Notes on Experiment #10

Prepare for this experiment!

Read the [OP-Amp Tutorial](#) before going on with this experiment.

For any Ideal Op Amp with negative feedback you may assume:

- \( V^- = V^+ \) (But not necessarily 0)
- \( I^- = I^+ = 0 \)
- Now write KCL equations everywhere except at V-sources and the Op-Amp output.
- Do some algebra to find your answer

**Part 2: Op Amp as a Linear Amplifier**

Since the circuit has negative feedback the above assumptions are true. Refer to Figure 3 in the experiment.

Let's find \( V_O = f(V_s) \)

**KCL at \( V^- \):**

\[
(V^- - V_s)/1K + (V^- - V_o)/10K = 0
\]

But \( V^- = V^+ = 0 \) So,

\[
V_O = - (10K/1K)V_s = -10V_s
\]

Let \( V_s = 1\cos(2000(\pi)t) \) volts. Then,

\[
V_O = -10(1\cos(2000(\pi)t)) = -10\cos(2000(\pi)t) \text{ volts.}
\]

Let \( V_s = 2\cos(2000(\pi)t) \) volts. Then,

\[
V_O = -10(2\cos(2000(\pi)t)) = -20\cos(2000(\pi)t) \text{ volts.}
\]
But in this case the output voltage exceeds the supply voltage of the opamp. So the 
opamp goes into "saturation" for \(|V_O| > 15\) volts. The result of this is that the peaks of the 
\(-20\cos(2000\pi t)\) are "clipped off" at +15 and -15 volts.

**Part 3: Op Amp as a Linear Adder**

Since the circuit has negative feedback the above assumptions are true. Refer to Fig.4 of 
the experiment.

Let's find \(V_O = f (V_a, V_b)\)

**KCL at \(V^-\):**

\[
\frac{(V^- - V_a)}{10K} + \frac{(V^- - V_b)}{20K} + \frac{(V^- - V_O)}{10K} = 0
\]

But \(V^- = V^+ = 0\) So,

\(V_O = -(10K/10K)V_a -(10K/20K)V_b = -1(V_a + 1/2V_b)\)

**Part 4: Op Amp as an Integrator**

Since the circuit has negative feedback the above assumptions are true. Refer to Fig. 5 of 
the experiment.

Let's find \(V_O = f (V_S)\)

**KCL at \(V^-\):**

\[
\frac{(V^- - V_S)}{R} + i_C + i_{100k} = 0
\]

But \(V^- = V^+ = 0\), assume \(i_{100k} = 0\) and

\[
i_C = C \frac{dV_C}{dt} = C \frac{d(0 - V_O)}{dt}
\]

So,

\[
-\frac{V_S}{R} - C \frac{dV_O}{dt} = 0
\]

\[
\frac{dV_O}{dt} = -\frac{V_S}{RC}
\]

So,

\(V_O = (-1/RC) \int_0^t V_S dt\)
Let $R = 10K$, $C = 0.02\mu F$ and $V_S = 4 \cos(10000\pi t)$ volts. Then,

$$V_o = -\frac{1}{10000 \times 0.02 \times 10^{-6}} \times \frac{(-4)}{10000\pi} \times \sin(10000\pi t)$$

Or, $V_o = 0.637 \sin(10000\pi t)$
The Basic Ideal Op-Amp Analysis Strategy

For any Ideal Op-Amp with negative feedback you may assume:

- $V^- = V^+$ (But not necessarily 0)
- $I^- = I^+ = 0$
- Now write KCL equations everywhere except at V-sources and the Op-Amp output.
- Do some algebra to find your answer
- Since the output voltage can not exceed the power supplies, check to see that

$V_{PS-} < V_O < V_{PS+}$

The Inverting Amplifier Configuration

![Figure 1](image)

Since the circuit in Figure 1. has negative feedback the above assumptions are true.
Let's find \( V_O = f(V_S) \)

**KCL at \( V^- \):**

\[
\frac{(V^- - V_S)}{R_1} + \frac{(V^- - V_O)}{R_F} = 0
\]

Note that in this case \( V^+ = 0! \) So,

\( V^- = V^+ = 0. \) So,

\( V_O = -\left(\frac{R_F}{R_1}\right)V_S. \) Note that the value of \( R_L \) does not matter!

