Amplifiers and Mixers

Introduction

Op-amp circuits are kind of like lego blocks. When you want a certain function, you plug in a given circuit. Some of the resistor values may need to be adjusted and/or calculated, but there's pretty much a standard op-amp circuit for various functions.

In this lecture, six commonly used op-amp circuits will be presented as in Table 1. If you want a certain function, just plug in the corresponding circuit.

Circuit	Relationship
Buffer	Y = X
Noninverting Amplifier	Y = +k X
Noninverting Summing Amplifier	Y = a A + b B + c C
Inverting Amplifier	Y = -k X
Summing Inverting Amplifier	Y = -a A - b B - c C
Instrumentation Amplifier	Y = k(A - B)

Table 1: Types of Op-Amp Circuits Covered in This Lecture

Each of these circuits assume ideal op-amps. As long as you do the following, the ideal op-amp model should work.

1) Keep 500 Ohms < R < 1M Ohms
- This keeps the output current less than 20mA (the max for an LM358)
- This keeps the input impedance (111M) irrelevant

2) Keep the gain < 100
- The gain bandwidth product for an LM358 is 1,2MHz
- Keeping the gain less than 100 allows you to operate up to 12kHz

3) Use a power supply that's at least 2V more than the maximum output voltage.
- If the output is to vary from -5V to +5V, use a power supply that's at least +/- 7V. This keeps the output from clipping.

Buffer

- Y = X
- High input impedance
- Low output impedance

The buffer circuit is used to prevent the output (Y) from loading the input (X). This is usually the first circuit I build to test if I have a good op-amp. Apply a sine wave at X and check to see that you also have a sine wave at Y with the same amplitude. If this circuit doesn't work, you have a bad op-amp.

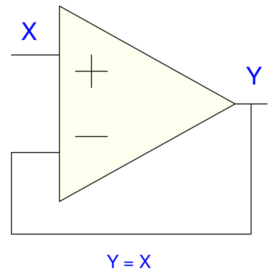

Figure 1: Buffer Circuit

A typical test circuit is shown in Figure 2 with CircuitLab. Here, a 5Vp sine wave is applied at X. Y should likewise be a 5Vp sine wave. R7 checks to make sure the op-amp is able to drive a 50mA load (5V @ 100 Ohms). If you're using an LM358 which is only rated to 20mA, R7 should be increased to 250 Ohms.

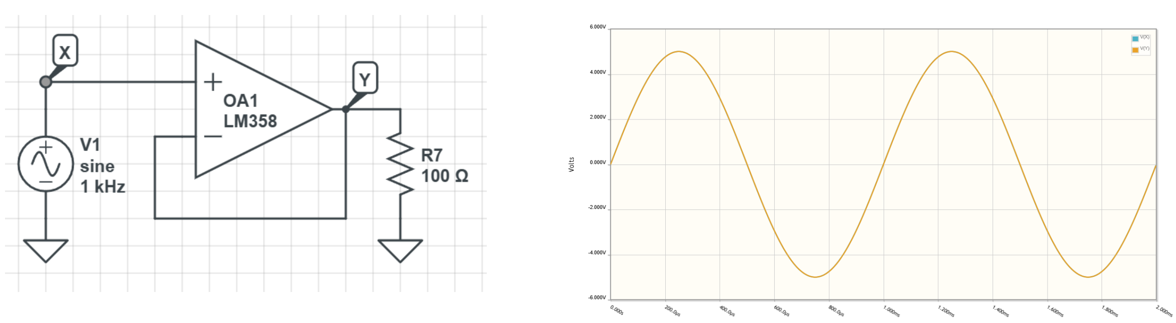

Figure 2: CircuitLab simulation checking that the op-amp is working properly

An example of where you would use a buffer circuit is in Figure 3. Here, a 2.5V reference voltage is generated using two a 5V source and two 100k resistors. The buffer circuit copies this voltage, but reduces the output impedance so that it is able to source or sink up to 20mA.

