DESIGN, SIMULATION, AND FABRICATION OF THERMAL ANGULAR ACCELEROMETERS

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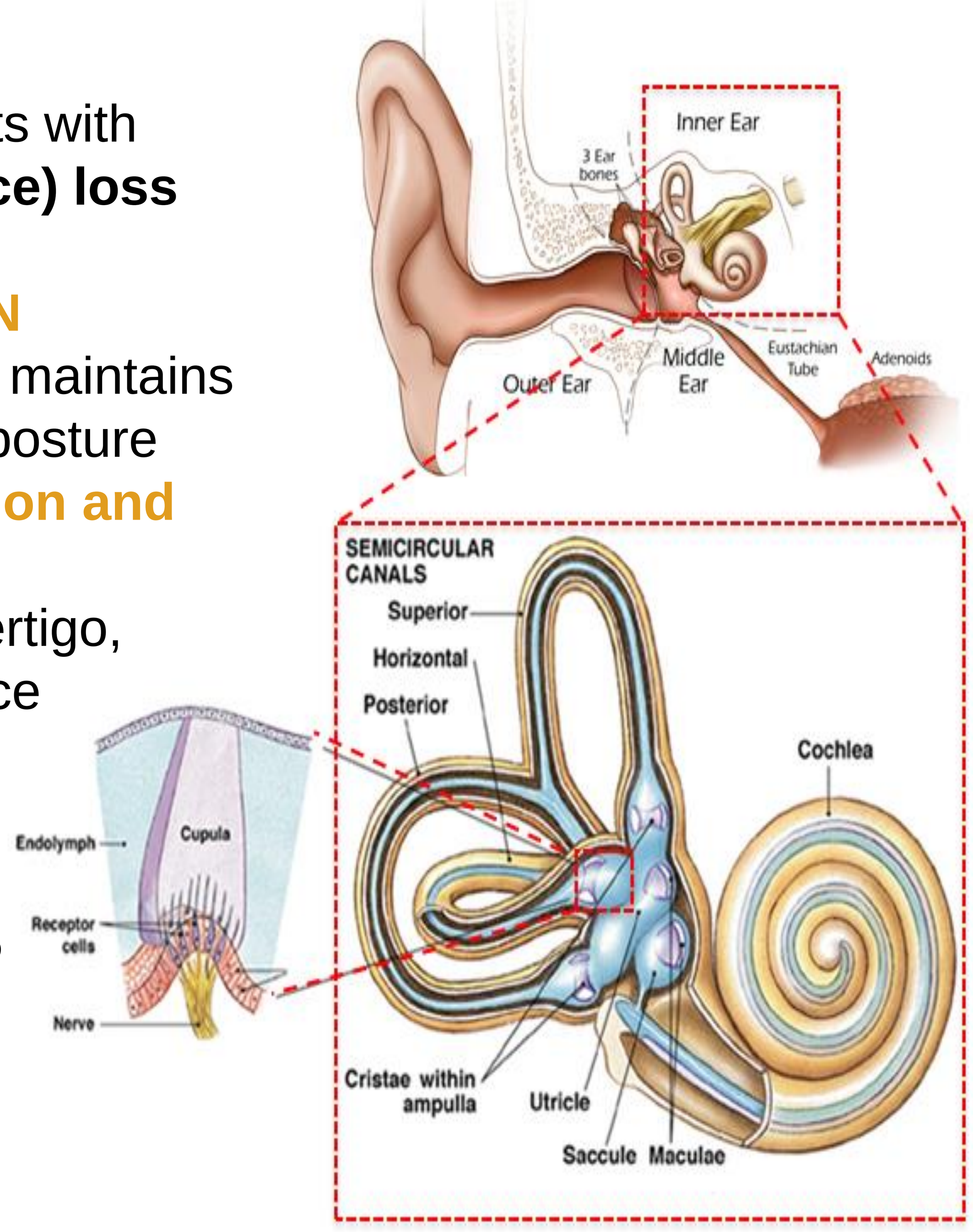
Introduction

