COE/EE152: Basic Electronics

Lecture 7
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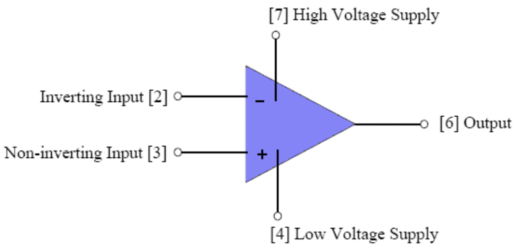
Outline

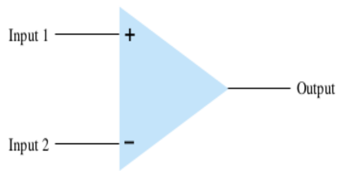
- Introduction to operational Amplifiers
- Operational Amplifiers

Operational Amplifiers

- Low cost integrated circuit which is able to amplify signals due to an external DC power supply
- The op-amp is a very high gain amplifier



a



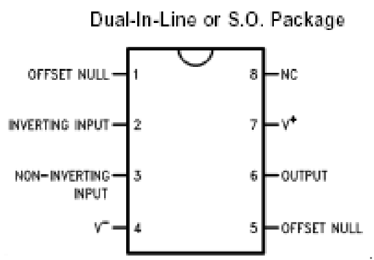
b

c

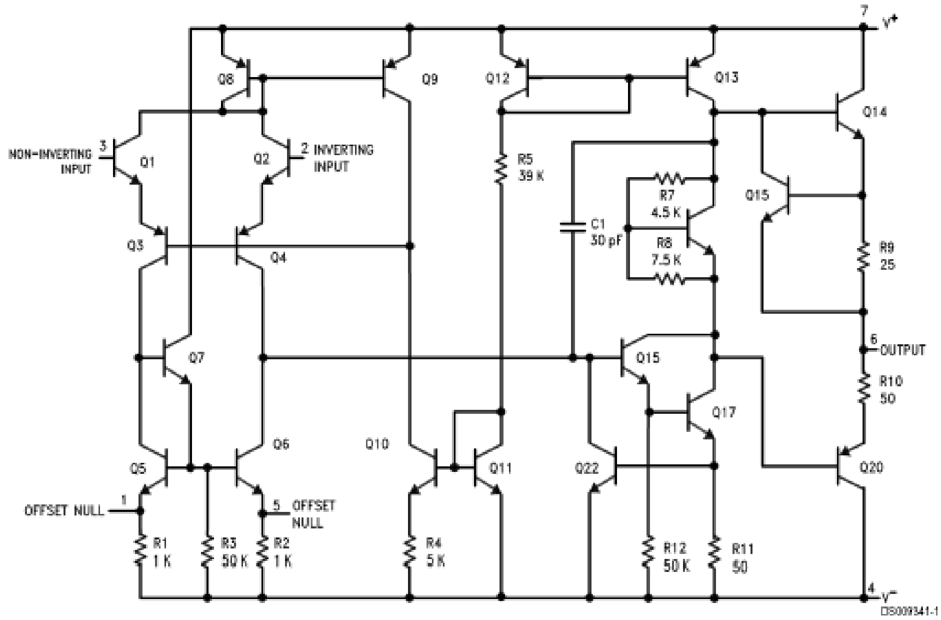
Operational amplifier circuit symbol ((a) 5 pin and (b) 3 pin) and IC (c)

LM741

- The most popular operational amplifier IC is LM741 by National semiconductor
- The internal circuitry is shown I the next slide but beyond the scope of this course



Internal Circuitry of LM741



Properties of Op-amps

- Ideal op-amp
  - Infinite input impedance
    - Will not load any source
  - Zero output impedance
    - Will drive any load
- Real Op-amps
  - Gain ~ 10^6
  - Input Impedance ~ 100 MΩ
  - Output Impedance ~ 100 Ω

Ideal Op-amp

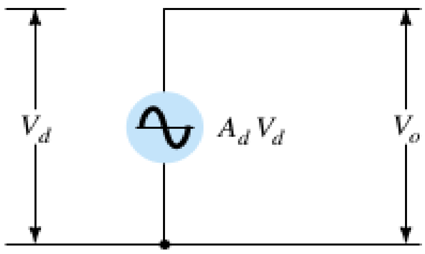
Characteristics of an ideal op-amp

- R_{in} = infinity
- R_{out} = 0
- A_{vo} = infinity (A_{vo} is the open-loop gain, sometimes A or A_v of the op-amp)
- Bandwidth = infinity (amplifies all frequencies equally)