Let \( V_S \) be a triangle wave with peaks at +2 and -2. See Figure 2. Let \( R_F = 6K \) and \( R_F = 2K. \) So,

\( V_O = -\left(\frac{6K}{2K}\right)V_S \) is an "upside down" triangle 3 times taller than \( V_S. \) So, the peaks of \( V_O \) are at +6 and -6. See Figure 2.

If \( V_{PS-} = -10 \) Volts and \( V_{PS+} = +10 \) Volts then the output voltage \( V_O \) is well within the power supply limits and linear amplification does indeed take place as seen in Figure 2.

![Figure 2](image.png)

Now let \( V_S \) be a triangle wave with peaks at +2 and -2. See Figure 3. Let \( R_F = 12K \) and \( R_F = 2K. \) So,
Vo = -(12K / 2K)Vs is an "upside down" triangle 6 times taller than Vs. So, the peaks of Vo should be at +12 and -12.

But if V_{PS-} = -10 Volts and V_{PS+} = +10 Volts then the output voltage Vo tries to exceed the power supply limits. When the output tries to go beyond the power supply limits we say that the op-amp is "in saturation." Linear amplification does not take place when the op-amp is in saturation. Output values are "clipped" at the supply values as seen in Figure 3.
The Summing-Inverter Configuration

Figure 4.

Since the circuit in Figure 4. has negative feedback the above assumptions are true.

Let's find $V_O = f(V_1, V_2)$

**KCL at $V^-$:**

$$(V-V_1)/R_1 + (V-V_2)/R_2 + (V-V_O)/R_F = 0$$

Note that since the current $I^- = 0$ then there is no voltage across $R_X$. So, $V^+ = 0$.

But $V^- = V^+ = 0$. So,

$$V_O = -[(R_F/R_1)V_1 + (R_F/R_2)V_2]$$
The Non-Inverting Configuration

Figure 5.

Since the circuit in Figure 5 has negative feedback the above assumptions are true.

\[
\frac{(V-0)}{R_1} + \frac{(V-V_O)}{R_F} = 0
\]

But \( V^- = V^+ = V_S \). So,

\[
V_O = \left( \frac{R_F}{R_1 + 1} \right) V_S
\]
The Voltage Follower Configuration

Figure 6.

Since the circuit in Figure 6. has negative feedback the above assumptions are true.

By inspection

\[ V_O = V_- = V_+ = V_S \]

We say that the output voltage follows the input voltage. They are in phase and have the same magnitude.

The Differential Configuration
Can you show that

\[ V_O = \left(\frac{R_F}{R_1} + 1\right)\left(\frac{R_X}{R_X + R_Y}\right)\left(V_{S2} - \frac{R_F}{R_1}V_{S1}\right) \]

Note that if all the resistors are the same value then

\[ V_O = V_{S2} - V_{S1} \]

**Finding the Output Current** \( I_O \)
Figure 8.

Since the circuit in Figure 8 has negative feedback the above assumptions are true.

Find $V_O$ first using the same procedures as in the inverting amplifier configuration. Then find $I_O$ by writing a KCL equation at $V_O$ using the KNOWN VALUE of $V_O$ and $V-$ that you just calculated.

KCL at $V_O$:

$$I_O = \frac{(V_O - V_-)}{R_F} + \frac{V_O}{R_L}$$

Note that since the current $I+ = 0$ then there is no voltage across $R_2$. So, $V_+ = 0$

**Practice Problem**

Can you find $V_O = f(V_S)$ for the circuit in Figure 9?
Figure 9.
ECE 210 Experiment #10

Operational Amplifiers

Purpose: To illustrate a few of the uses of op amps.


I. Introduction
   a. Op Amp Pin Conventions are as Follows:

Figure 1.
Note that pin number 1 is adjacent to the dot impression on the top of the IC (Integrated Circuit.) There may also be a notch cut out of the top of the IC on the end where pin 1 is located.

Insert the op amp across the groove in the breadboard so that each pin is inserted into a unique connector. Be careful, the pins are easy to bend.

b. **DC Power Supply Setup**

Two DC power sources are required to insure proper operation of the op amp. Select the +25 output on the DC supply. Adjust the voltage from the + side of the +25 output to COM to be +15 volts. Check to ensure the voltage is +15 by using the DMM as voltmeter. Select the -25 output on the DC supply. Adjust the voltage from COM to the - side of the -25 output to be +15 volts. Check to ensure the voltage is +15 by using the DMM as voltmeter. The COM terminal will be the circuit ground for all parts of this experiment. Be sure to make proper circuit ground connections for each circuit before connecting the power lines to pins 4 and 7. Failure to do this will almost certainly cause the op amp to burn out. See Figure 2.

