FUDMA Journal of Sciences (FJS)
Maiden Edition
Vol. 1 No. 1, November, 2017, pp 115-122

DESIGN AND IMPLIMENTATION OF A LOW COST HEARING AID DEVICE

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Abstract
Loss of hearing power might be due to several reasons such as; old age, hearing loud sound that can damage the auditory system and so on. Hearing aid device is an elecronic system used to enhance weak sound signals to a level that those with different levels of partial hearing loss can hear. This paper considers the design and implimentation of a low cost hearing aid device.Design equations were employed to calculate the physical parameters of the different units of the circuit. The frequency response test showed a constant flat response from $0\,Hz$ to about $20\,KHz$ at gain of $440$the maximum current drawn by the device is $9.16\times10^{-7}A$ per second. When tested on 4 people with partial hearing problem, the results showed that there was a significant improvement in the hearing ability of all the patients tested. The paper recommends that design of digital hearing aid be considered to enhance output signal quality and feedback control.

Keywords: *Hearing aid. Hearing loss, Transducer, Frequency response and Amplifier.*

Introduction

The number of people with hearing loss is rising due to global population and longer life expectancies (WHO, 2005). In our society there are so many individuals with one level of hearing impairment or the other, who do not pay any significant attention to their problem. One way to ascertain whether you have hearing impairment is to check if you fall into one or more of the categories stated below (Oyler et al., 1988).

i. If you have difficulty hearing conversation in a fairly noisy environment
ii. If you often ask people to repeat themselves
iii. If you turn up the volume of radio or television set when others hear comfortably
iv. If you have difficulty hearing whispers and low pitch sounds
v. If you hear loud sounds/voices as whisper etc.

With the above check-list in place, this study will first and foremost expose the need for individuals to pay attention to early signs of hearing impairment so as to take necessary action. Furthermore, a report by world health organization reveals the following (WHO, 2005): -

- Two hundred and seventy eight (278) million people worldwide have moderate to profound hearing loss in both ears.
- One – quarter of hearing loss cases begin during child hood and detecting and responding to this problem at early stage is vital for development of speech and language by these group of children
- Although properly designed and fitted hearing aid can improve communication in 90% of people with hearing impairment, current annual production of these aids meet less than 10% of the global need.

Moreover, the cost of available designs is beyond the reach of most people with this ailment. Hence there is need to increase the affordability and availability of hearing aids for the benefit of this large population with hearing impairment. The design and construction of hearing aid using locally available materials will raise hope for individuals who cannot afford the price of the sophisticated hearing aid style.

Hearing is one of the five senses along with vision, taste, smell and touch. Hearing is one of our most important senses because it alerts us to dangers we cannot always see. The ear serves as a receiver of incoming sounds. The human auditory system can generally hear sounds within the frequency range of 20 Hz and 20 kHz but the frequency range between 100 Hz and 6 kHz contains most of the information of human voice (Kinsler, et al., 1982).

Hearing problems could be that of complete deafness or partially impaired type. Human deafness (extreme insensitivity to sound) or hearing loss occur because of various degree of damages to the ear. Hearing loss refers to relative insensitivity to sound in the speech frequency range (Oyler, et. al., 1988). A hearing loss can happen when any part of the auditory system is not working in the usual way. Deafness, whatever the degree or cause, is generally a source of worry and frustration to the patient concerned as it affects almost all aspects of one's life.

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 (Yusuf, et. al., 2013). It is simply an electronic sound amplifier. 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, and injury from noise or intake of certain medicines (N.I.D.C.D, 2010).

Hearing aid device has attracted research interest since inception. Levitt (2007) worked on 'A Historical Perspective on Digital hearing aid'. This paper provides the author's perspective on the development of digital hearing aids and how digital signal processing approaches have led to changes in hearing aid design. Major landmarks in the evolution of digital technology are identified, and their impact on the development of digital hearing aids is discussed. Differences between analog and digital approaches to signal processing in hearing aids are identified. For instance, Digital hearing aids provide greater flexibility and more accurate control of frequency lowering than analog hearing aids. However, improvement in technology goes with higher efficiency and cost.

