Operational Amplifiers

or Op Amps for short

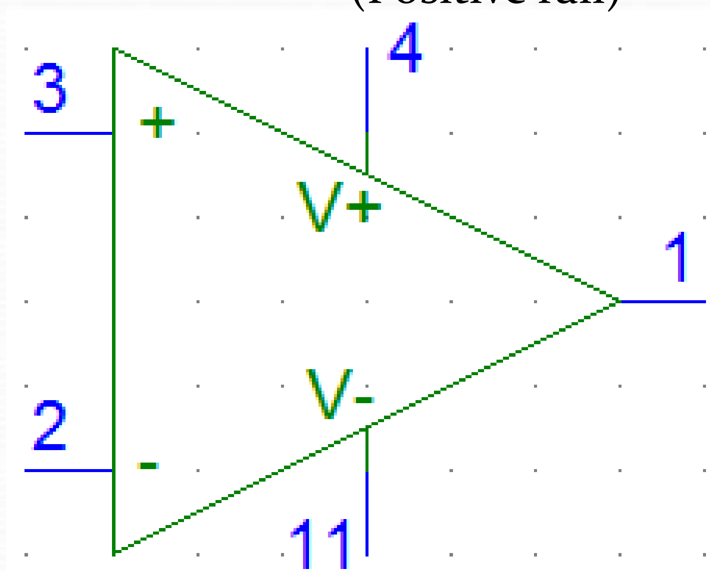
Op Amps Applications

- Audio amplifiers
  - Speakers and microphone circuits in cell phones, computers, mpg players, boom boxes, etc.
- Instrumentation amplifiers
  - Biomedical systems including heart monitors and oxygen sensors.
- Power amplifiers
- Analog computers
  - Combination of integrators, differentiators, summing amplifiers, and multipliers

Terminals on an Op Amp

Positive power supply
(Positive rail)

