*M. Tech. Credit Seminar Report, Electronic Systems Group, EE Dept, IIT Bombay submitted Nov 03*

# Audiometry techniques, circuits, and systems

Vineet P. Aras
(Roll No. 03307411)
Supervisor: Prof. P. C. Pandey

## Abstract

**Audiometry is the technique to identify and quantitatively determine the degree of hearing loss of a person by measuring his hearing sensitivity, so that suitable medical treatment or one of the appropriate hearing aids and assistive devices can be prescribed. In audiological investigations, the hearing sensitivity is tested for pure tones, speech or other sound stimuli. The result, when plotted graphically, is called an audiogram. The electronic instrument used for measuring the hearing threshold level is called an audiometer. Using it, the test tones of different frequencies and levels are generated and presented to the patient and hearing thresholds are determined on the basis of patient’s response. The auditory system and its disorders are described. Different audiometric tests, techniques and various audiometers are discussed.**

## 1. Introduction

There could be various disorders in the various parts of the ear. Audiological investigations help us to diagnose the nature of deafness and localise the site of disorder. The method by which patient's hearing sensitivity can be determined is termed as audiometry [1]. It helps in assessing the nature, degree, and probable cause of the hearing impairment. In this technique, auditory stimuli with varying intensity levels are presented to the person who responds to these stimuli. The minimum intensity level of these stimuli to which consistent responses are obtained is taken as the “threshold of hearing”. Depending on this threshold, the patient’s hearing sensitivity can be estimated by obtaining an audiogram. An audiogram is a plot of threshold intensity versus frequency. Then the best-suited medical treatment or hearing aid or other assistive devices can be prescribed. There are different audiometric procedures depending on the stimuli used. An audiometer is an instrument, which is used for carrying out these audiometric tests.

Dipak Patel [2], Pratibha Reddy [3], Ashish Kothari [4], and Chandrakant Singh [5] as part of their M. Tech. dissertations worked towards developing a microcontroller based pure tone audiometer with a provision for automated audiometry and computer/printer interface.

In the second section, disorders and working of the auditory system has been discussed. Third section describes the various investigations through audiometric techniques. Fourth section provide general description of audiometers along with features and specification of various audiometers. Summery is discussed in the last section.

## 2. Disorders of the Auditory system

Our system of hearing comprises of two sections viz. a peripheral section which is our ear and a central section located in the brain which carries the sensation from the ears to the auditory area of the cerebral cortex. The auditory area of the cerebral cortex (called auditory cortex) is the area of the brain, which is dedicated to and specialised in interpreting the sound which comes to our ears. The ear receives the sound in the form of sound energy, which is a form of vibration. This vibrating energy enters the external part of the ear (called external auditory meatus) and vibrates the ear drum (technically known as tympanic membrane). This vibration of the tympanic membrane is picked up by a chain of small bones called malleus, incus and stapes, which conduct this vibration to a specialised organ called cochlea [7]. The cochlea is the transducer of the hearing system. The function of the cochlea is to convent the vibratory energy into electrical energy. Once this has been achieved, this electrical energy enters the nerve of hearing (called auditory nerve) and carries the sensation through different parts of the brain to the auditory cortex, where the sensation of sound is analysed and interpreted. For proper hearing each and every part of this system right from the external auditory meatus to the auditory cortex has to be normal.

### 2.1 Auditory system

A disorder in any of them will cause deafness. The ear has three sections viz.- the external auditory meatus, the middle ear and the inner ear, as shown in Fig.1. The external ear is the area from the pinna (technically called auricle) to the ear drum. The middle ear is from the ear drum to the cochlea, it consists of the three small bones called ossicles which are placed in a closed space (called tympanum) filled with air. The inner ear is the portion of the ear deeper to this and it houses the transducer (called cochlea) and also the organ of balance (called vestibular labyrinth).

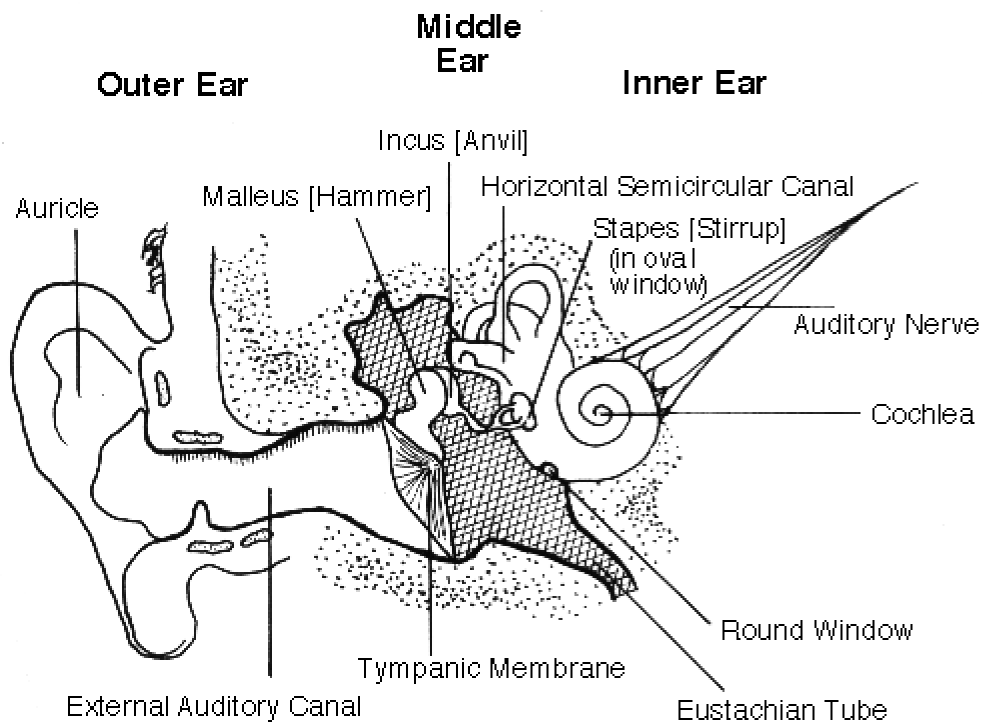


**Fig. 1.** The organ of hearing, consisting of the outer ear (auricle and pinna), the middle ear (ossicles) and the inner ear (cochlea). Adapted from [6].

