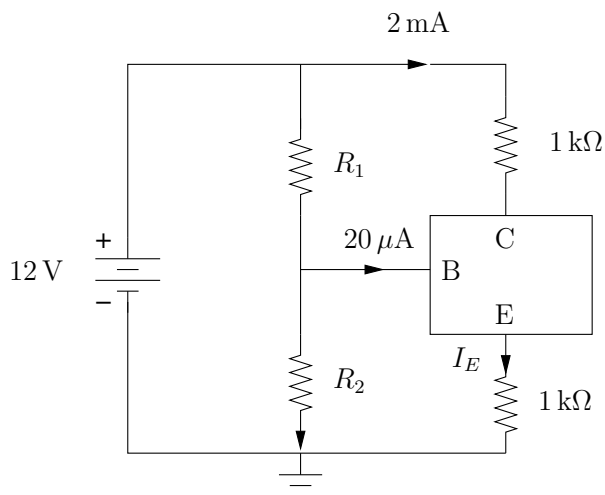


PHYS 235: Homework Problems

52. A “black box” with three terminals labeled E, B, and C is connected in the following illustrated circuit.

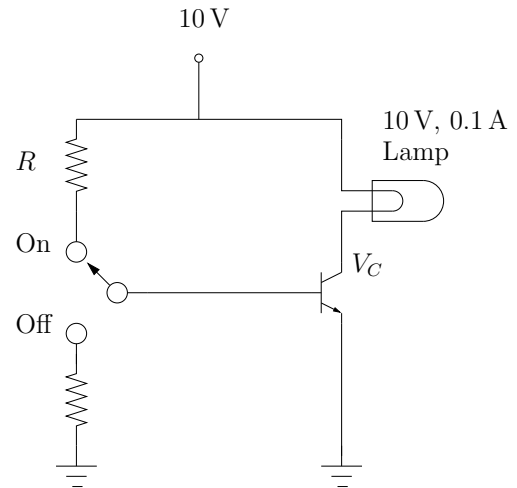
- (a) Calculate I_E .
- (b) Calculate V_C and V_E .
- (c) If terminal B is 0.6 V more positive than terminal E, calculate the ratio of R_1 and R_2 , assuming that I_d is very large compared to the $20\ \mu\text{A}$ flowing in the B lead. (The “black box” is a silicon NPN transistor.)
- (d) Calculate the approximate power dissipated in the “black box.”



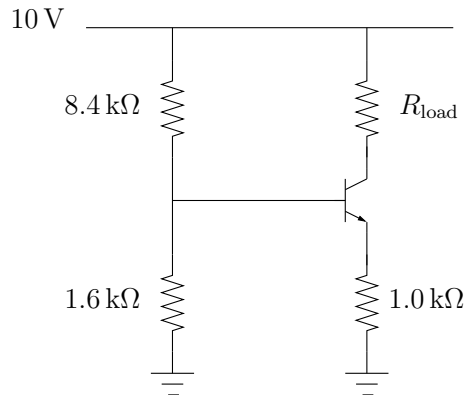
53. (a) Write a simple formula that expresses the relationship between I_C , I_B , and I_E in a bipolar transistor.
 - (b) Write an expression for I_C as a function of I_B and α .
 - (c) Write an expression for I_C as a function of I_B and β .
 - (d) Write an expression for I_C as a function of I_E and α .
 - (e) Write an expression for I_C as a function of I_E and β .
 - (f) Write an expression for I_B as a function of I_E and α .
 - (g) Write an expression for I_B as a function of I_E and β .
54. Fill in the blanks: The base voltage of an “on” silicon NPN transistor is always approximately _____ more _____ than the emitter.

55. Consider the illustrated circuit in which a mechanical switch is used to turn on a small control current that activates the transistor “switch” that enables a much larger current through the lamp. The manufacturer says that the lamp was designed for 1 V, 0.1 A operation; for the purposes of this exercise consider the lamp as a simple resistor of with $R_{\text{lamp}} = 100 \Omega$, and assume that $\beta = 100$ for this transistor. Fill in the following table giving the the base current I_B , the collector current I_C and the voltage at the collector V_C for the indicated values of R . For which resistor(s) will the lamp light be powered as it was designed to be?

