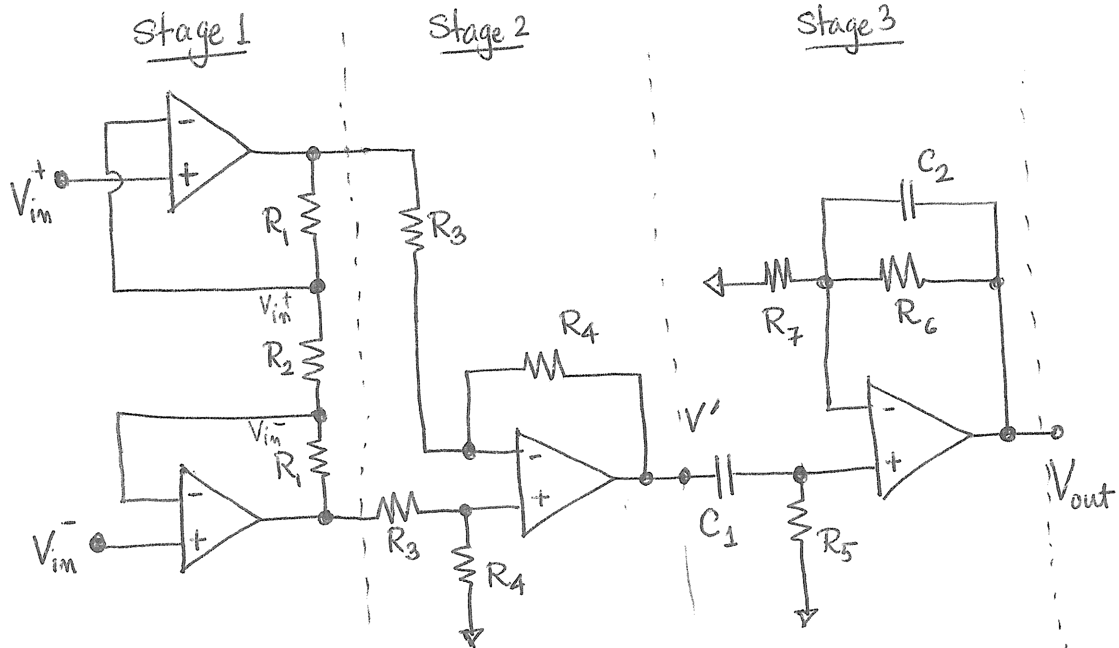
Solution to Exam 1

Problem 1

Part 1



Gain

$$G_1 = \frac{2R_1 + R_2}{R_2}$$

Gain

$$G_2 = -\frac{R_4}{R_3}$$

Transfer function

$$\frac{V_{out}(s)}{V'(s)} = \frac{R_6}{R_7} \frac{sC_1R_5}{(1+sR_5C_1)(1+sC_2R_6)}$$

For ~~a gain of 1000~~ derivation of the gain & transfer function see the end of this document or lecture notes.

Total gain $G = G_1 G_2 \cdot \frac{R_6}{R_7} = \left(\frac{2R_1+R_2}{R_2}\right)\left(-\frac{R_4}{R_3}\right)\left(\frac{R_6}{R_7}\right)$

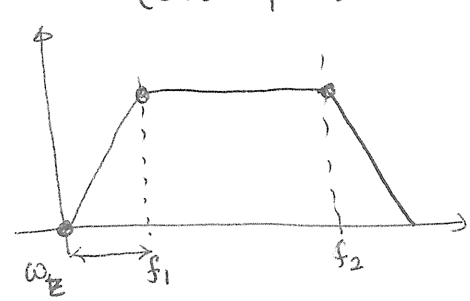
with zeros at $\omega_z = 0$, $\omega_{p1} = 1/R_5C_1$, $\omega_{p2} = 1/R_6C_2$

First satisfy the passband requirements

(Bode-plot)

$$f_1 = \frac{1}{2\pi R_5 C_1} = 0.1\,\text{Hz} \Rightarrow \quad (i)$$

$$f_2 = \frac{1}{2\pi R_6 C_2} = 10000\,\text{Hz} \quad (ii)$$



10
1 nF

$$R_6 = \frac{1}{2\pi C_2} \times 10^{-4}$$

Choose $C_2 = 10\,pF \Rightarrow R_6 = 1.6\ M\Omega$.

Using equation (i)

$$R_5 = \frac{1}{2\pi C_1} \times 10$$

For $C_1 = 1\,\mu F \Rightarrow R_5 = 1.6\ M\Omega$

To achieve a total gain of 1000

$$G = \left(\frac{2R_1 + R_2}{R_2}\right)\left(-\frac{R_4}{R_3}\right)\left(\frac{R_6}{R_7}\right)$$

$\downarrow$ 10, $\downarrow$ 10, $\downarrow$ 10

Choose $R_7 = 160\ K\Omega$

$R_3 = 10\ K\Omega$

$R_4 = 100\ K\Omega$

$R_2 = 10\ K\Omega$

$R_1 = 45\ K\Omega$

Part II

First calculate the displacement current

$$i_d = 2\pi f V_{rms} C_b$$

$$\simeq 2\pi\ 60\,Hz \times 120 \times 0.001 \times 10^{-12}$$

$$\simeq 50\,pA$$

Driven Right-leg system

$$v_{cm} = \frac{R_{RL}\, i_d}{(1 + 2R_f/R_a)}$$

$$\frac{R_{RL}}{(1+2R_f/R_a)} = \frac{2\times10^{-3}}{50\times10^{-12}} = 4\times10^{7}$$

Choose $R_{RL} \approx 40\,M\Omega$

and $R_f = 1\,k\Omega$ $R_a = 100\,k\Omega$ } You can choose any values for the given requirements

Part III

Interference at the biopotential amplifier due to common mode disturbance

$$v_{in} = v_{cm}\left(\frac{\Delta Z}{Z_{in}}\right)$$

where ΔZ is the difference in impedance of the input electrodes (Z_1, Z_2)

$Z_{in} \rightarrow$ input impedance of the amplifier.

Because the op-amp used for instrumentation amplifier is ideal

$\Rightarrow Z_{in} = \infty$

$$\boxed{v_{in} = 0V}$$