Design and Shape Optimization of Electromagnetic Bone Conduction Device Using Cantilever Structure

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Outline

Mechanism of Bone Conduction

Bone Conduction Device

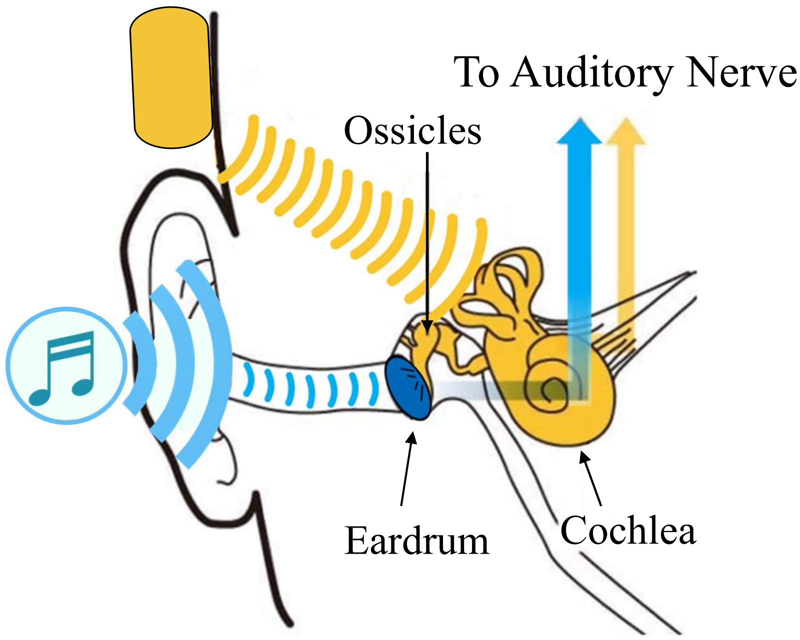
Bone vibration → Cochlea

→ Auditory nerve

Air Conduction

Air vibration→Eardrum→Cochlea

→Auditory nerve



Internal Structure of the Ear

Promising as a next-generation audio interface.

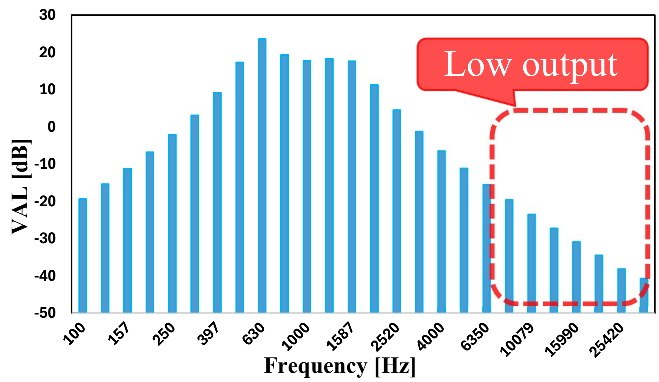
Research Background

Applications as Next-Generation Audio Interfaces

Audio Navigation Systems

Industrial Headsets

Ultrasonic Hearing Aids



Low output in high-frequency ranges.

➡ Shift to Cantilever structure

Realize a 2-way driving system.

➡ Adopt a dual-unit structure.

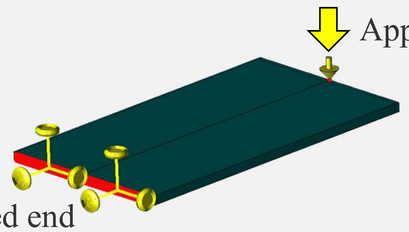
Goal: Improve output performance beyond the audible range(> 20 kHz).

Research Objectives

Features of Cantilever structure Device

① Diaphragm modification

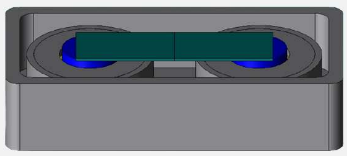
High output by using cantilever structure.



Improve high-frequency output by using a free-end design.

② Unit addition

High output by using dual-unit configuration.



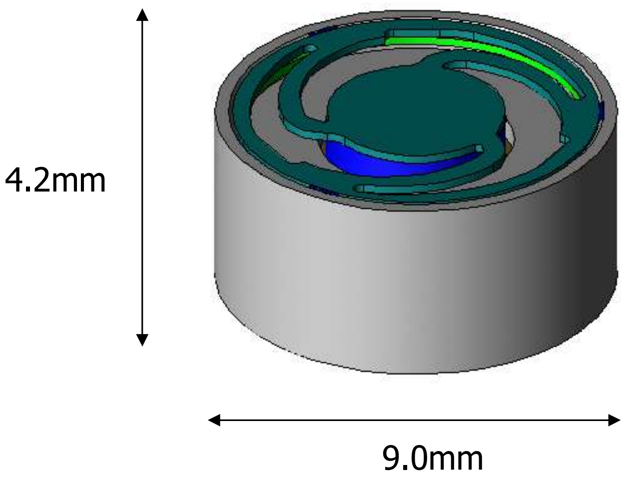
Adopt a dual-unit structure for future 2-way driving systems.

