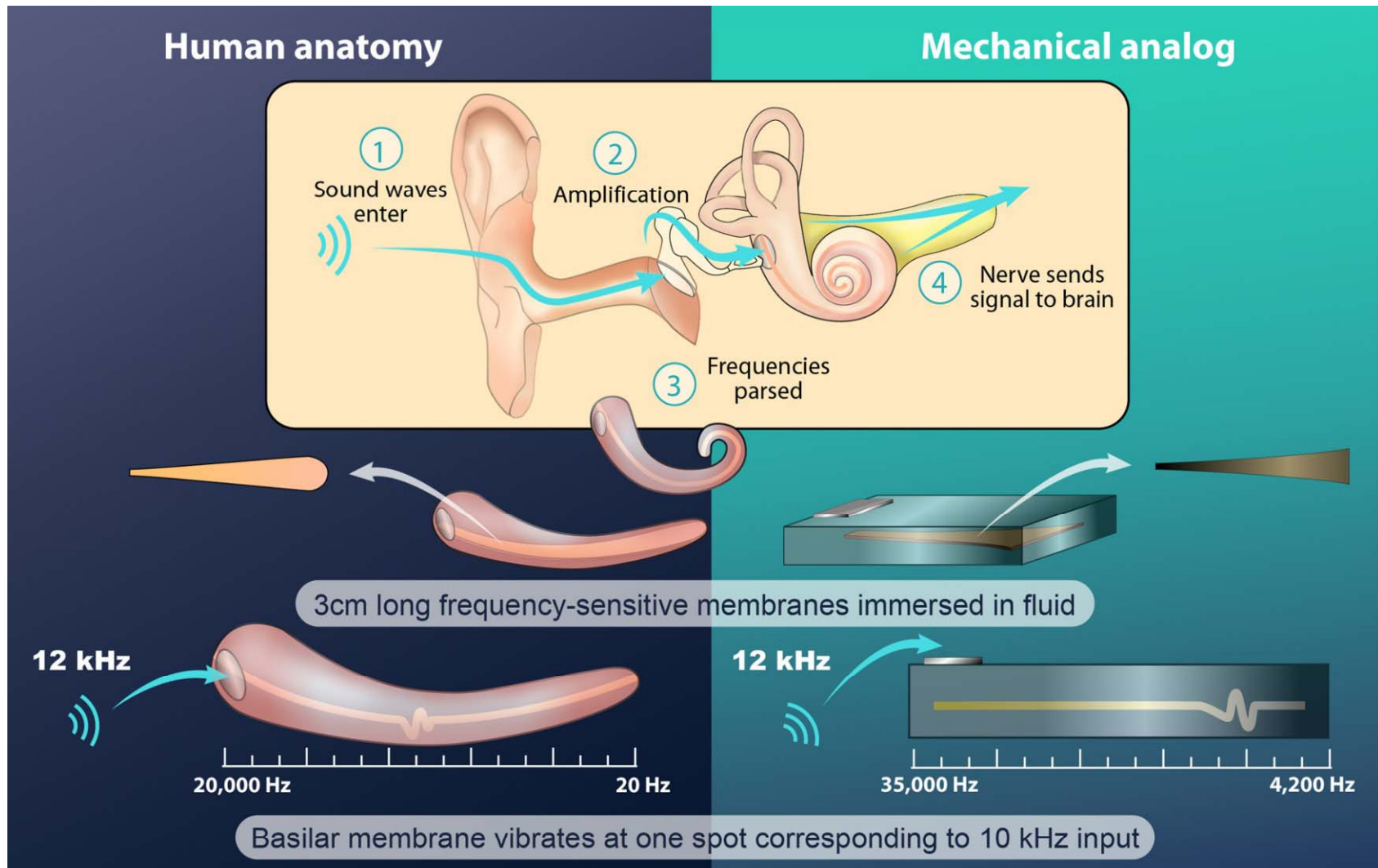


Low Noise CMOS Simulation of Outer Hair Cell Activity in the Mammalian Cochlea



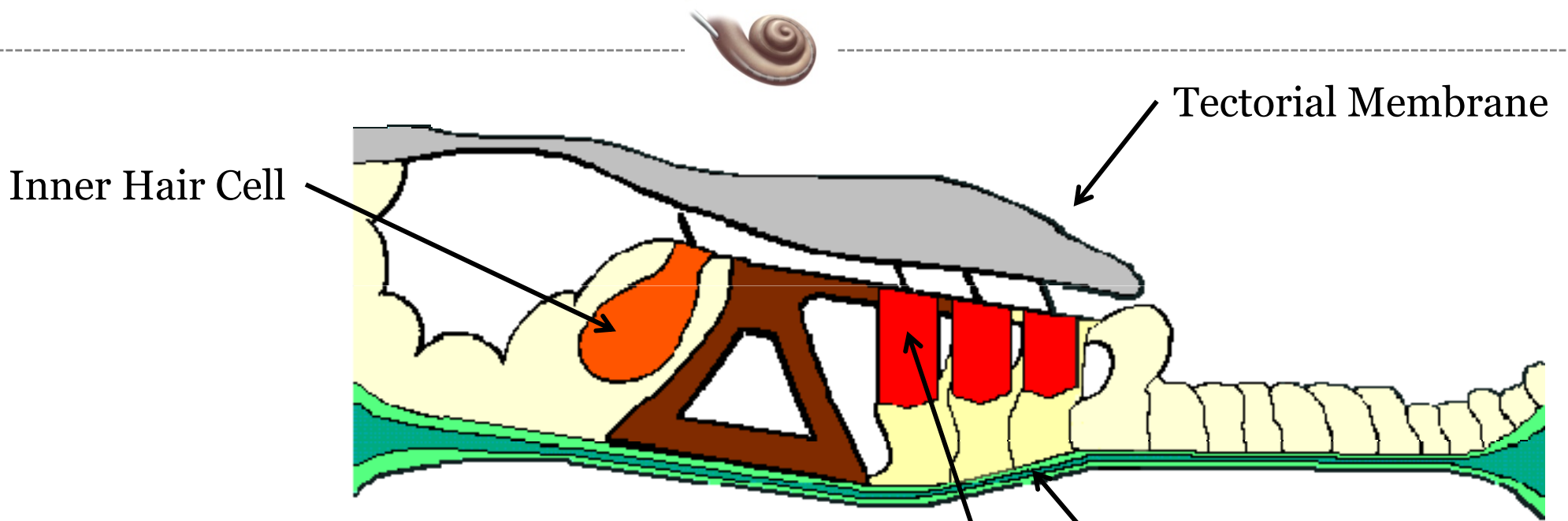
KAREN JUZSWIK
ROBERT LITTRELL
EDWARD TANG

Cochlea & MEMS Transducer



Picture courtesy of NSF

Outer Hair Cells



Inner Hair Cell

Tectorial Membrane

Basilar Membrane

Outer Hair Cell

- Outer Hair Cell Feedback
 - Enhance Sensitivity
- Tectorial Membrane & OHC
 - 2nd Order System Model
- Inner Hair Cell Sensing

