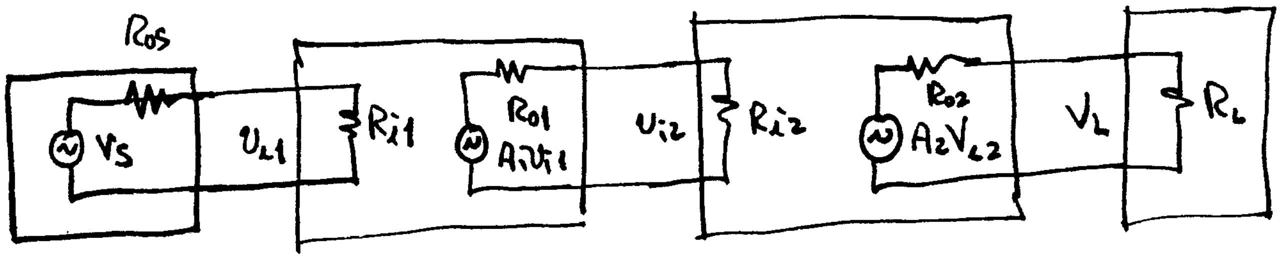
Phys 350/880
Homework Set #4

1.)



$\epsilon_A = \dfrac{V_L}{V_s}$. From analysis of each loop:

$$v_{i1} = \left(\frac{v_s}{R_{os}+R_{i1}}\right) R_{i1} = v_s \left(\frac{R_{i1}}{R_{os}+R_{i1}}\right)$$

$$v_{i2} = \left(\frac{A_1 v_{i1}}{R_{o1}+R_{i2}}\right) R_{i2} = A_1 v_1 \left(\frac{R_{i2}}{R_{o1}+R_{i2}}\right) = A_1 v_s \left(\frac{R_{i1}}{R_{os}+R_{i1}}\right)\left(\frac{R_{i2}}{R_{o1}+R_{i2}}\right)$$

$$v_L = \left(\frac{A_2 v_{i2}}{R_{o2}+R_L}\right) R_L = A_2 v_{i2} \left(\frac{R_L}{R_{o2}+R_L}\right) = A_2 A_1 v_s \left(\frac{R_{i1}}{R_{os}+R_{i1}}\right)\left(\frac{R_{i2}}{R_{o1}+R_{i2}}\right)\left(\frac{R_L}{R_{o2}+R_L}\right)$$

thus,

$$\epsilon_A = \frac{V_L}{V_s} = A_1 A_2 \left(\frac{R_{i1}}{R_{os}+R_{i1}}\right)\left(\frac{R_{i2}}{R_{o1}+R_{i2}}\right)\left(\frac{R_L}{R_{o2}+R_L}\right)$$

set #4, P.2 Cont

applying the result to the cases given :

$$A_{effective} = \frac{V_L}{V_s} = A_1 A_2 \left(\frac{R_{in1}}{R_{os} + R_{in1}} \right) \left(\frac{R_{in2}}{R_{o1} + R_{in2}} \right) \left(\frac{R_L}{R_{o2} + R_L} \right)$$

a.) $$A_{effective} = 200 \left(\frac{10k}{10k + .1k} \right) \left(\frac{50k}{50k + .1k} \right) \left(\frac{100}{100 + 10} \right) =$$

$$\boxed{E.A. = 181}$$

b.) $$E.A. = 200 \left(\frac{1k}{1k + 10k} \right) \left(\frac{100}{100 + 100} \right) \left(\frac{10}{10 + 10} \right)$$

$$\boxed{E.A = 4.55}$$

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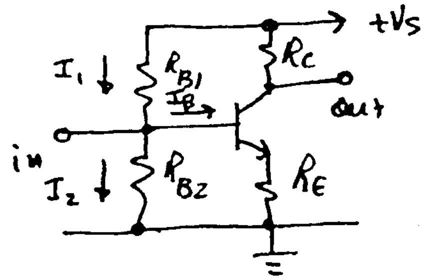
2.)



