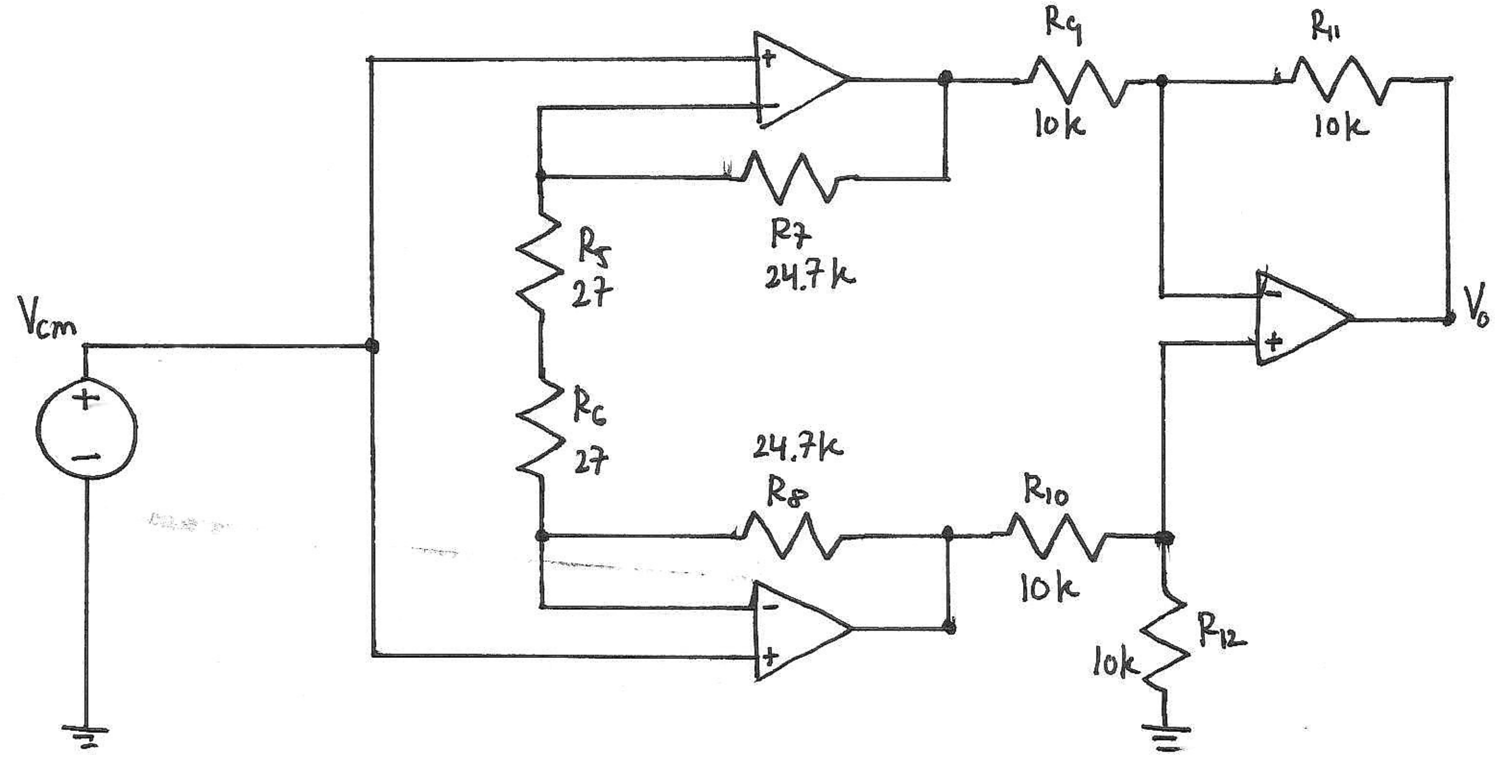
SIGNALS AND SYSTEMS - WEEK 7

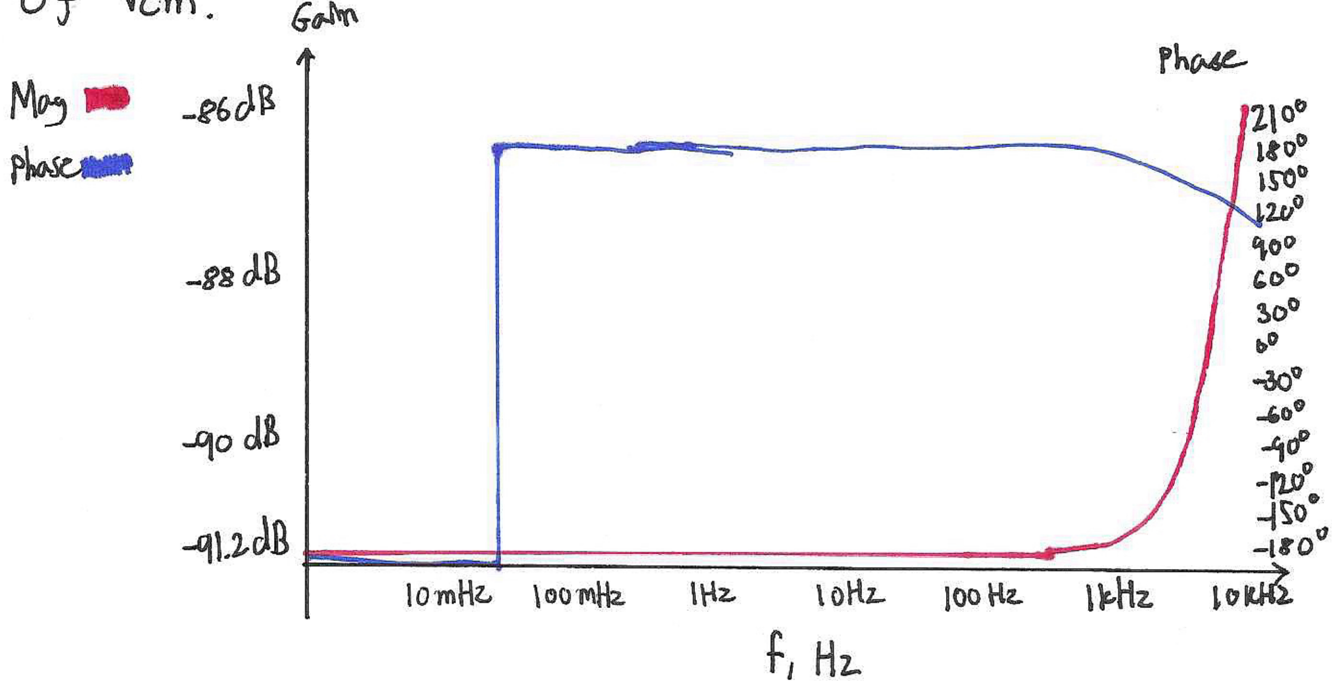
Problem 1

Calculate the common mode gain G_c, and CMRR.



Sol

Common mode gain G_c can be found with an ac sweep of Vcm.



Observe that $\left|\frac{V_o}{V_{cm}}\right| = |G_c| = -91.2$ dB

So, a common mode voltage gets attenuated by 91.2 dB.

$$CMRR = \frac{|G_d|}{|G_c|}$$

$$|G_d| = 1 + \frac{49.4\ k\Omega}{R_G} = 1 + \frac{49.4\ k\Omega}{54\ \Omega} = 916 = 59\ dB$$

$$CMRR = G_{d,dB} - G_{c,dB} = 59\ dB - (-91.2\ dB)$$

$$CMRR = 150\ dB \quad \text{(very good)}$$

Example

Given this setting

- $V_{cm} = 2\ V$
- $V_d = 5\ mV$

how much CMRR is needed if on the output of the in-amp want $V_{cm,o} = 2\ mV$ and $V_{d,o} = 5\ V$?

