ECE 343 Electronics II Exam e^0 Feb. 20, 2019

Name: Spencer Goulette

- Make sure you write your name on all pages.
- Detailed descriptions of how you solved the problem will get you maximum partial credit if your final answer is wrong.
- You must provide the correct unit along with your answer in the answer areas. An answer without its unit will be considered incorrect.
- You may use any calculator, as long as it is a calculator and not another instrument being used in calculator mode.
- A table of commonly used constants, parameters and equations was provided to you in class and on BlackBoard.
- Unless noted otherwise, assume room temperature conditions, i.e. T = 300K
- All MOSFETs in this exam are enhancement-mode MOSFETs, as studied in class to date.

Question	Grade	Out of
#1	15	15
#2	20	20
#3	20	22
#4	16	16
#5	22	27
Total Grade	93	100

YES OPIE!!!

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1. **(15 pts.)** Each correct answer is worth +1 points. ***Indicate if the following statements are True or False:***

__T__ Active loads are preferred in IC design because large gains can be obtained with small devices.

__F__ A cascode amplifier has a larger output voltage swing than a single stage common source amplifier when biased with the same supply voltages.

__F__ If a BJT and a MOSFET are biased with the same current, the MOSFET will most likely have the larger intrinsic gain.

__T__ A BJT's intrinsic gain is device parameter dependent.

__T__ A cascode amplifier has larger voltage gain than a single stage common source amplifier because it has larger output resistance.

__T__ A source follower is a suitable choice to put before a common gate stage to increase the input resistance of the amplifier.

__T__ A cascode current mirror's advantage over a simple current mirror is that its output current is more stable with respect to voltage variations across its output terminals.

__F__ A simple current mirror has a smaller voltage compliance range than a cascode current mirror.

__F__ Active loads don't have any advantages over resistors for discrete amplifier circuits.

__T__ A common gate amplifier is a current buffer.

__F__ The body effect makes a MOSFET's threshold voltage magnitude smaller.

__T__ Biasing amplifiers with current mirrors instead of resistor networks ensures operating point stability.

__T__ Using a current mirror as a load allows the amplifier designer to decouple the DC bias voltages from the small-signal voltage gain.

__F__ An amplifier's performance is independent of temperature.

__F__ A MOSFET is a current controlled current source.

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2. **(20 points).** Each of the questions below are quick calculation-questions, usually requiring a single equation.

a) A BJT is biased with a nominal collector current of I_{C0} = 2 mA has an output resistance of r_o = 40 kΩ and a collector-emitter voltage drop of V_{CE} = 8 V. What is the actual collector current, assuming $V_{CE,sat}$ is negligible?

$I_C = I_{C0}\left(1 + \frac{\Delta V_{CE}}{V_A}\right)$

$I_C = 2mA\left(1 + \frac{8V}{80}\right)$

I_C = 2.2 mA

$r_o = \frac{V_A}{I_{C0}} = 40k \cdot 2m = 8$

b) What is the intrinsic gain A_o of a BJT which has r_o = 300 kΩ at I_C = 200 µA?

$r_o = \frac{V_A}{I_C} = 300k = \frac{V_A}{200\mu}$

$V_A = 60$

$A_o = \frac{V_A}{V_T} = \frac{60}{26m} = 2,307.692308$

A_o = 2.31 kV/V

c) What is the output resistance of a MOSFET which has L = 0.5 µm, V_A' = 8 V/µm, and is biased with I_{DS} = 100 µA?

$r_o = \frac{V_A' L}{I_{DS}}$

$r_o = \frac{8V/\mu m \cdot 0.5\mu m}{100\mu A} = 40k$

r_o = 40kΩ

d) A MOSFET cascode current mirror is biased such that the transistors have a small signal transconductance of g_m = 0.1 mA/V and an output resistance of r_o = 200 kΩ?

$R_{out} = r_o + r_o + g_m r_o^2 \cong g_m r_o^2$

R_{out} = 4.4MΩ

actual: 4.4 MΩ

approx: 4 MΩ

e) A MOSFET has an intrinsic gain of A_O = 50 V/V when biased with I_{DS} = 400 µA. What is its intrinsic gain when it is biased with I_{DS} = 100 µA?

$A_o \propto \frac{1}{\sqrt{I_{DS}}}$

A_o = 100 V/V

$\frac{1}{\sqrt{\frac{1}{4} I_{DS}}} = \frac{1}{\frac{1}{2}\sqrt{I_{DS}}} = 2 \cdot \frac{1}{\sqrt{I_{DS}}}$

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3. **(22 points)** The small-signal equivalent circuit of a two-stage amplifier is shown in the figure below. The transistors have been replaced with their hybrid-π equivalent circuits. The component values are given below.

