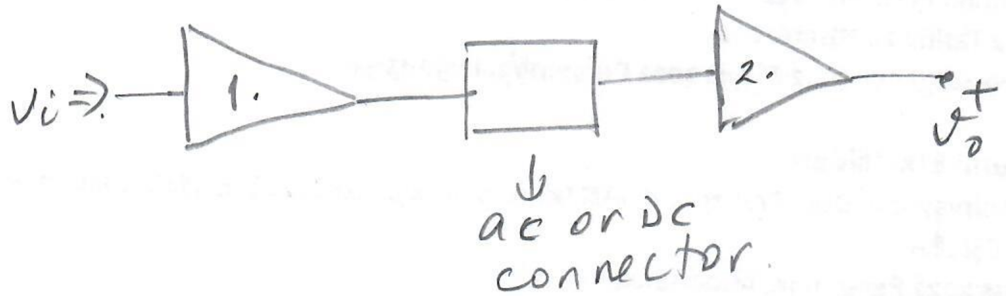
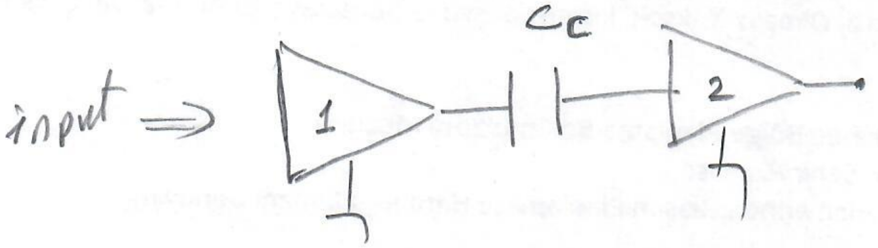
Multistage Amplifiers

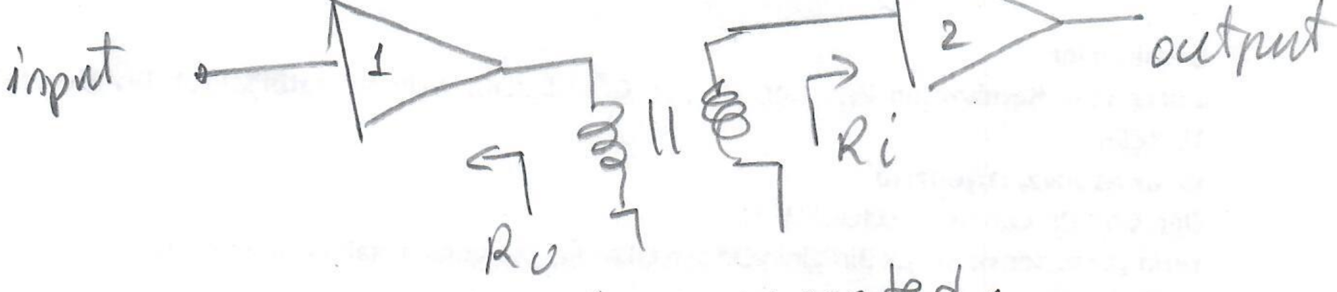
- AC amplifiers
- DC amplifiers.



1/ AC Amplifiers.

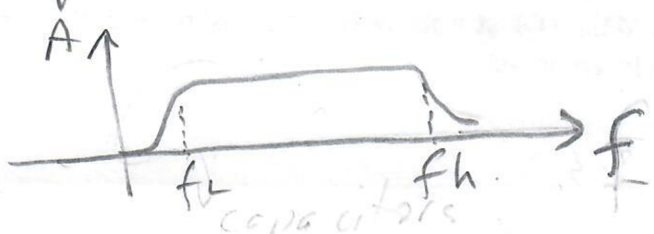


capacitor or a transformer used.



$R_o = R_i$ is expected.

Frequency - Gain graphic



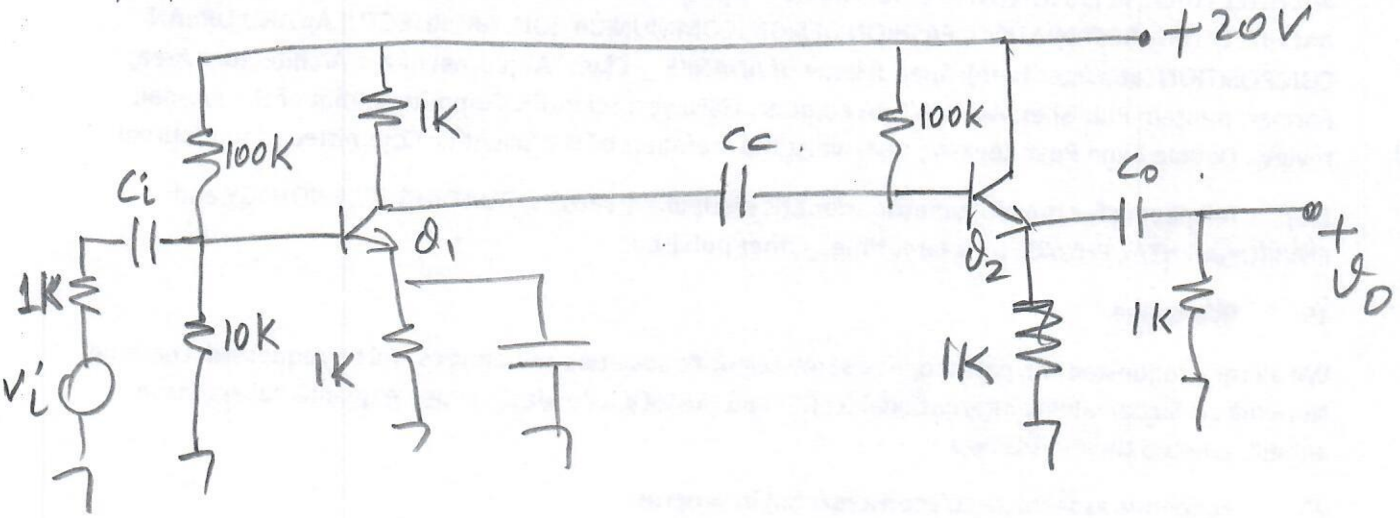
At low frequencies "c" are effective
" high frequencies $L \Rightarrow Z = wL$ "

