

Operational Amplifiers: Part II

1. Introduction

The name "operational amplifier" comes from this amplifier's ability to perform mathematical operations. Three good examples of this are the summing amplifier, the differentiator, and the integrator. In this experiment, the student will learn how to build a summing amplifier, a differentiator and an integrator using operational amplifiers and then design a final circuit that uses a combination of them.

The Op Amp used for the experiment is the LM741. The diagram for the LM741 is shown in Figure 1.

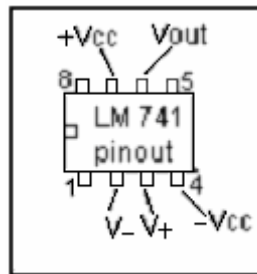


Figure 1: LM741 Pinout Diagram

2. Procedure

2.1. Equipment

- Tektronix TDS 3012B Digital Phosphor Oscilloscope
- Agilent E3631A DC Power Supply
- Agilent 33120A Waveform Generator
- Fluke 8050A Digital MultiMeter (DMM)
- Resistors, Capacitors, and LM741 Op Amps as Needed

2.2. Summing Amplifier

The summing amplifier can be used as an audio mixer. For that application, it allows the circuit to add waveforms (sounds) from different channels (vocals, instruments) together before sending the combined signal to a recorder. Figure 2 shows the circuit of a summing amplifier. In this circuit the resistor R_3 is used to limit the current through the op amp (what would the current be through R_3 in theory for an ideal Op Amp?).

2.2.1. **PRELAB** Theoretical Procedure

Using the summing amplifier equations given in Figure 2, compute the output voltage for the circuit. Assume $R_A = R_B = R_C = 1 \text{ k}\Omega$, $R_1 = R_2 = R = 10 \text{ k}\Omega$, $R_3 = 1 \text{ k}\Omega$, $+V_{CC} = 10 \text{ V}$, $-V_{CC} = -10 \text{ V}$, and $V_s = +5 \text{ V DC}$. **Record your result in Table 1.**

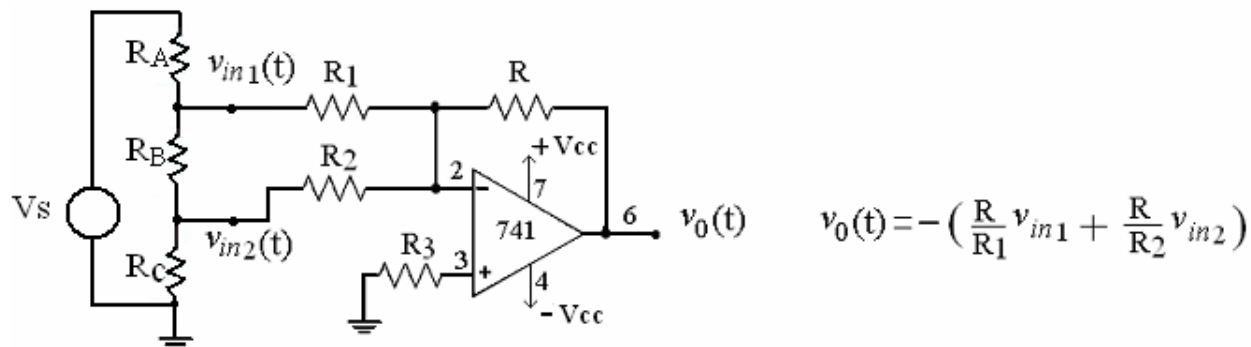


Figure 2: Summing Amplifier

2.2.2. Experimental Procedure

Connect the Op Amp circuit shown in Figure 2. Use the same voltages and resistances as listed above for the theoretical procedure.

Turn ON the output of the power supply. Measure V_{in1} , V_{in2} and V_o with the DMM. **Record these values in Table 1.**

Turn OFF the output of the power supply. Set the function generator to output a 5 Volts Peak-to-Peak (VPP), sinusoidal wave with a frequency of 1 kHz ($V_s = 5$ VPP, $f = 1$ KHz).

Turn ON the output of the power supply. Connect the function generator as the voltage source V_s to your summing amplifier.

