Georgia Institute of Technology

Introduction to Electronics

An introduction to electronic components and a study of circuits containing such devices.

School of Electrical and Computer Engineering

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Week 2:
Op Amps Part 1

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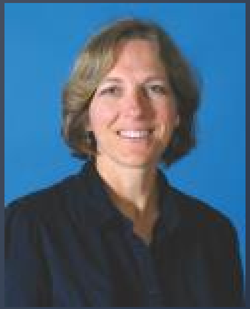
Introduction and Ideal Behavior



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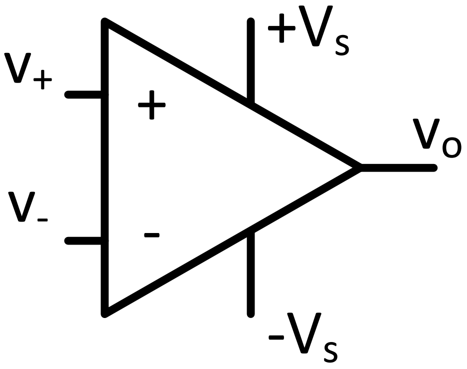
Introduce Op Amps and examine ideal behavior

Lesson Objectives

- Introduce Operational Amplifiers
- Describe Ideal Op Amp Behavior
- Introduce Comparator and Buffer Circuits

Operational Amplifiers (Op Amps)

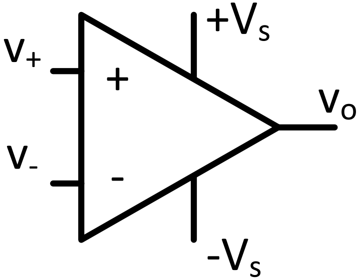


Specialized circuit made up of transistors, resistors, and capacitors fabricated on an integrated chip

Uses:

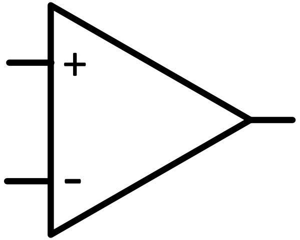
- Amplifiers
- Active Filters
- Analog Computers

Op Amps in Circuits



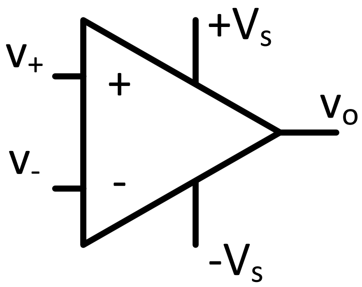
V_S = 10V, 15V

Symbol:

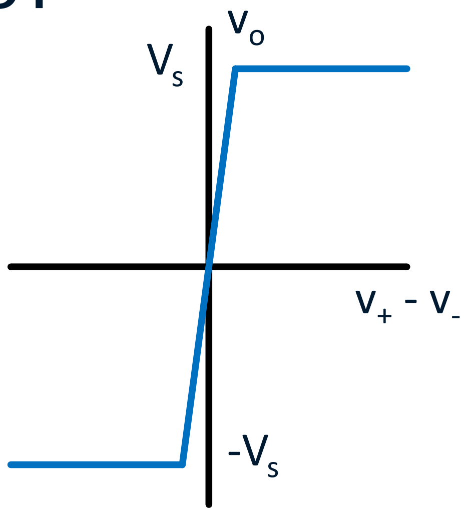


- Active Element: has its own power supply
- Symbol ignores the +/- V_S in the symbol since it does not affect circuit behavior

