Fundamentals of Electric Circuits

DC Circuits

Chapter 5. Operational Amplifiers

Operational Amplifiers

5.1. Introduction

+ Operational amplifier (*op amp*) → an electronic unit that behaves like a voltage-controlled voltage source

+ Op amp can: sum, amplify, integrate, or differentiate a signal

+ Op amp are popular in practical circuit designs because they are versatile, inexpensive, easy to use,…

+ In this chapter:

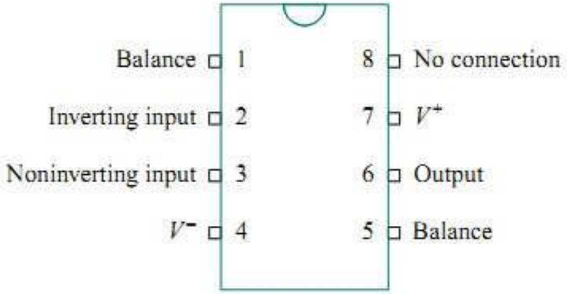
  - Ideal op amp first and the non-ideal op amp later
  - Op amp circuits: the inverter, voltage follower, summer and difference amplifier
  - Using nodal analysis as a tool to analyze circuits

5.2. Operational Amplifiers

+ *Op amp* → an active circuit element designed to perform mathematical operations of addition, subtraction, multiplication, division, differentiation, and integration

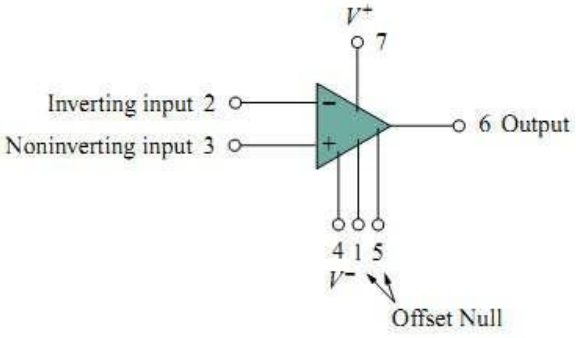
An op amp package

+ Op amp → an electronic device consisting of a complex arrangement of resistor, transistor, capacitor, and diodes → treat them as a circuit building block, study what takes place at its terminals



Dual in-line package of op amp

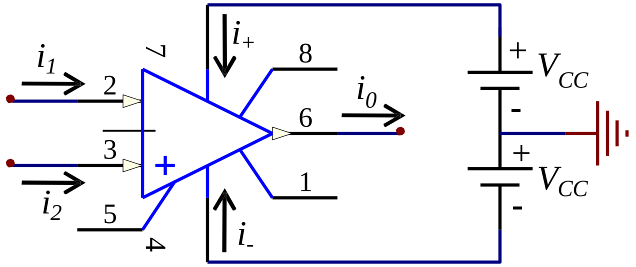
+ Several important terminals in an op amp:
  - inverting input: pin 2 (-)
  - non-inverting input: pin 3 (+)
  - output: pin 6
  - positive power supply V^+: pin 7
  - negative power supply V^-: pin 4



5.2. Operational Amplifiers

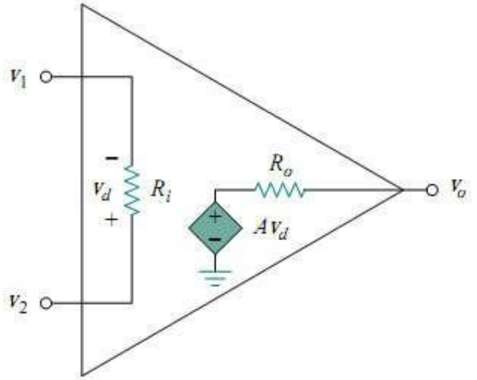
+ An op amp: → must be powered by a voltage supply:
  - often ignored in op amp circuit diagram
  - power supply currents must not be overlook

$$\boxed{i_0 = i_1 + i_2 + i_+ + i_-}$$



+ Equivalent circuit model of a non-ideal op amp:
  - Output section: Voltage-controlled source $A.v_d$ in series with output resistance R_0
  - R_i: Thevenin equivalent resistance seen at input terminals
  - R_0: Thevenin equivalent resistance seen at the output
  - Output voltage : $\boxed{v_0 = A.v_d = A.(v_2 - v_1)}$

    A: *Open-loop voltage gain* (gain of the op amp without any external feedback from output to input)

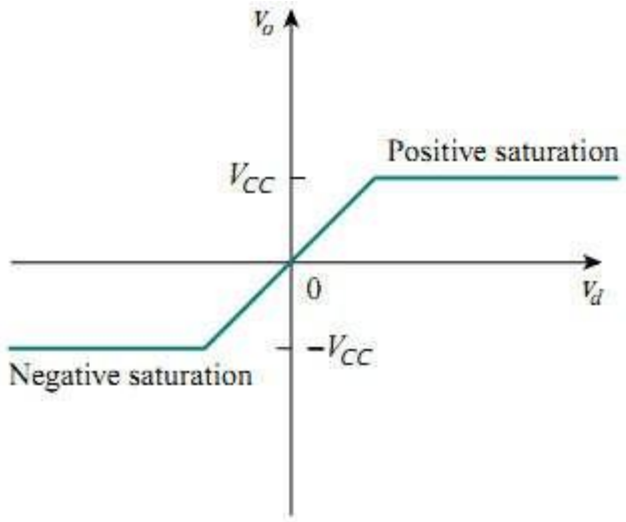


The equivalent circuit of the non-ideal op amp

5.2. Operational Amplifiers

+ Typical parameter values of op am:

Parameter	Typical range	Ideal value
Open-loop gain, A	10^5 - 10^8	∞
Input resistance, R_i	10^6 - $10^{13}\ \Omega$	$\infty\ \Omega$
Output resistance, R_0	10 - 100 Ω	0 Ω
Supply voltage, V_{cc}	5 - 24 V	



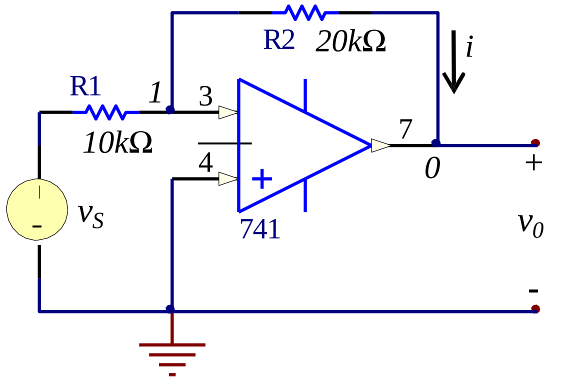
+ Modes of operation: 3 (depending on the v_0)

- Positive saturation: $v_0 = V_{cc}$
- *Linear region:* $-V_{cc} \leq v_0 = A.v_d \leq V_{cc}$
- Negative saturation: $v_0 = -V_{cc}$

5.2. Operational Amplifiers

741 parameter	Value
Open-loop gain, A	2.10^5
Input resistance, R_i	$2\ \mathrm{M}\Omega$
Output resistance, R_0	$50\ \Omega$

+ Example 1: Find the closed-loop gain V_0 / V_s. Determine current i when $V_s = 2V$