Using the oscilloscope measure, the input signals V_{in1} , V_{in2} , and the output signal V_o . Measure the voltage and frequency of the three waveforms. **Record these values in Table 2 and save snapshots** of V_o with each of the other two signals on the display (one at a time). Obtain your instructor's signature for the oscilloscope display.

IMPORTANT:

- **NEVER APPLY AN INPUT SIGNAL WHEN THE POWER SUPPLY IS SWITCHED OFF.**
- **THE INPUT VOLTAGE SHOULD NOT EXCEED THE SUPPLY VOLTAGE.**

2.3. The Differentiator

The differentiation is useful for obtaining velocity measurements from a signal representing a position or determining a signal's frequency. Figure 2a shows an ideal Op Amp differentiator with an input-output relationship that is theoretically correct, but has practical implementation issues.

Analyzing the circuit in Fig. 2a, we see that since the input circuit element is a capacitor, this circuit will only allow AC signal components and will block DC signal components. The faster and larger the change in input voltage is, the greater the input current,

therefore the greater the output voltage in response. Since the output voltage will reflect the rate of change of the input, this circuit will indeed perform differentiation. The general equation for the output voltage is shown in equation (1).

$$v_o(t) = -RC \frac{dv_{in}(t)}{dt} \quad (1)$$

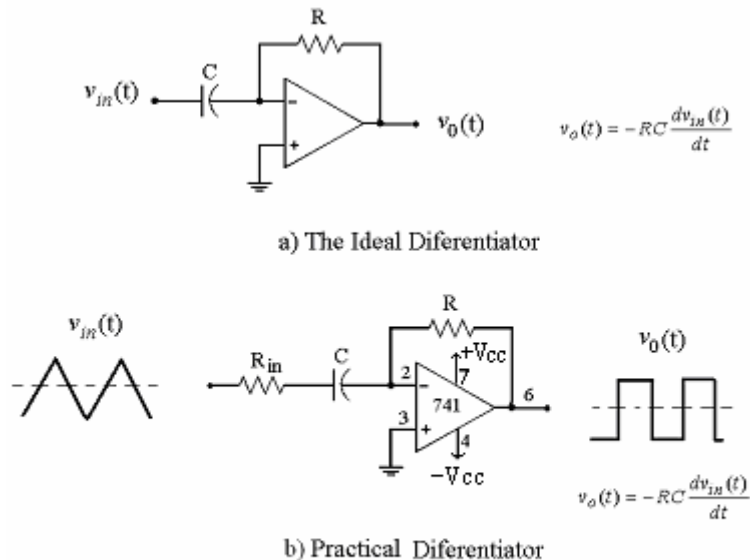


Figure 2. The op-amp Differentiator

The ideal Op Amp differentiator is not used in real applications. The basic reason for this is that high-frequency noise signals will not be suppressed by this circuit; instead, they will be amplified far beyond the amplification of the desired signal.

In some applications, it may be possible to add a series input resistor, as shown in Fig. 2b. This limits the high frequency gain of the circuit to the ratio R/R_{in} . The low frequency gain is still set by R and C , as before. The cutoff frequency, where these two effects meet, is determined by R_{in} and C , according to the expression: $f_{co} = (1/2\pi) R_{in}C$.

2.3.1. PRELAB Theoretical Procedure

On a sheet of paper, sketch the derivative of the following waveforms:

- sinusoidal waveform
- triangular waveform
- rectangular waveform

Include these sketches in your write-up (you may want to reformat them).

2.3.2. Experimental Procedure

Connect the differentiator shown in Fig. 2b. Use the following values for the components and voltages:

$R = 10 \text{ k}\Omega$, $R_{in} = 470 \text{ }\Omega$, $C = 0.022 \text{ }\mu\text{F}$, $+V_{CC} = 10 \text{ V}$, $-V_{CC} = -10 \text{ V}$

Set the function generator to provide the following input signals:

- $V_{in} = 2.5$ VPP, 2 KHz, sine wave
- $V_{in} = 2.5$ VPP, 2 KHz, square wave
- $V_{in} = 2.5$ VPP, 2 KHz, triangular wave

Turn ON the output of the power supply to provide the +10V and -10V to the Op Amp. Connect the signal generator to the input terminal V_{in} of your differentiator. Measure the voltage and frequency of the output waveforms. Repeat this for each of the inputs and **record these values in Table 3 and save snapshots** of V_o with the corresponding input for each of the three cases. Obtain your instructor's signature for the oscilloscope display.