When sound reaches the inner ear through the eardrum, this phenomenon is called air conduction. This is the usual path of sounds to reach the eardrum. Sound, particularly in the low frequency range, may reach the inner ear via the bones in the head rather than from the eardrum, this phenomenon being called bone conduction [6]. The normal process via the ear canal is called air conduction. Wearing earplugs results in a greater percentage of the sound heard coming from bone conduction. Normally only a small fraction of sound is received in this way; however, deaf people whose inner ear still functions normally may be able to hear sound conducted to the ear in this way, for instance by holding between the teeth a wooden rod connected to a vibrating object.

## 2.2 Sound perception

Sound is generated in nature whenever an object vibrates in an elastic medium like air. Sounds in nature are complex and not pure tone or sine waves [1]. However, all complex sounds can be considered as a mixture of different pure tone sounds of different frequencies.

The ear is not equally sensitive to all frequencies, particularly in the low and high Frequency ranges. The frequency response over the entire audio range has been charted, originally by Fletcher and Munson in 1933, with later revisions by other authors, as a set of curves showing the sound pressure levels of pure tones that are perceived as being equally loud [7]. The curves are plotted for each 10 dB rise in level with the reference tone being at 1 kHz, also called loudness level contours and the Fletcher-Munson curves, as shown in Fig.2. The lowest curve represents the threshold of hearing, the highest the threshold of pain.

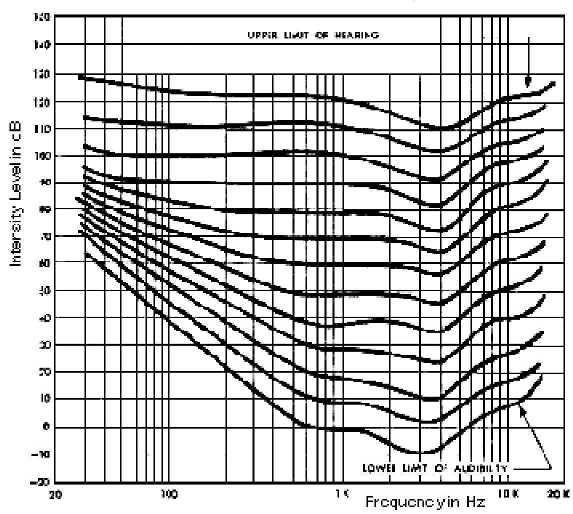


**Fig.2** Curves based on the studies of Fletcher and Munson showing the response of the human hearing mechanism as a function of frequency and loudness levels. Adapted from [7].

The curves are lowest in the range from 1 to 5 kHz, with a dip at 4 kHz, indicating that the ear is most sensitive to frequencies in this range. The intensity level of higher or lower tones must be raised substantially in order to create the same impression of loudness. The phon scale was devised to express this subjective impression of loudness, since the decibel scale alone refers to actual sound pressure or sound intensity levels.

Although human hearing ranges from 20 Hz to 20 kHz, there is little speech information above 8000 Hz, and perception of frequencies below 100 Hz is increasingly tactile in nature, making them difficult to assess. Also, the loss of hearing sensitivity is observed first at high frequency (8 kHz) and later on as the loss progresses, its effect is observed in the mid-frequency region (1-2 kHz) as well. By the time the loss is observed in the low frequency region, the subject will be near to deafness. Hence, audiometric tests carried out in the low frequency region do not give any significant information about hearing loss. Therefore, audiologists routinely test only in the range of 250-8000 Hz, often in octave steps. Standardized frequencies tested include 250, 500, 1000, 1500, 2000, 3000, 4000, 6000, and 8000 Hz. This represents octave intervals, by convention, but intervening frequencies may also be tested [7].

In acoustic measurements, sound level is often given in dB, taking sound pressure of 20 microPa as the reference level, and is known as sound pressure level (SPL).

$$\text{Sound level dB SPL} = 20 \log (\text{measured sound pressure} / 20 \text{ microPa})$$

However, in audiometry the sound level of pure tones is given in dB by taking average hearing threshold of normal hearing young adults as the reference, and is known as hearing level (HL) [2].

$$\text{Sound level dB HL} = 20 \log (\text{measured sound} / \text{average threshold of normal hearing})$$

The hearing threshold is frequency dependent, and hence SPL corresponding to a given HL varies with frequency. Intensity levels in audiometers are indicated in HL.

Table 1 gives the dB SPL (dB HL) threshold values of a normal person for standard frequencies. The "0 dB" hearing level in audiometry is a modal value derived from a large population of normals. Normal values for auditory thresholds were defined by the International Standards Organization (ISO) in 1984. These values are derived from large population studies of normal adults 18-30 years of age.

**Table 1** Threshold values in dB SPL for 0 dB HL (ISO, 1984) Adapted from [7]

| Frequency (Hz) | 250 | 500 | 1k | 1.5k | 2k | 3k | 4k | 6k | 8k |
|---|---|---|---|---|---|---|---|---|---|
| dB SPL | 25.5 | 11.5 | 7 | 6.5 | 9 | 10 | 9 | 10.5 | 13 |

Since both HL and SPL are logarithmic units, a certain increment in HL corresponds to the same value increment in SPL [1].