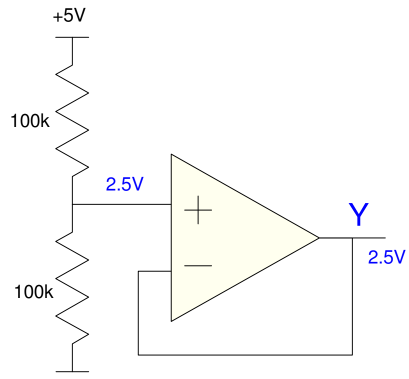

Figure 3: Application of a Buffer Circuit. Provide a 2.5V reference that capable of sourcing of sinking up to 20mA.

Noninverting Amplifier

Amplifiers are very common. Any time you have a small signal and want to make it larger, an amplifier is often the circuit you want.

A noninverting amplifier show in Figure 4 has a gain of

$$Y = \left(1 + \frac{R_1}{R_2}\right) X$$

There are several ways to get this result. Simplest is to note that R1 and R2 form a voltage divider:

$$V_m = V_p = X = \left(\frac{R_2}{R_1 + R_2}\right) Y$$

Solving for Y

$$Y = \left(\frac{R_1 + R_2}{R_2}\right) X = \left(1 + \frac{R_1}{R_2}\right) X$$

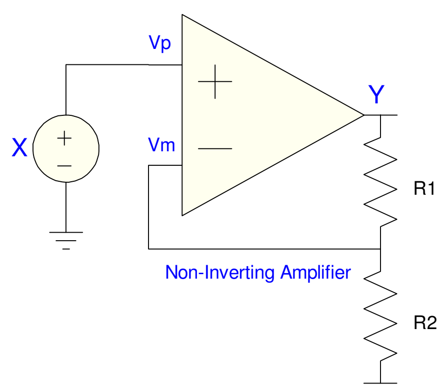

Figure 4: Noninverting amplifier

In Figure 5, a CircuitLab simulation of a noninverting amplifier with a gain of 1.5 is shown. Note that

- The output and the input are in phase (positive gain), and
- The output is 1.5x the input

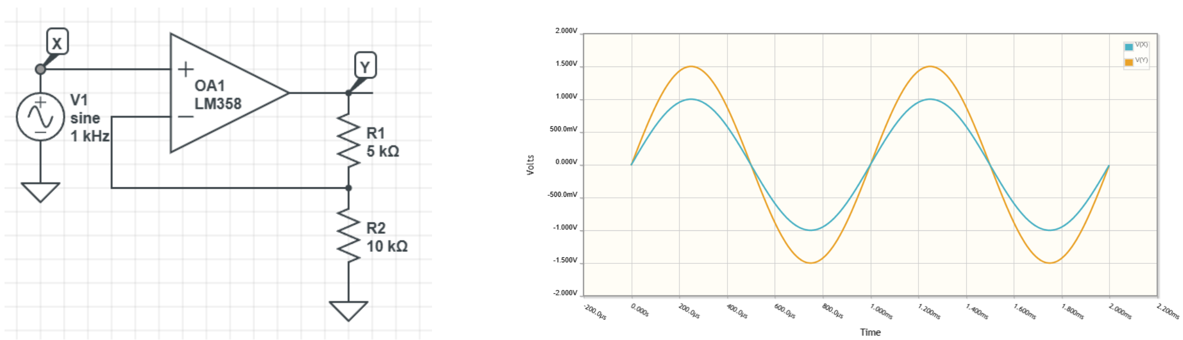

Figure 5: CircuitLab simulation of a noninverting amplifier with a gain of 1.5

Noninverting Summing Amplifier

With a slight modification, you can build a circuit which can amplify several signals. In this circuit, X is the weighted average of signals A, B, and C

$$X = \left(\frac{\frac{A}{Ra} + \frac{B}{R_b} + \frac{C}{Rc}}{\frac{1}{Ra} + \frac{1}{R_b} + \frac{1}{Rc}} \right)$$

Y is then a gain times X

$$X = \left(\frac{\frac{A}{Ra} + \frac{B}{R_b} + \frac{C}{Rc}}{\frac{1}{Ra} + \frac{1}{R_b} + \frac{1}{Rc}} \right)$$