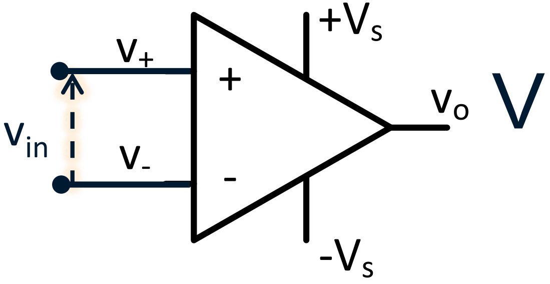
Open Loop Behavior

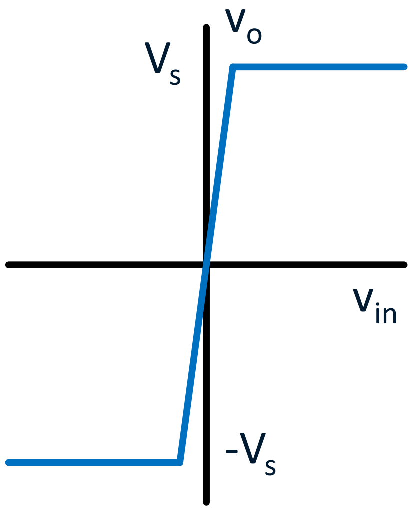


$$v_o = A(v_+ - v_-)$$



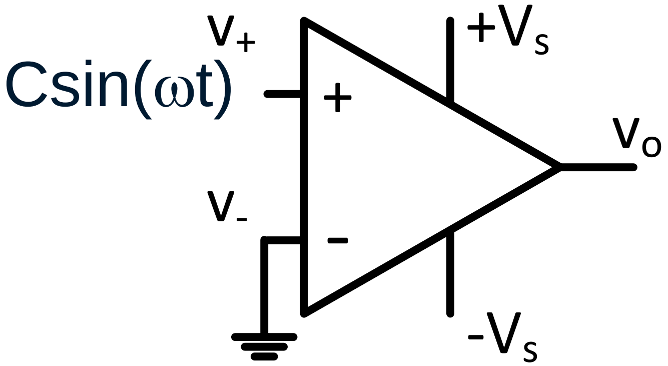
Comparator Circuit

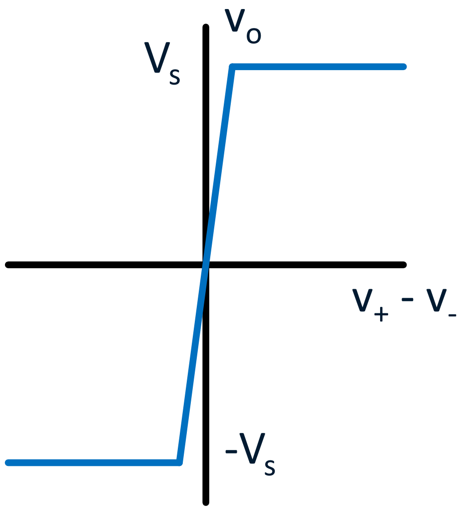




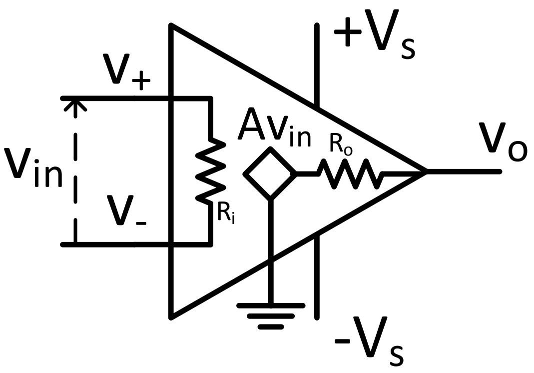
$$V_o = \begin{cases} V_s & \text{if } v_{in} > 0 \\ -V_s & \text{if } v_{in} < 0 \end{cases}$$

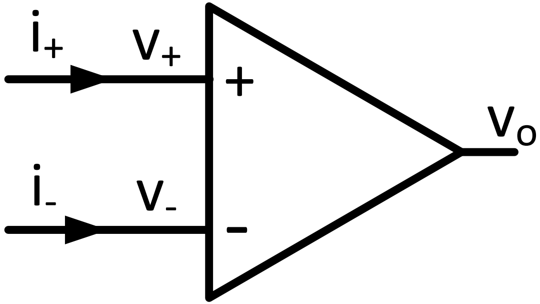
Example





Ideal Op Amp Behavior

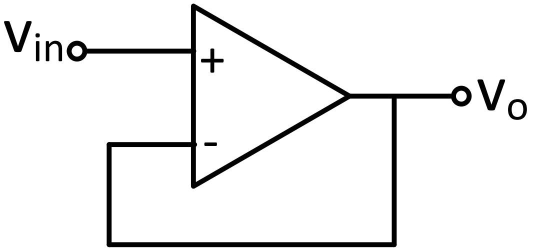




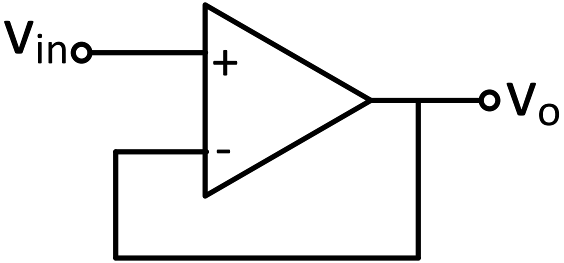
$$i_+ = i_- = 0$$

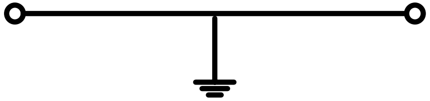
$$v_+ - v_- = 0$$

Buffer Circuit



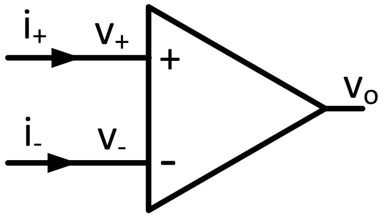
$$\boxed{V_{in} = V_o}$$





Summary

- Op amps are active devices that can be used to filter or amplify signals linearly
- Ideal op amps:



$$\boxed{\begin{array}{l} i_+ = i_- = 0 \\ v_+ - v_- = 0 \end{array}}$$

- Circuits: comparator and buffer

Remainder of Module 2: Op Amps

- Buffer Circuit
- Basic Amplifier Configurations
- Differentiators and Integrators
- Active Filters

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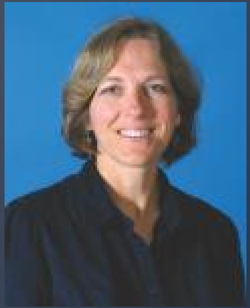

Buffer Circuits

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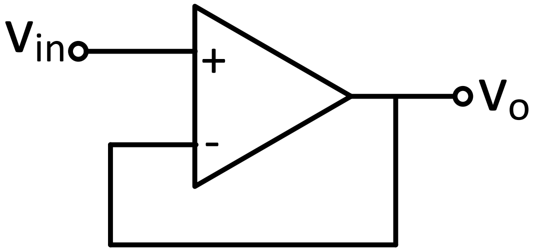
Demonstrate buffer circuit behavior

Lesson Objectives

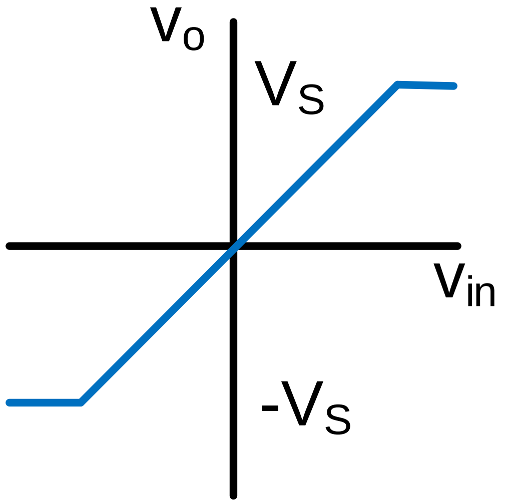
- Introduce physical op amps in circuits
- Examine Buffer Circuit behavior

