Alternate way - without calculating I_S

For $v_{BE} = 0.7V$

$$\frac{i_C}{10mA} = e^{\frac{0.7-0.76}{0.025}}$$

$$\therefore \; i_C = \underline{\underline{0.907mA}}$$

For $i_C = 10\mu A$

$$\frac{10\times10^{-6}}{10\times10^{-3}} = e^{\frac{v_{BE}-0.76}{0.025}}$$

$$v_{BE} = \underline{\underline{0.587V}}$$

5.9

$\beta = \frac{\alpha}{1-\alpha}$, for $\alpha \longrightarrow \alpha + \Delta\alpha$

$\beta \longrightarrow \beta + \Delta\beta$

$$\beta + \Delta\beta = \frac{\alpha + \Delta\alpha}{1-\alpha-\Delta\alpha} \quad \text{solve for } \Delta\beta$$

$$\Delta\beta = \frac{\alpha+\Delta\alpha}{1-\alpha-\Delta\alpha} - \frac{\alpha}{1-\alpha}$$

$$= \frac{\alpha}{1-\alpha} \cdot \frac{1+\Delta\alpha/\alpha}{1-\frac{\Delta\alpha}{1-\alpha}} - \frac{\alpha}{1-\alpha}$$

$$= \beta \times \frac{\Delta\alpha/\alpha + \Delta\alpha/1-\alpha}{1-\frac{\Delta\alpha}{1-\alpha}}$$

Thus,

$$\frac{\Delta\beta}{\beta} = \frac{\Delta\alpha}{\alpha} \cdot \frac{1+\frac{\alpha}{1-\alpha}}{1-\frac{\Delta\alpha}{1-\alpha}}$$

$$= \frac{\Delta\alpha}{\alpha} \; \frac{1-\alpha+\alpha}{1-\alpha-\Delta\alpha}$$

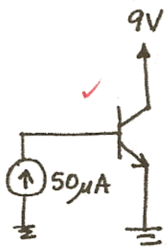
$$= \frac{\Delta\alpha}{\alpha} \; \frac{1}{1-\alpha-\Delta\alpha}$$

for small $\Delta\alpha$, $\frac{1}{1-\alpha-\Delta\alpha} \simeq \beta$

$$\therefore \; \frac{\Delta\beta}{\beta} \simeq \underline{\underline{\left(\frac{\Delta\alpha}{\alpha}\right)\beta}}$$

Q.E.D.

5.10



$\beta = 60$ to 300 ✓

$I_C = \beta I_B$ ranges from

$= 60\times50\mu A$ to $300\times50\mu A$

$= \underline{\underline{3mA \text{ to } 15mA}}$ ✓

$I_E = I_C + I_B$ ranges from

$= \underline{\underline{3.05mA \text{ to } 15.05mA}}$ ✓

Max Power $= 9\times I_{C\,max} = 9\times15$

$= \underline{135mW}$ ✓

5.11

$$i_C = I_S \, e^{v_{BE}/V_T}$$

$$10\times10^{-3} = I_S \, e^{0.7/0.025}$$

$$\Longrightarrow I_S = 6.91\times10^{-15} A$$

$$\alpha = \frac{i_C}{i_C+i_B} = \frac{10}{10+0.1} = 0.990$$

$$\beta = \frac{i_C}{i_B} = \frac{10}{0.1} = 100$$

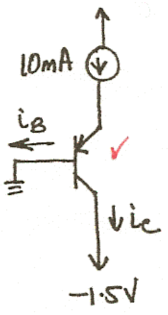
$$\frac{I_S}{\alpha} = 6.98\times10^{-15} A$$

$$\frac{I_S}{\beta} = 6.91\times10^{-17} A$$

for $i_C = 10\,mA$ $\quad v_{EB} = 0.685\,V$

$i_C = 5\,A$ $\quad v_{EB} = 0.840\,V$

5.18



$\beta = 10$

$$i_C = \alpha i_E = \frac{10}{11} \times 10 = \underline{\underline{9.09\,mA}}$$

$$i_B = i_E - i_C = \underline{\underline{0.91\,mA}}$$

$$i_C = I_S e^{V_{EB}/V_T}$$

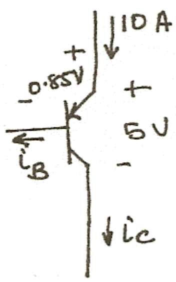
$$9.09 \times 10^{-3} = 10^{-16} e^{V_{EB}/0.025}$$

$$V_E = V_{EB} = \underline{\underline{0.803\,V}}$$

For $\beta = 1000$

$$i_C = \frac{\beta}{\beta+1} i_E = \frac{1000}{1001} \times 10 = \underline{\underline{9.99\,mA}}$$

5.19



for $\beta = 15$

$$i_E = (\beta+1)\, i_B$$

$$10 = (\beta+1)\, i_B$$

$$i_B = \frac{10}{16} = \underline{\underline{0.625A}}$$

Calculating I_{S1}

$$i_C = \frac{\beta}{\beta+1} i_E = I_{S1} e^{v_{EB}/V_T}$$

$$\frac{15}{16} \times 10 = I_{S1} e^{0.85/0.025}$$

$$I_{S1} = 1.608 \times 10^{-14} A$$

Compare this to

$$I_{S2} = i_C e^{-v_{EB}/V_T}$$

$$= 10^{-3} e^{-0.7/0.025}$$

$$= 6.914 \times 10^{-16}$$

$\therefore$ $I_S \propto$ Area

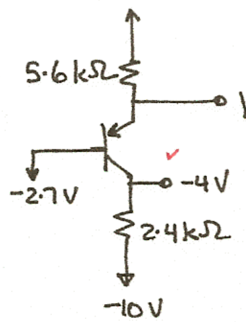
$$\frac{\text{Area 1}}{\text{Area 2}} = \frac{I_{S1}}{I_{S2}} = \frac{1.608 \times 10^{-14}}{6.914 \times 10^{-16}}$$

$$= \underline{\underline{23.3 \text{ times larger}}}$$

5.20

(a) $I_1 = \dfrac{10.7 - 0.7}{10} = \underline{\underline{1mA}}$

(b)



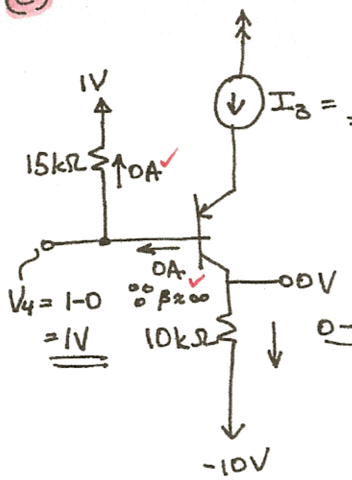
$V_2 = 12 - 5.6 \times 2.5 = \underline{\underline{-2V}}$

−or−

$V_2 = -2.7 + 0.7 = \underline{\underline{-2V}}$

$\dfrac{-4+10}{2.4} = 2.5\,mA$

(c)



$I_3 = \underline{\underline{1mA}}$ $\quad \therefore \alpha \approx 1$

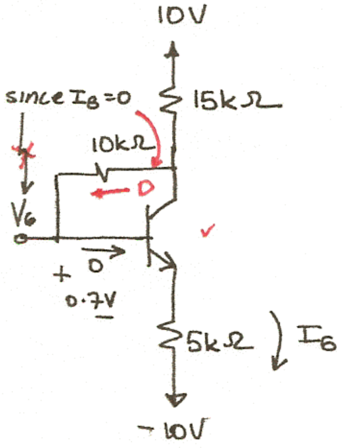
$V_4 = 1.0$

$= \underline{\underline{1V}}$

$\dfrac{0-(-10)}{10} = 1mA$

CONT

(d)



$I_E = I_c$ since $I_B = 0, \beta \to \infty$

$$\frac{V_6 - 0.7 + 10}{5} = \frac{10 - V_6}{15}$$ ✓

$15V_6 + 139.5 = 50 - 5V_6$

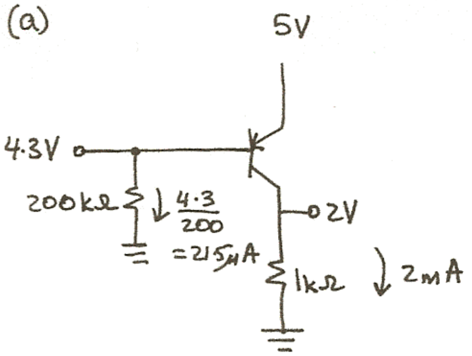
$V_6 = \underline{\underline{-4.475V}}$ ✓

$$I_5 = \frac{V_6 - 0.7 + 10}{5}$$

$$= \frac{-4.475 - 0.7 + 10}{5} = \underline{\underline{0.965mA}}$$ ✓

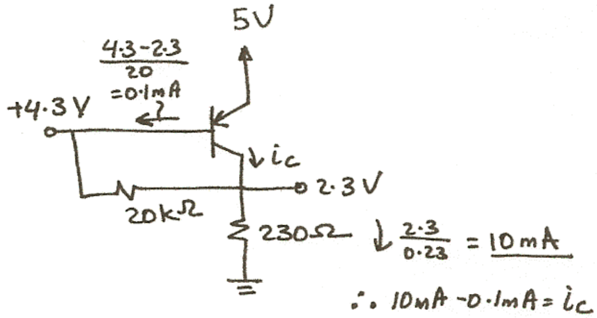
5.21

(a)



$$\frac{i_c}{i_B} = \beta = \frac{2}{0.0215} = \underline{\underline{93.0}}$$

(b)



