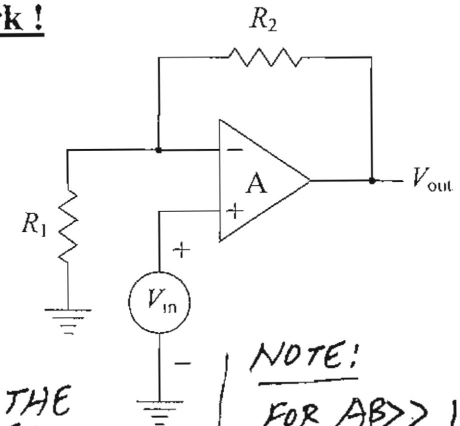
EEE 108 Fall 2013 **Final Exam** **Name:** KEY

Enter all answers in the boxes provided, and show all work !

1. a) (10 points) If an opamp is used in the circuit shown at right to create an amplifier with a voltage gain of 20, what is the minimum open-loop gain that the opamp must have in order for the amplifier's voltage gain to be accurate to within 1% ?



A_{min} = 1980 V/V

$$A_{\text{CLOSED LOOP (WITH FEEDBACK)}} = A_F = \frac{A}{1+A\beta}$$ WHERE β = THE FEEDBACK FACTOR

NOTE! FOR $A\beta >> 1$ $\Rightarrow A_F \approx \frac{1}{\beta}$ $\Rightarrow \beta \cong \frac{1}{A_F} = \frac{1}{20}$

IF A_F IS 1% LOW $\Rightarrow A_F = 0.99(20) = 19.8 = A_F$

SOLVING FOR A $\Rightarrow$ $$A = \frac{A_F}{1-\beta A_F} = \frac{19.8}{1-(\frac{1}{20})(19.8)} = 1980 = A_{MIN}$$

SO, A MUST BE ≥ 1980 FOR A_F TO BE WITHIN 1% OF THE IDEAL VALUE OF 20

b) (10 points) If the opamp used in the circuit above has a unity gain bandwidth of 1 GHz (i.e., the opamp gain = 1 at 1 GHz), then at what frequency will the opamp gain be equal to 20?

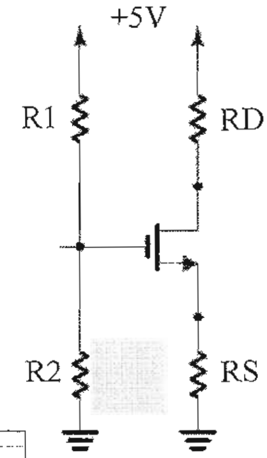
f = 50 MHz

SINCE THE OPAMP HAS A CONSTANT GAIN-BANDWIDTH PRODUCT BETWEEN THE -3dB FREQUENCY AND f_T, THE UNITY GAIN FREQ $\Rightarrow$