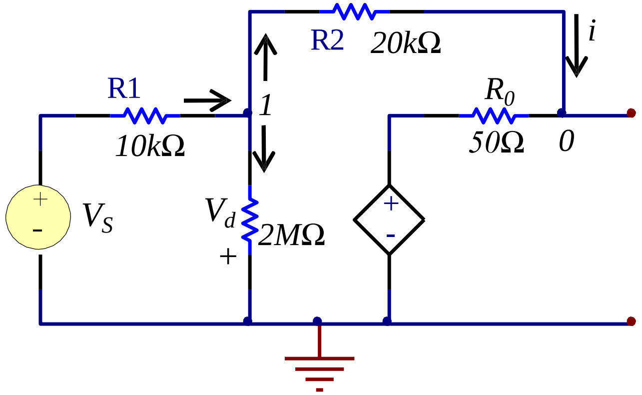
From op amp equivalent circuit → applying the nodal analysis:

At node 1:

$$\frac{V_s - V_1}{R_1} - \frac{V_1 - V_0}{R_2} - \frac{V_1}{R_i} = 0 \rightarrow V_1 = \frac{2V_s + V_0}{3}$$

At node 0:

$$\begin{cases} \dfrac{V_1 - V_0}{R_2} = \dfrac{V_0 - AV_d}{R_0} \\ V_d = -V_1 \end{cases} \rightarrow V_1 - V_0 = 400\left(V_0 + 2.10^6 V_1\right)$$



So we have a set of equations:

$$\begin{cases} V_1 - \dfrac{V_0}{3} = \dfrac{2}{3} V_s \\ \left(1 - 800.10^6\right) V_1 - 401 V_0 = 0 \end{cases}$$

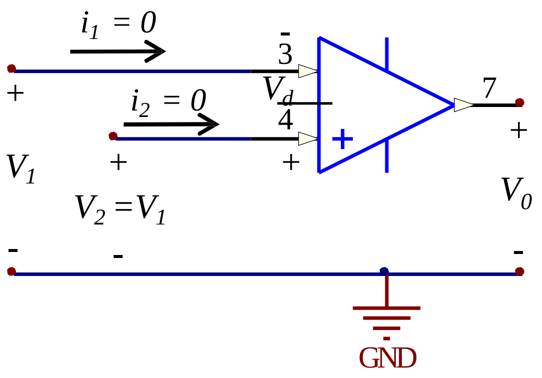
When $V_s = 2V$:

$$\begin{cases} V_1 = 20.067\,\mu V \\ i = \dfrac{V_1 - V_0}{R_2} = 0.2 mA \end{cases} \qquad \frac{V_0}{V_s} = -1.9999$$

5.3. Ideal Operational Amplifier

+ Ideal op amp → an amplifier with infinite open-loop gain ($A = \infty$), infinite input resistance ($R_i = \infty$), and zero output resistance ($R_O = 0$).

+ Important characteristics of an ideal op amp:



- Currents into both input terminals are zero

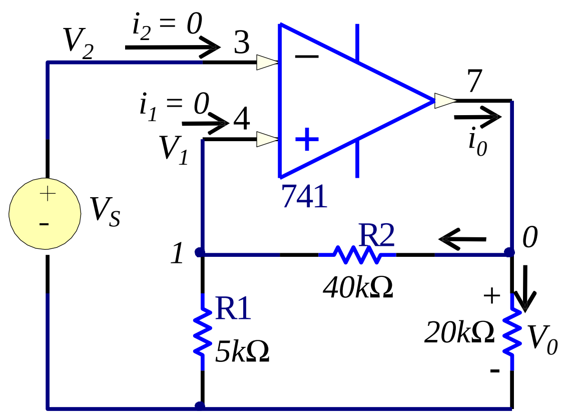
$$\boxed{i_1 = 0 \quad ; \quad i_2 = 0}$$

- Voltage across the input terminals is small

$$\boxed{V_d = V_2 - V_1 = 0 \quad ; \quad V_1 = V_2}$$

5.3. Ideal Operational Amplifier

+ Example 2: Considering 741 op amp as an ideal op amp. Calculate the V_0/V_s and find i_0 when $v_s = 1V$



As an ideal op amp, we have: $V_2 = V_S$

Since $i_1 = 0$ → R_1 and R_2 are in series

$$V_1 = \frac{V_0}{R_1 + R_2} R_1 = \frac{V_0}{9} \qquad V_2 = V_1 \rightarrow V_s = \frac{V_0}{9}$$

KCL at node 0: $$i_0 = \frac{V_0}{R_1 + R_2} + \frac{V_0}{20.10^3} = \frac{9V_s}{R_1 + R_2} + \frac{9V_s}{20.10^3}$$

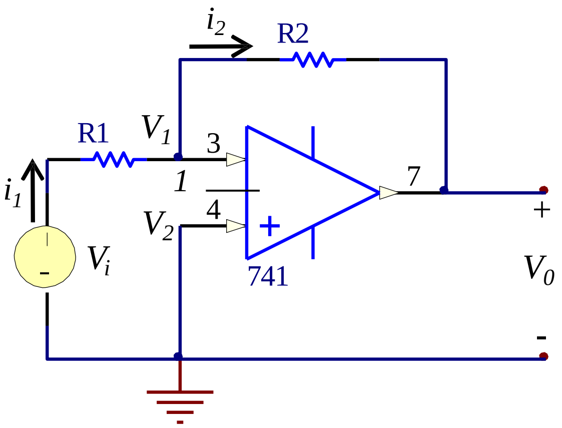
So when $v_s = 1V$:

$$\begin{cases} \dfrac{V_0}{V_s} = 9 \\ i_0 = 0.65mA \end{cases}$$

5.4. Inverting – Non-inverting Amplifier

5.4.1. Inverting Amplifier

+ Apply KCL at node 1

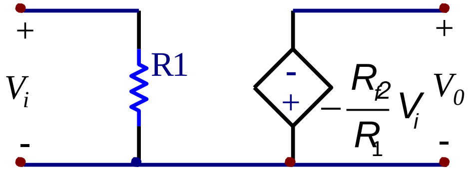


Ideal op amp

$$\left.\begin{array}{l} i_1 = i_2 \rightarrow \dfrac{V_i - V_1}{R_1} = \dfrac{V_1 - V_0}{R_2} \\ V_1 = V_2 = 0 \end{array}\right\} \rightarrow \boxed{V_0 = -\frac{R_2}{R_1} V_i}$$

+ Note:

$A_v = -\dfrac{R_2}{R_1}$ → voltage gain depends only on the external elements connected to the op amp

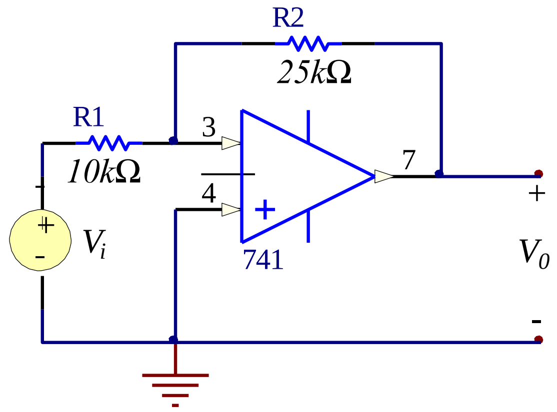


- Both the input signal and the feedback are applied at the inverting terminal of the op amp
- Inverting amplifier is used in a current to voltage converter

