Electronics
Operational Amplifier Circuits

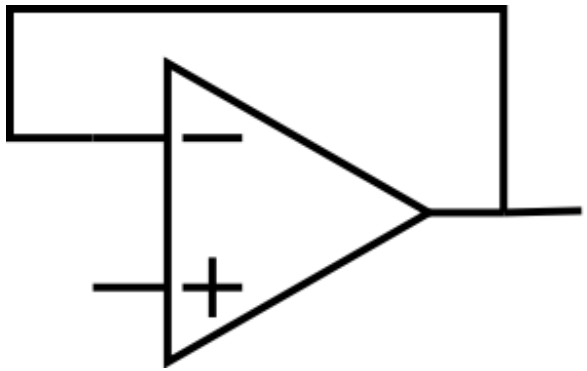
Terry Sturtevant

Wilfrid Laurier University

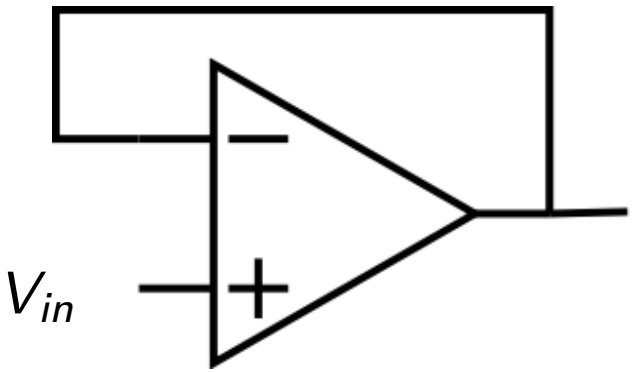
September 4, 2014

Buffer (or voltage follower)

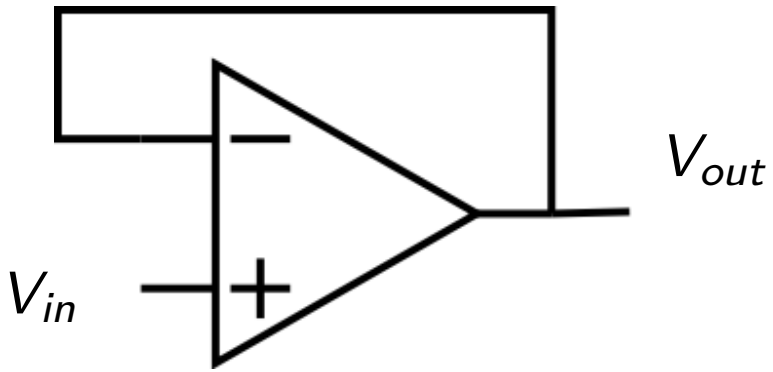
Buffer (or voltage follower)



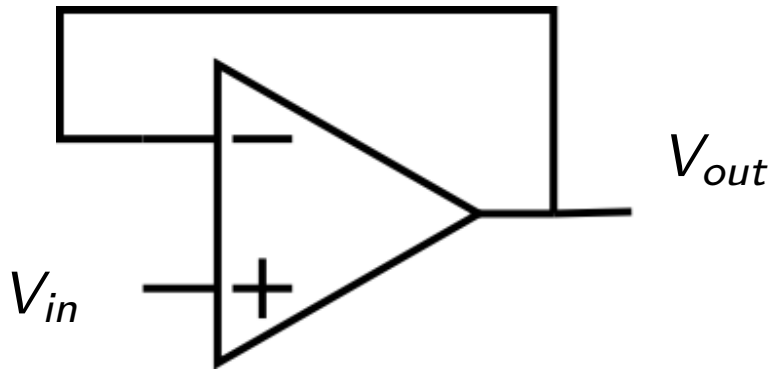
Buffer (or voltage follower)



Buffer (or voltage follower)

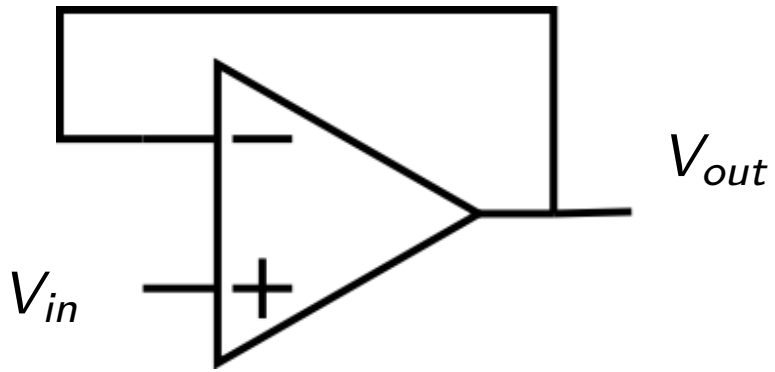


Buffer (or voltage follower)



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

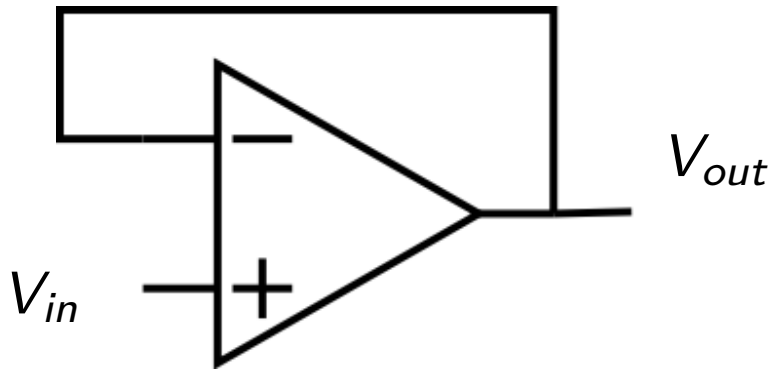
Buffer (or voltage follower)



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

$V_- \approx V_+$ (virtual equality)

Buffer (or voltage follower)



