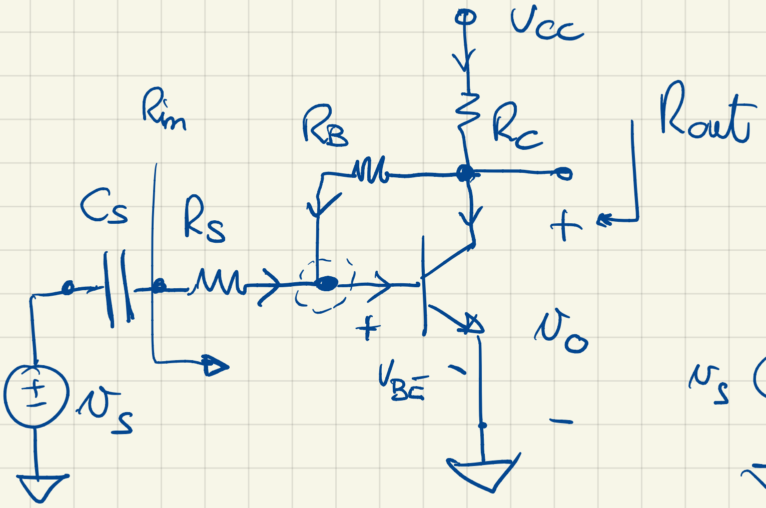
DISCUSS THE AMPLIFIER STABILITY.

BUT WE CAN ALSO SHAPE THE β-NETWORK TO ENHANCE THE AMPLIFIER'S STABILITY MARGINS (PHASE MARGIN AND/OR GAIN MARGIN)

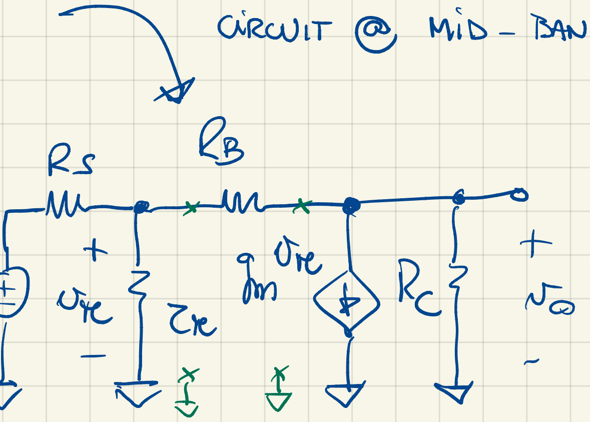
THIS IS CALLED COMPENSATION OF AN AMPLIFIER. THIS WILL BE THE OBJECT OF NEXT LESSONS.

EXAMPLE

CE AMPLIFIER WITH SELF-BIAS



SMALL SIGNAL EQUIVALENT CIRCUIT @ MID-BAND



1. FIND $A_v \triangleq \frac{v_o}{v_s}$, R_{in} AND R_{out}
2. DISCUSS THE POLE LOCATION
3. DRAW THE AMPLIFIER BLOCK DIAGRAM.

BIAS POINT ANALYSIS $V_{CC} = 5V$ $R_S = 100\Omega$

$I_C = 1mA$ $V_{BE} = 0.7V$

$I_B = 10\,\mu A$ $\beta_F = 100$ $\beta_0 = 200$

DESIGN CHOICE $V_o = V_{CC}/2 \rightarrow V_{R_B} = V_o - 0.7V = 1.8V$

$$R_B = \frac{V_{RB}}{I_B} = 180\,k\Omega$$

$$R_C = \frac{V_{CC} - V_o}{(\beta_F + 1)\,I_B} \cong 2.5\,k\Omega$$

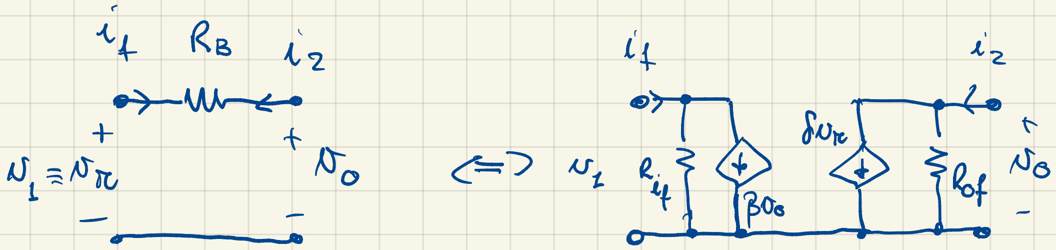
WITH CHOICES $V_{CE} = 2.5V > V_{CE_{SAT}}$ $I_C = 1mA$ F.A.R. BIAS ✓

