Lab 6 1-lead Electrocardiography

* Selecting Rg for instrumentation amplifier to reach at least 40dB gain.

$40\text{ dB} = 10^{\frac{40}{20}} = 100 \left(\frac{V}{V}\right)$

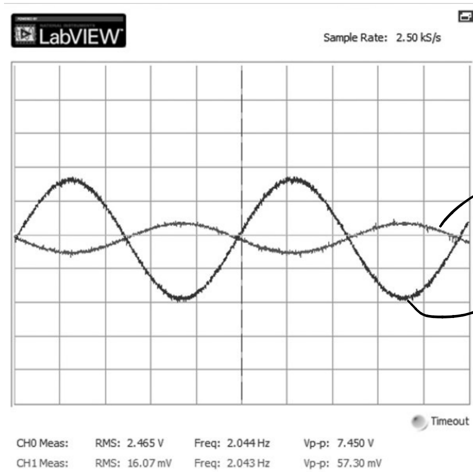
Gain of INA128: $1 + \frac{50k\Omega}{R_G} > 100 \Rightarrow R_g < 505\,\Omega$

Select $R_g = 470\,\Omega$ to achieve gain $= 1 + \frac{50k}{470} \approx 107 \left(\frac{V}{V}\right)$

Input sine wave

$\begin{cases} f = 2\text{ Hz} \\ 0.05\text{ Vpp} \end{cases}$

gain $= \frac{7.45}{57.3 \times 10^{-3}} \approx 130 \left(\frac{V}{V}\right)$



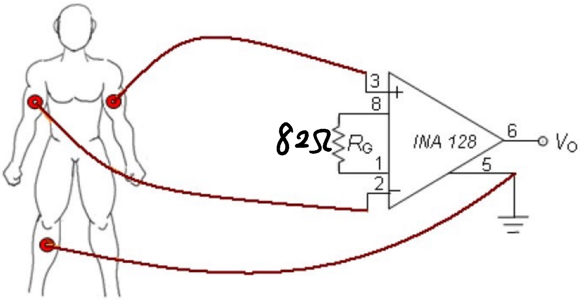
Input
50 mV/Div

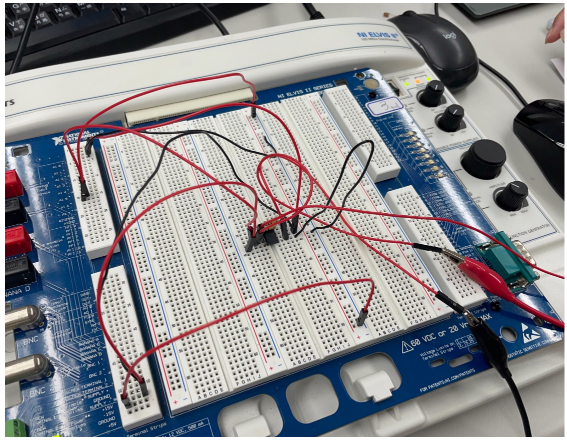
Output
2V/Div

However, after connecting ECG as the input signal, the gain isn't enough for us to observe the signal clearly. Thus, we add a resistor in parallel to decrease Rg. New $R_g = 470\,\Omega \,//\, 100\,\Omega \approx 82\,\Omega$

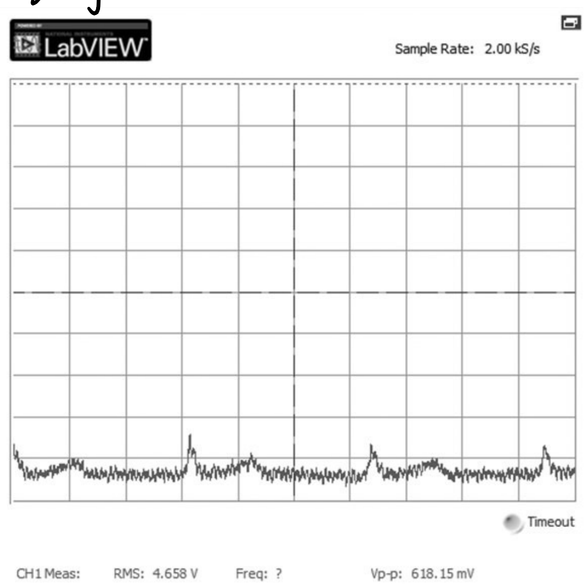
New gain $= 1 + \frac{50k}{82} \approx 610 \left(\frac{V}{V}\right)$

