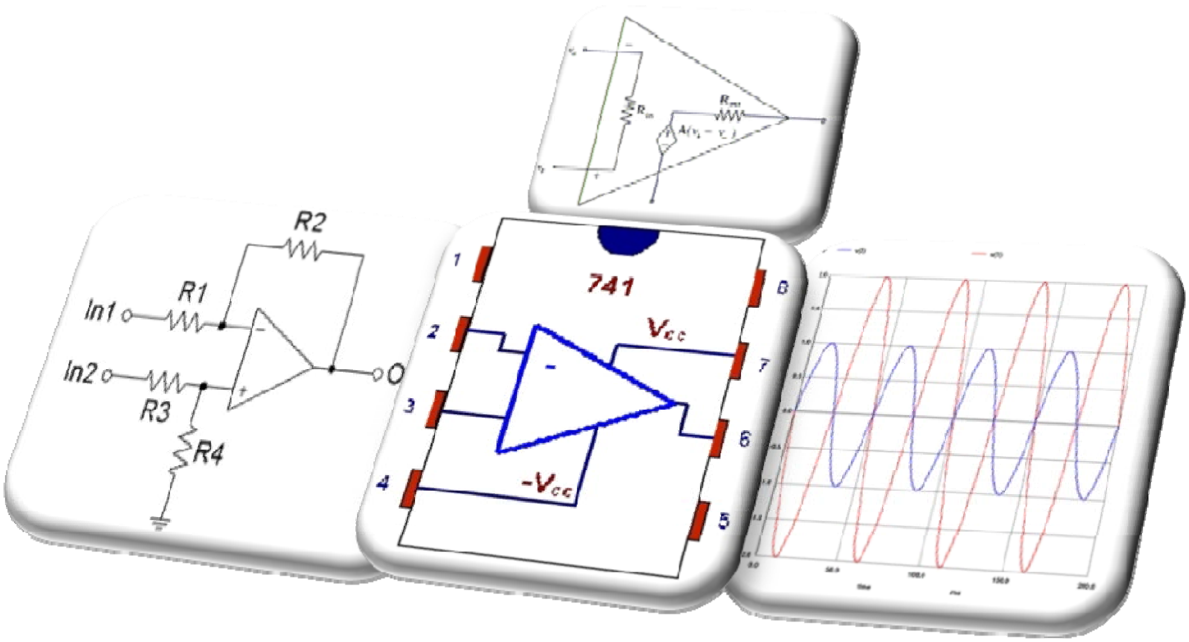
Fall | 2011

Experiment 8

Op-Amp Circuits



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I. OBJECTIVES

In this experiment you will investigate the characteristics of the following op-amp circuits:

- inverting amplifier
- non-inverting amplifier
- unit-gain buffer
- inverting adder
- integrator
- differentiator

II. MATERIAL AND PROCEDURE

A. INVERTING AMPLIFIER

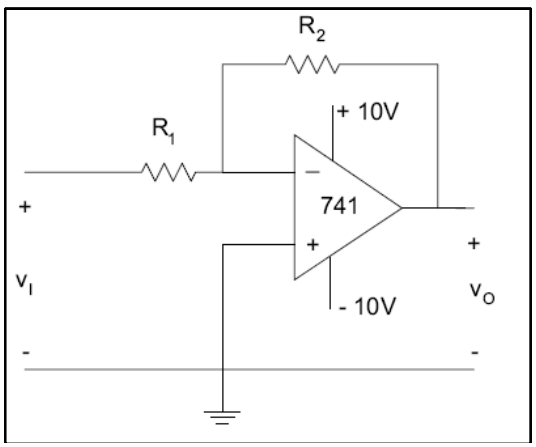

Figure A-1: Inverting Amplifier

The inverting amplifier is the most popular op-amp circuit (figure A-1). The basic disadvantage of this circuit is that its input impedance is low (equal to the value of R1 in the circuit shown above.)

- Why is a low input impedance considered a disadvantage?
- Prove theoretically that for an ideal op-amp, $v_0 = -\frac{R_2}{R_1}v_1$

A1. INVERTING AMPLIFIER PROCEDURE 1: THEORETICAL VS MEASURED

Verify this expression experimentally: Use a 1000 Hz sinusoidal input voltage with 200 mV peak-to-peak. Complete Table A-1, and verify that $v_0 = -\frac{R_2}{R_1}v_1$

R_1 (kΩ) / measured	R_2 (kΩ) / measured	v_0 pk-pk (theoretical) in V	v_0 pk-pk (measured) in V	v_0 phase angle in degrees
1 /	10 /			
2.2 /	10 /			
4.7 /	10 /			
2.2 /	22 /			
4.7 /	22 /			
10 /	22 /			

Table A-1: Theoretical and Measured value of inverting amplifier

Exercise
- Refer to in-lab 8 exercise A-1

A2. INVERTING AMPLIFIER PROCEDURE 2: BANDWIDTH

Determine the bandwidth of the inverting op-amp. The bandwidth in this case is equal to the frequency at which the magnitude of the gain drops to of its low frequency value (which, theoretically, is R2/R1.)

