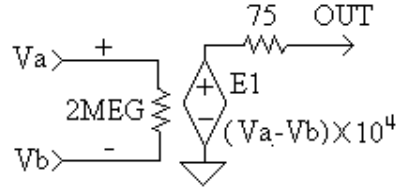# Experiment 13: Op-Amp / Controlled Voltage Source

Introduction

Ideal operational amplifier approximation assumes that op-amp input currents are negligible and can be ignored. The op-amp's input resistance is assumed to be infinite and its output resistance is assumed to be zero. The op-amp can be modeled as a voltage controlled voltage source whose output voltage is controlled by its input voltage.

Refer to the model diagram on the right. A typical (data book) value for an op-amp's input resistance is 2 megohms and output resistance is 75 ohms. When the op-amp is used in a circuit with negative feedback, the effective input resistance increases and output resistance decreases.

Objectives

This experiment will demonstrate that the operational amplifier acts as a voltage controlled voltage source. Also the validity of the ideal op-amp approximations will be investigated. The op-amp's input currents and voltages will be measured.

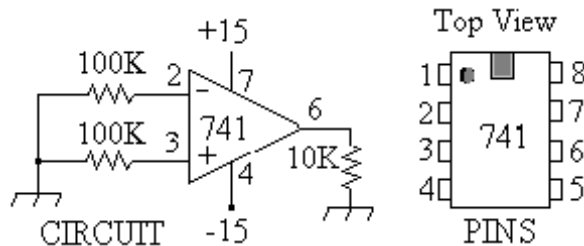## Procedure

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Equipment and Parts

Power Supply: +15, -15, and +5 V, DMM, Breadboard.
Op-amp: µA741.   Resistors: 10K, two 100K and two 150K, all ¼ watt, 5%.


Part 1: Input Currents

1.   Measure and record the values of your resistors.

Labeled Value	Measured Value		Labeled Value	Measured Value
100k(1)			100k(2)	
10k			150k	

2.   Connect the circuit below. Refer to the top view of the op-amp for pin numbering.

3. Carefully measure and record the voltages at pin 2 and pin 3 of the op-amp. Refer to the picture on the right. Note the dual polarity power supply connections, +15V and -15V, both referenced to ground.
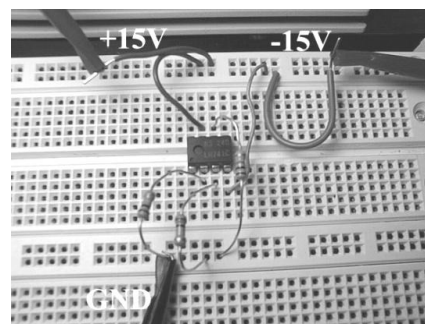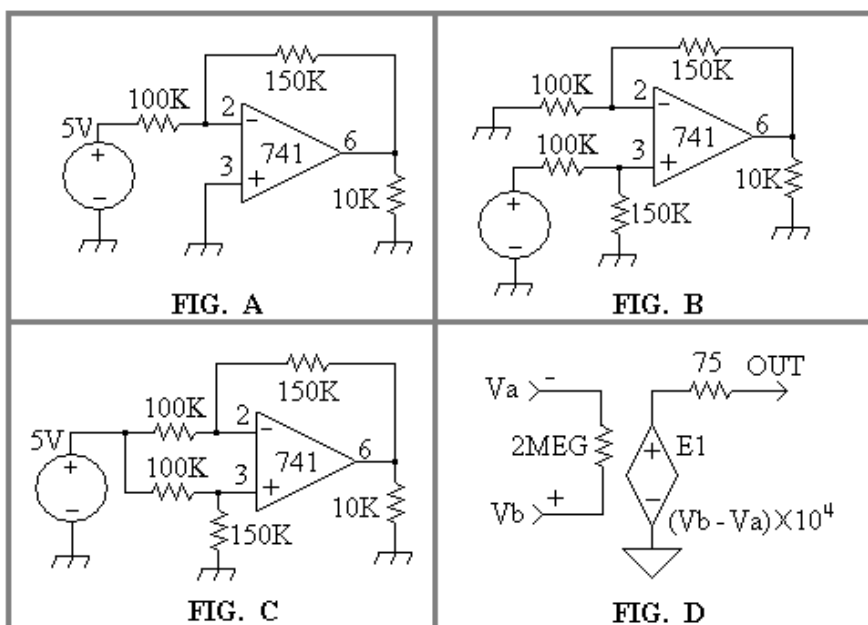

V_2 _____

V_3 _____

Part 2: Controlled Voltage Source

1. Connect the circuit in Figure A below:

FIG. A   FIG. B

FIG. C   FIG. D

2. Note that although the +15 V and -15 V supplies are not shown on the diagrams, however, the op-amp must have these voltages to operate.

