EE 414 Introduction to Analog Integrated Circuits
Take Home Exam-3

Due Date: April 08, 2015 (in class)

Problem 1: Figure 1 shows a single ended telescopic cascode differential amplifier. According to this topology,

a. Derive the short circuit current gain expression (short the output to ground, and find the $i_{sc}/(v_{in+} - v_{in-})$).
b. Derive the output resistance expression.
c. Derive the gain expression of this amplifier.
d. Derive the expression of gain bandwidth product (GBW product).
e. Derive the expression of the common mode rejection ratio (CMRR) of this amplifier.
f. Derive the expression of the maximum output swing in terms of the over drive voltage. *You can assume that all the voltage variations due to the differential inputs are very small except the output node. In other words, you can assume that all the nodes excluding the output node are at DC. In practice, on the other hand it is needed to put some margin due to the process and small signal variations at these nodes.*

Problem 2: Design a single ended cascode differential amplifier, shown, in Figure 1, satisfying the following requirements indicated in Table 1. Determine the transistor (W/L) ratios, and bias voltages. Explain your design clearly. Verify the operation in Cadence by using UMC 180nm 3.3 V transistors (N_33_MM and P_33_MM). Technology parameters which you need in your design are also shown in Table 2.

Table 1: Design specifications.

Power Budget	<20µA
Differential Input Capacitance ($=C_{GS,1,2}/2$)	<0.5pF
Output Swing	Between 1.15 and 2.15 (1V symmetric swing)
Gain Bandwidth Product	>50MHz
Load Capacitance	5pF

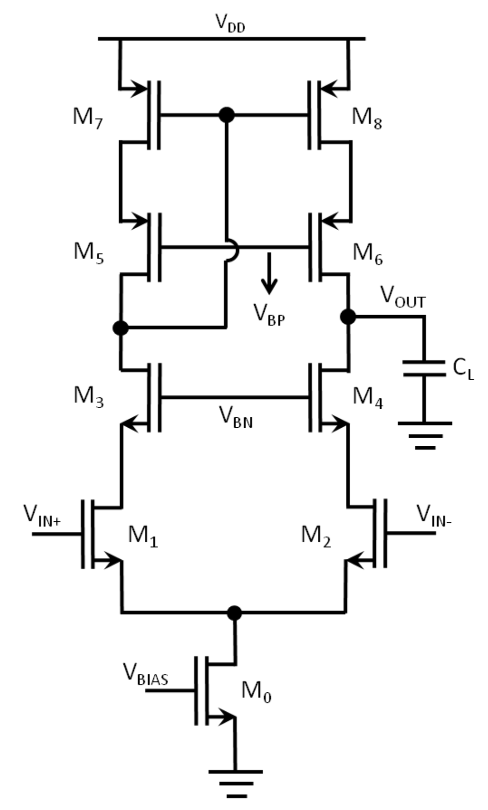

Figure 1: Single ended telescopic cascode differential amplifier.

Table 2: Technology parameters.

K_N'	$150\mu A/V^2$
K_P'	$70\mu A/V^2$
V_{TN} (W/L= 10/0.34)	0.65V
V_{TP} (W/L= 10/0.34)	-0.7V
L_{min}	0.34µm
λ_N	$0.02 \cdot L(V\cdot\mu m)^{-1}$
λ_P	$0.01 \cdot L(V\cdot\mu m)^{-1}$
C_{OX}	$5\ fF/\mu m^2$
V_{DD}	3.3V
• Ignore the body effect in your analyses!	

Note: For Problem 2, assume that the designed differential amplifier will be used as an inverting amplifier. That means that, common mode of the input is $V_{MID}=V_{DD}/2$.

Problem 3: Explain the superiority of the single ended telescopic cascode over the fully differential telescopic cascode in terms of single ended voltage and short circuit current gain? Is there a disadvantage of the single ended telescopic cascode comparing to the fully differential telescopic cascode in terms of bandwidth?

Hint: Bandwidth of a differential amplifier is mainly determined by the second dominant pole, and gate-to-source capacitance is much higher than the other parasitic capacitances.