## 2.4 Audiogram

An audiogram is a plot of threshold intensity versus frequency. The intensity scale in HL increases downwards, and hence the audiogram resembles like an attenuation response, a lower point on the audiogram indicating higher loss. A typical audiogram (dB HL vs. frequency graph) comparing normal and impaired hearing is shown in Fig.3. The dip or notch at 4 kHz as shown, or at 6 kHz, is a symptom of noise-induced hearing loss.

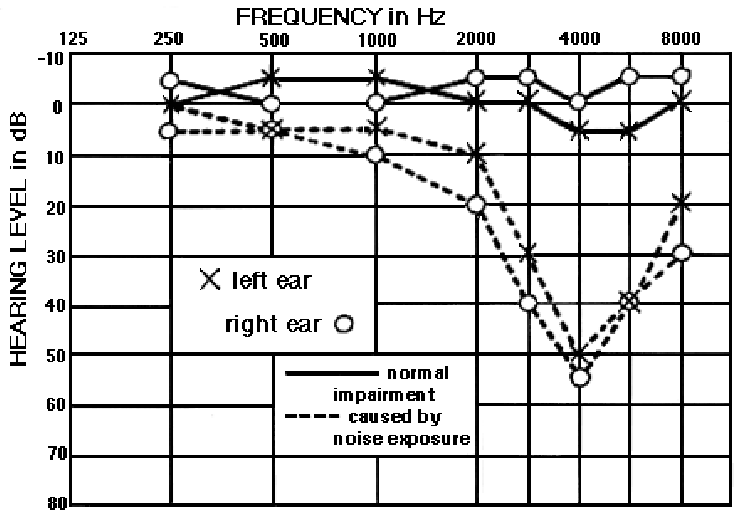


**Fig. 3** Audiogram of normal ears and impaired ears. Adapted [6].

Most thresholds are approximately 0 dB HL for a normal ear. Points below 0 dB HL on the scale denote louder threshold levels, whereas those above, expressed in negative decibels with respect to the zero level, are less intense levels which, because of individual hearing differences, some people may normally hear. Four separate curves can be obtained - right ear air conduction (AC), right ear bone conduction (BC), left ear AC, and left ear BC. This comprises the audiogram. The symbols used on most audiograms are
x - left air conduction
o - right air conduction

In normal individuals, a small discrepancy is often seen between air and bone conduction thresholds, the "AC-BC gap". At any given frequency the threshold for AC is somewhat lower than BC (i.e., a stronger signal is needed for BC).

## 2.5 Disorders of the auditory system

Each section of the ear has diseases specific to it and specific tests (investigations) are there to identify disorders in each portion. The common causes of disorder in the external auditory meatus is collection of either wax or fungal debris or foreign body in it. To diagnose this no investigation is required and your doctor can see it directly and clean it with instruments. This deafness due to blockage of the external ear is usually very slight.

The middle ear comprises of the eardrum, the ossicles, and the air space within the cavity of the middle ear. The common diseases affecting this portion are perforation in the ear drum, a stiffness or damage to the chain of small bones in the ear, and collection of fluid in the middle ear space (called middle ear effusion). A perforation can usually be diagnosed just by visualising the ear-drum; however the other middle ear disorders require special investigations for confirmation. Any deafness due to disorders in the external auditory meatus or in the middle ear is called conductive deafness because the primary function of these portions is the conduction of sound to the inner ear and disorders in these areas impede the conduction of sound to the cochlea [7]. A perforation in the ear drum or a stiffness of the ossicular chain can be corrected surgically. Collection of fluid in the middle ear is usually treatable by medicines but may sometimes require surgical management.

The diseases of the inner ear, i.e. the cochlea is difficult to treat. Disorders of the inner ear not only cause a deafness called sensorineural (perceptive) deafness but also may case a peculiar sensation of buzzing sounds in the ear called tinnitus [6]. However tinnitus is not specific only of cochlear damage and sometimes disorders of the middle ear and / or the portion of the auditory nerve in the brain can also cause tinnitus. Deafness due to disorders of the inner ear are commonly refractory to medical and surgical methods and usually hearing aids are the only option. Deafness may also occur due to diseases of the nerve carrying the sensation from the cochlea to the brain . One common disorder is acoustic neuroma which is primarily a tumor of the nerve of balancing but damages the nerve of hearing due to its close proximity to it. This disease if left untreated can be life threatening. Deafness due to disorder of the nerve is called retrocochlear deafness and deafness due to disorders of the nerves which carry the sensation of hearing still higher up to auditory cortex are called central deafness.

The common symptoms of disorders in the auditory system are difficulty in hearing normal conversation from a distance of 8 feet or a whisper from a distance of 3 feet, can hear people talk but have difficulty in understanding what they say i.e. spoken word appear jumbled up, hear comparatively less in one ear, require to raise the volume of which is uncomfortable to other people, hear whistling/buzzing sounds in the ear or in the head when actually such sounds are not there, have a sensation of blockage/heaviness in one or both ears.

## 3. The common investigations for hearing

Different audiological investigations help us to diagnose the nature of deafness and localise the site of disorder. The commonest investigation for deafness is pure tone audiometry. It measures hearing acuity (i.e. how perfectly the subject can hear) and tells us whether is deafness is conductive (disorder in external auditory meatus and / or middle ear) or sensorineural (disorder in the inner ear or in the nerve of hearing in the brain) or whether the deafness is mixed, i.e. a disorder combining both the conductive apparatus as well as the inner ear / nerve of hearing.

