Microelectronic Devices and Circuits- EECS105

Second Midterm Exam

Wednesday, November 15, 2000

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Your Name: Official Solutions
(last) (first)

Your Signature:

1. Print and sign your name on this page before you start.
2. You are allowed two 8.5"x11" handwritten sheets with formulas. No books or notes!
3. Do everything on this exam, and make your methods as clear as possible.

Problem 1	______	/30
Problem 2	______	/40
Problem 3	______	/30
TOTAL	______	/100

$\mu = 63$
$\sigma = 22$

Problem 1 of 3 Answer each question briefly and clearly. Sketch a simple drawing if it helps you make your point. (30 points)

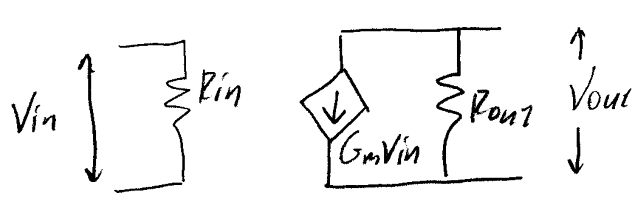
What physical mechanism limits the maximum f_T of a BJT? (6pts)

The transit time of the minority carriers across the base.

What is "base-width modulation" and how does it affect the behavior of BJT?(6pts)

The reverse-biased B-C junction has a large depletion region. As V_{CB} increases, the depletion region increases into the base making it shorter. This increases I_C as a function of V_{CB}, and this gives the transistor a non-infinite r_o (small-signal output resistance).

You are given a 2-port, which has R_{in}=1kΩ, R_{out}=100kΩ, and an open circuit voltage gain A_v = -10. Please draw the equivalent transconductance 2-port and calculate its R_{in}, R_{out}, and G_m. (6pts)



$\frac{V_{out}}{V_{in}} = -10 = -G_m R_{out} \Rightarrow$

$G_m = \frac{10}{R_{out}} = \frac{10}{10^5} = 10^{-4}$ S

$R_{in} = 1$ kΩ

$R_{out} = 100$ kΩ

Consider a CE amplifier. What is (are) the benefit(s) of using an ideal current source versus a resistor connected to the supply to bias the collector? (6 pts)

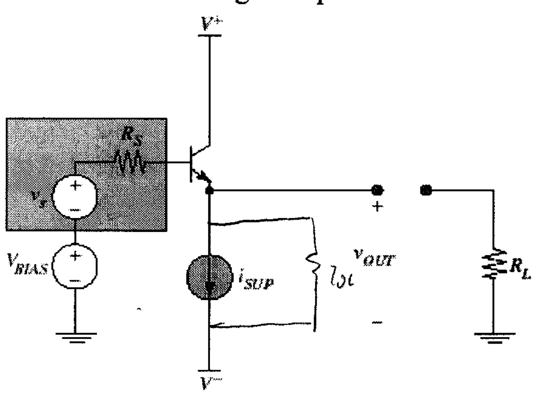
benefit to the gain: $A_v = -g_m (r_o // R_D)$

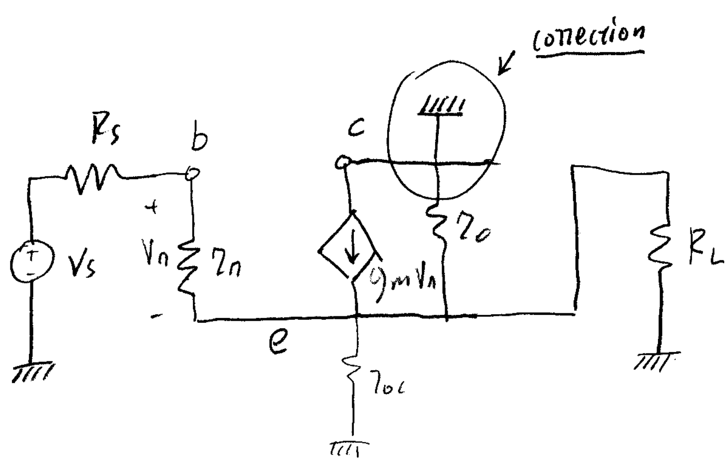
↑ this is small and reduces the gain...

