IJCTA, 9(39), 2016, pp. 121-125

Speech Transmission Using Ultrasonic Actuation of Piezo Elements for Cochlear Implants

Pooja Nag* Ansu Mathew* and Kapil Sadani*

Abstract : In this study, a method of direct audio transmission on to the cochlea has been proposed for people with dysfunctional outer and or middle ear. Here, the speech signal has been modulated by ultrasound such that it may be transmitted directly on to the cochlea where it is received and regenerated to its original form. The cycle basically comprises three stages the first being generation of the modulated ultrasound, reception of the attenuated signal and regeneration of the speech signal using small piezoelectric crystals. The proposed methodology may be utilized to device miniaturized, cheap and efficient hearing implant for ocular patients in India.

Keywords : Ultrasound, Hearing Aid, Cochlea, Implants, Modulation.

1. INTRODUCTION

1.1. Historical Background

It is believed that Aristotle first put forward that sound waves were sent directly to the brain [1]; the inner ear being separated from the outer by a membrane. Later, in the sixteenth century, Girolamo Cardano proved that transmission of sound is possible through the skin and the tooth. Girolamo Capivaccio demonstrated a method of assessing ear pathology with the aid of an iron rod held against the teeth. In the 18th century, Ludwig van Beethoven connected a wooden rod between his piano and teeth and claimed that he could hear music. However, till the eighteenth century, bone conduction was not thought of. People thought that the sound was being transmitted through air by the Eustachian tube. In the eighteenth century, fonifero, the first hearing aid based on bone conduction was developed. The device comprised an iron rod which was connected form the source directly on to the neck/ forehead/teeth of a deaf and he is said to have perceived sound. In 1879, Richard Rhodes developed a device which could convert the vibrations caused of speech into mechanical vibrations. The device was in the form of a fan which was to be pressed against the cheek of the listener. He called it an audiophone and patented it in 1879. The cfonifiero and audiphone may be represented as an animation as in Figure 1.

1.2. Functioning of the human ear

The structure of the ear is divided into three functional parts, the outer ear, the middle ear and the inner ear. The outer ear funnels and focusses sound waves. The middle ear contains the auditory canal and ends at the tympanic membrane. This membrane is connected to three small ear bones, the malleus, incus and stapes. In the inner ear, a structure called the cochlea converts the vibrations from the bones into electrical signals and sends it via the auditory nerve to the brain.

* Manipal Institute of Technology, Manipal University, Manipal-576104, Karnataka, India *E-Mail: sadani.kapil@manipal.edu*

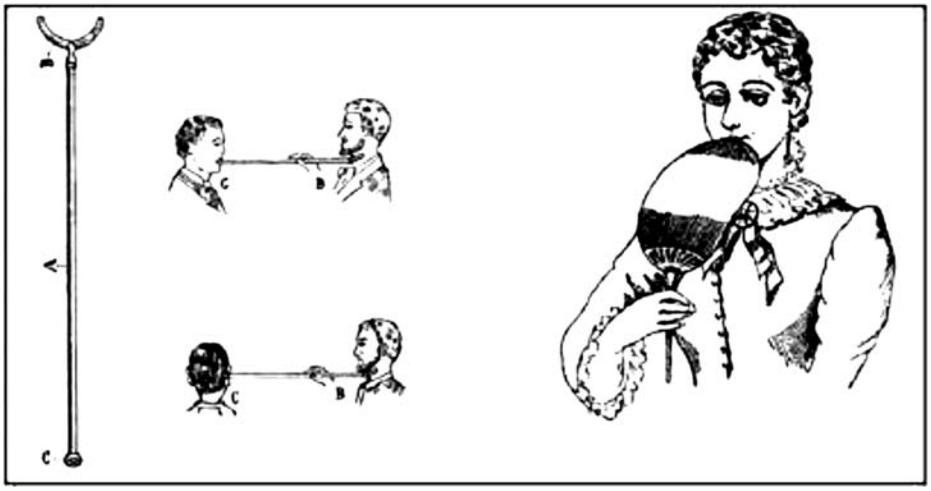

Figure 1: Paledino's fonifero, 1876 (left) and Rhodes' audiphone, 1879 (right)

