

# Electronics Operational Amplifiers

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## Ideal Operational Amplifiers

Analyzing Op Amp Circuits

Common Operational Amplifier Circuits

Other Operational Amplifier Circuits

## Basic Schematic Symbol

Showing power connections

Operational amplifier supply voltage rules

Equivalent circuit

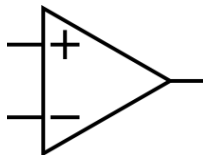
Negative feedback

# Ideal Operational Amplifiers

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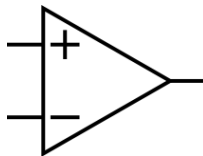


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inverting  
input

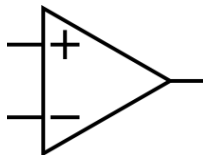


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non-inverting  
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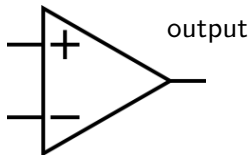
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Analyzing Op Amp Circuits  
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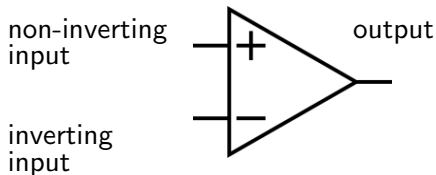
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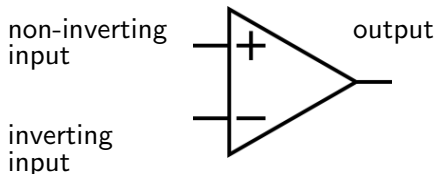


## Ideal Operational Amplifiers



- Output is proportional to the *difference* between the non-inverting and inverting inputs

## Ideal Operational Amplifiers

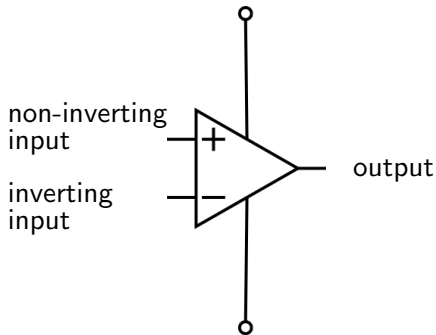


- Output is proportional to the *difference* between the non-inverting and inverting inputs
- Active device; requires power to work, even though power connections often not shown

Ideal Operational Amplifiers  
Analyzing Op Amp Circuits  
Common Operational Amplifier Circuits  
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Basic Schematic Symbol  
Showing power connections  
Operational amplifier supply voltage rules  
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Negative feedback

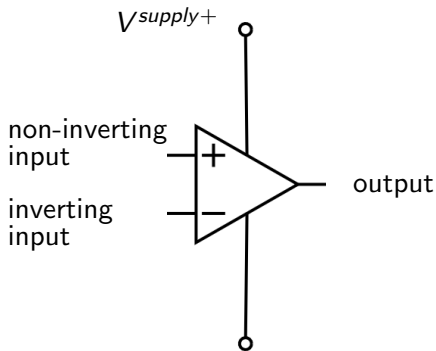
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Ideal Operational Amplifiers  
Analyzing Op Amp Circuits  
Common Operational Amplifier Circuits  
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Basic Schematic Symbol  
Showing power connections  
Operational amplifier supply voltage rules  
Equivalent circuit  
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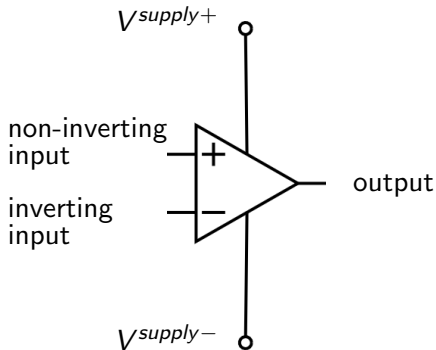
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Analyzing Op Amp Circuits  
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Operational amplifier supply voltage rules  
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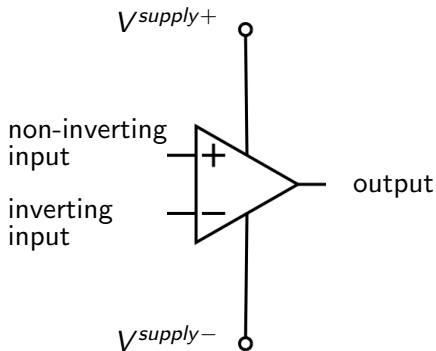
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Ideal Operational Amplifiers  
Analyzing Op Amp Circuits  
Common Operational Amplifier Circuits  
Other Operational Amplifier Circuits

Basic Schematic Symbol  
Showing power connections  
Operational amplifier supply voltage rules  
Equivalent circuit  
Negative feedback

## Showing power connections



Supplies are usually not shown, but must be used.