$w \to 0 \Rightarrow X_L \Rightarrow 0.$

$w \to \infty \Rightarrow X_L = \infty$

So, at low frequencies $X_C = \frac{1}{wC} \uparrow \Rightarrow A \downarrow$
" " high " $X_L = wL \uparrow \Rightarrow A \downarrow.$

For the circuit shown;



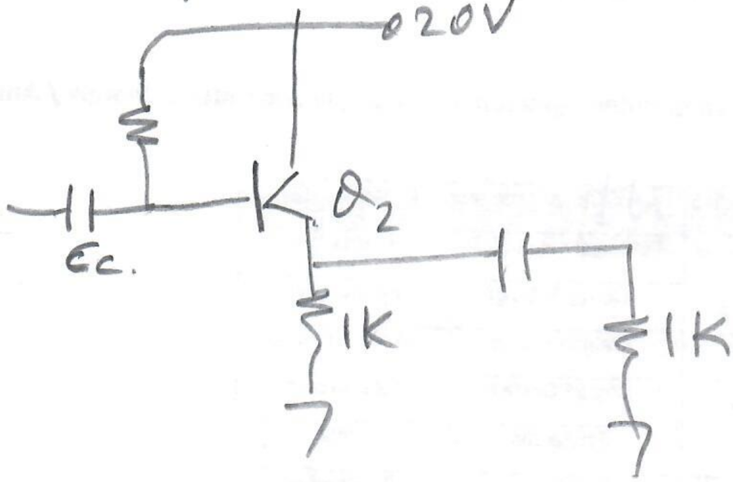
$h_{fe} = 100$, $V_o = 0{,}6V$, $I_{co} = 0A$, $V_{CESAT} \cong 0V$.
(capacitors are short for a.c)

a) Draw AC and DC load lines

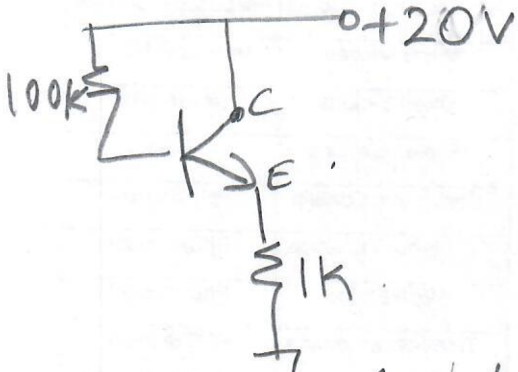
b) $A_v = \frac{v_o}{v_i}$

c) $v_{imax} = ?$

Let us start the solution from the output



DC Analysis / DC equivalent circuit:



KVL: for the input loop:

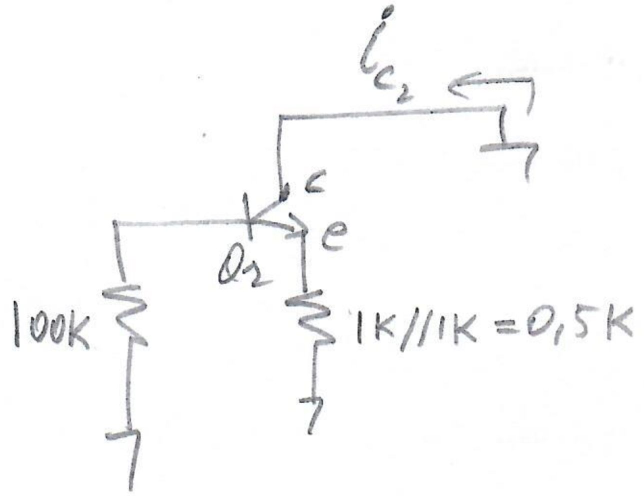
$$20 = 100K \cdot I_{BQ} + V_0 + 1K(1+100)\, I_{BQ_2}$$

$$I_{BQ} = 97\mu A \Rightarrow I_{CQ} = h_{fe} \cdot I_{BQ} = 9{,}7\ mA$$

$$V_{CEQ} = 20 - 1K \cdot I_{CQ} \Rightarrow \text{KVL (output)}$$

$$V_{CEQ} = 10{,}3V \cong 10V.$$

ac analysis



$v_{ce_2} = -500\, i_{c_2}$

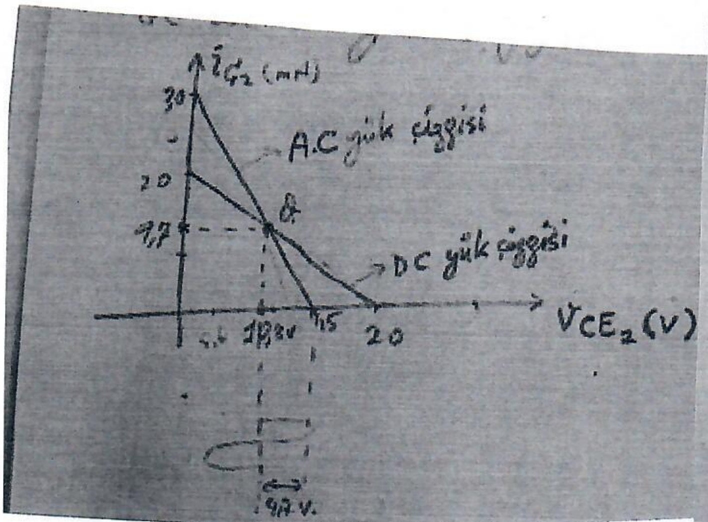
$i_{C_2} = I_{CQ_2} + i_{c_2}$

$v_{CE_2} = V_{CEQ_2} + v_{ce_2}$

$$v_{CE_2} = V_{CEQ_2} - 500\Omega\,(i_{C_2} - 9{,}7\,mA)$$

$$v_{CE_2} = 10 + 500 \times 9{,}7 \cdot 10^{-3} - 0{,}5K \cdot i_{C_2}$$

$$\boxed{v_{CE_2} = 15 - 0{,}5K \cdot i_{C_2}}$$ ac + DC eq.



