Design and Construction of Hearing Aid Device

Yusuf M.A[1], Zainab U.S[1], M.I Ilyasu[2], I.B. Shehu[3], I H Jibrin[5], S. Abdullahi[4] and A. Adedeji[1]

[1] *Department Of Electrical Engineering Sokoto State Polytechnic*
[2] *Department Of Physics Sokoto State Polytechnic*
[3] *Nuhu Bamalli Polytechnic, Zaria*
[4] *Department Of Physics Usmanu Danfodiyo University, Sokoto*
[5] *Federal Psychiatric Hospital, Kware, Sokoto*

Abstract: *Hearing aid device is a small electronic gadget that is fit in or behind the ear to improve one's hearing and consequently communication ability.This research work involves the design and development of a hearing aid device withpre-amplifier; an acoustic signal picked-up using a condenser microphone. TDA 2822M IC is configured to produce an audio amplification which is converted to audio signal through a headphone. Design equations were employed to calculate the physical parameters of the circuit. After the design, the circuit was constructed and tested on 5 people with partial hearing problem. The result showed that there was a significant improvement in the hearing ability of all the patients tested. Recommendations were proposed for further improvement.*
Keywords: *hearing aid, acoustic signal, pre-amplifier, condensermicrophone.*

I. Introduction

While some people are born with hearing problem some others develop it as they grow. This problem can occur as a result of disease, aging,injury from noise or intake of certain medicines(N.I.D.C.D, 2010). Hearing problems could be that of complete deafness or partially impaired type. Hearing problem could occur after a person learned to talk (post lingual) or those with trilingual deafnessthat is deafness that occurs before a person learns to talk. Deafness, whatever the degree or course, is generally a source of worry and frustration to the patient concerned as it affects almost all aspects of one's life. Various efforts have been made and still being made in attempt to overcome this ailment both medically and using technology. Measuring devices are now available to enable otolaryngologist's measure aspects of a patient's hearing sensitivity and prescribe remedy. Electronically, hearing aids of various grades, sophistication, sizes and costs have been developed. Hearing aids have the same basic components as any public-address system, but all the components are miniature and the amplified sound is delivered to the ear of only the hearing-aid user(Robert, 1992)

The microphone, amplifier (consisting of transistors and integrated electronic circuits), miniature receiver, and battery of a hearing aid are enclosed either in a chassis or shell, which is worn behind or within the ear or in the stem or temple portion of eyeglasses. A small tube directs the amplified sound from the receiver into the ear canal of the wearer.

Glovanni Batista Porta was the first to actually describe one of those early hearing aids. Porta wrote a book entitled *"Natural magic in which the woodeen aids shape animal ears"* in 1627. These hearing aiddevices were probably not manufactured in the way we know it today. (schum, 2004). In the 17th century, speaking tubes were adopted to a very special sort of hearing problem by puritan couples who were counting. Custom of the times required the two to sit across table from each other, and speaking tubes were used to ensure the privacy of their conservation. Later, anatomical, used to slightly enlarge the sound collection area of the ear may also have been worn by person suffering from collapse of entrance to the external auditory canal. (N.I.D.C.D, 2010). Thomas Alvan in 1832 invented the phonograph, incandescent light bulbs kinetoscopes (early moric cameras and projectors) and even stock tickness in 1886, Edisobn applied for a pattern on his carbon transmitter, which translate sound into elctrical signals, allowing it travel through wires and then been translated back in to sound, this mark the begining of first electric signal amplifier (Edward, 1969).In 1899 Miller Reese and J.Wilson established the evalution company in Alabama. They held the patern for the first practical hearing aid which employed a carbon microphone or transmitter, a battery and pair of earphones .The invention of vacuumtube marks the begining of electronic hearing aiddevice. The first appeared in 1922, but this type did not become practical until 1936 and did appears In a wearable version until 1980's. In 1952, integrated circuit (I.C) hearing aids popularly called electronic hearing aid appeared in few models and virtually replaced vacuum tube hearing aid by the end of 1953 (Geoffrey, 1998).