$g_m (r_o) > g_m (r_o // R_D)$

benefit to R_{out}: $R_{out} = r_o > R_{out} = r_o // R_D$

Sketch the small signal equivalent of the following amp (ignore all capacitors) (6 pts):



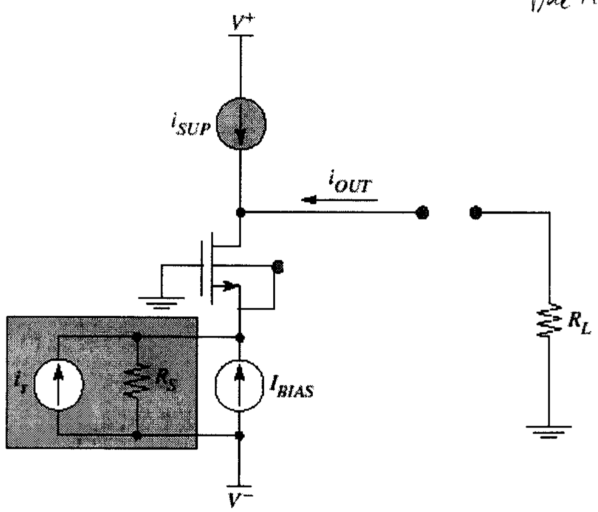


Problem 2 of 3 (40 points)

For each of the following questions, make sure that you show the expressions *__before__* *you plug in the specific values. A correct expression is worth 70% of the credit, even if the numerical calculation is incorrect!*

We want to "match" a car radio antenna to the radio input. The antenna acts as a small signal current source with an $R_s = 50\Omega$. The radio input "looks" like an ohmic load with $R_L=500\Omega$. We will use the following CG MOS amplifier in order to achieve decent current gain from the signal source to the load. Ignore all caps in answering the following questions:

bulk shorted to source



W/L = 2000/2

V_{Tn} = 1V

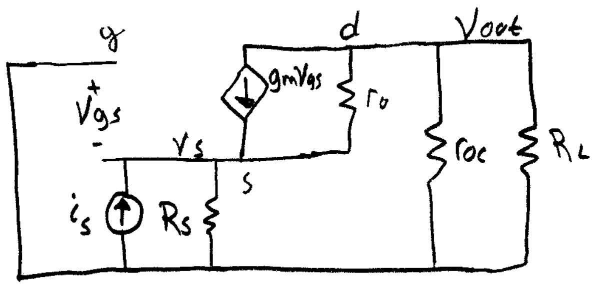
$\mu nCox=50\mu A/V^2$

$\lambda_n=0.05V^{-1}$ (for L=2μm)

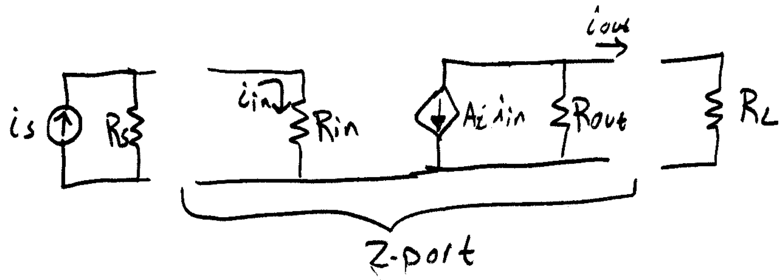
r_{oc}=infinite

I_{BIAS} = 1mA

a) Draw the equivalent small signal circuit of this amplifier (10pts)



b) Sketch the 2-port Current Amp equivalent, and write expressions for R_{in}, R_{out} and A_i. Assume that $r_o >> R_S$. (10 pts).



$$R_{IN} = \frac{1}{g_m} \qquad A_i = -1$$

$$R_{OUT} = r_o(1 + g_m R_S)$$

c) Calculate the overall (loaded) current gain, (note that V_{bs}=0V). (10pts)

$$i_{out} = -i_{in}\frac{R_{out}}{R_{out}+R_L} \qquad i_{in} = \frac{R_S}{R_S + R_{in}} i_s$$

$$\frac{i_{out}}{i_s} = -\left(\frac{R_S}{R_S + R_{IN}}\right)\left(\frac{R_{out}}{R_{out}+R_L}\right)$$

$$I_{BIAS} = I_D = 1mA \qquad g_m = \sqrt{2(W/L)\mu_n C_{ox} I_D} = \sqrt{2 \cdot 1000 \cdot 50\mu A/V^2 \cdot 1mA} = 0.01\ A/V$$

