EEC 114
PS #1

HW #1 Solutions

#1) Calculate Zero-Bias Junction Capacitance for Problem 1.1 and calculate @ 5V Reverse Bias and .3V Forward Bias. Assume a junction area of $2\times10^{-5}\ cm^2$.

First calculate ψ_0

$$\psi_0 = V_T \ln \frac{N_A N_D}{n_i^2} = .026 \ln \frac{(8\times10^{15})10^{17}}{(1.5\times10^{10})^2}$$

$$= \underline{\underline{.751V}}$$

For zero-bias

$$C_{j0} = A\left[\frac{q\epsilon N_A N_D}{2(N_A+N_D)}\right]^{1/2} \frac{1}{\sqrt{\psi_0 - V_D}}$$

V_D ← Bias Voltage

$$= 2\times10^{-5}\left[\frac{(1.6\times10^{-19})(1.04\times10^{-12})(8\times10^{15})10^{17}}{2(8\times10^{15}+10^{17})}\right]^{1/2}\frac{1}{\sqrt{.751-0}}$$

$$= \underline{\underline{.57pf}}$$

For 5V Reverse Bias

$$C_j = \frac{C_{j0}}{\left(1-\frac{V_D}{\psi_0}\right)^{1/2}} = \frac{.57pF}{\left(1-\frac{-5V}{.751V}\right)^{1/2}} = \underline{\underline{.21pF}}$$

For .3V Forward Bias

$$C_j = \frac{.57pF}{\left(1-\frac{.3V}{.751V}\right)^{1/2}} = \underline{\underline{.74pF}}$$

\# 2 SKETCH $I_C - V_{CE}$ CHARACTERISTICS IN E.A.R. for an npn XSTR where

$\beta = 100$ $BV_{CBO} = 120V$

$V_A = 50V$ $n = 4$

$$M = \frac{1}{1 - \left(\frac{V_{CB}}{BV_{CBO}}\right)^n} \quad (1.78) \Rightarrow \boxed{\frac{1}{m} = 1 - \left(\frac{V_{CB}}{BV_{CBO}}\right)^4}$$

BUT $V_{CB} = V_{CE} - V_{BE}$ Assume $V_{BE} = .7V$

Then $\underline{\underline{V_{CB} = V_{CE} - .7V}}$

$$I_C = \left(1 + \frac{V_{ce}}{50}\right)\left(\frac{m\,\alpha_F}{1 - m\alpha_F}\right) I_B \qquad \alpha_F = \frac{\beta_F}{\beta_F + 1} = \frac{100}{100+1} = .9901$$

Divide TOP AND BOTTOM BY m

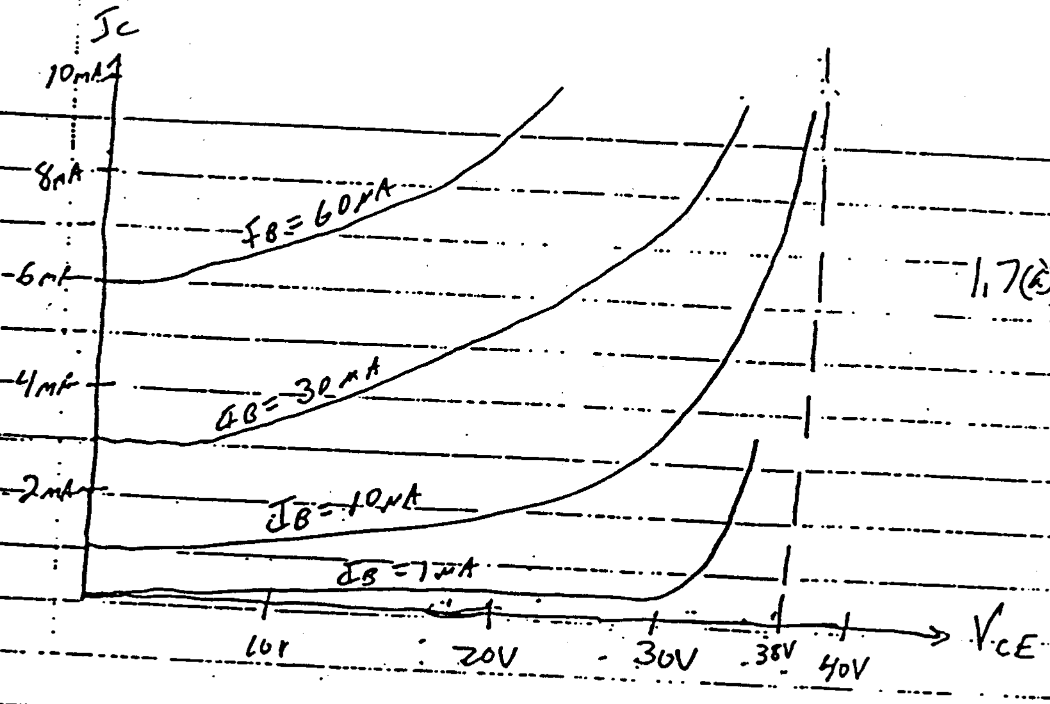
$$I_C = \left(1 + \frac{V_{ce}}{50}\right)\left(\frac{\alpha_F}{\frac{1}{m} - \alpha_F}\right) I_B = \boxed{\left(1 + \frac{V_{ce}}{50}\right)\left(\frac{.9901}{1 - \left(\frac{V_{ce} - .7V}{120V}\right)^4 - .9901}\right) I_B}$$