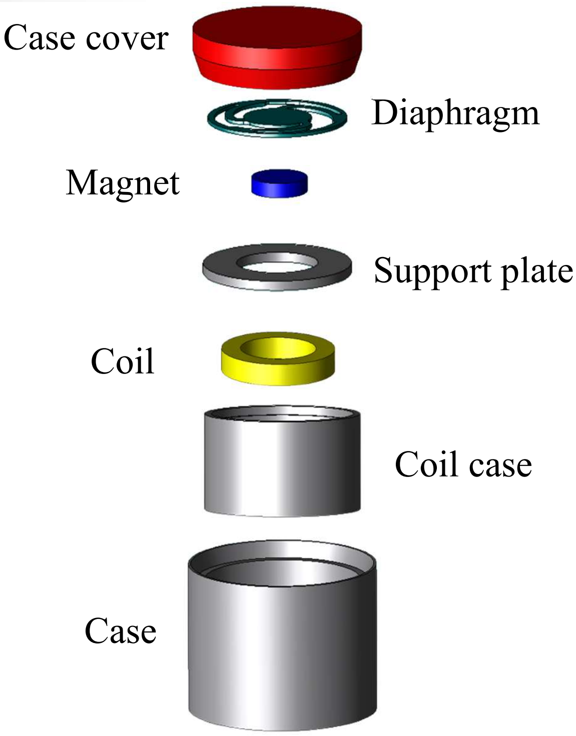
3D-FEM Analysis (Magnetic-Structural Coupling) ⟫ Experimental verification using a prototype.

➡ Evaluate effectiveness through both theoretical and experimental approaches.

Outline

Circular Diaphragm Model

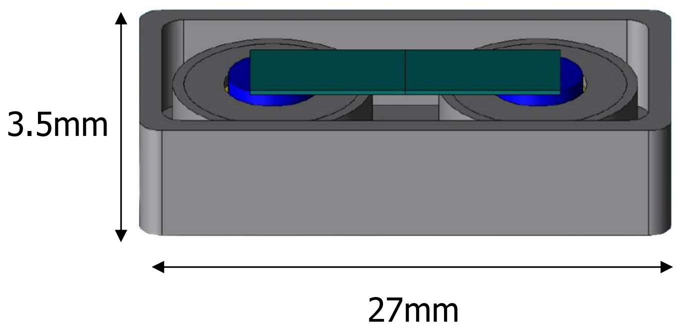




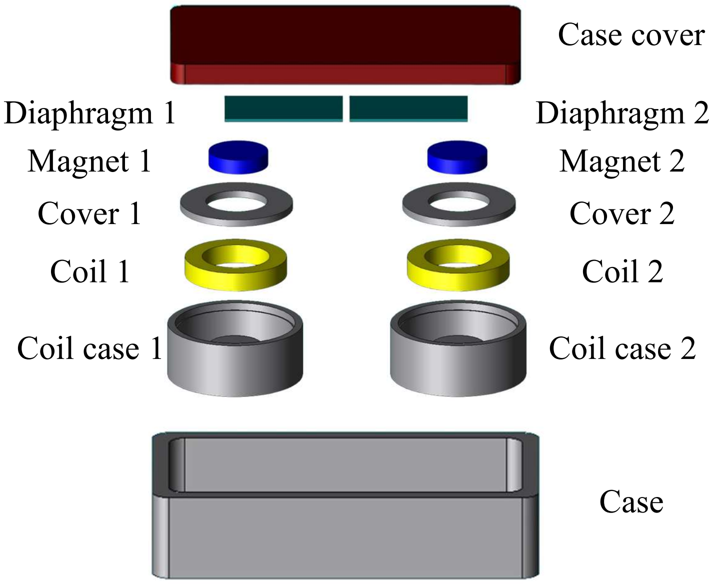
Challenge:

- ✕ Circular shape restricts the vibration amplitude.
- ✕ Short distance from the fix point reduces high-frequency output.

Cantilever Model



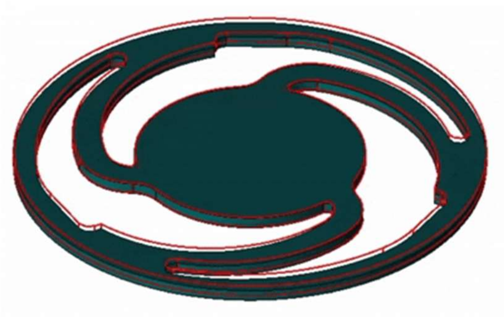
Overall View



Exploded View

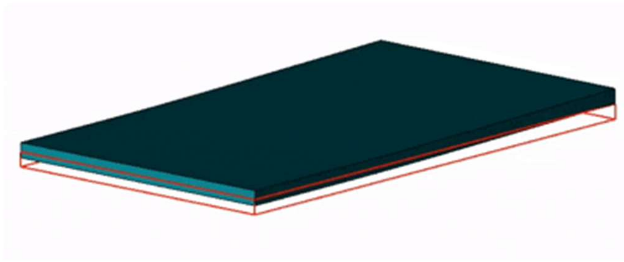
- ✓ Free-end design enables larger vibration displacement.
- ✓ Longer distance from the fix point maximizes output.