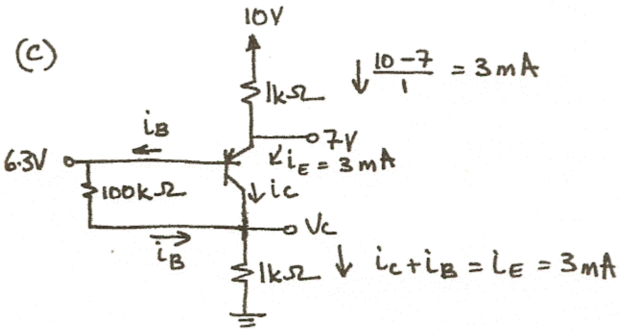
$\therefore 10mA - 0.1mA = i_c$

$9.9mA = i_c$

$$\frac{i_c}{i_B} = \frac{9.9}{0.1} = \beta$$

$\beta = \underline{\underline{99}}$

(c)



$V_c = 3 \times 1 = 3V$

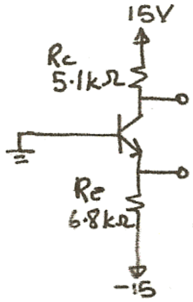
$$i_B = \frac{6.3 - 3}{100} = \frac{3.3}{100}$$

$$\beta + 1 = \frac{i_E}{i_B} = \frac{3 \times 100}{3.3}$$

$$\beta = \frac{300}{3.3} - 1 = \underline{\underline{89.9}}$$

5.22

$\alpha = 1$

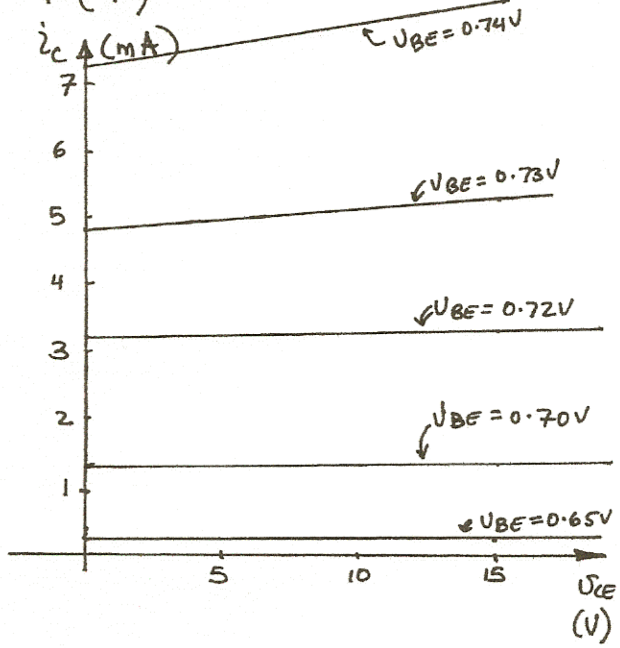


$V_c = 15 - 5.1 \times i_E = 15 - 5.1 \times 2.1 = \underline{\underline{4.3V}}$

$-0.7V$

$$i_E = i_c = \frac{-0.7 + 15}{6.8} = \underline{\underline{2.1mA}}$$

v_{BE} (V)	0.65	0.70	0.72	0.73	0.74
Intercept (mA)	0.2	1.45	3.22	4.80	7.16
Slope (mA/V)	0.002	0.015	0.032	0.048	0.072



5.38

$$r_o = \frac{1}{3\times10^{-5}} = \underline{\underline{33.3k\Omega}}$$

$$V_A = r_o I_C = 33.3\times10^{3} \times 3\times10^{-3}$$

$$= \underline{\underline{100V}}$$

$$r_o = \frac{V_A}{I_C} = \frac{100}{30} = \underline{\underline{3.3k\Omega}}$$

5.39

$$r_o = V_A/I_C = 200/I_C$$

$$@ I_C = 1mA \quad r_o = \underline{\underline{200k\Omega}}$$

$$@ I_C = 100\mu A \quad r_o = \frac{200}{0.1} = \underline{\underline{2.0M\Omega}}$$

5.40

$v_{BE} = 0.72V$ - $i_C = 1.8mA$ $v_{CE} = 2V$
$i_C = 2.4mA$ $v_{CE} = 14V$

$$r_o = \frac{\Delta v_{CE}}{\Delta i_C} = \frac{14-2}{2.4-1.8} = 20k\Omega$$

Near saturation $v_{CE} = 0.3V$

$$\therefore \frac{\Delta v_{CE}}{\Delta i_C} = \frac{0.3-2}{i_C - 1.8} = 20$$

$$i_C = \underline{\underline{1.72mA}}$$

Calculating v_{CE} for $i_C = 2.0mA$

$$\frac{\Delta v_{CE}}{\Delta i_C} = r_o$$

$$\frac{v_{CE}-2}{2-1.8} = 20 \Rightarrow v_{CE} = \underline{\underline{6V}}$$

Take the ratio of currents to find the Early Voltage (with Eq 5.36)

$$\frac{2.4}{1.8} = \underbrace{e^{\frac{v_{BE}-v_{BE}}{V_T}}}_{=1}\left(\frac{1+ 14/V_A}{1+ 2/V_A}\right)$$

$$2.4 + \frac{4.8}{V_A} = 1.8 + \frac{25.2}{V_A}$$

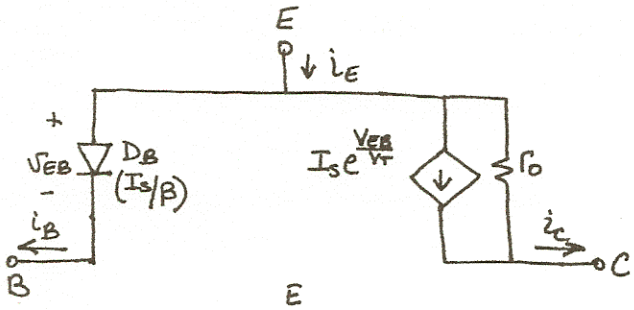
$$V_A = \underline{\underline{34V}}$$

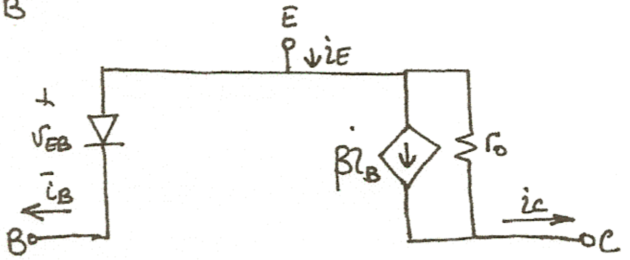
$$r_o = \frac{V_A}{I_C'} = \frac{34}{1.72} = \underline{\underline{19.8k\Omega}}$$

where I_C' is the current near saturation $\Leftrightarrow$ active boundary. As calculated above $I_C' = 1.72mA$

$\leftarrow$ $\approx$ to the above calculation of $20k\Omega$.

5.41





5.42

Large signal or DC β:

$$h_{FE} = \frac{\cancel{i_C}\ I_C}{\cancel{i_B}\ I_B} = \frac{1.2mA}{8\mu A} = \underline{150}$$

Small signal $h_{fe} = \frac{0.1mA}{0.8\mu A} = \underline{125}$

$$r_o = \frac{V_A}{I_C} = \frac{100V}{1.2mA} = 83.3k\Omega$$

$$\Delta i_c = h_{fe}\Delta i_B + \frac{\Delta v_{CE}}{r_o}$$

$$= 125 \times 2\mu A + 2/83.3k\Omega = 0.274mA$$

$$\therefore i_c = 1.2mA + \Delta i_c = \underline{1.474mA}$$

5.43

	$-55°C$	$25°C$	$125°C$
$I_c = 100\mu A$ $\beta \Rightarrow$	100	187	300
$I_c = 10mA$ $\beta \Rightarrow$	78	178	322

For $I_c = 100\mu A$

$$\text{Temp coef below } 25°C = \frac{187-100}{25+55} = \underline{\underline{1.09/°C}}$$

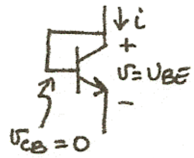
$$\text{Temp coef above } 25°C = \frac{300-187}{125-25} = \underline{\underline{1.13/°C}}$$

For $I_c = 10mA$

$$\text{Temp coef below } 25°C = \frac{178-78}{25+55} = \underline{\underline{1.25/°C}}$$

$$\text{Temp. coef above } 25°C = \frac{322-178}{125-25} = \underline{\underline{1.44/°C}}$$

5.44



$\therefore$ active mode operation

Use Eq. (5.27) & (5.28) but neglect $(e^{v_{BC}/V_T} - 1) = 0$ terms as $v_{BC} = 0$.

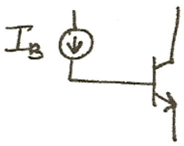
$$i = i_c + i_B$$

$$= I_S(e^{v_{BE}/V_T} - 1) + \frac{I_S}{\beta_F}(e^{v_{BC}/V_T} - 1)$$

$$= I_S \underbrace{(e^{v_{BE}/V_T} - 1)}_{\approx e^{v/V_T}} (1 + 1/\beta_F) \quad \frac{\beta_F + 1}{\beta_F} = \frac{1}{\alpha_F} \approx 1$$

$$= \underline{\underline{I_S e^{v/V_T}}} \quad \text{Q.E.D.}$$

5.45



$$V_{CEsat} = V_{CEoff} + \underbrace{\cancel{I_{Csat}}}_{0 \ \because \text{ collector is open}} R_{Csat}$$

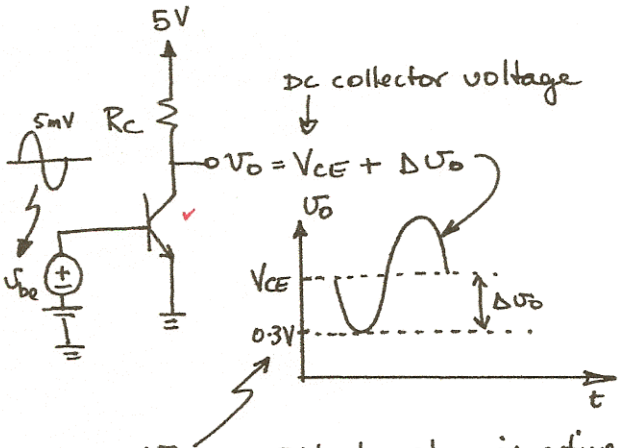
$$= V_T \ln\left(\frac{1}{\alpha_R}\right)$$

$$= 0.025 \ln \frac{1}{0.2} = \underline{\underline{40.2mV}}$$

5.56

Maximize gain, not magnitude

Since we are assuming linear operation we don't have to go to $i_c = I_s e^{v_{BE}/V_T}$ equation. ✓