OVERALL GOAL

- Restoring balance to patients with **bilateral vestibular (balance) loss**

BACKGROUND/MOTIVATION

- The human balance system maintains visual acuity and stabilizes posture through **sight, proprioception and inner ear sensors**
- Vestibular failure leads to vertigo, disequilibrium, and imbalance
- Consequence for vestibular failure can be falls, **the leading cause of fatal injuries** for persons over 65
- Over 40% of Americans experience dizziness



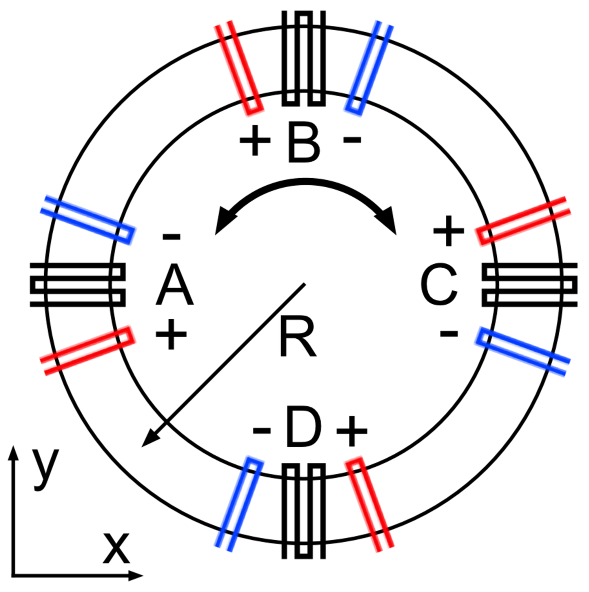
Schematic of vestibular system located in the inner ear. The three semicircular canals are responsible for detecting angular motion in three different planes. (Image courtesy of Dr. Robert Droual)

AVAILABLE SOLUTIONS

- Physical rehabilitation
- Sensory substitution
  1. **Vestibular implants**
  2. Auditory stimulation
  3. Tongue input
  4. Tactile input
  5. Electrical stimulation

Design & Fabrication

- **Approach:** Bio-inspired gas/liquid filled micro-torus with multiple thermal flow/acceleration sensors to measure angular acceleration
- **Sensor Design:** Heating resistor creates symmetric temperature profile that is distorted by applied angular/linear acceleration and sensed using two resistive temperature probes
- **Linear vs. Angular Acceleration:** (1) Characteristic response pattern used to distinguish linear and angular acceleration; (2) Closed micro-torus is intrinsically insensitive to linear acceleration



	A +	A −	B +	B −	C +	C −	D +	D −
α	↑	↓	↑	↓	↑	↓	↑	↓
+X	O	O	↑	↓	O	O	↓	↑
+Y	↑	↓	O	O	↓	↑	O	O

Temperature change (↑,↓,O) of sensors upon angular (α) and linear (+x,+y) acceleration.

- **Fabrication:** Two mask process with PECVD SiO_2 micro-bridges carrying aluminum heating resistors; micro-torus released by XeF_2 etching