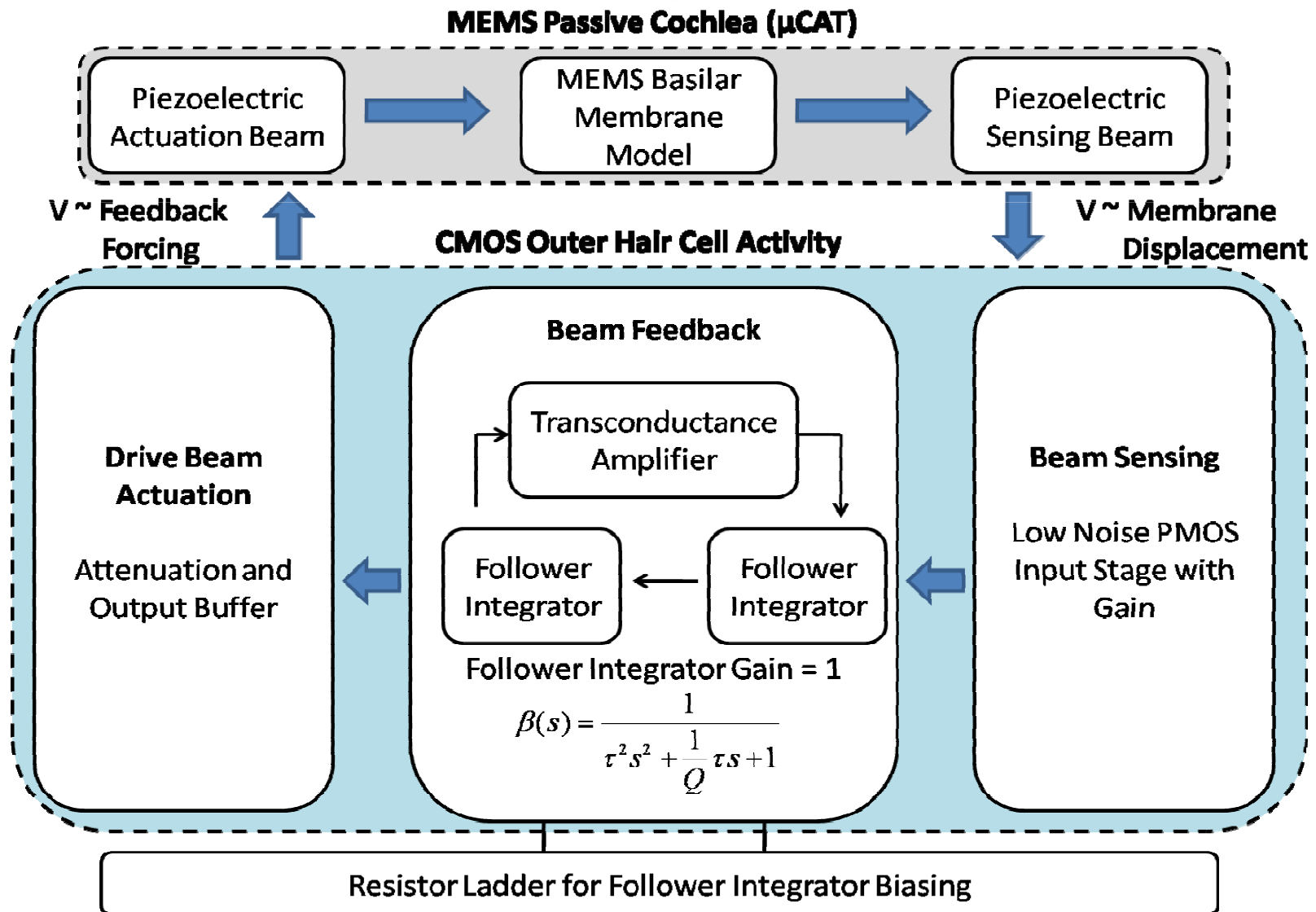
Goals & Specifications



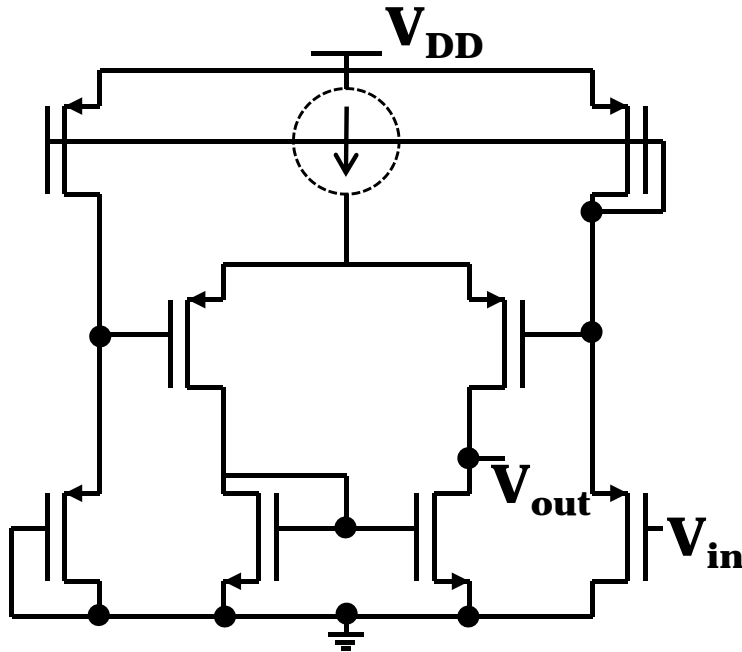
- Test theories of OHC operation
- Build a better transducer
- Modeling the 2nd order system of tectorial membrane and OHC

