EEE 51 Assignment 3

2nd Semester SY 2017-2018
Due: 5pm Tuesday, Feb. 20, 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. **Darlington Emitter Follower.** Tzuyu receives an invite to Jihyo's birthday party, but shown in the invitation are the NPN Darlington emitter follower in Figure 1, as well as their parameters. $V_{IN} = 16.4V$, $\beta_1 = \beta_2 = \beta = 200$, $I_{S1} = 8.12fA$, $I_{S2} = 10.15fA$, and $V_A \to \infty$ for both transistors. To attend the party, guests must send a four-letter reply that can be decoded by analyzing the circuit. Round your answers to three decimal places.

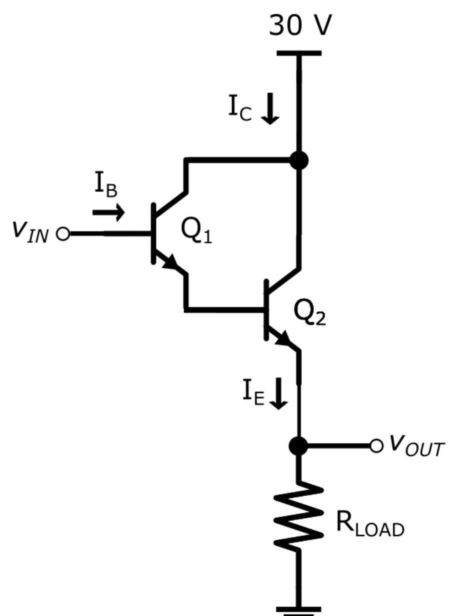

Figure 1: Darlington Emitter Follower

   (a) Express β_{eff} in terms of β. What is the advantage of using a Darlington pair over a single transistor? [2 pts]
   (b) Solve for the DC value V_{LOAD}. [1 pt]
   (c) Solve for $I_{C,tot}$. [2 pts]
   (d) Solve for A_v. Include and make sure to box the simplified version of your small signal circuit. Label everything accordingly. [4 pts]
   (e) If the input to the circuit is $26mV$ peak-to-peak, what is the amplitude of the output in mV? [1 pt]
   (f) The four-letter reply corresponds to the answers in (b) to (e). The numbers can be translated to the order of the letters in the English alphabet. (e.g. $A = 1$, $B = 2$, $C = 3$, etc.) For answers greater than

26, just add 26 to the original code, i.e. $A = 27$, $B = 28$, $C = 29$. What should be Tzuyu's reply to Jihyo? [0 pt, this is just for fun :)]

2. **MOSFET CS Amplifier with current source load**. Given the circuit below and provided the following parameters: $V_{DD} = 3V$, $k_n = 7mA/V^2$, $k_p = 0.48mA/V^2$, $V_{th,n} = 0.6V$, $V_{th,p} = -0.5V$, $\lambda_n = 0.1V^{-1}$, $\lambda_p = 0.05V^{-1}$ and $I_{DS1} = I_{SD2} = 0.5mA$ when both M1 and M2 are in saturation, solve for the following.

   (a) **Simple DC Biasing.** What would be the needed values of V_{BIAS1} and V_{BIAS2} if we want to bias the circuit such that $V_{OUT} = 1.5V$? [1 pt]

   (b) Draw the complete small-signal model of the circuit. Label the transistor terminals, the small-signal parameters of both transistors (r_π, r_o, g_m) and their values. You can assume that $\lambda_n V_{DS} << 1$ and $\lambda_p V_{SD} << 1$ for this part. [3 pts]

   (c) Find the expression for the small-signal gain, $\frac{v_{out}}{v_{in}}$. [2 pts]

   (d) Solve for the actual value of the small-signal gain. [1 pt]

   (e) Calculate the minimum and maximum output voltage, $V_{OUT,min}$ and $V_{OUT,max}$, possible while keeping both M1 and M2 in saturation. [2 pts]

