Week No - 6

Description of Operational Amplifier:

- **The types of Operational Amplifier.**
- **Comparator**
- **Zero detector**

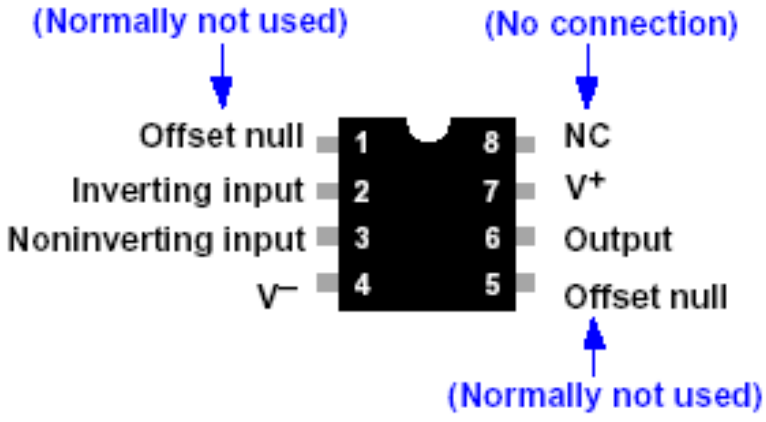
Operational Amplifier (Op-Amp)

- A combination of transistors, resistors, capacitors that
  - Amplifies the difference between two input voltages and
  - Produces a single output

Operational Amplifier Packaging

- Most operational amplifies now available as "dual-inline packages"
  - 14-lead dip package
  - 8-lead minidip package
  - Can contain more than one op-amp

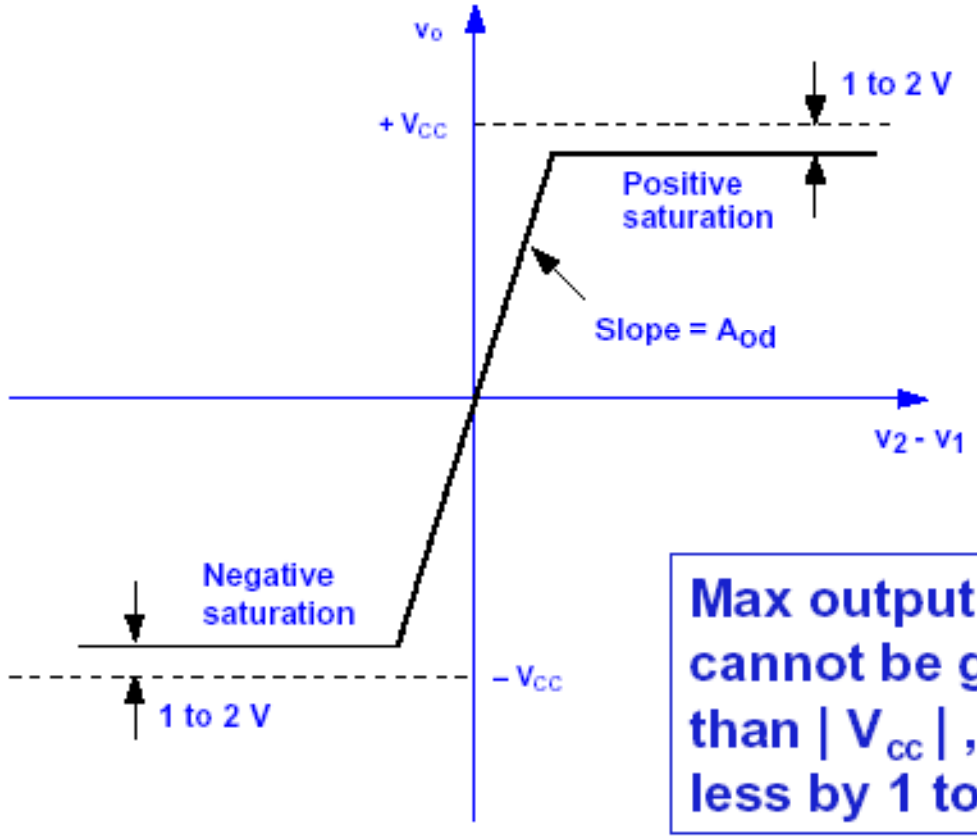
Minidip with one op-amp



Op-Amp Parameters

- A_{od} = differential or open-loop gain
- Output:
  - 180° out of phase with v_1 (inverting)
  - In phase with v_2 (non-inverting)
- Op-amp responds only to differences between v_2 and v_1
  - Common-mode signal when $v_2 = v_1 \neq 0$
  - Characteristic called "common-mode rejection"