The cochlea is a tapered tube that circles around itself. A membrane called basilar divides the tube lengthwise into two fluid-filled canals that merge at the tapered end. The bones transmit the vibration to the tube wherever they attach at the fenestra vestibuli. The resultant waves travel down the membrane where they are perceived by the around 16-20,000 hair cells (cilia) attached to a canal referred to as the organ of corti. The organ of corti transforms the vibrations of the aroused hair cells into nerve impulses. As it is the tapered end of the tube, waveforms traveling down the membrane tissue peak in amplitude at differing spots. The larger frequency peaks are found at a shorter distances down the tube than those of the lower frequencies. Owing to its tapered shape, the distance between pitches follows the same logarithmic distance as our perception of pitch.

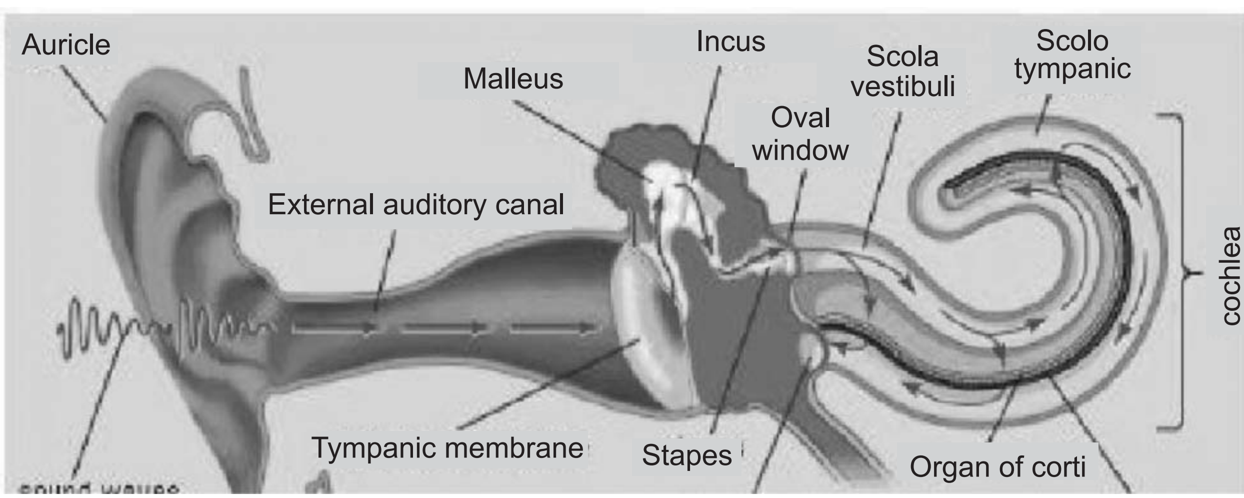

Fig. 2. Standard Audiological pathway for airborne sound (Encyclopedia Britannica, 1997).

1.3. Bone conduction

Bone conduction is the way sound energy is transmitted by the skull bones directly to the cochlea, causing sound perception by the cilia directly, thus bypassing the faulty parts of the middle and outer ear, if any.

The understanding of bone conduction essentially started by early research in the 1930's to the 1950's, by the Nobel Prize laureate von Békésy and Bárány [2]. In 1966 a study was presented [3] on experiments conducted on animals that greatly increased the understanding of bone conduction hearing. By using strobe photography and silver flakes as a marker, Békésy was able to observe that the basilar membrane moves like a surface wave when stimulated by sound. Bárány worked on the physiology and pathology of the vestibular (balancing apparatus) of the inner ear.

Bone conduction has several pathways, all of which contribute to how the sensation is perceived. They involve 'sound pressure in the ear and occlusion effect', 'inertia of the middle ear ossicles', 'inertia of the cochlear fluids' and fluid pressure transmission', and 'alteration of the cochlear space'. In order to narrow down the pathways this paper investigates the use of bone conducted ultrasonic vibrations to transmit auditory data.

