

A versatile low cost Electronic Stethoscope design

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Abstract: *To develop an electronic stethoscope to amplify the sound of the heart and reduce any background ambient noise thereby producing a perfect heart beat sound for hearing, and to verify the ability of the electronic stethoscope in performing a better function than the medical acoustic type without any side effect on the people, is the aim of this work. The device is developed and consists of two microphones whose signals are sent through a quad amp which implements an initial gain of three and filters the input via a five pole Sallen-Key low pass filter. The two filtered signals are sent to a mixer, which allows the user to select which input microphone they would like to use and adjust the bass and treble characteristics of the signal. Following the mixer, the signal is sent to another switch, which allows the user to choose between headphone or speaker output.*

I. Introduction

Stethoscope is one of the most important diagnostic tools in the medical world. Over almost two centuries, the stethoscope has been changed and refined often, but it has never strayed too far from the original design. Rene Theophile, a French physician, is attributed with the invention of the first stethoscope in 1816 when he was examining an obese patient. His first model of the stethoscope was simply a wooden tube resembling a candlestick. Over the years, this model has evolved into the device that we now recognize as the stethoscope through many small changes, such as adding earpieces for each ear and developing the combined bell and diaphragm chest piece [1]. A stethoscope is a very straightforward device. The chest piece consists of a shallow, bell-shaped piece and a clear, stiff diaphragm, which is then connected to the metal earpieces by a flexible tube [1,2]. The bell is used to pick up lower frequency sounds, and the diaphragm is used for higher frequency sounds. When the chest piece is placed on the skin, vibrations within in the body are amplified by either the bell or diaphragm. These acoustic pressure waves then travel up through the tubing, resonating to the earpieces and into the listener's ears.

Very few changes have been made to the overall design of the stethoscope over the years because it does its job so well. However, there are a few problems with current models. For example, with the standard acoustic stethoscope, the listener is not able to amplify the sounds. This is sometimes a problem if he or she is only getting very quiet sounds through the stethoscope. Also, the earpieces of stethoscopes can be quite uncomfortable. Although these are not enormous problems, current technology has introduced alternatives to the acoustic stethoscope. Stethoscopes are not only useful for doctors, but for home mechanics, exterminators, spying etc [2,3]. Stethoscopes can also be used to check scientific vacuum chambers for leaks, and for various other small-scale acoustic monitoring tasks. Standard stethoscope provides no amplification which reduces its use [2,3]. A Stethoscope uses op-amps to amplify the signal and includes a low pass filter to remove background noise.

A typical electronic stethoscope performs the following functions [3,4];

For listening to the heart beats for any irregular rate of beating.

To verify the operation of the lungs to know if there is fluid build up.

To check the blood pressure running through the veins.

To determine the process of digestive system in the stomach.

For prenatal care during pregnancy.

The field of applied science related to the art of healing by diagnosis, treatment, and prevention of disease. It encompasses a variety of health care practices evolved to maintain and restore health by the prevention and treatment of illness in human beings. Contemporary medicine applies biomedical sciences, biomedical research, genetics and medical technology to diagnose, treat, and prevent injury and disease, typically through medication or surgery, but also through therapies as diverse as psychotherapy, external splints & traction, prostheses, biologics, pharmaceuticals, ionizing radiation among others [4].

II. Types of stethoscope

2.1. Acousticstethoscope

The stethoscope is an instrument used for auscultation or listening to sounds produced by the body. It is used primarily to listen to the lungs, heart and intestinal tract. It is also used to listen to blood flow in peripheral vessels and the heart sounds of development.