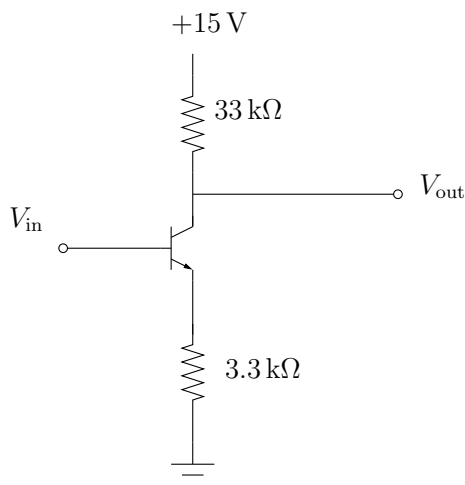
R	I_B	I_C	V_C
100 k Ω			
10 k Ω			
1 k Ω			



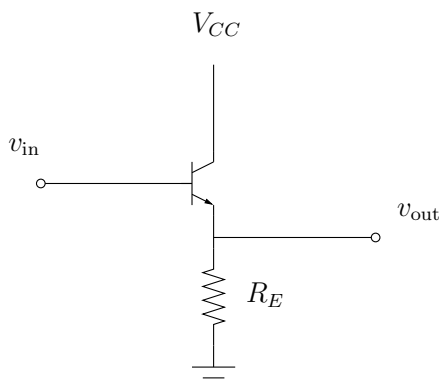
56. Calculate the current through the load resistor R_{load} in the illustrated circuit. (Use the “simplest” model of the transistor.) Does your result depend on the value of R_{load} ?



57. Consider the simple common-emitter amplifier discussed in class. (This is also part of the amplifier that some of you built in the optional part of the Introduction to Transistors Lab; see Fig. 8.4 in the 2008 edition of the lab manual.) Consider as the input the voltage $V_{in} = 1.59 + 0.33 \cos(\omega t)$, i.e., a signal that oscillates between $1.59 - 0.33 = 1.26 \text{ V}$ and $1.59 + 0.33 = 1.92 \text{ V}$.



- (a) Use the “simplest model” of transistors to calculate V_{out} when $V_{in} = 1.26 \text{ V}$.
- (b) Use the “simplest model” of transistors to calculate V_{out} when $V_{in} = 1.92 \text{ V}$.
- (c) Using the results you obtained in the previous parts of this problem determine the voltage gain for AC signals ($\Delta V_{out}/\Delta V_{in}$).
58. In class we showed that the input impedance of the simple voltage follower shown below is $(\beta + 1)R_E$. Show that the output impedance is given by $R_{source}/(\beta + 1)$, where R_{source} is the output impedance of the source that is providing v_{in} . Remember that the output impedance is $\Delta v_{out}/\Delta i_{out}$.



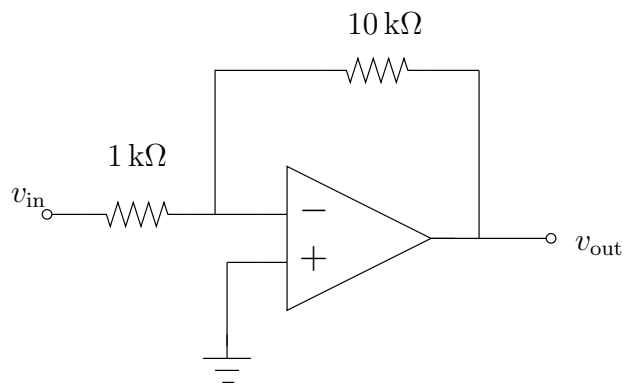
59. State the two rules for ideal op-amp behavior when the op-amp is hooked up with negative feedback.