$$g_m = \frac{I_C}{V_T} = 38 \cdot I_C = 38\ mS$$

$$V_T = 26\ mV \ @\ T = 300K$$

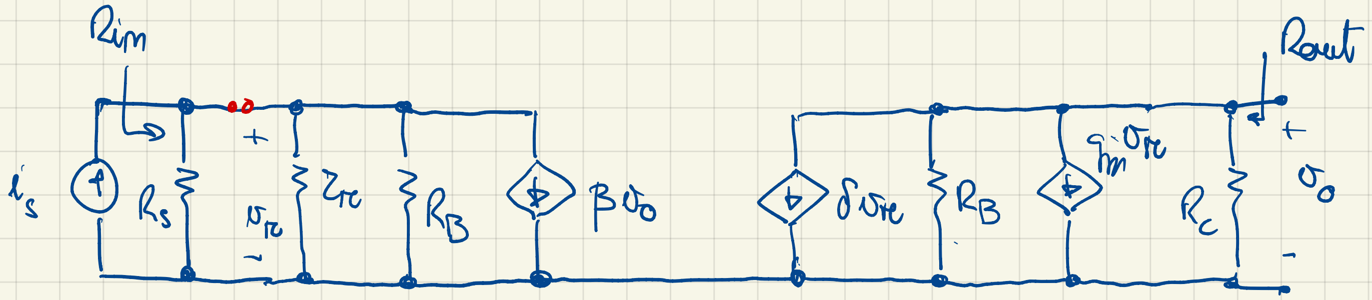
$$r_\pi = \frac{\beta_0}{g_m} \cong 5\ k\Omega$$

FEEDBACK TOPOLOGY: SHUNT - SHUNT (VOLTAGE SENSING, CURRENT MIXING) ⟹ TRANS-RESISTANCE AMPLIFIER



$$R_{if} = \left.\frac{v_1}{i_f}\right|_{v_o = 0} = R_B \qquad \beta = \left.\frac{i_f}{v_o}\right|_{v_1 \equiv v_\pi \equiv 0} = -\frac{1}{R_B}$$

$$R_{of} = \left.\frac{v_o}{i_2}\right|_{v_1 = v_\pi = 0} = R_B \qquad \delta = \left.\frac{i_2}{v_\pi}\right|_{v_o \equiv 0} = -\frac{1}{R_B}$$



$$i_s = \frac{v_s}{R_s}$$

- UNILATERALITY $\quad g_m - \frac{1}{R_B} \cong g_m \qquad \delta$ is NEGLIGIBLE

  $\nwarrow \simeq 5.\ \mu S$

- OPEN LOOP PARAMETERS $\quad (\beta = 0,\ \delta \cong 0)$

$$A_{ol} = \frac{v_o}{v_s} = -(R_s \| R_B \| r_\pi) \cdot g_m \cdot (R_B \| R_C) = -R_{in}^{ol}\, g_m \cdot R_{out}^{OL}$$

$$R_{in}^{ol} = R_s \| R_B \| r_\pi \qquad R_{out}^{ol} = R_B \| R_C$$

- CLOSED LOOP PARAMETERS

$$A_F \triangleq \frac{A_a}{1+\beta A_a} = -\frac{R_{in}^{a}\, g_m\, R_{out}^{a}}{1-\frac{1}{R_B}\cdot\left(-R_{in}^{a}\, g_m\, R_{out}^{a}\right)} = -\frac{R_{in}^{a}\, g_m\, R_{out}^{a}}{1+g_m \frac{R_{in}^{a}}{R_B}\cdot R_{out}^{a}}$$

$$\cong -\frac{10^2\cdot 38\cdot \cancel{10^{-3}}\; 2.5\, \cancel{10^3}}{1+\frac{10^4}{1.8\cdot 10^5}} \cong -\frac{10^4}{1.05} \cong 9.5\, 10^3\ [\Omega]$$

$$R_{in}^{F} = R_{in}^{OL}/(1+\beta A_a) \cong 95\ \Omega$$

$$R_{out}^{F} = R_{out}^{a}/(1+\beta A_a) \cong 2.35\ k\Omega$$

PARAMETER ADAPTATION

$$R_{in}' = \frac{1}{\frac{1}{R_{in}^{F}}-\frac{1}{R_s}} = \frac{1}{0.0105-0.01} = \frac{1}{0.0005} = 2\cdot 10^3\ \Omega$$