Schum, (2004) designed and constructed a low-cost hearing aid to produce an amplified sound for people with hearing loss. A 9 V dc was used as the power supply. The condenser microphone was used as input transducer to pick up sound from the environment for conversion to electrical signal, NPN transistor (BC548C) along with three capacitors and five resistors were used as pre-amplifier to amplify the input signal. The integrated circuit (IC) TDA 2822M, available in 8-pin mini chip package was used as power amplifier which further increases the signal before feeding to the ear phone. A 32 ohms ear phone was used as the output transducer to convert the amplified electrical signals back to sound.

Yusuf et. al. (2013) designed and constructed a hearing aid device. In their work, they used TDA 2822M IC configured to produce an audio amplification which is converted to audio signal through a headphone. They employed bridge type amplifier for their amplification. The result of the test they conducted using their designed and constructed hearing aid showed that there was a significant improvement in the hearing ability of all the patients tested.

The design of hearing aid carried out in this work employed stereo type amplification method using commonly available components.

Theory of the Design

The hearing device is made up of the power supply, input transducer, pre-amplifier, amplifier and the output transducer. The block diagram is as shown in the figure 1. Electronic circuits generally require direct current (d.c) to power components.

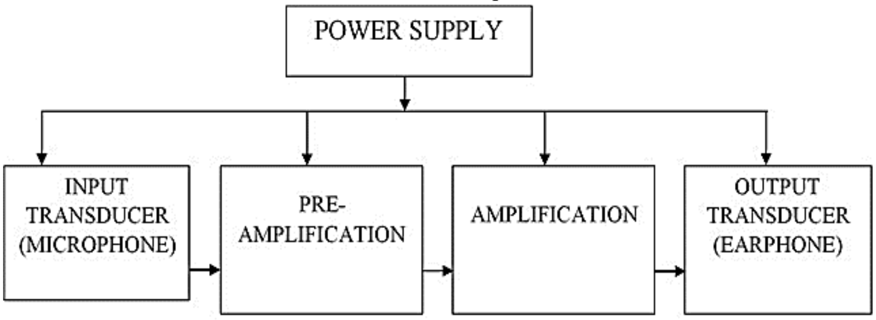

Fig.1 Block diagram of a hearing aid device system

The battery supplies the power to turn the electronic components on and off. A 1.5 volt battery was used for the power supply. The condenser microphone is an input transducer that picks up sound from the environment and converts it to electrical signal. The primary function of a pre-amplifier is to pick up signals from its primary source (microphone) and then operate on it in preparation for passage into the amplifier section for further amplification (Akande et al., 2007). Typically, a pre-amplifier amplifies the signal, controls its volume, and perhaps changes its input impedance (Horowitz and Hill, 2010; Lowenberg, 1976). The pre-amplification unit will be designed using an NPN transistor BC547 along with some capacitors and resistors.. Resistor (R) biases the internal circuit of the low-voltage condenser microphone for proper working. The audio output from the pre-amplifier stage is fed to the input of the amplifier circuit via capacitor (C) and volume control VR. The loud speaker serves as output transducer that converts the amplified electrical signals back to sound.

In practice what determines the working period of the device or the battery in particular is the quantity of charges available in the cell. This is because of the fact that the energy of the battery is a function of the quantity of charge inside it and the higher the quantity of electric charges inside the cell the longer its life span. And to minimize the power consumption of this device is one of the aims of this research. Power is related to current, voltage and time thus;

$$P = ivt \qquad (1)$$

If $t = 1sec$, then

$$P = iv \qquad (2)$$

Since v is constant then;

$$P \propto i \qquad (3)$$

Method

This work is done by designing each of the units shown in figure 1. The implementation of the project was first done on a bread board. The bread board provides a temporary platform to couple components and ensures the stages are working as expected before transferring it to a permanent board. Connection across each individual component was done using an insulated strand wires where necessary. When the functionality of the circuit is ascertained, it was transferred to a Vero board and the components were soldered on the board using soldering iron. The constructed device was tested for efficiency and then cased.

Design of hearing aid units

Power supply unit:
The components required in the design of a hearing aid device is such that requires low d.c voltage ($< 15\ V$) and consequently consumes small power in range of 10 milliwatts. The most common type of hearing aid battery is made of zinc oxide (or the Zinc-Air battery) and has a voltage of 1.4 V. For most hearing aids, each zinc-air battery (regardless of size) typically lasts about 2 weeks with regular use (Kuk, 2002). A hearing-aid battery is nonfunctional when its voltage falls below 1.2 V (Kuk,

2002). Therefore, a 1.5 V DC battery is used to power the device.