5.4. Inverting – Non-inverting Amplifier

5.4.1. Inverting Amplifier

+ Example 3: Calculate the output voltage v_0 and the current through R_1 and R_2 if $v_i = 0.5V$



For inverting amplifier: $$V_0 = -\frac{R_2}{R_1}V_i = -\frac{25}{10}.0.5 = -1.25V$$

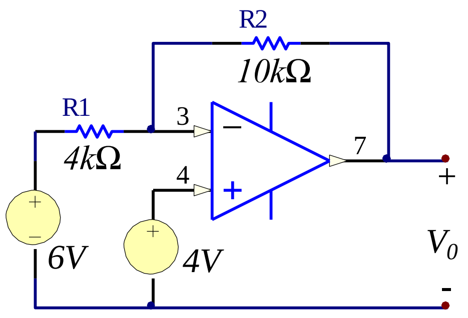
The current though the R_1 : $$i_{R1} = \frac{V_i - 0}{R_1} = \frac{0.5}{10^4} = 50\mu A$$

The current though the R_2 : $$i_{R2} = \frac{0 - V_0}{R_2} = \frac{1.25}{25.10^3} = 50\mu A$$

5.4. Inverting – Non-inverting Amplifier

5.4.1. Inverting Amplifier

+ Example 4: Calculate the output voltage v_0 of the given circuit



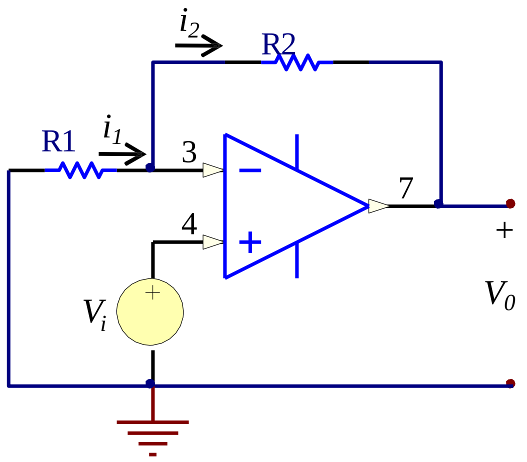
KCL at node 3:

$$\left.\begin{array}{c} \dfrac{6-V_3}{R_1}=\dfrac{V_3-V_0}{R_2} \\ V_3=4 \end{array}\right\} \rightarrow V_0=V_3-R_2\frac{6-V_3}{R_1}$$

$$\rightarrow V_0=4-10\frac{6-4}{4}=-1V$$

5.4. Inverting – Non-inverting Amplifier

5.4.2. Non-Inverting Amplifier



+ Non-inverting amplifier → op amp circuit designed to provide a positive voltage gain

- Input voltage V_i is applied directly at the non-inverting input terminal
- R1 is connected between the ground and the inverting terminal

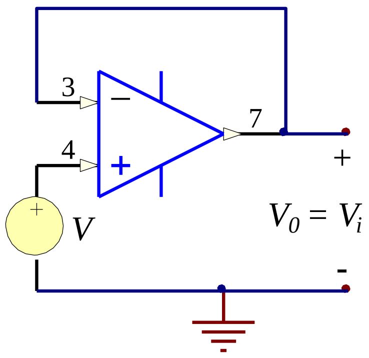
$$\left.\begin{matrix} \dfrac{0-V_3}{R_1} = \dfrac{V_3-V_0}{R_2} \\ V_3 = V_i \end{matrix}\right\} \rightarrow \frac{V_0}{R_2} = \frac{V_i}{R_1} + \frac{V_i}{R_2} \rightarrow \boxed{V_0 = \left(1+\frac{R_2}{R_1}\right)V_i}$$

5.4. Inverting – Non-inverting Amplifier

5.4.2. Non-Inverting Amplifier

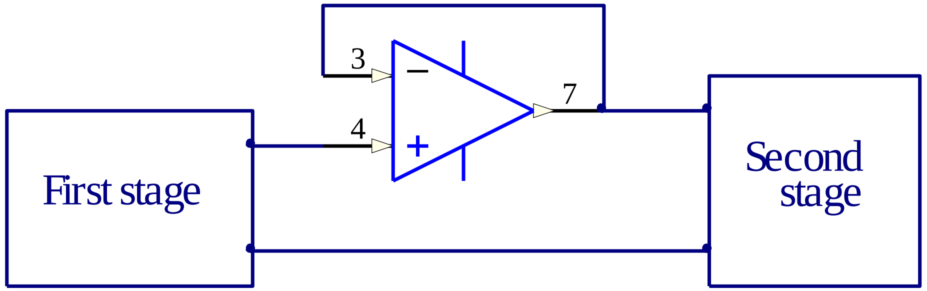
+ Note:

If $R_2 = 0$ or $R_1 = \infty$ → the voltage gain becomes 1
→ the circuit is call a *voltage follower* (or *unity gain amplifier*)



+ Characteristic of voltage follower:

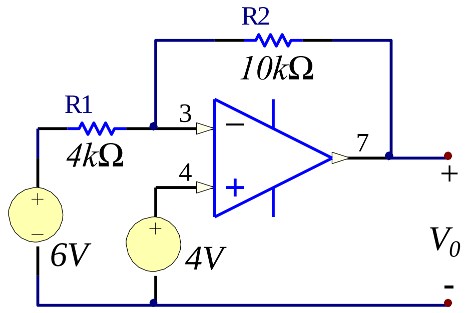
- Very high input impedance
- Useful as an intermediate – stage (or *buffer*) amplifier to isolate one circuit from another
- Minimize interaction between the two stages and eliminate inter-stage loading



Voltage follower used to isolate two cascaded stages of a circuit

5.4. Inverting – Non-inverting Amplifier

5.4.2. Non-Inverting Amplifier



+ Example 5: Calculate the output voltage v_0 of the given circuit

Using superposition: $V_0 = V_{01} + V_{02}$

V_{O1} is due to the 6V voltage source V_{O2} is due to the 4V voltage source

Calculate V_{O1}: Set the 4V voltage source to zero, the circuit becomes an inverting amplifier

$$V_{01} = -\frac{R_2}{R_1}V_{i1} = -\frac{10}{4}6 = -15V$$

Calculate V_{O2}: Set the 6V voltage source to zero, the circuit becomes an non-inverting amplifier

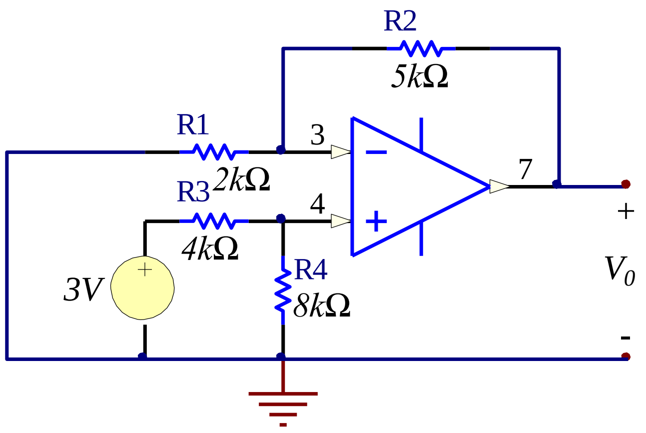
$$V_{02} = \left(1+\frac{R_2}{R_1}\right)V_{i2} = \left(1+\frac{10}{4}\right)4 = 14V$$

