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Dynamics Characterisation of Cymbal Transducers for Power Ultrasonics Applications

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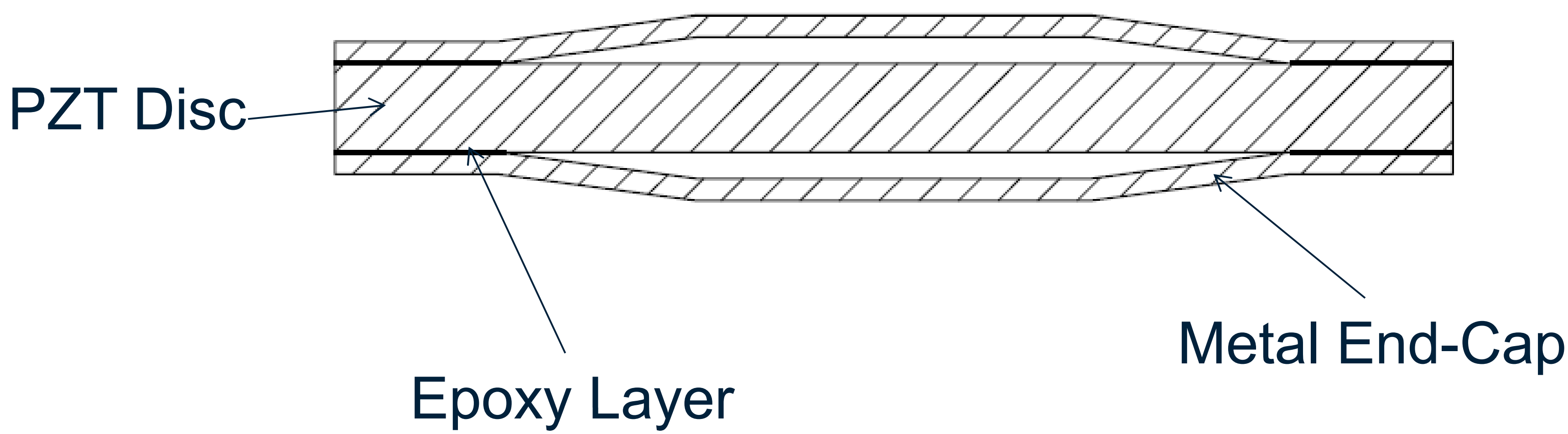
Outline

1. Introduction to Cymbal Transducers
2. Motivation
3. Summary of Work
4. Numerical Procedure
5. Experimental Procedure
6. Results
7. Conclusions

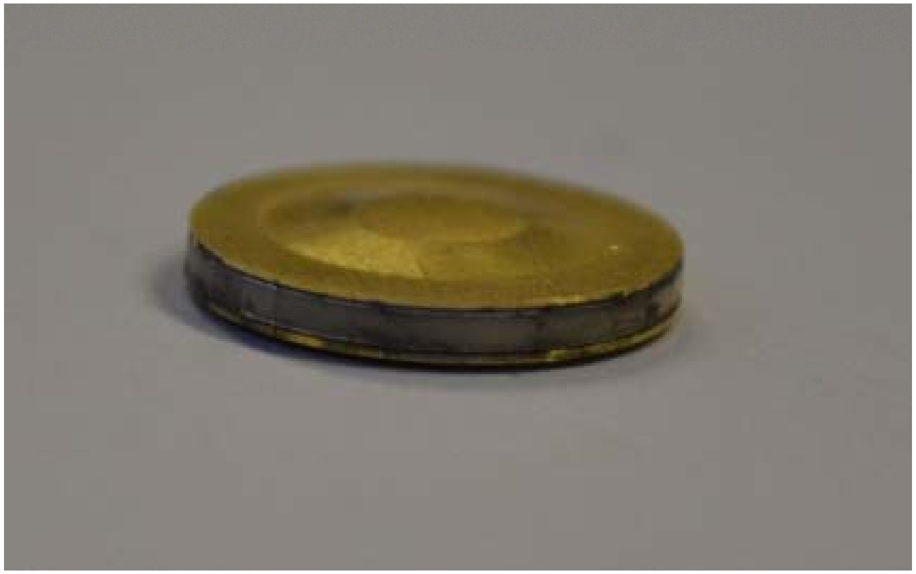
1. Introduction to Cymbal Transducers

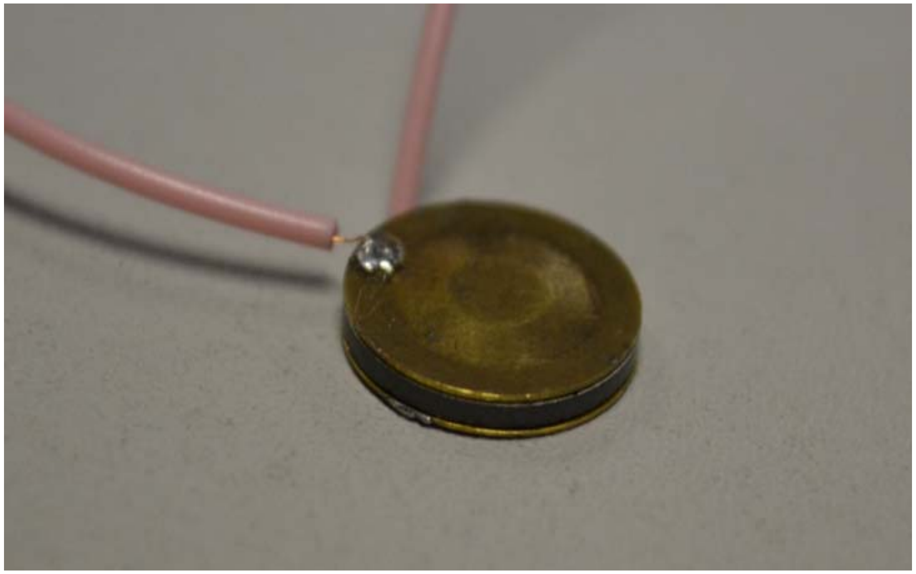
Converts high impedance, low displacement radial motion into low impedance, high displacement axial motion.



Background to the Standard Design

- Developed by Newnham et al. at the Penn State University in the early 1990's.
- They are a variation of the flextensional transducer, which themselves have been in existence since the 1920's.
- Traditional uses for cymbal transducers are for underwater and sonar applications, as actuators, sensing devices and more recently, energy harvesting.