<Phase 1>

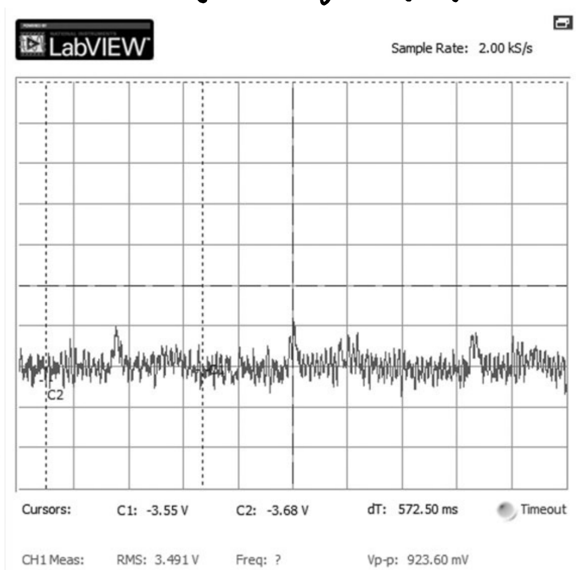




Body immobile

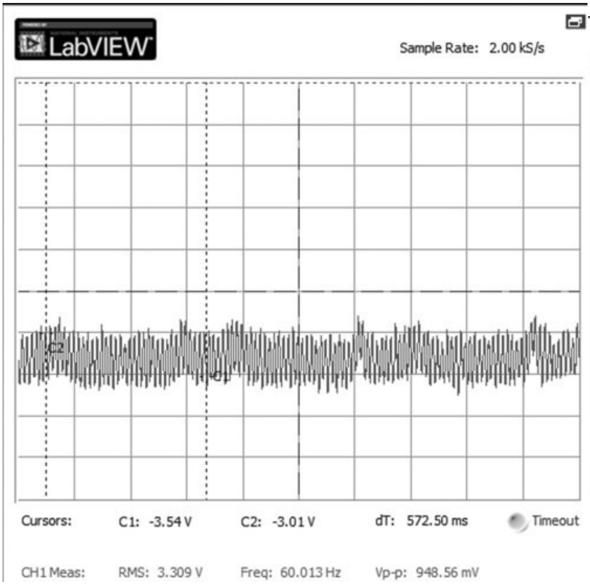


Hand / leg moving slightly.

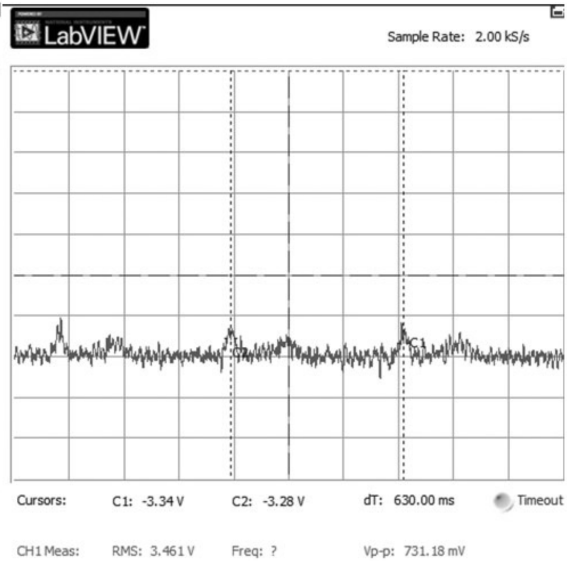


The output signal has more noise if the participant moves their hands and legs slightly. When the participant's body is immobile, the output signal can clearly observe the signal period. However, the signal isn't good enough to observe the P wave and T wave.

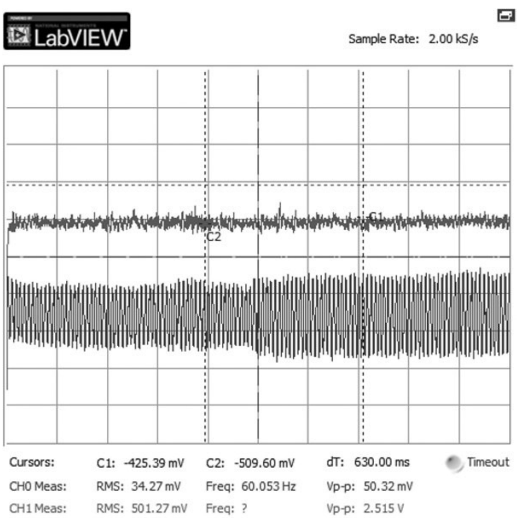
Remove cable on the right leg



Measure BPM & Vpp.

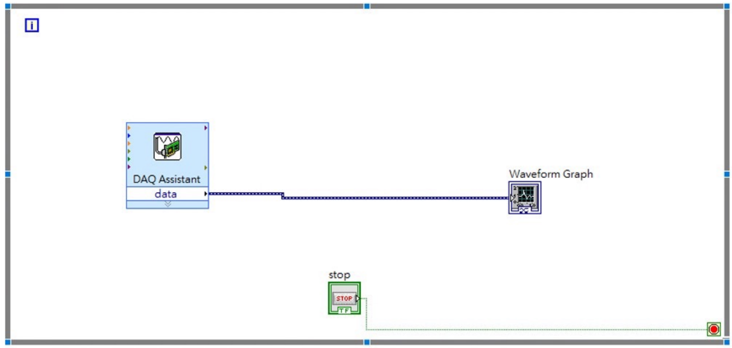


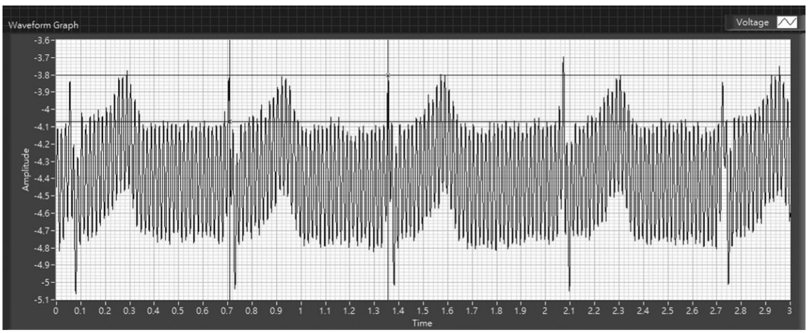
Removing the right leg cable will cause the reference pin5 on INA128 to connect directly to the ground. And thus, the noise ratio increases, and can't observe the signal clear. The time between two cursors is 0.63s, therefore, we can determine the BPM by 60/0.63 = 95.23 beats per minute (BPM). The ECG signal passed through the instrumentation amplifier has an output signal voltage peak to peak = 0.731V



Putting the input ECG signal and the output of INA128 on the same graph makes the waveform messy.

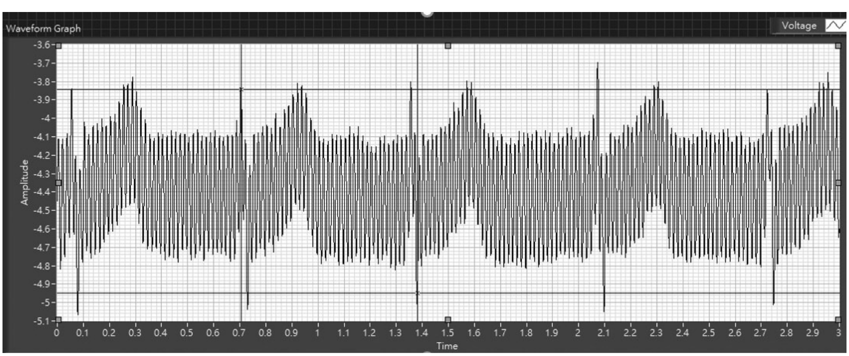
* Labview schematic :





Cursors:	X
Cursor 0	
Voltage	0.709
Cursor 1	
Voltage	1.355

$$BPM = \frac{60}{1.355 - 0.709} = 92.87 \text{ (beats per minute)}$$

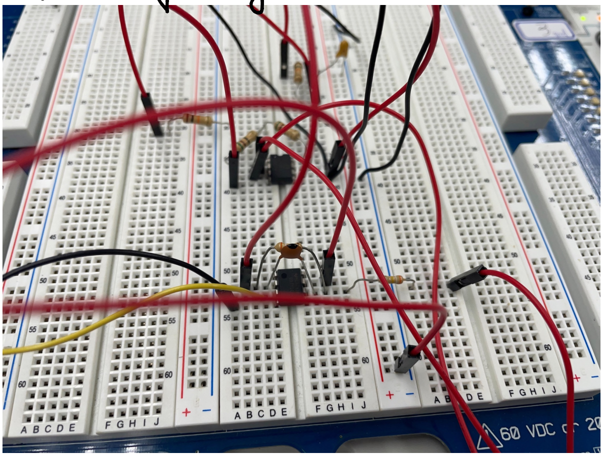


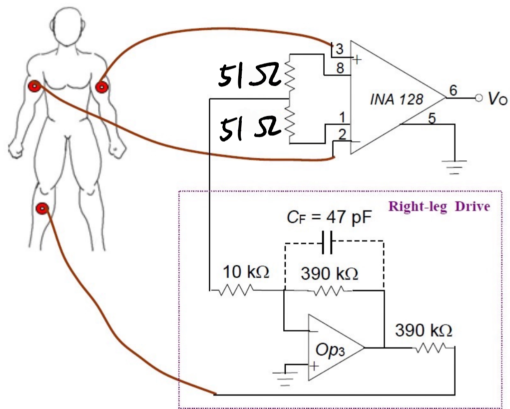
Cursors:	X	Y
Cursor 0		
Voltage	0.706	-3.84348
Cursor 1		
Voltage	1.382	-4.9498

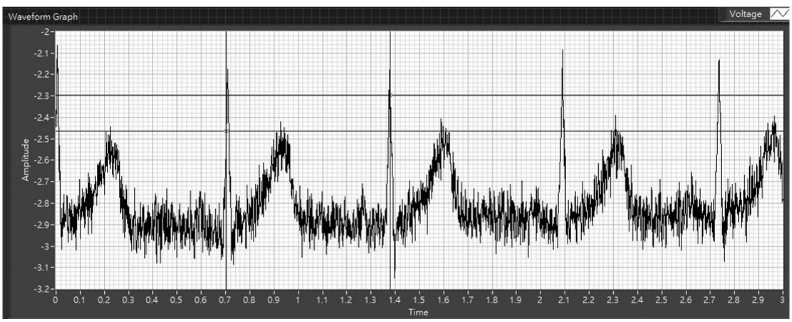
$$V_{p \cdot p} = (-3.84348) - (-4.9498) = 1.10632 \text{ (V)}$$

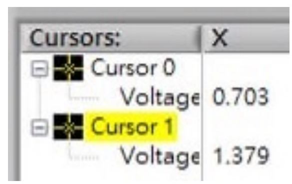
<Phase 2>

With right-leg driven circuit

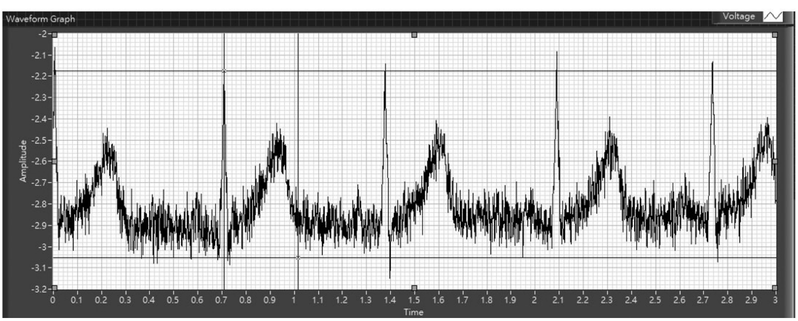


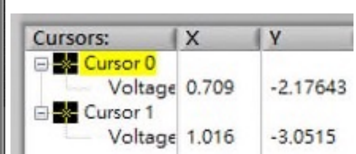






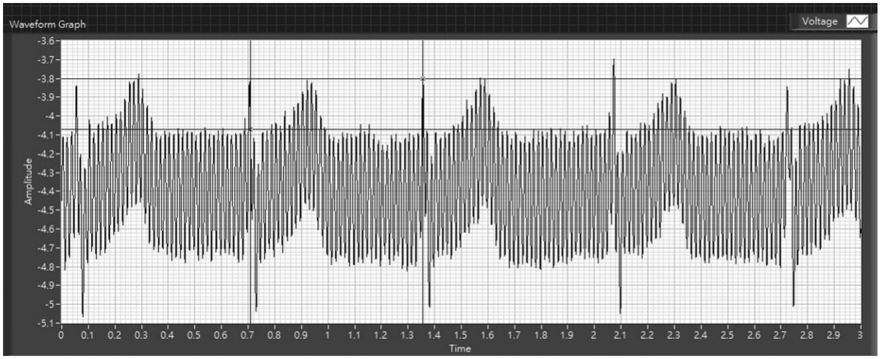
$$BPM = \frac{60}{1.379 - 0.703} = 88.75 \text{ (beats per minute)}$$



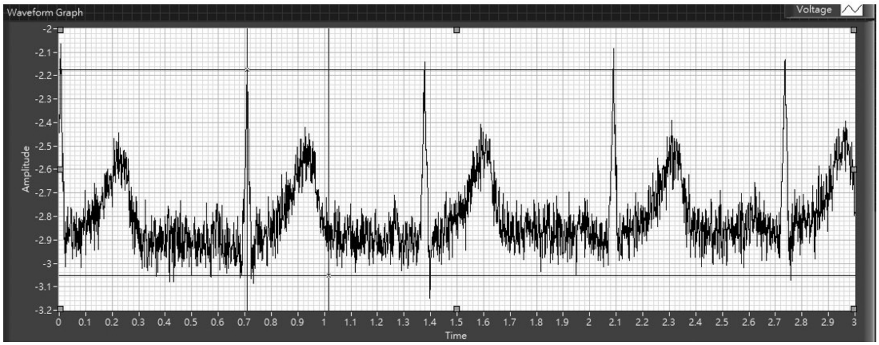


$$V_{p\cdot p} = (-2.17643) - (-3.0515) = 0.87507 \text{ (V)}$$

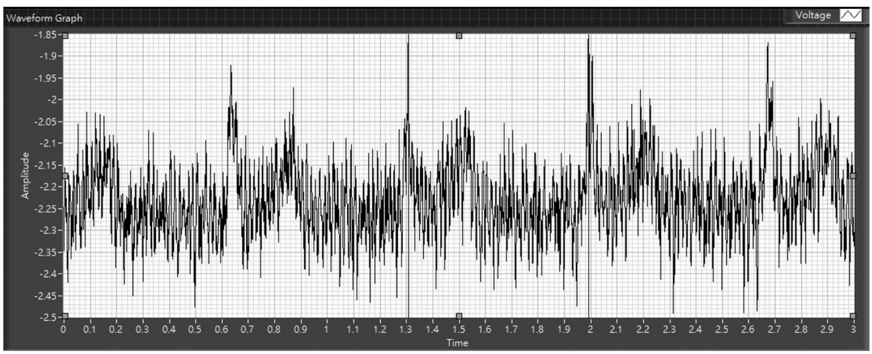
Without right-leg driven circuit



With right-leg driven circuit



With right-leg driven circuit (no 47μF C)



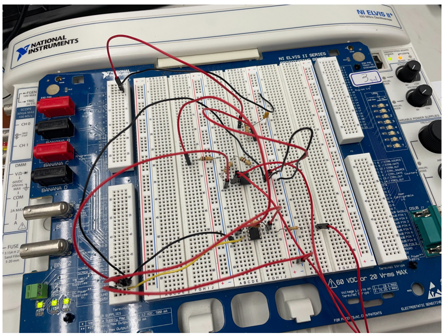
Add a right-leg-driven circuit on the input of the instrumentation amplifier to reduce a little noise, and we can now clearly observe the P wave with the QRS component. However, if we remove the 47uF capacitor on the driven circuit, the noise becomes larger.

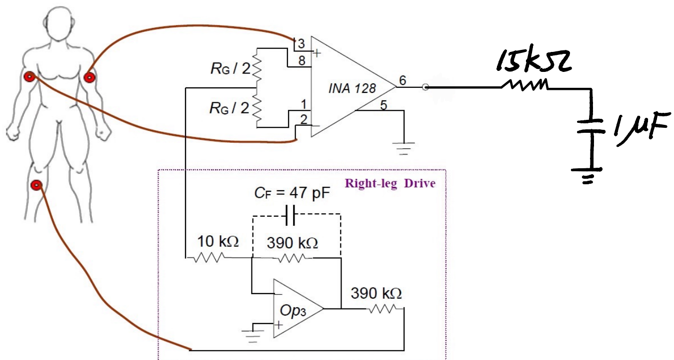
<Phase 3>

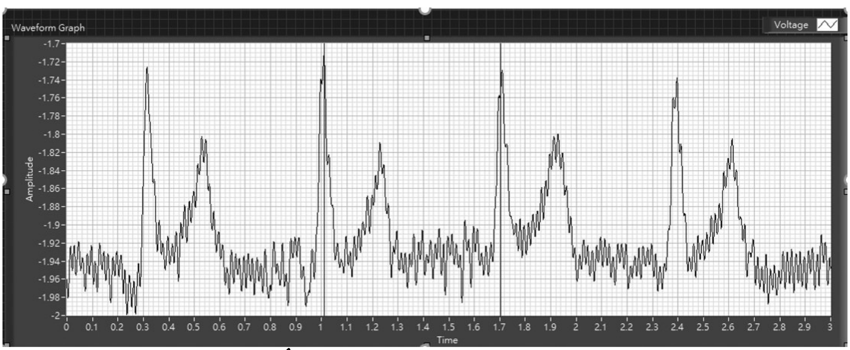
* Design LPF to the output signal.

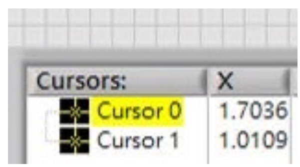
Since the frequency of ECG is $1 \sim 2$ Hz,

select $R_{Lp} = 15k\Omega$, $C_{Lp} = 1\mu F$, $f_0 = \frac{1}{2\pi R_{Lp} C_{Lp}} \approx 10$ Hz







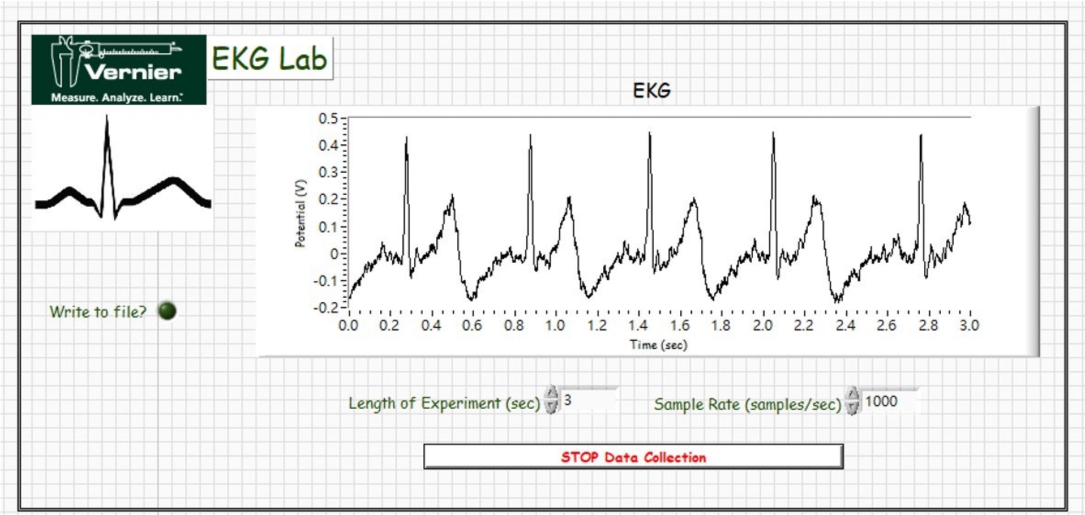


$$BPM = \frac{60}{1.7036 - 1.0109} = 86.61 \text{ (beats per minute)}$$

$$V_{p\text{-}p} = -1.73 - (-2) = 0.27 \text{ (V)}$$

After the signal passes the low-pass filter, the noise reduces so much that we can observe the signal clearly without interference. The QRS component can be observed clearly.

<Phase 4>



The commercial ECG sensor is much better than our circuit. However, if we can do some DSP tricks (moving average) on the signal output from the low pass filter, we can perhaps get a better result.

< Question & Discussion >

1. Is there noise (雜訊) associated with the ECG signal waveform measured in Step 1? If so, what is the source of the noise?

The source of the noise may come from the high-frequency power line interference, and that's the reason why we add a low pass filter in the last stage. Furthermore, the low-frequency baseline drift and electromyography are also the sources of the noise.

2. In Figure 2 circuit, what is the functionality of right-leg drive circuit (驅動右腳電路)?

Right-leg drive circuits can be used to eliminate noise interference from the human body. The body will act as an antenna which induced radio-frequency interference and result in a large noise. With the right leg driving circuit's help, we can actively eliminate the noise.

