LABORATORY 6

BASIC OP-AMP CIRCUITS

OBJECTIVES

1. To study the ac characteristics of the non-inverting op-amp configuration.
2. To study the ac characteristics of the inverting op-amp configuration.
3. To study the ac characteristics of the integrator op-amp configuration.
4. To simulate the integrator, non-inverting and inverting op-amp circuits using Micro-Cap software.

INFORMATION

Note: *Actual lab procedure follows this information section.*

The integrated circuit operational amplifier (op-amp) is an extremely versatile electronic device, which is encountered in a wide variety of applications ranging from consumer electronics (stereos, VCR's) to complex commercial applications and industrial controls. This versatility stems from the very high voltage gain (100,000 and higher for the 741) together with high input resistance (typically 1 MΩ) and low output resistance (typically 50Ω). These characteristics allow use of large amounts of feedback from output to input with the result that the desired output signal is dependent only on the external components.

Op-amps are direct coupled devices such that the input signal may be either AC or DC, or a combination of the two. The industrial standard op-amp, the 741, requires two power supplies, one positive and one negative. For most applications the magnitude of these two voltages is the same. All op-amps have two inputs connected in a differential mode, so that output voltage is $\mathbf{V_o = A(V_+ - V_-)}$ where $\mathbf{V_+}$ is the voltage at the non-inverting input and $\mathbf{V_-}$ is the voltage at the inverting input. **A** is the open loop gain of the op-amp.
The circuit symbol for an op-amp is shown in Figure 6.1. The pin connections for the 8 pin DIP package µA741 op-amp are given in Figure 6.2.

Chip Diagrams:

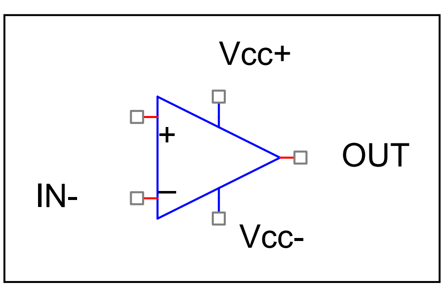

Figure 6.1 *Symbol for a basic op-amp*

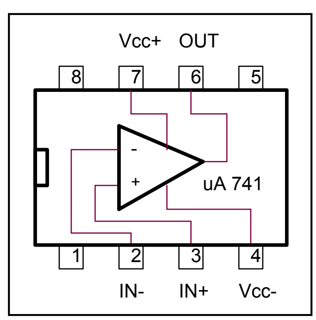

Figure 6.2 *The µA741 op-amp package.*

Ideally, an op-amp will have infinite open loop voltage gain A, infinite input resistance R_{in} and zero output resistance Ro. The input currents in the two differential inputs and the voltage difference between the two inputs will be vanishingly small. In practice these quantities are finite and in most applications can be ignored.

1. Basic non-inverting amplifier

The basic non-inverting op-amp configuration is shown in Figure 6.3. You can achieve a particular value of the closed-loop gain *Av* of the non-inverting amplifier by choosing the R1 and R2 values. The theoretical ideal characteristics are determined largely by the external biasing resistors, and are given by Equations (6.1), (6.2) and (6.3).

$$Rin = \infty\ \Omega \qquad \text{Equation (6.1)}$$

$$Ro = 0\ \Omega \qquad \text{Equation (6.2)}$$

$$Av = \frac{Vout}{Vin} = 1 + \frac{R_2}{R_1} \qquad \text{Equation (6.3)}$$

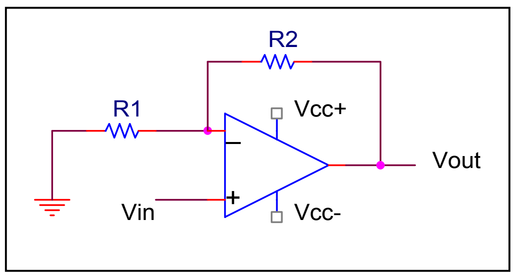

Figure 6.3 *Basic non-inverting amplifier*

2. Basic inverting amplifier

The basic inverting op-amp configuration is shown in Figure 6.4. You can achieve a particular value of the closed-loop gain *Av* of the inverting amplifier by choosing the R1 and R2 values.