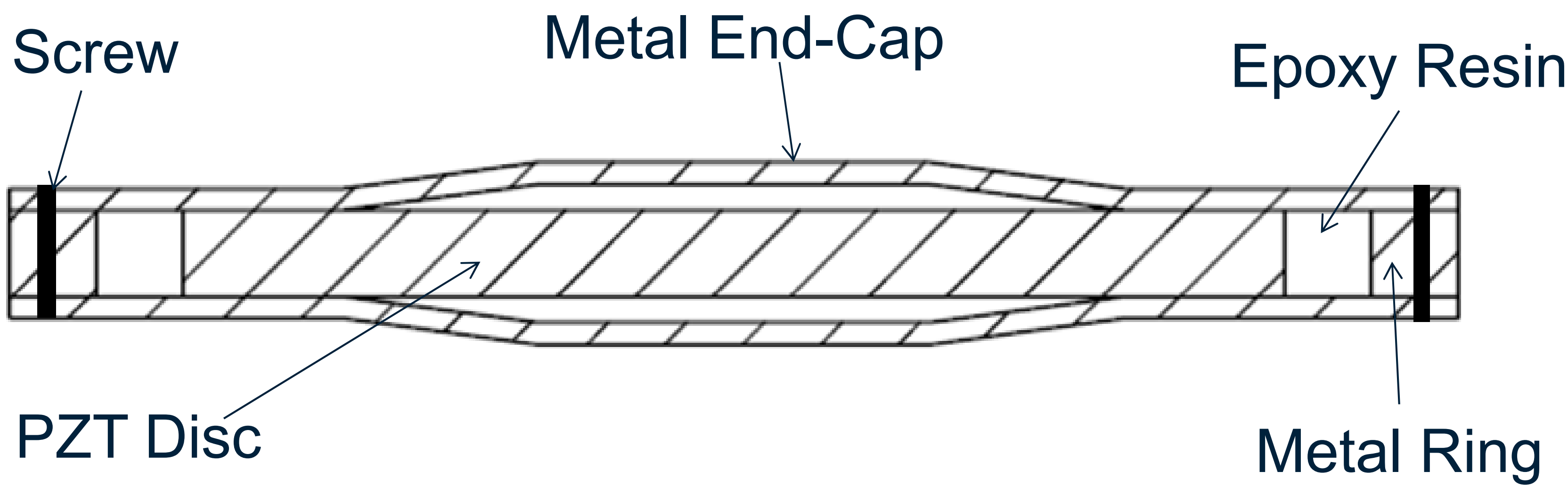


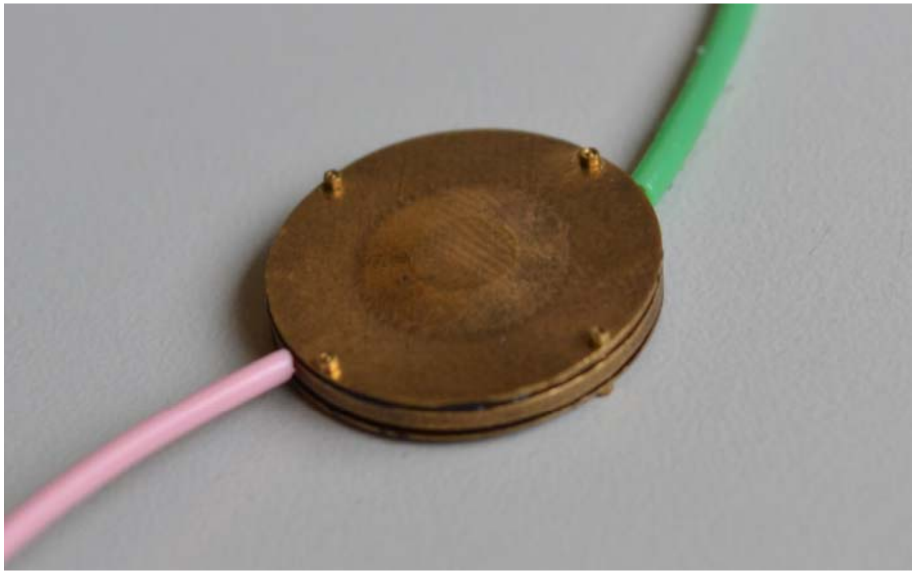


Background to the Modified Design

- Initially proposed by Shuyu Lin in 2010 [1].
- The aim was to produce cymbal transducers which could operate as sound projectors or ultrasonic radiators.
- Lin uses an expansion and contraction method to join the PZT to the metal ring, whereas this investigation employs high-strength epoxy resin.
- The resonance characteristics were studied by Lin.

[1] Lin, S. (2010). "*An improved cymbal transducer with combined piezoelectric ceramic ring and metal ring.*" Sensors and Actuators A: Physical 163(1): 266-276


Screw
Metal End-Cap
Epoxy Resin
PZT Disc
Metal Ring



2. Motivation

Incorporation of cymbal transducers in power ultrasonics applications is currently underdeveloped:

1. Depolarization of the piezoceramic must be avoided. However, amplitude saturation can occur before this stage at higher voltage levels.
2. The bonding agent used in the transducer possesses a finite mechanical strength, and so imposes a restriction on the performance.