USE The ABOVE EQUATION FOR DIFFERENT I_B's

PLOT FOR $V_{ce} = 0 \rightarrow BV_{CEO}$

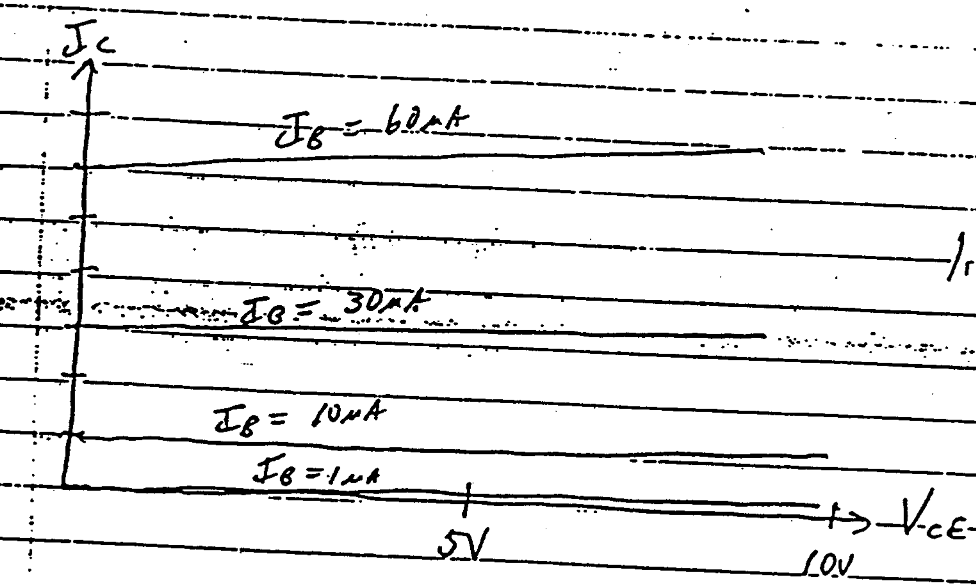
$$BV_{CEO} = \frac{BV_{CBO}}{\sqrt[n]{\beta_F}} = \frac{120}{\sqrt[4]{100}} = 37.9V$$

So PLOT FOR $V_{CE} = 0 \rightarrow 37V$ FOR PART (a)



I_C
10mA
8mA
6mA
4mA
2mA
$I_B = 60\mu A$
$I_B = 30\mu A$
$I_B = 10\mu A$
$I_B = 1\mu A$
10V
20V
30V
38V
40V
V_{CE}

1.7(A)



I_C
$I_B = 60\mu A$
$I_B = 30\mu A$
$I_B = 10\mu A$
$I_B = 1\mu A$
5V
10V
V_{CE}

1.7(B)

EEC 114 Fall

HW#1

Prof. Hurst

#3. $v_T := 26 \cdot 10^{-3}$ $\quad \beta_0 := 100$ $\quad r_b := 200$ $\quad r_c := 100$ $\quad r_{ex} := 4$ $\quad \eta := 1 \cdot 10^{-3}$

