1) For the circuit shown in Figure 1, determine output voltage V_o and current I_o. Assume an ideal opamp. Verify your by-hand answers in LTSpice; you must use an e or e2 source with open-loop gain of 100Meg in place of the ideal opamp, and you must use 0-V voltage source ammeters to verify any current flows in simulation.

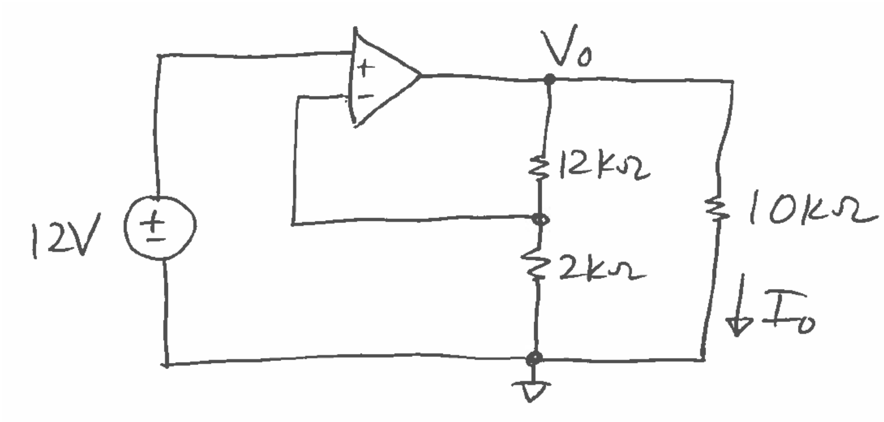


Figure 1. Circuit for Problem 1.

2) For the circuit shown in Figure 2, determine node voltages V_{in} and V_{out}, and determine currents I_1, I_2, I_3, and I_4. Assume an ideal opamp. Verify your by-hand answers in LTSpice; you must use an e or e2 source with open-loop gain of 100Meg in place of the ideal opamp, and you must use 0-V voltage source ammeters to verify any current flows in simulation.

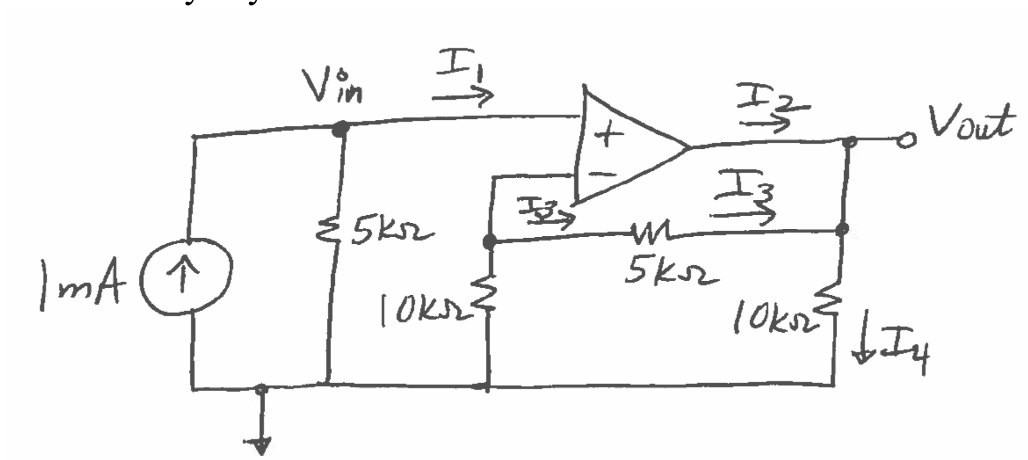
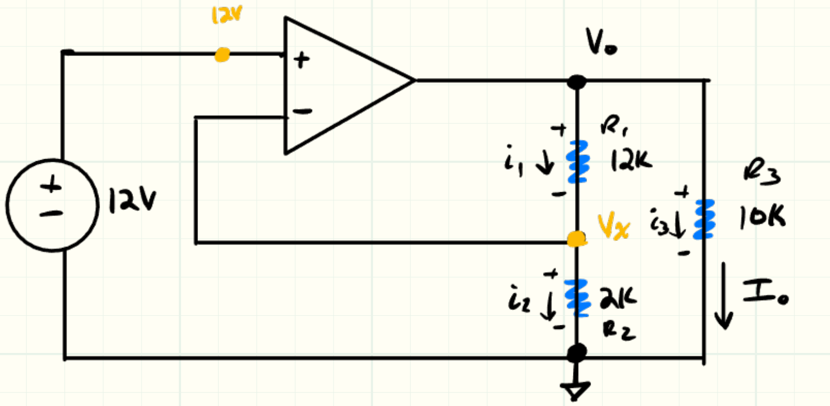


Figure 2. Circuit for Problem 2.