Comparison of Vibration Behavior



Circular Diaphragm
(Conventional Model)

Max Displacement: **0.032mm**

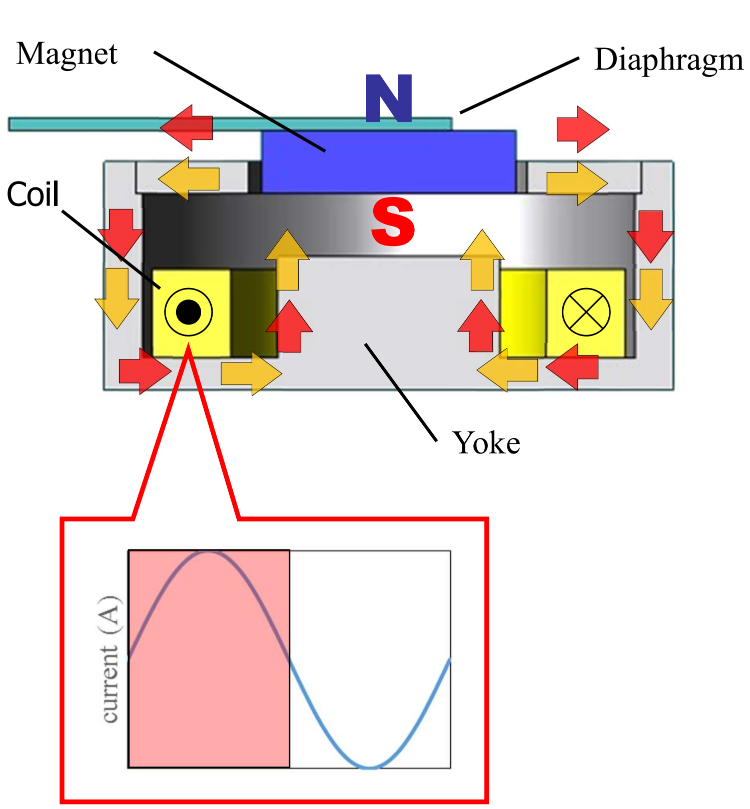


Cantilever (Proposed Model)

Max Displacement: **0.14mm**

- ✓ Larger amplitude due to longer distance from the support point.
- ✓ High displacement is achieved efficiently at high frequencies.

Operating Principle



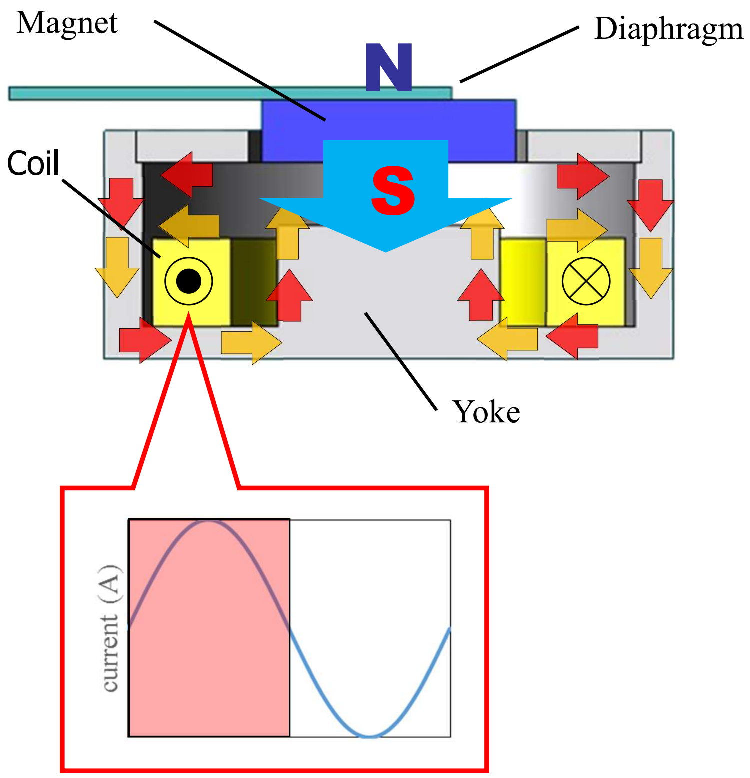
Magnetic flux
coil current flux
Diaphragm displacement

Counter-clockwise current flows:

Magnetic fluxes in the yoke reinforce each other.

The diaphragm displaces downward.

