

EEE 51 Assignment 5

2nd Semester SY 2017-2018

Due: 5pm Tuesday, March. 6, 2018 (Rm. 220)

Instructions: Write legibly. Show all solutions and state all assumptions. Write your full name, student number, and section at the upper-right corner of each page. Start each problem on a new sheet of paper. Box or encircle your final answer.

Starting from this homework onwards, answer sheets should be colored according to your lecture section. The color scheme is as follows:

THQ – yellow

THR – blue

THU – white

THX – green

WFX – pink

1. **BJT Differential Amplifier.** Given the BJT differential circuit shown in Figure 1. Assume that the two transistors are identical, and they are biased such that $I_{C1} = I_{C2} = \frac{I_{tail}}{2}$. Assume that V_A approaches infinity, and that the transistors remain in the forward active region in the following questions. Answer the following questions using the concepts discussed in class and in the notes.

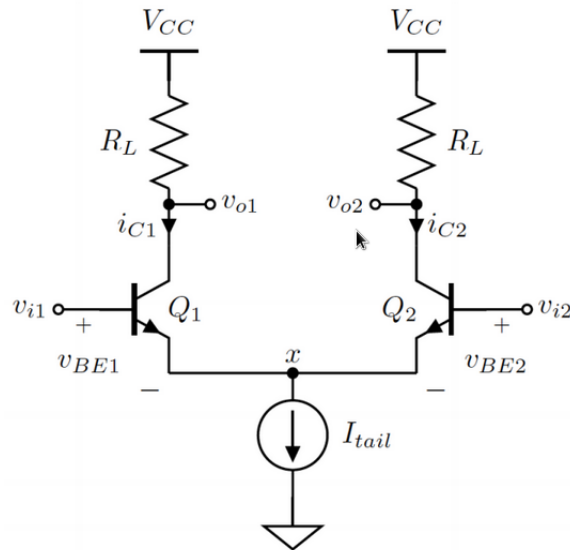


Figure 1: BJT Differential Amplifier.

- (a) Determine the behavior (increase or decrease or no change) of I_{C1} , I_{C2} , V_{O1} and V_{O2} for the following changes in DC input bias voltages. [4 pts]

Table 1: Behavior of collector currents and output voltages with respect to changes in input voltage.

	I_{C1}	I_{C2}	V_{O1}	V_{O2}
$\uparrow V_{I1}, \downarrow V_{I2}$				
$\downarrow V_{I1}, \uparrow V_{I2}$				
$\uparrow V_{I1}, \uparrow V_{I2}$				
$\downarrow V_{I1}, \downarrow V_{I2}$				

- (b) What is the difference between A_{cm} and A_{dm} . What is the effect of having a very high common mode gain? How does it affect the output of the differential amplifier? What would be its effect on the noise rejection of the differential amplifier? [3 pts]
- (c) During fabrication, the transistors Q_1 and Q_2 were fabricated such that the two transistors are mismatched (i.e. the transistors are not identical). What would be the effect of this mismatch on the behavior of the differential amplifier? What would be its effect on the output of the differential amplifier assuming that the two transistors are biased at the same voltage? Explain these effects. [3 pts]
2. **MOSFET Differential Pair.** Consider the circuit shown below. For this problem, assume that $\lambda = 0$ for both M1 and M2.