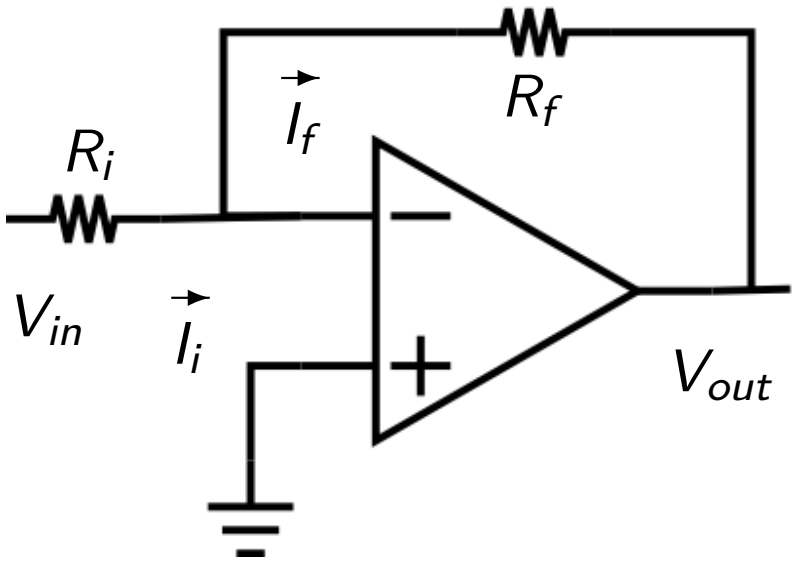
$V_- = V_{out}$ and $V_+ = V_{in}$

$V_- \approx V_+$ (virtual equality)

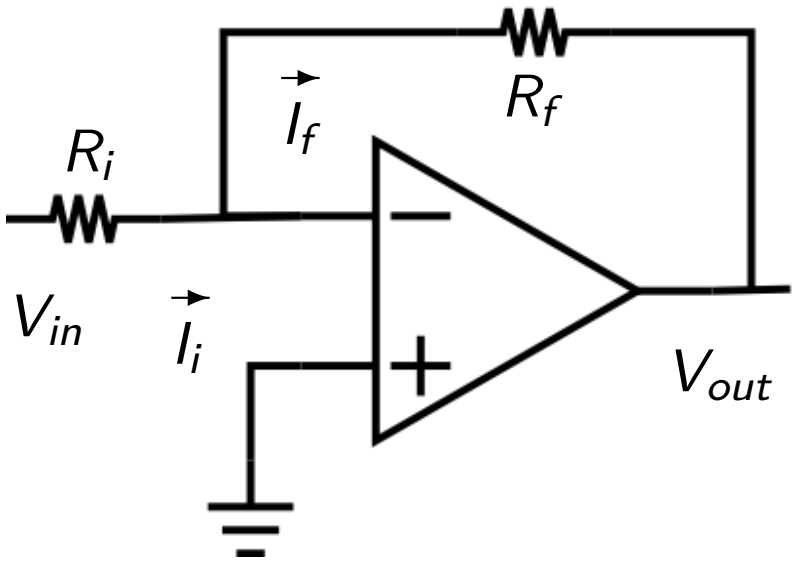
$\therefore V_{out} \approx V_{in}$

Inverting amplifier

Inverting amplifier



Inverting amplifier



Many op amp circuits are based on this.

$$V_+ = 0 \text{ (ground)}$$

$$V_+ = 0 \text{ (ground)}$$

$$I_f R_f = V_{out} - V_-$$

$$V_+ = 0 \text{ (ground)}$$
$$I_f R_f = V_{out} - V_-$$
$$I_i R_i = V_- - V_{in}$$

$V_+ = 0$ (ground)

$I_f R_f = V_{out} - V_-$

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

$V_- \approx V_+$ (virtual equality)

$V_+ = 0$ (ground)

$I_f R_f = V_{out} - V_-$

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

$V_- \approx V_+$ (virtual equality)

$I_f = I_i$ (no current into inputs)

$V_+ = 0$ (ground)

$I_f R_f = V_{out} - V_-$

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

$V_- \approx V_+$ (virtual equality)

$I_f = I_i$ (no current into inputs)

$\therefore \frac{V_{out}-0}{R_f} = \frac{0-V_{in}}{R_i}$

$V_+ = 0$ (ground)

$I_f R_f = V_{out} - V_-$

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

$V_- \approx V_+$ (virtual equality)

$I_f = I_i$ (no current into inputs)

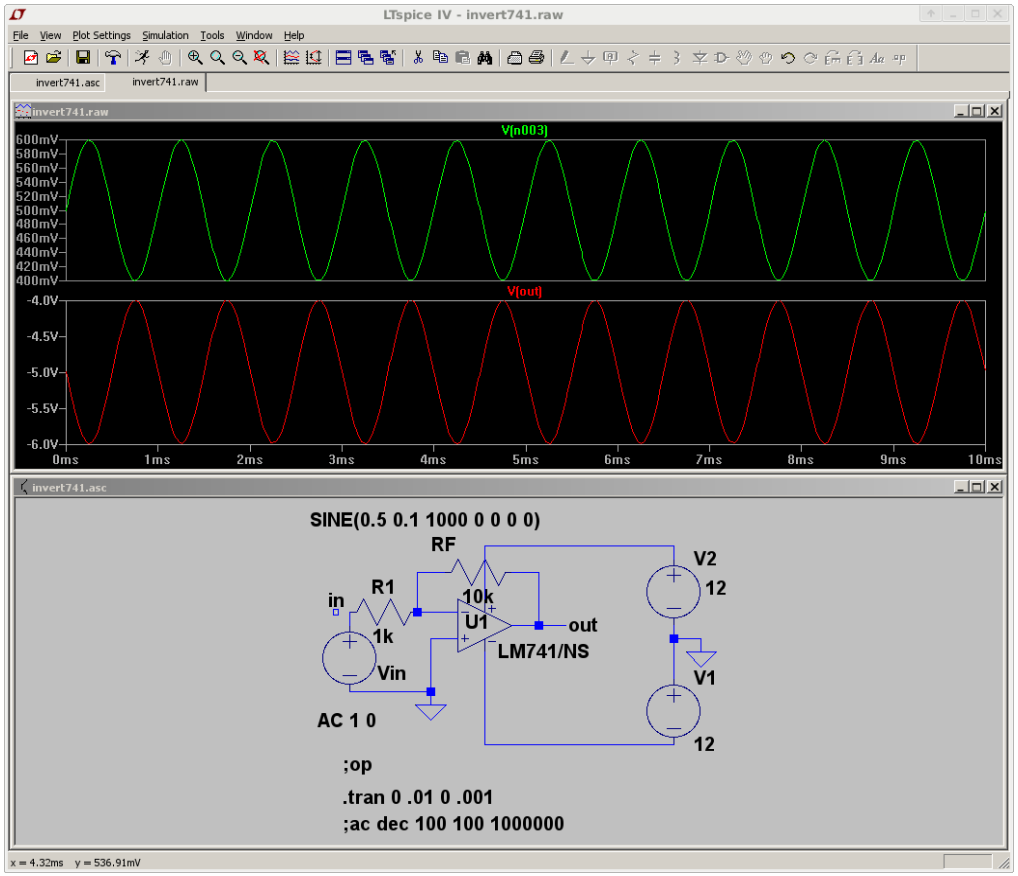
$\therefore \frac{V_{out}-0}{R_f} = \frac{0-V_{in}}{R_i}$

