The ECG-Amplifier Project

Lab. Project No. 1

Objective:

The objective of this experiment is to study some of the special amplification systems used in biomedical signal processing.

The purpose of this exercise is:

To design, construct and test a simple instrumentation amplifier, which can be used in recording ECG signals.

General Block Diagram

A general block diagram of a modern ECG amplifier is shown in Fig.1. It is designed around an instrumentation amplifier. In addition to the instrumentation amplifier it contains:

- An automatic offset (DC) cancellation circuit to keep the output always zero averaged
- A driven-right leg circuit to provide electrical safety and reduce the interference under normal operational conditions, and
- A low-pass filter that provides further amplification and limit the bandwidth of the overall system.

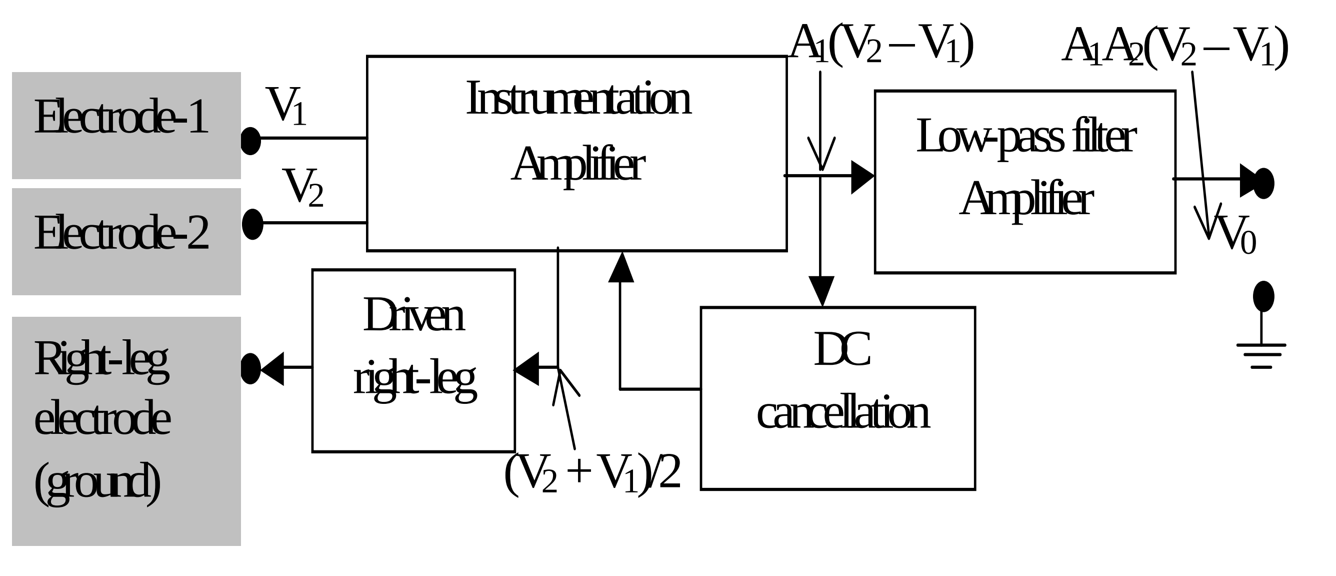


Fig. 1. General block diagram of an ECG amplifier.

Preliminary Work

1. Carefully study section 6.1 through 6.7 of Webster. You should be prepared to answer questions related to the placement of electrodes on the body, and the functioning of the amplifier circuit given in Fig. 6.22.
2. Circuits of a three-stage ECG amplifier with offset compensation (DC cancellation) and driven-right leg amplifier is shown in figures below. Calculate the unknown component values to fulfil the following requirements:
   a. Common Rejection Ratio (CMMR) of the first stage (differential input-differential output): 5.4;
   b. Differential gain of stage-1 and stage-2 combined: 54;
   c. Lower cut-off frequency: 0.5 Hz;
   d. Low frequency gain of low-pass filter stage: 19;
   e. High cut-off frequency: 194 Hz.
3. Find the total gain of the system.
4.

The Instrumentation Amplifier

The circuit diagram of the instrumentation amplifier is shown in Fig. 2.