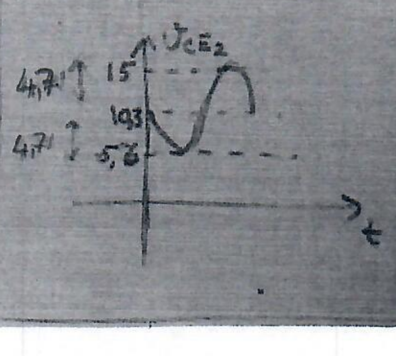
$v_o = -v_{ce_2}$

$v_o = 4{,}7 \sin \omega t$.

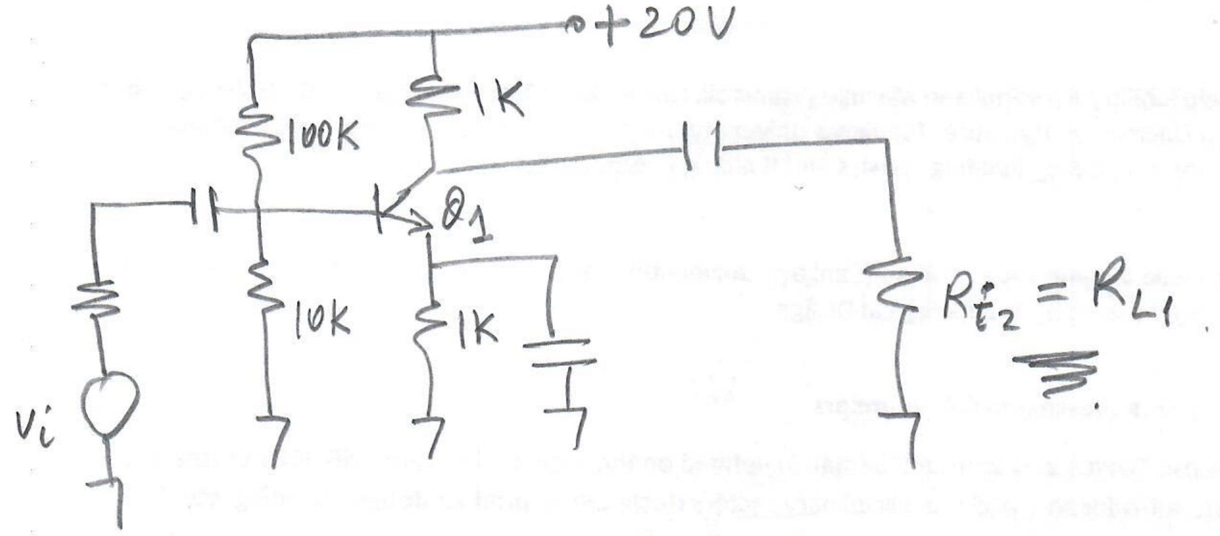
(eğer istersen iz veya $v_{CE_2} = 15 - 0{,}5K\, i_{C_2}$)

$i_{C_2} = 0 \quad v_{CE_2} = 15$

$v_{CE_2} = 0 \quad i_{C_2} = 20$

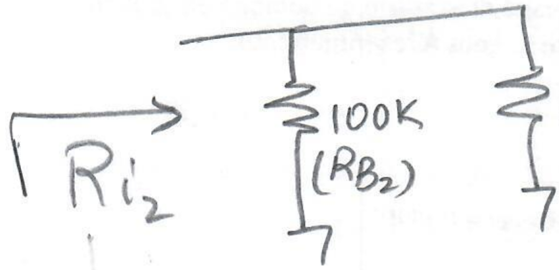


Let us now solve the 1. amplifier.



Note that $R_{i_2} = R_{L_1}$

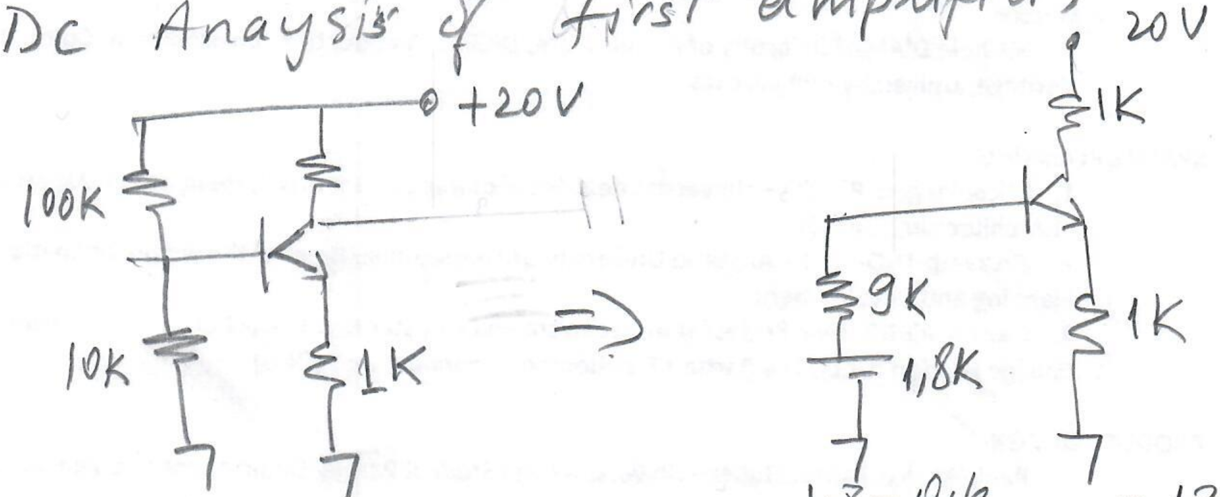
According to the common emitter of Q_2



$$R_i' = h_{ie} + R_{e_2}(1+100) = 51K$$
$$1 + 0{,}5K\,(101) = 51K$$

$$R_{i_2} = 100K // R_i' = 100K // 51K \cong 33K$$

DC Anaysis of first amplifier;