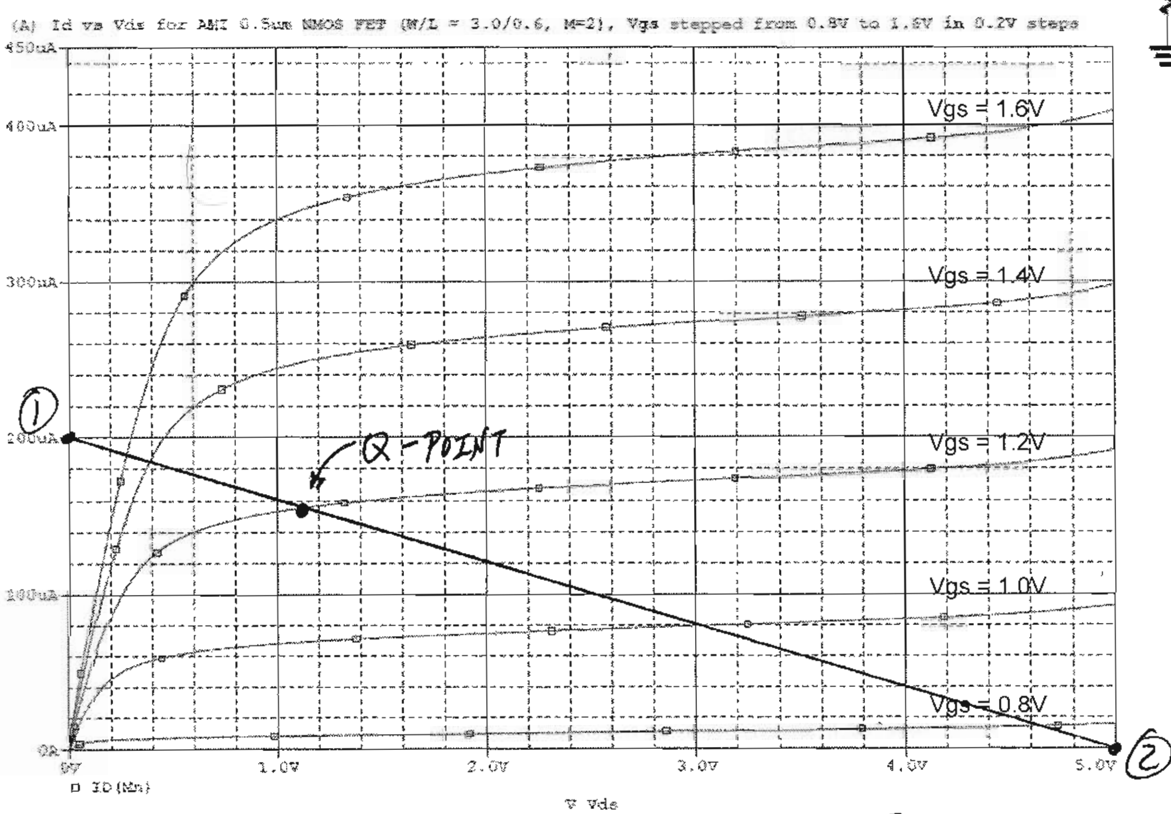
$$f(20) = (1GHz)(1)$$

$$\Rightarrow f = \frac{1GHz}{20} = \frac{1000MHz}{20} = 50MHz = f$$

2. (15 points) Draw a load line for the MOSFET circuit shown on the Id-Vds curves provided below, and use it to find the operating point for the MOSFET. Use RD = 16.5kΩ, RS = 8.5kΩ and assume Vgs = 1.2V.



Vds =	1.1	V
Id =	155	μA



LOAD LINE EQUATION:

$$V_{DD} - I_D R_D - V_{DS} - I_D R_S = \emptyset$$

$$V_{DD} - V_{DS} - I_D (R_D + R_S) = \emptyset$$

Q-POINT IS WHERE LOAD LINE INTERSECTS $V_{GS} = 1.2V$ LINE

$\Rightarrow$ $\boxed{\text{Q-POINT: } I_D \approx 155\mu A, \; V_{DS} \approx 1.1V}$

NEED 2 POINTS TO PLOT THIS LINE:

USE: $V_{DS} = \emptyset \Rightarrow I_D = \dfrac{V_{DD}}{R_D + R_S} = \dfrac{5V}{25k\Omega} = 200\mu A$

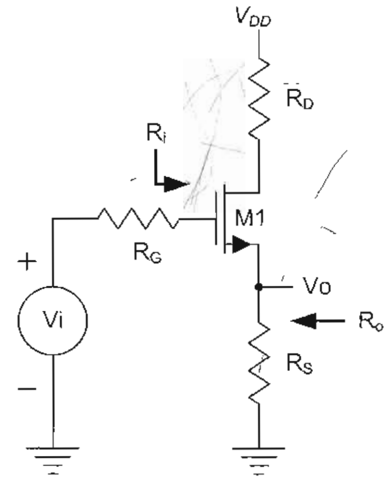
$I_D = \emptyset \Rightarrow V_{DS} = V_{DD} = 5V$

POINT #1, #2:

① $V_{DS} = \emptyset$, $I_D = 200\mu A$

② $V_{DS} = 5V$, $I_D = \emptyset$

3. (15 points) Find the low frequency voltage gain for the amplifier shown at right. Assume the MOSFET is biased in saturation with Id = 100μA, Rs = 4 kΩ and $R_G = R_D = 0$. Use: $k'_N = 100\mu A/V^2$, W/L = 20/0.4, and neglect both channel-length modulation and body effect.



A = $+\phi.8$ V/V

INPUT ON GATE
OUTPUT ON SOURCE $\Big\} \Rightarrow$ COMMON-DRAIN AMP!
(A.K.A. "SOURCE FOLLOWER")

$$\Rightarrow A_V = \frac{+g_m R_S}{1 + (g_m + g_{mb} + g_{ds}) R_S}$$

(FROM CLASS NOTES)

NEGLECT BODY EFFECT $\Rightarrow g_{mb} = \phi$

NEGLECT CHANNEL-LENGTH MODULATION $\Rightarrow g_{ds} = \phi$ $(r_{ds} = r_o = \infty)$ $(\lambda = \phi)$

$$\Rightarrow A_V = \frac{+g_m R_S}{1 + g_m R_S}$$

WITH: $R_S = 4K\Omega = 4000\Omega$

WHERE: $g_m = \sqrt{2k'_N \left(\frac{W}{L}\right) I_D} = \left[2(100\times10^{-6})\left(\frac{20}{0.4}\right)(100\times10^{-6})\right]^{1/2}$

$$g_m = 1 \times 10^{-3}\ A/V$$

$$\Rightarrow A_V = \frac{(1\times10^{-3})(4000)}{1 + (1\times10^{-3})(4000)} = \frac{4}{1+4} = \frac{4}{5} = \phi.8$$

$$\Rightarrow \boxed{A_V = +\phi.8}$$

REMEMBER, FOR A SOURCE FOLLOWER THE GAIN IS ALWAYS + AND < 1

4. (15 points) Write a brief paragraph of 100 words or less to describe the 2 different parts of a bipolar transistor's base current, and explain why one of these typically dominates in a modern bipolar transistor.