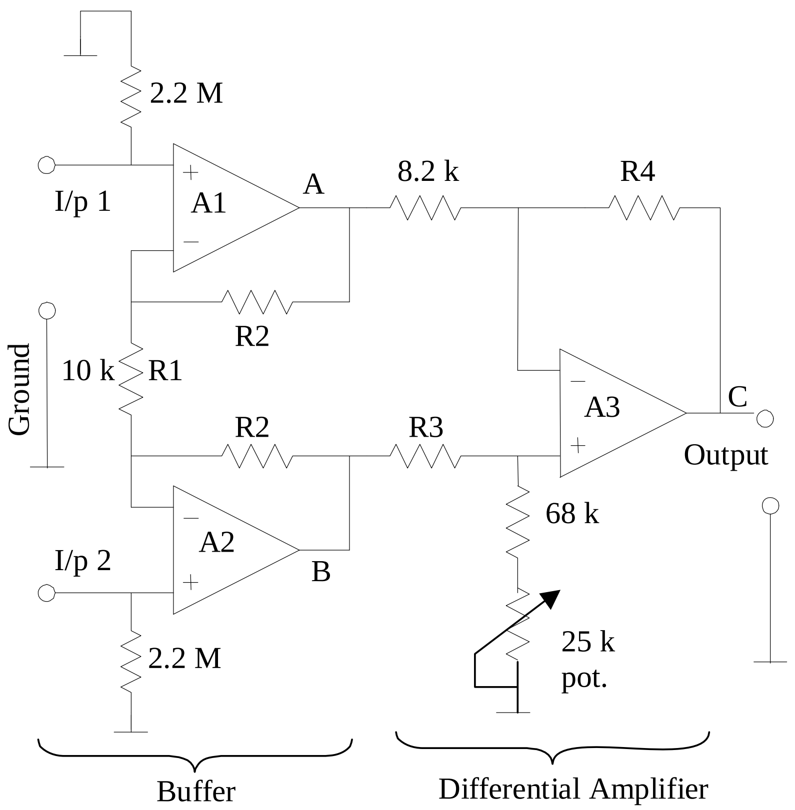


Fig. 2. The instrumentation amplifier.

Preliminary Work

1. Assume that the CMRR of the differential amplifier (stage-2) is 60 dB. What is the CMRR of the system?
2. You have supplied with one of each of the following OP-AMPs; 072 (dual of 071), 351 and 741. Which one would you choose for A1, A2, A3 and A4? Why?

Experimental Procedure

1. Assemble the circuit shown in Fig. 2 on a breadboard. Use the component values you have chosen in the Preliminary Work section. Perform the following checks:
   i. A student other than the one who assembled the circuit should verify that correct values of components have been used and that connections are correct;
   ii. Connect an ammeter (full scale 30-150 mA) in series with one of the DC supply lines. Apply both +12 volts and -12 volts supply voltages and verify that only a few milliamperes flow to the circuit. If so, continue with the experiment. If not, check the circuit first for wrong connections,

then, if everything else fails, for damaged components;

iii. Connect the oscilloscope to the output of stage three and observe that there are only a few tens of millivolts of noise when both inputs are shorted to ground.

iv. If the output appears to be zero at any time, close S1 temporarily to relieve a possible saturation.

2. Tie the two inputs together and apply 1 volt at 50 Hz between the ground and the common input. Observe the output voltage of A3 (point C) and adjust the potentiometer until you obtain the minimum possible voltage.
3. Apply 5 mV at 50 Hz to each input while the other is grounded and measure the voltages at points A, B, C and the output. Calculate the differential gain for stages I, and II.
4. Determine the value of the differential input voltage necessary to cause the saturation of the output.
5. Apply a common mode input signal at 50 Hz sufficient to produce a measurable output signal. Minimize the output by adjusting the potentiometer. Increase the input up to 5 volts-peak and continue minimization. Measure the best CMMR you can obtain.

Offset (DC) Cancellation Circuit

Modify the instrumentation amplifier as shown in Fig. 3 by inserting an integrator between the output and non-inverting input of A_3.