Operating Principle

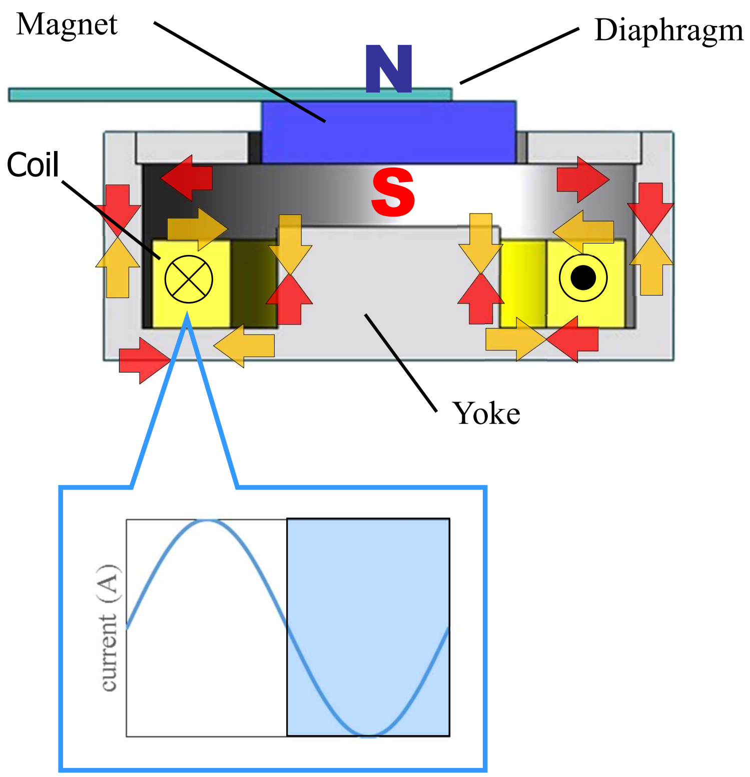


Magnetic flux
coil current flux
Diaphragm displacement

Counter-clockwise current flows:

Magnetic fluxes in the yoke
reinforce each other.
The diaphragm
displaces downward.

Operating Principle



Magnetic flux
coil current flux
Diaphragm displacement

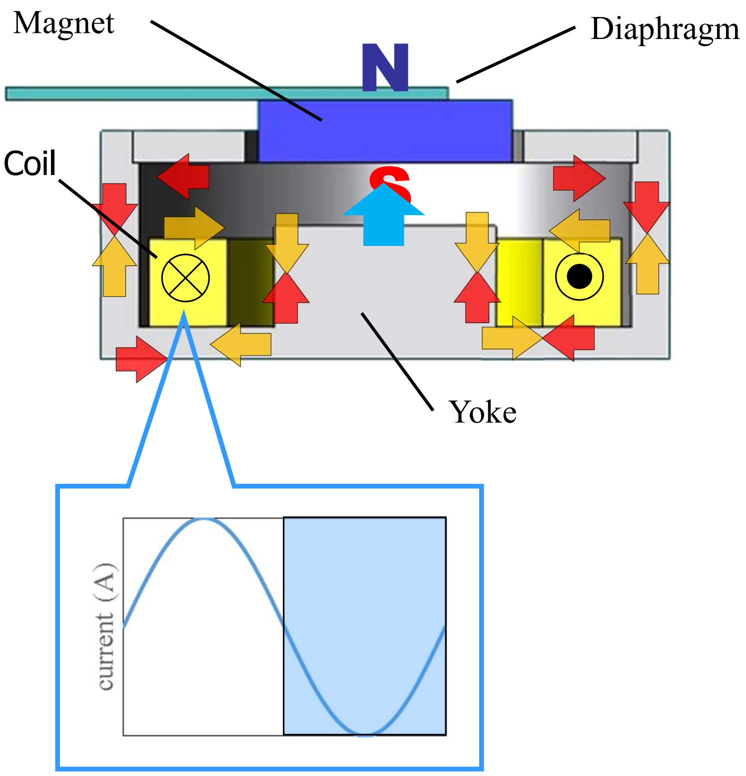
Counter-clockwise current flows:

Magnetic fluxes in the yoke
reinforce each other.
The diaphragm
displaces downward.

clockwise current flows:

Magnetic fluxes in the yoke
oppose each other.

Operating Principle



Magnetic flux
coil current flux
Diaphragm displacement

Counter-clockwise current flows:

Magnetic fluxes in the yoke reinforce each other.

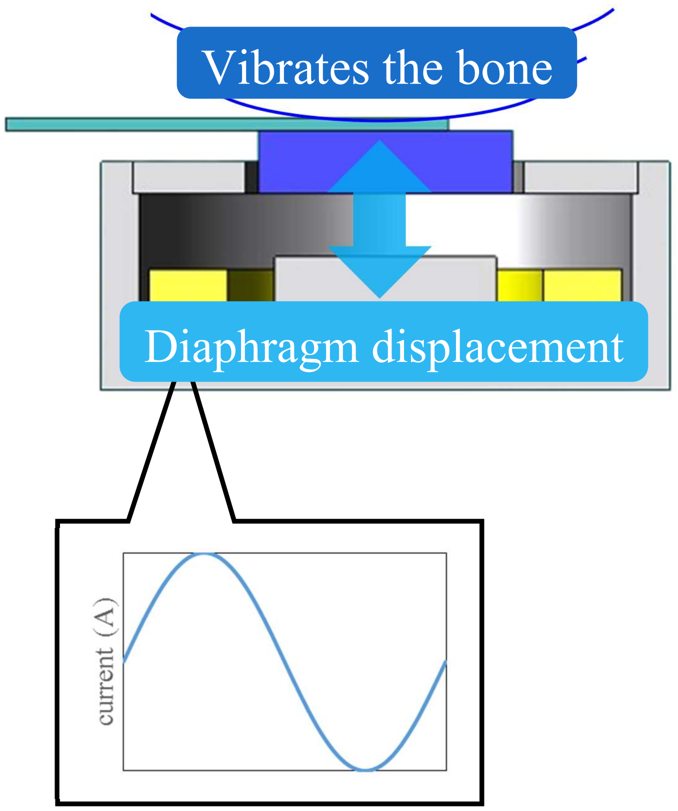
The diaphragm displaces downward.

clockwise current flows:

Magnetic fluxes in the yoke oppose each other.

The diaphragm displaces upward.