• $A \geq 15$: CHOOSE $A = 15$

$$A = \frac{R_C}{R_E} \Rightarrow \frac{R_C}{R_E} = 15$$

• $R_{out} \leq 3k$: CHOOSE $R_{out} = 3k$

$$R_{out} = \boxed{R_C = 3k}$$

$$\boxed{R_E = \frac{R_C}{A} = \frac{3k}{15} = 200\Omega}$$

• AIM for $V_C = \frac{V_S}{2} = \frac{15V}{2} = 7.5V$ at No-Signal:

need $I_C = \frac{V_{RC}}{R_C} = \frac{V_S - V_C}{R_C} = \frac{7.5V}{3k} = 2.5ma$

and $I_B \cong \frac{I_C}{h_{fe}} = \frac{2.5ma}{100} = 25\mu A$ typical

and $V_E = I_E R_E \cong I_C R_E = (2.5ma)(.2k) = 0.5V$

and $V_B = V_E + V_F = 0.5 + 0.7 = 1.2V$ silicon

• $R_{in} \geq 12k$: TRIAL & ERROR METHOD

$R_{in} = R_{B1} // R_{B2} // (h_{fe}+1)R_E$; $(h_{fe}+1)R_E \approx 20k$ here,

so $R_{B1}//R_{B2}$ large enough to yield $R_{in} \geq 12k$.

($R_{B1} // R_{B2} \geq 30k$ since $30k//20k = 12k$)

R_{B2} is Smaller, So $\boxed{\text{TRY } R_{B2} = 40k}$

$I_2 = \frac{V_B}{R_{B2}} = \frac{1.1V}{40k} = 27.5\mu A$; $I_1 = I_2 + I_B = 27.5 + 25 = 52.5\mu A$

$$\boxed{R_{B1} = \frac{V_S - V_B}{I_1} = \frac{13.8V}{52.5\mu A} = 262.9K}$$

• CHECK : $R_{in} = R_{B1} // R_{B2} // (h_{fe}+1)R_E = 292.6k // 40k // 20k = 12.75k$ ok

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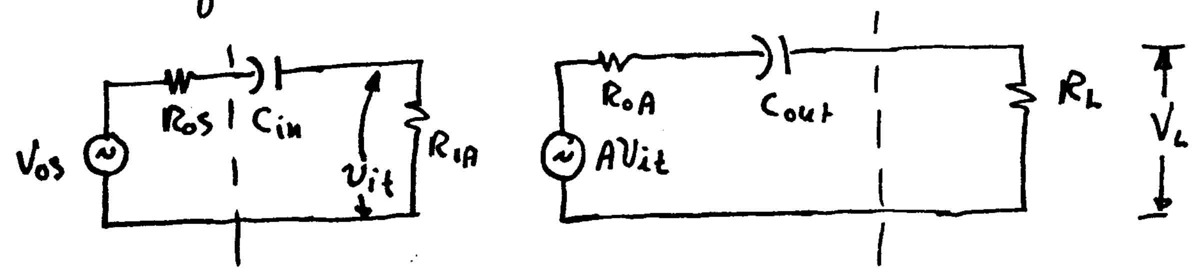
3.) $X_c = \frac{1}{2\pi f C} \Rightarrow \underline{C_{in}} = \frac{1}{2\pi f X_{cin}}\bigg|_{10\,Hz} = 1.33 \times 10^{-6}\,F$ $\boxed{1.33\,\mu F}$

$$\underline{C_{out}} = \frac{1}{2\pi f X_{cout}}\bigg|_{10\,Hz} = \frac{1}{(2\pi)(10)(3k)} \; \boxed{\begin{aligned} &= 5.31 \times 10^{-6}\,F \\ &= 5.31\,\mu F \end{aligned}}$$

4.) Equivalent circuit:



For this case : $\underline{R_{os} = R_{iA} = 12k}$ & $\underline{X_{cout} = 3k}$

$\underline{R_{oA} = R_L = 3k}$ $\underline{X_{cin} = 12k}$

- Input loop analysis: $V_{it} = I_{in} R_{iA} = R_{iA}\left\{\frac{V_{os}}{(R_{os}+R_{iA}) - jX_{cin}}\right\}$

$$|V_{it}| = V_{os}\left|\frac{R_{iA}}{(R_{os}+R_{iA}) - jX_{cin}}\right|$$

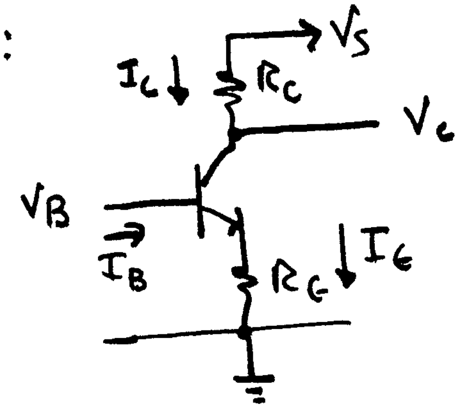
$$= V_{os}\left|\left(\frac{\cancel{12k}}{\cancel{12k}[2-j]}\right)\right| = V_{os}\sqrt{\frac{1}{5}}$$

- Output loop Analysis: $V_L = I_{out} R_L = R_L\left\{\frac{AV_{it}}{(R_{oA}+R_L) - jX_{cout}}\right\}$

$$|V_L| = |V_{it}|(15)\left\{\left|\frac{\cancel{3k}}{\cancel{3k}(2-j)}\right|\right\} = |V_{it}|(15)\sqrt{\frac{1}{5}}$$

- Result : $\boxed{\left|\frac{V_L}{V_{os}}\right| = EA = 15\left(\frac{1}{\sqrt{5}}\right)\left(\frac{1}{\sqrt{5}}\right) = 3}$! !

