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Optimization of MEMS Capacitive Accelerometer as Fully Implantable Middle Ear Microphone for Hearing Aid

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INTRODUCTION

- Hearing loss is the third leading chronic disability following arthritis and hypertension.
- 9 out of every 10 children who are born deaf are born to parents who can hear.
- Profound hearing disability in India is about one million.
- 1.2 million people with severe hearing disability.
- 0.9 million people with moderate hearing disability and 7.1 million people with very mild hearing disability.

CONTD….

- Two common hearing loss are

1)Sensorineural hearing loss : This is caused by damage to the cochlea , the snail-shell like structure of the inner ear containing hair cells, the movement of which is interpreted by the brain as sound.

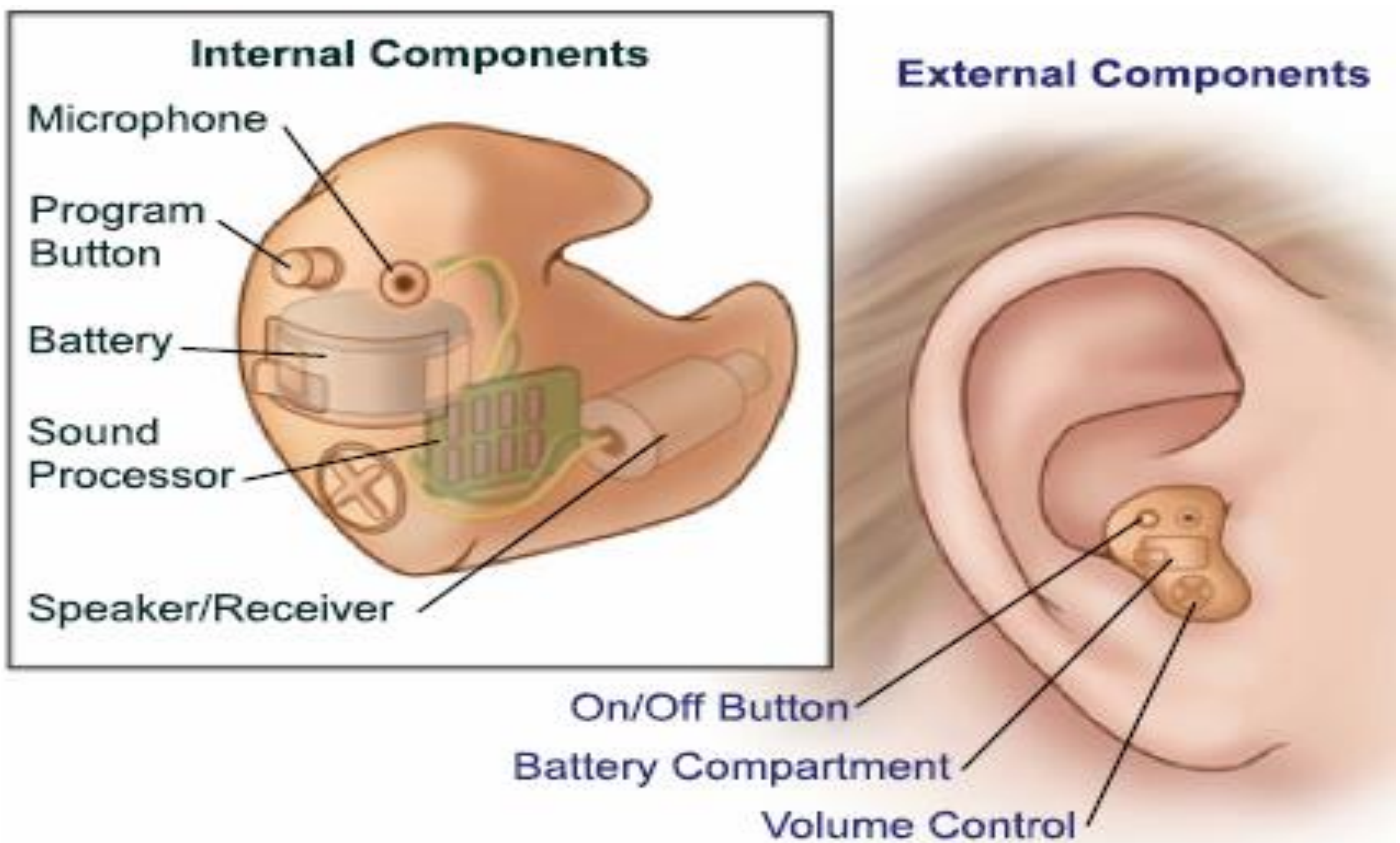
2)Conductive hearing loss: It relates to the problem of conducting sound waves along the route between the outer ear to the middle ear

The conductive hearing loss can be treated by surgery and the sensorineural hearing loss by cochlear implants.

