

# Implantable Microphone for Cochlear Hearing System

WEN H. KO\*, DARRIN J. YOUNG,  
*the EECS Department, Case School of Engineering,  
CWR University, Cleveland, OH, USA.*

CLIFF A. MEGERIAN,  
*Otolaryngology Department, Medical School  
CWR University, Cleveland, OH, USA.*

For severe hearing loss or deaf cases, partially implant cochlear hearing system, has gained acceptance and has enabled the totally deaf person to gain hearing and speech functions. However, the use of external microphones and electronics presents reliability problem in sporting events, inconvenience, and social stigma concerns. It is desirable to develop totally implantable hearing systems. This article presents a feasibility study to use MEMS displacement sensor as an implantable microphone to implement a totally implant cochlear hearing aid system. We characterized vibration characteristics at the umbo using standard laser vibrometer technique on temporal bones to determine the required sensor sensitivity, dynamic range, and frequency response. The sensor module to convert umbo vibration to high fidelity electrical sound signal was studied on the lab simulator and on temporal bones. The experimental results of displacement sensors with special coupling devices were presented. The feasibility of using micro-displacement sensor as implant microphone is evaluated based on established sensor performance and calculations.

## 1. Introduction

Over 20 million people in the United States, many more through out the world, suffer from conductive as well as sensorineural hearing loss. While external hearing aids can offer moderate rehabilitation, inherent limitations, such as ear canal irritations, distortion and occasional ringing, and social problem with being perceived as handicapped, have deprived many patients of clear hearing. For severe hearing loss or deaf cases, partially

implant Cochlear hearing system, as shown in Figure 1, have gained acceptance and has enabled the totally deaf person to gain hearing and speech functions. However, the external microphone and electronics presents concerns on reliability in sporting events, inconvenience, and social stigma. It is, therefore, desirable to develop totally implantable high-performance hearing aid systems [1-3]. The proposed totally implant cochlear hearing system is shown in Figure 2.

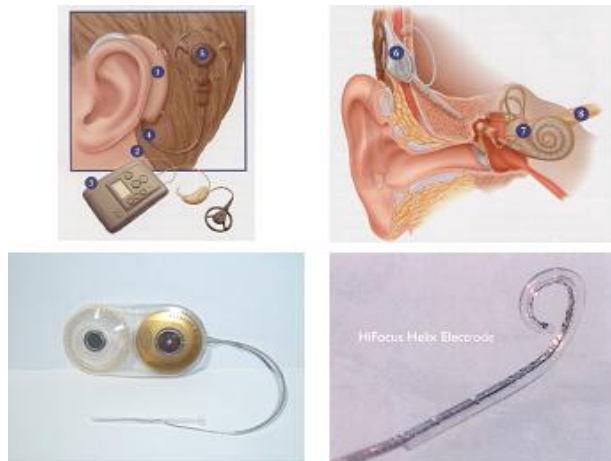


Figure 1 The cochlear implant hearing system

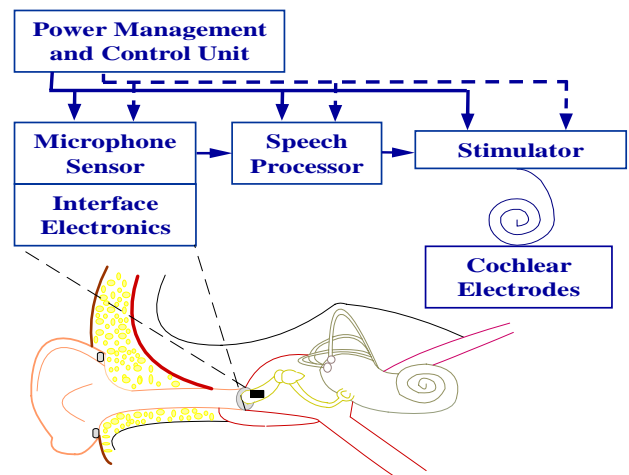


Figure 2 Totally implant cochlear hearing system

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The implant microphone sensor will be coupled to the ossicular bone to convert the sound vibration to electrical signal to be processed to stimulate cochlear electrodes in the same way as the present cochlear hearing system. This article reports the results of a feasibility study on displacement type implant microphone sensor.

## 2. Characterization of Umbo Vibration

The location of the microphone sensor in the ossicular Chain was studied and was selected to be at the umbo where the vibration has maximum amplitude [4, 5]. We characterized the umbo vibration characteristics along different axes, on several preserved and fresh temporal bones. The measurement set up is shown in Figure 3.