Non-inverting
Input terminal



Output terminal

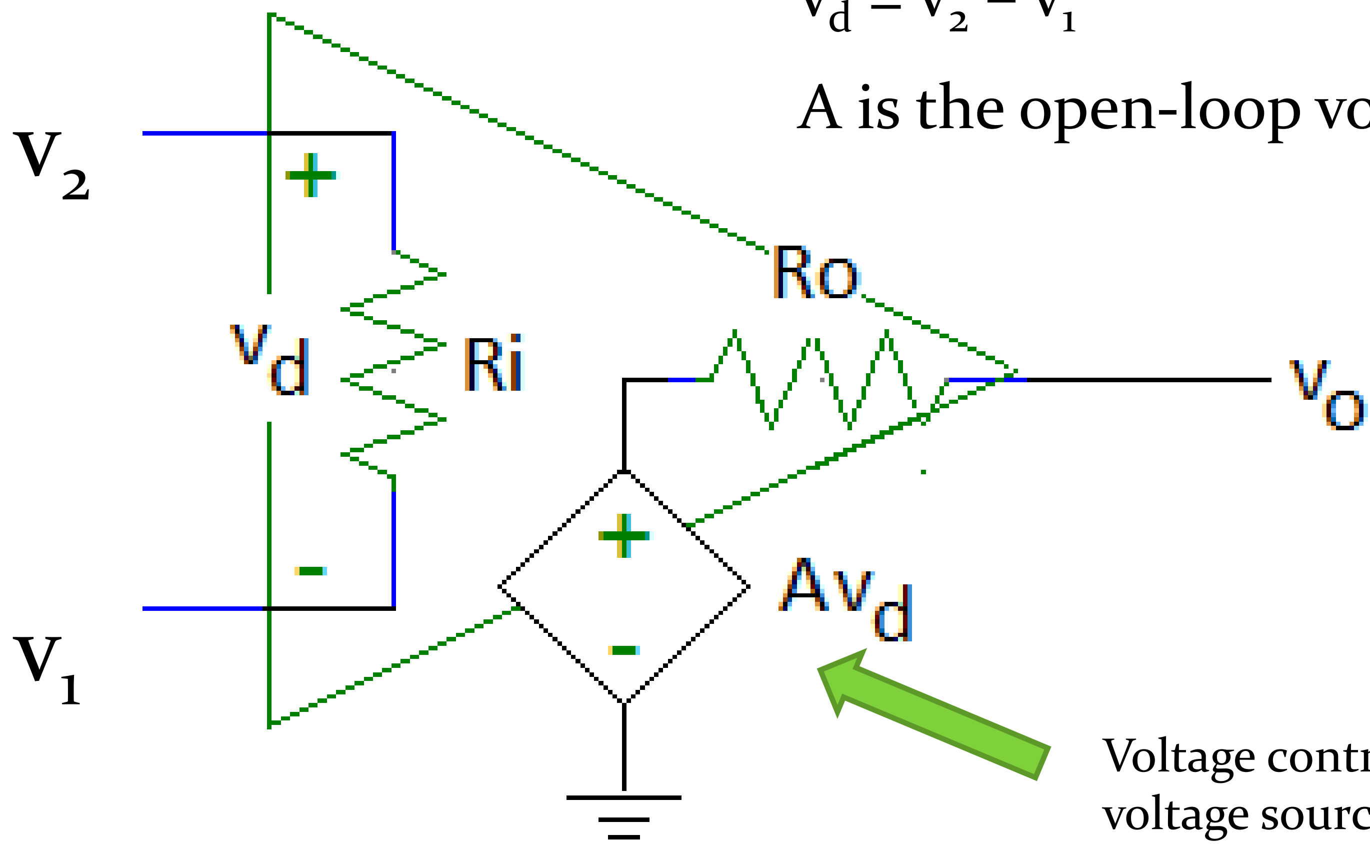
Inverting input
terminal

Negative power supply
(Negative rail)

Op Amp Equivalent Circuit

$v_d = v_2 - v_1$

A is the open-loop voltage gain



Voltage controlled
voltage source

Typical Op Amp Parameters

Parameter	Variable	Typical Ranges	Ideal Values
Open-Loop Voltage Gain	A	10^5 to 10^8	∞
Input Resistance	Ri	10^5 to 10^{13} Ω	∞ Ω
Output Resistance	Ro	10 to 100 Ω	0 Ω
Supply Voltage	Vcc/V^+ -Vcc/V^-	5 to 30 V -30V to 0V	N/A N/A

How to Find These Values

- Component Datasheets
  - Many manufacturers have made these freely available on the internet
    - Example: LM 324 Operational Amplifier

National Semiconductor

August 2000

LM124/LM224/LM324/LM2902
Low Power Quad Operational Amplifiers

General Description

The LM124 series consists of four independent, high gain, internally frequency compensated operational amplifiers which were designed specifically to operate from a single power supply over a wide range of voltages. Operation from split power supplies is also possible and the low power supply current drain is independent of the magnitude of the power supply voltage.

Application areas include transducer amplifiers, DC gain blocks and all the conventional op amp circuits which now can be more easily implemented in single power supply systems. For example, the LM124 series can be directly operated off of the standard +5V power supply voltage which is used in digital systems and will easily provide the required interface electronics without requiring the additional ±15V power supplies.

Unique Characteristics

- In the linear mode the input common-mode voltage range includes ground and the output voltage can also

Advantages

- Eliminates need for dual supplies
- Four internally compensated op amps in a single package
- Allows directly sensing near GND and V_{OUT} also goes to GND
- Compatible with all forms of logic
- Power drain suitable for battery operation

Features

- Internally frequency compensated for unity gain
- Large DC voltage gain 100 dB
- Wide bandwidth (unity gain) 1 MHz (temperature compensated)
- Wide power supply range:
  Single supply 3V to 32V
  or dual supplies ±1.5V to ±16V
- Very low supply current drain (700 µA)—essentially independent of supply voltage
- Low input biasing current 45 nA

LM124/LM224/LM324/LM2902 Low Power Qua

dB

- Decibels

Since $P = V^2/R$

$$10 \log (P/P_{ref}) \text{ or } 20 \log (V/V_{ref})$$

In this case:

$$20 \log (V_o/V_{in}) = 20 \log (A) = 100$$

$$A = 10^5 = 100{,}000$$

Electrical Characteristics

$V^+ = +5.0V$, (Note 7), unless otherwise stated

Parameter	Conditions	LM124A			LM224A			LM324A			Units
		Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
Input Offset Voltage	(Note 8) $T_A = 25°C$		1	2		1	3		2	3	mV
Input Bias Current (Note 9)	$I_{IN(+)}$ or $I_{IN(-)}$, $V_{CM} = 0V$, $T_A = 25°C$		20	50		40	80		45	100	nA
Input Offset Current	$I_{IN(+)}$ or $I_{IN(-)}$, $V_{CM} = 0V$, $T_A = 25°C$		2	10		2	15		5	30	nA
Input Common-Mode Voltage Range (Note 10)	$V^+ = 30V$, (LM2902, $V^+ = 26V$), $T_A = 25°C$	0		$V^+-1.5$	0		$V^+-1.5$	0		$V^+-1.5$	V
Supply Current	Over Full Temperature Range										
	$R_L = \infty$ On All Op Amps										mA
	$V^+ = 30V$ (LM2902 $V^+ = 26V$)		1.5	3		1.5	3		1.5	3	
	$V^+ = 5V$		0.7	1.2		0.7	1.2		0.7	1.2	
Large Signal Voltage Gain	$V^+ = 15V$, $R_L \geq 2k\Omega$, ($V_O = 1V$ to $11V$), $T_A = 25°C$	50	100		50	100		25	100		V/mV
Common-Mode	DC, $V_{CM} = 0V$ to $V^+ - 1.5V$,	70	85		70	85		65	85		dB