Summary of Characteristics

Parameter	Ideal Op-Amp	Typical Op-Amp
G_{OL}	∞	10^5 - 10^9
Common Mode Gain	0	10^{-5}
Bandwidth	∞	1-20 MHz
Input Impedance	∞	10^6 Ω (bipolar) 10^9-10^{12} Ω (FET)
Output Impedance	0	100-1000 Ω

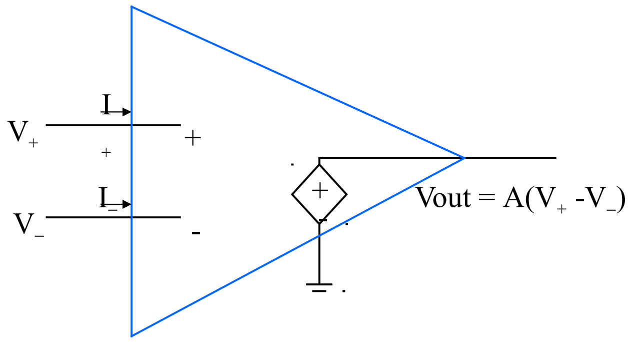
Ideal Op-amp Model



$$V_d = V_+ - V_- \quad (\textit{Differential Voltage})$$
$$A_d = \textit{open-loop differential mode gain}\,(A_v)$$
$$A_d = A = A_v = \frac{V_0}{V_d}$$

Important op-amp behaviour

$$V_+ = V_-$$
$$I_+ = I_- = 0$$



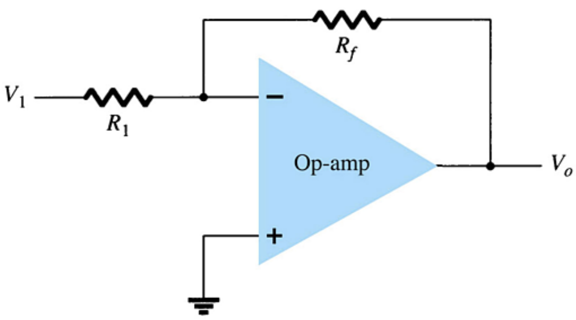
Op-amp Gain

- Op-amps have very high gain. They can be connected in ***open-loop*** or ***closed-loop***
  - **Open-loop** refers to a configuration where there is no feedback from output to the input. The gain is usually in excess of 10,000. In this mode the slightest noise is greatly amplified
  - **Closed-loop** configuration reduces gain. The gain is controlled by *negative feedback* which improves the characteristics of the op-amp

Op-Amp Applications

- Amplifier
  - Inverting Amplifier
    - The output signal in an amplified inversion of the input signal
  - Non-inverting Amplifier
    - The input signal is not inverted at the output but only amplified
  - Unity Follower (Buffer)
- Operations (Mathematical)
  - Summation
  - Difference
  - Integration
  - Differentiation
- Op-amps are also used for:
  - Filers (High, Low and Band Pass)
  - Comparator
  - A/D converters

Inverting Amplifier



$$R_1\,current = R_f\,current$$

$$\frac{V_1 - V_-}{R_1} = \frac{V_- - V_0}{R_f}$$

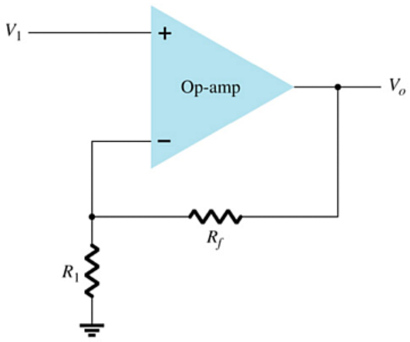
$$V_- = V_+ = 0$$

$$\frac{V_1}{R_1} = \frac{V_0}{R_f}$$

$$A_V = \frac{V_o}{V_1} = -\frac{R_f}{R_1}$$

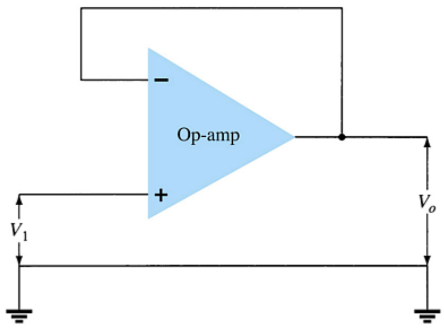
Negative sign shows 180° phase shift of input