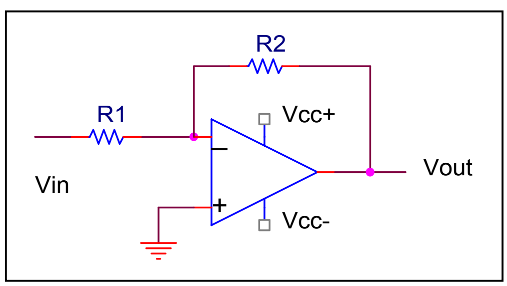

Figure 6.4 *Basic inverting amplifier*

The theoretical ideal characteristics are determined largely by the external biasing resistors, and are given by Equations (6.4), (6.5) and (6.6).

$$Rin = R_1 \qquad \text{Equation (6.4)}$$

$$Ro = 0\ \Omega \qquad \text{Equation (6.5)}$$

$$Av = \frac{Vout}{Vin} = -\frac{R_2}{R_1} \qquad \text{Equation (6.6)}$$

3. Basic integrator circuit

The standard integrator using an ideal op-amp is given in Figure 6.5. The function of an integrator is to perform mathematical integration upon the input. A square wave, when integrated, will become triangular. A triangular wave, when integrated, will become a parabolic waveform, which is close to a sine wave.

A practical op-amp at low frequencies has small DC off-set voltages and currents, which can sometimes create havoc with the output of an integrator circuit. The integrator may saturate and the output voltage becomes pegged at either the positive or negative saturation level. This problem is not noticeable in our lab.

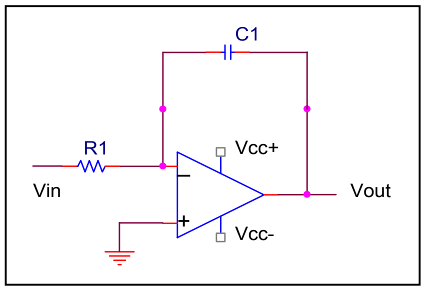

Figure 6.5 *The ideal integrator circuit*

EQUIPMENT

1. Digital multimeter (Fluke 8010A, BK PRECISION 2831B or BK PRECISION 2831C)
2. PROTO-BOARD PB-503 (breadboard)
3. Digital Oscilloscope Tektronix TDS 210
4. Function Generator Wavetek FG3B
5. Dual Voltage Power Supply
6. Resistors: 10 kΩ, 270 kΩ, 2.2kΩ
7. Capacitors 470pF, 2x100nF, 1uF
8. uA741 op-amp

PRE-LABORATORY PREPARATION

The lab preparation must be completed before coming to the lab. Show it to your TA at the beginning of the lab and get his/her signature in the Signature section of the Lab Measurements Sheet.

During your pre-lab you must prepare several *Micro-Cap* simulations and plot the input and output waveforms for different op-amp applications. Please refer to the following remarks for *Micro-Cap* circuit set up and simulation:

- For a sine wave signal source (used for simulating the circuits in Figures 6.7 and 6.8), use a 1MHz Sine Source from the *Micro–Cap* library. The Sine Source can be found under the **Component** menu by selecting **Analog Primitives** then **Waveform Sources** then **Sine Source**. Set the required frequency to F=**1k**(Hz) and the AC Amplitude to A= **0.2**(V) in the model description area of the signal source. **Note** that A=0.2V corresponds to a magnitude of *Vp-p*=0.4V.
- For a square wave signal source (for simulating Figure 6.10), use the Pulse Source with the square setting from the *Micro-Cap* library. The Pulse Source can be found under the

Component menu by selecting **Analog Primitives** then **Waveform Sources** then **Pulse Source**. From the dialog box for the Pulse Source, select SQUARE from the box on the right-hand side. Set the required amplitude and frequency of the square wave signal by changing the amplitude, duration and repetition period of the pulse sequence in the model description area of the square wave signal source. For a 1 kHz square signal, set the pulse parameters as follows: P1=**0**, P2=**0**, P3=**500U**, P4=**500U** and P5=**1M**.
Set the signal amplitude in fields VZERO to **-0.2**(V) and VONE to **0.2**(V). Note that this corresponds to a magnitude of $V_{p\text{-}p}$ = 0.4V.