Ideal Operational Amplifiers  
Analyzing Op Amp Circuits  
Common Operational Amplifier Circuits  
Other Operational Amplifier Circuits

Basic Schematic Symbol  
Showing power connections  
**Operational amplifier supply voltage rules**  
Equivalent circuit  
Negative feedback

# Operational amplifier supply voltage rules

Ideal Operational Amplifiers  
Analyzing Op Amp Circuits  
Common Operational Amplifier Circuits  
Other Operational Amplifier Circuits

Basic Schematic Symbol  
Showing power connections  
**Operational amplifier supply voltage rules**  
Equivalent circuit  
Negative feedback

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Ideal Operational Amplifiers  
Analyzing Op Amp Circuits  
Common Operational Amplifier Circuits  
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Basic Schematic Symbol  
Showing power connections  
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- When an op amp hits one of the rails, its output can be called **saturated**, or we can say the op amp is *in saturation*.

**Ideal Operational Amplifiers**  
Analyzing Op Amp Circuits  
Common Operational Amplifier Circuits  
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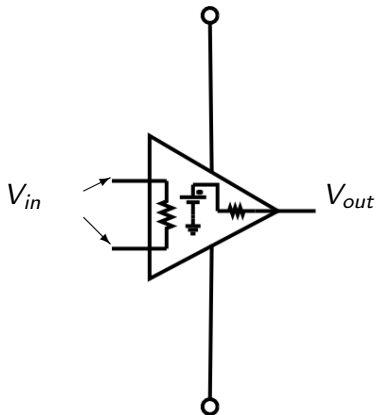
Basic Schematic Symbol  
Showing power connections  
Operational amplifier supply voltage rules  
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Negative feedback

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Ideal Operational Amplifiers  
Analyzing Op Amp Circuits  
Common Operational Amplifier Circuits  
Other Operational Amplifier Circuits

Basic Schematic Symbol  
Showing power connections  
Operational amplifier supply voltage rules  
**Equivalent circuit**  
Negative feedback

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**Ideal Operational Amplifiers**  
Analyzing Op Amp Circuits  
Common Operational Amplifier Circuits  
Other Operational Amplifier Circuits

Basic Schematic Symbol  
Showing power connections  
Operational amplifier supply voltage rules  
**Equivalent circuit**  
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# Operational amplifier equivalent circuit

Ideal Operational Amplifiers  
Analyzing Op Amp Circuits  
Common Operational Amplifier Circuits  
Other Operational Amplifier Circuits

Basic Schematic Symbol  
Showing power connections  
Operational amplifier supply voltage rules  
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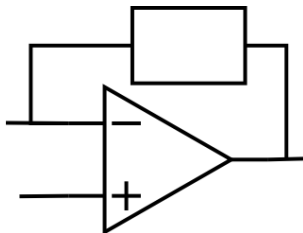
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- $V_{out} = A_v (V_+ - V_-)$

**Ideal Operational Amplifiers**  
Analyzing Op Amp Circuits  
Common Operational Amplifier Circuits  
Other Operational Amplifier Circuits

Basic Schematic Symbol  
Showing power connections  
Operational amplifier supply voltage rules  
Equivalent circuit  
**Negative feedback**

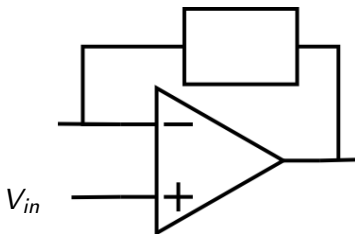
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Ideal Operational Amplifiers  
Analyzing Op Amp Circuits  
Common Operational Amplifier Circuits  
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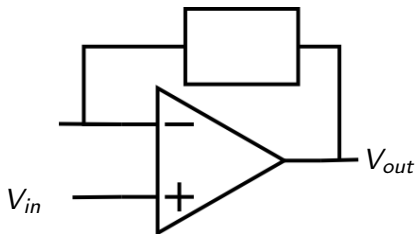
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Ideal Operational Amplifiers  
Analyzing Op Amp Circuits  
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Showing power connections  
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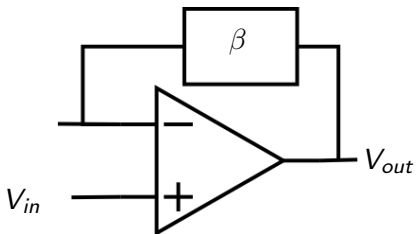
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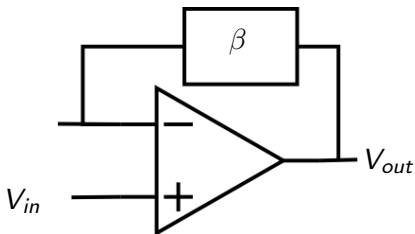
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Analyzing Op Amp Circuits  
Common Operational Amplifier Circuits  
Other Operational Amplifier Circuits