3. Summary of Work

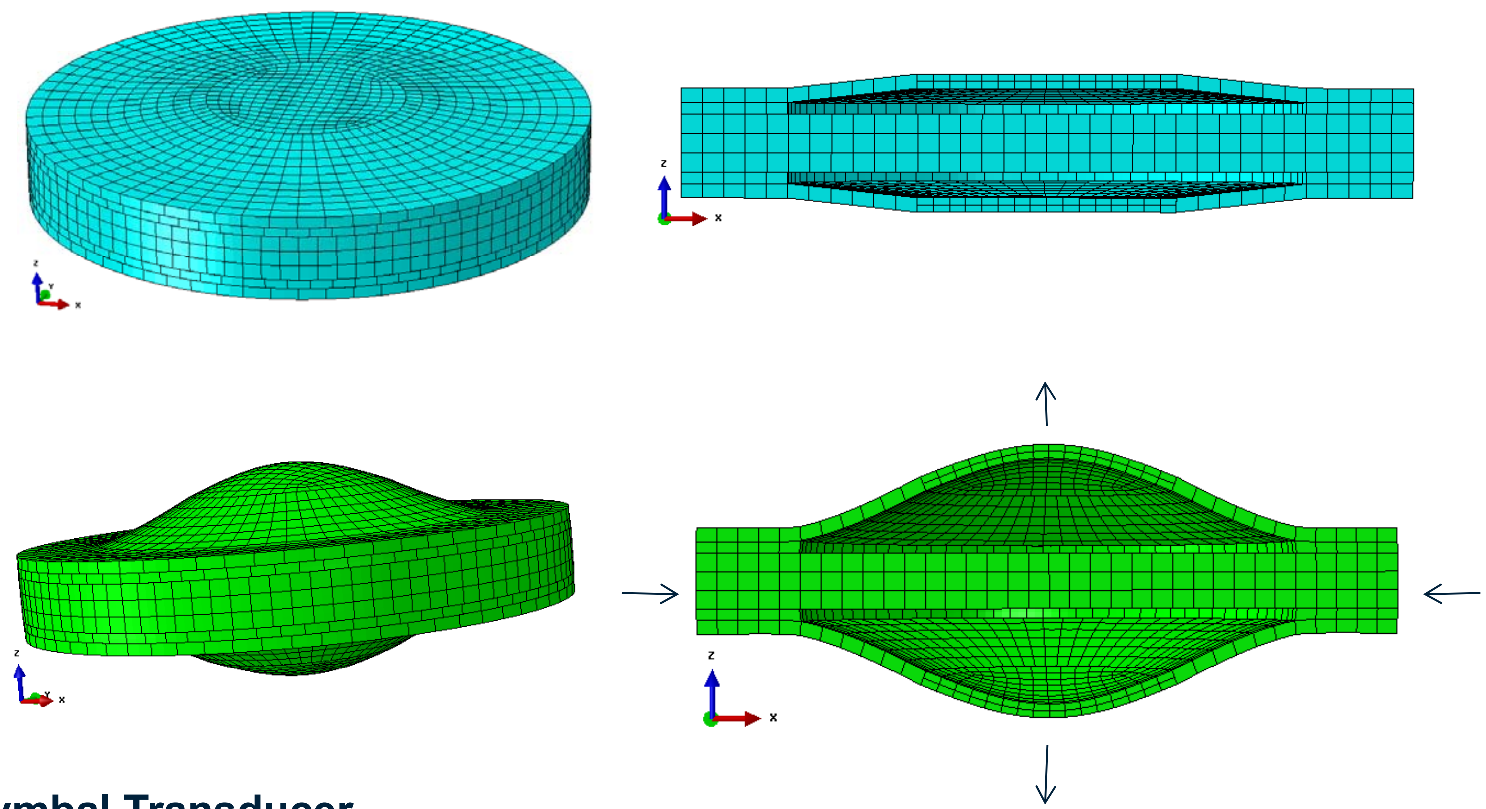
1. Compare two different cymbal transducer designs, one utilising a metal ring to improve mechanical coupling, thereby allowing greater amplitudes to be reached.
2. Identify the linear behaviour over a specific voltage range, to assess the impact of higher voltage levels on different cymbal transducers.
3. Identify any debonding or operational limits of both devices.
4. Complement the experimental results with Finite Element Analysis.

4. Numerical Procedure

Used Abaqus Finite Element Analysis.

Undeformed

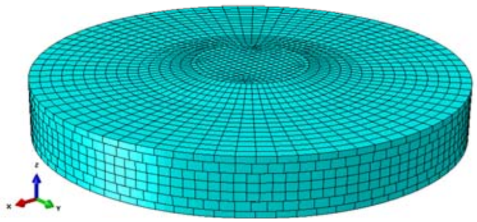
Deformed

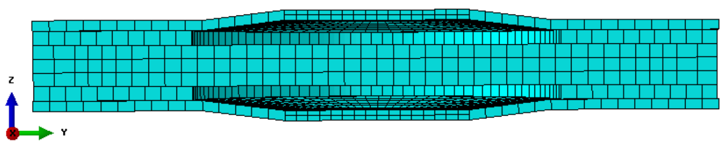


The Standard Cymbal Transducer

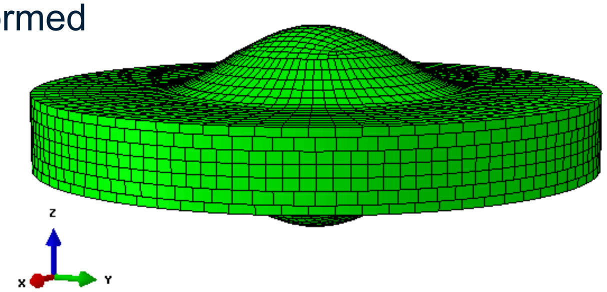
Output displacements for given voltages over a designated frequency range were computed for both transducers.

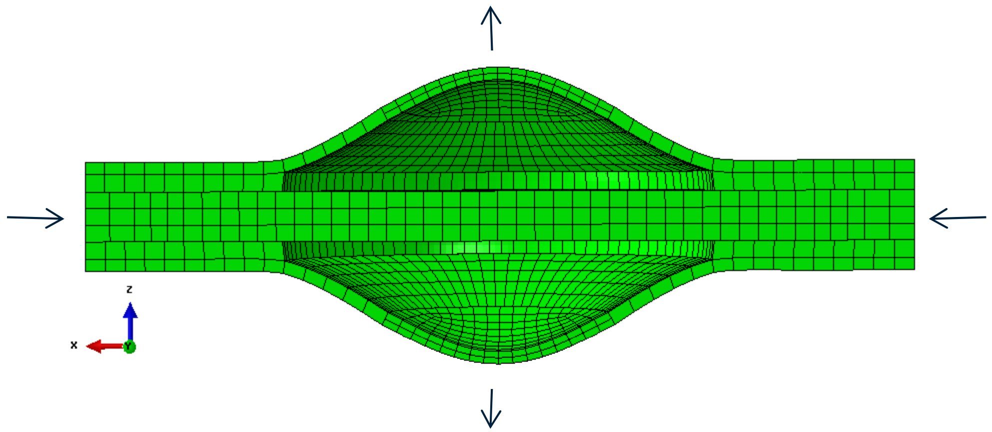
Undeformed





Deformed





The Modified Cymbal Transducer

5. Experimental Procedure

The experimental process was performed in three steps:

1. Assembly of the cymbal transducers.
2. Impedance analysis.
3. Dynamics characterisation using a 1D LDV system.

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Assembly of the Cymbal Transducers

Dimension	Standard Design	Modified Design
PZT Thickness	1.0	1.0
End-Cap Thickness	0.25	0.25
Total Ø	12.7	16.7
Base Cavity Ø	9.0	9.0
Apex Cavity Ø	4.5	4.5
Max. Cavity Depth	0.3	0.3
Ring Inner Ø	N/A	14.7
Ring Outer Ø	N/A	16.7
Ring Thickness	N/A	1.0

All stated values are in mm.

Component Dimensions

Device Materials

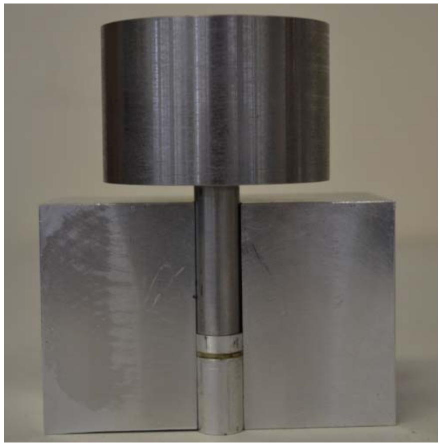
1. Brass cymbal-shape end-caps were cut from 0.25mm-thick sheet.
2. Hard PZT-402 was sandwiched between the end-caps.
3. For the modified design, 0.50mm-diameter brass threaded screws were sourced, and 1mm-thick brass rings were cut.
4. Eccobond® LV Insulating Epoxy Resin was selected because it tends to be much stronger than conductive epoxies [2].