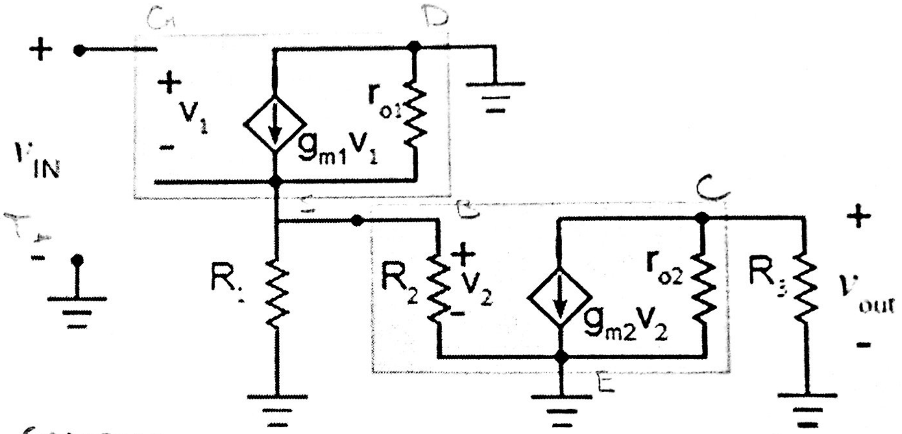
$g_{m1} = 5$ mA/V	$r_{o1} = 20$ kΩ	$g_{m2} = 40$ mA/V	$r_{o2} = 40$ kΩ
$R_1 = 20$ kΩ	$R_2 = 5$ kΩ	$R_3 = 40$ kΩ	

(a) Identify if the transistors are MOSFET or BJT. Explain how you determined transistor type.

(b) Identify each of the two stages: CS / CE, CG / CB, or SF / EF.

(c) Calculate the overall voltage gain, Gv, of the amplifier.

a. 1st transistor doesn't have an r_π, but has an open resistance as the input so it is a MOSFET. The 2nd transistor does have an r_π, so it is a BJT



b. Drain is connected to common, so Source Follower. Emitter is connected to common, so Common Emitter.

c. $G_v = A_{v1} \cdot A_{v2}$

$$A_{v1} = \frac{R_1 \| R_2 \| r_\pi}{R_1 \| R_2 + 1/g_{m1}} = \frac{20k \| 5k}{20k \| 5k + 1/5mA/V} = 0.9524 \text{ V/V}$$

$A_{v2} = -g_{m2}(r_{o2} \| R_3)$

$A_{v2} = -40mA/V(40k \| 40k)$

$A_{v2} = -800$

$\boxed{G_v = -762 \text{ V/V}}$

(a) Transistor 1 MOSFET

Transistor 2 BJT

(b) Stage 1 SF

Stage 2 CE

(c) Gv −762 V/V

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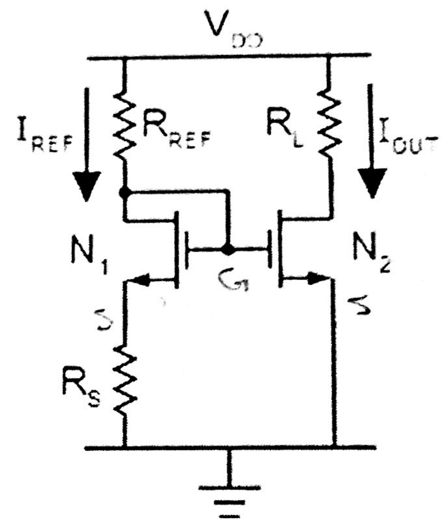
4. (16 points) The current mirror in the figure below is designed with MOSFETs that have $k_n = 10\ mA/V^2$ and $V_t = 0\ V$. The circuit is to have $I_{load} = 20\ mA$ and $I_{ref} = 200\ \mu A$. $V_{DD} = +10V$. Calculate the values of R_S and R_{REF} needed to meet these design specifications.



$k_n = 10mA/V^2$

MOSFET N_1 and N_2 are the same

$I_{out} = \frac{1}{2} k_n V_{ov_2}^2$

$20m = \frac{1}{2} \cdot 10mA/V^2 \cdot V_{ov_2}^2$

$V_{ov_2} = \sqrt{\frac{20m \cdot 2}{10mA/V^2}} = 2$

$V_{ov_2} = V_{GS_2} - V_t$

$V_{ov_2} = V_{GS_2} = 2$

$V_G = 2V$

$I_{ref} = \frac{1}{2} k_n V_{ov}^2$

$200\mu = \frac{1}{2} \cdot 10mA/V^2 \cdot V_{ov}^2$

$V_{ov} = \sqrt{\frac{200\mu \cdot 2}{10mA/V^2}}$

$V_{ov} = 0.2V$

$V_{ov} = V_{GS} - V_t$

$\cancel{V_{GS} = 0.2V}$

$V_{GS} = V_G - V_S$

$V_S = V_G - V_{GS} = 2 - 0.2$

$V_S = 1.8V$

$R_S = \frac{1.8}{200\mu} = 9k\Omega$

$R_{ref} = \frac{V_{DD} - V_G}{I_{ref}} = \frac{10 - 2}{200\mu} = 40k\Omega$

RREF 40kΩ

RS 9kΩ

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5. (27 points) The common gate amplifier in figure 5 below is from lab project Task 2. The MOSFETs are the ALD1106 NMOS and ALD1107 PMOS FETs, whose relevant parameters are given below. The signal source resistance is $R_{sig} = 1\ k\Omega$ and the load resistance is $R_L = 100\ k\Omega$. The bias current is $I_{ref} = 100\ \mu A$. The coupling capacitances C_S and C_D are very large. The supply voltages are ±5 V.