$v_o \geq 0.3V$ to stay in active Mode. ✓

$$A_v = -\frac{I_c R_c}{V_T} = -\frac{V_{cc} - V_{CE}}{V_T} \checkmark$$

On the verge of saturation

$$V_{CE} - \Delta v_o = 0.3V$$

peak value

for linear opearation $\Delta v_o = A_v v_{be}$

$$V_{CE} - |A_v v_{be}| = 0.3$$

$$(5 - I_c R_c) - |A_v \times 5\times10^{-3}| = 0.3$$

$$5 - |A_v V_T| - |A_v \times 5\times10^{-3}| = 0.3 \checkmark$$

$$|A_v (0.025 + 0.005)| = 5 - 0.3 \checkmark$$

$$|A_v| = 156.67$$ Note A_v is negative. ✓

$$\therefore A_v = -156.67 \text{ V/V} \checkmark$$

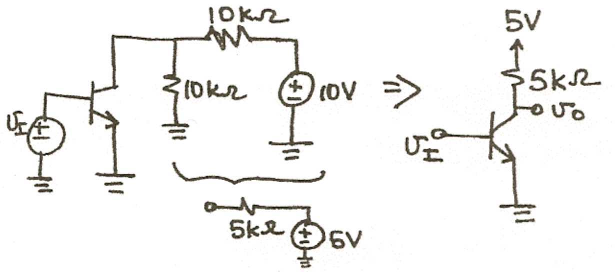
Now we can find the dc collector voltage. Refer to sketch of the output voltage, we see that

$$|\Delta v_o| = |(A_v \times 0.005)| \checkmark$$

$$\therefore V_{CE} = 0.3 + |A_v| 0.005 \checkmark$$

$$= \underline{\underline{1.08 V}} \checkmark$$

5.57

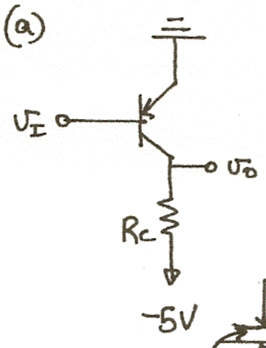


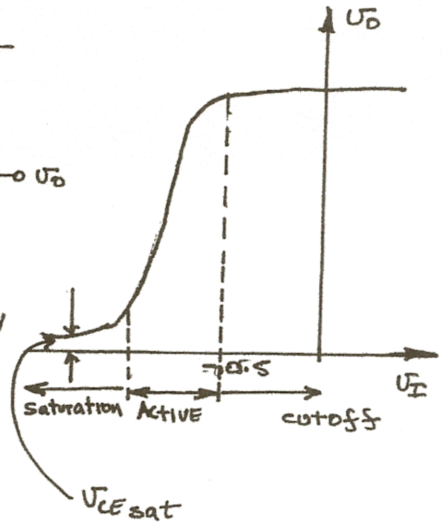
$$\frac{v_o}{v_I} = -\frac{I_c R_c}{V_T} = \frac{-0.5 \times 5}{0.025}$$

$$= \underline{\underline{-100 \text{ V/V}}}$$

5.58

(a)





$$\frac{v_o}{v_I} = -\frac{I_c R_c}{V_T}$$

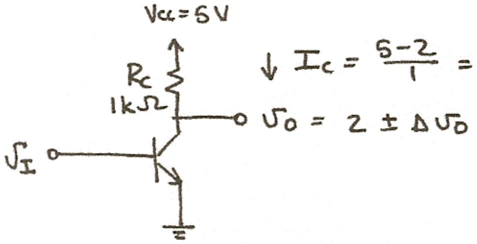
CONT.

But $v_{CE} = 0.5V$ & $\frac{I_C R_C}{V_T} = 100$ as shown above.

$$\therefore A_v = \frac{-100}{1 + \frac{2.5}{100+2.5}}$$

$$= -97.7 \, V/V$$

5.60



Small signal voltage gain

$$A_v = -\frac{I_C R_C}{V_T} = \frac{-3\times1}{0.025} = -120 \, V/V$$

If we assume linear operation around the bias point we can use A_v.

$\Delta v_O = -120 \times 5 \times 10^{-3} = -0.6V$ for $\Delta v_{BE} = 5mV$

$\Delta v_O = 120 \times 5 \times 10^{-3} = 0.6V$ for $\Delta V_{BE} = -5mV$

Using the transistor exponential characteristics as in Example 5.2: for $\Delta v_{BE} = 5mV$:

$$\frac{i_c}{3mA} = e^{\Delta v_{BE}/V_T} = e^{5/25}$$

$$i_c = 3.66 mA$$

$$v_O = 5 - 3.66 = 1.34 \, V$$

$$\Delta v_O = 1.34 - 2 = -0.66V$$

For $\Delta v_{BE} = -5mV$

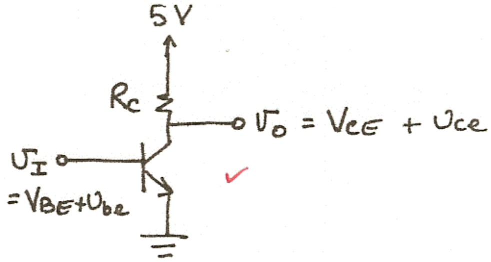
$$i_c = 3 \times e^{-5/25} = 2.46mA$$

$$v_O = 5 - 2.46\times1 = 2.54V$$

$$\Delta v_O = 2.54 - 2 = 0.54V$$

Δv_{BE} (mV)	Δv_O (V) Exponential	Δv_O (V) Linear
+0.5	−0.66	−0.6
−0.5	+0.54	+0.6

5.61



(a) For maximum gain you would bias at the largest current since $A_v = -I_C R_C / v_T$. This also means you would bias at the edge of saturation $A_v = -\frac{V_{CC} - V_{CEsat}}{V_T}$

$$= -\frac{(5-0.3)}{0.025} = \frac{4.7}{0.025}$$

$$= -188 \, V/V$$

However any signal swing at the output would automatically drive it into saturation.

(b) for $A_v = -100 V/V$

$$A_v = \frac{V_{CC} - V_{CE}}{V_T} = \frac{5 - V_{CE}}{V_T} = 100$$

$$V_{CE} = 2.5V$$

CONT.

(c) For a dc collector current of 0.5mA

$$R_c = \frac{5-2.5}{0.5} = \underline{\underline{5\,k\Omega}}$$

(d) $I_S = 10^{-15}A \Rightarrow$

$$I_C = I_S\, e^{V_{BE}/V_T}$$

$$0.5\times10^{-3} = 10^{-15}\, e^{V_{BE}/0.025}$$

$$V_{BE} = \underline{\underline{0.673V}}$$

(e) If we assume linear operation we can use A_v to find the output change for $v_{be} = 5mV$

$$v_{ce} = A_v v_{be} = -100 \times 0.005$$

$$= -0.5\,V \sim \text{peak sine wave.}$$

$\therefore$ the output is a $\underline{\underline{0.5V_p \text{ sine wave}}}$

(f) for $v_{ce} = 0.5$

$$i_c = \frac{0.5}{5} = \underline{\underline{0.1mA\ \text{peak}}}$$

This current is superimposed on I_C.

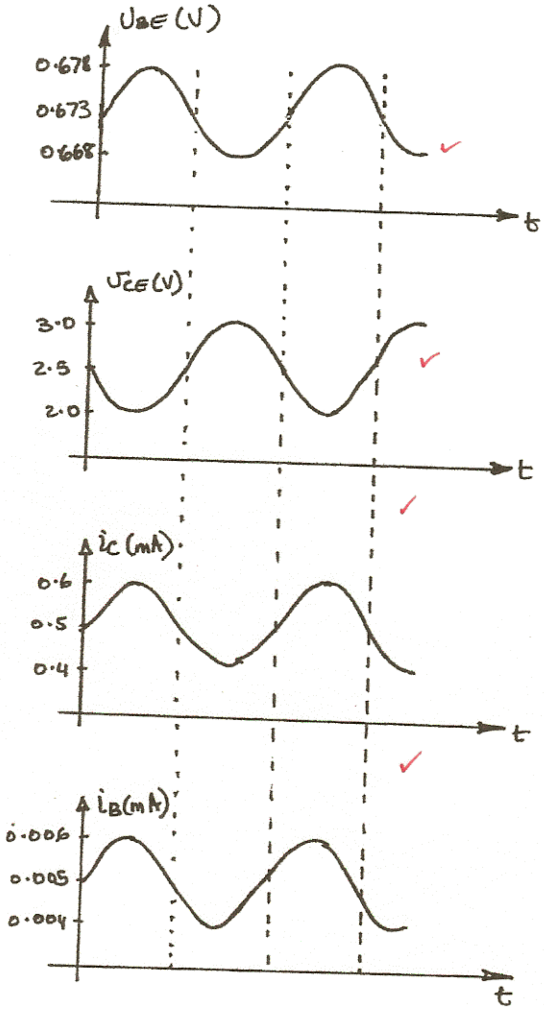
(g) $I_B = I_C/\beta = \dfrac{0.5}{100} = \underline{\underline{0.005mA}}$

$$i_b = \frac{i_c}{\beta} = \frac{0.1}{100} = \underline{\underline{0.001\,mA_p}}$$

(h) $r_{in} = \dfrac{v_{be}}{i_b} = \dfrac{0.005}{0.001\times10^{-3}}$

$$= \underline{\underline{5k\Omega}}$$

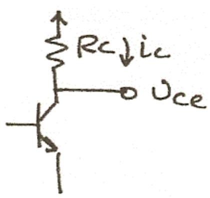
(i) See sketches that follow:



5.62

Eq (5.56)

$$A_v = \frac{v_{ce}}{v_{be}} = -\frac{I_C R_C}{V_T}$$



But $v_{ce} = -i_c R_c$

$$\therefore \frac{-i_c R_c}{v_{be}} = \frac{-I_C R_C}{V_T}$$

Now $g_m = \dfrac{\text{output current}}{\text{input voltage}} = \dfrac{i_c}{v_{be}}$

$$\therefore g_m R_c = \frac{I_C R_C}{V_T}$$

$$\underline{\underline{g_m = I_C/V_T}}$$

load line between points N and M. To obtain the coordinates of point M, we solve the load line and line L_2 to find the intersection M and the load line and line L_3 to find N:

For Point M:

$i_C = 8 + \frac{8}{100} v_{CE}$ & $i_C = 10 - v_{CE}$

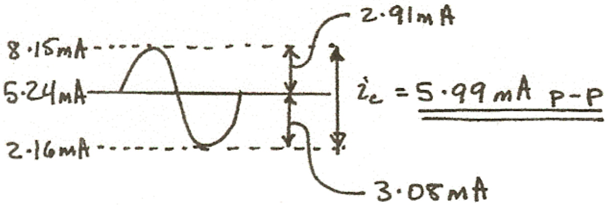
$\therefore i_C|_M = 8.15\,mA$ $\quad V_{CE}|_M = 1.85\,V$

For Point N:

$i_C = 2 + 0.02 v_{CE}$ & $i_C = 10 - v_{CE}$

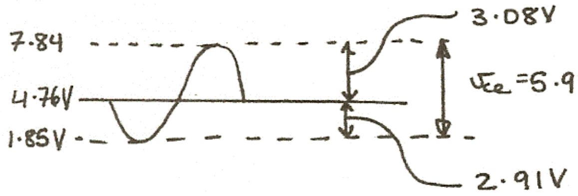
$v_{CE}|_N = 7.84\,V$ $\quad i_C|_N = 2.16\,mA$

Thus the collector current varies as follows



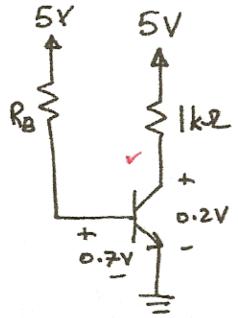
$i_c = \underline{\underline{5.99\,mA\ p\text{-}p}}$

And the collector voltage varies as:



$v_{ce} = 5.99\,V$

5.65



$\frac{\beta_F}{\beta_{forced}}$ = overdrive factor = 10

$\therefore \beta_{forced} = \frac{\beta_F}{10} = \frac{20}{10}$

$= \underline{\underline{2}}$

for $V_{CEsat} = 0.2V$

$5 - I_{Csat} \times 1 = 0.2$

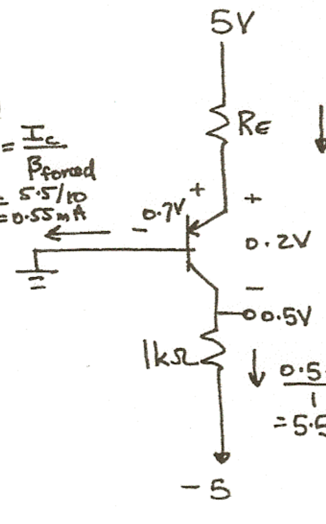
$I_{Csat} = 5 - 0.2 = 4.8\,mA$

$I_B = \frac{I_{Csat}}{\beta_{forced}} = \frac{4.8}{2} = 2.4\,mA$

$\therefore R_B = \frac{5-0.7}{2.4} = \frac{4.3}{2.4} = \underline{\underline{1.8\,k\Omega}}$

5.66

want $\beta_{forced} = 10$



② $I_B = \frac{I_C}{\beta_{forced}} = 5.5/10 = 0.55\,mA$

③ $5.5 + 0.55 = 6.05\,mA$

$\frac{0.5+5}{1}$ ① $= 5.5\,mA$

$R_E = \frac{5-0.7}{6.05} = \underline{\underline{710\,\Omega}}$

$V_E = \underline{2.49V}$

$V_C = 2.49 + 0.2 = \underline{2.69V}$

$V_B = V_E + 0.7 = \underline{\underline{3.19V}}$

Check : $I_C = \frac{5-2.69}{1} = 2.31mA$

$I_B = \frac{5-3.19}{10} = 0.181mA$

$\frac{I_C}{I_B} = \frac{2.31}{0.181} = 12.76 < 100$

Hence we are in saturation as assumed!

(C) $\underline{R_B = 1k\Omega}$ - expect saturation - use circuit in (b)

$I_B = \frac{5-(V_E+0.7)}{R_B} = \frac{4.3 - V_E}{1}$

$I_C = \frac{5-(V_E+0.2)}{1} = \frac{4.8-V_E}{1}$

$I_E = I_B + I_C = V_E$

$4.3 - V_E + 4.8 - V_E = V_E$

$V_E = \underline{\underline{3V}}$

$V_B = \underline{\underline{3.7V}}$

$V_C = \underline{\underline{3.2V}}$

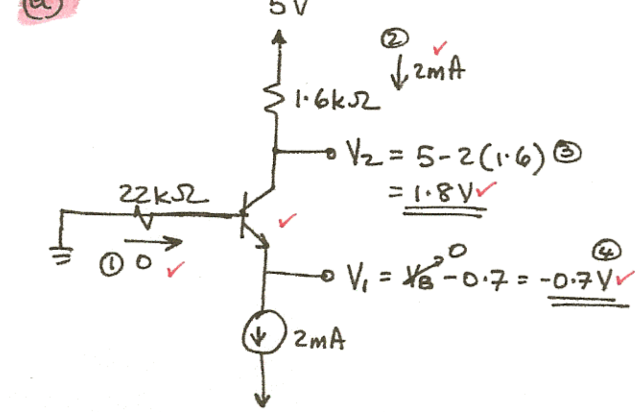
Check $I_B = 4.3 - 3 = 1.3mA$

$I_C = 4.8 - 3 = 1.8mA$

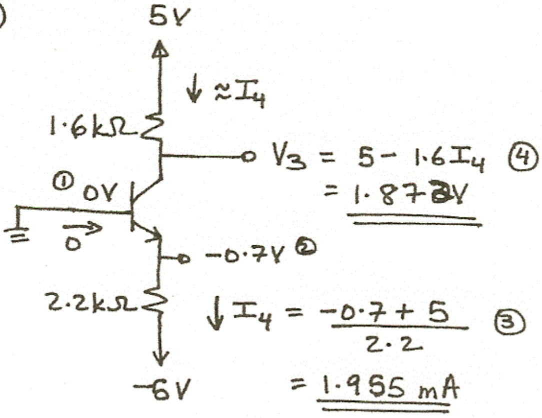
$\frac{I_C}{I_B} = \frac{1.8}{1.3} = 1.4 < 100$ ∴ SATURATION AS ASSUMED

5.79

(a)

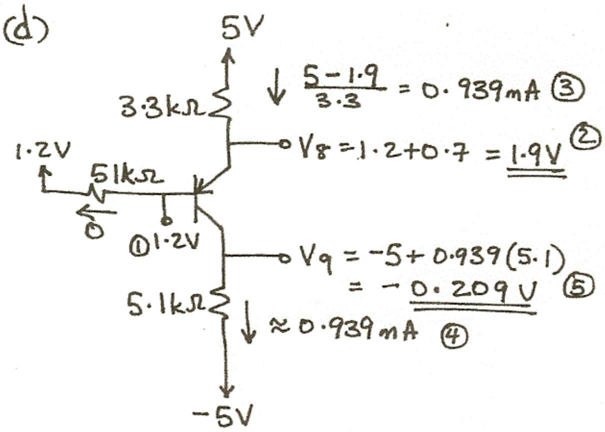


(b)



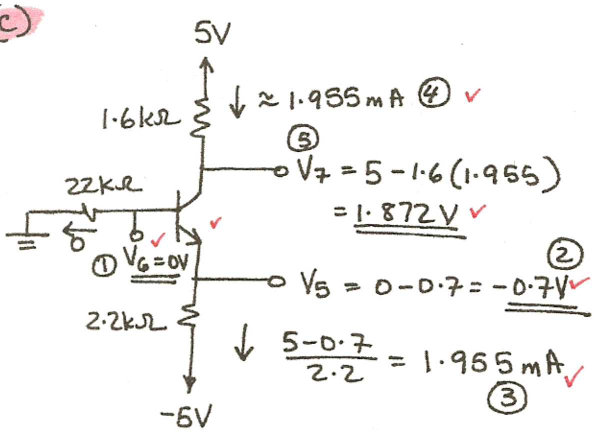
see below for part (c)

(d)

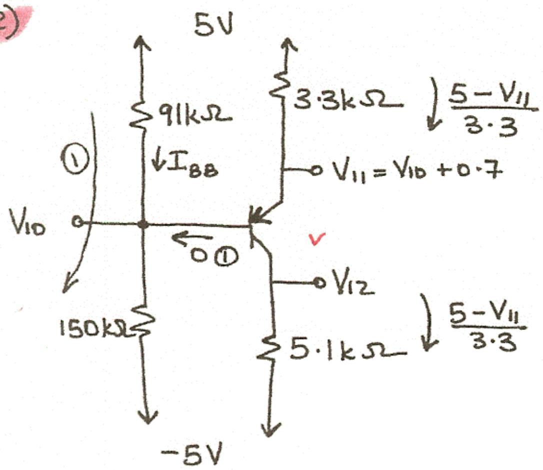


CONT.