2. HEADSTAGE DESIGN CONSIDERATIONS

In this study, audio (speech) has been modulated by ultrasound of frequency 1MHz to propagate from the mastoid to the cochlea, where the speech signal is recovered. The design is principally based on three piezoelectric elements, the first of which generates the ultrasound modulated speech to be transmitted through the soft tissue, the second to receive the same and the third to regenerate the speech signal directly onto the cochlea.

2.1. Modulation of Audio Signal

In the first stage, the input speech (audio) is modulated by 1 MHz ultrasound. The piezo is placed externally on the mastoid, and transmits ultrasonic signal as vibrations into the temporal bone through the intermediary soft tissue (Figure 3). In Figure 3(*a*) it is assumed that the medium through which the beam propagates is lossless and homogeneous and that the waveform of the pulses do not change during propagation but as the beam is conical and diverges, there is slight attenuation of its intensity. In 3(*b*) the beam actually traverses a living tissue which is a nonlinear attenuator. The beam is deviated as the result of the inhomogeneity and there exist maxima and minima along the same cross section, under certain circumstances. Owing to the non linearity, the higher frequency components are attenuated more than the central frequency and the curve shifts downwards [5].

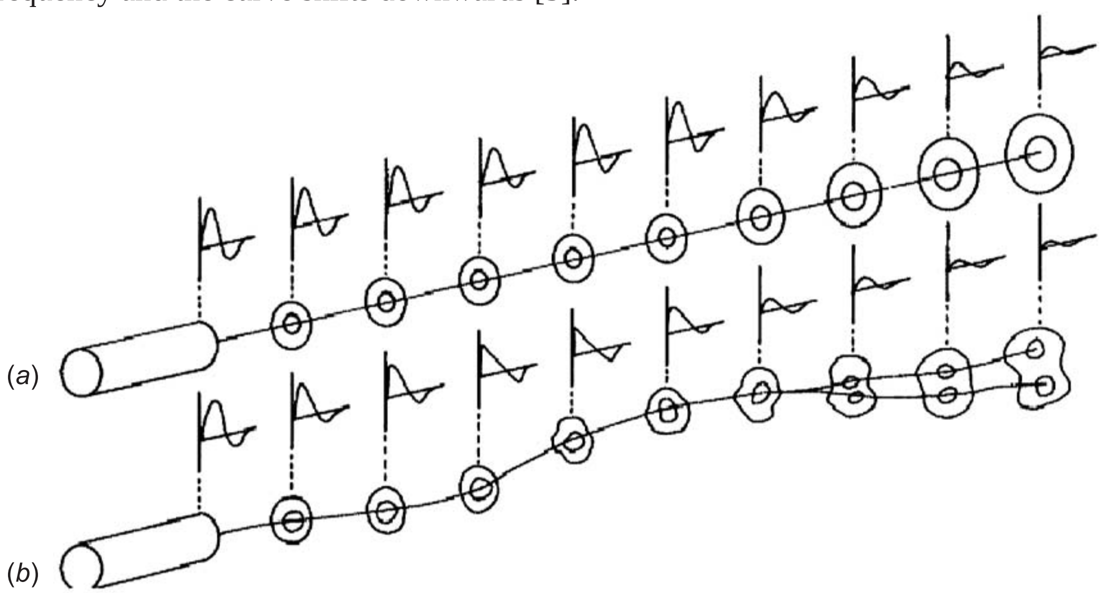

Fig. 3. Ultrasonic beam produced by a pulsating electrical signal to piezoelectric crystal. A) Beam traversal through a homogeneous and lossless medium B) Beam traversal through a living tissue

2.2. Modelling the skin attenuation

Equivalent circuit model [4] is developed with components which emulates sound attenuation in human tissue intensity. The loss is generally due to the thickness of the cartilage bone.