So we obtain the output voltage: $V_0 = V_{01} + V_{02} = -1V$

5.4. Inverting – Non-inverting Amplifier

5.4.2. Non-Inverting Amplifier

+ Example 6: Calculate the output voltage v_0 of the given circuit



Apply KCL at node 3 and 4:

$$\begin{cases} -\dfrac{V_P}{R_4} + \dfrac{V_i - V_P}{R_3} = 0 \\ -\dfrac{V_N}{R_1} + \dfrac{V_0 - V_N}{R_2} = 0 \\ V_N = V_P \end{cases} \rightarrow \begin{cases} V_i = \dfrac{R_3 + R_4}{R_4} V_P \\ V_0 = \dfrac{R_1 + R_2}{R_1} V_P \end{cases}$$

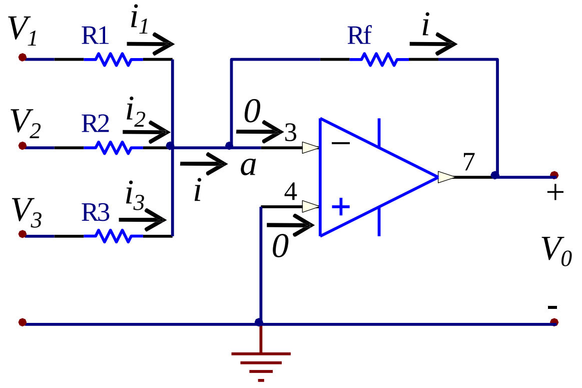
$$\rightarrow V_0 = \frac{R_1 + R_2}{R_1} . \frac{R_4}{R_3 + R_4} V_i = \frac{2+5}{2} . \frac{8}{4+8} .3 = 7V$$

5.5. Summing Amplifier

+ Summing amplifier → op amp circuit that combines several inputs and produces an output that is the weighted sum of the inputs

+ Summing amplifier → a variation of the inverting amplifier

+ As an example, for the given circuit, apply KCL at node *a:*



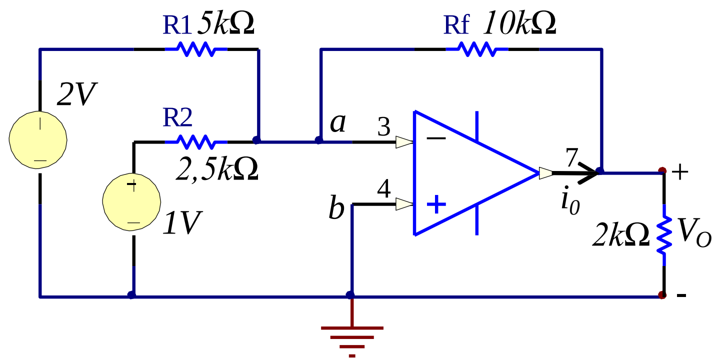
$$i = i_1 + i_2 + i_3 \rightarrow \frac{V_a - V_0}{R_f} = \frac{V_1 - V_a}{R_1} + \frac{V_2 - V_a}{R_2} + \frac{V_3 - V_a}{R_3}$$

Because of $V_a = V_4 = 0$:

$$\boxed{V_0 = -\left(\frac{R_f}{R_1}V_1 + \frac{R_f}{R_2}V_2 + \frac{R_f}{R_3}V_3\right)}$$

5.5. Summing Amplifier

+ Example 7: Calculate the output voltage v_0 *and* i_0 of the given circuit



Apply the equation of summing amplifier to calculate V_0

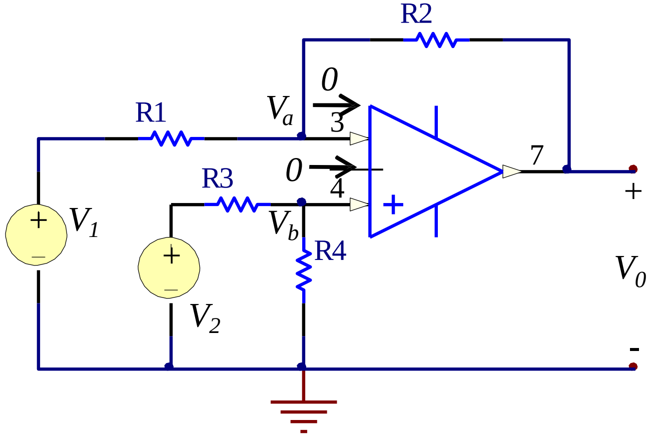
$$V_0 = -\left(\frac{R_f}{R_1}V_1 + \frac{R_f}{R_2}V_2\right) = -\left(\frac{10}{5}.2 + \frac{10}{2,5}.1\right) = -8V$$

Calculate the current i_0

$$i_0 + i_f = i_{load} \rightarrow i_0 = i_{load} - i_f = \frac{V_0}{R_{load}} - \frac{0 - V_0}{R_f} = -\frac{8}{2.10^3} - \frac{8}{10.10^3} = -4.8mA$$

5.6. Difference Amplifier

+ Difference (differential) amplifier → circuit that amplifies the difference between two inputs but rejects any signals common to the two inputs



KCL at node *a*: $$\frac{V_1 - V_a}{R_1} = \frac{V_a - V_0}{R_2} \rightarrow V_0 = \left(1 + \frac{R_2}{R_1}\right) V_a - \frac{R_2}{R_1} V_1$$

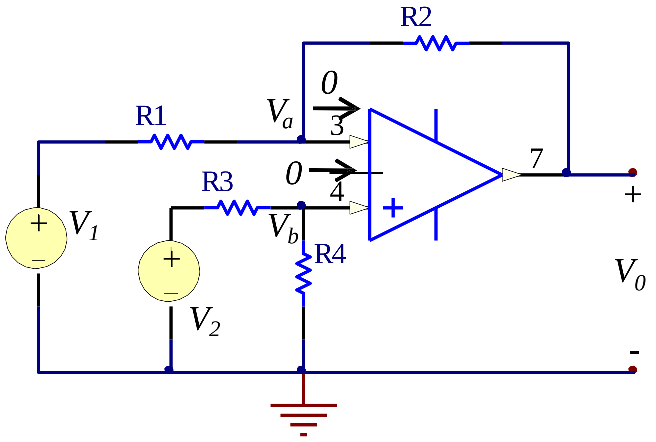
KCL at node *b*: $$\frac{V_2 - V_b}{R_3} = \frac{V_b}{R_4} \rightarrow V_b = \left(\frac{R_4}{R_3 + R_4}\right) V_2$$

Output voltage:

$$V_a = V_b \rightarrow V_0 = \left(\frac{R_1 + R_2}{R_1}\right)\left(\frac{R_4}{R_3 + R_4}\right) V_2 - \frac{R_2}{R_1} V_1 \rightarrow \boxed{V_0 = \frac{R_2}{R_1} \frac{\left(1 + \frac{R_1}{R_2}\right)}{\left(1 + \frac{R_3}{R_4}\right)} V_2 - \frac{R_2}{R_1} V_1}$$