[continued on next page]

Austin Riha | HW 5 | Problem 1



$V_x = 12V$

KCL @ V_x

$i_1 = i_2$

$G_1(V_o - V_x) = G_2(V_x - 0)$

$G_1 V_o - G_1 V_x = G_2 V_x$

$G_1 V_o = G_1 V_x + G_2 V_x$

$V_o = V_x\left(\frac{G_1 + G_2}{G_1}\right)$

$V_o = 12V\left(\frac{1/12k + 1/2k}{1/12k}\right)$

$\boxed{V_o = 84V}$

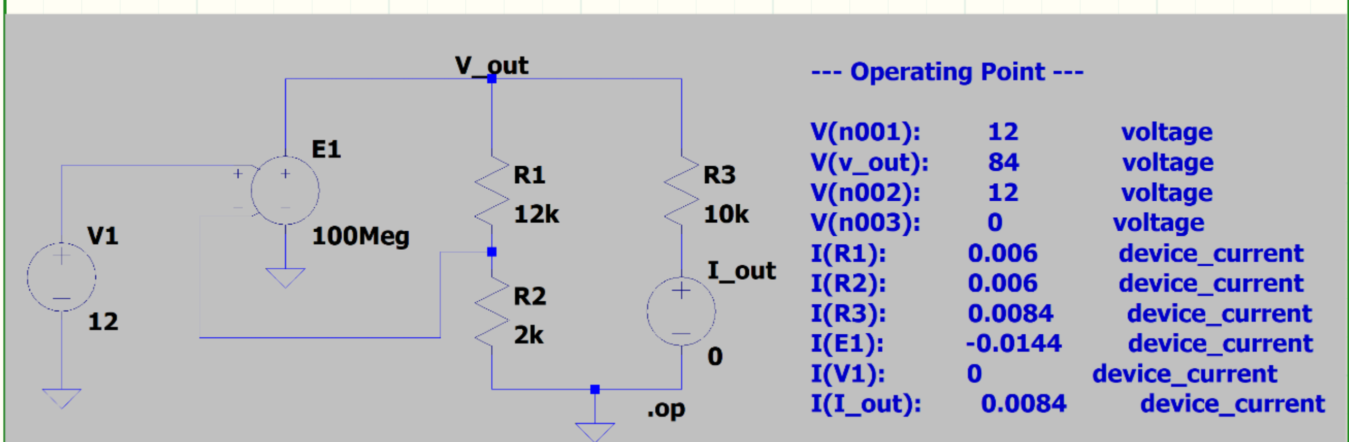
$V = IR$

$V_o = I_o R_3$

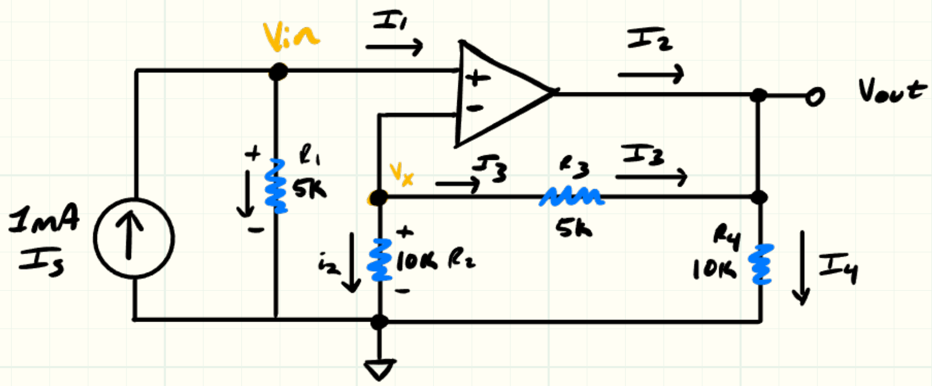
$84V = I_o(10k\Omega)$

$I_o = 84V/10k\Omega$

$\boxed{I_o = 8.4\,mA}$



Austin Riha | HW5 | Problem 2



$V_{in} = 5V$
$V_{out} = 7.5V$
$I_1 = 0A$
$I_2 = 1.25mA$
$I_3 = -500\mu A$
$I_4 = 750\mu A$