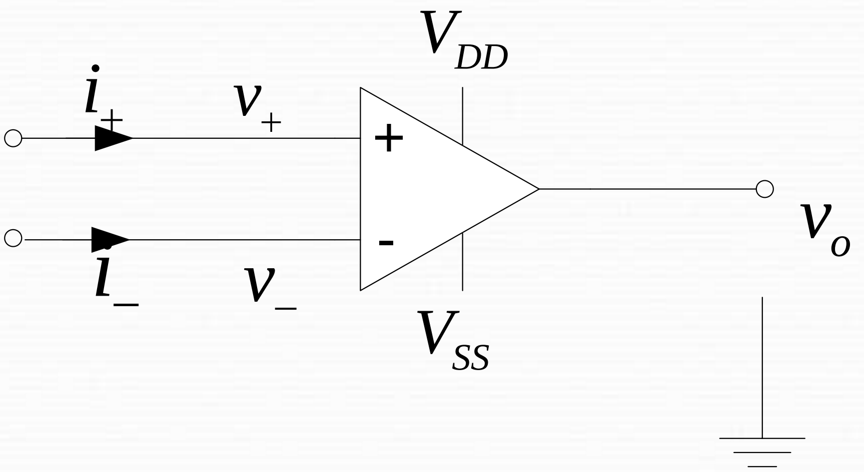
Large Signal Voltage Gain = A

- Typical
  - A = 100 V/mV = 100V/0.001V = 100,000
- Minimum
  - A = 25 V/mV = 25 V/0.001V = 25,000

Operational Amplifiers (Op Amps)

- **Ideal Op Amp**
- Non-inverting Amplifier
- Unity-Gain Buffer
- Inverting Amplifier
- Differential Amplifier
- Current-to-Voltage Converter
- Non-ideal Op Amp

Ideal Op Amp



$$V_{SS} < v_0 < +V_{DD}$$

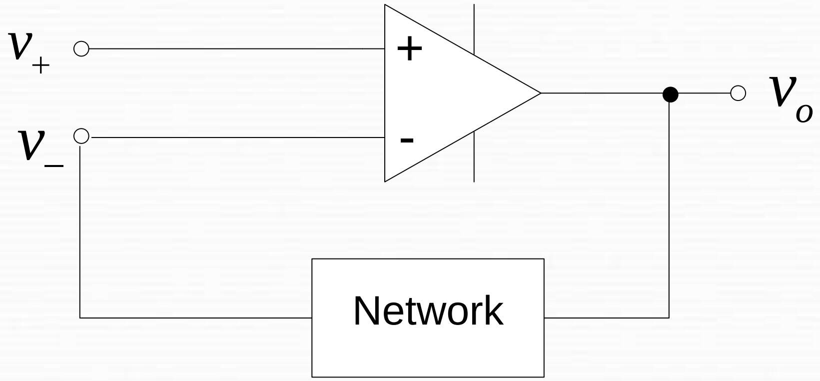
1) $$v_0 = A_v\left(v_+ - v_-\right)$$

The open-loop gain, A_v, is very large, approaching infinity.

2) $$i_+ = i_- = 0$$

The current into the inputs are zero.

Ideal Op Amp with Negative Feedback



Golden Rules of Op Amps:

1. The output attempts to do whatever is necessary to make the voltage difference between the inputs zero.

2. The inputs draw no current.

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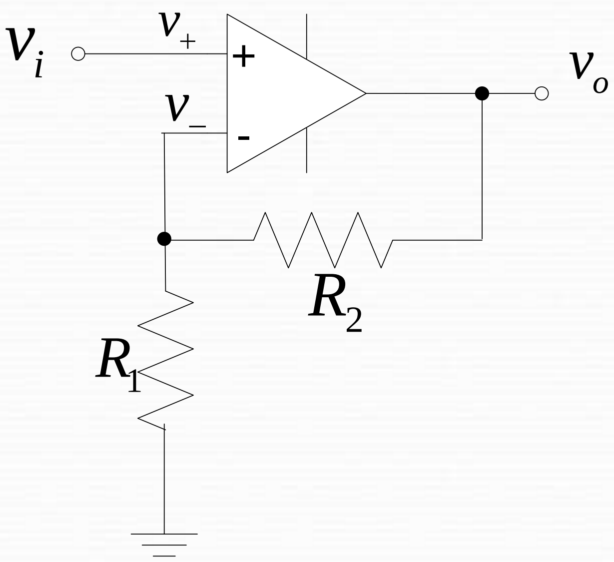
Non-inverting Amplifier