Tympanometry is also a common audiological investigation. It assesses the structural integrity of the middle ear. It helps us to diagnose the nature of the disorder in the middle ear in cases of conductive or mixed deafness. It can tell us whether there is any stiffness of the ossicular chain or whether the ossicular chain is broken or whether there is collection of fluid in the middle or the ear drum had become immobile due to adhesions in the middle ear.

If audiometry test has diagnosed the deafness to be sensorineural in type, there are some specialised test like- short increment sensitivity index (SISI), tone decay, speech audiometry and acoustic reflex tests which can tell us whether the disorder is in the cochlea or in the nerve of hearing [6]. The brain-stem evoked response audiometry (BERA) is used for sensorineural deafness and is usually done to objectively assess the site of lesion in retrocochlear type of sensorineural deafness (i.e. if a lesion is expected in the auditory nerve or in the neural pathways which carry the sensation through the brain). It also is used to objectively assess the hearing acuity of children who can not respond properly.

## Audiometry

Audiometry is the technique to identify the nature of hearing loss and to determine the threshold of hearing by recording responses of the patient after presenting him with auditory stimuli with varying intensity levels. There are different audiometric techniques and procedures used for achieving this. For air conduction testing, stimuli are presented to each ear independently with specialized earphones. For bone conduction testing, a bone vibrator is placed onto the mastoid process of either right or left temporal bone;

external auditory canals are not usually occluded [8]. All equipment must be continually calibrated to conform with international standards. This ensures that a gradual loss of hearing noted on serial testing is truly valid and not due to machine error. Audiometry is performed in an isolated sound-dampened environment. As with other psychoacoustic testing, all audiometric equipment is discretely arranged so that visual (nonacoustic) cues are minimized [8].

### 3.1 Masking in Audiometry

In audiometry, both ears are tested separately. In air and bone conduction audiometry where sound is applied to one ear, the contra lateral cochlea is also stimulated by transmission through the bone of the skull. In case the sound in one ear is sufficient to stimulate the second ear, it is called cross hearing.

During the air conduction test, the stimuli while passing from test ear to cochlea of the non-test ear gets attenuated. This loss of sound energy is called interaural attenuation and varies between 45 to 80 dB [1]. However, during bone conduction test, the cochleae of both sides are equally stimulated i.e. the inter-aural attenuation is of 0 dB. Hence, cross hearing is a serious concern in case of bone conduction test than it is for air conduction. A bone vibrator is placed over the mastoid process of the appropriate ear and pure tones are transmitted. Factors such as vibrator placement and pressure may influence results. Fewer frequencies are tested: 250, 500, 1000, 2000, 3000, and 4000 Hz. In addition, audiometer output is limited to approximately 80 dB due to distortion and other technical factors. Interrupted signals in an ascending series are again preferred. Whenever cross hearing is suspected, it is necessary to remove the non-test ear from procedure.

A simple procedure by which this can be done is to deliver a noise to the non-test ear in order to remove it from the test procedure by masking. Here masking noise which is loud enough to prevent the tone reaching and stimulating the non-test ear, but at the same time it should not mask the sensitivity of the test ear "overmasking" [1]. Thus, an audiologist should provide appropriate level of masking. The masking noise is often selected to be a wide-band noise, or narrow band noise with the band centered about the test frequency. Wide-band noise has uniform power density spectrum over all the audible frequency range i.e. from 250 Hz to 8 kHz. However the masking effect is actually contributed by frequency components centered on the test tone frequency, over a bandwidth of about 1/3 to 1/2 octave, known as critical band. Broadband noise bandpass filtered with a band approximately corresponding to the critical band is known as narrow band noise, and compared to wide band noise it gives the same masking effect at a lower sound pressure level.

### 3.2 Techniques and Procedures

There are two types of audiometric techniques, subjective type and objective type.

In subjective test, the patient has to respond when he hears the presented sound. Subjective type audiometric test involves presentation of systematically varying acoustic stimuli to the subject and recording the responses.

Objective test only requires co-operation from the patient towards attachment of the measuring electrodes or probes.

There are different audiometeric procedures depending on the stimuli used.

### 3.2.1 Pure Tone Audiometry

Pure tone audiometry is a procedure for determination of the extent of hearing loss and the cause, i.e. conduction or sensorineural loss. The subject's hearing threshold for acoustic stimuli of different frequencies are measured. The initial level of the stimuli is selected by the audiologist.

**Procedure**

In this technique, at the outset, patient is instructed to signal the audiologist each time a tone is perceived. A variety of response signals may be employed - responding "yes" with each tone, tapping the rhythm of tones, or pointing to the ear where the tone is heard, or better by a response switch. For air conduction thresholds, earphones are comfortably positioned and the better ear tested first, if known. If not known, some audiologists will quickly screen each ear using the same initial frequency and the better ear tentatively determined. Tones are often presented in an ascending series, that is, from low to high frequency [8]. Initially a single frequency stimulus at some presumed level is presented to the patient. Initially a pure tone of 30 dB HL is presented to the subject. If the response is positive, the tone level is decreased in steps of 10 dB till the patient does not give response. On the other hand, after applying 30 dB tone at first time, if the patient does not hear it, the level is raised in steps of 10 dB step until it is heard for first time. Once, the response is positive, the tone is decreased by 10 dB. If the patient hears this tone, the tone is again decreased by 5 dB. If the patient does not hear it, the tone is again raised by 5 dB. In this way by several presentations, the hearing threshold is obtained. Often, tone intensities slightly above and below this auditory threshold are tested to verify and help "hone in" on the precise threshold value. The minimum presentation level at which the subject responds at least 50% times (3 responses out of 6 tone presentations), is taken as the hearing threshold.

