

Introduction to Electronics



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

Week 2: Op Amps Part 1





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Introduction and Ideal Behavior

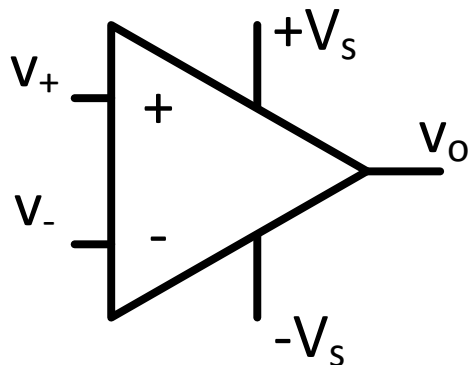
Introduce Op Amps and examine ideal behavior



Lesson Objectives

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

Operational Amplifiers (Op Amps)

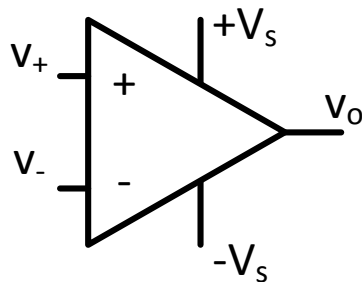


Specialized circuit made up of transistors, resistors, and capacitors fabricated on an integrated chip

Uses:

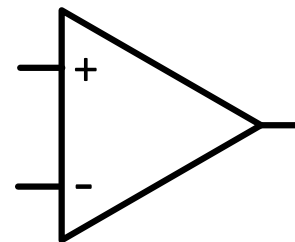
- Amplifiers
- Active Filters
- Analog Computers

Op Amps in Circuits



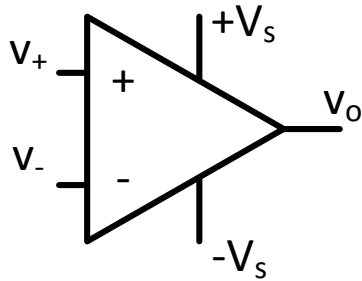
$V_s = 10V, 15V$

Symbol:

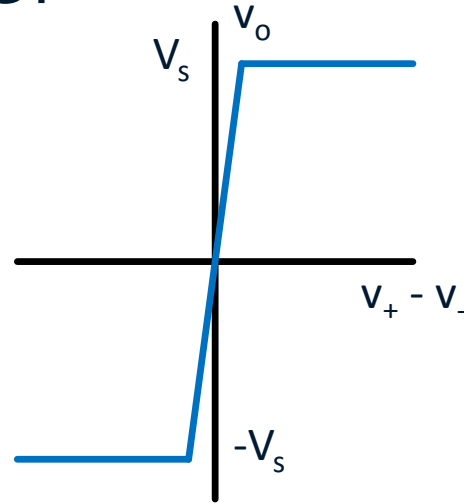


- Active Element: has its own power supply
- Symbol ignores the $\pm V_s$ in the symbol since it does not affect circuit behavior

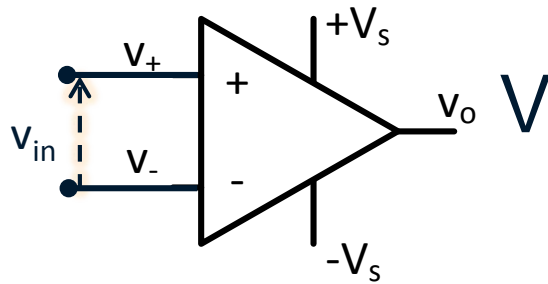
Open Loop Behavior



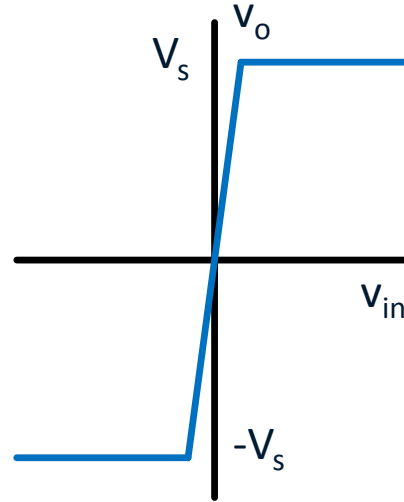
$$v_o = A(v_+ - v_-)$$



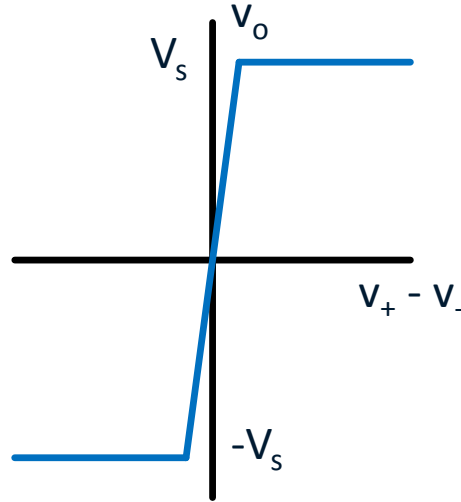
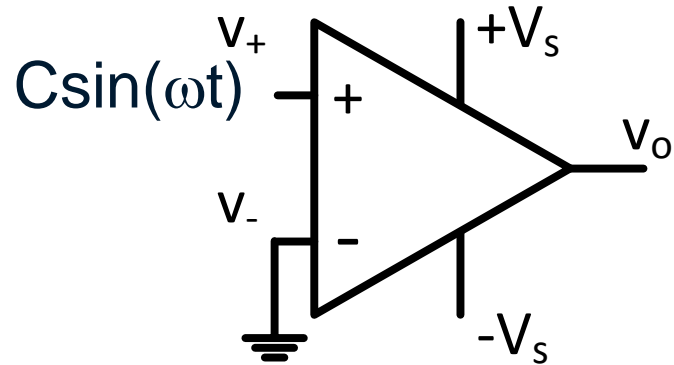
Comparator Circuit



