EEE 51 Assignment 8

2nd Semester SY 2018-2019
Due: 5pm Tuesday, April 23, 2019 (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.

Answer sheets should be color coded according to your lecture section. The color scheme is as follows:

THQ – yellow
THU – white
WFX – pink

1. **Operational Amplifier.**

An operational amplifier with three blocks as shown in Figure 1 is being designed. The first block is a high gain block with a maximum gain of 2000 and with transfer function $H_1(s)$. The second block has a maximum gain of 50 and its transfer function is $H_2(s)$. This block is a high swing block. The last block is just a buffer.

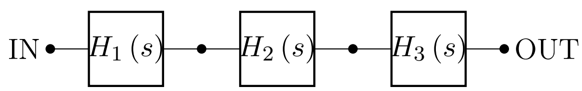

Figure 1: Blocks in an Operational Amplifier

The transfer functions are:

$$H_1(s) = k_1 \frac{s\left(1+\frac{s}{\omega_Z}\right)}{\left(1+\frac{s}{\omega_{P1}}\right)\left(1+\frac{s}{\omega_{P2}}\right)}$$

$$H_2(s) = k_2 \frac{s}{\left(1+\frac{s}{\omega_{P3}}\right)\left(1+\frac{s}{\omega_{P4}}\right)}$$

$$H_3(s) = k_3 \frac{s}{\left(1+\frac{s}{\omega_{P5}}\right)\left(1+\frac{s}{\omega_{P6}}\right)}$$

with $f_Z = 100\,\text{kHz}$, $f_{P1} = 15\,\text{Hz}$, $f_{P2} = 25\,\text{kHz}$, $f_{P3} = 10\,\text{Hz}$, $f_{P4} = 100\,\text{kHz}$, $f_{P5} = 20\,\text{Hz}$, and $f_{P6} = 20\,\text{kHz}$.

(a) Give the values of:

i. k_1 (round to nearest whole number) (1 pt)
ii. k_2 (round to 3 decimal places) (1 pt)
iii. k_3 (round to 3 decimal places) (1 pt)

(b) Draw/Sketch the frequency response (magnitude and phase) of the op amp. You may attach a separate sheet for the plots should you wish to print them. You may use the approximations or the exact values for the Bode plot. Label the slopes, the -3dB points, and the maximum gain (in dB). Assume no loading effects between blocks. What is the transfer function $H(s)$ of the whole amplifier? (6 pts)

(c) The amplifier will be used for an audio speaker. Will it be usable if the audible range of an average human is from 20 Hz to 20 kHz? Explain your answer. (1 pt)

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2. **Frequency analysis practice circuits.** Frequency-dependent components like capacitors and inductors could affect and vary the input and output impedances of amplifier circuits at certain operating frequencies. For the circuits shown below in Fig. 2 and ignoring all other intrinsic capacitances,

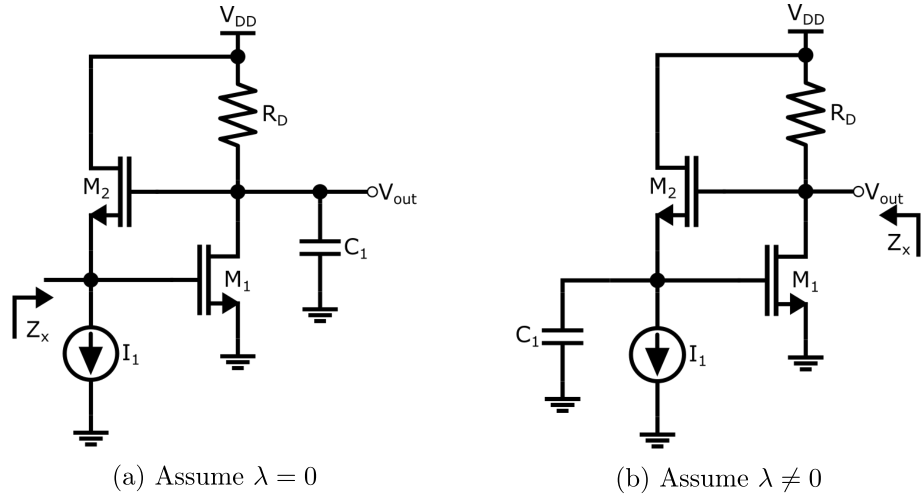

Figure 2: Impedance analysis for simple amplifier circuits

   (a) Get the expression for Z_x. Express your answers in the form $Z_x(s) = A\frac{\left(1+\frac{s}{z}\right)}{\left(1+\frac{s}{p}\right)}$. [4 pts]
   (b) What is Z_x at $f = 0Hz$? [2 pts] at $f \to \infty Hz$? [2 pts]
   (c) Roughly sketch $|Z_x|$ against frequency. Label the important points as solved from the previous item. [2 pts]

3. **Struggles from Miller Effect.** For this problem, assume the following when necessary: T=300K, $V_{BE,on} = 0.7V$, $V_{CE,sat} = 0.2V$, $\beta = 200$, $V_A = 100V$, $R_S = 50\Omega$, $I_C = 1mA$. Ignore the parasitic capacitances of the transistors.

