

ESE 206: Electrical Circuits and Systems II - Lab

"REAL" OPERATIONAL AMPLIFIER OPERATION

I. Purpose:

The objective of this Experiment is two-fold: First it is to familiarize the student with important ways in which practical op-amp circuits depart from the ideal op-amp model. Second, is to explore, selectively, ways to compensate for some of the imperfections in applications such as the Miller integrator.

II. Components and Equipment:

- 1 - Digital Multimeter
- 1 - two-channel oscilloscope with x10 probes
- 1 - waveform generator
- 1 - 741-type op-amp, provided in the 8 pin dual in-line (DIP) package shown in Figure 1.
- 1 - Two power supplies at + 10 V and - 10 V.
- 2 - each 1 k Ω , 10 k Ω , 1 M Ω resistors.
- 1 - 5 k Ω potentiometer.
- 1- 100 nF capacitor.
- 2 - 10 μ F capacitors for power supply bypassing (i.e. connected each between pin 4 and ground and pin 7 and ground, respectively).

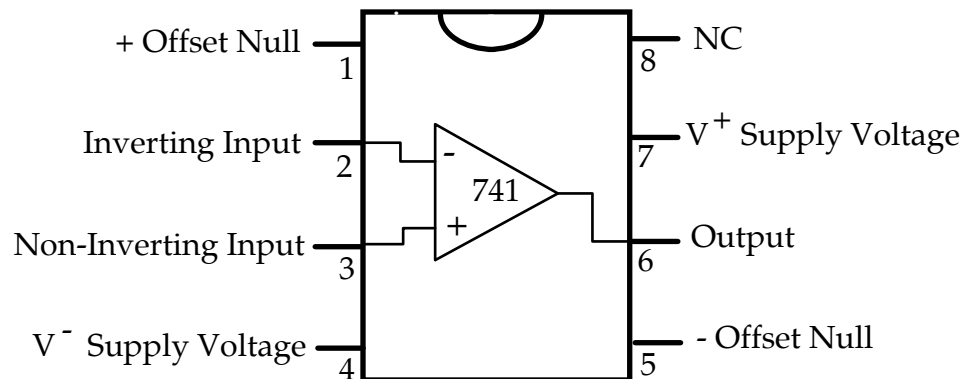


Figure 1 LM 741 Op-amp Dual In-line Package Pin Connections

III. Prelab Assignment:

1. Read Sections on “Integrators,” “Finite Gain and Bandwidth” (section 2.5 and 2.6 - particularly 2.5.2 and 2.6.3), “DC imperfections” and “Large Signal Operation” (sections 2.7 and 2.8) of the Sedra & Smith (5th Edition) text.

2. Voltage and current offset measurement:

A particular op-amp has $V_{OS} = 1 \text{ mV}$, $I_B = 80 \text{ nA}$, and $I_{OS} = 20 \text{ nA}$, with reference polarities as defined in Fig. 2.33 and Fig. 2.34 of the Sedra & Smith text (5th Edition). Although the polarity of I_{OS} is not defined, for the pre-lab you can assume that the current flowing into the inverting terminal is larger than the one flowing into the non-inverting terminal. This op-amp is to be tested using the configuration in Fig. 2. Determine the values of v_C (voltage at node C) that are observed under the following conditions (you can use superposition to calculate the overall effect of offset voltage and current):

- with $R_1 = \text{infinite}$, $R_2 = R_3 = 1 \text{ M}\Omega$;
- with $R_1 = \text{infinite}$, $R_2 = 1 \text{ M}\Omega$, $R_3 = 0 \Omega$;
- with $R_1 = 1\text{k}\Omega$, $R_2 = 1 \text{ M}\Omega$, $R_3 = 0 \Omega$.

