ESE 3400: Medical Devices Lab

Lec 5: September 19, 2022

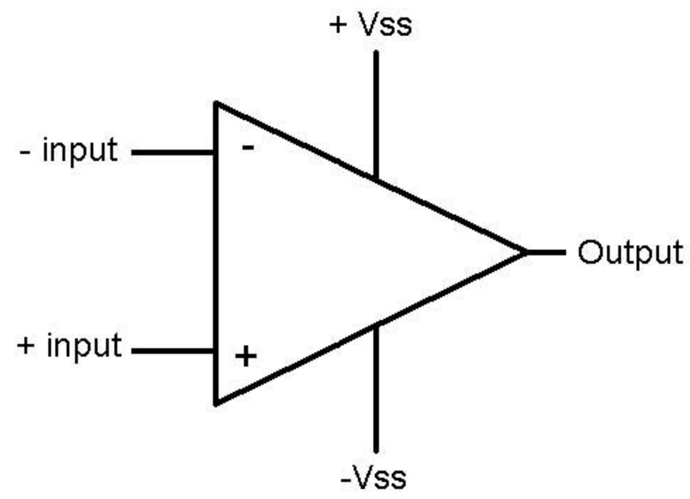
Signal Conditioning/Interface Circuits, Pt. 1

Lecture Outline

- Amplification
  - Opamp
  - Practical Opamp Circuits
- Biopotential Amplifier
- Lab 3 Setup
  - LT Spice
  - Amplification and filter schematic

Amplification

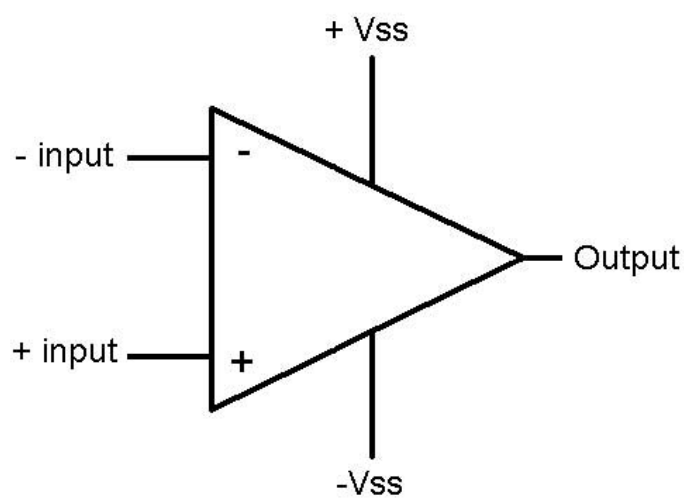
- Sensor outputs may (read: amost always) need amplification for any sort of acquisition and data analysis
- Use operational amplifier to do this
  - Amplifies differential input: Out = $A(V_{in+}-V_{in-})$, where A is large



Opamp

Ideal Opamp

- The ideal opamp characterized by seven properties
  - Knowledge of these properties is sufficient to design and analyze a large number of useful circuits

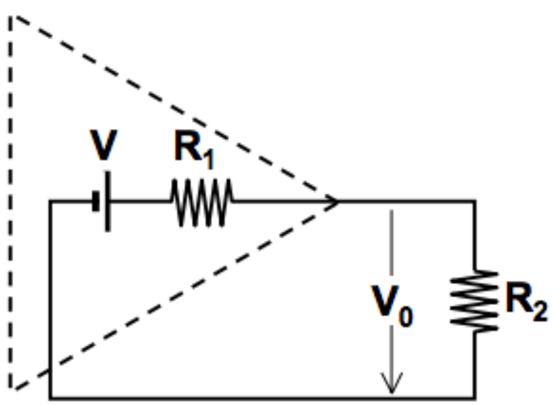


Basic Opamp Properties

- Property No.1: Infinite Open-Loop Gain
  - Open-Loop Gain A_{VOL} is the gain of the opamp without positive or negative feedback
  - In the ideal opamp A_{VOL} is infinite
    - Typical values range from 20,000 to 200,000 in real devices
- Property No.2: Infinite Input Impedance
  - Input impedance is the ratio of input voltage to input current, $Z_{in}=V_{in}/I_{in}$
  - When Z_{in} is infinite, the input current $I_{in}=0$
    - High-grade opamps can have input impedance in the TΩ range
    - Some low-grade opamps, on the other hand, can have mA input currents

Basic Opamp Properties

- Property No. 3: Zero Output Impedance
  - The ideal opamp acts as a perfect internal voltage source with no internal resistance
    - This internal resistance is in series with the load, reducing the output voltage available to the load
    - Real opamps have output-impedance in the 10-20Ω range
  - Example



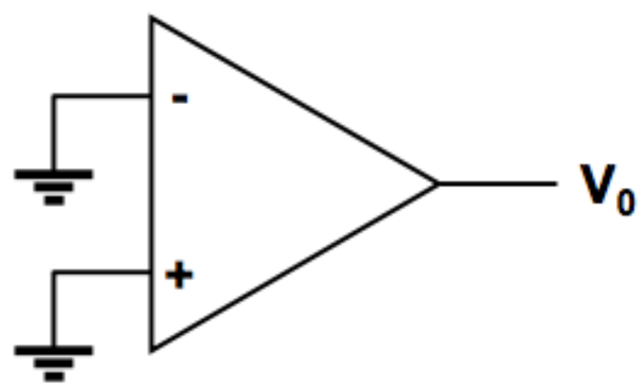
$$V_0 = \frac{VR_2}{R_1 + R_2}$$

Basic Opamp Properties

- Property No. 4: Zero Noise Contribution
  - In the ideal opamp, zero noise voltage is produced internally
    - That is, any noise at the output must have been at the input as well
  - Practical opamp are affected by several noise sources, such as resistive and semiconductor noise
    - These effects can have considerable effects in low signal-level applications

Basic Opamp Properties

- Property No. 5: Zero output Offset
  - The output offset is the output voltage of an amplifier when both inputs are grounded
  - The ideal opamp has zero output offset, but real opamps have some amount of output offset voltage

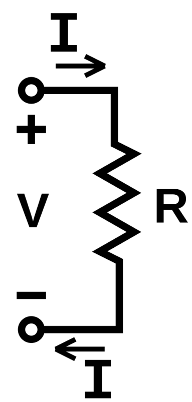


Basic Opamp Properties

- Property No. 6: Infinite Bandwidth
  - The ideal opamp will amplify all signals from DC to the highest AC frequencies
  - In real opamps, the bandwidth is rather limited
    - This limitation is specified by the Gain-Bandwidth product
      - $GBW = f_{3dB} * Gain_{3dB}$
    - Some opamps, such as the 741 family, have very limited bandwidth of up to a few KHz
- Property No. 7: Differential Inputs Stick Together*
  - In the ideal opamp, a voltage applied to one input also appears at the other input
  - *when connected in feedback