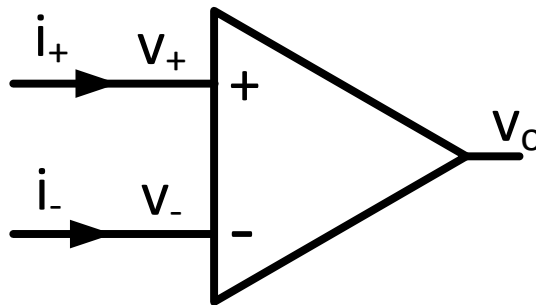
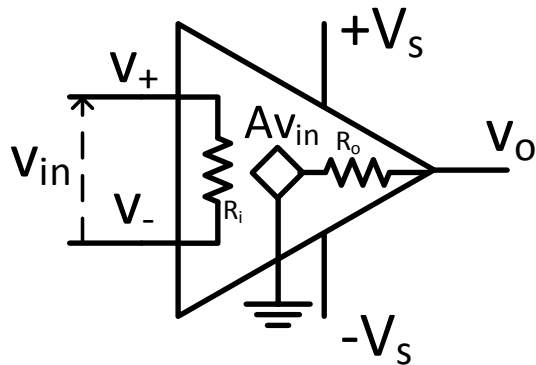
$$V_o = \begin{cases} V_s & \text{if } v_{in} > 0 \\ -V_s & \text{if } v_{in} < 0 \end{cases}$$



Example

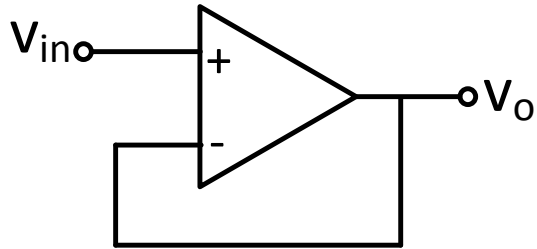


Ideal Op Amp Behavior

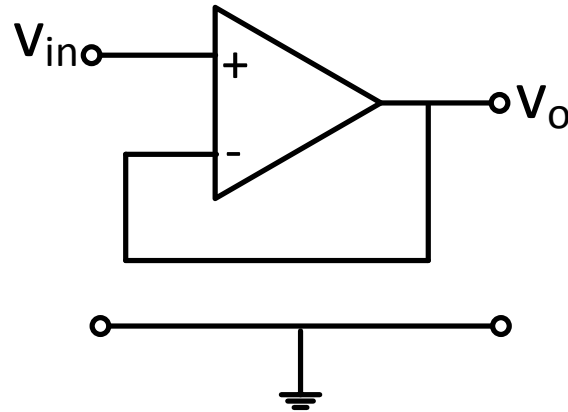


$$\begin{aligned} i_+ &= i_- = 0 \\ v_+ - v_- &= 0 \end{aligned}$$

Buffer Circuit

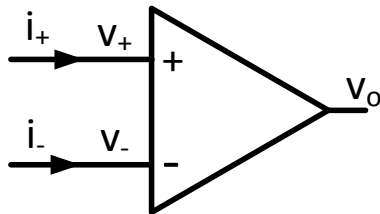


$$V_{in} = V_o$$



Summary

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



$$\begin{aligned} i_+ &= i_- = 0 \\ v_+ - v_- &= 0 \end{aligned}$$

- Circuits: comparator and buffer

Remainder of Module 2: Op Amps

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

Buffer Circuits



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Demonstrate buffer circuit behavior

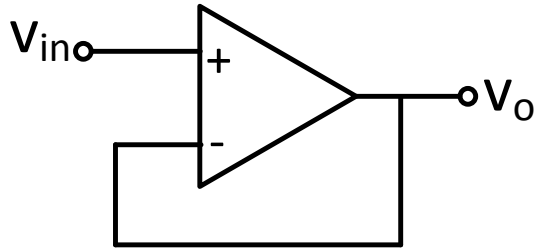


Lesson Objectives

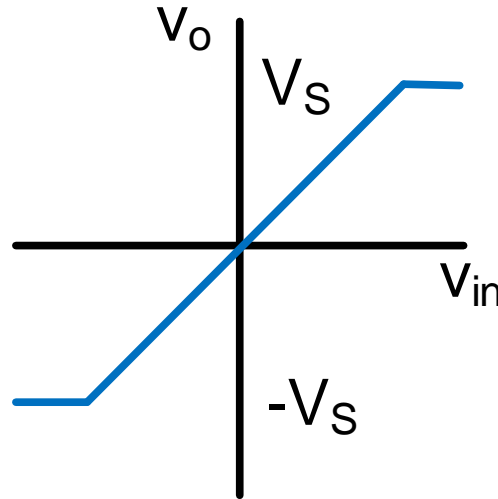
- Introduce physical op amps in circuits
- Examine Buffer Circuit behavior