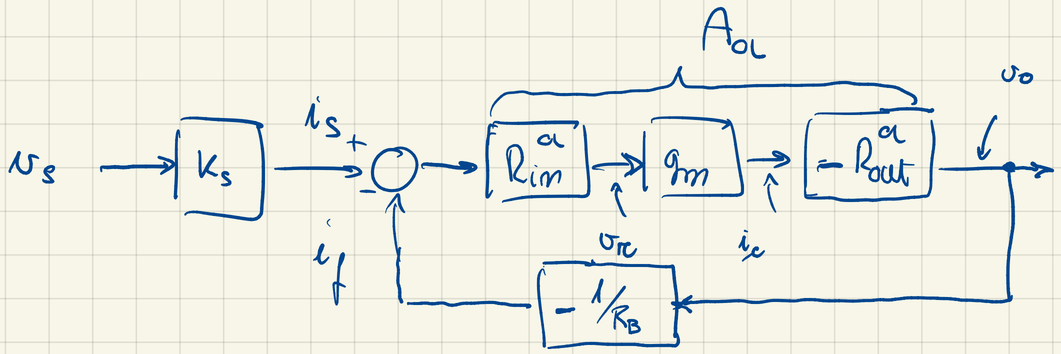
$$R_{in} = R_s + R_{in}' = 2.1\ k\Omega$$

$$R_{out} = R_{out}^{F}$$

K_s INPUT SCALING FACTOR

$$A_v = \frac{v_o}{v_s} = \frac{v_o}{i_s}\cdot\frac{i_s}{v_s} = A_F\cdot \frac{1}{R_s}$$

BLOCK DIAGRAM OF THE AMPLIFIER



○ POLE LOCATION (CONSIDERING ONLY $C_S \Rightarrow C_\pi$ AND C_μ NEGLIGIBLE)

$$R_{C_S} = R_{in} = R_S + R_{in}' = 2.1\ k\Omega$$

$$\tau_{C_S} = C_S \cdot R_{C_S} \Rightarrow \omega_{C_S} = \frac{1}{\tau_{C_S}} = f_p = \frac{\omega_{CS}}{2\pi}$$

$$R_{C_S}^{a} = R_S + r_\pi // R_B \cong 4.9\ k\Omega$$

FEEDBACK MADE R_{C_S} SMALLER $\Rightarrow$ τ_{C_S} BECAME SMALLER

$\Rightarrow$ ω_p is LARGER !!

NO BANDWIDTH WIDENING IS FOUND.

EXERCISE #1

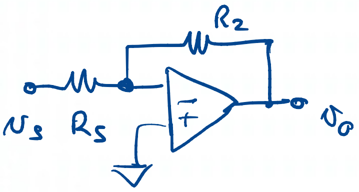
Consider the amplifier in the figure, whose parameters at T = 25°C are the following:
V_{CC}=24V, R_2=500kΩ, R_3=3kΩ, R_S=100kΩ

Q1: I_{C1}=0.6mA, V_{BE}=0.7V, β_F=50, β_0=80
Q2: V_{BE}=0.7V, β_F=50, β_0=80

Considering C_1 a short circuit at mid-band, determine:

1) The bias values of I_{C2}, V_{CE1}, V_{CE2} and the value of R_1; ←
2) The type of feedback and the value of β;
3) The open loop amplifier gain A_{OL};
4) Voltage gain $A_V=V_o/V_s$
5) Input resistance R_{in}.

