EXPERIMENT 3

Circuit Construction and Operational Amplifier Circuits

Introduction

In this experiment you will learn how to build your own circuits using a temporary assembly technique known as breadboarding. You will breadboard several circuits containing resistors and operational amplifiers (op-amps). You will use the Analog Trainer breadboard system, in addition to the DMM, oscilloscope, and function generator.

Experiment Objectives:

• Learn how to construct circuits using an analog breadboard system.
• Learn to build and test several important op-amp circuits.

Bring to Lab:

Your completed Pre-Lab. Turn this in when you get to lab. Several sheets of Engineering Paper.

Breadboarding

It is often useful to build an electronic circuit in a non-permanent form that allows for quick and easy changes. This is called prototyping. A convenient device used by circuit designers for prototyping is the breadboard, or proto-board.

A breadboard is a plastic block containing an array of connection holes called tie-points. Each tie-point is connected to several others by metal strips inside the block. The tie-point holes are designed so that the common sizes of hookup wire can make a secure connection when the ends are stripped of insulation and inserted directly into the holes.

In this experiment, we will use an Analog Trainer that includes a breadboard, several power supplies, a function generator, some potentiometers (variable resistors), meters, a loudspeaker, and external connection jacks all in one portable unit. A photograph of the Analog Trainer is shown in Figure 1. The breadboard area can be used regardless of whether the main power is turned on. However, use of the built-in power supplies (+5V, +15V variable, and –15V variable) and the function generator requires turning on the main power.

Figure 2 shows how the breadboard tie points are connected internally. There are two different types of areas on the breadboard– component areas and power strips. The component areas are connected vertically, while the power strips are connected horizontally.

Theory: Operational Amplifier (Op-Amp) Circuits

Operational amplifiers are one of the most widely used electronic devices. Although the op-amp is actually a complicated transistor circuit, its function is quite simple. It produces an output equal to the difference between two
inputs, multiplied by a large number called the \textit{gain}. The op-amp is studied in detail in electronics courses, but in this experiment we will simply build and study a few of the most common application circuits.

Figure 1. Analog Trainer Breadboard System.

Figure 2. Close-up of breadboard. Red lines indicate internal connection patterns. Arrows mean the pattern is repeated across the board. Horizontally-connected strips are usually used to distribute power supply voltages.
The operational amplifier we will use is on a single integrated circuit chip (IC) which can be easily mounted on the breadboard. The op-amp circuit symbol is shown in Figure 3.

![Operational Amplifier Circuit Symbol](image)

**Figure 3. Operational Amplifier Circuit Symbol.**

The op-amp equation is

$$V_{OUT} = A(V_1 - V_2)$$

where $A$ is called the open-loop gain. The open-loop gain of a particular op-amp is given on manufacturer data sheets, usually expressed in volts per millivolt (V/mV). Typical values are in the range of 200 V/mV.

The terminal labeled with a “+” sign is called the NON-INVERTING terminal. The terminal labeled with a “−” sign is called the INVERTING terminal.

The voltages $V_+$ and $V_−$ are DC power supply voltages which provide the necessary power to operate the transistor circuitry inside the op-amp. Typical values are in the range of ±5 to ±15 V. An important consideration in op-amp circuit design is that $V_{OUT}$ cannot be outside the range of the power supply voltages.

Almost all practical applications of op-amps use a negative feedback configuration, in which the output is connected back to the inverting terminal. This is called closed-loop operation. Four of the most important op-amp circuits are introduced next.

**The Inverting Amplifier**

An op-amp circuit called the inverting amplifier is shown in Figure 4.

For this circuit, it can be shown that the output voltage is:

$$V_{OUT} = \left(\frac{R_f}{R_{1N}}\right) V_{IN}$$

......Eq. 1

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The gain of an amplifier circuit is defined as the ratio of output voltage to input voltage. We will denote the gain by $A_V$, and we can write Equation 2:

$$GAIN = A_V = \frac{V_{OUT}}{V_{IN}} = -\left(\frac{R_F}{R_{IN}}\right)$$

......Eq. 2

There are three points worth noting about this amplifier:

- The gain is always negative, since resistors always have positive values. This means if the input is a positive voltage, the output will be negative, and vice-versa. This is why this amplifier is called “inverting.”
- The output can be greater than the input (gain greater than one), as long as it does not exceed the power supply voltage range.
- The gain can be varied by using a variable resistor for $R_F$ or $R_{IN}$.

Example 1:
Let $V^+ = 15$ V and $V^- = -15$ V. Let $R_F = 10$ kΩ and $R_{IN} = 1$ kΩ, and $V_{IN} = 0.1$ V. Then

$$V_{OUT} = -\frac{10,000}{1,000} (0.1) = -1.0 \text{ V}.$$  

Since this is not more negative than $V^-$, it is OK.