Buffer Circuit

- Use to boost power without changing voltage waveform

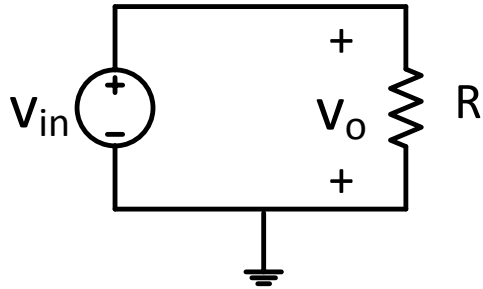


$$V_{in} = V_o$$

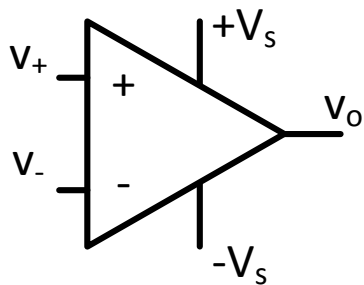


Saturation
Nonlinearity

Example: Without Buffer



Physical Op Amps

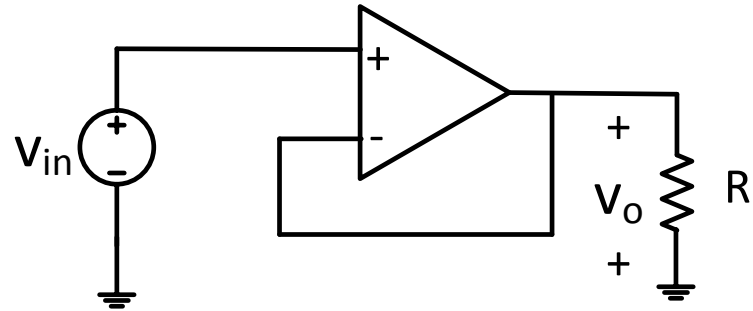
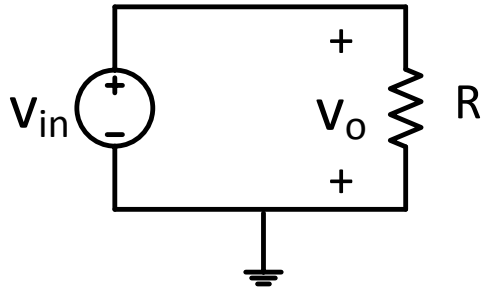


$$V_s = 15V$$

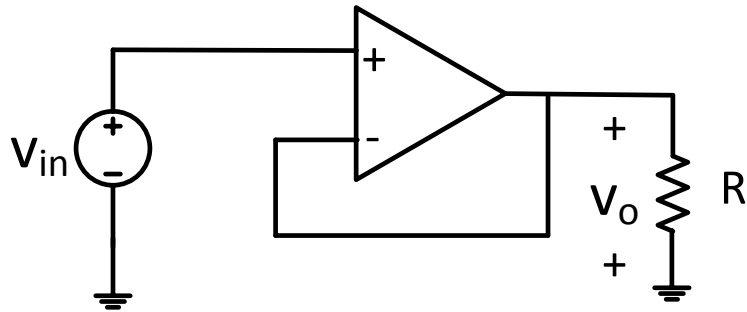
Signal	PIN
v_-	2
v_+	3
$-V_s$	4
v_o	6
$+V_s$	7



Example: With Buffer



Example: With Buffer



Summary

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



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Basic Op Amp Amplifier Configurations

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

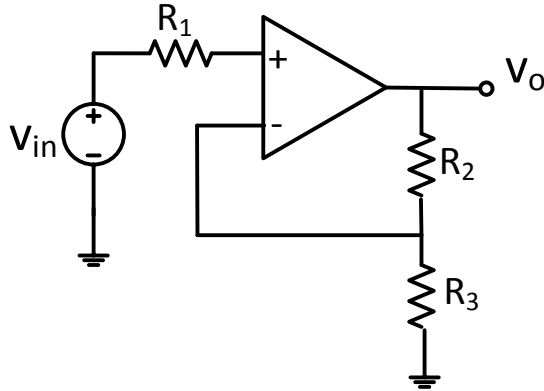
A photograph of a building with a prominent copper-roofed tower. The word 'TECH' is displayed in large, white, block letters on the building's facade. The building is illuminated with warm lights, suggesting dusk or dawn.

