1.11 npn transistor

$r_b = 100\Omega$, $r_c = 100\Omega$, $\beta_0 = 100$, $r_o = 50k\Omega$ @ $I_C = 1mA$ … ③

$\psi_0 = 0.55V$

$f_T = 600MHz$ @ $I_C = 1mA$, $V_{CB} = 10V$ … ①

C_{je} is constant in the forward-bias region

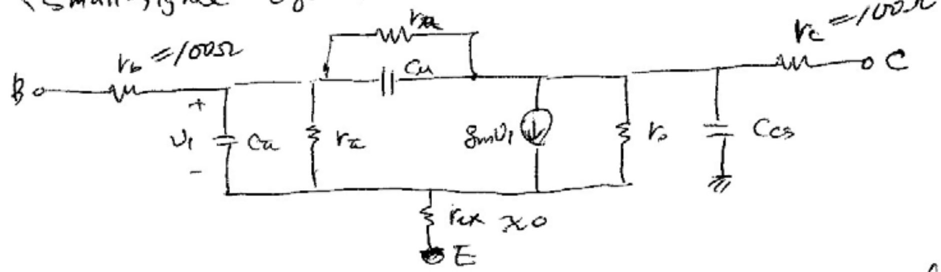
$f_T = 1GHz$ @ $I_C = 10mA$, $V_{CB} = 10V$ … ②

$C_\mu = 0.15pF$ @ $V_{CB} = 10V$

$r_\mu = 5\beta_0 r_o$

$C_{cs} = 1pF$ @ $V_{CS} = 10V$

<small-signal equivalent circuit>



• for τ_F and C_{je}, from ① and ②

$$\begin{cases} \frac{1}{2\pi \cdot 600M} = \tau_F + \frac{V_T}{1mA} C_{je} + \frac{V_T}{1mA} C_\mu \\ \frac{1}{2\pi \cdot 1G} = \tau_F + \frac{V_T}{10mA} C_{je} + \frac{V_T}{10mA} C_\mu \end{cases}$$

$C_\mu = 0.15pF$. $V_T = 0.026$

$\Rightarrow \tau_F = 147ps$. $C_{je} = 4.4pF$

• for V_A, from ③

$V_A = r_o I_C = 50V$

(a) $I_C = 0.1mA$	$I_C = 1mA$	$I_C = 5mA$
$g_m = \frac{I_C}{V_T} = 3.8mA/V$	$38mA/V$	$190mA/V$
$r_\pi = \frac{\beta_0}{g_m} = 26k\Omega$	$2.6k\Omega$	530Ω
$r_o = \frac{V_A}{I_C} = 500k\Omega$	$50k\Omega$	$10k\Omega$
$r_\mu = 5\beta_0 r_o = 250M\Omega$	$25M\Omega$	$5M\Omega$
$C_\pi = C_b + C_{je} = \tau_F g_m + C_{je} = 5.0pF$	$10pF$	$32.4pF$
$C_\mu = 0.15p\sqrt{\frac{1-\frac{-10}{0.55}}{1-\frac{-2}{0.55}}} = 0.31pF$	$0.31pF$	$0.31pF$
$C_{cs} = 1p\sqrt{\frac{1-\frac{-10}{0.55}}{1-\frac{-15}{0.55}}} = 0.82pF$	$0.82pF$	$0.82pF$

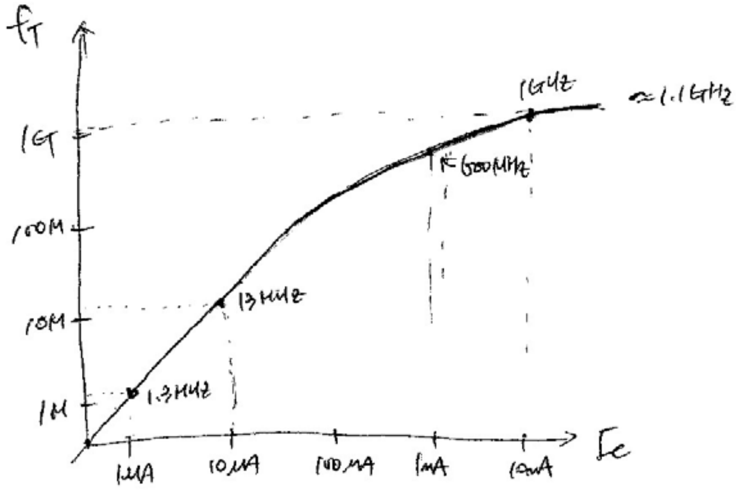
$m_c = m_s = 0.5$ are used.

(b) $$f_T = \frac{1}{2\pi\left(\tau_F + \frac{C_{je}}{g_m} + \frac{C_\mu}{g_m}\right)} = \frac{1}{2\pi\left\{\tau_F + \frac{V_T}{I_C}(C_{je}+C_\mu)\right\}}$$

When $\frac{V_T}{I_C}(C_{je}+C_\mu) \gg \tau_F$, $f_T \cong \frac{I_C}{2\pi V_T(C_{je}+C_\mu)}$ $\Rightarrow$

I_C	f_T
$1\mu A$	$1.3MHz$

when $\frac{V_T}{I_C}(C_{je}+C_\mu) \ll \tau_F$, $f_T \cong \frac{1}{2\pi\tau_F} \approx 1.1GHz$.