[2] Jindong Zhang et al. (2001), *Modeling and Underwater Characterization of Cymbal Transducers and Arrays*, IEEE Transactions on Ultrasonics, Ferroelectrics and Frequency Control, Vol. 48, No. 2, pp. 560 – 568, March 2001

Assembly of the Transducers

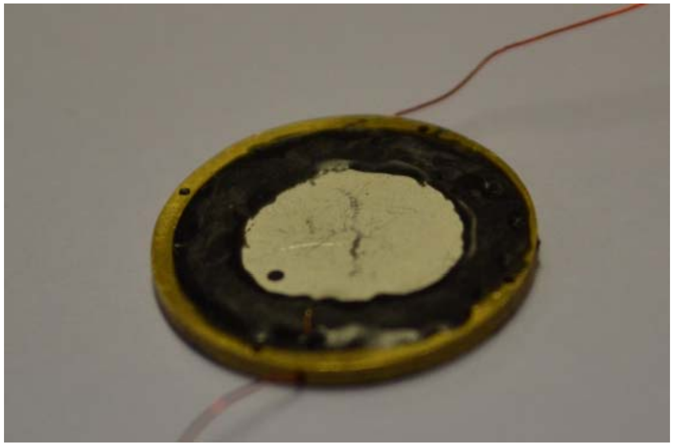
Standard Cymbal Transducer

1. Epoxy Resin applied.
2. Surfaces of the PZT had small solder spots deposited to ensure conductivity between the PZT and the connecting wires.
3. Left to cure for 24 hours at room temperature in a custom rig (below).



Modified Cymbal Transducer

1. Connecting wires fed through small holes in metal ring.
2. Gap between metal ring and PZT filled with epoxy.
3. Left to cure for 24 hours before screws applied.



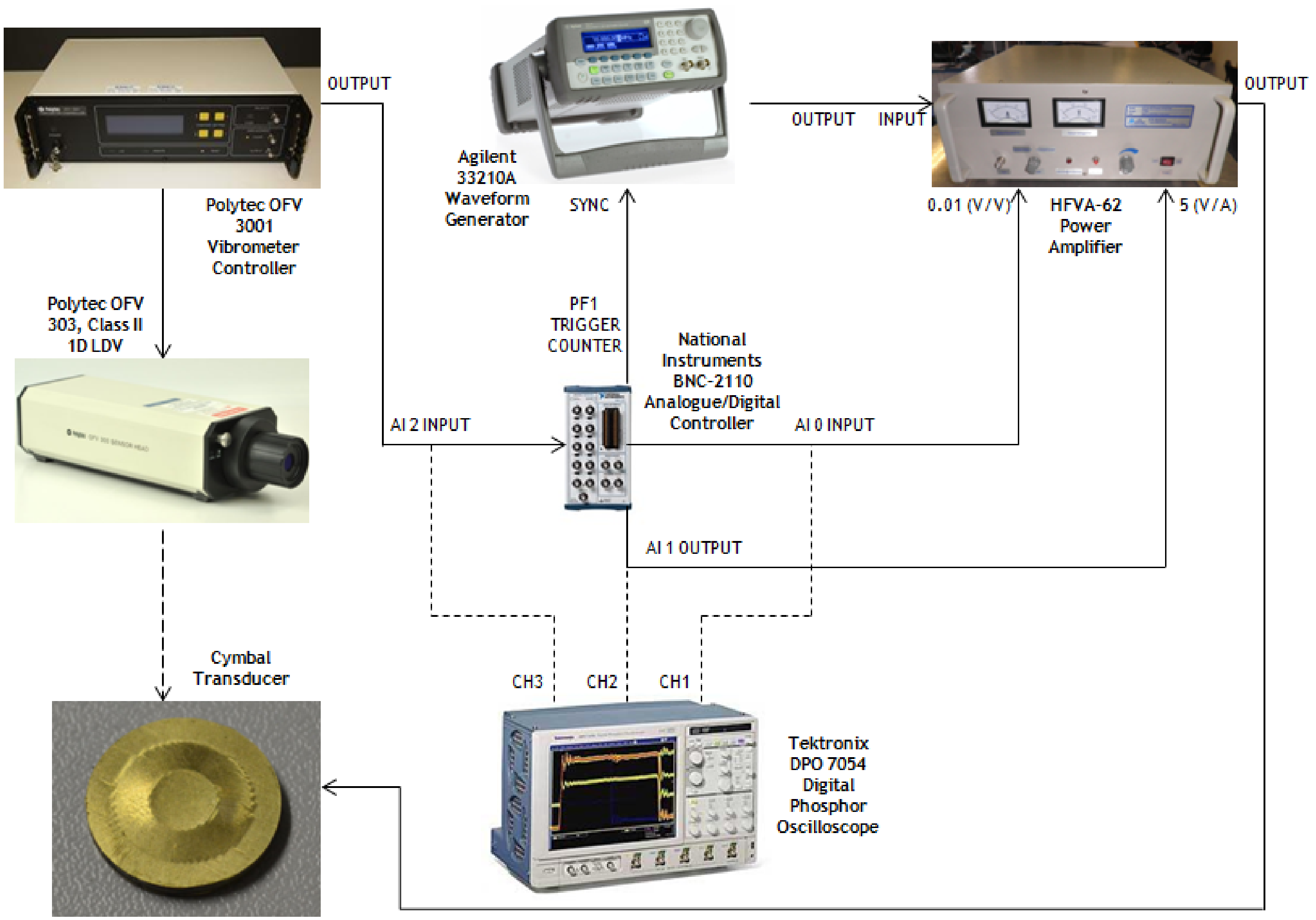
Impedance Analysis

Performed using the Agilent 42491A Impedance/Gain Phase Analyzer.

A frequency spectrum was generated for both cymbal transducers.

This allowed us to determine whether or not the cymbal operated effectively over the required driving voltage range, if we had good connectivity, such as avoiding short-circuits, and to identify the overall quality of the assembly.