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. 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, 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 traveling up to the listener's ears [3,4]. The bell transmits low frequency sounds, while the diaphragm transmits higher frequency sounds. This two-sided stethoscope was invented by Rappaport and Sprague in the early part of the 20th century. One problem with acoustic stethoscopes was that the sound level is extremely low. This problem was surmounted in 1999 with the invention of the stratified continuous (inner) lumen, and the kinetic acoustic mechanism in 2002. Acoustic stethoscopes are the most commonly used. A recent independent review evaluated twelve common acoustic stethoscopes on the basis of loudness, clarity, and ergonomics. They did acoustic laboratory testing and recorded heart sounds on volunteers. The results are listed by brand and model.

2.2 Electronicstethoscope

An electronic stethoscope (stetho-phone) overcomes the low sound levels by electronically amplifying body sounds. However, amplification of stethoscope contact artefacts, and component cut-offs (frequency response thresholds of electronic stethoscope microphones, pre-amps, amps, and speakers) limit electronically amplified stethoscopes' overall utility by amplifying mid-range sounds, while simultaneously attenuating high- and low- frequency range sounds. Currently, a number of companies offer electronic stethoscopes. Electronic stethoscopes require conversion of acoustic sound waves to electrical signals which can then be amplified and processed for optimal listening. 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. Another method, used in Welch-Allyn's Meditron stethoscope, comprises placement of a piezoelectric crystal at the head of a metal shaft, the bottom of the shaft making contact with a diaphragm [5,6]. 3M also uses a piezo-electric crystal placed within foam behind a thick rubber-like diaphragm. Think labs'

Rhythm 32 inventor, Clive Smith uses an Electromagnetic Diaphragm with a conductive inner surface to form a capacitive sensor. This diaphragm responds to sound waves identically to a conventional acoustic stethoscope, with changes in an electric field replacing changes in air pressure. 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, can be a recording device, and can provide noise reduction, signal enhancement, and both visual and audio output [6]. Around 2001, Stetho-graphics introduced PC-based software which enabled a phonocardiograph, graphic representation of cardiologic and pulmonology sounds to be generated, and interpreted according to related algorithms. All of these features are helpful for purposes of telemedicine (remote diagnosis) and teaching. Electronic stethoscopes are also used with Computer-aided Auscultation programs to analyse the recorded heart sounds pathological or innocent heart murmurs.

2.3 Recording stethoscopes

Some electronic stethoscopes feature direct audio output that can be used with an external recording device, such as a laptop or MP3 recorder. The same connection can be used to listen to the previously-recorded auscultation through the stethoscope headphones, allowing for more detailed study for general research as well as evaluation and consultation regarding a particular patient's condition and telemedicine, or remote diagnosis [7].

III. Methodology of research

The components used for the design of an electronic stethoscope are as listed below:-

- a). Chest piece
- b). A pre amplifier circuit
- c). Operational amplifier circuits
- d). a low pass filter circuit
- e). Electret microphone
- f). Regulators consisting of resistor circuits and capacitors
- g). Earpiece

- h). 12 Volts power source
- f). Output (ear piece/ loud speaker)

When the chest piece is placed on the patient, the earpiece allows the internal sound energy from the patient through the conductor travels through the ear of the clinician or medical personnel. The physical connection is made between the ear tips and the human ear. The pressure, ear tip seal, ear tip insertion angle are all variables that can affect the connection. The chest piece usually consist of two parts that can be placed on the patient for sensing sound i.e. low frequency sound when the diaphragm is placed against the body of the patient skin, body sound vibrates the diaphragm creating acoustic pressure wave which can travel to the listeners ear. The large side can be used for adult patient while the small side is especially useful for paediatric or thin patient, around bandages and carotid assessment. The human body translates the pressure wave into sound and allows the listener to hear what they are examined. Hence, the chest piece is part of the stethoscope that is placed on a location where the users wants to hear sound



Figure 1: Chest piece separated from the stethoscope. (*The American Journal of Cardiology*)

