1A P3/4 Examples Cribs

1) i) $g_m = \left.\frac{\partial I_D}{\partial V_{GS}}\right|_{V_{DS}}$ from graph $\approx 4.6\,mS$

$r_d = \left.\frac{1}{\frac{\partial I_D}{\partial V_{DS}}}\right|_{V_{GS}} \approx 40\,k\Omega$

Depletion mode as V_{GS} is $-ve$ (could also be a JFET)

ii) Operating point P $V_{GS} = -1V$

$\Rightarrow V_G = -1V$

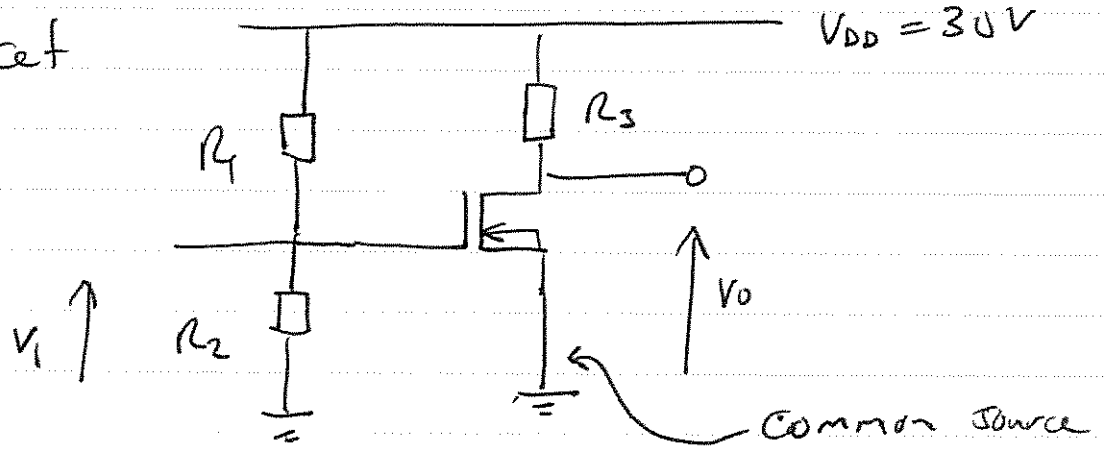
$R_1 = 1\,M\Omega$ (or suitably large R to set R_{in} of the amplifier)

$I_{DS} = 4mA$ $V_{DS} = 10V$

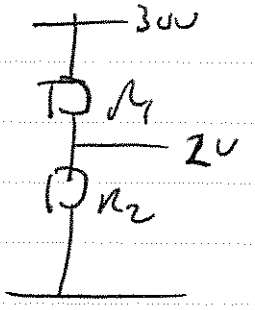
$\Rightarrow R_D = \frac{20-10}{4\times10^{-3}} = 2.5\,k\Omega$