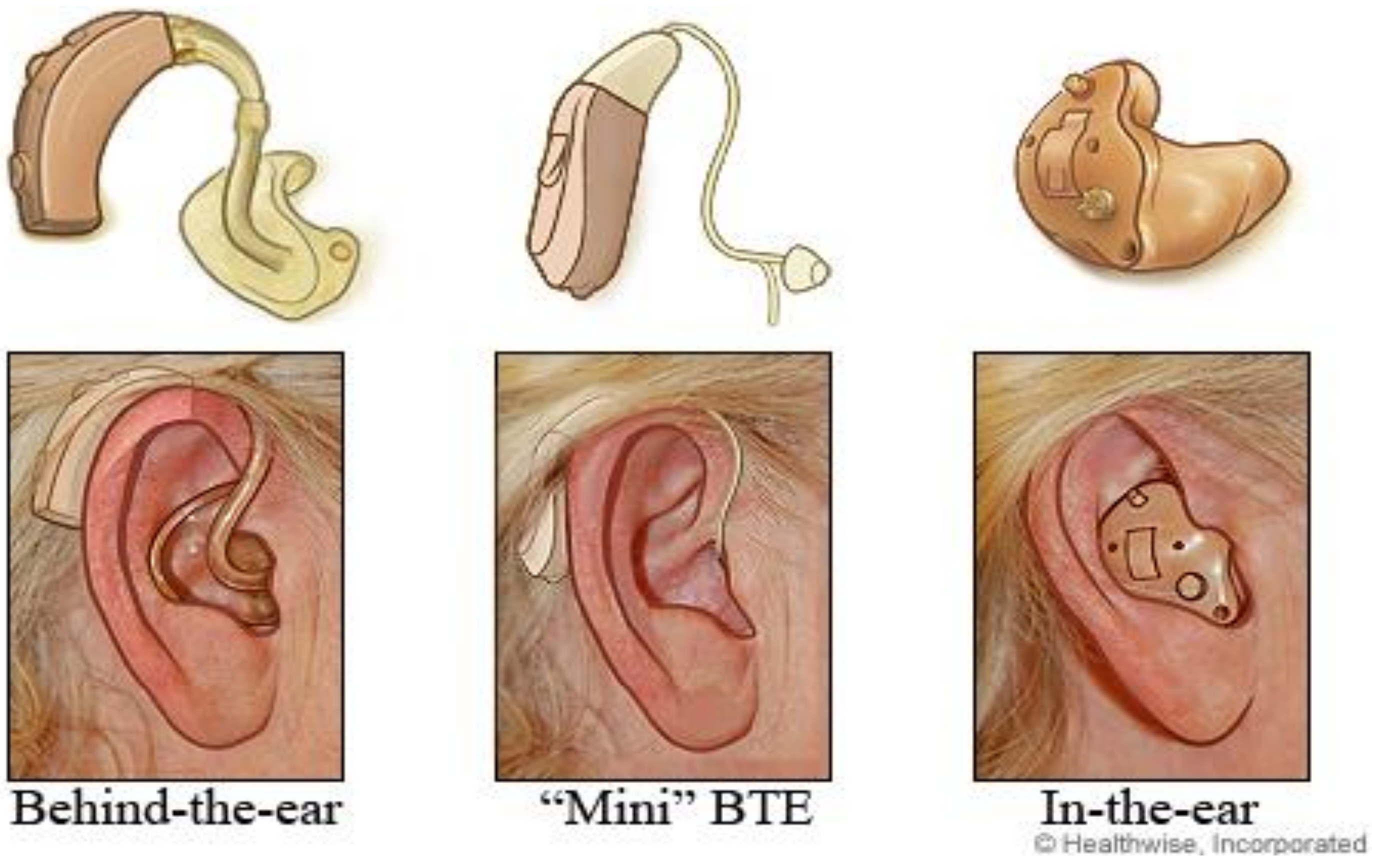
CONVENTIONAL HEARING AID!!!

- Hearing aids makes sounds louder. There are many different styles of hearing aids. And you can add special features to your hearing aids. But almost all hearing aids have these parts:
- A microphone, to pick up sound.
- An amplifier, to make the sound louder.
- A speaker, to deliver the sound into the ear.

CONTD….


Internal Components
Microphone
Program Button
Battery
Sound Processor
Speaker/Receiver
External Components
On/Off Button
Battery Compartment
Volume Control

TYPES OF HEARING AIDS



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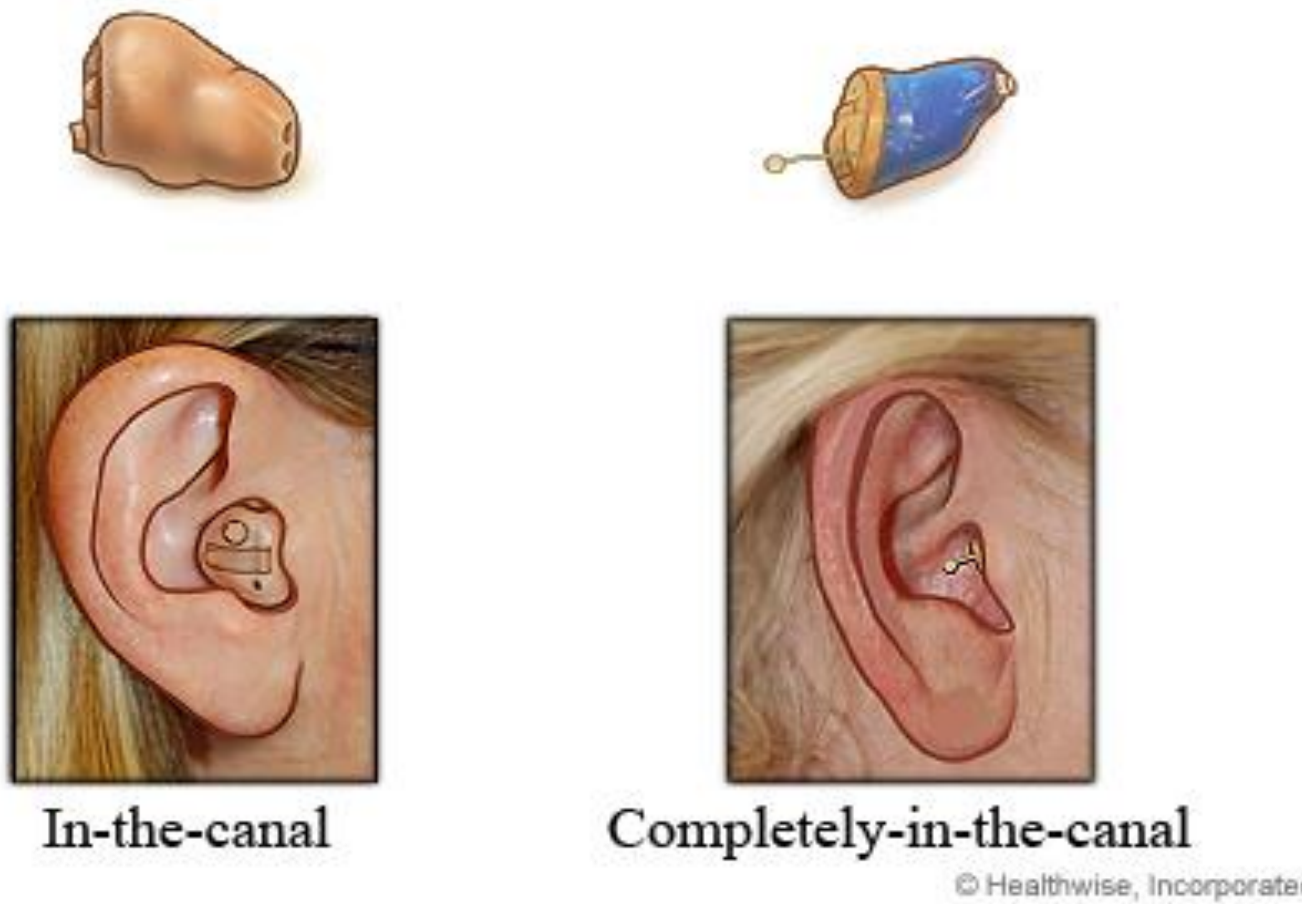
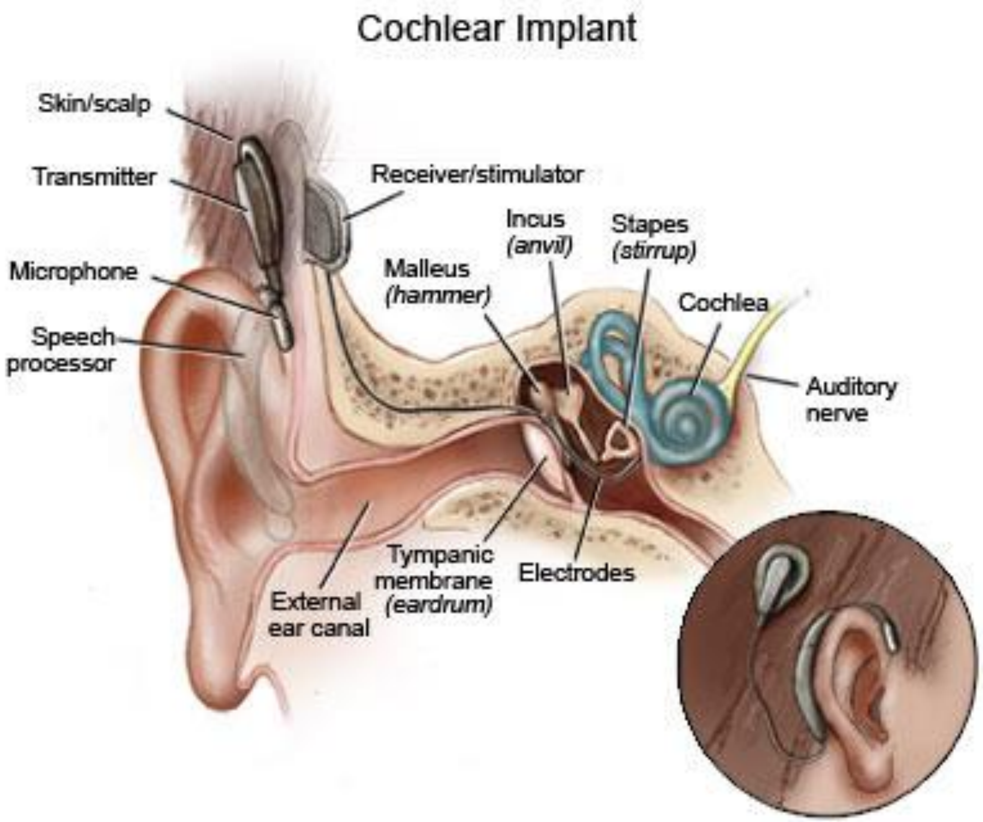