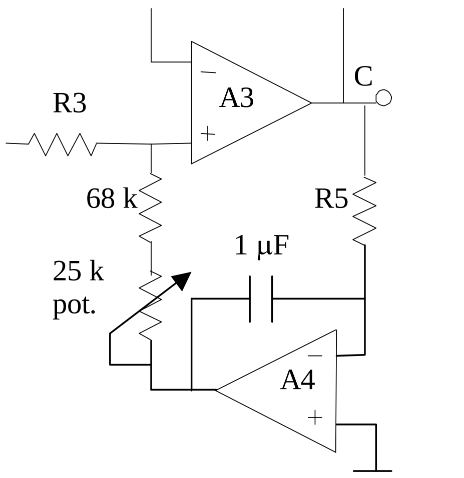


Fig. 3. Circuit for offset voltage cancellation

Preliminary Work

1. Prove that the instrumentation amplifier with offset voltage cancellation circuitry will include a high-pass filter feature.
2. Select R_5 to have a cut-off frequency at around 0.3 Hz.

Experimental Procedure

1. Repeat steps 2 and 3 in the previous section and observe for any difference. In case of difference, check your circuit and connections.
2. Add a DC offset voltage around 0.1 volt to your input signal. Observe the output at point C as you vary the offset voltage. The output should settle around “0” volt immaterial of the level of the input voltage. If not, check your circuit.

The Driven-Right Leg Circuit

The driven-right leg circuit serves two purposes:

- It reduces the common-mode voltage due to interference;
- It provides safety to the patient in case a dangerously high voltage is applied by isolating the patient from the ground.

Circuit diagram of the instrumentation amplifier modified to include the offset compensation and driven-right leg circuits are shown in Fig. 4.