![Figure 2](image-url)

**Signal Source:**
Turn on the signal generator, and adjust its AC output to minimum with the output amplitude knob. Adjust the DC offset of the signal generator to zero. Check to ensure the DC offset is zero by using the DMM as a DC voltmeter for accuracy.

II. Op Amps as Linear Amplifiers

In this part you will set up an op amp as a linear amplifier with a gain of 10, and inspect the input and output to see how well or poorly it behaves as such a device. Operational amplifiers must be treated with care; they are powerful but can be destroyed by abuse. In particular it is very abusive to apply voltages to the input terminals before fully powering up the opamp, or to exceed certain maximum limits. Therefore, you will (a) set up the signal source but with zero output; (b) set up the rest of the circuit; (c) have your instructor check the circuit; and THEN (d) power the circuit up for the experiment.

**Inverting Amplifier Circuit:** wire up the circuit in Figure 3 below, checking carefully to see that it is correct, but with ALL POWER OFF (no connection to pins 4 and 7 yet) and the signal generator disconnected from the rest of the circuit. Connect $V_{s1}$ to CH1 and $V_o$ to CH2 of the scope. Set the scope to display both of them simultaneously.

Note: Set the scope to trigger off of CH1 for all parts of this experiment. Your instructor will show you how to do this.
Have your instructor check your circuit before any power is turned on. Power up the op amp by applying the 15 volt sources. Be sure the polarities are correct. Set the function generator to a 1 KHz sinusoidal function. Now gently increase the amplitude of $V_{S1}$. You should see an inverted and amplified version of $V_{S1}$ at $V_O$. Adjust $V_{S1}$ to have a peak-to-peak voltage of 2 volts. Set the vertical scales for CH1 to 1V/D and CH2 to 5V/D. Sketch one cycle of both $V_{S1}$ and $V_O$ on the same set of axis (just as you see on the scope.) Be sure to note the scales. Is the amplifier working as expected? Is the gain correct? Is the output inverted with respect to the input? Repeat the above using a triangle input voltage of 2 volts peak-to-peak. Be sure to sketch the results.

Experiment with the amplitude of the input signal to see the effect of overdriving the op amp with a signal too big for it to amplify faithfully. Set the amplitude of the triangle wave to 4 volts peak-to-peak. What happens to $V_O$? Sketch the signals.

Reduce the input to 2 volts peak-to-peak and experiment with the effect of the DC offset of the input signal. Is the DC offset amplified? Set the DC offset to 0.5 volts and sketch the signals.

III. The Op Amp as a Linear Adder

Set up circuit in Figure 4, using the same precautions as before to protect the op amp from damage. In this circuit the output should be a linear addition of the two input signals $V_{S1}$ and $V_{S2}$. Use a triangle wave with 4 volts peak-to-peak amplitude for $V_{S1}$ with the DC offset set to zero. Use the Sync output of the function generator as $V_{S2}$. Display $V_{S1}$ and $V_{S2}$ on the scope. Set the vertical scales of both channels to 1V/D. Sketch one cycle of each function. Keeping $V_{S1}$ connected to CH1 display $V_O$ on CH2. Sketch $V_O$. Figure out just what the relationship should be between $V_O$ and the two inputs, and see if what you observe is what you would expect on the basis of the theory. If you have time, experiment with the sine and the square wave for $V_{S1}$. 
IV. The Op Amp as an Integrator

Set up the circuit in Figure 5 with the scope set to display $V_s(t)$ and $V_o(t)$ on CH1 and CH2. Select $R=10K$ and $C=0.02\mu F$. Set $V_{S1} = 4\cos(10000\pi t)$ volts. Be sure that the DC offset is set to zero. Figure out the theoretical relationship between $V_s(t)$ and $V_o(t)$ for this circuit ignoring the current through the 100K resistor, and figure out what the output should be if the input signal is (1) a sinusoid (as above); (2) a square wave; (3) a triangle wave. Then apply these signals to the circuit and check your predictions.

Note: Try setting the coupling to AC (for both channels) if the images are not centered on the display. Your instructor will show you how to do this.

If the current through the 100K resistor is very small compared to the current through the capacitor, your analysis will be accurate. This will be true for signals at the frequency your instructor suggests. The 100K resistor is provided to avoid saturation of the op amp due to DC offset - a technical matter you can ignore for the time being.
Figure 5.