$\therefore V_{out} = -\frac{R_f}{R_i} V_{in}$

600mV

400mV
-4V

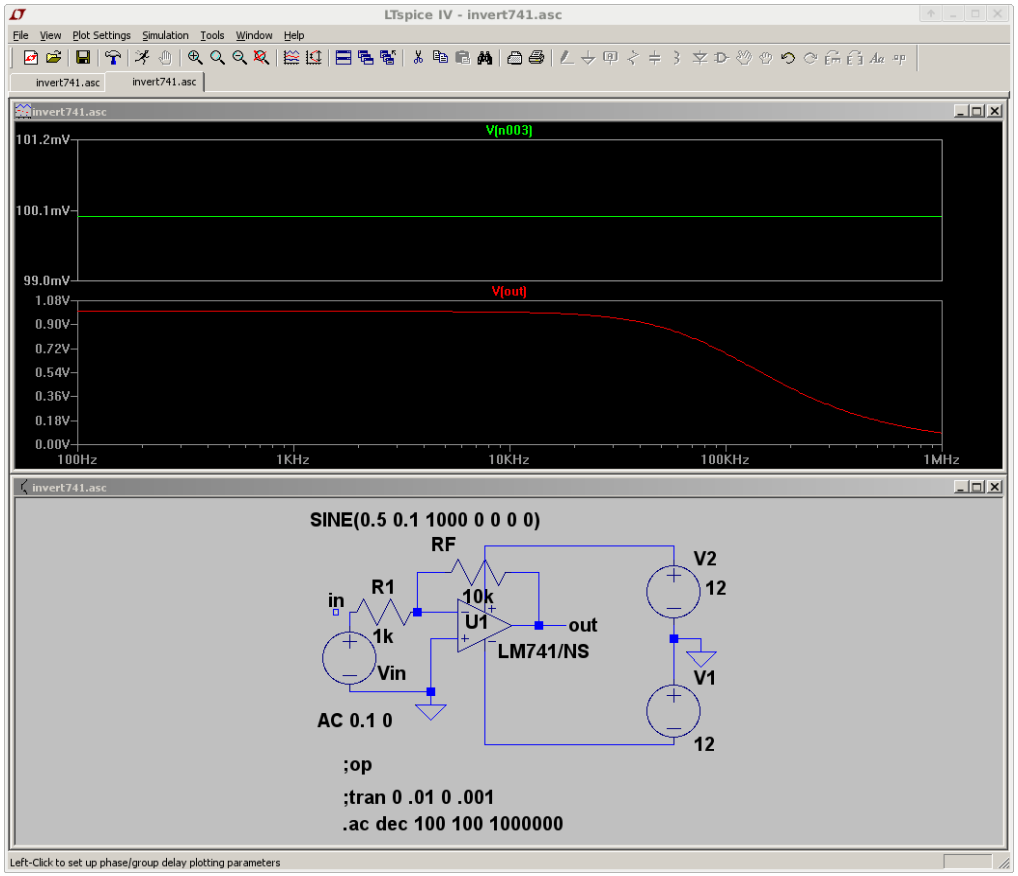
-6V



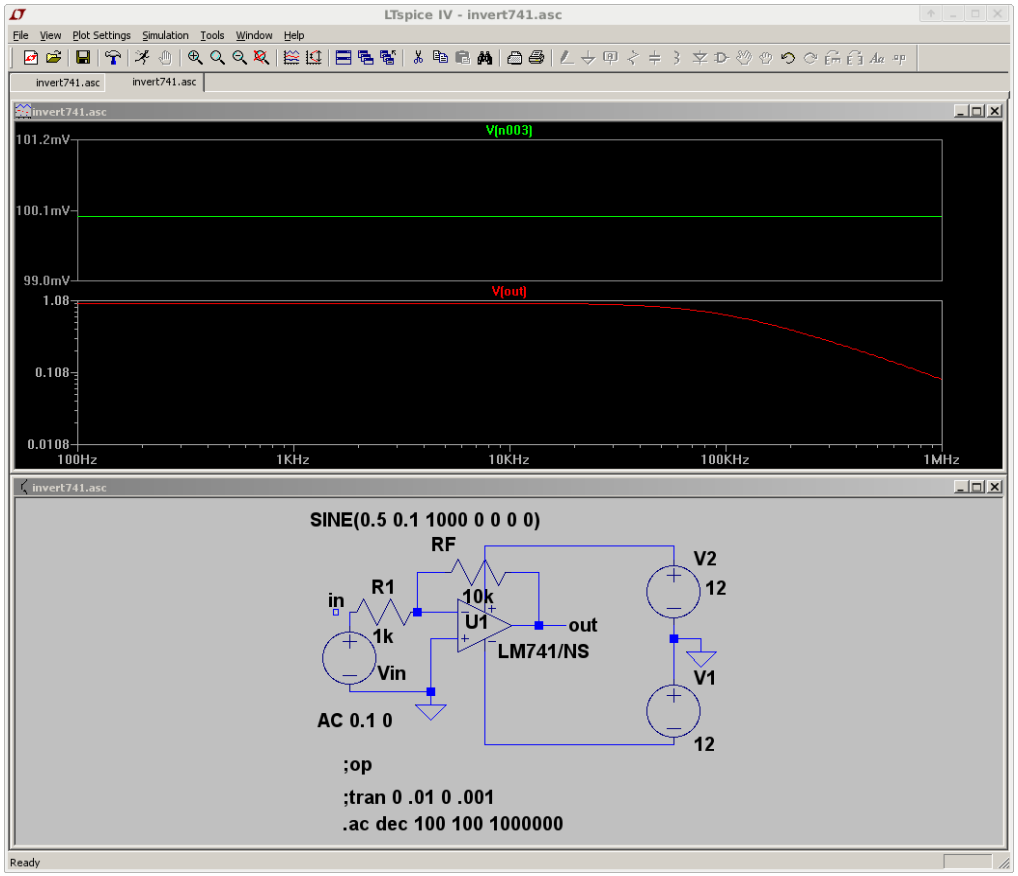
This is the circuit with a gain of 10.

