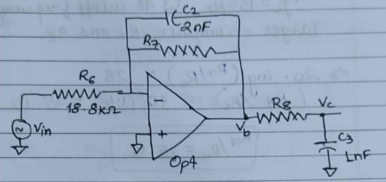
Analog Lab
Exp ⇒ 12 - 13

1) $\boxed{\text{ECG Amplifier}}$

(a) $\boxed{\text{2nd Order Low Pass Filter}}$

Circuit Design ⇒



LPF (150Hz)
"Low Pass Filter"

Equations ⇒

- $\dfrac{V_b}{V_{in}} = \dfrac{-A}{1+s\tau_L}$; A ⇒ DC gain of the inverting amplifier.
- $\dfrac{V_c}{V_{in}} = -\dfrac{A}{1+s\tau_L} \cdot \dfrac{1}{1+s\tau_2}$; τ_L ⇒ time constant of transfer func. from V_{in} to V_b

The filter is of 2nd order. The poles located at $(1/\tau_L)$ and $(1/\tau_2)$. The pole frequency should nearly be equal.

Simulation:-

(A) Requirements:-

Lowpass Filter having:
- → DC gain = 28 dB
- → $f_c = 150\,Hz$ (3 dB cutoff frequency)

Target - compute R_7 and R_8.

$$\Rightarrow 20 \cdot \log(R_7/R_6) = 28$$

$$(R_7/R_6) = 10^{(1.4)} = 25.12$$

$$\boxed{R_7/R_6 = 25.12}$$

3 dB cutoff frequency

$$\left.\frac{V_c}{V_{in}}\right|_{s=j\omega} = \frac{1}{\sqrt{2}} = \frac{A}{(1+j\omega\tau)^2}$$

$\Rightarrow \tau_1 = \tau_2 \qquad \Rightarrow R_7C_2 = R_8C_3$

Given, $C_2 = 2nF$ and $C_3 = 1nF$ (given)

$$\Rightarrow \boxed{2 \cdot R_7 = 1 \cdot R_8}$$

Also, $f_c = \dfrac{1}{2\pi R_8 C_3} = 150\ Hz$

$$R_8 = \frac{1}{2\pi \cdot 150 \cdot 1\times10^{-9}} = 1.061\,M\Omega$$

$R_8 = 1.061\,M\Omega \qquad R_7 = 0.531\,M\Omega$

At 3dB frequency;

$$20 \log\left(1+(\omega\tau)^2\right) = 3$$

$$1+(\omega\tau)^2 = 10^{3/20} \Rightarrow \omega\tau = 0.642$$

$$\omega_c\tau = 0.642 \quad (\omega = \omega_c = \text{corner freq})$$

$$\tau = R_8C_9 = \frac{0.642}{2\pi \cdot 150} \Rightarrow \boxed{R_8 = 681.49\,k\Omega}$$

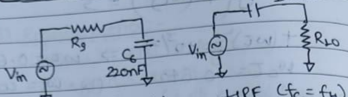
$$\boxed{R_7 = R_8/2 = 340.746\,k\Omega}$$

$$\boxed{R_6 = R_7/25.12 = 13.56\,k\Omega}$$

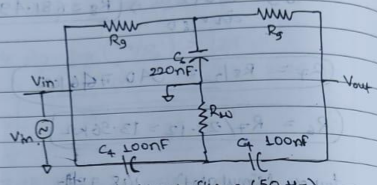
$f_{cut\ off}$ (simulated) = 148.9 Hz

A_{dc} = 28.02 dB.

(b) Notch Filter



LPF ($f_c = f_L$) HPF ($f_c = f_H$).



Notch filter (50 Hz).

Simulation:-

(A) LPF (Low Pass Filter):-

let $F_L = 10$Hz.

$$\Rightarrow \frac{1}{2\pi \cdot R_9 C_6} = 10 \Rightarrow R_9 = \frac{1}{2\pi \cdot 10 \cdot C_6}$$

$$\boxed{R_9 = 72.34\,k\Omega}$$

- f_L (theoretical) = 10 Hz
- f_L (simulation) = 10.07 (−3dB cutoff)

(B) HPF (High Pass Filter):-

let $F_H = 90$Hz.

$$R_{10} = \frac{1}{2\pi \cdot 90 \cdot C_9} \Rightarrow \boxed{R_{10} = 17.683\,k\Omega}$$

