University of Utah Electrical Engineering Department ECE 2100 Experiment No. 2 Linear Operational Amplifier Circuits II

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Minimum required points = 51 Grade base, 100% = 85 points Recommend parts should be supplemented by at least one extra part

Lab Objectives

1.) Learn about some of the limitations of op amps

2.) Work with op amps and op amp circuits.

Check out from stockroom:

- Wire kit
- Two 10x scope probes
- Other parts if and when needed, see text

Parts	Experiments
Parts from lab 1	all
TLO84 op amp (or as a second choice: LM324)	2-5
Two 0.01 μF and two 0.1 μF capacitors (values not critical)	2-5, 6
Two 1 k Ω , 3.3 k Ω , 10 k Ω , 20 k Ω , 47 k Ω , and four 100 k Ω resistors	mixed
Condenser microphone and IR emitter (May only be available for check-out)	2,4
10 k Ω trim potentiometer, single turn (trim pot) (any size from 5 k Ω to 100 k Ω will do)	3
Two 100 Ω resistors, 2N3904 and 2N3906 transistors	3
Speaker (May only be available for check-out)	3
IR phototransistor, (dark gray part) (May only be available for check-out)	4

Power supply

(3 pts) Hook up the power supply to the 741 op-amp just like you did in the last lab, in fact, if you followed the directions last time, it should still be on your proto board. As in the last lab, these power connections will not be shown in subsequent schematics, although they need to exist. Either draw the power supply connections in your lab notebook or refer back to an earlier drawing in the last lab.



Scope Probes & 10x Probe Compensation

In this lab you may want to use 10x scope probes instead of the BNC-to-clip cables (1x) that you used last time. The 10x refers to the fact that the input impedance to the scope is 10 times higher when you use a 10x scope probe. When you hook the scope directly to your circuit, the circuit "sees" a load of 1 M Ω in parallel with about 13 pF. When you use a 10x probe, the circuit will instead "see" a load of 10 M Ω in parallel with about 1.3 pF. This lessens the effect of the scope on the circuit, making your measurement more accurate. The price of this higher impedance is that the scope will only get one tenth the signal that it would with a 1x probe. You need to be aware of these tradeoffs in scope performance to get the most accurate measurements from the scope. In this lab neither the input impedance nor the signal strength will be a problem, so the only reason to use the 10x probes is that they're a little nicer to use.

There is , however, one little "gotcha" with 10x probes. Notice that I said that the scope input capacitance was "about" 13 pF? Well, each scope is a little different and the scope probe will need to be adjusted or "compensated" each time it is used with a different scope, this is especially true in our lab, where the same probes are used with the Tektronics and HP scopes. The frequency response of an uncompensated probe can seriously mess-up your measurements. You should always compensate a 10x probe before using it.

To compensate a probe:

- 3) Connect it to the scope as normal.
- 4) Switch it to 10x if it has a switch.
- 5) Determine how to adjust your probe. Most probes have a small adjustment screw somewhere on the probe. Some probes adjust by twisting some part of the probe. (In rare cases the adjustment may be located at the scope end of the probe lead.)
- 6) Find a small metal contact near the scope screen marked with a square wave, "Probe Adjust", "Cal", or something similar. This is a square wave output provided by the scope specifically for probe adjustment. Connect the probe tip to this contact.
- 7) Adjust the scope controls to get a trace. You should see a good square wave if the probe is properly compensated.
- 8) If the leading edge of the square wave is distorted (rounded or peaked), adjust the probe for the best possible square wave (squarest).

Experiment 1, Higher gain noninverting amplifier (48 points, Recommended)

At the end of the last lab you made a noninverting amplifier with a gain of 21. You also found that the corner frequency of this amplifier was about equal to the published Bandwidth of the op amp divided by 21. Now you're going to see if that pattern holds for an amplifier with a gain of 101. You'll also see a new phenomenon (slew rate) that can distort the output and limit the frequency response.



(5 pts) Increase the gain of the noninverting amplifier by

replacing the 20 k Ω R_f with a 100 k Ω resistor to change the gain to 101. Confirm this gain at a low frequency (take measurements and calculate the gain). Use a small input signal. If you can see any distortion in the output waveform, turn down the input amplitude. Also remember, if you want the scope voltage measurements to make sense, you must let the scope know if your probes are 1x or 10x (Hit **A1** and the right-most button under the

screen, repeat for A2 if necessary). It won't detect the probe type automatically.

(4 pts) Turn up the frequency until you find the -3 dB point (f_c). Again, watch for any distortion of the output waveform and turn down the input amplitude if you see any. How does your measured f_c compare to your expected f_c ($f_T/101$)? (f_T is shown as Bandwidth on the data sheet.)

