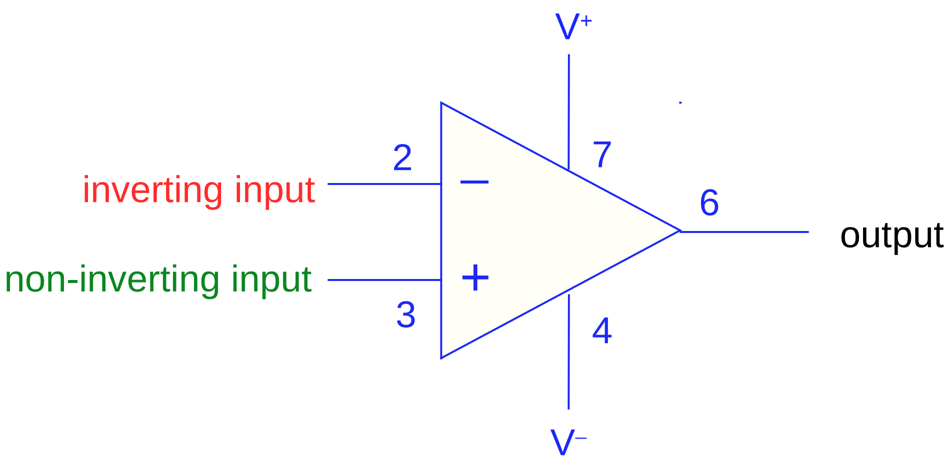
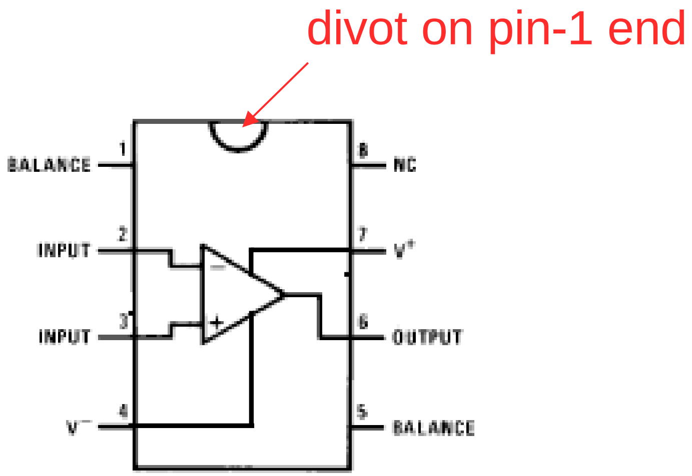
Op-Amp Introduction

Operational amplifier (Op-amp) is made of many transistors, diodes, resistors and capacitors in integrated circuit technology.

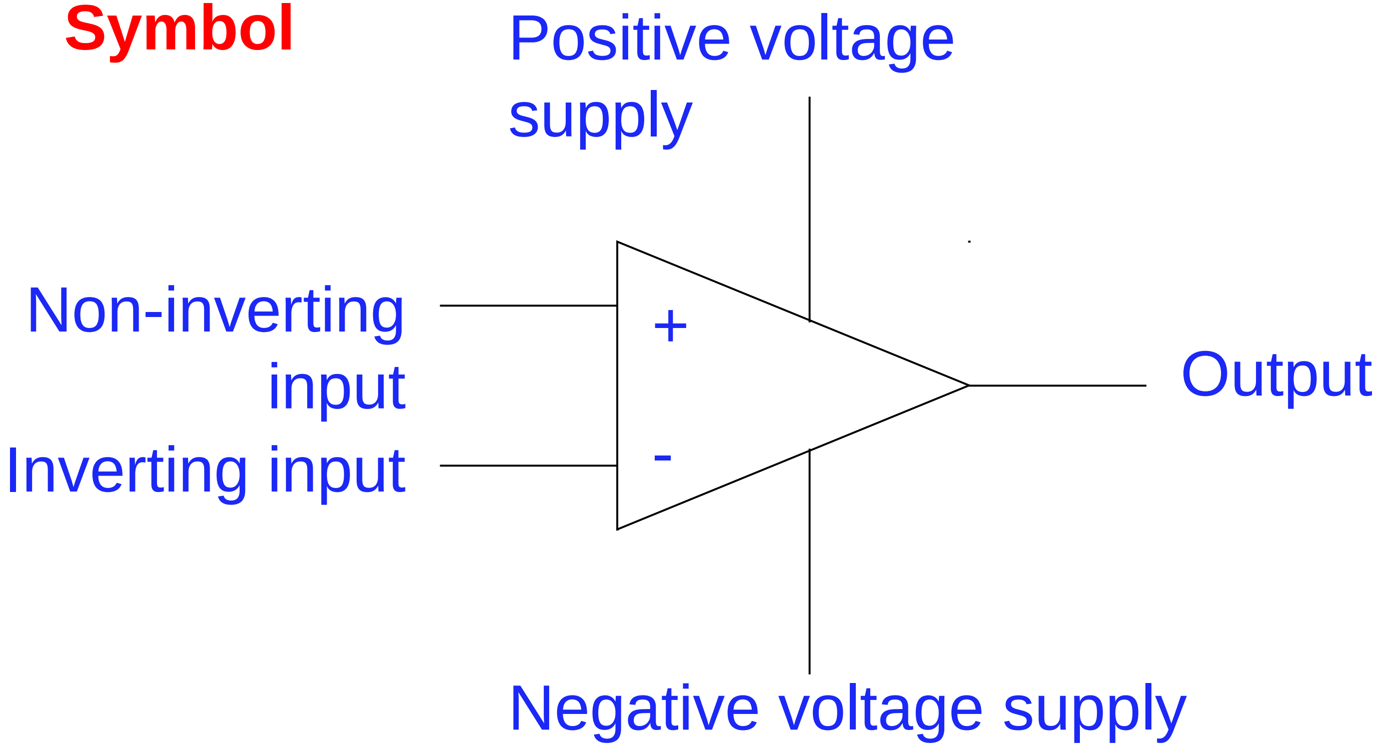
It is a very high-gain, high input resistance directly-coupled negative-feedback amplifier which can amplify signals having frequency ranging from 0 Hz to a little beyond 1 MHz. They are made with different internal configurations in linear ICs. An OP-AMP is so named because it was originally designed to perform mathematical operations like summation, subtraction, multiplication, differentiation and integration etc. in analog computers.