$V_{in} = V_x$

$V_x = 1mA \cdot 5k\Omega$

$V_x = 5V$

$V_{in} = 5V$

KCL @ V_x

$0 = i_3 + i_2$

$0 = G_3(V_x - V_{out}) + G_2(V_x - 0)$

$0 = G_3 V_x - G_3 V_{out} + G_2 V_x$

$G_3 V_{out} = V_x(G_2 + G_3)$

$V_{out} = V_x\left(\frac{G_2 + G_3}{G_3}\right)$

$V_{out} = V_x\left(\frac{G_2}{G_3} + 1\right)$

$V_{out} = 5V\left(R_3/R_2 + 1\right)$

$V_{out} = 5V(1/2 + 1)$

$V_{out} = 7.5V$

$I_1 = 0A$

$I_4 = \frac{(V_{out} - 0)}{R_4} = \frac{7.5V}{10k\Omega}$

$I_4 = 750\mu A$

$I_3 = \frac{V_x - V_{out}}{R_3} = \frac{5V - 7.5V}{5k\Omega}$

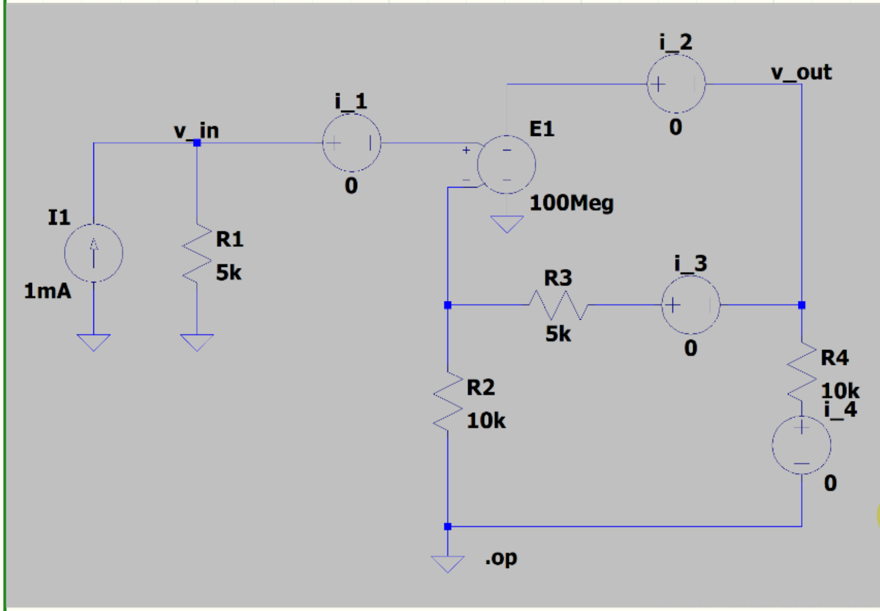
$I_3 = -500\mu A$

$I_2 + I_3 = I_4$

$I_2 = I_4 - I_3$

$I_2 = (750\mu A - (-500\mu A))$

$I_2 = 1.25mA$



--- Operating Point ---

V(v_in):	5	voltage
V(n002):	5	voltage
V(n001):	7.5	voltage
V(n003):	5	voltage
V(n004):	7.5	voltage
V(v_out):	7.5	voltage
V(p001):	0	voltage
I(I1):	0.001	device_current
I(R1):	0.001	device_current
I(R2):	0.0005	device_current
I(R3):	0.0005	device_current
I(R4):	0.00075	device_current
I(E1):	-0.00125	device_current
I(I_1):	0	device_current
I(I_2):	0.00125	device_current
I(I_3):	-0.0005	device_current
I(I_4):	0.00075	device_current

3) For the circuit shown in Figure 3, assume an ideal opamp and $V_1 = V_2 = 4$ V. Determine the output voltage V_0. Verify your by-hand answer in LTSpice; you must use an e or e2 source with open-loop gain of 100Meg in place of the ideal opamp, and you must use 0-V voltage source ammeters to verify any current flows in simulation.

