

**EE3204 D2015**  
**HW Set 3**

Due in class Friday April 3.

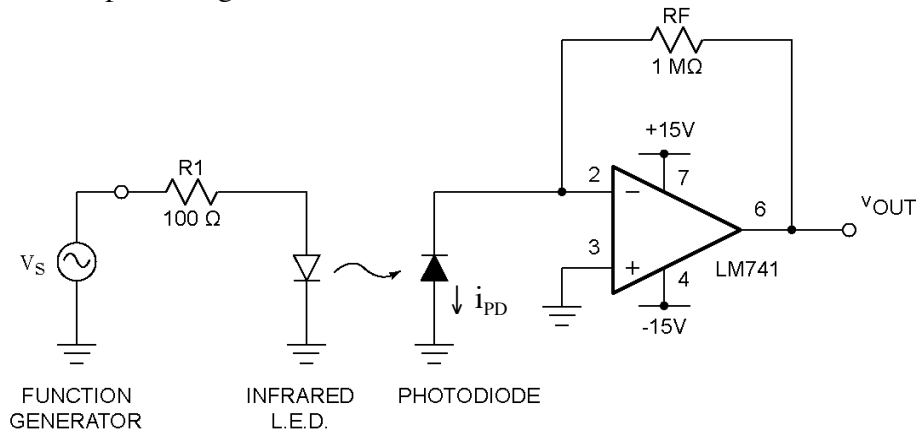
To make life easier on the graders:

- Be sure your NAME and ECE MAILBOX NUMBER are prominently displayed on the upper right of what you hand in.
- When appropriate, indicate answers with a box or underline
- Work as neatly as possible

All problems from 6th edition

1) Text 2.22 (p. 110) [Transresistance circuit]

This circuit, also called a transimpedance amplifier, is used to convert the signal current from a photodiode (for example, in the infrared transmission circuit from Lab 1, or a fiberoptic data communication system, or the read laser detection in an optical CD or DVD drive) to an output voltage.



2) [Effect of errors on transresistance circuit]

With  $R_F=1M\Omega$ , the transresistance circuit from Lab 1 (above) has an output scale factor of  $1\text{ V}/\mu\text{A}$ . If the input signal range of the photodiode current  $i_{PD}$  is 0 to  $1\mu\text{A}$ , then the signal range at  $v_{OUT}$  is 0 to 1V. Recall that the transducer model of the photodiode is a current source; for this problem you may assume it is an ideal current source.

- a) Find the error at  $v_{OUT}$  if the op-amp offset voltage  $V_{OS}$  is equal to the worst-case LM741C offset voltage error of 6 mV.
- b) Determine the maximum allowable offset error  $V_{OS(MAX)}$  so that the resulting error at  $v_{OUT}$  is no more than 0.1% of the 1V signal range at  $v_{OUT}$ .
- c) Find the error at  $v_{OUT}$  if the op-amp input bias current  $I_B$  is equal to the worst-case LM741C bias current error of 500nA.
- d) Determine the maximum allowable bias current error  $I_{B(MAX)}$  so that the resulting error at  $v_{OUT}$  is no more than 0.1% of the 1V signal range at  $v_{OUT}$ .

- 3) Text 2.36 (p. 113) [Weighted summing circuit]

See the configuration in Figure 2.10 on page 66.

- 4) [Effect of errors on weighted summing circuit]

With the circuit from the previous problem:

- a) Find the error at  $v_o$  if the op-amp offset voltage  $V_{OS}$  is equal to the worst-case LM741C offset voltage error of 6 mV.
- b) Find the error at  $v_o$  if the op-amp input bias current  $I_b$  is equal to the worst-case LM741C bias current error of 500nA.

- 5) Text \*2.78 (p. 118) [Voltage to current converters]

- 6) Text 2.94 (p. 121) [Op-amp DC errors]

- 7) Text 2.96 (p. 121) [Op-amp DC errors]

