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Electronic Modeling of Human Ear

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ABSTRACT- Electronic model of human ear is a simplified representation of the auditory system for the purposes of analyzing this system. It allows one to observe more closely the behavior of the system and to make predictions regarding its performance under altered input conditions and different system parameters. Modeling of the human ear function has been described by adopting various approaches and a comparison between different models of the human ear was made. In this project lumped-parameter model have been used for the modeling of human ear function and a study was made in Baghdad teaching hospital on twenty people aged between 6 to76 years old by using two devices which are the pure tone audiometer and the tympanometer. Visual Basic program version 6.0 is used on the data obtained in this study in order to determine the type of the hearing loss for the patients as this model is suitable for patients with middle ear dysfunction. The obtained results of the electronic model of the middle ear show that the frequencies above 17.5 kHz will be removed. That is due to the middle ear can not deal with frequencies above 20 kHz and the type of the hearing loss can be determined directly by using a program that analyzes the data obtained from the patient by using pure tone audiometer and tympanometer devices.

I. INTRODUCTION

The auditory system has been the focus of intensive research. Knowledge on physiology and engineering has provided the possibility for creation of models which until a certain extension tries to describe and mimic the hearing mechanisms. Mathematical and computational models are used to build quantitative simulations that describe a system and bring insights about the system itself or its behavior under certain conditions. Auditory models might be used for several purposes, such as help on tracking problems on hearing or speech fields [1].

GOODE et al., in 1993, discussed the possibility of designing prosthesis that has particularly good acoustic function at some frequencies at the expense of function at other frequencies [2].Prosthesis designed for improved high frequency response could be used for example in a patient with a high frequency sensor neural component to the hearing loss.

The crucial problem in modeling is deciding what the optimal level of details is and what the possible simplifications are. The amount of details and the computational and mathematical burden go against each other Increasing the level of details leads to complex and computational expensive models. Furthermore, all the effort put on those details modeling might be wasted if the final user of the models does not care about them [3].In order to better understand signal propagation in the ear, a time-domain model of the tympanic membrane and of the ossicular chain is derived by PURIA and ALLEN, in 2003, for the cat. Ossicles were represented by a two-port network and the tympanic membrane is discretized into a series of transmission lines, each one characterized by its own delay and reflection coefficient [4].

The ear is the organ of hearing. Hearing is a series of events in which the ear converts sound waves into electrical signals and causes nerve impulses to be sent to the brain where they are interpreted as sound [5].

The ear has three main parts: the outer, middle, and inner ear. The outer ear is divided into the auricle and external auditory canal. The middle ear is an air-containing space, which is normally sealed laterally by the eardrum, and has three small bones, (the malleus, the incus, and the stapes) which are involved in sound conduction. Sound is collected by the auricle and directed through the outer ear canal. Air molecules under pressure cause the tympanic to vibrate. These move the ossicles and cause vibration of the oval window. The vibration is transferred to the snail-shaped cochlea in the inner ear; the cochlea is lined with sensitive hairs which trigger the generation of nerve signals that are sent to the brain [6].

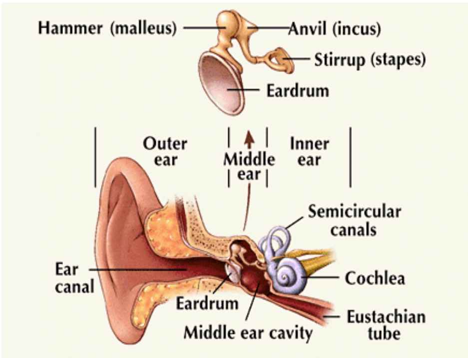

Fig 1. Structures of the human ear [5].

A. Middle Ear Function

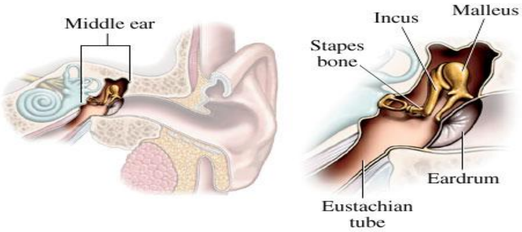

Fig 2. Middle ear function [5]

The vibration of the ear drum causes in sequence, the malleus (hammer), the incus (anvil), and the stapes (stirrup), to vibrate and transfer the vibrations to the oval window of the inner ear. The middle ear has two functions:

1. Impedance matching: Fluid in the cochlea is much harder to vibrate than air. If sound waves in the air struck the oval window directly, they would mostly bounce off. The ear drum picks up weak vibrations over a large area. The ossicles then act like a lever

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system, concentrating these movements to more forceful vibrations over the smaller area of the oval window. These more forceful vibrations are able to displace the oval window against the cochlear fluid.