TECH

Lesson Objectives

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

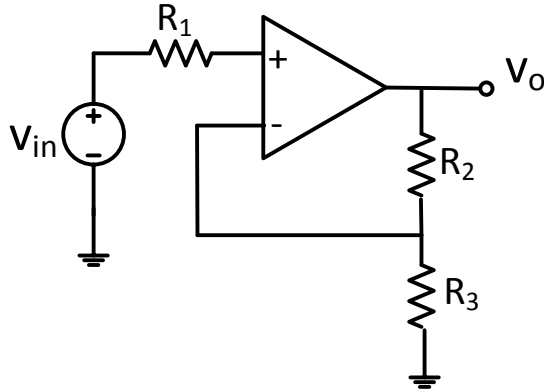
Non-Inverting Amplifiers



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

$$V_o = G V_{in} \quad \text{Gain: } G = \frac{R_2 + R_3}{R_3}$$

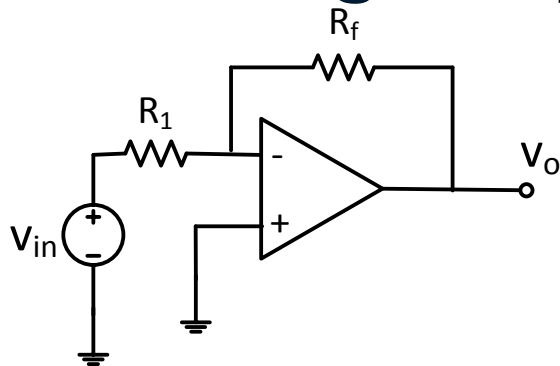
Non-Inverting Amplifier Example



If $R_2 = R_3 = 200\Omega$,

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

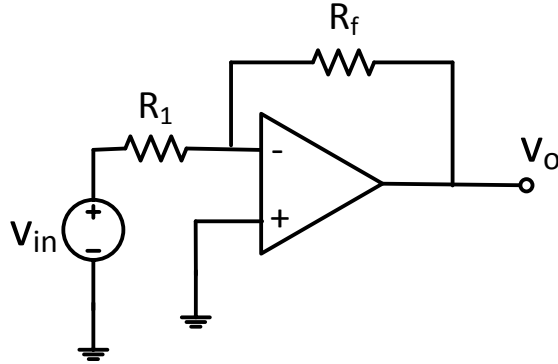
Inverting Amplifier



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

$$V_o = G V_{in}$$

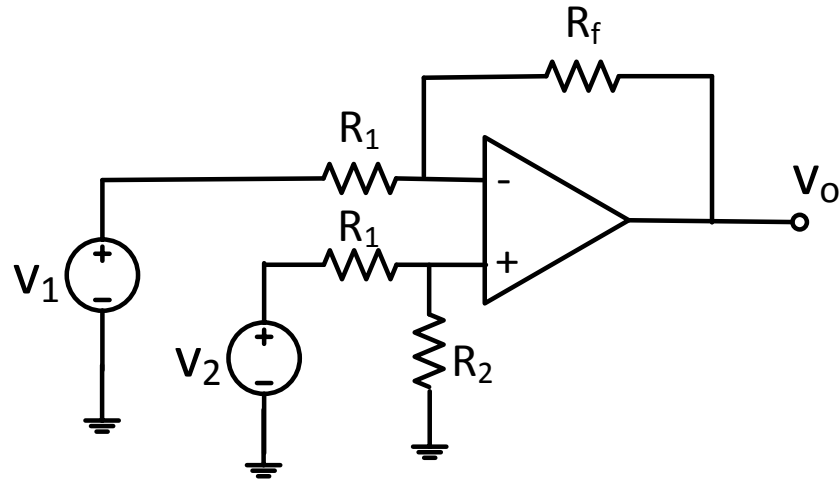
Inverting Amplifier Example



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

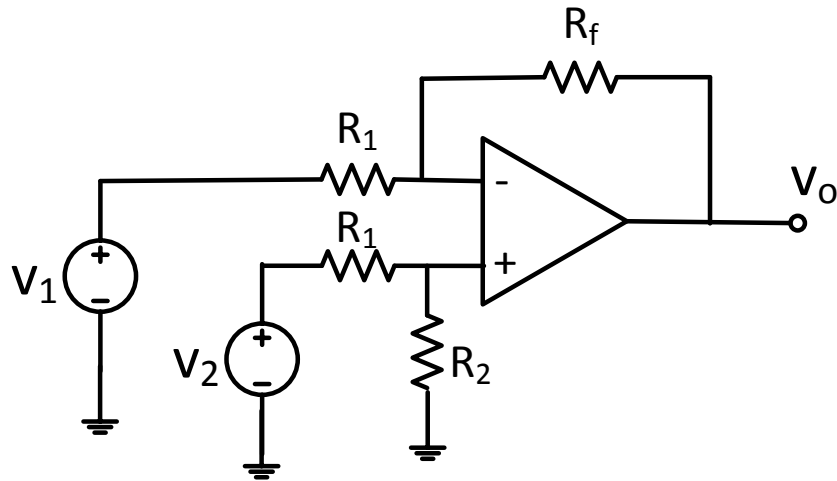
- If $G > 1$, the input is amplified
- If $G < 1$, the input is attenuated

Difference Circuit



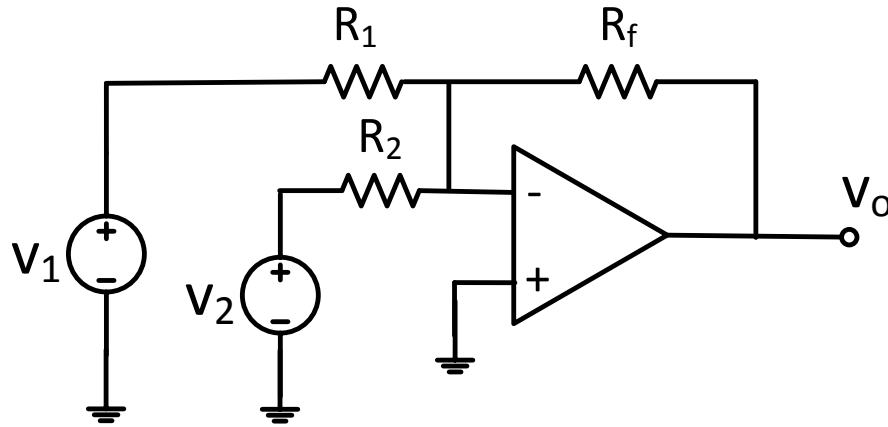
$$V_o = \frac{R_f}{R_1} (V_2 - V_1)$$

Difference Circuit



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

Summing Amplifier



$$V_o = G_1 V_1 + G_2 V_2$$

$$G_1 = -\frac{R_f}{R_1} \quad G_2 = -\frac{R_f}{R_2}$$

Summary

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



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Differentiators and Integrators