(4 pts) Change the input coupling of both analog channels (A1 and A2) to AC to eliminate any DC offset in your signals and make phase measurements more accurate. Measure the phase shift at f_c . Clever use of the scope's time measurements would help here. Use the **Time Cursors** to measure the difference between the sine wave zero crossings (Δt) and the **Time Period** to measure the overall period. (Phase shift = $\Delta t/T \times 360^\circ$). A shift to the left is leading (+ angle) and a shift to the right is lagging (- angle). The math of a single-pole filter says that the phase angle of the output should be -45° at f_c . How does your measured angle compare? (If you can't measure the right phase, make sure that the scope is triggering on one channel only.)

(8 pts) Measure the gain again at $5f_c$ and then measure both the gain and phase shift again at $10f_c$. Did the gain should decrease by a factor of 2 between $5f_c$ and $10f_c$ (-20dB per decade roll-off)? Is the phase shift nearly -90° at $10f_c$? These are the theoretically expected results.

Slew rate

(8 pts)Change the frequency to about 100 kHz and the input voltage to about 0.8 Vpp (shown as 400 mVpp on the HP). Notice that the output signal looks triangular. The op amp simply can't change its output voltage fast enough to keep up with the input. The straight ramp in the output indicates that the op amp is changing its output as fast as it can (*slewing*). The slope of that ramp is its *slew rate*. Sketch this waveform in your notebook and indicate the slewing on the drawing. Measure this slope. (Measure only the straight part of the line--don't include the rounded tops and bottoms where the op amp isn't slewing.). Use the time cursors and the volts / div marks on the scope to help you. (Make certain that the scope "knows" that you're using 10x probes). Calculate your slew rate as volts/µs. Find the slew rate on a data sheet and compare it to your measured slew rate. Note: Your measured value may be higher than that shown in the data sheet, and the part would still be within spec.

(6 pts) Turn down the frequency until you no longer see the slew rate distortion. Try to find the highest frequency with no distortion (f_{max}). Measure the output voltage (V_{pp}). Measure the frequency and compare to the theoretical maximum distortionless frequency ($f_{max} = SR/\pi V_{pp}$). Because the op amp has a limited slew rate, there will be a trade-off between maximum output voltage and maximum frequency. If you want a larger output voltage swing without the slew rate distortion (output triangular) then you'll have to limit the input frequency. If you want to handle higher frequencies, then you'll have to limit the output voltage swing. The slew rate makes you choose.

Clipping (saturation)

(7 pts) Change the input coupling of both analog channels (**A1** and **A2**) back to **DC**. Turn down the input frequency to about 1 kHz. Turn up the input voltage until the output clips

both top and bottom (tops and bottoms of the output waveform are cut off) Sketch this waveform in your notebook, and indicate the clipping on the drawing. Measure both clipping levels as L- and L+ (see textbook, p. 15). Find the output limits on a data sheet and compare them to your measurements. (Look for "Output Voltage Swing" for $V_s = \pm 15V$ and RL > 10 k Ω .)

(6 pts) Remember to write some conclusion to this part of the experiment. You should say something about frequency response vs gain, phase angles, slew, & clipping.

Note Concerning Experiments 2 - 7:

None of the these experiments are recommended, but you will still have to do at least one to get a reasonable number of points in this lab. Please don't try them all, there are too many. Experiments 2 - 5, below, are related to each other.

- 2, Microphone amp
- 3, Speaker amp
- 4, Infrared transmitter
- 5, Infrared receiver

I suggest you collaborate with another team. One team builds the microphone amp and

the other builds the speaker amp. Then you can hook your two circuits together with a wire to make a whole system and test both circuits. The microphone team could then continue by constructing the IR transmitter and the speaker team could build the IR receiver to make an IR audio link. If you can't find another team to collaborate with, I suggest you make the microphone amp and/or the speaker amp, although any circuit could be tested on its own except the IR transmitter. I further suggest that you use TLO84 or LF353 op amps, these op amps are better than the 741 and they contain more than one op amp per package. The pin-outs are shown at right.

Experiment 2, Microphone amplifier (12 points,

up to 20 if tested with speaker amp.) (3 pts) Construct the circuit shown at right.

(7 pts) Test the circuit, preferably by hooking it to a copy of the speaker amplifier which is the following circuit. If that is not possible, observe the output with the scope. Demonstrate your working circuit to your lab TA in order to get credit.