IMPORTANT:

- **NEVER APPLY AN INPUT SIGNAL WHEN THE POWER SUPPLY IS SWITCHED OFF.**
- **THE INPUT VOLTAGE SHOULD NOT EXCEED THE SUPPLY VOLTAGE.**

2.4. The Integrator

In Fig. 3a, the feedback element is a capacitor. This circuit is an ideal op-amp integrator with input-output relationship that is theoretically correct, but again has practical implementation issues.

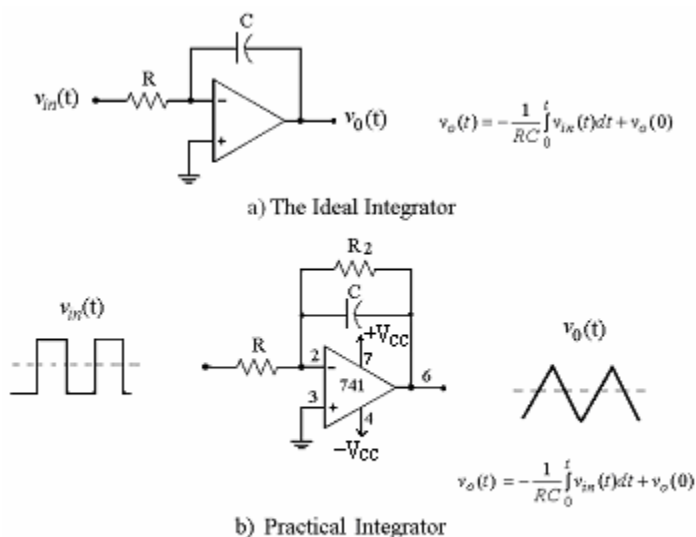


Figure 3. The op-amp Integrator

Observe that any feedback current must be based on a change in output voltage. As feedback current flows, the capacitor will gain an electric charge, which will change according to the cumulative effects of the output signal. If the input voltage is zero, no input current will flow. Therefore no feedback current can flow and the output voltage

will remain constant. If the input voltage is non-zero, the basic equation for the output voltage is shown in equation (2),

$$v_o(t) = -\frac{1}{RC} \int_0^t v_{in}(t) dt + v_o(0) \quad (2)$$

where R is the input resistance in Ω , C is the feedback capacitance in Farads, and $v_o(0)$ is a fixed constant representing the accumulated voltage from the past. If the input voltage is constantly changing, the output voltage at any instant will be the integral of all past input voltage values. For example, a bipolar sine wave input will actually produce another sine wave as its output, at a phase angle of 90° from the input sine wave. Technically, the output will be an inverted cosine wave.

Notice the following in the integrator: (1) If the input is a constant positive DC voltage, the output will be a negative linear ramp. There is no exponential factor in an Op Amp integrator. The equation for the ramp will be $v_o = -v_{in} t / (RC)$, where t is time in seconds. (2) The integrator has an automatic and natural tendency to damp out any high-frequency noise that may appear in the input signal. (3) It is essential to avoid any long-term DC offset in the input voltage. If such an offset is present, it will cause the output voltage to gradually shift toward one extreme or the other, and stay there. An offset problem can be avoided by limiting the time during which the integration process is allowed to continue. At the end of that time, the circuit is reset back to its initial conditions before being allowed to repeat the operation.