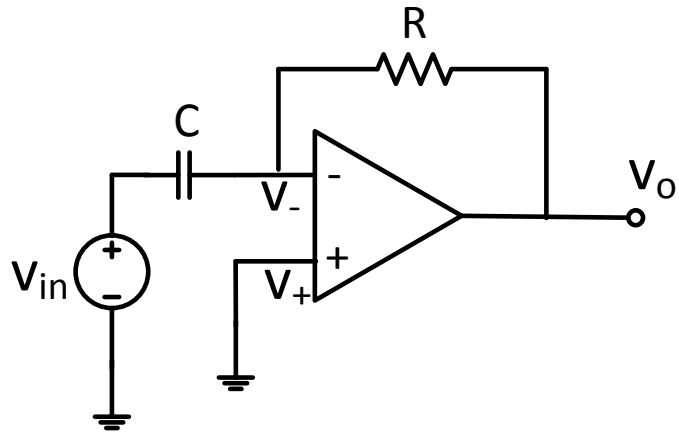
Introduce Integrating and Differentiating Op Amp Circuits



Lesson Objectives

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

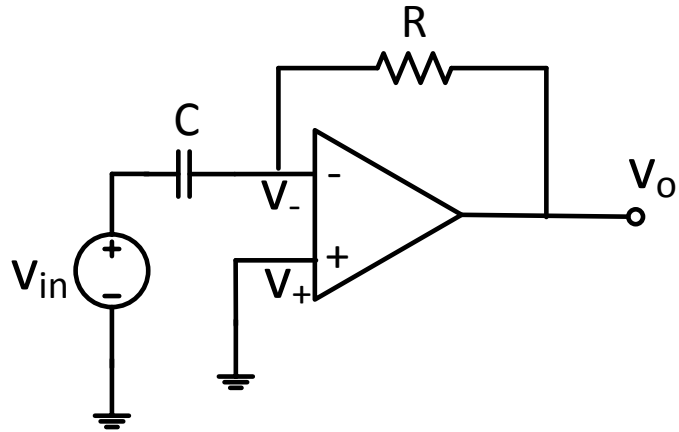
Differentiator Circuit



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

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

Differentiator Circuit

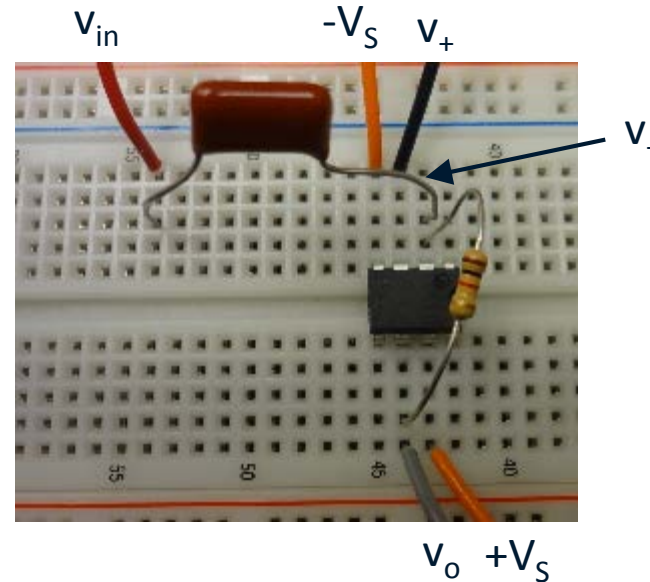
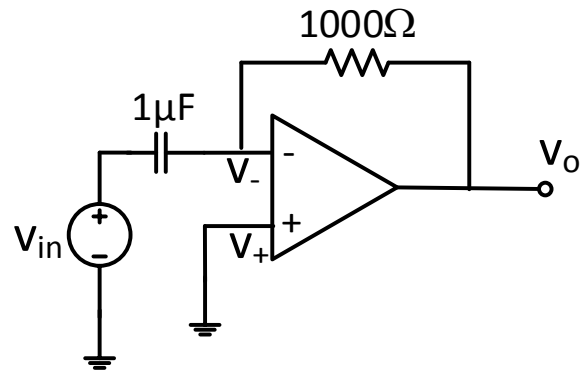


Derivation:

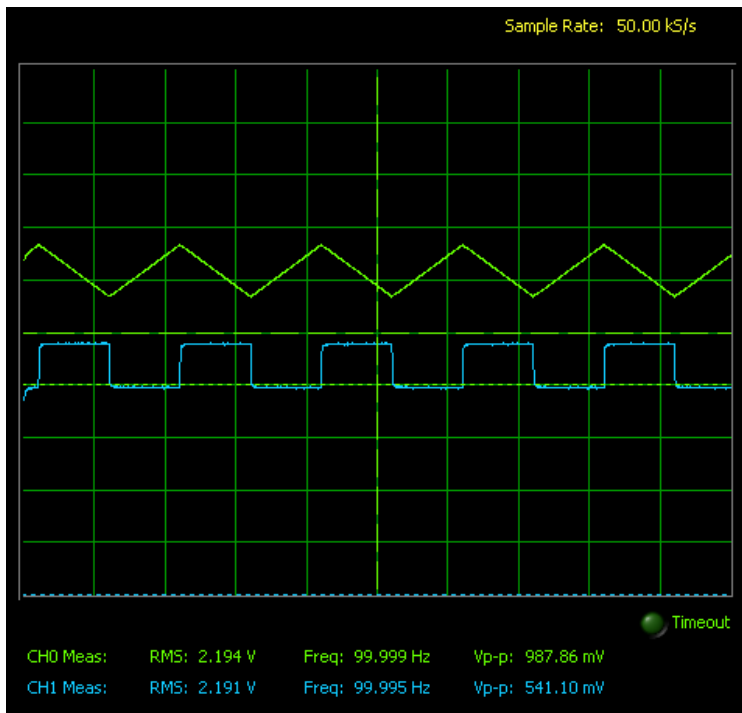
1. KVL: $V_{in} = V_c + R i + V_o$
2. $V_{in} = V_c$
3. $V_o = -R i = -RC(dV_{in} / dt)$

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

Differentiator Example

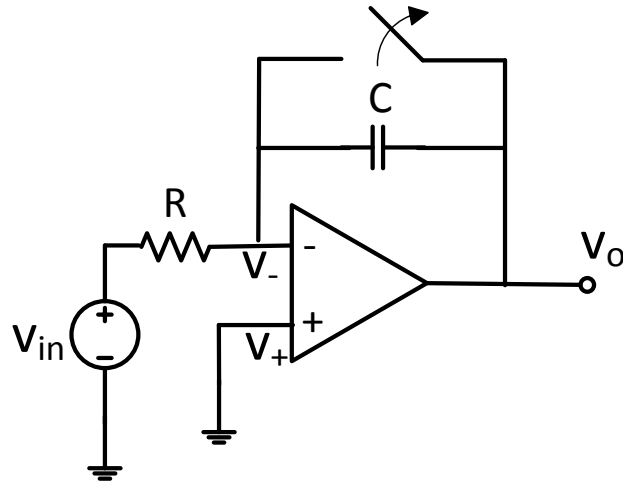


Results



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

Integrator Circuit

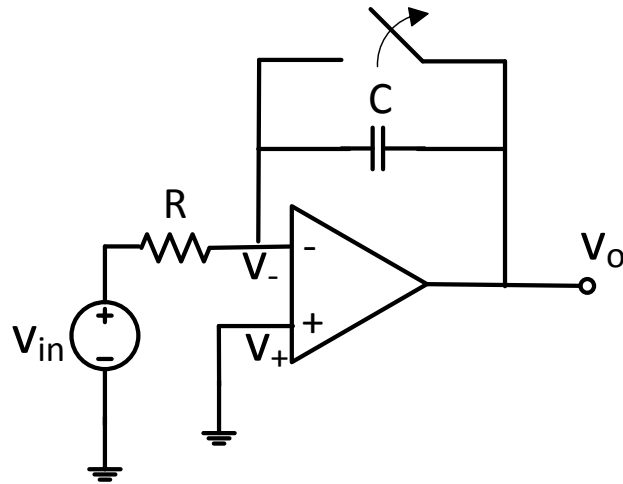


$$i = C \frac{dV_c}{dt}$$

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

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

Integrator Circuit



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

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

Derivation:

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

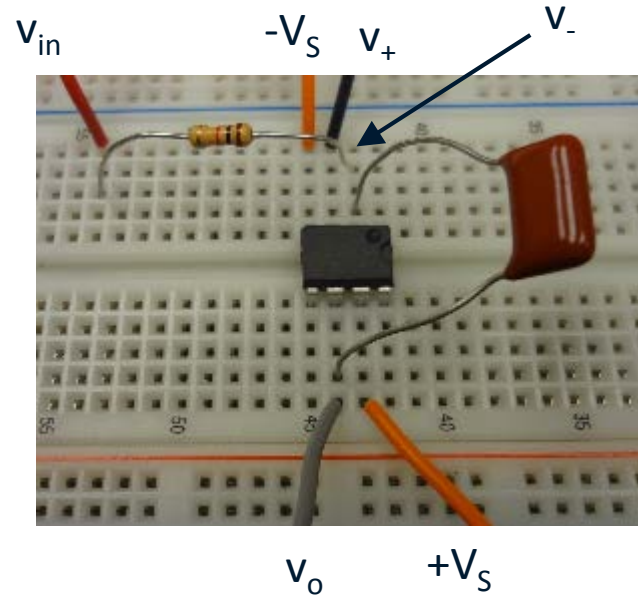
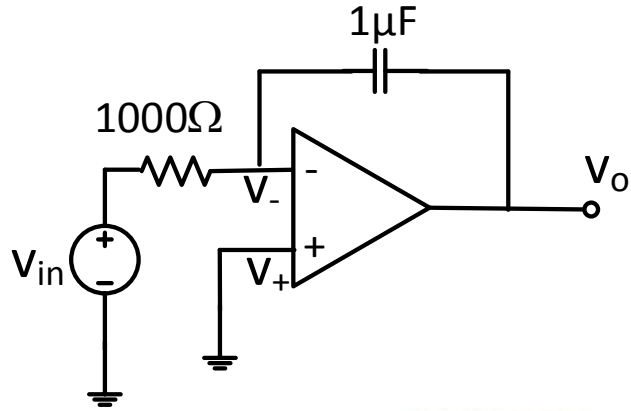
For $t > 0$: $V_{in} = iR$ $i = V_{in}/R$