60. For the illustrated amplifier, determine

(a) the voltage gain A_v ,

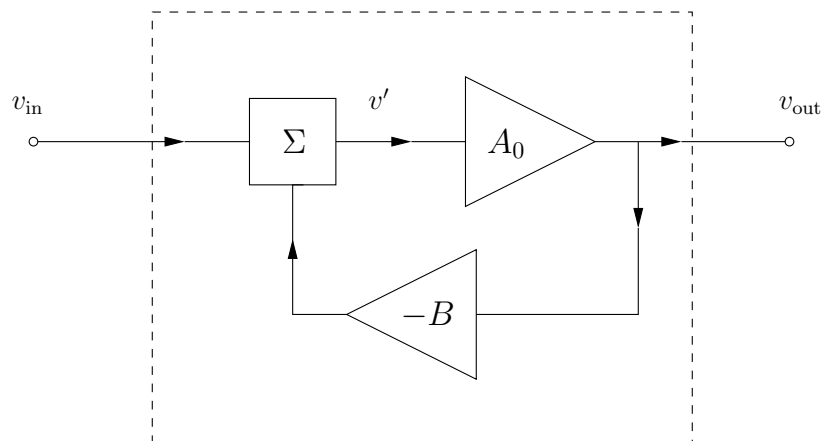
(b) the input impedance, and

(c) the qualitative effect on sinusoidal signals of adding a 1600 pF capacitor in parallel with the 10 k Ω resistor.



61. Why is an amplifier with a voltage gain of 1 (i.e., with $v_{\text{out}} = v_{\text{in}}$) of any use to anyone?

62. Consider the simple generalized negative feedback amplifier discussed in class.

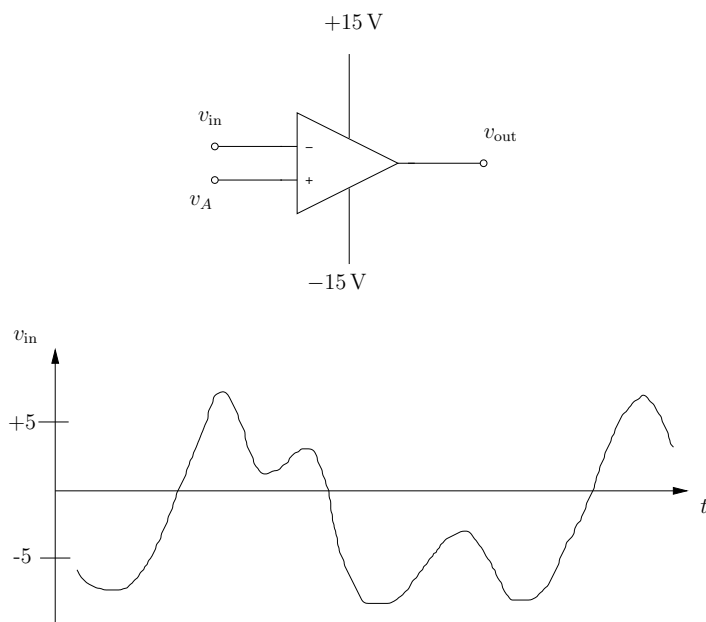


- (a) Derive the expression that gives the closed-loop gain A_v in terms of the open-loop gain A_0 and the percentage of the output B fed back into the summing amplifier.
- (b) Show using specific numerical values in your formula that if $A_0 = 10^6$ and $B = 0.01$, then a 20% change in A_0 results in a 0.002% change in A_v .
- (c) Prove that a fractional change in the open-loop gain $\Delta A_0/A_0$ results in an approximate fractional change in the closed-loop gain given by

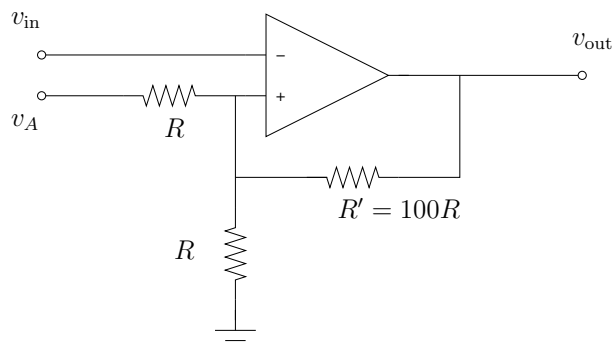
$$\frac{\Delta A_v}{A_v} \simeq \frac{1}{(1 + A_0 B)} \frac{\Delta A_0}{A_0} \simeq \frac{1}{A_0 B} \frac{\Delta A_0}{A_0}.$$