In-the-canal
Completely-in-the-canal
© Healthwise, Incorporated

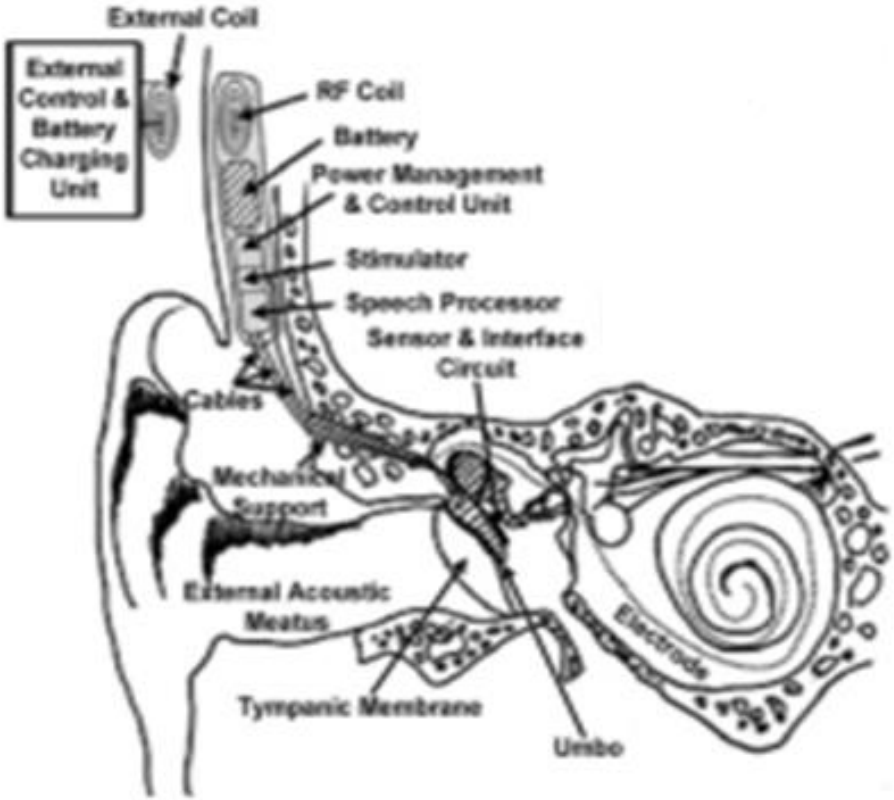
COCHLEAR IMPLANT



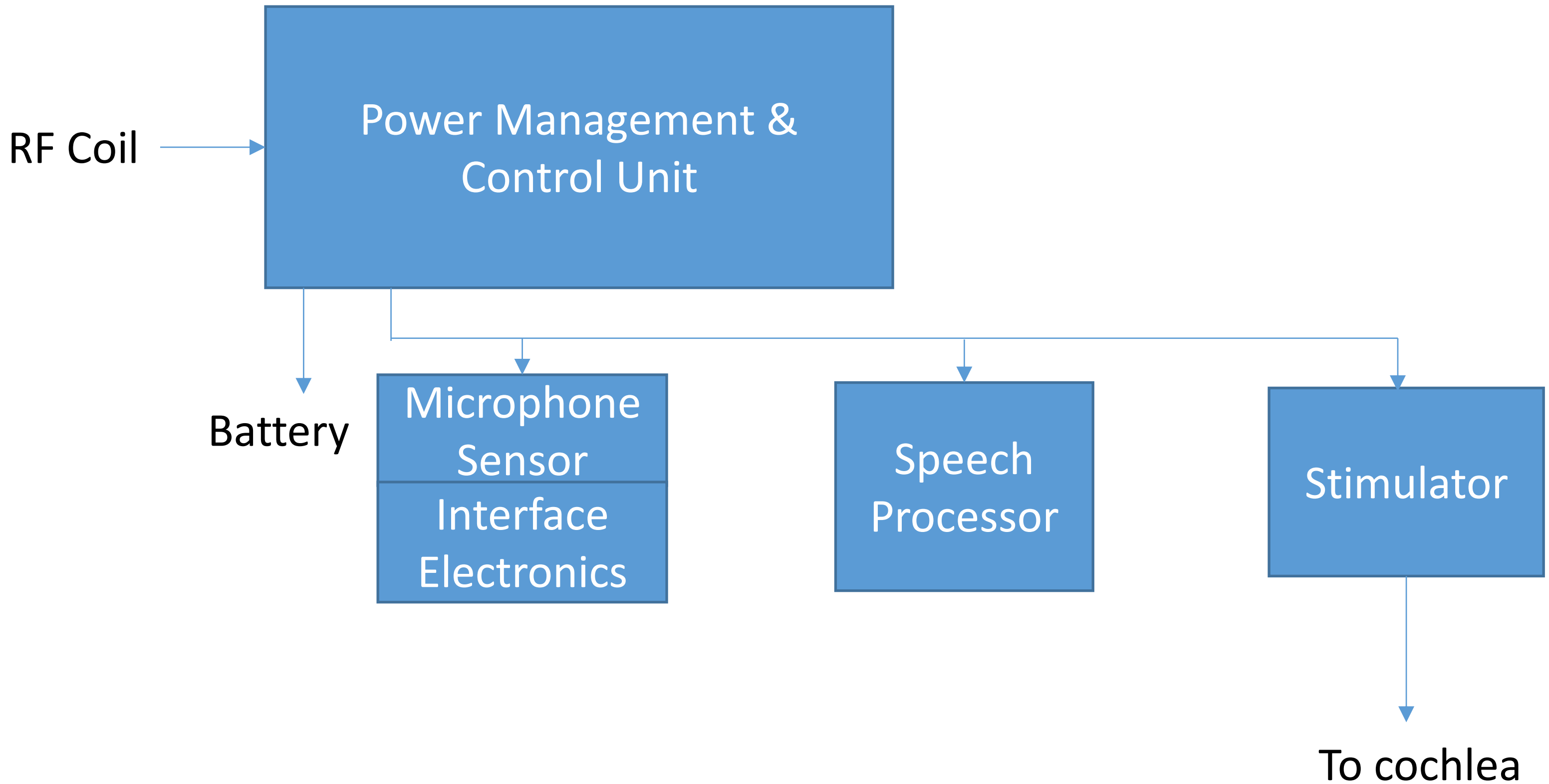
MOTIVATION

- The use of external accessories such as microphones and electronics presents reliability, practicality, and social stigma concerns. Therefore it is highly desirable to develop fully implantable high performance hearing aid devices.

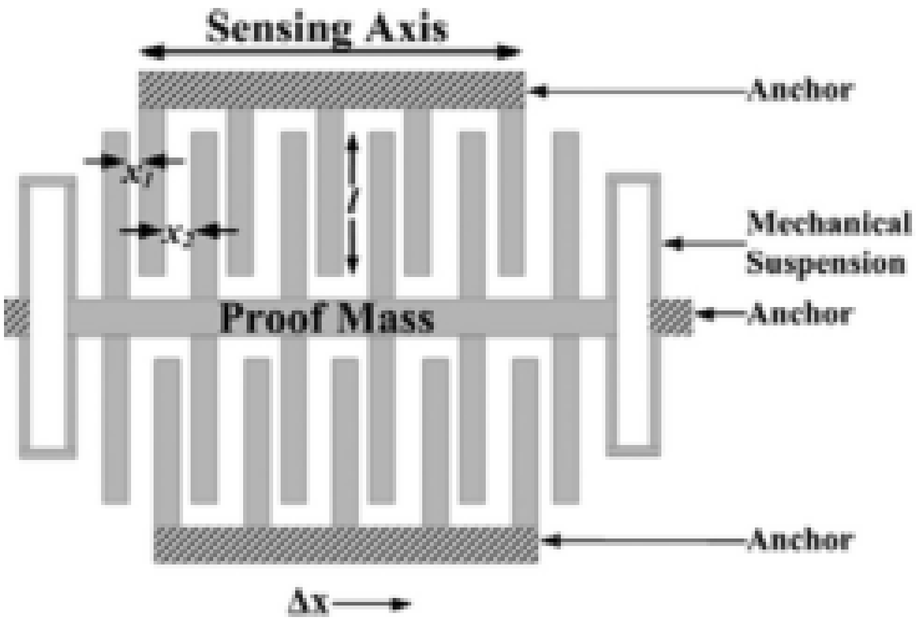
FULLY IMPLANTABLE MIDDLE EAR MICROPHONE



SIGNAL & CONTROL DIAGRAM



CAPACITIVE ACCELEROMETER AS MICROPHONE



$$C_{s+nom} = \left(\frac{\varepsilon_0 lt}{x_1} + \frac{\varepsilon_0 lt}{x_2}\right) \times N = C_{s+1} + C_{s+2}$$

$$\Delta C_{s+} = \left(\frac{\varepsilon_0 lt}{x_1}\frac{\Delta x}{x_1} - \frac{\varepsilon_0 lt}{x_2}\frac{\Delta x}{x_2}\right) \times N$$

Under external acceleration, the proof mass and movable fingers move along the direction of body force, the fixed comb remains stationary. This movement changes the capacitance between the fixed and the movable finger which is measured using electronic circuitry

CONTD….

- The sensitivity can be enhanced by extending x_2 much larger than x_1, in (2) . On the other hand, enlarging x_2 would reduce the number of fingers that can be fabricated within a given length, thus causing a sensitivity degradation.
- Analysis reveals that the device sensitivity $\Delta Cs/\Delta x$, as a function of gap ratio, can be maximized with a gap ratio of approximately 2.5 based on a device length of 1 mm, finger overlap length and thickness of 100 and 25 µm, respectively.
- In the prototype designs, x_1 is chosen to be 2 and x_2 is varied from 2 µm to 10 µm, to analyse the relationship of sensitivity with gap ratio.

