ECE 3040 Microelectronic Circuits

Exam 3

April 23, 2007

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Print your name clearly and largely: Solutions

Instructions:
DO NOT TAKE APART ANY PAGES OF THIS EXAM AND SHOW ALL WORK ON THE PROVIDED PAGES. Read all the problems carefully and thoroughly before you begin working. You are allowed to use 1 new sheet of notes (1 page front and back), your notes sheet from the previous exams as well as a calculator. There are 100 total points in this exam. Observe the point value of each problem and allocate your time accordingly. SHOW ALL WORK AND CIRCLE YOUR FINAL ANSWER WITH THE PROPER UNITS INDICATED. Write legibly. If I cannot read it, it will be considered a wrong answer. Do all work on the paper provided. Turn in all scratch paper, even if it did not lead to an answer. Report any and all ethics violations to the instructor. Good luck!

Sign your name on ONE of the two following cases:

I DID NOT observe any ethical violations during this exam:

I observed an ethical violation during this exam:
First 30% Multiple Choice and True/False (Select the most correct answer)

1.) (6-points total) Identify the bias mode of the following MOS capacitors.
   (A) Inversion    (B) Accumulation    (C) Depletion

2.) (4-points) For the three capacitors in problem 1, which is true:
   a) They could be used to make a NMOS MOSFET
   b) They could be used to make a PMOS MOSFET
   c) The diagrams clearly show the Source-Gate bias
   d) The diagrams clearly show the Drain-Source bias
   e) The diagrams clearly show the Body-Contact bias

3.) (4-points) True/False: An enhancement mode MOSFET was invented after the depletion mode NMOS MOSFET and can conduct current in it's drain-source circuit even with VGS=0 volts.

4.) (4-points) In the MOSFET transistor to the right, what is the voltage across the pinched off region?
   a) VGS-VS
   b) VGS
   c) VDS
   d) VDS
   e) Not enough information given to solve

5.) (3-points) True/False: A well designed current amplifier should have a very low input resistance.

6.) (9-points) Name three improvements that feedback can do to a voltage amplifier
   a) Increase bandwidth (freq. response)
   b) Increase input resistance
   c) Decrease output resistance
   d) Allows finite gain
   e) Creates a virtual ground

Others: 

7) (20-points) Sketch and label all break frequencies, the voltage gain in flat regions in a Bode plot (gain in dB vs Log(frequency)). You may assume that this "Clementon Designed" Op-Amp is ideal in every way EXCEPT that its open loop gain is an atrocious 200 V/V. To receive full credit the asymptotes and an estimate of the actual gain curve should BOTH be sketched on the same plot. *Hint: you may find it helpful to determine the feedback factor, $\beta$ as part of your solution. Also, to make the math easier, please note that $R_1 = 1\text{K}\text{ohm}$.

You may also use the following results for the three standard op-amp configurations but these results may or may not be needed for this problem.

$$A_v = V_{ou}/V_{in} = -(R_2/R_1)$$

$$A_v = V_{ou}/V_{in} = 1+(R_2/R_1)$$

$$A_v = V_{ou}/V_{in} = 1$$

$$\beta = \frac{-V_{in}}{V_{ou}} = \frac{R_1}{R_1 + \frac{1}{C_1s}} + \frac{R_2}{R_2 + \frac{1}{C_2s}}$$

$$\beta = \frac{R_1}{1 + R_1 C_1 s} + \frac{R_2}{1 + R_2 C_2 s} = \frac{R_1}{R_1 + R_2 (1 + R_1 C_1 s)} = \frac{R_1}{R_1 + R_2} = 0.0099$$

$$A_{closed} = \frac{A_{open}}{1 + \beta A_{open}} = \frac{100}{1 + 0.0099(200)} = 67.1 \text{ V/V}$$

Note: $A_v \neq 1 + \frac{R_2}{R_1} = 101$
Extra work can be done here, but clearly indicate with problem you are solving.

\[ dB = 20 \log(A_v) \]

\[ \log(f) \]
Pulling all the concepts together for a useful purpose:

I.) *(50-points)* Given the following circuit, (a) Identify the configuration of BOTH of the two stages (common _ ). (b) What is the AC voltage gain, \( V_{in}/V_{out} \)? You may assume all capacitors have infinite capacitance. You may assume all inductors have infinite inductance. Additionally consider the circuit to be operated at low frequencies where you can neglect all small signal capacitances.