- For R1 = 1 KΩ and R2 = 10 KΩ, measure the output when the input is a 200 mV peak-to-peak sinusoidal with variable frequency. Increase the frequency starting from 1000 Hz until the gain drops to 0.7071 times its ***measured*** low frequency value. Note the value of this frequency.
- Repeat the bandwidth measurement for R1 = 10 KΩ and R2 = 22 KΩ, and for R1 = 2.2 KΩ and R2 = 10 KΩ.
- Can you find a relationship between low-frequency gain and bandwidth?

Exercise
- Refer to in-lab 8 exercise A-2

A3. INVERTING AMPLIFIER PROCEDURE 3: HIGH INPUT

Use a 1000 Hz sinusoidal input voltage with 3 V peak-to-peak. Measure the output voltage and the phase angle. Comment on the result.

Exercise
- Refer to in-lab 8 exercise A-3

B. NON-INVERTING AMPLIFIER

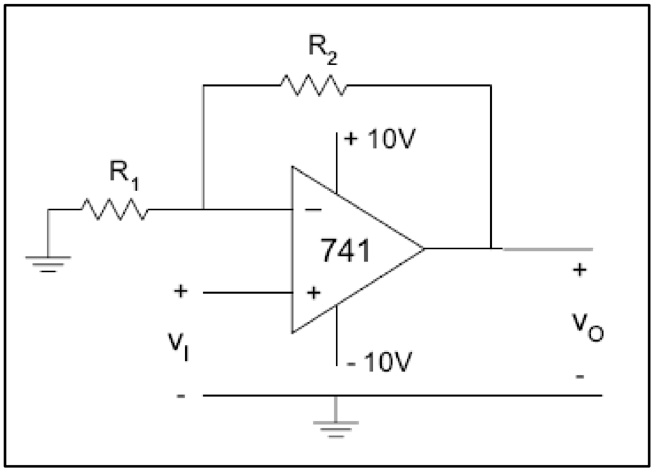

Figure B-1: Non-Inverting Amplifier

The non-inverting amplifier is the second most popular op-amp circuit (figure B-1). It offers an advantage over the inverting configuration in that the input impedance is that of the op-amp itself (which, ideally, is *infinite*) rather than R1.

- Prove theoretically that for an ideal op-amp, $v_0 = (1 + \frac{R_2}{R_1})\, v_1$.

B1. NON-INVERTING AMPLIFIER PROCEDURE 1: THEORETICAL VS MEASURED

Verify this expression experimentally: Use a 1000 Hz sinusoidal input voltage with 200 mV peak-to-peak. Complete Table B-1, and verify that $v_0 = (1 + \frac{R_2}{R_1})\, v_1$.

R_1 (kΩ) / measured	R_2 (kΩ) / measured	v_0 pk-pk (theoretical) in V	v_0 pk-pk (measured) in V	v_0 phase angle in degrees
1 /	2.2 /			
1 /	4.7 /			
4.7 /	10 /			
2.2 /	10 /			
10 /	22 /			

Table B-1: Theoretical and Measured value of non- inverting amplifier

Exercise

- Refer to in-lab 8 exercise B-1

B2. NON-INVERTING AMPLIFIER PROCEDURE 2: BANDWIDTH

Determine the bandwidth of the non-inverting op-amp. As before, the bandwidth is equal to the frequency at which the magnitude of the gain $\frac{v_O}{v_1}$ drops to $\frac{1}{\sqrt{2}}$ of its low frequency value (which, theoretically, is $1 + \frac{R_2}{R_1}$)

- For R1 = 1 KΩ and R2 = 4.7 KΩ, measure the output when the input is a 200 mV peak-to-peak sinusoidal with variable frequency. Increase the frequency starting from 1000 Hz until the gain drops to 0.7071 times its ***measured*** low frequency value. Note the value of this frequency.

- Repeat the bandwidth measurement for R1 = 10 KΩ and R2 = 22 KΩ.