Specific situations are as follows. If profound hearing loss is expected, frequencies from 125-500 Hz are tested first (some audiologists screen initially at 500 Hz then skip to 4000 Hz, if normal hearing expected). If a tone is not audible even at maximum audiometer output, "no response" is recorded [8]. If 100% correct response occurs at a minimal intensity, testing below 0 dB is possible. Thus, certain individuals may demonstrate greater hearing sensitivity and thresholds down to -20 dB are measurable.

The results of the audiometry are reported in an audiogram. Different shapes of audiograms are associated with different types of hearing loss [1]. When prescribing hearing aids the audiogram will guide the degree of amplification required at various frequencies. For site of lesion testing, "conductive" loss implies a lesion in the external auditory meatus, tympanic membrane, and/or middle ear. "Sensorineural" loss usually implies a lesion in the cochlea or acoustic nerve (cranial nerve VII), but not the cortex. With most cases of sensorineural loss, both AC and BC are significantly impaired and hearing loss is more pronounced as the frequency increases. "Central" hearing loss refers to a lesion in the brainstem or auditory cortex. This cannot be adequately evaluated by pure tone audiometry [8]. "Nonorganic" hearing loss implies an intact auditory circuit with deafness due to other factors (e.g., malingering, psychosis).

Otosclerosis and chronic otoitis media result in a mixed conduction and sensorineural deafness [9]. There is a marked decrease in sensitivity for AC thresholds with BC relatively spared. Both low and high frequencies are equally impaired in this case. If a large mass component is playing a role (e.g., serous otitis media), thresholds may be more impaired at higher frequencies. If conductive loss is due to stiffness of the stapes (e.g., early otosclerosis), AC thresholds may be preferentially elevated at lower frequencies. Presbycusis is the loss of high frequency sensitivity with age [9]. There is a constant loss of sensitivity for AC and BC, steadily worsening from low to high frequency. This pattern is often seen with the normal aging process.

### 3.2.2 Tone Decay Test (TDT)

Of all the auditory tests designed for detection of the site of pathology in the sensorineural pathway, the tone decay test is the most commonly used [7]. This is because the test can be reliably carried out on any pure tone audiometer. It has been statistically shown that a pathology in the auditory nerve causes an abnormally rapid deterioration in the threshold of hearing of a tone if presented continuously to the ear. In this test, we try to quantify the deterioration in the auditory nerve. This test can be carried out with or without detecting the hearing threshold of the subject.

**Procedure**

The operator selects the frequency. The subject is instructed to press the response switch as soon as he hears the tone and he will once again press the switch if he doesn't hear the tone. The duration between these two responses is measured. The tone is presented and the level is incremented, starting form 30 dB HL, until the subject responds. If the subject is able to hear the tone for more than one-minute [1], the tone level is decremented in steps of 5 dB, and the same procedure is repeated until the tone is audible for less than a minute. If the subject is not able to hear the tone continuously for more than one minute, the intensity is incremented by 5 dB and again tested for the same. The tone is either incremented or decremented without switching off the tone. The lowest intensity for which patient is able to hear the tone for about 1 min. is considered as threshold at that frequency for tone decay test. Similarly, the testing is done for other frequencies and the relation between threshold and frequency is obtained. Tone decay test is used to diagnose the sensorineural deafness [1].

**Interpretation**

Tone decay is usually classified as normal if decay is 0 to 5 dB, as mild if 10 to 15 dB, as moderate if 20 to 25 dB, and as severe if 30 dB or above. Severe decay is considered to be suggestive of a retrocochlear lesion and warrants further investigation. If tone decay in excess of 30 dB exists the patient should be subjected to thorough and detailed neuro-otological examination.

### 3.2.3 Short Increment Sensitivity Index (SISI) Test

The SISI test is used to detect the pathology in cochlear or retrocochlear lesions [1]. This test is normally carried out after finding the pure tone hearing threshold using normal pure tone audiometry This test determines the capacity of a patient to detect a brief 1 dB increment in intensity, provided at 5 seconds interval at a particular frequency.

**Procedure**

In SISI test, the operator will select the test frequency and set the level to 20 dB suprathreshold level. The tone is presented with brief bursts of 1 dB modulation above the carrier tone at every 5 s. The 1 dB increment is presented for an interval of 300 ms, out of which the rise time and fall time are 50 ms each. The patient is asked to press the response button whenever he detects a change in the level [1]. Twenty such bursts are given and out of them, the number of bursts the patient is able to detect is recorded. The no. of responses is converted to percentage and stored as the test results. The same procedure is repeated for each frequency, and the result is stored. A SISI audiogram is plotted on the basis of percent score for each of the test frequencies.

**Interpretation**

Scores between 70% to 100% indicate a cochlear lesion especially if the test is done at frequency of 1k Hz and above. If the test is done at 2k – 4k Hz, scores of 80% to 100% only are typical of cochlear lesions. Scores of 0 to 20% suggest a retrocochlear pathology but may also be seen in patients without any sensorineural impairment. 70%  to 100% are positive SISI while 0 to 20% are negative SISI [1].

### 3.2.4 Bekesy Audiometry

This is another form of pure tone audiometry, its specialty being that, a self-recording audiometer is used in which the changes in intensity as well as frequency are done automatically by means of a motor [1]. The change in frequency can occur in forward or in backward manner. Conventionally, a forward change is used. The motor drive attenuator is controlled by a switch, which is operated by the patient. The patient presses the switch as soon as he hears a sound and releases it as soon as he stops hearing the sound. The audiometer is so programmed that a tracing is recorded only when the patient presses the switch, the frequency being continually changed either in the forward or backward manner/ A graphical representation of the patients hearing threshold across the entire frequency range is thus obtained by the successive crossing and recrossing of the hearing threshold in the form of a jugged line. Two tracings are recorded for each ear, one by presenting a continuous tone and other by presenting a pulsed tone [1].

