PRINCIPLES OF EE1 LAB

Lab

Operational Amplifiers

Full name: ……………………………………………

Student's ID:….. …………………………………….

Class: …………………………………………….....

Date: ………………………………………………….

I. Objectives

This lab introduces the operational amplifier or "op amp". The circuit is already constructed for you on a single IC (integrated circuit) and in this lab we will use the IC in several of its most popular configurations

II. Introduction

Ideal operational amplifiers (Op-Amps) are two-ports that can produce an output voltage which is directly proportional to their input voltage (linear operation). Op-Amps can be operated in two ways: open loop and closed loop. The latter circuit connection is the only one that can force the Op-Amp to operate in its linear region. An *equivalent circuit model* can be used to model or simulate the ideal Op-Amp or to incorporate deviations from ideality. The standard *inverting* and *non-inverting configurations* are explored.

The lab experiments include the realization of both configurations and the experimental determination of the circuit parameters that demonstrate the function of the circuit and allow for Op-Amp parameter derivation.

III. Theory

3. Operational Amplifiers

3.1 Op Amp Terminal Characteristics

A 741 Op-Amp is shown in Fig. 1 below. Op-Amps have two input terminals; the input voltage V_i to the Op-Amps is taken across these terminals. One terminal is called inverting or negative and the voltage there is usually denoted as V_n and the other as non-inverting (V_p) so that $V_i=(V_p-V_n)$. The output is taken between V_o and ground. Additional terminals (such as V^+ or +Vcc, V^- or -Vcc) are used for bias, offset etc.

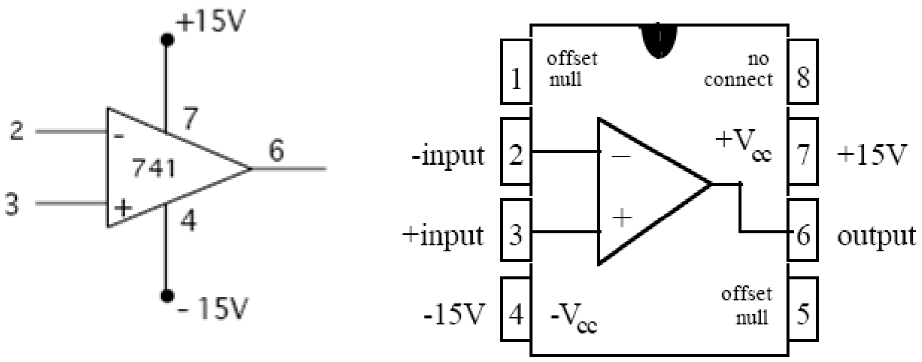


Fig.1. Pinout for the 741 Opamp

The realistic model of an operational amplifier is given in your text and repeated below with equivalent notation. It involves separate input and output circuits. The input consists of an input resistance R_i between the inverting and noninverting terminals. The output consists of a voltage dependent voltage source (with voltage A_vV_i) in series with an output resistance R_o. Note that the only connection between the input and output is through the proportionality relation of the dependent source.

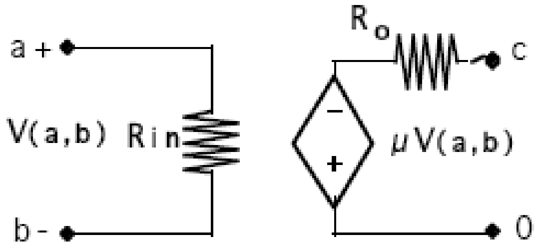


Fig. 2. An Op-am equivalent circuit.

The parameters involved are as follows:

1. **Input Voltage V_i:** $V(a,b)=V_i=(V_p-V_n)$.

2. **Output Voltage V_o:** The output voltage of an Op-Amp is proportional to the input voltage, provided it remains less in absolute value than the DC bias voltages V^+ and V^-.

3. **Input Resistance R_i:** The input resistance appears between the inverting and noninverting terminal (so that V_i appears across R_i) and can be found by dividing the input voltage V_i by the current entering the non-inverting input terminal V_p or exiting the inverting terminal V_n.

4. **Open Loop Voltage Gain μ or A_v:** The open loop voltage gain is the proportionality constant in the dependent source equation where $V = A_vV_i$ (or $V=\mu V(a,b)$).

5. **Output Resistance R_o:** The output resistance appears as a resistor in series with the dependent source. In the presence of a non-zero output resistance R_o, the output voltage across a load R_L is not all of $V = A_vV_i$ and can be found by analyzing the voltage divider between R_o and R_L.