- 63. (a) Explain why negative feedback will increase rather than decrease the input impedance of an amplifier.
- (b) Explain why a large input impedance is usually desirable.
- 64. Design an amplifier with op-amps that takes four inputs v_A , v_B , v_C , and v_D , and produces an output $v_{\text{out}} = v_A + 2v_B + 4v_C + 8v_D$.
- 65. Design an op-amp amplifier that will give a constant current I_L through a load resistance, independent of the value R_L of the load resistance; the output current should be proportional to the input voltage. Choose component values that will give a current I_L of 1 mA for a 10 mV input. (Look back at the transistor current source for ideas.)
- 66. (a) Design a current-to-voltage converter to convert a $1 \mu\text{A}$ DC input current from a constant current source into a 2 V signal.
- (b) Now consider an AC input current with an amplitude of $1 \mu\text{A}$ and a frequency of 100 Hz. There is also AC noise present at 10,000 Hz. Redesign your current-to-voltage converter so that your output voltage has an amplitude of 2 V, and the noise is significantly attenuated.

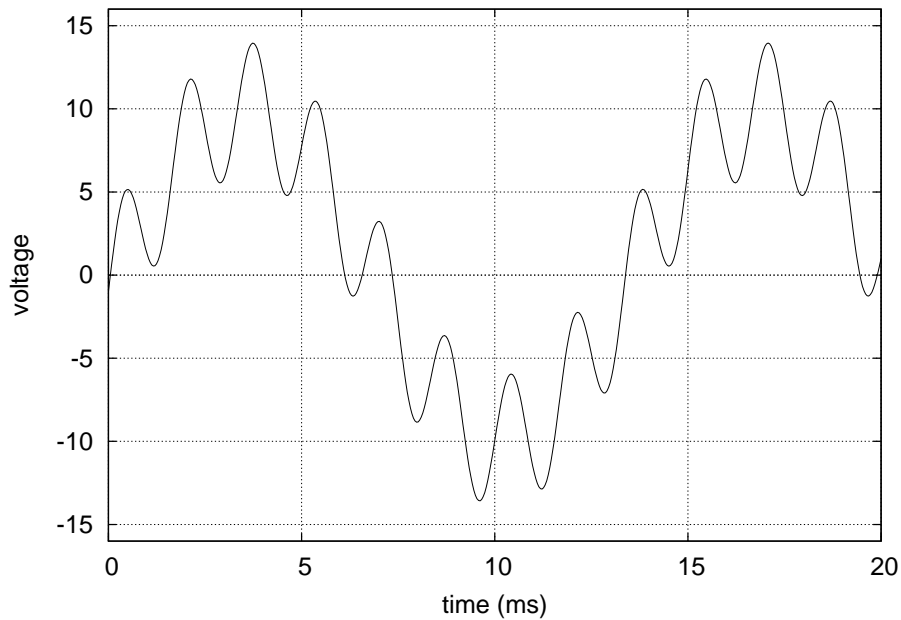
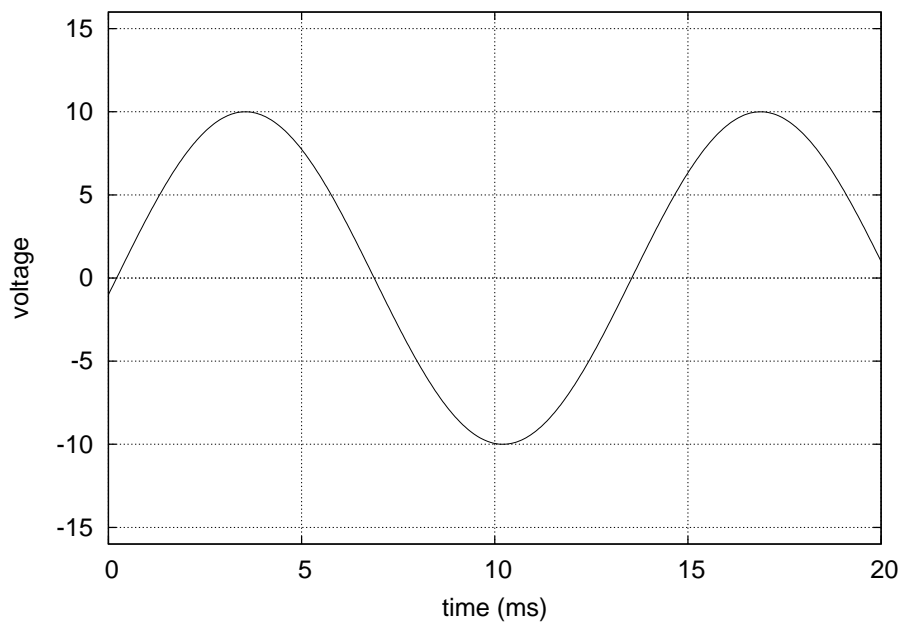
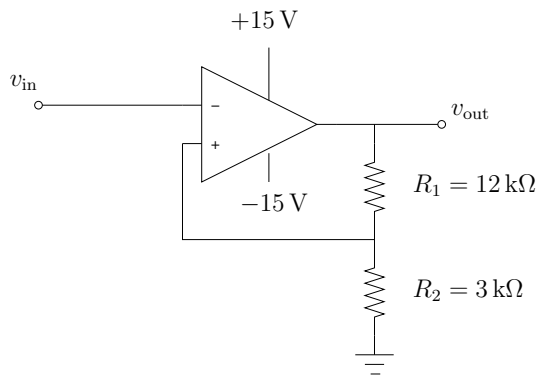
67. (a) Sketch the output v_{out} of the illustrated op-amp when $V_A = +5$ V.
 (b) Sketch the output v_{out} of the illustrated op-amp when $V_A = -5$ V.