Buffer Circuit

- Use to boost power without changing voltage waveform



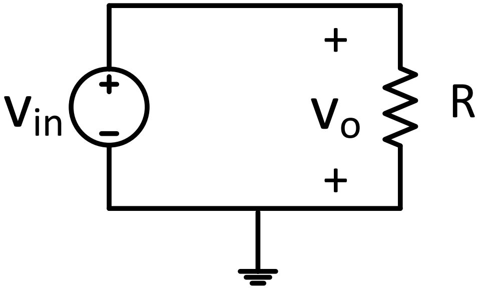
$$\boxed{V_{in} = V_o}$$



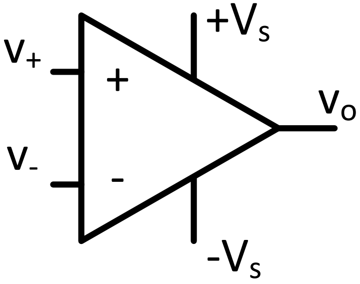
Saturation

Nonlinearity

Example: Without Buffer



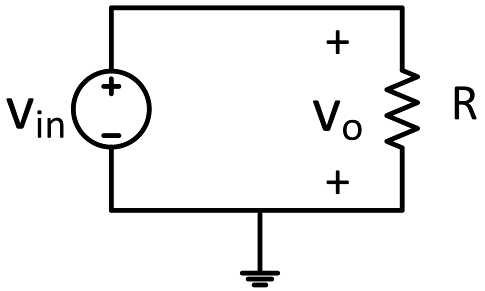
Physical Op Amps

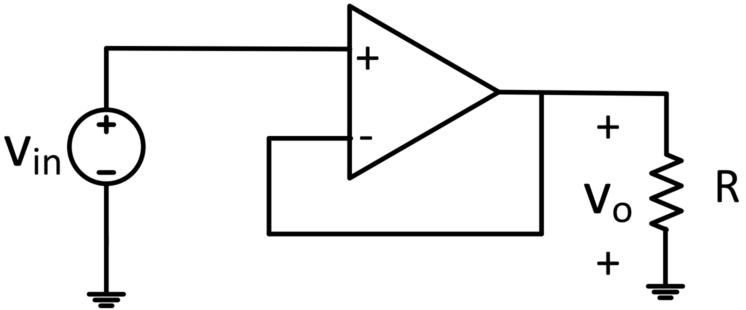


V_S = 15V

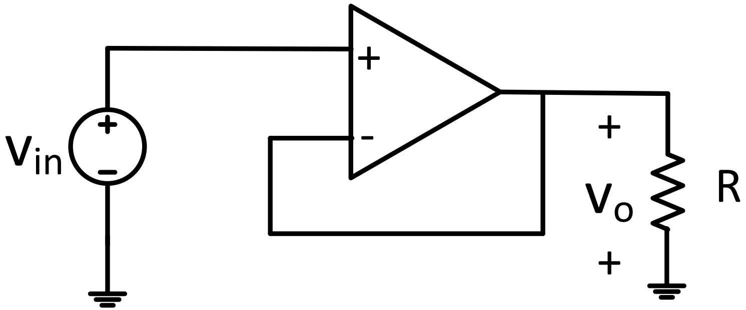
Signal	PIN
v_-	2
v_+	3
$-V_S$	4
v_O	6
$+V_S$	7

Example: With Buffer



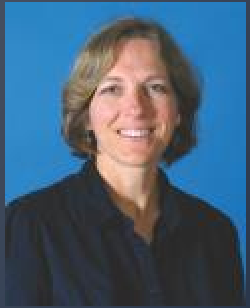


Example: With Buffer



Summary

- Buffers boost the power without changing the voltage waveform
- Demonstrated physical op amp circuits



Basic Op Amp Amplifier Configurations

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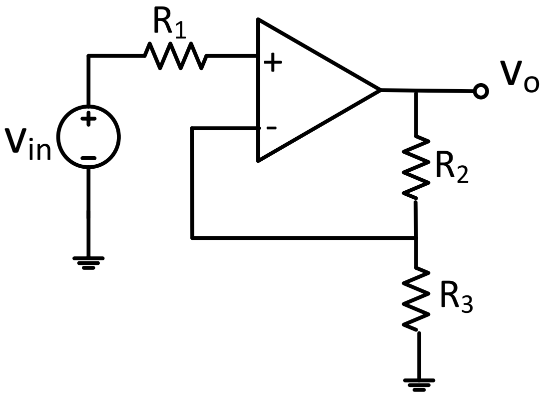
Introduce Inverting and Non-Inverting Amplifiers, Difference and Summing Amplifiers

Lesson Objectives

- Introduce
  - Inverting and Non-Inverting Configurations
  - Difference and Summing Configurations
- Introduce the Gain of a circuit