Sol

Common mode gain: $\frac{V_{cm,o}}{V_{cm}} = \frac{2\ mV}{2V} = \frac{1}{1000} = -60\ dB$

Differential gain: $\frac{V_{d,o}}{V_d} = \frac{5\ V}{5\ mV} = 1000 = 60\ dB$

Our in-amp needs at least $CMRR = 60\ dB - (-60\ dB) = 120\ dB$ to fulfill requirements.

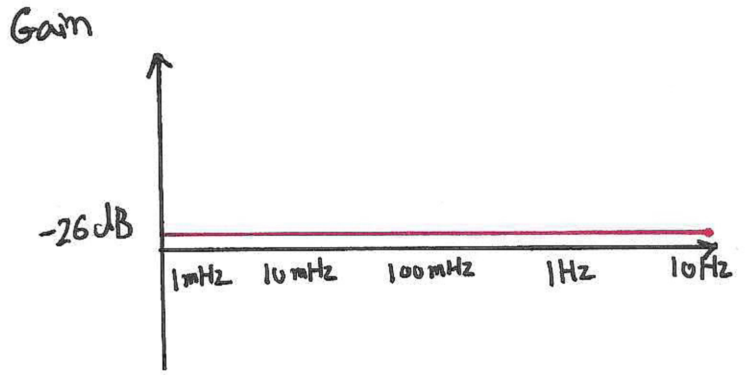
Problem 2

Create an imbalance (asymmetry) in the in-amp by setting $R_{11} = 11\ k\Omega$.

What is CMRR now?

Sol

We plot the frequency characteristic $\frac{V_o}{V_{cm}}$ again to find $|G_c|$.



$|G_c| = -26$ dB

$|G_d| = 59$ dB

$$CMRR = 59\,dB - (-26\,dB) = 85\ dB$$ (Pretty bad)

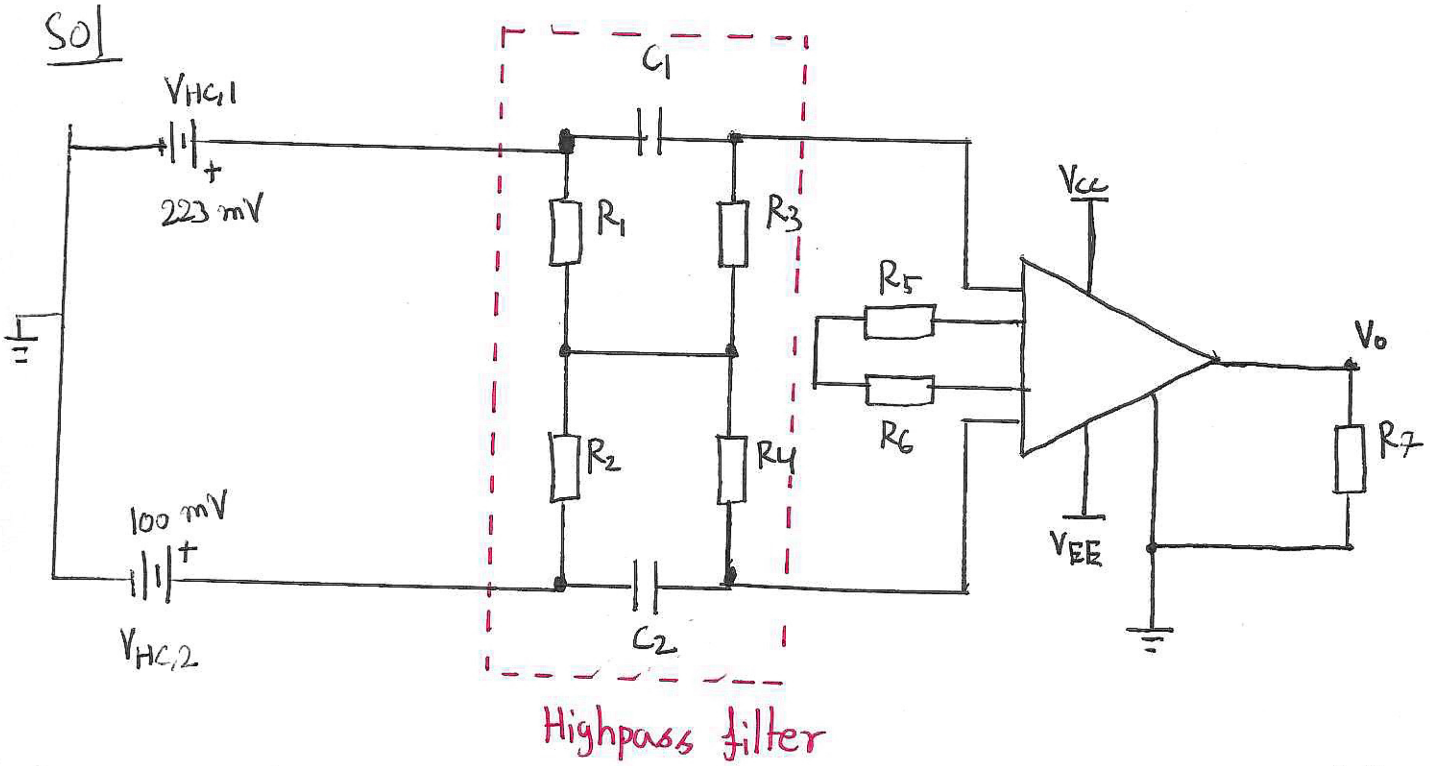
Observation:

It's very important for in-amps to have perfect symmetry, because imbalance lowers the CMRR significantly.

Problem 3

Set both half-cell batteries to $V_{HC} = 223$ mV.
Then, set one to 100 mV, the other to 223 mV.
What will be the output?

Sol



Due to the highpass filter, any DC-voltage will be filtered away and not appear on the in-amps input terminals. So, we expect $V_o \approx 0$ V in this case, regardless of if $V_{HC,1}$ and $V_{HC,2}$ are different.

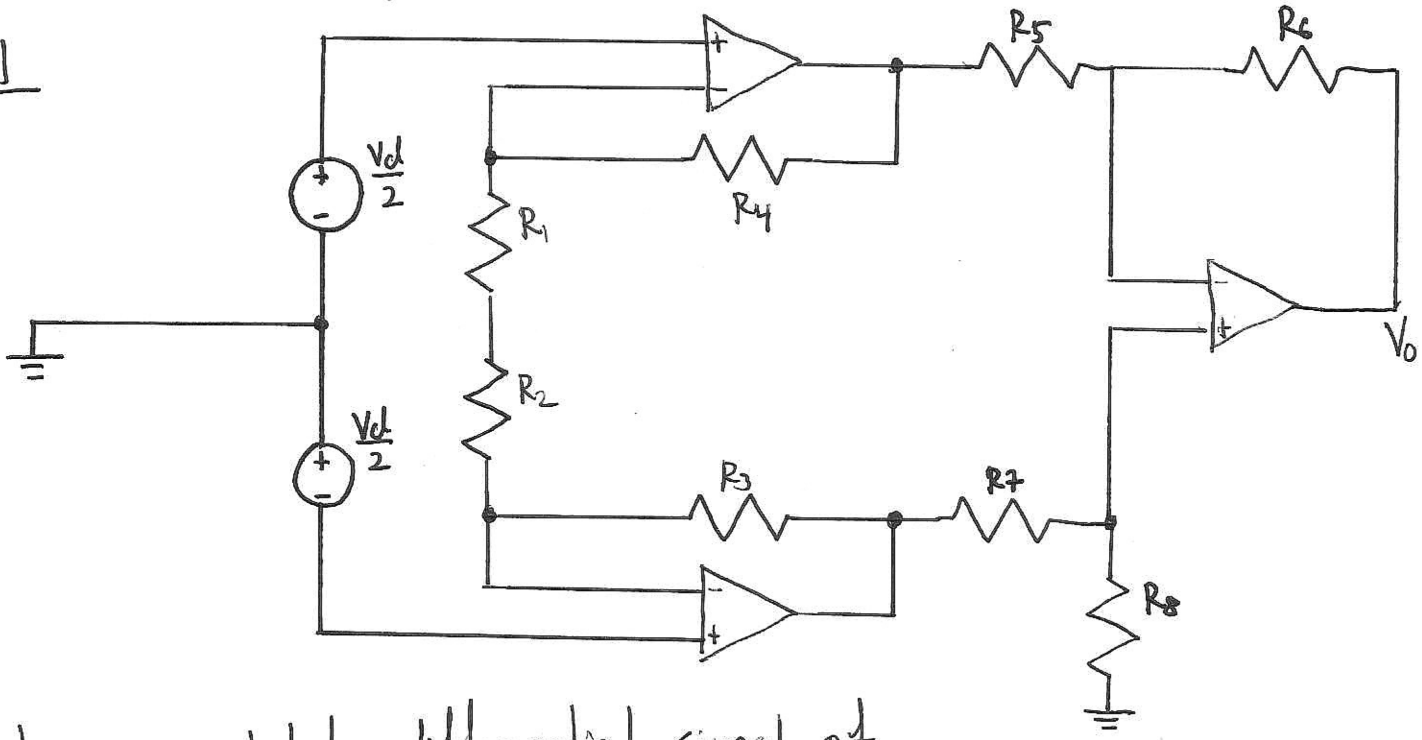
Some offset voltage (-44 mV) may appear at V_o, but this is caused by the in-amp itself.