Operational Amplifiers (Op Amp)

Symbol



- At a minimum, op amps have 3 terminals: 2 input and 1 output.
- An op amp also requires dc power to operate. Often, the op amp requires both positive and negative voltage supplies (V+ and V-).

Characteristics of the Ideal Op Amplifier

- Differential input resistance is infinite.
- Differential voltage gain is infinite.
- CMRR is infinite.
- Bandwidth is infinite.
- Output resistance is zero.
- Offset voltage and current is zero.

a) No difference voltage between inverting and noninverting terminals.

b) No input currents.

The ideal op-amp

- Infinite voltage gain
  - a voltage difference at the two inputs is magnified infinitely
  - in truth, something like 200,000
  - means difference between + terminal and – terminal is amplified by 200,000!
- Infinite input impedance
  - no current flows into inputs
  - in truth, about 10^{12} Ω for FET input op-amps
- Zero output impedance
  - rock-solid independent of load
  - roughly true up to current maximum (usually 5–25 mA)
- Infinitely fast (infinite bandwidth)
  - in truth, limited to few MHz range
  - slew rate limited to 0.5–20 V/μs

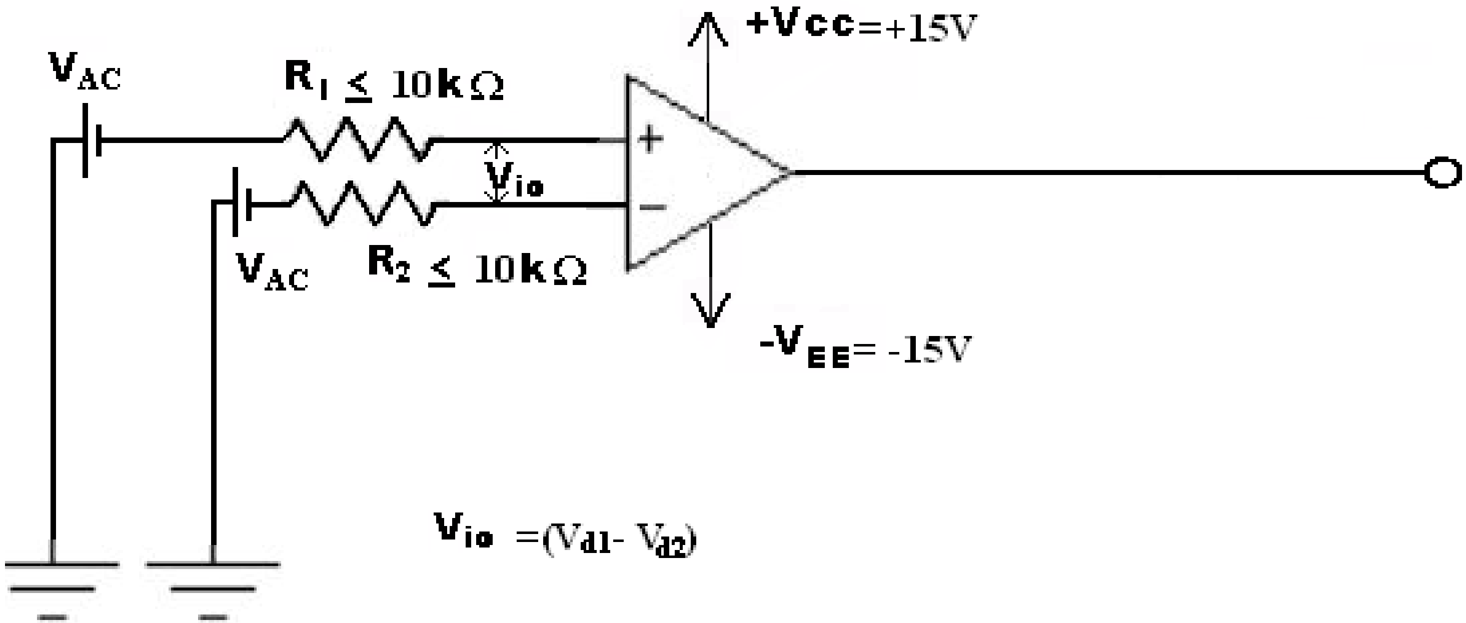
Parameters of OP-AMP

- Input offset voltage
- Input offset current
- Input BIAS current
- Common mode rejection ratio
- Slew rate

Input offset voltage

- Input offset voltage is the voltage that must be applied between the **two input terminals** of an op-amp to **null the output**.
- Typical value of **741 IC is 6mV dc**.