(c)



(e)



Loop ①

$5 - 91 I_{BB} - 150 I_{BB} + 5 = 0$

$I_{BB} = \dfrac{10}{91+150}$

$V_{10} = -5 + 150 I_{BB}$

$= -5 + \dfrac{150}{91+150} \times 10$

$= \underline{\underline{1.224V}}$

$V_{11} = V_{10} + 0.7 = \underline{\underline{1.924V}}$

$\therefore I_c \approx I_E = \dfrac{5 - V_{11}}{3.3}$

$V_{12} = -5 + \left(\dfrac{5-V_{11}}{3.3}\right) 5.1 = \underline{\underline{-0.246V}}$

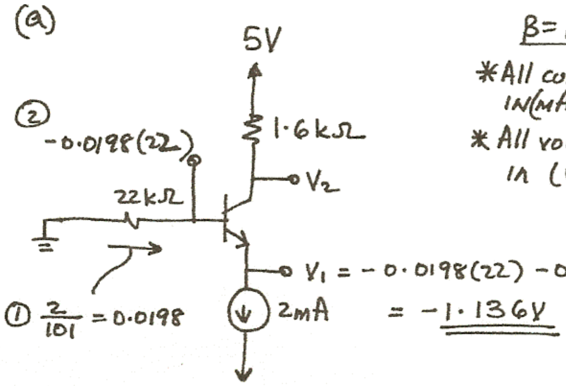
5.80

(a)

$\beta = 100$

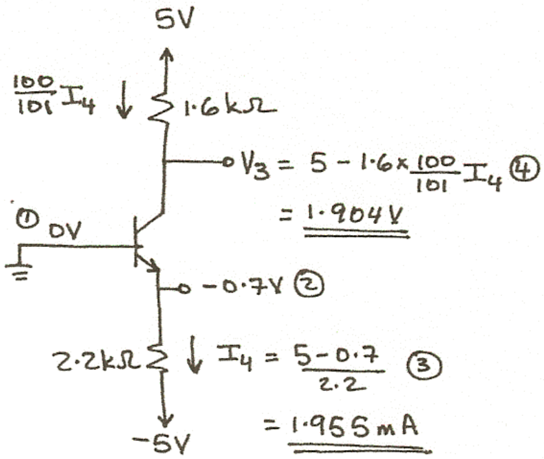
*All currents in (mA)

*All voltages in (V)

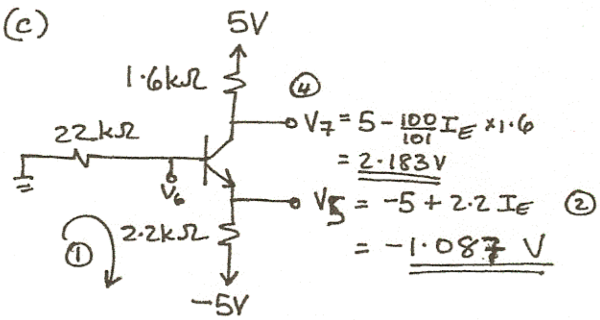


④ $V_2 = 5 - 2\left(\frac{100}{101}\right) 1.6 = \underline{1.832V}$

(b)



(c)



Loop ① $0 - \frac{I_E}{101} 22 - 0.7 - 2.2 I_E + 5 = 0$

$I_E = 1.778 mA$

③ $V_6 = V_5 + 0.7 = \underline{\underline{-0.387 V}}$

CONT

For I_C: $I_C = I_S e^{V_{be}/V_T}$

for $V_{be} = 0.690 \rightarrow I_C = 1\,mA$

$\Rightarrow I_S = 1.032 \times 10^{-15}$

for $V_{BE} = 0.678 \rightarrow I_C = 0.618\,m$

$V_{BE} = 0.702 \rightarrow I_C = 1.62\,m$

I_C ranges from 0.618 mA to 1.62 mA.

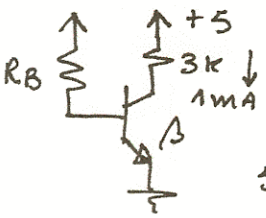
③ If $R_C = 3K\Omega$

$V_{CE} = 5 - 3K \times 0.62m = 3.14V$

$V_{CE} = 5 - 3K \times 1.62m = 0.14V$

This circuit is too sensitive to parameter variations as shown here for a 1% resistor tolerance.

5.89



$R_B = ?$ if $\beta = 100$

$I_B \times \beta = I_C$

$$\frac{5-0.7}{R_B} = \frac{1m}{100}$$

$\rightarrow R_B = \underline{\underline{430K\Omega}}$

$V_{CE} = 5V - 3K \cdot 1mA = 2V$

If $\beta = 50$: $I_C = \frac{5-0.7}{430K} \times 50$

$I_C = 0.50\,mA$

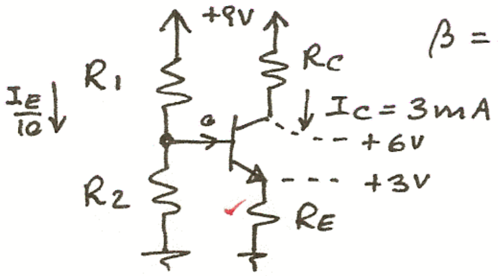
$\Rightarrow V_{CE} = 5 - 3K \times 0.5m = +3.5V$

If $\beta = 150$: $I_C = 1.5\,mA$

$V_{CE} = 0.5V$

This design is too sensitive to variations of β.

5.90



$\beta = \infty$

$R_C = \frac{3V}{3mA} = 1K\Omega$ ✓

$R_E = \frac{3V}{3mA} = 1K\Omega$ ✓

$V_b = 0.7 + 3 = 3.7V$ ✓

$R_1 = \frac{9 - 3.7}{I_E/10} = 17.7K\Omega$ ✓

$9V = (R_1 + R_2)\frac{I_E}{10} \rightarrow R_2 = 12.3K$ ✓

Choose suitable 5% resistors

$R_1 = 17.7K \rightarrow 18K\Omega$ ✓

$R_2 = 12.3K \rightarrow 13K\Omega$ ✓

$R_C = R_E = 1K$

$V_{BB} = \frac{9 \times 13}{18+13} = 3.77V$ ✓

For these values of R and $\beta = 90$: $R_B = 18 \parallel 13 = 7.55K\Omega$

$I_E = \frac{3.77 - 0.7}{1K + \frac{7.55K}{91}} = \underline{\underline{2.83mA}}$ ✓

$V_E = (2.83)(1) = \underline{\underline{2.83V}}$

$\alpha = 0.989 \Rightarrow I_C = \underline{\underline{2.80mA}}$ ✓

If R_E is reduced by $\sim \frac{7.55K}{91}$

$\rightarrow R_E = 910\Omega$?

$\Rightarrow I_E = 3.09mA$

$I_C = 3.05mA$.

$I_B = \frac{2.83}{91} = \underline{\underline{31.1\mu A}}$

$V_B = (2.83)(1) + 0.7 = \underline{\underline{3.53V}}$

$V_C = 9 - (2.8)(1) = \underline{\underline{6.2V}}$

Selection of a value for R_C:

The voltage gain is directly proportional to R_C,

$$\frac{v_o}{v_s} = \frac{v_e}{v_s} \cdot \frac{v_o}{v_e}$$
$$= \frac{R_{in}}{R_s + R_{in}} \cdot \frac{\alpha R_C}{r_e}$$
$$\simeq \frac{100}{100+100} \cdot \frac{R_C}{0.1}$$
$$= 5R_C, \quad R_C \text{ in } k\Omega.$$

For an emitter-base signal as large as 10mV, the signal at the collector will be $g_m R_C \times 0.010$ volts. Thus the maximum collector voltage in the positive direction will be:

$$v_C|_{max} = V_C + 0.01\, g_m \cdot R_C$$
$$= -10 + I_C R_C + 0.01 \times \frac{1}{0.1} \times R_C$$
$$= -10 + 0.25 R_C + 0.1 R_C$$
$$= -10 + 0.35 R_C$$

To prevent saturation, $v_C|_{max} \leq V_B$ which is 0V.
Thus to obtain maximum gain while allowing an emitter-base signal as large as 10mV and at the same time keeping the transistor in the active mode we select R_C from:

$$-10 + 0.35 R_C = 0$$
$$\Rightarrow R_C = \underline{\underline{28.6\ k\Omega}}$$

Voltage gain $= \frac{v_o}{v_s} = 5R_C = 143\ V/V$

$\boxed{5.124}$

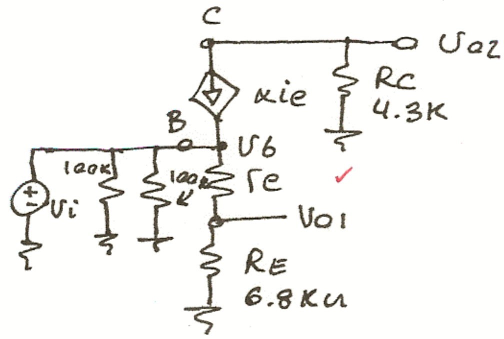
Refer to Fig P5.124
For large β, the DC base current will be ~ 0
Thus the DC voltage at the base can be found directly using the voltage-divider rule

$$V_B = 15 \cdot \frac{100}{100+100} = 7.5V$$

if: $V_{BE} = 0.7$

$$V_E = 7.5 - 0.7 = 6.8V$$
$$\rightarrow I_E = \frac{6.8V}{6.8k\Omega} = \underline{1mA}$$

$\underline{\underline{I_C = I_E}}$



$$v_b = v_i$$
$$\rightarrow \frac{v_{o1}}{v_i} = \frac{R_E}{R_E + r_e} \quad \text{Q.E.D.}$$

Also,
$$i_e = \frac{v_b}{r_e + R_E} = \frac{v_i}{r_e + R_E}$$

and,
$$v_{o2} = -\alpha i_e \cdot R_C$$
$$= -\frac{\alpha R_C v_i}{r_e + R_E}$$

Thus,
$$\frac{v_{o2}}{v_i} = \frac{-\alpha R_C}{R_E + r_e} \quad \text{Q.E.D.}$$

CONT.

