EE 140/240A **ANALOG INTEGRATED CIRCUITS** **SPRING 2014**

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Homework 1

Due: Friday, 31 January 2014 at 8am

This is an individual assignment!
For all problems you may assume that each operational amplifier is an ideal op-amp. For every op-amp, gain can be assumed infinite, input impedance is infinite, and output impedance is zero. Also, the inputs are differential, and the output is single ended.

PROBLEM 1 (10pts): Negative Feedback Amplifier with Resistive Network at Input.
In this problem, a lossy connector is placed in between the source (v_{in}) and the input terminal of the op-amp. This connector between the input of the op-amp and the desired input voltage can be modeled as a resistive network.

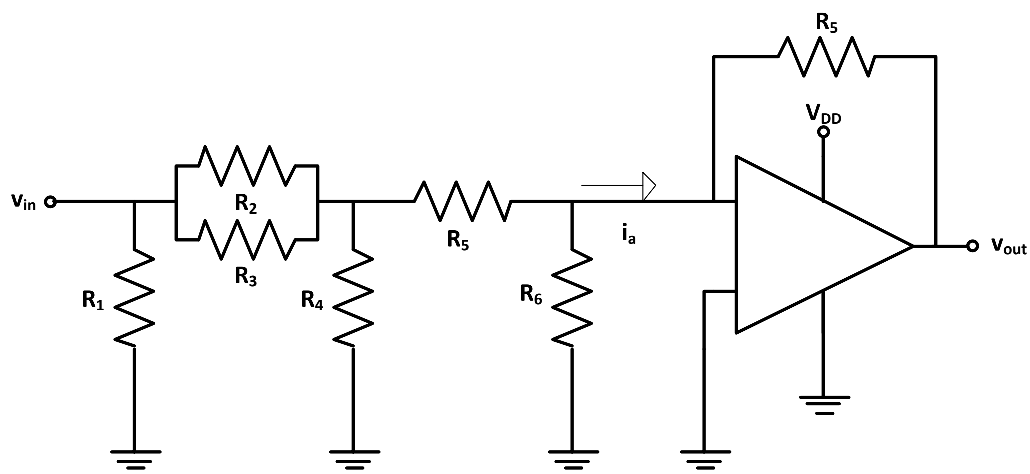

Figure 1

a. Place the "+" and "-" signs on the appropriate input port of the op-amp.
b. Find $\frac{i_a}{v_{in}}$.
c. Find $\frac{v_{out}}{v_{in}}$.

PROBLEM 2 (10pts): Instrumentation Amplifier
Instrumentation amplifiers are used to make precise voltage measurements in many practical instruments.

a. For the amplifier topology in Figure 2, place the "+" and "-" signs on the appropriate input port of each op-amp.
b. Find the differential gain of this amplifier $\frac{v_{out}}{v_1-v_2}$.
c. Common-mode rejection ratio (CMRR) is very important for instrumentation amplifiers because their inputs are often coming through long cables. Please determine the CMRR for this amplifier, as a ratio of the differential gain (from part b.) and the common-mode gain, which is defined as $\frac{v_{out}}{(v_1+v_2)/2}$.

d. Can the CMRR be made very large for this amplifier? What is the relationship between the resistors in the amplifier that would make the CMRR very large? With this setting of resistors, could you use just one resistor to adjust the differential mode gain?