Operating Principle



Counter-clockwise current flows:

Magnetic fluxes in the yoke reinforce each other.

The diaphragm displaces downward.

Magnetic fluxes in the yoke oppose each other.

The diaphragm displaces upward.

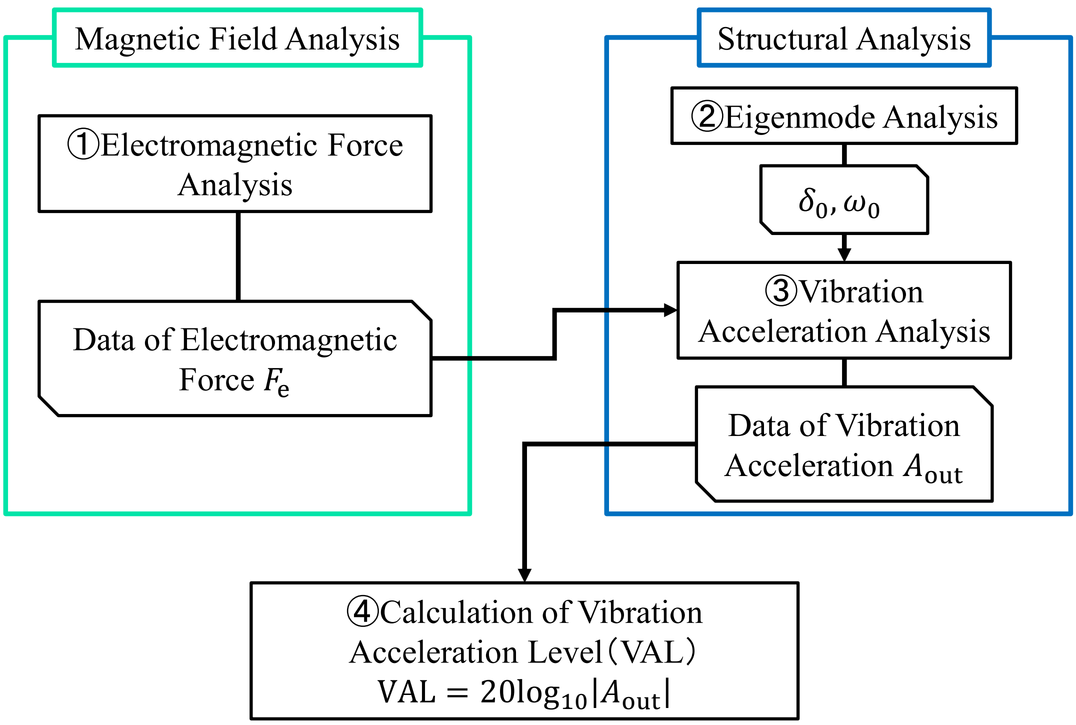
The attractive force between the yoke and magnet changes.

The diaphragm vibrates.

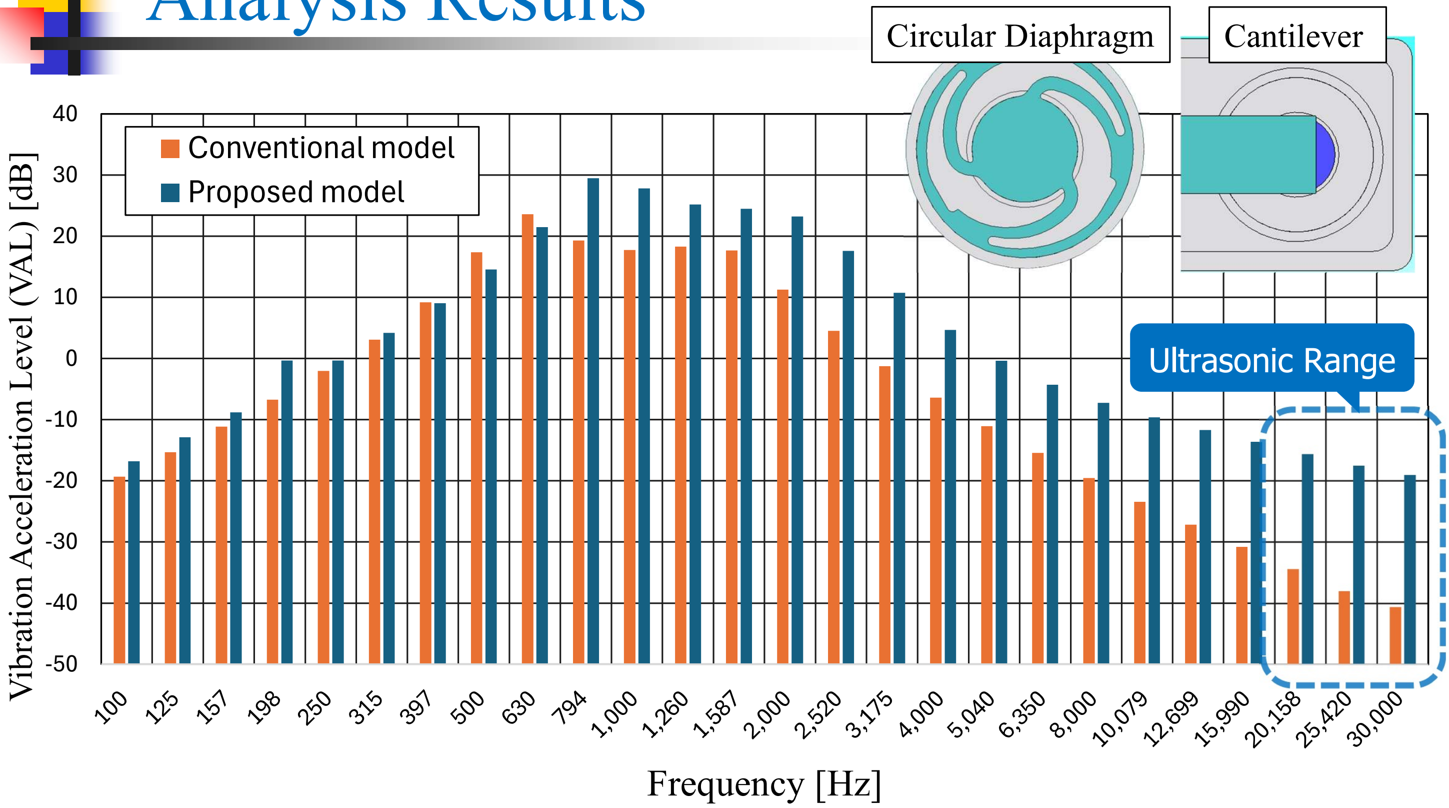
Sound is generated.