5.6. Difference Amplifier

+ A difference amplifier must reject a signal common to the two inputs: $V_0 = 0$ when $V_1 = V_2$



$$\rightarrow \frac{R_1}{R_2} = \frac{R_3}{R_4}$$

+ So the output voltage of a difference amplifier:

$$V_0 = \frac{R_2}{R_1}(V_2 - V_1)$$

+ If $R_2 = R_1$, and $R_3 = R_4$ → the difference amplifier becomes a subtractor: $V_0 = V_2 - V_1$

+ Remarks

- A difference amplifier → also known as a subtractor
- Difference amplifier → used in varios applications (*instrumentation amplifier*)

5.6. Difference Amplifier

+ Example 8: Design an op amp circuit with inputs V_1 and V_2 such that $V_0 = -5V_1 + 3V_2$

Solution 1: Using only one op amp

Rewrite: $$V_0 = 5\left(\frac{3}{5}V_2 - V_1\right)$$

From the output voltage equation of a difference amplifier: $$V_0 = \frac{R_2}{R_1}\frac{\left(1+\frac{R_1}{R_2}\right)}{\left(1+\frac{R_3}{R_4}\right)}V_2 - \frac{R_2}{R_1}V_1 \rightarrow \begin{cases} \boxed{\frac{R_2}{R_1} = 5 \quad (1)} \\ \frac{\left(1+\frac{1}{5}\right)}{1+\frac{R_3}{R_4}} = \frac{3}{5} \end{cases}$$

and from: $$\frac{\frac{6}{5}}{1+\frac{R_3}{R_4}} = \frac{3}{5} \rightarrow 1+\frac{R_3}{R_4} = 2 \rightarrow \boxed{R_3 = R_4 \quad (2)}$$

From (1) and (2), we can choose: $$R_1 = 10k\Omega \rightarrow R_2 = 50k\Omega$$
$$R_3 = 20k\Omega \rightarrow R_4 = 20k\Omega$$

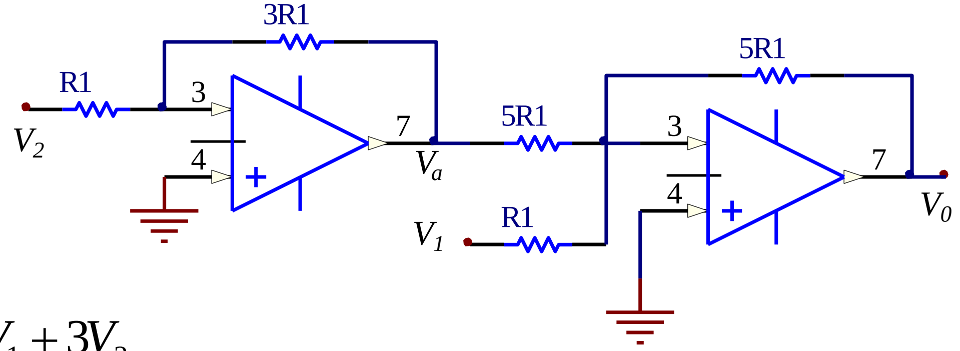
5.6. Difference Amplifier

+ Example 8: Design an op amp circuit with inputs V_1 and V_2 such that $V_0 = -5V_1 + 3V_2$

Solution 2: Using 2 op amp → one inverting amplifier and one 2-inputs inverting summer

Output voltage of the first stage:

$$V_a = -\frac{3R_1}{R_1}V_2 = -3V_2$$



Output voltage of the second stage:

$$V_0 = -\left(\frac{5R_1}{R_1}V_1 + \frac{5R_1}{5R_1}V_2\right) = -(5V_1 - 3V_2) = -5V_1 + 3V_2$$

In this case, we can choose: $R_1 = 10k\Omega$

5.6. Difference Amplifier

+ Example 9: Find the relationship between V_0 and two inputs of an instrumentation amplifier

There are not current into A_1, and A_2, the current *i* flows through the 3 resisters

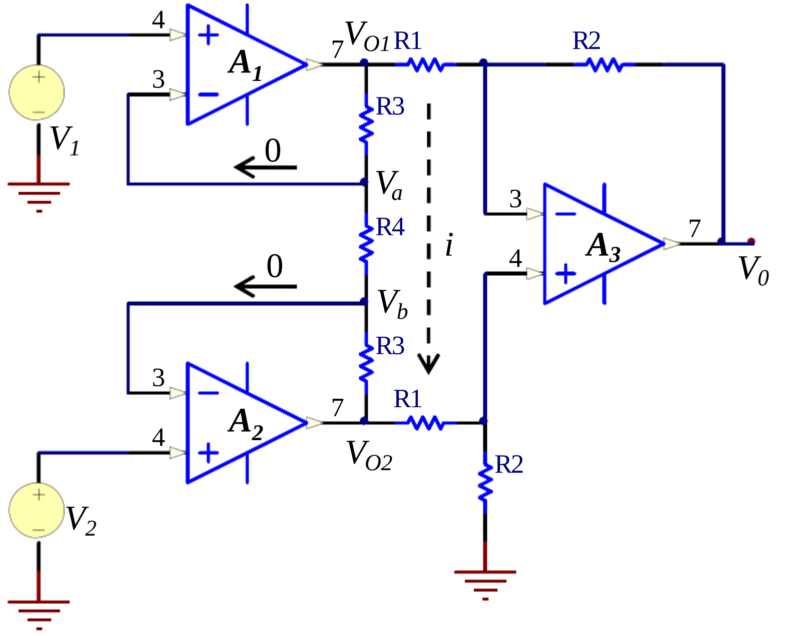
$$V_{01} - V_{02} = i(2R_3 + R_4)$$

$$i = \frac{V_a - V_b}{R_4} \qquad V_a = V_1, V_b = V_2 \quad \rightarrow i = \frac{V_1 - V_2}{R_4}$$

Therefore: $$V_{01} - V_{02} = (V_1 - V_2)\left(1 + 2\frac{R_3}{R_4}\right)$$

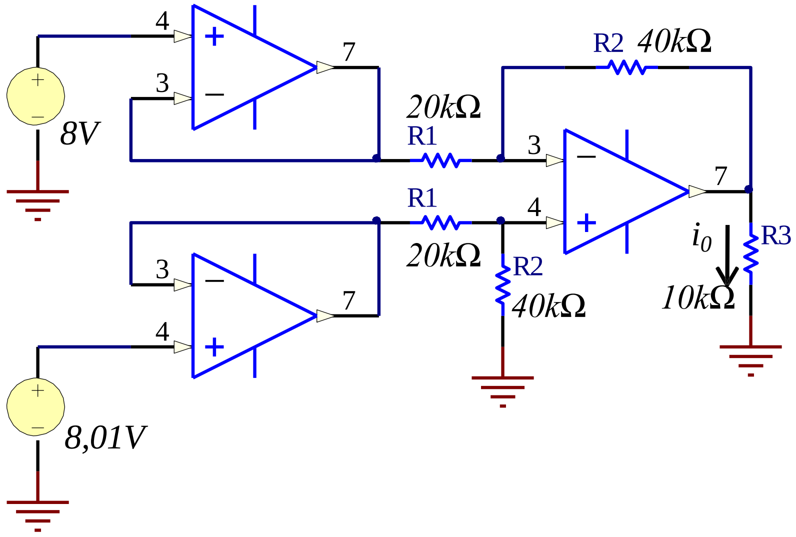
In this case, we have the output voltage of the difference amplifier:

$$V_0 = \frac{R_2}{R_1}(V_{02} - V_{01}) \rightarrow \boxed{V_0 = \frac{R_2}{R_1}\left(1 + 2\frac{R_3}{R_4}\right)(V_2 - V_1)}$$