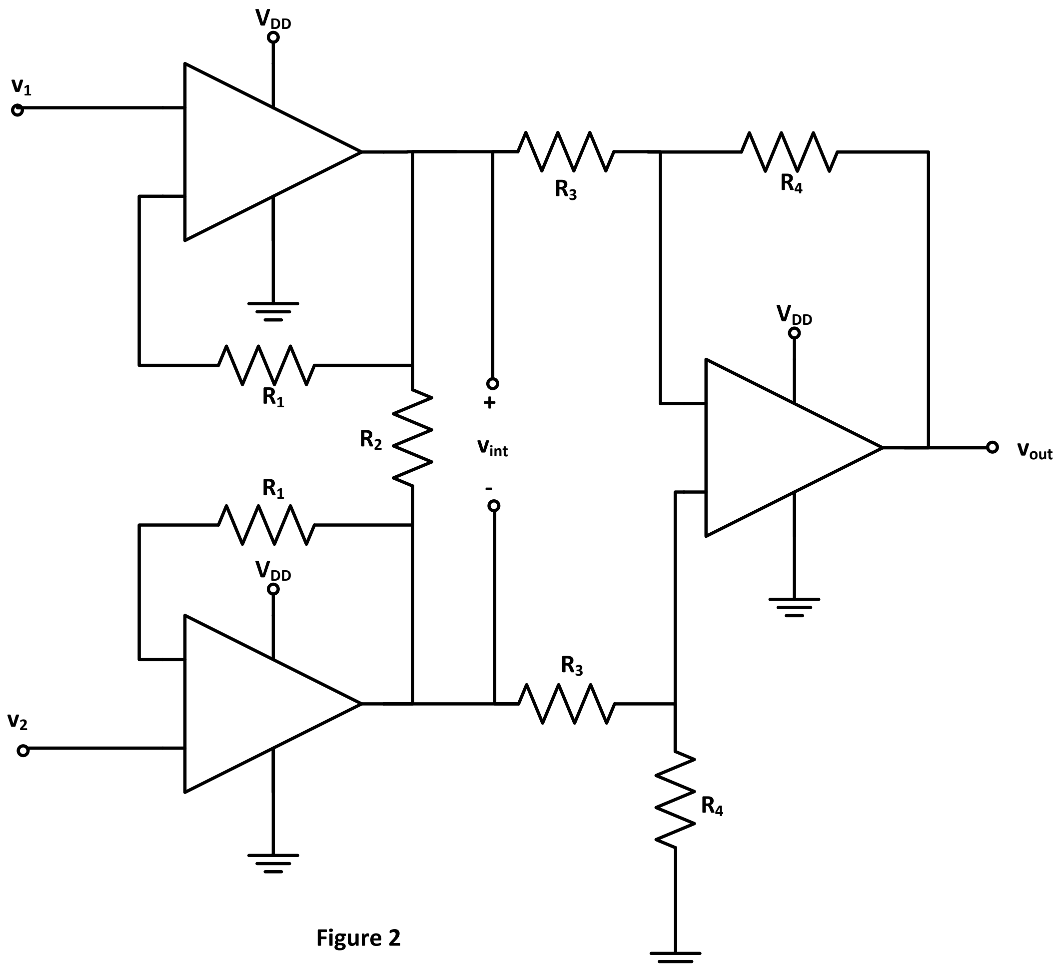

Figure 2

PROBLEM 3 (10pts): PNP Transistor
A PNP transistor has an emitter area of 10µm × 10µm. The doping concentrations are as follows: in the emitter $N_A = 10^{19}\text{cm}^{-3}$, in the base $N_D = 10^{18}\text{cm}^{-3}$, and in the collector $N_A = 10^{15}\text{cm}^{-3}$. The transistor operates at T = 300K, where $n_i = 1.5 \times 10^{10}\text{cm}^{-3}$. For holes diffusing in the base, Lp = 10µm and Dp = $1\text{cm}^2/\text{s}$. For electrons diffusing in the emitter, Ln = 5µm and Dn = $2.5\text{cm}^2/\text{s}$. Calculate the saturation current Is and β_F assuming that the transistor is in Forward Active regime and base width W is 1µm.

PROBLEM 4 (10pts):
Calculate the DC operating points including the current flowing through each branch and DC voltage at each node for the circuit shown in Figure 3:
$V_{CC} = 5V$, $\beta f = 100$, $VA \rightarrow \infty$, $rb = 0$, $V_{BE(on)} = 0.7V$, $V_{CE(sat)} = 0.2V$.
Calculate small-signal parameters of Q1 and Q2.
Calculate the smallest V_{CC} for which transistors are still in forward active region.

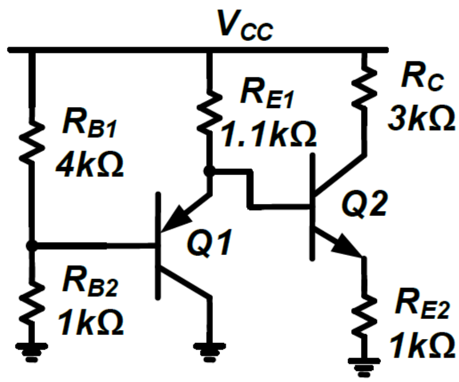

Figure 3

EXTRA PROBLEMS FOR EE 240A STUDENTS:

PROBLEM 5 (10pts): Front-end Amplifier Design
Design Problem: You are a system engineer at Konoha Semiconductor designing the analog front-end of a photo-detector-based motion sensor. The photo-detector can be modeled as a current source with a parallel shunt resistance. In this application, the precise intensity of light appearing at the photo-detector needs to be measured, so the gain of the front-end amplifier must be set so that for a current $i_{in} = 5\ \mu A$, the voltage at the output equals 30 mV.
Due to manufacturing variability and temperature dependence, the shunt resistance of the photo-detector varies between $1000\ \Omega - 3000\ \Omega$. However, our CTO Chris Uzamaki wants the gain to not vary by more than 5% across all possible shunt resistances. Using an ideal op-amp and as many discrete resistors as you like (valued from $10\ \Omega - 10\ k\Omega$), design a front-end amplifier that meets these specifications. A system block diagram is included in Figure 4 below. (Hint: the input of this front-end amplifier should be single ended.)