Dynamics Characterisation



Driving the Cymbal Transducers

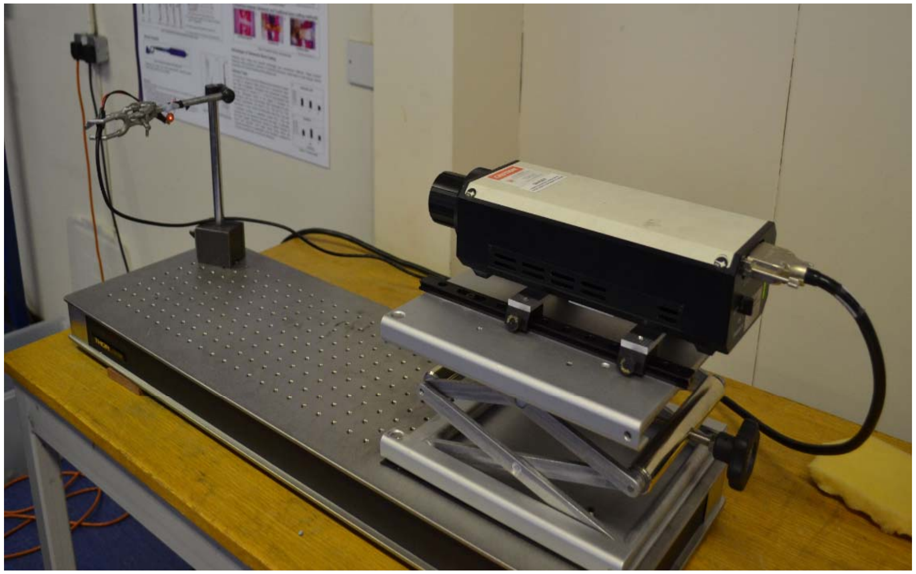
The following steps were taken:

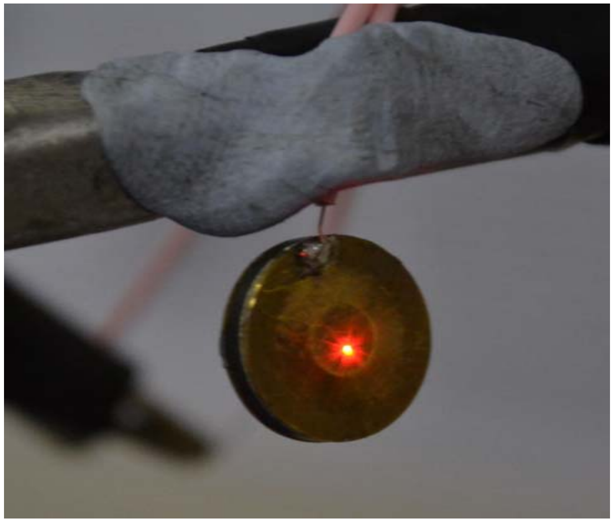
1. The impedance analysis indicated the resonance frequency.
2. The transducers were then driven at a series of increasing Voltages in a frequency band around resonance.
3. A burst-sine signal was used, with 2-4s between bursts depending on Voltage level.
4. LabVIEW was used to record all vibration amplitude data.

6. Results

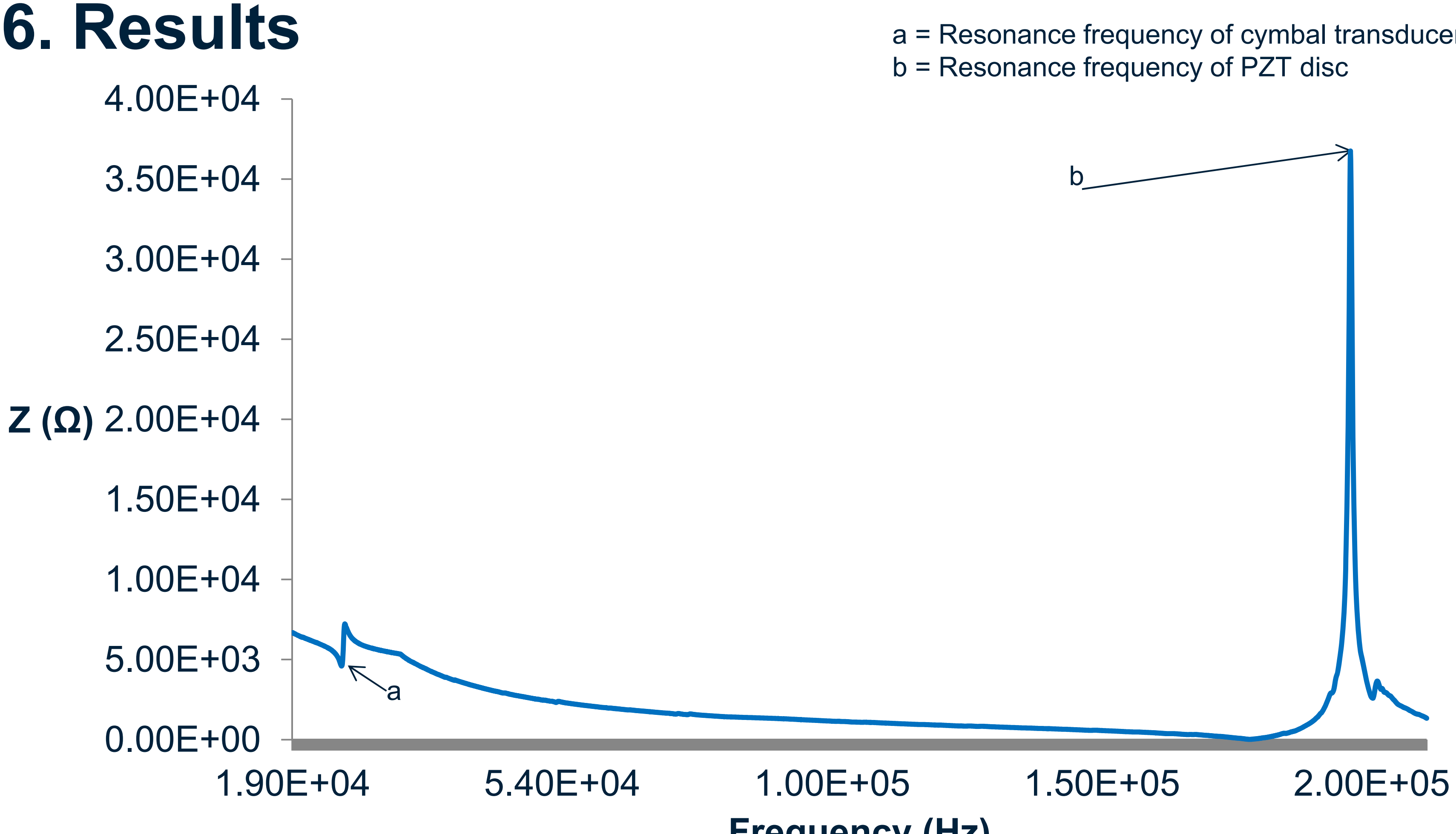
Transducer	Resonance Frequency (Experimental, Hz)	Resonance Frequency (Numerical, Hz)
Standard	21838	24280
Modified	25136	25416