Ohm's Law and Kirchoff's Laws

- Ohm's Law
  - V = IR



- KCL – Kirchoff's Current Law
  - The sum of the currents into a node = 0
- KVL – Kirchoff's Voltage Law
  - The sum of the voltage differences around any closed loop in a circuit must be zero

KCL

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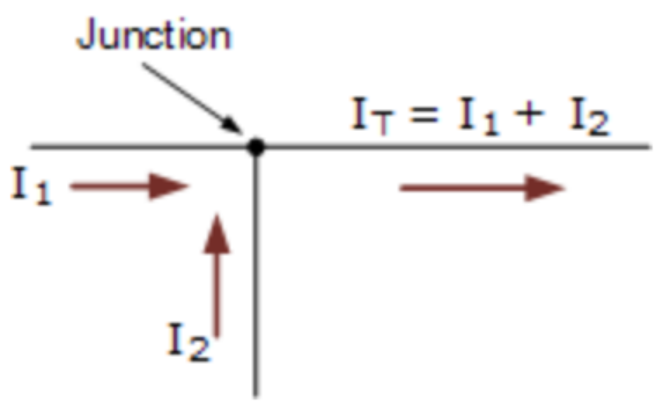

KVL

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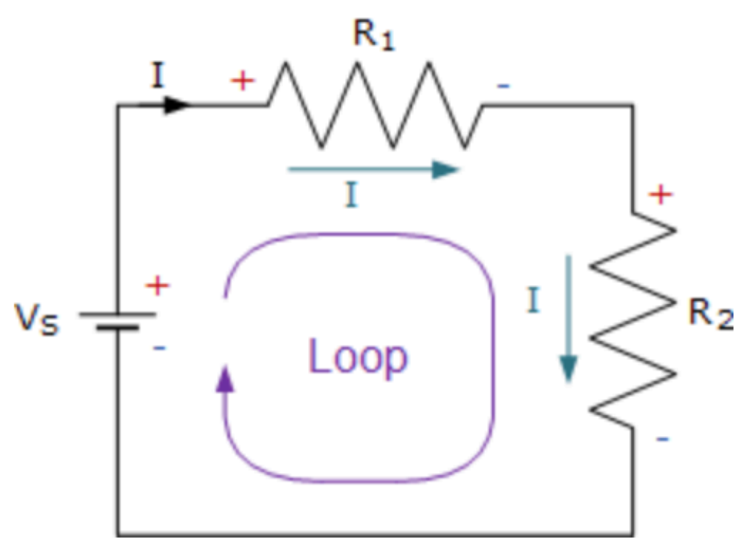
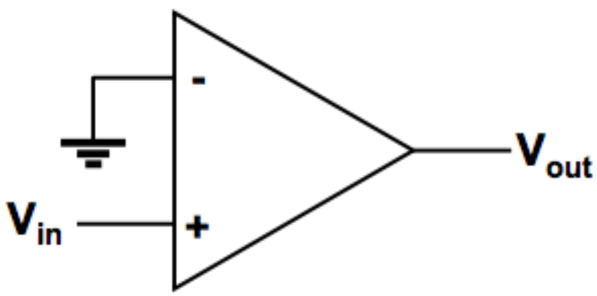
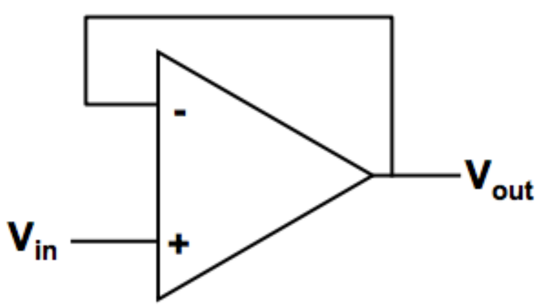


Opamp Practical Circuits

- A)

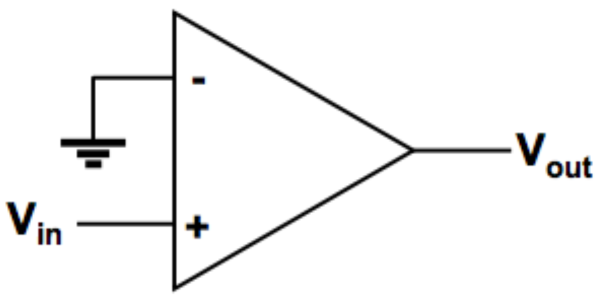


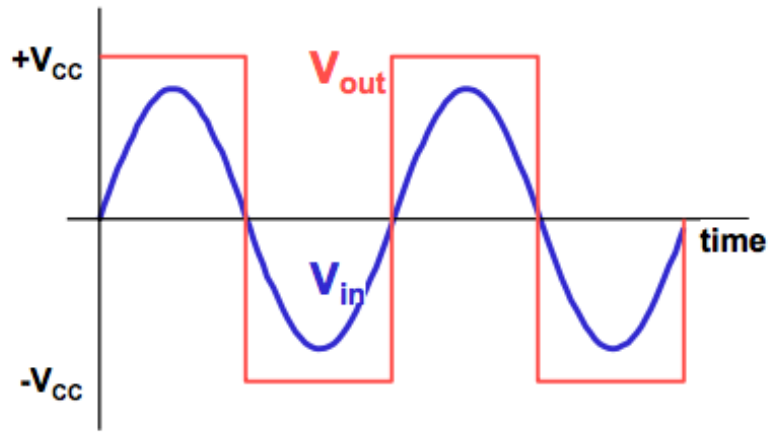
- B)