MOST POPULAR CASE

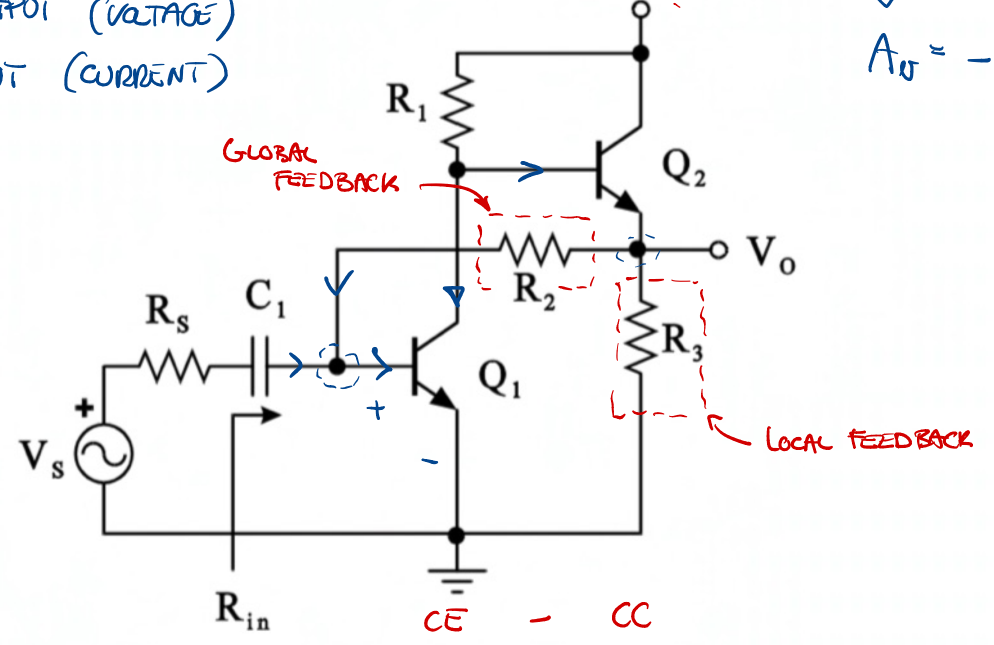


$A_v = -\frac{R_2}{R_S} = -5$

FEEDBACK TOPOLOGY ?

SHUNT @ OUTPUT (VOLTAGE)

SHUNT @ INPUT (CURRENT)



$A_v = -5$?

1. BIAS POINT ANALYSIS

$$I_{B_1} = \frac{I_{C_1}}{\beta_{F_1}} = 12\,\mu A$$

$$V_o = V_{BE_1} + R_B \cdot I_{B_1} = 0.7V + 12\cdot10^{-6}\cdot 5\cdot10^{5} = 6.7V$$

$$V_{CE_2} = V_{CC} - V_o = 24 - 6.7 = 17.3\,V \gg V_{CE_{SAT}}$$

$$I_{R_3} = \frac{V_O}{R_3} = \frac{6.7}{3k} = 2.23\ mA$$

$$I_{E_2} = I_{R_3} + I_{B_1} = 2.242\ mA$$

$$I_{B_2} = \frac{I_{E_2}}{\beta_{F_2}+1} = \frac{2.24}{51} = 44.8\ \mu A$$

$$I_{R_1} = I_{B_2} + I_{C_1} = 0.6\ mA + 45\ \mu A = 0.645\ mA$$

$$V_{B_2} = V_O + V_{BE_2} = 7.4\ V = V_{CE_1} >> V_{CE_{SAT_1}} = 0.2\ V$$

$$V_{R_1} = V_{CC} - V_{B_2} = 24 - 7.4 = 16.6\ V$$

$$R_1 = \frac{V_{R_1}}{I_{R_1}} = \frac{16.6}{0.645} \cdot 10^3 \cong 25.7\ k\Omega$$

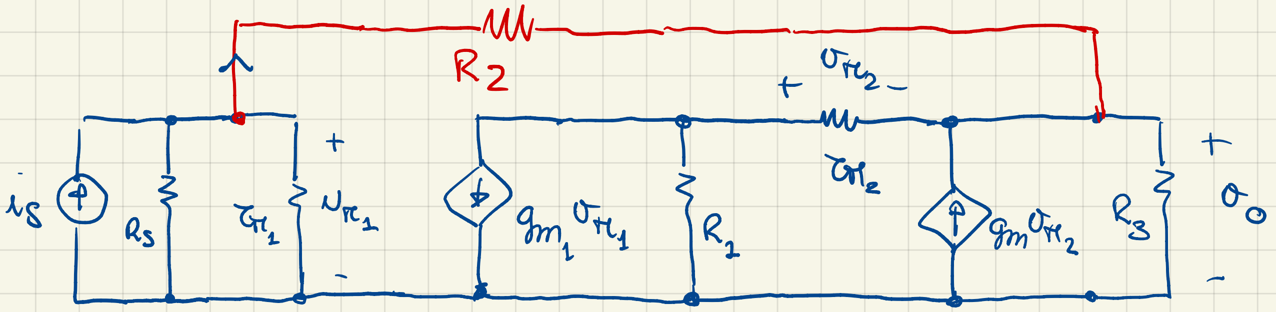
BOTH TRANSISTORS ARE BIASED IN THE FORWARD ACTIVE REGION. ✓

SMALL SIGNAL CIRCUIT PARAMETERS

$$g_{m_1} = \frac{I_{C_1}}{V_T} \cong 25\ mS \qquad g_{m_2} = \frac{I_{C_2}}{V_T} \cong 85\ mS$$

$$r_{\pi_1} = \frac{\beta_{o1}}{g_{m_1}} \approx 3.25\ k\Omega \qquad r_{\pi_2} = \frac{\beta_{o2}}{g_{m_2}} = 946\ \Omega$$

2.