System description and design

The block diagram of the system is shown in Fig. 1 with thePower unit, input unit, amplifieying unit and the output unit.
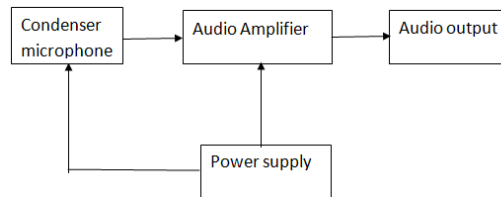

Fig. 1.0 Block diagram of hearing aid

Power supply unit

The entire circuit of hearing aid device designed in this paper consumes a very small amount of power within the range of 10 milliwatts. Furthermore, the voltageRequirement of every major component is within the range of 1.8 volts and 15 volts. Therefore, for portability, a 3V DC battery is used to power the circuit.

Design analysis of input Transducer

A transducer is a device which converts one form of energy into another form. The transducer used in this paper is the condenser type microphone.Fig 2.0 shows the bias circuit for the microphone, It is designed so that an optimal steady current of about 1mA is fed to the microphone.
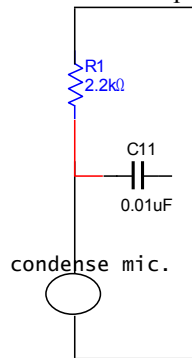

Fig. 2. Biased condenser microphone

$$v_{cc} = i_{dc} RT \qquad \text{(Robert, 1992)}$$

RT = effective series resistance of microphone

$3 = 1 \times 10^{-3} \times RT \qquad (where i_{dc} = 1mA)$

$RT = 3K\Omega$

The microphone used has a DC resistance of 600Ω

But $RT = R_1 + micDC$ resistance

Therefore $R_1 = RT - micDC$ resistance

$R_1 = 3k\Omega - 600\ \Omega$

$R_1 = 2.4\ k\Omega$

A standard 2.2 $k\Omega$ carbon resistor has been selected.

The coupling capacitor C_{11} should have a reactance (X_c) of few kilo ohms at the main audible frequency of about 20Hz. Thus 1600Ω is choosen to be used.

Considering $x_c = \frac{1}{wc}$

$C_{11} = 1/2 \times \pi \times 20 \times 1600$

$C_{11} = 0.01\mu f$

Pre-Amplifier Design

Fig 3.0shows the pre-amplifier circuit; andthe sole function of this stage is to amplify the input sound from the microphone. Usually, the electrical signals produced by microphones are weak and faint hence the need to strengthen it by a pre-amplifier circuit.
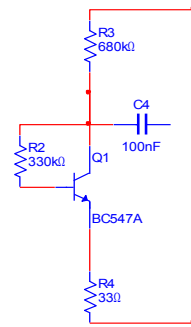
Fig. 3.0 Common emitter amplifier configuration using a BC547

Capacitors C_{11} and C_{12} are called coupling capacitors. Their functions are to block any DC components in the input and outputs of the pre-amplifier to prevent upsetting the DC bias of the pre-amplifier. Any small-value capacitor (usually 10nf to 100nf) will serve the purpose.

It is desired that the coupling capacitor C_{12} should have a reactance (X_c) of few kilo ohms at the minimum audible frequency of 20Hz and X_c is choosen to be about 80kΩ.

$Therefore Xc = 1/wc$

$C_{12} = 1/2\pi f Xc$

$c_{12} = 1/2 \times \pi \times 20 \times 80 \times 10^3$

$C_{12} = 99.5 \times 10^{-9} f$

Hence $100nf$ was choosen

The pre-amplifier stage of this paper was designed to produce a gain (A) of 500, so that the faint, weak signal produced by the microphone will be amplified 500 times before being further processed. The transistor selected for this purpose is BC547. Thus the following informations were obtained from data sheet;

$H_{fe} = 800$

$Icmax = 100mA$

$P1max = 625mA$

$Freq. Typ = 300MHz$

For the transistor to operate in the linear region, choice has been made of $Vc = ½Vcc and Ic = 2.2mA$

$Therefore Vc = ½(3)$

$But Vout = Vcc - IcRc$

Substituting for $Rc = R3 \; and \; Vcc = 3V$ we have

$1.5 = 3 - 2.2 \times 10^3 \times R_3$

$R_3 = 1.5/2.2 \times 10^{-3}$

$R_3 = 681.81Ω$

680Ω resistor was choosen.

But

$$\beta = \frac{1}{A}$$
$$\beta = \frac{1}{500} = 0.002$$

$\beta = 0.002$

Where the overall gain is given by *A* while the feedback ratio is represented by $\boldsymbol{\beta}$.

