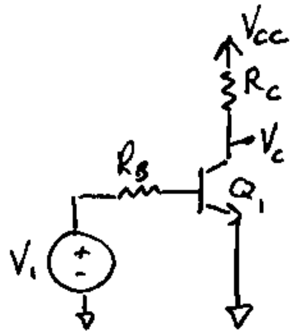
1)



Find V_1 that saturates the transistor.

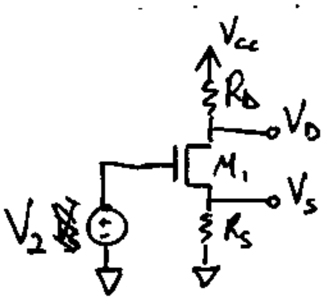
$$V_{CE,sat} = V_C$$

$$I_{C,sat} = \frac{V_{CC} - V_{CE,sat}}{R_C} = I_S e^{\left(\frac{V_{BE}}{V_{Th}}\right)} \rightarrow V_{BE_{sat}} = V_{Th} \ln\left(\frac{I_{C,sat}}{I_S}\right)$$

$$I_{B_{sat}} = \frac{I_{C,sat}}{\beta}$$

$$V_1 = I_{B,sat} R_B + V_{BE,sat} = \frac{R_B I_{C,sat}}{\beta} + V_{Th} \ln\left(\frac{I_{C,sat}}{I_S}\right)$$

$$\boxed{V_1 = \frac{R_B}{\beta}\left[\frac{V_{CC} - V_{CE,sat}}{R_C}\right] + V_{Th} \ln\left(\frac{V_{CC} - V_{CE,sat}}{I_S R_C}\right)}$$



$$V_{DS,Tri} = V_{GS} - V_T \qquad V_S = I_D R_S \qquad V_D = V_{CC} - I_D R_D$$

$$V_{DS,Tri} = V_{CC} - I_D(R_D + R_S) = V_2 - I_D R_S - V_T$$

$$I_D = \frac{W}{2L} \mu_n C_{ox} (V_{GS} - V_T)^2 = \frac{W}{2L} \mu_n C_{ox} (V_{DS})^2$$

$$V_{DS} = V_2 - I_D R_S - V_T$$

$$V_{DS} = V_2 - \frac{W}{2L}\mu_n C_{ox}(V_{DS})^2 - V_T \rightarrow \frac{W}{2L}\mu_n C_{ox} V_{DS}^2 + V_{DS} + V_T - V_{in} = 0$$

$$V_{DS} = V_{CC} - \frac{W}{2L}\mu_n C_{ox}(V_{DS})^2 (R_D + R_S) \rightarrow \underbrace{\frac{W}{2L}\mu_n C_{ox}}_{K} V_{DS}^2 \underbrace{(R_D + R_S)}_{R_T} + V_{DS} - V_{CC} = 0$$

$$V_{DS} = \frac{-1 \pm \sqrt{1 + 4 K R_T V_{CC}}}{2 K R_T}$$

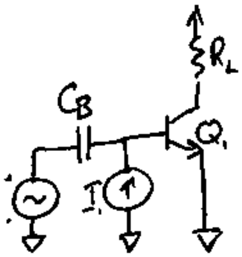
$$I_D = K\left[\frac{-1 + \sqrt{1 + 4 K R_T V_{CC}}}{2 K R_T}\right]^2 = \cancel{K}\left[\frac{1}{4K^2 R_T^2} + \frac{2\sqrt{1 + 4 K R_T V_{CC}}}{2 \cancel{K} R_T} + \frac{1 + 4 K R_T V_{CC}}{4 K^2 R_T^2}\right]$$

$$= \frac{2}{4 K R_T^2} + \frac{V_{CC} + \sqrt{1 + 4 K R_T V_{CC}}}{R_T}$$

$$\boxed{V_{in} = V_{DS} + I_D R_S + V_T = \frac{-1 + \sqrt{1 + 4 K R_T V_{CC}}}{2 K R_T} + R_S\left[\frac{2}{4 K R_T^2} + \frac{V_{CC} + \sqrt{1 + 4 K R_T V_{CC}}}{R_T}\right] + V_T}$$

2) Calculate g_m, r_π, + r_o in the following Circuit.

