

Florida Atlantic University – Biomedical Signal Processing Lab

Experiment 2 – Signal Transduction: Building an analog Electrocardiogram (ECG)

1. Introduction:

The Electrocardiogram (ECG) is a technique of recording bioelectric currents generated by the heart. From a recorded ECG waveform, clinicians can evaluate the conditions of the patient’s heart and perform further diagnostics. ECG records are obtained by the sensing of several electrodes, also known as leads.

The output of an ECG recorder is a graph with time represented on the x-axis and voltage represented on the y-axis. The amplitude of a measured ECG signal varies between 1 mV and

5 mV. Hence, there is a need to amplify the recorded signal.

The objective of this lab is to build a 3-lead ECG amplifier analog circuit using the ua741 operational amplifiers (op-amps) included in your lab kit. After the design and assembly of your circuit, you will be required to record your ECG signal using inexpensive electrodes.

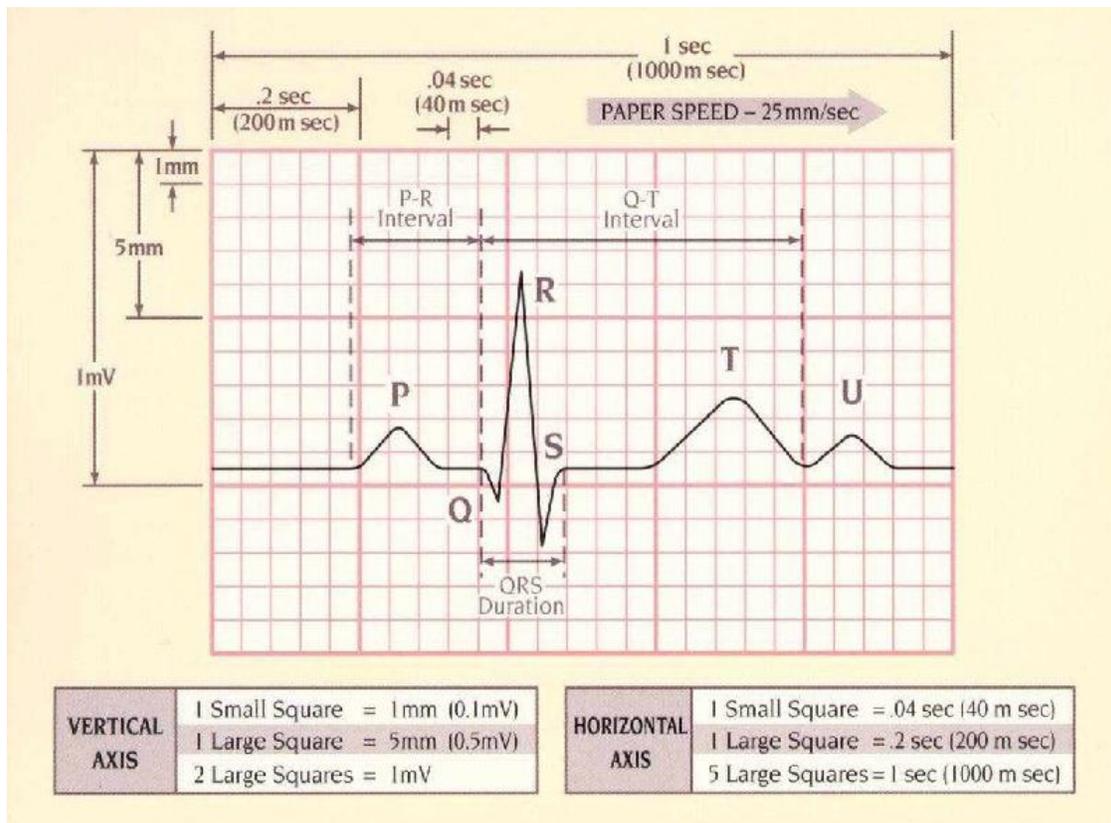


Figure 1. ECG Waveform.

2. Pre-lab (15% of the final Report grade). Should be completed prior to the in-class meeting.

- ✓ Refresh your memory on op-amp circuits, and complete the table below:

	Schematic	Gain formula (V_{out}/V_{in})
Non-inverting amplifier		
Inverting amplifier		
Difference amplifier		

Table 1. Op-Amp configurations

- ✓ Complete Table 2 below with configurations of low-pass, high-pass and midband pass filters:

	Schematic	Cut-off frequency (f_c) formula
Low-pass filter		
High-pass filter		
Midband pass filter		

Table 2. Filters configurations

- ✓ What is the 3 dB bandwidth of an amplifier?