However, $\beta = \frac{R3}{R2}$

Where;

$A \approx 1/\beta$

Therefore,

$R_2 = \frac{R_3}{\beta}$

$R_2 = \frac{680}{0.002}$

$R_3 = 340KΩ$

Thus, to produce a gain of 500, R_2 needs to be 340KΩ while R_3 is 680Ω. But resistors are manufactured in standard values and 340KΩ is not a standard value. However, a 330KΩ resistor is the nearest and available standard value that will produce a gain close to 500. (Robert, 1992)

However emitter to ground voltage is typically around one-fourth and one-tenth of supply voltage, but selecting the extreme case of one-tenth will permit calculating the emitter resistor (R_4) as follows;

$$V_E = 1 / 10 V_{cc}$$
$$V_E = 3/10 = 0.3V$$

Also,

$$R_E = V_E/I_E \approx V_E/I_c = 0.3/10mA$$
$$I_{csat} = 10mA(\text{Source; data sheet})$$
$$R_E = 30\Omega$$

Where $R_E = R_4$ and I_c is the collector current of BC547 transistor at saturation voltage. However, a 33Ω resistor is used because 30Ω is not a standard value.

Now the base current I_b was calculated by using the relatoinship below;

$$I_b = V_{cc} - V_{BE}/R_2$$
$$where V_{cc} = 3$$
$$V_{BE} = 0.7$$
$$R_2 = 330K\Omega$$
$$I_b = 3 - 0.7/330 \times 10^3$$
$$I_b = 6.96\mu A$$

Medium Power Amplifier Stage

The medium power amplifier amplifies the output of the pre-amplifier to an audible level. It comprises of the TDA2822M IC and those external components needed to make the IC function properly. As shown in fig 4.0, this other external components are capacitors C_{14}, C_{15}, C_{16}, C_{17}, C_{18} and resistors R_6 and R_7, Their valuesare specified by the manufacturer's datasheet which provides values that are most appropriate.
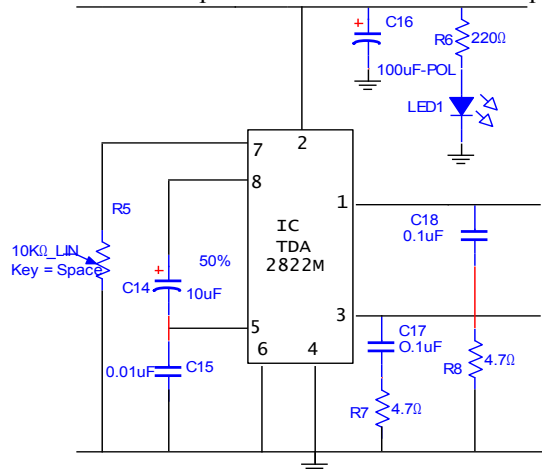

Fig. 4.0 Tda2822m Amplifier Circuit

RC Decoupling Unit

In this project, resistor, R_5 and capacitor, C_{13} form an RC decoupling circuit. They are connected across the power supply to smooth out noise. When the power supply is switched ON, the capacitor (through the resistor), charges to the supply voltage (in this case V_{CC}) and then draws a small amount of current to compensate for its own leakage. However, when the supply voltage falls below its maximum value, the capacitor will present a potential higher than the supply voltage and the stored energy will flow into the load, helping to maintain the supply voltage. The time constant (T) produced by this RC circuit is given by;

$$T = RC \dots\dots\dots\dots\dots\dots\dots\dots\dots..3.0$$

For decoupling purposes, the following points must be noted when selecting capacitors;

Large electrolytic capacitors (between 22μf and 100μf) are most effective because they absorb drops and/or spikes better(wikipedia, 2011).

- A shorter time constant is better suited to deal with higher frequency variations in voltage.

In this paper, a 47μf capacitor is used to achieve a 5 millisecond time constant. Thus, from equation 3.0

$5 \times 10^{-3} = R_3 \times 47 \times 10^{-6}$

$R_3 = 106\Omega$

Therefore, a 100Ω resistor is used because it is the closest and available standard value resistor that will produce a time constant close to 5ms