IMPORTANT DESIGN CONSIDERATIONS

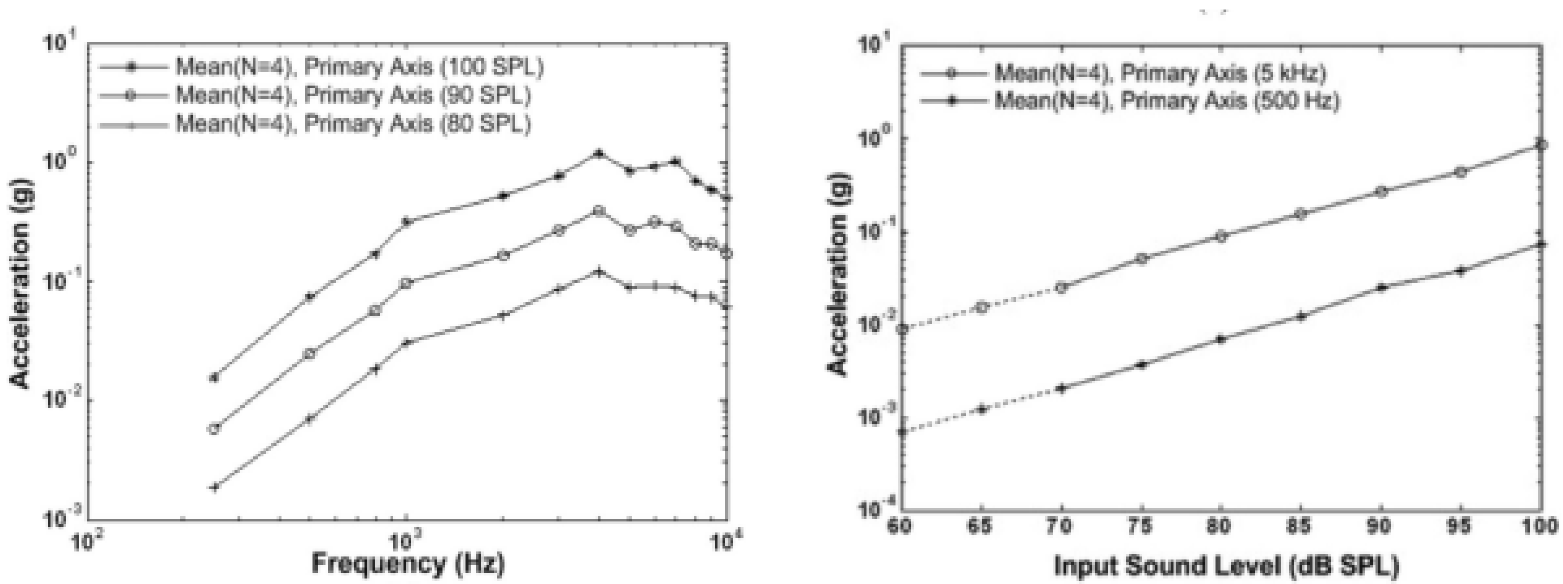
- **Constraint on total packaged mass**

It has been shown that adding a mass greater than 20 mg on umbo can potentially result in a significant damping effect on the frequency response of the middle ear ossicular chain, particularly at frequencies above1kHz. Therefore, the total packaged mass of the sensing system needs to be kept below 20 mg.

- **Constraint on the area of the packaged sensor**

The average length of the long process of the malleus is between 6.5 and 8mm and the size of the umbo tip is typically between 1.5 and 2 mm, which is comparable to the height of the eardrum cone. The spacing between the umbo and the oval window of the cochlea varies between 2 and 3mm. Therefore, the overall prototype microsystem should exhibit a packaged dimension less than3.5mm×6.5mm so that it can be implanted on the umbo without touching other structures inside the middle ear cavity.

