EE 210

Sol^{n} to HA # 2

1 $R_C = \frac{V_{CC} - V_{CE}}{I_C} = \frac{5-3}{0.5\,mA} = \underline{4\,K\Omega}$ $\quad I_B = \frac{I_C}{\beta} = \frac{0.5\,mA}{100} = \underline{5\,\mu A}$

$R_B = \frac{V_B - V_{BE}}{I_B} = \frac{5-0.7}{5\,\mu A} = \underline{860\,K\Omega}$

At onset of sat., $V_{CE} = \underline{0.7V}$ ⇒ with I_B unchanged, I_C will remain unchanged ⇒ $R_C = \frac{5-0.7}{0.5\,mA} = \underline{8.6\,K\Omega}$

With R_C further doubled to $\underline{17.2\,K\Omega}$, the pot. drop across it will drive Q into hard sat., with $V_{CE}(sat) = \underline{0.1V}$ (assumed).

⇒ $I_{C,sat} = \frac{5-0.1}{17.2\,K\Omega} = \underline{284.9\,\mu A}$ (note the reduction in I_C)

V_{BE} will adjust itself to $\underline{0.8V}$ in hard sat.

∴ $I_{B,sat} = \frac{5-0.8}{860\,K\Omega} = \underline{4.88\,\mu A}$ ⇒ $\beta_{sat} = \frac{I_{C,sat}}{I_{B,sat}} = \frac{284.9}{4.88} = \underline{58.4}$

Degree of sat. (DoS) $= \frac{\beta}{\beta_{sat}} = \frac{100}{58.4} = \underline{1.7}$

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2 $C_\pi = C_{je} + \tau_F g_m$ ⇒ $C_{\pi_2} - C_{\pi_1} = \tau_F (g_{m2} - g_{m1})$ ∵ $C_{je_1} = C_{je_2}$

⇒ $8 - 6 = \tau_F \left(\frac{2}{26} - \frac{1}{26}\right)$ ⇒ $\tau_F = \underline{52\,pS}$ & $C_{je} = 6pf - 52\,pS \times \frac{1}{26} = \underline{4pf}$

∵ EB jn. is forward biased, apply thumb rule $C_{je} \simeq 2C_{jeo}$, which gives $C_{jeo} = \underline{2pf}$.

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3 For both $I_C = 1mA$ & $10mA$, V_{CB} is held constant at $10V$ ⇒ C_μ remains constant. $f_T = \frac{g_m}{2\pi(C_\pi + C_\mu)} = \frac{1}{2\pi\tau}$ where τ is an effective time $= \frac{C_\pi + C_\mu}{g_m}$. ∴ for $I_C = 1mA$, $\tau_1 = \frac{1}{2\pi f_{T1}} = \underline{0.265\,nS}$, & for $I_C = 10\,mA$, $\tau_2 = \frac{1}{2\pi f_{T2}} = \underline{0.159\,nS}$. Thus, $0.265\,nS = \tau_F + \frac{C_{je} + C_\mu}{g_{m1}}$ (∵ τ_F, C_{je}, & C_μ are constants) with $g_{m1} = \frac{1}{26}\,\mho$, & $0.159\,nS = \tau_F + \frac{C_{je} + C_\mu}{g_{m2}}$ with $g_{m2} = \frac{1}{2.6}\,\mho$. $C_\mu = 0.15pf$ is given. Solving, we get $C_{je} = \underline{4.38pf}$ & $\tau_F = \underline{147.22pS}$

Also, $C_\mu = \dfrac{C_{\mu 0}}{\left(1-\frac{V_{BC}}{V_0}\right)^{1/2}}$ (assumed that the jn. is abrupt)

with $V_{BC} = -10V$, $C_\mu = 0.15pF$, & $V_0 = 0.55V$ (given) $\Rightarrow C_{\mu 0} = \underline{0.657pf}$

$\therefore$ with $V_{BC} = -2V$ $\quad C_\mu = \dfrac{0.657pF}{\left(1+\frac{2}{0.55}\right)^{1/2}} = \underline{0.305\ pf}$

$r_o = 50\ K\Omega$ at $I_C = 1\ mA \Rightarrow V_A = I_C r_o = \underline{50V}$

Now, we have all the reqd. parameters to obtn. the small-signal model.