Closed-loop voltage gain

$$A_F = \frac{v_o}{v_i}$$

$$v_i = v_+ = v_- = \frac{R_1}{R_1 + R_2} v_o$$

$$A_F = \frac{v_o}{v_i} = 1 + \frac{R_2}{R_1}$$

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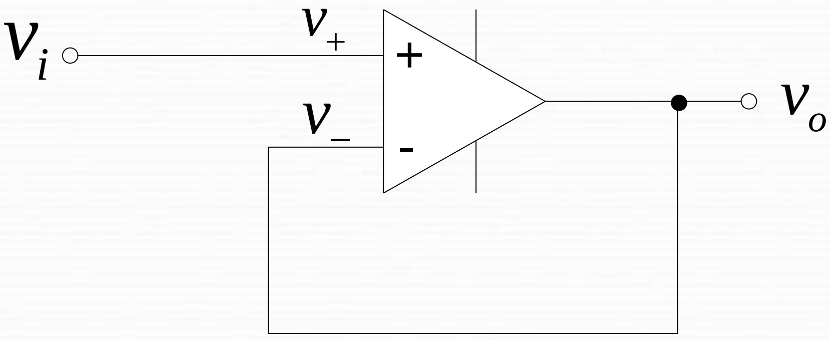
Unity-Gain Buffer



Closed-loop voltage gain

$$A_F = \frac{v_o}{v_i}$$

$$v_i = v_+ = v_- = v_o$$

$$A_F = \frac{v_o}{v_i} = 1$$

Used as a "line driver" that transforms a high input impedance (resistance) to a low output impedance. Can provide substantial current gain.

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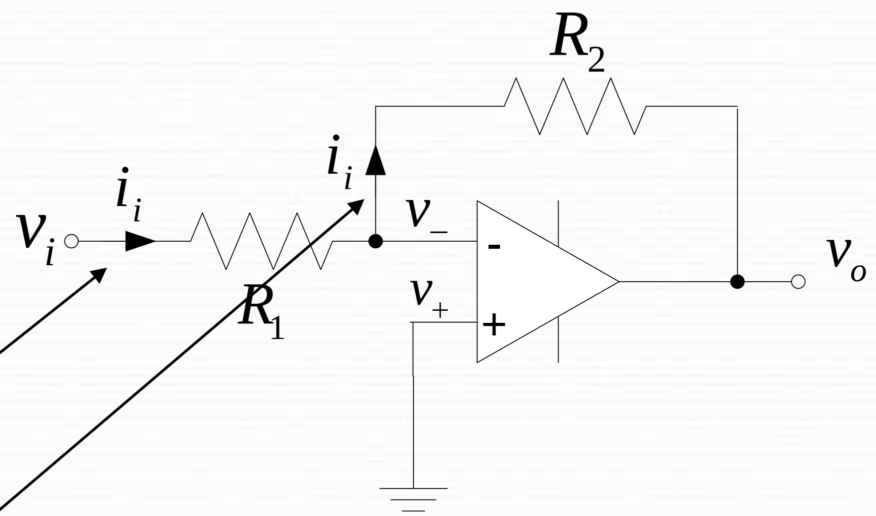
Inverting Amplifier