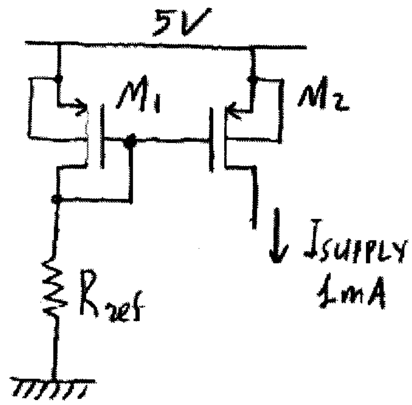
$$R_{IN} = \frac{1}{g_m} = 100\Omega \qquad r_o = \frac{1}{\lambda I_D} = \frac{1}{(0.05V^{-1})(1mA)} = 20k\Omega$$

$$R_{out} = r_o(1 + g_m R_S) = 20k\Omega(1 + 0.01\ A/V \cdot 50\Omega) = 30k\Omega$$

$$\frac{i_{out}}{i_s} = -\left(\frac{50\Omega}{50\Omega + 100\Omega}\right)\left(\frac{30k\Omega}{30k\Omega + 500\Omega}\right) = -(0.333)(0.9836)$$

$$\frac{i_{out}}{i_s} = -0.328$$

d) You are now going to design part of the biasing circuit for this amplifier. The p-channel transistors transistors M_1 and M_2 have both the sameW/L. Find the value of R_{ref} so that this current source delivers the 1mA of supply current that is needed (assume that the load draws no DC current). (10pts).



W/L = 2000
V_{Tp} = -1V
$\mu pCox$=25$\mu A/V^2$
Isupply needed = 1mA

ignore effect of λ

$$I_{ref} = \frac{V_{G_1} - 0}{R_{ref}} = \frac{\mu_p C_{ox}}{2}\left(\frac{W}{L}\right)(V_{SG} + V_{Tp})^2$$

$$I_{ref} = I_{supply} = 1mA$$

$$V_{SG_1} = -V_{Tp} + \sqrt{\frac{I_{D_1}}{\frac{\mu_p C_{ox}}{2}\left(\frac{W}{L}\right)}} = 1V + \sqrt{\frac{1mA}{\frac{25\mu A/V^2}{2}(2000)}}$$

$$V_{SG_1} = 1.2V$$

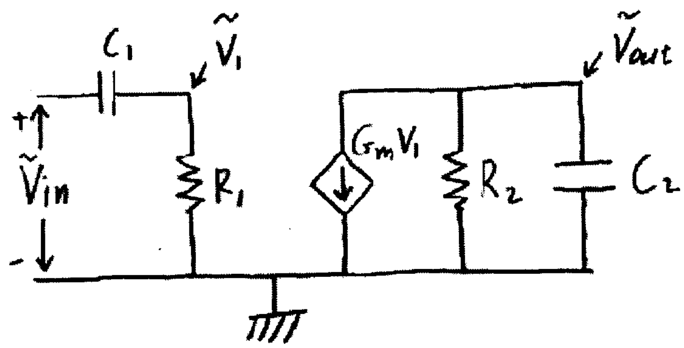
$$V_{G_1} = 5V - V_{SG_1} = 5V - 1.2V = 3.8V$$

$$R_{ref} = \frac{V_{G_1}}{I_{ref}} = \frac{3.8V}{1mA} = 3.8k\Omega$$

Problem 3 of 3 (30 points)

For each of the following questions, make sure that you show the expressions <u>before</u> you plug in the specific values. A correct expression is worth 70% of the credit, even if the numerical calculation is incorrect!

a) Derive the transfer function Vout/Vin expression of the following amplifier (10 pts).



$$\frac{\tilde{V}_{out}}{\tilde{V}_{in}} = \frac{R_1}{R_1 + \frac{1}{j\omega C_1}}\left[-G_m \cdot \left(R_2 \parallel \frac{1}{j\omega C_2}\right)\right] = -G_m R_2 \frac{j\omega R_1 C_1}{(1 + j\omega R_1 C_1)(1 + j\omega R_2 C_2)}$$

time constants: $\tau_1 = R_1 C_1 = \frac{1}{10^4 \text{ rad/sec}}$ $\tau_2 = R_2 C_2 = \frac{1}{10^6 \text{ rad/sec}}$

$G_m R_2 = 10$

b) Plot amplitude and phase Bode plots when R_1=10kΩ, C_1= 0.01μF, R_2=1kΩ, C_2=0.001μF, G_m=0.01S. (10 pts for each plot).