Buffer (or voltage follower)
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\[ V_- = V_{out} \text{ and } V_+ = V_{in} \]
Buffer (or voltage follower)

$V_− = V_{out}$ and $V_+ = V_{in}$

$V_− \approx V_+$ (virtual equality)
Buffer (or voltage follower)

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

$$V_- \approx V_+ \text{ (virtual equality)}$$

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

Many op amp circuits are based on this.
Inverting amplifier

Many op amp circuits are based on this.
\[ V_+ = 0 \text{ (ground)} \]
\[ V_+ = 0 \text{ (ground)} \]
\[ I_f R_f = V_{out} - V_- \]
Common Operational Amplifier Circuits

Other Operational Amplifier Circuits

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

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

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

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

$V_- \approx V_+ \text{ (virtual equality)}$
$V_+ = 0$ (ground)

$I_f R_f = V_{out} - V_-

I_i R_i = V_- - V_{in}

V_- \approx V_+ \text{ (virtual equality)}

I_f = I_i \text{ (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)

$\therefore \frac{V_{out} - 0}{R_f} = \frac{0 - V_{in}}{R_i}$
\[ V_+ = 0 \text{ (ground)} \]

\[ I_f R_f = V_{out} - V_- \]

\[ I_i R_i = V_- - V_{in} \]

\[ V_- \approx V_+ \text{ (virtual equality)} \]

\[ I_f = I_i \text{ (no current into inputs)} \]

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

\[ \therefore V_{out} = -\frac{R_f}{R_i} V_{in} \]
Common Operational Amplifier Circuits
Other Operational Amplifier Circuits

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

600mV
400mV
-4V
-6V

This is the circuit with a gain of 10.
Remember the effects of rolloff at high frequencies.
A logarithmic scale is helpful sometimes.
Common Operational Amplifier Circuits
Other Operational Amplifier Circuits

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

Summing amplifier

\[ V_{out} = -\frac{R_f}{R_1} (V_1 R_1 + V_2 R_2) \]

Can be extended to many inputs

Terry Sturtevant
Electronics Operational Amplifier Circuits
Summing amplifier

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

Can be extended to many inputs.
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

\[ V_{out} = (1 + \frac{R_f}{R_i}) V_{in} \]
Non-inverting amplifier

\[ V_{out} = \left(1 + \frac{R_f}{R_i}\right) V_{in} \]
Differential amplifier
Differential amplifier

\[ V_{out} = \frac{V_2 - V_1}{R_3 + R_1} \times R_f \]
Other Operational Amplifier Circuits

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

\[ V_{out} = \frac{V_1 R_2}{R_1 + R_2} \left(1 + \frac{R_f}{R_3}\right) - V_2 \frac{R_f}{R_3} \]
Common Operational Amplifier Circuits
Other Operational Amplifier Circuits

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

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

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

- Integrator circuit
- Differentiator circuit
- Logarithmic amplifier circuit
- Exponential amplifier circuit

Note that all of the following circuits are variations of the basic inverting amplifier circuit.
Other Operational Amplifier Circuits

Note that all of the following circuits are variations of the basic inverting amplifier circuit.
Integrator circuit
Differentiator circuit
Logarithmic amplifier circuit
Exponential amplifier circuit

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.
Integrator circuit
Differentiator circuit
Logarithmic amplifier circuit
Exponential amplifier circuit

Integrator

Output is the integral of the input over time.

$$V_{\text{out}} = -\frac{1}{RC} \int V_{\text{in}} \, dt$$

Often has a large resistor in parallel with C to avoid saturation.
Integrator circuit
Differentiator circuit
Logarithmic amplifier circuit
Exponential amplifier circuit

Integrator

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

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

\[ V_{\text{out}} = -RC \frac{dV_{\text{in}}}{dt} \]
Differentiator

The output of a differentiator is the derivative of the input over time. The equation for the output voltage, $V_{out}$, is given by:

$$V_{out} = -RC \frac{dV_{in}}{dt}$$
Differentiator

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

\[ V_{out} = -RC \frac{dV_{in}}{dt} \]
Differentiator

The output is the derivative of the input over time.

\[ V_{out} = -RC \frac{dV_{in}}{dt} \]
Logarithmic amplifier

Logarithmic amplifier circuit

Output is related to the logarithm of the input.

\[ V_{out} \propto -\ln V_{in} \]
Logarithmic amplifier

The output voltage $V_{out}$ of a logarithmic amplifier circuit is related to the logarithm of the input voltage $V_{in}$ by the equation $V_{out} \propto -\ln V_{in}$. The diagram shows a typical logarithmic amplifier circuit with a diode ($D$) and a resistor ($R$) connected to the input $V_{in}$. The output $V_{out}$ is taken from the non-inverting terminal of the operational 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

\[ V_{\text{out}} \propto -e^{V_{\text{in}}} \]
Exponential amplifier

\[ V_{out} \propto -e^{V_{in}} \]
Exponential amplifier

Output is related to the exponential of the input.
Exponential amplifier

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

\[ V_{out} \propto -e^{V_{in}} \]