Current into op amp is zero

$$v_- = v_+ = 0$$

$$i_i = \frac{v_i - 0}{R_1} = \frac{v_i}{R_1}$$

$$i_i = \frac{0 - v_0}{R_2} = \frac{-v_0}{R_2}$$



$$\frac{v_i}{R_1} = \frac{-v_0}{R_2}$$

$$A_F = \frac{v_o}{v_i} = -\frac{R_2}{R_1}$$

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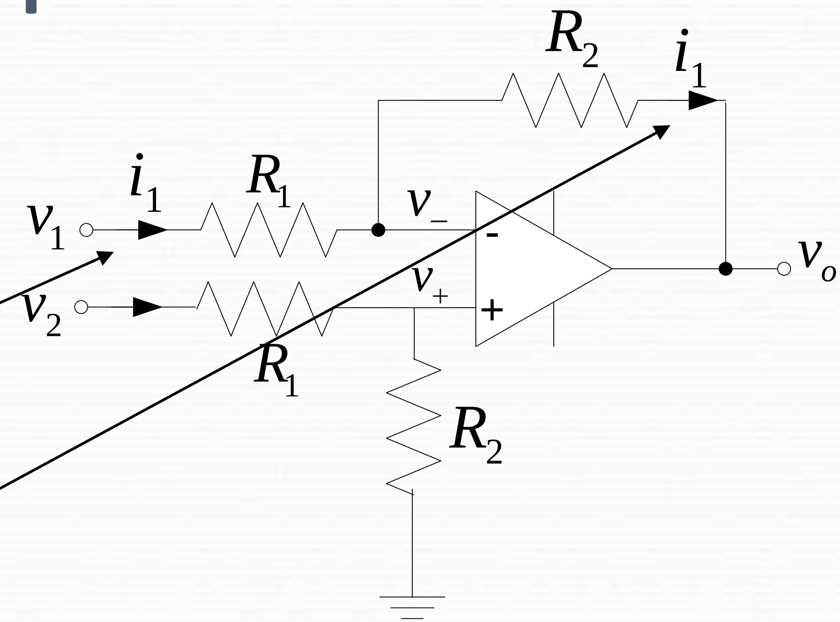
Differential Amplifier

Current into op amp is zero



$$v_- = v_+$$

$$i_1 = \frac{v_1 - v_-}{R_1}$$

$$i_1 = \frac{v_- - v_0}{R_2}$$

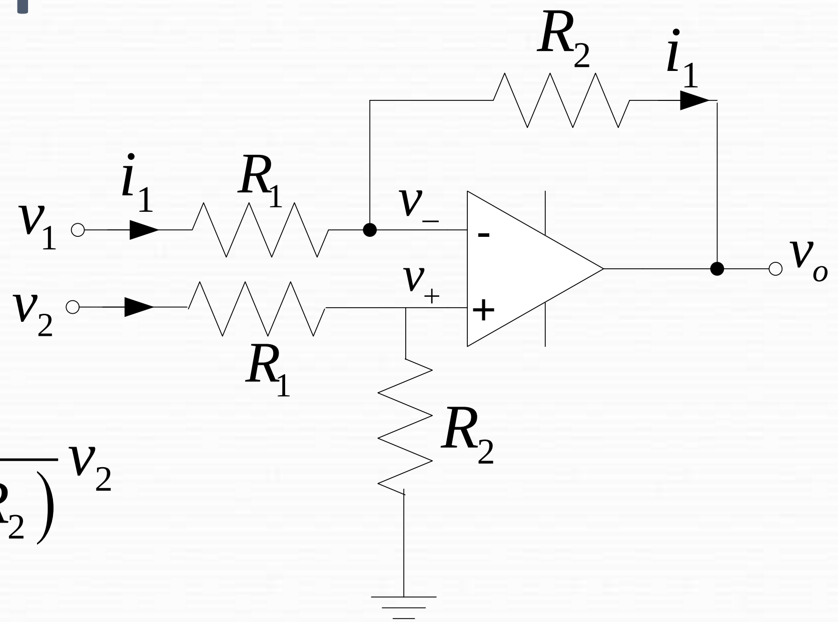
$$v_+ = \frac{R_2}{R_1 + R_2} v_2$$

$$\frac{v_1 - v_+}{R_1} = \frac{v_+ - v_0}{R_2}$$

$$\frac{v_1 - \frac{R_2}{R_1 + R_2} v_2}{R_1} = \frac{\frac{R_2}{R_1 + R_2} v_2 - v_0}{R_2}$$

Differential Amplifier

$$\frac{v_1 - \dfrac{R_2}{R_1 + R_2} v_2}{R_1} = \frac{\dfrac{R_2}{R_1 + R_2} v_2 - v_0}{R_2}$$