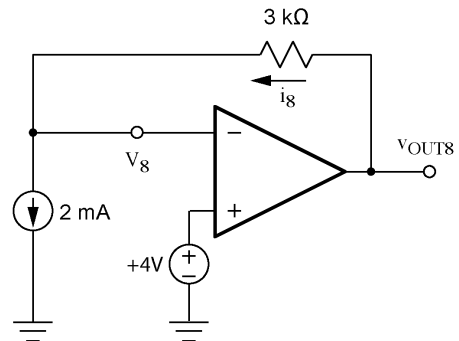
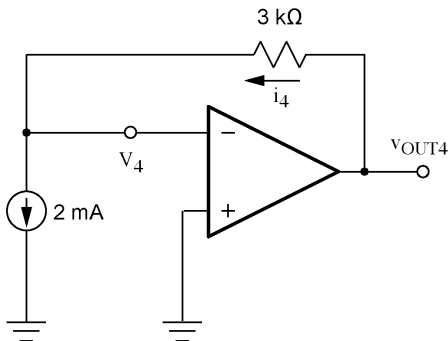
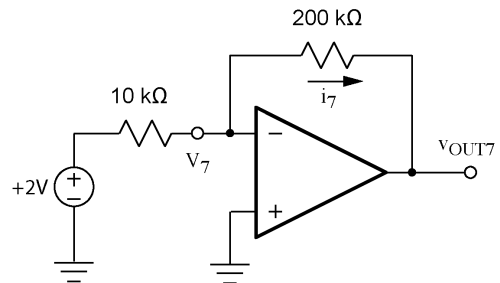
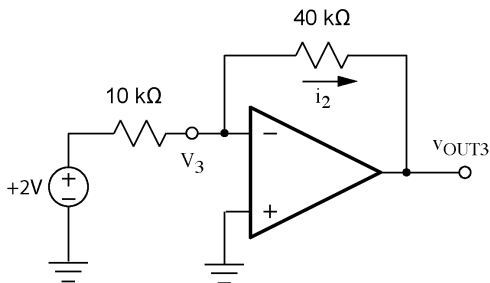
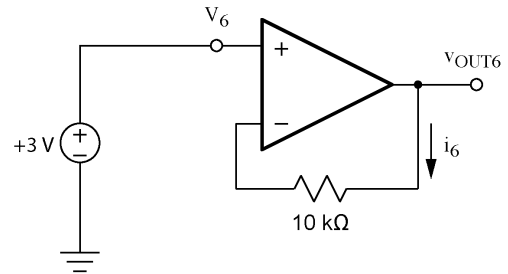
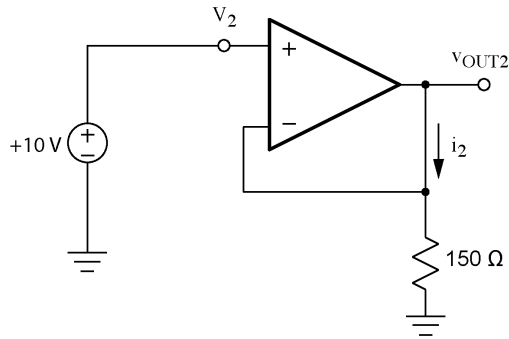
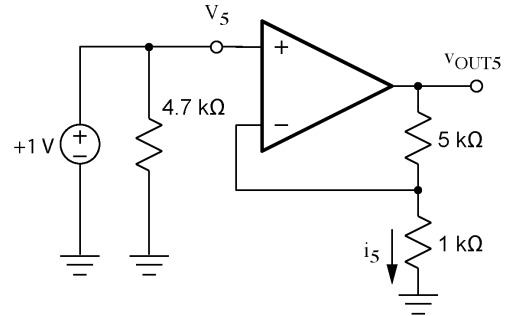
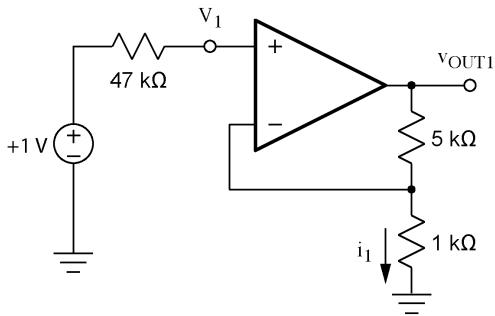
Even if the signal is AC only, the DC errors can limit the dynamic range. Although AC coupling with capacitors as shown in Fig. 2.36 helps, if the AC signal frequencies are low then the required capacitors may be large (and expensive!).

- 8) Text 2.126 (p. 123) [Slew rate limiting]

9)

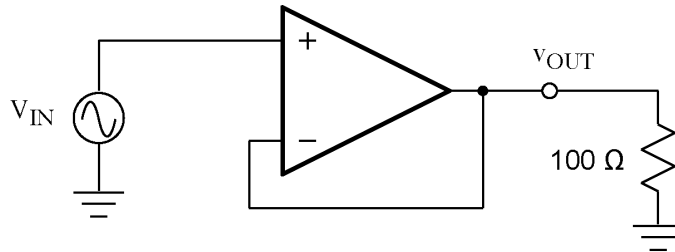
[Practice with op-amp analysis]

For each of the op-amp circuits shown below, determine the op-amp output voltage and the indicated voltage  $v_1, i_1$ , etc. Assume the op-amps to be ideal EXCEPT for output voltage limit of  $\pm 15V$  and output current limit of  $\pm 30mA$ .



10-11) {weight = 2 problems} [Op-amp selection]

In this problem, the circuit shown below is used to drive an ultrasonic transducer in a medical imaging application. The transducer is modeled as a  $100\Omega$  resistance. The input is a pure sine wave (zero DC component) which can range in frequency from 1kHz to 1MHz.