3.2 Linear Operation and Saturation

Op-Amps have two regions of operation: *linear* and *saturation*. In the *linear region*, the *voltage transfer characteristic*, i.e. the mathematical relationship between the input and output voltages, is linear. This holds true when the output voltage lies in the range

$$V^- \le V_o \le V^+$$

From the definition of voltage gain given above, i.e. $V_o = A_vV_i$, one can see that this range corresponds to input voltages in the range of

$$\frac{V^-}{A_v} \le V_i \le \frac{V^+}{A_v}$$

In this range the output voltage is directly proportional to the input voltage, by the factor A_v.

For input voltages outside this range, the Op Amp is said to be *saturated*, and its output is bounded by the DC bias voltages. In other words, the output voltage is clamped to V^- when $V_i<V^-/A_v$ and to V^+ when $V_i>V^+/A_v$.

3.3 Characteristics of an *Ideal* Op-Amp

1. **$R_i = \infty$:** According to the definition of input resistance given above, an infinite input resistance means that no current flows into or out of the input terminals. This greatly simplifies the analysis of Op-Amp circuits.

2. **$R_o = 0$:** In this case the entire dependent source voltage appears across the load resistance or as the input of another device.

3. **$\mu = A_V = \infty$**: If the output voltage is to be finite it follows from the definition of voltage gain, that $V_i = V_o / A_v$ will go to zero if A_v is infinite. This, however, assumes that there is some way for the input to be affected by the output. Indeed this will only happen if there is such a connection namely a *negative feedback mechanism* in the form of *a connection between the output and the inverting terminal* (closed loop operation). If such connection does not exist, then the output will be saturated (open loop operation). For closed loop operation, it is said that a *virtual short* exists between the positive and negative input terminals. This means that if an Op-Amp is operating in its linear region (if it is *unsaturated*) then Vi ≈ 0, or equivalently $V_p \approx V_n$. This also simplifies the circuit calculations at the input terminals, because V_p and V_n can be represented by a single variable. When one of the two terminals is grounded, then the voltage at both terminals is zero and the other terminal is called a *virtual ground*.

3.4 Building Amplifier Circuits Using Op-Amps

There are two standard closed-loop connections for an Op-Amp. Both have in common the connection (R_f) from the output terminal to the inverting input terminal. This connection provides *the negative feedback* and ensures the virtual short. The analysis is simple for *ideal* Op-Amps since:

(a) the two input terminals are at the same voltage and

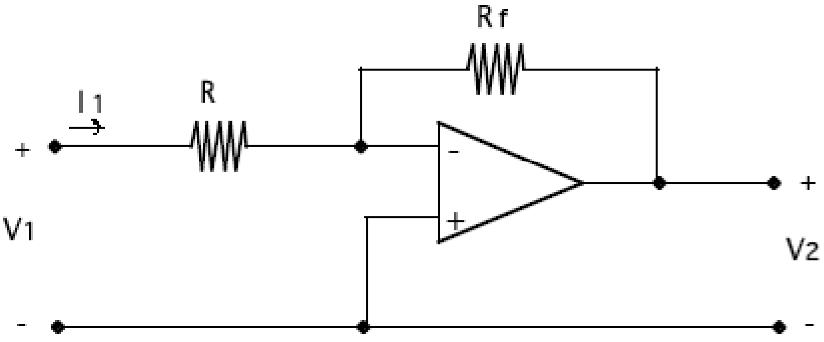
(b) there is no current into the input terminals.

The analysis usually derives a gain or amplification. It is important to note that this is the gain of the *whole stage* (or the closed loop gain) and should not be confused with the gain of the Op Amp alone.

One last note: negative feedback does not guarantee that the amplifier will not saturate. If the input is such that the output, based on the amplification of the whole stage, is expected to be larger than the bias voltage in absolute value ($V_o> V^+$ or $V_o< V^-$) then the output *will* be clamped to V^+ (or V^-).

3.4.1 The Inverting Amplifier

V_1



V_2

Fig. 3. An inverting amplifier

Circuit analysis of the inverting amplifier in Fig. 3 yields the equation,

$$V_2 = K\,V_1 = (-R_f/R)V_1 \quad (1)$$

Thus, the theoretical gain K of the whole stage (that is, the entire Op-Amp circuit of Fig 3.) is given by

$$K = V_2/V_1 = (-R_f/R).$$

3.4.2. The Non-Inverting Amplifier

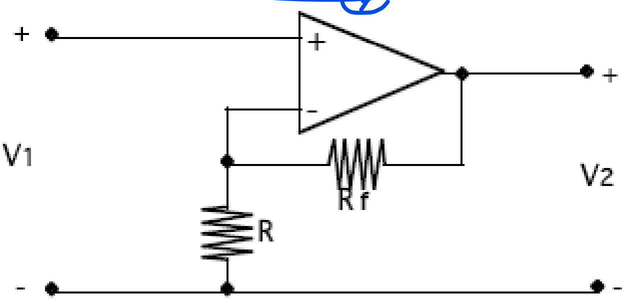
Circuit analysis of the non-inverting amplifier shown in Fig. 4 yields the equation,

$$V_2 = (1+R_f/R)V_1 \quad (2)$$

Thus, the theoretical gain K of the whole stage is given by

$$K = V_2/V_1 = (1 + R_f/R).$$

V_1



V_2

Fig. 4. A non-inverting amplifier.