From the SSM $R_1 = R_G$ $R_3 = R_D$
$R_2 = r_d$

2 a) cct



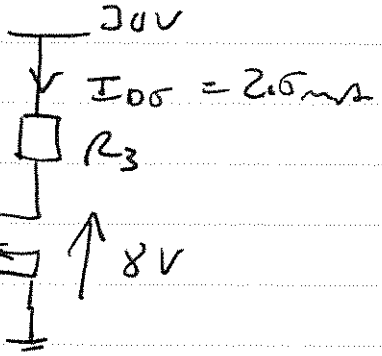
b) P.D. at input to gate



$\Rightarrow \frac{R_2}{R_1+R_2} \times 30 = 2$

$\Rightarrow \frac{R_1}{R_2} = 14$

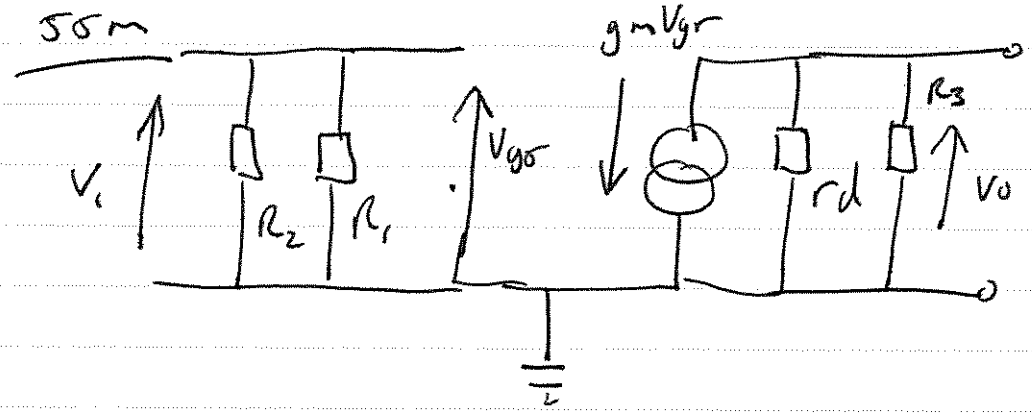
Drain resistor R_2



$\Rightarrow \frac{30-8}{R_3} = 2.5 \times 10^{-3}$

$R_3 = 8.8 k\Omega$ (8.2 kΩ std val)

c)



Gain $= \frac{V_o}{V_i}$ At input $V_i = V_{gs}$

at output $\frac{0-V_o}{rd \,//\, R_3} = g_m V_{gs}$

$\Rightarrow V_o = -g_m V_{gs} R_3 // rd$ $\Rightarrow \frac{V_o}{V_i} = -g_m R_3 // rd$

$= 4 \times 10^{-3} \times \frac{8.8k \times 10k}{8.8k + 10k}$

$= -18.7$

d) From 50m $R_{in} = \frac{V_i}{I_i} = R_1 // R_2 = \frac{R_1 R_2}{R_1 + R_2}$

If $R_{in} = 100k\Omega$ & $R_1 / R_2 = 14$

$\Rightarrow R_2 = 107k\Omega$ $R_1 = 1.5M\Omega$

nb

R_2 is not a standard value. If we choose $R_1 = 100k\Omega$ then $R_1 // R_2 < 100k\Omega$ which does not fit the brief. If we choose $R_2 = 120k\Omega$ (std value) then $R_1 = 1.7M\Omega$ ($1.8M\Omega$ std value)

This would give $V_{GS} = 1.875V$ (should be ok)

$R_{in} = 112.5k\Omega$ (meets spec)

3) This is a self biasing FET circuit. By setting the DC value of V_S to be 3V higher than V_G we can set $V_{GS} = -3V$

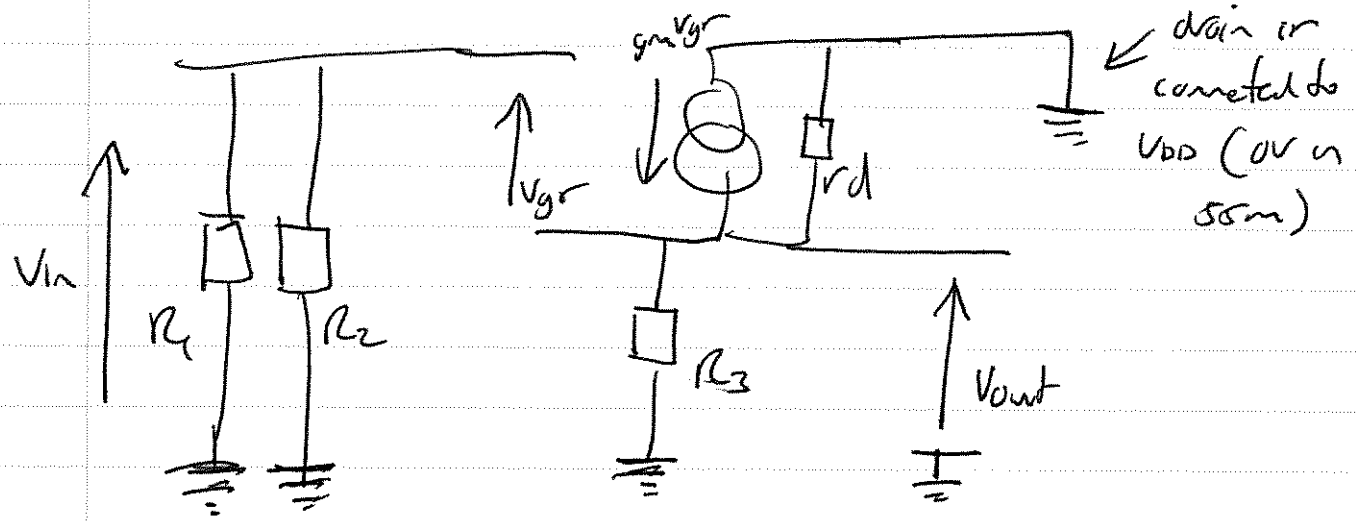
$\Rightarrow$ at source $V_S = 20 - V_{DS} = 13V$