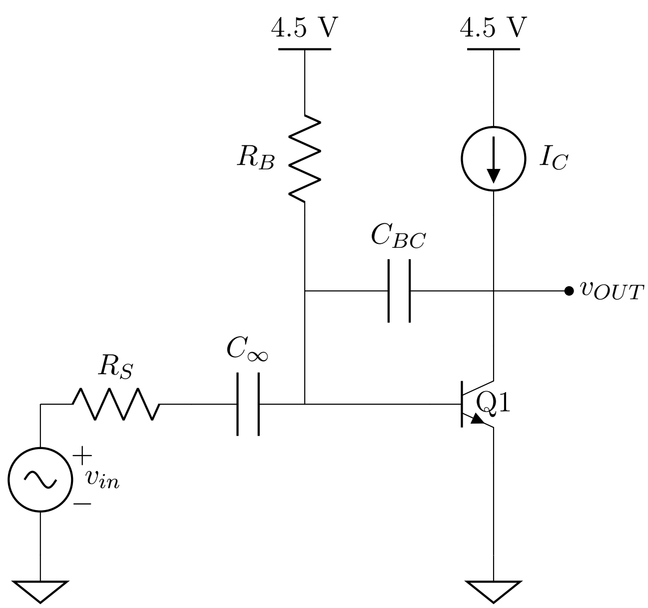

Figure 3: Common Emitter with Miller Capacitance

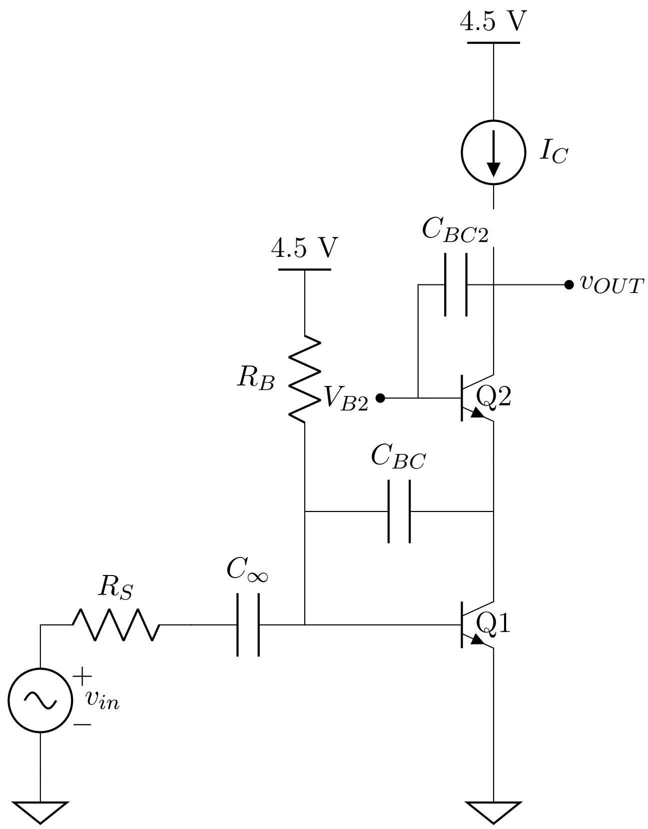

Figure 4: Cascode with Miller Capacitance

(a) Determine the DC gain of the amplifier in fig. 3. (1 pt)

(b) Solve for the transfer function of the amplifier in fig. 3. Write it in the form: $K\frac{(1+\frac{s}{\omega_{z1}})(1+\frac{s}{\omega_{z2}})...(1+\frac{s}{\omega_{zn}})}{(1+\frac{s}{\omega_{p1}})(1+\frac{s}{\omega_{p2}})...(1+\frac{s}{\omega_{pn}})}$ (1pt)

(c) What is the 3-dB bandwidth of the amplifier? Express your answer in rad/s. (1 pt)

Suppose you added a cascode, as shown in fig. 4 such that $V_{CE1} = 0.3V$.

(d) Draw the small-signal model. Label the values of the small-signal parameters, and the components. Do NOT use the Miller approximation. (1 pt)

(e) Solve for the transfer function of the amplifier in fig. 4. Write it in the form: $K\frac{(1+\frac{s}{\omega_{z1}})(1+\frac{s}{\omega_{z2}})...(1+\frac{s}{\omega_{zn}})}{(1+\frac{s}{\omega_{p1}})(1+\frac{s}{\omega_{p2}})...(1+\frac{s}{\omega_{pn}})}$ (3pts)

(f) Determine the I_C needed such that the circuit in fig. 4 will have the same DC gain as in fig. 3. (1 pt)

(g) What is the 3-dB bandwidth of the amplifier for the calculated I_C? Express your answer in rad/s. (1 pt)

(h) Did the cascode increase, decrease, or not affect the bandwidth of the amplifier? Explain this in relation to the Miller capacitance/effect. (1 pt)

TOTAL: 30 points.