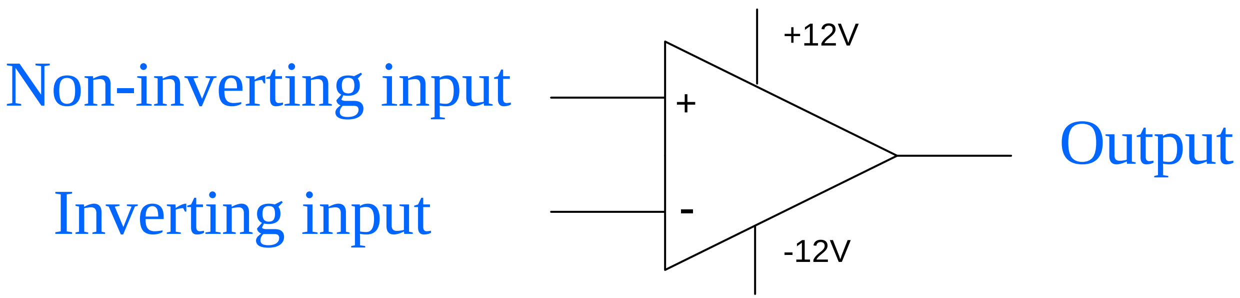
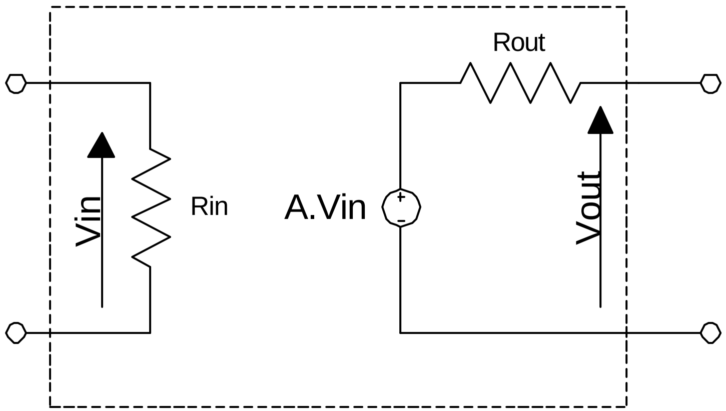
Operational Amplifiers

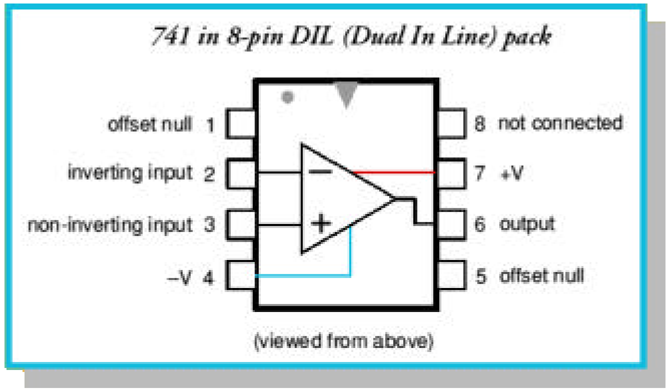
- Before digital computers became so universal, analog computers were popular for solving problems such as differential equations.
- The basic building block of the analog computer is the *operational amplifier*.
- The outstanding characteristic of the op-amp is its high gain — typically 10^5 to 10^6 which is much greater than can be obtained from a single transistor.



Model of Op-Amp

- The operational amplifier is always connected to supply voltages
- Typically split supplies of ±12V or ±15V are used
- By convention, these supply connections are usually omitted from schematic diagrams
- A model of a real op-amp is given below
- Note that Rin is typically very large (say 10MΩ) and Rout is typically small (say 25Ω). The open-loop gain, A, is of the order of 10^6

