# PHY 305F – ELECTRONICS LABORATORY I
## Fall Semester 2003

## EXPERIMENT 5
## OPERATIONAL AMPLIFIERS
## Lab notebook is due at 1 PM in MP238 on November 17

LEARNING OBJECTIVES:

(1) To become familiar with the basic properties of op-amps, including imperfections such as frequency limitations, phase shifts, maximum signal swing limitations, slew rate, offset voltages and currents, noise, and drift.

(2) To gain practice in wiring chips into circuits.

(3) To learn how op-amps perform in three basic configurations: inverting, non-inverting, and integrating.

REFERENCES:

R.E. Simpson, Introductory Electronics for Scientists and Engineers, 2nd Edition, Chapters 9 & 10.

A.J. Diefenderfer and B.E. Holton, Principles of Electronic Instrumentation, 3rd Edition, Chapter 9.

P. Horowitz and W. Hill, The Art of Electronics, 2nd Edition, Chapter 4.

L.R. Fortney, Principles of Electronics, Analogue and Digital, Chapter 8.

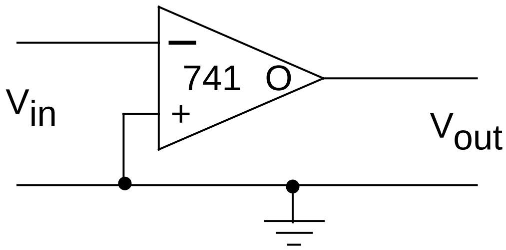
S.D. Senturia and B.D. Wedlock, Electronic Circuits and Applications, Chapters 4 & 5.

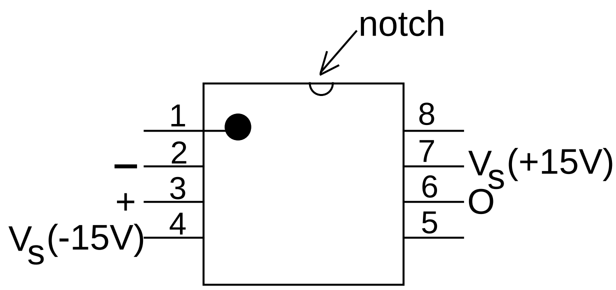
D.V. Bugg, Electronics: Circuits, Amplifiers, and Gates, Chapters 7 & 8.

G. Rizzoni, Principles and Applications of Electrical Engineering, 3rd Edition, Chapter 12.

WHAT TO DO:

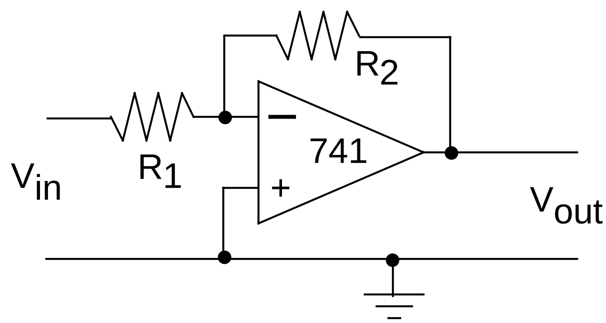
(1) Op-amps are always use with feedback and never in open loop. This exercise illustrates why. Investigate quickly (10 minutes) and qualitatively the open loop characteristics of the 741 op-amp, using a very small DC signal on the input and a CRO to measure the input and output signals. Connect the op-amp as shown in the figure below. There are five pins on the 741 which require connections. These are $V_s$(+15V), $V_s$(-15V), – (input), + (input), and O (output). For this part, do not connect anything to the other pins. In particular, note the extremely high gain, the susceptibility to noise and drift, and the saturation of output signal at levels slightly lower in magnitude than the power supply voltages. You will find the op-amp unusable this way. Comment on why op-amps are not used in open loop configurations. Estimate a lower limit on the open loop gain.



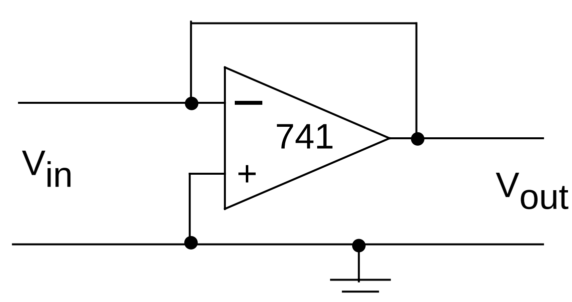

TOP VIEW OF 741

(2) Set up the 741 op-amp in a simple voltage-derived shunt-fed feedback configuration as shown in the figure at right. Use $R_1 = R_2$ = approximately 10 kΩ. Measure the gain of the circuit at DC and at several AC frequencies less than 5 kHz. Compare your results with the gain that you calculate for this circuit.