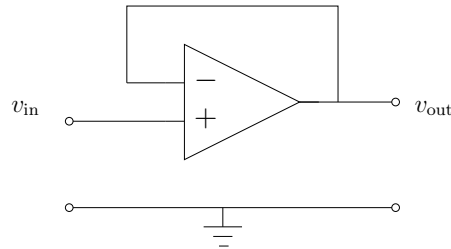
68. In lab you investigated the operation of a Schmitt trigger. Your trigger made transitions at reference voltages that were near 0 V. In the illustrated circuit the transitions have been shifted away from zero because of the voltage v_A . Determine the transition voltages for this more general Schmitt trigger. Express your answer in terms of v_A , R , and the saturation voltage of the op-amp V_{CC} . (You may assume that the negative saturation voltage is $V_{EE} = -V_{CC}$).



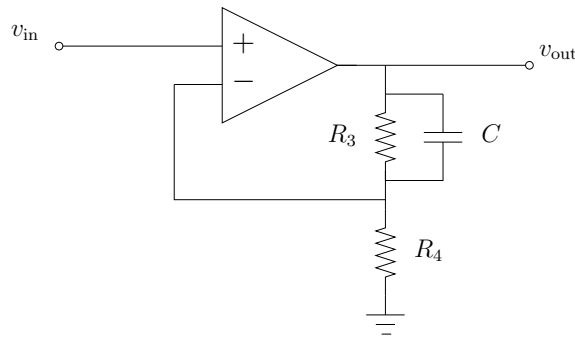
69. Sketch the output v_{out} of the illustrated op-amp for the two illustrated inputs.



70. Ideal op-amps are assumed to have open-loop gains A_0 that are infinite, and this infinite open-loop gain leads to equal voltages at the inverting and non-inverting inputs (when the op-amp is placed in a circuit with negative feedback). The following circuit is a voltage follower, and for an ideal op-amp $v_{\text{out}} = v_{\text{in}}$. For this problem assume that the op-amp is **not** ideal, and A_0 is finite. (All other properties of the op-amp may be assumed to be ideal; for example, you may still assume that the inputs draw no current.) Determine v_{out} in terms of v_{in} and A_0 . Show that you recover the ideal op-amp result in the limit $A_0 \rightarrow \infty$.