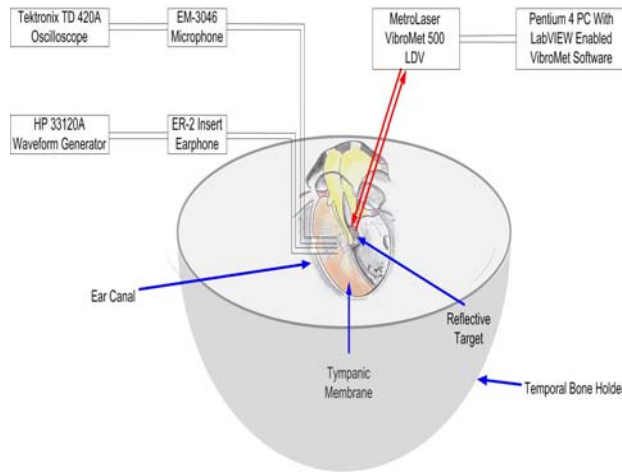


Figure 3 The temporal bone measurement set up

Laser Doppler Vibrometer was used to measure the vibration displacement amplitude at umbo along two axes. The maximum vibration amplitude was measured to be along the lateral axis (perpendicular to the umbo surface). The average results on displacement amplitude from 200Hz to 10KHz, at 60, 80, and 100 SPL input to the ear canal are shown in Fig. 4-a. The acceleration responses calculated from the displacement data and frequency are given in Figure 4-b. These results are consistent with the published data on umbo response to sound input measured on temporal bones [4-7]. In principle, either MEMS accelerometer or displacement sensor may be used as microphone sensor. In order to detect 40dB to 100 dB SPL sound, the sensor needs to sense displacement from 0.1 to 100 nanometers, in the 300 to 2 KHz range, and even smaller displacement in the 2 to 8 KHz range. While the acceleration sensor has to sense 2

g to 30 $\mu$ -g over the desired 200 to 8KHz range. Both cases present significant engineering challenges.

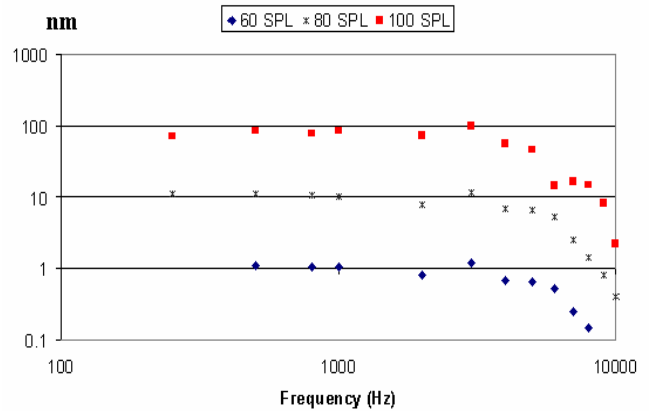


Figure 4a Umbo displacement vs. frequency at 60, 80 and 100 dB SPL

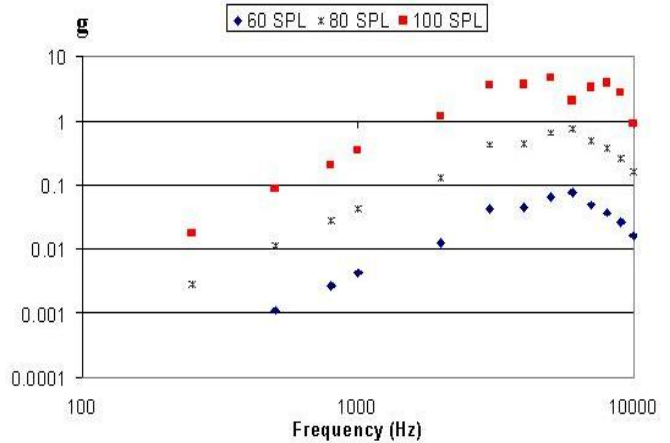


Figure 4b Umbo acceleration vs. frequency at 60, 80 and 100 dB SPL

## 3. Implantable Microphone Sensors

For implantable microphone sensors, besides high sensitivity and wide dynamic range, the size, weight, biocompatibility of the package, and the force and mass loading effects on the umbo are important considerations. In the literature, there are conventional type microphones packaged to be implant under the skin. They are not suited for the cochlear system. Magnetic sensor was tried on malleus head [3]. The result is encouraging. However, i) the weight, size and the loading effect are large; ii) the magnetic materials is objectionable for patients go through MRI examination. Using an acceleration sensor for conversion may be an approach [5]. The sensitivity, noise, packaged weight, and the size

are major challenges. This article reports on using displacement sensor with a coupler for the implant sensor.