$\underline{I_C = 0.1mA}$: $g_m = 3.846\ m℧$, $r_\pi = 26\ k\Omega$, $r_o = 500\ k\Omega$, $r_\mu = 250\ M\Omega$,
$C_b = \tau_F g_m = 0.566\ pF$, $C_\pi = C_{je} + C_b = 4.946\ pF$, $C_\mu = 0.305pF$.

$\underline{I_C = 1mA}$: $g_m = 38.46\ m℧$, $r_\pi = 2.6\ k\Omega$, $r_o = 50k\Omega$, $r_\mu = 25M\Omega$, $C_b = 5.66pf$,
$C_\pi = 10.04pF$, $C_\mu = 0.305pF$.

$\underline{I_C = 5mA}$: $g_m = 192.3\ m℧$, $r_\pi = 520\Omega$, $r_o = 10\ K\Omega$, $r_\mu = 5M\Omega$, $C_b = 28.31pF$,
$C_\pi = 32.69\ pF$, $C_\mu = 0.305pF$.

Check all these nos. for their correctness.*

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The small-signal model will be identical to that given in class.

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$\underline{4}$ $\beta = \dfrac{\beta_0}{1+jf/f_\beta}$. Now, with $\beta_0 = 100$ & β of only 9 at $f = 50MHz$, it is prudent to assume that $f \gg f_\beta$.

$\Rightarrow |\beta| = \dfrac{\beta_0 f_\beta}{f} = \dfrac{f_T}{f} \Rightarrow f_T = f|\beta| = \underline{450\ MHz}$

Now, $f_T = \dfrac{g_m}{2\pi(C_\pi + C_\mu)} \Rightarrow C_{je} + \tau_F g_m + C_\mu = \dfrac{g_m}{2\pi f_T}$

We have $g_m = \frac{1}{26}℧$, $\tau_F = 0.25ns$, & $C_\mu = 0.6pF$

$\Rightarrow C_{je} = \dfrac{1}{26 \times 2\pi \times 450 \times 10^6} - 0.25ns \times \dfrac{1}{26} - 0.6pF = \underline{3.4pF}$

Small-Signal model parameters for $\underline{I_C = 2mA}$:

$g_m = \dfrac{I_C}{V_T} = \dfrac{2mA}{26mV} = \underline{76.923\ m℧}$, $r_\pi = \beta_0/g_m = \underline{1.3k\Omega}$, $r_o = \dfrac{V_A}{I_C} = \underline{20k\Omega}$,

$C_{je} = 3.4pF$, $C_b = \tau_F g_m = 19.23pF$, $C_\pi = C_{je} + C_b = \underline{22.63pF}$,

& $C_\mu = \underline{0.6pf}$.

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5 $C_\pi = C_{je} + \tau_F g_m = 5pF + 26ps \times \frac{2}{26} = \underline{\underline{7pF}}$ $\qquad C_\mu = \underline{\underline{0.5pF}}$ (given)

$$f_T = \frac{g_m}{2\pi(C_\pi + C_\mu)} = \frac{2}{26} \times \frac{1}{2\pi(7pF + 0.5pF)} = \underline{\underline{1.63\ GHz}}$$

$$f_\beta = \frac{f_T}{\beta_o} = \underline{\underline{16.32\ MHz}}$$

(Note how small f_β is as compared to f_T, of course, the difference depends on β_o)

$$f_\alpha = (\beta_o + 1) f_\beta = \underline{\underline{1.65\ GHz}}$$

(Note that f_α is so very slightly larger than f_T).

$$f_{max} = \frac{1}{2\pi \tau_F} = \underline{\underline{6.12\ GHz}}$$

(way higher than f_β, & almost 4 times that of f_T & f_α)

The transistor cannot be operated for any freq. higher than f_{max}.

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