$$I_{DS} = \frac{V_S - 0}{R_3} \Rightarrow R_3 = \frac{13}{2.6 \times 10^{-3}} = 5k\Omega$$

We want $V_{GS} = -3V \Rightarrow V_G = 10V$

P.D. at gate $V_G = \frac{R_2}{R_1 + R_2} \times V_{DD} \Rightarrow R_2 = 2M\Omega$

b) SSM — draw what we would appear in the ckt starting with the FET



c) at input we can see that

$$V_{in} = V_{gs} + V_{out}$$

At output we see that r_d is in parallel with R_3 hence the current source is pushing the current through $r_d \,//\, R_3$

$$\Rightarrow V_{out} = g_m V_{gs} \, R_3 // r_d$$

Combine to get

$$\frac{V_{out}}{V_{in}} = \frac{g_m R_3 // r_d}{1 + g_m R_3 // r_d} = 0.958$$

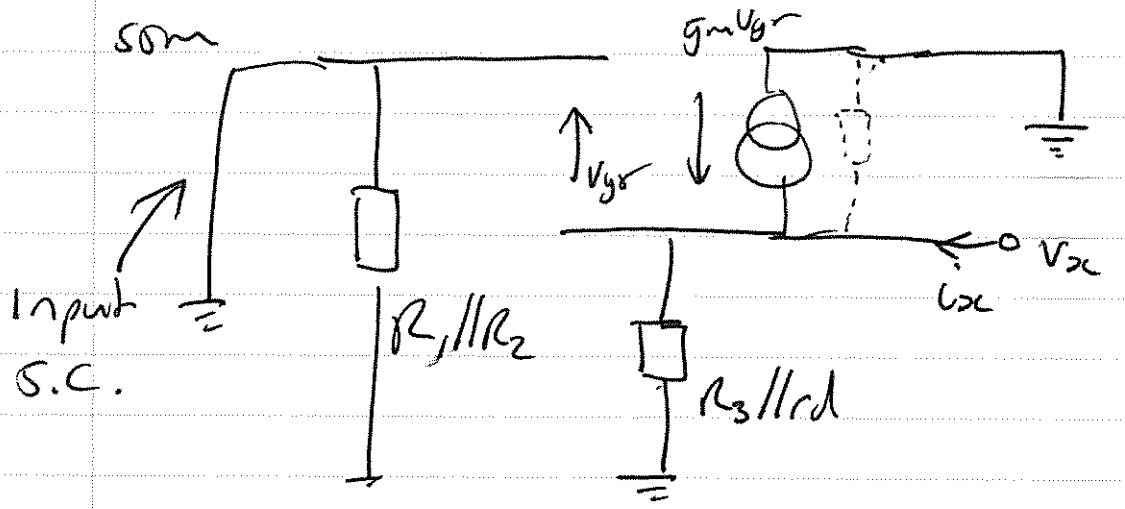
$$\approx 1$$

$$R_{in} = \frac{V_1}{i_1} = R_1 // R_2 = 1\,M\Omega$$

3c (cont) When calculating R_{out} be careful or $R_{out} \neq r_d // R_3$

To find R_{out} we apply a test voltage V_x at the output & measure the current i_x with the input shorted ~~out~~ circuited.