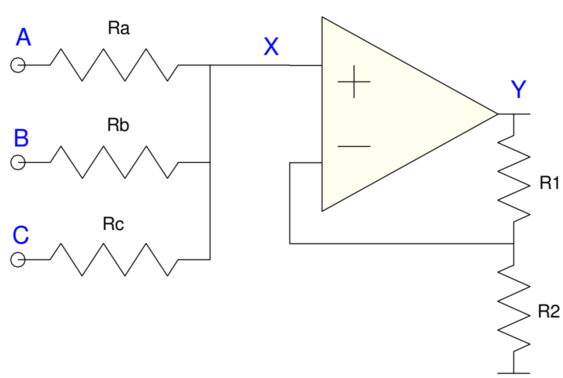

Figure 6: Noninverrting Summing Amplifier

In CircuitLab, you can see this amplification and summing with the following circuit

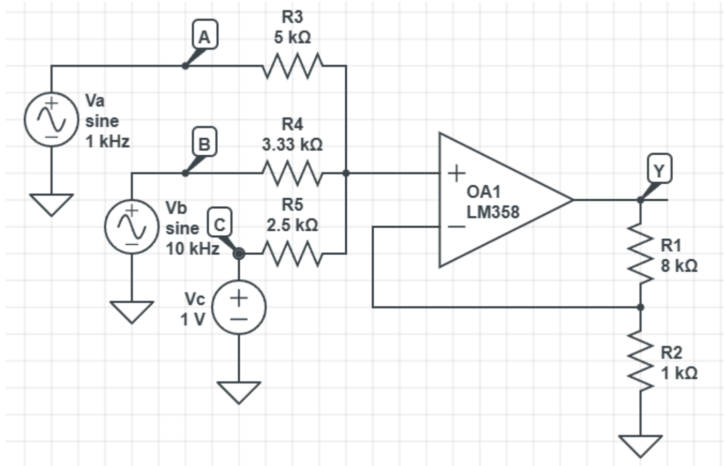

Figure 7: Generate the weighted sum of two sine waves and a constant

Running a time-domain simulation shows that Y is the sum of the three waveforms

- It has a 1kHz component from input A
- It has a 10kHz component from input B, and
- It has a DC offset from input C

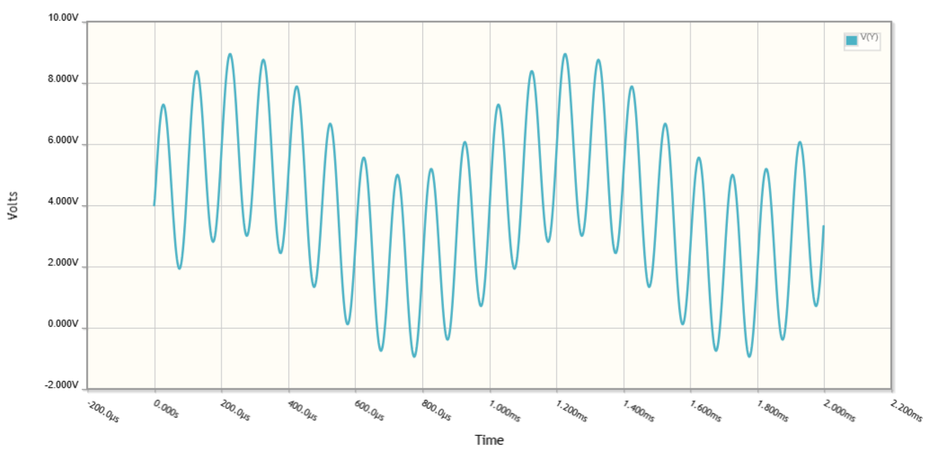

Figure 8: Output of the noninverting summing amplifier. Three signals can be seen on Y.

With this circuit, you can implement a function such as

Y = 2A + 3B + 4C.