$$V_{in} = iR + V_c + V_o$$

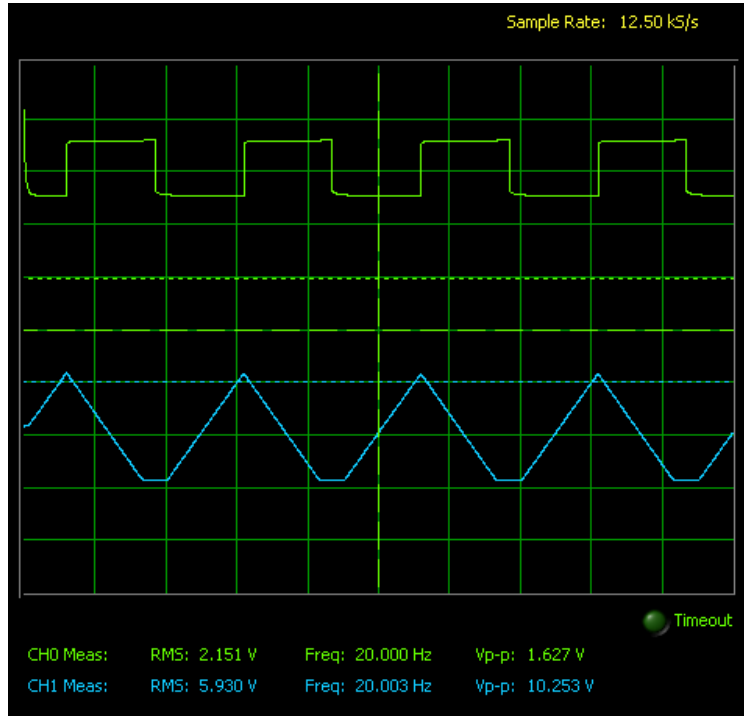
$$V_o = -V_c = -1/C \int_0^t V_{in}/R dt$$



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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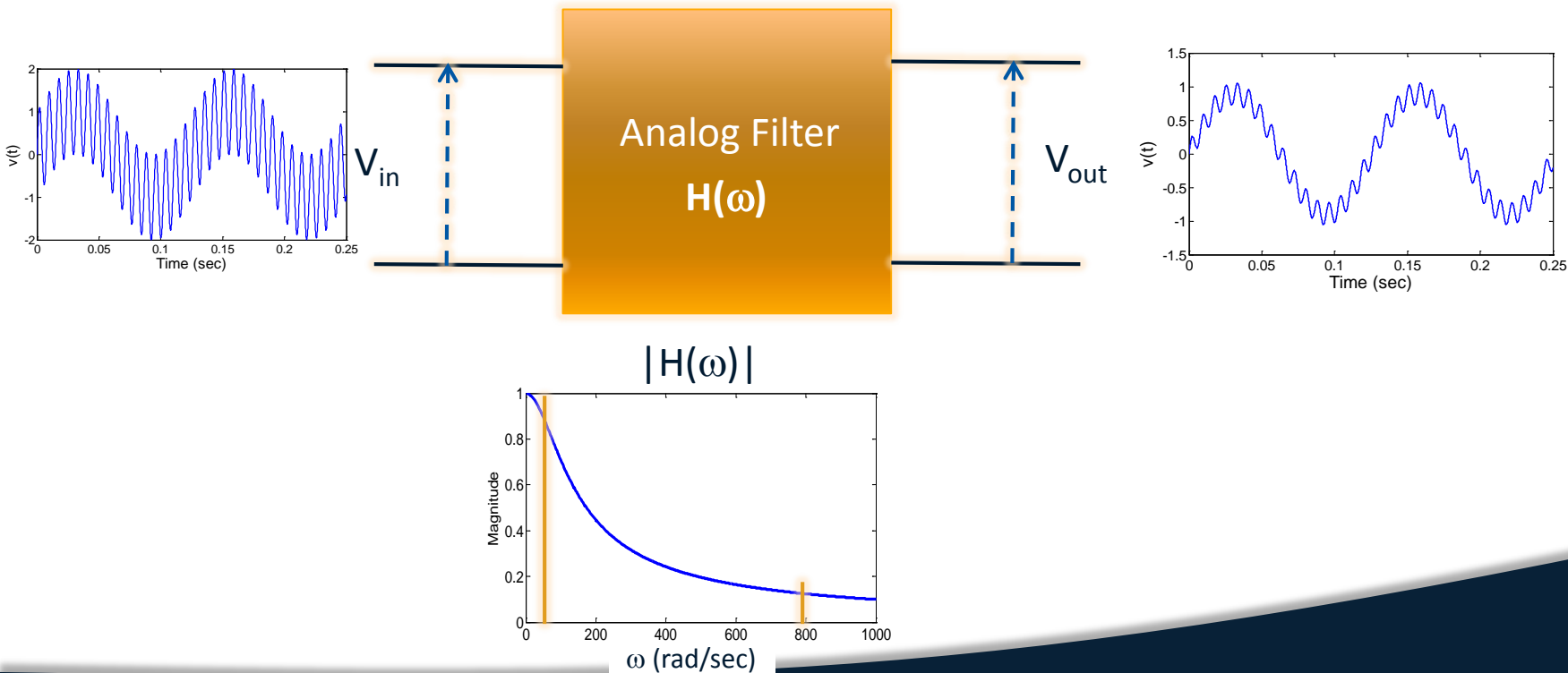
Introduce active filters and show different types of filters