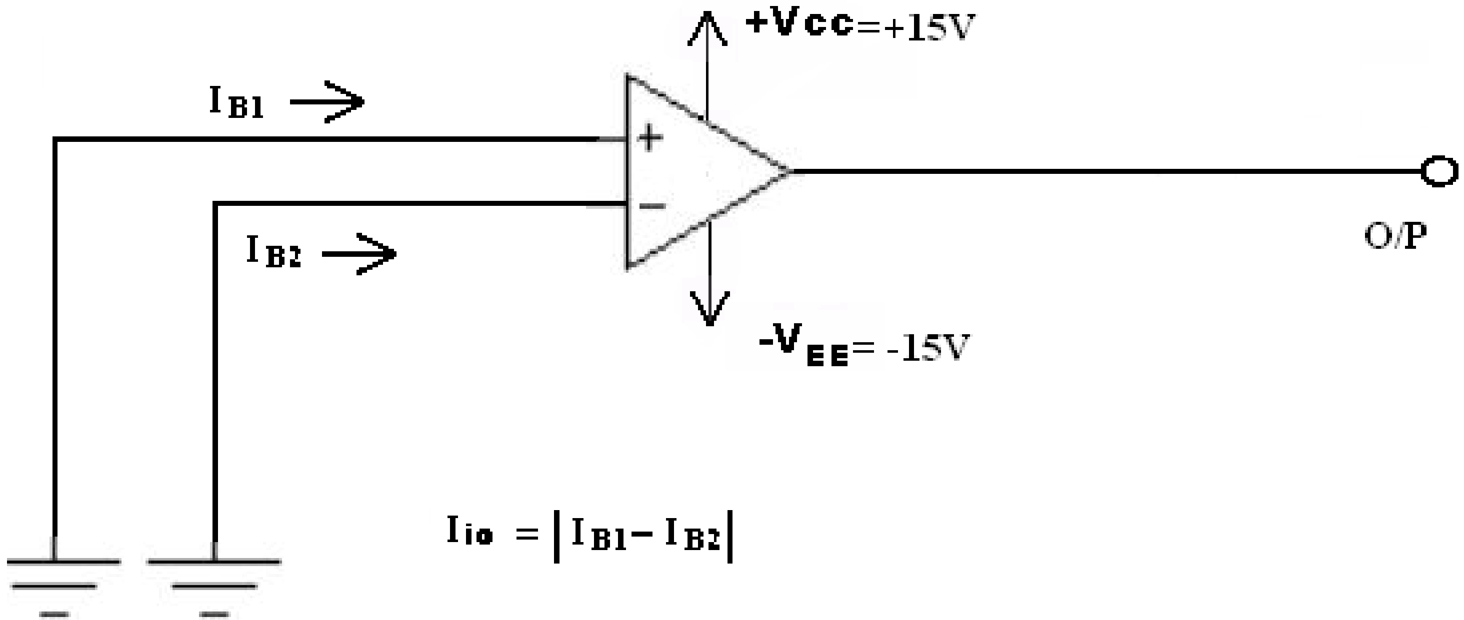
Input offset voltage



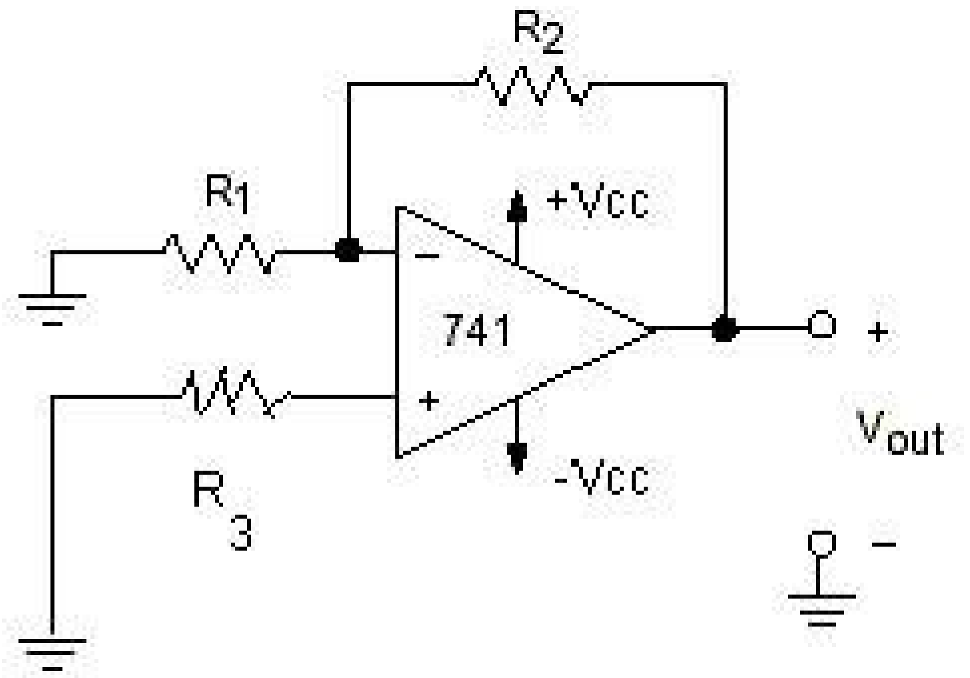
Input offset current

- The algebraic difference between **the current in the inverting** and **non inverting terminal** is known as the **input offset current Iio.**
- As the matching between two terminals increases,the difference between IB1 and IB2 become smaller.
- Typical value for **741 IC is 200mA(max).**