$$R_{out} = \left.\frac{V_x}{i_x}\right|_{i/p\ SC}$$



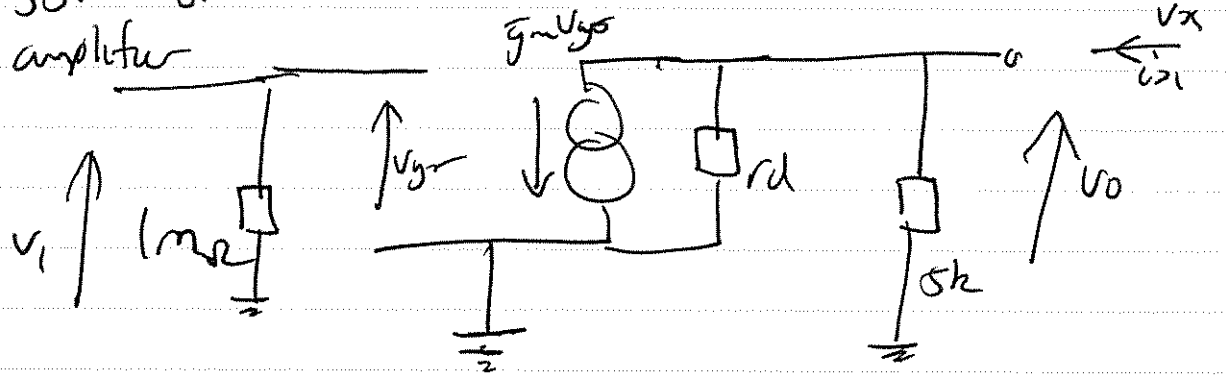
At the input we see that $V_{gs} = -V_x$

Sum currents at output

$$i_x + g_m V_{gs} = \frac{V_x - 0}{R_3 // r_d} \quad \leftarrow \text{sub}$$

$$\Rightarrow \frac{V_x}{i_x} = \frac{R_3 // r_d}{1 + g_m R_3 // r_d} = 192\,\Omega$$

4) 50m of amplifier



Need to calculate Rout for amplifier

$$\Rightarrow \quad R_{out} = \frac{V_x}{i_x} \Big|\Big|_{p\ oc}$$

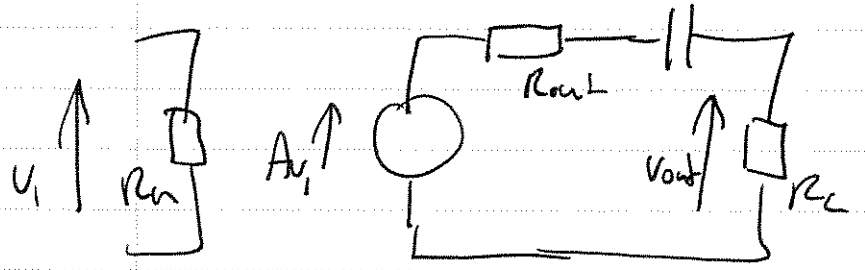
if $V_i = 0$ (i/p oc) then $V_{gs} = 0$

$$\Rightarrow V_{gs} g_m = 0$$

$$\Rightarrow \quad \frac{V_x}{i_x} = r_d \,||\, 5k$$

$$\Rightarrow \quad R_{out} = 3.33 k\Omega$$

We can now use the amplifier model:

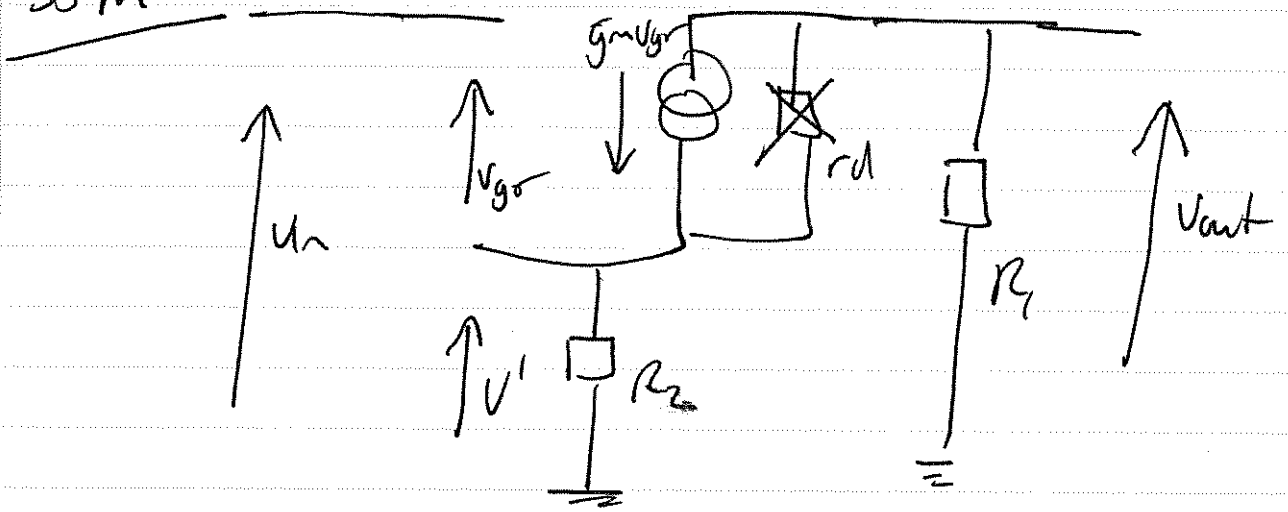


From data bracket earlier lectures we can find the 4/52 or 3dB frequency

$$f = \frac{1}{2\pi C (R_L + R_{out})}$$

$$\Rightarrow C = 2.08 \mu F \quad (3dB\ point)$$

5 SSM



Remove r_d (∞)

at input $V_{in} = V_{gs} + V'$ (1)

at output $\frac{0 - V_{out}}{R_1} = g_m V_{gs}$ (2)

at source $V' = g_m V_{gs} R_2$ (3)

Combine (1) (2) & (3) to get the gain

$$\frac{V_{out}}{V_{in}} = \frac{-g_m R_1}{1 + g_m R_2}$$ ← R_2 reduces gain

If we include capacitor C the replace R_2 with Z, where:

$$Z = R_2 // C = \frac{R_2}{1 + j\omega C R_2}$$

Substitute into above equations for the gain

$$\frac{V_{out}}{V_{in}} = \frac{-g_m R_1}{1 + \frac{R_2}{1+j\omega C R_2}} \times \frac{(1+j\omega C R_2)}{(1+j\omega C R_2)}$$

$$= \frac{-g_m R_1 (1+j\omega C R_2)}{1 + g_m R_2 + j\omega C R_2}$$

R_2 is required for the biasing to define the operating point (at or Q3) but it reduces the overall gain. The solution is to bypass R_2 with a suitable capacitor C to remove R_2 from the circuit at suitable frequencies

$$\Rightarrow \frac{V_{out}}{V_{in}} = -g_m R_1 \quad (R_2 \text{ bypassed})$$

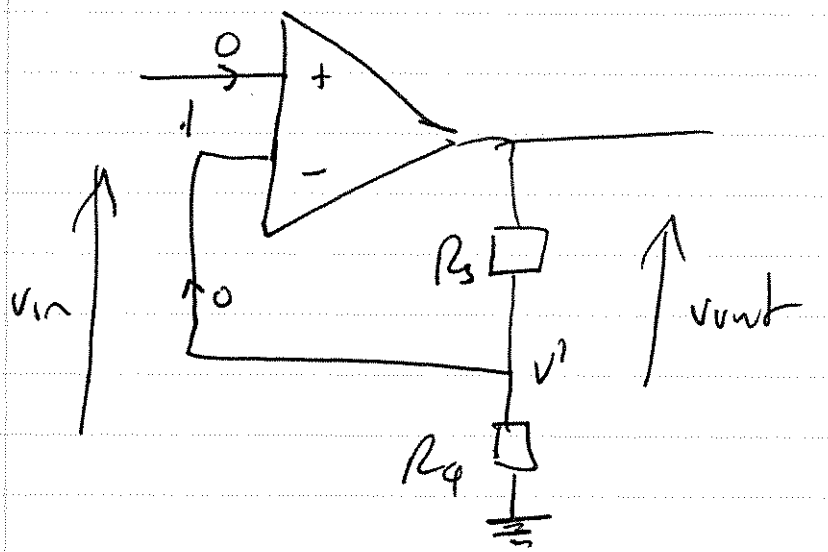
At $f = 1.59$ Hz Gain $= -9$

$f = 159$ Hz Gain $= -53$

$f = 15.9$ kHz Gain $= -80$

No the ckt is not complete. The gate voltage is not defined at DC as the FET has ∞ input resistance. We need to add a resistor or potential ~~divider~~ divider at the gate to provide a suitable DC bias to set V_{GS}.