First, create a weighted average for X

$$X = \left(\frac{2A+3B+4C}{9}\right)$$

Pick your favorite resistor - such as a 10k for the base resistance. Then, amplify X by 9 to clear the denominator

$$Y = 9X = 2A + 3B + 4C$$

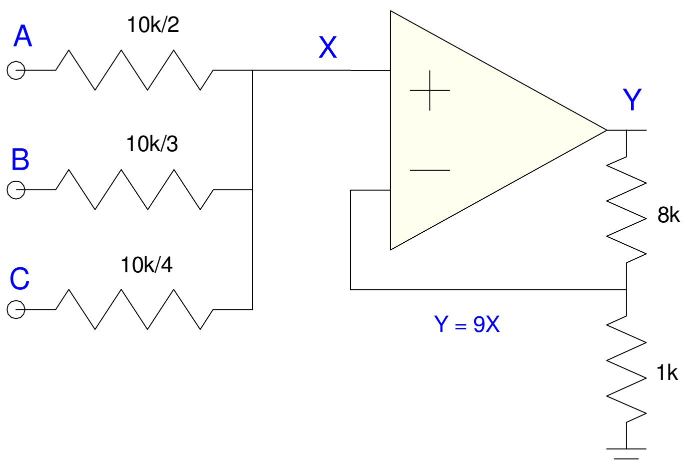

Figure 9: Circuit to implement Y = 2A + 3B + 4C

Inverting Amplifier

Another common amplifier is the inverting amplifier. Whereas the noninverting amplifier has a minimum gain of +1.000, the inverting amplifier can have a gain that goes down to 0 and up to infinity (or actually 100 due to the gain-bandwidth limitations of a LM358 op-amp).

There are several ways to derive the input/output relationship for this circuit. Simplest is to note that Vp = Vm = 0V. This means that

$$I_1 = \frac{X}{R_1}$$

I2 = I1 due to conservation of current. Y is then

$$Y = -R_2 I_2$$

or

$$Y = -\left(\frac{R_2}{R_1}\right)X$$

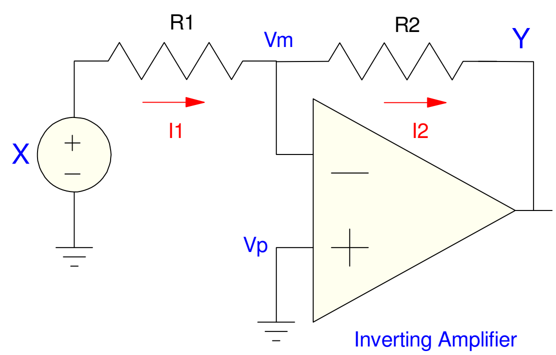

Figure 10: Inverting Amplifier

For example, design a circuit with a gain of -1.5.

To do this, pick some value for R1, such as 1k. R2 is then 1.5x R1 or 1.5k. The circuitlab simulation in Figure 11 shows that the output (orange) is 1.5x larger than the input (blue), and 180 degrees out of phase (the negative gain).

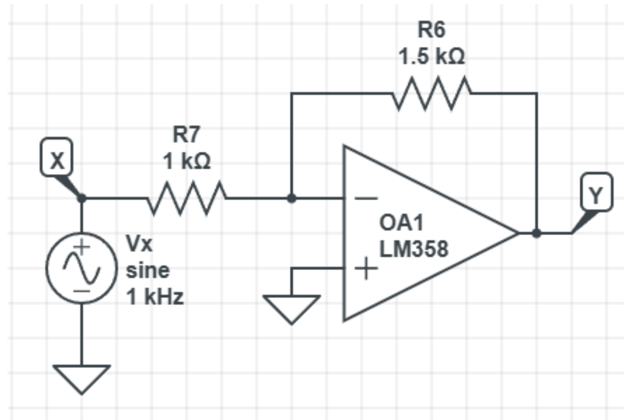

Figure 11: CircuitLab simulation of an inverting amplifier with a gain of -1.5x

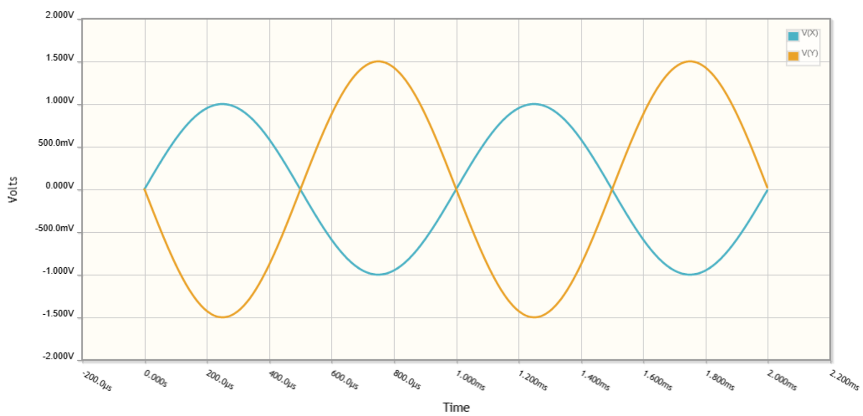

Figure 12: Corresponding time-domain simulation result.
The output (orange) is 1.5 times larger than the input and inverted.