100mV

1V



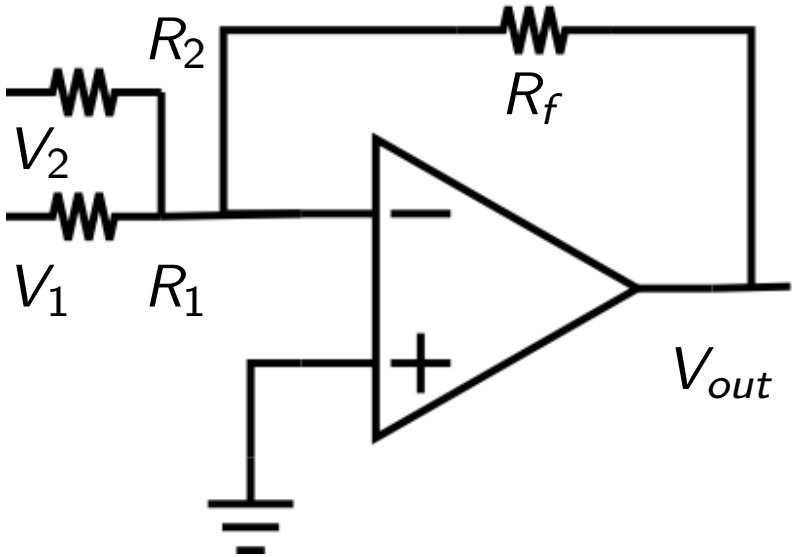
Remember the effects of rolloff at high frequencies.



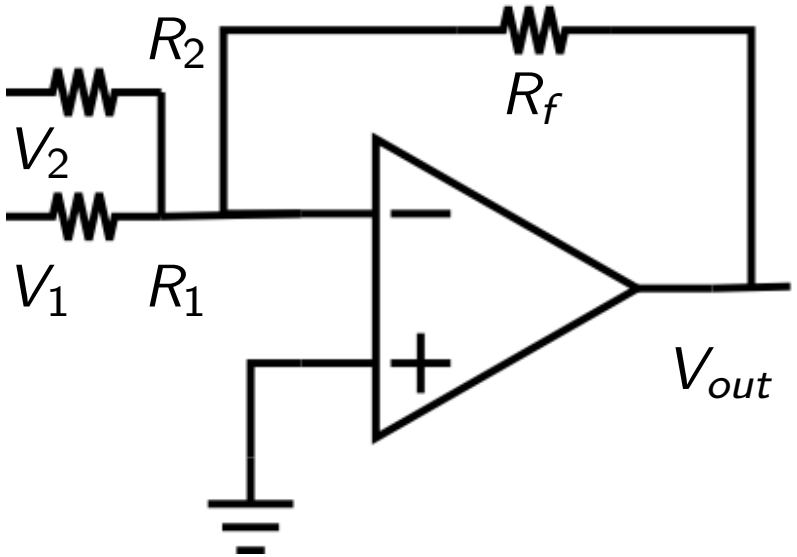
A logarithmic scale is helpful sometimes.