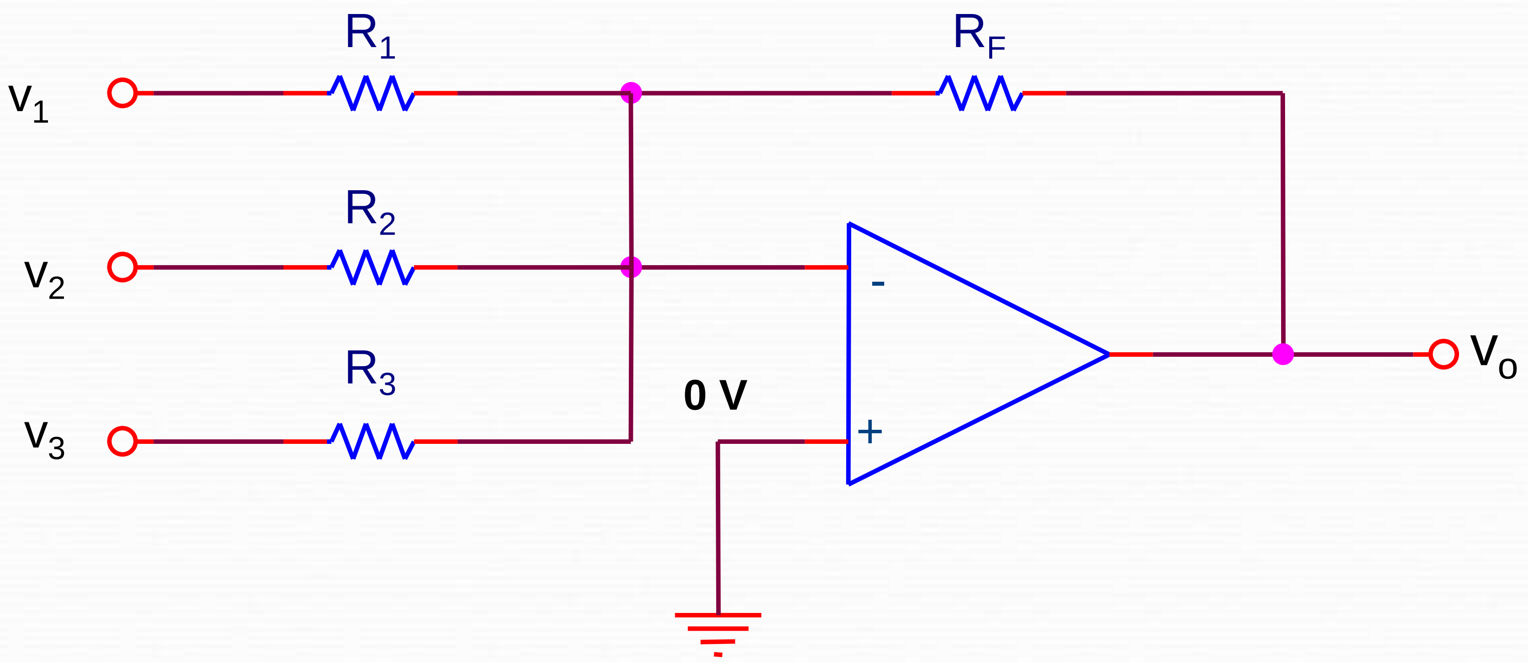


$$v_0 = -\frac{R_2}{R_1} v_1 + \frac{R_2}{R_1 + R_2} v_2 + \frac{R_2^2}{R_1\left(R_1 + R_2\right)} v_2$$

$$v_0 = -\frac{R_2}{R_1} v_1 + \frac{R_2}{R_1 + R_2}\left(1 + \frac{R_2}{R_1}\right) v_2$$