Input offset current



Input BIAS current

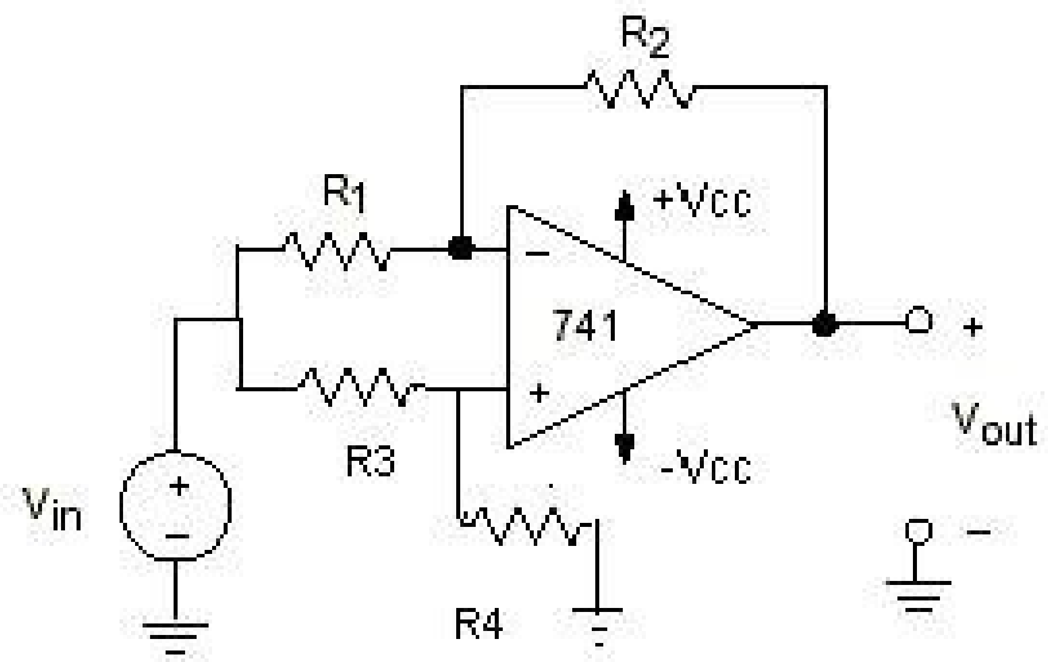


Common Mode Rejection Ratio

- When the same voltage is applied to **both the input terminals** the voltage is called a **common mode voltage** Vcm and the op-amp is said to be operating in the common mode configuration
- CMRR is defined as the **ratio of the differential voltage** gain to **common mode gain.**

CMRR = Ad/Acm

Common Mode Rejection Ratio

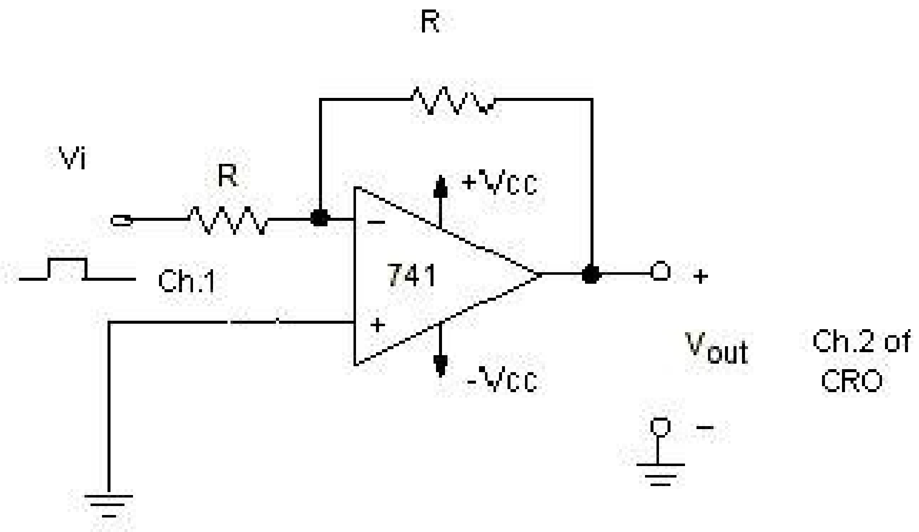


Slew Rate

- Slew rate is defined as the **maximum rate of change of output voltage per unit of time** and is expressed as volt per micro second.

SR=(|dVo|/|ds|)max ie V\µs

Slew Rate



Concept of Virtual Ground

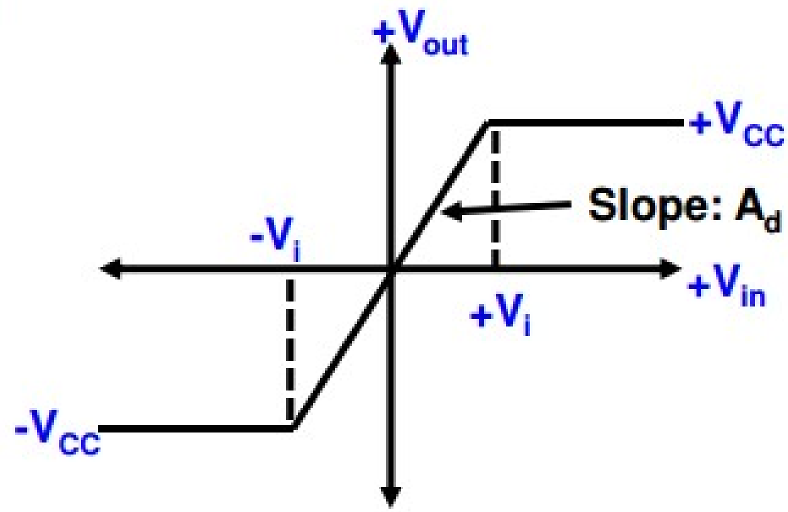
➢ An Op-Amp has a very high gain typically order of 10^5.