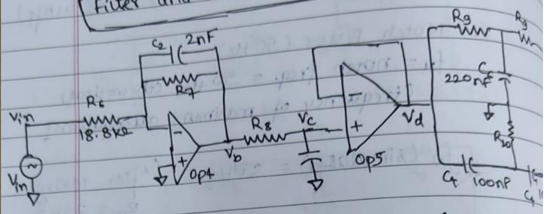
- f_H (theoretical) = 90 Hz
  f_H (simulation) = 89.41 Hz (−3dB cutoff)

(c) Notch Filter (50 Hz)

f_N = notch freq. = 50 Hz (theoretical)
(frequency of maximum attenuation)

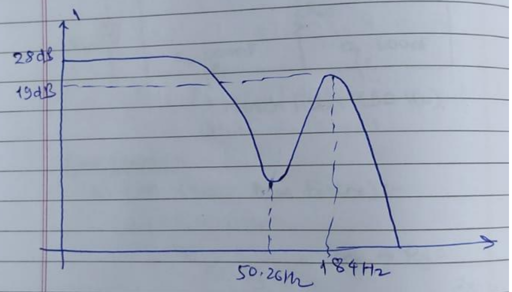
f_N (simulated) = 50 Hz. (after taking
$R_9 = 39k\Omega$
$R_{10} = 9k\Omega$)

(c) Combined 2nd Order Low Pass Filter and Notch Filter Response



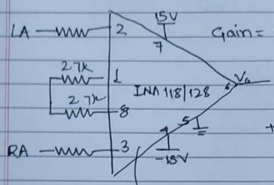
LPF (150 Hz)

(Notch filter

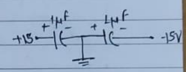


EE 230 Analog Lab
Lab 12
05/04/24

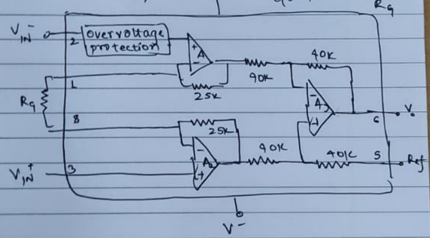
1) ECG Amplifier
(a) Instrumentation Amplifier (INA)