	Specifications
Bandwidth	20Hz – 20kHz
Max Adjustable Gain	40 dB
Input Referred Noise (1kHz)	38nV/ $\sqrt{\text{Hz}}$
Max Input Signal	276 μV

Block Diagram



Stage 1 – Beam Sensing



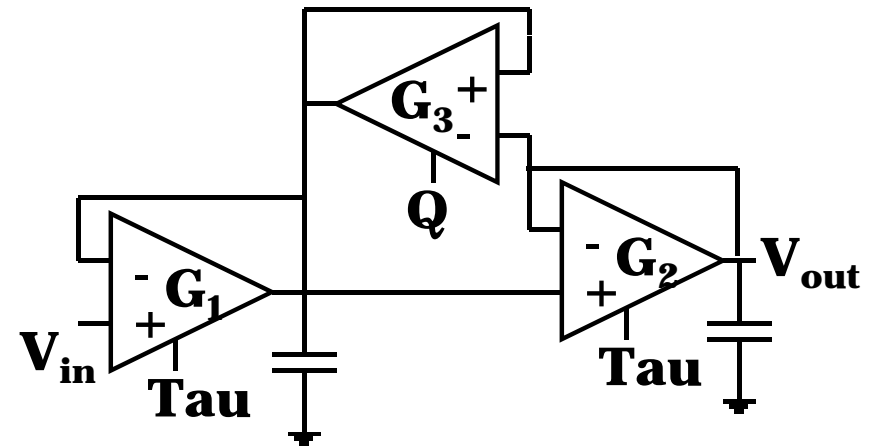
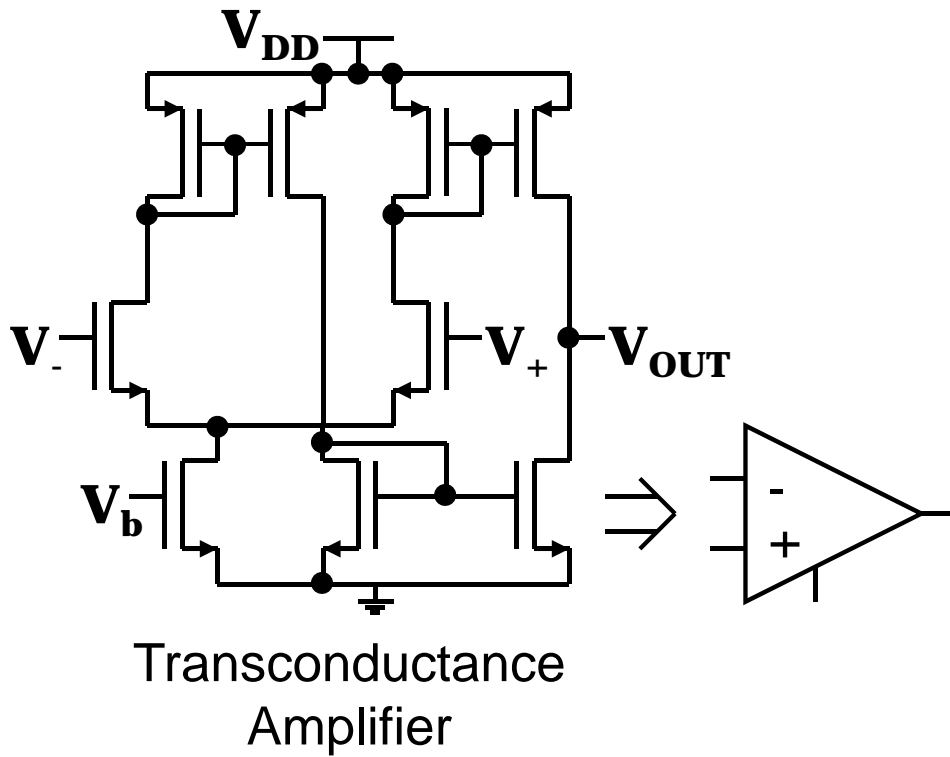
- PMOS Differential Amplifier
- Noise Sources
- Biasing of Input
- Single Ended Conversion

$$E_{eq}^2 = (E_{white}^2 + E_{1/f}^2) \Delta f = \left(\frac{8kT(1 + g_{mbs}/g_m)}{3g_m} + \frac{KF}{2fC_{ox}WLK'} \right) \Delta f$$