- To obtain input and output waveforms for certain circuits, you must run "TRANSIENT ANALYSIS". To get the best results for your plots set the **Transient Analysis Limits** as follows:
  - *Time parameters:* Time Range = **5m**; Maximum Time Step = **0.00001**;
  - *Plot parameters (for questions 1 and 3 of pre-lab):*

	P	*X-Expression*	*Y-Expression*	*X-Range*	*Y-Range*
Input signal	**1**	**T**	**V(1)***	**5m,0,0.5m**	**1,-1,0.2**
Output signal	**2**	**T**	**V(2)***	**5m,0,0.5m**	**12,-12,2**

Note: *V(1) and V(2) are the AC input and output voltages at corresponding nodes of the simulation circuit set up. In your particular case they could have different numeration.

  - *Plot parameters (for question 5 of pre-lab):*

	P	*X-Expression*	*Y-Expression*	*X-Range*	*Y-Range*
Input signal	**1**	**T**	**V(1)***	**5m,0,0.5m**	**1,-1,0.2**
Output signal	**2**	**T**	**V(2)***	**5m,0,0.5m**	**15,-15,2**

The following *Micro-Cap* simulations and plots of the input and output waveforms for different op amp applications must be prepared for your pre-lab:

1. **[8 MARKS]** Simulate the non-inverting amplifier shown in Figure 6.7. Plot both the output and input waveforms for a *sine waveform* input signal with $Vin_{p\text{-}p}$=0.4V at 1kHz.
2. **[3 MARKS]** From your plots calculate the voltage gain Av of the non-inverting amplifier circuit. Also calculate the theoretical voltage gain Av using Equation (6.3). Enter the values in Table 6.1 of the Lab Measurements Sheet.
3. **[8 MARKS]** Simulate the inverting amplifier shown in Figure 6.8. Plot both the output and input waveforms for a *sine waveform* input signal with $Vin_{p\text{-}p}$=0.4V at 1kHz.
4. **[3 MARKS]** From your plots calculate the voltage gain Av of the inverting amplifier circuit. Also calculate the theoretical voltage gain Av using Equation (6.6). Enter the values in Table 6.2 of the Lab Measurements Sheet.
5. **[8 MARKS]** Simulate the real integrator circuit shown in Figure 6.10. Plot both the output and input waveforms for a *square waveform* input signal with $Vin_{p\text{-}p}$ =0.4V at 1kHz.

Note: *For each simulation, print the Micro-Cap circuit set-up with node numbers. This will help your TA to correct any mistakes in your simulations. Bring all required plots to your lab session and submit them to your TA. You will use these plots to draw practical results of your experiments during the lab session.*

PROCEDURE

The pin connections for the 8 pin DIP package uA741 op-amp are given in Figure 6.2. Throughout this experiment use the external dual DC Power Supply Unit shown in Figure 6.6. Use the dual trace oscilloscope to observe the shape and to measure the amplitude of the input and output waveforms.

To use the Power Supply Unit:

- Turn the Power Supply ON. Adjust the voltage of the Power Supply to 12V. This will set both positive and negative power sources respectively to +12V and –12V.
- Turn the Power Supply OFF before connecting to the circuits.
- Connect the **POS** terminal of the Power Supply to the **Vcc+** of your circuit. Connect the **NEG** terminal of the Power Supply to the **Vcc-** of your circuit. Connect the **COM** terminal of the Power Supply to the ground of your circuit

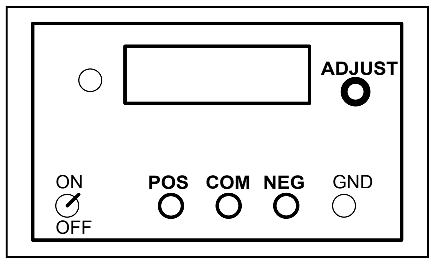

Figure 6.6 *Front panel of power supply unit*

1. Non-inverting amplifier measurements

1.1. Build the circuit of Figure 6.7 using an 8-pin uA741 op-amp with R_1 = 10kΩ, R_2 = 270 kΩ. To achieve better circuit stability, connect 100nF capacitors between pins #4 and #7 of the uA741 and the Ground, as shown in Figure 6.7.

When the layout has been completed, have your TA check your breadboard for errors and get his/her signature in the Signature section of the Lab Measurements Sheet. You will be penalized marks if your sheet is not initialed.