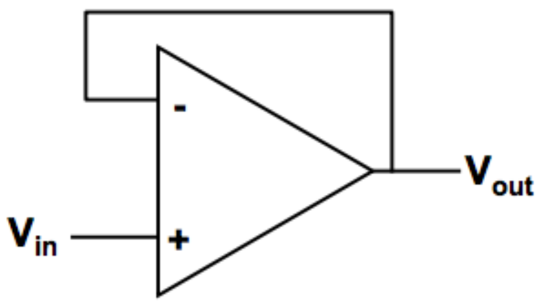
Opamp Practical Circuits

- A) Voltage comparator





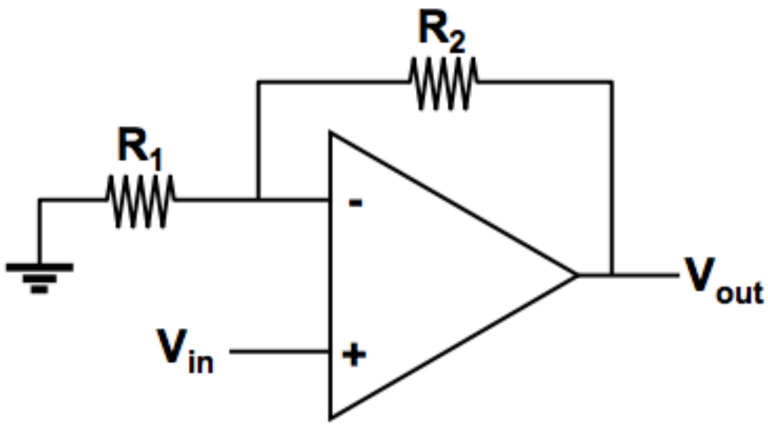
- B) Voltage follower (Buffer)



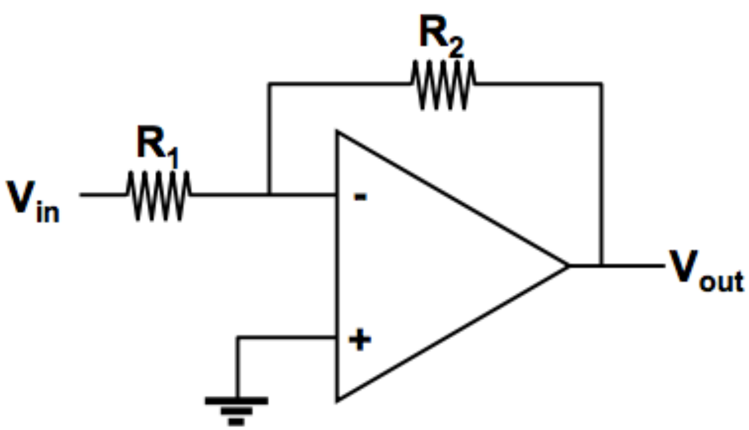
$V_{out} = V_{in}$

Opamp Practical Circuits

- C)

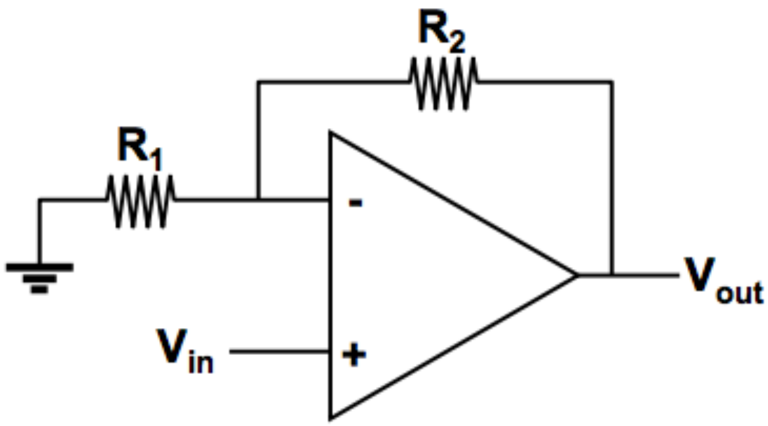


- D)



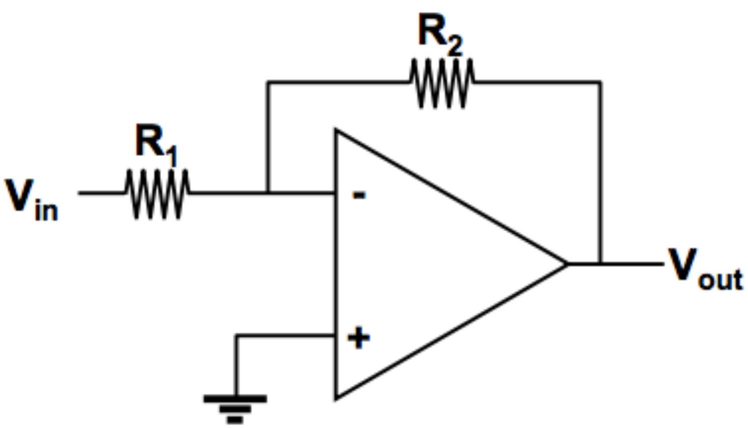
Opamp Practical Circuits

- C) Non-inverting amplifier



$$V_{out} = \left(1 + \frac{R_2}{R_1}\right) V_{in}$$

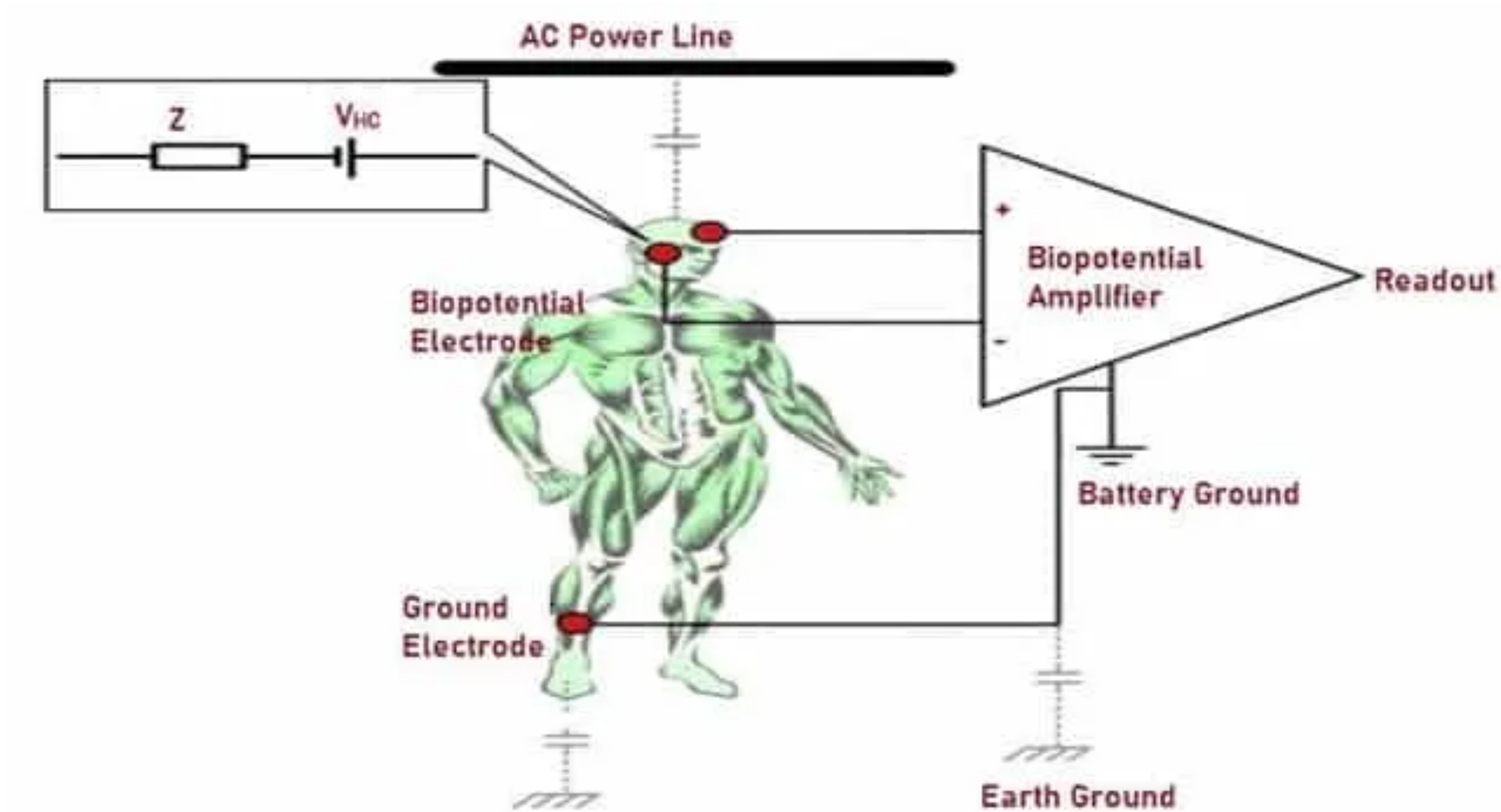
- D) Inverting amplifier



$$V_{out} = -\frac{R_2}{R_1} V_{in}$$

Biopotential Amplifier

- Differential amplifier



Biopotential Amplifier

- Differential amplifier

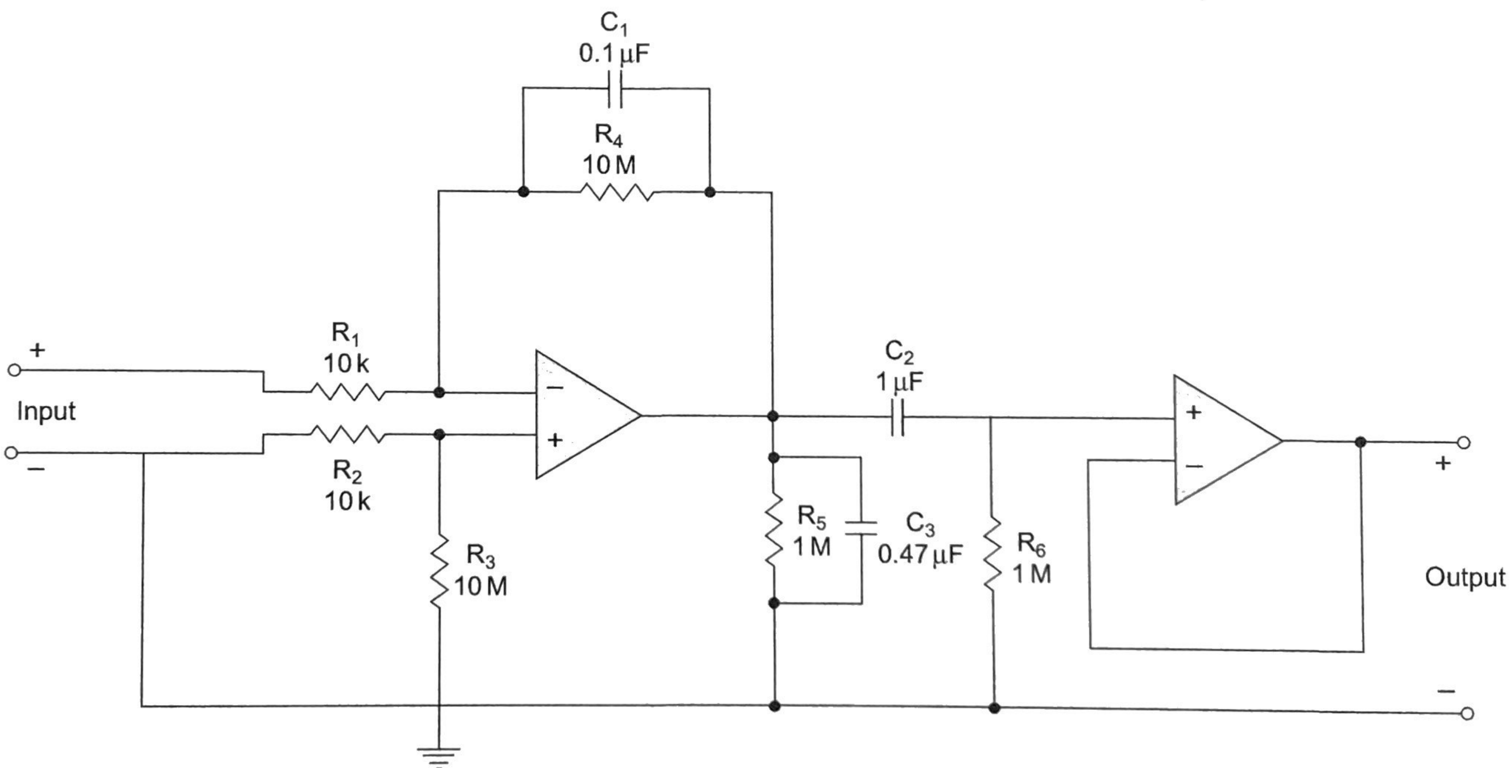


FIGURE 1.20

Differential biopotential amplifier.

Adapted from Prutchi and Norris (2005).

Biopotential Amplifier

- Differential amplifier

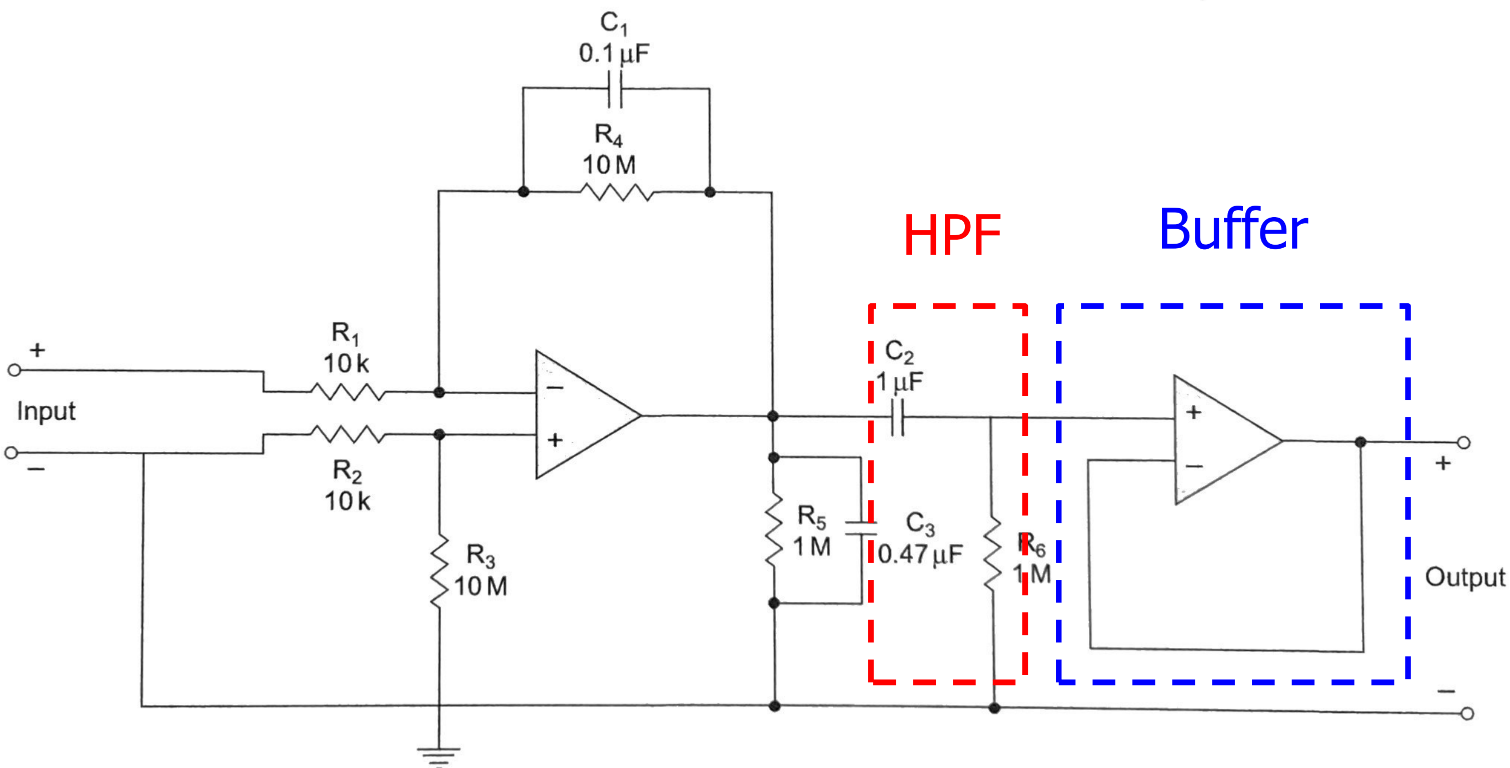


FIGURE 1.20

Differential biopotential amplifier.

Adapted from Prutchi and Norris (2005).

Biopotential Amplifier

- Differential amplifier

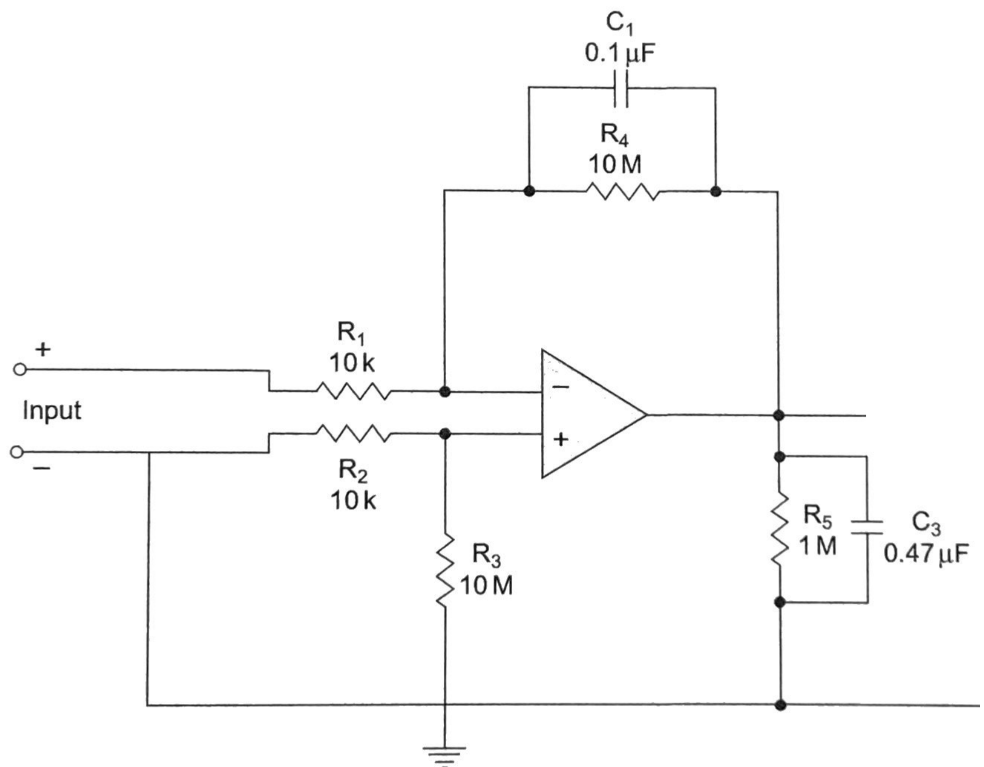


FIGURE 1.20

Differential biopotential amplifier.

A(

Biopotential Amplifier

- Differential amplifier

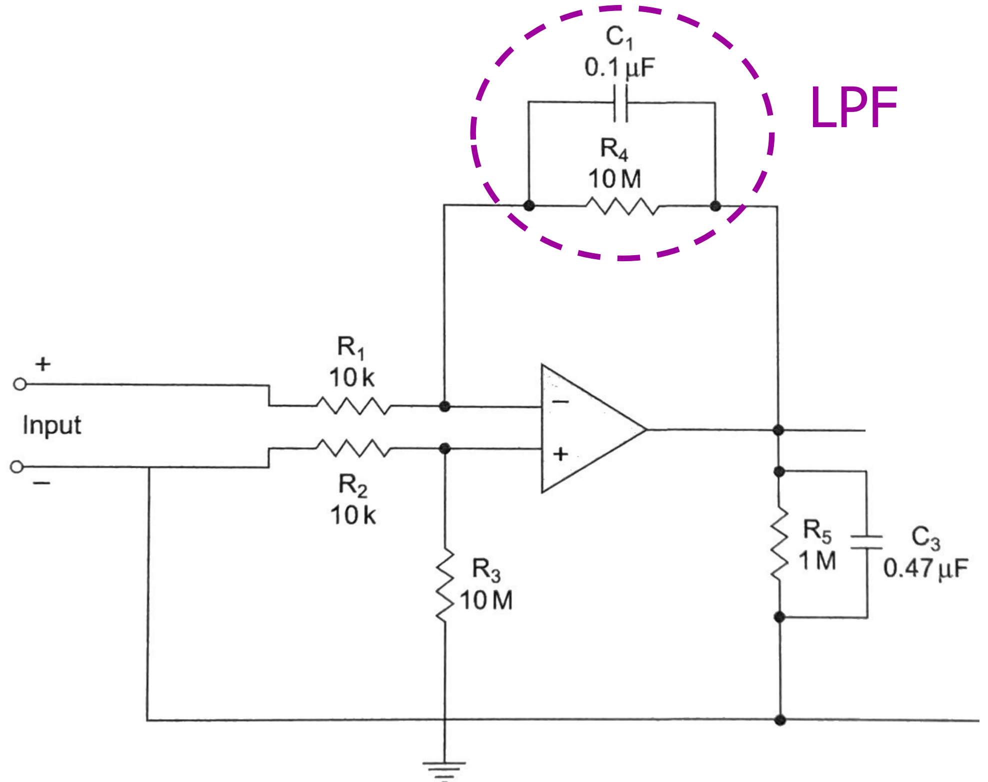


FIGURE 1.20

Differential biopotential amplifier.

Ac

Biopotential Amplifier

- Differential amplifier

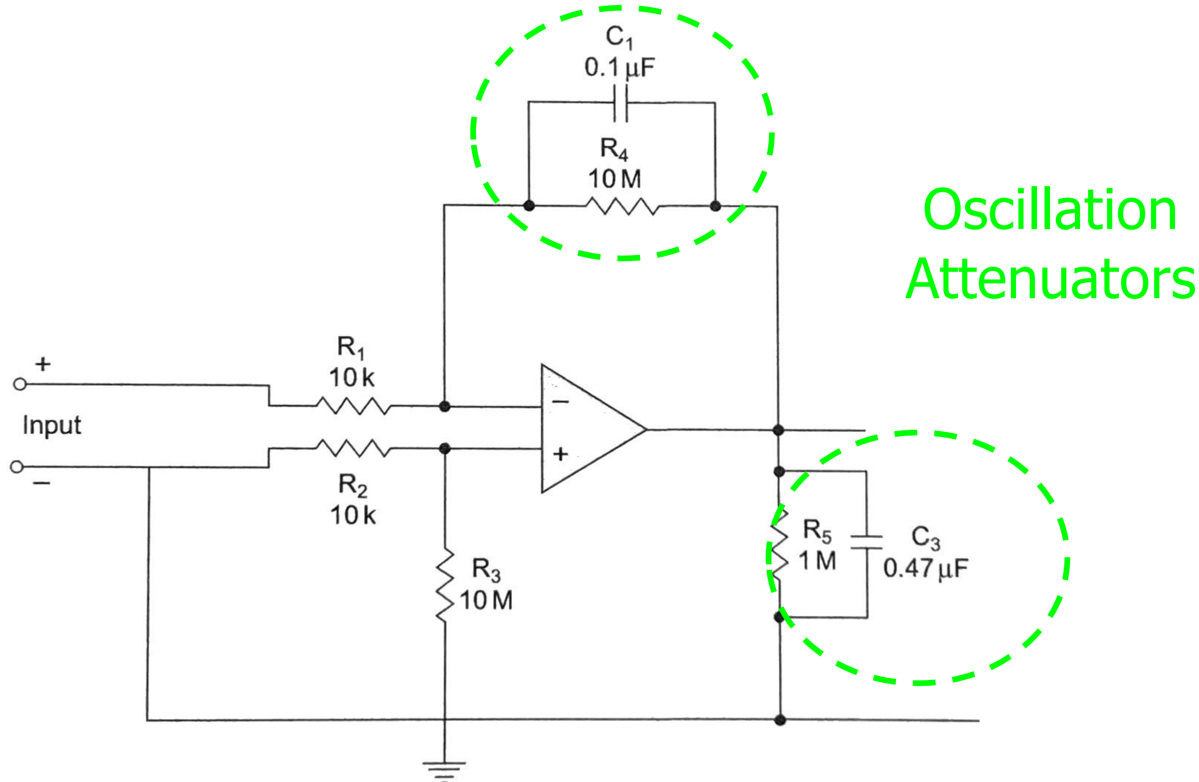


FIGURE 1.20

Differential biopotential amplifier.