Grading will be based as such: part a=5 points, part b=18 points for DC solution (gate, source and drain voltages along with drain current), 9 points for the conversion to the small signal model and 18 points for small signal analysis.

Use the following parameters (note that \( V_T \) and \( \lambda \) vary with transistor type):

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>( K_n ) for NMOS Depletion Transistors</td>
<td>20 ( \mu A/V^2 )</td>
</tr>
<tr>
<td>( V_T ) for NMOS Depletion Transistors</td>
<td>-4.0V</td>
</tr>
<tr>
<td>( \lambda ) for NMOS Depletion Transistors</td>
<td>0.0 ( V^{-1} )</td>
</tr>
<tr>
<td>Length (L) for NMOS Depletion Transistors</td>
<td>10 ( \mu m )</td>
</tr>
<tr>
<td>Width (W) for NMOS Depletion Transistors</td>
<td>10 ( \mu m )</td>
</tr>
<tr>
<td>( K_n' ) for NMOS Enhancement Transistors</td>
<td>30 ( \mu A/V^2 )</td>
</tr>
<tr>
<td>( V_T ) for NMOS Enhancement Transistors</td>
<td>+0.75V</td>
</tr>
<tr>
<td>( \lambda ) for NMOS Enhancement Transistors</td>
<td>0.1 ( V^{-1} )</td>
</tr>
<tr>
<td>Length (L) for NMOS Enhancement Transistors</td>
<td>10 ( \mu m )</td>
</tr>
<tr>
<td>Width (W) for NMOS Enhancement Transistors</td>
<td>10 ( \mu m )</td>
</tr>
<tr>
<td>( K_p ) for PMOS Depletion Transistors</td>
<td>40 ( \mu A/V^2 )</td>
</tr>
<tr>
<td>( V_T ) for PMOS Depletion Transistors</td>
<td>+3.0V</td>
</tr>
<tr>
<td>( \lambda ) for PMOS Depletion Transistors</td>
<td>0.0 ( V^{-1} )</td>
</tr>
<tr>
<td>Length (L) for PMOS Depletion Transistors</td>
<td>10 ( \mu m )</td>
</tr>
<tr>
<td>Width (W) for PMOS Depletion Transistors</td>
<td>10 ( \mu m )</td>
</tr>
<tr>
<td>( K_p' ) for PMOS Enhancement Transistors</td>
<td>50 ( \mu A/V^2 )</td>
</tr>
<tr>
<td>( V_T ) for PMOS Enhancement Transistors</td>
<td>-1.75V</td>
</tr>
<tr>
<td>( \lambda ) for PMOS Enhancement Transistors</td>
<td>0.1 ( V^{-1} )</td>
</tr>
<tr>
<td>Length (L) for PMOS Enhancement Transistors</td>
<td>10 ( \mu m )</td>
</tr>
<tr>
<td>Width (W) for PMOS Enhancement Transistors</td>
<td>10 ( \mu m )</td>
</tr>
</tbody>
</table>

\[ \text{Part a) Stage 1 Common Source} \]
\[ \text{Stage 2 Common Drain} \]
\[
\overset{\text{Stage 1}}{\text{DC:}} \quad V_{\text{TH,1}} = \frac{\frac{900}{100} \cdot 100}{V_{\text{TH,2}}} = \frac{9}{\frac{100}{100} + \frac{900}{100}} = 1 - \frac{9}{8}
\]
\[
\Rightarrow \quad V_{\text{TH,1}} = -7 \, \text{V}
\]
\[
R_{\text{TH,2}} = R_3 + R_1 \parallel R_2 = 100 \, \text{k}\Omega + 1.8 \, \text{k}\Omega
\]
\[
V_{\text{TH,2}} = \frac{9}{\frac{100}{100} + \frac{900}{100}} = \frac{9}{8}
\]
\[
\Rightarrow \quad V_{\text{ES,2}} = 2 \, \text{V}
\]