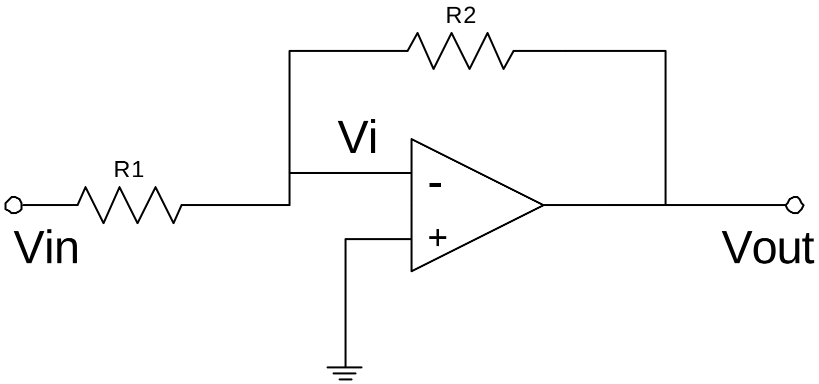




Comments

- An ideal op-amp would have infinite gain, infinite input resistance, and zero output resistance
- We will mainly use the ideal model for simple analysis. The approximation is quite good for real op-amps in many practical cases.
- In particular, we will assume infinite input resistance, and zero output resistance.
- We will assume a large gain A and take the limits of performance as A tends to infinity.

Inverting Amplifier



$$\frac{Vout}{Vin} = -\frac{R2}{R1}$$

Since infinite input resistance, current through R1 must equal current through R2

$$\frac{Vin - Vi}{R1} = \frac{Vi - Vout}{R2}$$

$$Vi - Vout = \frac{R2}{R1}(Vin - Vi)$$

But $Vout = -AVi$, so

$$-\left(\frac{1}{A} + 1\right)Vout = \frac{R2}{R1}(Vin + \frac{Vout}{A})$$

$$-\left(\frac{1}{A} + 1 + \frac{R2}{A.R1}\right)Vout = \frac{R2}{R1}Vin$$

For A tending to infinity, bracketed term approaches 1

$$\frac{Vout}{Vin} = -\frac{R2}{R1}$$

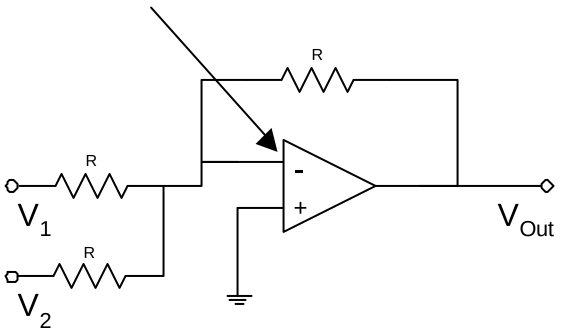
Virtual Earth

- In the example, note that as A tends to infinity, the voltage on the inverting input tends to zero
  - with very high gain (approaching infinity) the voltage at the inverting input must be zero or else the output voltage would also be very large
- Thus in this configuration we say that the inverting input is a *virtual earth* point. That is, its potential is zero but it is not physically connected to earth.
- The virtual earth concept makes analysis quite easy.

Summer

- The following circuit can be used to add/subtract voltages to perform arithmetic

