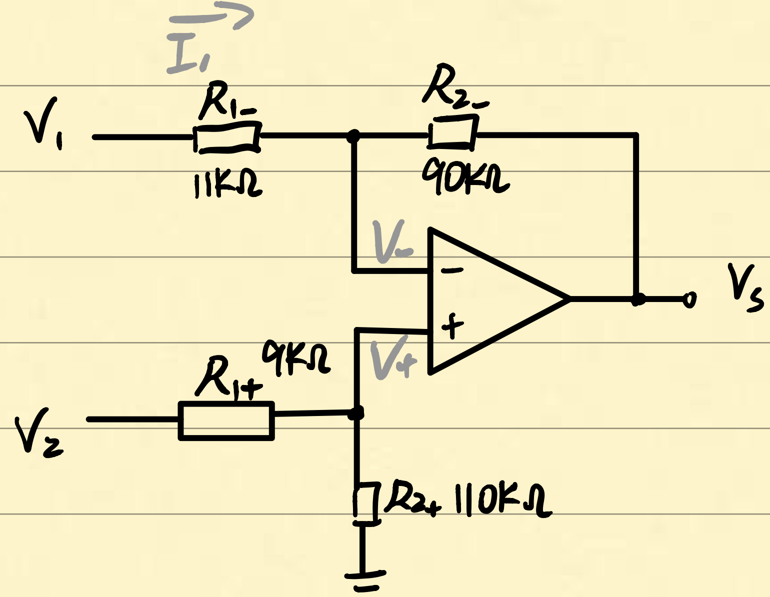
Problem 1:



a) what are output Voltage V_3 and common mode A_{cm} gain if the input voltage are $V_1 = 1V$ and $V_2 = 1V$?

$A_{cm} = 0.3058$	$V_3 = 0.3058$

$$V_+ = V_2 \cdot \frac{R_{2+}}{R_{1+}+R_{2+}} = 1 \cdot \frac{110K}{9K+110K} = 0.9244V$$

$$V_- = V_+ = 0.9244V$$

$$I_{1-} = \frac{V_1 - V_-}{R_{1-}} = 6.873 \times 10^{-6} A, \quad I_+ = I_- = 0A$$
$$= I_{2-}$$

$$V_3 = V_- - I_{1-} \cdot R_{2-} = 0.3058V$$
$$A_{cm} = \frac{V_3}{\frac{V_1+V_2}{2}} = 0.3058$$

b) What are the output voltage V_{out} and differential-moude A_{dm} gain if $V_1 = 0.5, V_2 = -0.5$

$\boxed{A_{dm} = -8.333}$ $\boxed{V_s = -8.333V}$

$$V_+ = V_2 \cdot \frac{R_{2+}}{R_{1+}+R_{2+}} = -0.5 \cdot \frac{110K}{9K+110K} = -0.4622V$$

$$V_- = V_+ = -0.4622V$$

$$I_L = \frac{V_1 - V_-}{R_L} = \frac{0.4622V}{11K\Omega} = 8.75 \times 10^{-5}A$$

$$V_s = V_- - I_L \cdot R_{2-} = -8.333V$$

$$A_{dm} = \frac{V_s}{(V_1 - V_2)} = -8.333$$

c) What is the common mode rejection ratio CMRR in dBs?