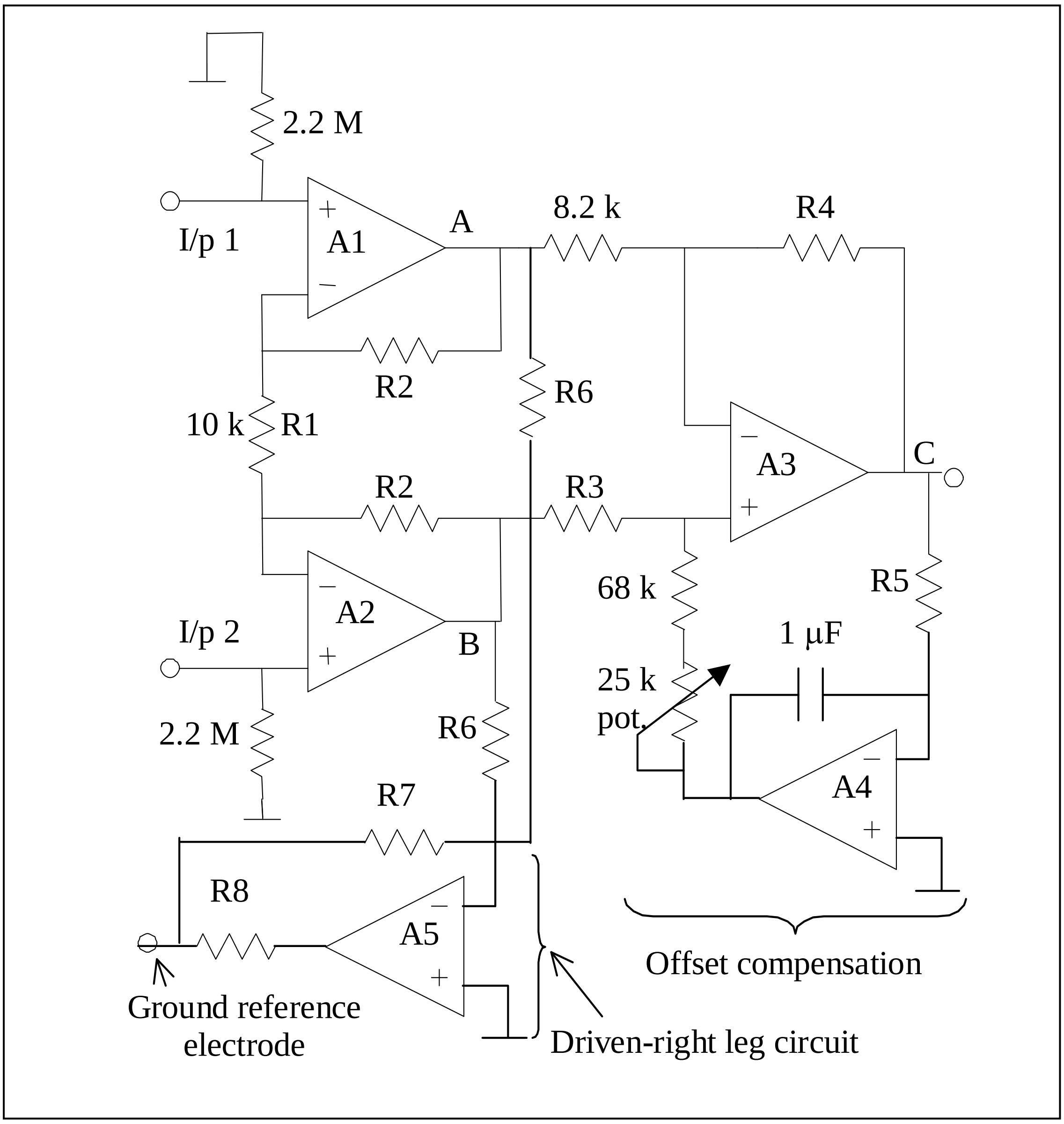
Preliminary Work

1. Design the driven-right leg circuit so that:

   a. The current through the patient will be 100 μA (rms) in case if 127 V (rms) appears across the patient.

   b. The effective grounding impedance should be 10 kΩ or less.

2. Calculate the maximum common-mode voltage that can appear on the patient assuming that the op-amp saturates at ± 10 V.



Experimental Procedure

It is difficult to test the driven-right leg circuit with resources available in the Biomedical Engineering Lab at the moment. The test will be carried out during recording the ECG from the body.

The Low-Pass Filter

The last block in the ECG amplifier is the low-pass filter that limits the bandwidth of the amplifier. The high-pass filter function is already accommodated in the instrumentation amplifier section via the offset cancellation feature. There still may be some DC offset voltage existing at the output of the instrumentation amplifier due to the bias currents and input offset voltage of the differential amplifier. However, this offset voltage is at low level and can be managed by the offset adjustment of the ECG measurement and/or display system. Hence, the last stage is designed as a low-pass filter.

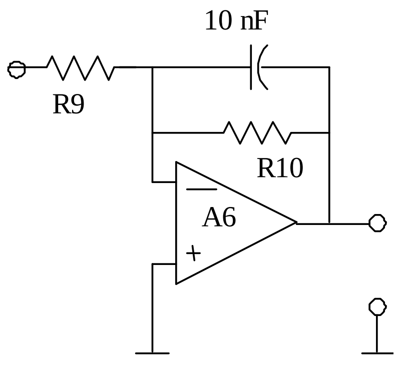


Fig. 5. Circuit diagram of the low-pass filter

Preliminary Work

1. Calculate the unknown components for:

   a. Low frequency gain around 19
   b. The cut-off frequency around 150 Hz.

2. Calculate the overall gain of the system at 40 Hz.
3. Draw the frequency response plot for the overall system.

Experimental Procedure

1. Determine the frequency response of the circuit before attaching it to the output of the instrumentation amplifier.
2. Draw the frequency response you have obtained carefully and try to identify any discrepancy you observe in the characteristic.
3. Modify your design, if necessary to meet the requirements stated in the preliminary work.

The ECG Amplifier - Complete

The circuit diagram of the ECG amplifier with all parts attached is shown in Fig. 6. Mark unknown component values on the figure.

Preliminary Work

Calculate the gain and cut-off frequencies of the complete system using the values obtained in previous sections.