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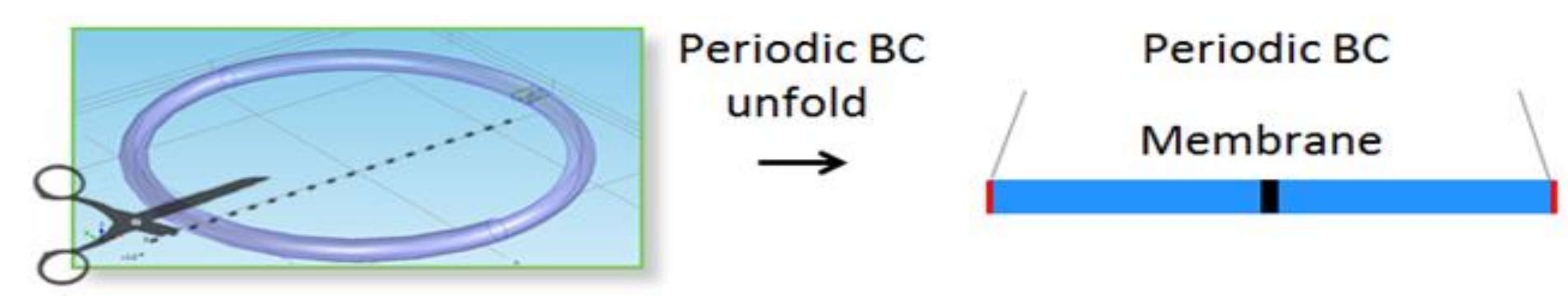
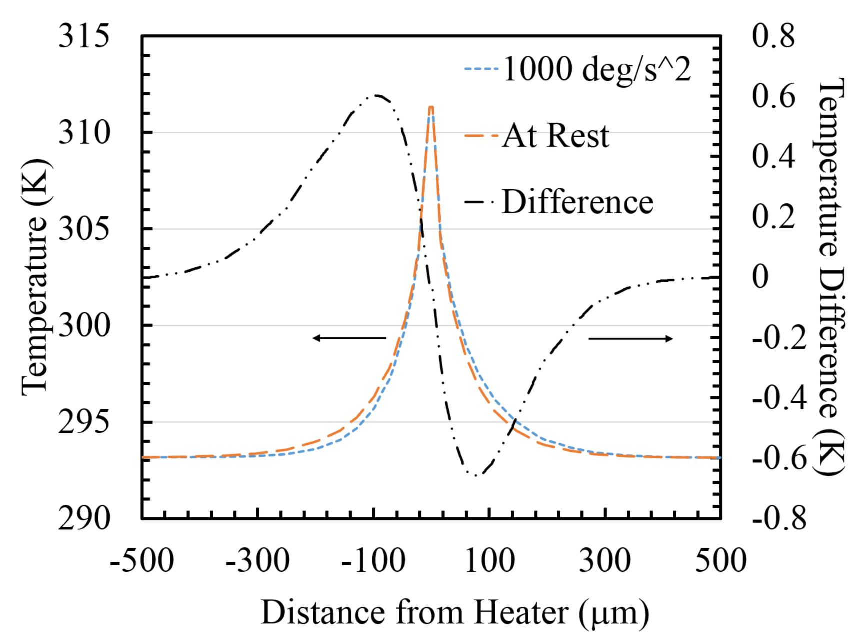
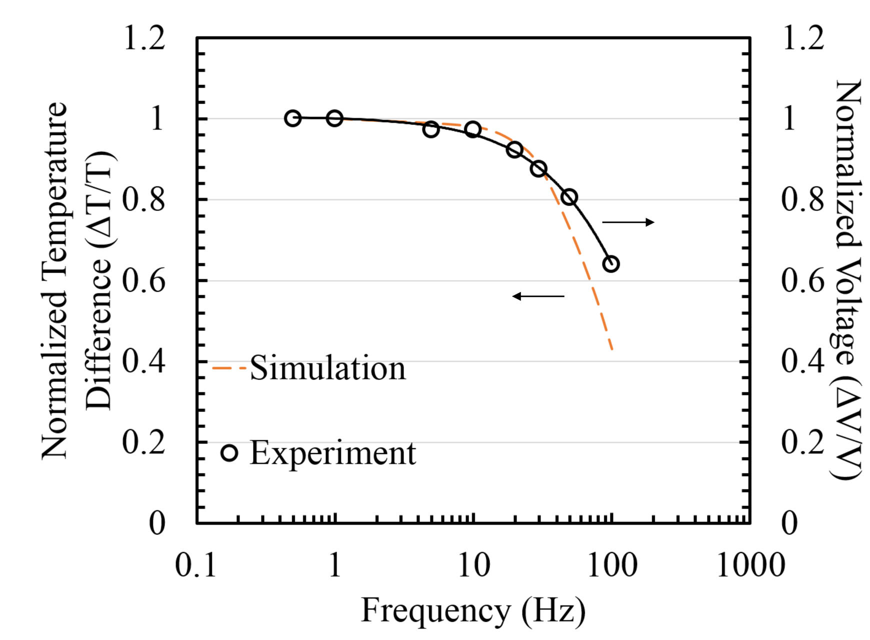
Simulation



Simplified 2-D COMSOL model by unwrapping torus and applying periodic BCs.