1.15. NMOS

$W = 10\mu$ $L = 1\mu$ $K' = 194\ \mu A/V^2$ $\lambda = 0.024 V^{-1}$ $t_{ox} = 80Å$

$\phi_f = 0.3V$ $V_{to} = 0.6V$ $N_A = 5 \times 10^{15}$

(a) $V_t = 0.6$

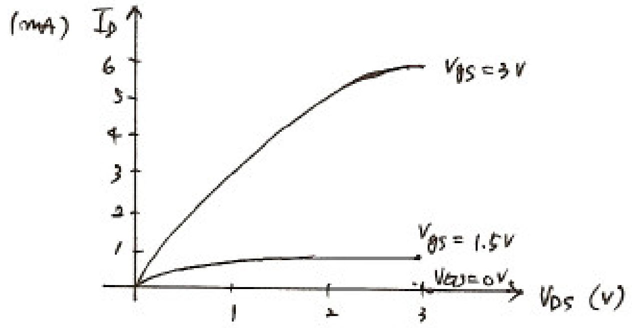
$$\frac{K'}{2} \cdot \frac{W}{L} = 97 \times 10 = 970\ \mu A/V^2$$

In the triode region

$$I_D = 0.97 \left[2 \times (V_{GS} - 0.6) V_{DS} - V_{DS}^2 \right] \ mA$$

In the saturation region

$$I_D = 0.97 (V_{GS} - 0.6)^2 (1 + 0.024 V_{DS}) \ mA$$

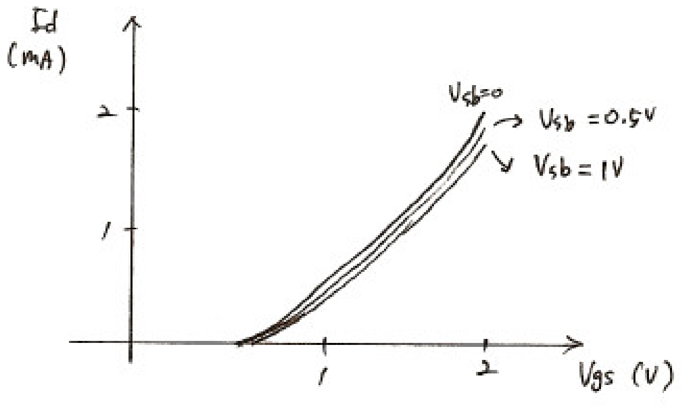


(b) $\gamma = \frac{1}{C_{ox}} \sqrt{2 q \epsilon N_A} = 0.095 \sqrt{V}$

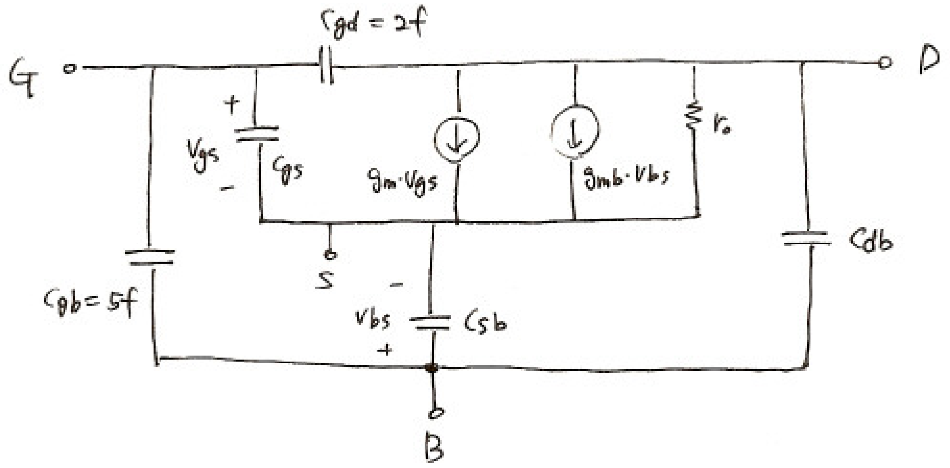
$C_{ox} = \frac{\epsilon_{ox}}{t_{ox}} = 4.3\ fF/\mu m^2$

$V_t = V_{to} + \gamma \left(\sqrt{2\phi_F + V_{SB}} - \sqrt{2\phi_F} \right)$

VSB	0V	0.5V	1V
Vt	0.6V	0.626V	0.647V



1.16



$V_t = 0.647\,V$

$I_D = \frac{k'}{2} \cdot \frac{W}{L} (V_{GS} - V_t)^2 (1 + \lambda V_{DS}) = 127\ \mu A$

$g_m = \frac{2 I_D}{V_{GS} - V_t} = 720\ \mu A/V$

$g_{mb} = \frac{\gamma \cdot g_m}{2\sqrt{2\phi_f + V_{SB}}} = 27\ \mu A/V$

$r_o = \frac{1}{\lambda I_D} \cong 327\ k\Omega$

$C_{sb} = \frac{C_{sb0}}{\sqrt{1 + \frac{V_{SB}}{\Psi_0}}} = 12.8f$

$C_{db} = \frac{C_{db0}}{\sqrt{1 + \frac{V_{DB}}{\Psi_0}}} = 8.7f$

$C_{gs} = \frac{2}{3} C_{ox} W L + 2f = 30.7f$