DESIGN AND DEVELOPMENT OF AN ELECTRONIC STETHOSCOPE

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Abstract
This paper describes the design and development of an electronic stethoscope that can be used to listen to heart and lung sounds in the human body.

This design shows a simplified way of obtaining a reliable and effective electronic stethoscope without making use of computers, micro controllers and softwares as part of the components of the stethoscope operating unit thus minimizing cost and complexities of maintenance.

The design can be divided into the following sections (i)Dual polarity power source (ii) Condenser microphone biasing section (iii) Pre-amplifier section (iv) Main amplifier section (iv) LED driver section.

The work was design and developed and found to work successfully.

Keywords: Electronic Stethoscope, Condenser Microphone, Voltage follower, Amplifier.

Introduction

The Stethoscope is an acoustic medical device for listening to internal sounds in human body which is known in medical terms as auscultation. Heart sound auscultation is one of the most basic ways to access the state of cardiac function [Habin w. etal, 2009], [Yang T. etal, 2010].

Stethoscope have been in use for auscultation of heart, lung for over two centuries now [WHO, 2011].

Types of stethoscopes:

Different forms of Stethoscopes have been used over time and these stethoscopes can be classified as either acoustic or electronic. The acoustic and electronic stethoscopes are available on the market [Marie-Claude G. et al, 1998]

(a) Acoustic stethoscopes

Acoustic stethoscopes are familiar to most people, and operate on the transmission of sound from the chest piece, via air-filled hollow tubes, to the listener's ears [en. Wikipedia. Org /wiki/ stethoscope, 2014]. The chest piece usually consists of two sides that can be placed against the patient for sensing sound, a diaphragm (plastic disc) or bell (hollow cup). If the diaphragm is placed on the patient's body, sounds vibrate the diaphragm, creating acoustic pressure waves which travel up the tubing to the listener's ears. If the bell is placed on the patient, the vibrations of the skin directly produce acoustic pressure waves which traveling up to the listener's ears. The bell transmits low frequency sounds, while the diaphragm transmits higher frequency sounds.

(b) Electronic stethoscopes

An electronic stethoscope overcomes the low sound levels of the acoustic stethoscope by electronically amplifying body sounds, electronic stethoscopes require conversion of acoustic sound waves to electrical signals which can then be amplified and processed for optimal listening [Telehealthtechnology, 2014]. Unlike acoustic stethoscopes, which are all based on the same physics, transducers in electronic stethoscopes vary widely. The simplest and least effective method of sound detection is achieved by placing a microphone in the chest piece. This method suffers from ambient noise interference and has fallen out of favour. Piezoelectric crystal at the head of a metal shaft has also been used as a stethoscope sensor. Clive Smith designed a stethoscope sensor that uses Electromagnetic Diaphragm with a conductive inner surface to form a capacitive sensor, the diaphragm responds to sound waves identically to a conventional acoustic stethoscope, with changes in an electric field replacing changes in air pressure [http://wwwthinklabs.com/#!patents/cp4k, 2014], this preserves the sound of an acoustic stethoscope with the benefits of amplification. Because the sounds are transmitted electronically, an electronic stethoscope can be a wireless device, and can be a recording device, and can provide noise reduction, signal enhancement, and both visual and audio output. In the year 2001, stethographics introduced PC-based software which enabled a phonocardiograh, graphic representation of cardiologic and pulmonologic sounds to be generated, and interpreted according to related algorithms [en.Wikipedia.Org/wiki/stethoscope, 2014]. All of these features are helpful for purpose of telemedicine (remote diagnosis) and teaching.

Review of Past Related Work

Several electronic stethoscope have been designed in the past which includes Design of Embedded stethoscope [MihirVaidya, etal, 2013], **A Cost-Effective Indigenous Wireless Electronic Stethoscope using Radio Frequency [M-ul-Hasan, etal, 2014]** and Web based remote digital stethoscope [Ying-Wen B. etal, 2005]. These stethoscope requires micro controllers, computers and softwares for design and operations which tends to increase cost and difficulties of implementation. This paper describes the design of a stethoscope that can operate effectively without the aid of a computer, a micro controller or a software operated device thus reducing cost.