If you are hooked to a speaker amplifier, even if it's someone else's, you may conduct the "Feedback" and/or "Volume control" sections of experiment 3 for the points listed there.

(2 pts) As always, conclude.

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Experiment 3, Speaker amplifier (20 points)

(5 pts) Construct the circuit shown at right. The drawing below shows a suggested method of hooking up the transistors. The transistors are used to provide extra current amplification needed to drive the speaker.





The part shown between the input and the op amp is a potentiometer, used as a volume control in this case. Describe in your notebook how the volume control works.

(7 pts) Test the circuit, preferably by hooking it to a copy of the microphone

amplifier shown previously. If that is not possible, input signals from the HP function generator. Demonstrate your working circuit to your lab TA in order to get credit.

Feedback

(4 pts) This section can only tried in if your circuit is hooked to a microphone circuit. Turn up the volume and bring the speaker and mic close enough to one another that the circuit begins to squeal on its own. What is causing this sound? Perform some experimentation and list a couple of things you can do stop feedback.

Volume control

(4 pts) The pot that you're using for a volume control is linear, but your hearing is not. With a relatively constant level of input, turn the volume control up and down. Does the response seem linear to you? That is, when the volume control is half-way up, does the output sound half as loud? At what setting of the control does the output sound half as loud?

Potentiometers

To adjust the volume, you'll use an adjustable resistor called a *potentiometer*. (The name comes from its old-time use in voltage measurements.) All potentiometers (pots) and volume controls work in a similar manner, with a moveable slider or "wiper" that makes contact with a resistor

somewhere between its two ends. A rotary potentiometer is shown here, first in its package, then as bare workings, and finally as a schematic symbol. The resistance of a pot is the full resistance between the two outside terminals and is usually written on the part somewhere.



Almost every time you turn a knob on a stereo, TV, or instrument in the lab, you are turning a potentiometer.

The resistor in a potentiometer can have a linear or an audio "taper". Audio taper potentiometers are used as volume controls in audio circuits. Your hearing does not respond linearly to changes in loudness, so the resistor in a volume control should be ponlinear to compensate.

Experiment 4, Infrared transmitter (12

points)

This circuit should only be made if you are collaborating with another team who are making the IR receiver.

(3 pts) Construct the circuit shown at right.

(7 pts) Test the circuit, preferably by hooking it to a copy of the microphone amplifier shown previously. If that is not possible, input signals from the HP function generator. You will need to aim your LED at an IR receiver (next circuit). At that end, a speaker amp or a scope can show if the circuit is actually working properly. Demonstrate your working circuit to your lab TA in order to get credit.

Ma

+

'R₁

1kΩ

-15V

IR LED

Experiment 5, Infrared receiver (12

points)

(3 pts) Construct the circuit shown at right.

(7 pts) Test the circuit, preferably by hooking it to a copy of the speaker amplifier. If that is not possible, observe the output with the scope. Use an IR transmitter like that shown above or an infrared remote control to demonstrate your working circuit to your lab TA in order to get credit.

Note About Experiments 6 & 7

These two experiments are provided primarily so that you may ignore them. You should probably only consider these if you did not have the opportunity to do any of the experiments 2 - 5.

Experiment 6, Inverting amplifier (8 points)

Make the inverting amplifier shown. At a low frequency, confirm the expected gain of this amplifier (20). Also note the inversion.



Light

Diode

LED

Emitting

cathode



Experiment 7, Miller Integrator (14 points) Now comes Miller time. An integrator performs a mathematical integration of the input waveform. A true integrator is unstable because even the slightest DC at the input would drive the output into saturation. The R_f is added in parallel with the capacitor to limit this effect. With the R_f in place the circuit is known as a *running average* integrator or a *Miller* integrator.



(6 pts) Make the integrator shown. Set the v_{in} frequency at 2 kHz. Measure the phase shift. Accounting for the inversion of the signal, is this the phase shift expected of an integrator (inversion: 180°, integration: -90°)?

(4 pts) Change the input to a 500 Hz square wave. Sketch the shape of the output waveform. It's not quite triangular, is it? Why? With the circuit still running, and as you observe the output, remove R_f . Note that the output does become straight-lined triangle wave, and that it quickly drifts up or down the screen. Try replacing and removing R_f several times.

(2 pts) If you want to, play with the offset of the function generator to see if you can bring the output back to center by adding a little DC to the input. This will probably take less than 1 mV of DC offset, which is rather tricky to get on the HP. Set the offset to 0.001 V and then push the > button until you change the VDC to mVDC. Now you can adjust to a lower offset. Actually, this isn't very important and you may skip it, but it is kind of fun to play with. Comment in notebook.