Experimental and Numerical Results





6. Results



Impedance-Frequency Spectrum of the Standard Brass Cymbal Transducer

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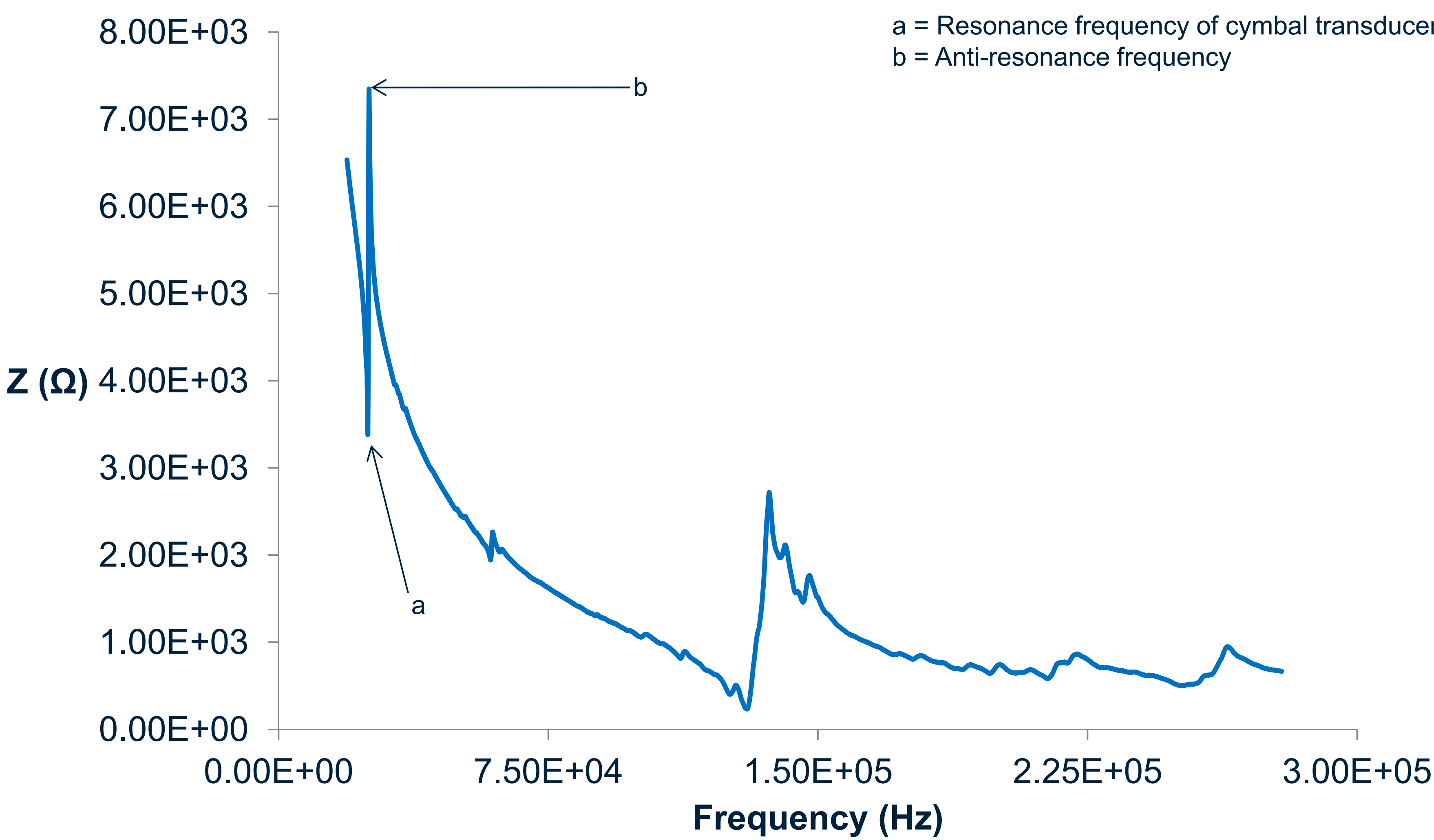
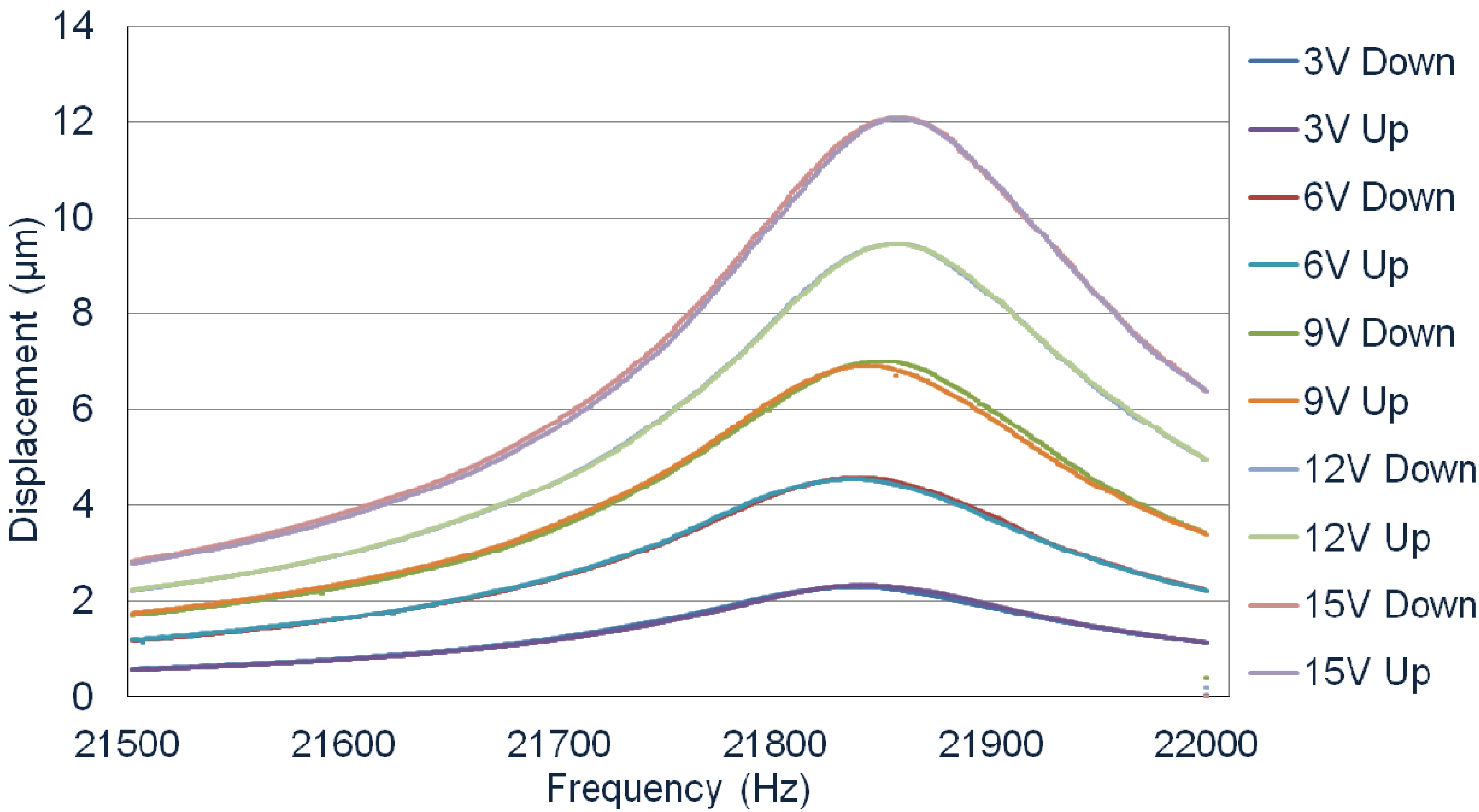
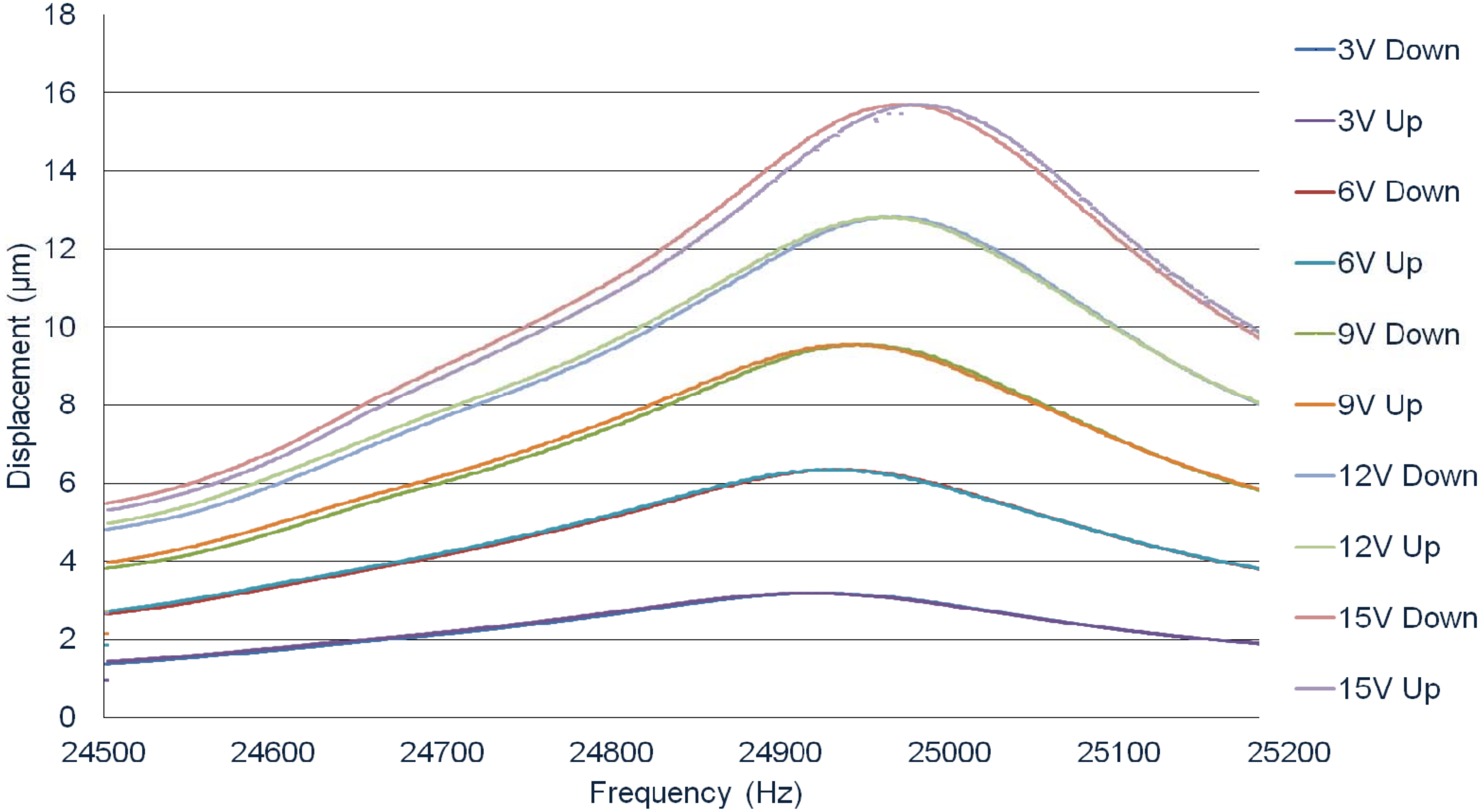