1.2. Apply a 1kHz sinusoidal voltage signal from the Signal Generator to the input and use the dual trace oscilloscope to observe both input and output waveforms. Adjust the magnitude of the input signal until clipping occurs on either the positive or negative peak of the output voltage. Determine the maximum possible ac voltage swing, i.e. maximum peak to peak voltage that can be obtained at the output of the circuit without clipping. Compare this to the DC power supply voltages. Put this information in section 1.1 of the Lab Measurements Sheet.

1.3. For $Vin_{p\text{-}p}$=0.4V at F=1kHz measure the amplitude of the output signal *Vout* and calculate voltage gain of this circuit. Record data and compare the values with pre-lab calculations in Table 6.1 of the Lab Measurements Sheet.

1.4. Draw the input and output waveforms on top of your simulations plots. In section 1.3 of the Lab Measurements Sheet compare how close your practical results are to the simulations.

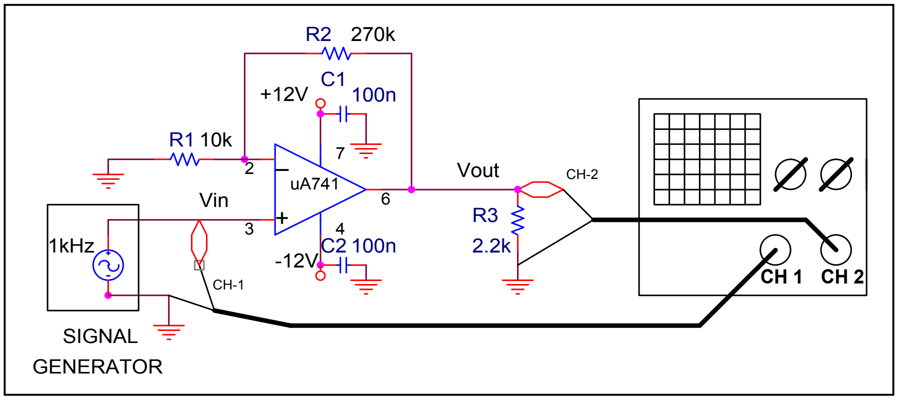

Figure 6.7 *Measurement circuit for non-inverting amplifier*

1.5. Turn the oscilloscope into "XY Mode"* and observe the curve on its display. Vary the input signal amplitude and explain what happens when you change the magnitude of the input signal before and after the output signal becomes saturated. Draw the XY waveform in Figure 6.12 in section 1.4 and answer question in section 1.5 of the Lab Measurements Sheet.

* To turn the oscilloscope into "XY Mode", first press the "DISPLAY" button and then by pressing the soft button "FORMAT", assigned to display, choose "XY" mode. You can confirm that you are in the correct mode if an "XY Mode" notice is displayed in the bottom right corner of the oscilloscope's display.

2. Inverting amplifier measurements

2.1. Build the circuit of Figure 6.8 using an 8-pin uA741 op-amp with R_1 = 10kΩ, R_2 = 270 kΩ. To achieve better circuit stability, connect 100nF capacitors between the pins #4 and #7 of the uA741 and the Ground, as shown in Figure 6.8.

When the layout has been completed, have your TA check your breadboard for errors and get his/her signature in the Signature section of the Lab Measurements Sheet. You will be penalized marks if your sheet is not initialed.

2.2. Apply a 1kHz sinusoidal voltage signal from the Signal Generator to the input and use the dual trace oscilloscope to observe the shape and to measure the amplitude of the input and output waveforms.

2.3. For $Vin_{p\text{-}p}$=0.4V at F=1kHz measure the amplitude of the output signal *Vout* and calculate voltage gain of this circuit. Record data and compare the values with pre-lab calculations in Table 6.2 in section 2.1 of the Lab Measurements Sheet.

