

### III Lead ECG Pulse Measurement Sensor

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**Abstract** - Heart rate sensing is very important. Method of measuring heart pulse by using an electrocardiogram (ECG) technique is described. Electrocardiogram is a measurement of the potential difference (the electrical pulse) generated by a cardiac tissue, mainly the heart. This paper also reports the development of a three lead ECG hardware system that would be the basis of developing a more cost efficient, portable and easy to use ECG machine. Einthoven's Three Lead method [1] is used for ECG signal extraction. Using amplifiers such as the instrumentation amplifier AD620BN and the conventional operational amplifier Ua741 that would be used to amplify the ECG signal extracted develop this system. The signal would then be filtered from noise using Butterworth filter techniques to obtain optimum output. Also a right leg guard was implemented as a safety feature to this system. Simulation was carried out for development of the system using P-spice Program.

#### 1. INTRODUCTION

Monitoring of cardiovascular pulse is widely used in health care, sport training; sleep studies and psycho-physiological (polygraph) examinations. Various contact measurement methods have been developed to estimate a subject's cardiovascular pulse. The golden standard for pulse measurement is Electro-Cardio- Graphy (ECG). ECG signal is the measurement of the potential difference of pulse waves that are generated from heart cells called the pacemaker cells. ECG recording requires the use of a signal amplifier and at least three electrodes. ECG readings can be used to monitor the conditions of heart (detect diseases such as Parkinson disease, Myocarditis, etc). There are many type of ECG machine in the market today such as 3 Lead, 12 Lead and 15 Lead ECG machine. However, these machine are expensive, not portable and not user friendly. These ECG machine cost from a minimum price of USD 620 (RM 2200) and are big and bulky therefore not portable. Moreover the 12 lead ECG system usually requires the patient to remove his or her clothes to enable 6 electrode placement on the chest and 3 electrode placement on the limbs, making it difficult an uncomfortable for patients. Hence, this thesis elaborates on the development of three lead ECG pulse measurement system for Electrocardiogram (ECG) signal extraction. The system develop also produces an ECG signal of the same quality however smaller therefore the hardware is more portable than a standard 3 lead ECG machine available in the market today. The Einthoven's 3 Lead Methods is used for ECG signal acquisition and the hardware designed comprises of amplifiers to amplify the signal and filters to remove noise as shown in Figure 1. P-spice simulations are run on all stages of development before any hardware implementation.

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## 2. METHOD

### 2.1 Amplification Stage 1

Figure 2 is a circuit diagram used for the 1<sup>st</sup> stage using an AD620BN instrumentation amplifier. A 100mV sinusoidal signal was chosen to be the input voltage,  $V_{in}$  and fed to amplifier. The variable resistor was then adjusted slowly to provide a minimum output voltage,  $V_{o1}$  of 10V. The value of the variable resistor for a gain 100 is calculated as below [1]:

$$RV = (R1+R2)/(A1-1)$$

Where  $R1$  and  $R2$  are the internal resistance of the in amp

Assuming  $R1 = R2 = 24.7k\Omega$

And choosing  $A1 = 100$

$R_v = 500 \Omega$

The output results are as follows

$$\begin{aligned} \text{The gain } A1 &= V_{o1} / V_{in} \\ &= 10.78 \text{ V} / 100.0\text{mV} \\ &= 107.8 \end{aligned}$$

which is approximate to the minimum desired gain of  $A1_{\text{desired}} = 100$

### 2.2 Filter Stage 1

This filter was built using the Sallen Key architecture method [2] in order to have Butterworth 4<sup>th</sup> order response. In order to achieve the 4<sup>th</sup> order response, two 2<sup>nd</sup> order low pass filters were cascaded together. The cut off frequency was chosen to be 0.05 Hz as it the minimum frequency of the ECG signal. To design this filter, considerations on cut off frequency, gain and quality were taken into account. The transfer function of a 2<sup>nd</sup> order high pass filter is described as below,

$$V_o/V_{in} = 1/[1 - f_c^2/f^2 - \sqrt{2}j f_c/f]$$

The gain,  $A_{fl}$  for the filter is described as,

$$\begin{aligned} A_{fl} &= |(V_o/V_{in})| \\ &= 1/\sqrt{[(1 - f_c^2/f^2)^2 + 2(f_c^2/f^2)]} \end{aligned}$$