$n := 0.5$ $\quad \psi_0 := 0.55$ $\quad C_{\mu 0} := 10 \cdot 10^{-15}$ $\quad C_{cs0} := 20 \cdot 10^{-15}$ $\quad \tau_F := 15 \cdot 10^{-12}$

$C_{je0} := 20 \cdot 10^{-15}$

$$g_m(I_C) := \frac{I_C}{v_T}$$

$$r_\pi(I_C) := \frac{\beta_0}{g_m(I_C)}$$

$$C_{je} := 2 \cdot C_{je0}$$

$$C_b(I_C) := \tau_F \cdot g_m(I_C)$$

$$r_o(I_C) := \frac{1}{\eta \cdot g_m(I_C)}$$

$$r_\mu(I_C) := 5 \cdot \beta_0 \cdot r_o(I_C)$$

$$C_\mu(V_{BC}) := \frac{C_{\mu 0}}{\left(1 - \frac{V_{BC}}{\psi_0}\right)^n} \qquad C_{cs}(V_{cs}) := \frac{C_{cs0}}{\left(1 + \frac{V_{cs}}{\psi_0}\right)^n} \qquad C_\pi(I_C) := C_b(I_C) + C_{je}$$

$$f_T(I_C, V_{BC}) := \left(\frac{1}{2 \cdot \pi}\right) \cdot \left(\frac{g_m(I_C)}{C_\pi(I_C) + C_\mu(V_{BC})}\right)$$

$$f_{Tpeak} := \frac{1}{2 \cdot \pi \cdot \tau_F}$$

$I_C := 1 \cdot 10^{-3}$ $\quad V_{BC} := -1$ $\quad V_{CS} := 2$

$g_m(I_C)$ float,3 $\rightarrow 3.85 \cdot 10^{-2}$ 38.5 mA/V $\quad C_{cs}(V_{CS})$ float,3 $\rightarrow 9.29 \cdot 10^{-15}$ 9.29 fF

$r_\pi(I_C)$ float,3 $\rightarrow 2.60 \cdot 10^{3}$ 2.6 kΩ $\quad C_\pi(I_C)$ float,3 $\rightarrow 6.17 \cdot 10^{-13}$ 0.617 pF

$r_o(I_C)$ float,3 $\rightarrow 2.60 \cdot 10^{4}$ 26 kΩ $\quad C_b(I_C)$ float,3 $\rightarrow 5.77 \cdot 10^{-13}$ 0.577 pF

$r_\mu(I_C)$ float,3 $\rightarrow 1.30 \cdot 10^{7}$ 13 MΩ $\quad f_T(I_C, V_{BC})$ float,3 $\rightarrow 9.83 \cdot 10^{9}$ 9.83 GHz

$C_\mu(V_{BC})$ float,3 $\rightarrow 5.96 \cdot 10^{-15}$ 5.96 fF $\quad f_{Tpeak}$ float,3 $\rightarrow 1.06 \cdot 10^{10}$ 10.6 GHz

4. Form the EQUIVILANT npn XSTR

For $r_b = 100\Omega$ $r_c = 100\Omega$ $\beta_0 = 100\Omega$ $\psi_0 = .5V$ $r_\mu = 5(3.6$

$I_C = .1mA, 1mA, 5mA$ $V_{CB} = 2V$, $V_{CS} = 15V$

@ $I_C = 1mA$ $g_m = \frac{10^{-3}A}{26mV} = \underline{38mA/V}$

$f_T = \frac{1}{2\pi} \frac{g_m}{C_\pi + C_\mu} \Rightarrow C_\pi + C_\mu = \frac{g_m}{2\pi f_T} = \frac{38mA}{2\pi(600\times10^6)}$

$= \underline{10.1pF}$ ← f_{T_1}

SINCE $C_\mu = .15pF$

$\therefore C_\pi = 9.95pF$

SO $f_{T_1} = 600MHz$ @ $I_C = 1mA$ $\tau_{T_1} = \frac{1}{2\pi(600\times10^6)} = \underline{265ps}$

$f_{T_2} = 1000MHz$ @ $I_C = 10mA$ $\tau_{T_2} = \frac{1}{2\pi(1000\times10^6)} = \underline{159ps}$