Outline

Analysis Method of Bone Conduction Devices

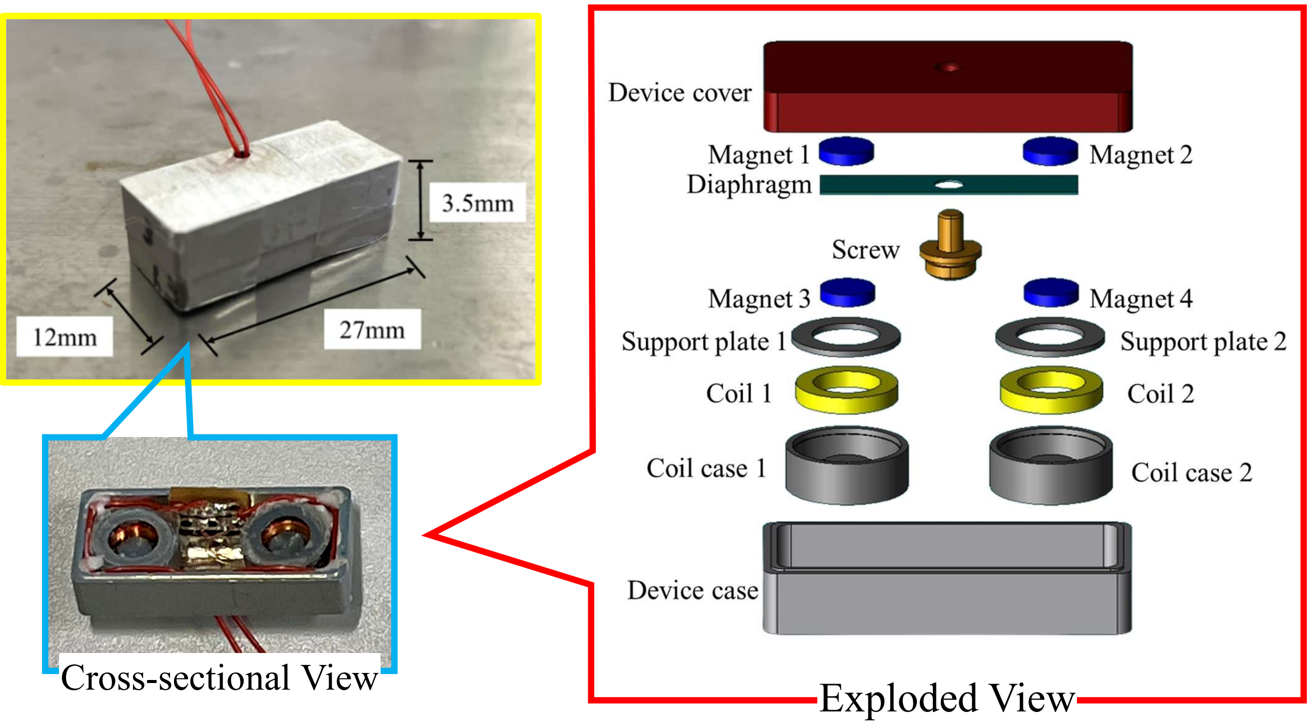


Analysis Results



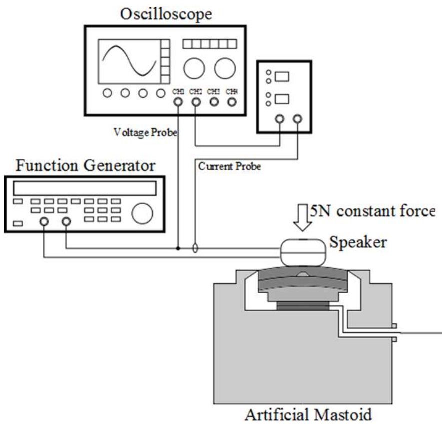
- ✓ Increased output in the high-frequency
- ✓ Resonance frequency: 794 Hz.