Problem 4

Apply two differential voltages $\frac{V_d}{2} = 2.5\ mV$ with $f = 10\ Hz$.

What will the output be?

Sol



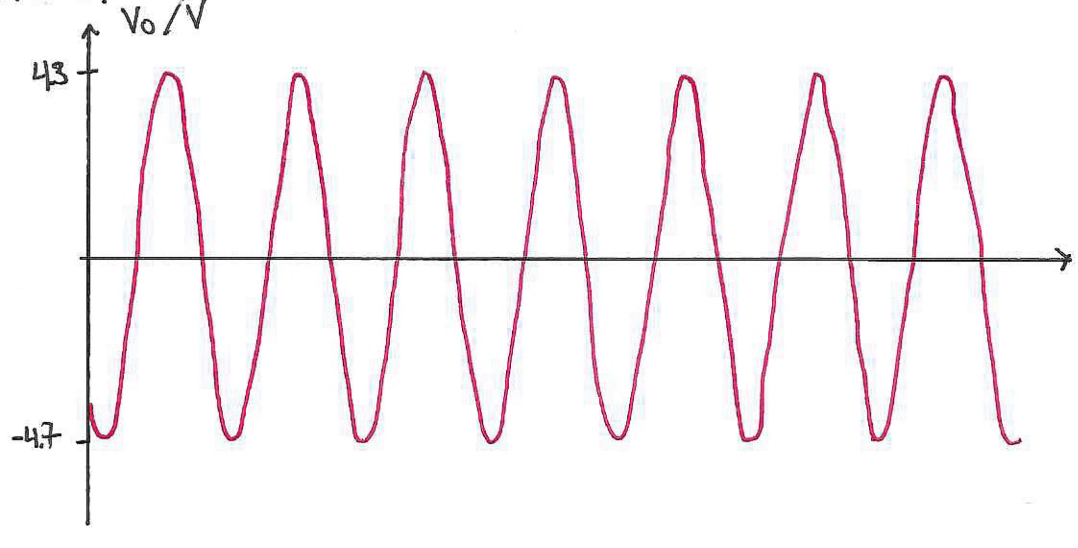
We have a total differential signal of

$$V_d = 5\ mV \cdot \sin(2\pi \cdot 10\ Hz)$$

We expect an output voltage

$$V_o = V_d \cdot G_d = 4.58 \cdot \sin(2\pi \cdot 10\ Hz)$$

with $V_{pp} = 9.16\ V$.