IV. Calculation

4.1 Calculate the gain K for the inverting amplifier circuit in Fig. 5 assuming that the Op-Amp is ideal and using the resistance values specified in 5.1.1.

4.2 Express the Gain K for the non-inverting amplifier of Fig.6 in term of R2 and R1, assuming that the Op-amp is ideal.

4.3 Given the results of question 4.2, calculated values R1 and Rf that produce the circuit gain of 10.

V. Simulation/Experiment

You will be using the "741" Op-Amp which is biased at +15V and -15V. The chip layout is shown in Fig. 1. The standard procedure on such chip packages (DIP15) is to identify pin 1 as the one to the left of the notch in the chip package. The notch always separates pin 1 from the last pin on the chip. In the case of 741, the notch is between pins 1 and 8. Pins 2, 3, and 6 are the inverting input V_n , the non-inverting input V_p, and the amplifier output V_o respectively. These three pins are the only three terminals that usually appear in an Op-Amp circuit schematic diagram.

Required equipment (Offline lab):

Electronic board with Power Supply
Digital Multimeter
741 Operational Amplifier
10KΩ, 100KΩ, 2.2KΩ Resistors

5.1 Experiment 1: Inverting Amplifier

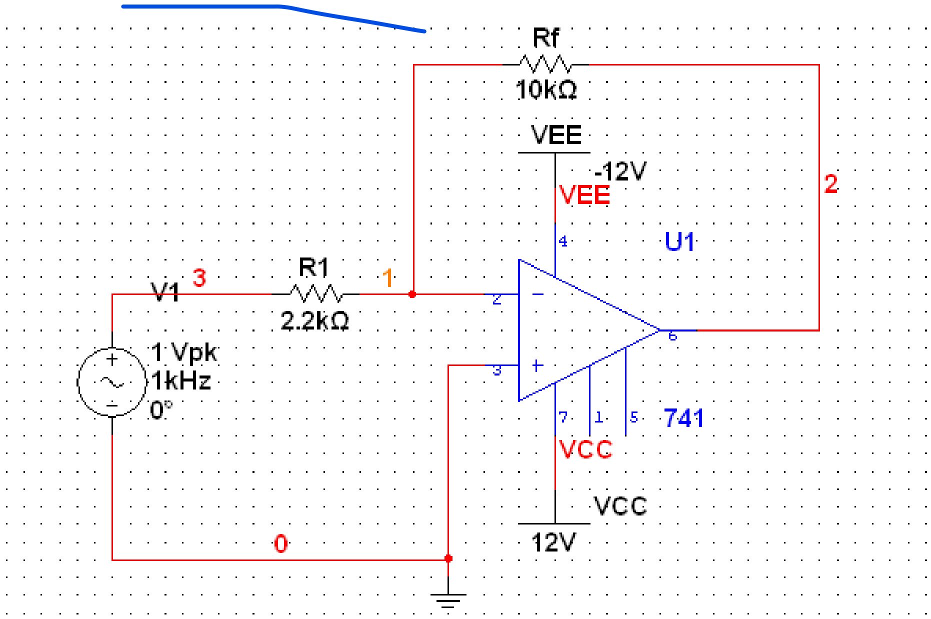


Fig. 5. An inverting amplifier configuration.

Procedure phase shift = 180

4.54V

5.1.1 Construct the circuit in Fig. 5 with R1 =2.2kΩ, and R_f =10kΩ, 1V input signal at 1Khz. Measure the gain. Sketch the results on the oscilloscope.