6



Op-Amp ideal

$\Rightarrow A = \infty$

$V_+ = V_-$

no input current due to $R_{in} = \infty$

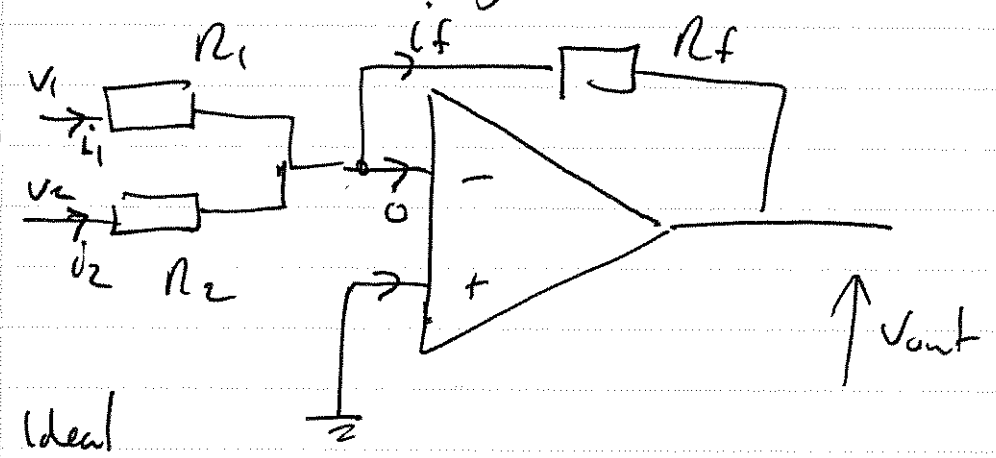
$V_+ - V_- = 0 \Rightarrow \quad V' = V_{in}$

R_3 & R_4 form a potential divider

$$V_{out} = V_{in} \frac{R_4}{R_3 + R_4} \quad \Rightarrow \frac{V_{out}}{V_{in}} = \frac{R_3 + R_4}{R_4}$$

$\Rightarrow$ Non-inverting amplifier.

7)



Ideal

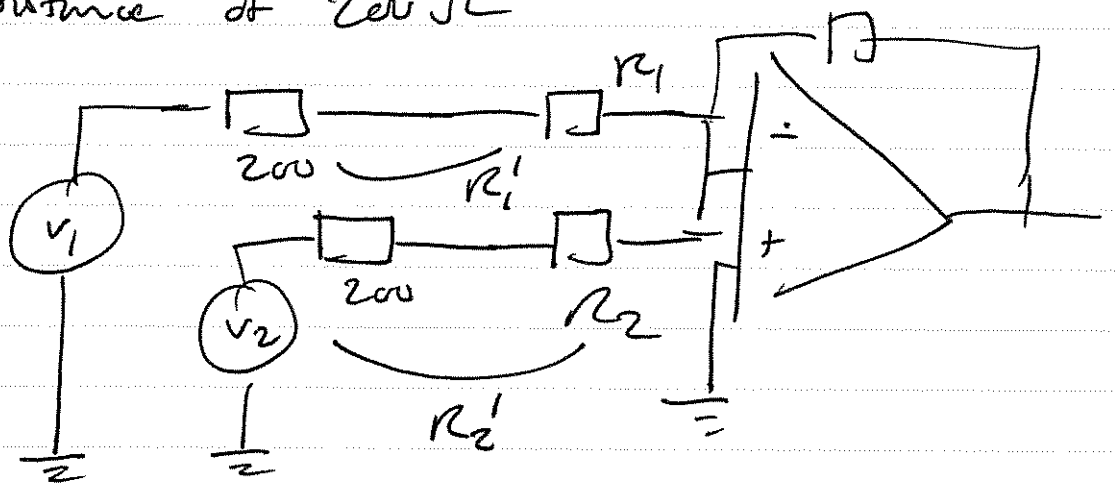
$\Rightarrow V_+ = V_- = 0$ no current into inputs