2. Gating: Muscles in the middle ear are able to reduce the transmission efficiency of the ossicles in order to protect the inner ear from loud noise. These muscles are activated before you speak (a preprogrammed response) or after a sustained loud noise such as at a rock concert (a reflexive response) [5].

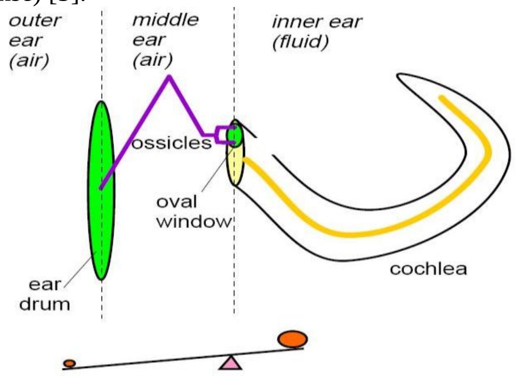

Fig 3. Middle ear as a lever system [5]

B. Type of Hearing Loss

Hearing loss can be categorized by where or what part of the auditory system is damaged. There are three basic types of hearing loss: conductive hearing loss, sensor neural hearing loss and mixed hearing loss.

1. Conductive Hearing Loss

Conductive hearing loss occurs when sound is not conducted efficiently through the outer ear canal to the eardrum and the tiny bones, or ossicles, of the middle ear.

Conductive hearing loss usually involves a reduction in sound level, or the ability to hear faint sounds. This type of hearing loss can often be medically or surgically corrected [6].

2. Sensor neural Hearing Loss

Sensor neural hearing loss occurs when there is damage to the inner ear (cochlea) or to the nerve pathways from the inner ear (retro cochlear) to the brain. Sensor neural hearing loss not only involves a reduction in sound level, or ability to hear faint sounds, but also affects speech understanding, or ability to hear clearly. Sensor neural hearing loss can be caused by diseases, birth injury, drugs that are toxic to the auditory system, and genetic syndromes .Sensor neural hearing loss may also occur as a result of noise exposure, viruses, head trauma, aging, and tumors [7].

3. Mixed Hearing Loss

Sometimes a conductive hearing loss occurs in combination with a sensor neural hearing loss. In other words, there may be damage in the outer or middle ear and in the inner ear (cochlea) or auditory nerve. When this occurs, the hearing loss is referred to as a mixed hearing loss [6].

C. The Pure Tone Audiometer

The auditory system can be stimulated via sound energy that is sent through air to the ear drum (air conduction) or by placing a bone vibrator against the skull (bone conduction). Sound sent through air tests all parts of the auditory system—the outer ear, middle ear, inner ear and central auditory pathways. In contrast, sound conducted through bone bypasses the outer and middle ear.

It directly sets up a traveling wave in the cochlea and stimulates the cochlea and central auditory pathways. By comparing the auditory thresholds using these two methods, the site of hearing loss can be determined [7].

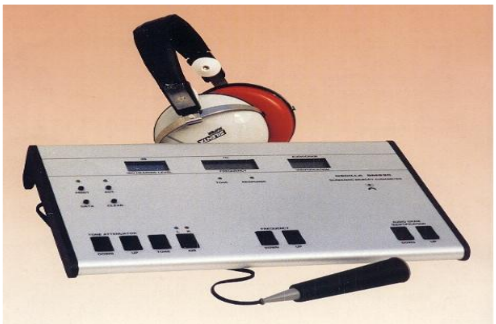

Fig 4. Pure Tone Audiometer device [8]

D. Tympanometry

Tympanometry is an examination used to test the condition of the middle ear and mobility of the eardrum (tympanic membrane) and the conduction bones, by creating variations of air pressure in the ear, it is not a hearing test, but rather, a measure of energy transmission through the middle ear. This test should not be used to assess the sensitivity of hearing and the results of this test should always be viewed in conjunction with pure tone audiometry.

Tympanometry testing is conducted on all examinees age six to nineteen. The tympanometer device as shown in Fig 9, tests the function of the middle ear by first measuring the impedance or flexibility of the eardrums and then by measuring the integrity of the bones in the middle ear [10]. Tympanometry is a valuable component of the audiometric evaluation. In the evaluation of hearing loss, tympanometry is a valuable component of the distinction between sensorinueural and conductive hearing loss, when evaluation is not apparent via Weber and Rinne testing [9].

Fig 5 Tympanometer device [9].