Amplifiers are referred to active circuits since their operation is based on active devices. They are distinguished from passive circuits by their ability to provide power gain, which is essential to most electronic systems. This need for power gain is most evident in wireless communication systems, where the signal received may be in the microvolt range, which is too weak to process without amplification. Small signal amplifiers are used to increase the voltage amplitude and/or the current amplitude of a signal, to provide some increase in the power of the signal [11]. Transistors can be used in virtually all small signal amplifiers, either built into an integrated circuit or used in the discrete form. The choice of either NPN or PNP bipolar or FET depends on the design consideration. In this work, a FET transistor was selected. FETs are different from the bipolar junction transistor in that they amplify voltage changes at the input into current changes at the output. That is, they depend on the voltage change between the gate and the source to produce a current change between drain and source. Their large resistance looking into the gate is a property very useful to its selection.

Filters are used in circuits which require the separation of signals according to their frequencies. A low pass filter is provided to remove high frequency noise and also acts as an anti-aliasing filter, since sigma delta ADC (codec) is chosen, the requirement on the analog anti-aliasing filters are minimal. This is because oversampling relaxes the requirement on the base band anti-aliasing filter. Therefore, a simple first order active low-pass filter is sufficient. The simplest way to make a filter is by using passive components (RLC) which works well for high frequencies. However, at audio frequencies, the inductors become problematic, as it becomes very large [12] heavy and expensive. For low frequency application as this design demands, a low pass active filter is selected, with second order Butterworth at an upper cut off frequency of 400Hz.

Basically, op-amp is such an amplifier which has a very high sensitivity and gain. If it gets a small amount of input voltage, it can amplify it very well. Thus, the amplification depends on the supply voltage, if the gain is high enough, the output voltage will be crossing the operating voltage, hence it will saturate and its output voltage will be the same as its operating voltage. The operational amplifier (Op-Amp) used is in the inverting mode used as a preamplifier circuit with a design gain of -100. The inverting signal is re-inverted for balance the phase shift with another op-amp of a gain of -100. The power amplifier is developed with the use of a push pull op-amp to give the desired current range to drive the output transducer.

The electret microphone used, picks up a negligible sound and converts it to an electrical format, reason because an electret mic is a transducer that converts one form of energy to another (basically sound energy to electrical energy).

IV. Operational analysis of an electronic stethoscope

Some stethoscope must be placed directly on the skin, while others can work effately through clothing. For the stethoscope, listeners place the chest piece on the area to be tested and a low-pitched or low frequency sound is heard. A stethoscope is used in conjunction with a device to measure blood pressure (sphygmomanometer). The stethoscope detects sound of blood passing through artery.