Summing amplifier

Summing amplifier

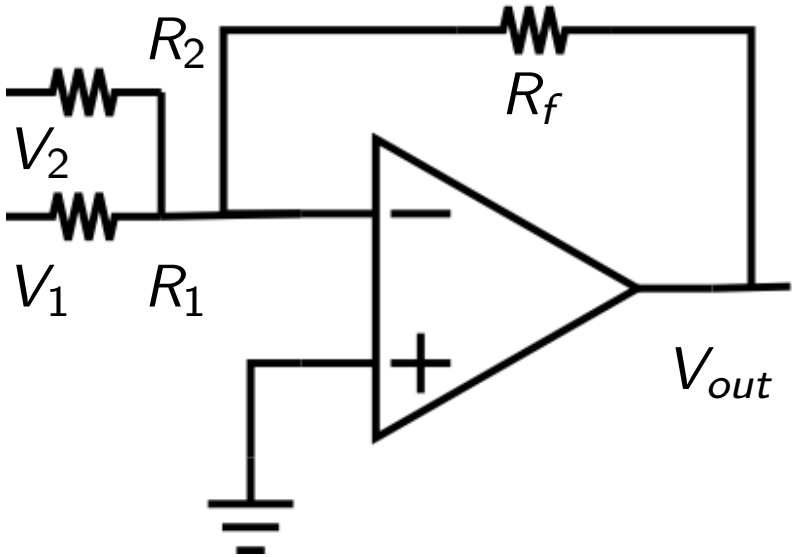


Summing amplifier



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

Summing amplifier

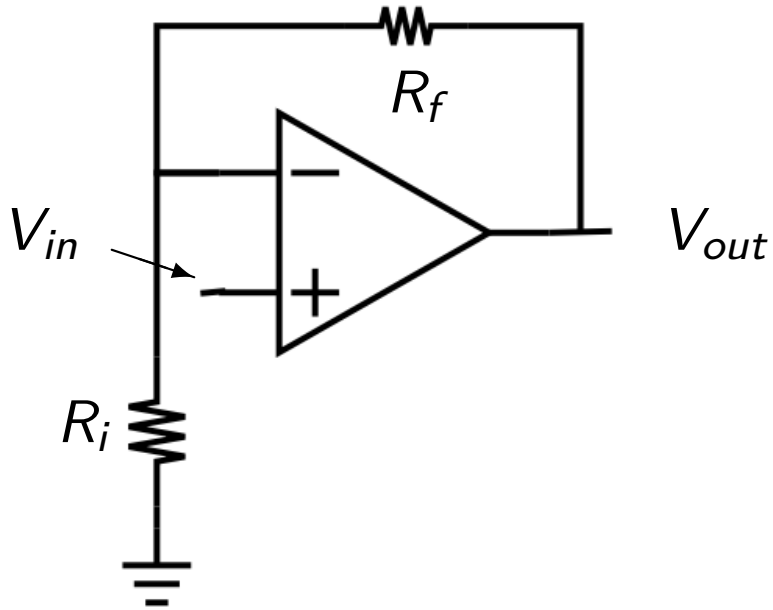


$$V_{out} = -R_f \left(\frac{V_1}{R_1} + \frac{V_2}{R_2} \right)$$

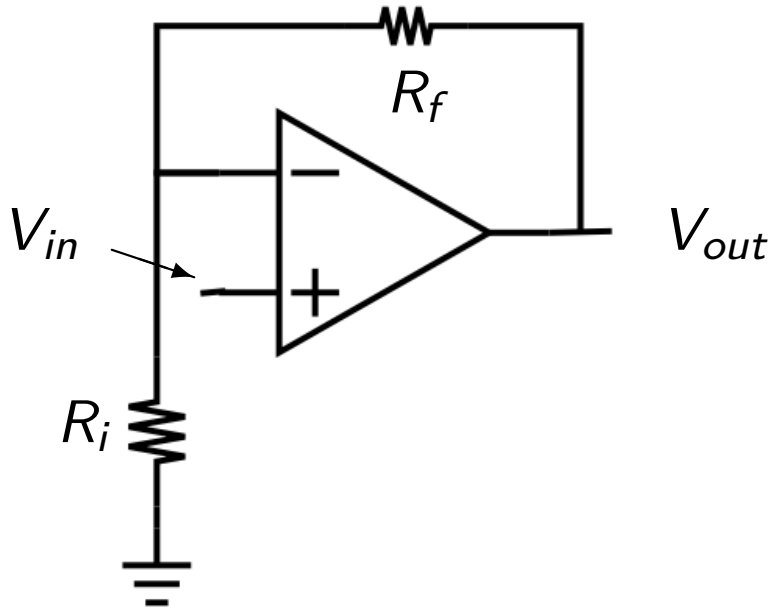
Can be extended to many inputs

Non-inverting amplifier

Non-inverting amplifier



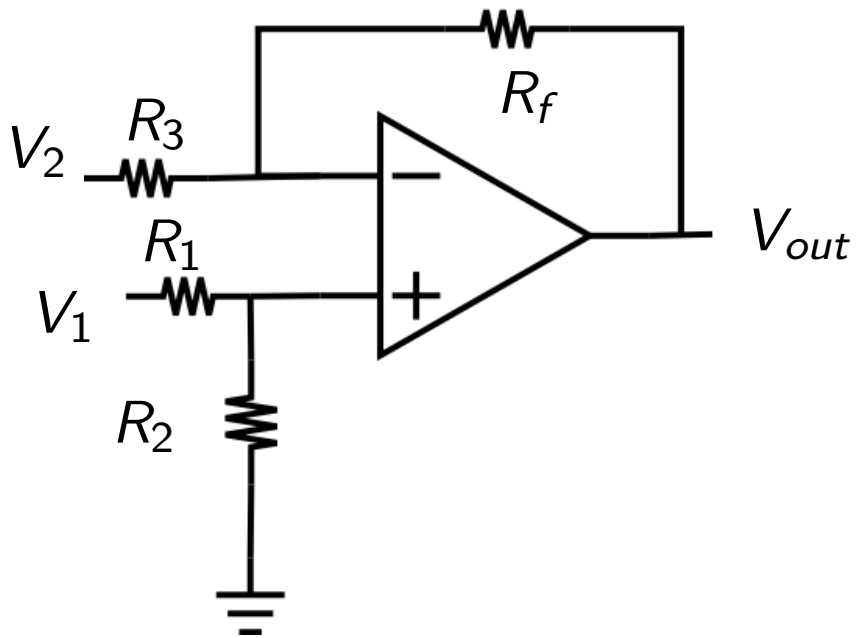
Non-inverting amplifier



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

Differential amplifier

Differential amplifier



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

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

Simplified if $R_f = R_2$ and $R_1 = R_3$

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

Simplified if $R_f = R_2$ and $R_1 = R_3$