5.) Basic amplifying section:



$A = \dfrac{\Delta V_c}{\Delta v_B}$

$V_c = V_S - I_c R_c \Rightarrow \Delta v_c = -\Delta I_c R_c$

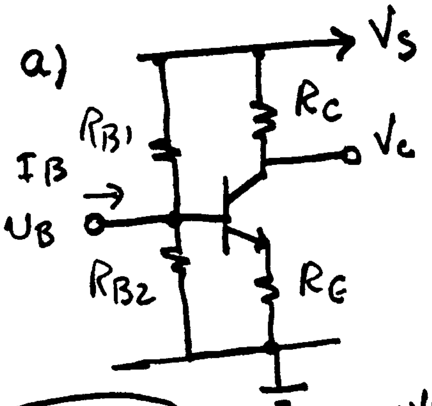
$V_E = I_E R_E \Rightarrow \Delta v_E = \Delta I_E R_E$

$V_B = V_E + 0.7 \Rightarrow \Delta v_E = \Delta v_B$

$I_E = I_B + I_c \cong I_c$

$$\therefore \boxed{\frac{\Delta v_c}{\Delta v_B} = \frac{-\Delta I_c R_c}{\Delta v_E} = \frac{-\Delta I_c R_c}{\Delta I_E R_E} = \frac{-\cancel{\Delta I_c} R_c}{\cancel{\Delta I_c} R_E} = -\frac{R_C}{R_E}}$$

6.) a)



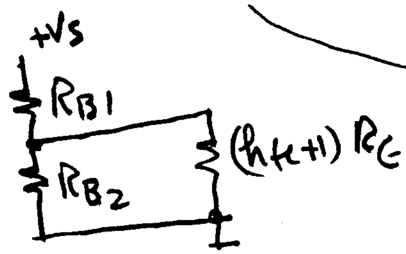
$R_{in} = \dfrac{\Delta v_B}{\Delta I_B}$. For basic amplifying section: $\Delta v_B = \Delta v_E$ (see #5)

$= \Delta I_E R_E$

$= (h_{fe}+1)\Delta I_B R_E$

$\therefore \dfrac{\Delta v_B}{\Delta I_B} = (h_{fe}+1) R_E$

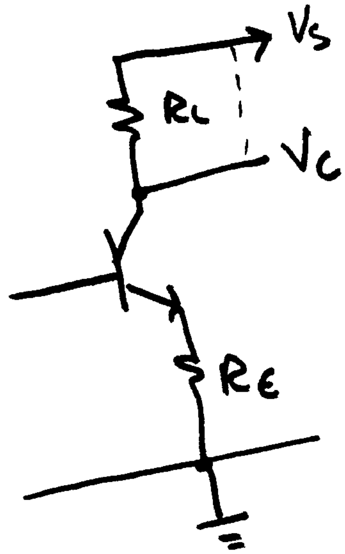
equivalent net result is:



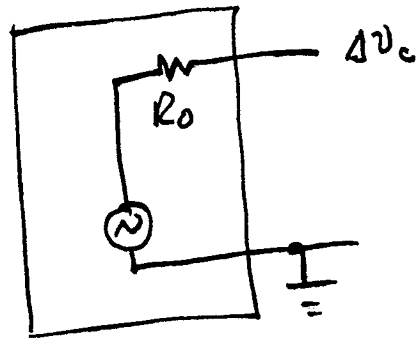
Since V_S is constant, + Δv_B is what matters, V_S = "ground" for changing signals (any constant V is "ground".)

$$\therefore \boxed{R_{in} = R_{B1} /\!/ R_{B2} /\!/ (h_{fe}+1) R_E}$$

6.) b. Rout :



$\Rightarrow$



strategy : use thevenin's theorem + approach that

$$R_o = \frac{v_o\big|_{open}}{I_o\big|_{short}}$$

Since $v_o = \Delta v_c$, $v_o\big|_{open} = R_c \Delta I_c$. using the idea that

all points of constant voltage (such as V_s) are "a.c ground",

$I_o\big|_{short} = \Delta I_c$.