Impedance-Frequency Spectrum of the Modified Brass Cymbal Transducer



Vibration Response of the Standard Brass Cymbal Transducer



Vibration Response of the Modified Brass Cymbal Transducer

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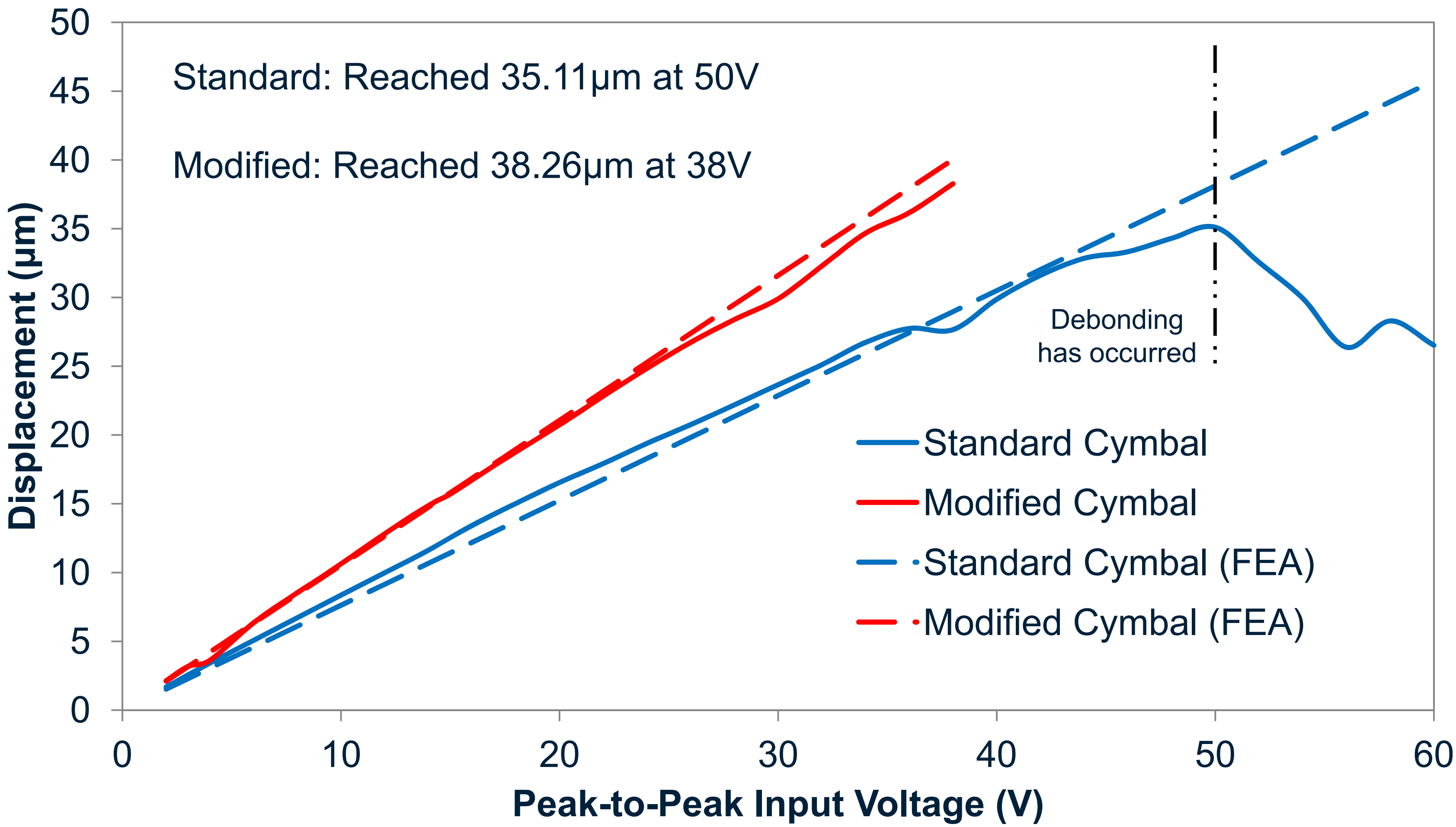

Driving Both Cymbal Transducers

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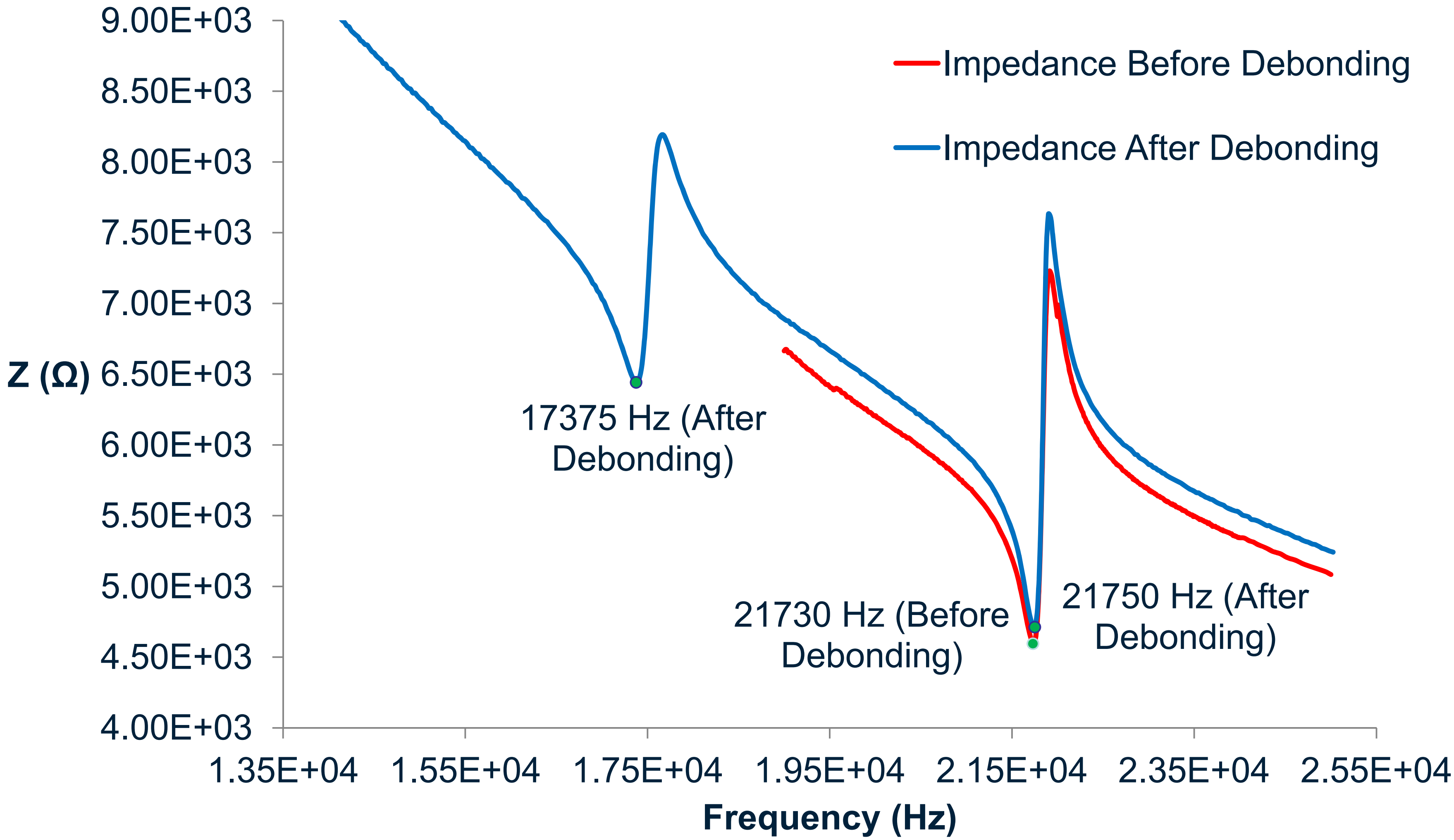

Impedance Analysis (Pre and Post Debonding) of the Standard Brass Cymbal Transducer

7. Conclusions

- The brass ring, coupled with the brass screws, improves the mechanical coupling in the modified device, and allows higher vibration amplitudes to be reached.
- This type of transducer has shown promise for power ultrasonic applications, through its high displacement, broadband, low ultrasonic frequency response.
- There is a good level of agreement between numerical and experimental data.

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Acknowledgments

I would like to thank Andrew Mathieson of the Dynamics Research Group, University of Glasgow, for experimental advice, and the Engineering and Physical Sciences Research Council (Grant EP/P50418X/1) for the funding and support of this project.