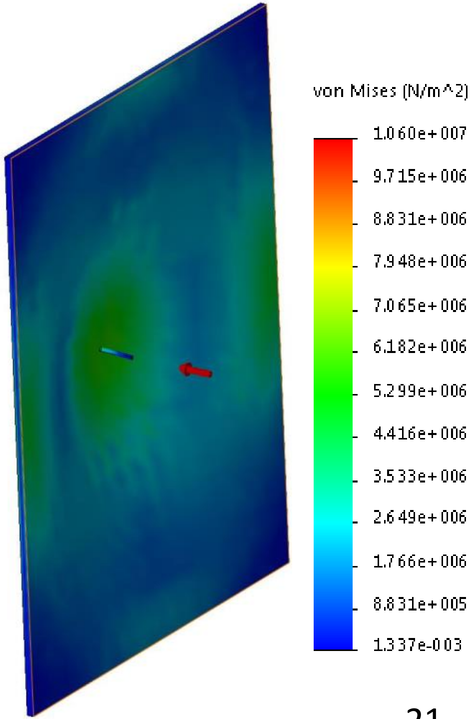
Manual pump, stainless steel 316, HiP Model 112-5.75-5, pressure rating 5000psi

Confined gasket closure vessel, stainless steel 316, HiP Model GC-33, pressure rating 5000psi, inside diameter of 127mm, and depth of 254mm. It is suitable for liquids and gas, and its maximum working temperature is around 425°C

- Connector interfacing will be necessary, which HiP has stated will be possible
- A protective enclosure may be required

A prototype was modelled in finite element analysis, in mild steel. The dimensions are (400x300x5 mm)





Possible Routes of Investigation

Parameters of interest

- Flexural transducer cap material, and associated mechanical properties (E, ν, ρ)
- Cap thickness
- Cap radiating face diameter
- Driver material type and thickness
- Bonding mechanism
- Backing material
- Environmental conditions, comprising pressure and temperature
- Environmental fluid type
- Frequency and mode of operation
- Amplitude of sound propagation
- Source level, losses and efficiency
- HiFFUT fabrication method
- Application of the HiFFUT

Project Gantt Chart