Amplifiers & Mixers

ECE 211 Circuits I

Lecture #15

Please visit Bison Academy for corresponding
lecture notes, homework sets, and solutions

Op-Amp Circuits

Op-amp circuits are like Leggo blocks

- Given a desired funciton
- Plug in an op-amp circuit

This lecture looks at some common op-amp circuits

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)

Ideal Op-Amp: Limitations

Keep 100 < R < 1M

- Lower limit: 50mA
- Upper limit: R << R_in = 111M

Keep gain < 100

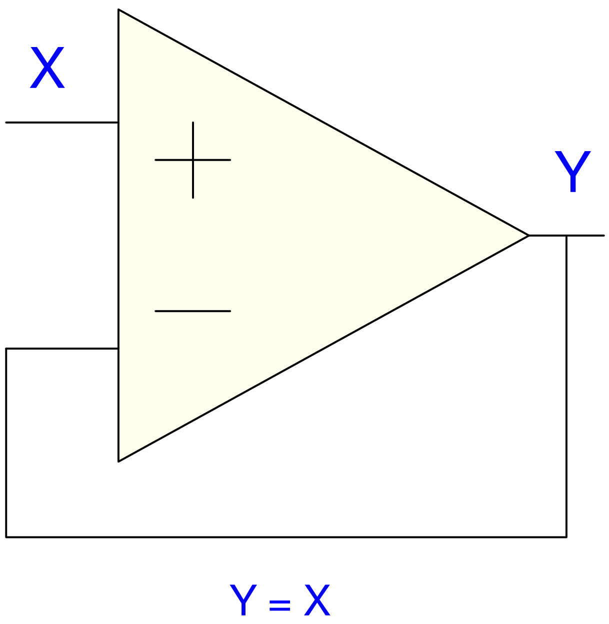
- Gain Bandwidth product = 1MHz
- Gain of 100 out to 10kHz