THE BASE CURRENT IN A BJT CONSISTS OF:

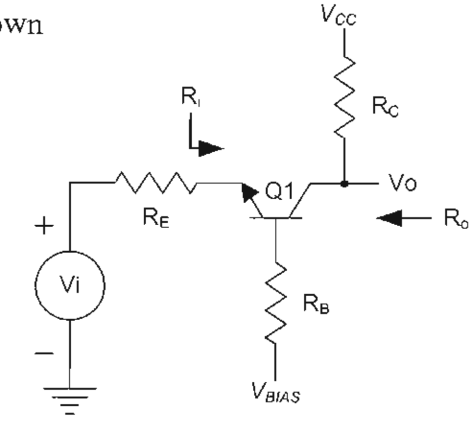
1) THE CARRIERS INJECTED FROM THE BASE BACK INTO THE EMITTER, AND

2) THE CARRIERS INJECTED FROM THE EMITTER INTO THE BASE WHICH RECOMBINE WHILE CROSSING THE BASE BEFORE REACHING THE COLLECTOR

MODERN BJTs HAVE VERY NARROW BASE REGIONS, SO VERY FEW CARRIERS RECOMBINE IN THE BASE. THIS MAKES #2 ABOVE NEGLIGABLE, SO #1 DOMINATES.

THAT IS, THE BASE CURRENT IS DOMINATED BY THE CARRIERS INJECTED FROM THE BASE INTO THE EMITTER SINCE VERY FEW CARRIERS RECOMBINE IN THE BASE ON THIER WAY TO THE COLLECTOR.

5. (15 points) Find the low frequency voltage gain for the amplifier shown at right. Assume the BJT is biased in the forward-active region with $I_C = 1mA$, $R_E = 50\Omega$, $R_C = 2.0\ k\Omega$ and $R_B = 2.5\ k\Omega$. Use: $\beta = 100$, $V_T = kT/q = 25mV$, and neglect base-width modulation.



A = +19.90 V/V

INPUT ON EMITTER
OUTPUT ON COLLECTOR $\Rightarrow$ COMMON-BASE AMP!

FROM CLASS NOTES: $A_V = \dfrac{+\beta R_C}{R_B + r_\pi + (\beta+1)R_E}$

$\beta = g_m r_\pi \Rightarrow r_\pi = \dfrac{\beta}{g_m}$

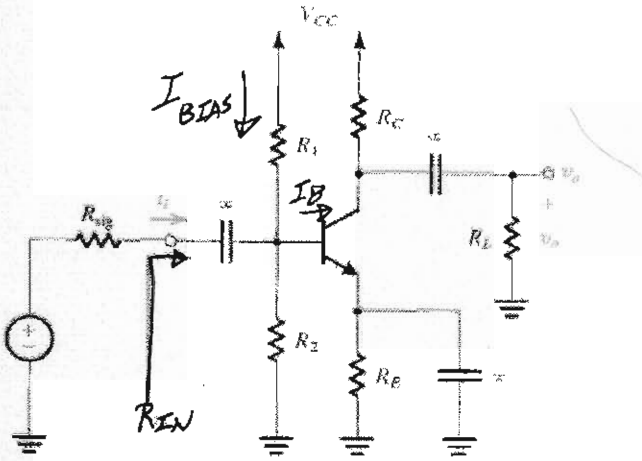
NOW, $g_m = \dfrac{I_C}{V_t} = \dfrac{1mA}{25mV} = \dfrac{1}{25}\ A/V = g_m \Rightarrow r_\pi = \dfrac{\beta}{g_m} = 25(100)$

$r_\pi = 2500 = 2.5K\Omega$

$\Rightarrow A_V = \dfrac{+\beta R_C}{R_B + r_\pi + (\beta+1)R_E} = \dfrac{+(100)(2.0K\Omega)}{2.5K\Omega + 2.5K\Omega + (101)(50\Omega)}$

$\boxed{A_V = +19.90}$

6. a) (10 points) For the bipolar amplifier circuit shown at right choose the values of R_C and R_E to set the bias current to $I_C = 1mA$ and the maximum peak-to-peak output voltage swing to 2 Vp-p while keeping the BJT in the forward active region. Use: $V_{CC} = 3V$, $R_1 = 2.0\ k\Omega$, $R_2 = 1\ k\Omega$, $\beta = 100$, $V_A = \infty$, $V_{BE} = 0.7V$ and $V_T = kT/q = 25mV$.