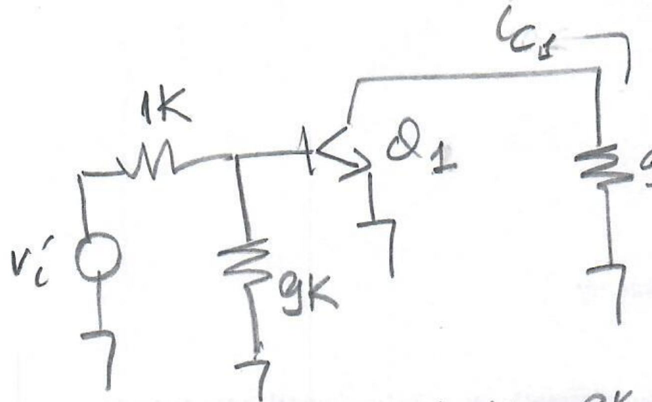


$$I_{BQ_1} = \frac{1{,}8 - 0{,}6}{9K + (101)K} = 13\,\mu A$$

$$I_{CQ_1} = h_{fe} I_B = 1{,}3\ mA$$

$$V_{CEQ_1} = 20 - 2K\, I_{CQ_1} = 17{,}4\ V$$

ac. analysis:



$970\Omega = R_{C_2} // R_i$

$= 1K // 33K = 970\Omega$

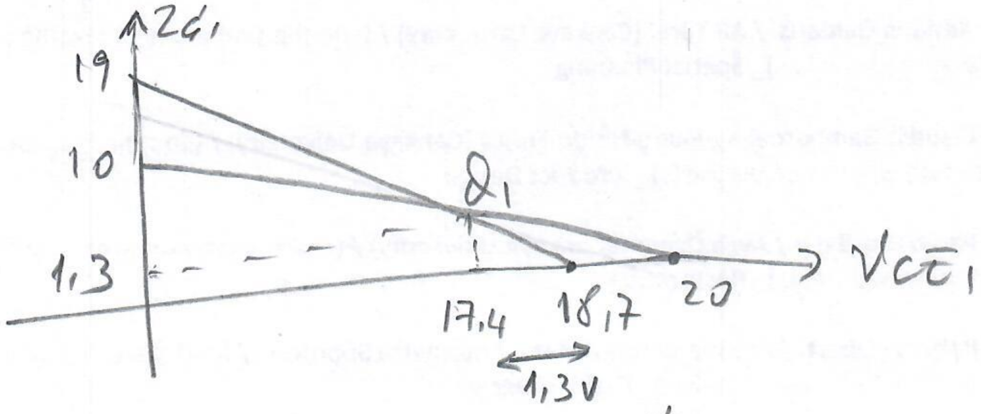
$100K // 10K = 9K.$

ac equation

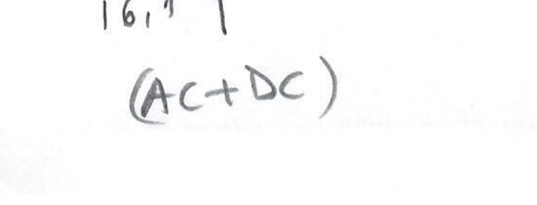
$$v_{ce_1} = -970\, i_{c_1}$$

$$v_{CE_1} - V_{CEQ_1} = -970\,(i_{C_1} - I_{CQ_1})$$

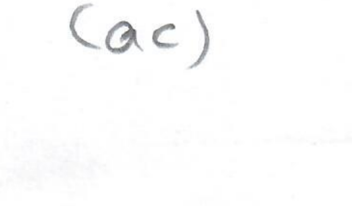
$$v_{CE_1} = 17,4 + 970\, I_{CQ_1} - 970\, i_{C_1}$$



$$v_o = 1,3 \sin \omega t$$

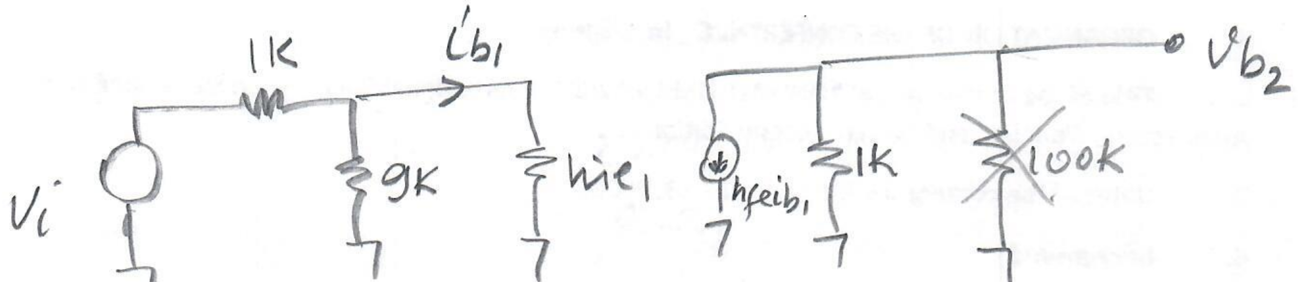


(AC+DC)



(ac)

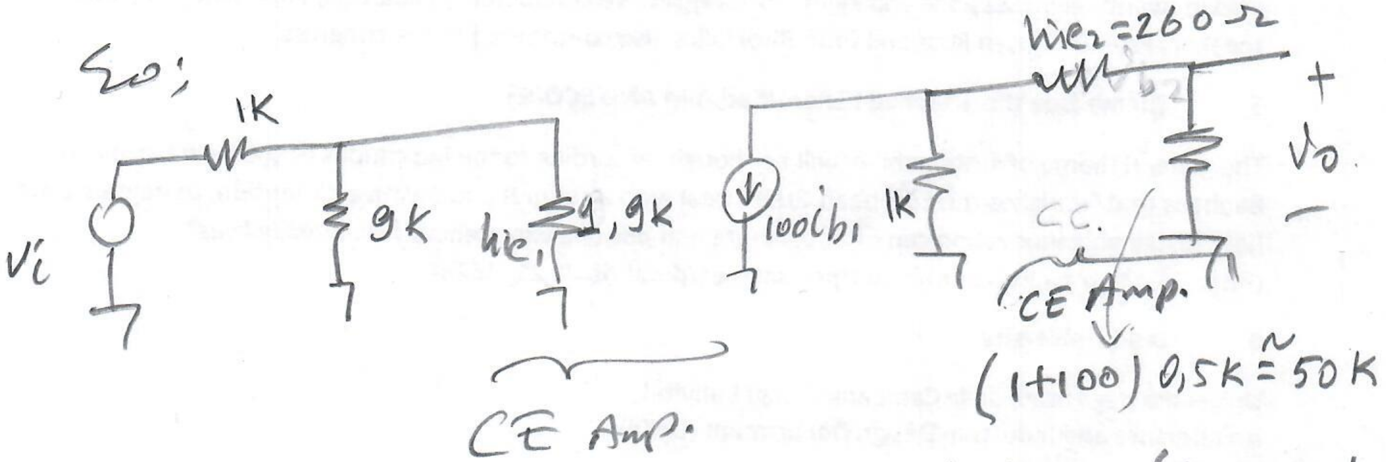
To calculate the gain of the 1. amplifier, the equivalent circuit:



$1K // 100K \cong 1K.$

$h_{ie_2} = 260 = \dfrac{h_{fe} \cdot 26mV}{I_{EQ}}$, $h_{ie_1} = 1,9K$ (calculated)

So;



$v_o \cong v_{b_2}$. (h_{ie_2} neglected)

overall voltage gain of the Amplifier:

$A_v = A_{v_1} \times A_{v_2}$

$v_{b_2} = -1K\,(h_{fe} \cdot i_{b_1})$ ...... (almost total current passes through 1K, because other resistance (50K+260Ω)

$\dfrac{v_{b_2}}{i_{b_1}} = -100 \cdot 10^3$

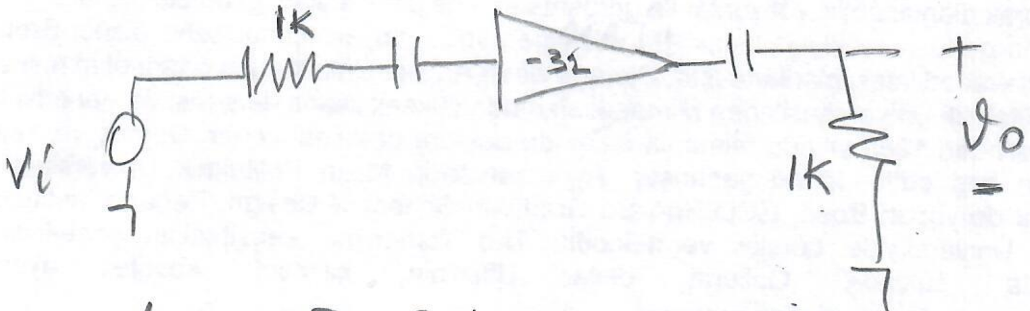
$\dfrac{i_{b_1}}{v_i} = 0,321 \cdot 10^{-3}$ Thus:

$A_{v_1} = \dfrac{v_{b_2}}{v_i} = \dfrac{v_{b_2}}{i_{b_1}} \cdot \dfrac{i_{b_1}}{v_i} = -100 \cdot 10^3 \times 0,32 \times 10^{-3} \cong -32$

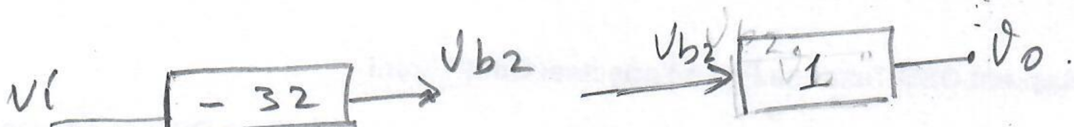
$A_{v_2} = 1 \quad \Rightarrow \quad A_v = A_{v_1} \cdot A_{v_2} = -32$

To find $v_{imax} = ?$

That is the maximum voltage applied so that output is not distorted. In other words, beyond v_{imax}, output voltage starts distorting.



$$v_{CE_1} = \mp 1{,}3V$$

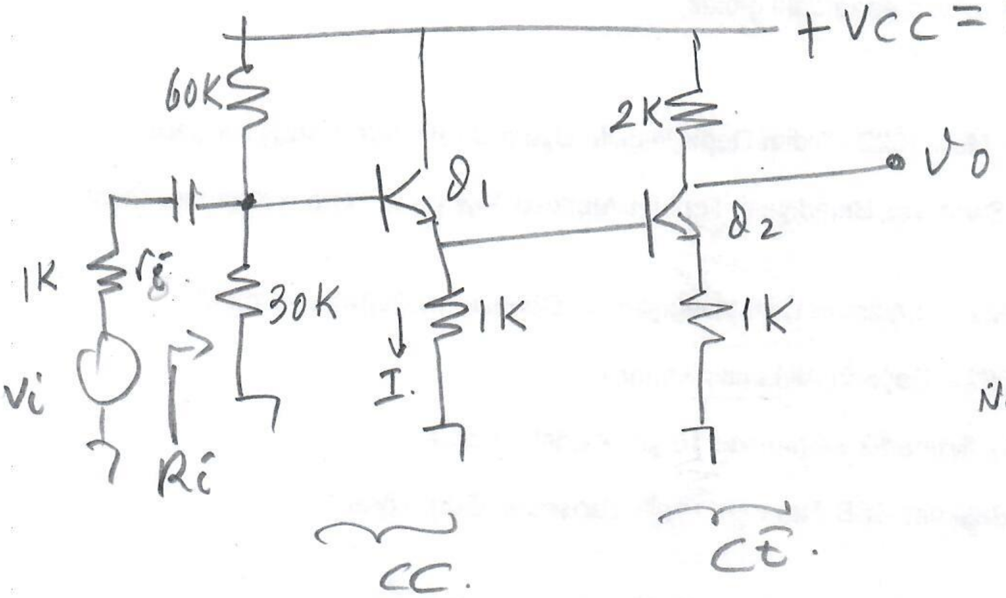


$$v_o = v_{b2} = v_{CE_2}$$

$$A_v = \frac{v_o}{v_i} = -32 \Rightarrow v_i = \frac{1{,}3}{32} = 40{,}5\ mV$$

$$v_{imax} = \mp 40{,}5\ mV.$$

DC Amplifiers



Direct connection

Number of stages ≤ 3

Solution:

$CC \Rightarrow A_V = 1$

CE Aproximate solution

$$A_{V_2} \cong -\frac{R_C}{R_E} = \frac{2K}{1K} = -2$$

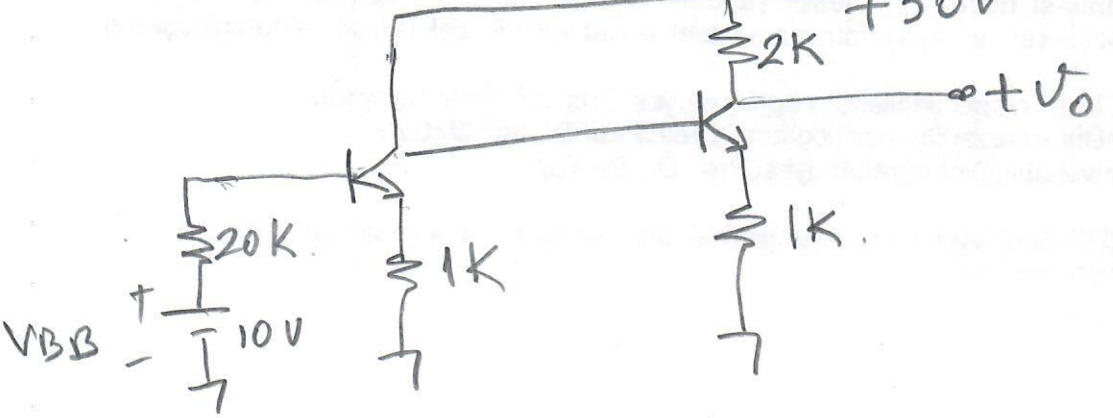
$R_i \gg r_i \Rightarrow$

$V_{b_1} = V_i$

Question: Find $\underline{V_0 (P-P) = ?}$, $I_{CO} = 0$, $V_{CE_{SAT}} = 0$

$h_{fe_1} = h_{fe_2} = 20$, $V_0 = 0{,}6V$,

DC equivalent circuit / DC Analysis



$20K = 30K // 60K \Rightarrow R_{TH}$

$$V_{TH} = V_{BB} = \frac{30 \cdot 30}{90} = \frac{900}{90} = 10V$$

$I >> I_{BQ_2} \Rightarrow I_{E_1} = I$

$$I_{EQ_1} = \frac{10-0{,}6}{\underbrace{\frac{20K}{21}}_{(1+hfe)} + 1K} = 4{,}81\,mA$$

$V_{EQ_1} = 1K \cdot I_{EQ_1} = 4{,}81\,V$, $V_{EQ_2} = V_{EQ_1} - 0{,}6\,V$

$V_{EQ_2} = 4{,}21\,V$

$$I_{EQ_2} = \frac{V_{EQ_2}}{1K} = 4{,}21\,mA.$$

$$I_{BQ_2} = \frac{I_{BQ_2}}{1+hfe} = \frac{4{,}21}{21} = 0{,}2\,mA.$$

$I_{EQ_1} \cong I = 4{,}81\,mA >> I_{BQ_2} = 0{,}2\,mA$ ...... O.K. ✓

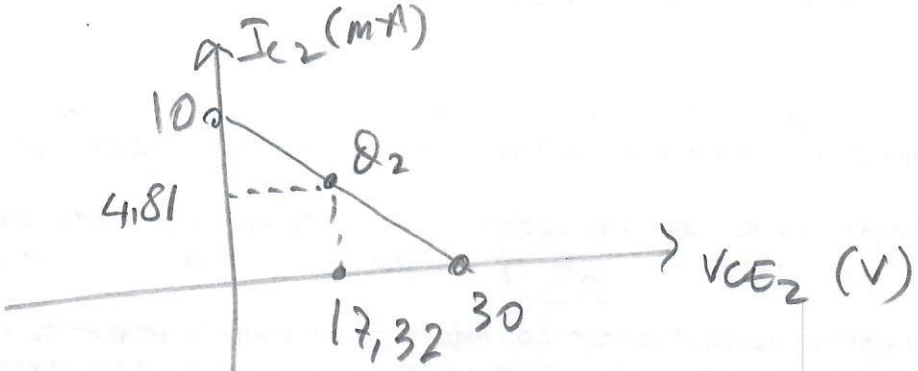
$V_{CE_2} = 30 - 3K\, I_{CQ_2} = 30 - 3K(4{,}21mA) = 17{,}37\,V.$

$V_{CQ_2} = 30 - 2K(4{,}21mA) = 21{,}58\,V$

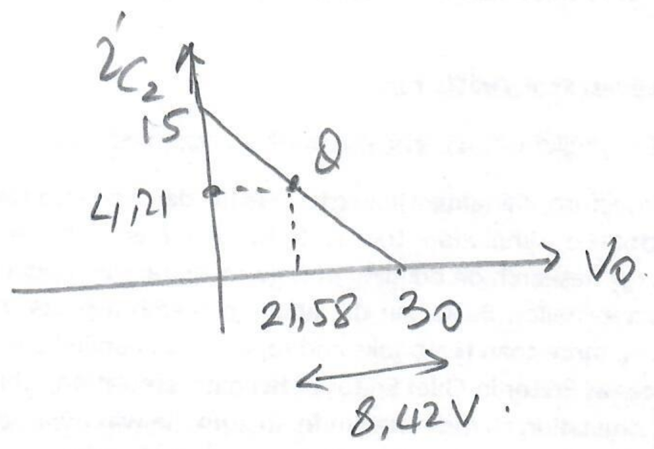
$V_{CE_1} = 30 - 1K \times \underbrace{4{,}81\,mA}_{I} = 25{,}19\,V.$

So, we can plot load lines:

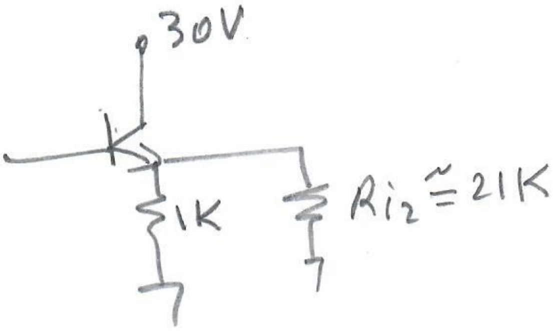
$$V_{CE_2} = 30 - 3K\, I_{CQ_2}$$

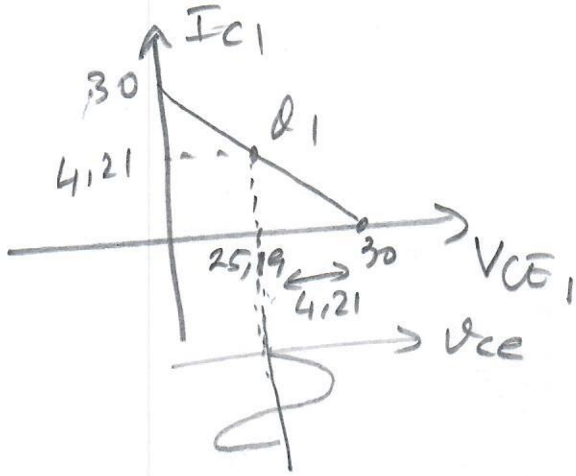


$$V_{C_2Q} = V_o = 30 - 2k\, I_{c_2}$$



$$R_{i_2} = h_{ie_2} + (1+h_{fe})R_e = 118 + 21K \cong 21K$$





So, $V_{CE_1} = V_{cc} - 1K\, I_{c_1}$

$= 30 - 1K \cdot I_{c_1}$

$v_{ce_1} = 1K \cdot i_{c_1}$

$$v_{ce2} = -(R_c + R_e)\, i_{c2}$$

$$i_{c2}(p-p) = 2 \times 4{,}21\,mA = 8{,}42\,mA.$$

$$v_o(p-p) = 8{,}42 \times \underbrace{2K}_{R_c} = 16.84\ \text{volt}.$$

To find $v_i = ?$

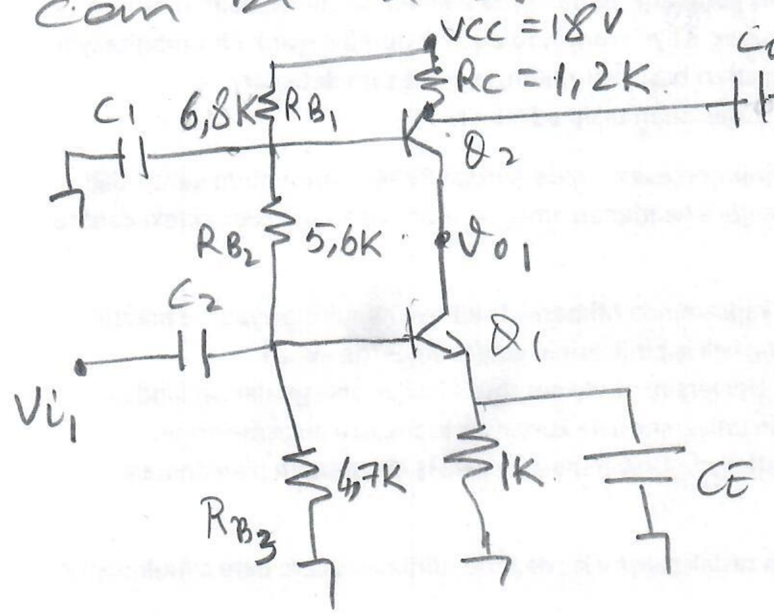
$$A_v = A_{v_1} \cdot A_{v_2} = \underbrace{1}_{A_{v_1}} \cdot \underbrace{(-2)}_{A_{v_2}} = -2$$

$$\frac{V_o}{V_i} = A_v = -2 = \frac{16{,}84(p-p)}{V_i}$$

$$v_i = 8{,}42(p-p)$$

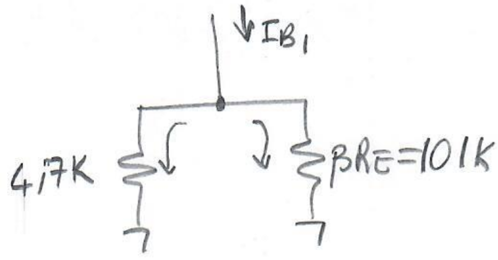
cascode Amplifiers.

At high frequencies CB connection has better frequency response; i.e. larger band width.
CB has comperatively lower input empedance, so a cascode amplifier can be a solution.



$\beta_1 = \beta_2 = 100$

$I_{E_2} = I_{E_1}$ or $I_{C_2} = I_{C_1} \Rightarrow I_{B_2} = I_{B_1}$



$$V_{B_1} = \frac{R_{B_3} \cdot V_{CC}}{R_{B_1} + R_{B_2} + R_{B_3}} = \frac{84{,}6}{17{,}1} = 4{,}95V.$$

$$I_{E_1} \cong \frac{V_{E_1}}{R_E} = \frac{V_{B_1} - V_{BE}}{R_E} = \frac{4{,}95 - 0{,}7}{1K} = 4{,}25mA$$

$I_{4,7K} \cong I_{B_1}$

$$h_{ie_1} = \frac{25mV \cdot h_{fe}}{I_{E_1}} = 612\ \Omega$$

Since $I_{E_1} = I_{E_2} \Rightarrow h_{ie_1} = h_{ie_2}$

$$A_{v_1} = \frac{v_{o1}}{v_{i1}} \cong - \frac{h_{fe} \cdot R_L}{h_{ie_1}} =$$

$R_L \to h_{ib_2}$

$$h_{ib_2} \cong \frac{h_{ie}}{h_{fe}}.$$

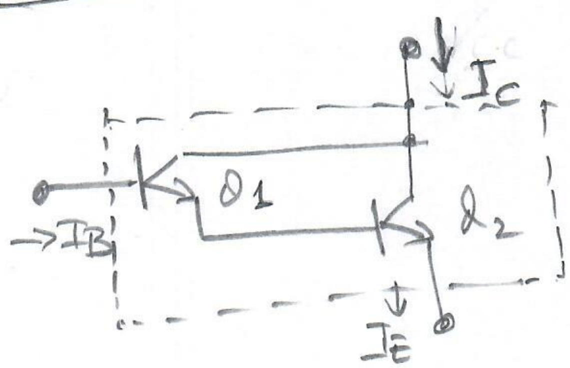
$$A_{v_1} = \frac{v_{o1}}{v_{i1}} = -\frac{h_{fe} \cdot h_{ib_2}}{h_{ie_1}}$$

$$A_{v_1} = \frac{\cancel{h_{fe}} \cdot \cancel{h_{ie_2}}}{\cancel{h_{fe}} \cdot \cancel{h_{ie_1}}} = -1$$

$$A_{v_2} = + \frac{R_L \cdot h_{fe}}{h_{ie_2}} = \frac{R_C \cdot h_{fe}}{h_{ie_2}} = \frac{1{,}2K \times 100}{612}$$

$$A_{v_2} \cong 196. \quad \Rightarrow \quad A_v = A_{v_1} \times A_{v_2} = (-1)(196) = -196.$$