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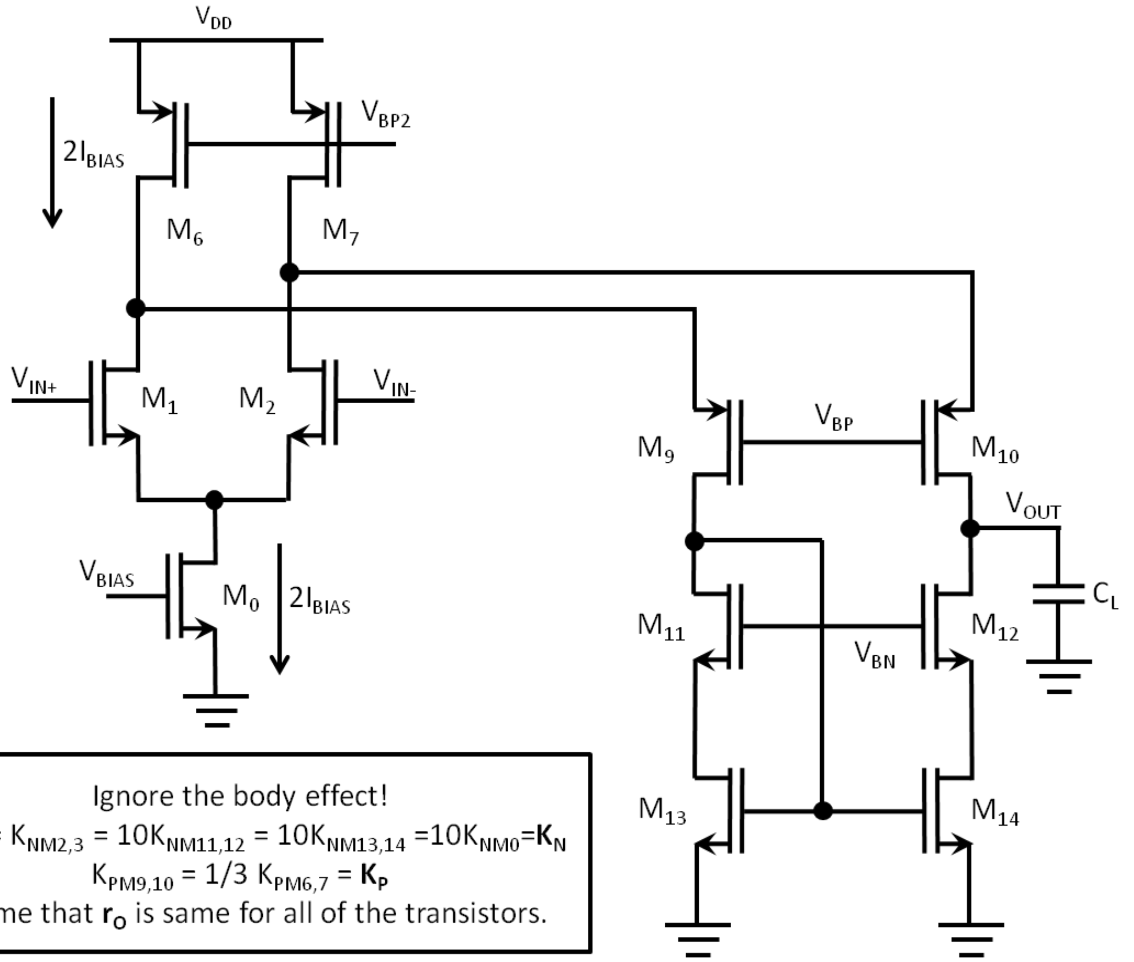
Problem 4: (Not to be collected) Figure 2 shows a single ended folded-cascode differential amplifier. According to this topology,

a. Derive the short circuit current gain expression (short the output to ground, and find the $i_{sc}/(v_{in+} - v_{in-})$).
b. Obtain the output resistance (you are not required to perform a detailed analysis).
c. Obtain the gain expression of this amplifier.
d. Obtain the expression of the gain bandwidth product (GBW product) (ignore all the parasitic capacitances).
e. Derive the expression of the common mode rejection ratio (CMRR) of this amplifier.
f. Derive the expression of the maximum output swing in terms of the over drive voltage. *You can assume that all the voltage variations due to the differential inputs are very small except the output node. In other words, you can assume that all the nodes excluding the output node are at DC. In practice, on the other hand it is needed to put some margin due to the process and small signal variations at these nodes.*



Ignore the body effect!
$K_{NM1,4} = K_{NM2,3} = 10K_{NM11,12} = 10K_{NM13,14} = 10K_{NM0} = \mathbf{K_N}$
$K_{PM9,10} = 1/3\ K_{PM6,7} = \mathbf{K_P}$
Assume that $\mathbf{r_O}$ is same for all of the transistors.

Figure 2: Single ended folded-cascode differential amplifier.