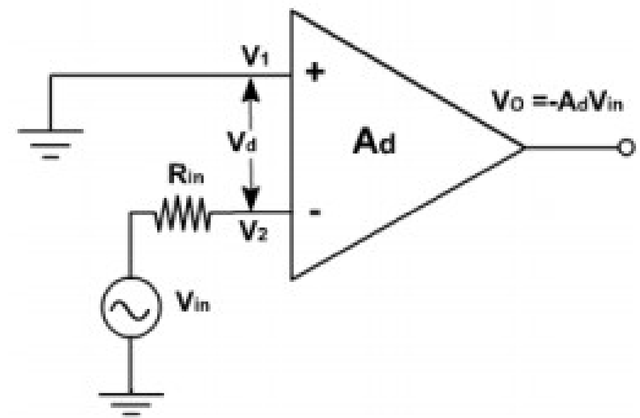
➢ If power supply voltage V_{cc} =15V Then maximum input voltage which can be applied

$$V_d = V_{cc}/A_d = 15/10^5 = 150\mu V$$

i.e. Op-Amp can work as a linear amplifier (from $+V_i$ to $-V_i$) if input voltage is less than 150µV. Above that Op-Amp saturates.

➢ if V_1 is grounded then V_2 can not be more than 150 µV which is very very small and close to ground.



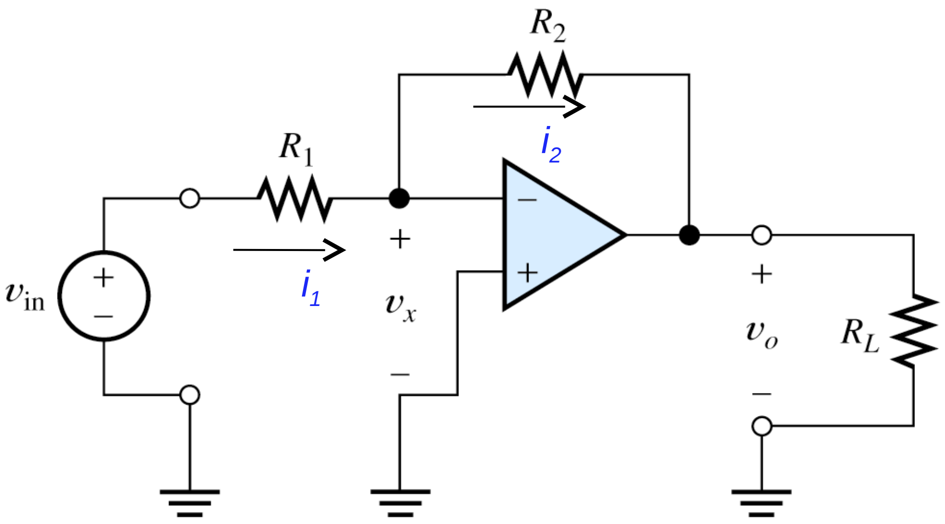


➢ Therefore V_2 can also be considered at ground if V_1 is at ground. Physically V_2 is not connected to the ground yet we considered V_2 at ground that is called virtual ground.

Inverting Amplifier

Op-amp are almost always used with a negative feedback:

- Part of the output signal is returned to the input with negative sign
- Feedback reduces the gain of op-amp
- Since op-amp has large gain even small input produces large output, thus for the limited output voltage (lest than V_{CC}) the input voltage v_x must be very small.
- Practically we set v_x to zero when analyzing the op-amp circuits.



The inverting amplifier.

with $v_x = 0$ $\quad i_1 = v_{in} / R_1$

$i_2 = i_1$ and

$v_o = -i_2 R_2 = -v_{in} R_2 / R_1$

so

$A_v = v_o / v_{in} = -R_2 / R_1$

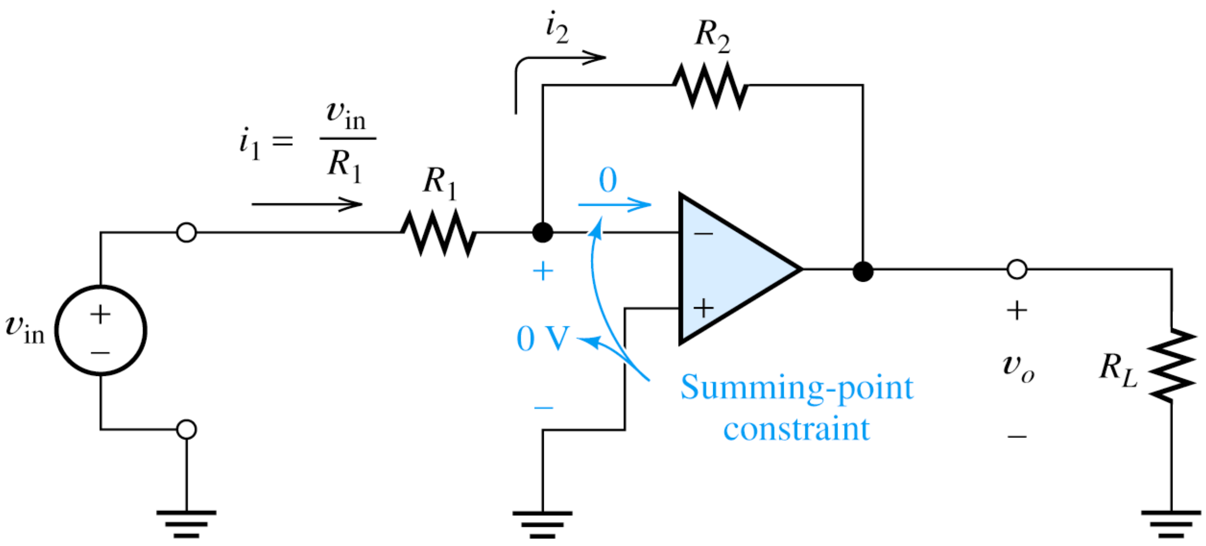
Inverting Amplifier

Since $v_o = -i_2 R_2 = -v_{in} R_2 / R_1$

Then we see that the output voltage does not depend on the load resistance and behaves as voltage source.