**Interpretation**

In type I, the tracings for the continuous and pulsed tones are superimposed upon each other, found in normal ears and ears with conductive deafness. In type II, the tracings for the continuous and pulsed tones are superimposed up to 1k Hz, but above 1k Hz, the tracing for continuous tone falls below that of the pulsed tone. In type III, the tracing for continuous tone falls considerably below that of the pulsed tone right from the start. In type IV, the tracing for continuous tone falls below that of pulsed tone right from low frequencies but not as much as type III. In type V, the continuous tone is above the pulsed tone [1].

### 3.2.5 Speech Audiometry

While pure tone threshold testing attempts to assess sensitivity, speech audiometry testing attempts to address the integrity of the entire auditory system by assessing the ability to here clearly and to understand speech communication. The main use of speech audiometry is in the identification of neural types of hearing loss, in which both the reception as well as the discrimination of speech is impaired more markedly than in cochlear or conductive hearing loss. There are two types of speech audiometric tests, “speech discrimination test” and “speech reception threshold test”.

**Speech discrimination test**

In this test, lists of monosyllable speech discrimination words are presented over earphones for each ear which patient is asked to repeat. The percentage of the total number of words presented which the patient is able to identify correctly gives the speech discrimination score (SDS). The SDS is determined when the patient repeats 50% of the words correctly.  The result of this test is from 0 to 100 %. Generally, a high score is associated with normal hearing or conductive hearing loss and low score is associated with sensorineural loss.

**Speech reception threshold test**

This test is similar to the speech discrimination test except for the fact that this test uses two syllable words with equal stress (spondees) and the words are attenuated successively. The SRT (speech reception threshold) is the lowest hearing level in dB HL at which 50 % of a list spondee words are correctly identified by a subject. For estimating SRT, a group of 6 spondee words is presented at 25 dB above the average pure tone audiometry threshold for 500 Hz and 1000 Hz, and then at successively lower intensities. When the level is such that the subject is able to identify 3 words out of 6 correctly, the level is taken as SRT. The SRT of a normal subject is very closely related to his pure tone hearing threshold and the SRT is generally 2 dB lower than average of pure tone hearing level thresholds at 500 Hz and 1 kHz. A list of 36 such words in English language are prepared by the Central Institute for the Deaf.

A way of differentiating between neural and other types of hearing loss is by graphically plotting the performance intensity function. This is done by ascertaining the speech discrimination score at different sensation levels and plotting the percentage of correctly identified words as a function of the intensity of presentation of the words.

## 4. Audiometer

An audiometer is an instrument, which is used for carrying out these audiometric tests and procedures. Audiometer can be of different types, depending upon the frequency range, range of acoustic output, mode of acoustic presentation, masking facility, procedures used, and types of acoustic stimuli. It is capable of generating pure tones at a specific frequency, specific intensity, and duration, either singly or in series.

A conventional audiometer instrument has dials or knobs with calibrated scale for frequency selection and for tone masking noise level selection. The variation of the level of the stimulus is done manually by the audiologist after carefully observing the responses of the subject. The limitations and drawbacks of this conventional audiometer are that the interrupter switch is used for tone switching and needs to be mechanically silent. The presence of mechanical parts makes the instrument more susceptible to wear and tear. Calibration is necessary, at least, once in six months.

The advancement in technology has made the various switching tasks simple, flexible, and noise free. Also the procedure can be automated. Application of microprocessor/PC in audiology offers many advantages in terms of flexibility and simplicity of use, over their conventional counterparts. Increased accuracy and precision removes the need for frequent calibration of audiometer, which was required for earlier audiometers.

A general block diagram of an audiometer is shown in Fig.4. It consists of two channels, namely tone generator and noise generator, and each channel having an attenuator, equalization circuit, and power amplifier. The tone generator or oscillator should have a frequency range from 250 Hz to 8 kHz, controlled by frequency control. Each of the frequency should be within 3% of the indicated frequency. The generated tone should be stable. The equalization circuit is required firstly, to provide frequency dependent attenuation in order to calibrate the output sound levels in dB HL and secondly, to provide different amount of attenuation for different output devices used (headphone, loudspeaker, and vibrator). The attenuator, known as the as hearing or tone level control, should be capable of controlling the output sound level over a desired range in steps of 5 dB. Calibration should ensure the output sound level to be within $\pm$ 3 dB of the indicated value. For the masking purpose, the noise generator should provide wide-band noise, which has energy spectrum equally distributed over the test frequency range i.e. up to 8 kHz. There should also be a facility for narrow band noise, wherein the narrow band noise output should be distributed around the test frequency. The output power available from the power amplifier determines the maximum sound pressure level available from the headphones and the bone vibrator. The amplifier must have low distortion and a good S/N ratio to meet the standard requirements. A response switch is given to the patient, to indicate his response.

