Signature\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Name (print, please)\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Lab section (Mon/Wed/Fri) \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Lab partner's name \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

ECE 2100 Experiment III

Dependent Sources

# Introduction

For beginning circuit students, the concept of a dependent source is a difficult one to grasp. Usually one is familiar with independent sources, since batteries and wall plugs are commonly experienced and relatively easy to understand. However, it is difficult to imagine what a dependent source is, how it would work, and for what it would be useful. The purpose of this laboratory is to explore a dependent source and confirm that such a device can be built easily and inexpensively. The device that you will work with costs less than $1.00 and is called an *operational amplifier*.

Before proceeding with the lab, you are encouraged to review the discussion of ac signals provided in the ECE 2100 N.E.R.D. folder entitled “Review of ac Signals”. That document defines a number of terms that are used to describe periodic waveforms and that are important for labs in ECE 2100 and beyond.

**Research Question**

## What experiments can be performed to understand the operation of a dependent source?

## Components Required

## Integrated Circuits

## LM741 (op amp): this is an IC in a small black plastic package with 4 pins (contacts) protruding from either side

**Resistors**

270 Ω (1)

10 kΩ (1)

Various other resistors

## Methods

## In this experiment we will observe the operation of a dependent source. We will do this by building a voltage amplifier from an LM471 operational amplifier. The amplifier will be used to amplify a periodic signal obtained from the function generator, and the output will be observed on the oscilloscope. The amplifier can be modeled using a dependent source; we will examine this model and use it to predict the output of the amplifier circuit.

***Data***

## The data we collect will be the output of the amplifier when the input is connected to two periodic signals: a sinusoid, and a square wave.

***Data Analysis***

## We will use a circuit model that includes a dependent source to predict the output of the voltage amplifier.

**Pre-Lab Assignment**

1. Step 5: Calculate the output voltage of the circuit in Figure 4, according to the instructions in that step.

2. Step 9: Design a voltage divider that can be used to generate the voltage required for this step.

**Procedure and Results**

***Power Supply***

We will build a voltage amplifier using an LM741 op amp, of which there should be three in your lab kit. The op amp requires separate connections to +15 [V], -15 [V], and ground. The power supply configuration for doing this is given in Figure 1. These connections can be made to the banana plugs on your breadboard, or using the spring clips available among the cables provided at the lab bench..



**Figure 1.** Power supply configuration. The ground connection is connected to the third prong on the power cord of the power supply, and therefore to all of the other instrument ground connections through their power cords.

***Circuit Build***

1. Construct the circuit in Figure 2 on your breadboard. Be sure you have inserted the op amp in a way that does not “short” the leads on one side of the IC to those on the other. For now, do not connect the power supplies; these are indicated by the arrows pointing to +/- 15 [V].

For Rfeedback, choose a resistor or combination of resistors such that the ratio of Rfeedback to Rin is reasonably close to 22. Resistor Rin must be as shown in the diagram, i.e., Rin = 270 [].



**Figure 2.** Op-amp circuit. The triangle symbol represents the op amp. The numbers in the boxes are the op amp package pins, which are explained in Figure 3 below. One side of each power supply is connected to the op amp (the negative supply at pin 4 and the positive side at pin 7) and the other side is connected to ground.

The figure below shows the LM741 pin-out. In other words, it shows which pins correspond to the numbered locations in Figure 2.



**Figure 3.** Pin numbering scheme for the LM741 op-amp. The chip is being viewed from the top. The small circle or indent, whichever is present, indicates the location of pin 1.

***Sinusoidal Input***

1. Double-check your circuit, and in particular, ***test the supply voltages that will be applied to your op amp.*** If you apply these voltages in the wrong polarity you may destroy the op amp.

2. Using the three parallel BNC connectors on your bench, connect the function generator to one of input channels of the oscilloscope, and to your circuit input vin. Set the function generator to a sinusoid of frequency 1 [kHz]. Make sure that the amplitude of your input voltage is less than 0.5[V]. Connect the output of your circuit vout to a second input channel on the oscilloscope.

3. Vary the input signal amplitude, always keeping it less than 0.5[V]. Describe briefly the relationship between the input signal and the output signal. In particular, describe the relative amplitude and phase of the signals.