Thus the output impedance of the inverting amplifier is zero.

The input impedance is R_1 as $Z_{in}=v_{in}/i_1=R_1$

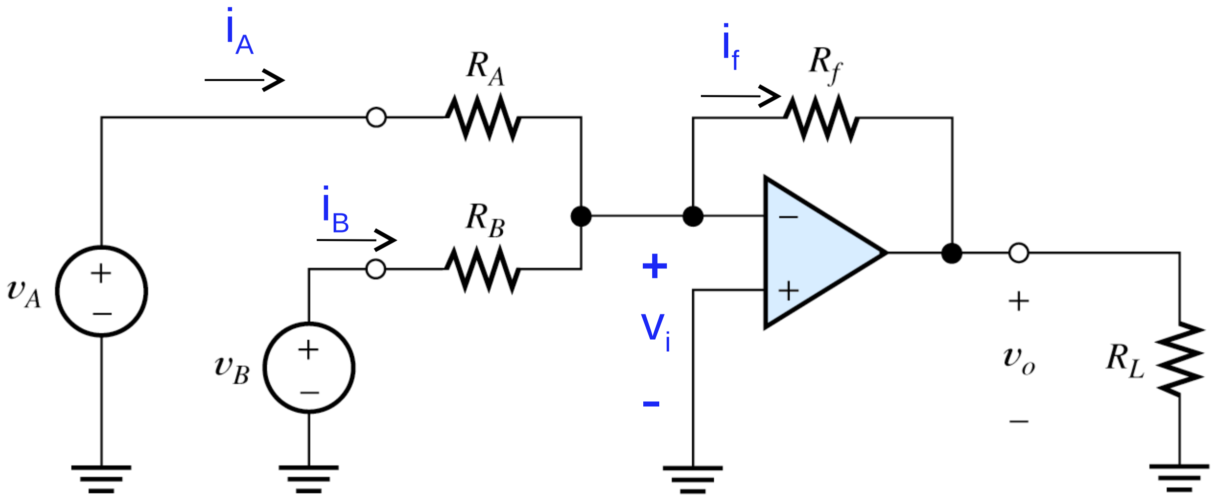


We make use of the summing-point constraint in the analysis of the inverting amplifier.

Summing Amplifier

The output voltage in summing amplifier is

$v_o = -i_f * R_f$ since $v_i = 0$



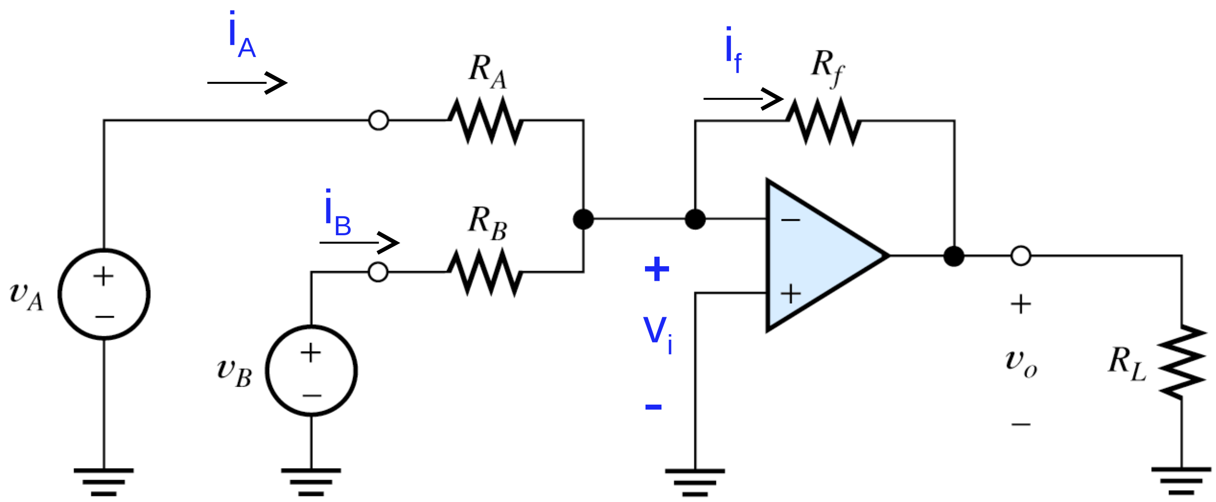
Summing amplifier. See Exercise 14.1.

Summing Amplifier

The output voltage in summing amplifier is

$v_o=-i_f{*}R_f$ since $v_i=0$

$i_f=i_A+i_B=v_A/R_A+v_B/R_B$ => $v_o=-(v_A/R_A+v_B/R_B){*}R_f$



Summing amplifier.