The above prototype employs a simple amplitude modulation circuit wherein an input from the microphone modulates the 1MHz Ultrasound (carrier) which oscillates a piezo-element. The piezo element is kept on contact with cartilage using standard USG-gel. On the other side of the cartilage is a piezo-receptor which receives the vibrations, converts into suitable electrical signals and is demodulated.

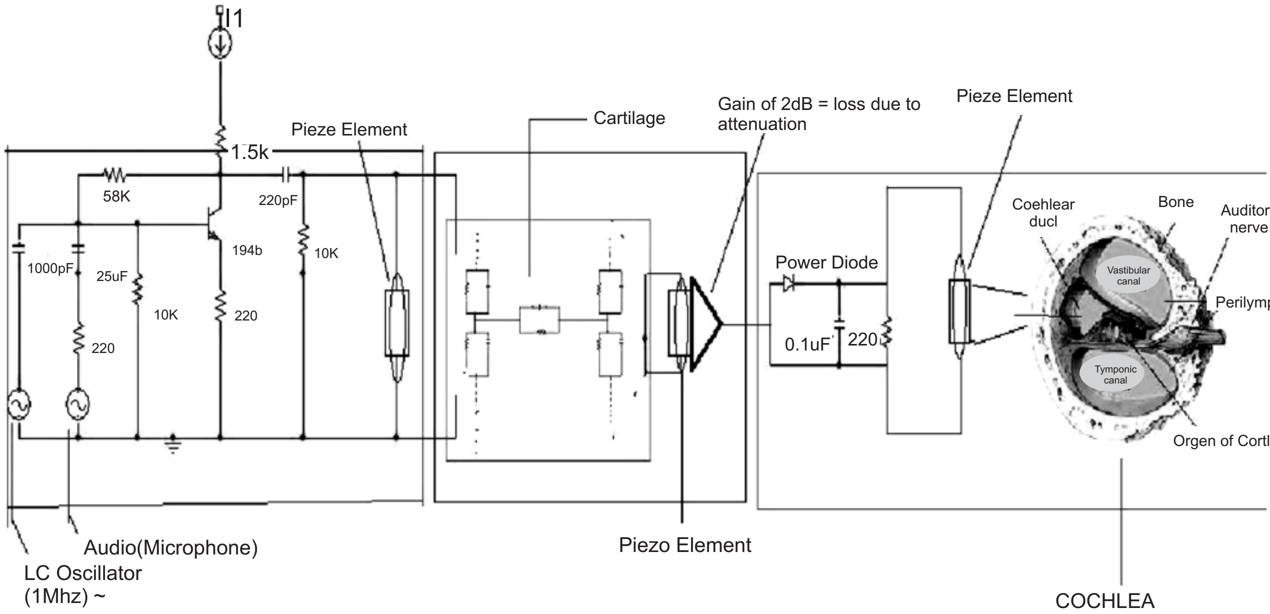

Figure 4: Our Model of a cochlear implantable hearing aid based on ultrasonic bone conduction.

Table 1

Material	*Propagation speed, c (ms-1)*	*Characteristics impedance, Z (106kg m-2s-1)*	*Attenuation Coefficient, 'a' at 1Mhz (dB cm^{-1})*
Air	330	0.0004	1.2
Blood	1570	1.61	0.2
Brain	1540	1.58	0.9
Fat	1450	1.38	0.6
Liver	1550	1.65	0.9
Muscle	1590	1.70	1.5-3.5
Skull bone	4000	7.80	13
Soft Tissue	1540	1.63	0.6

2.3. Reception and Regeneration

It has been proposed that attenuation coefficient is 0.6 for soft tissue (Table 1) [4]. It has been computed that the average attenuation is around 2 dB for modulated signal of peak to peak value less than 0.7 volt (Figure 5). The attenuation in the human tissue is compensated for using an instrumentation amplifier with pre-calibrated gain. The signal from the compensatory amplification stage is used to regenerate the message signal. The third piezoelectric device converts the recovered signal into mechanical vibration, propose to be directed onto the cochlea which transforms the vibrations through the cochlear liquids and associated structures into a neural signal.