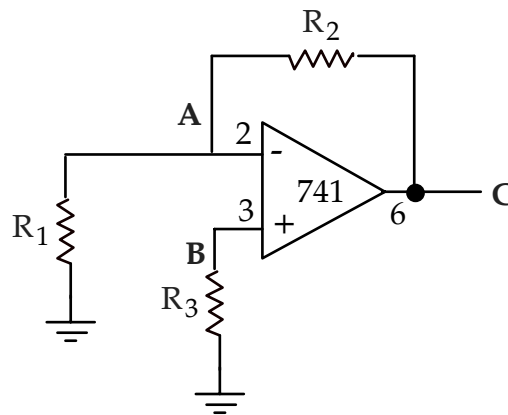


Figure 2 Circuit for the Measurement of Offsets

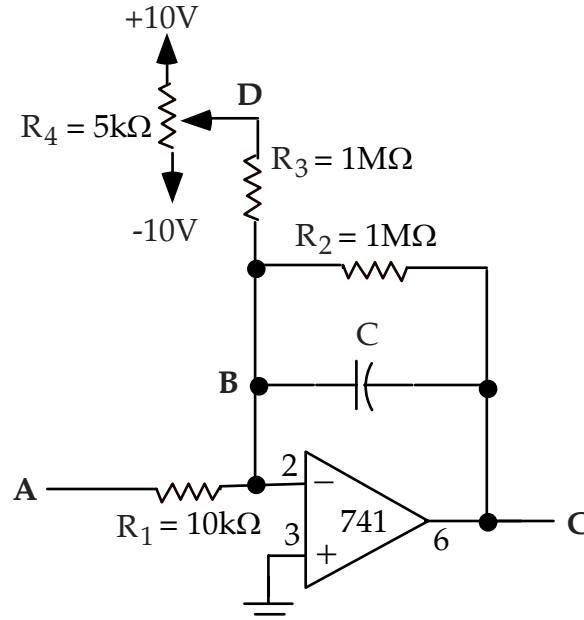


Figure 3 Miller Integrator with DC feedback and Offset Control

3. Integrator Offset Control:

Using the op amp offsets $V_{OS} = 1 \text{ mV}$, $I_B = 80 \text{ nA}$, and $I_{OS} = 20 \text{ nA}$ for the Miller integrator circuit in Fig. 3, find the value of v_D that forces $v_C = 0$ when $v_A = 0$. Assume that the negative input has the higher inward-directed biasing current.

4. Integrator Operation:

(a) The output $v_C(t)$ of the Miller integrator in Fig. 4a, with $C = 100 \text{ nF}$ capacitor, is observed in Fig. 4b to change linearly from an initial (rest) state of -3 V at time $= 0 \text{ s}$, to a final state of $+8 \text{ V}$, time $= 1000 \mu\text{s}$ (or 1 ms). Describe the input signal $v_A(t)$ that will produce this output (assume that $v_C = 0$ when $v_A = 0$, i.e. the op amp is free of DC offset). You can ignore feedback resistor R_2 for all frequencies higher than 0 Hz (i.e. $\omega CR_2 \gg 1$ or $R_2 \gg$ the impedance associated with the capacitor C in the region between 0 and 1 ms)

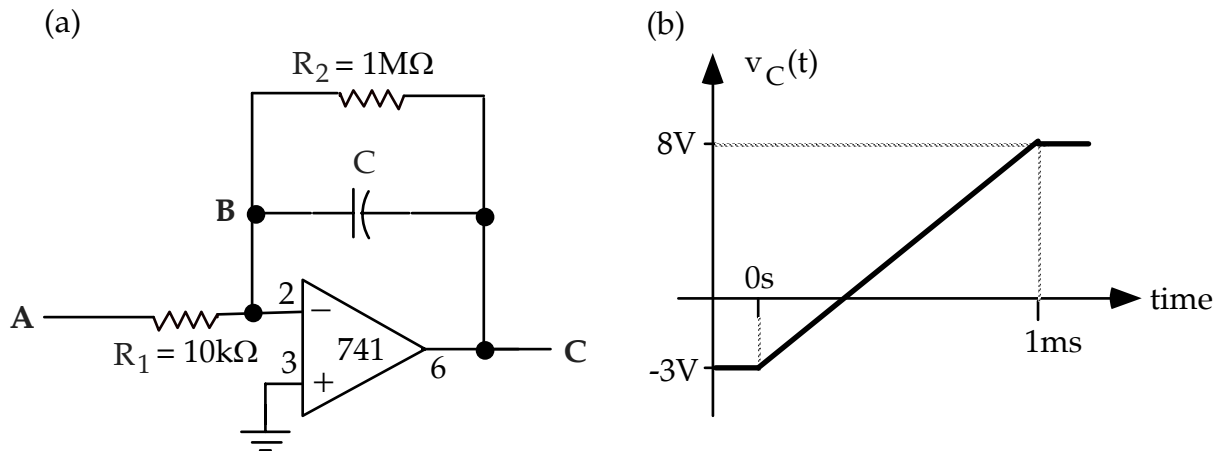


Figure 4 (a) Miller Integrator and (b) output waveform $v_C(t)$ for Pre-lab part 4.

5. Small-Signal Frequency Response:

A single pole inverting amplifier with a nominal closed-loop gain of 100 V/V has a 3 dB cutoff at 12.7 kHz . What is the unity gain frequency?