$\boxed{CMRR_{dB} = 28.7\ dB}$

$$CMRR = \frac{A_{dm}}{A_{cm}} = \left|\frac{-8.33}{0.306}\right| = 27.2$$

$$20\lg|CMRR| = 28.7dB$$

d) Calculate output Voltage V_s if $V_1 = 1.05V$ and $V_2 = 0.95V$

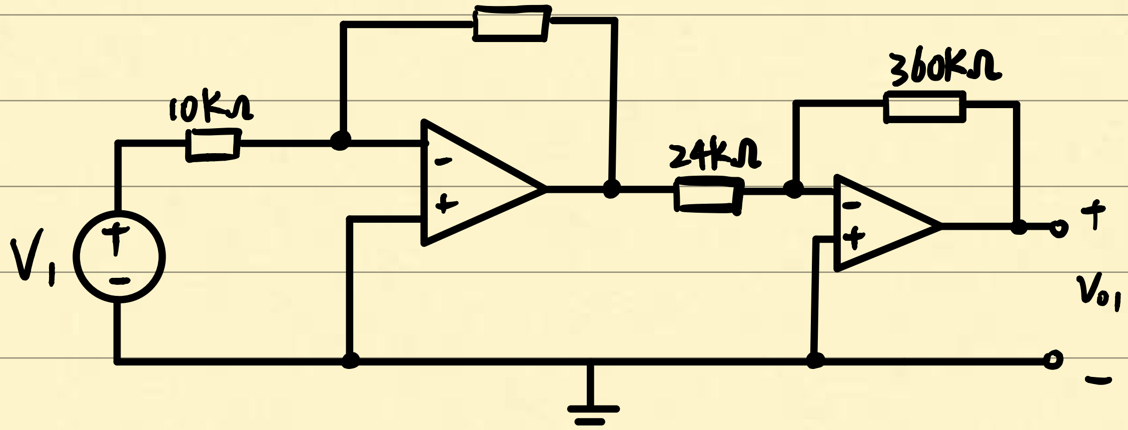
$\boxed{V_s = -0.527V}$

$$V_s = (V_1 - V_2) \cdot A_{dm} + \frac{V_1+V_2}{2} \cdot A_{cm}$$

$$= -0.833 + 0.306\ V$$

$$= -0.527\ V$$

Problem 2: Cascaded op-amps



a) What are voltage gain A_v, and R_{in}, R_{out}?
ideal? $(A \to \infty)$

$A_v = 70.5$	$R_{in} = 10k\Omega$	$R_{out} = 0\Omega$

ideal: $R_{in} = 10k\Omega$

$$A_v = \left(-\frac{47K}{10K}\right)\cdot\left(-\frac{360K}{24K}\right) = 70.5$$

$R_{out} = 0\Omega$ (ideal)

b) What are A_v^{actual}, R_{in}, R_{out} when op-amps have $A = 10^4$ and op-amp $R_o = 200\Omega$

$A_v = 70.35$	$R_{in} = 10.005k\Omega$	$R_{out} = 0.3145$

$$\beta_1 = \frac{10K}{10K+47K} = 0.17544, \quad T_1 = A\beta_1 = 1754.4$$

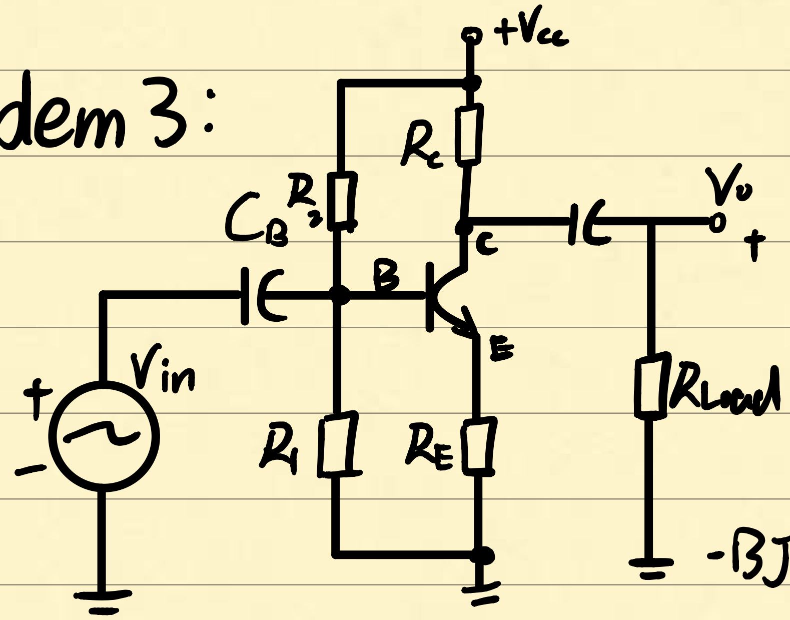
$$\beta_2 = \frac{24K}{24K+360K} = 0.0625, \quad T_2 = A\beta_2 = 625$$

$$A_v^{actual} = A_{v_1}\cdot\frac{T_1}{1+T_1}\cdot A_{v_2}\cdot\frac{T_2}{1+T_2} = 70.35$$

$$R_{in} = R_1 + \left(R_{id} // \frac{R_2}{1+A}\right) = 10.005k\Omega$$

$$R_{out} = \frac{R_o}{(1+T_2)} = 0.3195\Omega$$

Problem 3:



Ambient temperature $T=300K$

$V_{cc}=16V$, $R_C=2K\Omega$

$R_E=0.75K\Omega$

$R_1=2K\Omega$ $R_2=8K\Omega$

-BJT(三极管): $V_{BE}=0.7V, \beta=100$

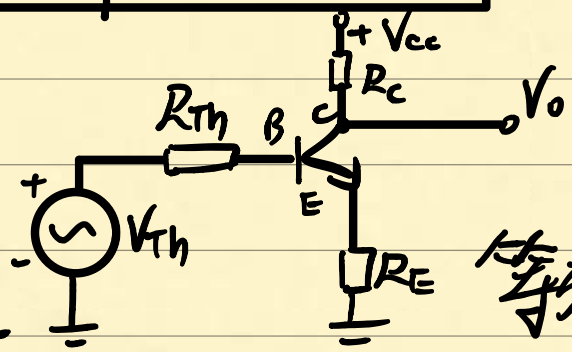
$V_A=130V$

$r_e=\dfrac{26mV}{I_c}$ $r_o=\dfrac{V_A}{I_c}$

a) operation point Q and re at 300K

$V_{CEQ}=7.088V$	$I_{CQ}=3.23\,mA$	$r_e=8.045\Omega$

at 300K, $r_e=\dfrac{26mV}{I_c}$.