Output Unit

A 32 ohms earphone is used in the output unit of this project as recommended by the manufacturers of the TDA2822M IC. According to the IC's datasheet, this 32 ohms earphone will produce an output of about 1.3 watts.
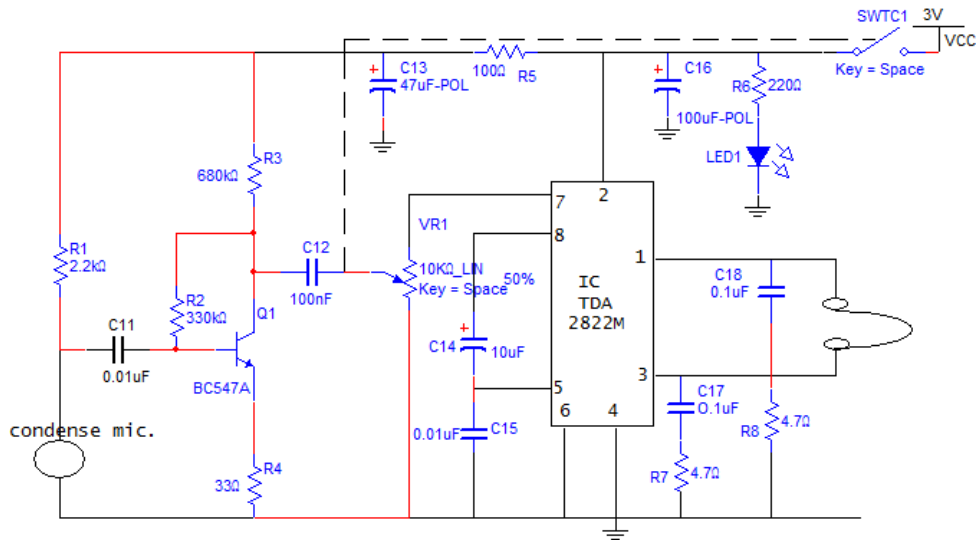

Fig 5.0 the complete circuit diagram

In the circuit shown in fig 5.0 above, capacitors C_{11} and C_{12} are called coupling capacitors. Their functions are to block any DC components in the input and outputs of the pre-amplifier. The pre-amplifier comprises of R_5 and capacitor c_{13} which decouples the power supply of the preamplifier stage, while capacitor C_{12} and resistors, R_2, R_3 and R_4 with transistor T_1forms a negative feedback amplifier which stabilizes the overall gain (A). Resistor, R_4 is known as an emitter swamping resistor which also adds stability to the amplifier. The medium power amplifier amplifies the output of the pre-amplifier to an audible level. It comprises of the TDA2822M IC and those external components needed to make the IC function properly. This other external components are capacitors C_{14}, C_{15}, C_{16}, C_{17}, C_{18} and resistors R_6 and R_7. Resistor, R_5 and capacitor, C_{13} form an RC decoupling circuit which are connected across the power supply to smooth out noise. Finally a 32 ohms earphone is used in the output unit.

II.   Materials used and Construction

The components used are: condensed mic, R_1=2.2kΩ, R_2=330kΩ, $R_3 = 680kΩ, R_{12} = 33Ω$, R_5=10kΩ, R_6 =220Ω, R_7=4.7Ω, R_8 =4.7Ω, , Q_1 =BC547A , C_{11} =0.01μf, C_4=100nf, $C_{13} = 47μf, C_{14} = 10μf, C_{15} = 0.01μf$, $C_{16} = 100μf, C_{17} = 0.1μf, C_{18} = 0.1μf$, V$R_1$=10kΩ, LED- Red, TDA 2822M, switch and battery (3V) and earphone.
The components for the circuit were first assembled on a bread board and tested. After it was found to work as anticipated the components were transferred to a Vero board for the final construction.

TESTS
Frequency Response Test

After the construction of the amplifier stage, it was subjected to tests to determine its frequency response which indicates the range of frequencies for which the appliance is suitable. To do this, a signal generator was used to feed signals of fixed amplitude but varying frequency to the amplifier. The gain at each signal variation was found by using a double beam oscilloscope to measure and compare the output and input signals. The experimental set up is as shown in Fig. 6.
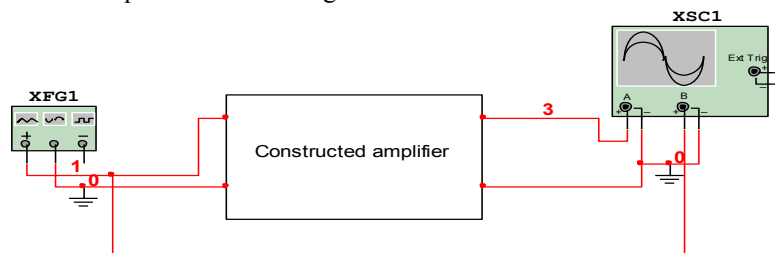

Fig. 6 Set up to determine the frequency response of the amplifier

Test of Device on Deaf People

1) The device was tested on seven (7) people from Sokoto with various degrees of hearing problems. To conduct the test a tape recorder was placed at a distance from the patient. With the device placed on the ears, the sound on the player was adjusted to a level that he could just barely hear the sound. The hearing aid was then removed to see if they could still hear the sound. This process was repeated severally using different sounds of different frequencies and magnitude.