Basic Schematic Symbol  
Showing power connections  
Operational amplifier supply voltage rules  
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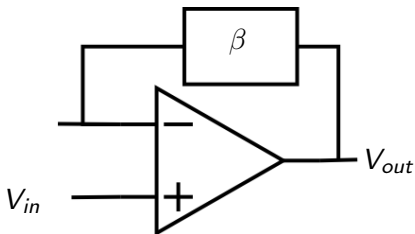


## Negative feedback



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**Ideal Operational Amplifiers**  
Analyzing Op Amp Circuits  
Common Operational Amplifier Circuits  
Other Operational Amplifier Circuits

Basic Schematic Symbol  
Showing power connections  
Operational amplifier supply voltage rules  
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- $R_{in} \approx R_{in} (1 + \beta A)$
- $R_{out} \approx \frac{R_{out}}{(1 + \beta A)}$
- $gain = \frac{1}{\beta}$ ; i.e. **the output depends only on the feedback, not on the op amp characteristics**

**Ideal Operational Amplifiers**  
Analyzing Op Amp Circuits  
Common Operational Amplifier Circuits  
Other Operational Amplifier Circuits

Basic Schematic Symbol  
Showing power connections  
Operational amplifier supply voltage rules  
Equivalent circuit  
**Negative feedback**

**You will virtually **never** use positive feedback!**

Ideal Operational Amplifiers  
Analyzing Op Amp Circuits  
Common Operational Amplifier Circuits  
Other Operational Amplifier Circuits

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Showing power connections  
Operational amplifier supply voltage rules  
Equivalent circuit  
Negative feedback

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Ideal Operational Amplifiers  
Analyzing Op Amp Circuits  
Common Operational Amplifier Circuits  
Other Operational Amplifier Circuits

Basic Schematic Symbol  
Showing power connections  
Operational amplifier supply voltage rules  
Equivalent circuit  
Negative feedback

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**Ideal Operational Amplifiers**  
Analyzing Op Amp Circuits  
Common Operational Amplifier Circuits  
Other Operational Amplifier Circuits

Basic Schematic Symbol  
Showing power connections  
Operational amplifier supply voltage rules  
Equivalent circuit  
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**Ideal Operational Amplifiers**  
Analyzing Op Amp Circuits  
Common Operational Amplifier Circuits  
Other Operational Amplifier Circuits

Basic Schematic Symbol  
Showing power connections  
Operational amplifier supply voltage rules  
Equivalent circuit  
**Negative feedback**

## Terminology

- Without feedback is called *open loop* configuration

Ideal Operational Amplifiers  
Analyzing Op Amp Circuits  
Common Operational Amplifier Circuits  
Other Operational Amplifier Circuits

Basic Schematic Symbol  
Showing power connections  
Operational amplifier supply voltage rules  
Equivalent circuit  
Negative feedback

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Ideal Operational Amplifiers  
Analyzing Op Amp Circuits  
Common Operational Amplifier Circuits  
Other Operational Amplifier Circuits

Basic Schematic Symbol  
Showing power connections  
Operational amplifier supply voltage rules  
Equivalent circuit  
Negative feedback

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# Analyzing Op Amp Circuits; ideal assumptions with closed loop circuits

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- Instead of thinking of the device as an amplifier, you can think the purpose of the device is to keep the inputs equal

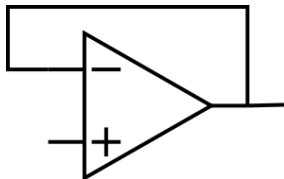
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Analyzing Op Amp Circuits  
**Common Operational Amplifier Circuits**  
Other Operational Amplifier Circuits

### Buffer circuit

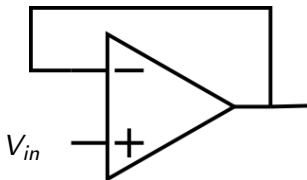
Inverting amplifier circuit  
Summing amplifier circuit  
Non-inverting amplifier circuit  
Differential amplifier circuit