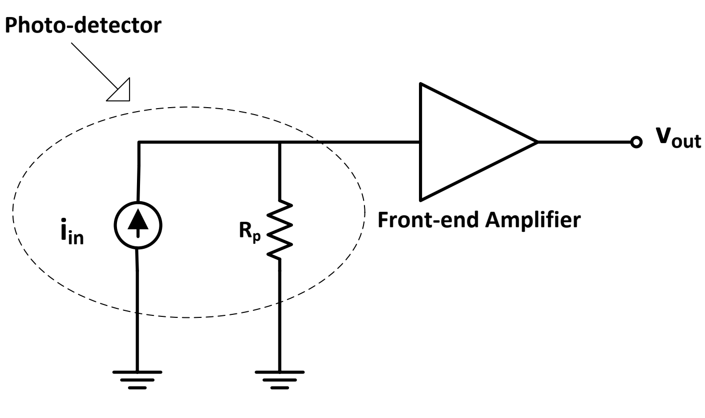

Figure 4

PROBLEM 6 (10pts): Input Impedance of Amplifiers
Sometimes feedback is used in amplifier topologies to create certain desired input impedance values. The schematic below (Figure 4) demonstrates one such example.

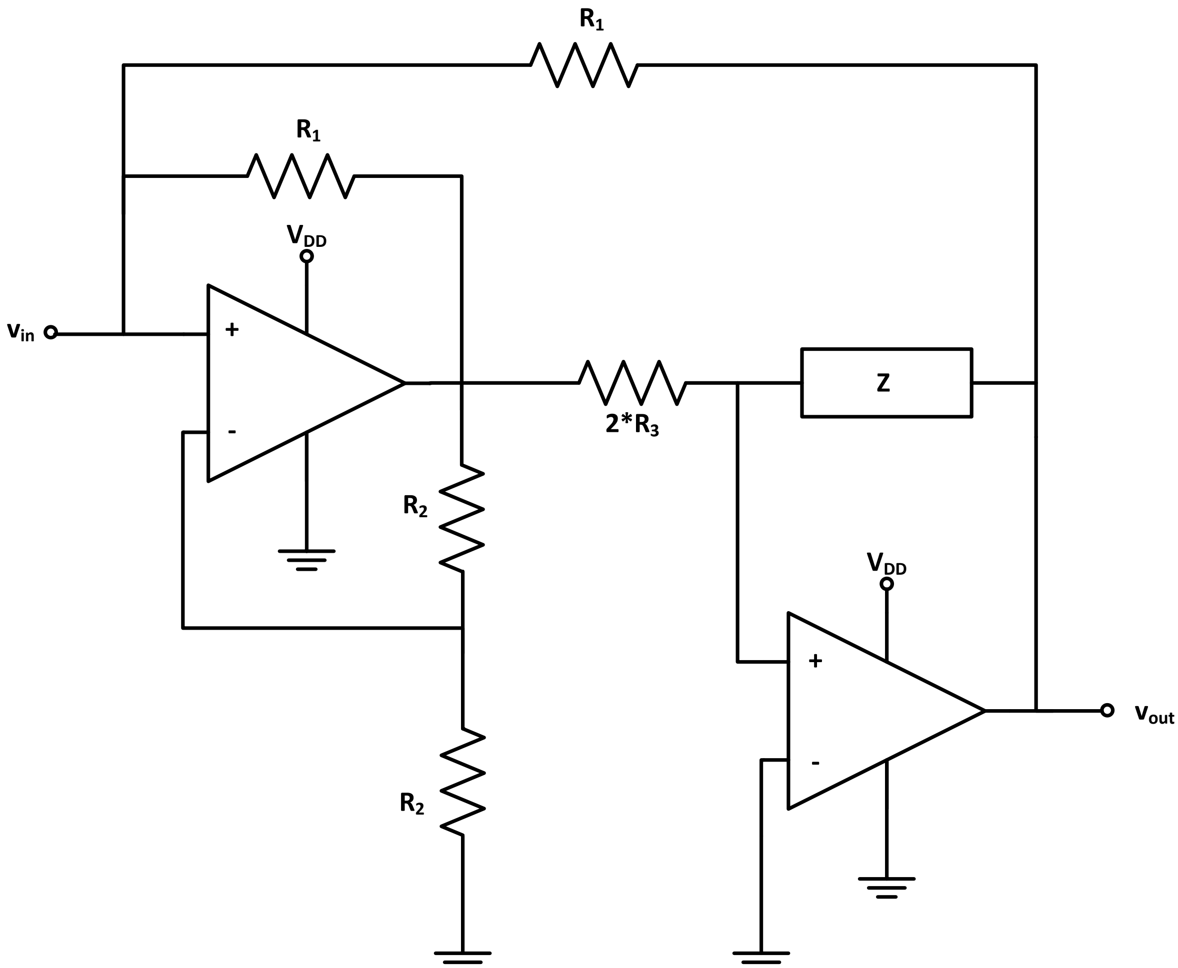

Figure 4

a. Find the input impedance of this circuit ('looking into' v_{in} terminal).
b. What is the use of this circuit?