$V_{pp} = 4.3V - (-4.7) = 9V$ matches almost expection.

Any DC-offset will be highpass filtered.

Problem 5

Does changing the highpass filter components affect the DC-voltage attenuation?

Sol

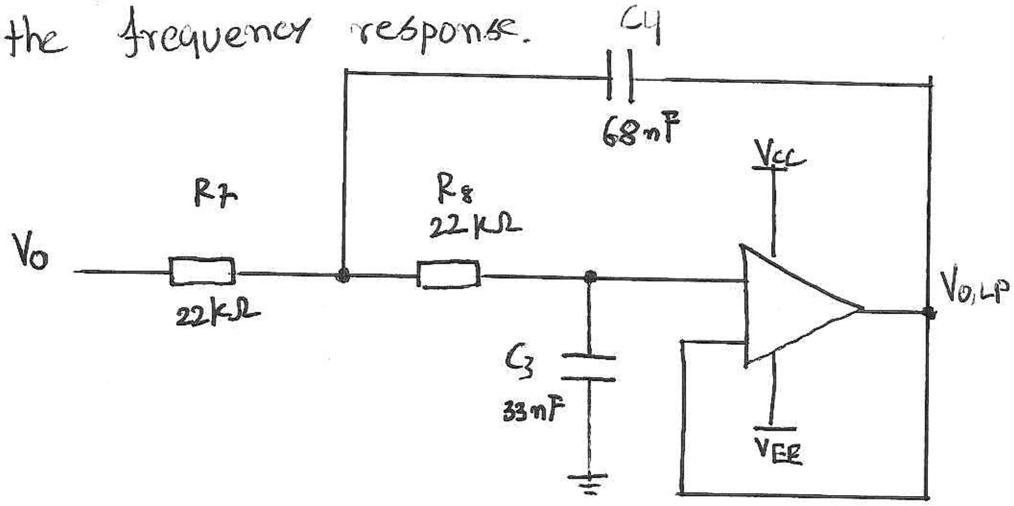
No.

The component values only affect cutoff frequency.

However, any highpass filter provides ∞ DC voltage attenuation.

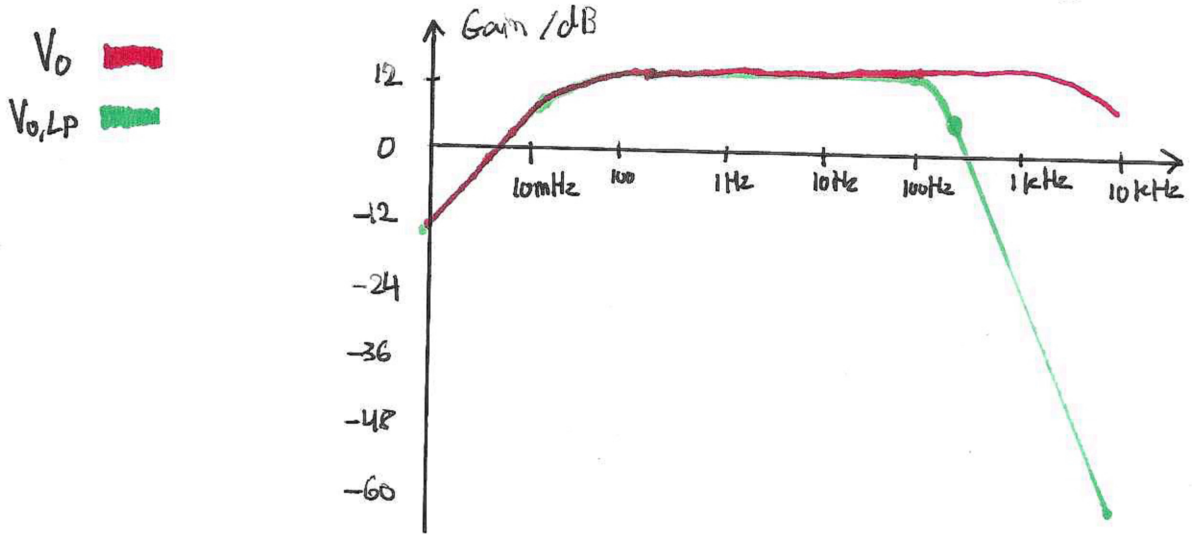
Problem 6

Cascade a lowpass filter after the in-amp and see how it affects the frequency response.