5.6. Difference Amplifier

+ Example 10: Find the current i_0 of the given instrumentation amplifier circuit



$$V_0 = \frac{R_2}{R_1}\left(V_{i+} - V_{i-}\right) = \frac{40}{20}\left(8.01 - 8\right) = 0.02V$$

$$i_0 = \frac{V_0}{R_3} = \frac{0.02}{10.10^3} = 2\mu A$$

5.7. Cascaded op amp Circuit

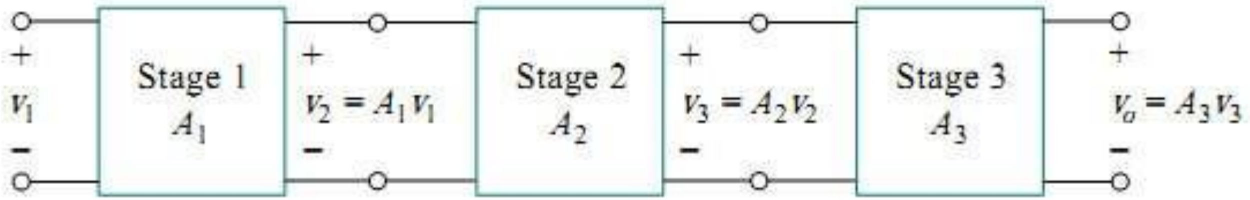
+ Cascade connection: head-to-tail arrangement of two or more op amp circuits such that the output of one is the input of the next

→ Each op amp circuit in the string is called a *stage*

→ Op amp circuits can be cascaded without changing their input-output relationship because of:

- Infinite input resistance
- Zero output resistance

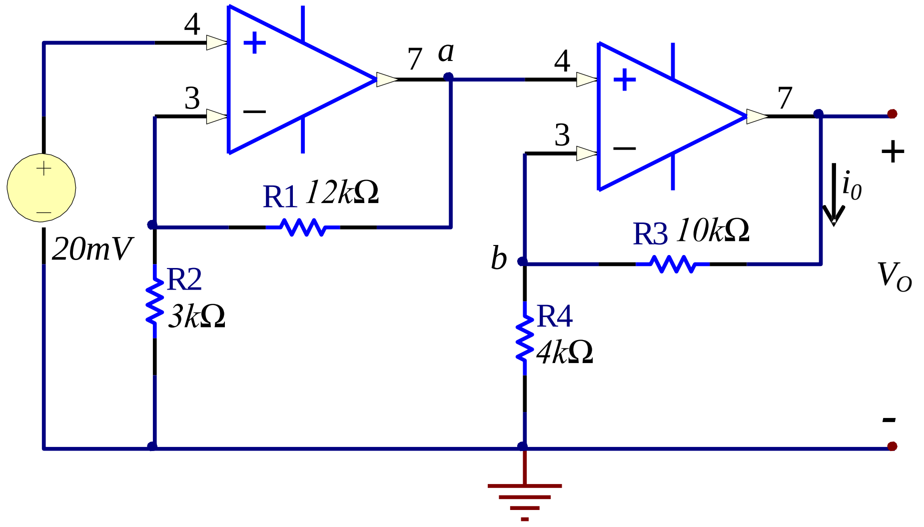
+ In cascaded connection: The original input signal is increased by the gain of the individual stage



$$\boxed{A = A_1 . A_2 . A_3}$$

5.7. Cascaded op amp Circuit

+ Example 11: Find the voltage v_0 and the current i_0 of the given circuit



The cascaded circuit consists of two non- inverting amplifiers

Output of the first stage:

$$V_a = \left(1+\frac{R_1}{R_2}\right)V_i = \left(1+\frac{12}{3}\right).20 = 100mV$$

Output of the second stage:

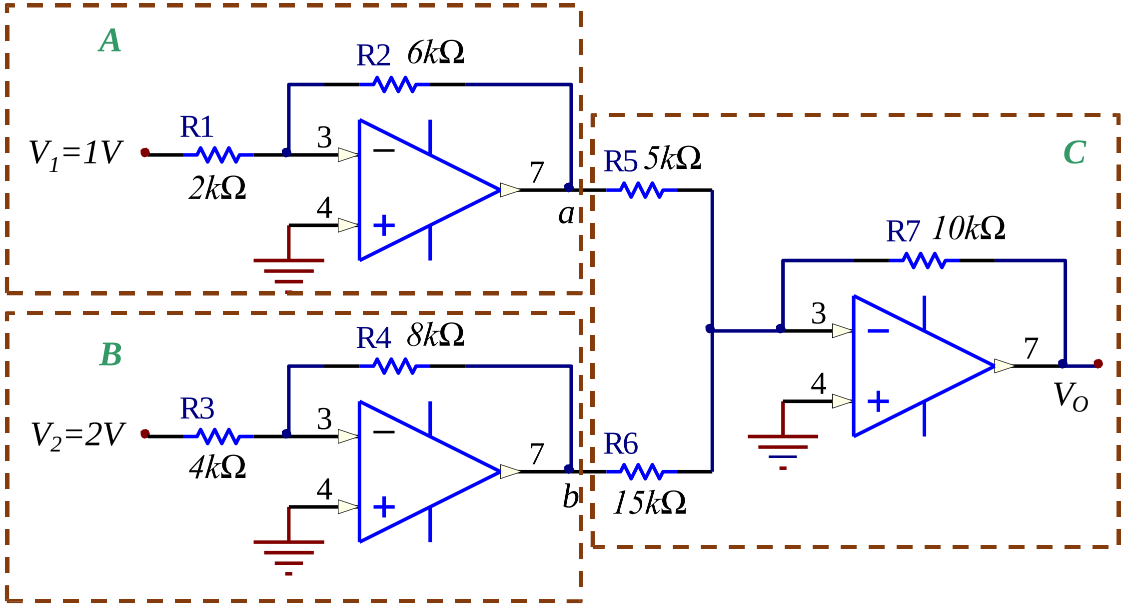
$$V_0 = \left(1+\frac{R_3}{R_4}\right)V_a = \left(1+\frac{10}{4}\right).100 = 350mV$$

The current i_0 flows through the resistor R_3 :

$$i_0 = \frac{V_0 - V_b}{R_3} = \frac{V_0 - V_a}{R_3} = \frac{350-100}{10.10^3} = 25\mu A$$

5.7. Cascaded op amp Circuit

+ Example 12: Find the voltage v_0 of the given circuit



Circuit consists of two inverters *A* and *B* and a summer *C*

$$V_a = -\frac{R_2}{R_1}V_1 = -\frac{6}{2}.1 = -3V$$

$$V_b = -\frac{R_4}{R_3}V_2 = -\frac{8}{4}.2 = -4V$$

Output of the given circuit:

$$V_0 = -\left(\frac{R_7}{R_5}V_a + \frac{R_7}{R_6}V_b\right) = \left(\frac{10}{5}3 + \frac{10}{15}4\right) = 8.66V$$