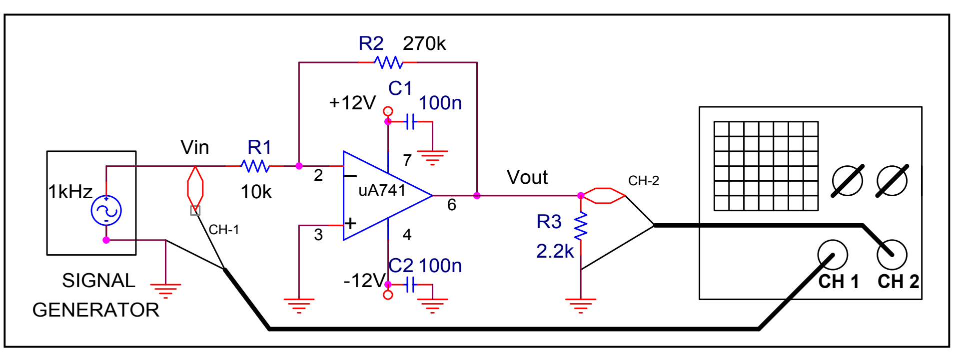

Figure 6.8 *Measurement circuit for inverting amplifier*

2.4. Draw the input and output waveforms on top of your simulations plots. In section 2.2 of the Lab Measurements Sheet compare how close your practical results are to the simulations.

2.5. Input resistance measurements.

Using a Digital Multimeter, measure the AC input current of the inverting amplifier, as shown in Figure 6.9. Read the input voltage RMS* value on your oscilloscope. Record the measured values and calculations in Table 6.3 at section 2.3 of the Lab Measurements Sheet. Compare the result to the theoretical expectation in section 2.4 of the Lab Measurements Sheet.

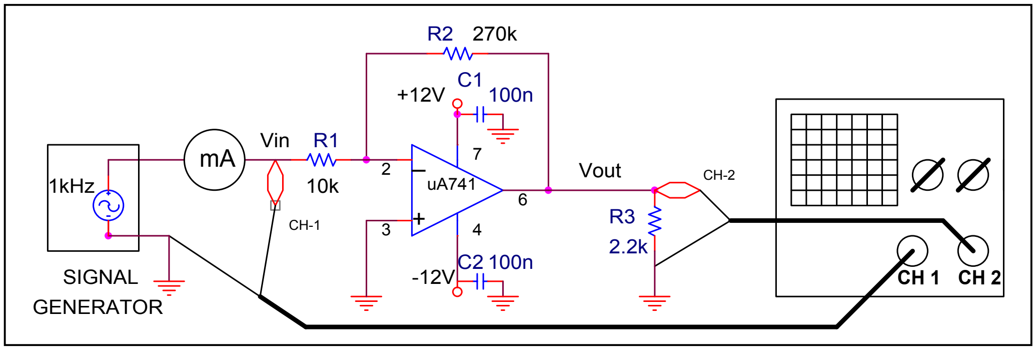

Figure 6.9 *Input resistance measurements.*

***Note**: Switch the oscilloscope voltage measurement mode for the Channel 1 from "peak-to-peak" mode (p-p) to "Cyc-RMS" mode by pressing the assigned display button to the CH1.

3. Integrator measurements

3.1. Connect the circuit of figure 6.10 using an 8-pin uA741 op-amp, R_1 = 10kΩ and C=470pF. To achieve better circuit stability, connect 100nF capacitors between the pins #4 and #7 of the uA741 and the Ground, as shown in Figure 6.10.

When the layout has been completed, have your TA check your breadboard for errors and get his/her signature in the Signature section of the Lab Measurements Sheet. You will be penalized marks if your sheet is not initialed.

3.2. Apply a $Vin_{p\text{-}p}$=0.4V, f = 1kHz square waveform voltage signal from the Signal Generator to the input and use the dual trace oscilloscope to observe both input and output waveforms.

3.3. Draw the input and output waveforms on top of your simulations plots. Compare how close your practical results are to the simulations. Determine if the output waveform is what you would expect from an ideal integrator. How close is the waveform to the ideal integrator circuit? Record your observations in section 3.1 of the Lab Measurements Sheet.