等效

$$R_{Th}=R_1//R_2=\frac{1}{\frac{1}{2k}+\frac{1}{8k}}=1.6K\Omega$$

$$V_{Th}=\frac{R_1}{R_1+R_2}\cdot V_{cc}=\frac{2K}{2K+8K}\cdot 16V=3.2V$$

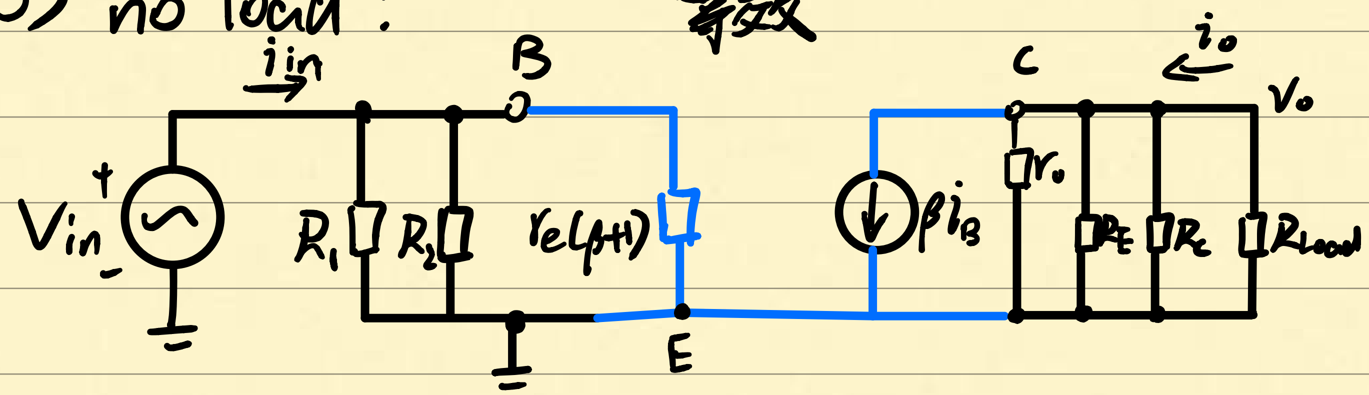
$$I_{BQ}=\frac{V_{Th}-0.7}{R_{Th}+(1+\beta)R_E}=3.23\times10^{-5}A,\ I_{cQ}=\beta I_B=3.23\times10^{-3}A$$

$$V_{CEQ}=V_{cc}-I_{cQ}R_c-I_{BQ}(1+\beta)\cdot R_E=7.088V$$

$$r_e=\frac{26mV}{I_c}=8.045\Omega$$

b) no load:

等效



$R_{in} = 538.88\Omega$	$R_{out} = 538.16\Omega$	$A_v[1] = -66.23$ (负)	$A_v[dB] = 36.42dB$

$$r_o = \frac{V_A}{I_C} = 40248\Omega$$

$$R_{in} = R_1 // R_2 // r_e \cdot (1+\beta) = 538.88\Omega$$

$$R_{out} = r_o // R_E // R_C = 538.16\Omega$$

$$A_{v\_noload} = \frac{V_{out}}{V_{in}} = \frac{-\beta \cdot i_{in} \cdot R_{out}}{i_{in} \cdot r_e \cdot (1+\beta)} = -66.23$$

$$A_{v\_noload\_dB} = 20\lg |A_{v\_noload}| = 36.42$$

C) with load: known $i_{out} = 1 \cdot \sin(1000t)\,mA$, $V_{in} = 100 \cdot \sin(1000 \cdot t)\,mV$

$R_{Load}[k\Omega]$	Load Av [1]	[dB]	Ai [1]	[dB]	Ap [1]	[dB]
6.08	60.8	35.68dB	5.388	14.63dB	327.59	25.16dB

$$i_{in} = \frac{V_{in}}{R_{in}} = 1.856 \times 10^{-4} \cdot \sin(1000 \cdot t)$$

(负参数)

$$V_{out} = i_{out} \cdot R_{out} + Av\_noload \cdot V_{in} = (0.538 - 6.623) \sin(1000t)$$
$$= -6.08 \cdot \sin(1000 \cdot t)$$

$$Av\_load = \frac{V_{out}}{V_{in}} = 60.8 \ \ldots\ldots 35.68\,dB$$

$$A_i = \frac{i_{out}}{i_{in}} = 5.388 \ \ldots\ldots 14.63\,dB$$

$$A_p = |Av\_load| \cdot |A_i| = 327.59 \ \ldots\ldots 25.16\,dB$$

☆ $10\lg A_p =$

$$R_{Load} = \left| \frac{V_{out}}{I_{out}} \right| = 6.08\,k\Omega$$