Virtual earth



$$Vout = -(V1 + V2)$$

Sum of currents into virtual earth point must equal zero

$$\frac{V1}{R} + \frac{V2}{R} + \frac{Vout}{R} = 0$$

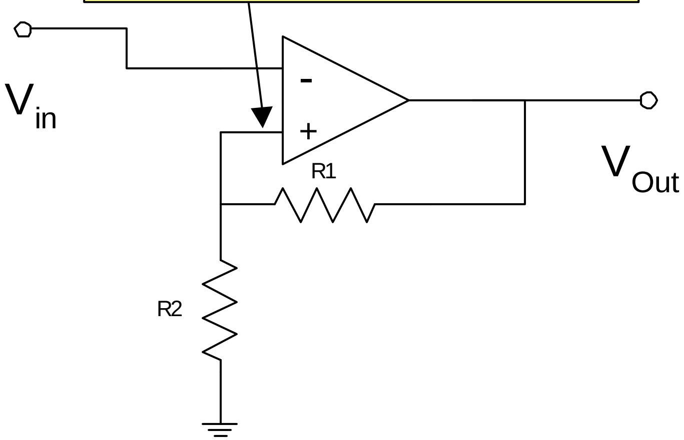
$$Vout = -(V1 + V2)$$

Note the negative sign on the output

Non-Inverting Amplifier

- We can also configure the op-amp as a non-inverting amplifier

Input must follow V_{in} so V_{out} remains reasonable



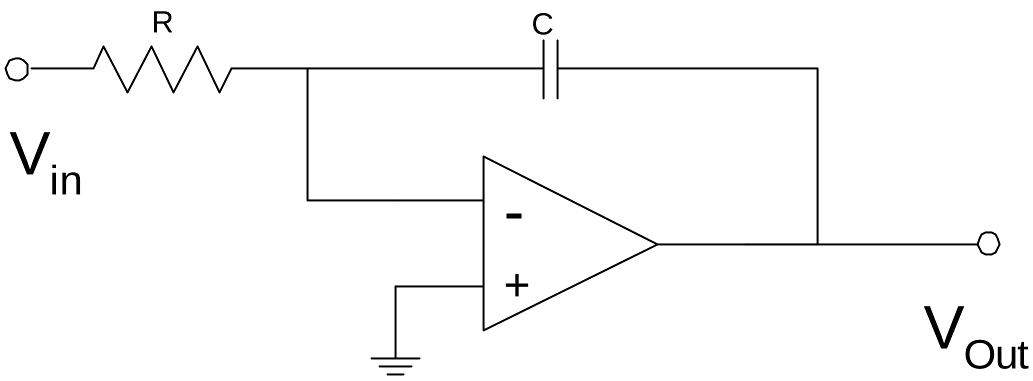
$$\frac{R2}{R1+R2}Vout = Vin$$

$$\frac{Vout}{Vin} = \frac{R1+R2}{R2}$$

$$\boxed{\frac{Vout}{Vin} = \frac{R1+R2}{R2}}$$

Integrator

- The following circuit acts as an inverting integrator



$$\frac{Vin}{R} + C\frac{dVout}{dt} = 0$$

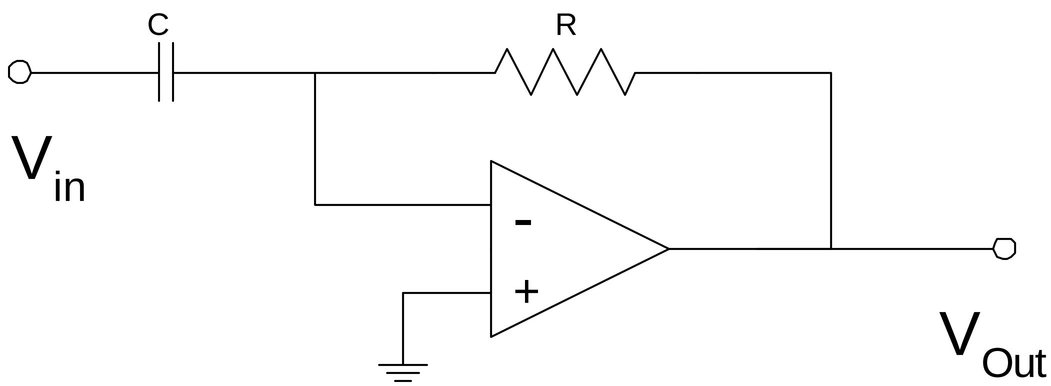
$$\frac{dVout}{dt} = -Vin\frac{1}{RC}$$

$$Vout = -\frac{1}{RC}\int Vin\,dt$$

$$Vout = -\frac{1}{RC}\int Vin\,dt$$

Differentiator

- The following circuit acts as an inverting differentiator



$$\frac{Vout}{R} + C\frac{dVin}{dt} = 0$$

$$Vout = -RC\frac{dVin}{dt}$$

$$Vout = -RC\frac{dVin}{dt}$$