DARLINGTON PAIR



$$I_{E1} = I_{B2}$$

$$I_{C2} = h_{fe_2} \cdot I_{B2} = h_{fe_2} \cdot I_{E1}$$

$$I_{C1} = h_{fe_1} \cdot I_{B_1} = I_B.$$

$$I_{E1} = (1 + h_{fe}) I_{B_1} = (1 + h_{fe}) I_B.$$

$$I_C = I_{C1} + I_{C2}$$

$$I_C = h_{fe_1} I_B + h_{fe_2}(1 + h_{fe_1}) I_B$$

$$I_C = \left[h_{fe_1} + h_{fe_2}(1 + h_{fe_1})\right] I_B.$$

$I_E = I_{E_2} = (1+h_{fe_2}) I_{B_2}$

$I_E = (1+h_{fe_2})(1+h_{fe_1}) I_B$

if $h_{fe_1}, h_{fe_2} \gg 1$ so,

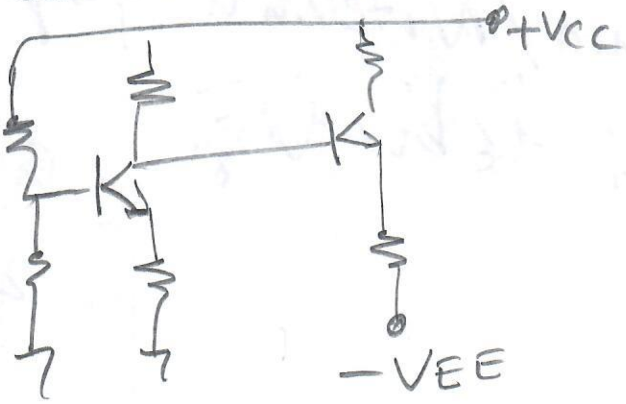
$I_C = (h_{fe_1} \cdot h_{fe_2} + h_{fe_1}) I_B$.

$I_E \cong h_{fe_1} \cdot h_{fe_2} \cdot I_B \Rightarrow I_E = \beta_1 \cdot \beta_2 I_B$

$I_C = (1+\beta_2)\beta_1 \cdot I_B \Rightarrow I_C = \beta_1 \cdot \beta_2 \cdot I_B$

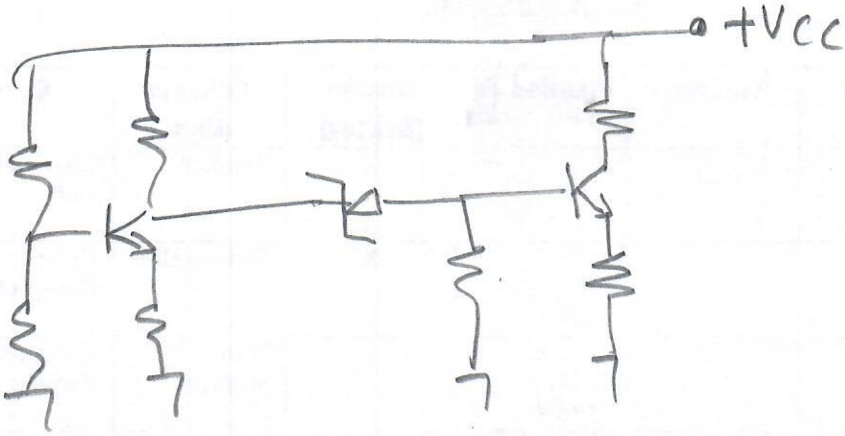
$$\frac{I_C}{I_B} = A_I = \beta_1 \cdot \beta_2$$

In general, $h_{fe_2} < h_{fe_1}$,
Q_2 transistor goes to saturation early.
so, to prevent that, oditional V_{EE}
source can be used.

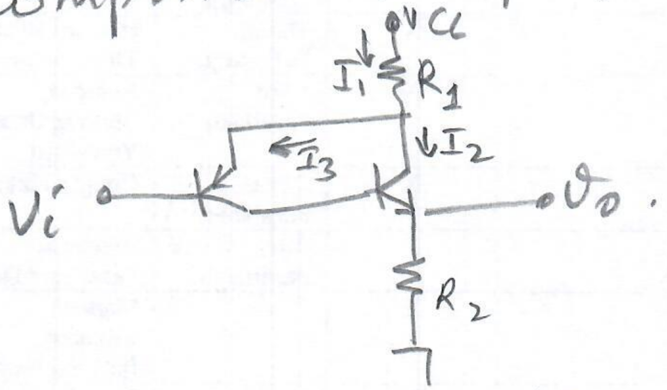


$$I_{EQ_{2new}} = \frac{V_{EQ_{2ed}} - V_{EE}}{R_E}$$

other alternative is to use zener diode
at the base of the Q_2 transistor, which
keeps the V_{B_2} constant, to set the I_{B_2}.



Composite Amplifier.



$$V_{CC} = I_1 R_1 + \underset{\parallel}{V_{EB}} + v_i$$

$$V_{CC} = I_1 R_1 + v_o + v_i$$

$$\frac{V_{CC} - (v_i + v_o)}{R_1} = I_1 \cong \frac{v_o}{R_2} \cong I_2$$

$$v_o = \frac{R_2}{R_1}\left[\overset{\text{constant}}{V_{CC}} - v_i - \overset{\text{constant}}{v_o}\right]$$

output voltage is proportinal to v_i