6. Slew-Rate Limiting:

- (a) An op-amp has a 5-V full power bandwidth of 100 kHz . What is its slew rate?
- (b) An op-amp has a 5-V full power bandwidth of 100 kHz . What is the highest frequency at which a 2 V peak symmetrical sinusoidal wave can be reproduced without slew distortion?

IV. Experimental Procedure:

1. Offset Measurement:

Goal: To investigate a simple approach to finding bias current, offset current, and offset voltage by indirect measurement using your DVM.

Build the circuit of Figure 2, with ± 10 V supplies, including the two bypass capacitors of 10 μ F. Using this circuit, measure the voltage v_C for the following conditions:

- a) with $R_1 = \text{infinite}$, $R_2 = R_3 = 1 \text{ M}\Omega$;
- b) with $R_1 = \text{infinite}$, $R_2 = 1 \text{ M}\Omega$, $R_3 = 0 \Omega$;
- c) with $R_1 = 1\text{k}\Omega$, $R_2 = 1 \text{ M}\Omega$, $R_3 = 0 \Omega$.

The offset voltage is typically around 1 to 2 mV so that some of the measured values will be very small. Measuring small signals in the millivolt range is not easy. It should also be mentioned that the actual values of the offset voltage and offset current will most likely be different from the ones mentioned in the pre-lab. The datasheet of the opamp usually give the maximum and minimum values so that any value between these two extremes are possible.

Record your data for these three conditions in a table with headings V_C , R_1 , R_2 , R_3 . Later (when writing your report) use the three measurements to find the offset voltage V_{OS} , I_{B1} and I_{B2} or (I_{OS} and I_B). Compare the measured values with the ones given in the [datasheet](#).

2. Integrator Offset Control:

Goal: To explore a practical way to compensate for the offset of an integrator circuit.

Assemble the circuit in Fig. 3 using ± 10 V supplies and $R_1 = 10 \text{ k}\Omega$, $R_2 = 1 \text{ M}\Omega$, $R_3 = 1 \text{ M}\Omega$, $R_4 = 5\text{k}\Omega$ and $C = 0.1\mu\text{F}$. Also include the bypass capacitors for the power supplies.

Using the DMM:

With node A connected to ground, and measuring v_C , adjust R_4 to force v_C to 0 V. Measure the corresponding value of v_D .

3. Miller Integrator Operation:

Goal: To illustrate the response of the Miller integrator to square and sinusoidal input waveforms.

Use the circuit in Fig. 3 with compensation R_4 adjusted to make $V_C = 0$ V. Connect a function generator to the input terminal A.

Use the dual-channel oscilloscope with external triggering for the following measurements.

- a) Adjust the generator to provide a 1 kHz symmetric square wave at input v_A with an amplitude of $1V_{pp}$ and zero offset. Using your oscilloscope monitor the waveforms v_A and

v_C . It may be necessary to fine adjust the voltage V_D to keep the output voltage symmetrical around the 0V (i.e. without offset voltage). Sketch the input and output waveforms, noting peak amplitudes and zero crossing times.

- b) Switch the generator to provide a 1 kHz sine wave at input v_A with an amplitude of $1V_{pp}$. Sketch the input and output waveforms, noting the peak amplitudes and zero crossing times.
- d) Find the frequencies at which voltage transfer function $|V_C / V_A| = 0.1$ and 10.0 . You may want to adjust the input signal level to make the display more convenient while maintaining an undistorted sine wave output.

In your report provide a Bode (magnitude) plot for the integrator you evaluated above.

4. Small-Signal Frequency Response:

Goal: To explore the small-signal frequency effects in an inverting op-amp circuit.

Assemble the circuit in Figure 5 using ± 10 V supplies. Initially set the function generator to provide a 100 Hz sine wave.