Stage 2 – Beam Feedback



- Transconductance amplifier
- Subthreshold devices
- Follower integrator
- Adjustable damping and time constant

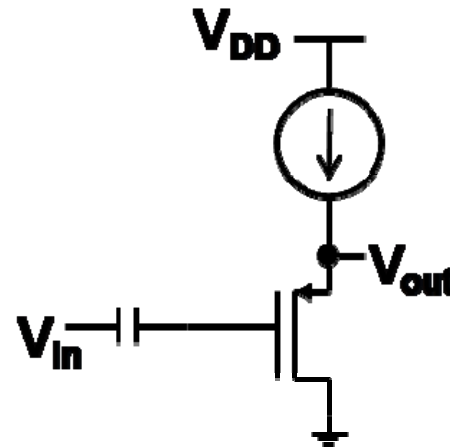


$$\beta(s) = \frac{1}{\tau^2 s^2 + \frac{1}{Q} \tau s + 1}$$

Stage 3 – Drive Beam Actuation



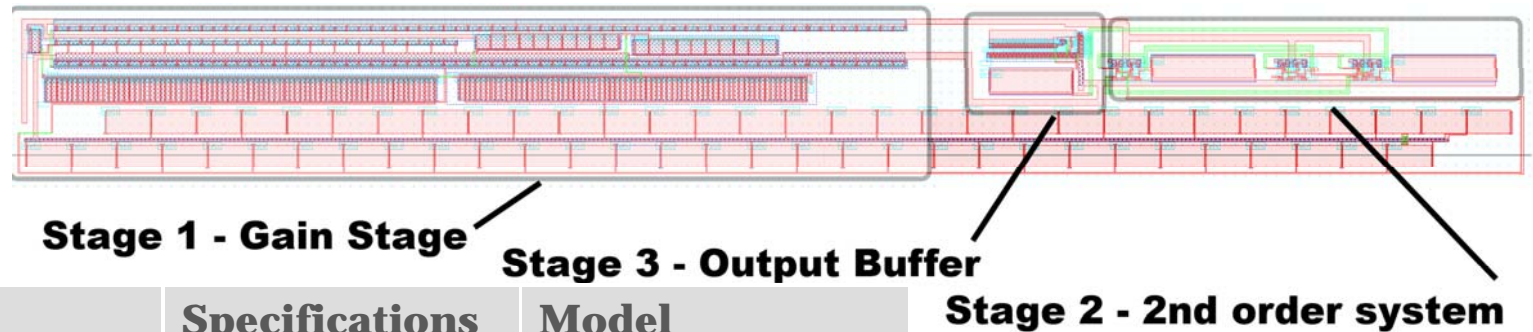
- Buffer between output of second order system and output impedance
- Source follower topology
- Coupling capacitor
- Adjustable attenuation



Circuit Performance



- All specifications are exceeded
- At process corners, the time constant and quality factor show significant variation as cited by Lyon and Mead (1988)