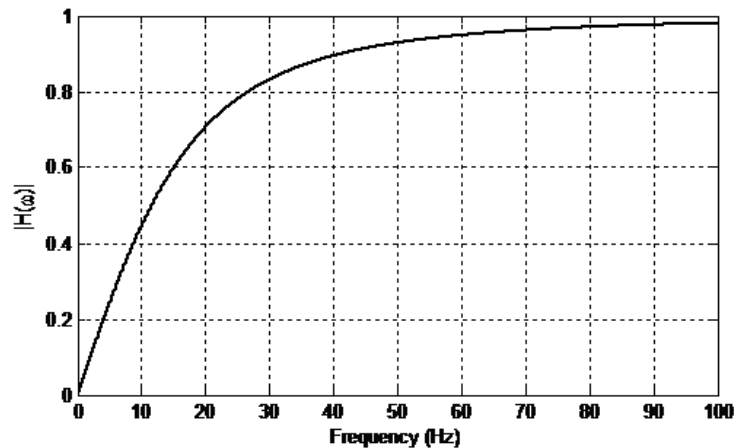
Lesson Objectives

- Introduce active filter circuits

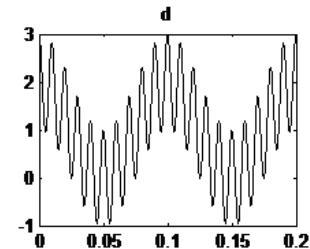
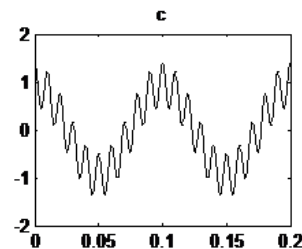
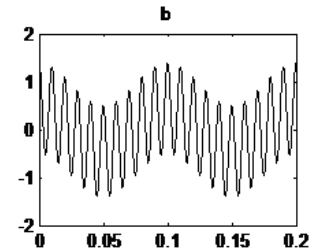
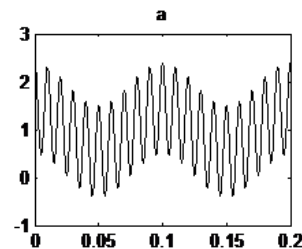
Analog Filters



Quiz



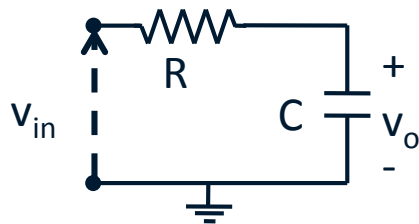
$$V_{in} = 1 + \cos(10(2\pi t)) + \cos(100(2\pi t))$$



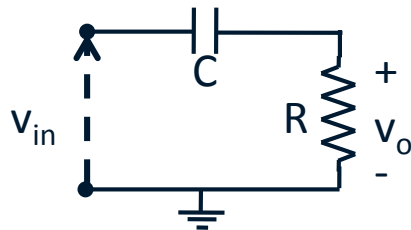
$$V_{out} = 0.45\cos(10(2\pi t) + \theta_1) + 0.97\cos(100(2\pi t) + \theta_2)$$

Summary of RC and RLC (Passive) Filters

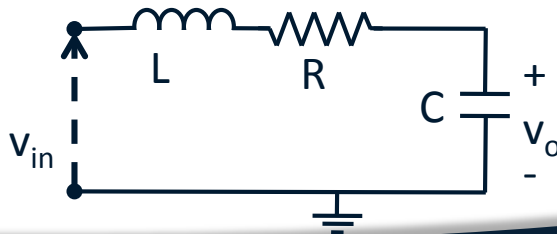
RC Lowpass:



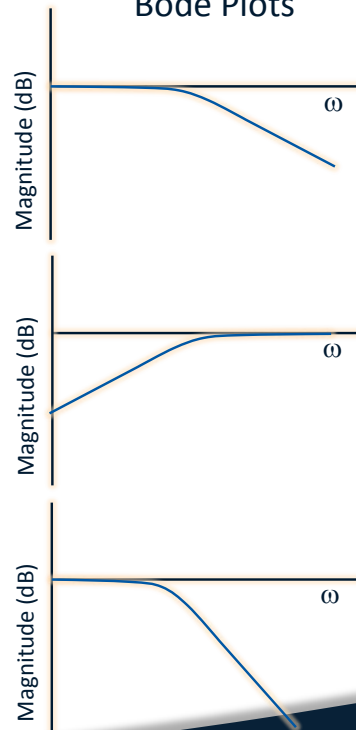
RC Highpass:



RLC Lowpass:

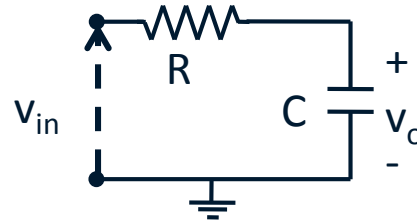


Bode Plots



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