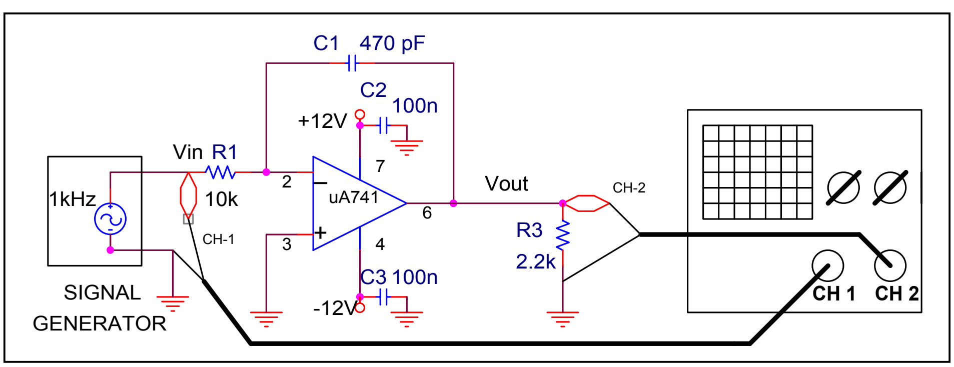

Figure 6.10 *Integrator measurements circuit*

3.4. Apply a f = 1kHz triangle waveform voltage signal from the Signal Generator to the input and use the dual trace oscilloscope to observe both input and output waveforms.

3.5. For a triangular input signal with Vin_{p-p}=0.4V, draw the input and output waveforms in Figure 6.13 of the Lab Measurements Sheet. Determine if the output waveform is what you would expect from an ideal integrator. How close is the waveform to the ideal integrator circuit? Record your observations in section 3.3 of the Lab Measurements Sheet.

4. OPTIONAL

Operational amplifiers can also be used to build active filters and signal generators circuits. In the next lab, an astable multivibrator is used to generate a saw-tooth waveform signal. The astable multivibrator is basically an op-amp with positive feedback. A typical astable multivibrator, illustrated in Figure 6.11, is able to generate square waveform signals with adjustable frequency.

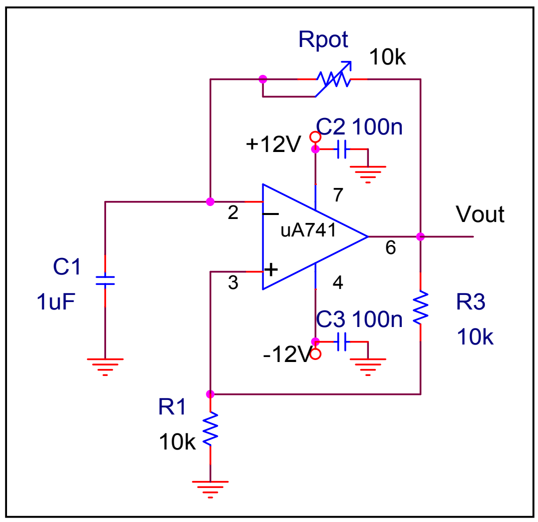

Figure 6.11 *Typical astable multivibrator circuit*

4.1. Connect the circuit on the breadboard and show it to your TA.
4.2. Observe and draw waveforms at pin 2 (input) and pin 6 (output) of the op-amp in Figure 6.14 of the Lab Measurement Sheets.
4.3. Explain how this circuit operates. What is the range of output signal change when you change the potentiometer position and its resistance?

LAB MEASUREMENTS SHEET – LAB 6

Name ___________________________

Student No______________________

Workbench No_____

NOTE: Questions are related to observations, and must be answered as a part of the procedure of this experiment.

Sections marked * are pre-lab preparation and must be completed BEFORE coming to the lab.

1. Non-Inverting Amplifier

1.1. Determine the maximum possible ac voltage swing, i.e. maximum peak to peak voltage that can be obtained at the output of the circuit. Compare this to the DC power supply voltages.

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1.2. Voltage gain measurements

Table 6.1 *Non-Inverting amplifier measurements*

Vin (V) *(measured)*	$Vout$ (V) *(measured)*	$Av = \frac{Vo}{Vin}$	* Vin (V) *(simulated)*	* $Vout$ (V) *(simulated)*	* $Av = \frac{Vo}{Vin}$	* $Av = 1 + \frac{R_2}{R_1}$