Keep Vo away from the power supplies

- Clipping results if Vo is too large

Buffer

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



Buffer in CircuitLab

Do hand calculations at DC

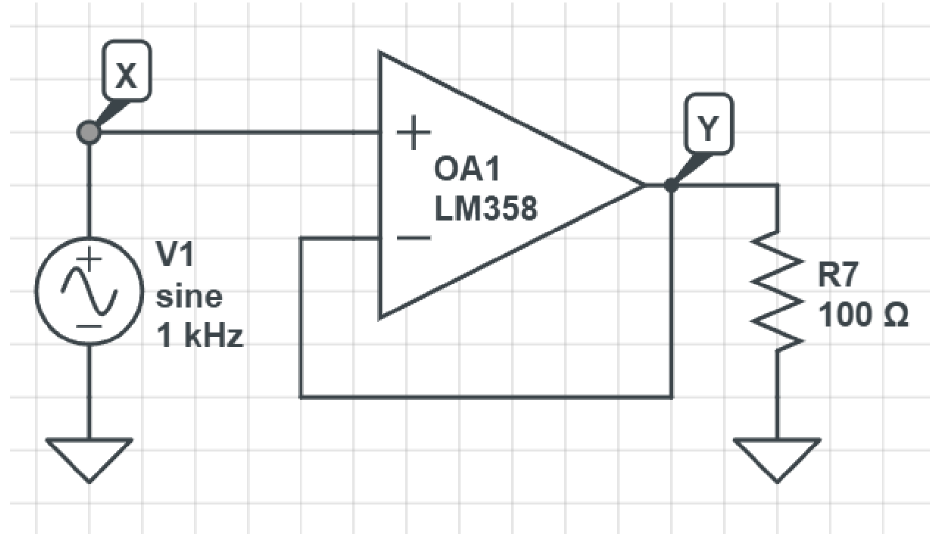
- Vin = 1V
- Vout = 1V

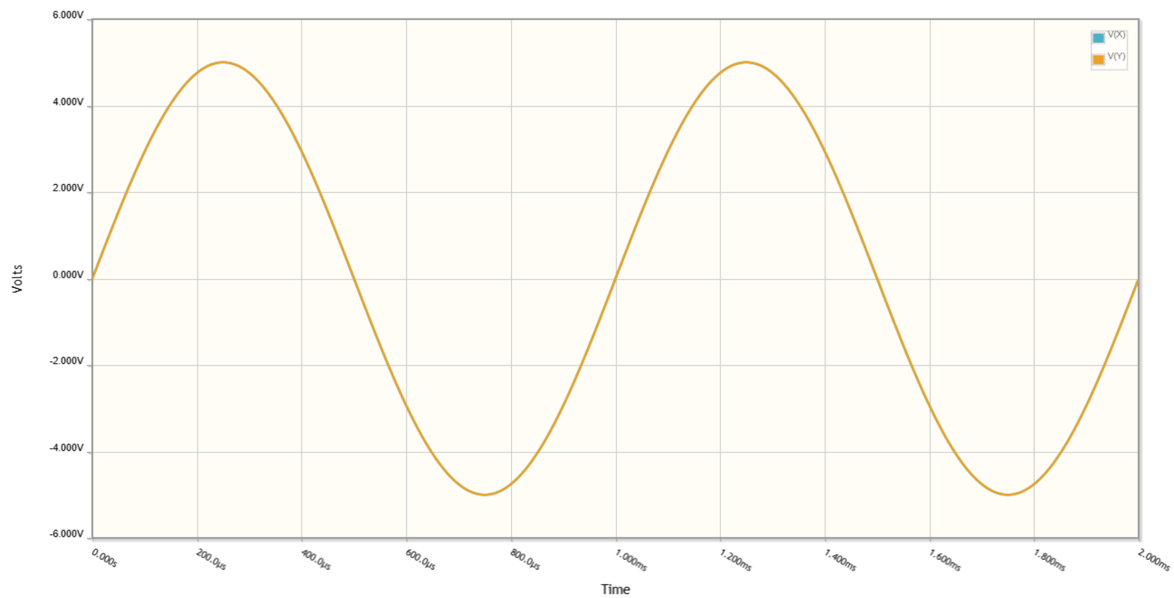
Simulate with a sine-wave

- Shows that Y = X
- -5V to +5V

Add 100 Ohms at the output

- You can drive a load
- Source up to 50mA
- Sink up to 50mA

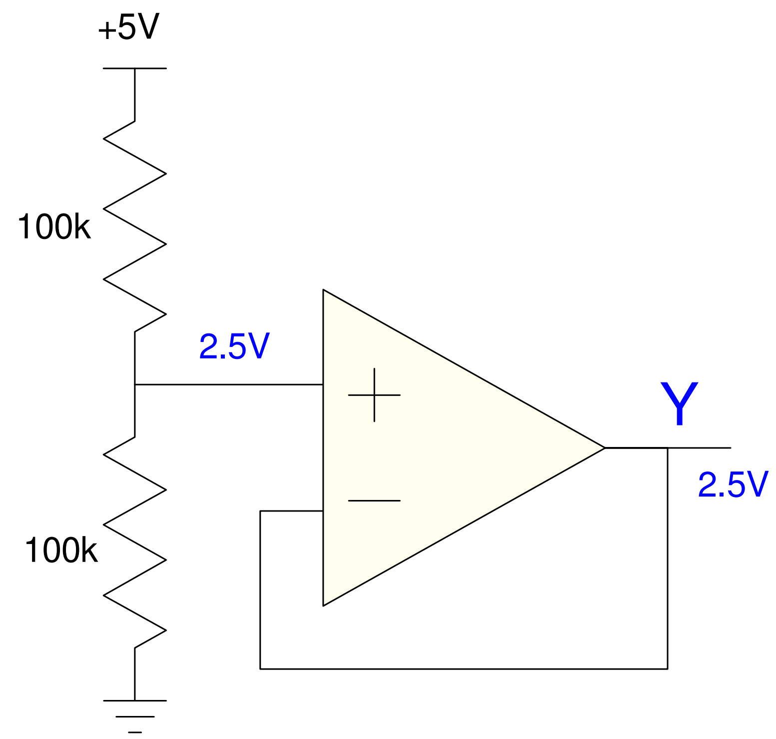




Buffer Application

Create a 2.5V power supply

- Capable of sourcing / sinking 50mA
- Using a 5V power supply



Noninverting Amplifier

Voltage node equations

$$V_p = X$$

$$V_m = V_p$$

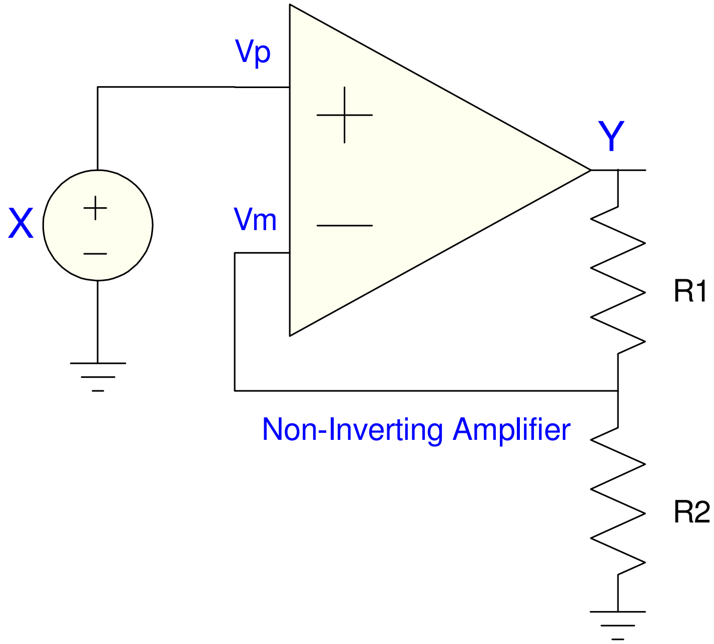
$$\left(\frac{V_m - Y}{R_1}\right) + \left(\frac{V_m}{R_2}\right) = 0$$

Figure it out

$$V_m = V_p = X$$

$$X = \left(\frac{R_2}{R_1 + R_2}\right) Y \qquad \textit{voltage division}$$

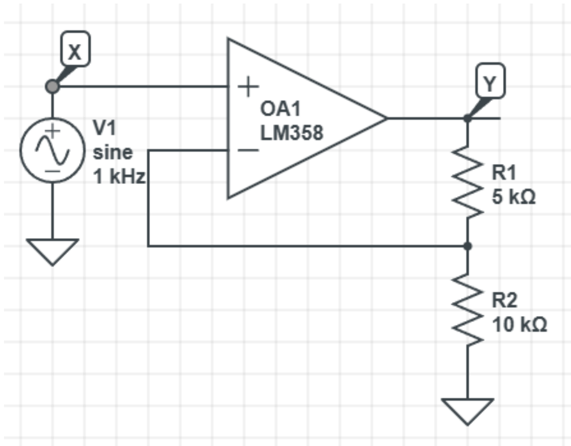
$$Y = \left(1 + \frac{R_1}{R_2}\right) X$$



Non-Inverting Amplifier in CircuitLab

Design a circuit which has a gain of 1.5x

$$1 + \frac{R_1}{R_2} = 1.5$$

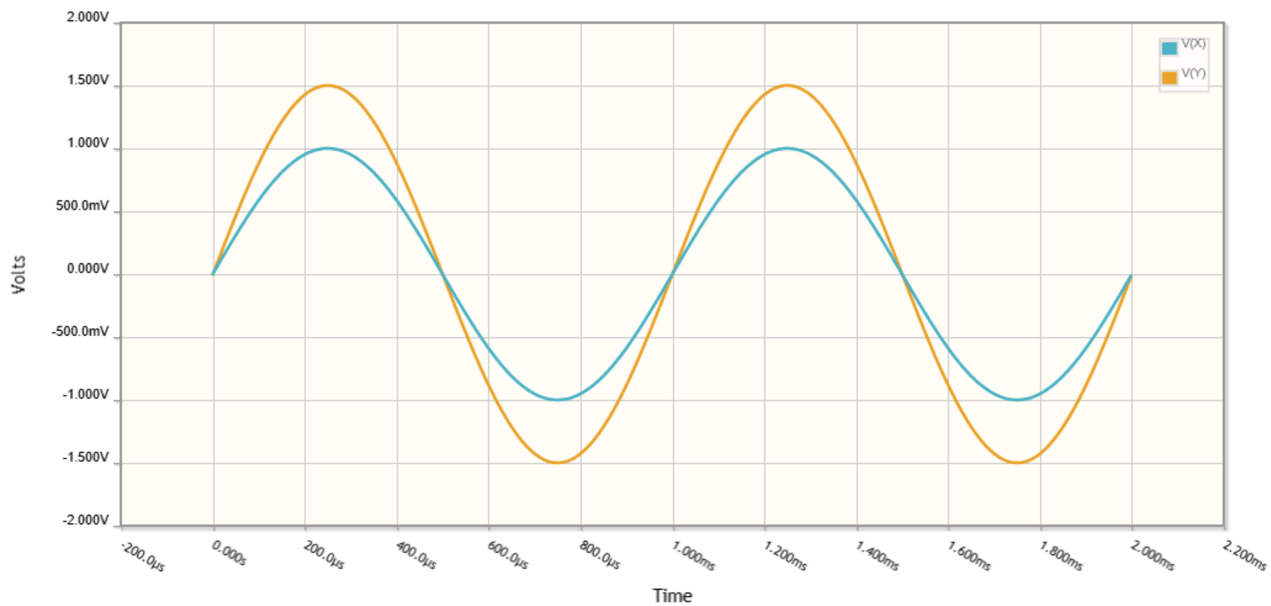


Check at DC

- 1.000V input prodices 1.500V output

Check at AC

- Sine wave in
- Produces a sine wave out
- That is 1.5x larger
- That is in phase



Non-Inverting Summing Amplifier

Votage Nodes:

$$V_p = V_m$$

$$\left(\frac{X-A}{R_a}\right) + \left(\frac{X-B}{R_b}\right) + \left(\frac{X-C}{R_c}\right) = 0$$

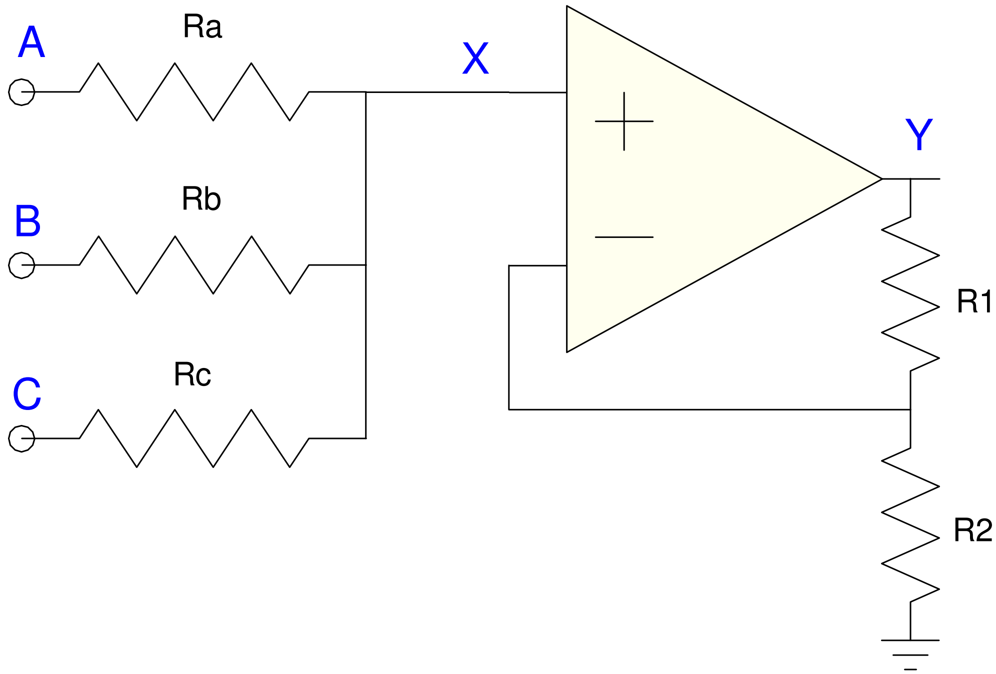
$$\left(\frac{V_m-Y}{R_1}\right) + \left(\frac{V_m}{R_2}\right) = 0$$

By Inspection:

- X is a weighted average of A, B, C

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

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

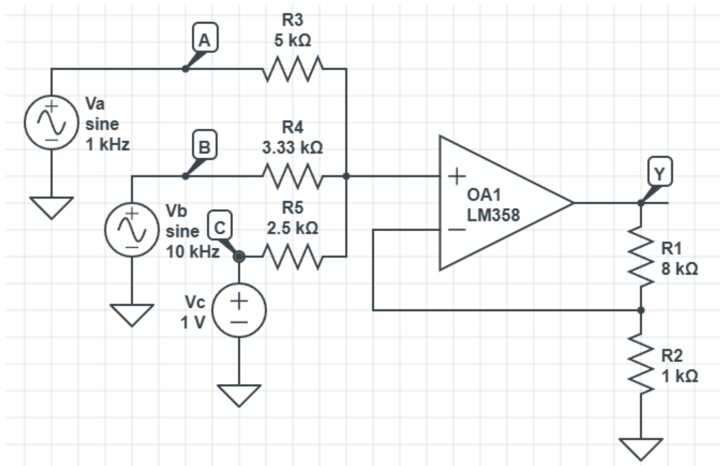


Non-Inverting Summing Amplifier

- CircuitLab Simulation

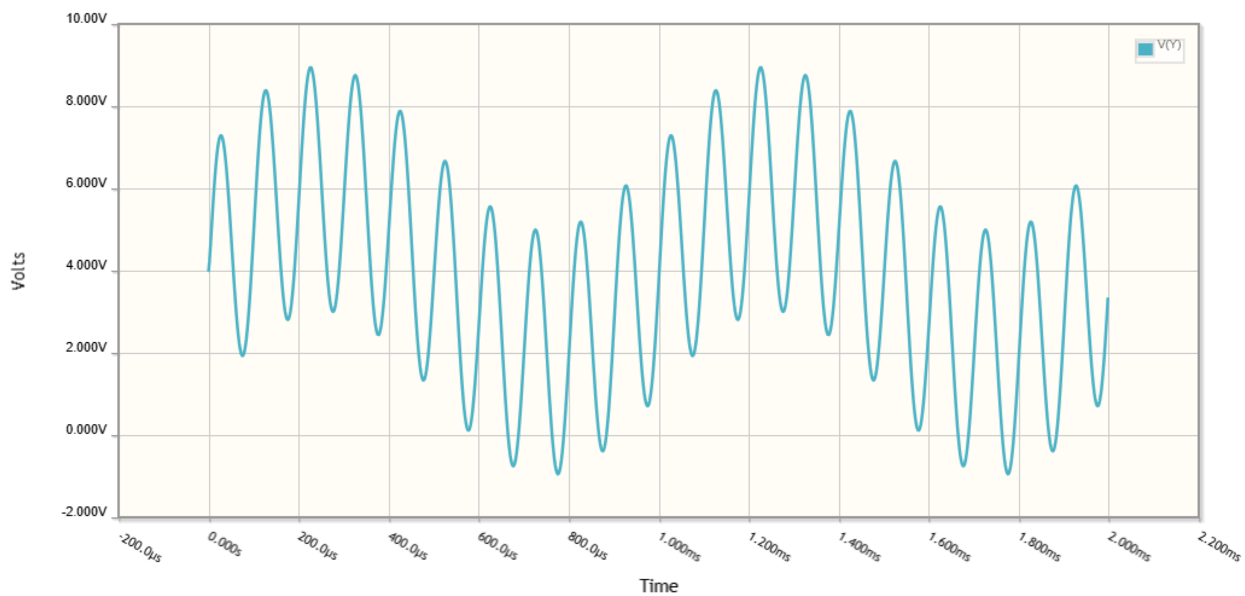
Y = 2A + 3B + 4C

- A = 1Vp, 1kHz sine wave
- B = 1Vp, 10kHz sine wave
- C = 1V DC signal



Y contains all three signals

- 1kHz component (2Vp)
- 10kHz component (3Vp)
- DC offset (4V)