Cantilever Model: Prototype



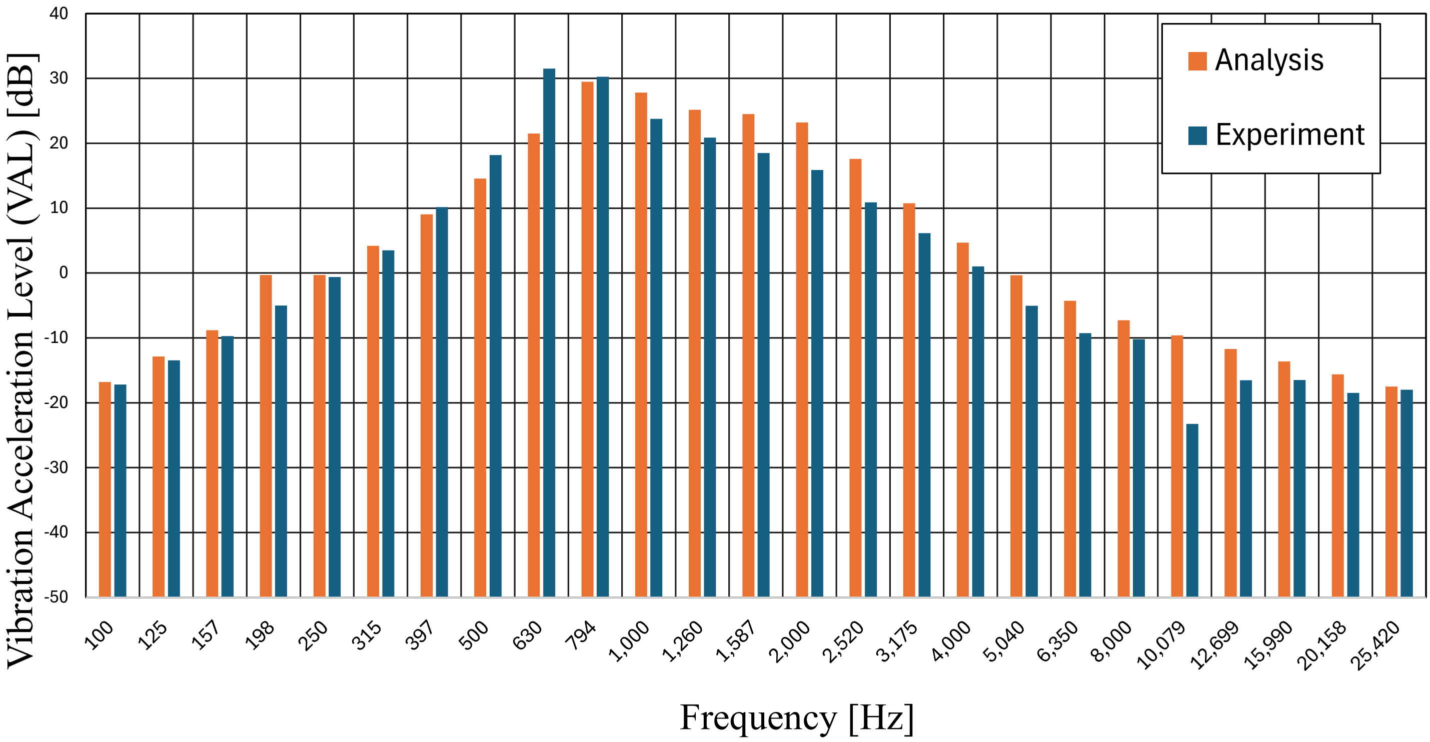
- ✓ The diaphragm is fixed with a screw.
- ✓ Two additional magnets were added to fix the diaphragm

Experimental Setup Overview



1. Measure output acceleration using an artificial mastoid.
2. Fix device to mastoid under 5 N constant load.
3. Apply sinusoidal voltage as a simulated audio signal.
4. Sweep 100–30,000 Hz in 1/3 octave steps.
5. Analyze frequency characteristics using an FFT analyzer.

Experiment vs. Analysis



✓ Generally matches analysis results

✓ Slightly lower resonance frequency

Outline

Mechanical Design Method using GA

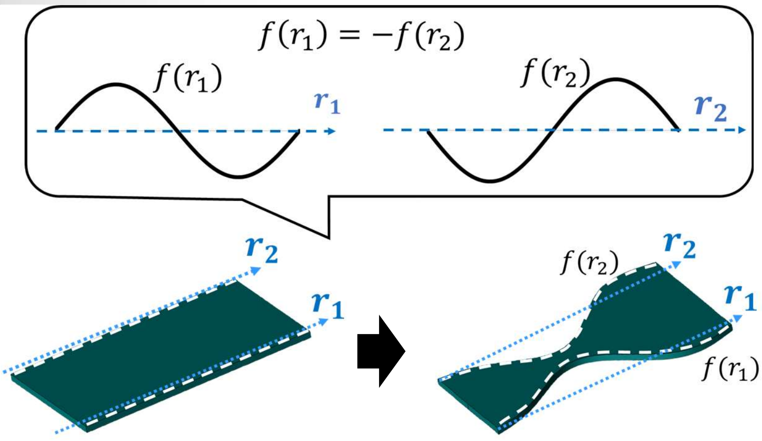
➢ Design Method

Diaphragm shapes $f(r_1)$ & $f(r_2)$ are defined by a trigonometric series:

Amplitude Frequency

$$f(x) = a_0 + \sum_{n=1}^{3} (a_n \cos p_n x + b_n \sin q_n x)$$

$$(0 \leq x \leq b_0)$$



Original model Optimized model

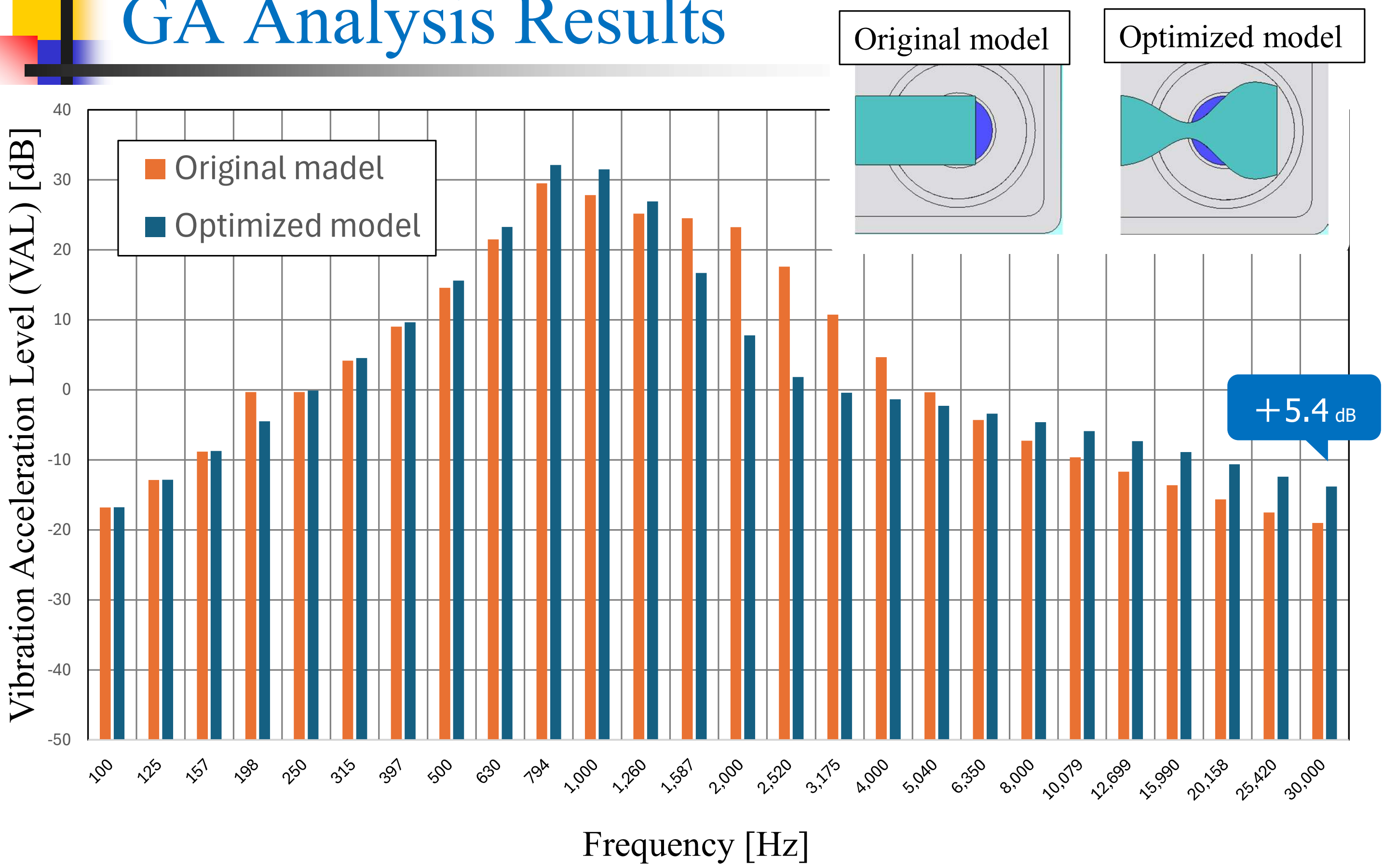
GA Conditions

- ✓ $f(r_1) = -f(r_2)$ (Symmetric shape)
- ✓ Objective function: Maximize VAL at 30kHz
- ✓ Parameters: Population :100
  Max generations :100
- ✓ Design variables: 14 variables (a_1~a_3 , p_1~p_3 , b_1~b_3 , q_1~q_3)

Parameter	Value
a_0	0.5~2.5
a_1, a_2, a_3	−1~1
b_0	3~9
b_1, b_2, b_3	−1~1
p_1, p_2, p_3	−3~3
q_1, q_2, q_3	−3~3

Shape optimization using 14 variables to improve output.

GA Analysis Results



✓ VAL increased by 5.4 dB at 30 kHz.
✓ Decreased in the range of 1587–5040 Hz.

Conclusion

Objectives & Results

Optimization of the proposed model and measurement of the prototype to improve high-frequency output of bone conduction devices.

- Improved high-frequency output over the conventional model.
- Confirmed effectiveness through prototype measurement.
- Shape optimization improved VAL by 5.4 dB at 30 kHz.

Future Work

- GA optimization using multiple objective functions.
- Optimal design and prototype fabrication for 2-way drive.