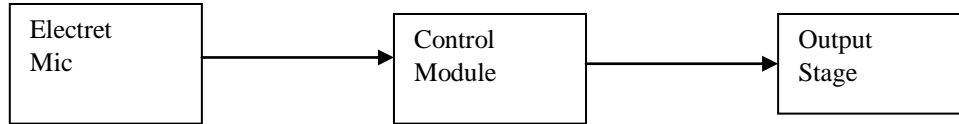


Figure 2: Block Diagram of an Electronic Stethoscope

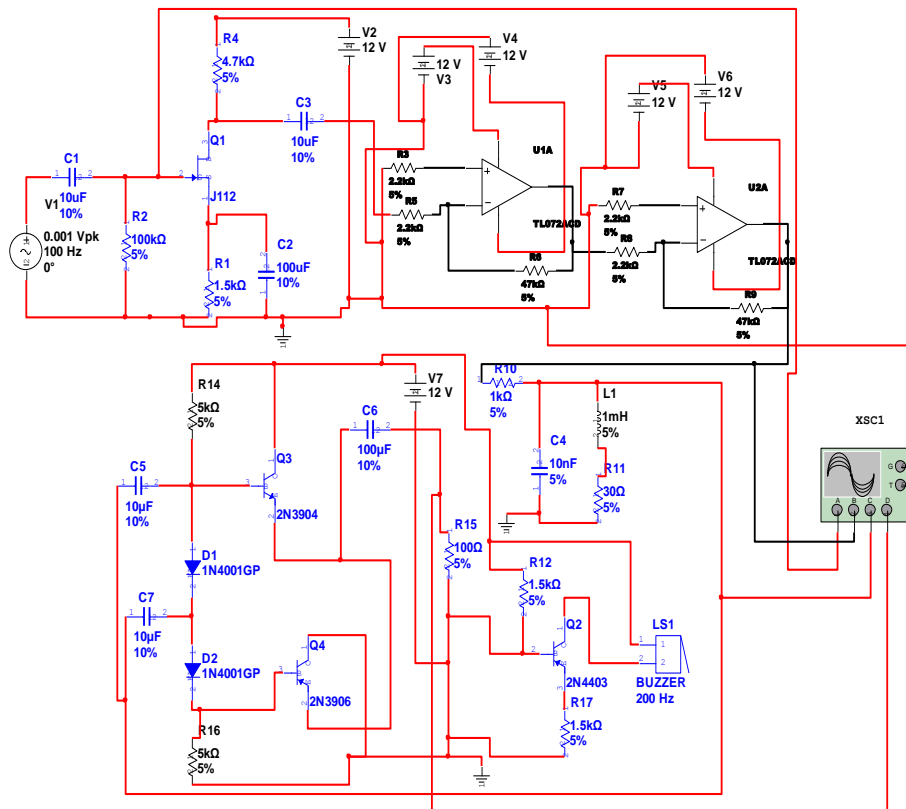


Figure 3: Circuit design for an electronic stethoscope.

The operation of the circuit may be understood from the assumption that when a small a.c signal is applied to the gate, it produces variations in the gate-to-source voltage. This produces variations in the drain current. As the gate-to-source voltage increases, the drain current also increases, and the voltage drop across the resistor R2 also increases. This causes the drain voltage to decrease. It means that the positive half cycle of the output voltage (i.e. the output voltage at the drain is 180° out- of phase with the input voltage at the gate. The a.c equivalent circuit of a common source amplifier obtained by short-circuiting the capacitors and the d.c supplies, with the FET replaced by its low frequency model [15,16], shows that,

$$A_v = V_o / V_{in} \dots\dots\dots 1$$

And the current through R2 = R_d (by current divider rule) is

$$i_d = r_d(g_m \cdot v_{gs}) / (R_d + r_d) \dots\dots\dots 2$$

where g_m is the FET transconductance in mA/V or mS; and v_{gs} is the gate -to- source voltage.

The output voltage is,

$$V_o = - i_d \cdot R_d = - R_d \cdot r_d(g_m \cdot v_{gs}) / (R_d + r_d) \\ = - g_m \cdot R_d \parallel r_d \cdot v_{gs} = - g_m \cdot r_L \cdot v_{gs} \dots\dots\dots 3$$

(r_L = (R_d ∥ r_d))

Thus,

$$V_o = - g_m \cdot r_L \cdot v_{in} \dots\dots\dots 4$$

Therefore,

$$A_v = V_o / V_{in} = - g_m \cdot r_L$$

And the input resistance

$$R_i = V_{in} / i_{in}$$

with the output resistance

$$R'_o = (r_L = R_d \parallel r_d)$$

And the voltage gain ,

$$A_v = -g_m \cdot r_L$$

Substituting the values of the parameters for 2N4416 FET : $V_{gs} = -6v$, $P_d = 300mW$, $V_{dg} = 35$, $V_{dss} = 30V$, $I_{dss} = 5mA$ and, $I_{gss} = 100pA$ and $r_d = 100k$ then ;

$$r_L = R_d \parallel r_d = \frac{R_d \times r_d}{R_d + r_d} = \frac{10 \times 100}{10 + 100} = 1000/110 = 9.09k$$