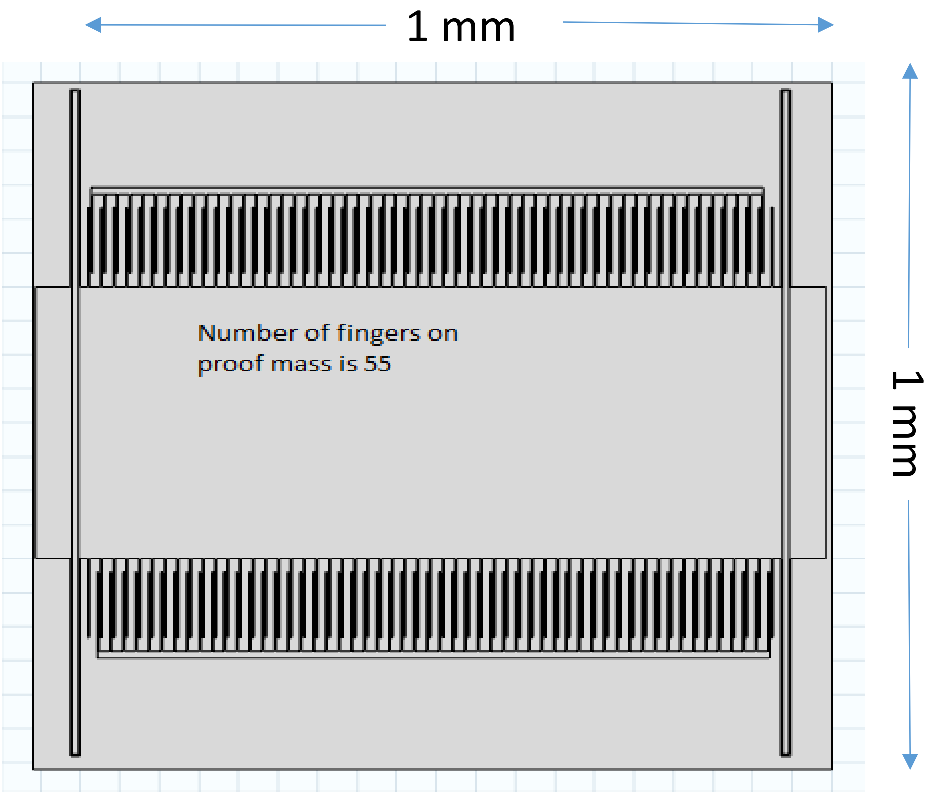
Umbo Acceleration Measurements

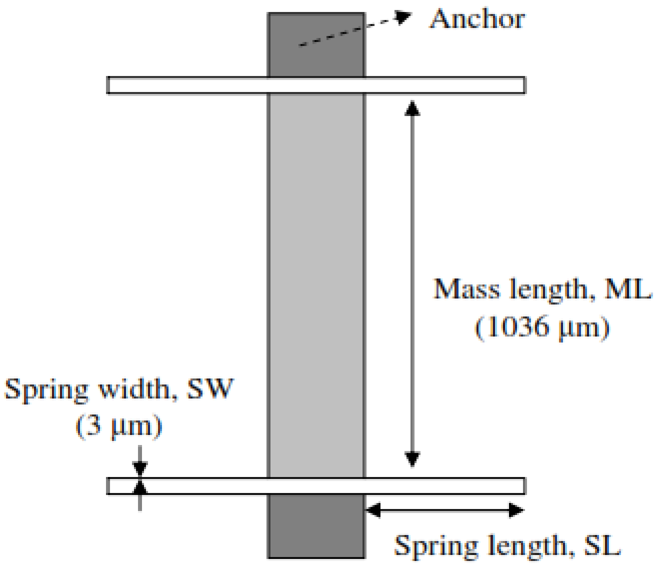


(a) (b)

Acceleration response curves of umbo along the primary axis. (a) Acceleration frequency response at 80-, 90-, and 100-dB SPL. (b) Loudness response at 500 Hz and 5 kHz. [1]