Answer:

- ✓ Provide definition of the common mode input into a differential amplifier?

Answer:

- ✓ Provide definition of the differential input into a differential amplifier?

Answer:

- ✓ What is the common-mode rejection ratio? How do we calculate it?

Answer:

3. Circuit Design:

Our goal is to design a circuit that amplifies the differential input voltage and significantly reduces common-mode voltage level. To achieve this goals, a differential amplifier consisting of two main stages as described below is to be built:

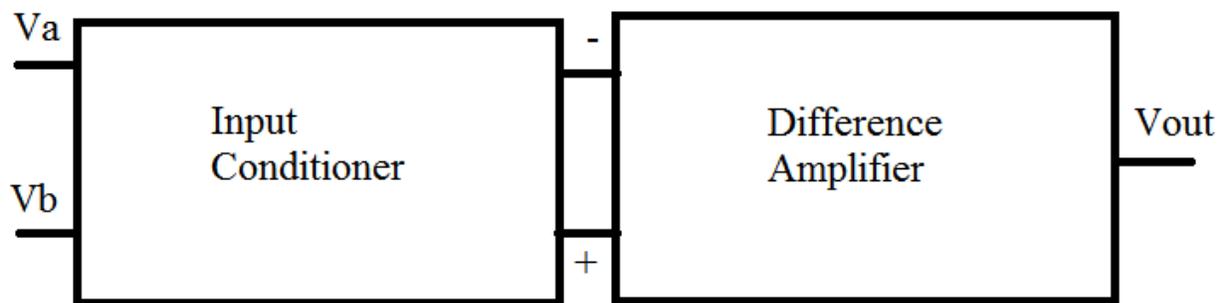


Figure 2: Block Diagram of the differential amplifier

The input conditioner's role is to ensure a very large input impedance (ideally, it approaches infinity), and to apply a gain. In the Difference Amplifier stage, the difference of the conditioned input signal will be amplified.

The main considerations of our analog design are as follows:

- I. Amplifier Gain: how much amplification is needed given that raw ECG signal is between 0.1 to 5 mV?
- II. Circuit noise level: how can we reduce power-line interference?

Below is the schematic of the main circuit you will be designing and assembling during this experiment:

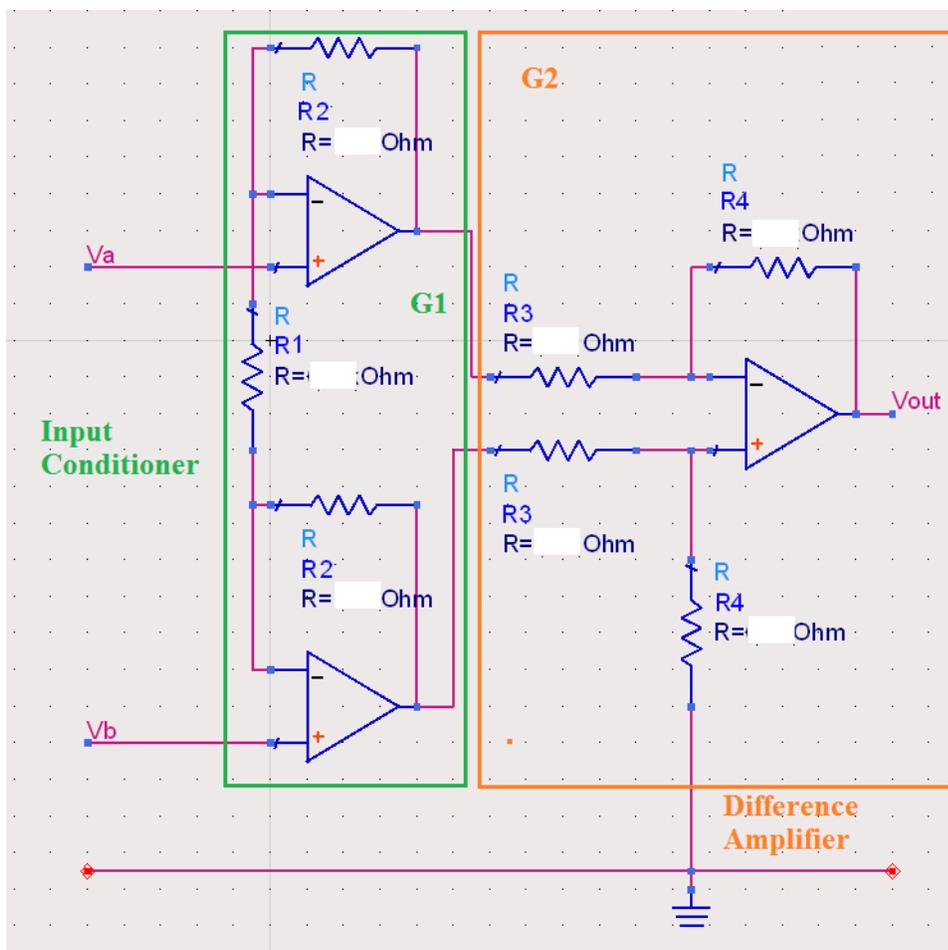


Figure 3: 3-lead Differential Amplifier schematic

Note that the Input Conditioner gain $G1$ is:

$$G1 = 1 + \frac{2R2}{R1} \quad (1)$$

The Difference Amplifier gain $G2$ is:

$$G2 = -\frac{R4}{R3} \quad (2)$$

And therefore, the total Gain of the amplifier is:

$$G_T = G1 \times G2 \quad (3)$$

4. Procedure:**Part A**

- I. Design a differential amplifier with a total gain of $G_T = -1000$.

Using equations 1-3, choose appropriate resistors values

(Refer to Figure 3 for resistors numbers):

	Resistance Value ()
R1	
R2	
R3	
R4	

Table 3. Resistors Values, chosen to design an ECG amplifier

- II. Simulate the circuit in Figure 2 using ADS or PSPICE software and make sure that your resistors' values, calculated above, allow to generate indeed a gain of 1000. Attach a separate sheet of paper, containing results of your transient simulation (for the simulation use 5 mV p-p Sinusoidal **differential** input signal with a frequency of 20 Hz; use +/- 6 V batteries to power the op-amps).
- III. Build the circuit of Figure 3 using your chosen resistors' values. To test the differential gain of your circuit (A_d), connect the positive pin the function generator to V_a and ground its negative pin. V_b input should also be grounded. Your input signal should be a 60 Hz sine wave of 5 mV peak-to-peak amplitude. Calculate gain using the output and input signals amplitudes from the obtained oscilloscope image:

$$A_d = \quad V/V;$$

Observe the Output waveform and save a picture of the oscilloscope image.

- IV. To test the common mode gain of your circuit (A_{CM}), connect the positive pin of the function generator to V_a and, using a jumper wire, to V_b . The negative pin of the function generator should be grounded. Your input should be a 60 Hz 5 V peak-to-peak signal. Calculate gain using the input and output amplitude values from the obtained oscilloscope Image:

$$A_{CM} = \quad V/V;$$

Observe the Output waveform and save a picture of the oscilloscope image.

- V. Calculate the common mode rejection ratio of your amplifier as follows:

$$CMRR = \frac{A_d}{|A_{CM}|} \quad (4)$$

Part B

- I. In order to obtain a better image of an ECG signal it is very important to get rid of interference. The ability of our differential amplifier to reduce the common mode input helps to reject the electrical power system interference. For additional noise reduction a filtering component has to be added to the main circuit. Filter is meant to amplify the signals of desired frequency range while keeping the inputs of undesired frequency ranges unchanged (filtering them out). Figure 4 represents an ECG amplifier, obtained by adding a filter to the circuit of Figure 3 and changing the resistors values so that the total gain of the amplifier G_T remains close to 1000 V/V.
- II. Calculate the theoretical gain value of the circuit in Figure 4:

$$G1 = 1 + \frac{2R_2}{R_1} = \quad \text{V/V};$$

$$G2 = -\frac{R_4}{R_3} = \quad \text{V/V};$$

$$G3 = -\frac{R_6}{R_7} = \quad \text{V/V};$$

$$G_T = G1 \times G2 \times G3 = \quad \text{V/V};$$

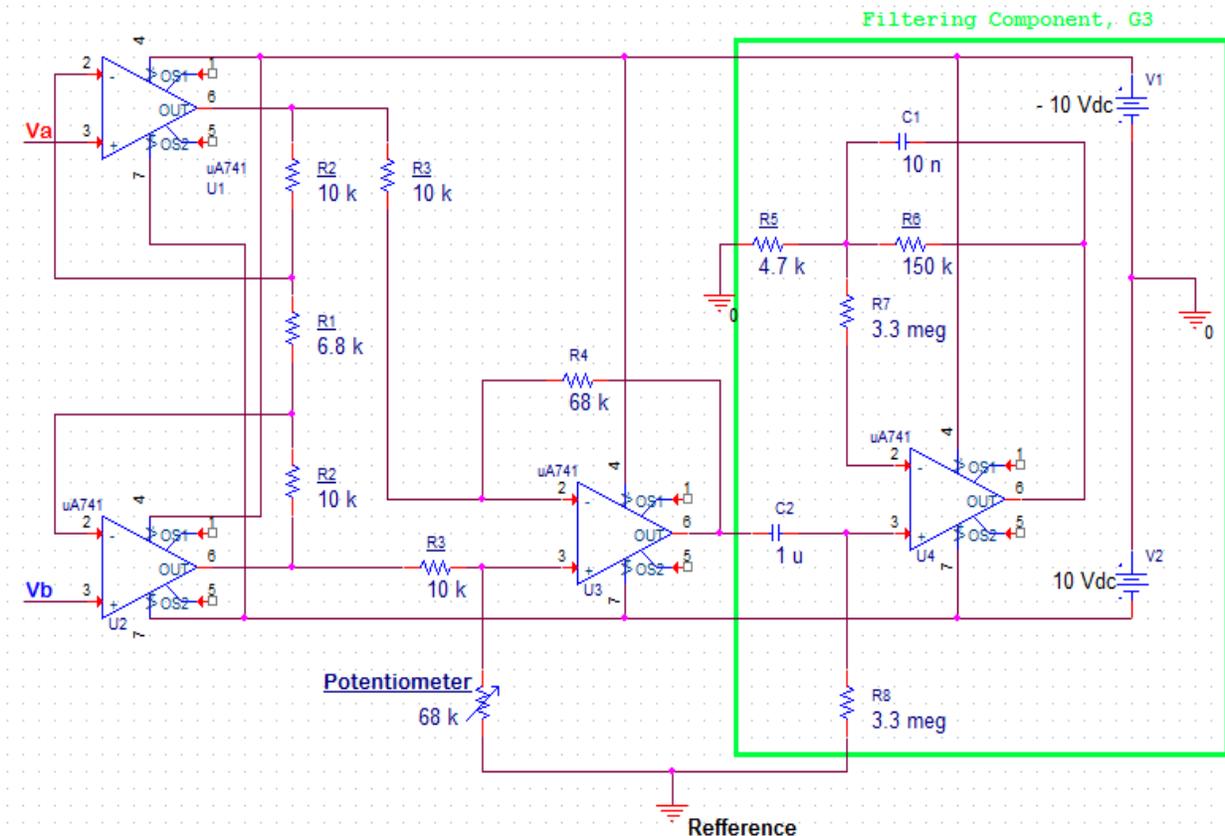


Figure 4. ECG amplifier with filter

- III. Build the circuit of Figure 4. Calculate the cut-off frequency of the filter, using equation (5) provided below:

$$f_c = \frac{1}{2\pi \times R6 \times C1} \quad (5)$$

$$f_c = \quad \text{Hz};$$

- IV. To determine the actual cut-off frequency of the circuit follow the steps provided below:

1. Connect positive pin of a GFG 3015 Function generator to the Va input of the ECG circuit and ground its Vb input, using a jumper wire (same way as you did for differential gain testing in Part A). Connect channel 1 of the oscilloscope to the Va input and channel 2 of the oscilloscope to pin 6 of the op-amp U4 (filtering component of the circuit).
2. On a GFG 3015 Function generator use a “FUNC” button to select the SIN waveform of the input.
3. Using “AMPL” button to choose 10mV peak-to-peak amplitude of the input signal.
4. Press “LIN S” button to choose linear scale of the frequencies sweep.
5. Press “RATE” button to select the speed of the frequency sweep. Type in 0.01Hz for your rate value.
6. Set the starting frequency by pressing “START” and typing in 1.5 Hz.
7. Set the ending frequency by pressing “SHIFT”, then “START” and typing in 150 Hz.
8. Press “MOD/ON” to initiate sweeping.
9. On the oscilloscope screen now you should be able to observe a 20 mV p-p input signal (CH1) and a magnified output signal (CH2). The frequencies of the input (and output) will slowly be changing in the range 1.5Hz-150Hz. As the frequency value varies, you should be able to observe that the gain value varies as well.
10. Find and save the oscilloscope image of the input frequency value at which the output amplitude reaches its maximum ($V_{out, max}$). Use Figure 5 as you reference. This value should be used for your midband gain calculation and it should be close to the theoretical gain value you have determined above. Calculate the actual midband gain value and compare it to the theoretical:

Frequency value (from the oscilloscope image) = Hz;

$$A_{d \text{ actual}} = \frac{V_{out, max}}{V_{in}} = \quad \text{V/V};$$

$$A_{d \text{ theoretical}} = \quad \text{V/V};$$

$$\% \text{ error} = \quad \%;$$

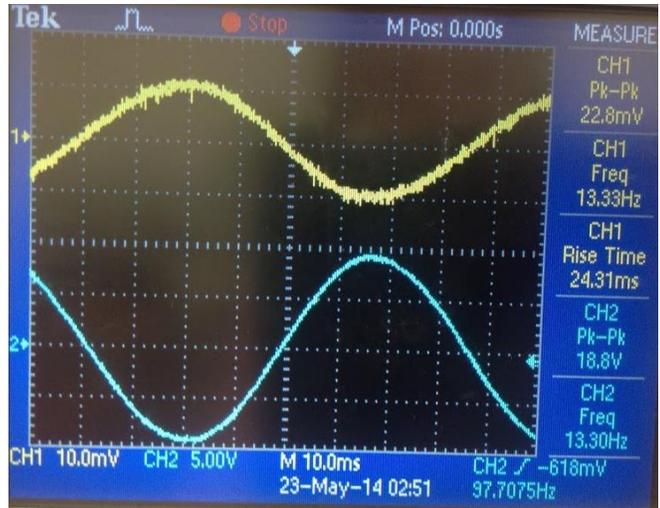


Figure 5. Midband gain reference image.

11. To determine the cut-off frequency of the circuit (f_c), first calculate the output value at the cut-off frequency:

$$V_{out,cut-off} = V_{out,max} \times 0.707 = \quad V;$$

Now find the frequency value (from your oscilloscope image) at which the output signal reaches the amplitude of your calculated $V_{out, cut-off}$ value (use Figure 6 as a reference). This frequency is the actual upper cut-off frequency (f_c) of the ECG amplifier. Compare it to the theoretical value, calculated above:

$f_{c, measured} = \quad$ Hz;

$f_{c, calculated} = \quad$ Hz;

% error = \quad %;

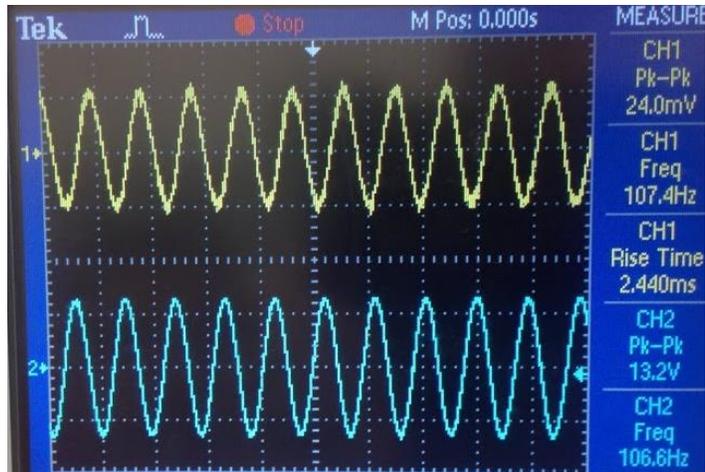


Figure 6. Cut-off frequency reference image.

Part C:

- V. Now that you have calculated the values of the electronic components and tested your circuit, go ahead and put three electrodes, connected to a group member, as your circuit inputs:
- V_a should be connected to your left wrist, V_b to your right wrist and the ground (reference) should be connected to your left leg. Do not forget to apply the electrode gel to your skin surface before connecting it to the electrodes.
 - The schematic that will help you to make the correct connections is represented in Figure 7 below:

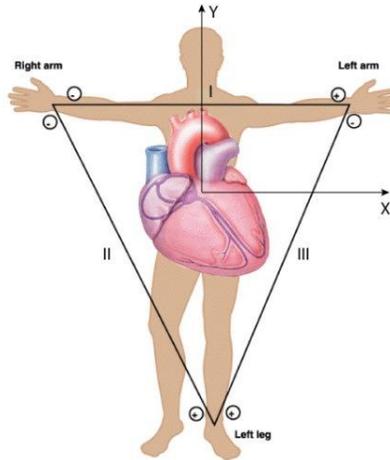


Figure 7: 3-lead ECG electrode placement

- VI. With the electrodes connected to your wrists and leg, connect the oscilloscope to your circuit output (pin 6 of U4) and observe your ECG signal being recorded.
- VII. Press “Run/Stop” button on the oscilloscope, and make sure to register the oscilloscope image of your ECG waveform. **Save and attach the obtained oscilloscope image.**
- VIII. You might want to compare your waveform with Figure 8 below:



Figure 8. ECG signal recorded reference image.

Results and Comments: