DSP Lab 2 Report
DSP Lab 2: ECG Circuits, Signal Sampling and Digitization

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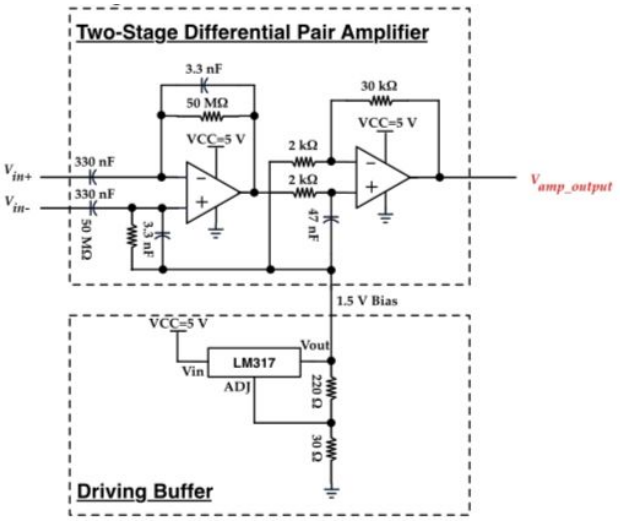
1a. Specification:

Following the schematic Fig. (a) below, build the ECG signal amplification circuits with the provided circuit elements. Capture and describe the waveform at this stage.



(a) ECG signal amplification circuits.

Fig 1(a)

1b.Implementing:

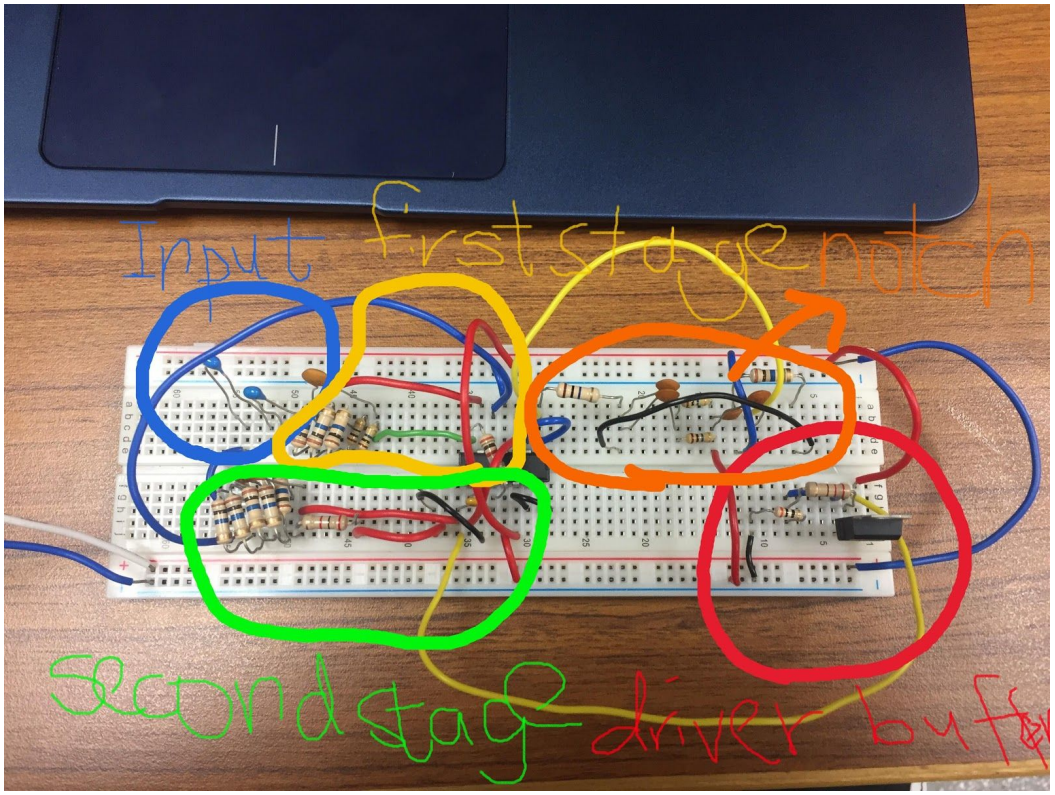


Fig 1(b)

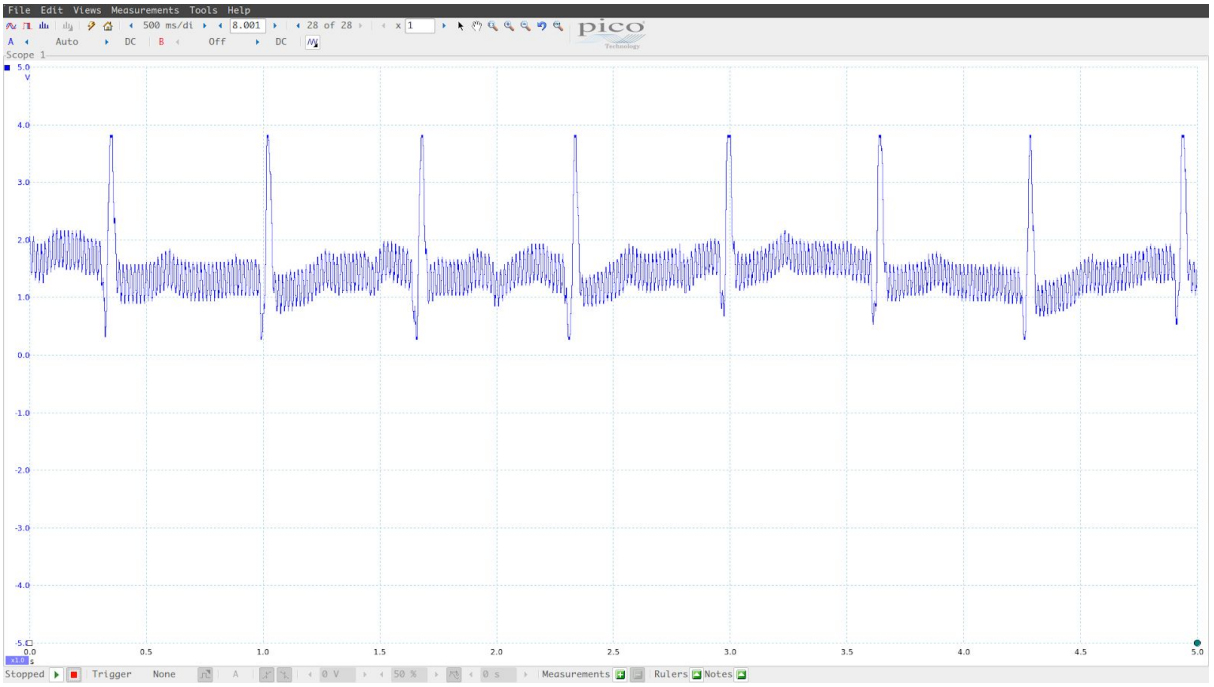

File Edit Views Measurements Tools Help
500 ms/di
8.001
28 of 28
Auto
DC
Off
DC
pico
Scope 1
5.0
V
4.0
3.0
2.0
1.0
0.0
-1.0
-2.0
-3.0
-4.0
-5.0
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
Stopped
Trigger
None
Measurements
Rulers
Notes

Fig 1(c)

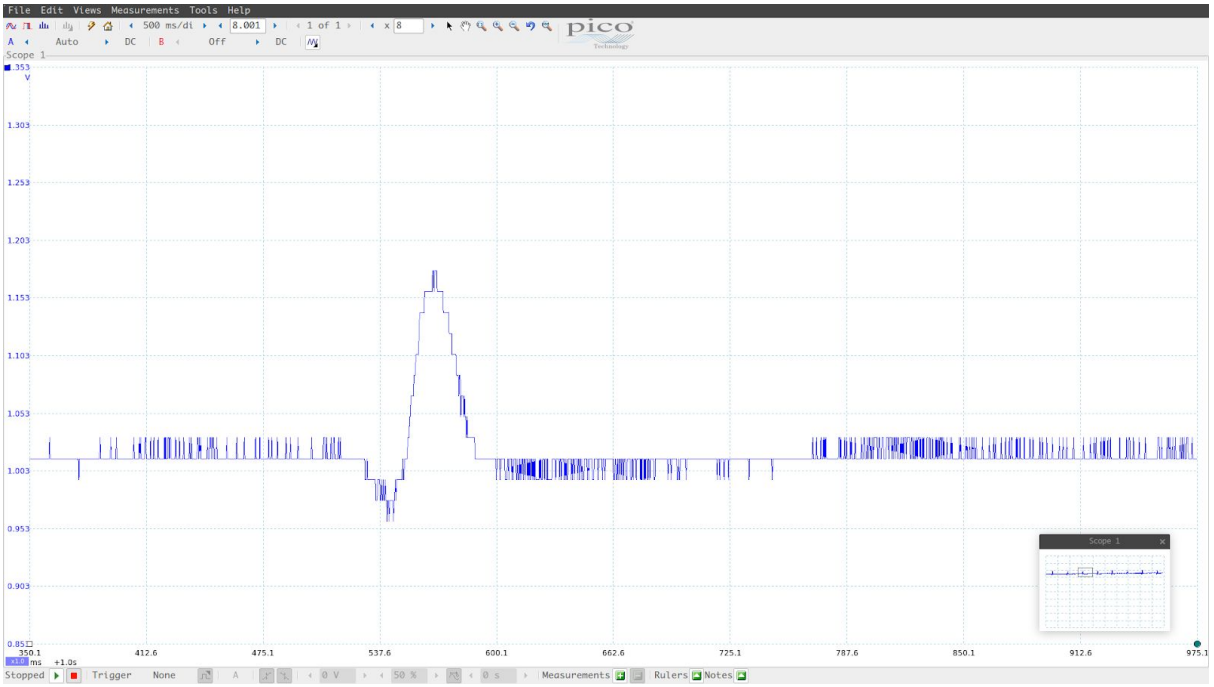
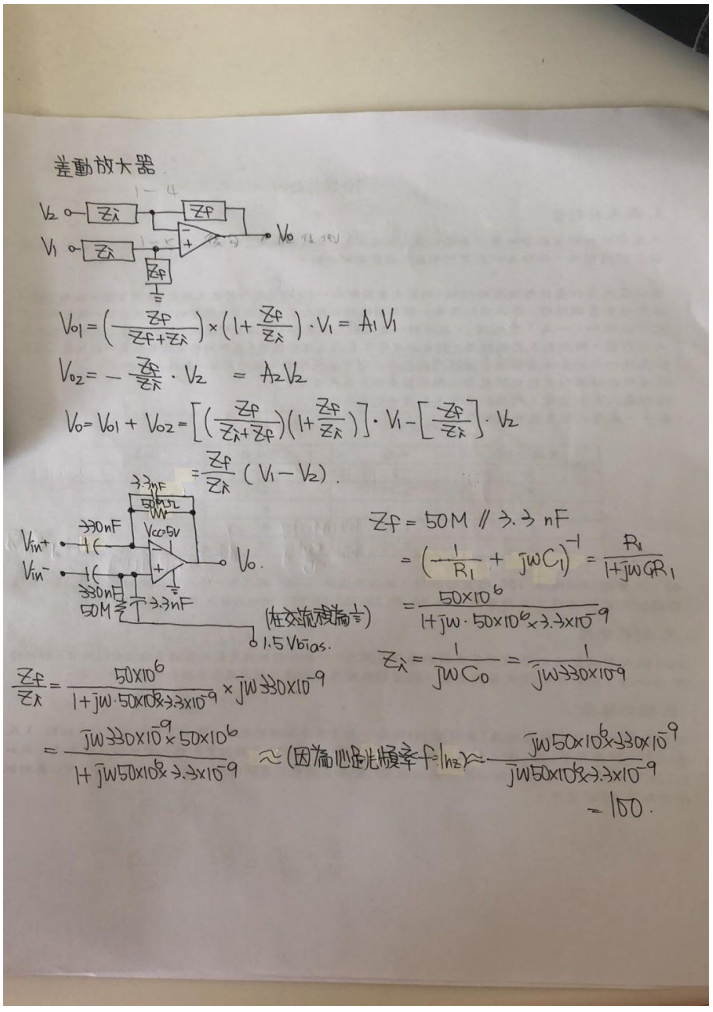

File Edit Views Measurements Tools Help
500 ms/di
8.001
1 of 1
Auto
DC
Off
DC
pico
Scope 1
1.353
V
1.303
1.253
1.203
1.153
1.103
1.053
1.003
0.953
0.903
0.853
350.1
412.6
475.1
537.6
600.1
662.6
725.1
787.6
850.1
912.6
975.1
+1.0s
Stopped
Trigger
None
Measurements
Rulers
Notes

Fig 1(d)

1c.**Discussion:**

從Fig1(e)圖中, 差動放大器細節公式如下:



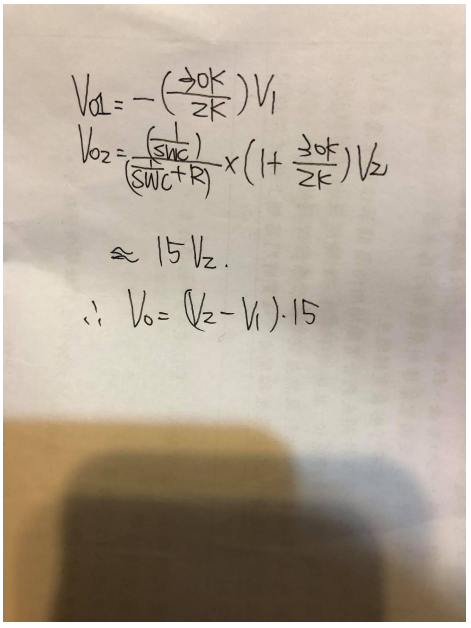


Fig 1(e)

上圖的Fig 1(d)是第一層stage的output

Fig 1(c)是第二層stage的output

可以看到 第一層經過公式運算確實是放大了100倍

由此也可推得, 第二層放大了15倍

2a.Specification:

To remove the 60-Hz power noise, we can add a notch filter after the amplifier output. Capture and describe the waveform at this stage. Compare the output signal with that of V amp_output .

2b.Implementing:

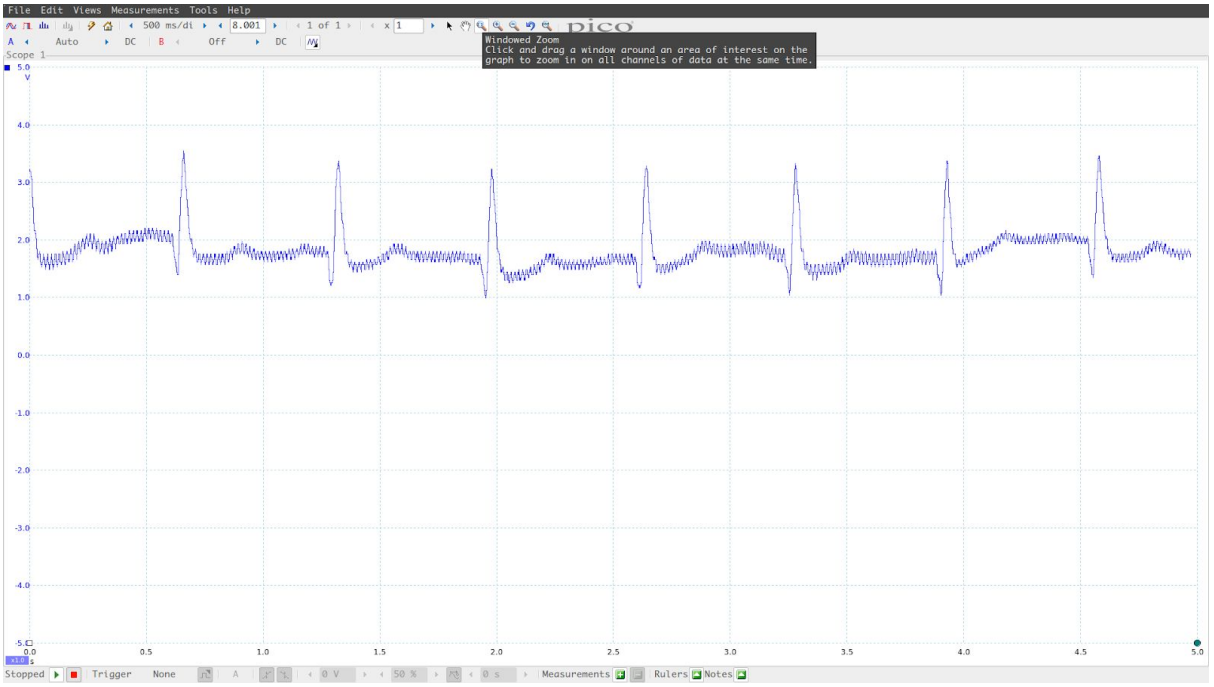


Fig 2(a)

2c.Discussion:

比較第一題,使用notch_filter濾掉60hz的power Interference,time_domain中訊號的背景值較第一題來的小,訊號也比較清楚。

notch filter根據公式:

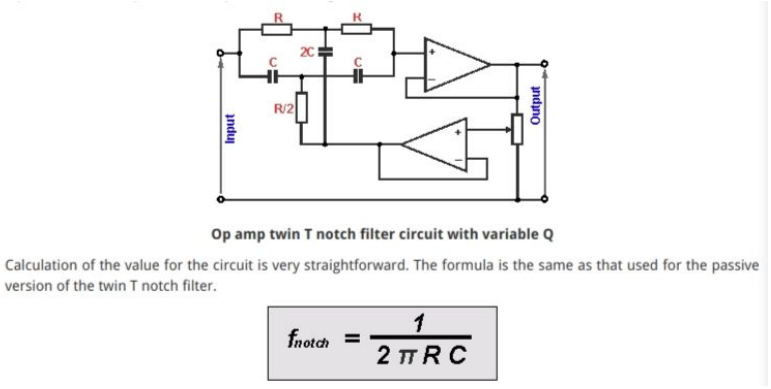


Fig 2(b)

對上實驗的capacitor跟resistor:

C=270pf,R=10M　　代入公式我們知道它無法通過的頻率是58.9hz約等於60hz

所以上圖來看,有關60hz power interference所造成的效果在notch filter被濾掉了。

3a.Specification:
Connect the above circuitry (V filter_output) with Arduino platform. We use the ADC in Arduino for the signal sampling and digitization. With the provided sample codes, you can save/monitor the ECG signals on a PC.
2b.Implementing:

Without notch filter:

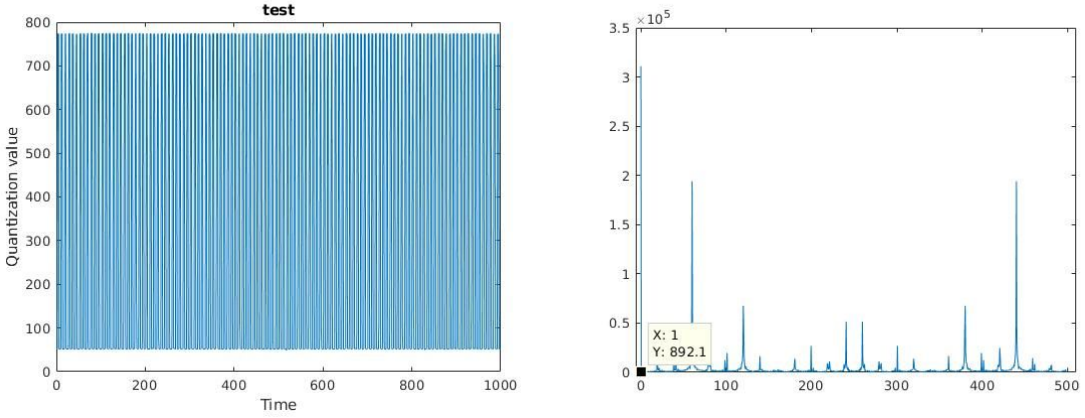


Fig 3(c)

Add notch filter:

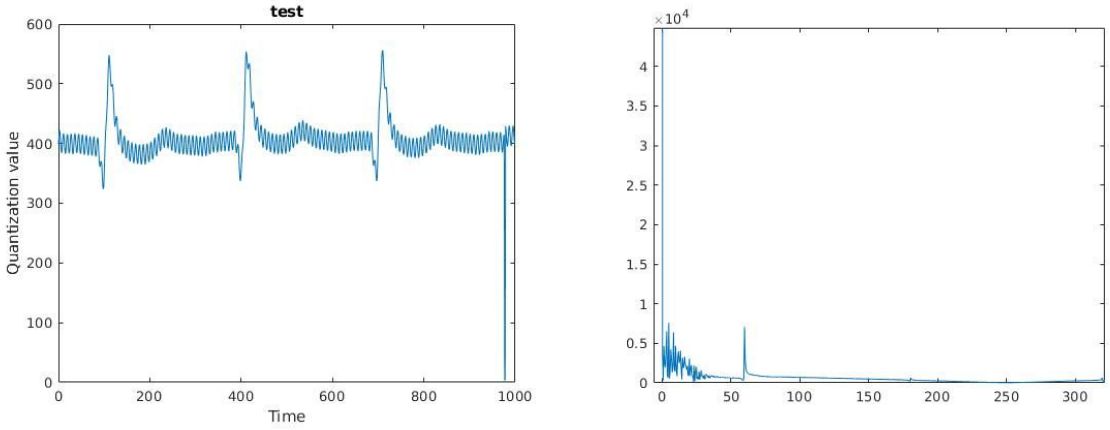


Fig 3(d)

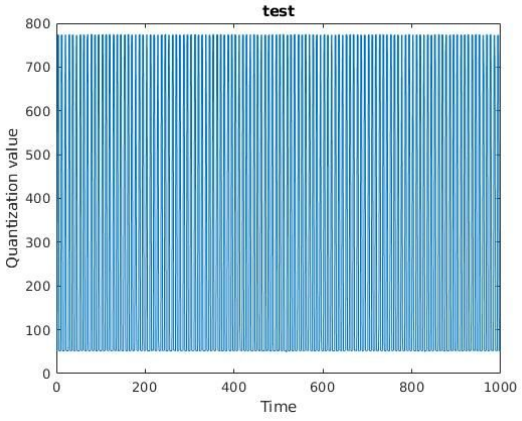
3c.Discussion:
從圖中, 沒有加上notch所產生的訊號圖在time_domain,frequency_domain,可以看到頻譜的60hz,120hz,180hz都有power interference的現象產生。
加上了notch filter可以看到,以60hz產生的power interference都被濾掉了。
由於 ECG 中還有許多 noise，其中我覺得市電頻率(60Hz)占大多數，從上圖未 經過 Filter 的 FFT 圖可以看出，在 60Hz 的地方有很大的突起，也就代表 noise 的 數量很多，而在 DSP 課有提過，Harmonic frequency 會以基頻的倍數出現，稱為 泛音，也就是以 60Hz 的倍數，所以週期性訊號會有 Harmonic 的產生，會因為這 個現象在頻率 60、120、180…的地方都有值，不過還是以 60Hz 的值居多。

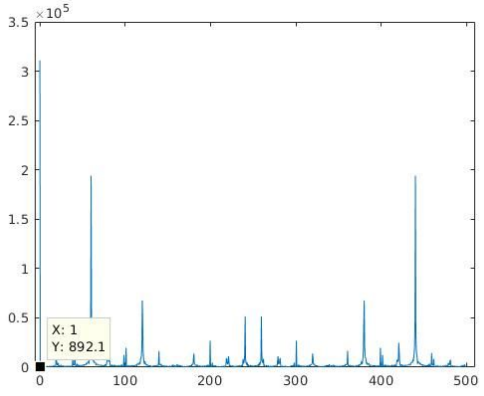
Extra Question:
1a. Specification:
Please compare your recorded ECG signals with and without 50 to 60-Hz notch filtering in TIME and in FREQUENCY DOMAIN (should be included in your report).
From your results, what would be the suppression ratio in dB of the analog notch filter?

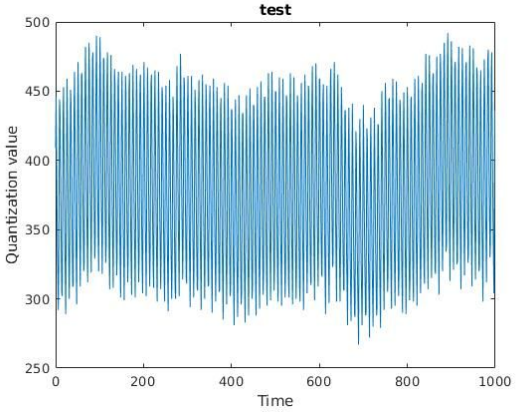
1b.Implementing:
如上圖

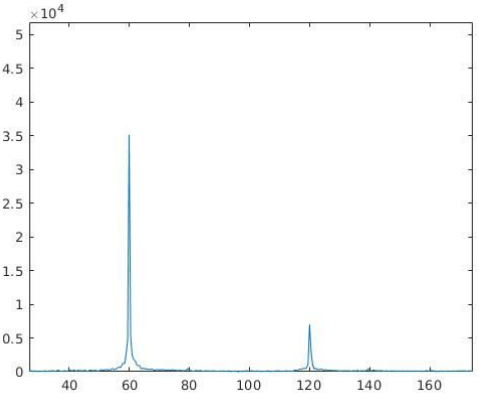
1c.Discussion::
由上圖,可以看到有notch filter和沒有notch filter的差異,以frequency60hz的signal 高度來說,沒有加notch filter的是 2x10e5,加了notch filter的是0.75x10e4
計算出來的suppression ratio是-26db。

2a.Specification:
Please analyze the recorded ECG signals in TIME and in FREQUENCY DOMAIN to see by what kind of noises (see the ECG introduction slides) the signals are contaminated. (better included in your report)
2b.Implementing:
Without notch filter:









2c.Discussion
由四圖看到,實驗中所遇到的noise包括power-line interference,baseline noise,
可以透過notch filter將它們濾掉並且去除

3a.Specification
In addition to the 60-Hz (f0) power-line noise, do you see 120-Hz (2*f0), 180-Hz (3*f0), and even 240-Hz (4*f0) harmonic noises. If you do, why? (better included in your report)

3b.Implementing:

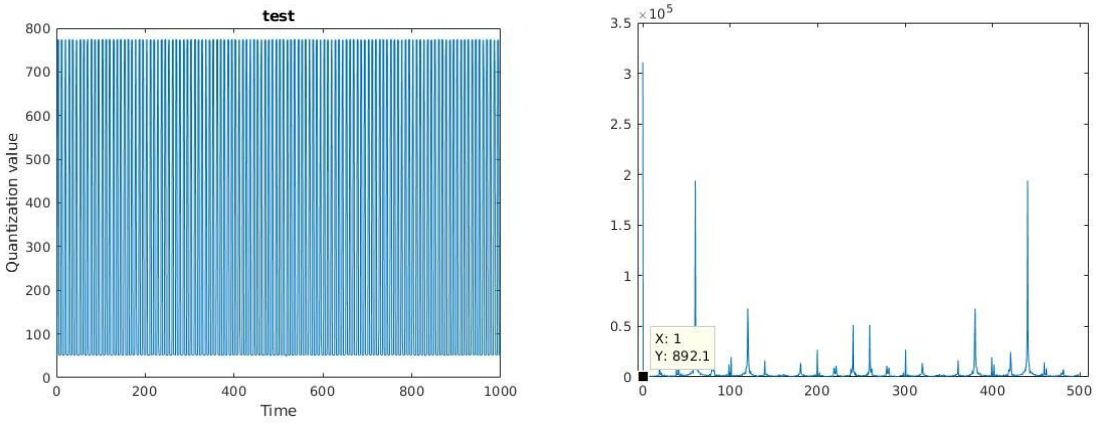


Fig 3(a) no notch filter

3c.Discussion:
會出現harmonic noise的原因如下:
A pure sinusoidal voltage is a conceptual quantity produced by an ideal AC generator built with finely distributed stator and field windings that operate in a uniform magnetic field. Since neither the winding distribution nor the magnetic field are uniform in a working AC machine, voltage waveform distortions are created, and the voltage-time relationship deviates from the pure sine function. The distortion at the point of generation is very small (about 1% to 2%), but nonetheless it exists. Because this is a deviation from a pure sine wave, the deviation is in the form of a periodic function, and by definition, the voltage distortion contains harmonics.

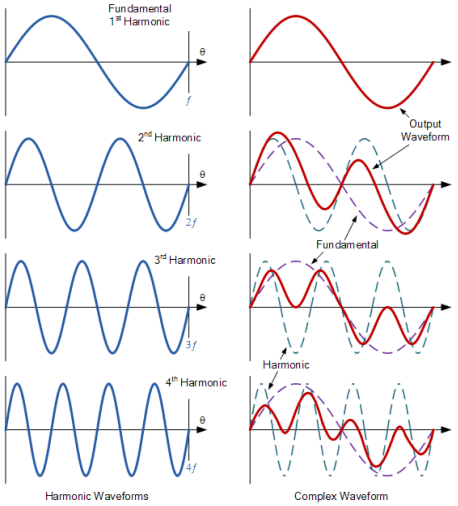


Fig3(b)

大致上的意思是,理想理論狀況下,交流電的產生是建立在均勻的磁場分佈與均勻的線圈密度,但現實上,交流電的電壓波形會因為磁場分佈不均或是線圈繞組分佈不均而產生偏差近於出現1%-2%的distortion,而這些偏差是以週期性出現,這種偏差導致,sine波並非一個完整的波形,而是可以想成是很多以60hz的基頻波或是60hz的倍數波去做疊加而產生出來的(如fig3(b))

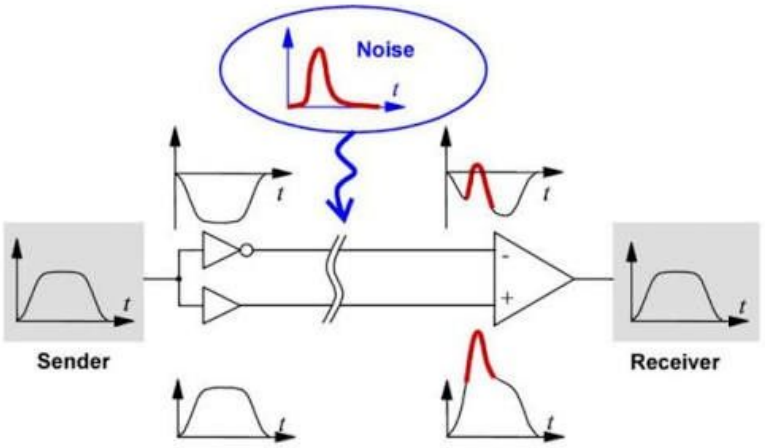
4a.Specification
Based on the recorded signals, you may try to design FIR filters (as learned in Introduction of DSP) to remove the noises. (what kind of filters can be applied to remove the harmonic noises mentioned in 3)
e.g., digital 60-Hz notch filter

4c.Discussion:
在幾次的量測下,出現的noise大致上有四個
baseline noise,Electromyography,power interference Noise,Motion Artifact
那解決的方法如下:
利用notch filter我濾掉了有關power interference以及baseline和motion artifact的雜訊。

5a. Specification:
What is the proper sampling rate for the ECG signal?
5c.Discussion:
因為市電頻率,在60hz附近,為了不使它aliasing,所以**sample rate盡量取在120hz以上**.

6a.Specification:
Please comment why differential amplifier is used for ECG signal amplification
6c.Discussion:
(1)ECG訊號通常都只有mV,或uv等級,透過differential amplifier可以有效放大訊號100倍甚至因為two stage增加到1500倍,便於觀察。
(2)因為當身體訊號有共同雜訊,在兩邊訊號輸入的時候,在output端,因為輸入端兩端訊號有雜訊的時域是相同的,經過differential amplifier會被抵銷,消除,最後output端的訊號並不會因為這些雜訊而有影響,換句話說,在放大訊號的同時,也消除掉了共同雜訊。

Advantage of using Differential amplifier is its ability to reject the common mode noise signal ..... i.e. when sensed signal is applied to its common mode differential inputs....noise signal is equally sensed by the individual inputs and get cancelled or rejected at the output terminal.
示意圖如下:



7a. Specification:

Can you derive the system transfer function or frequency response of the analog notch filter? The system transfer function or frequency response can be used to derive the corresponding digital notch filter via impulse invariant transformation or Bilinear transformation. You may need it in Lab 3

7c.Discussion:

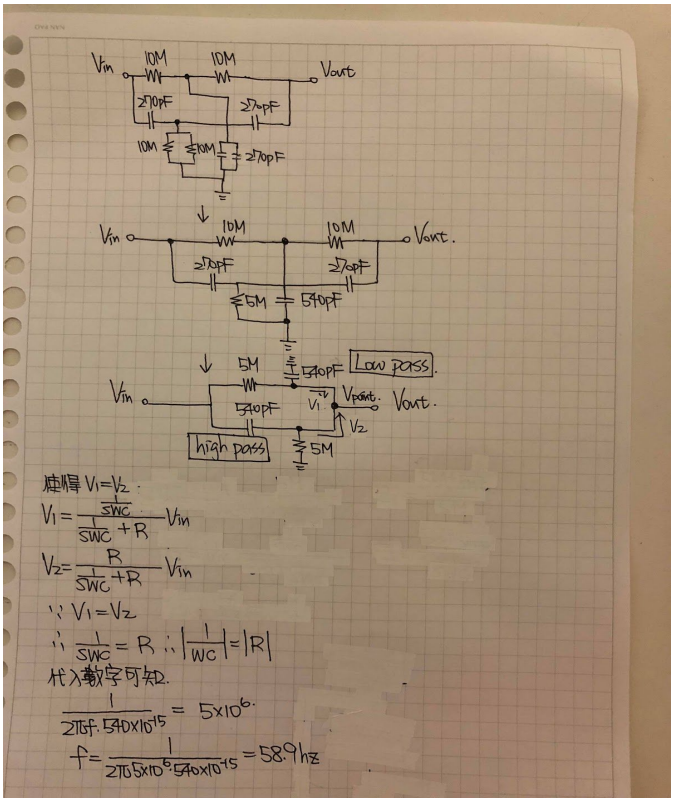


Fig.7(a)