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

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

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, $V_{out} = V_1 - V_2$

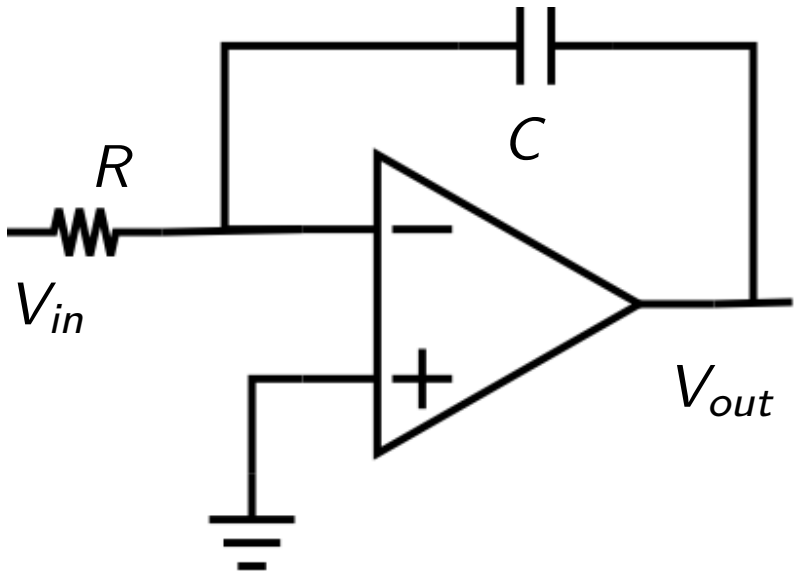
Other Operational Amplifier Circuits

Other Operational Amplifier Circuits

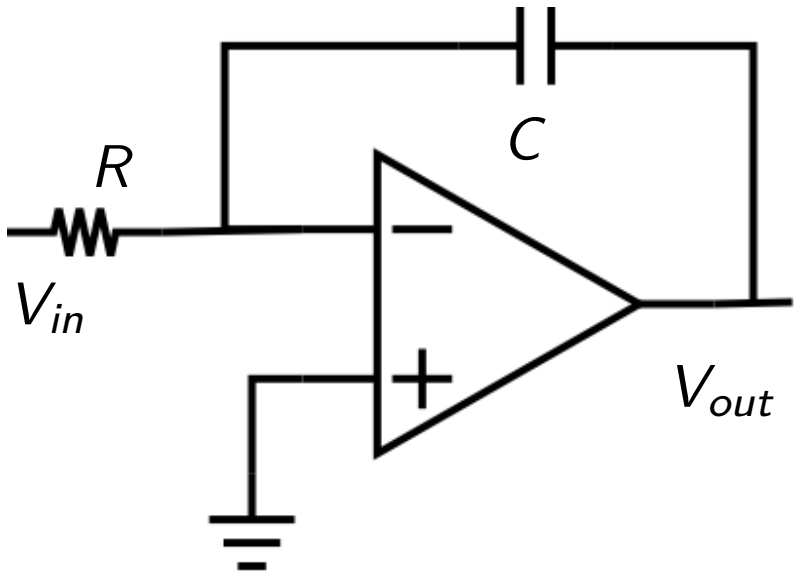
Note that *all* of the following circuits are variations of the basic inverting amplifier circuit.

Integrator

Integrator

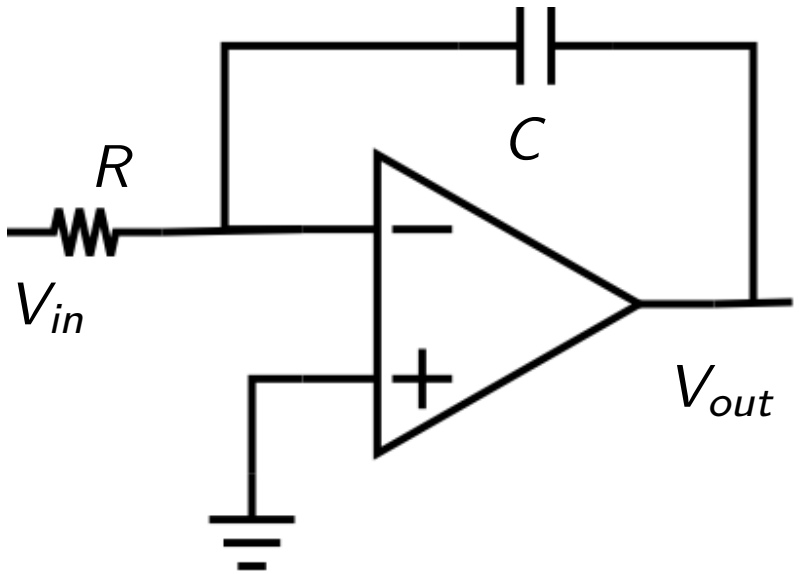


Integrator



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

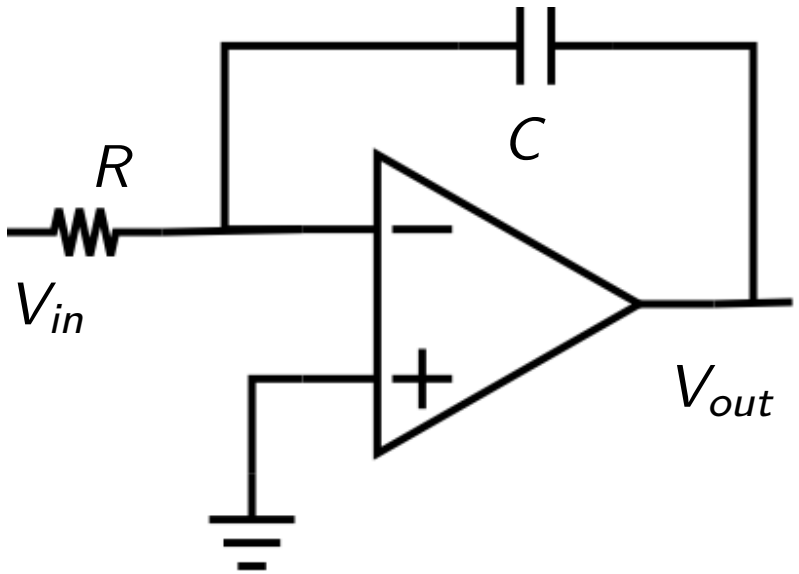
Integrator



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

$$V_{out} = -\frac{1}{RC} \int V_{in} \mathrm{d}t$$

Integrator



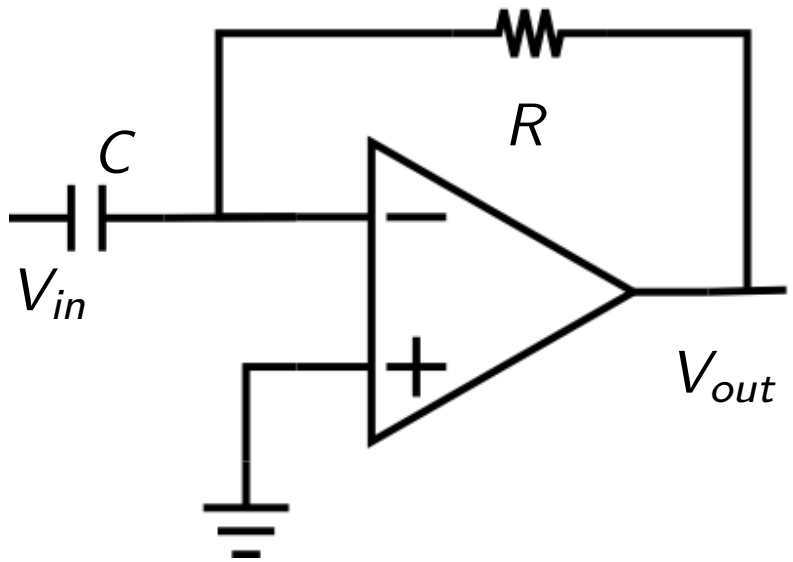
Output is the *integral* of the input over time.