2) The above test was conducted on 3 completely deaf people.

III.   Results

Result of Test of Amplifier Gain against Frequency

The result of the test on the frequency response of the amplifier is tabulated in Table 1 and plotted in Fig. 7

Table 1 Gain Measurement Amplifier.

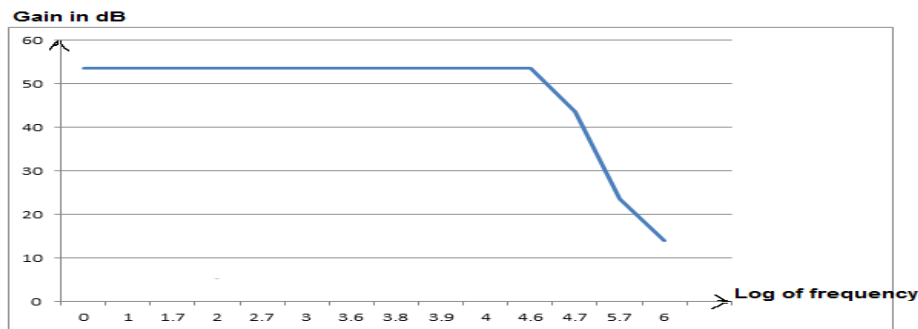| Input Frequency (f) Hz	Input Frequency Log (f) Hz	Input voltage (V_{in}) mV	Output voltage (V_o)	Gain (V_O/V_{in})	Gain 20Log (V_O/V_{in}) dB
0	0	20	9.8V	480	53.6
10	1.0	20	9.8V	480	53.6
50	1.7	20	9.8V	480	53.6
100	2.0	20	9.8V	480	53.6
500	2.7	20	9.8V	480	53.6
1000	3.0	20	9.8V	480	53.6
4000	3.6	20	9.8V	480	53.6
6000	3.8	20	9.8V	480	53.6
8000	3.9	20	9.8V	480	53.6
10000	4.0	20	8.4V	480	53.6
40000	4.6	20	5.2V	260	48.2
50000	4.7	20	3.0V	150	43.6
500000	5.7	20	300mV	15	23.5
1000000	6.0	20	100mV	5	14. 0

Fig. 7 A plot of the frequency response of the amplifier

Result of Test on the Application of Device

The result of the response of those with partial deafness and those with complete deafness is tabulated in Table 2

Table 2 Response to use of hearing aid

Degree of deafness	Response to use of hearing aid
Partial deafness	Improvement in hearing
Complete deafness	No improvement in hearing

IV.   Discussion

The frequency response curve of the amplifier showed that the amplify signals within the audio frequency domain. This means that the amplifier is useful for the purpose for which it is being designed. On the test of the final product on people with hearing impairment the result showed that there was significant improvement in their hearing ability in all the cases. The volume control was also found to be very useful as the user is able to control the level of signal he listens to. Signals that are two loud may course further damage to the ears.

It was realized that hearing aid device is in capable of truly correcting a hearing loss, but an aid to make sound more accessible. In situations where the primary auditory cortex does not receive regular stimulation, this part of the brain losses cells which process sound. As cell losses increases, the degree of hearing loss increases. When the loss of cell is not much, hearing aid can be of enormous importance.

V.   Conclusion

The aim of this paperwas to design a system that pre-amplify an acoustic signal Picked up by a condenser microphone. The pre-amplified signal is then further amplified before being converted to sound by another transducer (speaker). The designed and constructed circuit was tested on different set of people with different degree of hearing problem. The final test showed that the device could prove very useful for people with partial hearing problems.

Recommendations

For further improvement,it is recommended that a wireless hearing aid device should be designed and constructed to reduce the weight.

The casing of the hearing aid should be made up of more portable, qualitative and lighter plastic material so as to reduce the overall weight and size..

More care should be taken so as to avoid feedback signal between the microphone and the headphone which may result in noisy signal.

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