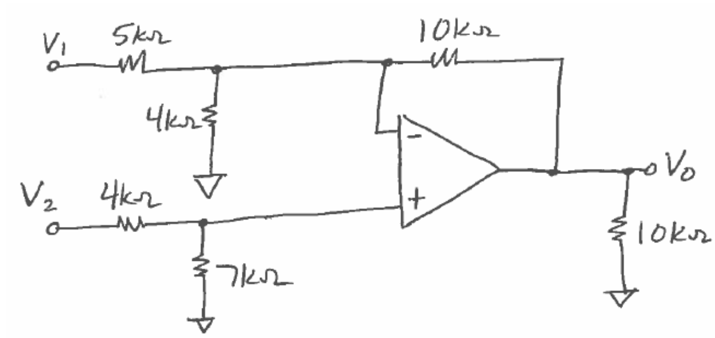


Figure 3. Circuit for Problem 3.

4) Assuming an ideal opamp for the circuit shown in Figure 4, find V_o and I_o. Verify your by-hand answers in LTSpice; you must use an e or e2 source with open-loop gain of 100Meg in place of the ideal opamp, and you must use 0-V voltage source ammeters to verify any current flows in simulation.

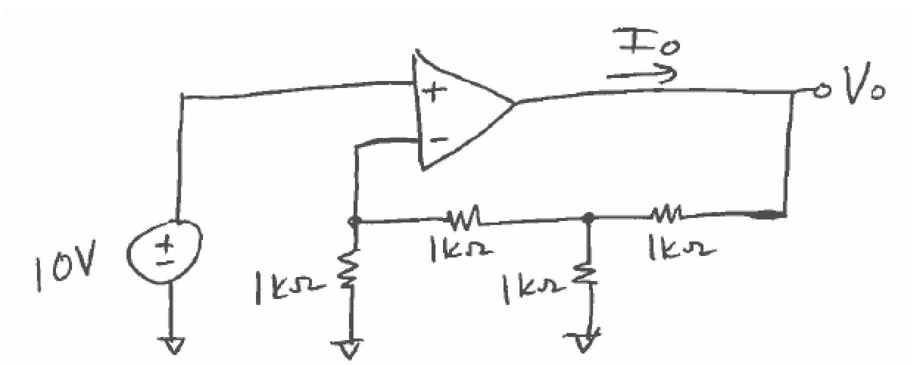
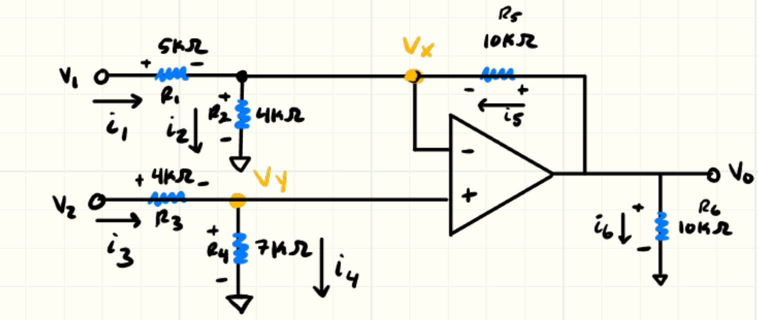


Figure 4. Circuit for Problem 4.

Austin Piha | HW5 | Problem 3



$V_o = (-8V) + (14)$

$\boxed{V_o = 6V}$

$V_o = V_o' + V_o''$

Superposition 1 (V_o')

$V_1 = 4V \quad V_2 = 0 \quad V_y = V_x = 0$

KCL @ V_x

$i_1 + i_5 = i_2$

$G_1(V_1 - V_x) + G_5(V_o' - V_x) = G_2(V_x - 0)$

$G_1V_1 - G_1V_x + G_5V_o' - G_5V_x = G_2V_x$

$G_1V_1 + G_5V_o' = V_x(G_1 + G_2 + G_5)$

$V_o' = V_x\left(\frac{G_1 + G_2 + G_5}{G_5}\right) - \frac{G_1}{G_5}V_1$

$V_o' = -R_5/R_1 \, V_1$

$V_o' = -\frac{(10k\Omega)}{(5k\Omega)}(4V) \qquad \underline{V_o' = -8V}$

Superposition 2 (V_o'')