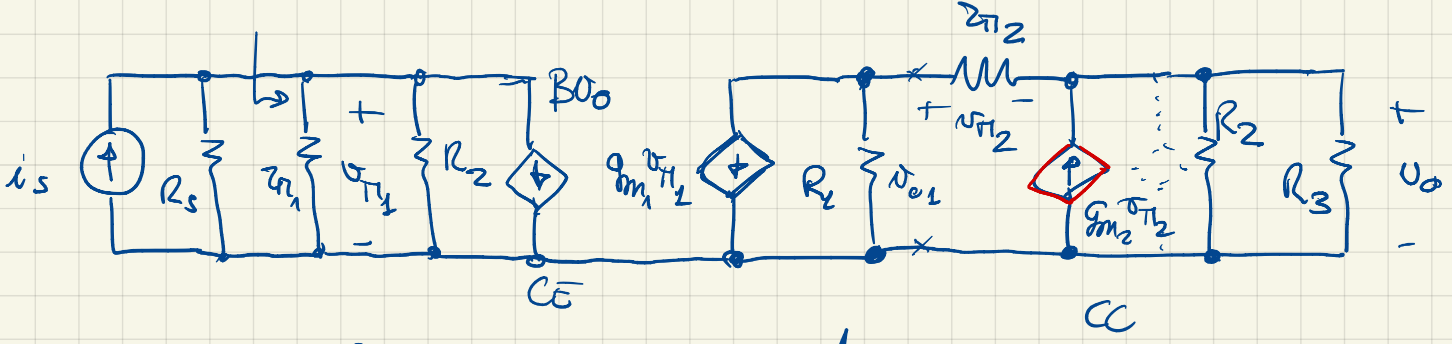


$$i_s = \frac{v_s}{R_s}$$

FEEDBACK TOPOLOGY: SHUNT - SHUNT →

TRANSRESISTANCE AMPLIFIER

3. EQUIVALENT CIRCUIT



NEGLECTING δ AND WITH $\beta = -\frac{1}{R_2}$

OPEN LOOP PARAMETERS $\beta = 0$

$$\frac{v_o}{i_s} = A_{OL} = -\underbrace{\left(R_s \,//\, R_2 \,//\, r_{\pi_1}\right)}_{\simeq\, r_{\pi_1}} \underbrace{g_{m_1}}_{24\,mS} \cdot \underbrace{\left(R_1 \,//\, R_{in_2}^{CC}\right)}_{25\,k} \cdot \underbrace{\frac{(\beta_0+1)\, R_2//R_3}{r_{\pi_2} + (\beta_0+1) R_2//R_3}}_{\cong\, 1} \cong -1.9\,M\Omega$$

$$R_{in_2}^{CC} = r_{\pi_2} + (\beta_0+1)\, \underbrace{R_2//R_3}_{2.98\,k\Omega} \cong 242\,k\Omega$$

$$A_F = \frac{A_{OL}}{1+\beta A_{OL}} = \frac{-1.9\cdot 10^6}{1+3.8} = -396\,k\Omega$$ (DIFFERS FROM $-R_B$)

T IS NOT >> 1

4. $$A_v = \frac{v_o}{v_s} = \underbrace{\frac{v_o}{i_s}}_{A_F} \cdot \underbrace{\frac{i_s}{v_s}}_{i_s = \frac{1}{R_s}} = \frac{A_F}{R_s} \; -3.96$$ (INSTEAD OF -5)

5. $$R_{in} = \frac{1}{\frac{1}{R_{in}^F} - \frac{1}{R_s}} \cong 706\,\Omega$$ WITH $$R_{in}^F = \frac{R_{in}^{OL}}{1+\beta A_{OL}}$$

HOMEWORK

EXERCISE #2

Consider the two stage amplifier in the figure below. The circuit parameters at T=25°C are the following:

$V_{CC} = 24$ V, $R_S = 0.6$ kΩ, $R_1 = 300$ kΩ, $R_2 = 270$ kΩ, $R_3 = 4.7$ kΩ, $R_F = 10$ kΩ

Q_1: $I_{DSS} = 1$ mA, $V_T = 5$ V, $r_d = \infty$

Q_2: $I_{CQ} = -2$ mA, $V_{CEQ} = -8$ V, $V_{BE} = -0.65$ V, $\beta_F = \beta_0 = 100$, $r_o = \infty$

Determine:

1) the values of resistances R_4 e R_L;

2) the type of feedback;

3) the feedback gain β;

4) the open loop amplifier gain A_{OL};

5) the closed loop amplifier gain A_F;

6) the voltage gain of the circuit $A_V = V_O/V_S$;

7) the indicated output resistance R_{OUT}.