Non-inverting Amplifier



$$
\begin{aligned}
R_1\,current &= R_f\,current \\
\frac{0-V_-}{R_1} &= \frac{V_- - V_0}{R_f} \\
V_- &= V_+ = V_1 \\
\frac{V_1}{R_1} &= \frac{V_1 - V_0}{R_f} \\
A_V &= \frac{V_o}{V_1} = 1+\frac{R_f}{R_1}
\end{aligned}
$$

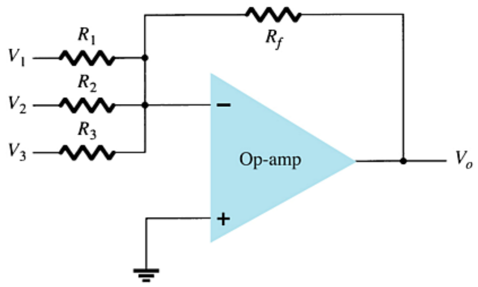
Unity Follower



$$
\begin{aligned}
V_0 &= V_- \\
V_- &= V_+ = V_1 \\
&\Rightarrow V_0 = V_1
\end{aligned}
$$

Input voltage is regenerated at the output
The gain here is unity

Summation

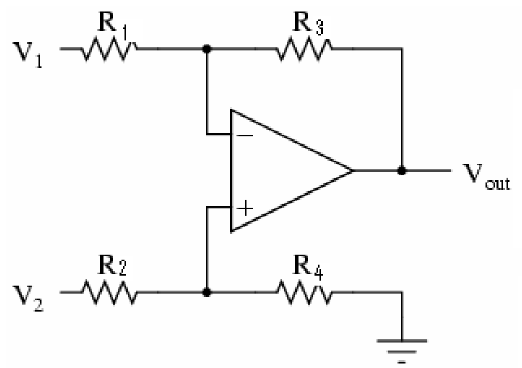


Because the op-amp has a high input impedance, the multiple inputs are treated as separate inputs.

$$\frac{V_1}{R_1}+\frac{V_2}{R_2}+\frac{V_3}{R_3} = -\frac{V_0}{R_f}$$

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

Difference



$$\frac{V_1-V_-}{R_1} = \frac{V_- - V_{out}}{R_3}$$

$$\frac{V_2-V_+}{R_2} = \frac{V_+}{R_4}$$

$$V_- = V_+$$

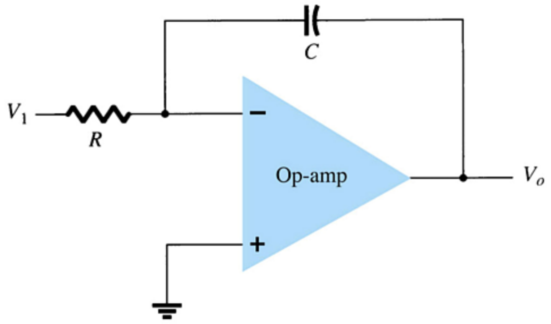
Solving:

$$V_{out} = \frac{V_2(R_3+R_1)R_4}{(R_4+R_2)R_1} - \frac{V_1R_3}{R_1}$$

if all resistors are equal:

$$V_{out} = V_2 - V_1$$

Integration: Integrator



$$\frac{v_1}{R} = -\frac{dv_0}{dt}C$$

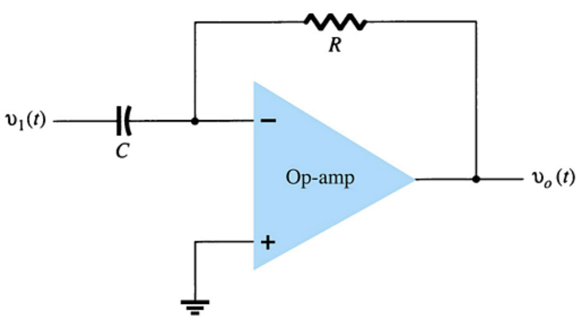
$$dv_0 = -\frac{1}{RC}v_1 . dt$$

$$v_0 = -\frac{1}{RC}\int v_1 . dt$$

The output is the integral of the input. Integration is the operation of summing the area under a waveform or curve over a period of time. This circuit is useful in low-pass filter circuits and sensor conditioning circuits.

v_0 and v_1 are functions of time

Differentiation: Differentiator



$$C\frac{dv_1}{dt} = -\frac{v_0}{R}$$

$$v_0 = -RC\frac{dv_1}{dt}$$

The differentiator takes the derivative of the input. This circuit is useful in high-pass filter circuits.

v_0 and v_1 are functions of time