Op-Amp Transfer Characteristics



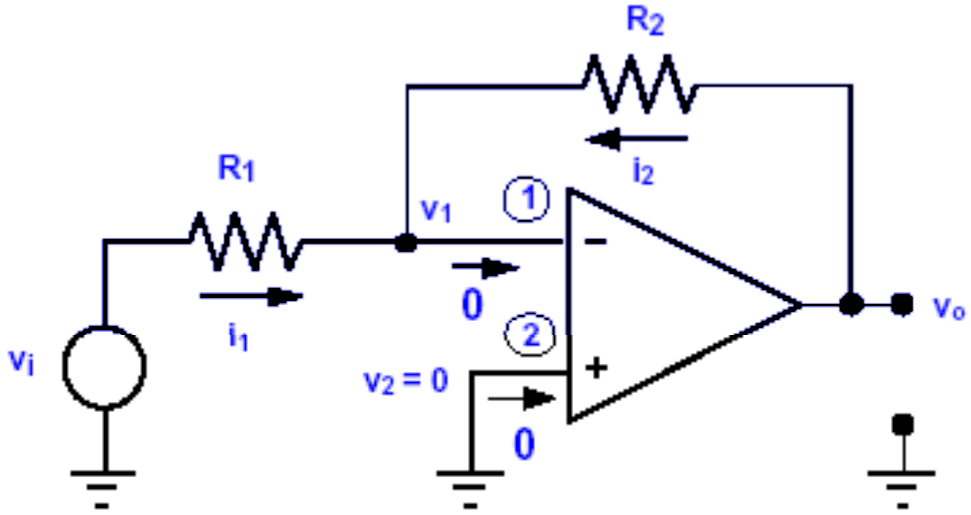
Max output voltage cannot be greater than $|V_{cc}|$, usually less by 1 to 2 V

Ideal Op-Amp Characteristics

- Effective input resistance = infinity
- Effective output resistance = zero
- Internal differential gain, A_{od} = infinity
- Differential input voltage (v_2-v_1) = zero

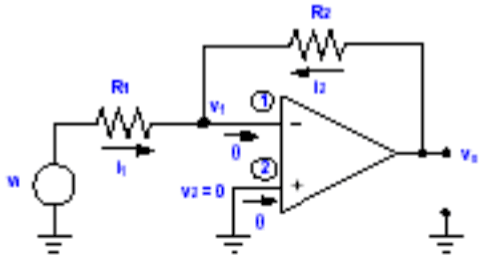
- Operation of op-amp without external control is impractical

Inverting Op-Amp Amplifier



- R_2 feedback resistor — connects output back to input
- Negative feedback because v_o is 180° out-of-phase with v_1 — therefore subtracts from input — decreases available gain.

Ideal Op-Amp Inverting Amplifier



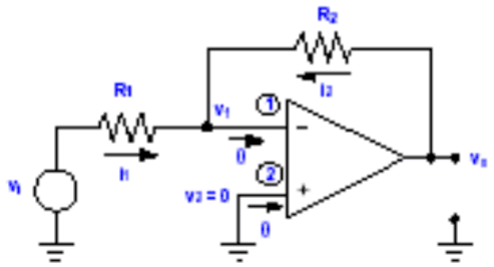
- Transfer function or voltage gain

$$v_o = -\frac{R_2}{R_1} v_i \qquad A_V = \frac{v_o}{v_i} = -\frac{R_2}{R_1}$$

- Input resistance.