Summing Amplifier

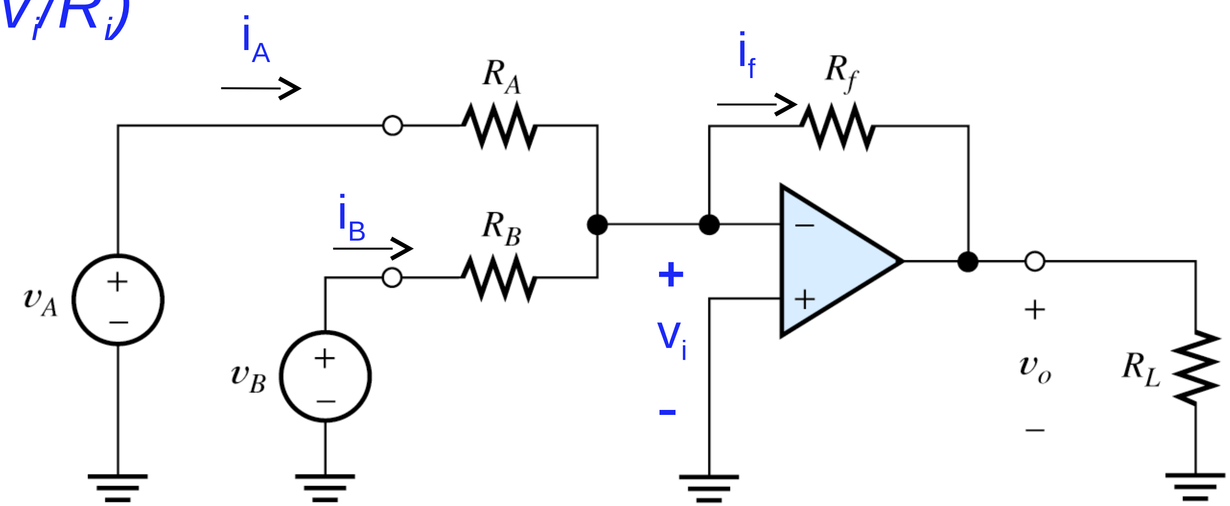
The output voltage in summing amplifier is

$v_o = -i_f * R_f$ since $v_i = 0$

$i_f = i_A + i_B = v_A/R_A + v_B/R_B$ => $v_o = -(v_A/R_A + v_B/R_B) * R_f$

For n inputs we will have

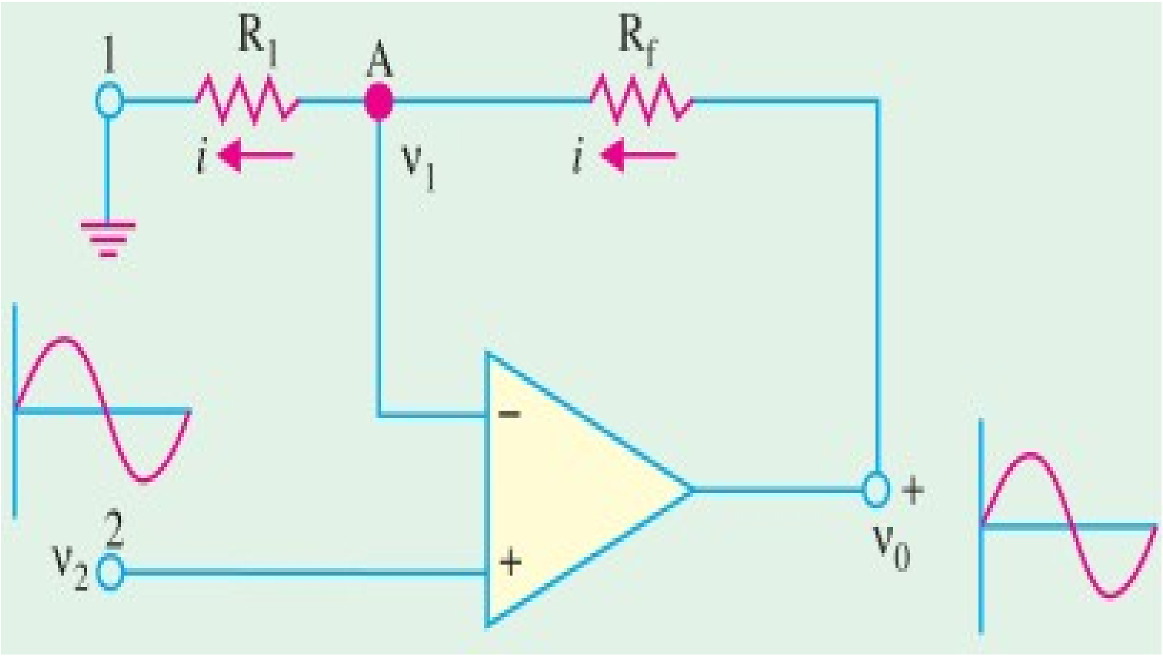
$v_o = -R_f * \Sigma_i (v_i/R_i)$



Summing amplifier.

Noninverting amplifier

This circuit is used when there is need for an output which is equal to the input multiplied by a positive constant. Since input voltage ν_2 is applied to the non-inverting terminal, the circuits is also called non-inverting amplifier.



$$v_{in} = v_2 = iR_1, v_0 = i(R_1 + R_f)$$

$$A_v = \frac{v_0}{v_{in}} = \frac{i(R_1 + R_f)}{iR_1} \quad \text{or} \quad A_v = \frac{R_1 + R_f}{R_1} = \left(1 + \frac{R_f}{R_1}\right)$$