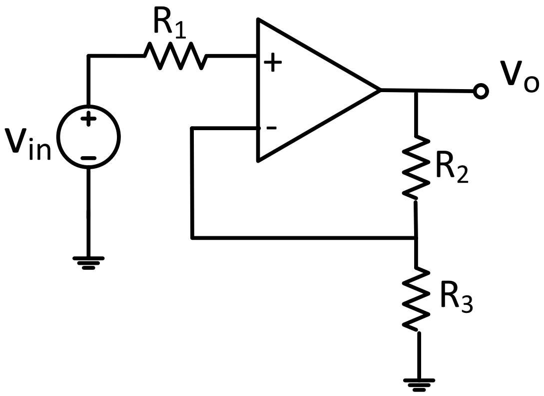
Non-Inverting Amplifiers



$$\boxed{V_o = \frac{R_2 + R_3}{R_3} V_{in}}$$

$$V_o = GV_{in} \qquad \text{Gain}: G = \frac{R_2 + R_3}{R_3}$$

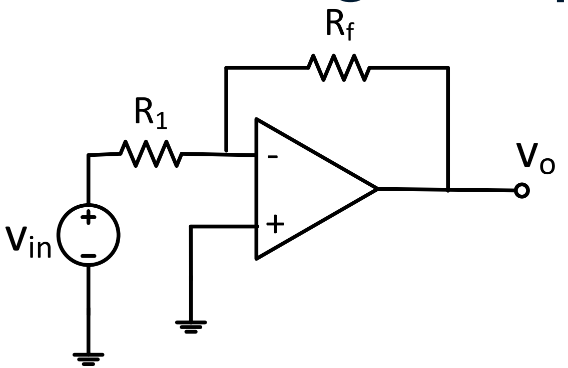
Non-Inverting Amplifier Example



If $R_2 = R_3 = 200\Omega$,

- Since,G > 1, the input is amplified
- If G < 1, the input is attenuated

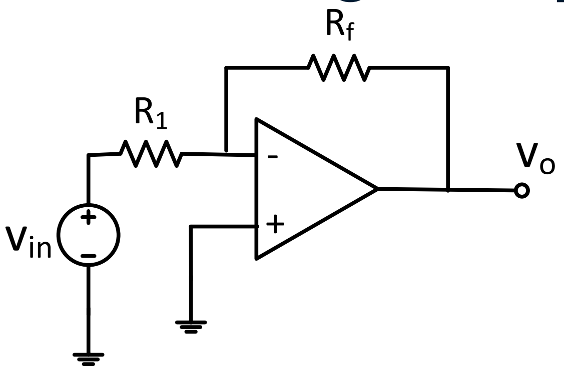
Inverting Amplifier



$$\boxed{V_o = -\frac{R_f}{R_1} V_{in}}$$

$$V_o = GV_{in}$$

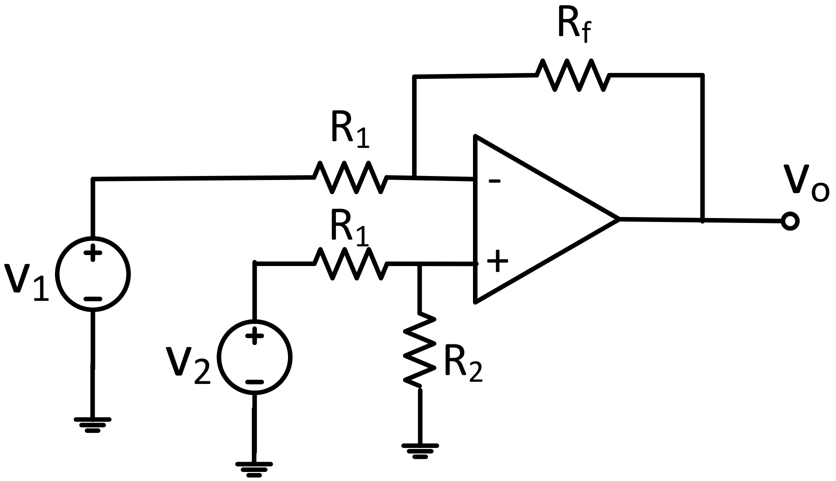
Inverting Amplifier Example



$R_1 = 1000\Omega$, $R_f = 2000\Omega$

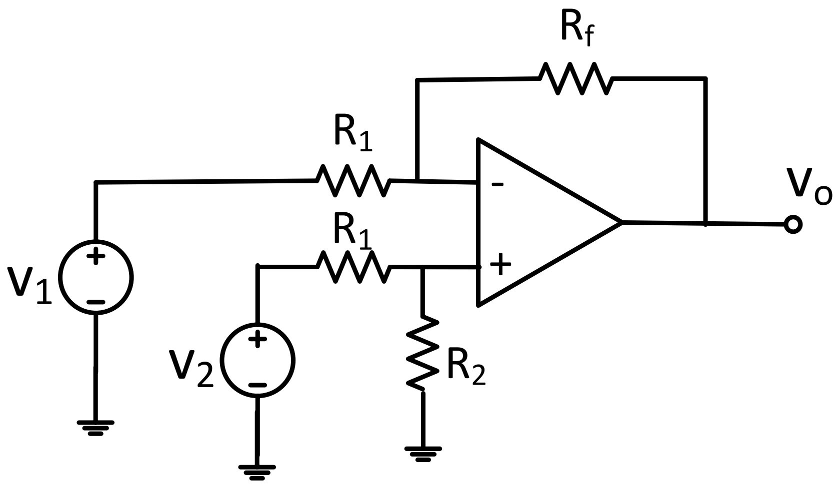
- If,G > 1, the input is amplified
- If G < 1, the input is attenuated

Difference Circuit



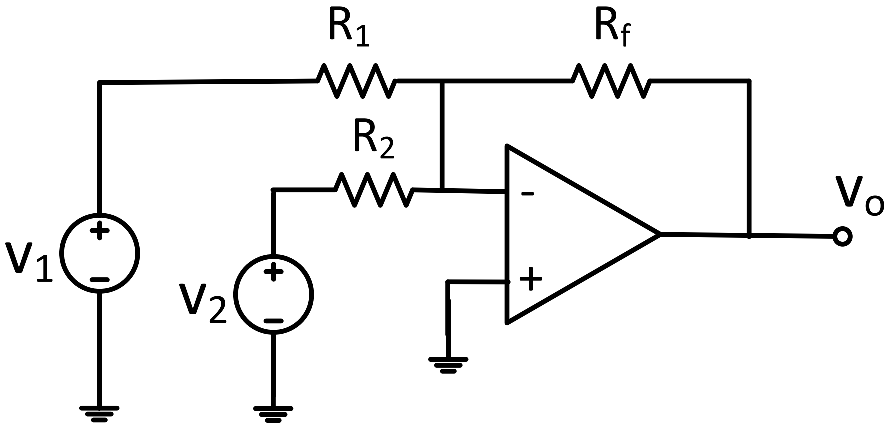
$$\boxed{V_o = \frac{R_F}{R_1}(V_2 - V_1)}$$

Difference Circuit



$$V_o = \frac{R_F}{R_1}(V_2 - V_1)$$

Summing Amplifier



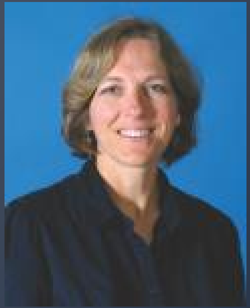
$$V_o = G_1 V_1 + G_2 V_2$$

$$G_1 = -\frac{R_F}{R_1} \qquad G_2 = -\frac{R_F}{R_2}$$

Summary

- Gain: $\boxed{V_o = GV_{in}}$
- Amplifier Circuit Configurations
  - Non-Inverting Amplifier
  - Inverting Amplifier
  - Difference Amplifier
  - Summing Amplifier