ACCELEROMETER PROTOTYPE 1

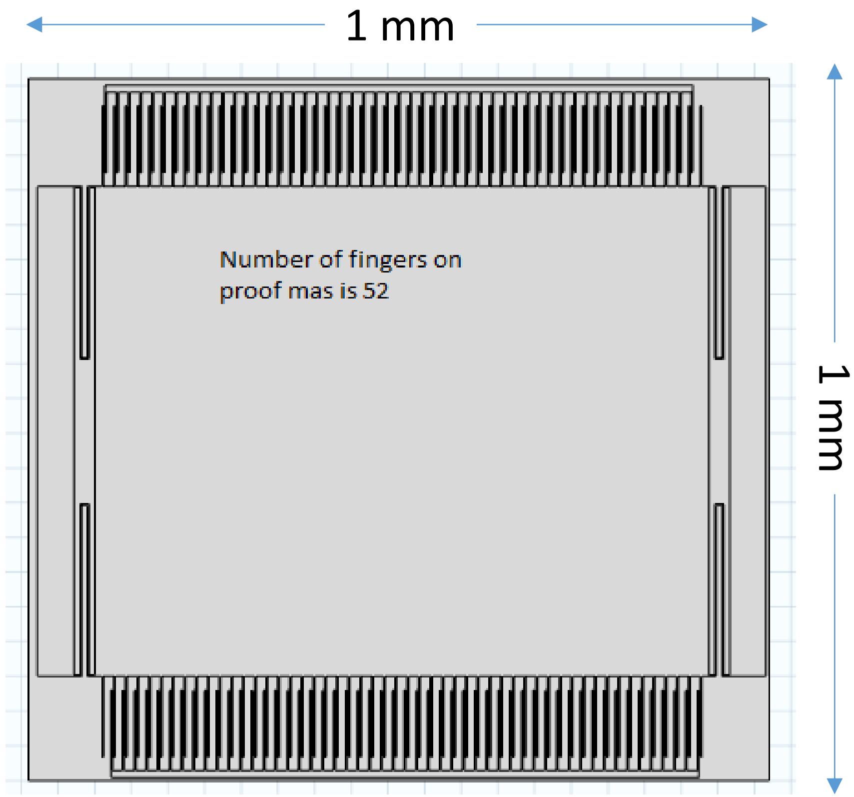


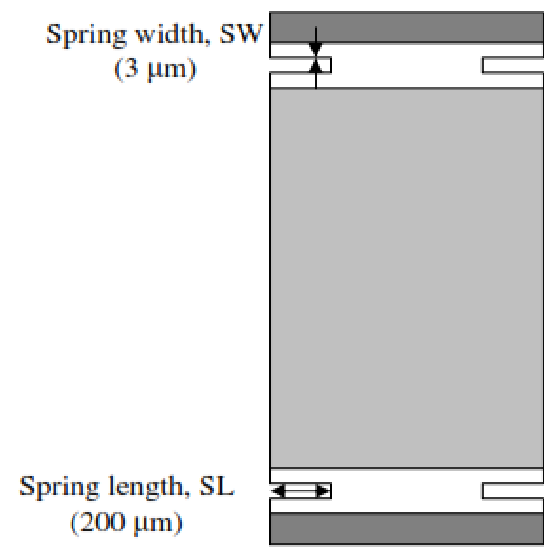


$$k_{total} = \frac{2Eh(SW)^3}{(SL)^3}$$

E is the Young's Modulus
h is the thickness of the spring beam

ACCELEROMETER PROTOTYPE 2



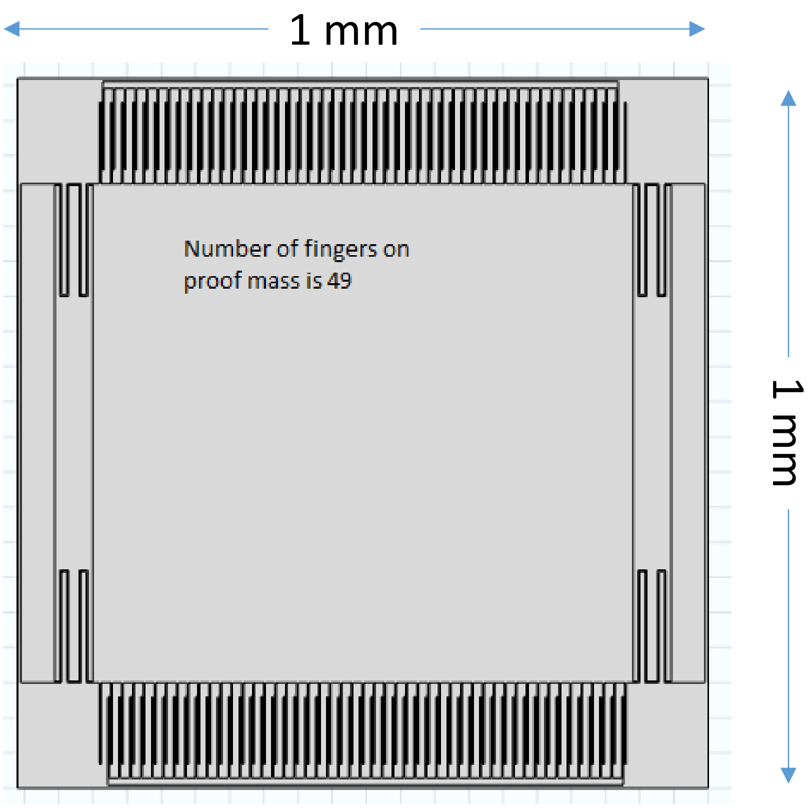


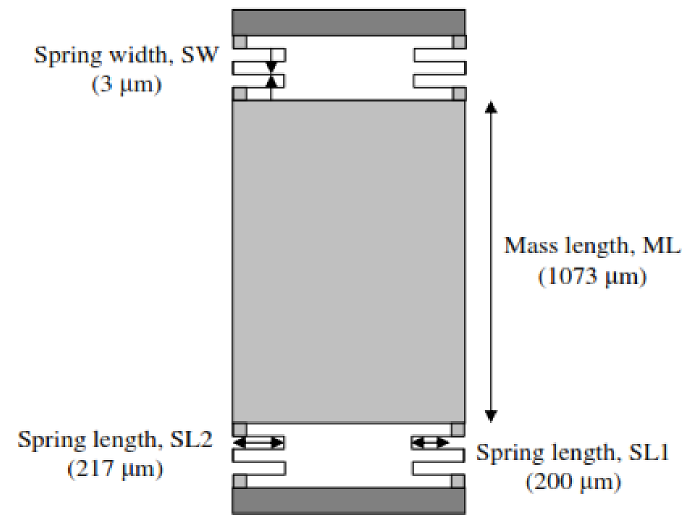
$$k_{total} = \frac{2Eh(SW)^3}{(SL)^3}$$

E is the Young's Modulus

h is the thickness of the spring beam

ACCELEROMETER PROTOTYPE 3





$$k_{total} = \frac{Eh(SW)^3}{(SL_1)^3 + (SL_2)^3}$$

E is the Young's Modulus

h is the thickness of the spring beam

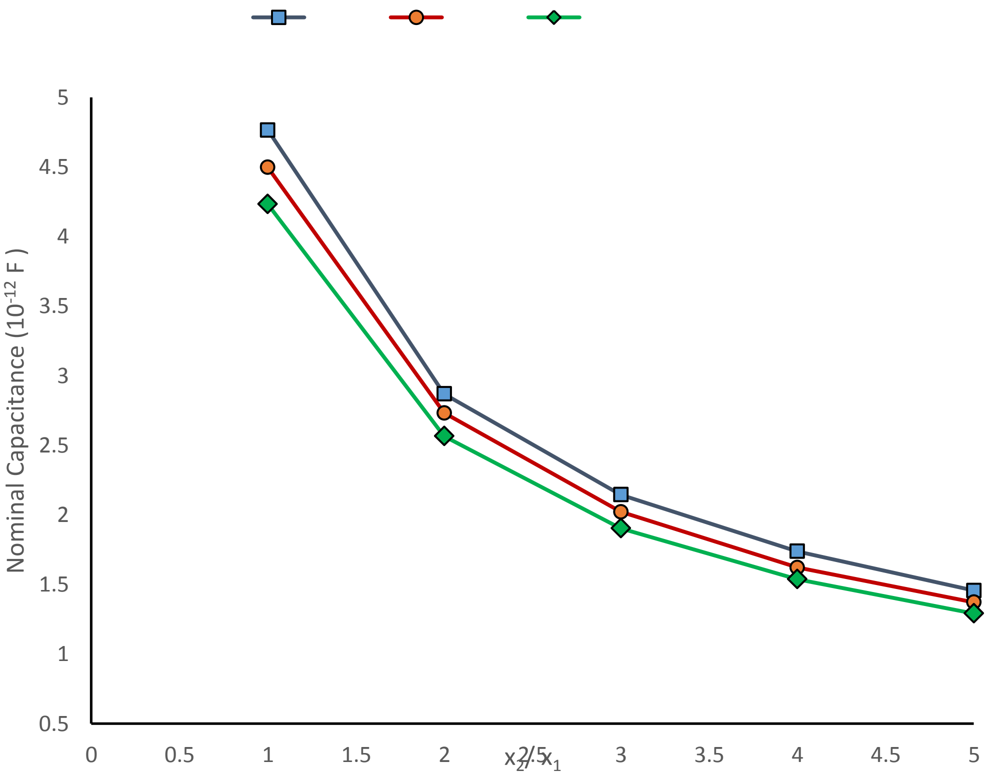