   (f) Assuming that M1 and M2 are biased properly, what is the maximum peak to peak input voltage, $v_{in,p-p}$ you can use and still keep both M1 and M2 in saturation? [1 pt]

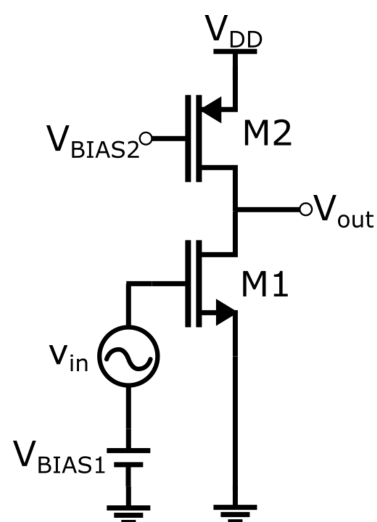

Figure 2: CS amplifier with current source load

3. **Introduction to Current Mirrors**. In reality, we do not have ideal current sources. So we use circuits that behave approximately like current sources such as current mirrors. The circuit diagram of a current mirror is shown in Figure 3. By varying the value of resistor R_1, the current and the bias voltage (V_{GS_1}) of transistor M_1 can be varied. Since the gates of M_1 and M_2 are connected, the gate voltages of the two transistors are equal. Therefore, by changing the resistance of R_1, we can control the gate voltage of M_2 which controls the drain current of M_2. This operation makes the current mirror behave like a variable current source.

   Given that $V_{DD} = 12V$, $k_p = k_n = \frac{1\,\text{mA}}{V^2}$, $V_{TH,n} = 3V$, $V_{TH,p} = -2.5V$, $\lambda_n = 0.1V^{-1}$, $\lambda_p = 0.05V^{-1}$.

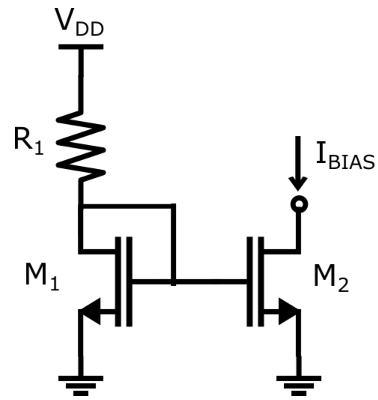

Figure 3: Current Mirror Circuit Diagram

(a) If the value of R_1 is $1\,\text{k}\Omega$, what is the gate-source voltage of transistor M_2? [1 pt]

(b) What is the value of I_{BIAS}, assuming that M_2 is in saturation? [1 pt]

(c) Draw the small-signal model of the current mirror. Label all transistor terminals and all small-signal parameters. [2 pts]

(d) What is the small-signal output resistance, r_o, of the current mirror? [1 pt]

(e) A PMOS common-source amplifier with current mirror biasing is shown in Figure 4. If we use the I_{BIAS} in (b), draw the small signal model of the amplifier. Label all transistor terminals and small-signal parameters with your calculated values. [3 pts]

(f) What is the small-signal gain, A_V, of the CS amplifier? [1 pt]

(g) What is the maximum output swing of the common emitter amplifier such that the transistor remains in saturation? [1 pt]

(h) Plot V_{IN} vs. V_{OUT} of the common-source amplifier. [2 pts]

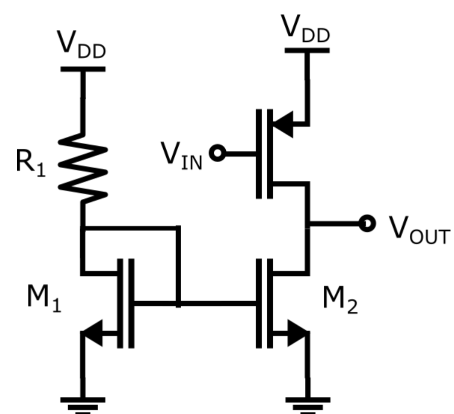

Figure 4: Common Source amplifier with current mirror biasing

TOTAL: 32/32 points.