# Electronics Operational Amplifier Circuits

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#### Buffer circuit

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

# Buffer (or voltage follower)

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# Buffer (or voltage follower)



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

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#### Buffer circuit

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# Buffer (or voltage follower)



$$V_{-} = V_{out}$$
 and  $V_{+} = V_{in}$   
 $V_{-} pprox V_{+}$  (virtual equality)

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#### Buffer circuit

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# Buffer (or voltage follower)



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

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### Inverting amplifier

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#### Inverting amplifier



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### Inverting amplifier



Many op amp circuits are based on this.

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#### $V_+ = 0$ (ground)

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$$V_+ = 0$$
 (ground)  
 $I_f R_f = V_{out} - V_-$ 

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

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$$egin{aligned} V_+ &= 0 \ ( ext{ground}) \ I_f R_f &= V_{out} - V_- \ I_i R_i &= V_- - V_{in} \ V_- &\approx V_+ \ ( ext{virtual equality}) \end{aligned}$$

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$$\begin{split} V_{+} &= 0 \text{ (ground)} \\ I_{f}R_{f} &= V_{out} - V_{-} \\ I_{i}R_{i} &= V_{-} - V_{in} \\ V_{-} &\approx V_{+} \text{ (virtual equality)} \\ I_{f} &= I_{i} \text{ (no current into inputs)} \end{split}$$

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

$$I_{f}R_{f} = V_{out} - V_{-}$$

$$I_{i}R_{i} = V_{-} - V_{in}$$

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

$$I_{f} = I_{i} \text{ (no current into inputs)}$$

$$\therefore \frac{V_{out} - 0}{R_{f}} = \frac{0 - V_{in}}{R_{i}}$$

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

$$I_{f}R_{f} = V_{out} - V_{-}$$

$$I_{i}R_{i} = V_{-} - V_{in}$$

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

$$I_{f} = I_{i} \text{ (no current into inputs)}$$

$$\therefore \frac{V_{out} - 0}{R_{f}} = \frac{0 - V_{in}}{R_{i}}$$

$$\therefore V_{out} = -\frac{R_{f}}{R_{i}} V_{in}$$

Other Operational Amplifier Circuits

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This is the circuit with a gain of 10.

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Other Operational Amplifier Circuits

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Remember the effects of rolloff at high frequencies.

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Other Operational Amplifier Circuits

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A logarithmic scale is helpful sometimes.

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## Summing amplifier

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### Summing amplifier



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### Summing amplifier



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

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## Summing amplifier



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

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## Non-inverting amplifier

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### Non-inverting amplifier



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### Non-inverting amplifier



$$V_{out} = \left(1 + rac{R_f}{R_i}
ight)V_{in}$$

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## Differential amplifier

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## Differential amplifier



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Other Operational Amplifier Circuits

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$$V_{out} = rac{V_1R_2}{R_1+R_2}\left(1+rac{R_f}{R_3}
ight) - V_2rac{R_f}{R_3}$$

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$$V_{out} = rac{V_1 R_2}{R_1 + R_2} \left(1 + rac{R_f}{R_3}
ight) - V_2 rac{R_f}{R_3}$$
  
Simplified if  $R_f = R_2$  and  $R_1 = R_3$ 

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

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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  $R_1 = R_3$   
 $\therefore V_{out} = \frac{R_f}{R_1} (V_1 - V_2)$   
If all resistors are equal,  $V_{out} = V_1 - V_2$ 

## Other Operational Amplifier Circuits

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# Other Operational Amplifier Circuits

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

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Integrator circuit

Differentiator circuit Logarithmic amplifier circuit Exponential amplifier circuit

#### Integrator

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Integrator circuit

Differentiator circuit Logarithmic amplifier circuit Exponential amplifier circuit

#### Integrator



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Integrator circuit

Differentiator circuit Logarithmic amplifier circuit Exponential amplifier circuit

#### Integrator



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

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Integrator circuit

Differentiator circuit Logarithmic amplifier circuit Exponential amplifier circuit

#### Integrator



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

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Integrator circuit

Differentiator circuit Logarithmic amplifier circuit Exponential amplifier circuit

#### Integrator



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

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

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

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#### Differentiator

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#### Differentiator



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### Differentiator



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

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Integrator circuit Differentiator circuit Logarithmic amplifier circuit Exponential amplifier circuit

### Differentiator



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

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

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Integrator circuit Differentiator circuit Logarithmic amplifier circuit Exponential amplifier circuit

### Logarithmic amplifier

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#### Logarithmic amplifier



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### Logarithmic amplifier



Output is related to the *logarithm* of the input

## Logarithmic amplifier



Output is related to the <code>logarithm</code> of the input  $V_{out} \propto - \ln V_{in}$ 

Integrator circuit Differentiator circuit Logarithmic amplifier circuit Exponential amplifier circuit

### Exponential amplifier

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Integrator circuit Differentiator circuit Logarithmic amplifier circuit Exponential amplifier circuit

#### Exponential amplifier



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#### Exponential amplifier



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

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## Exponential amplifier



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