$V_1 = 0 \quad V_2 = 4V \quad V_y = V_x$

KCL @ V_y

$i_3 = i_4$

$G_3(V_2 - V_y) = G_4(V_y - 0)$

$G_3V_2 - G_3V_y = G_4V_y$

$G_3V_2 = V_y(G_3 + G_4)$

$V_y = V_2\left(\frac{G_3}{G_3 + G_4}\right)$

$V_y = (4V)\left(\frac{1/4000}{1/4000 + 1/7000}\right)$

$V_y = 2.545V$

KCL @ V_x

$i_1 + i_5 = i_2$

$G_1(V_1 - V_x) + G_5(V_o'' - V_x) = G_2(V_x - 0)$

$G_1V_1 - G_1V_x + G_5V_o'' - G_5V_x = G_2V_x$

$G_1V_1 + G_5V_o'' = V_x(G_1 + G_2 + G_5)$

$G_5V_o'' = V_x(G_1 + G_2 + G_5) - G_1V_1$

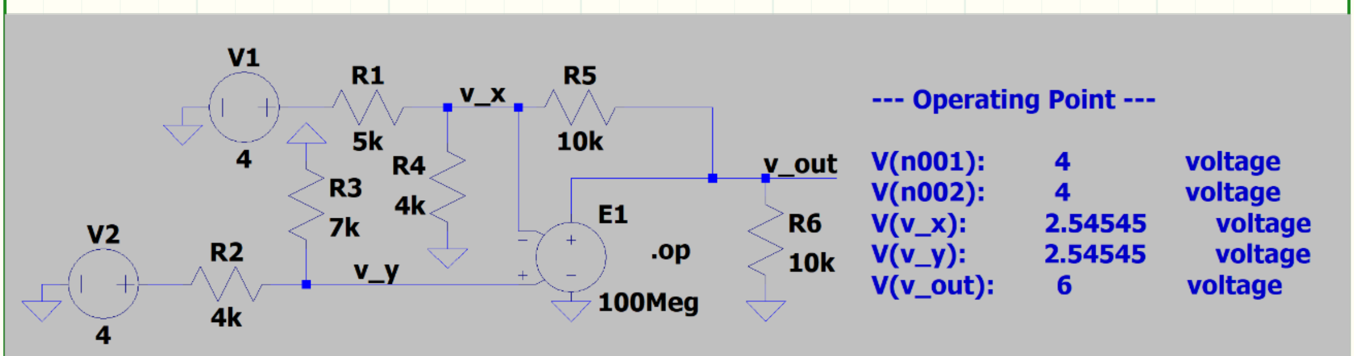
$V_o'' = V_x\left(\frac{G_1 + G_2 + G_5}{G_5}\right) - \cancel{\frac{G_1}{G_5}V_1}^{\,0}$

$V_o'' = V_x\left(\frac{G_1}{G_5} + \frac{G_2}{G_5} + 1\right)$

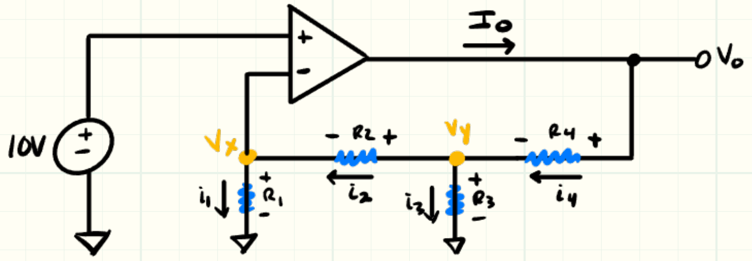
$V_o'' = V_x\left(\frac{R_5}{R_1} + \frac{R_5}{R_2} + 1\right)$