Differentiators and Integrators



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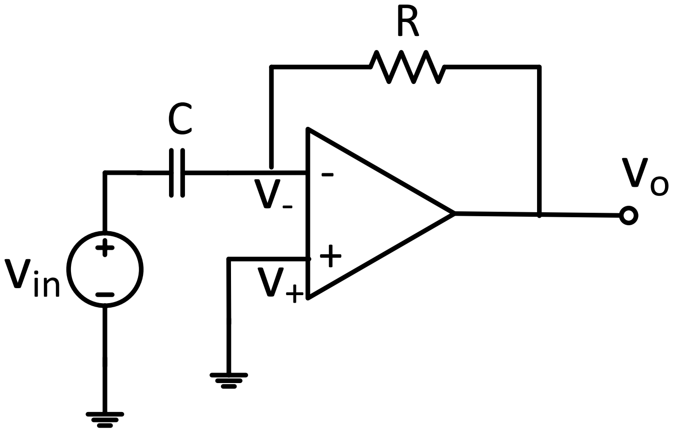
Introduce Integrating and Differentiating Op Amp Circuits

Lesson Objectives

- Introduce Differentiators and Integrators
- Demonstrate the performance of both circuits on an oscilloscope

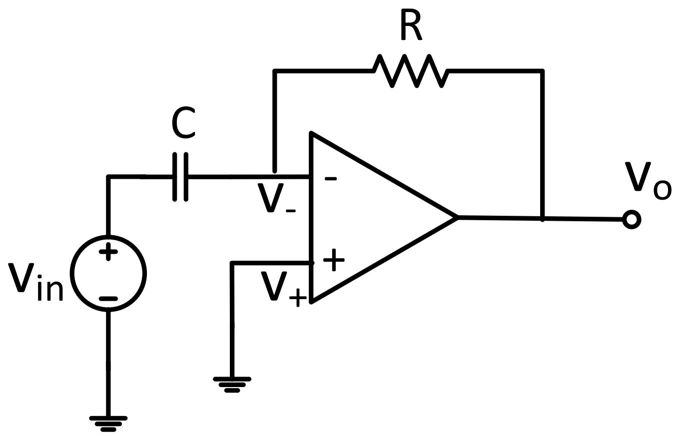
Differentiator Circuit



$$i = C\frac{dV_c}{dt}V_c$$

$$\boxed{V_o = -RC\frac{dV_{in}}{dt}}$$

Differentiator Circuit

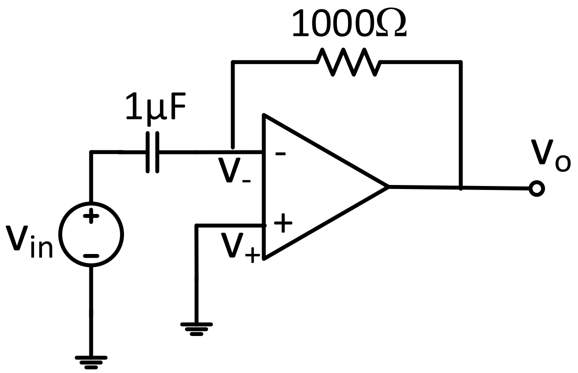


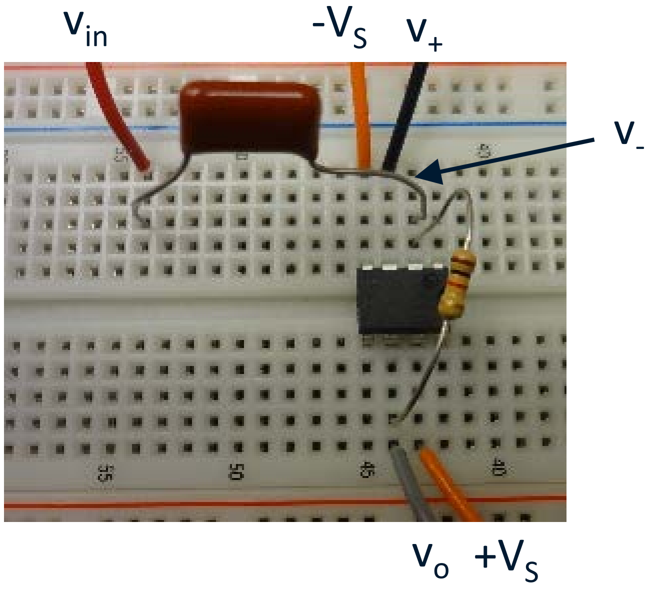
$$V_o = -RC\frac{dV_{in}}{dt}$$

Derivation:

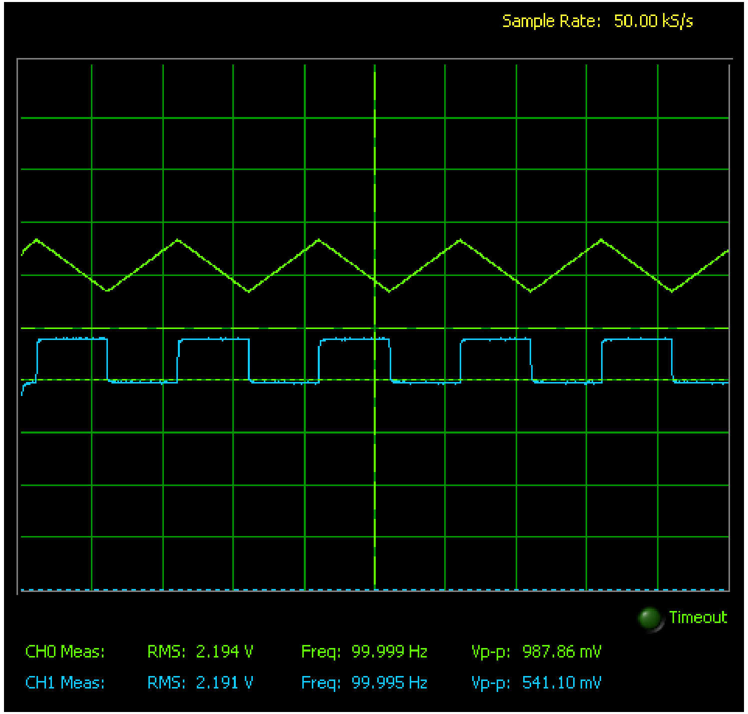
1. KVL: $V_{in} = V_c + Ri + V_o$
2. $V_{in} = V_c$
3. $V_o = -Ri = -RC(dV_{in} / dt)$