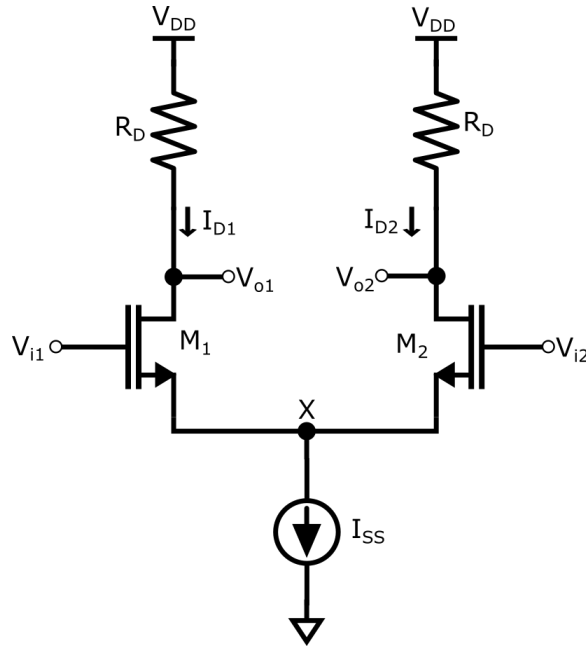


Figure 2: MOSFET Differential Pair

- (a) **Derive** an expression for $I_{D1} - I_{D2}$ as a function of the differential input voltage, $V_{id} = V_{i1} - V_{i2}$. Assume that M1 and M2 are symmetric and saturated. [3 pts]
Note: While expressions for I_{D1} and I_{D2} are already on the lecture slides, this is an exercise on being able to derive such equations. You can start by identifying the voltage at node X in terms of V_{i1} and V_{i2} .
- (b) Determine the slope of the characteristic equation (the equivalent G_m) you get from (a). [2 pts]
- (c) For this question onwards, use $I_{SS} = 1mA$ and $k = 2.5mA/V^2$. At equilibrium, determine the gate overdrive voltage, $V_{GS} - V_{th}$, of both transistors. [1 pt]
- (d) What are the drain currents of M1 and M2 if $V_{id} = 50mV$? [1 pt]
- (e) What is the equivalent G_m if $V_{id} = 50mV$? [1 pt]
- (f) For what value of V_{id} does G_m drop by 10% from equilibrium? By 90%? [2 pts]
3. **MOSFET Differential Amplifier with Active Load.** Dahyun wants to attend a concert with Sana, but she finds out that the venue's speakers are broken, so she decides to build her own amplifier. She designs the amplifier shown in Figure 3 with the following parameters: $k_n = 10 \frac{mA}{V^2}$, $k_p = 8 \frac{mA}{V^2}$, $V_{TH,n} = 0.3V$, $V_{TH,p} = -0.5V$, $\lambda_n = 0$, and $\lambda_p = 0.05V^{-1}$. $V_{DD} = 12V$, $V_P = 8.2V$, and $I_{tail} = 200mA$. The non-ideal current source has a finite resistance $R_{tail} = 1000\Omega$ and has a $V_{min} = 1V$. Similar transistors are perfectly matched (i.e. M1 and M2 are matched; M3 and M4 are matched). Dahyun needs to extract the amplifier's specifications, so now she asks for your help.

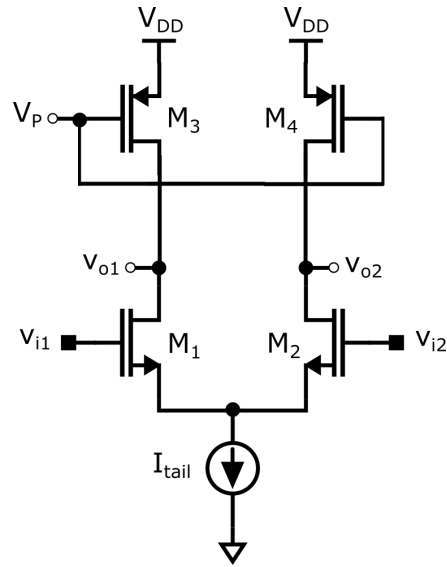


Figure 3: MOSFET Differential Amplifier with Active Load

- What is the common mode input range (ICMR) of the amplifier? [2 pts]
- Solve for A_{dm} . Be sure to include the small signal circuit and label everything accordingly. [4 pts]
- Solve for A_{cm} . Be sure to include the small signal circuit and label everything accordingly. [3 pts]
- The concert will be able to push through if the common mode rejection ratio (CMRR) of the amplifier is greater than 100. Will Dahyun be able to take Sana to the concert? [1 pt]

TOTAL: 30 points.