ALD 1107: $\mu_p C_{ox} W/L = 200\ \mu A/V^2$, $V_{tp} = -0.75$ V, $\lambda = 0.03$

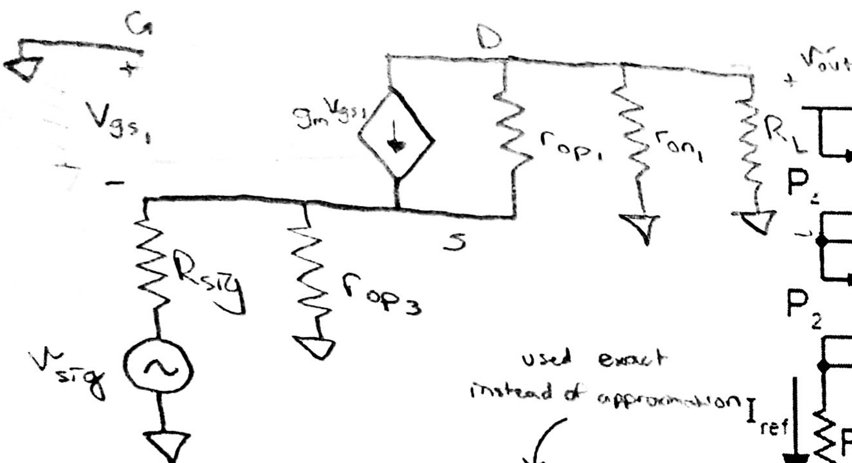
ALD 1106: $\mu_n C_{ox} W/L = 500\ \mu A/V^2$, $V_{tn} = 0.75$ V, $\lambda = 0.03$

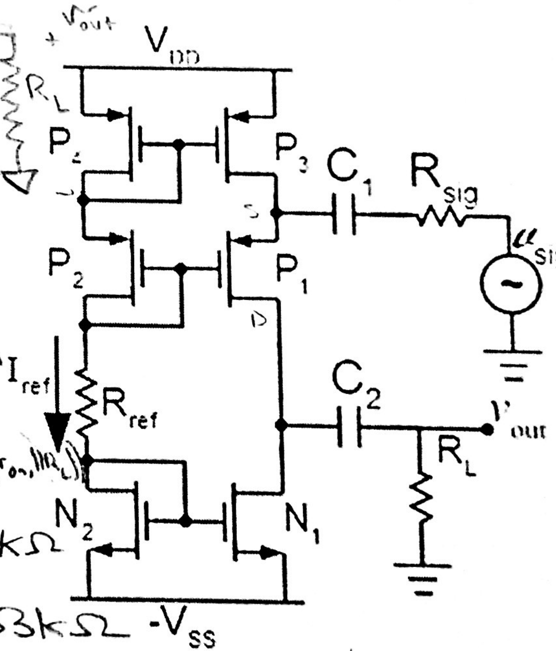
6/6 **(a)** Draw the small signal equivalent model of the amplifier.

12/16 **(b)** What are the input resistance and output resistance of the amplifier, including the effects of R_{sig} and R_L?

4/5 **(c)** What is the overall voltage gain, Gv, of the amplifier?

a.





used exact instead of approximation

b. $R_{in} = r_{op3} \,||\, \left(\frac{1}{g_{mp1}} + \cancel{r_{on1}||R_L + g_{mp1} g_{mp1} \frac{1}{(r_{on1}||R_L)}}\right)$

$r_{op} = \frac{1}{\lambda I_{DS}} = \frac{1}{0.03 \cdot 100\mu} = 333k\Omega$

$r_{on} = \frac{1}{\lambda I_{DS}} = \frac{1}{0.03 \cdot 100\mu} = 333k\Omega$

$g_{mp1} = \sqrt{2 k_p I_{DS}} = \sqrt{2 \cdot 200\mu \cdot 100\mu} = 200\ \mu A/V$

$R_{in} = 333k \,||\, \left(\frac{1}{200\mu} + \cancel{77k + 77k}\right)$

$R_{in} = 108k\Omega$

$R_{out} = r_{on1} \,||\, \left(r_{op1} + (r_{op3}||R_{sig}) + g_{mp1} r_{op1} (r_{op3}||R_{sig})\right)$

$R_{out} = 333k \,||\, \left(333k + (333k||1k) + 200\mu\ 333k\ (333k\,||\,1k)\right)$

$R_{out} = 182\ k\Omega$

c. $G_v = \frac{R_{in}}{R_{in}+R_{sig}} \cdot \frac{R_L}{R_{out}+R_L} \cdot g_{mp} R_{out}$

$G_v = \frac{108k}{108k + 1k} \cdot \frac{100k}{182k + 100k} \cdot 200\mu \cdot 182k$

$G_v = 12.8\ V/V$

(b) R_{in} $108k\Omega$

R_{out} $182k\Omega$ 8/8

(c) Gv $12.8\ V/V$