Design Consideration

The Electronic Stethoscope circuit designed comprises of the following sessions:

i) Dual Polarity Power Source
ii) Condenser Microphone Biasing Section
iii) Pre-amplifier Section
iv) Low pass Filter Section
v) Voltage follower Section
vi) Main Amplifier Section
 (a) Amplifier
 (b) Voltage reference setting
 (c) Gain and Frequency calculation
vii) LED Driver Section

Dual Polarity Power Source

The circuit was designed to utilize power from two 9V alkaline batteries based on the Op-amp datasheet for UA741C, it requires positive and negative supply voltage in the range of (4.5V to 18V). 9V was used because it is almost midway between 4.5V and 18V and thus a surge condition will have a lesser probability of taking it outside the permissible voltage range of operation. Also, 9V will cause lesser stress on the op-amp compared to when 18V is used.

The 9V supply was achieved by connecting two 9V battery in series and the centre of the connection was tapped to the ground. The circuit schematics of figure 2.1 below shows the methodology used.

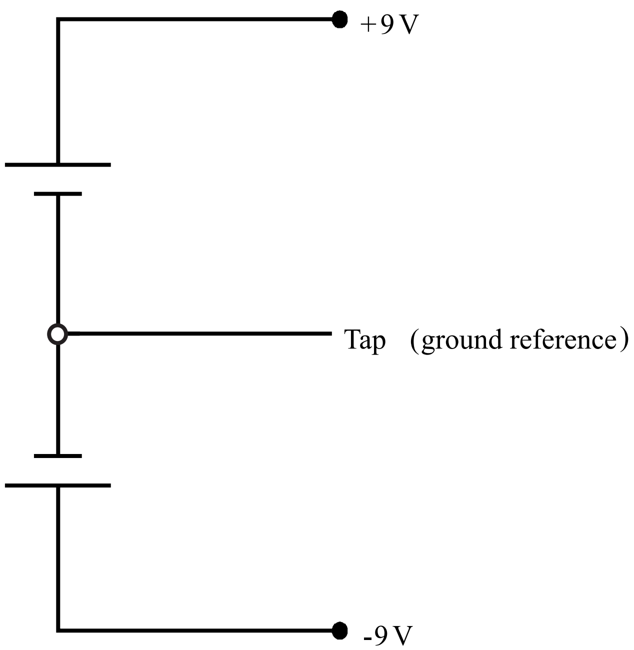

Figure 2.1: Dual Polarity Power Source

With the power source obtained for our circuit the next section of design is the microphone biasing section.

Condenser Microphone Biasing Section

The condenser microphone used in this stethoscope is the very sensitive electrets condenser microphone with model number XF180. It requires a constant current source of 2-20mA. To be sure of the value to settle for, the condenser microphone was connected to the input sound port of a laptop computer and then the biasing current was measured. The measured current was about 0.72mA. A safety factor of 1.4 was considered hence 1mA was used in the design. Using ohms law as shown in equation 1

$$R = V/I \qquad (1)$$

From a 9V constant voltage supply (obtained from a 1000uF capacitor i.e. C1) we have R1 = 9V/10K_= 0.9mA.

Thus the current requirement of the condenser microphone is obtained through a 10k resistor. The circuit schematics of figure 2.2 shows the configuration adopted.

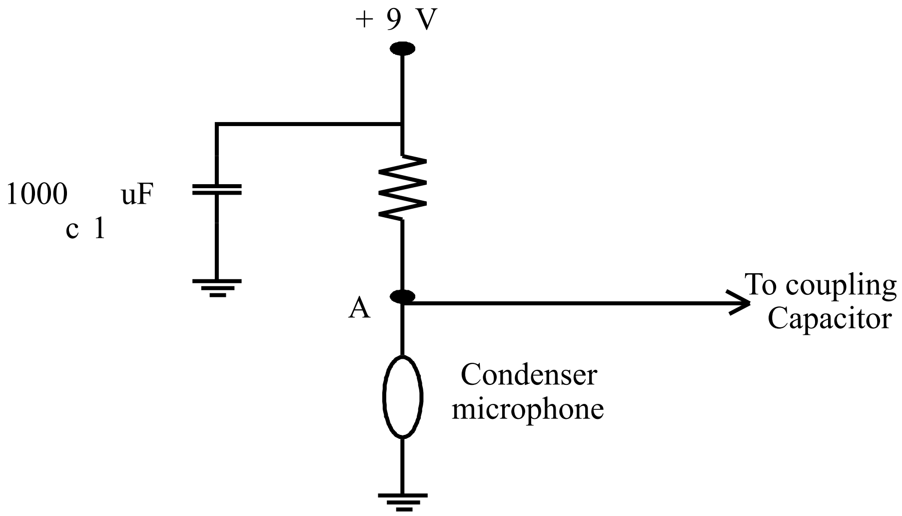

Figure 2.2: Condenser Microphone Biasing

A voltage divider network is formed between the condenser microphone and the 10K resistor. The condenser microphone has impedance since its basic principle involves varying capacitance.