SO $265_{ps} = \tau_F + 26(C_\mu + C_{je})$

$159ps = \tau_F + 2.6(C_\mu + C_{je})$

SUBTRACTING: $106ps = 23.4(C_\mu + C_{je})$

$\Rightarrow 4.53 = C_\mu + C_{je}$ BUT $C_\mu = \underline{.15pF}$

SO $C_{je} = 4.53pF - .15pF = \underline{4.38pF}$

plugging BACK IN $\tau_F = \underline{147ps}$

$C_{\mu_0} = C_\mu \left(1 + \frac{10}{.5}\right)^{1/2} = \underline{.687pF}$

$C_{cs_0} = C_{cs}\sqrt{1 + \frac{V_{cs}}{\psi_0}} = \underline{4.58pF}$

(cont)

\# 4i

i) So for $I_C = .1mA$ $V_{CB} = 2V$ $V_{CS} = 15V$

$$C_\mu = \frac{.687pF}{\sqrt{1+\frac{2V}{.5}}} = .307pF$$

$$C_{cs} = \frac{C_{cs0}}{\sqrt{1+\frac{V_{cs}}{\psi_0}}} = \frac{4.58pF}{\sqrt{1+\frac{15}{.5}}} = .823pF$$

$$g_m = \frac{.1\times10^{-3}}{26\times10^{-3}} = 3.85mA/V$$

$$C_b = \underbrace{(147\times10^{-12})}_{\tau_F}\underbrace{(3.85\times10^{-3})}_{g_m} = .565pF$$

$$C_\pi = C_b + C_{je} = .565pF + 4.38pF$$
$$= 4.95pF$$

$$r_\pi = \frac{\beta_0}{g_m} = \frac{100}{3.85\times10^{-3}} = 25.97k\Omega$$

$$r_o = \frac{V_A}{I_C} \Rightarrow r_o = \frac{50V}{.1mA} = 500k\Omega$$

$$r_\mu = 5\times\beta_0 r_o = 250M\Omega$$

$r_b = 100\Omega$

$r_c = 100\Omega$

$r_{ex} = 1\Omega$

ii) For $I_C = 1mA$

$g_m = 38.5mA/V$ $r_\pi = 2.6k\Omega$ $C_b = 5.7pF$

$C_\pi = 10pF$ $r_o = 50k\Omega$ $r_\mu = 25M\Omega$

All other elements same as in i)

iii) @ 5mA $g_m = 193mA/V$ $C_\pi = 32.7pF$

$r_\pi = 520\Omega$

$r_o = 10k\Omega$

$C_b = 28.3pF$ $r_\mu = 5M\Omega$

#5) If the area of the transistor in prob 1.11 was effectively doubled by connecting two transistors in parallel, which model parameters in the small-signal composite model would differ from those in the original device if the <u>TOTAL</u> collector current was unchanged? what is the relationship between the parameters of the composite and original devices?

the parameters to be considered are.

g_m, r_π, r_μ, r_o, β_o, C_π, C_μ, C_{cs}

(1) lets consider the resistances first.

r_π, r_μ, r_o, and g_m are all functions of the collector dc current. The problem states that the dc collector current remains unchanged.

$\Rightarrow$ r_π, r_μ, r_o, and g_m are unchanged.

(2) current gain, β_o

$\beta_o = \frac{I_C}{I_B}$, I_C and I_B remain unchanged

$\Rightarrow$ β_o remain unchanged

(3) C_μ & C_{cs}

These capacitances are junction caps from eq. 1.20 used in prob 1.2

$$C_{junction} = A(\text{constant})^{1/2} \frac{1}{\sqrt{\Psi_0 - V_D}}$$

C_μ & C_{cs} are directly proportional to area and are twice the values of the original device

#5 cont'd)

(4) $C_\pi = C_b + C_{je}$

$C_b = \tau_F g_m$

as noted before, g_m does not change:

$\tau_F = \dfrac{W_B^2}{2D_n}$, the width of the base does not change, the length does. So τ_F (the transit time across the base) does not change.

$\Rightarrow$ C_b does not change

C_{je} is a junction cap, so it is twice the value of C_{je} in the original device.