\[
I_{0S} = 60 \, \text{mA} = \left(\frac{10}{10}\right) \cdot \frac{1}{2} \left(30 \cdot 10^{-6}\right) \left(V_{\text{ES}} - 0.75\right)^2 \left(1 + 0.1 \left(V_{\text{ES}}\right)\right)
\]
\[
60 \, \text{mA} = 15 \cdot 10^{-6} \left(2 - 0.75\right)^2 \left(1 + 0.1 \left(V_{\text{ES}}\right)\right)
\]
\[
V_{\text{ES}} = 15.6 \, \text{V}
\]

\[
\overset{\text{Assumption}}{\text{Assumption:}} \quad \left(V_{\text{ES}} - V_{\text{OS}}\right) = \left(3 - 0.75\right) = 1.25 \, \text{V} < V_{\text{ES}} = 15.6 \, \text{V}
\]

\[
\overset{\text{Stage 2}}{\text{DC:}} \quad V_0 = 0 \, \text{V} \quad \Rightarrow \quad V_{\text{ES}} = -9 + I_{0S} R_S = \left(-9 + I_{0S} R_S\right)
\]
\[
V_0 = 9 \, \text{V} \quad \Rightarrow \quad V_{\text{OS}} = 9 \, \text{V} - (-9 + I_{0S} R_S)
\]
\[
R_{\text{TH,3}} = 18 \, \text{V} - I_{0S} R_S
\]

\[
I_{0S} = \left(\frac{10}{10}\right) \cdot \frac{1}{2} \left(30 \cdot 10^{-6}\right) \left(V_{\text{ES}} - 0.75\right)^2 \left(1 + 0 \left(V_{\text{ES}}\right)\right)
\]
\[
= (10 \cdot 10^{-6}) \left(V_{\text{ES}}^2 + 8 V_{\text{ES}} + 16\right)
\]
\[
I_{0S} = 10 \cdot 10^{-6} \left(21 - 18 I_{0S} R_S + I_{0S}^2 R_S^2 + 72 - 8 I_{0S} R_S + 16\right)
\]
\[
0 = 1000 I_{0S}^2 - 3.6 \quad I_{0S} + 1.69 \cdot 10^{-3}
\]
\[
I_{0S} = \frac{3.6 \pm \sqrt{(3.6)^2 - 4(1000)(1.69 \cdot 10^{-3})}}{2(1000)}
\]
\[
I_{0S} = 5.55 \, \text{mA} \quad \text{or} \quad 3.99 \, \text{mA}
\]

\[
V_{\text{OS}} = 12.45 \, \text{V}
\]

\[
V_{\text{ES}} = 12.45 \, \text{V}
\]

\[
V_{\text{ES}} = 7.45 \, \text{V} \quad \text{or} \quad V_{\text{OS}} = 12.45 \, \text{V}
\]
Convers to Small signal Model:

\[ g_m = \frac{I_{ds}}{V_{ds}-V_T} = 9.6 \times 10^{-5} \, \text{s} \]  
\[ g_m = \frac{555 \, \text{mA}}{1.48 \, \text{V}} = 375 \, \text{mS} \]

\[ R_0 = \frac{V_{ds}}{I_{ds}} = \frac{60 \, \text{V}}{10 + 15.6} \approx 3.6 \, \text{k}\Omega \]

AC Solution

\[ V_{s} = V_{in} \]
\[ V_{A} = -g_{m} V_{s} = \frac{V_{s}}{R_0} \]
\[ V_{R2} = gm \cdot \frac{V_{s}}{R_0} = (1 + g_{m} R_0) \cdot \frac{V_{s}}{R_0} \]
\[ V_{R2} = \frac{1}{1 + g_{m} R_0} \cdot \frac{V_{s}}{R_0} \]

\[ A_v = \left( \frac{V_{s}}{V_{in}} \right) \left( \frac{V_{A}}{V_{s}} \right) \left( \frac{V_{R2}}{V_{A}} \right) \left( \frac{V_{R2}}{V_{R2}} \right) \]

\[ A_v = (1) \left( -g_{m} \frac{V_{s}}{R_0} \right) \left( \frac{1}{1 + g_{m} R_0} \right) \left( g_{m} R_0 \right) \]

\[ A_v = \left( -0.6 \times 10^{-5} \right) \left( \frac{426.6 \, \text{k}\Omega}{1000 \, \text{k}\Omega} \right) \left( \frac{1}{1 + 1.489} \right) \]

\[ A_v = -16.62 \, \text{V/V} \]