11.11V

5.1.2 Calculate and measure the gain with R1 = 2.2kΩ and Rf = 100kΩ. Compare results with previous case. Sketch the results on the oscilloscope.

phase shift = 183.6

a. Compare the measured/simulated output signal in 5.5.1 and 5.1.2? Explain the differences.
b. Find the phase difference between the input and output of inverting amplifier? Why is this called an inverting amplifier?

phase diff = 3.6 inverting because it has phase shift

5.2 Experiment 2: Non-Inverting Amplifier

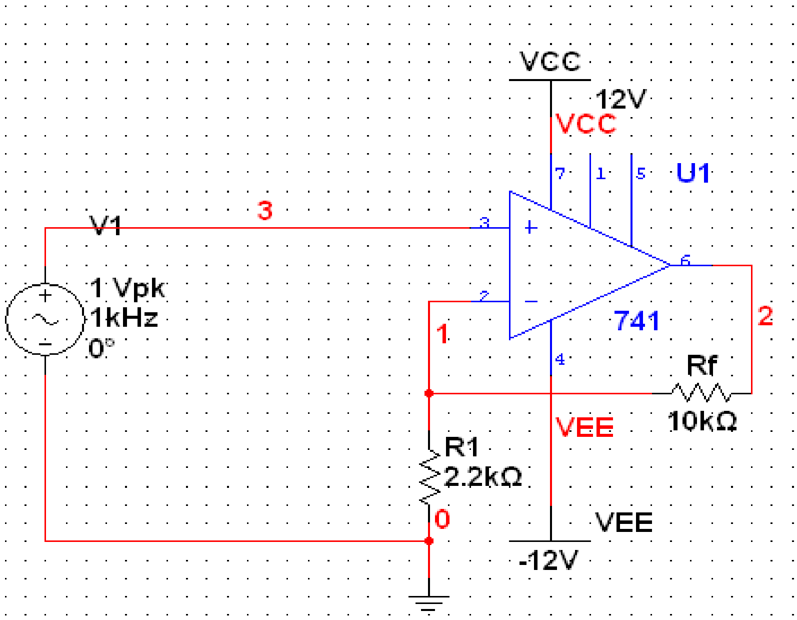


Fig. 6. A non-inverting amplifier configuration

5.2.1 Construct the non-inverting amplifier shown in Fig. 6 with R1 = 2.2kΩ and Rf = 10kΩ. Measure the gain. 6.16V

5.2.2 Repeat section 5.2.1 with R1 = 2.2kΩ and Rf = 100kΩ. Compare the results. 12.22V

a. Compare the measured/simulated output signal in 5.2.1 and 5.2.2? Explain the differences.
b. Find the phase difference between the input and output of inverting amplifier? Why is this called an inverting amplifier?

phase difference = 0

non- inverting because no phase shift

5.3 Experiment 3: Comparator using OPAM

Note: Function generator and oscilloscope are not used in this experiment.

Build the circuit as followed:

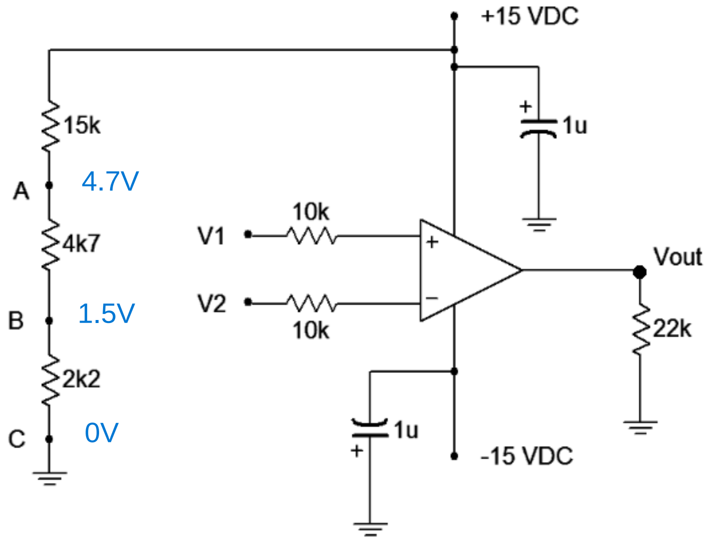


Fig. 7. OPAM Comparison circuit

5.3.1 Calculate the **DC** voltages at points A, B, and C.

5.3.2 Using the input combinations listed in Table 2, apply the appropriate signals to V1 and V2. Measure the output voltage and record values in Table 1. Conclude on the working principle of the OPAM used in the comparison circuit (show the relationship between V^{+}, V^{-} *and* V_{OUT}).

Table 1.

V1 (Volts)	V2 (Volts)	V_{OUT} (Volts)
$= V_A$	$= V_A$	13.8653
$= V_A$	$= V_B$	13.958
$= V_A$	$= V_C$	13.958
$= V_B$	$= V_A$	-13.958
$= V_B$	$= V_B$	13.8635
$= V_B$	$= V_C$	13.958
$= V_C$	$= V_A$	-13.958
$= V_C$	$= V_B$	-13.958
$= V_C$	$= V_C$	13.8626

THE END