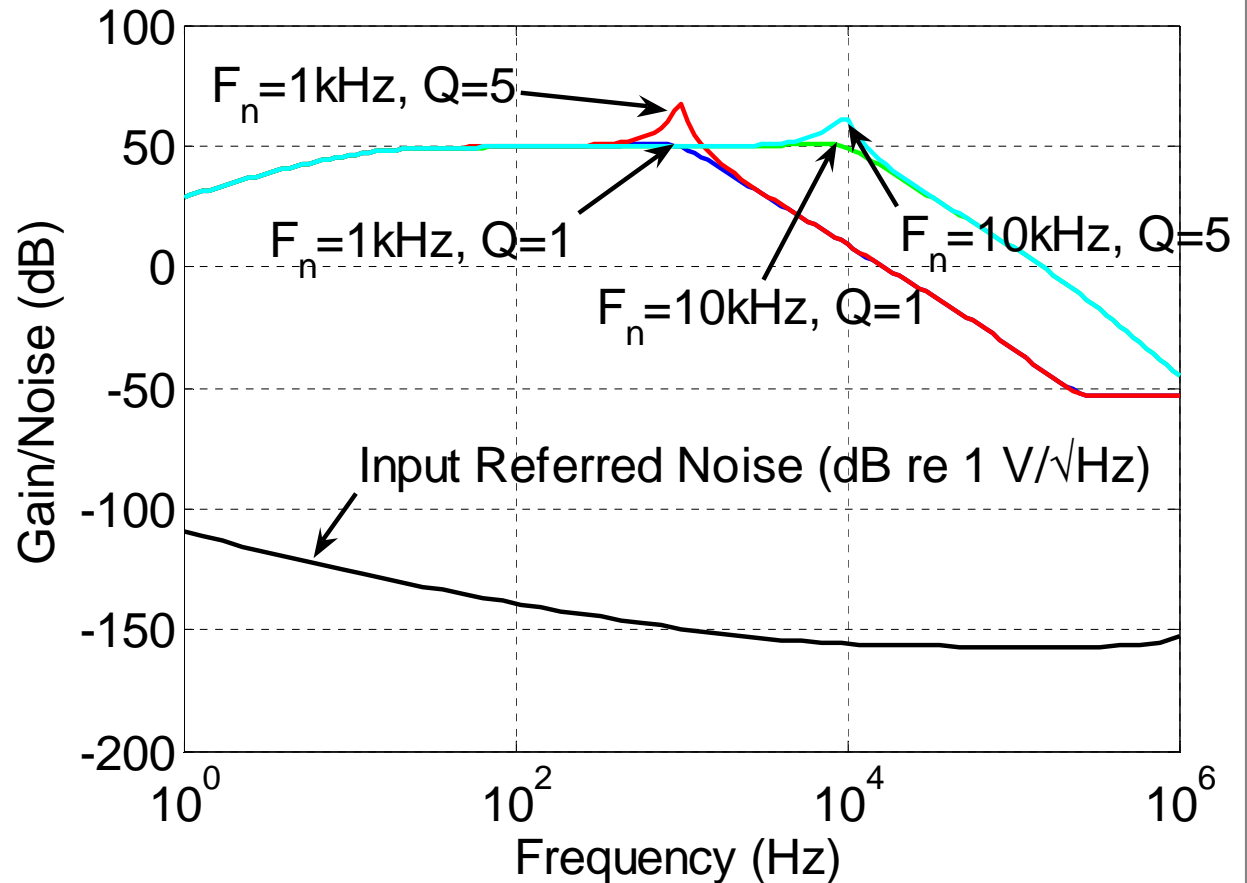


	Specifications	Model
Bandwidth	20Hz – 20kHz	11Hz – 185kHz
Max Adjustable Gain	40 dB	49.5 dB
Input Referred Noise (1kHz)	38nV/ $\sqrt{\text{Hz}}$	37.5nV/ $\sqrt{\text{Hz}}$
Max Input Signal	276 μV	>1 mV
Total Area	N/A	0.084 mm ²

Circuit Performance



- Response of circuit can be adjusted with external voltage for specified natural frequency and quality factor
- Input referred noise is below the self noise of a piezoelectric sensor
- Gain is 49.5 dB