A lab simulation model was built with vibrometer calibrated PZT as the vibration source to generate audio vibrations equivalent to 40 to 100 SPL sound levels. A coupling device was developed that can transmit vibrations to sensors while limit the loading force when large off-set displacements between the umbo and the sensor presents. The sensor signals, corresponding to the vibration at various sound levels are amplified 1000 times by a low noise amplifier, with a measured noise density of 4 to 6 nV/route-from 250 Hz to 8 KHz. The simulation unit including the vibration source, the sensor, and the amplifier are housed inside of an acoustic isolation box. The amplified signal is then fed to scope, meters, and signal analyzers. The output voltages and wave forms are recorded for analysis. Various types of sensors were tested in the laboratory to compare the sensitivity of the sensors and the transmission coefficient of the coupling devices. From these laboratory experiments, the electrets capacitive microphone was selected as the sensor for the feasibility study to sense the vibration at the umbo responding to ranges of sound levels and frequencies. The experimental set up is shown in Figure 5. Calibrated sound signals, at 60 and 95 dB SPL, are applied to the ear canal, the output of the electrets sensor, coupled to the

measured and recorded. The results are shown in Figures 6 and 7. Figure 6 gives the noise and background interferences measured at the amplifier output, but referred back to the amplifier input, at various conditions. Figure 7 shows the measured sensor signals, from 250Hz to 8 KHz, with 95 and 60 dB SPL sound apply to the ear canal. The noise spectral density of the sensor and coupling device without interferences [measured in the acoustic isolation box] is also shown in figure 7 for the estimation of the Signal-to-Noise ratio when the frequency bandwidth is known. In the cochlear implant systems the total sound bandwidth is divided into channels, some channels have several 100 Hz bandwidth and others have several KHz. The S/N ratio can be calculated for each channel according to bandwidth assignment in the specific system. It is observed that the sensor signal received has two components. One is the vibration signal through the coupling device and the other, the signal transmitted directly from the tympanic membrane as shown in Figure 8.

**4. Conclusion**

These results indicate that the displacement sensor can be used to sense the vibration at the umbo and convert it into electrical signal with good frequency fidelity. However, sensors with much higher sensitivity

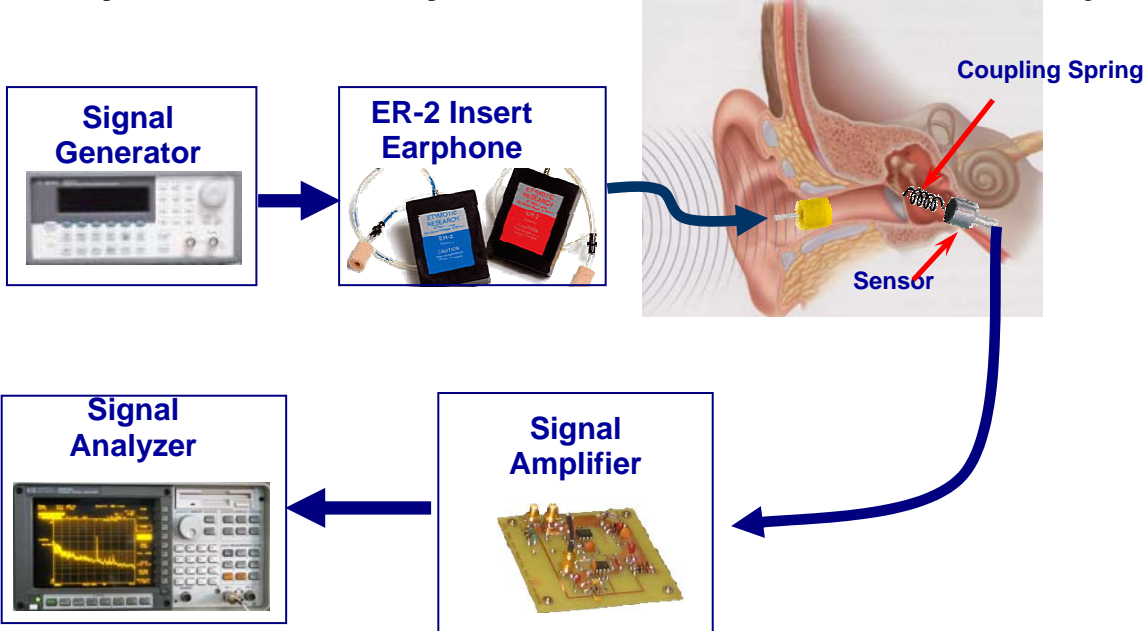


Figure 5 Measurement set-ups for the temporal Bone experiment

umbo of the temporal bone through the coupling device, are amplified by the low noise amplifier and were