$$\therefore \boxed{R_o = \frac{v_o\big|_{open}}{I_o\big|_{short}} = \frac{R_c \cancel{\Delta I_c}}{\cancel{\Delta I_c}} = R_c}$$

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8.) a.) Ignoring base current $\Rightarrow$ $I_1 = I_2 = I$

$$I = \frac{V_S}{90k} = \frac{12V}{90k} = \frac{4}{30} ma$$

$$= 133 \mu a$$

$$\boxed{\begin{aligned} V_B &= I R_{B2} = 1.0V \\ V_E &= V_B - V_f = 0.3V \\ V_C &= V_S - I_C R_C = 12V - 3k = 9V \end{aligned}}$$

$$\rightarrow I_E = \frac{V_E}{R_E} = \frac{.3V}{.3k} = \underline{1ma} = I_C$$

b.) Considering base current:

- $I_1 = I_2 + I_B$
- $I_E \cong I_C = h_{fe} I_B$

- $V_B = I_2 R_{B2} = V_S - I_1 R_{B1} \Rightarrow I_1 = \frac{V_S - V_B}{R_{B1}}$; $I_2 = \frac{V_B}{R_{B2}}$
- $V_E = V_B - V_f$
- $V_E = I_E R_E \cong I_C R_E \Rightarrow I_B = \frac{I_E}{h_{fe}} = \frac{V_E / R_E}{h_{fe}} = \frac{(V_B - V_f)}{R_E h_{fe}}$
- $V_C = V_S - I_C R_C$

$$I_1 = I_2 + I_B \Rightarrow \left\{ \frac{V_S - V_B}{R_{B1}} = \frac{V_B}{R_{B2}} + \frac{V_B - V_f}{R_E h_{fe}} \right.$$

By algebra $\Rightarrow$ $V_B \left(1 + \frac{R_{B1}}{R_{B2}} + \frac{R_{B1}}{R_E h_{fe}}\right) = V_S + V_f \frac{R_{B1}}{R_E h_{fe}}$

$$\boxed{\begin{aligned} \underline{V_B} &= \frac{V_S + V_f \frac{R_{B1}}{R_E h_{fe}}}{\left(1 + \frac{R_{B1}}{R_{B2}} + \frac{R_{B1}}{R_E h_{fe}}\right)} = \underline{1.19V} \\ \underline{V_E} &= V_B - V_f = 1.19V - 0.7V = \underline{\underline{0.49V}} \\ \underline{V_C} &= V_S - I_C R_C = V_S - \frac{V_E}{R_E} R_C = \underline{\underline{7.1V}} \end{aligned}}$$

$I_C = I_E = \frac{V_E}{R_E}$ $\Leftarrow$

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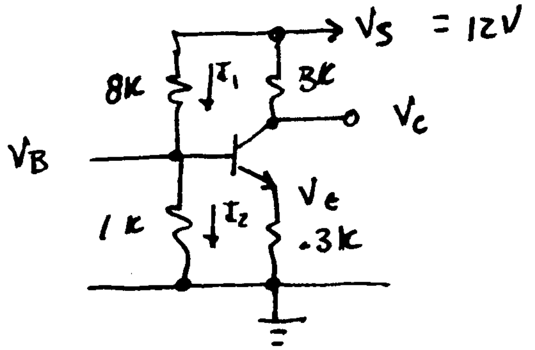
7.)



Since $I_1 = I_2$ $(= I)$

$$\underline{I} = \frac{12V}{8K + 1K} = \frac{12V}{9K} = \underline{\frac{4}{3}\,ma}$$

$$\boxed{\underline{V_B} = I R_{B2} = \frac{4}{3} V}$$

$$\boxed{V_E = V_B - V_F = \frac{4}{3}V - 0.7V = 0.63V}$$

$V_C = V_S - I_C R_C$ $\qquad$ $I_C \cong I_E$; $\underline{I_E} = \frac{V_E}{R_E} = \frac{0.63V}{0.3K} \doteq \underline{2.1ma}$
$= I_C$

$$\therefore \boxed{V_C = 12V - (2.1ma)(3k) = 5.7V}$$

I_B is neglible for several reasons. Consider the following:

- <u>at most</u> $I_C = V_S / R_C = 12V/3K = \underline{4\,ma}$
- for $I_C = 4ma$, $I_B \cong 4ma / \underbrace{100}_{h_{FE}} = 40\,\mu a$
- compared to $\frac{4}{3}$ ma $(1333\frac{1}{3}\,\mu A)$, $40\,\mu A$ is negligible