$$R_d + r_d = 10 + 100$$

From shockey's equation [15],

$$I_D = I_{Dss} (1 - V_{gs} / V_p)^2 \quad \dots 5$$

Where ,

$$dI_D = g_m = -2 I_{Dss} (1 - V_{gs} / V_p) \dots\dots\dots 6$$

$$\frac{dI_{Dss} V_p}{I_D}$$

substituting the values, we have from equation 6,

$$I_D = 5 \times 10^{-3} (1 - (-6)/(-3))^2 = 5mA$$

Thus ,

$$R_s = V_{gs} / I_p = 6 / 0.005 = 1.2k\Omega$$

And from

$$V_{Ds} = V_{DD} - I_D (R_D + R_s) \quad \text{with } V_{Ds} = V_{DD}/2, \text{ we have}$$

$$= 9 + 6 - 5 \times 10^{-3} R_D$$

And

$$R_D = 2.1 k\Omega, \text{ where we select } 2.2 k\Omega$$

From equation 6,

$$g_m = \frac{-2 \times 5 \times 10^{-3} (1 - (-6)/(-3))}{-3} = 3.333 \times 10^{-3} \text{ S} = 3.33mS.$$

The class B push-pull amplifier is designed for the buffer which consist of capacitors C_1 , C_2 and C_3 are coupling capacitors to prevent the transistor dc bias voltages from being affected by the input circuit or the load circuit. The amplifier voltage gain is measured by dividing the ac peak to peak output voltage V_o by the ac peak to peak input voltage V_{in} . Because the push pull is an emitter follower configuration, the voltage gain should be close to unity.

The design was simulated on a multism -10 version, with an input sinusoidal voltage of 1microvolt, and the output response is as shown with measured signals of figure 4. The output voltage from the pre amplifier circuit with transistor T1 gives 1.8uV, while the output response from the op-amp 2 gives a voltage of 3.54mV. The output from the op-amp serves as an input to a low pass filter circuit with 101uV and the output fed to a push pull amplifier which gives a voltage of 6.02V to drive the output device, which in this design is a 200Hz buzzer. Also, a square wave form was used as an input with results of figure 5. The output voltage from the pre amplifier circuit with transistor T1 gives 0.100mV, while the output response from the op-amp 2 gives a voltage of 100mV. The output from the op-amp serves as an input to a low pass filter circuit and the output fed to a push pull amplifier which gives a voltage of 140mV to drive the output device. An impulse voltage of 0.1mV was used as an input with a design parameter of initial value of -1mV, pulse voltage of 1uV, delay time of zero volts, rise and fall time of 1ns and a pulse width of 0.5ms. The response the design is as shown in figure 6. The output voltage from the pre amplifier circuit with transistor T1 gives 2.75uV, while the output response from the op-amp 2 gives a voltage of 3.64mV. The output from the op-amp serves as an input to a low pass filter circuit and the output fed to a push pull amplifier which gives a voltage of 6.02V to drive the output device. Apart from the low cost value of the design at less than N15,000(fifteen thousand Naira only) Nigerian currency compared to the acoustic value type of about N25,000 (Twenty thousand Naira only); the development gives a very clear sound from the output response device, with better sensitivity.