Inverting Summing Amplifier

If you add another resistor to the input, you get an inverting summing amplifier as shown in Figure 13

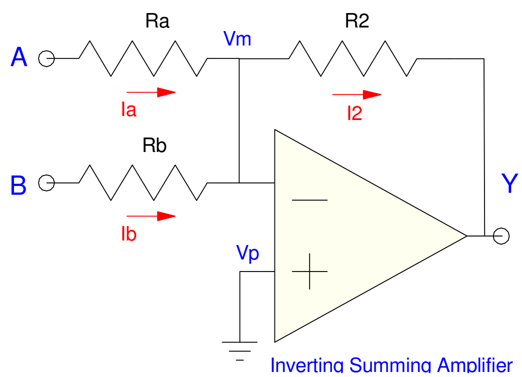

Figure 13: Inverting summing amplifier

Probably the easiest way to derive this circuit's equations is to note that Vm = Vp = 0. This lets you calculate Ia and Ib

$$I_a = \left(\frac{A}{R_a}\right)$$

$$I_b = \left(\frac{B}{R_b}\right)$$

Due to conservation of current,

$$I_2 = I_a + I_b$$

From Ohm's law, this generates the output Y

$$Y = -R_2 I_2$$

$$Y = -R_2\left(\frac{A}{R_a} + \frac{B}{R_b}\right)$$

or

$$Y = -\left(\frac{R_2}{R_a}\right)A - \left(\frac{R_2}{R_b}\right)B$$

In CircuitLab, you can see this in action.

- Let A be a 1Vp sine wave
- Let B be a 1VDC signal

Finally, pick the resistors so that

$$Y = -3A - 2B$$

The resulting CircuitLab simulation is showin Figures 14 and 15. Note in figure 15 that

- Y has a DC offset of -2V (-2 times B), and
- Y is a 6Vpp inverted sine wave (-3 times A)