# Buffer (or voltage follower)

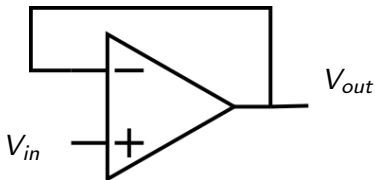
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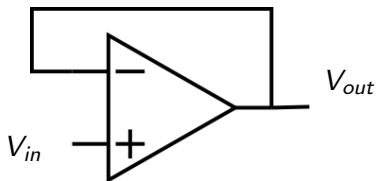
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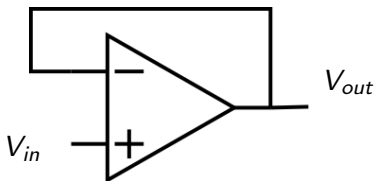


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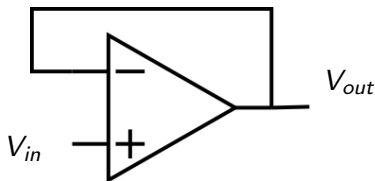
- $V_{-} = V_{out}$  and  $V_{+} = V_{in}$

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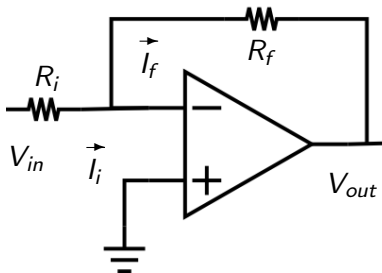
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- $V_- = V_{out}$  and  $V_+ = V_{in}$
  - $V_- \approx V_+$  (virtual equality)
- $\therefore V_{out} \approx V_{in}$

## Inverting amplifier



- Many op amp circuits are based on this.

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- $I_i R_i = V_- - V_{in}$

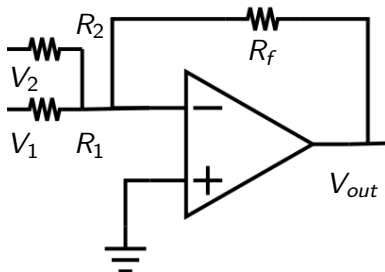
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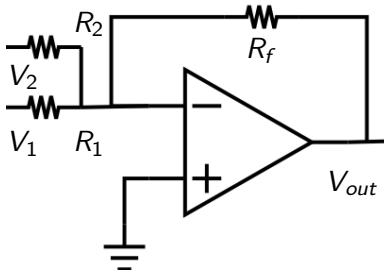
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- $I_f = I_i$  (no current into inputs)
  - $\therefore \frac{V_{out} - 0}{R_f} = \frac{0 - V_{in}}{R_i}$
  - $\therefore V_{out} = -\frac{R_f}{R_i} V_{in}$

## Summing amplifier



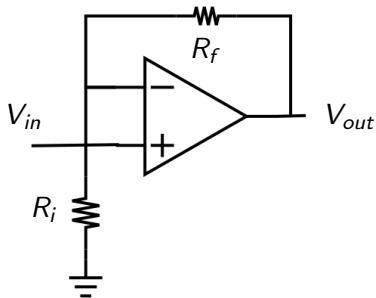
- $$V_{out} = -R_f \left( \frac{V_1}{R_1} + \frac{V_2}{R_2} \right)$$

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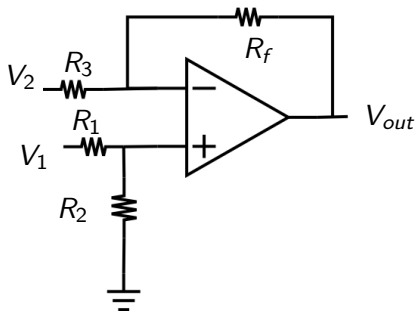
- $V_{out} = -R_f \left( \frac{V_1}{R_1} + \frac{V_2}{R_2} \right)$
- Can be extended to many inputs

## Non-inverting amplifier



- $$V_{out} = \left(1 + \frac{R_f}{R_i}\right) V_{in}$$

## Differential amplifier



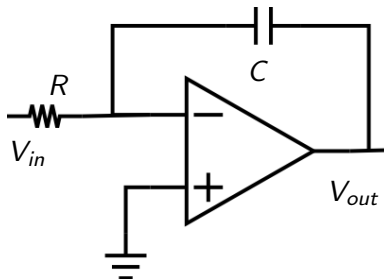
- $$V_{out} = \frac{V_1 R_2}{R_1 + R_2} \left( 1 + \frac{R_f}{R_3} \right) - V_2 \frac{R_f}{R_3}$$