3. For the circuit in Figure A, measure and record the voltages on pins 2, 3, and 6 of the op-amp.

V_2 _____ V_3 _____ V_6 _____

4. Connect the circuit in Figure B. Measure and record the voltages on pins 2, 3, and 6 of the op-amp.

V_2 _____ V_3 _____ V_6 _____

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5.   Connect the circuit in Figure C.   Measure and record the voltages on pins 2, 3, and 6 of the op-amp.

V_2 _____ V_3 _____ V_6 _____

Analysis

1.   Use the pin 2 to ground and the pin 3 to ground voltages from part 1, step 3, to calculate the currents into pins 2 and 3.   Indicate the current's direction using positive for current into the pin, and negative for current out of the pin.

You should convince yourself that these currents are very small, and that they can indeed be ignored when using the node voltage method to analyze the circuit.

2.   Use the node voltage method to calculate the output voltage of the circuit in Figure C. Show that the output voltage of the circuit in Figure C can be calculated using the superposition principle. The output of the circuit in Figure C can be obtained as the superposition of the outputs of the circuits in Figures A and B.

3.   Figure D is a simple voltage controlled voltage source model of the op-amp. Use this model and the node voltage method to calculate the output voltage in Figure C.

4.   Use the model in Figure D to simulate the circuit in Figure C.   Compare the simulation to your measurements.


PSpice Voltage Controlled Voltage Source Simulation

An op-amp is an example of a device which can be modeled by a voltage controlled voltage source. The *PSpice* part name for this source is "*E*" and it is found in the "*analog*" library.

The diagrams below show how an op-amp is modeled.   Rin is the op-amp's nominal input resistance and Ro is the op-amp's nominal output resistance. Values for these can be found in an op-amp data book.   Typically Rin is about 2 megohms and Ro is about 75 ohms.   The gain of the part "*E*" is set by double clicking on it. A value of 10,000 is typical for an op-amp.
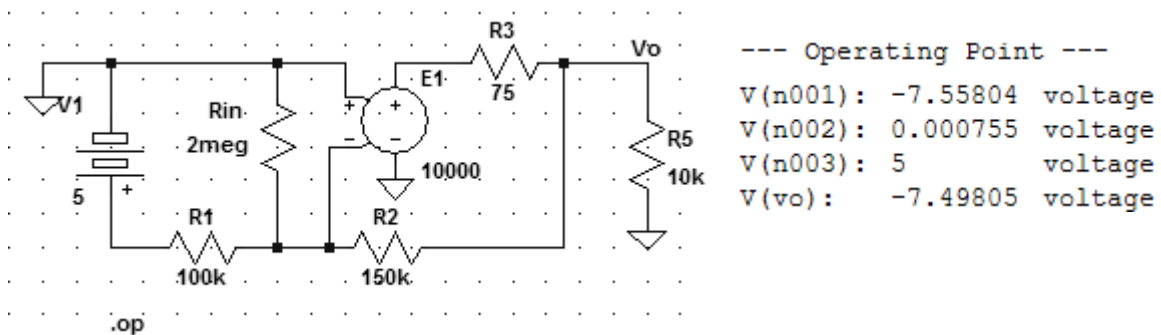