(3) Set up the amplifier, using the configuration of part 2, for a gain of 100. (Set $R_1 \approx 1$ kΩ and calculate $R_2$.) For as large an <u>undistorted</u> voltage as possible, plot the gain as a function of frequency from 10 Hz to 2 MHz on a <u>log-log</u> graph with about three points per decade. Also, indicate on the graph the value of the DC gain. (*As a reminder, you should be sketching your graphs while making your measurements to check your results as you proceed.*) Note that there may be noise apparent in your output signal which should affect your error estimates. Repeat these measurements and plots for a gain of 5, keeping $R_2$ unchanged. Note the trend of the phase difference between the output and input signals for the above curves in the two regions: *gain constant* and *gain decreasing* as a function of frequency. Show that the product of the DC gain and the bandwidth is approximately constant for the above two gains. (Bandwidth, here, may be defined as the frequency at which the gain has a value of $1/\sqrt{2}$ of its DC value.)

(4) Qualitatively observe that the unity gain amplifier (voltage-derived, series-fed feedback configuration) shown in the figure at right, has in fact, a gain of +1. Measure the DC output of the unity gain amplifier with the input connected to ground. Measure the output again with a resistor of approximately 1MΩ connected across the input. Hence deduce approximate values for both the input offset voltage and the input bias current. Compare your results to the data sheets.

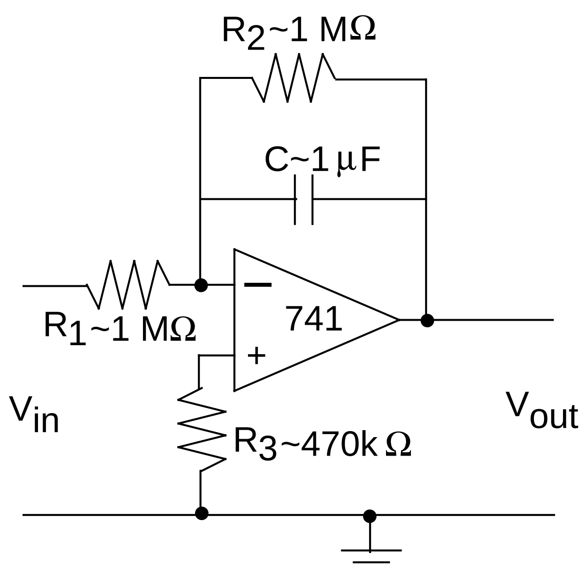


(5) With the amplifier of part 2 set for a gain of 10, find the maximum undistorted sine wave output at 100 Hz, 10 kHz, and 100 kHz. Record the form of the first visible distortion. The amplifier output can change its voltage only at a certain maximum rate, called the slew rate, i.e.,

$$\frac{dv_o}{dt} \leq \text{slew rate}.$$

From your observations, find the slew rate and verify that it is independent of frequency and amplitude of the input signal. (Note: A square wave also particularly demonstrates the slew rate.)

(6) Set up the integrator circuit shown in the figure below. Plot the frequency response on a log-log graph in the range of 3 Hz to 1 kHz (pure sine wave). Note the phase relation between the output and input signals. Observe the output signal for square and triangular wave shapes on the input. With the input voltage = 0, verify the cancellation of the input bias current by looking at the effect of shorting $R_3$. Remove the feedback capacitor shunt resistor $R_2$, and find the rate of change of the output voltage with the input voltage = 0, and then with the input voltage set to several small negative and positive values. Can you interpret quantitatively what you see? (If, with $R_2$ removed, the output voltage swings to saturation, the circuit may be put back into operation by a momentary shorting of the feedback capacitor C.)




COMMENTS:

(1) If at all possible, use the same 741 chip for all parts of the experiment.

(2) In using the CRO to measure both input and output voltages of the op-amp configuration, with the input derived from the Wavetek Function Generator, it is most convenient to use the CRO on external trigger, and to derive the external trigger pulse from the pulse output on the Wavetek.

(3) In making measurements of input and output voltages on the op-amp, you will have to decide which of the CRO and/or your two voltmeters is the appropriate instrument to use in each case.

(4) At each step in the experiment, be sure that you understand what you see, and explain in your lab notebook how the circuits are operating.