$$v_0 = \frac{R_2}{R_1}\left(v_2 - v_1\right)$$

INVERTING SUMMING AMPLIFIER



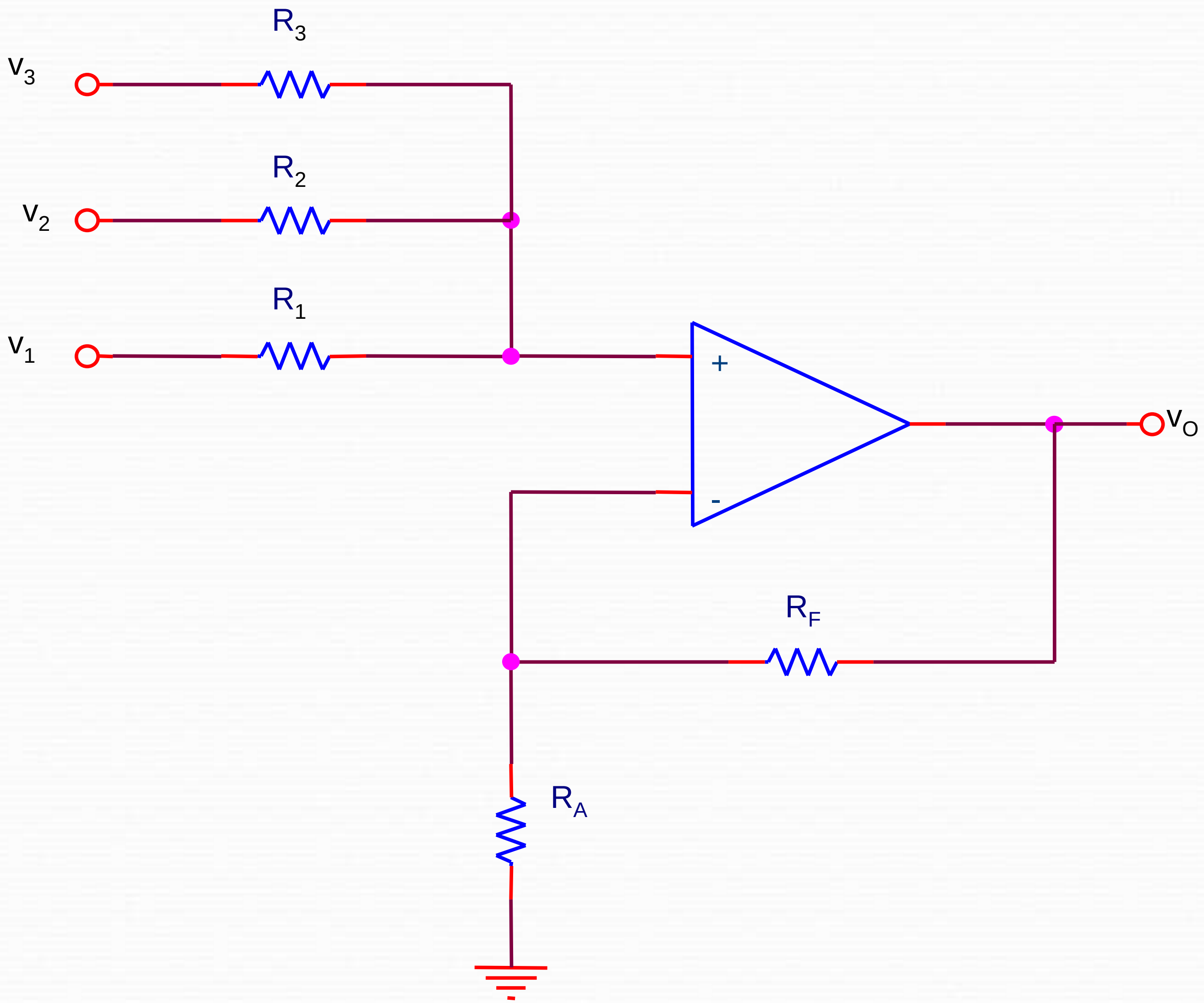
GAIN CALCULATIONS

$$i_1 + i_2 + i_3 = -i_o$$

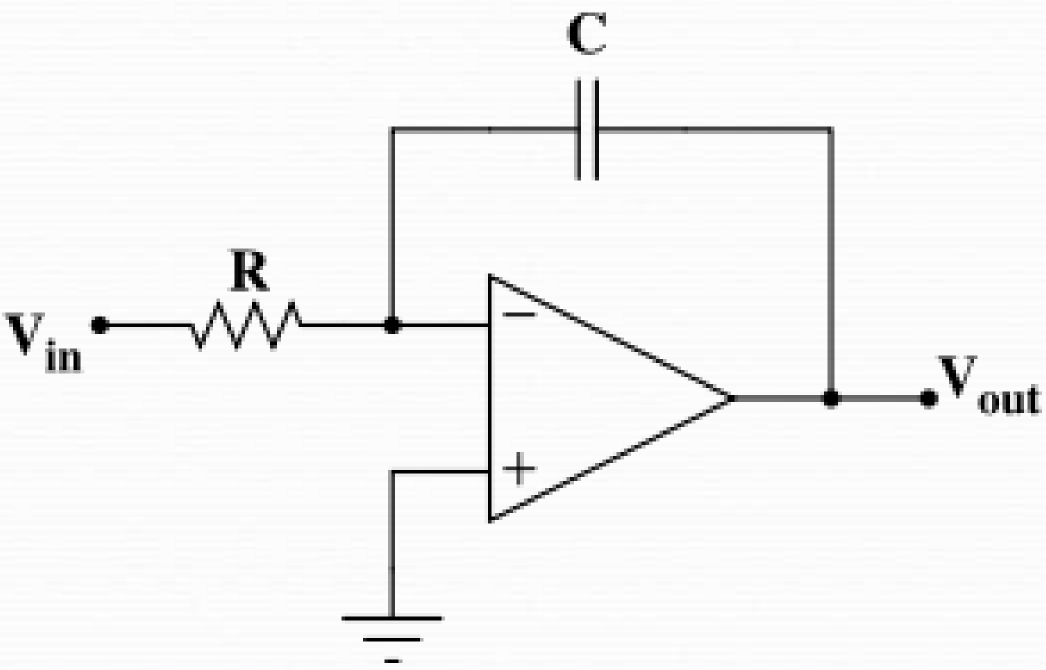
$$\frac{v_1}{R_1} + \frac{v_2}{R_2} + \frac{v_3}{R_3} = -\frac{v_o}{R_F}$$

$$v_o = -\left[\left(\frac{R_F}{R_1}\right)v_1 + \left(\frac{R_F}{R_2}\right)v_2 + \left(\frac{R_F}{R_3}\right)v_3\right]$$