Substituting $r_e = \frac{V_T}{I_E} = 25\,\Omega$

and $R_E = 6.8\,k\Omega$, $R_C = 4.3\,k\Omega$
and $\alpha \simeq 1$ gives

$$\frac{v_{o1}}{v_i} = \frac{6.8}{0.025+6.8} = \underline{\underline{0.996\ V/V}}$$

$$\frac{v_{o2}}{v_i} = -\frac{4.3}{6.8+0.025} = \underline{\underline{0.63\ V/V}}$$

If the node labeled v_{o2} is connected to ground:
$R_E = 0$

$$\frac{v_{o2}}{v_i} = -\frac{\alpha R_C}{r_e}$$

5.125

If: $R_i = 10\,K\Omega$, $A_{vo} = 100\ V/V$
$R_o = 100\,\Omega$, $R_{sig} = 2\,K\Omega$ and
$R_{in} = 8\,K\Omega$ when $R_L = 1\,K\Omega$
then:

$$G_m = \frac{A_{vo}}{R_o} = \frac{100}{100} = \underline{\underline{1\ A/V}}$$

$$A_v = A_{vo}\cdot\frac{R_L}{R_L+R_o} = \frac{100\times 1K}{1K+100} = \underline{\underline{91\ V/V}}$$

$$G_{vo} = \frac{R_i}{R_i+R_{sig}}\cdot A_{vo} = \frac{10K}{10K+2K}\times 100 = \underline{\underline{83.3\ V/V}}$$

$$G_v = \frac{R_{in}}{R_{in}+R_{sig}}\times A_{vo}\times\frac{R_L}{R_L+R_o}$$

$$= \frac{8K}{8K+2K}\times 100\times\frac{1K}{1K+100} = \underline{\underline{72.7\ \frac{V}{V}}}$$

$$R_{out} = \frac{G_{vo}}{G_v}\cdot R_L - R_L = \frac{8.3\times 1K}{72.7} - 1K$$

$$= \underline{\underline{146\,\Omega}}$$

$$A_i = \frac{v_o/R_L}{v_i/R_{in}} = A_v\cdot\frac{R_{in}}{R_L} = 91\times\frac{8K}{1K}$$

$$= 728\ A/A\ //$$

5.126

Refer to Fig. P5.126
$R_i = 900\,K\Omega$
$A_{vo} = 10\ V/V$
$R_o = 1.43\,K\Omega$
$R_{in} = 400\,K\Omega$ when $R_L = 10\,K\Omega$

(a) $i_i \equiv v_i/R_{in}$

$$\Rightarrow \frac{v_i}{R_{in}} = \frac{v_i}{R_i} - f\cdot i_o$$

where $i_o = \frac{A_{vo} v_i}{R_o+R_L}$

$$\rightarrow \frac{v_i}{R_{in}} = \frac{v_i}{R_i} - f\cdot\frac{A_{vo} v_i}{R_o+R_L}$$

Solving for f:

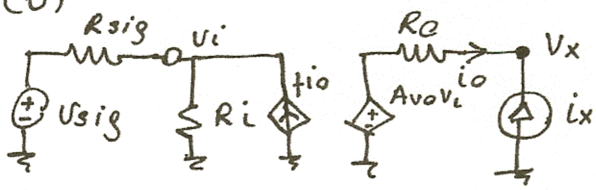
$$f = \left(\frac{1}{R_i} - \frac{1}{R_{in}}\right)\cdot\frac{R_o+R_L}{A_{vo}}$$

Thus,

$$f = \left(\frac{1}{900K} - \frac{1}{400K}\right)\cdot\frac{(1.43K+10K)}{10}$$

$$f = \underline{\underline{-1.6\times 10^{-3}}}$$

(b)



$$R_{out} = \left.\frac{v_x}{i_x}\right|_{v_{sig}=0}$$

If $v_{sig}=0$: on the left hand side

$$v_i = f\cdot i_o\,(R_{sig}\,\|\,R_i)$$

$$v_i = (-1.6\times 10^{-3}\times(100K\,\|\,900K)\,i_o$$

$$= -144\cdot i_o$$

On the right hand side:

$$V_x = R_o i_x + A_{vo}\cdot v_i$$

$$= R_o\cdot i_x + A_{vo}(-144\,i_o)$$

$$= R_o\,i_x + A_{vo}(+144)\,i_x$$

CONT.

5.129

$I_C = 0.2\,mA \Rightarrow r_e = 123.76\,\Omega$

$R_i = (\beta+1)(r_e + R_E)$

$= (101)(123.76 + 125) = \underline{\underline{25.1\,K\Omega}}$

$$\frac{v_o}{v_s} = \frac{-\alpha R_C}{r_e + R_E} \times \frac{R_i}{R_i + R_s}$$

$$= \frac{-100}{101} \frac{\times 24K}{(123.76+125)} \times \frac{25.1K}{25.1K + 10K}$$

$$= -\underline{\underline{68.30}}\ V/V$$

$R_o = R_C = \underline{\underline{24\,K\Omega}}$

With $10\,K\Omega$ load

$$\frac{v_o}{v_s} = -68.30 \times \frac{10}{10+24} = \underline{\underline{-20\,\frac{V}{V}}}$$

Without R_E $\quad V_\pi \leq 5\,mV$

$$V_\pi = \frac{(\beta+1)\,r_e}{(\beta+1)r_e + R_s} \cdot V_s$$

$$= \frac{(101)\cdot(123.76)}{(101)\cdot(123.76) + (10K)} \cdot v_s \leq 5\,mV$$

$\Rightarrow V_s \leq \underline{\underline{9\,mV}}$

With R_E

$$V_\pi = \frac{(\beta+1)r_e \cdot v_s}{(\beta+1)(r_e + R_E) + R_s} \leq 5\,mV$$

$$V_s \leq 5m\frac{[(101)(123.76 + 125) + 10K]}{101 \times 123.76}$$

$V_s \leq \underline{\underline{14\,mV}}$

5.130

Refer to Fig. P5.130

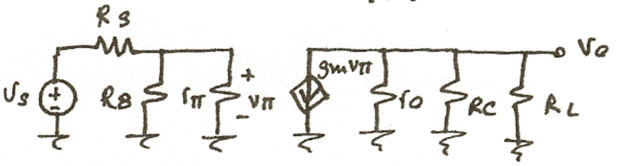
$$I_E = \frac{V_{BB} - V_{BE}}{R_E + R_B/(\beta+1)}$$

where, $V_{BB} = V_{CC} \cdot \frac{R_2}{R_1 + R_2}$

$$= 9 \cdot \frac{15}{27+15} = 3.21\,V$$

$R_B = R_1 \,||\, R_2 = 15 || 27 = 9.64\,K\Omega$

Thus, $I_E = \dfrac{3.21 - 0.7}{1.2 + \frac{9.64}{101}} = \underline{\underline{1.94\,mA}}$



$$g_m = \frac{I_C}{V_T} = \frac{0.99 \times 1.94}{0.025} = 76.8\,\frac{mA}{V}$$

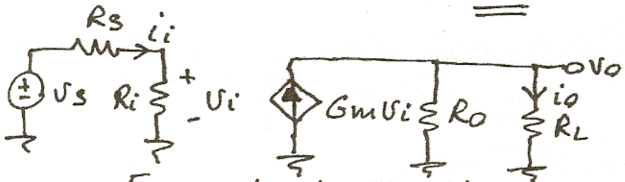
$$r_\pi = \frac{\beta}{g_m} = \frac{100}{76.8} = 1.3\,K\Omega$$

$$r_o = \frac{V_A}{I_C} = \frac{100}{0.99 \times 1.94} = 52.1\,K\Omega$$

$R_i = R_B || r_\pi = 9.64 || 1.3 = \underline{\underline{1.15\,K\Omega}}$

$G_m = -g_m = -\underline{\underline{76.8}}\,\frac{mA}{V}$

$R_o = R_C || r_o = 2.2 || 52.1 = \underline{\underline{2.11}}\,K\Omega$



Equivalent circuit

$$A_v = \frac{v_o}{v_s} = \frac{v_i}{v_s} \cdot \frac{v_o}{v_i}$$

$$= \frac{R_i}{R_s + R_i} \cdot \frac{G_m (R_o || R_L)\, v_i}{v_i}$$

$$= \frac{-1.15}{10 + 1.15} \times 76.8 \times (2.11 || 2)$$

$$= -\underline{8.13}\ V/V$$

$$A_i = \frac{i_o}{i_i} = \frac{v_o . R_L}{v_s / (R_s + R_i)}$$

CONT.

$$\rightarrow A_i = \frac{v_o}{v_s} \cdot \frac{R_s + R_i}{R_L}$$

$$= -8.13 \times \frac{(10 + 1.15)}{2}$$

$$= \underline{\underline{-45.3}} \text{ A/A}$$

5.131

Refer to Fig. P5.130.