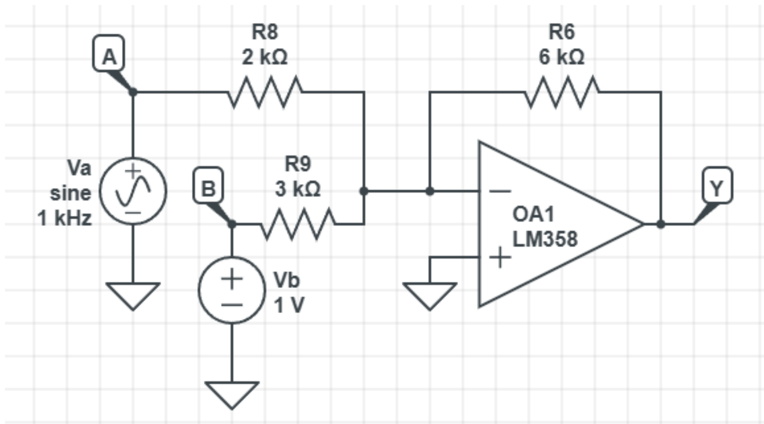

Figure 14: Summing inverting amplifier: Y = -3A - 2B

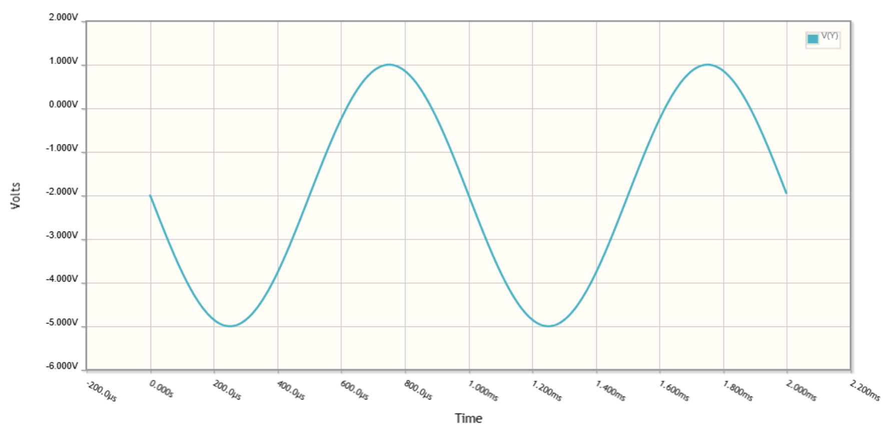

Figure 15: CircuitLab simulation result

Differential Amplifier

Finally, if you want to amplify the difference between two voltages, there is the differential amplifier:

$$Y = \left(\frac{R_1}{R_2}\right)(A - B)$$

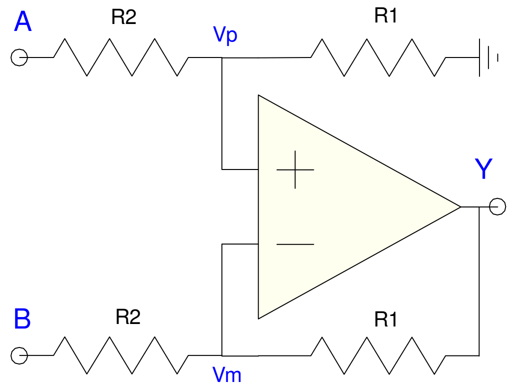

Figure 16: Differential amplifier: $Y = \left(\frac{R_1}{R_2}\right)(A - B)$

There are several ways to derive these equations. Superposition works fairly well. From superposition, you know that Y is of the form

$$Y = aA + bB$$

To find 'a', let B=0 and let A=1V. From voltage division

$$V_p = \left(\frac{R_1}{R_1 + R_2}\right) \cdot 1V$$

This is a non-inverting amplifier, so

$$Y = \left(1 + \frac{R_1}{R_2}\right) V_p = \left(\frac{R_1}{R_2}\right)$$

This is 'a'.

To find 'b', let A=0 and B=1V. Vp = 0V by voltage division. From B, this is an inverting amplifier

$$Y = -\left(\frac{R_1}{R_2}\right) \cdot 1V$$

This is 'b'. The net result is thus

$$Y = \left(\frac{R_1}{R_2}\right)(A - B)$$

The instrumentation amplifier is pretty much the do-everything circuit

- It provides a positive gain (connect the input to A)
- It provides a negative gain (connect the input to B)
- It provides a gain and an offset.

For example, design a circuit to implement

$$Y = 7X - 4$$

Solution: Rewrite this as

$$Y = 7\left(X - \tfrac{4}{7}\right)$$

Match terms

$$Y = \left(\tfrac{R_1}{R_2}\right)(A - B)$$

and you get the corresponding circuit

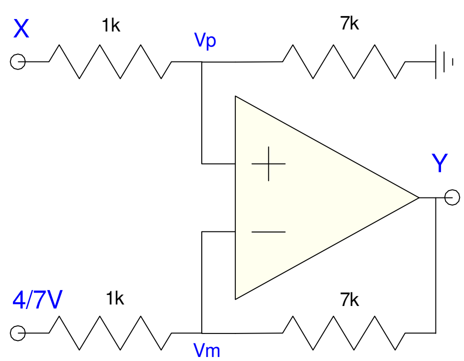

Figure 17: Instrumentation Amplifier implementing Y = 4X - 7

Summary

Op-amp circuits are kind of like legos. If you want a certain function, plug in a certain circuit. This lecture covered six commonly used op-amp circuits. If you ever need one of these functions, just plug and play.

- Buffer Y = X
- Non-Inverting Y = k * X
- Non-Inverting Summing Y = aA + bB + cC
- Inverting Y = -k*X
- Inverting Summing Y = -aA - bB - cC
- Differential Y = k * (A - B)