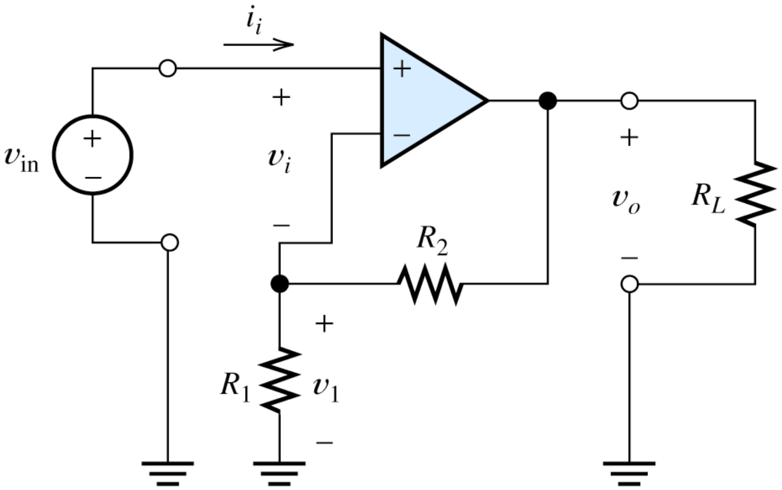
Voltage (Unity) Follower

Special case of noninverting amplifier is a voltage follower

Since in the noninverting amplifier

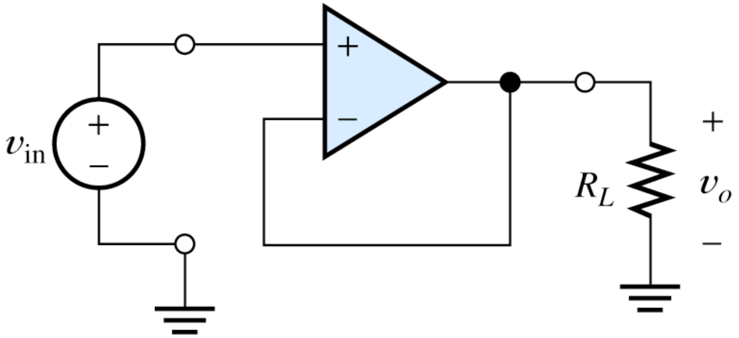
$v_o = v_1(1+ R_2/R_1)$ so when R2=0

$v_o = v_1$



Noninverting amplifier.

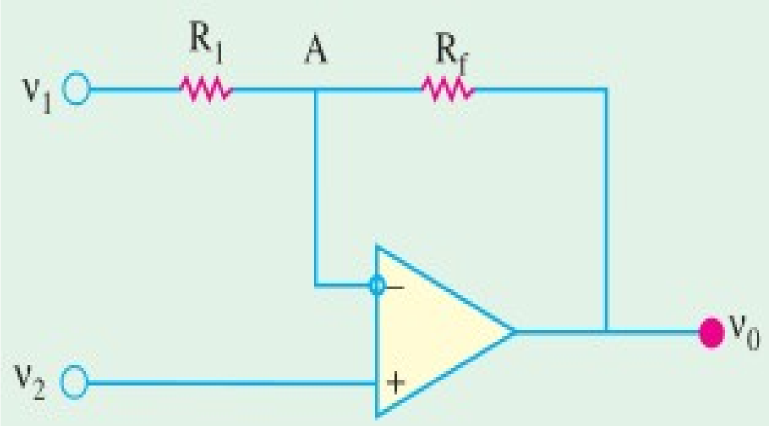
=>



The voltage follower which has $A_v = 1$.

Differencing (Subtract) Amplifier

The function of a subtractor is to provide an output proportional to or equal to the difference of two input signals.



$$v_0 = v_0' + v_0''$$

$$v_0' = -\frac{R_f}{R_1} \cdot v_1$$

$$v_0'' = \left(1 + \frac{R_f}{R_1}\right) v_2$$

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

Since $R_f \gg R_1$ and $R_f/R_1 \gg 1$, hence

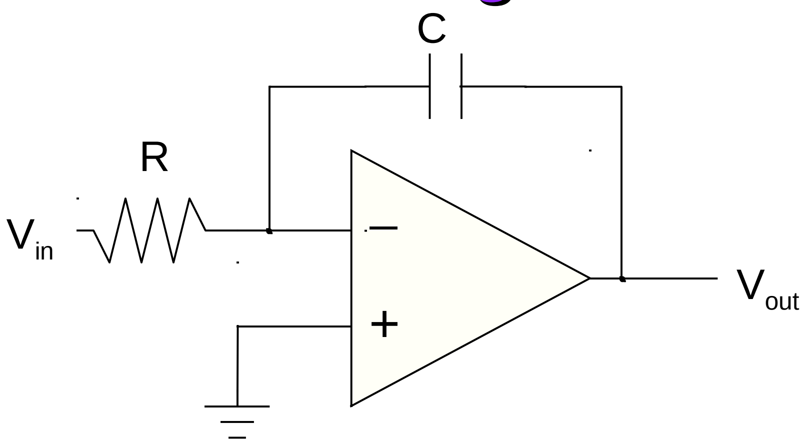
$$v_0 \cong \frac{R_f}{R_1}(v_2 - v_1) = K(v_2 - v_1)$$

Further, If $R_f = R_1$, then

$$v_0 = (v_2 - v_1) = \text{difference of the two input voltages}$$

Obviously, if $R_f \neq R_1$, then a scale factor is introduced.

Integrator



- $I_f = V_{in}/R$, so $C \cdot dV_{cap}/dt = V_{in}/R$
  - and since left side of capacitor is at virtual ground:

    $-dV_{out}/dt = V_{in}/RC$
  - so $$V_{\text{out}} = -\frac{1}{RC}\int V_{in}\,dt$$
  - and therefore we have an integrator (low pass)