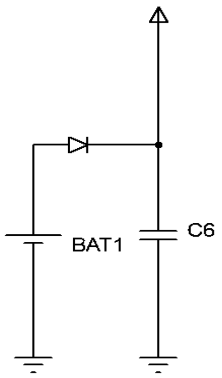

Fig.2. Power supply unit

In figure 2, diode is used to reduce the voltage across source and capacitor C_6, a decoupling capacitor ensures that only direct current is passed and blocks a.c components. Though the input is a d.c source, yet due to the high frequency (10 KHz) at which the output transducer is consuming power, there will be a little ripple on the voltage supply by the battery and hence the input need to be filtered by decoupling capacitor. For decoupling purposes, the following points must be noted when selecting capacitors;

- Large electrolytic capacitors (between 22 µf and 100 µf) are most effective because they absorb drops and/or spikes battery (Duncan, 1985).
- A shorter time constant is better suited to deal with higher frequency variations in voltage.

A capacitor of 100 nf capacitance is used, since the frequency is significantly high

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. Figure 3 shows the bias circuit for the microphone. It is designed so that an optimal steady current of about 1 mA is fed to the microphone.

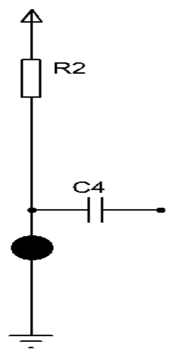

Fig. 3 input transducer

$$V_{cc} = i_{dc}R_T \quad (4)$$

where $R_T =$ Effective series resistance of microphone and $i_{dc} = 1\ mA$is the steady d,c current throuh the microphone and V_{cc} is the supply voltage. From equation 4,

$$R_T = \frac{V_{cc}}{i_{dc}} = \frac{1.5}{1 \times 10^{-3}} = 1.5\ K\Omega$$

The microphone used has a dc resistance of 600 Ω

But $R_T = R_2 + R_{mic}$

There fore $R_2 = R_T - R_{mic}$

R_2= 1.5 $k\Omega$ − 600 Ω

R_2= 1.44 $k\Omega$ Preferred value of $R_2 = 2.2\ K\Omega\ (carbon\ resistor)$.

The coupling capacitor C_4 should have a reactance (X_c) of few kilo ohms at the minimum audible frequency of about 20 Hz. Thus 1.6 KΩ is chosen. Considering

$$X_c = \frac{1}{\omega C} \quad (5)$$

$$C_4 = \frac{1}{2\pi \times 20 \times 1600} = 0.01\mu F$$

Pre-amplifier stage
Figure 4 shows the pre-amplifier circuit; and the 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.

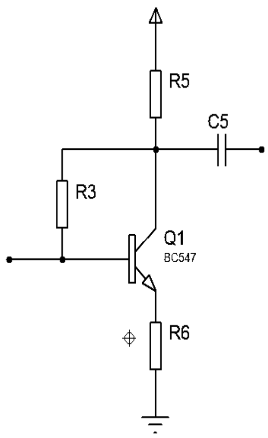

Fig. 4 Common emitter amplifier configuration using a BC547

Capacitor C_5 is called coupling capacitors. The functions are to block any DC components in the input from passing through the output of the pre-amplifier to prevent upsetting the DC bias of the pre-amplifier It also couples the output of the pre-amplifier to the next stage. Any small-value capacitor (usually 10 nf to 100 nf) will serve the purpose. It is desired that the coupling capacitor C5 should have a reactance (X_c) of few kilo ohms at the minimum audible frequency of 20 Hz, hence, $X_c$is choosen to be about 90 kΩ.