Exercise • Refer to in-lab 8 exercise B-2

C. UNITY-GAIN NON-INVERTING AMPLIFIER

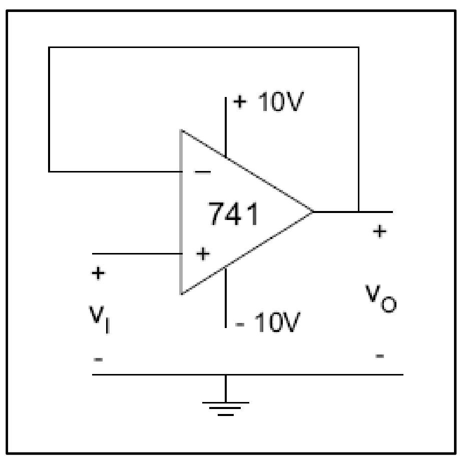

Figure C-1: Unity gain amplifier

Prove theoretically that $v_O = v_I$.

C1. UNITY AMPLIFIER PROCEDURE

- Using a 1 V peak-to-peak sinusoidal input voltage, verify experimentally that at low frequencies $v_O = v_I$. (refer to figure C-1).

- Determine the range of frequencies for which the gain $\frac{v_O}{v_1}$ is almost unity (i.e. $v_O = v_I$.). Find the upper limit of this range; that is the frequency f_0 beyond which the gain starts to drop below 1. Note that beyond f_0, the circuit acts effectively as an attenuator.

- Determine the bandwidth of the unity-gain non-inverting op-amp. As before, the bandwidth is equal to the frequency at which the magnitude of the gain $\frac{v_0}{v_1}$ drops to $\frac{1}{\sqrt{2}}$ (since the low-frequency gain is theoretically equal to 1.)
- How does this bandwidth compare with that of the non-inverting amplifier?

Exercise

- Refer to in-lab 8 exercise C-2

D. INVERTING ADDER

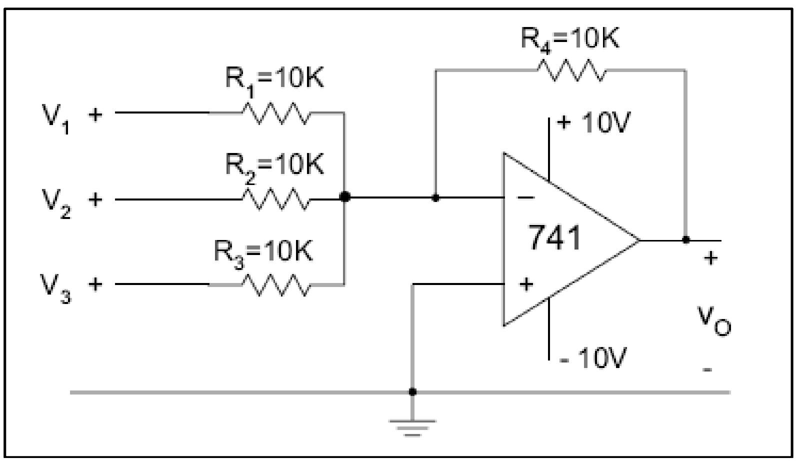

Figure D-1: Inverting Adder

Prove theoretically that (refer to figure D-1):

$$v_0 = -(\frac{R_4}{R_1}v_1 + \frac{R_4}{R_2}v_2 + \frac{R_4}{R_3}v_3)$$

If $R_1 = R_2 = R_3 = R_4$, as shown in the circuit above, then $-v_0 = v_1 + v_2 + v_3$. Verify this relationship experimentally by connecting different sources to the inputs and observing the output.

Use the circuits that were covered so far in this experiment to build a non-inverting adder circuit.

E. INTEGRATOR

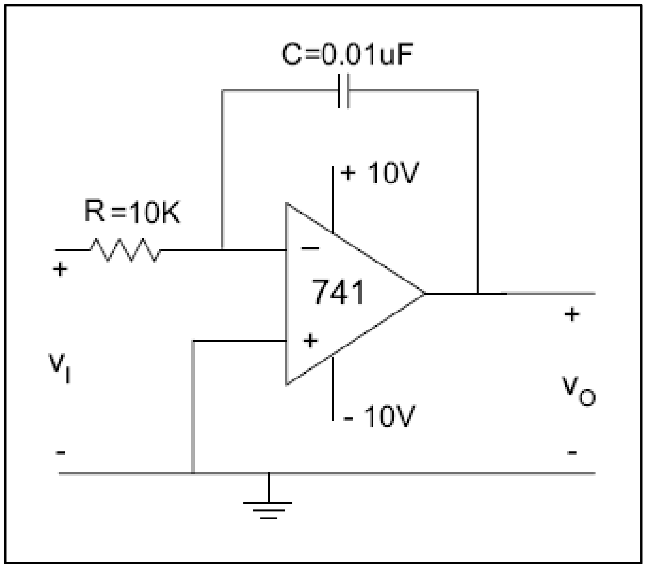

Figure E-1: Integrator

The fundamental operation of an op-amp integrator (figure E-1) is similar to the inverting amplifier except that the input current is transferred to a feedback capacitor rather than resistor.