When sound is incident on the condenser microphone, node A will experience a fluctuation of voltage around 4.5V (balanced reference point). The balanced reference implies that in the absence of sound pressure, R1 and Z1 (impedance of condenser microphone) share the 9V source equally as a result node A is at 4.5V. Variation in sound pressure generates between 1-2mV which is then coupled through a DC blocking capacitor to the pre-amplifier.

Pre-Amplifier Section

The pre-amplifier is a low gain stage in order to prevent noise and useful signal from being amplified exceedingly. Employing a gain of 50 and using the op-amp as an inverting amplifier and taking R2 as 2.2KΩ

Magnitude of Gain= (R4/R2)…………(2)

Then R4 = 2.2KΩ x 50 = 110KΩ

We select R4 = 100KΩ based on resistors available in the market, hence the magnitude of the gain of the pre-amplifier is A = R4 /R2 = 100/2.2 = 45.45

Also, the value of R3 was chosen as 2.2KΩ to minimize the effect of input offset current.

The unity gain frequency or gain bandwidth product of a UA741C (LM741C) is 1MHz,

Closed loop gain bandwidth = unity gain frequency/closed lood gain..........(3)

so the closed loop gain bandwidth of the pre-amplifier is 1000000/45.45 22 KHz

This indicates we can amplify a signal whose frequency is up to 22 KHz and since the audible range of the human ear is between 20Hz-20 KHz, it makes the circuit suitable for audio signal amplification.

In addition, taking C2 as 0.047uF and R2 as 2.2K forms a low pass network with a cut-off frequency of:

F = 1/ (2RC)…...........…………………(3)

$F = 1/ (2 \text{ x } \text{ x } 2200 \text{ x } 0.047\text{x}10^{-6}) = 1539.2 \quad 1540\text{Hz}$

With this frequency, the pre-amplifier stage will have an upper limit frequency of 1540Hz.

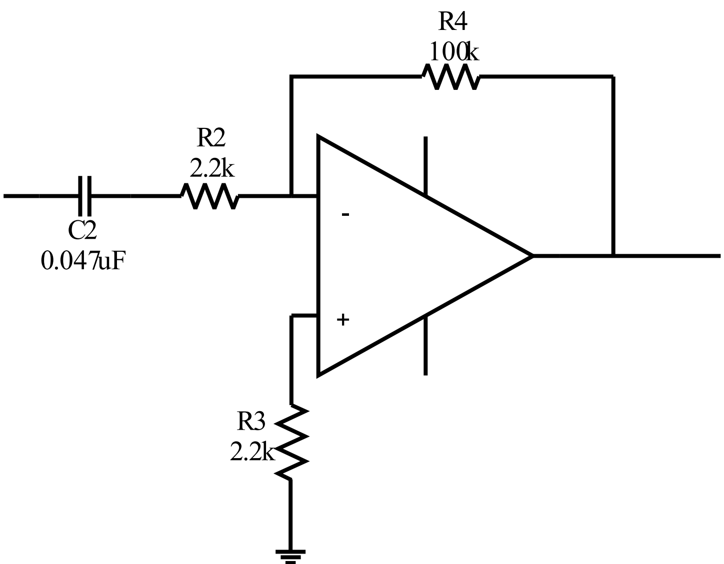

Figure 2.3: Op-amp as an Inverting Amplifier.

Low Pass Filter Section

The frequency of heart beat is within a useful range of 0-100Hz and thus trying to amplify signals with frequencies above 100Hz would not be necessary, hence the cut-off frequency of the pre-amplifier stage which was 1540Hz was sufficient to have allowed usable acoustic signal to pass through before attenuating signals with frequencies higher than 1540Hz.

A Second Order Butterworth Filter was chosen for the design of the filter stage due to its smooth pass-band and moderate roll off.