Example 2:
Let $V^+ = 15$ V and $V^- = -15$ V. Let $R_F = 100$ kΩ and $R_{IN} = 500$ Ω, and $V_{IN} = -1$ V. Then

$$V_{OUT} = -\frac{100,000}{500} (-1) = 200 \text{ V}.$$  

Since this is larger than $V^+$, the actual output will be limited by the power supply to about 15 V.
The Non-inverting Amplifier

A non-inverting amplifier circuit is shown in Figure 5.

Figure 5. A non-inverting amplifier.

For this circuit, it can be shown that the output voltage is:

$$V_{OUT} = \left(1 + \frac{R_F}{R_{IN}}\right) V_{IN}$$

......Eq. 3

and so the gain is:

$$GAIN = A_v = \frac{V_{OUT}}{V_{IN}} = \left(1 + \frac{R_F}{R_{IN}}\right)$$

......Eq. 4

There are three points worth noting about this amplifier:

- The gain is always positive and greater than or equal to one, since resistors always have positive values. This means if the input is a positive voltage, the output will be positive, and vice-versa. This is why this amplifier is called “non-inverting.”
- The output can be greater than the input (gain greater than one), as long as it does not exceed the power supply voltage range.
- The gain can be varied by using a variable resistor for $R_F$ or $R_{IN}$. 

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The Unity-Gain Amplifier (Buffer)
An important special case of the non-inverting amplifier circuit is shown in Figure 6. This circuit requires no resistors, and provides a gain of exactly one, i.e., the output voltage is equal to the input voltage. This circuit "buffers", or isolates, the input from the output, which is often a desirable feature, for example when connecting real-world signals into delicate computer circuitry.

\[ V_{OUT} = V_{IN} \]

\[ GAIN = A_v = \frac{V_{OUT}}{V_{IN}} = 1 \]

There are three points worth noting about this amplifier:

- The gain is exactly equal to one, which means the output is equal to the input (as long as both are within the power supply range).
- The gain cannot be varied.
- Any current supplied to the output is provided by the DC power supplies V+ and V– rather than by the input voltage source. This is referred to as "buffering."

The Difference Amplifier
The difference amplifier circuit is shown in Figure 7. (This circuit is sometimes called a "differential amplifier.") This circuit provides an output equal to the difference between two inputs, multiplied by a variable gain.
For this circuit, it can be shown that the output voltage is:

\[ V_{OUT} = \frac{R_2}{R_1} (V_1 - V_2) \]

......Eq. 9

and the gain is:

\[ GAIN = A_v = \frac{V_{OUT}}{(V_1 - V_2)} = \frac{R_2}{R_1} \]

......Eq. 10

There are two points worth noting about this amplifier:

- This circuit requires two matched pairs of resistors.
- To change the gain, the matched pairs must be changed in tandem (i.e., both \( R_1 \)'s or \( R_2 \)'s must be changed at the same time).
Your Name

Prelab Questions (10 points)

Answer these questions before coming to lab and turn them in when you arrive. You may do your work on separate paper (for example you might want to do your work on a computer), but please attach your work to this sheet for submission.

For questions 1 - 4, assume the power supply voltages are \( V^+ = 12 \text{ V} \) and \( V^- = -12 \text{ V} \).

1) An inverting amplifier has \( R_f = 20 \text{ k}\Omega \) and \( R_{\text{IN}} = 5 \text{ k}\Omega \). What is the gain?

2) For the amplifier in question (1), what is the output voltage if the input voltage is +2 V? \text{Ans.}: -8 V

3) A non-inverting amplifier has the same resistor values as in question (1). What is the output voltage if the input voltage is +2 V? \text{Ans.}: 10 V

4) A difference amplifier has \( R_2 = 1 \text{ M}\Omega \) and \( R_1 = 100 \text{ k}\Omega \). What is the output if \( V_1 = 1 \text{ V} \) and \( V_2 = -1 \text{ V} \)? (The prefix M stands for "meg" which is \( 1 \times 10^6 \).) \text{Ans.}: Approx. 12 V.

5) Using the web, find the data sheet for an op-amp similar to the one we will be using. You can find this at the following web site for Texas Instruments:

http://www.ti.com

by using the search box and typing in the part number: TL082. Then you should get a list of choices. In the list, click on the TL082 Product folder, and then click on Data Sheet. This should bring up the data sheet in PDF. The first page should be a description, and the second page should include several chip pin-out diagrams for various packages. Print out the first two pages of the data sheet and bring them to lab with you.