Therefore

$$X_c = \frac{1}{\omega C} \quad (6)$$

$$C_5 = \frac{1}{2\pi f X_c} = \frac{1}{2\pi \times 20 \times 90 \times 10^3} = 88.4 \times 10^{-9} f$$

Hence $100nf$ was chosen. The pre-amplifier stage of this project work 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 information's were obtained from data sheet;

$$Hfe = 900$$

$$I_{cax} = 100mA \; PI_{cax} = 625 \; mA$$

$$Freq.Typ = 300 \; MHz$$

For the transistor to operate in the linear region, choice has been made of $V_c = \frac{1}{2} V_{cc}$ *and* $i_c = 2.2 \; mA.$

But

$$V_{out} = V_{cc} - I_c R_c \qquad (7)$$

Substituting for $R_c = R_5$ *and* $V_{cc} = 1.5 \; V$ we have

$$0.75 = 1.5 - 2.2 \times 10^{-3} \times R_5$$

$$R_5 = \frac{0.75}{2.2 \times 10^{-3}}$$

$$R_5 = 340.9 \; \Omega$$

$$\therefore \; R_5 = 330\Omega \; (preferred \; value)$$

$$\beta = \frac{1}{A} \qquad (8)$$

where the overall gain is given by (**A**) while the feedback ratio is represented by β.

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

$\beta = 0.002$

However, $\beta = \frac{R_5}{R_3}$

Therefore,

$$R_3 = \frac{R_5}{\beta} \qquad (9)$$

$$R_3 = \frac{340}{0.002} = 170 \; K\Omega$$

Thus, to produce a gain of 500, R3 needs to be 170 KΩ while R5 is 330 Ω. However, emitter to ground voltage V_E typically ranges from one-fourth to one-tenth of supply voltage, but selecting the extreme case of one-tenth will permit calculating the emitter resistor (R6) as follows;

$$V_E = \frac{1}{10} V_{cc} \; or \; \frac{V_{cc}}{10} \qquad (10)$$

$$V_E = \frac{1.5}{10} = 0.15 \; V$$

Also,

$$R_E = \frac{V_E}{I_E} \; (11)$$

where $I_E = I_C$ is the emitter current and I_C is the collector current

Therefore

$$R_E = \frac{V_E}{I_C} = \frac{0.15}{10 \times 10^{-3}} = 15 \; \Omega$$

$I_{csat} = 10\text{mA}$ (Source; data sheet)

$$R_E = 15 \; \Omega$$

Where $R_E = R_6$ *and* I_{Csat} is the collector current of BC547 transistor at saturation voltage. However, a 33 Ω resistor is used in the design. Now the base current I_b was calculated by using the relation;

$$I_b = \left(\frac{V_{CC} - V_{BE}}{R_3}\right) \qquad (12)$$

where

$$V_{CC} = 1.5 \; V, V_{BE} = 0.7 \; V, R_3 = 170 \; K\Omega,$$

$$\therefore I_b = \frac{1.5 - 0.7}{170 \times 10^3} = 4.7 \; \mu A$$

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 figure 5. This external components are capacitors C1, C2, C3,and resistors R1and R_{V1}. C1, C2, C3 and R1 are biasing elements and their values are obtained directly from the TDA2822M datasheet. Rv_1 function to adjust the volume of the devices and it's value is also suggested in the datasheet.

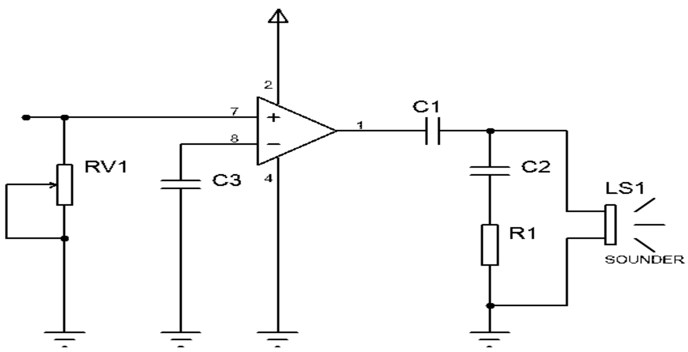

Fig.5. TDA2822m Circuit for stereo Amplifier

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 ear phone will produce an output of about 1.3 watts.

At the end of the design, the entire units were coupled together on a breadboard to check the functionality before soldering on a vero board. The complete circuit diagram is shown in figure 6.