Assume the op-amp to be ideal except for the following:

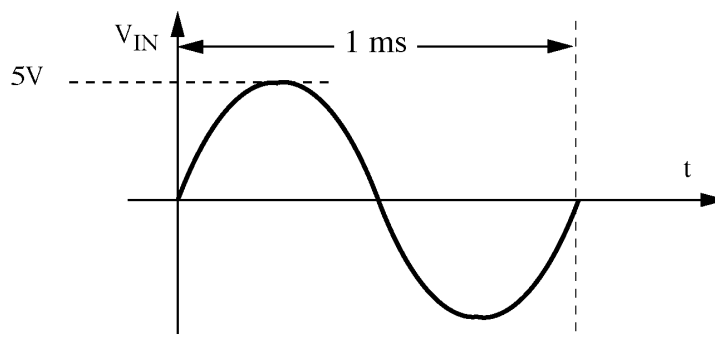
- Finite bandwidth  $f_T$
- Slew rate limiting SR
- Output current limit  $I_{OMAX}$

Performance specifications for a range of op-amps are given below:

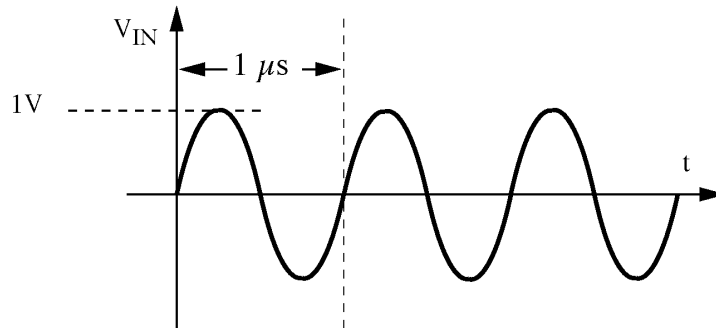
Op-amp	$f_T$	SR	$I_{OMAX}$	Cost
LM741	1.0 MHz	0.5 V / $\mu$ s	25 mA	\$ 0.47
LF356	3.5 MHz	12.0 V / $\mu$ s	30 mA	\$ 1.10
LM318	15.0 MHz	70.0 V / $\mu$ s	25 mA	\$ 2.55

For parts (a) and (b), you use the LM741 (from your lab kit) in the circuit.

- a) Given an input of a 5V peak, 1kHz sine wave: Carefully plot the resulting output voltage. Be sure to indicate any interesting values of amplitude or other waveform characteristics.



- b) Given an input of a 1V peak, 1MHz sine wave: Carefully plot the resulting output voltage. Be sure to indicate any interesting values of amplitude or other waveform characteristics.



- c) Given the choices from the table above, what is the lowest cost op-amp that would provide undistorted output waveforms for both (a) and (b)? Note: if none of the above would meet the required specifications, identify the lowest cost single (one op-amp per package) op-amp from one of the manufacturer selection guides on the course website.
- d) DC errors aren't mentioned in the problem statement, and in fact, for this kind of application, offset error and bias current error aren't really a concern. Why not? What is different about this problem vs. (for example) the gain of 500 amplifier you saw in Lab 1?

This is a nice feature of some applications: even though there are many different op-amp error specifications, it is unlikely that an application will require critical performance in all error sources.

12-13) {weight = 2 problems} [How things (don't) work]

A classic criticism of a university education is that “in the classroom, you learn how things work, but not why things don't work.” This problem is about things going wrong.

- a) In an effort to measure the bandwidth of an LM741 nonverting gain = +10 amplifier (shown on the next page), a colleague applies a 2V peak sine wave input to the circuit and records the scope waveform as shown.

Your colleague calculates the gain by taking the ratio of peak amplitudes:

$$\frac{v_{out(pk)}}{v_{in(pk)}} = \frac{14.2 V}{2.0 V} = 7.1$$

and claims that since this is  $\approx 1/\sqrt{2}$  of the maximum value of gain (10), the measurement in this scope photo can be used to determine the closed-loop bandwidth (3-dB frequency  $f_{3-dB}$ ).

Why is this incorrect? Why can't this measurement from this scope photo be used to determine the 3-dB frequency  $f_{3dB}$  (bandwidth) of the amplifier?

- b) Determine the maximum input amplitude  $v_{in(pk)MAX}$  that can be used for an accurate measurement of the closed-loop bandwidth.
- c) What do you expect for the closed-loop bandwidth  $f_{3dB}$  of the amplifier?
- d) Another colleague suggests using the bandwidth-risetime relationship:

$$\underbrace{BW}_{f_{3-dB}} \times t_r = 0.35$$

Why is this incorrect? Why can't this measurement of the risetime of  $v_{OUT}$  from this scope photo be used to determine the 3-dB frequency  $f_{3dB}$  (bandwidth) of the amplifier?

- e) Assuming a step input, determine the maximum input step amplitude  $v_{in(STEP)MAX}$  that can be used for an accurate measurement of the closed-loop bandwidth using the bandwidth-risetime relationship.