$V_{out} = -\frac{1}{RC} \int V_{in} \mathrm{d}t$

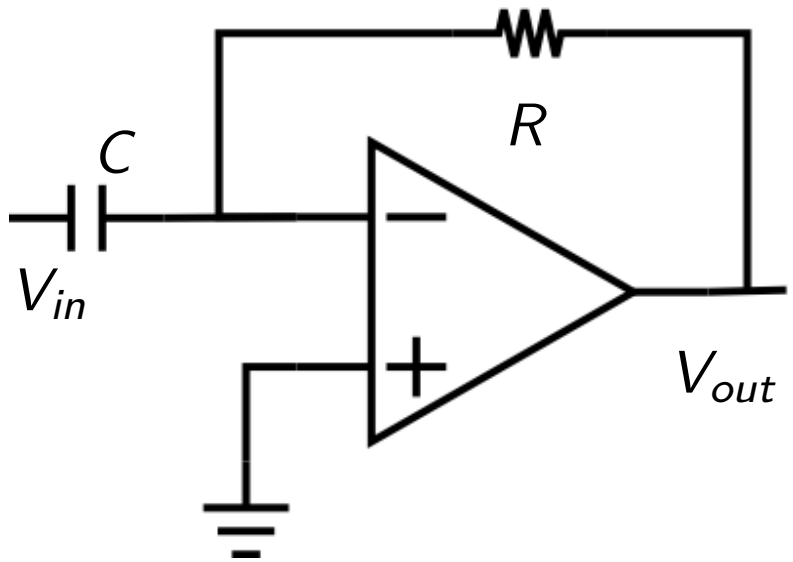
Often has a large resistor in parallel with C to avoid saturation

Differentiator

Differentiator

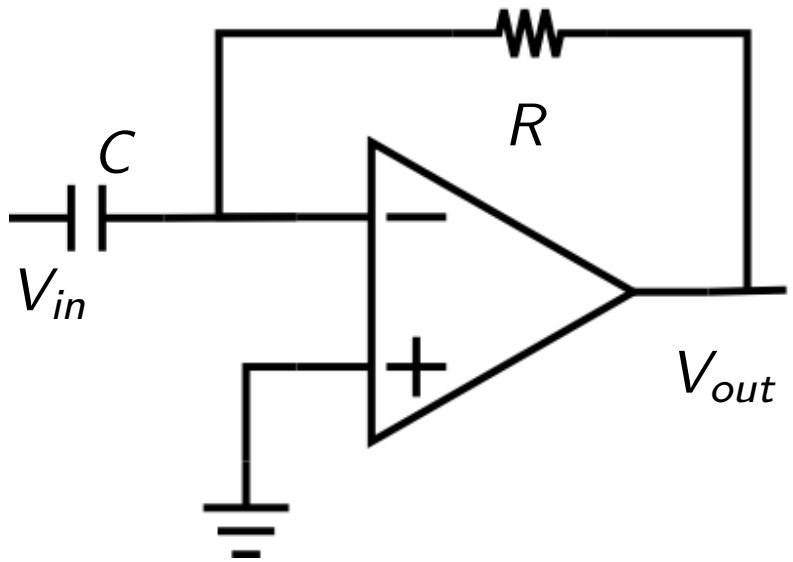


Differentiator



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

Differentiator

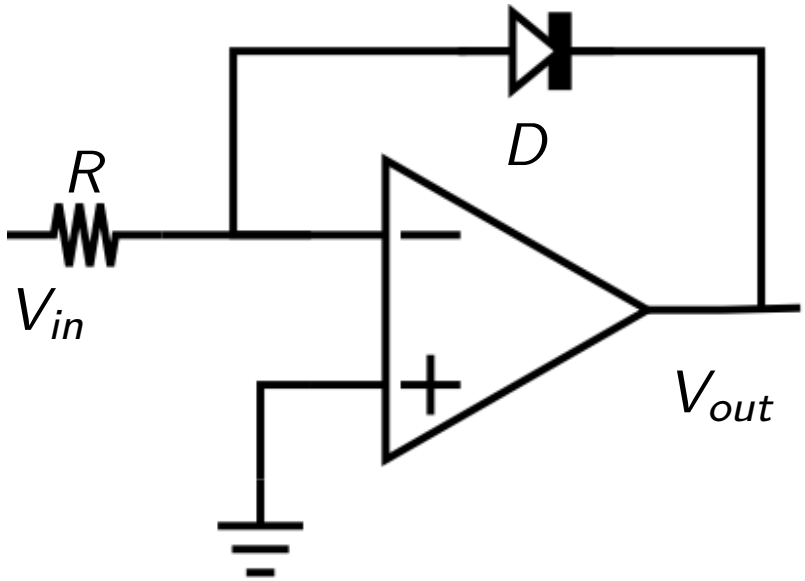


Output is the *derivative* of the input over time.

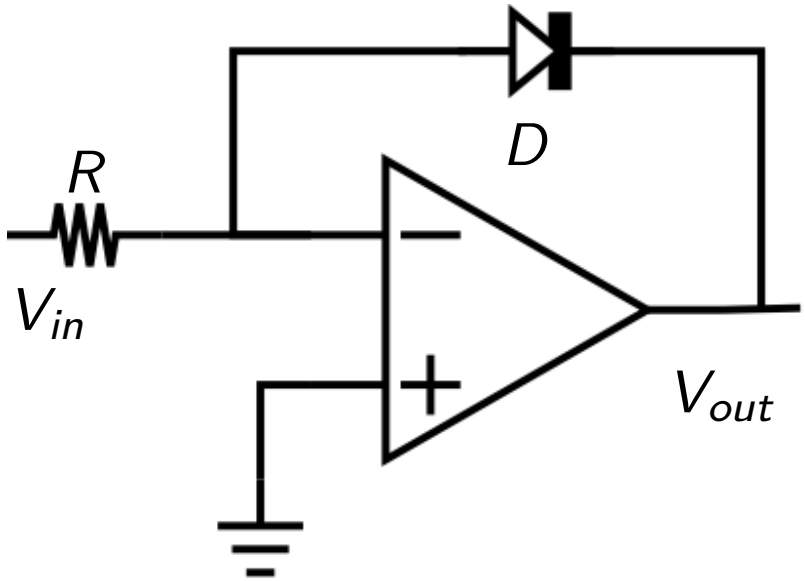
$$V_{out} = -RC \quad \frac{\mathrm{d}V_{in}}{\mathrm{d}t}$$