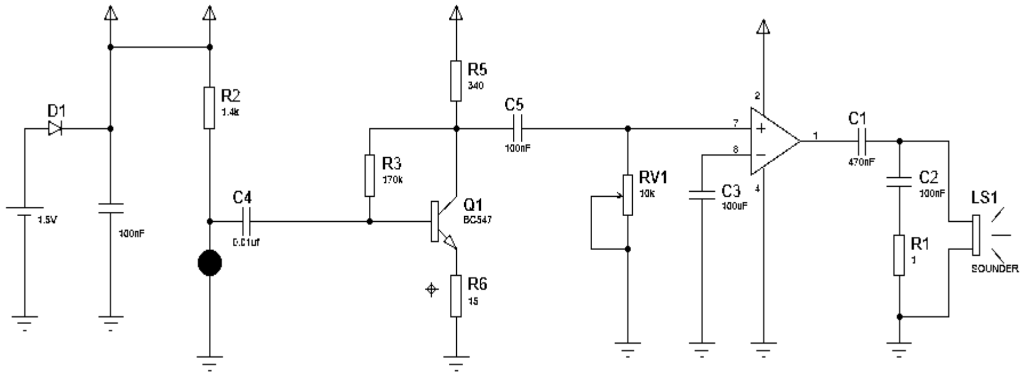

Fig.6 Complete Circuit of Constructed Hearing Aid Device

Fig.7(a) Device before casing, *(b) Device after casing*

Casing
After the construction was completed, a suitable transparent plastic was used to case the circuit for the purpose of protection .

Testing
After the construction, the device was tested from three different points of view, frequency response of the device, its current consumption and testing on people with hearing loss.

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.

In order to determine the frequency response of the device, both the input and output transducer of the device were disconnected, and replaced with signal generator and oscilloscope probe respectively. Signal of 5 mV amplitude was feed to the device at different frequencies while the shape and amplitude of the amplified output from the device was read from the oscilloscope.The result is shown in the table 1

Measurement of the device power consumption
In order to determine the device power consumption, the total current that was drawn out of the battery is measured with a digital ammeter. The current that flow through the constructed device was measured with the digital ammeter for two hours at an interval of 10 minutes and the results are shown in table 2.

Test of device on deaf people
The device was tested on four (4) people from Kurfi local government with various degrees of hearing problems. To conduct the test a tape recorder was placed at a distance of 10m from the patient. With the ear phone of the device fixed into the ears, the sound on the player was adjusted to a level that one 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. The result is as shown in table 3

Result and Discission

Result

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 frequency response is plotted in as shown in fig. 8.

Result of measurement of device power consumption
The result of power consumption of the hearing aids device as given by the current that flows through the device at the interval of 10 minutes is shown in the table 2.

Result of testing the hearing aids on hearing impaired persons: The result of the response of those with partial deafness and those with complete deafness is tabulated in table 3.

Table 1: Gain Measurement of Amplifier.

Input freq. (f)(Hz)	Input freq. log(f)	Input voltage V_{in}(mV)	Output voltage (V_o)(V)	Gain V_o/V_{in}	Gain : $20\log(V_o/V_{in})$(dB)
0	0	5	2.20	440	52.9
10	1.0	5	2.20	440	52.9
50	1.7	5	2.20	440	52.9
100	2.0	5	2.20	440	52.9
500	2.7	5	2.20	440	52.9
1000	3.0	5	2.20	440	52.9
4000	3.6	5	2.20	440	52.9
6000	3.8	5	2.20	440	52.9
8000	3.9	5	2.20	440	52.9
10000	4.0	5	2.10	420	52.5
40000	4.6	5	1.60	320	50.1
50000	4.7	5	1.20	240	47.6
500000	5.7	5	0.3	60	35.6
1000000	6.0	5	0.1	20	26.0