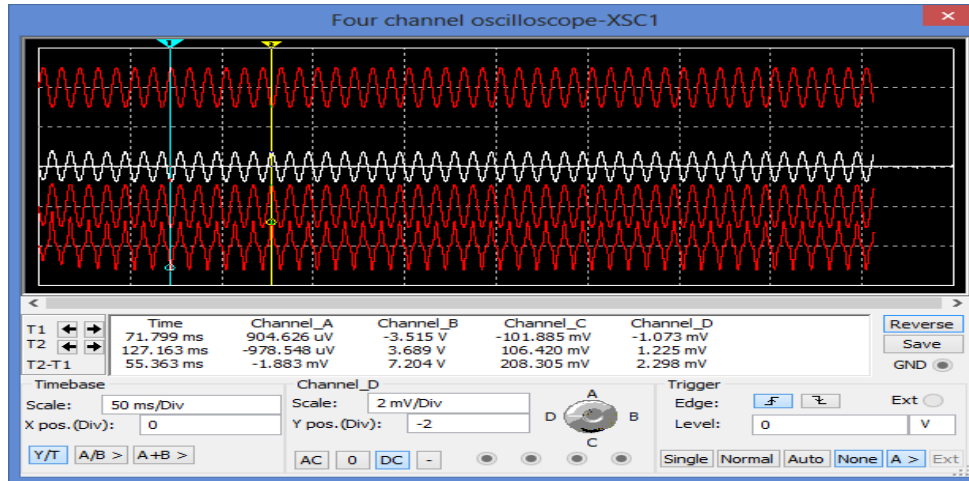


Figure 4: Analysis of design response at various points of measurement with sinusoidal input.

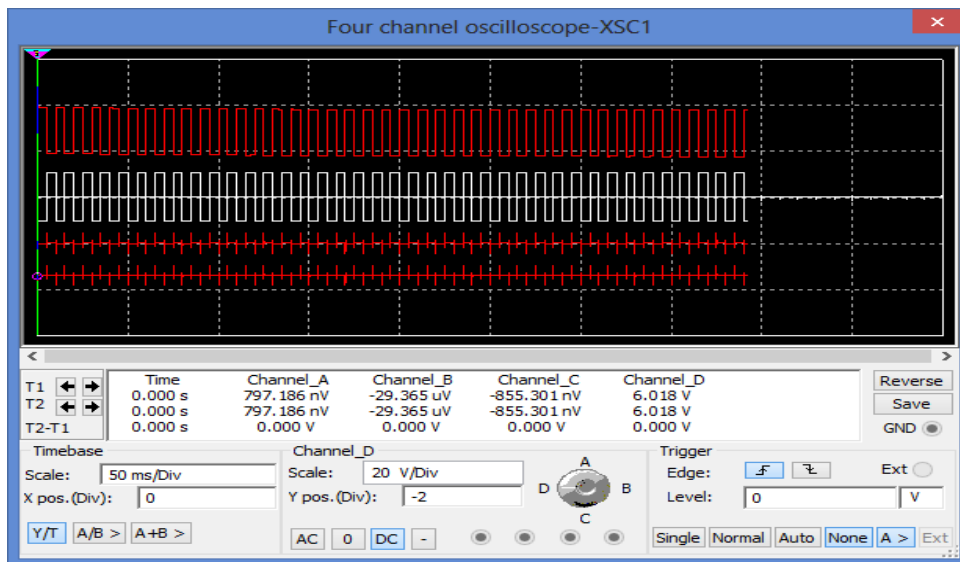


Figure 5: Analysis of design response at various points of measurement with sinusoidal input.