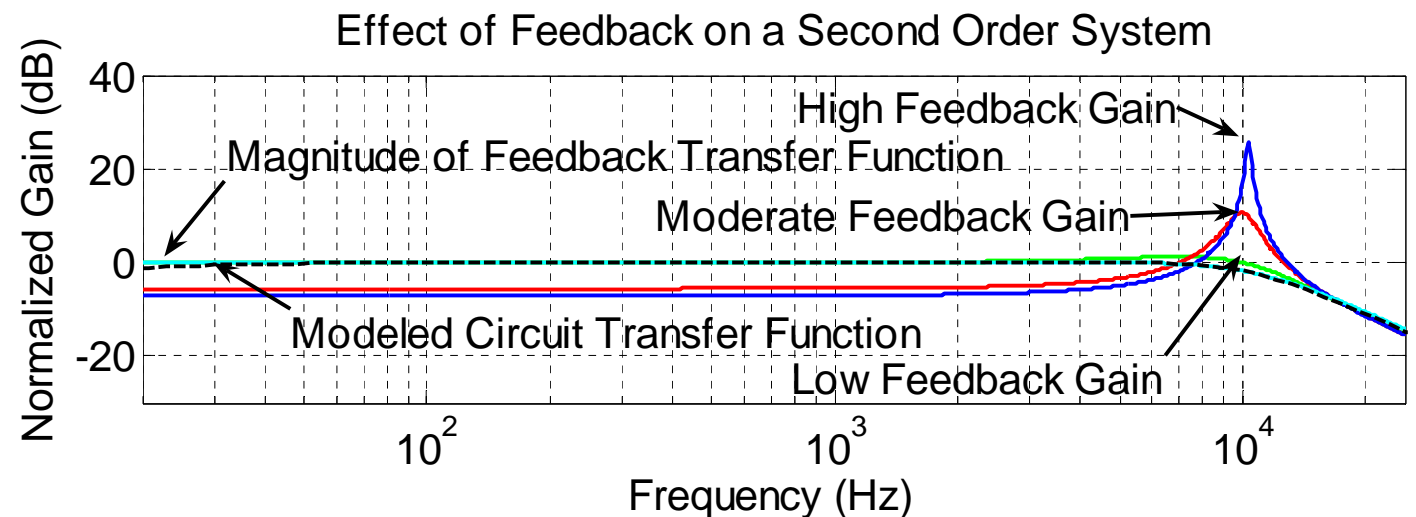
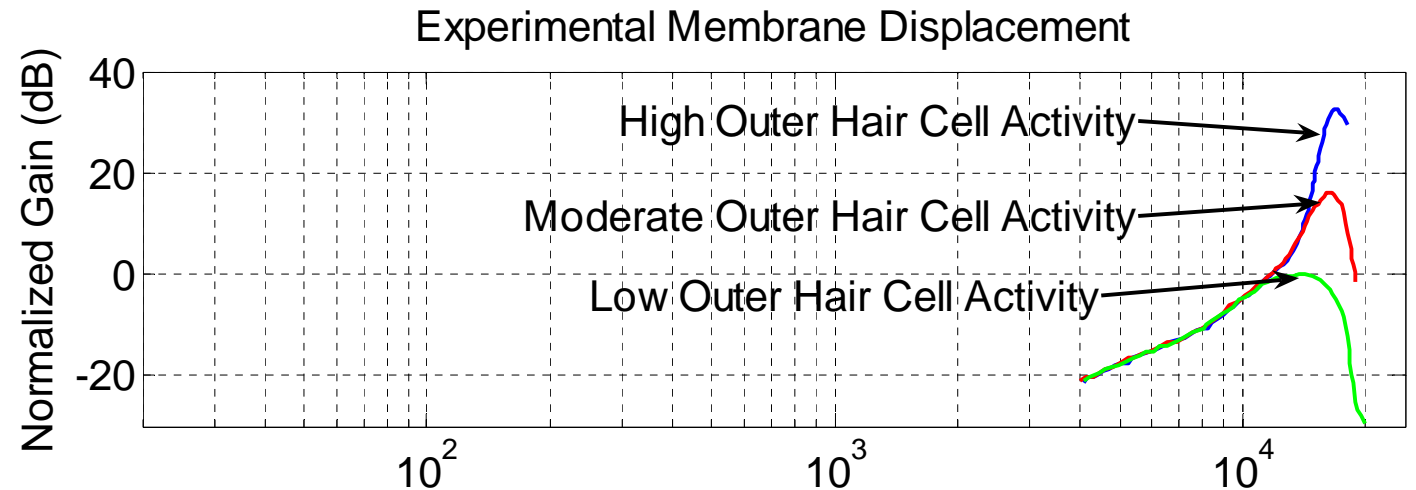
Mimicking OHC Activity



- Qualitative comparison: circuitry Vs. OHC feedback

- Experiments by Cooper (1998) on a Guinea Pig

- Response of 2nd order system





Questions?