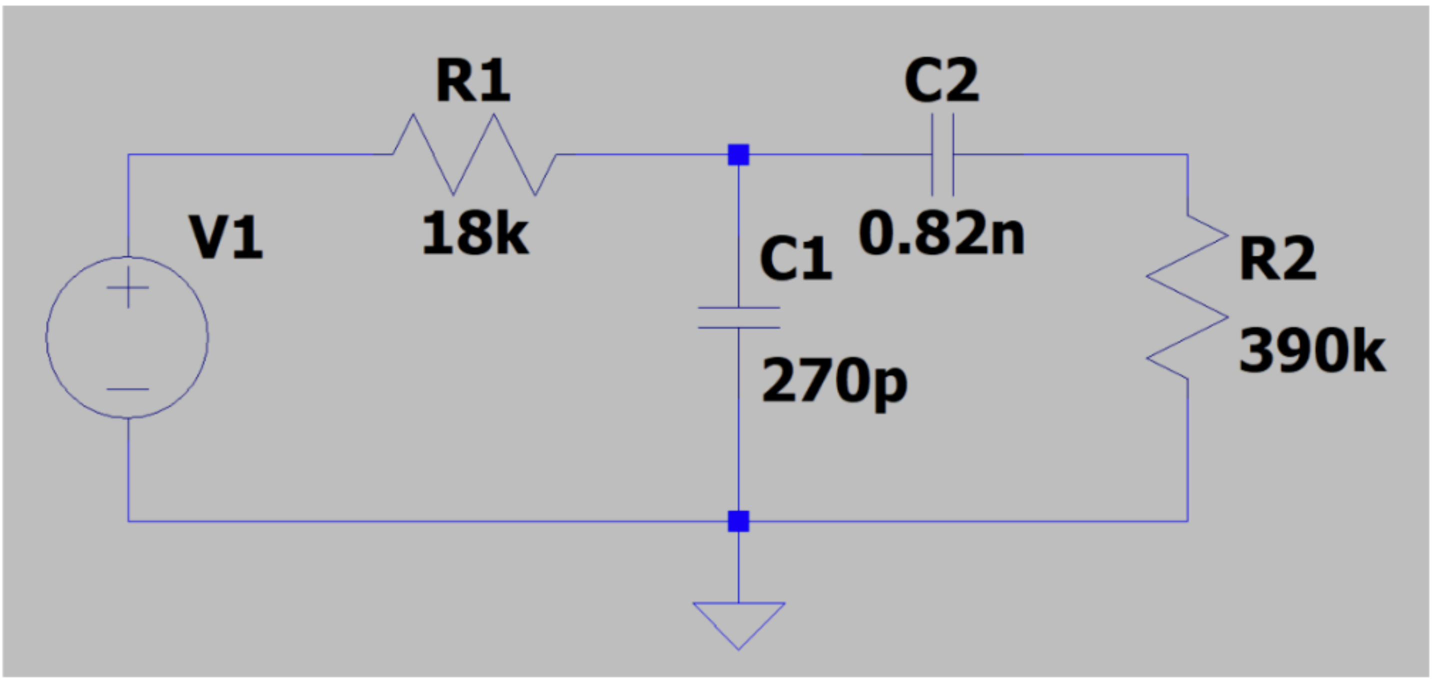
Lab 3

- LT Spice
- Simulate the signal conditioning specific to our ECG design

LT Spice

- Circuit Simulator
  - LTspice is high performance SPICE simulator software, including a graphical schematic capture interface. Schematics can be probed to produce simulation results—easily explored through LTspice's built-in waveform viewer.