A Sallen and Key configuration was used because of its gain accuracy, low number of pole pair and because of its ability to act as a buffer. A second order filter design using the Sallen and Key configuration was also used because it can give a roll off of 40dB/decade.

$f_{cut\text{-}off}$ required is 100Hz

a Capacitor of 0.047F was selected from which the value of the resistor was gotten as follows:

$f_{cut\text{-}off}$ =1/(2RC) therefore

$R = 1/(2\pi Cf_{cut\text{-}off})$…......………...(4)

$R = 1/(2 \text{ x } \text{ x } 0.047 \text{ x } 10^{-6} \text{ x } 100) = =$ 33862.7 33KΩ

Hence a 33kΩ Resistor was chosen as the value for R7. The value of R8 was selected such that the gain of this low pass filter section would not be greater than 1.6 in order to prevent instability and maintain the reliability of the filter circuit.

Non inverting Gain = 1 + (R7/R8) ....(4)

Using a gain value of 1.6 which is less than two,

1.6 = 1 + (33kΩ/R8) , this results in R8 = 55KΩ

The value 55KΩ is not an available resistor in the market therefore 56KΩ was chosen as the value for R8.

Two capacitors are employed because the circuit is a low pass Second Order Butterworth Filter (using Sallen and Key equal component configuration).

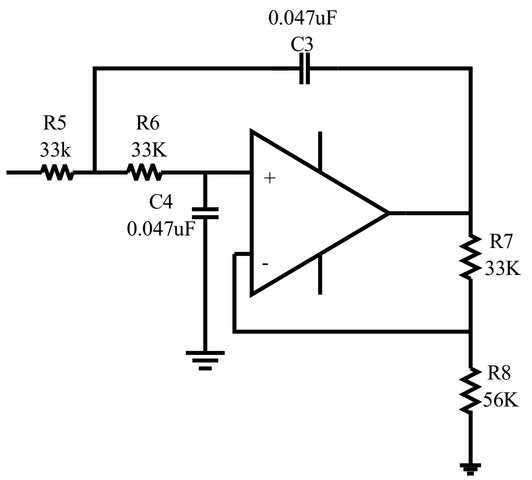

Figure 2.4: Low Pass, Second Order Butterworth Sallen-and-Key Filter

A low pass filter was used to ensure that only sound within 0-100Hz was allowed. This greatly reduces the extraneous noises.

Voltage Follower Section

The output of the low pass filter goes into a voltage follower which is used so that signals from the low pass filter are effectively (maximally) transferred to the main amplifier stage. This is achieved due to the theoretical infinite input impedance and zero output impedance of the voltage follower.

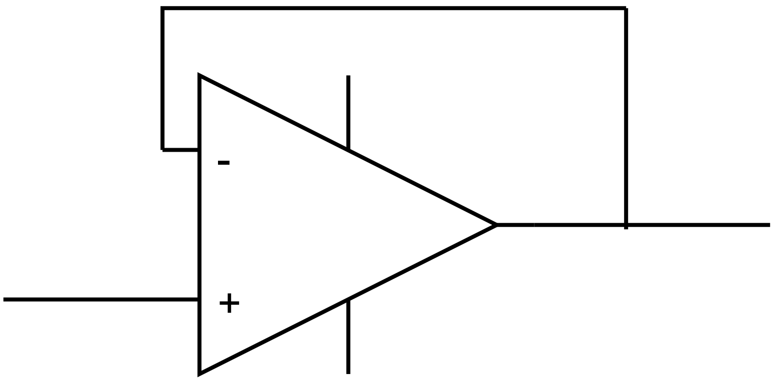

Figure 2.5: Op-amp Voltage Follower

Main Amplifier Section

This section comprises of the Amplifier, the Voltage reference setting, Gain calculations

Amplifier

The amplifier stage is made up of a non-inverting opamp, a single supply and a voltage referenced at 4.5V. Thus there is a voltage swing from 4.5V to 9V and from 4.5V to 0V. This range of swing is chosen rather than from +9V to 0V and from 0V to –9V which may damage our headphones due to high current value.