Summing Amplifier Application

Design

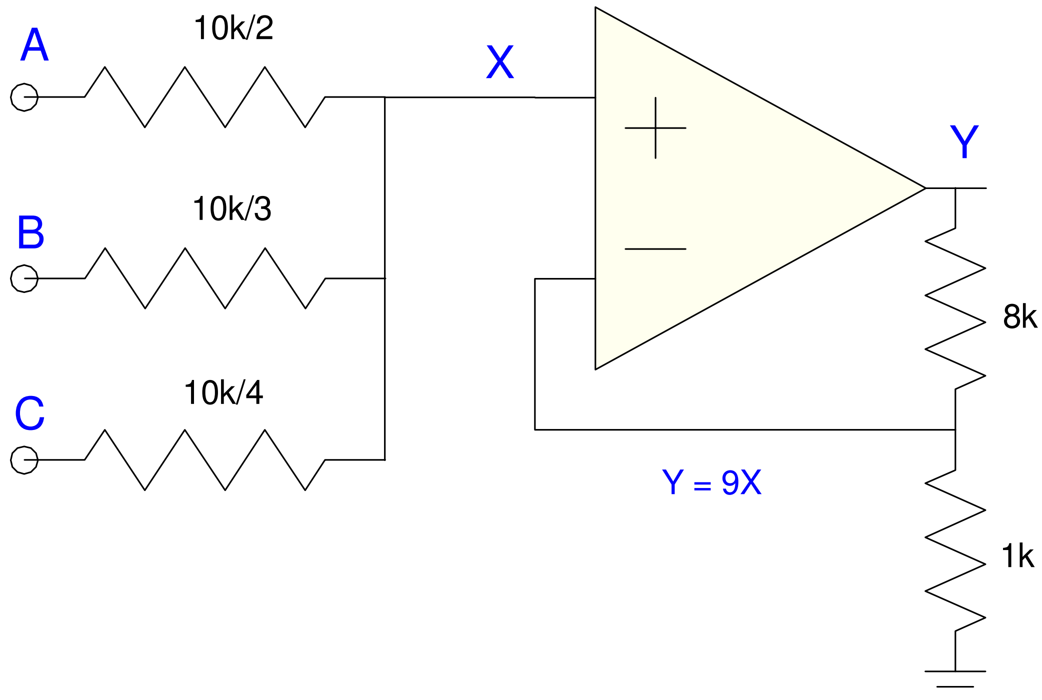
- Y = 2A + 3B + 4C

Create a weighted average for X

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

Clear the denominator

$$Y = 9X$$



Inverting Amplifier

Voltage Nodes

$$V_p = V_m$$

$$V_p = 0$$

$$\left(\frac{V_m - X}{R_1}\right) + \left(\frac{V_m - Y}{R_2}\right) = 0$$

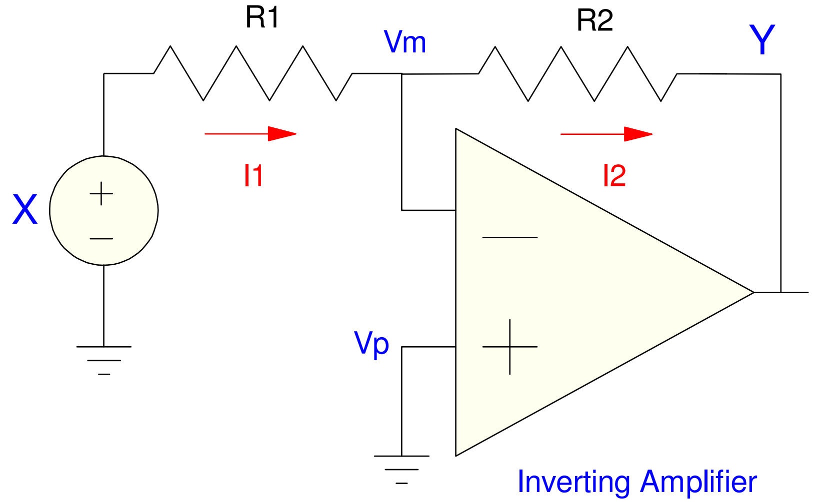
By inspection

$$V_p = V_m = 0$$

$$I_1 = I_2 = \left(\frac{X}{R_1}\right)$$

$$Y = -R_2 I_2$$

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



Inverting Amplifier

CircuitLab Simulation

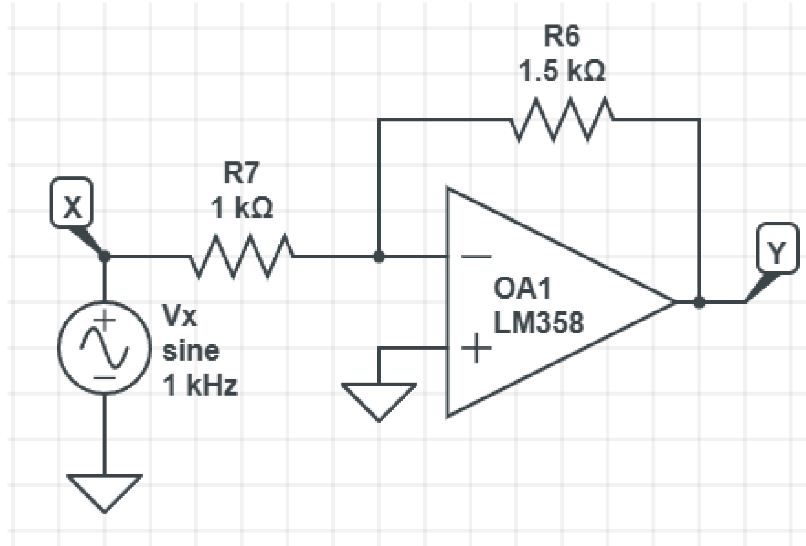
$$gain = -\left(\frac{R_6}{R_7}\right) = -1.5$$

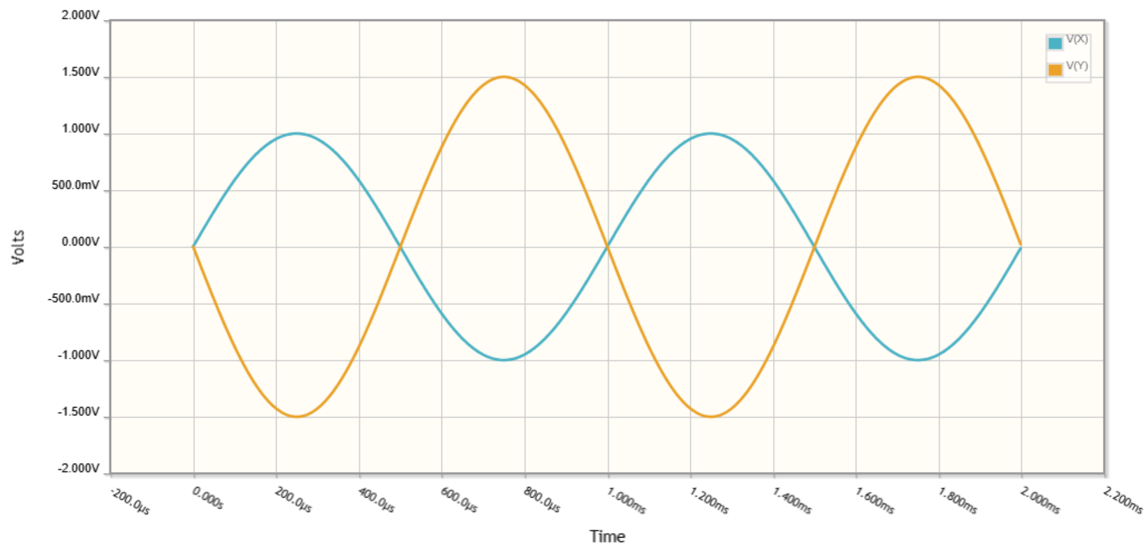
DC Test

- 1.000V in produces
- -1.500V out

AC Test

- 1Vp sine wave in produces
- 1.5Vp sine wave out
- That's 180 degrees out of phase





Inverting Summing Amplifier

Voltage Nodes

$$V_p = V_m$$

$$V_p = 0$$

$$\left(\frac{V_m - A}{R_a}\right) + \left(\frac{V_m - B}{R_b}\right) + \left(\frac{V_m - Y}{R_2}\right) = 0$$