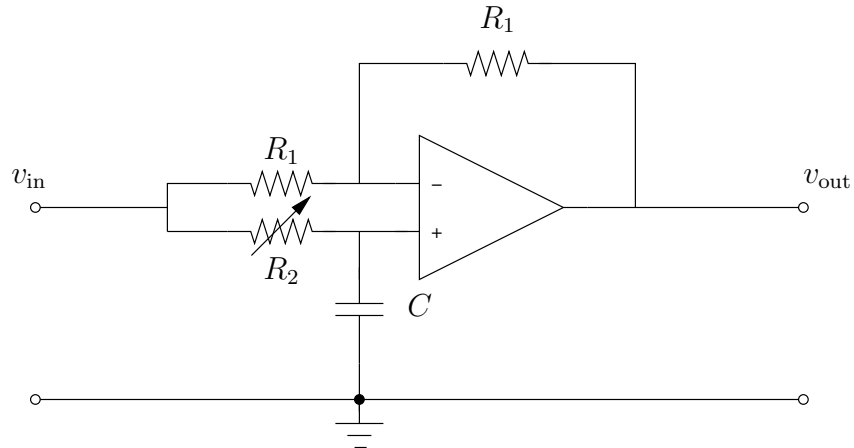


71. The illustrated amplifier is a slight modification of a circuit that should be familiar to you.

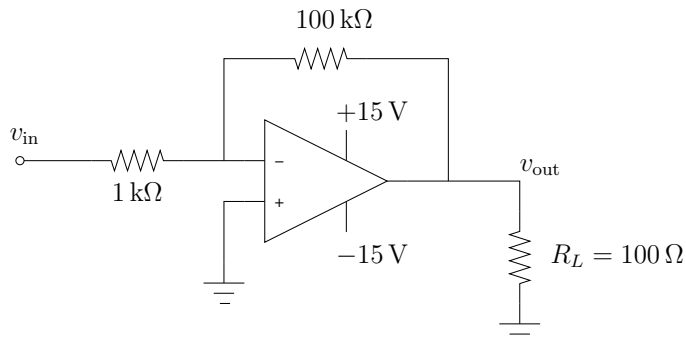


- (a) What is the gain of the amplifier A_v for DC signals, i.e., when $\omega = 0$? (You should be able determine this from applications of derivations done previously in class and lab.)
- (b) What is the gain of the amplifier A_v for sinusoidal AC signals when $\omega \rightarrow \infty$? (You should be able determine this from applications of derivations done previously in class and lab.)
- (c) What is the gain of the amplifier A_v when $\omega = 1/(R_3C)$?

72. What does the illustrated circuit do? (Consider a sinusoidal input v_{in} , and determine v_{out} .) There is a nice formula that gives the output as a general function of input frequency ω , R_2 , and C , but it might be easier to start by calculating the output for the specific values $\omega = 2\pi \times 10^3 \text{ s}^{-1}$, $C = 10 \text{ nF}$, and $R_2 = 15.915 \text{ k}\Omega$.

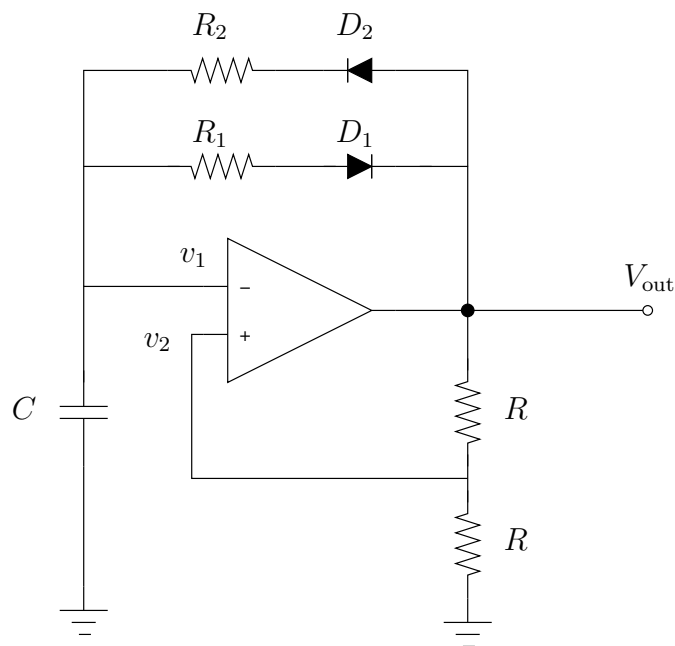


73. The output impedance of most op-amps is *extremely* low when negative feedback is used. When you tried to determine the output impedance in lab by decreasing the value of the load resistance R_L (the way you did with voltage dividers) you probably saw something go “wrong” with the sinusoidal signal output voltage v_{out} before the amplitude dropped to half of its open-circuit value. Typical inexpensive op-amp chips can supply a maximum current of approximately 25 mA, and if they are used in a way that calls for more current the output wave is distorted. (One manifestation in lab was a flat-topped sine wave that looked like clipping.) Calculate the maximum amplitude sinusoidal input that will produce a non-distorted output across a load resistor $R_L = 100 \Omega$ in the illustrated circuit. Repeat your calculation for $R_L = 1 \text{ k}\Omega$.