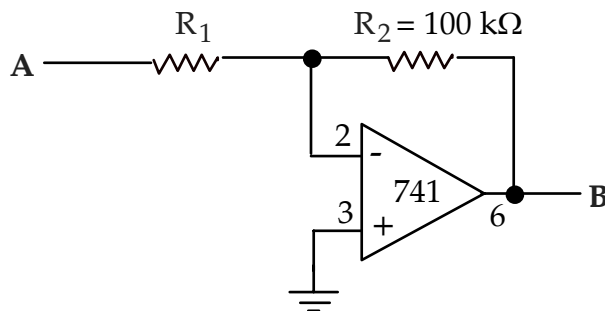


Figure 5 High-Gain Inverting Amplifier for Frequency Response Measurement

- a) Insert a 10 kΩ resistor for R_1 and, while observing the input v_A , adjust the function generator amplitude to provide a peak **output** (amplitude) at V_B of **1.0 V** at 100 Hz (or 2.0 V peak-to-peak at 100 Hz). Measure and record the voltage peak amplitudes v_A and v_B and compute the closed-loop gain v_B/v_A (please note the sign reversal between the input and output). Does the measured gain correspond to the calculated one of $-R_2/R_1$?
- b) Raise the frequency of the function generator to the value at which v_B is reduced by 3dB (i.e. to $1/\sqrt{2} = 0.707$ of its peak value at 100 Hz). Record the frequency as f_1 . [You may need to adjust the input signal level to maintain an undistorted sine wave output.]
- c) Raise the frequency of the function generator to the value at which v_B is reduced to $v_B = v_A$. Record the frequency as f_2 . You may need to adjust the input signal level to maintain an undistorted sine wave output.]

d) Change resistor R_1 to 50 k Ω and repeat a), b).

Tabulate the data in a) through d) , i.e. for each of value of R_1 , record R_2/R_1 , f_1 and f_2 . Also record in tables for each value of R_1 the measured values for v_A , v_B and v_B/v_A at 100 Hz, at f_1 and at f_2 .

In your report consider the relationship between closed-loop gain and 3dB bandwidth of the inverting amplifier. [Hint: Review the section (2.5) of frequency response of the Sedra & Smith text.] What is the upper 3dB frequency of each of the amplifiers tested? What is their Gain-Bandwidth Product for the op-amp? Estimate the unity-gain frequency of the open-loop op-amp. Sketch a Bode magnitude plot for both the open-loop and closed-loop these amplifiers.

5. Slew-Rate Limiting

Goal: To explore the slew rate-limited behavior of an op-amp output for large signals.

Assemble the circuit shown in Fig. 6.

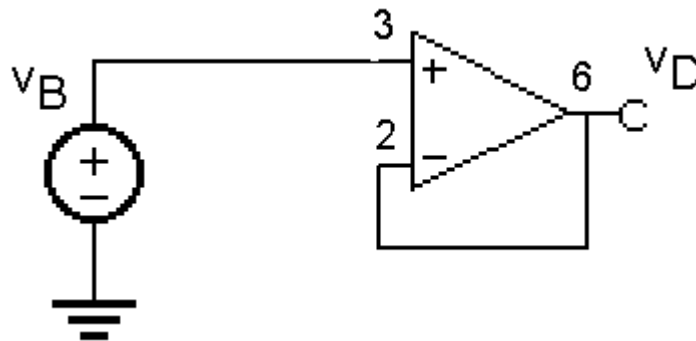


Figure 6: Circuit for Evaluating the Slew Rate and its effect on the output.

- Apply a **square wave** input voltage with peak amplitude of 10 V_{pp} (i.e. -5V to +5V) and frequency of 1 kHz. Observe the output voltage. Does the Op-amp slew? If so, measure the slew rate (in V/s).
- Next, apply a 1 kHz **sine wave** input at B, i.e. v_B , and adjust the input signal amplitude v_B until the v_D waveform begins to clip. Reduce the input amplitude slightly to eliminate the clipping. Note the peak amplitude for v_D .
- Keeping v_B fixed and observing v_D , increase the frequency of v_B until the v_D waveform begins to show visible distortion. Note this frequency as f_3 . Sketch the observed output waveform v_D . What is the full-power bandwidth?
- Keeping the input frequency at f_3 , lower amplitude of v_B to half its value in c). Sketch the observed output waveform v_D . Compare this waveform with that observed in c).
- Keeping v_B as in d), increase the frequency of v_B until the v_D waveform begins to show some distortion. Note this frequency as f_4 . Sketch the observed output waveform v_D .

Record the values for the peak amplitudes of v_B or v_D at each f (i.e. at 1 kHz, f_3 , f_4), from the measurements obtained in b) through e) above.

- f) In your report calculate the full-power bandwidth of the op-amp (see section c) and use the data collected in section c) to estimate the slew rate (SR). Compare the calculated slew rate (in section c) with the measured value of the slew rate in section a).

Also, summarize the results of your measurements in terms of the unity gain bandwidth, offset voltage, offset current, bias currents, and slew rate. How do your measured values compare with those listed in the datasheet for the 741 OpAmp? (datasheet: see e.g. <https://www.seas.upenn.edu/~ese216/handouts/LM741DataSheet.pdf>).

Remember datasheets give only the maximum or minimum values for the op-amp specifications. Your measured values should be within the limits (max) specified in the datasheet.

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Updated by J. Van der Spiegel, March 2, 2007.