$V_o'' = (2.545)\left(\frac{10k}{5k} + \frac{10k}{4k} + 1\right)$

$V_o'' = 14V$



Austin Riha | HW5 | Problem 4



* all resistors are same so, i'll label them all as R *

$V_x = 10V$

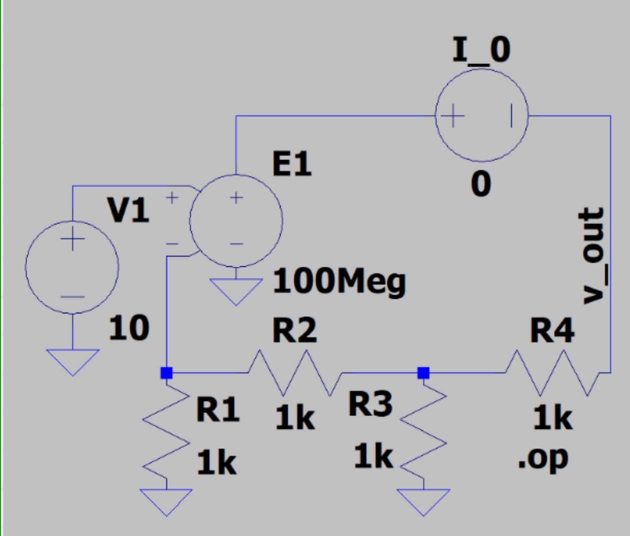
KCL @ V_x

$$i_1 = i_2$$
$$G_1(V_x - 0) = G_2(V_y - V_x)$$
$$G_1 V_x = G_2 V_y - G_2 V_x$$
$$V_x(G_1 + G_2) = G_2 V_y$$
$$V_y = V_x\left(\frac{G_1 + G_2}{G_2}\right)$$
$$V_y = V_x\left(\frac{G_1}{G_2} + 1\right)$$
$$V_y = 10V\left(\frac{1/R}{1/R} + 1\right)$$
$$V_y = 20V$$

KCL @ V_y

$$i_4 = i_2 + i_3$$
$$G_4(V_o - V_y) = G_2(V_y - V_x) + G_3(V_y - 0)$$
$$G_4 V_o - G_4 V_y = G_2 V_y - G_2 V_x + G_3 V_y$$
$$G_4 V_o = V_y(G_2 + G_3 + G_4) - G_2 V_x$$
$$V_o = V_y\left(\frac{G_2 + G_3 + G_4}{G_4}\right) - \frac{G_2}{G_4} V_x$$
$$V_o = (20V)\left(\frac{3k\Omega}{1k\Omega}\right) - \frac{R_4}{R_2}(10V)$$
$$\boxed{V_o = 50V}$$

$$I_o = i_4$$
$$i_4 = \frac{V_o - V_y}{R_4}$$
$$i_4 = \frac{50V - 20V}{1k\Omega}$$
$$\boxed{I_o = 30mA}$$



--- Operating Point ---

V(n001):	50	voltage
V(n002):	10	voltage
V(n003):	10	voltage
V(n004):	20	voltage
V(v_out):	50	voltage
I(R1):	0.01	device_current
I(R2):	0.01	device_current
I(R3):	-0.02	device_current
I(R4):	-0.03	device_current
I(E1):	-0.03	device_current
I(V1):	0	device_current
I(I_0):	0.03	device_current

<u>A few notes on expectations for all problems on this assignment and all future assignments in this course:</u>

Note that ideal opamps in this course will be simulated in LTSpice with an e or e2 dependent source with open-loop gain set to 100Meg. **To be clear:** you *must* use an e or e2 source in place of the opamp in simulation with an open-loop gain of 100Meg, so you are advised to resist the temptation to go looking for things that look like an opamp symbol for your LTSpice verifications (*because they *are* there in LTSpice, but you should not use them*), and just simply follow the instructions provided here in the assignment instead.

Make sure to include appropriate units with your numerical answers and list your answers in proper engineering notation format with 2 decimal places of precision! **That means no fractions, no square roots, no instances of π, etc.** Note that this applies to all problems in this course, not just the ones on this assignment!

The same LTSpice verification rules mentioned above will be in place for future assignments: key voltage nodes must be labeled and *unless the node voltage is directly related to the voltage of interest relative to your reference node*, <u>voltages of interest should be created with an E source having a voltage gain of 1</u>, and any currents that need verifying should be captured with a properly-oriented 0-V voltage source ammeter. You should expect zero credit for not following these instructions.

Additionally, to permit an efficient comparison of your by-hand and simulated results, you should write out your LTSpice verification results and attach any supporting evidence that you verified your by-hand work in LTSpice; include your supporting evidence in your ONE PDF FILE that you submit on Canvas. If these instructions are not followed, expect zero credit.

Furthermore, on all future assignments, expect zero credit if 1) your by-hand and simulated results agree but the results are incorrect, 2) you do not perform the LTSpice verification altogether, 3) you only do the LTSpice verification but not the by-hand solution, 4) your by-hand and simulated results do not match by both sign and magnitude, or 5) you copy your by-hand work and/or LTSpice verification results from others.