The Schematic of the main amplifier is shown in figure 2.6

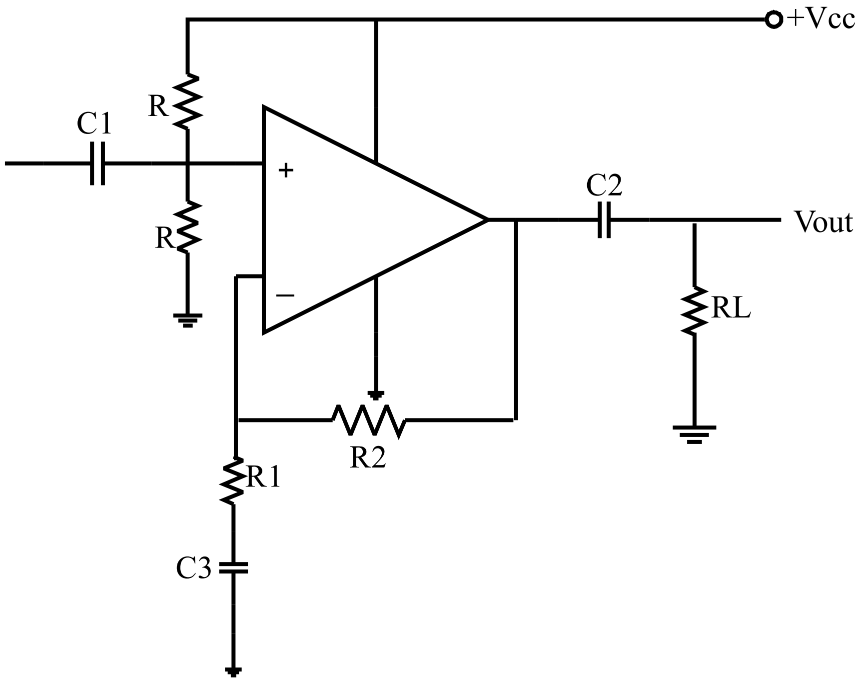

Figure 2.6: Single Supply Non-inverting Amplifier

Voltage Reference Setting

With respect to the schematics of Fig 2.6. under D.C. condition, the capacitor is an open circuit and this is shown in the schematics in figure 2.7 below:

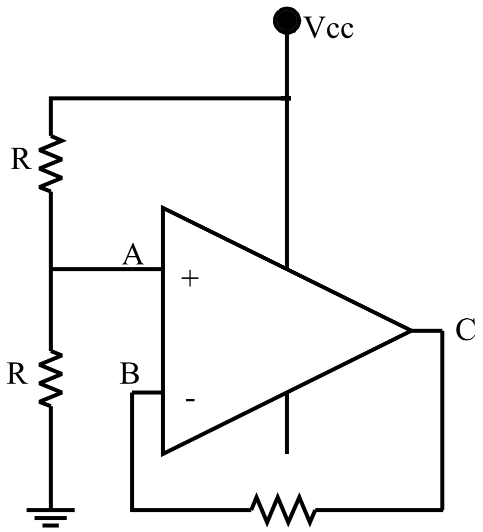

Figure 2.7: DC Condition for Single Supply Non-inverting Amplifier

Node A above is at Vcc/2 since the Vcc Voltage is divided equally between the two resistors R in the resistor network. By virtual earth concept, node A and node B must be at the same potential since terminal B is bootstrapped to be at the potential of node A. Hence point C must be at the potential of node B since no current should flow through R2 in d.c. condition. Point C is thus at Vcc/2 (the reference level). For this case R = 10K and point C is at Vcc/2 = 9/2 => 4.5V. Hence we have set the reference voltage.

Gain Calculation

The amplifier stage will have a gain of 2500 (chosen arbitrarily)

The formula for the non-inverting amplifier is

$A_V = 1 + (R17/R16)$……………....(5)

If R16 = 3.9 , then 2500 = 1 + (R17/3.9) or R17 = (2500 – 1)3.9

Therefore R17 = 9746.1 10K based on 5% tolerance of resistors.