$V_{CC} = 9V \quad V_{BB} = \frac{1}{3} V_{CC} = 3V$

Neglecting the base current,

$$R_1 + R_2 = \frac{9}{0.2} = 45 \text{ k}\Omega$$

$$\frac{R_2}{R_1 + R_2} = \frac{1}{3}$$

$$\Rightarrow R_2 = \underline{15 \text{ k}\Omega}, \quad R_1 = \underline{\underline{30 \text{ k}\Omega}}$$

$$R_B = R_1 \| R_2 = \frac{30 \times 15}{45} = 10 \text{ k}\Omega$$

$$I_E = \frac{V_{BB} - V_{BE}}{R_E + \frac{R_B}{\beta + 1}}$$

$$2 = \frac{3 - 0.7}{R_E + 10/101} \Rightarrow R_E = \underline{\underline{1.05 \text{ k}\Omega}}$$

Use $R_E = \underline{\underline{1 \text{ k}\Omega}}$

The resulting I_E will be

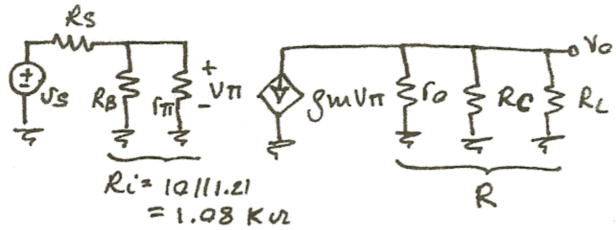
$$I_E = \frac{3 - 0.7}{1 + 10/101} = 2.09 \text{ mA}$$

$$I_C = \alpha I_E = 0.99 \times 2.09 = 2.07 \text{ mA}$$

$$g_m = \frac{I_C}{V_T} = \frac{2.07}{0.025} = 82.9 \frac{\text{mA}}{\text{V}}$$

$$r_\pi = \frac{\beta}{g_m} = \frac{100}{82.9} = 1.21 \text{ k}\Omega$$

$$r_o = \frac{V_A}{I_C} = \frac{100}{2.07} = 48.3 \text{ k}\Omega.$$



$R_i = 10 \| 1.21$
$= 1.08 \text{ k}\Omega$

$$\frac{v_o}{v_s} = \frac{v_\pi}{v_s} \cdot \frac{v_o}{v_\pi} = \frac{R_i}{R_s + R_i} \cdot \frac{-g_m v_\pi R}{v_\pi}$$

$$= \frac{-1.08}{10 + 1.08} \times 82.9 \times R$$

To obtain $\frac{v_o}{v_s} = -8 \frac{V}{V}$ we use:

$$R = \frac{8 \times 11.08}{1.08 \times 82.9} = 0.99 \text{ k}\Omega$$

Now $R = r_o \| R_C \| R_L$

$0.99 = 48.3 \| R_C \| 2$

$\Rightarrow R_C = 2.04 \text{ k}\Omega$

use $R_C = \underline{\underline{2 \text{ k}\Omega}}$

Check: $V_C = 9 - 2.07 \times 2 = 4.86V$ while $V_B \simeq 3V$. Thus in active mode as assumed.

5.132

Refer to Fig. P5.130

$$V_{BB} = 9 \cdot \frac{47}{82 + 47} = 3.28 V$$

$$R_B = 47 \| 82 = 29.88 \text{ k}\Omega$$

$$I_E = \frac{3.28 - 0.7}{3.6 + \frac{29.88}{101}} = 0.66 \text{ mA}$$

$$I_C = 0.99 \times 0.66 = 0.65 \text{ mA}$$

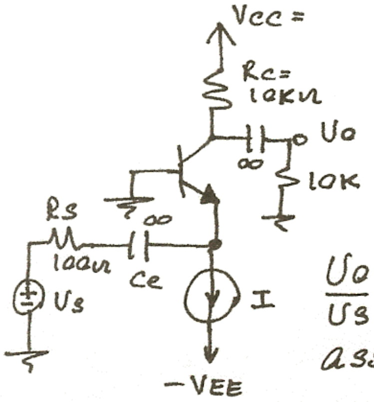
$$g_m = \frac{0.65}{0.025} = 26 \frac{\text{mA}}{\text{V}}$$

$$r_\pi = \frac{100}{26} = 3.85 \text{ k}\Omega$$

$$r_o = \frac{100}{0.66} = 151.5 \text{ k}\Omega$$

CONT.

5.139



$R_i = r_e$

$r_e = \frac{25m}{I} = 100$

$I = \frac{25m}{100} = \underline{\underline{0.25m}}$

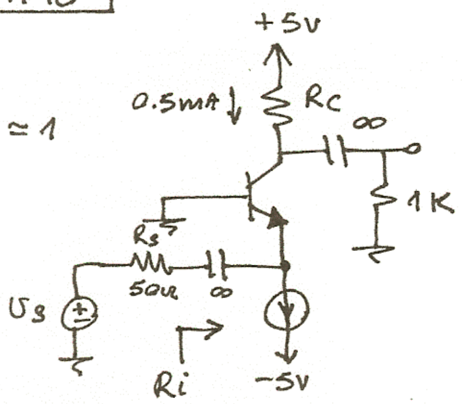
$\frac{V_o}{V_s} = -\alpha \frac{(R_c \| R_L)}{R_s + r_e}$

assuming $\alpha = 1$

$\frac{V_o}{V_s} = \frac{10 \| 10}{(0.100)\,2} = \underline{\underline{-25}}\ \frac{V}{V}$

5.140

$\alpha \simeq 1$



$R_i = \frac{V_T}{I} = 50\Omega \Rightarrow I = \underline{\underline{0.5mA}}$

$V_c = 5 - 0.5.R_c$

$V_{cmin} = V_c - 0.01\, g_m\, (R_c \| 1K)$

To prevent saturation $V_{cmin} = 0$

$\rightarrow 0 = V_c - 0.01 \times 20\, (R_c \| 1)$

$= 5 - 0.5\, \frac{R_c}{R_c + 1}$

$5R_c + 5 - 0.5R_c^2 - 0.5R_c - 0.2R_c = 0$

$0.5R_c^2 - 4.3R_c + 5 = 0$

$R_c = \frac{4.3 + \sqrt{4.3^2 + 10}}{1}$

$= 9.64\,K\Omega$

Select $R_c = \underline{\underline{9.1\,K\Omega}}$

$V_c = 0.45V$

$\frac{V_o}{V_s} = \frac{R_i}{R_s + R_i}\, g_m\, (R_c \| 1)$

$= \frac{50}{50+50} \times 20 \times (9.1 \| 1)$

$= \underline{\underline{9}}\ V/V$

For $V_{be\,max} = 10mV$

$V_{s\,max} = 20mV$

$V_{c\,max} = 180mV$

Thus the collector voltage swings from

$(0.45 - 0.18)V$ to $(0.45 + 0.18)V$

i.e $\underline{\underline{\text{from } 0.27V \text{ to } 0.63V}}$

5.141

Refer to Fig P5.141

$R_i = r_e = \frac{V_T}{I_E} = \frac{V_T}{0.5} = \underline{\underline{50\Omega}}$

To find the voltage gain V_o/V_s first note that

$\frac{V_e}{V_s} = \frac{R_i}{R_s + R_i} = \frac{50}{50+50} = 0.5$

Then,

$\frac{V_c}{V_e} = \alpha \times \frac{(\text{Total resistance at c})}{r_e}$

$\simeq \frac{1 \times (100K\Omega \,\|\, 1K\Omega)}{50\Omega}$

$= 19.8\ V/V$

Thus, $\frac{V_o}{V_s} = 19.8 \times 0.5 = \underline{\underline{9.9}}\ V/V$

For $\beta = 40$, $I_E = \dfrac{8.3}{1+\frac{100}{41}} = \underline{\underline{2.41\,mA}}$

$V_E = 1 \times 2.41 = \underline{\underline{2.41V}}$

$V_B = 2.41 + 0.7 = \underline{\underline{3.11V}}$

For $\beta = 200$, $I_E = \dfrac{8.3}{1+\frac{100}{201}} = \underline{\underline{5.54\,mA}}$

$V_E = +\underline{\underline{5.54V}}$

$V_B = +\underline{\underline{6.24V}}$

(b) $R_i = 100K\Omega \,//\, (\beta+1)[r_e + (1//1)]$

$= 100 \,//\, (\beta+1)[r_e + 0.5]$

For $\beta = 40$, $I_E = 2.41mA$

$\rightarrow r_e = 10.37\,\Omega$

thus $R_i = 100 \,//\, 41 \times (0.01037 + 0.5)$

$= 100 \,//\, 21$

$= \underline{\underline{17.3\,\Omega}}$

For $\beta = 200$, $I_E = 5.54mA$

$\rightarrow r_e = 4.51\,\Omega$

thus $R_i = 100 \,//\, 201(0.0045 + 0.5)$

$= 100 \,//\, 101.4$

$= \underline{\underline{50.3\,K\Omega}}$

(c) $\dfrac{v_o}{v_s} = \dfrac{v_b}{v_s} \cdot \dfrac{v_o}{v_b}$

$= \dfrac{R_i}{R_s + R_i} \cdot \dfrac{(1//1)}{(1//1) + r_e}$

For $\beta = 40$,

$\dfrac{v_o}{v_s} = \dfrac{17.3}{10 + 17.3} \times \dfrac{0.5}{0.5 + 0.01037}$

$= \underline{\underline{0.621}}\ V/V$

For $\beta = 200$,

$\dfrac{v_o}{v_s} = \dfrac{50.3}{10 + 50.3} \cdot \dfrac{0.5}{0.5 + 0.0045}$

$= \underline{\underline{0.827}}\ V/V$

5.144

Refer to Fig. P5.144

$I_E = \dfrac{5 - 0.7}{3.3 + \frac{100}{101}} = \underline{\underline{1.00\,mA}}$

$r_e = \dfrac{25}{1.00} = 25\,\Omega$

$R_i = (\beta+1)[r_e + (3.3 // 1)]$

$= \underline{\underline{80.0\,K\Omega}}$

$\dfrac{v_o}{v_s} = \dfrac{v_b}{v_s} \cdot \dfrac{v_o}{v_b} = \dfrac{R_i}{R_s + R_i} \cdot \dfrac{(3.3 // 1)}{r_e + (3.3//1)}$

Thus,

$\dfrac{v_o}{v_s} = \dfrac{80}{100 + 80} \times \dfrac{(3.3 // 1)}{0.025 + (3.3//1)}$

$= \underline{\underline{0.430}}\ V/V$

$\dfrac{i_o}{i_i} = \dfrac{v_o / R_L}{v_s / (R_s + R_i)}$

$= \dfrac{v_o}{v_s} \cdot \dfrac{(R_s + R_i)}{R_L}$

$= 0.43 \times \dfrac{(100 + 80)}{1}$

$= \underline{\underline{77.4}}\ A/A$

$R_{out} = 3.3 \,//\, \left[r_e + \dfrac{100}{\beta+1}\right]$

$= 3.3 \,//\, \left[0.025 + \dfrac{100}{101}\right]$

$= \underline{\underline{0.776}}\ K\Omega$

5.145

Refer to Fig 5.63(a)

$R_o = r_o \,//\, [r_e + 10K/\beta+1]$

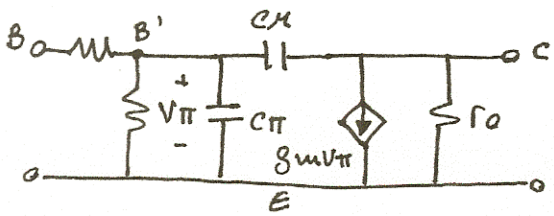
CONT.