GEOMETRY PARAMETERS

Geometry Parameters	Values (µm)
Thickness of the plate	25
Width of finger	2
Finger overlap length	96
Width of spring beam	2
Length of finger	116

- The geometry of proof mass and spring for each parameter is designed for resonant frequency of 10000 Hz.
- The acceleration of umbo is measured in the frequency range from 250 Hz to 10 kHz with input tones between 70 and 100 dB SPL.
- Corresponding to this input voice signal, the acceleration values from 0g to 1g are applied to the designed structures

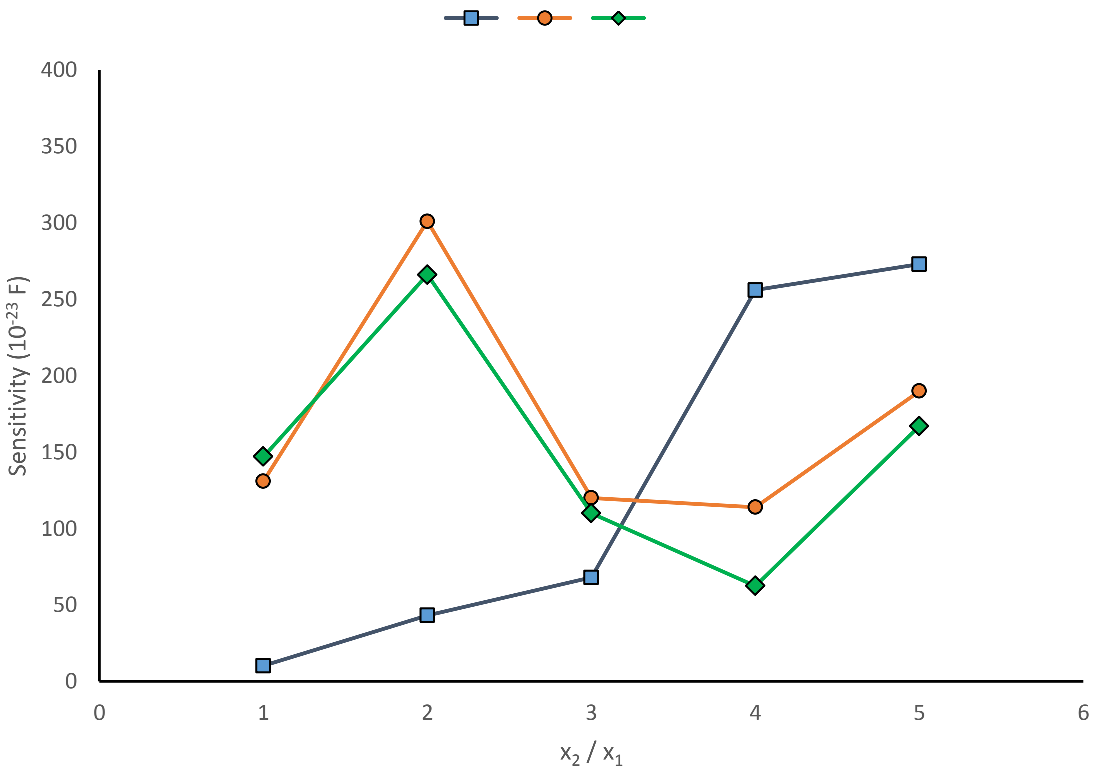
NOMINAL CAPACITANCE VS GAP SPACING RATIO