Differentiator Example



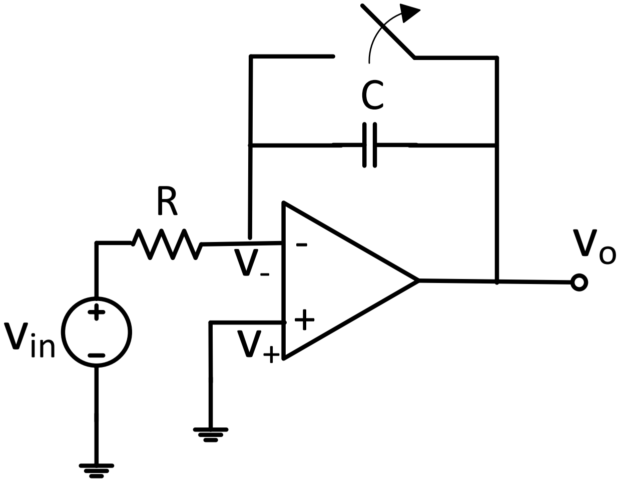


Results



$$V_o = -RC\frac{dV_{in}}{dt}$$

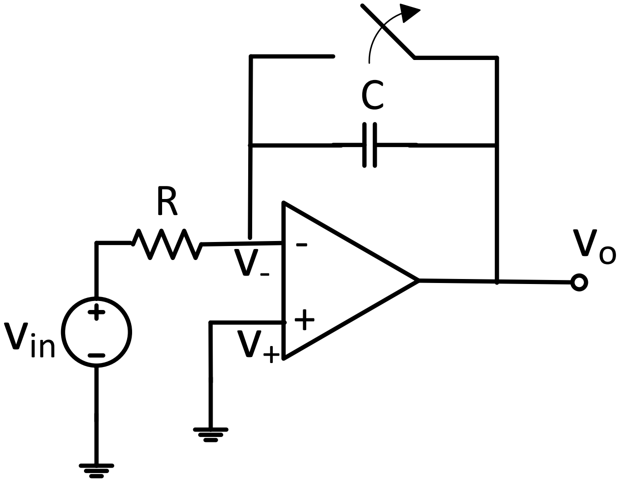
Integrator Circuit



$$i = C\frac{dV_c}{dt}V_c \qquad V_c = \frac{1}{C}\int_0^t i\,dt$$

$$\boxed{V_o = \frac{-1}{RC}\int_0^t V_{in}\,dt}$$

Integrator Circuit



$$V_o = \frac{-1}{RC}\int_0^t V_{in}\,dt$$

$$i = C\frac{dV_c}{dt}V_c \qquad V_c = \frac{1}{C}\int_0^t i\,dt$$

Derivation:

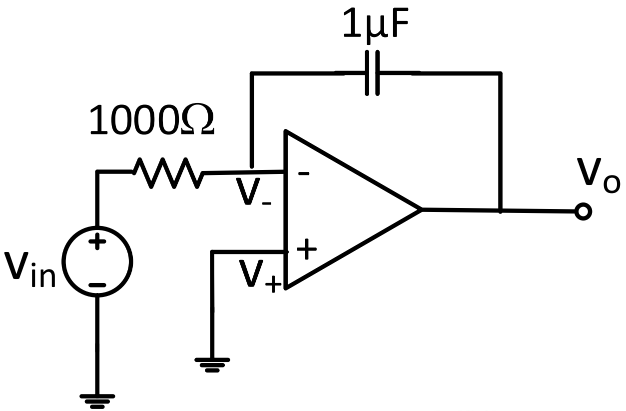
For t<0: V_{in} = iR and V_o = 0

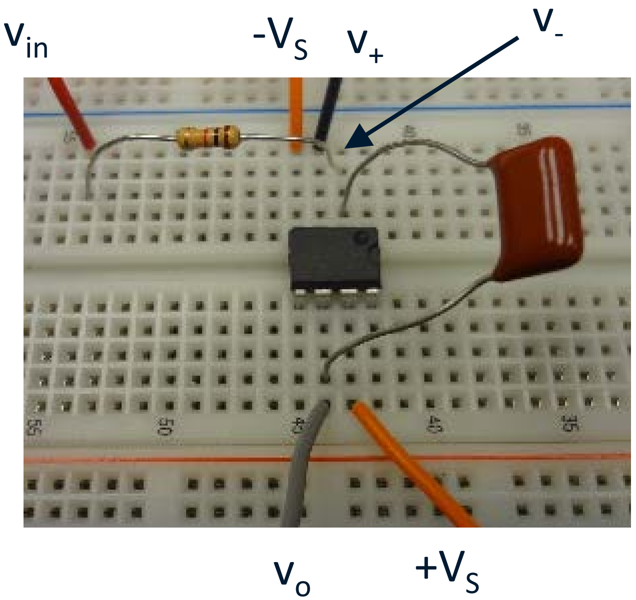
For t>0: V_{in} = iR $\qquad$ i = V_{in}/R