Sol

The lowpass should attenuate high frequent signals.



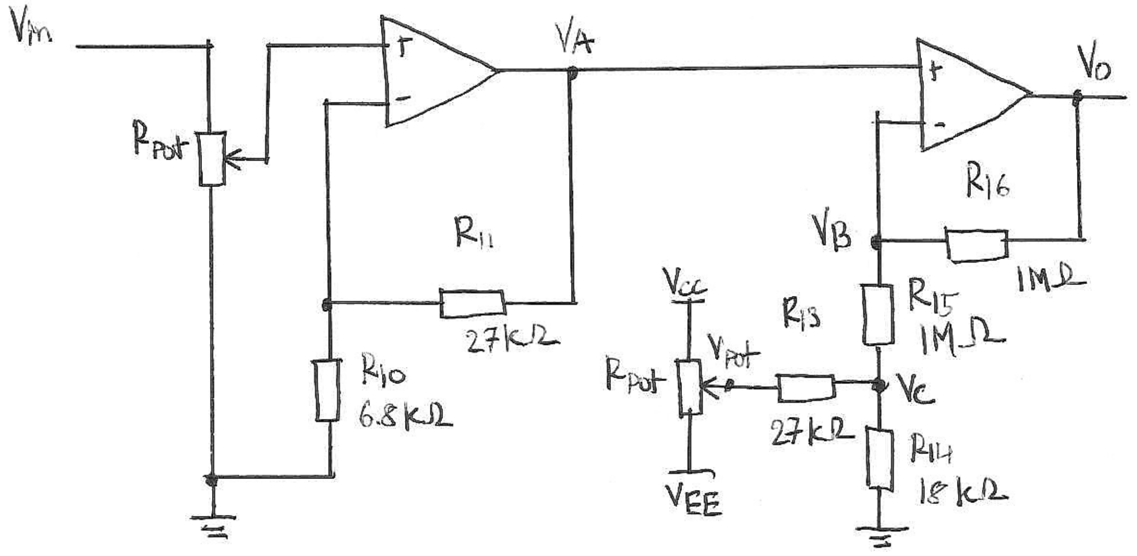
$|V_{o,LP}(10\ Hz)| = 13\ dB$

$|V_{o,LP}(1\ kHz)| = -20\ dB$

$$\frac{|V_{o,LP}(1\ kHz)|}{|V_{o,LP}(10\ Hz)|} = -20\ dB - 13\ dB = -33\ dB$$

Problem 7

To make sure $V_0 \in [0, 5\ V]$ a gain stage and offset stage can be used in extension to the Lp-filter. Find max gain and offset.



Sol

Call wiper position of first potentiometer $\alpha \in [0, 1]$.

$$V_A = \alpha V_{in}\left(1 + \frac{R_{11}}{R_{10}}\right)$$

Write node equations for V_B and V_C.

$$\frac{V_B - V_0}{R_{16}} + \frac{V_B - V_C}{R_{15}} = 0$$

$$\frac{V_C - V_B}{R_{15}} + \frac{V_C - V_{pot}}{R_{13}} + \frac{V_C}{R_{14}} = 0$$

Constraint: $V_B = V_A$.

Inserting values and solving for V_0, V_C yields:

$$V_0 = \underbrace{\alpha V_{in} \cdot 9.88}_{\text{Gain}} - \underbrace{0.395\ V_{pot}}_{\text{offset}}, \quad V_{pot} \in [-9V, 9V]$$

Max: Gain $= 9.88 \approx 10$, offset $= \pm 3.56$ V