3. RESULTS AND DISCUSSION

The input to the microphone (normal human speech) is modulated by a carrier of 1 MHz generated by the LC oscillator circuit. The signals are converted to ultrasonic vibrations using a piezoelectric crystal. For testing the circuit, the first (transmitting) piezo was placed on one side of the thenar space (webbing of the human hand) and a second piezo was placed on the other side to receive the modulated signal.

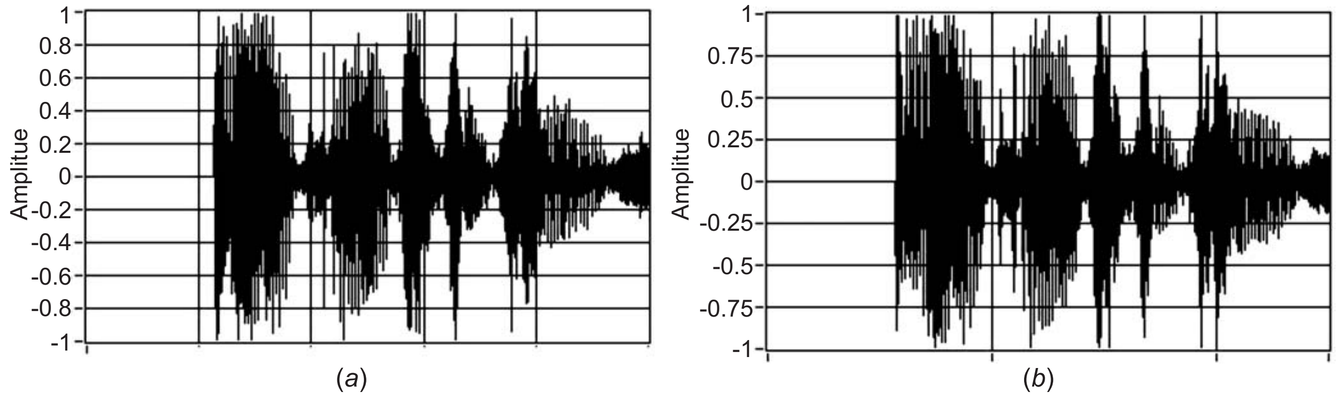

Figure 5: (*a*) Modulating Signal – Speech, (*b*) Regenerated Signal (From the last piezo)

The transmitted speech signal is recovered from the last piezo element which is proposed to be mounted on the cochlea. In Figure 5 & Figure 6 are the waveforms of the transmitted and received vibrations. On playing back the output, it could easily be deciphered as the intended speech with obvious little distortions.

4. CONCLUSION

Bone conduction technology and its applications have been reviewed and a model has been proposed where in ultrasonic vibrations are utilized to carry audio signals to the cochlea, following the steps of generation, propagation, reception and regeneration using small piezo electric transducers. The device proposed of hereof is very cheap, stable, durable and processes acceptable reproducibility. Work remains to check whether functionalities of the device are as per medical standards so that the proposed implant could be carried out.

5. REFERENCES

1. S. Stenfelt, "Acoustic and physiologic aspects of bone conduction hearing," PubMed, Vol. 71, pp.10-21, 2011.
2. Von Békésy G, "Experiments in Hearing", Jour Acoust Soc Am 88:2905. doi: 10.1121/1.399656, 1990
3. Tonndorf J, Bone conduction. Studies in experimental animals. Acta Oto-Laryngol. Suppl. 213, 1966
4. Villarreal DL, Schroeder D, Krautschneider WH (2012) Equivalent Circuit Model to Simulate the Neuromuscular Electrical Stimulation. In Tagungsband ICT.Open Rotterdam, 22-23
5. Wells PNT (1999) Ultrasonic imaging of the human body. Reports Prog Phys 62:671–722. doi: 10.1088/0034-4885/62/5/201.