By inspection

$$V_p = V_m = 0$$

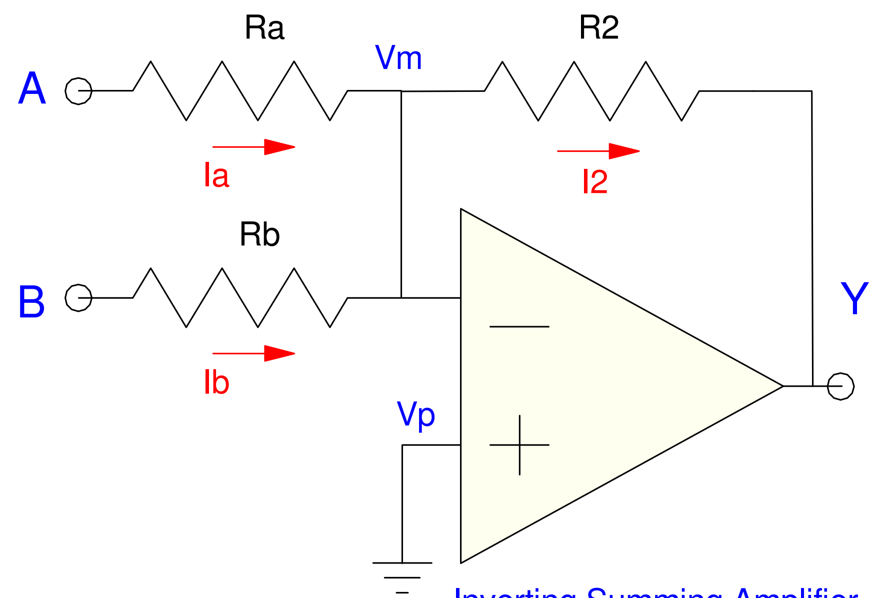
$$I_a = \left(\frac{A}{R_a}\right)$$

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

$$I_2 = I_a + I_b$$

$$Y = -I_2 R_2$$

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



Inverting Summing Amplifier

Inverting Summing Amplifier

CircuitLab Simulation

$$Y = -\left(\frac{R_6}{R_8}\right)A - \left(\frac{R_6}{R_9}\right)B$$

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

A:

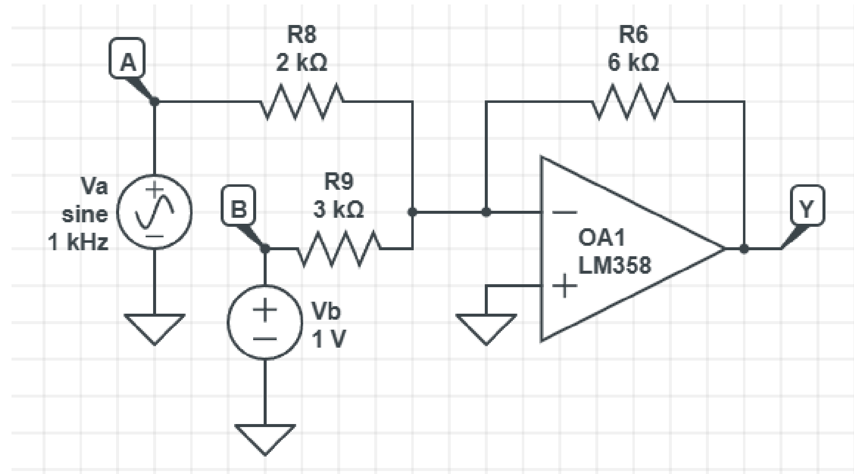
- 1Vp sine wave

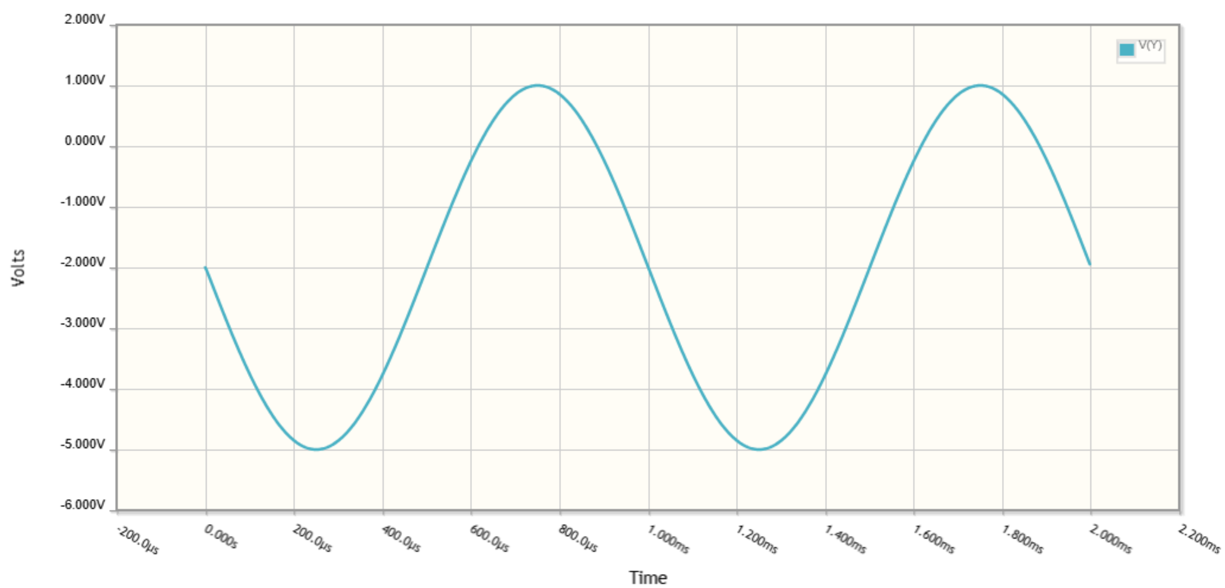
B:

- 1VDC

Y

- 3Vp sine wave
  - *180 degree out of phase from A*
- With a -2V offset





Differential Amplifier

Voltage Nodes

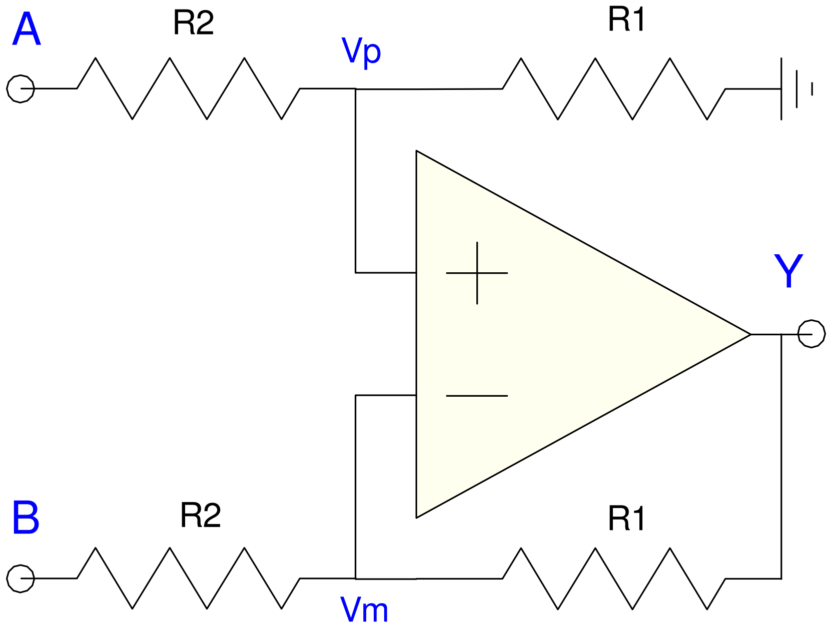
$$V_p = V_m$$

$$\left(\frac{V_p - A}{R_2}\right) + \left(\frac{V_p}{R_1}\right) = 0$$

$$\left(\frac{V_m - B}{R_2}\right) + \left(\frac{V_m - Y}{R_1}\right) = 0$$

Solve (time passes)

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



Differential Amplifier

You know the answer is in the form of

$$Y = aA + bB$$

Let A = 0

$$V_p = 0$$

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

Let B = 0

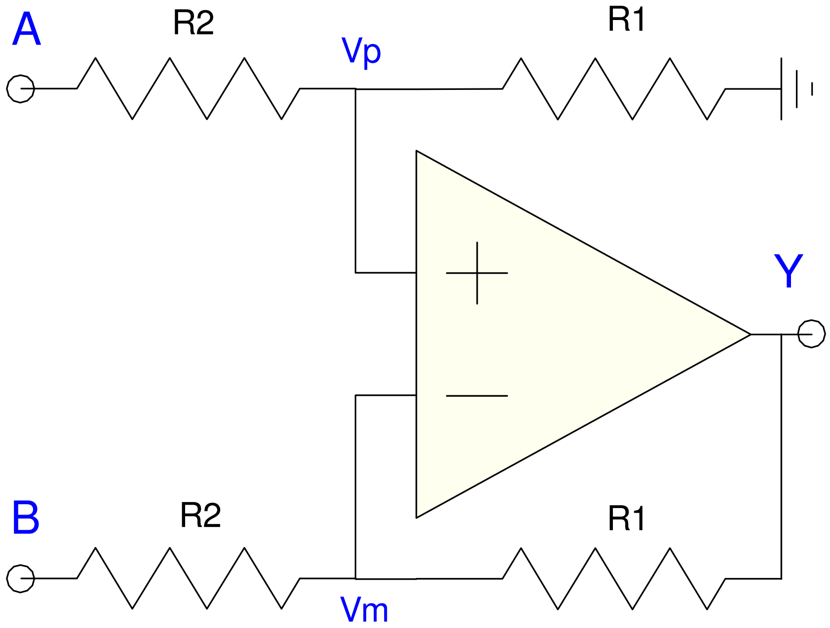
$$Y = \left(\frac{R_1+R_2}{R_2}\right)V_p$$

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

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

Net

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



Example:

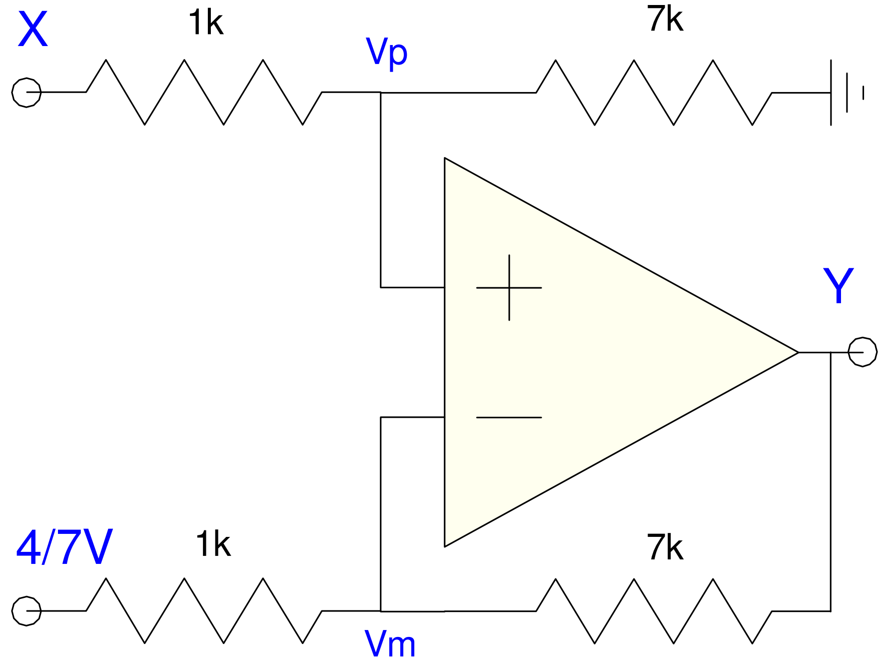
Design a circuit to implement

$$Y = 7X - 4$$

Rewrite as

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

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

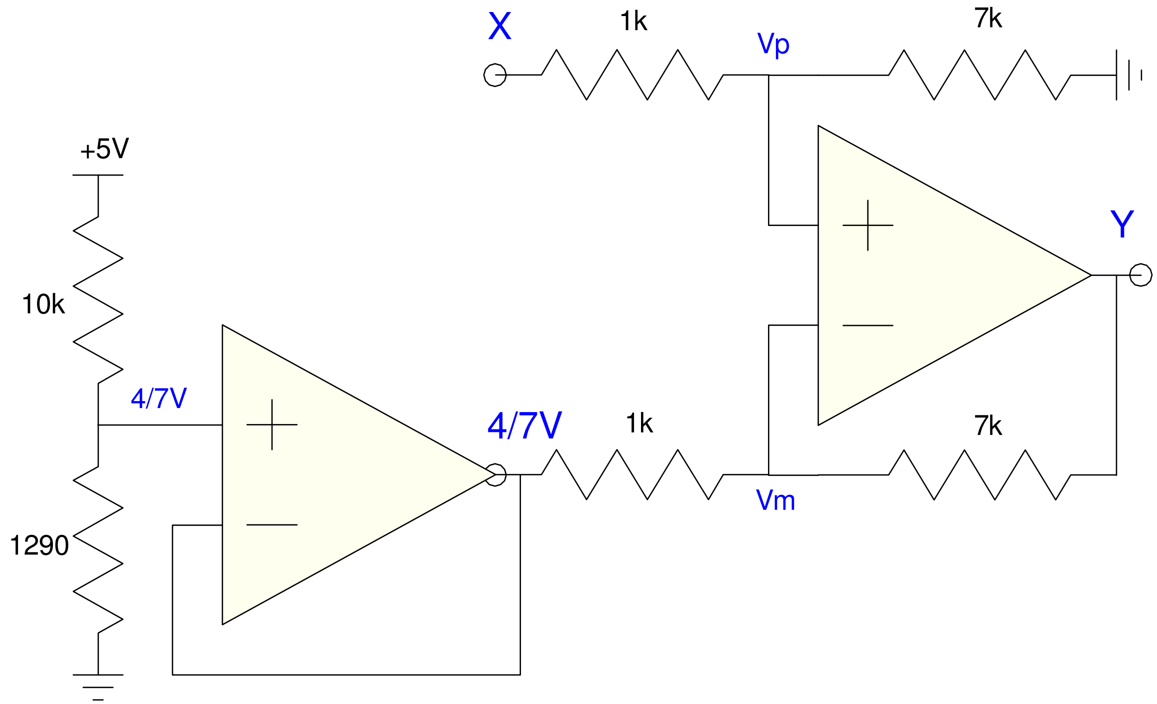


Implement 4/7V & 1k

- Assume +5V is available

Option #1: Buffer op-amp

- Voltage divider creates 4/7V
- Buffer drives load

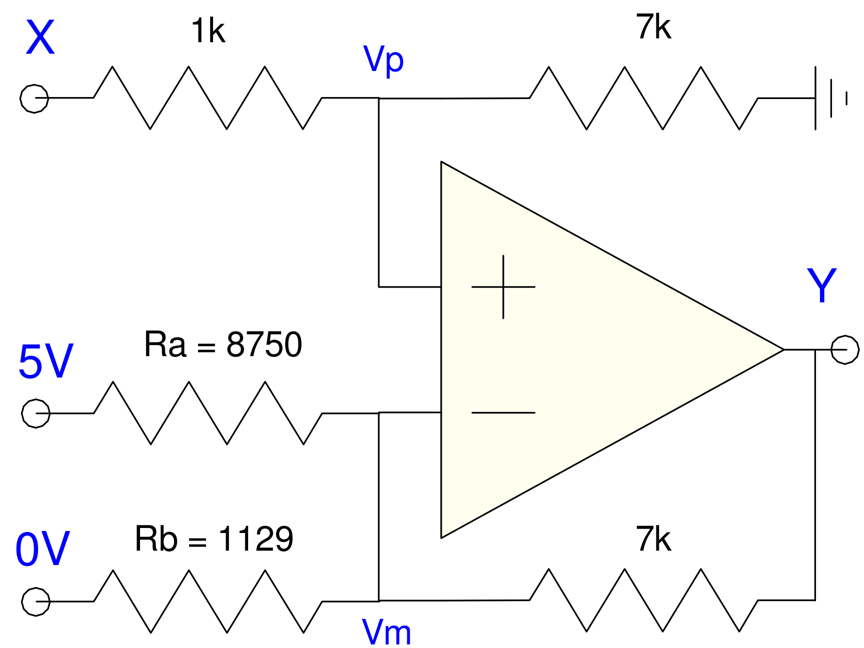


Implement 4/7V & 1k

- Assume +5V is available

Option #2: Use a Thevenin equivalent

- Vth = 4/7V
- Rth = 1k



For the circuit shown:

$$V_{th} = \frac{4}{7}V = \left(\frac{R_b}{R_a+R_b}\right)5V$$

$$R_{th} = 1k = \left(\frac{R_aR_b}{R_a+R_b}\right)$$

$$R_a = \left(\frac{5V}{4/7V}\right)1k = 8750\Omega$$

$$R_b = 1129\Omega$$

Summary

With op-amps, you can build several types of amplifiers

- Buffer
- Non-Inverting
- Non-Inverting Summing
- Inverting
- Inverting Summing
- Differential

These are like Lego blocks

- Given a function
- Plug in the corresponding circuit