Logarithmic amplifier

Logarithmic amplifier

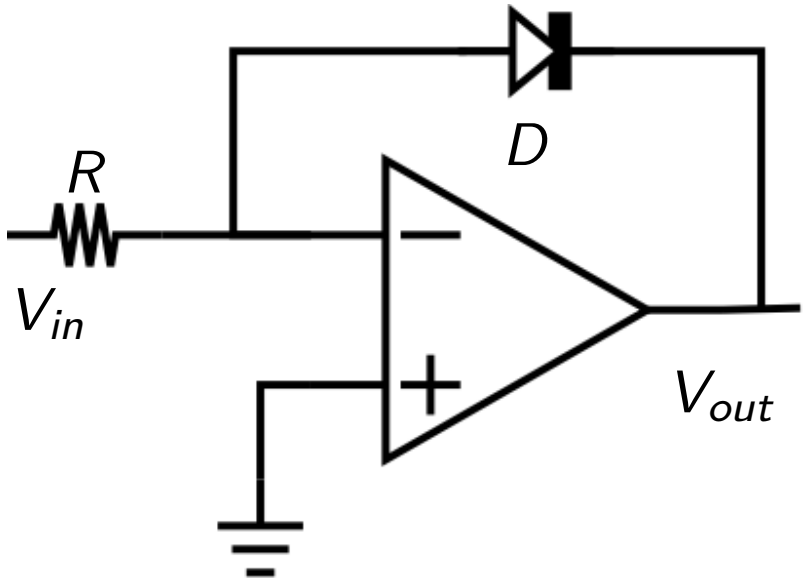


Logarithmic amplifier



Output is related to the *logarithm* of the input

Logarithmic amplifier

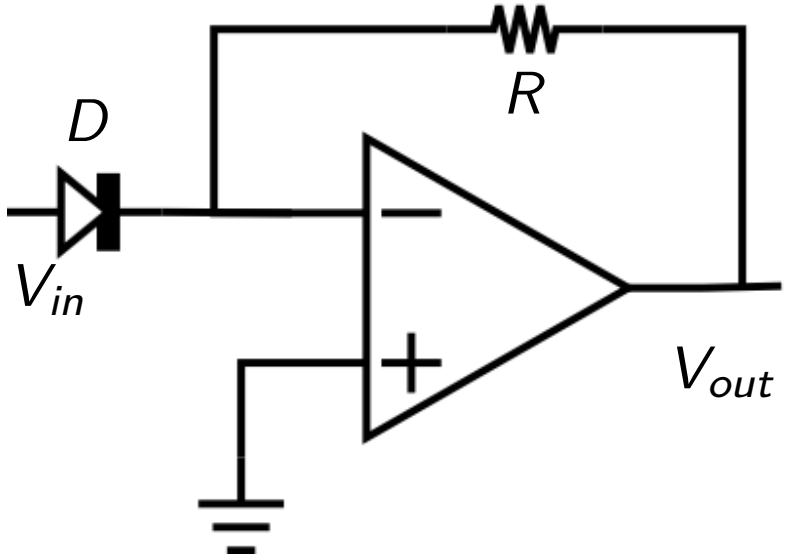


Output is related to the *logarithm* of the input

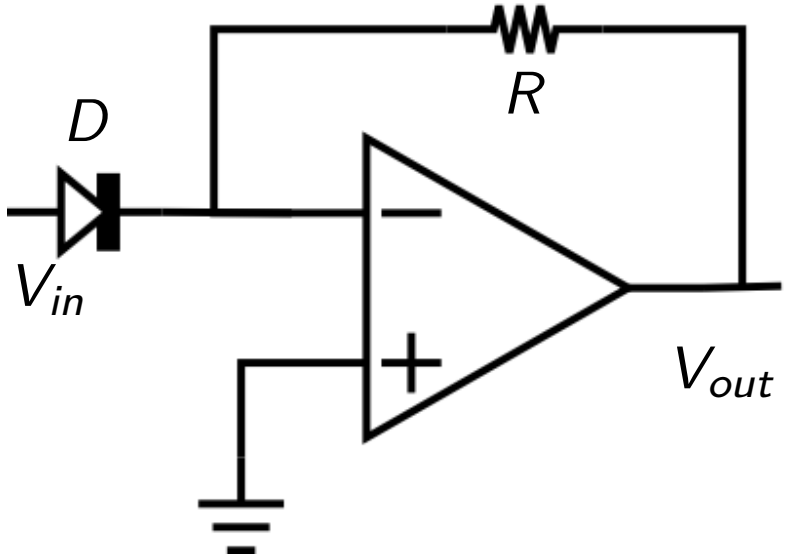
$V_{out} \propto -\ln V_{in}$

Exponential amplifier

Exponential amplifier

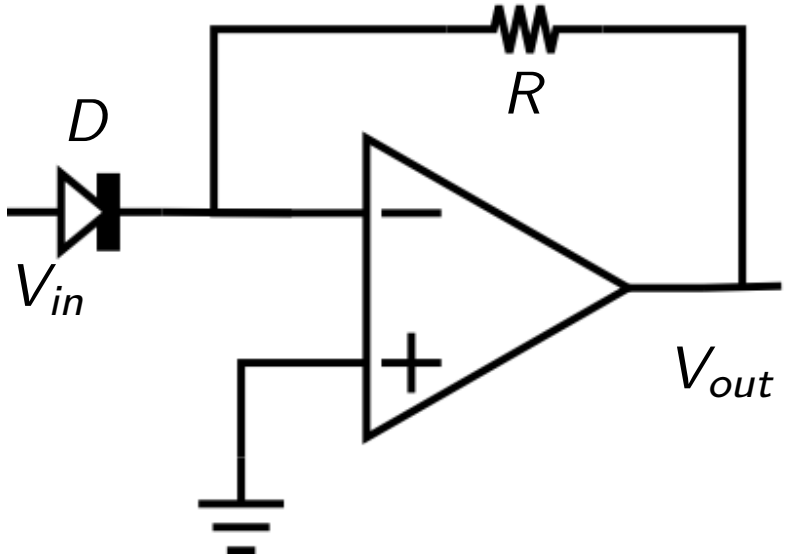


Exponential amplifier



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

Exponential amplifier



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

$V_{out} \propto -e^{V_{in}}$