Equation above can further be simplified in term of resistance of  $R3$  and  $R4$ ,

$$A_{fl} = 1 + (R4/R3)$$

The cut off frequency  $F_{c1}$  can be related as per equation below,

$$F_{c1} = 1 / [2\pi\sqrt{(R1 \cdot R2 \cdot C1 \cdot C2)}]$$

The quality,  $Q$  of the filter is,

$$Q = \sqrt{(R1 \cdot R2 \cdot C1 \cdot C2) / [R1 \cdot C1 + R2 \cdot C1 + R1 \cdot C2 \cdot (1 - A_{fl})]}$$

Thus, the calculated value for 4<sup>th</sup> Order High Pass Filter parameters are shown in Table 1.

### 2.3 Amplification Stage 2

For this stage, an active amplification filter was designed to have a gain of 10 and a cut off frequency of 0.05Hz. the filter was designed using a UA741 operational amplifier. The 2<sup>nd</sup> Stage Amplifier gain is estimated based on the correlations describe in equations below[2].

$$f_{3dB} = 1 / 2 \pi R_1 C$$

With gain calculation,

$$A_2 = R_2 / R_1$$

Thus, at  $f_{3dB} = 0.05$  Hz, the calculated gain is,

$$A_2 = 20$$

### 2.4 Filtering Stage 2

This filter was built using the Sallen Key architecture method[2] in order to have Butterworth 4<sup>th</sup> order response. In order to achieve the 4<sup>th</sup> order response, two 2<sup>nd</sup> order low pass filters were cascaded together. To design this filter, considerations on cut off frequency, gain and quality were taken into account. The transfer function of a 2<sup>nd</sup> order low pass filter is described as below,

$$V_o/V_{in} = 1 / [1 - f_c^2/f^2 - \sqrt{2}jfc/f]$$

The gain,  $A_{fl}$  for the filter is described as,

$$A_{fl} = |V_o/V_{in}| \\ = 1 / \sqrt{[(1 - f_c^2/f^2)^2 + 2(fc^2/f^2)]}$$

Equation above can further be simplified in term of resistance of R3 and R4,

$$A_{fl} = 1 + (R_4/R_3)$$

The cut off frequency  $F_{c1}$  can be related as per equation below,

$$F_{c1} = 1 / [2\pi \sqrt{(R_1 * R_2 * C_1 * C_2)}]$$

The quality, Q of the filter is,

$$Q = \sqrt{(R_1 * R_2 * C_1 * C_2) / [R_1 * C_1 + R_2 * C_1 + R_1 * C_2 * (1 - A_{fl})]}$$

Thus, the calculated value for 4<sup>th</sup> Order Low Pass Filter parameters are shown in Table 2.

### 2.5 Right Leg Guard

Placement of electrodes on the human body is an excellent path for current flow and since the ECG runs on a 15V power supply, the user must be protected by placing a right leg guard in the ECG system. The right leg guard is placed at the input terminal of the instrumentation amplifier and also connected to the right leg of the user. The buffering circuit is chosen is the right leg guard [3]. This is because it is easy to design and low cost. In case of leakage current, the right leg guard will direct the leakage current to the ground and the user would be protected from getting electrocuted. The circuit diagram that could be use s a right leg guard is shown in Figure 3. Furthermore, the right leg guard also improves the impedance of an instrumentation amplifier. This is because the right leg guard reduces capacitive losses that reduce the input impedance of the in-amp. The Right Leg Guard was also being tested using ammeter at output node which gives the reading of

$$I_{out} = 0 \text{ Amp}$$

This result was matched with the desired current output of 0 Amp.