The number of fingers and hence the capacitance decreases with increasing gap spacing.



CAPACITIVE SENSITIVITY VS GAP SPACING RATIO

Capacitive sensitivity varies randomly with gap spacing ratio



CONCLUSION

- The optimum value of sensitivity is obtained at gap ratio of 2 for prototype 2.
- The optimised results will be used in selecting the prototype structure for designing high performance MEMS accelerometer for fully implantable hearing aid applications.

REFERENCES

[1] Darrin J. Young , Mark A. Zurcher, “MEMS Capacitive Accelerometer Based Middle Ear Microphone”, IEEE TRANSACTIONS ON BIOMEDICAL ENGINEERING, VOL. 59, NO. 12, DECEMBER 2012.

[2] W. Ko, A. Maniglia, and R. Zhang, “ Studies of MEMS Acoustic Sensors as Implantable Microphones for totally Implantable Hearing Aid Systems” *IEEE Trans. On Biomedical Cicuits, Vol 3, No. 5, Oct 2009.*

[3] W. Ko, A. Maniglia, and R. Zhang, “A preliminary son the implantable middle ear hearing aid,” in *Proc. IEEE 9th Annu. Conf. Eng. Med. Biol.*, 1987, p. 1890.

[4] H. Zenner, M. Maassen, R. Lehner, J. Baumann, and H. Leysieffer, “An implantable hearing aid for inner ear hearing loss: Short-term implantation of microphone and transducer,” *Otolaryng. Head Neck Surgery*, vol. 45, no. 10, pp. 872–880, Oct. 1997.

CONTD…..

[5] A. Vujanic, R. Pavelka, N. Adamovic, C. Kment, S. Mitic, W. Brenner, and G. Popovic, “Development of a totally implantable hearing aid,” in *Proc. 23rd Int. Conf. Microelectronics*, Yugoslavia, May 2002, vol. 1, NI S.

[6] A. Maniglia, H. Abbass, T. Azar, M. Kane, P. Amantia, Garverick, W. Ko, W. Frenz, and T. Falk, “The middle ear bioelectronic microphone for a totally implantable cochlear hearing device for profound and total hearing loss,” *Amer J. Otol.*, vol. 20, pp. 602–611, 1999.

[7] D. Chen, D. Backous, M. Arriaga, R. Garvin, D. Kobylek, T. Littman, S. Walgre, and L. David, “A totally implantable middle ear device for sensorineural hearing loss,” *Otolaryng. Head Neck Surgery*, vol. 131, no. 6, pp. 904–916, 2004. *Head Neck Surgery*, vol. 137, pp. 206–212, 2007.

CONTD…

[8] D. Zurcher, J. Young, M. Semaan, C. Megerian, and W. Ko, “MEMS middle ear acoustic sensor for fully implantable cochlear prosthesis,” in *Proc. 20th IEEE Int. Conf. MEMS*, Japan, 2007, pp. 11–14. [10] P. Huang, J. Guo, C. A. Megerian, D. Young, and W. Ko, “A laboratory study on a capacitive displacement sensor as an implant microphone in totally implant cochlear hearing aid systems,” in *Proc. Int. Conf. IEEE EMBS*, Lyon, France, Aug. 2007, pp. 5691–5694.

[9] W. Ko, P. Huang, J. Guo, R. Zhang, D. Young1, and C. Megerian, “MEMS acoustic sensors for totally implantable hearing aid systems,” in *Proc. IEEE Int. Symp. Circuits and Systems*, Seattle, WA, May 2008, pp. 1812–1817.

CONTD…

[10] Sang-Soo Je, Fernando Rivas, " A Compact and Low Cost MEMS Loudspeaker for Digital Hearing Aids", *IEEE Trans. On Biomedical Circuits, Vol 3, No. 5, Oct 2009.*

[11] S. Lee, R. Ried, and R. White, "Piezoelectric cantilever microphone and microspeaker," *J. Micro Electromechan. Syst.*, vol. 4, pp. 238–242, 1996.

[12] R. Heydt, R. Pelrine, J. Joseph, J. Eckerle, and R. Kornbluh, "Acoustical performance of an electrostrictive polymer film loudspeaker," *J. Acoust. Soc. Amer.* , vol. 107, no. 2, pp. 833–839, 2000.

[13] M. Cheng, W. Huang, and S. R. Huang, "A silicon microspeaker for hearing instruments," *J. Micromechan. Microeng.*, vol. 14, pp. 859–866, 2004.

CONTD….

[14] S.-S. Je and J. Chae, “An electromagnetically actuated micromachined loudspeaker for hearing aids applications,” in *Proc. IEEE Sensors Conf.*, 2007, pp. 1024–1027.

[15] M. Gad-el-Hak, *MEMS Applications*, 2nd ed. New York: Taylor & Francis Group, 2005.

[16] Sang-Soo Je, Jeonghwan Kim,” A Directional Capacitive Mems Microphone Using Abstract Nano-Electrodeposits”, Department of Electrical Engineering, Arizona State University.

[17] MEDER Electronics applications, www.meder.com

THANK YOU !!!!

QUESTIONS??