$V_A = 60\,V$ + $\beta_o = 200$



$$g_m = \frac{I_c}{V_{Th}}$$

$$r_\pi = \frac{\beta}{g_m}$$

$$r_o = \frac{V_A}{I_c}$$

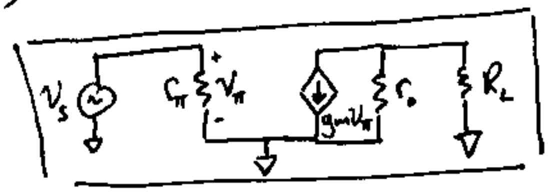
a) $I_1 = I_B = .5\mu A$
$I_c = \beta I_B = 100\mu A$

$$\boxed{g_m = \frac{100\mu A}{V_{Th}} = \frac{100\mu A}{25mV} = 0.004\,\mho = 4mS \quad r_\pi = \frac{\beta}{g_m} = \frac{200}{.004\mho} = 50k\Omega \quad r_o = \frac{60}{100\mu A} = 600k\Omega}$$

b) $I_1 = I_B = 50\mu A$
$I_c = \beta I_B = 10mA$

$$\boxed{g_m = \frac{10mA}{25mV} = 0.4\mho = 400mS \quad r_\pi = \frac{200}{0.4\mho} = 500\Omega \quad r_o = \frac{60}{10mA} = 6k\Omega}$$

c)



d) Increased bias current will decrease the output resistance

$$\boxed{r_o \propto \frac{1}{I_c}}$$

e) Increased bias current will decrease the input resistance

$$\boxed{r_\pi = \frac{\beta}{g_m} = \frac{\beta V_{Th}}{I_c} \propto \frac{1}{I_c}}$$

3)

	$1\,mA,\ V_{CE} = 10\,V_{DC}$	$10\,mA,\ V_{CE} = 10\,V$
$h_{ie} = r_\pi$:	$2 - 8\,k\Omega$	$0.25 - 1.25\,k\Omega$
$h_{fe} = \beta_0$:	$50 - 300$	$75 - 375$
$\frac{h_{ie}}{h_{re}} = r_\mu$:	$2.5 - 10\,M\Omega$	$0.625 - 3.12\,M\Omega$
$\frac{2}{h_{oe}} = r_o$:	$57k - 400\,k\Omega$	$10k - 80\,k$
$C_{ob} = C_\mu$:	$8\,pF$	$8\,pF$

$10\,V_{DC}$ @ $100\,kHz$

$$\tau_F = \frac{1}{2\pi f_T} - \frac{C_{jef}}{g_m} - \frac{C_\mu}{g_m}$$

$$= \frac{1}{2\pi f_T} - \frac{2C_{jeo}}{g_m} - \frac{C_\mu}{g_m}$$

$g_m = \frac{\beta}{r_\pi}$:	$.15 - .006\ \mho$	~~0.2-1.5 kΩ~~ $0.3 - 1.5\ \mho$
τ_F :	$\sim 1.4 \times 10^{-10}\,s$	$\sim 3.4 - 5 \times 10^{-10}\,s$
$C_\pi = C_{jec} + \tau_F g_m =$	$71\,pF$	$150 - 800\,pF$

4)

Find upper bound on τ_F

$$\tau_F = \frac{1}{2\pi f_T} - \frac{C_{jef}}{g_m} - \frac{C_\mu}{g_m}$$

Worst cases:

$f_{T_n} \rightarrow I_c = \sim 6mA$, $V_{CE} = 3vdc$, $f_T = 350MHz \rightarrow g_m = .21$

$C_{ob} = C_\mu \rightarrow V_{CB}\ 30$, $C_\mu = 5pF$, Same result from figure 5

Figure 4 $\rightarrow$ Cje worst case $\approx 6.6pF$ @ 200MHz

$C_{jef} = 2C_{je} = 13.2pF$

$$\tau_{F_{max}} = \frac{1}{2\pi \cdot 350MHz} - \frac{13.2pF}{.21} - \frac{5pF}{.21} = 3.7 \times 10^{-10}\ s$$