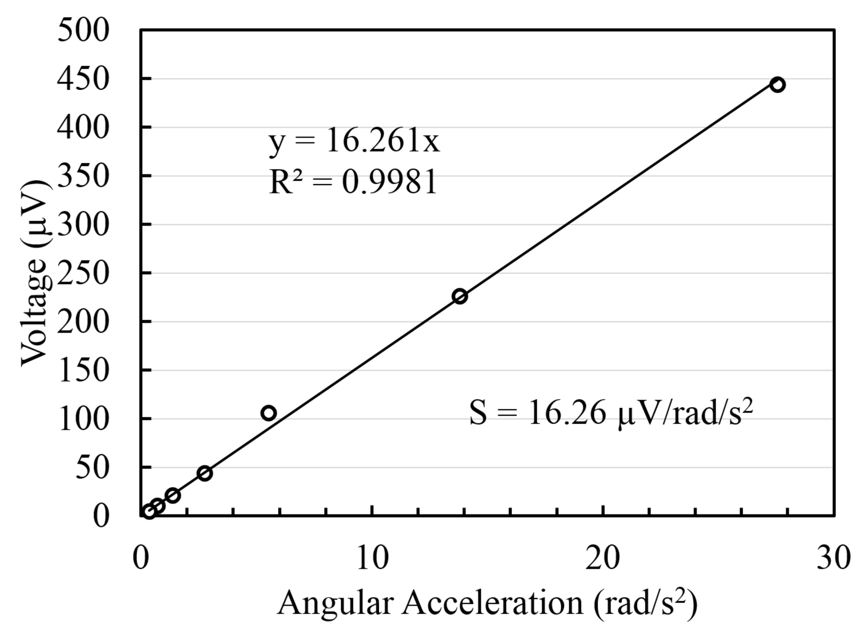


Simulated temperature profile along torus (left and right of a heater) for α=0 and 1000deg/s², as well as temperature difference between profiles, indicating optimal location of T-probes.

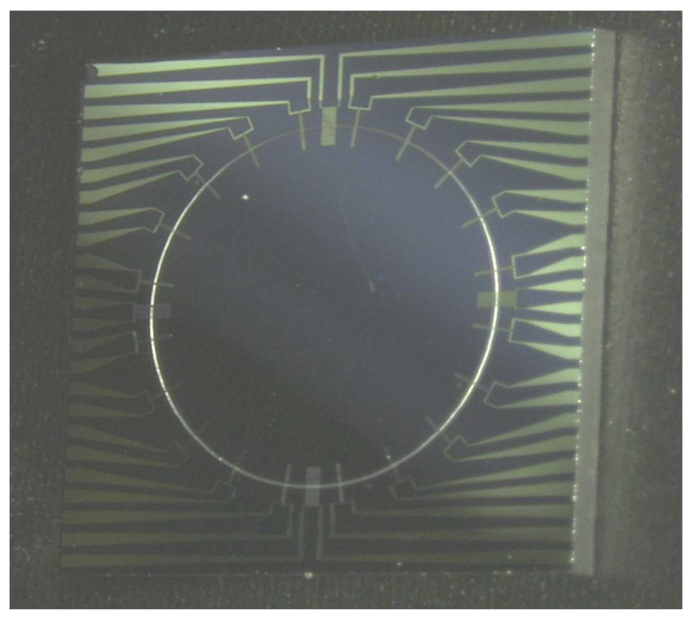


Simulated and measured frequency transfer characteristic. A peak angular acceleration of 1000deg/s² was applied in case of the FEM simulation.