(e) $\frac{v_o}{v_s} = \frac{v_{b1}}{v_s} \cdot \frac{v_{e1}}{v_{b1}} \cdot \frac{v_o}{v_{e1}}$

$= 0.833 \times 0.997 \times 0.995$

$= \underline{\underline{0.826}}$ V/V

5.149



$r_x = \underline{100\,\Omega}$

$g_m = \frac{I_C}{V_T} = \frac{0.5\,mA}{25\,mV} = \underline{\underline{20\,mA/V}}$

$r_\pi = \frac{\beta_o}{g_m} = \frac{100}{20} = \underline{\underline{5\,k\Omega}}$

$r_o = \frac{V_A}{I_C} = \frac{50V}{0.5\,mA} = \underline{\underline{100\,k\Omega}}$

$C_\mu = \frac{C_{\mu o}}{\left(1 + \frac{V_{CB}}{V_{oc}}\right)^{0.5}} = \frac{30}{\left(1 + \frac{2}{0.75}\right)^{0.5}} = \underline{\underline{15.7}}\,fF$

$C_{je} \simeq 2C_{jeo} = 2 \times 20 = 40\,fF$

$C_{de} = \tau_F g_m = 30 \times 10^{-12} \times 20 \times 10^{-3} = 600\,fF$

$C_\pi = C_{je} + C_{de} = \underline{\underline{0.640}}\,pF$

$f_T = \frac{g_m}{2\pi(C_\pi + C_\mu)} = \frac{20 \times 10^{-3}}{2\pi(0.64 + 0.016) \times 10^{-12}}$

$= \underline{\underline{4.85}}$ GHz

5.150

$|h_{fe}| \simeq f_T / f$

- At $I_C = 0.2\,mA$, $|h_{fe}| = 2.5$ at $f = 500\,MHz$, thus:

$f_T = 2.5 \times 500 = \underline{\underline{1.25}}$ GHz

- At $I_C = 1.0\,mA$, $|h_{fe}| = 11.6$ at $f = 500\,MHz$, thus:

$f_T = 11.6 \times 500 = \underline{\underline{5.8}}$ GHz

$f_T = \frac{g_m}{2\pi(C_\pi + C_\mu)}$

$C_\pi + C_\mu = \frac{g_m}{2\pi f_T} \rightarrow C_\pi = \frac{g_m}{2\pi f_T} - C_\mu$

$C_\pi(I_C = 0.2\,mA) = \frac{8 \times 10^{-3}}{2\pi \times 1.25 \times 10^9} - 0.05 \cdot 10^{-12}$

$= 0.9686\,pF$

$C_\pi(I_C = 1.0\,mA) = \frac{40 \times 10^{-3}}{2\pi \times 5.8 \times 10^9} - 0.05 \times 10^{-12}$

$= 1.0476\,pF$

Since $C_\pi = C_{je} + \tau_F g_m$,

$C_{je} + 8 \times 10^{-3} \tau_F = 0.9686 \times 10^{-12}$ (1)

$C_{je} + 40 \times 10^{-3} \tau_F = 1.0476 \times 10^{-12}$ (2)

Solving Eqn. (1) and (2) together yields,

$C_{je} = \underline{\underline{0.95\,pF}}$, $\tau_F = \underline{\underline{2.47\,ps}}$

5.151

$f_T = \frac{g_m}{2\pi(C_\pi + C_\mu)}$

$= \frac{80 \times 10^{-3}}{2\pi(10 + 1) \times 10^{-12}}$

$= \underline{\underline{4.24\,GHz}}$

$f_\beta = f_T / \beta_o = (4.24/150) \times 10^9$

$= \underline{\underline{28.26\,MHz}}$

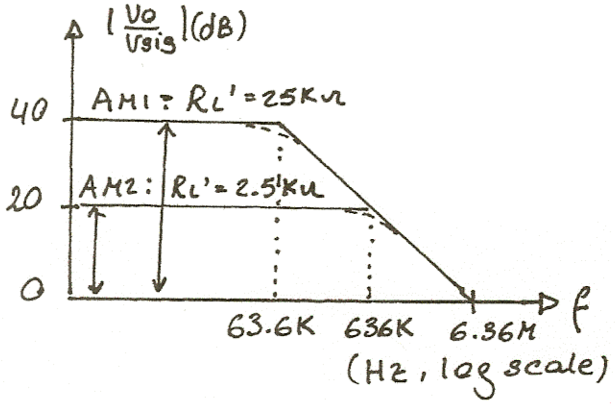
5.152

At $I_C = 2\,mA$ the diffusion part of C_π is: $10 - 2 = 8\,pF$

CONT.

$$f_H = \frac{1}{2\pi \times 10^{-12} \times 100 \times 2.5 \cdot 10^3}$$

$f_H = \underline{\underline{636}}\ KHz$



$GP = 6.36 \times 10^6 = A_M \times f_H$

when $A_M = 1 \Rightarrow f_H = \underline{\underline{6.36 \cdot 10^6}}\ Hz$

$$R_L' = \frac{1}{2\pi\,(6.36 \times 10^6)\,\underbrace{C_\mu}_{1 \times 10^{-12}} \times \underbrace{\beta}_{100}}$$

$R_L' = \underline{\underline{250\Omega}}$

5.159

Refer to Fig. P5.159

$R_{in} = R_1 \,//\, R_2 \,//\, (r_x + r_\pi)$

where $R_1 = 33K\Omega$, $R_2 = 22K\Omega$

Next →

CONT.

$r_x = 50$ and,

$$r_\pi = \frac{\beta_0}{g_m} = \frac{120}{0.3\times 40} = \frac{120}{12} = 10K\Omega$$

$$R_{in} = 33 \,\|\, 22 \,\|\, 10.05 = \underline{\underline{5.7\,K\Omega}}$$

$$A_M = -\frac{R_{in}}{R_{in}+R_s}\cdot\frac{r_\pi}{r_\pi + r_x}\cdot g_m\,(R_c\|R_L\|r_o)$$

$$= -\frac{5.7}{5.7+5}\cdot\frac{10}{10+0.05}\cdot 12\,(4.7\|5.6\|300)$$

$$= \underline{\underline{-16.11}}\ \text{V/V}$$

$$R'_{sig} = r_\pi \,\|\, [r_x + (R_1\|R_2\|R_{sig})]$$

$$= 10K \,\|\, [50 + (33\|22\|5)K]$$

$$= \underline{\underline{2.69\,K\Omega}}$$

$$R'_L = r_o \,\|\, R_C \,\|\, R_L = 300\|4.7\|5.6\,(K\Omega)$$

$$= 2.53\,K\Omega$$

$$C_\pi + C_\mu = \frac{g_m}{2\pi\cdot f_T} = \frac{12\cdot 10^{-3}}{2\pi\times 700\cdot 10^{6}} =$$

$$= 2.73\,pF$$

$$C_\pi = (2.73 - 1)\,pF$$

$$= 1.73\,pF$$

$$C_{in} = C_\pi + C_\mu(1 + g_m R'_L)$$

$$= 1.73p + 1p(1 + 12\times 2.53)$$

$$= 33\,pF$$

$$f_H = 1/2\pi\, C_{in}\cdot R'_{sig}$$

$$= 1/2\pi\times 33\cdot 10^{-12}\times 2.69\cdot 10^{3}$$

$$= \underline{\underline{1.79\,MHz}}$$

5.160

$$R_{in} = R_1 \,\|\, R_2 \,\|\, r_\pi$$

where $r_\pi = \frac{\beta}{g_m}$ and $g_m = \frac{I_C}{V_T}$

$$g_m = \frac{0.8}{0.025} = 32\,mA/V$$

$$r_\pi = \frac{200}{32} = 6.25\,K\Omega$$

$$R_{in} = 68\|27\|6.25 = 4.72\,K\Omega$$

$$R'_L = R_C\|R_L = 4.7\|10 = 3.2\,K\Omega$$

$$A_M = \frac{R_{in}}{R_s + R_{in}} \times -g_m R'_L$$

$$= \frac{-4.72}{10 + 4.72}\times 32\times 3.2$$

$$= \underline{\underline{-32.8}}\ \text{V/V}$$

$$C_T = C_\pi + C_\mu(1 + g_m R'_L)$$

where $C_\pi + C_\mu = \frac{g_m}{2\pi f_T} = \frac{32\times 10^{-3}}{2\pi\times 10^{9}}$

$$= 5.1\,pF$$

$$C_\pi = 5.1 - 0.8 = 4.3\,pF$$

$$C_T = 4.3 + 0.8\,(1 + 32\times 3.2)$$

$$= 87\,pF$$

The resistance seen by C_T is R_T,

$$R_T = r_\pi \| R_1 \| R_2 \| R_s$$

$$= 6.25\|68\|27\|10 = 3.2\,K\Omega$$

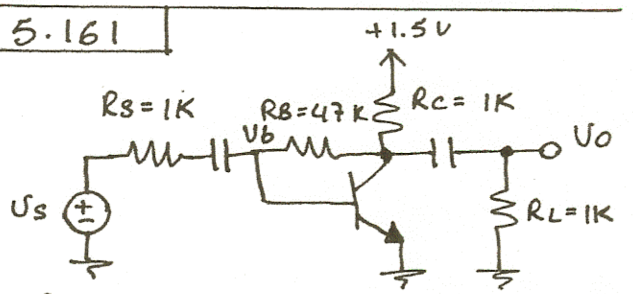
Thus

$$f_H \simeq \frac{1}{2\pi C_T R_T}$$

$$= \frac{1}{2\pi\times 87\times 10^{-12}\times 3.2\times 10^{3}}$$

$$= \underline{\underline{572}}\ KHz$$

5.161



$\beta = 100$, $C_\mu = 0.8\,pF$, $f_T = 600\,MHz$

CONT.