Gain = 10.25 = $1 + \frac{50}{5.4}$

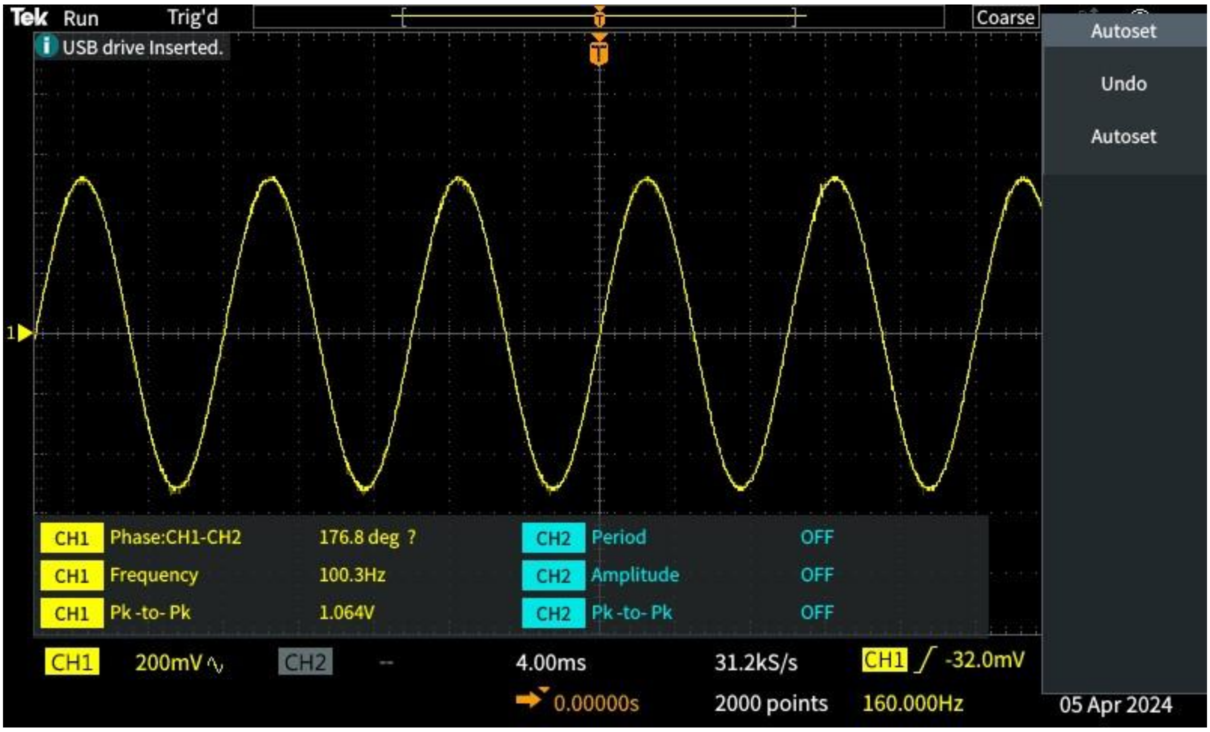


Gain = $1 + \frac{50k\Omega}{R_G}$

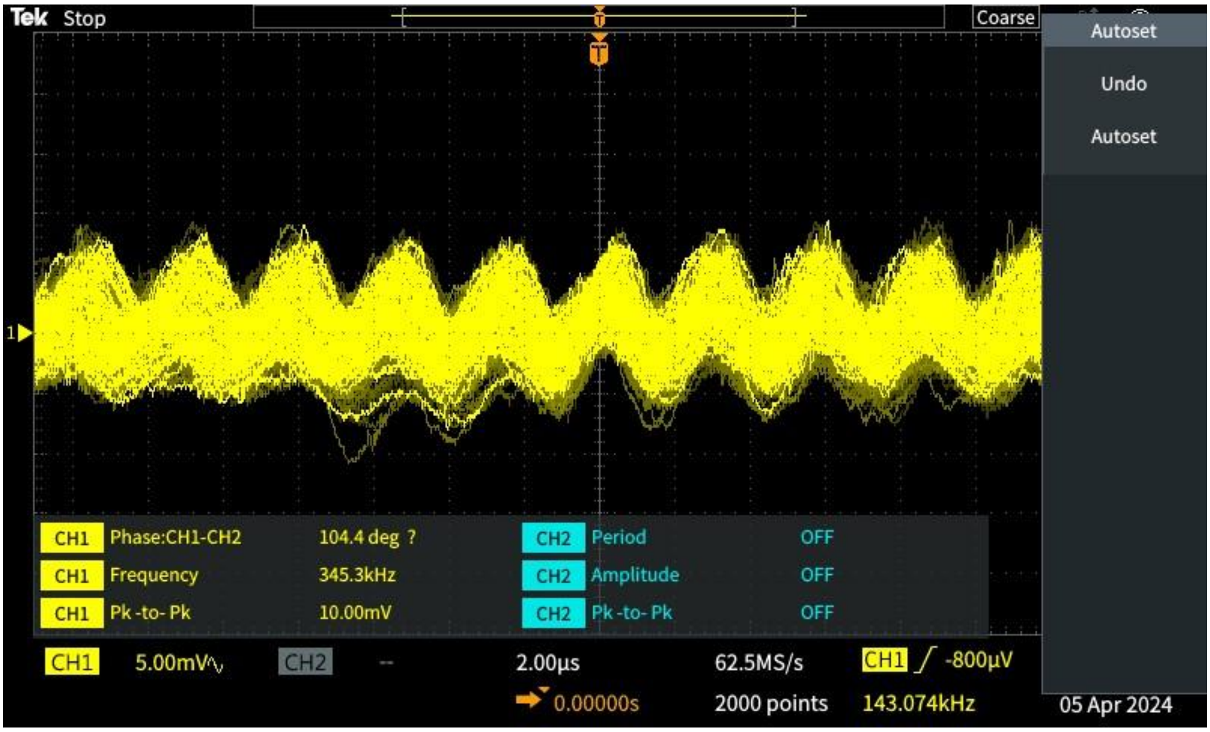


(i) Vout = 1.064 V_{pp}
Gain = $\frac{1.064 V_{pp}}{100 mV_{pp}}$ = 10.6

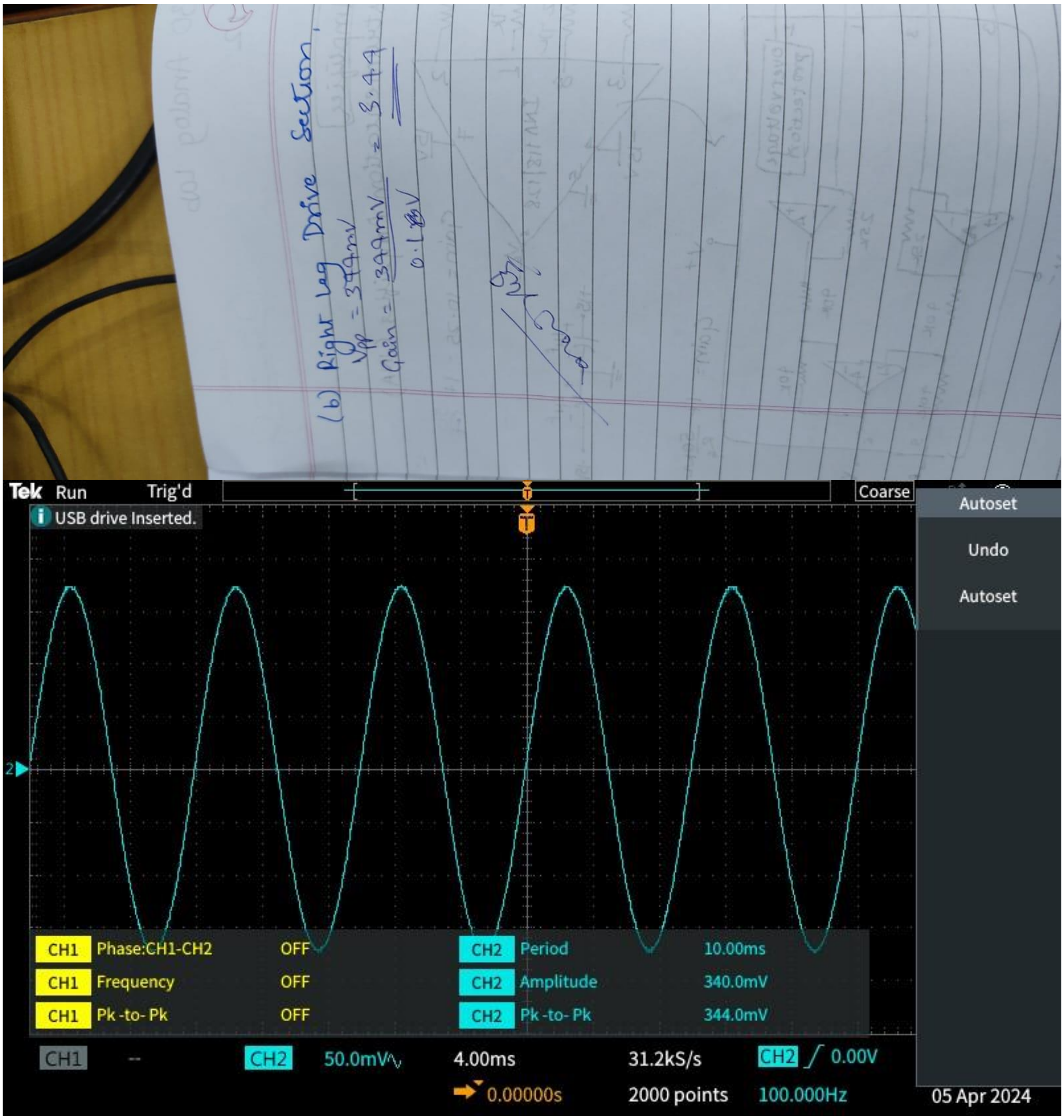
(ii) In common mode, noise ~ 3mV.



Tek Run Trig'd
Coarse
USB drive Inserted.
Autoset
Undo
Autoset
CH1 Phase:CH1-CH2 176.8 deg ?
CH1 Frequency 100.3Hz
CH1 Pk-to-Pk 1.064V
CH2 Period OFF
CH2 Amplitude OFF
CH2 Pk-to-Pk OFF
CH1 200mV
CH2 --
4.00ms
0.00000s
31.2kS/s
2000 points
CH1 -32.0mV
160.000Hz
05 Apr 2024



Tek Stop
Coarse
Autoset
Undo
Autoset
CH1 Phase:CH1-CH2 104.4 deg ?
CH1 Frequency 345.3kHz
CH1 Pk-to-Pk 10.00mV
CH2 Period OFF
CH2 Amplitude OFF
CH2 Pk-to-Pk OFF
CH1 5.00mV
CH2 --
2.00µs
0.00000s
62.5MS/s
2000 points
CH1 -800µV
143.074kHz
05 Apr 2024


(b) Right Leg Drive Section,
Vpp = 349mV
Gain = 349mV / 0.1V = 3.49
Tek Run Trig'd
Coarse
USB drive Inserted.
Autoset
Undo
Autoset
CH1 Phase:CH1-CH2 OFF
CH1 Frequency OFF
CH1 Pk-to-Pk OFF
CH2 Period 10.00ms
CH2 Amplitude 340.0mV
CH2 Pk-to-Pk 344.0mV
CH1
CH2 50.0mV
4.00ms
31.2kS/s
CH2 0.00V
0.00000s
2000 points
100.000Hz
05 Apr 2024