LT Spice BP Filter Example



Lab 3

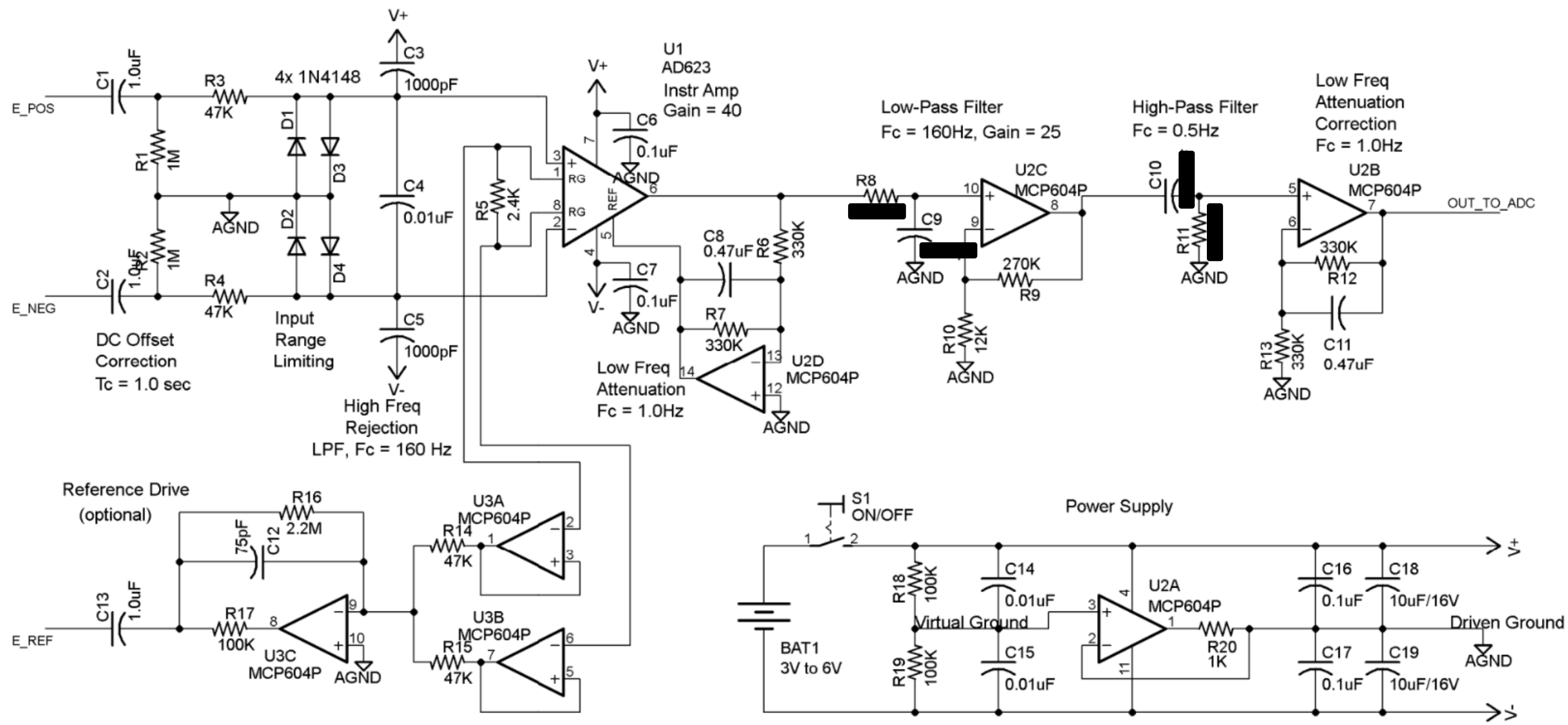
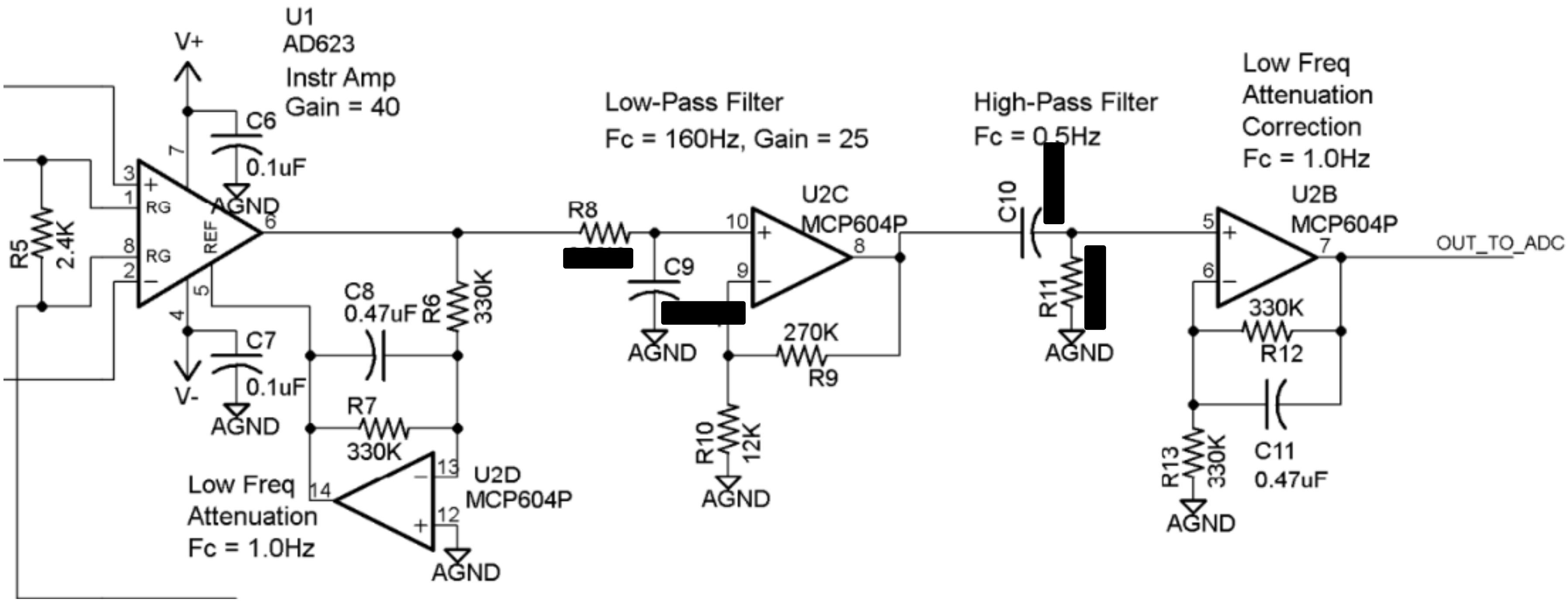
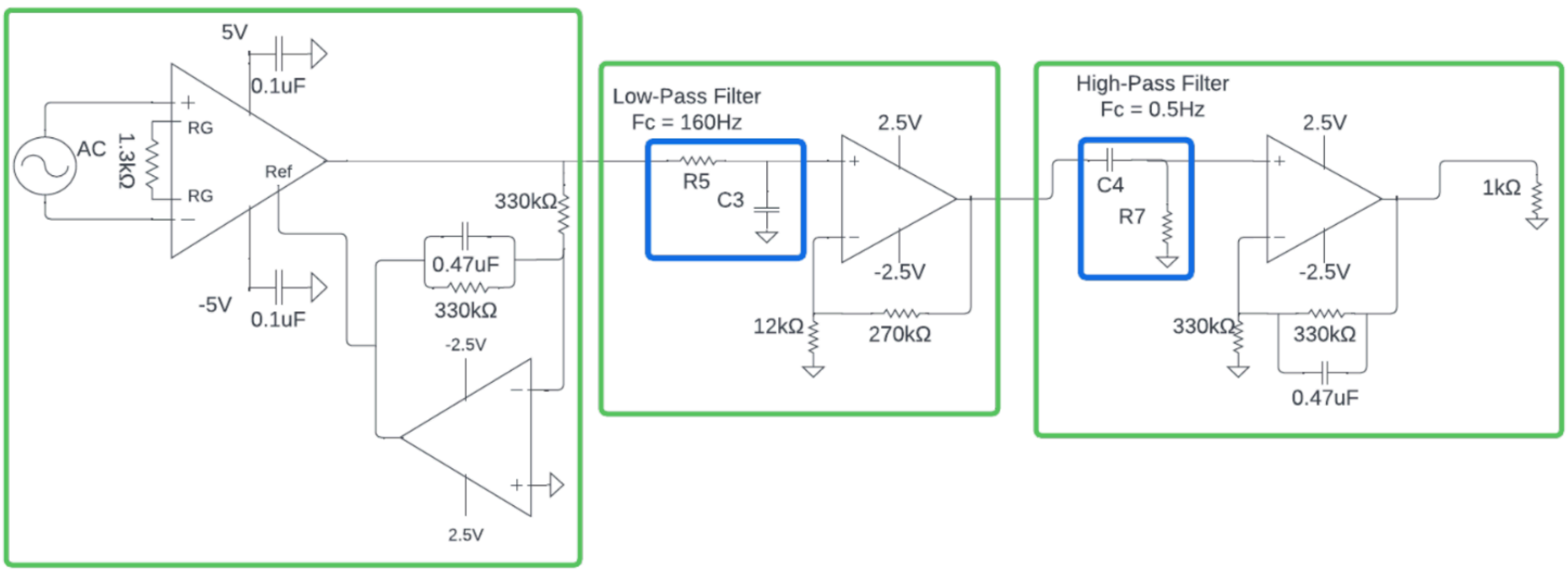


Figure 2: Schematic of 2-Electrode ECG Amplifier with Optional Driven Reference Electrode

Lab 3


U1
AD623
Instr Amp
Gain = 40
V+
V-
C6
0.1uF
C7
0.1uF
AGND
R5
2.4K
RG
REF
Low-Pass Filter
Fc = 160Hz, Gain = 25
R8
[redacted]
C9
[redacted]
U2C
MCP604P
270K
R9
R10
12K
High-Pass Filter
Fc = 0.5Hz
C10
[redacted]
R11
[redacted]
Low Freq
Attenuation
Correction
Fc = 1.0Hz
U2B
MCP604P
330K
R12
C11
0.47uF
R13
330K
OUT_TO_ADC
C8
0.47uF
R6
330K
R7
330K
U2D
MCP604P
Low Freq
Attenuation
Fc = 1.0Hz

Lab 3


5V
0.1uF
AC
1.3kΩ
RG
RG
Ref
-5V
0.1uF
330kΩ
0.47uF
330kΩ
-2.5V
2.5V
Low-Pass Filter
Fc = 160Hz
R5
C3
2.5V
-2.5V
12kΩ
270kΩ
High-Pass Filter
Fc = 0.5Hz
C4
R7
2.5V
-2.5V
1kΩ
330kΩ
330kΩ
0.47uF

Big Ideas

- Amplification
  - Use operational amplifier with differential signaling
- Biopotential Amplifier
  - Designed to amplify and filter sensor outputs for data acquisition or driving

Admin

- Finish Lab 2 and submit deliverables in Canvas by next lab day at midnight