than the one used is needed to sense 40dB SPL or lower level sound for the total 8 KHz bandwidth. The high performance strain sensors [9] is being Modified for this purpose. The characterization and design techniques of the coupling devices are being developed.

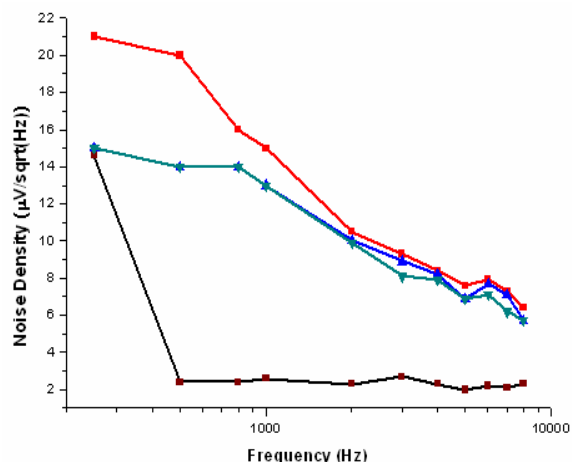


Figure 6 Noise spectrum densities (NSD) measured

- BSD of Amplifier alone
- ▲— NSD of Amplifier + Microphone, in vacuum
- ▼— NSD of Amplifier + Microphone, in isolation box
- NSD of Amplifier + Microphone, in lab environment

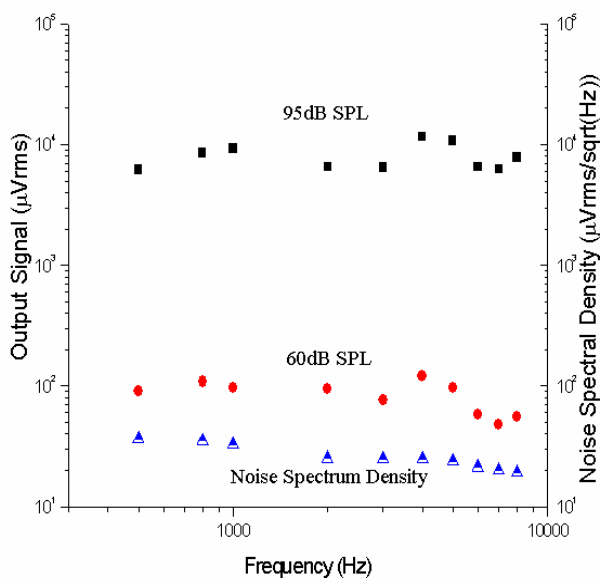


Figure 7 Temporal Bone experiment results

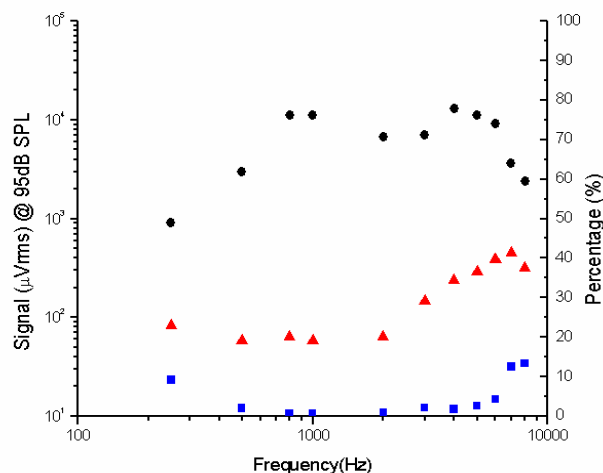


Figure 8 The source components of sensor signals, at 95 dB SPL input

- Total sensor Output.
- ▲ Output from direct acoustic transmission
- Ratio of acoustic transmitted output to the total output

**Keywords:** Vibration sensor, Implant hearing device, Totally implantable cochlear system.

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