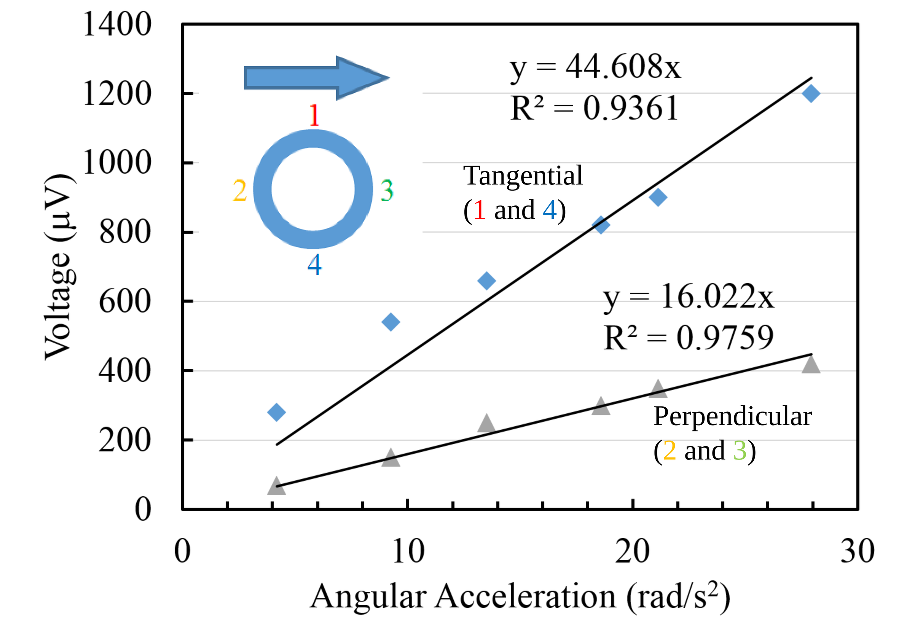
Inertial Testing



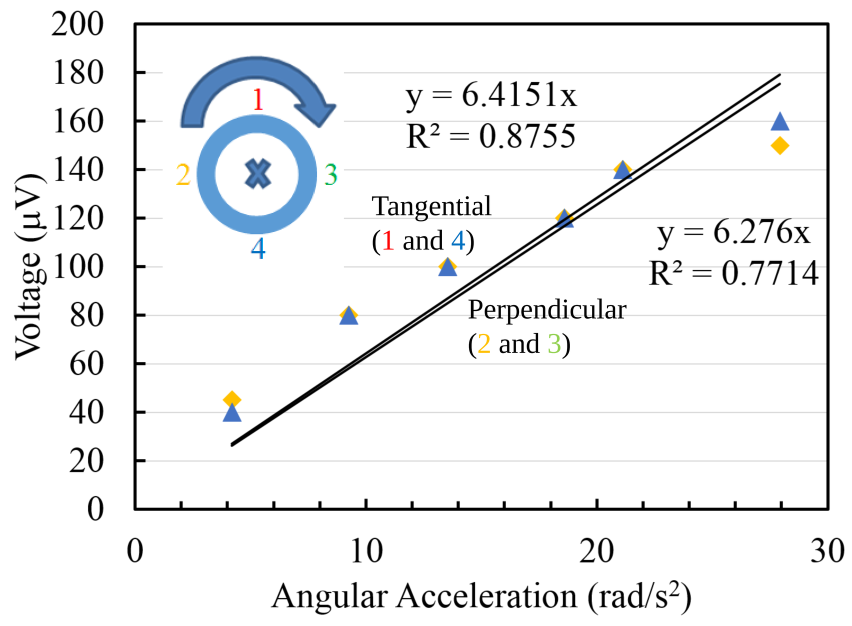
Output voltage change across temperature probe biased with 1mA as a function of the angular acceleration applied (f=2Hz).



Optical image of fabricated device with R=2.85mm, featuring 4 heaters and 20 temperature probes.



RMS output voltage change across different temperature probes on the same device undergoing angular acceleration superimposed by (tangential) linear acceleration.



RMS output voltage change across different temperature probes on the same device undergoing angular acceleration only.