E1. INTEGRATOR: THEORETICAL CALCULATION

Prove theoretically that $v_0 = -\frac{1}{RC}\int v_1 dt$ given that :Vin is a square wave of 1000 Hz frequency and 1 V pk-pk. Compute Vout pk-kp. Show your detailed solution.

Exercise • Refer to in-lab 8 exercise E-1

E2. INTEGRATOR: THEORETICAL VS MEASURED

- Apply a *symmetrical square* wave signal at the input with a frequency of 1000 Hz and 1 V peak-to-peak. Observe the output on the oscilloscope and measure its frequency and peak-to-peak voltage. Increase the frequency from 1 KHz to 10 KHz in steps of 3 KHz and note how the peak-to-peak output voltage varies by completing Table E-1.

f (Hz) at input	f (Hz) at output	v_0 pk-pk in Volts	Area Under Curve
1000			
4000			
7000			
10000			

Table E-1: Measured and theoretical value for integrator

To verify experimentally that $v_0 = -\frac{1}{RC}\int v_1 dt$, you should prove that the peak to-peak output voltage is equal, in absolute value, to the area enclosed under the square wave (for 0 < t < T/2 or for T/2 < t < T) divided by the product RC.

Exercise

- Refer to in-lab 8 exercise E-2

E3. INTEGRATOR: BANDWIDTH

- Increase the frequency of the input above 10 KHz, and observe the output. At what frequency does the output stop corresponding to the integral of the input (i.e. the output waveform stops resembling a triangular waveform)? Note that you may need to increase the peak-to-peak value of the input voltage to be able to observe the output at high frequencies.

- Find out what causes the deterioration in the integration action of the op-amp in the circuit shown above.

Exercise

- Refer to in-lab 8 exercise E-3

F. DIFFERENTIATOR

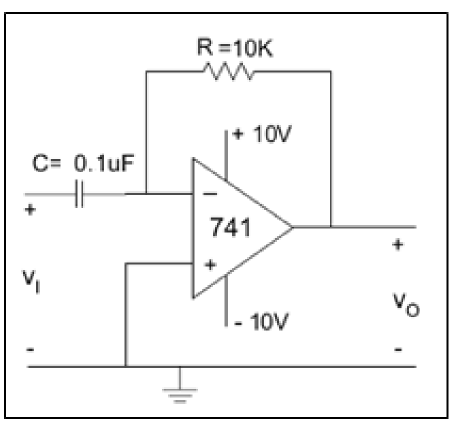

Figure F-1: Differentiator

Prove theoretically that (refer to figure F-1): $v_0 = -RC\frac{dv1}{dt}$.

F1. DIFFERENTIATOR: THEORETICAL CALCULATION

Vin is a triangular wave of 100 Hz frequency and 1 V pk-pk. Compute Vout pk-kp. Show your detailed solution.

Exercise
- Refer to in-lab 8 exercise F-1

F2. INTEGRATOR: THEORETICAL VS MEASURED

Apply a symmetrical triangular wave signal at the input with a frequency of 100 Hz and 1 V peak-to-peak. Observe the output on the oscilloscope and measure its frequency and peak-to-peak voltage. Increase the frequency from 100 Hz to 1000 Hz in steps of 300 Hz and note how the peak-to-peak output voltage varies by completing Table F-1.

f (Hz) at input	f (Hz) at output	v_0 pk-pk in Volts	Area Under Curve
1000			
4000			
7000			
10000			

Table F-2: Measured and theoretical value for differentiator

To prove experimentally that $v_0 = -RC\frac{dv1}{dt}$. , you should prove that the output voltage level is equal, in absolute value, to the product RC multiplied by the slope of the triangular input signal.

III. OUTCOMES

By the end of Experiment I, students:

- Should know the difference between the characteristics inverting amplifiers and non-inverting amplifiers.
- Should be familiar with some applications of unity gain amplifier
- Should know how to compute (experimentally and theoretical) the characteristics of the different amplifiers circuits; inverting, non-inverting, unity, adder, integrator, and differentiator.