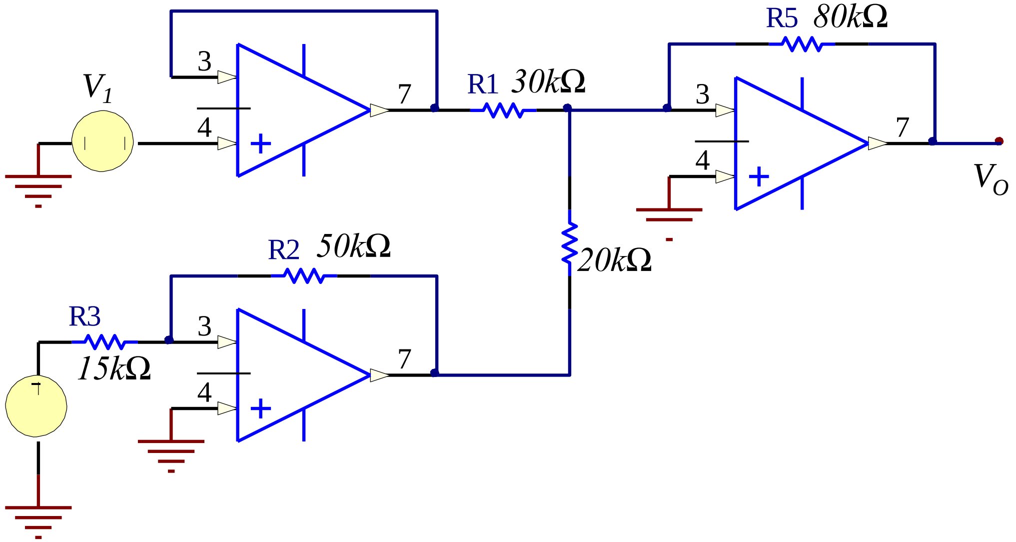
5.7. Cascaded op amp Circuit

+ Example 13: Find V_0 if $V_1 = 2V,\ V_2 = 1.5V$

$$V_{21} = V_1 = 2V$$

$$V_{22} = -\frac{R_2}{R_3}V_2 = -\frac{50}{15}.1.5 = -5V$$

$$V_0 = -\left(\frac{R_5}{R_1}V_{21} + \frac{R_5}{R_4}V_{22}\right) = -\left(\frac{80}{30}.2 - \frac{80}{20}.5\right) = 14.67V$$



5.8. Applications

+ Pratical applications of op amp circuits:

- Inverters, summers, integrators, differentiators, subtractors, logarithmic amplifiers
- Instrumentation amplifiers, calibration circuits
- DAC, voltage-to-curent converters, current-to-voltage converter
- Analog computers
- Filters, clippers, rectifier, regulators, level shifters
- Comparators, gyrators, oscillator

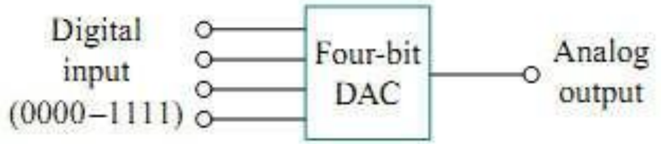
5.8. Applications

5.8.1. DAC – Digital to Analog Converter

+ Digital-to-analog converter (DAC):

→ Transforms digital signals into analog form

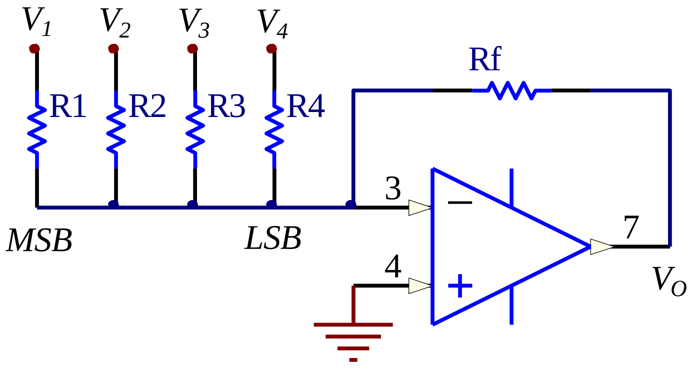
→ Can be realized by using the binary weighted ladder



- The bits are weights according to the magnitude of their place value

- Their weights decrease value of R_f/R_n → each lesser bit has half the weight of the next higher

$$V_0 = -\left(\frac{R_f}{R_1}V_1 + \frac{R_f}{R_2}V_2 + \frac{R_f}{R_3}V_3 + \frac{R_f}{R_4}V_4\right)$$



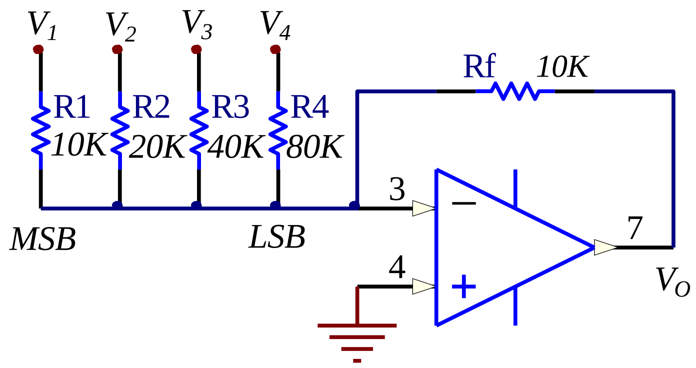
Binary weighted ladder type

- V1, … V4 can assume only two voltage levels (0, 1) (*binary code*) → DAC provides a single output that is proportional to the inputs

5.8. Applications

5.8.1. DAC – Digital to Analog Converter

+ Example 14: Obtain the analog output for binary inputs [0000], [0001], [0010], … [1111]



Inputs [B]	Value [D]	$-V_0$
0000	0	0
0001	1	0.125
0010	2	0.25
0011	3	0.375
0100	4	0.5
0101	5	0.625
0110	6	0.75
0111	7	0.875
1000	8	1.0
1001	9	1.125
…		
1111	15	1.875

$$V_0 = -\left(\frac{R_f}{R_1}V_1 + \frac{R_f}{R_2}V_2 + \frac{R_f}{R_3}V_3 + \frac{R_f}{R_4}V_4\right)$$

$$V_0 = -\left(V_1 + 0.5V_2 + 0.25V_3 + 0.125V_4\right)$$

Each bit has a value of 0.125V → cannot represent a voltage between 1V → 1.125V (*DAC resolution*)