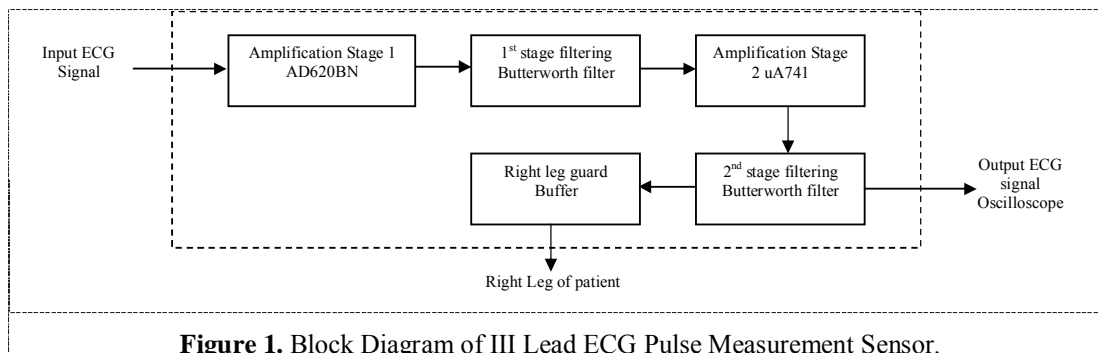
### 3. RESULT AND DISCUSSION

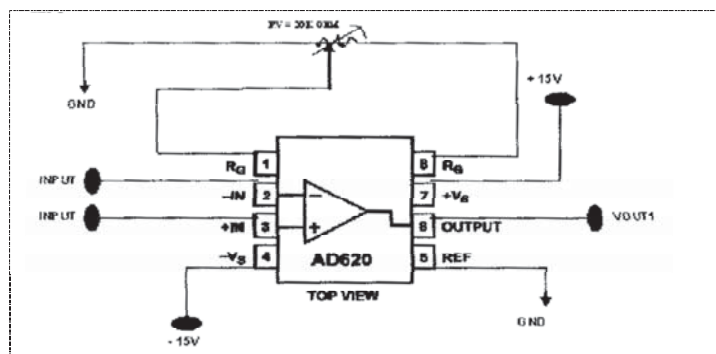
The 4<sup>th</sup> Order ECG System was designed using the 4<sup>th</sup> order high pass and low pass filters which was integrated with the 1<sup>st</sup> and 2<sup>nd</sup> stage amplifiers together with the right leg guard. The designed system was simulated by putting a sinusoidal input of 20 mV 15 Hz into the system. The system then tested with the acquired ECG signal. The output signal then observed to make sure the signal displayed from the ECG system was creating noise. Figure 4 shows the integrated circuit diagram for the 4<sup>th</sup> Order ECG System.

Figure 5 shows the output result from the oscilloscope output of the integrated 4<sup>th</sup> Order ECG System. From the output result, we can calculate the heart rate variability in beats per minutes by using Barros and Ohnishi method[4]. They define a compose time series formed by the time difference (in seconds) between two consecutive R-waves as  $x = [t_1, t_2, \dots, t_n]$  it can be written as  $hrv = [60/t_1, 60/t_2, \dots, 60/t_n]$ . The overall output gain is,  $A = 929.5$ . The III lead ECG system design could be used as basis to develop a heart beat detector for monitoring purpose. The 4th order ECG system may not be accurate but may still be used to develop a heart beat detector where the QRS complex signal is the main concern. Since the QRS complex wave can be seen clearly in the ECG signal produced by the 4th order ECG system, it can be used to calculate the heart beat rate per minute hence be used as a beat detector. The objective to develop a low cost, portable and easy to use III Lead ECG System was successfully accomplished. The 4th Order ECG System output is suitable for application concerning heartbeat detection.

### REFERENCES

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- [2] George Clayton and Steve Winder, Operational Amplifiers, 4<sup>th</sup> Edition, Philadelphia, PA : W.B Saunders Company, 2000, Chapter 11
- [3] Arpad Barna and Dan I. Porat, Operational Amplifiers, 2<sup>nd</sup> Edition, Boston, MA: Little, Brown, 1989, Chapter 4
- [4] Darold Wobschall Circuit Design For Electronic Instrumentation, 2<sup>nd</sup> Edition, Armonk, NY: Futura, 1995
- [5] Charles Kitchin and Lew Counts, A Designer's Guide to Instrumentation Amplifiers, Report





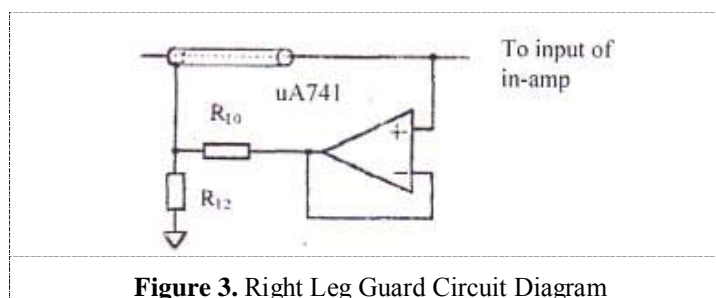
**Figure 2.** AD620BN Instrumentation Amplifier Circuit Diagram