Experimental Procedure

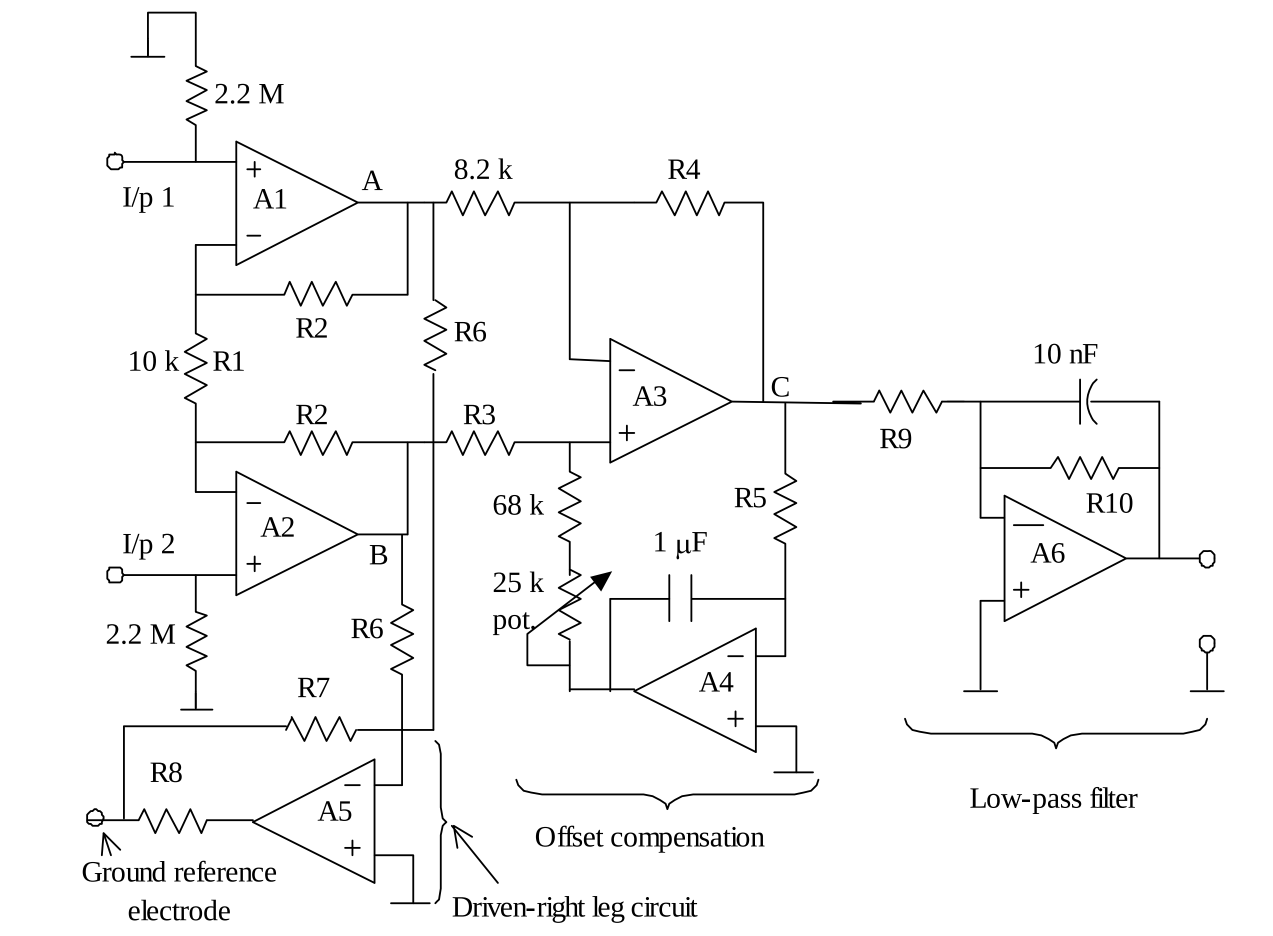


Fig. 6. Complete circuit diagram of the ECG amplifier.

1. Leave the driven-right leg circuit idle at the moment. Using the frequency sweep facility of the function generator and/or the techniques you already know determine the frequency response of the system.
2. Connect 100 kΩ resistors between the inputs and the non-inverting terminals of A1 & A2. Try to measure your friends ECG on Lead-I by using the electrodes supplied. Observe the signal and record the amplitude levels at various stages of the system including the output of the op-amp used for the driven-right leg circuit. Use the chart recorder to record a short duration of the output.
3. Now observe the ECG between V3 and V5 electrode positions on the chest. Record several periods.
4. Connect the right-leg to the driven-right leg circuit and repeat procedures 2 & 3.
5. Repeat the procedure on a different subject.

Conclusion

1. Compare the differential and common mode gains with those you have calculated. Compare the CMMR with the theoretical value. Try to explain any discrepancies.
2. Why do you get more noise and less ECG signal from Lead I as compared to the chest Leads?
3. On the chart recordings you have made, identify the P, Q, R, S, T and U waves by comparing to Fig.4.14 of Webster. Calculate the heart rate for each subject. Is the period between every beat constant?
4. What components would you change if you have redesigned the circuit for monitoring ECG (not clinical)?