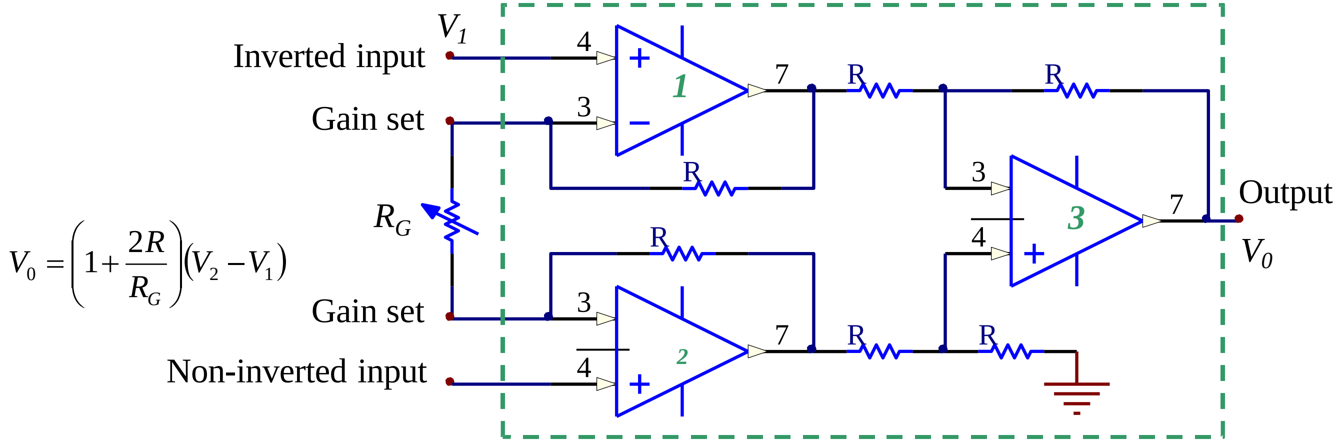
5.8. Applications

5.8.2. Instrumentation Amplifier (IA)

+ Typical applications of IAs: isolation amplifiers, thermocouple amplifiers, data acquisition systems

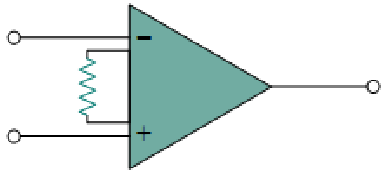
+ Output voltage of IAs:

$$V_0 = \left(1 + \frac{2R}{R_G}\right)(V_2 - V_1)$$



Small differential signal voltages superimposed on larger common-mode voltages

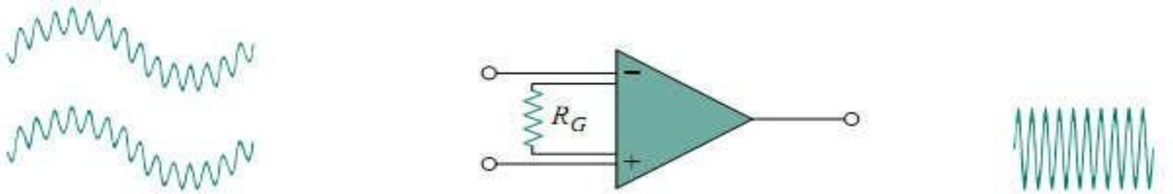
Since the common-mode voltages are equal, they cancel each other



Schematic diagram

5.8. Applications

5.8.2. Instrumentation Amplifier



Small differential signals riding on larger common–mode signals | Instrumentation amplifier | Amplified differential signal, No common-mode signal

+ Three main characteristics:

→ *Voltage gain is adjusted* by one extern resistor R_G

→ *Input impedance of both inputs is very high* and does *not vary* as the gain is adjusted

→ *Output V_O depends on the difference* between the inputs V_1 and V_2, not on the voltage common to them (common-mode voltage)

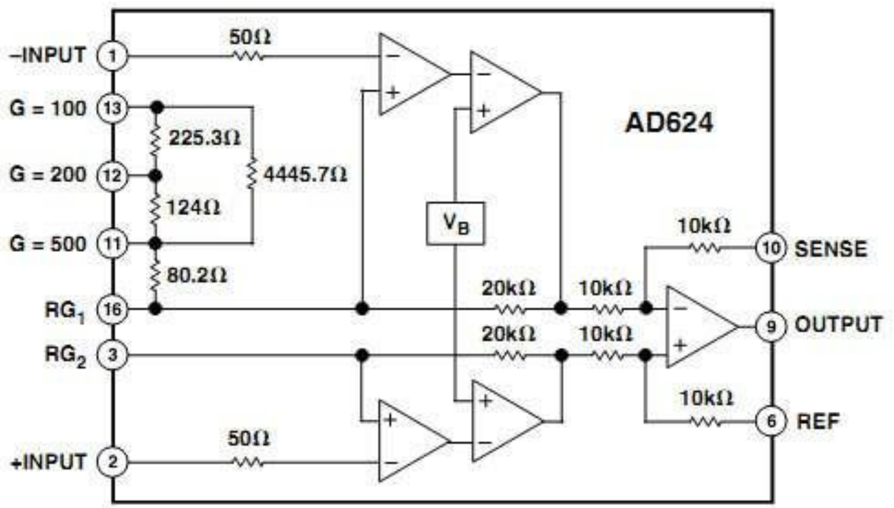
5.8. Applications

5.8.2. Instrumentation Amplifier

+ Precision Intrumentation amplifier AD624

CMRR: *Common Mode Rejection Ratio*
PSRR: *Power Supply Rejection Ratio*
TC: *Temperature Change*

FUNCTIONAL BLOCK DIAGRAM



FEATURES
Low Noise: 0.2 μV p-p 0.1 Hz to 10 Hz
Low Gain TC: 5 ppm max (G = 1)
Low Nonlinearity: 0.001% max (G = 1 to 200)
High CMRR: 130 dB min (G = 500 to 1000)
Low Input Offset Voltage: 25 μV, max
Low Input Offset Voltage Drift: 0.25 μV/°C max
Gain Bandwidth Product: 25 MHz
Pin Programmable Gains of 1, 100, 200, 500, 1000
No External Components Required
Internally Compensated

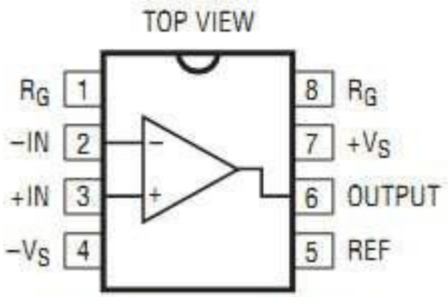
Price (100 - 499)	Price (1000)
$4.82	$4.09

Datasheet:
http://www.analog.com/static/imported-files/data_sheets/AD620.pdf

5.8. Applications

5.8.2. Instrumentation Amplifier

+ LT167 – Single resistor gain, programmable, precision intrumentation amplifier



N8 PACKAGE
8-LEAD PDIP

S8 PACKAGE
8-LEAD PLASTIC SO

$T_{JMAX} = 150°C$, $\theta_{JA} = 130°C/W$ (N8)
$T_{JMAX} = 150°C$, $\theta_{JA} = 190°C/W$ (S8)

APPLICATIONS

- Bridge Amplifiers
- Strain Gauge Amplifiers
- Thermocouple Amplifiers
- Differential to Single-Ended Converters
- Medical Instrumentation

FEATURES

- **Single Gain Set Resistor: G = 1 to 10,000**
- **Gain Error: G = 10, 0.08% Max**
- **Input Offset Voltage Drift: 0.3μV/°C Max**
- **Meets IEC 1000-4-2 Level 4 ESD Tests with Two External 5k Resistors**
- Gain Nonlinearity: G = 10, 10ppm Max
- Input Offset Voltage: G = 10, 60μV Max
- Input Bias Current: 350pA Max
- PSRR at G = 1: 105dB Min
- CMRR at G = 1: 90dB Min
- Supply Current: 1.3mA Max
- Wide Supply Range: ±2.3V to ±18V
- 1kHz Voltage Noise: $7.5nV/\sqrt{Hz}$
- 0.1Hz to 10Hz Noise: $0.28\mu V_{P-P}$
- Available in 8-Pin PDIP and SO Packages