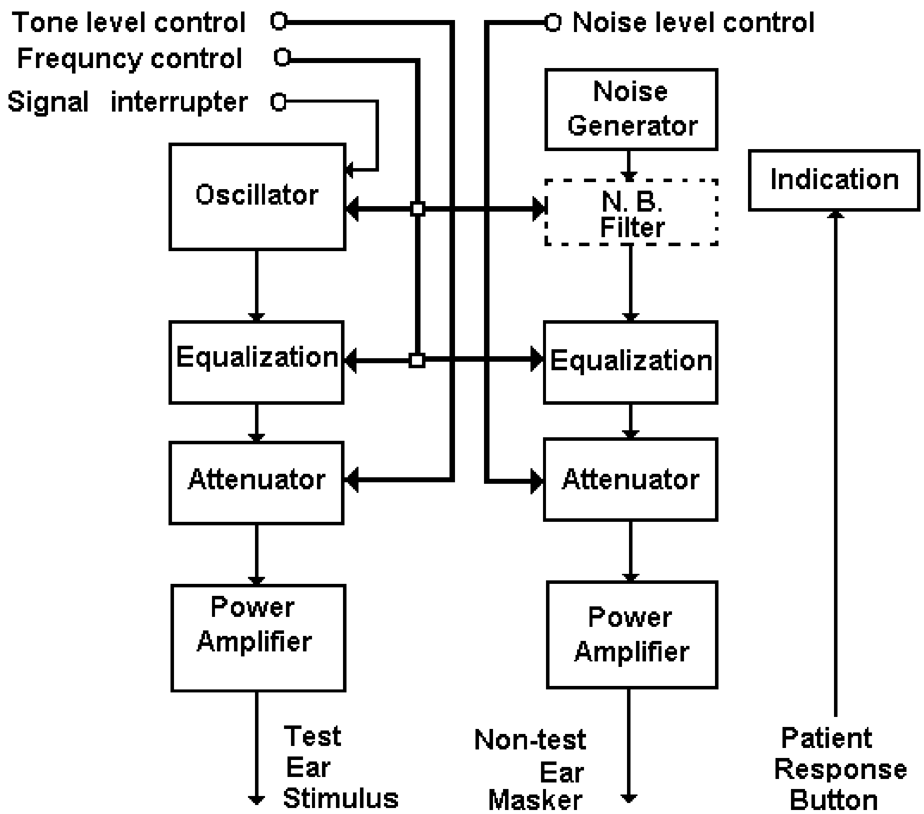


**Fig.4** General block diagram of an audiometer. Adapted from [2].

## 4.1 Features and specifications of various Audiometers

**Fonix (FA-10, FA-12)**

*Audiometer type:* microprocessor-based audiometers Type 3A with pure/warble tone wide-band/narrow-band masking noise. Facility of air and bone conduction. Facility of SISI, ABLB, MLB.

*Frequencies:*
(air) 125, 250, 500, 750, 1000, 1500, 2000, 3000, 4000, 6000, 8000
(bone) 250, 500, 750, 1000, 1500, 2000, 3000, 4000, 6000, 8000

*Attenuator:* -10 to 110 dB HL in 5-dB steps. An additional -2.5 dB of setting is available by pressing the 2.5 dB button.

*Tone output range:*
*Telephonics (TDH39) 100 Ohms*
250 Hz -10 to 90 dB HL
500 Hz to 6 kHz -10 to 110 dB HL
8 kHz -10 to 90 dB HL

(*bone) (Radioear B-71) 100 ohms*
250 Hz -10 to 40 dB HL
500 Hz to 750 Hz -10 to 60 dB HL
1 kHz to 3 kHz -10 to 70 dB HL
4 kHz -10 to 60 dB HL
6 kHz -10 to 40 dB HL
8 kHz -10 to 30 dB HL

(*speaker) (one speaker driven) 8 ohms*
125 Hz -10 to 50 dB HL
250 Hz -10 to 70 dB HL
500 Hz -10 to 80 dB HL
1 kHz to 6 kHz -10 to 85 dB HL
8 kHz -10 to 80 dB HL

*Minimum Amplitude Range:* (air) 125 Hz -10 to 75 dB HL

*Warble Tone:* 10% frequency deviation at a modulation frequency of 5 Hz (±1/2 Hz).

*Noise Generator:*
White Noise: flat (±2 dB) to 8 kHz
Speech Noise: weighted random noise with a sound pressure spectrum density constant from 250-1000 Hz, falling off at a rate of 12 dB/octave from 1000 to 4000 Hz, within ±5 dB.
Narrow-band masking noise: as defined in ANSI 3.6  1989.

*Channel Inputs:*
Tone: pure, pulsed pure, warble, pulsed warble.
Speech Microphone: with adjustable gain control.
Noise: Speech, narrow band, or white.
External: 100K input impedance. Min signal = 100 mV RMS. Max signal = 8 volts peak.

*Channel Outputs:*
Speaker: (One channel driven): Four watts RMS typical into 8 ohm sound field speakers (optional).
Earphones: Telephonics TDH39P: 100 ohm.
Bone Vibrator: (Radioear B-71 or equivalent): 100 ohm.

*Interface:* Allows remote control of almost all aspects of audiometer operation through RS232.

*Power supply:* 105V  130V or 220V 50-60 Hz

*Weight:* 11 lbs (5 kg) without accessories

*Size:* 18.25" x 13.5" x 5.5" (45.6 x 33.8 x 13.8 cm) [10].

**Audiometrics, Inc (AZ26)**

*Audiometer type:* microprocessor-based audiometers Type 4 with Wide Band, High Pass, Low Pass noise. Facility of air and bone conduction. Facility of Manual or automatic testing. Painted metal cabinet

*Frequencies:* Frequency Accuracy ± 3%.
250, 500, 1000, 2000, 3000, 4000, 6000, 8000 Hz.

*Attenuator:* -10 TO 120 dB HL in 5-dB steps.

*Tone output range:*

| Frequency (Hz) | 250 | 500 | 1000 | 2000 | 3000 | 4000 | 6000 | 8000 |
|---|---|---|---|---|---|---|---|---|
| Air $L_{max}$ (dBHL) | 100 | 100 | 120 | 120 | 120 | 100 | 100 | 100 |

*Minimum Amplitude:* (air) 125 Hz -10 dB HL

*Noise Generator:* Wide Band, High Pass, Low Pass.

