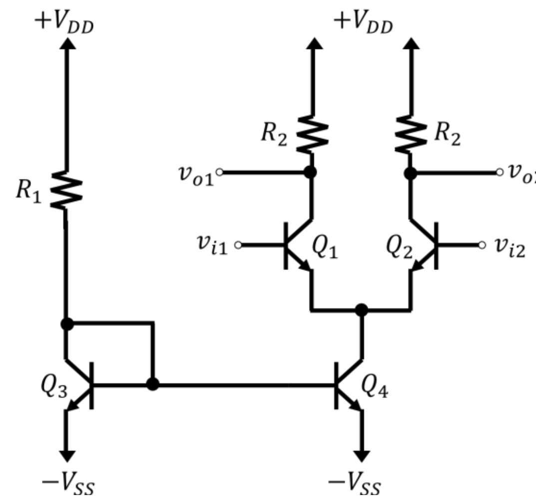
EE 430 SPICE ASSIGNMENT #1
DIFFERENTIAL AMPLIFIER DESIGN

Due: Oct. 28, 2020.

In this assignment, you will design a differential amplifier satisfying the required differential gain, input impedance, and single-ended common-mode gain; when fed by a small-signal. Then you will simulate your circuit on LTSpice to compare the simulation results with hand calculations.



A. Hand design: Design the bipolar differential amplifier and the current source and bias network ($R_1, Q_3, and\ Q_4$) above such that: (i) Differential gain: $A_d \geq 200\frac{V}{V}$, (ii) Input differential resistance: $R_{id} \geq 50\ k\Omega$, and (iii) $\boldsymbol{A_{cm} < 0.1}$ where A_{cm} is the single-ended common-mode gain (the gain to a common-mode input signal when the output is measured not differentially but from one of the outputs with respect to ground). Design the circuit with BJTs having $\beta = 200, V_A = 100\ V, and\ V_{BE} = {\sim}0.7\ V\ in\ Forward\ Active$. Use $+V_{DD} = 9\ V$ and $-V_{SS} = -9\ V$. Clearly show your steps.

Design Suggestion for Part A.

1. Derive $A_d, R_{id}, and\ A_{cm}$ expressions. (When deriving A_{cm} and R_{id} you can ignore r_o of Q1 and Q2. Needless to say, you cannot ignore r_o of Q4 when deriving A_{cm}. Do not ignore r_o of Q1 or Q2 when deriving A_d).
2. Plug the "dc currents", "resistors", "V_{th}", "β", "V_A", etc. into $A_d, R_{id}, and\ A_{cm}$ expressions and simplify the expressions to the extent possible (e.g., manipulate the expressions and then replace $V_A = 100\ V, \beta = 200$, etc.)
3. Consider the three design constraints. You basically have each constraint represented in terms of the dc currents, and resistors.
4. Start with dc current selection satisfying your constraint(s) => Find R1, and other parameters associated with the dc current selected.
5. Then based on the constraint(s) => Find R2.

In your simulations on the next page, use the BJT model 2N2222 of NXP, which has a SPICE model as below with V_A and β highlighted:

SPICE Model

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.model 2N2222 NPN(IS=1E-14 VAF=100 BF=200 IKF=0.3 XTB=1.5 BR=3 CJC=8E-12 CJE=25E-12 TR=100E-9 TF=400E-12 ITF=1 VTF=2 XTF=3 RB=10 RC=.3 RE=.2 Vceo=30 Icrating=800m mfg=NXP)
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B. DC Analysis: In LTSpice do a DC operating point simulation (.op) with both inputs connected to ground. Find the simulated DC values for $I_{R1}, I_{C3}, I_{C4}, I_{C1}, I_{C2}, V_{B3}, V_{E1,2}, V_{O1}, V_{O2}$. Compare them with your hand calculations. Additionally, comment on the matching between I_{R1} *and* I_{C4} and comment on the theoretical vs. simulated match between I_{R1} *and* I_{C4}.

C. Transient Analysis: In LTSpice do a transient simulation (.tran) for 100 ms.

<u>For differential small-signal input simulations:</u>
Apply $v_{id} = 1\, mV_p\ sinusoidal\ signal\ at\ 100\ Hz.$ [i.e., $v_{id1} = +\frac{v_{id}}{2} = 0.5\ mV \sin(2 * \pi * 100Hz * t)$ and $v_{id2} = -\frac{v_{id}}{2} = 0.5\ mV \sin((2 * \pi * 100Hz * t) + \pi)$ with DC offset = 0V.]
<u>For common-mode small-signal input simulations:</u>
Apply $v_{cm} = 1\, mV_p\ sinusoidal\ signal\ at\ 100\ Hz.$ [i.e., $v_{icm1} = v_{icm2} = v_{cm} = 1\ mV \sin(2 * \pi * 100Hz * t)$ with DC offset = 0V.]

1. For the differential small-signal input, what is the expected emitter voltage of Q1 and Q2, $v_{e1}(= v_{e2})$? Plot the simulated waveform. What is the simulated value of $v_{e1}(= v_{e2})$?
2. Plot $v_{id}, v_{od}(v_{od} = v_{o2} - v_{o1}),\ and\ i_{id}$. Note that i_{id} is the base current of Q1 ($i_{id} = i_{b1}$). Calculate the simulated $A_d = v_{od}/v_{id}$ and $R_{id} = v_{id}/i_{id}$. Compare the values with your design targets.
3. If the simulation results do not match the design constraints, tune your circuit to achieve the goals.
4. For the common-mode small-signal input, plot v_{cm} and v_{ocm}. ($v_{ocm} = v_{ocm2} = v_{ocm1}\ when\ the\ input\ is\ a\ common - mode\ signal$)

Report Requirements
A. In part A, your hand calculations must follow a flow, you must show every step for derivations, and clearly present how/why you select the parameters with any approximations you might have made.
B and C. For parts B and C, in addition to answering the questions and plotting the simulation results requested, fill the table below, and explain the reasons for any discrepancy exceeding 10%.

	I_{R1}	I_{C3}	I_{C4}	I_{C1}	I_{C2}
Hand calculations					
Simulated					
Percent discrepancy					

	V_{B3}	$V_{E1,2}$	V_{O1}	V_{O2}	A_d	R_{in}	A_{cm}
Hand calculations							
Simulated							
Percent discrepancy							