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II. ELECTRONIC MODEL OF MIDDEL EAR

Modeling the equation describing the human ear function is complex and its solution is tedious, so using electronic circuits modeling have advantages that the functional relationship of the modeled system become clear almost on sight. Different characteristics of human ear could be easily simulated by varying adjustable electrical components of the model. In order to design a model with the same characteristics of human middle ear the following components are needed:

1- Threshold Finding Circuit,
2- Limiting and Amplification Circuit,
3- Band Reject Filter Circuit, and
4- Low Pass Filter.

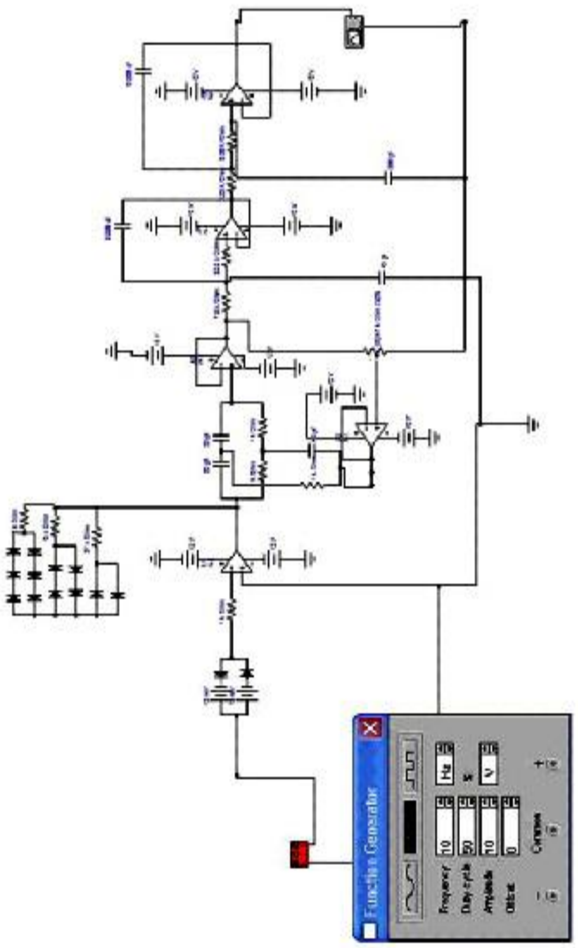

Fig 6. Circuit Diagram of the whole electronic model.

A. Threshold Finding Circuit

It consists of double-ended series diode limiter; each arm consists of a DC voltage source of 15mV and silicon diodes with 16mV threshold voltage.

B. Limiting and Amplification Circuit

It consists of amplifier with different amplification ratio depending on the value of the input voltage which will turn on one of the feedback arms of the amplifier.

C. Band Reject Filter Circuit

The function of this circuit is to reject some frequencies to make the model function similar as the human middle ear. In the band reject filter circuit, the magnitude of capacitances and resistances will cause to reject the frequencies of 4 kHz*2π. These frequencies have the same value that needed for the middle ear performance.

D. Low Pass Filter Circuit

This circuit consists of two stages of second order low pass filter

The obtained results show that the frequencies above 17.5 kHz will be removed. That is due to the middle ear cannot deal with frequencies above 20 kHz.

The overall circuit of the electronic middle ear model will be as shown in Fig. 6, this model will operate like the human middle ear and its function is like the function of the middle ear in amplification of the sound wave and protection of the inner ear by gating of the loud sounds.

III. CONCLUSIONS

1. Modeling of the human ear function has been described by adopting various approaches.
2. The finite element method is usually used in modeling complex electro-mechanical biological system, although it is accurate and intuitive method to model the human ear, it is hard to integrate the finite element method algorithm into a digital hearing aid chip because of the seriously complex data processing algorithm of the finite element method and in addition the finite element method obtain only approximate solutions and many input data are required.
3. The simplest modeling is the lumped-parameter modeling in which different characteristics of human ear could be easily simulated by varying adjustable electrical components of the model.
4. The designed electronic model of the middle ear work like the natural human middle ear and the obtained results of this model show that the frequencies above 17.5 kHz will be removed. That is because the middle ear can not deal with frequencies above 20 kHz.
5. As this model is suitable for patients with middle ear dysfunction, so it is important to determine the type of the hearing loss for the patients. The type of the hearing loss can be determined directly by using a program that analyzes the data obtained from the patient by using pure tone audiometer and tympanometer devices.
6. The benefit of modeling the human ear is to observe the behavior of the auditory system and to make predictions regarding its performance under altered conditions (different frequencies) and different system parameters.

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