**Table 1:** Calculated value of 4<sup>th</sup> Order High Pass Filter Parameters

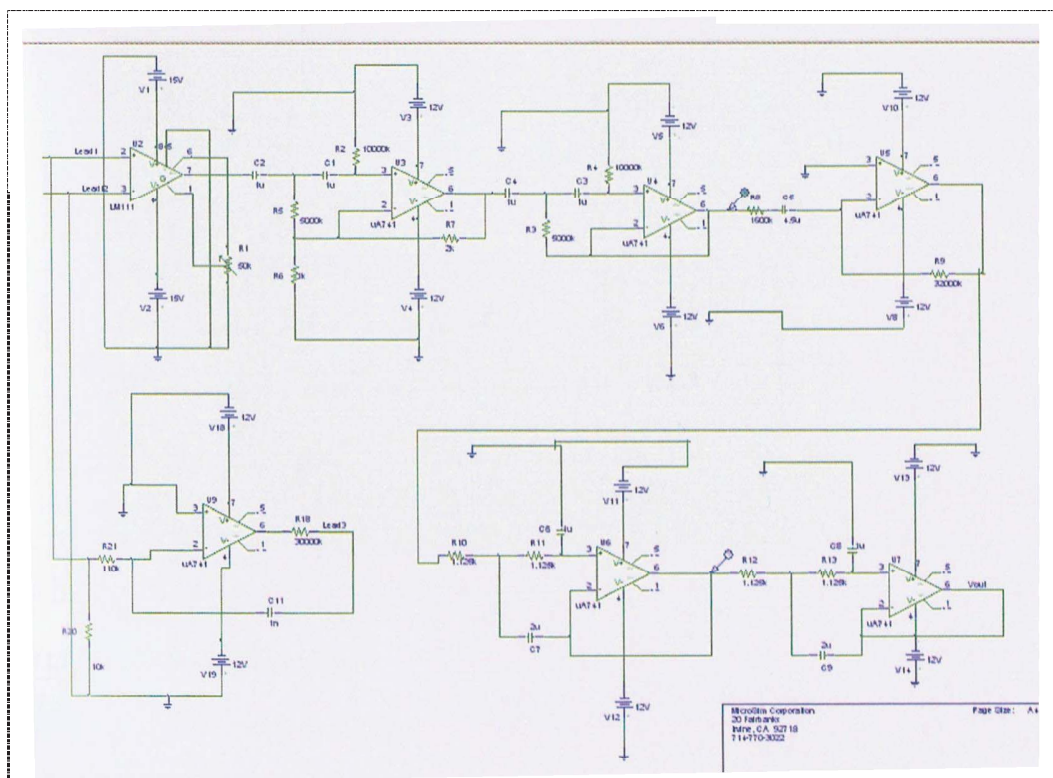
	Af1	Q	Fc (Hz)	R1 (kΩ)	R2 (kΩ)	R3 (kΩ)	R1 (kΩ)	C1 (μF)	C2 (μF)
<b>Stage 1</b>	3	0.5412	0.05	5000	10000	1	2	1	1
<b>Stage 2</b>	1	1.3065	0.05	5000	10000	∞	0	1	1

**Table 2:** Calculated value of 4<sup>th</sup> Order Low Pass Filter Parameters

	Af2	Q	Fc (Hz)	R1 (kΩ)	R2 (kΩ)	R3 (kΩ)	R1 (kΩ)	C1 (μF)	C2 (μF)
<b>Stage 1</b>	1	0.5412	50	1125	1125	∞	0	1	2
<b>Stage 2</b>	1	1.3065	50	1125	1125	∞	0	1	2

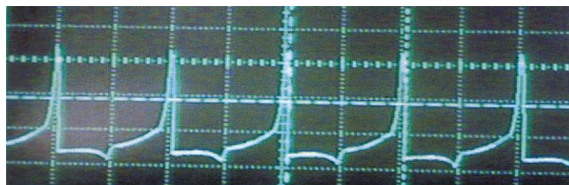


**Figure 3.** Right Leg Guard Circuit Diagram



**Figure 4.** Integrated Circuit Diagram for the 4<sup>th</sup> Order ECG System

R-R interval



**Figure 5.** Output Result from Oscilloscope for the 4<sup>th</sup> Order ECG System