*Channel Inputs:* Tone, Speech Microphone, Noise.

*Channel Outputs:* Speaker, Earphones: TDH39P, Bone Vibrator: Radioear B-71

*Auto Threshold Determination:* Modified Hughson Westlake according to ISO 8253-1.

*Interface:* Built-in RS232C input/output computer interface.

*Built-in Printer***:** Thermal printer. Paper width: 112mm

*Power supply:* 100, 110, 120, 220, 230 or 240 V, AC 50-60 Hz.

*Weight:* 9.5 kg / 21lbs.

*Size:* 48 x 40 x 16 cm / 19 x 16 x 6 inches [11].

**Audiometer developed at IIT Bombay**

*Audiometer type:* dual channel microcontroller based audiometer, with pure/warble tone/AM tone stimulus and wide-band/narrow-band masking noise. Facility of air and bone conduction. Facility of auto testing, SISI test, tone decay test and speech audiometry.

*Circuit size:* two double-sided PCBs with PTH. PCB-1 of 14.5 cm x 13.5 cm and PCB-2 of 10 cm x 13.5 cm.

*Attenuator:* crystal controlled test tone frequencies, with intensity level controlled in 5 dB steps.

*Tone output range:* for air conduction and bone conduction are 0 to $L_{max}$(dBHL) for different frequencies as given below

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Frequency (Hz) | 250 | 500 | 1000 | 1500 | 2000 | 3000 | 4000 | 6000 | 8000 |
| Air $L_{max}$ (dBHL) | 90 | 100 | 100 | 100 | 100 | 100 | 100 | 90 | 80 |
| Bone $L_{max}$ (dBHL) | 40 | 50 | 50 | 50 | 50 | 50 | 50 | | |

*Warble tone:* frequency deviation of ±10% with one sweep in two seconds.

*Amplitude modulated tone:* amplitude deviation of ± 5 dB with one sweep in one second.

*Noise Generator:* Masking noise: broadband/narrow-band noise over 0-60 dBHL range in 5 dB step. Wide-band noise: flat spectrum up to 8 kHz, with approx. 12 dB/octave roll off on the higher side. Narrow-band noise: centered at test tone frequency, 3-dB BW = 0.55
octave, 20-dB BW = 4 octave.

*Channel Outputs:* Headphone type TDH-39 (software calibration for other headphones, by changing a table). Bone Vibrator type Oticon 70127 (software calibration for others)

*Control and indication:* control through 4x4-matrix keypad of size 9x9 cm. 16 characters x 2 lines LCD display with font 5x7 or 5x10 dots.

*Operation:* software controlled menu driven manual / automated modes.

*Result Storage:* for one set of the test results with rewrite facility.

*Interfacing:* serial port (TxD, RxD, and GND), TTL level, baud rate of 2400 bits per second, 7 bit data, and even parity.

*Self test:* internal monitoring of output levels.

*Power supply:* +5V, 20 mA for digital and ± 5V, 120 mA for analog [2].

## 5. Conclusion

Audiometry has established itself as a valuable method for quantitatively determining the degree of hearing loss of a person. In comparison to other methods Pure tone audiometry has been popular because of its simplicity and ease with which the type of disorder can be identified from the shape of the audiogram. If Audiometry test has diagnosed the deafness to be sensorineural in type, there are some specialised test like- SISI, ABLB, Tone Decay, Speech Audiometry tests. The use of improved Audiometers incorporating various facilities should make possible a higher level of research into the use of audiometers in the study of hearing disorders and analysis.

**Acknowledgement**

I express my gratitude to my guide, Prof. P. C. Pandey, for his invaluable help and guidance which effectively contributed in successful completion of this seminar. He was instrumental in providing technical, moral and administrative support. It is a privilege to work under his guidance.

I am also very thankful to the members of SPI Lab for their cooperation extended.

# References

[1] A. Biswas, *Clinical Audio-Vestibulometry*, Mumbai: Bhalani Publishing House, 1995

[2] Dipak Patel / P. C. Pandey (Guide), "A microcontroller based audiometer," *M.Tech. dissertation*, EE Dept., IIT Bombay, 2002.

[3] Pratibha L. Reddy / P. C. Pandey (Guide), "A microcontroller based audiometer", *M.Tech. dissertation*, EE Dept., IIT Bombay, 2001.

[4] Ashish S. Kothari / P. C. Pandey (Guide), "A microcontroller based audiometer," *M.Tech. dissertation*, EE Dept., IIT Bombay, 1999.

[5] C. K. Singh / P. C. Pandey (Guide), "A microcontroller based audiometer," *M.Tech. dissertation*, EE Dept., IIT Bombay, 1997.

[6] R. M. Schafer, http://www.sfu.ca/sonic-studio/, site of School of Communication, Simon Fraser University, accessed on 24 Sep 03.

[7] Barry Truax, *Acoustic Ecology,* Cambridge Street Publications, 1999.

[8] Dr Clive Prince, http://www.drgenie.com/Procedures, site of UBC Faculty of Medicine, accessed on 5 Oct 03.

[9] Dr Stewart McMorran, http://www.gpnotebook.co.uk, site of UK Medical Encyclopedia, accessed on 6 Oct 03.

[10] Gererdene Gibbons, http://www.frye.com/products/audiometers, site of Fonix Ltd, U.S.A, accessed on 11 Nov 03

[11] Mike Matheney, http://www.audiometrics.com, site of Audiometrics, Inc., LA, U.S.A., accessed on 11 Nov 03