Calculation of the cut-off frequencies was carried out using equation 3

The first capacitor C5 sees a thevenin resistance of R14 in parallel with R15 (figure 2.8) The resultant resistance is thus 5K. Therefore;

$$f_1\ cut\text{-}off = \frac{1}{2\pi RC} = \frac{1}{2 \times \pi \times 5000 \times 10 \times 10^{-6}} = 3.18Hz$$

The combination of C5 and R14 | | R15 thus acts as a high pass filter network that passes frequency above 3.2Hz. This is acceptable since the frequency we wish to amplify is from 0-100Hz. The value of RL was taken as 32 because a 32 headphone was used and also C7 was taken as 1000F

$$f_2\ cut\text{-}off = \frac{1}{2\pi RC} = \frac{1}{2 \times \pi \times 32 \times 1000 \times 10^{-6}} = 4.97Hz$$

Therefore signals from 5Hz upwards to 100Hz can be heard (which is the maximum frequency allowed by the low pass filter)

The cut off frequency of the by-pass capacitor is determined with R16 and C6 as seen in figure 2.8

$$f_3\ cut\text{-}off = \frac{1}{2\pi RC} = \frac{1}{2 \times \pi \times 3.9 \times 0.1 \times 10^{-6}} \approx 408KHz$$

R16 and C6 act as a low pass filter section that will pass all frequency from 0-408Khz. This is acceptable since the maximum usable frequency (i.e. 100Hz) lies within this range.

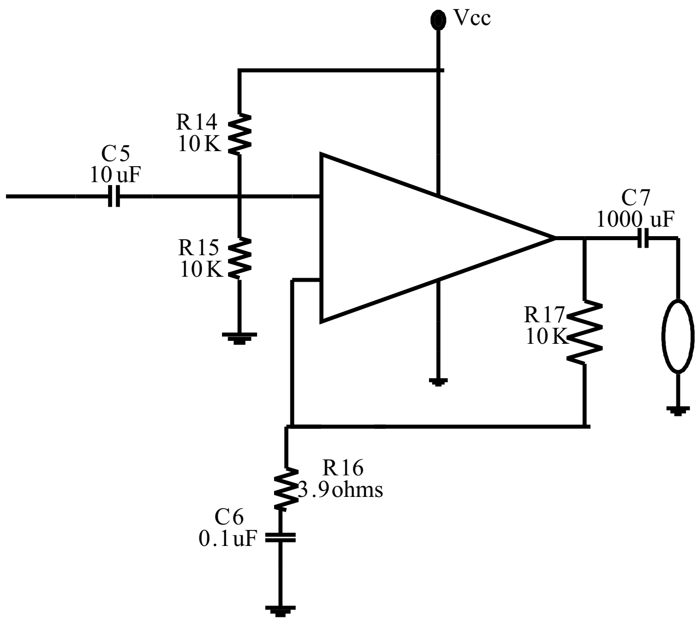

Fig 2.8 Single Supply Non-inverting Amplifier with Voltage Reference

LED Driver Section

The LED driver is an inverting amplifier with a gain A = R12/R10 => 330/4.7 = 70.2 For a 2mV signal peak to peak the input voltage to drive the LED driver can be found.

The total gain = gain of pre-amplifier x gain of low pass filter x LED driver gain….(6)

Therefore A_{total} = 45 x 1.6 x 70 5040. Voltage swing to drive LED is: V = 5040 x 2mV = 10.1V or 5.05 Swing

The current through the LED is:

$I=(V_{swing} – 1.3)/R$ …………………….(7)

$$I = \frac{5.05 – 1.3}{1K} = 3.75mA$$

The 1.3V is the voltage drop of each LED. The low current was necessary to ensure that the rhythm of the heart does not stress the LED when it comes on and off continuously. R9 = 4.7K was taken to minimize noise due to input-offset current.

The Complete Working Circuit Diagram.