$\Rightarrow i_f = i_1 + i_2$

$$\frac{0 - V_{out}}{R_f} = \frac{V_1 - 0}{R_1} + \frac{V_2 - 0}{R_2} \quad \Rightarrow V_{out} = -\left(\frac{R_f}{R_1} V_1 + \frac{R_f}{R_2} V_2\right)$$

7 a) $R_f = 100k \Rightarrow \frac{R_f}{R_1'} = 200 \quad \frac{R_f}{R_2'} = 40$

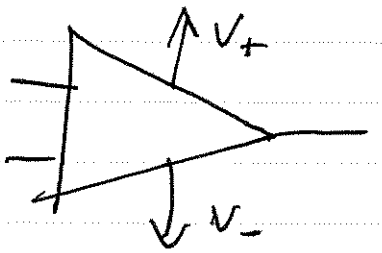
Both input sources have an internal resistance of 200Ω



$$\Rightarrow \frac{R_f}{200 + R_1} = 200 \qquad R_1 = 300\Omega$$

$$\frac{R_f}{200 + R_2} = 40 \qquad R_2 = 2300\Omega$$

b) Op-amp has bipolar supply



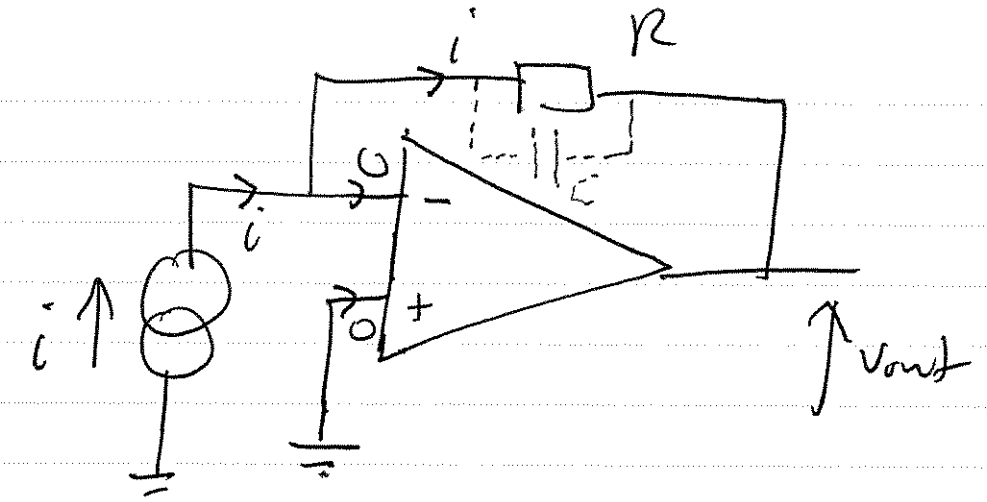
Output voltage should not exceed either ± V to avoid clipping of the output signal.
Max output voltage will occur when both v_1 and v_2 are at max (or peak) values

$v_1 = 10mV$ $\quad V_{out} = 200 \times 10 \times 10^{-3} + 40 \times 50 \times 10^{-3}$

$v_2 = 50mV$ $\quad = 4V$ (max output)

$\Rightarrow +V$ & $-V$ should be larger than $+4$ & $-4V$

8)



No current into inputs

Op-amp ideal $\Rightarrow V_+ = V_- = 0V$

$\Rightarrow i$ must travel through R

$$\Rightarrow \frac{0 - V_{out}}{R} = i$$

$$\frac{V_{out}}{i} = -R$$

b) Replace R with $Z = R \| C$

$$Z = \frac{R}{1 + j\omega CR}$$

$$\Rightarrow \frac{V_{out}}{i} = \frac{-R}{1 + j\omega CR}$$

3dB frequency (1/√2, 70% etc) $1 = \omega CR$

$$f_z \quad \frac{1}{2\pi RC} = 8\,kHz$$