74. Make a qualitative sketch of v_1 , v_2 , and v_{out} vs. time for the illustrated circuit for the following two cases:

- $R_2 = 2R_1$, and
- $R_2 = R_1/2$.



75. Convert the following binary number to decimal:

$$(10110)_2 = (\underline{\hspace{2cm}})_{10}$$

76. Convert the following decimal number to binary:

$$(49)_{10} = (\underline{\hspace{2cm}})_2$$

77. Convert the following decimal number to hexadecimal:

$$(49)_{10} = (\underline{\hspace{2cm}})_{16}$$

78. Convert the following hexadecimal number (base 16) to decimal:

$$(3F2)_{16} = (\underline{\hspace{2cm}})_{10}$$

79. Convert the following decimal number to binary coded decimal (BCD):

$$(63)_{10} = (\text{_____})_{\text{BCD}}$$

80. Convert the following binary coded decimal (BCD) number to decimal:

$$(10010111)_{\text{BCD}} = (\text{_____})_{10}$$

81. Write the truth tables for the following functions of two binary variables, and sketch the standard gate symbol. (You should be able to do this without looking them up.)

(a) AND

(b) NAND

(c) OR

(d) NOR

(e) XOR

(f) XNOR

82. Draw a schematic diagram showing how you would implement the following functions using only NAND gates.

(a) $F = \overline{A}$

(b) $F = A + B$

(c) $F = A \cdot B$

(d) $F = A \cdot \overline{B} + \overline{A} \cdot B$

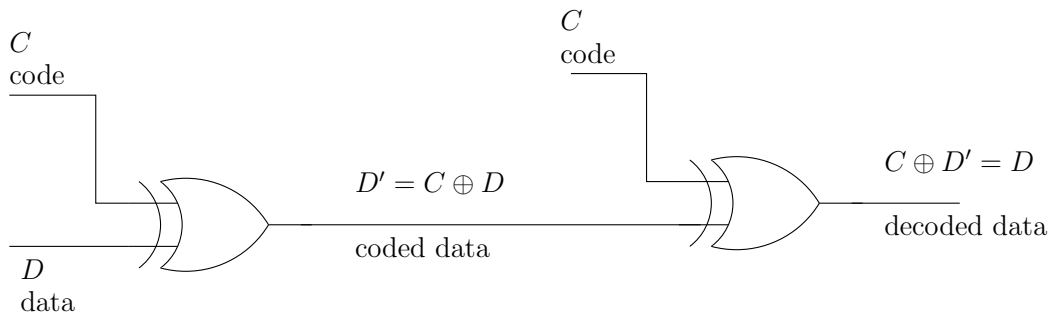
83. An XOR gate can be used to encode and decode data. Let's work through a simple example.

(a) The ASCII code (American Standard Code for Information Interchange) is a common case-sensitive *alphanumeric* code that represents letters as numbers. Find an ASCII table and translate the the word "Hi" into a decimal number and a binary number:

$$\text{Hi} \longrightarrow (\text{_____})_{10} = (\text{_____})_2$$

(b) Imagine that the binary ASCII code for "Hi" is translated into a string of pulses that are fed to the data input in the circuit below. At the same time a string of coding pulses are fed to the C input. Determine the binary number that represents the coded data D' if the code is 01110100110111.

(c) Verify that the second XOR gate returns the original message.



84. Design a flip-flop (latch) using cross-coupled NOR gates instead of the cross-coupled NAND gates you used in lab. (You should be able to do this without using any “external” resources, but if you get stuck you can look this up in your text or on-line.) Give the truth table for your flip-flop. Should your inputs be labeled (S, R) , or $(\overline{S}, \overline{R})$?