R_C =	1 kΩ
R_E =	0,297 kΩ

FIRST, $I_C = 1mA$ AND $\beta = 100$

$\Rightarrow I_B = \frac{I_C}{\beta} = 10\mu A$

SINCE $I_{BIAS} = \frac{3V}{3K\Omega} = \frac{V_{CC}}{R_1+R_2} = 1mA >> I_B \Rightarrow$ CAN NEGLECT I_B WHEN FINDING BASE VOLTAGE!

$\Rightarrow V_{BASE} \cong V_{CC}\left(\frac{R_2}{R_1+R_2}\right) = 3V\left(\frac{1}{1+2}\right) = 1V = V_{BASE}$

$V_{EMITTER} = V_{BASE} - V_{BE} = 1.0V - 0.7V = 0.3V = V_{EMITTER}$

$I_C = 1mA \Rightarrow I_E = \frac{\beta+1}{\beta} I_C = 1.01mA \Rightarrow R_E = V_{EMITTER}/I_E = \frac{0.3}{1.01mA} = \boxed{R_E = 297\Omega}$

FOR 2Vp-p SWING: SET $V_{COLLECTOR} = V_{CC} - 1V \Rightarrow R_C = \frac{1V}{1mA} = \boxed{1K\Omega = R_C}$ NOTE AT $V_{O\,MIN} = V_{CC} - 2V \Rightarrow V_{BC} = 0$

b) (10 points) What is the low frequency voltage gain for this amplifier if $R_{sig} = 50\ \Omega$ and $R_C = R_L = 500\ \Omega$?

A =	−9,82 V/V

INPUT ON BASE, OUTPUT ON COLLECTOR $\Rightarrow$ COMMON EMITTER AMP!

FOR GAIN CALCS, ALL CAPS = SHORTS $\Rightarrow R_E = 0$, $R_C \| R_L = 250\Omega$

VOLTAGE GAIN (CLASS NOTES) $= \frac{-\beta(R_C \| R_L)}{R_B + r_\pi + (\beta+1)R_E} = \frac{-\beta(R_C\|R_L)}{R_B + r_\pi}$ SINCE $R_E = 0$

R_B HERE $= R_{SIG} \| R_1 \| R_2 = (50\Omega)\|(2K\Omega)\|(1K\Omega) = 46.5\Omega = R_B$ (THEVENIN'S EQUIVALENT)

$g_m = \frac{I_C}{V_T} = \frac{1mA}{25mV} = \frac{1}{25}\frac{A}{V}$, $r_\pi = \frac{\beta}{g_m} = (25)(100) = 2500 = 2.5K\Omega = r_\pi$

$\Rightarrow A = \frac{-\beta(R_C\|R_L)}{R_B + r_\pi} = \frac{-(100)(500\Omega \| 500\Omega)}{46.5\Omega + 2500\Omega} = \boxed{-9.82 = A}$

BONUS (5 points) : In 100 words or less briefly explain why the maximum voltage gain for a single transistor amplifier can be easily determined from just knowing the bias voltages across the BJT collector and emitter resistors (or the MOS drain and source resistors). Also explain when this simple circuit analysis technique fails, and why.

TO SEE THIS, TAKE A LOOK AT THE GAIN EQUATION FOR A CE AMP:

$$A = \frac{-\beta R_C}{R_B + r_\pi + (\beta+1)R_E} \approx \frac{-\beta R_C}{(\beta+1)R_E} \approx \frac{-R_C}{R_E} \cong \frac{-I_C R_C}{I_E R_E} = \frac{-V_{RC}}{V_{RE}}$$

$$\Rightarrow A \approx \frac{-V_{RC}}{-V_{RE}} = \frac{-(\text{BIAS VOLTAGE ACROSS } R_C)}{(\text{BIAS VOLTAGE ACROSS } R_E)} \checkmark$$

THIS ASSUMES THAT $(\beta+1)R_E \gg R_B + r_\pi$

SIMILAR ANALYSIS CAN BE DONE FOR CB, AND MOS CS, CG AMPS (FOR CC, CD, $A \approx 1$)

NOW, THIS APPROXIMATION ASSUMES THAT $(\beta+1)R_E \gg R_B + r_\pi$

IF THAT IS NOT TRUE, THIS APPROXIMATION WILL FAIL.

ALSO, IF A LOAD RESISTOR IS CAPACITOR COUPLED IN PARALLEL WITH R_C, OR R_E IS BYPASSED WITH A CAPACITOR, THIS APPROXIMATION WILL FAIL.