V_{in} = iR + V_c + V_o

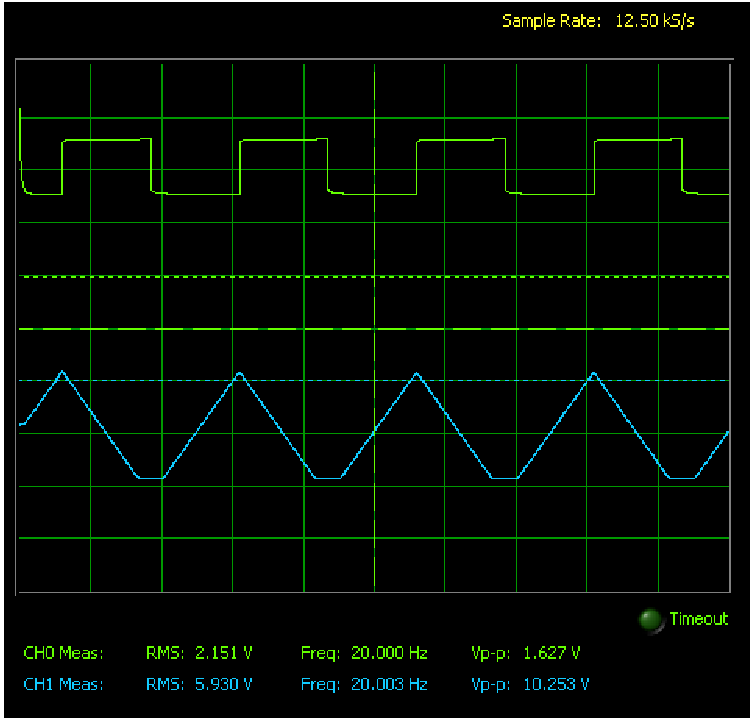
V_o = -V_c = -1/C $\int_0^t V_{in}/R\,dt$

Integrator Example





Results

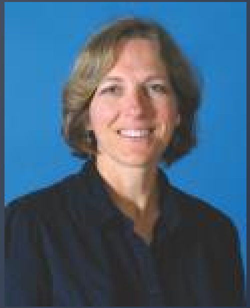


$$V_o = \frac{-1}{RC}\int_0^t V_{in}\,dt$$

Summary

- Differentiator and Integrator Op Amp circuits examined

Active Filters



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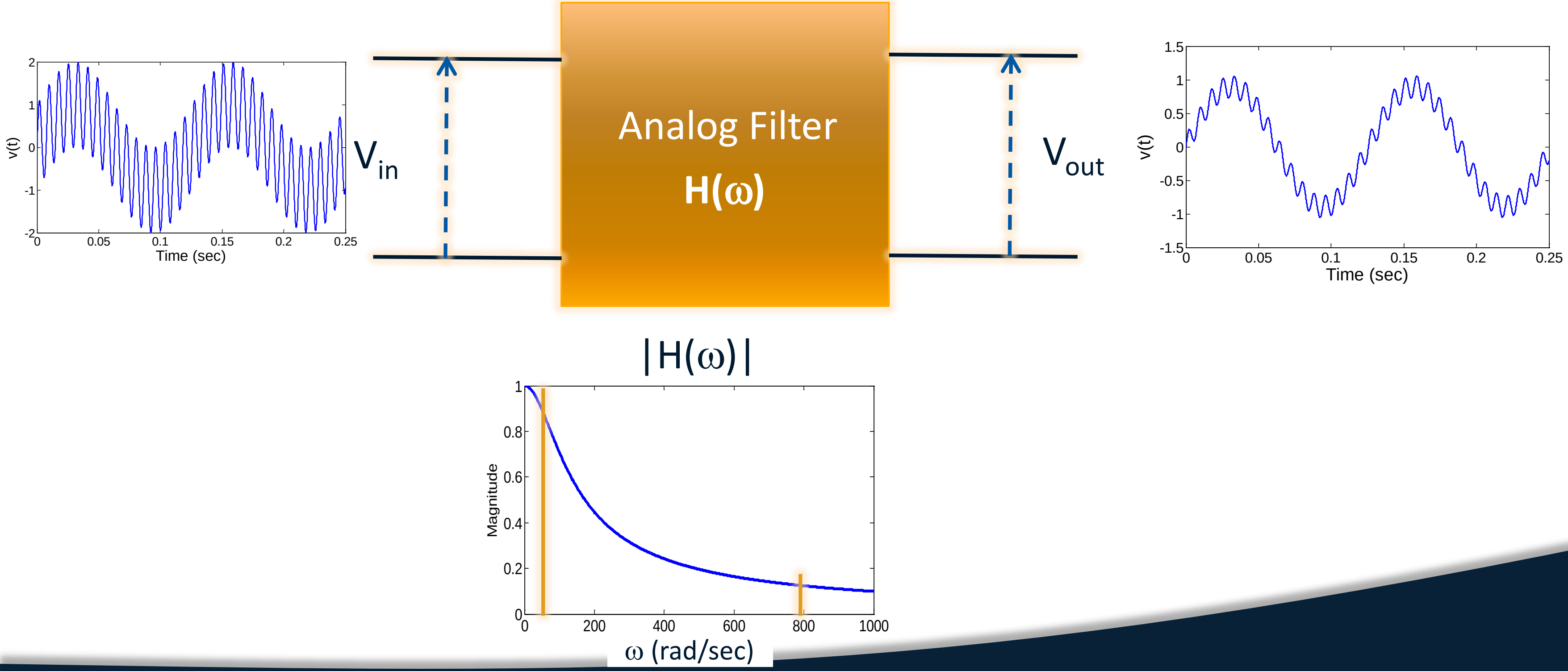
Introduce active filters and show different types of filters