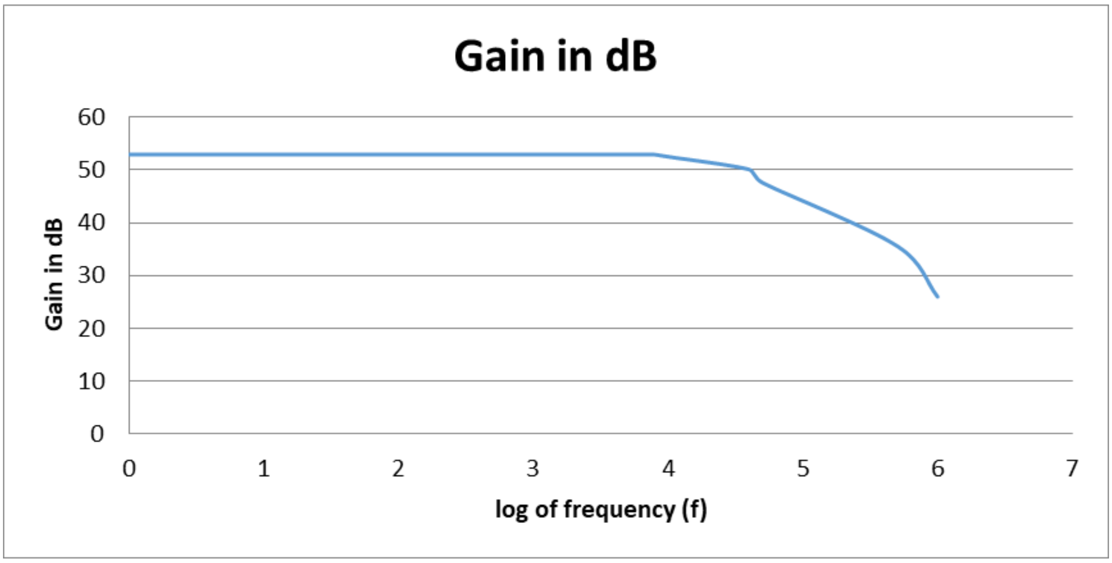

Fig. 8: A plot of the frequency response of the amplifier

Table 2: Measurement of the Device Power Consumption

$Time\ T$ (mins)	I (mA)	P = IV (mW) V = 2.2V
10	33	76.2
20	33	76.2
30	32	70.4
40	32	70.4
50	31	68.2
60	31	68.2
70	31	68.2
80	30	66.0
90	29	63.8
100	29	63.8
110	29	63.8
120	28	61.6

Table 3: Response of 4 persons with hearing loss to sound with the hearing aid

Distance(m)	$1^{st} person$	$2^{nd} person$	$3^{rd} person$	$4^{th} person$
5.0	$+1$	$+1$	$+1$	$+1$
10.0	$+1$	$+1$	$+1$	$+1$
20.0	$+1$	$+1$	$+1$	$+1$
30.0	$+1$	$+1$	$+1$	$+1$
40.0	$+1$	$+1$	1	$+1$
50.0	$+1$	$+1$	$+1$	$+1$
60.0	$+1$	$+1$	$+1$	0
70.0	0	$+1$	0	$+1$
80.0	0	0	0	-1
90.0	0	-1	0	-1
100.0	0	-1	-1	-1

$+1$ *means very significant improvement, 0 stands for significant improvement and* -1 *stands for low improvement.*

Table 4: 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

Discussion

The frequency response curve of the amplifier (fig. 8) showed that amplified signals remained constant within a wide range of frequency (0 Hz – 20 KHz) which falls within the audio frequency domain. This means that the amplifier is useful for the purpose for which it was designed. There will be no alteration of sound due to noise or interference within this frequency range.

The result of power consumption shown in table 2 reveals that the device draws maximum current of $9.16\times10^{-6}A$ per second. Consequently, the power consumption is low. This implies that the cell will last longer, hence cost of maintainance will be low.

The results obtained based on the amplifying response of four (4) different hearing impaired persons showed that, all were able to hear the different sounds produced by the tape recorder even at the lowest volume from 0m to 60m, after which the amplifying response varied from significant to low for each of the person's tested.

In the final analysis, 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 sound he listens to. Sound that are too loud may cause further damage to the ears.

The results obtained from the various test shows that the system was efficient as amplified sound was produced by their output transducers (earphone). However, noisy output was produced when the hearing aid is closed to noisy environment. This is because the diaphragm of the microphone is very sensitive to noise.

Conclusion and Recommendations

Conclusion

A low cost hearing aid device was designed and constructed using locally available components. The designed and constructed circuit was tested on different set of people with different degree of hearing problem. The result shows that the device could improve the hearig ability of people with partial hearing loss. Though, the device had no impact on persons suffering from complete deafness, the merits include moderate sensitivity, low current consumption, use of commonly available electronics components and light weight.

Recommendations

For further enhancement in the quality of the hearing aid device, it is recommended that a low cost digital hearing aid device be designed and constructed which could be useful for signal enhancement, The casing of the hearing aid should be made up of more portable and lighter plastic material to enhance compactness.

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