1.3. Compare how close your practical gain result is to the theoretically calculated value.

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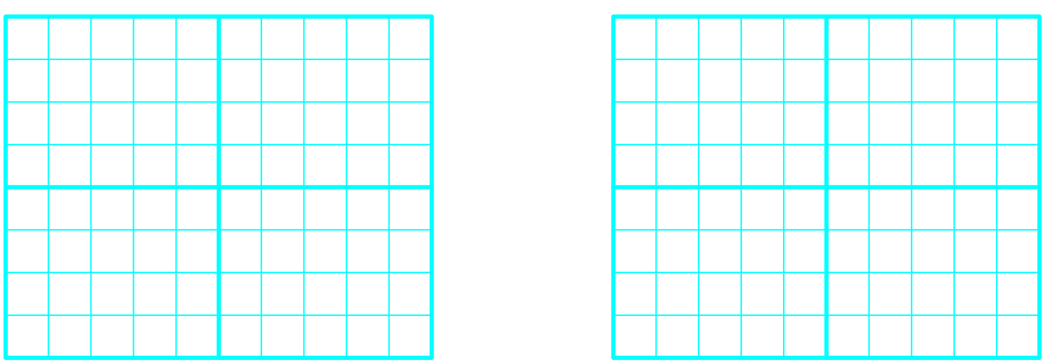
1.4. The X-Y mode waveforms in non-saturated and saturated mode



a) Non-saturated mode b) Saturated mode

Figure 6.12 *The X-Y mode waveforms*.

1.5. Explain what happens with X-Y waveform when you change the magnitude of the input signal before and after the output signal became saturated.

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2. Inverting Amplifier

2.1. Voltage gain and input and output resistance measurements.

Table 6.2 *Inverting amplifier measurements*

Vin (V) (*measured*)	*Vout* (V) (*measured*)	$Av = \frac{Vo}{Vin}$	**Vin* (V) (*simulated*)	**Vout* (V) (*simulated*)	$* Av = \frac{Vo}{Vin}$	$* Av = -\frac{R_2}{R_1}$

2.2. Compare how close your practical gain result in Table 6.2 is to the theoretically calculated value.

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2.3. Input resistance measurements.

Table 6.3 *Input resistance measurements*.

Vin (V)	*Iin* (A)	$Rin = \frac{Vin}{Iin} (\Omega)$

2.4. Compare how close the measured *Rin* value is to the theoretically calculated value.

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3. Integrator

3.1. Determine if the output waveform to a square waveform input is what you would expect from an ideal integrator. How close is the waveform?

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3.2. Draw the input and output waveforms of the integrator circuit for the triangle waveform input signals.

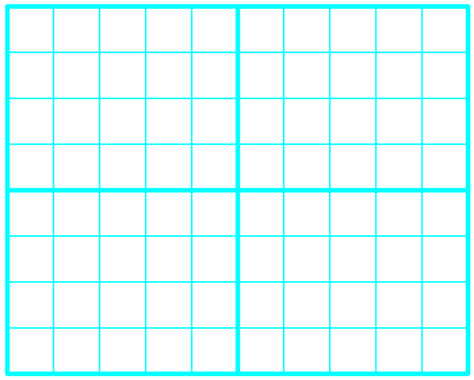

Figure 6.13 *Input/output signal waveforms for triangular input voltage*

3.3. Determine if the output waveform is what you would expect from an ideal integrator. How close is the waveform?

4. OPTIONAL

This space is for the optional part of the procedures.

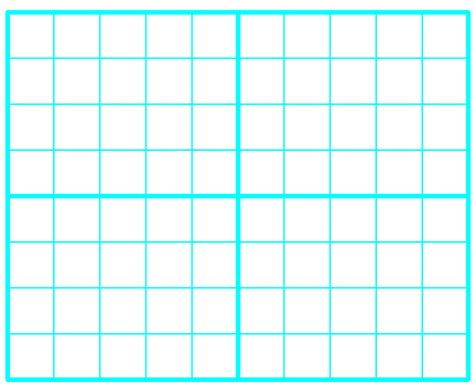

Figure 6.14 *Signal waveforms at pins 2 and 6 of the op-amp*

SIGNATURES **TA name:__________________________**

To be completed by TA during the lab session.

Check Boxes					TA Signature	Student's Task
						Pre-lab completed.
						Circuit of Figure 6.7 connected and equipment used correctly
						Circuit of Figure 6.8 connected and equipment used correctly
						Circuit of Figure 6.10 connected and equipment used correctly
						Data collected and observations made

MARKS

To be completed by TA after the lab session.

Granted Marks	Max. Marks	Student's Task
	30	Pre-lab preparation
	15	Circuit of Figure 6.7 connected and equipment used correctly
	15	Circuit of Figure 6.8connected and equipment used correctly
	15	Circuit of Figure 6.10 connected and equipment used correctly
	25	Data collected and observations made
	100	**Total**