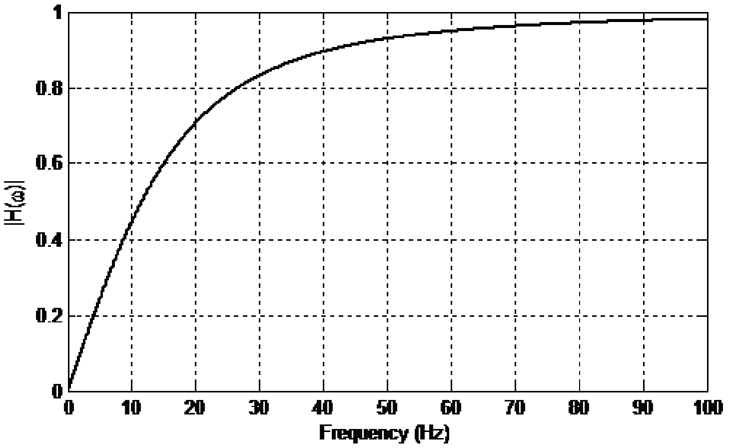
Lesson Objectives

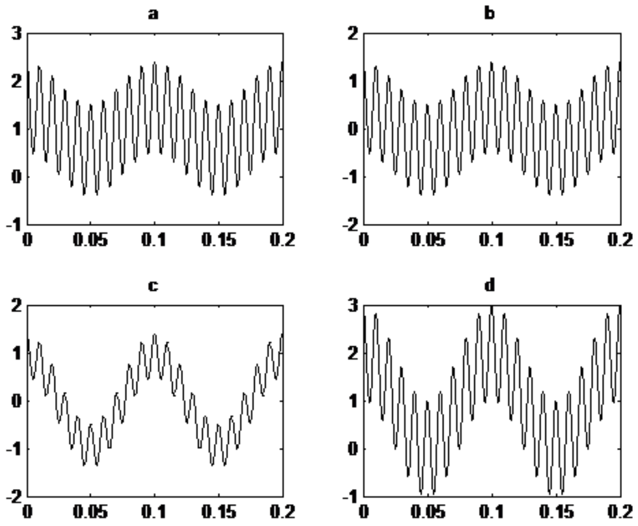
- Introduce active filter circuits

Analog Filters



Quiz





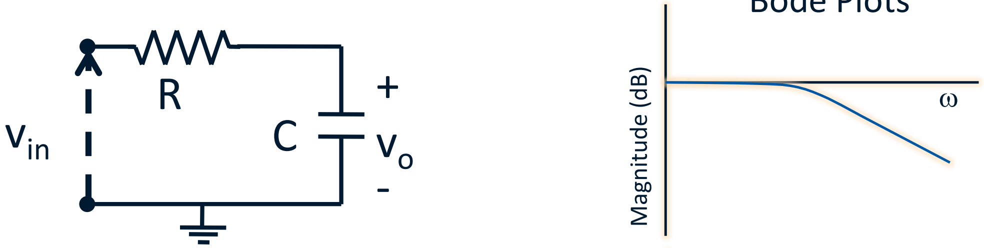
$V_{in} = 1 + \cos(10(2\pi t)) + \cos(100(2\pi t))$

$V_{out} = 0.45\cos(10(2\pi t)+\theta_1) + 0.97\cos(100(2\pi t) +\theta_2)$

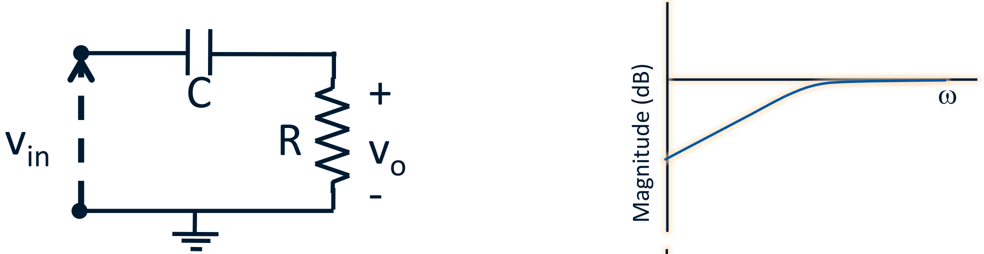
Summary of RC and RLC (Passive) Filters

Bode Plots

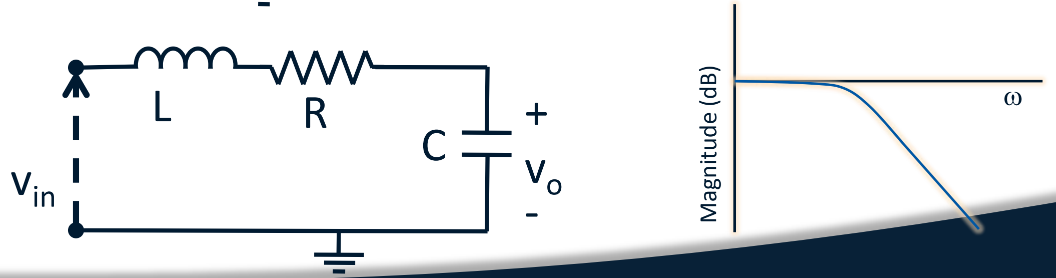
RC Lowpass:



RC Highpass:

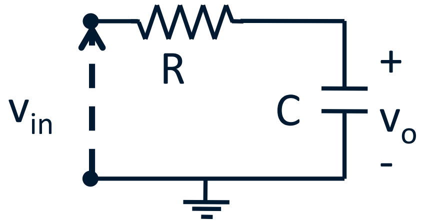


RLC Lowpass:



Limitations of RLC Passive Filters

- Depletes power

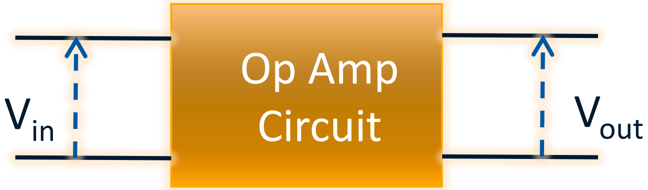


- No isolation

Active Filters

Active – has its own power supply

- Most common active filters are made from op amps
- Provide isolation



Summary

- An **analog filter** is a circuit that has a specific shaped frequency response
- A **active filter** is made of op amps and has its own power supply. Advantages over RLC passive filters:
  - Provides isolation (cascade filters)
  - Boosts the power
  - Can provide sharper roll-off