Op-Amp   Voltage Controlled
                       Voltage Source Model

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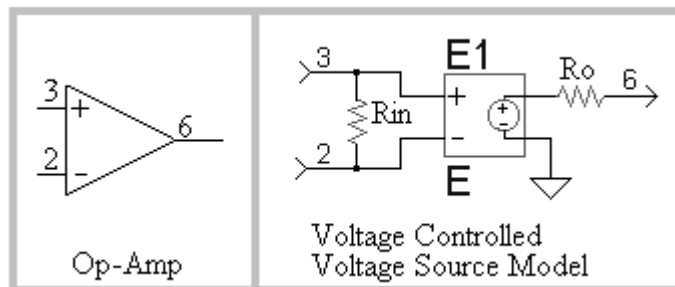
Example Circuit
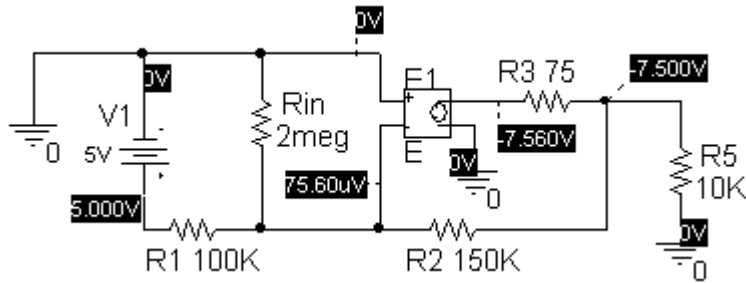
V1 was set to 5 volts. Part "*E*" is in the "*Analog*" library. Its gain was set to 10,000. The simulation type was set to "*Bias Point*". The "*V*" button was enabled in the main menu to display the voltages directly on the schematic diagram. The simulation must be run before the voltages appear.

Example: LTspice Voltage Controlled Voltage Source Simulation


```
--- Operating Point ---

V(n001):  -7.55804  voltage
V(n002):  0.000755  voltage
V(n003):  5         voltage
V(vo):    -7.49805  voltage
```
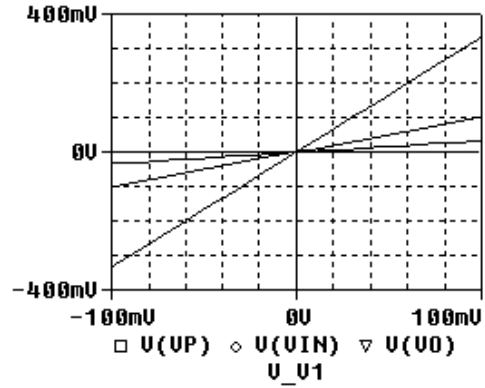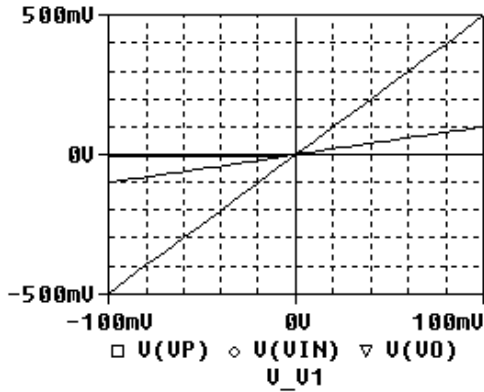
Example: OrCAD PSpice Analog Behavior Model (ABM) Simulation

PSpice is able to perform math operations using the parts in the ABM library. This example uses the parts "DIFF" and "GAIN" to model a non-inverting op-amp. V1 was swept from -100 mV to +100 mV.

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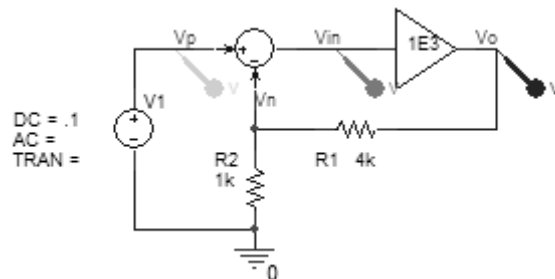
Compare the graph below on the left where the gain was set to 1000, to the one on the right, where the gain was set to 10.

Model equations: $Vin = Vp - Vn$ $\quad Vo = A \cdot Vin = A \cdot (Vp - Vn)$ $\quad Vn = \dfrac{R2}{R2 + R1} Vo = B \cdot Vo$

$$Vo = \frac{A}{1 + A \cdot B} Vp = \frac{1}{\dfrac{1}{A} + B} Vp \implies if\ A \rangle\rangle Vp,\ then\ Vo = \frac{1}{B} Vp = (1 + \frac{R1}{R2}) Vp$$

Note that if A>>1, then the gain of the circuit is that of an ideal op-amp.