To provide an additional layer of safety, we will include resistors to limit the maximum current flowing from our circuit to the electrodes. We will employ a factor of safety of 1000; therefore, **the maximum current will be limited to 10 μA.** Given a supply voltage of **5V** calculate the value of the resistors to achieve a current of 10 μA.

R = 500 k Ω

Round this up to the next resistor available (100kΩ, 150kΩ, 200kΩ, or 1MΩ)

R_P = 1 M Ω

Measurement with an Instrumentation Op Amp

The first stage of amplification uses an AD623 instrumentation amplifier. Locate the formula for setting the gain in the datasheet (https://www.analog.com/media/en/technical-documentation/data-sheets/ad623.pdf) and write it below:

$Gain\ Formula =$ $1 + \frac{100k}{R_g}$

The gain should be between 40 and 60. This will be adjusted later during the tuning phase. Determine an appropriate value for the gain resistor R_G in the circuit shown above.

Stage 1 Gain Resistor R_G = 2k Ω (1.7k + 2.6k) Ω

Gain: 51

Passive High Pass Filter Design (Stage 1)

We will use a high pass filter to eliminate baseline (DC) drift (e.g. low frequency noise). Generally, the heart rate is above 60 beats per minute (BPM), so we will want to design filter with a fc below 1 Hz. Given f_c = 0.16 Hz and a capacitor C_{HP} = 1 μF, calculate the appropriate resistor value for the first-order analog filter used in the ECG circuit.

Formula for Cutoff Frequency: $f_c = \frac{1}{2\pi R_{HP} C_{HP}}$

Given:

C_{HP} = 1 μF

High Pass Frequency (f_c) = 0.16Hz

Find:

R_{HP} = 994718 Ω

Passive Notch Filter Design (Stage 3)

In the second stage or buffer amplifier, we remove 60 Hz noise in stage 3. 60 Hz noise is a particular issue in our electronics lab. This design follows the Twin-T notch topology. Since this design is particularly sensitive to tolerances in component values, you should measure resistances carefully and trim values. The corner frequency (f_C) is found by:

$$f_C = \frac{1}{4\pi R_N C_N}$$

Verify that for the circuit components given in figure 1 that fc ≈ 60 Hz. Again, measure component values carefully in this design and match them as well as possible.

Find:

f_c = 68.95 Hz

Active Low Pass Filter Designs (Stage 5)

Following another buffer (stage 4), is a 1st order active low pass filter. In this design, we want a gain of 10-15 and a low-pass cutoff frequency (f_C) that removes 60 Hz noise and does not overly affect our ECG measurement. Recall that a lower cutoff frequency will provide greater 60 Hz noise attenuation, but too aggressive of a cut-off could lead to signal distortion. Write the formula for the inverting gain and cutoff frequencies (see *Design with Operational Amplifiers and Analog Integrated Circuits* by Sergio Franco, Section 3.2 First Order Active Filters). To design for the gain in the passband, assume that the contributions of the capacitor are negligible (i.e.- the jωC term goes to 0).

$$Gain = -R_2/R_1$$

$$f_C = \frac{1}{2\pi R_2 C_1}$$

Assume the magnitude of the gain is 10 and fc = 10.6 Hz. Use these formulas to select components knowing we'll use: **C_1 = 0.1 μF**. Find R_1 and R_2.

Given:

|Gain| = 10 V/V

f_C = 10.6 Hz

Find:

R_1 = 15 kΩ

R_2 = 150 kΩ

Stage 6*: Options

The simplest option for stage 6 is shown in *Figure 1*, an inverting amplifier. However, you're can pick which design you'd like to try. There are 3 options for stage 6:

1. Duplicate stage 5.
2. Design an inverting amplifier with a gain of about -10 V/V (shown in *Figure 1*).
3. Create an active high pass filter to try to remove offsets.

If you choose option 3, then you should replace R1 with a capacitor and resistor in series, as shown in *Figure 2*.

The design equations for this topology are:

$$Gain = -R_2/R_1$$

$$fc = \frac{1}{2\pi R_1 C_1}$$

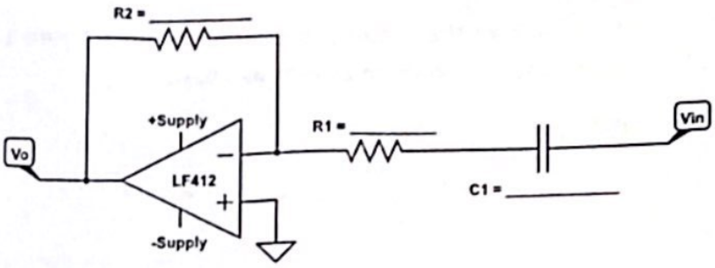

Figure 2. Active High Pass Filter with gain (Franco).

If you choose this high pass design, then assume the magnitude of the gain is 10 and fc ≈ 0.01-0.05 Hz. Use these formulas to select components knowing we'll use: **C_1 = 100 µF**. Find R_1 and R_2.

Given:

|Gain| = 10 V/V

f_C = 0.01-0.05 Hz

Find:

R_1 = 50 kΩ

R_2 = 0.0002Ω

If you choose the inverting amplifier, as shown in Figure 1, then choose R1 and R2 such that you satisfy the gain equation:

$$Gain = -R_2/R_1$$

Find:

R_1 = ____________

R_2 = ____________

If you choose to duplicate stage 5, state that here:

____