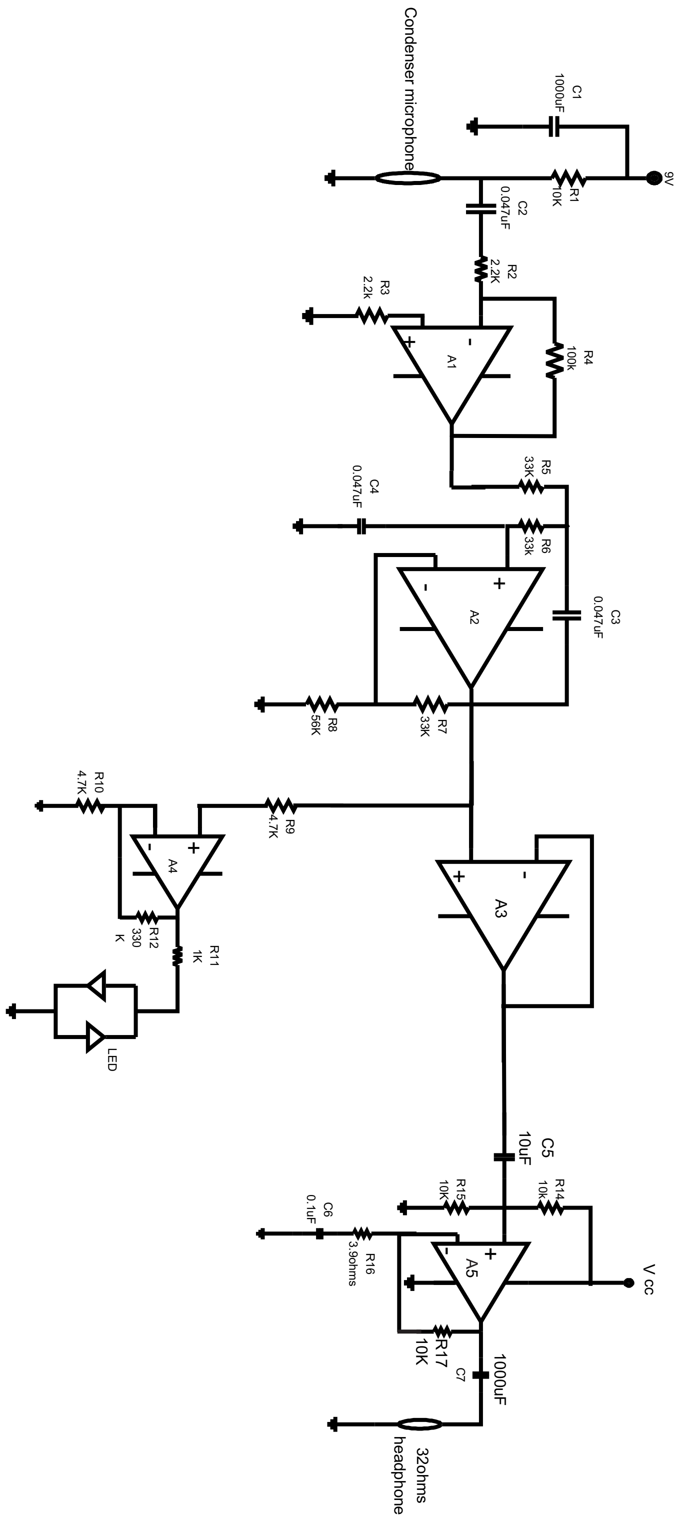

Figure 2.8 Schematics of the Electronic Stethoscope

Working Principle

When the switch of the stethoscope is depressed, the circuit is made since power is supplied, and a constant current of about 0.9mA biases the condenser microphone. The condenser microphone possesses fixed impedance when no sound pressure impinges on the condenser microphone.

The value of this fixed impedance is such that there is equal voltage division between the biasing resistor R1 and the fixed impedance of the microphone. When the stethoscope chest piece collects heart sound, it feeds the sound through the tube to impinge on the condenser microphone. The impedance of the microphone varies and results in voltage variation corresponding to the heart sound. This voltage is then fed to the pre-amplifier stage where it is amplified a little (together with noise). At the low pass filter section, signals with frequencies above 100Hz are filtered out and useful signal is amplified with a gain of 1.6. The output of the filter is coupled through a voltage follower (buffer) in order for maximum signal to be delivered to the amplifier stage. The amplifier section carries out further amplification of the signal depending on signal level fed to input of the pre-amplifier section. The LED driver produces visual display of the heart rhythm. The complete circuit schematics is shown in Fig 2.8

Construction

The use of bread board and initial letting is the logical first stage as it is essential to prove the functionality of the design, temporary connection was made on the bread board and this was subject to variations necessary to achieve the desired result. Wire leads were used to interconnect components simply by inserting the wires at the appropriate holes.

Positioning and soldering of components:

Before actual positioning, the surface of the vero board was cleared with the sand paper to remove traces of dirt and oxide deposits. The components were now positioned appropriately after scrapping their legs with razor to heat up for sometime. Actual soldering was now done ensuring that excess lead does not shut circuit two copper conductors.

Testing And Result

This work was tested several times for the functionality of the design of the circuit and it was working very well like the foreign made stethoscope sold in the Nigerian market.

Conclusion

The design and development of an electronic stethoscope was described in this work. The developed device cost was seven thousand six hundred and eighty naira which is less costly compared to the ones available in the market.

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