3. The lab deliverable must consist of the results outlined in Section G – Lab Reports.

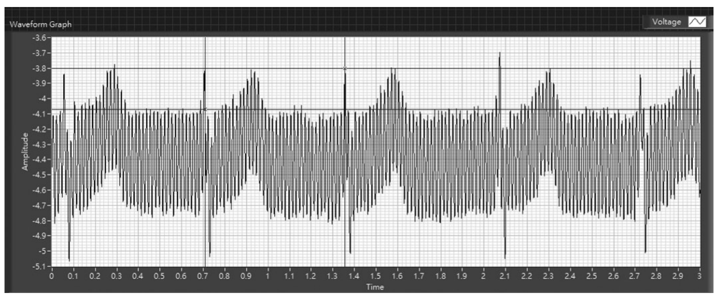
$R_g = 470 // 100 = 82\,\Omega$

V_o Vpp = 1.10 V

ECG Vpp ≃ 5 mV (from net)

Heart rate = 92.87 bpm

gain = 220 (V/V)



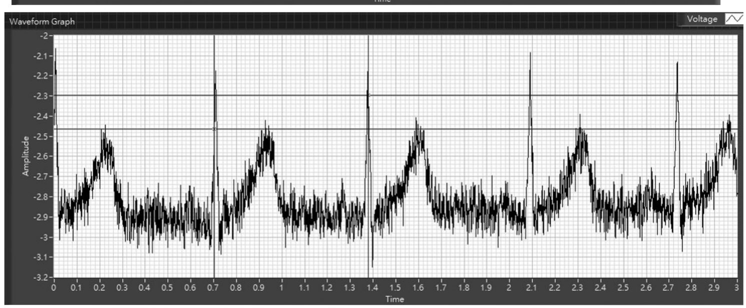
$R_g = 102\,\Omega$

V_o Vpp = 0.87 V

ECG Vpp ≃ 5 mV (from net)

Heart rate = 88.75 bpm

gain = 174 (V/V)



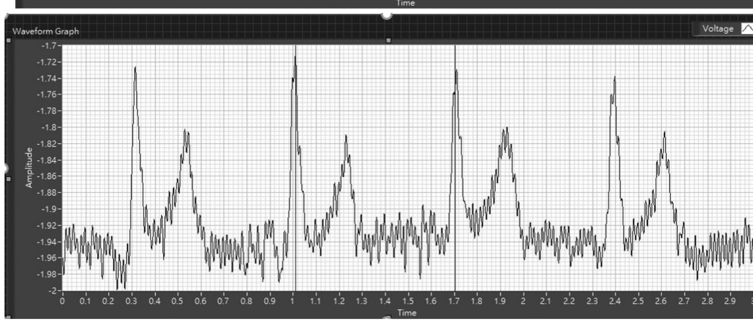
$R_g = 102\,\Omega \begin{cases} R_{LP} = 15\,k\Omega \\ C_{LP} = 1\,\mu F \\ f_0 = 10\,Hz \end{cases}$

V_o Vpp = 0.27 V

ECG Vpp ≃ 5 mV (from net)

Heart rate = 88.75 bpm

gain = 54 (V/V)



4. How well does ECG signal waveform measured in NI EKG Sensor agree with ECG signal waveform measured in Step 1? Could we use either method measuring ECG signal to determine whether the subject's ECG signals are normal?

In step 1, the result contains so much noise. It has a large difference from commercial ECG sensors. The result from the NI EKG Sensor is good enough for machine learning to perform an algorithm on it to predict whether the participant's ECG is normal or not. However, it is still difficult for human beings to use only eyes to determine whether the subject's ECG signal is normal. We can use machine learning techniques to find the pattern of the ECG signal and use the model to predict whether the subject has a normal ECG or not.

* Feedback :

I think it is quite interesting in this lab. First, it is surprising that when adjusting the scale on the oscilloscope, the subject can feel a little current pass through the hand. ECG signals can be used in various kinds of applications. One of the most amazing applications is using ECG signals to detect whether the subject suffers from Covid-19 or not. Currently, using rapid-test and PCR is the main method to test, however, it cost a lot and is not reusable. In my lab, my junior used ECG signals with a neural network model to predict whether the subject is suffering from Covid-19. The accuracy is 99.8% with only 10 seconds of calculation time on the embedded board. It is exciting for me to see the ECG in other applications.