***RMS Amplitude***

4. The digital multimeter can be used to measure ac signal amplitudes. The multimeters in the lab measure the “root-mean-square” or “rms” amplitude, which for voltage is defined as

 (2)

There is a similar definition for currents. For a sine wave, we can show that

 (3)

**Note that this result is valid for sine waves only.** For other periodic waveforms, *Vrms* will have a different relationship to *Vm*.

Use the multimeter to find the rms values of the input and the output sinusoidal waveforms. Do this by connecting the multimeter to the input and output terminals of your circuit. Record your answers in your lab notebook.

***Equivalent Circuit***

5. The circuit model for the circuit of Figure 2 is shown in Figure 4. Note that the dc power connections are not shown here, but they must be in place for this equivalent circuit to be valid.



**Figure 4.** Circuit model for the operational amplifier circuit.

In this circuit there is a voltage-dependent current source. This means that the current through the source is a function of the voltage in another part of the circuit. This is what is found in amplifier equivalent circuits.

Using the equivalent circuit of Figure 4, calculate the output voltage expected for an input of 0.3[V] and -0.3[V] dc. In doing the calculations, assume that a signal source represented by a Thévenin voltage of magnitude 0.3[V] and a Thévenin resistance of 50[] is connected at the input. In addition, assume that you are measuring the output with an oscilloscope having an input resistance of 1[M]. Record your answers in your notebook in the form given in Table 1.

**Table 1**. Calculated output voltage of Figure 4.

|  |  |
| --- | --- |
| *vTH of source* | *vout* |
| 0.3[V] |  |
| -0.3[V] |  |

***Square Wave Input***

6. Disconnect the function generator from your circuit, but leave it connected to the oscilloscope through the parallel BNC connectors. Set the function generator for a **square wave** with an amplitude of 0.3[V] and a period of 1[ms] using the scope to check that the signal has the correct amplitude and period. Then re-apply the function generator to your circuit input. Note that the voltage you measured on the oscilloscope when the function generator was disconnected is not the same as *vin* of Figure 4 because of the 50[] source resistance of the function generator. Do not adjust the source to make *vin* equal to 0.3[V] – leave it as it is. Measure the output voltage vout with the oscilloscope. Sketch the input and output voltage waveforms in your notebook, with time as the abscissa and voltage as the ordinate.

7. Since the function generator in the lab has a Thévenin resistance of 50[] and the oscilloscope has an input resistance of 1[M], your calculations in Part 5 should relate to your measurements in Part 6. State whether this is the case or not, and explain any discrepancies.

8. As discussed above, the rms value of a periodic waveform depends on what the waveform is. In particular, for a **square wave** with no dc component,

 (4)

Verify that this is the case using the multimeter to measure the rms value of the output voltage in Part 6.

***Output Resistance***

9. The Thévenin equivalent resistance measured at the output of an amplifier is a useful parameter. The measurements in this part of the lab will allow you to determine this equivalent resistance for the amplifier used in this lab exercise.

Using the 2 – 6.5 [V] dc voltage source and two resistors, design a voltage divider to supply a **dc** voltage of 0.3[V] across the 270[] input resistor. The value 0.3 [V] should appear across the input resistor ***after*** connecting your voltage divider to it. There should be no ac signal applied for this step. Then, measure the open circuit voltage and the short circuit current at the output. Record your answers in the table below.

**Table 2.** Open circuit voltage and circuit current of amplifier.

|  |  |
| --- | --- |
| Quantity | Result |
| *vOC* |  |
| *iSC* |  |
| *RTH* |  |

# Conclusion

1. The equivalent circuit in Figure 4 has a voltage-dependent current source. Use the source transformation theorem to convert this to a voltage-dependent voltage source. Draw the equivalent circuit that would result.
2. The voltage gain of the amplifier, *Av*, in Figure 4 can be defined as the ratio of the output voltage *vout* to the amplifier input voltage *vin*. Calculate *Av* for the amplifier of Figure 4 assuming no load is connected at the output. We may also define the gain of the overall circuit, *As*, as the ratio of *vout* to the source voltage *vS*. Assuming a 50[] Thévenin resistance in the source, calculate *As*, again assuming no load is connected at the output.
3. The output resistance of an amplifier circuit such as the one in Figure 4 can be defined as the Thévenin equivalent resistance of the circuit with respect to the output terminals when a source is attached at the input. In fact, you can determine the amplifier output resistance from your measurements in Part 9. Compare this result with a calculation of the output resistance using the circuit of Figure 4. The Thévenin resistance of the source should not be important for this calculation. Prove that this is a true statement for this particular amplifier.