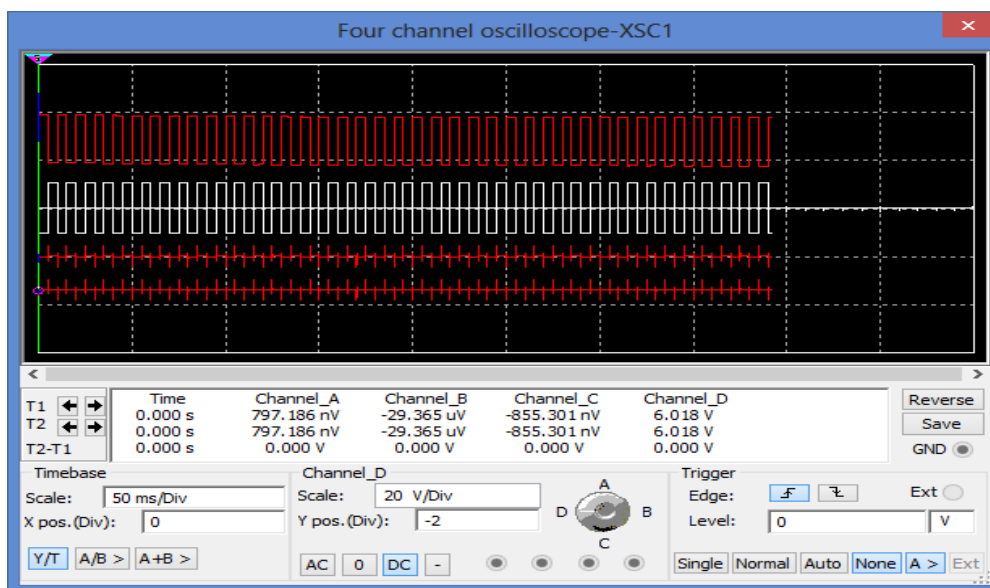


Figure 6: Analysis of design response at various points of measurement with pulse input.

A stethoscope functions in a way that it is used by healthcare professional to examine and evaluate their patients, typically, it is used to listen to the rhythm or sound made by the body since faints beat cannot be heard by mere ear except with a stethoscope. For the heart, normally it beats at an even rate, when the stethoscope is placed on it, it is heard by the healthcare professional both normal and also abnormal sound can be heard such as; murmur, irregular rate and other sound that might not be normal. Hence, the rhythm of one's heartbeat can be heard through a stethoscope to determine if there are any abnormal sounds. For the lungs, it is helpful to determine if there is a fluid build-up in the lungs and if there are any breathing difficulties. If someone or a patient has a common flu or cold or suffer from abnormal breathing condition, medical personnel can listen to the breathing sound by placing the stethoscope on the lungs and a sound is heard that alerts them to inflammation the air passage and fluid and congestion. To monitor the blood pressure, the blood running through the vein can be heard with the use of stethoscope, this is another way to count the heartbeats and listen to the blood running through the veins. When the blood pressure cuff is inflated on the arms, medical personnel are trained to hear the heart beating in the veins. The first beat they hear is the top number of the blood pressure and the last beat they hear is the bottom number. In the digestive system i.e. stomach of a patient, the sounds made by the intestines and other parts of the stomach can be listened to by the stethoscope, this can aid in determining if there are any stomach disorders or internal abnormalities. It also aids food digestion and even when the digestive system is empty, the stomach and bowels makes popping and gurgling noises. Some noises maybe heard by the ears but stethoscope is much more sensitive to these noises, the absence of some could means an obstruction in your bowels and a large number of noise could signal or signifies an infection or illness.

It is equally of note very useful in prenatal care, as an obstetrician uses a stethoscope to listen a baby's heartbeat in the uterus or listen to the baby's movement in the womb. During pregnancy, the movement of the baby, the heartbeat of the baby in the womb can be monitored by a stethoscope. Using stethoscope, the listener can hear normal and abnormal respiratory, cardiac, pleural, arterial, venoms, interne, foetal and intestinal sound.

The advantages of an electronic stethoscope over acoustic type include; i. It is more sensitive than the acoustic type, ii. the output sound can be varied i.e. (distinct sound output), iii. it can be connected to an external sound amplifier and the sound can be heard by all persons present in the place for training and lecturing purposes, iv. It produces a clearer output sound compare to the acoustic type; while the disadvantages include: i. It is expensive and ii. It has a high cost of maintenance, iii. It is useless if the battery is down or drained.

V. Conclusions

Electronic stethoscope is a device used to measure blood pressure by detecting the blood sound pressure, heart and lungs beat, digestive system of the stomach, prenatal care (pregnancy). The project aim at designing an electronic stethoscope, a circuit is design to perform the same function as the conventional stethoscope.

The entire circuit runs on a 12v battery source using a low cost electronic component like resistors, capacitors, and op-amps and the required design is achieved.

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