2.4.1. **PRELAB** Theoretical Procedure

On a separate piece of paper, sketch the integral of the following waveforms:

- a) sinusoidal waveform
- b) triangular waveform
- c) rectangular waveform

2.4.2. **Experimental Procedure**

Connect the differentiator shown in Fig. 3b. Use the following values for the components and voltages:

$R_2 = 4.7 \text{ k}\Omega$, $R = 47 \text{ k}\Omega$, $C = 0.1 \text{ }\mu\text{F}$, $+V_{CC} = 10 \text{ V}$, $-V_{CC} = -10 \text{ V}$

Set the function generator to provide the following input signals:

- a. $V_{in} = 2.5 \text{ VPP}$, 2 KHz, sine wave
- b. $V_{in} = 2.5 \text{ VPP}$, 2 KHz, square wave
- c. $V_{in} = 2.5 \text{ VPP}$, 2 KHz, triangular wave

Turn ON the output of the power supply to provide the +10 V and -10 V to the Op Amp. Connect the signal generator to the input terminal V_{in} of your integrator. Measure the voltage and frequency of the output waveforms. Repeat this for each of the inputs and **record these values in Table 4 and save snapshots** of V_o with the corresponding

input for each of the three cases. Obtain your instructor's signature for the oscilloscope display.

IMPORTANT:

- **NEVER APPLY AN INPUT SIGNAL WHEN THE POWER SUPPLY IS SWITCHED OFF.**
- **THE INPUT VOLTAGE SHOULD NOT EXCEED THE SUPPLY VOLTAGE .**

2.5. PRELAB Student Design

Using any combination of Op Amps, resistors with resistances of 1 k Ω or more, and capacitors, create a circuit that produces the output given by equation (3). Make sure to use the practical Op Amps rather than the theoretical implementations.

$$v_o = -\frac{1}{10}v_{in} + \frac{1}{5}\frac{dv_{in}}{dt} \quad (3)$$

V_{CC} and $-V_{CC}$ should be set to **+/- 20 V**, respectively. Apply the following two signals as input(s) to your circuit (one and then the other):

- 5 Volt DC Signal
- 2 VPP 7.5 Hz Sine Wave

Measure the voltage (and frequency for the latter) of the input and output waveforms. **Record these values in Table 5 and save snapshots** of V_o with the corresponding input for each of the three cases. Obtain your instructor's signature for the oscilloscope display. Also, **include a schematic of the circuit you built** (akin to Figures 2, 3, and 4) **with all resistances and capacitances labeled.**

3. Conclusions

This concludes lab 5. However, for the post lab, you will need to do some PSpice[®] simulation. This week you are not required to complete a full report. Instead, it is sufficient to write a memo which includes the following:

- The Data Entry and Lab Instructor Signature Page with all recorded numbers and signatures.
- Any snapshots and circuit diagrams requested in the procedure.
- PSpice[®] schematics* and simulation results for Figures 2, 3b, and 4b in addition to the schematic for the student designed Op Amp.
- Comments on how the theoretical results compare to the experimental results for each of the four subsections in the procedure.

*Use the "OPAMP" model from the parts list to represent the LM741 (or UA 741). The transient analysis link on the ECE 2006 website will be of help. In addition, you will need to use several new parts such as C, VSIN, VPWL, etc. Lastly, when simulating the Op Amps, **do not** insert the resistor between the input and ground in Figure 2.

Data Entry and Lab Instructor Signature Page

Attach this page to your write-up.

Table 1: Measurements for Summing Amplifier with DC Voltages

Measurement	V_o (Volts)	V_{in1} (Volts)	V_{in2} (Volts)
Theoretical		N/A	N/A
Experimental			

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Table 2: Measurements for Summing Amplifier Output with Waveform Input

Waveform	Amplitude (VPP)	Frequency (kHz)
V_{in1}		
V_{in2}		
V_o		

Signature for 2.2.2. – Waveform I/O for Summing Amplifier _____

Table 3: Measurements for Differentiator Amplifier Output with Waveform Input

Input Waveform	Amplitude (VPP)	Frequency (kHz)
Sine		
Triangle		
Square		

Signature for 2.3.2. – Waveform I/O for Differentiator Amplifier _____

Table 4: Measurements for Integrator Amplifier Output with Waveform Input

Input Waveform	Amplitude (VPP)	Frequency (kHz)
Sine		
Triangle		
Square		

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Table 5: Output Measurements for Student Designed Circuit

Input Waveform	Amplitude (VPP)	Frequency (kHz)
DC Signal		
Sine Wave		

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