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 $\therefore V_{out} = \frac{R_f}{R_1} (V_1 - V_2)$

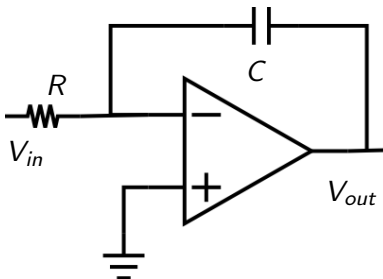
- $V_{out} = \frac{V_1 R_2}{R_1 + R_2} \left( 1 + \frac{R_f}{R_3} \right) - V_2 \frac{R_f}{R_3}$
- Simplified if  $R_f = R_2$  and  $R_1 = R_3$   
 $\therefore V_{out} = \frac{R_f}{R_1} (V_1 - V_2)$
- If all resistors are equal,  $V_{out} = V_1 - V_2$

## Integrator



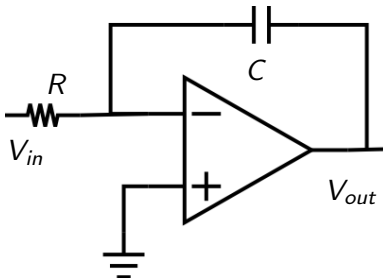
- Output is the *integral* of the input over time

## Integrator



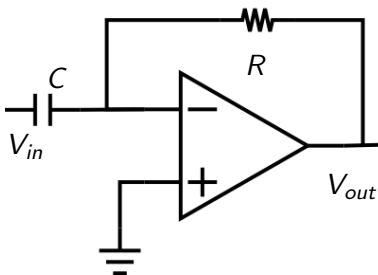
- Output is the *integral* of the input over time
- $V_{out} = -\frac{1}{RC} \int V_{in} dt$

## Integrator



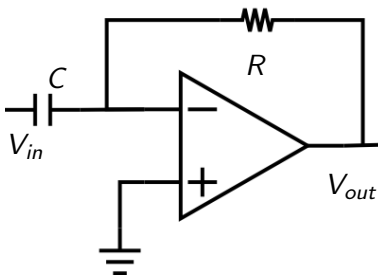
- Output is the *integral* of the input over time
- $V_{out} = -\frac{1}{RC} \int V_{in} dt$
- Often has a large resistor in parallel with  $C$  to avoid saturation

## Differentiator



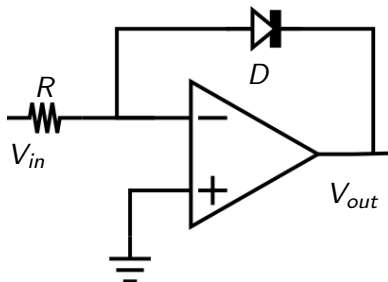
- Output is the *derivative* of the input over time

## Differentiator



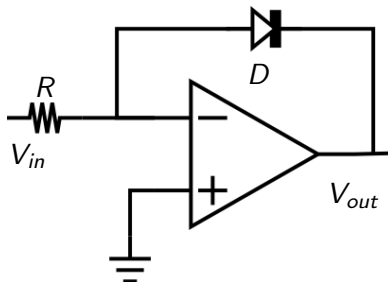
- Output is the *derivative* of the input over time
- $V_{out} = -RC \frac{dV_{in}}{dt}$

## Logarithmic amplifier



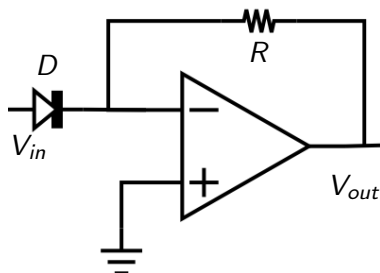
- Output is related to the *logarithm* of the input

## Logarithmic amplifier



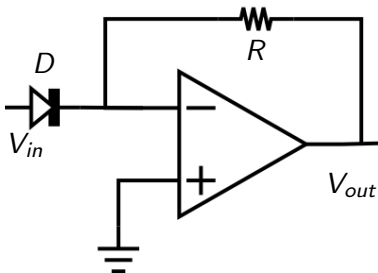
- Output is related to the *logarithm* of the input
- $V_{out} \propto -\ln V_{in}$

## Exponential amplifier



- Output is related to the *exponential* of the input

## Exponential amplifier



- Output is related to the *exponential* of the input
- $V_{out} \propto -e^{V_{in}}$