相關公式推導可以參考這個網址:

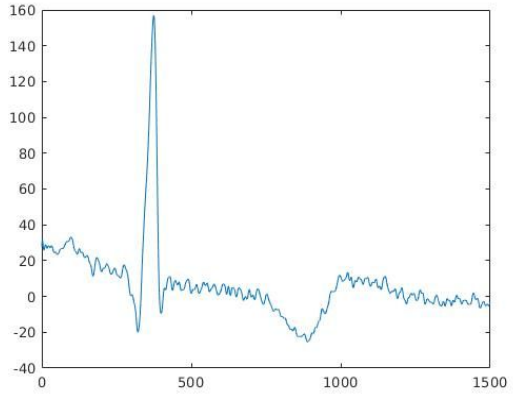
http://fourier.eng.hmc.edu/e84/lectures/TwinT/node1.html

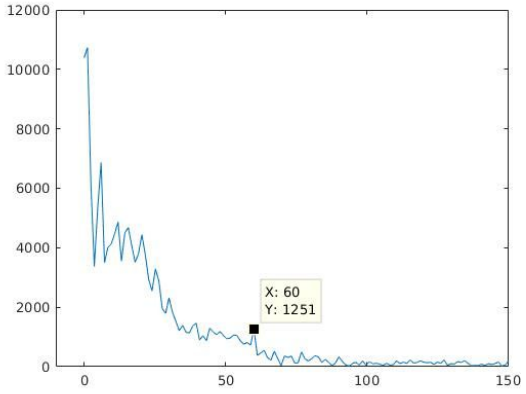
$$H(j\omega) = \frac{v_{out}}{v_{in}} = \frac{1 + (j\omega\tau)^2}{1 + 4j\omega\tau + (j\omega\tau)^2} = \frac{(j\omega)^2 + \omega_n^2}{(j\omega)^2 + 4j\omega\omega_n + \omega_n^2}$$

Fig 7(b)

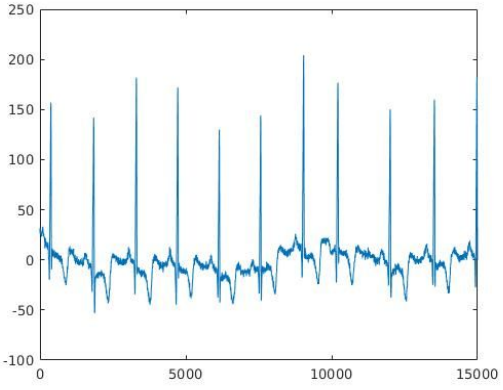
8a. Specification:
Please find the given MATLAB data file – ECG.mat where a raw ECG signal and Fs (in Hz) used to acquire the ECG signal are stored, and perform Fourier analysis over (a) a single ECG wavelet (i.e., one beat cycle) and (b) the whole ECG signal.
Please tell what ECG information you can obtain via the Fourier spectra (a) and (b), respectively.

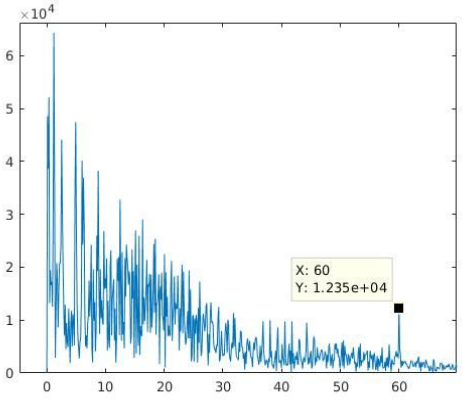
8b.Implementing:
(a)single ECG cycle





(b)whole ECG signal





8c.Discussion:
(1)由二圖可以觀察到,以ECG.mat中,fs=1800hz,加上一個週期大概是1500個點,
1500/1800=0.833
代表一次心跳的週期大概是0.833hz,一分鐘心跳次數大概是72下,落在正常心跳範圍內。

(2)兩者來說，單一週期的心跳訊號比很多週期的心跳訊號來的清楚可見,以紀錄很多週期的心跳在頻域的狀況,可以把他想成單一週期的心跳訊號經過傅立葉轉換後會跟其他週期的impulse signals繼續做convolution造成他的頻域是很多impluse訊號和單一週期的心跳轉換到頻域的訊號相乘,相當於將單一週期的心跳訊號[頻域的訊號]一直做shift外乘上sinc function(因為在時域只取了有限個點)再做疊加。取單一週期的心跳訊號比較適合用來觀察並且處理。

D.Conclusion:

本次實驗中,探討了不少實際層面的問題，power interference就上網查了不少資料,增加不少新知識,順便補救一下我因為子路實驗都抄家傳導致很爛的電子學,電路學的觀念,透過實作,分析了時域,頻域上所遇到雜訊的問題,以及電路上transfer function的基本知識,萌生了走系統A組的信心。