NON-INVERTING SUMMING AMPLIFIER

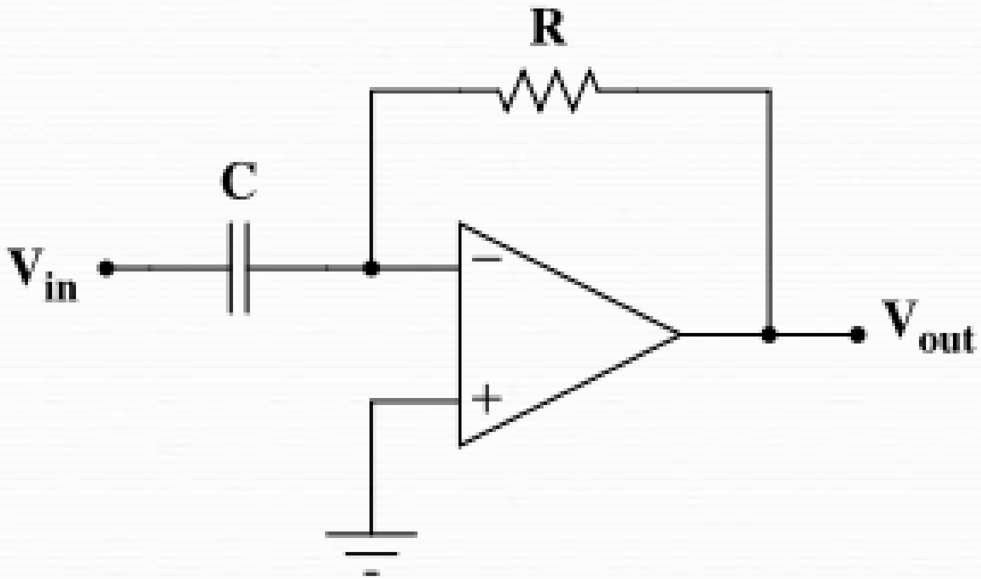


Integrating Op-Amp



$$V_{\mathrm{out}} = \int_0^t -\frac{V_{\mathrm{in}}}{RC}\,dt + V_{\mathrm{initial}}$$

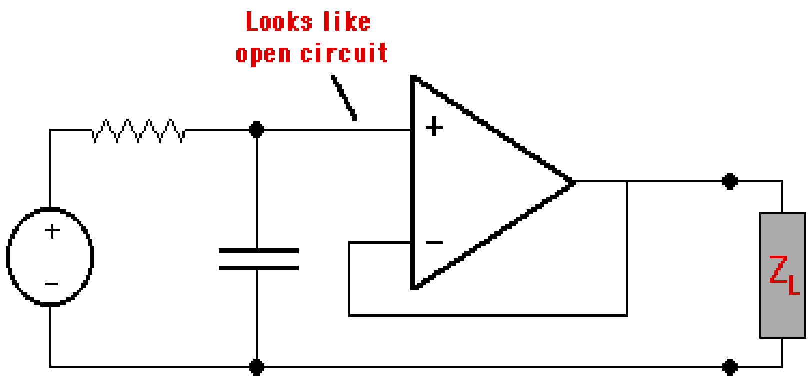
Differentiating Op-Amp



$$V_{\mathrm{out}} = -RC\left(\frac{dV_{\mathrm{in}}}{dt}\right)$$

(where V_{in} and V_{out} are functions of time)

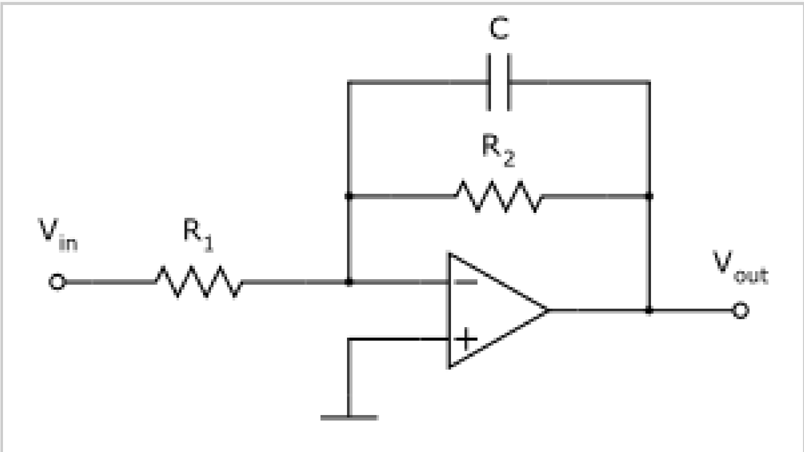
Filters



- Decouple the low-pass RC filter from the load.

Uses: Simple audio. Remove frequencies over 20kHz (audible)

Low-pass Filter (active)



An active low-pass filter

- Cutoff frequency
- This works because the capacitor needs time to charge.