$$R_i = \frac{v_i}{i_i} = \frac{v_i}{v_i/R_1} = R_1$$

Virtual Ground

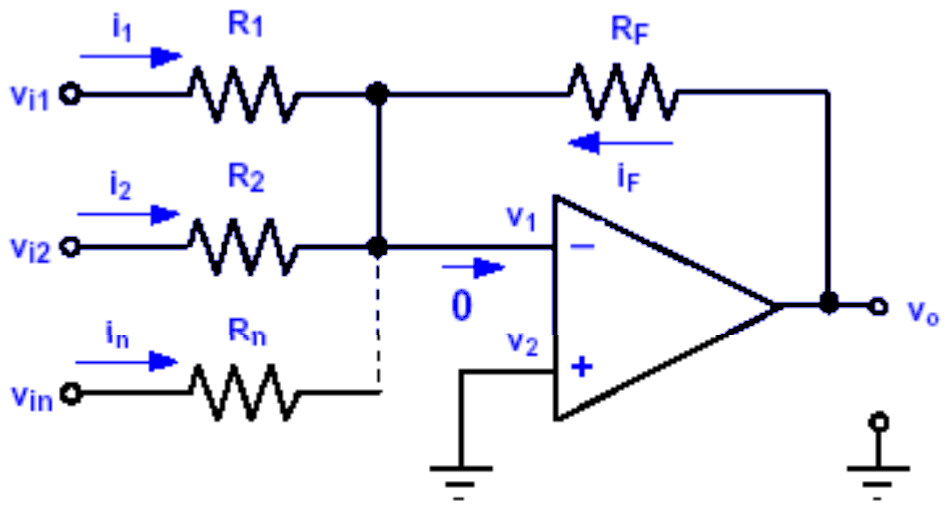


- A_{od} = infinity
- $v_2 - v_1 = 0$
- Node 2 is grounded
- Therefore, $v_2 = 0$

- $v_1 = -v_2$; therefore, $v_1 = 0$
- Since $v_1 = 0$, node 1 is considered to be at "virtual ground"
- Then, $i_1 = -i_2$ and $v_i / R_1 = -v_o / R_2$

$$v_o = -\frac{R_2}{R_1} v_i \qquad A_V = \frac{v_o}{v_i} = -\frac{R_2}{R_1}$$

Weighted Summing Amplifier

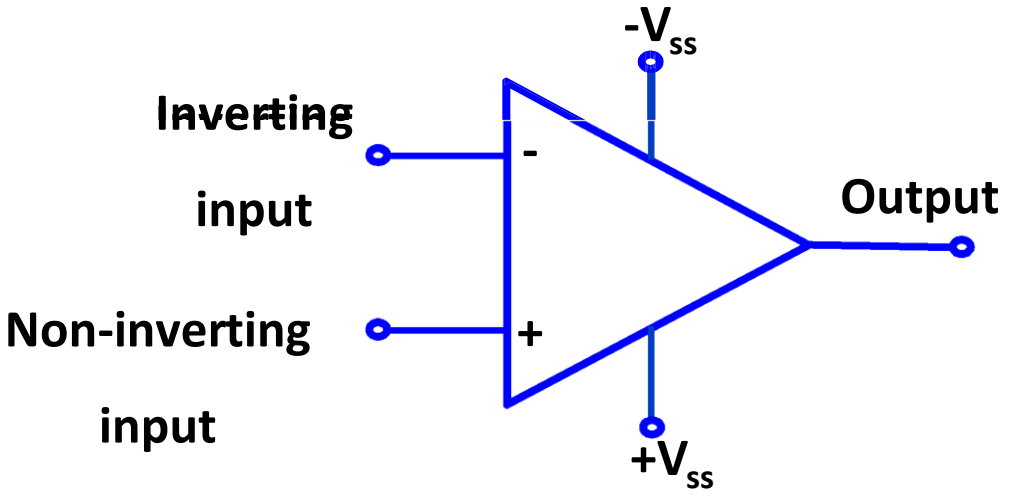


$$i_1 + i_2 + \cdots i_n = -i_F$$

$$v_o = \sum_{i=1}^{n} -\frac{R_F}{R_i} v_{i\,i}$$

Op-amp

- It has two inputs: the inverting input (-) and the non-inverting input (+), and one output.
- It has usually two supplies ($\pm V_{ss}$) but it can work with one.

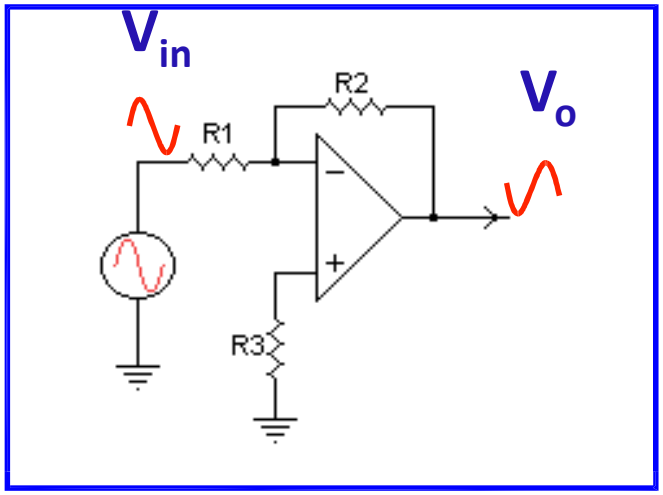


Symbol of op-amplifier

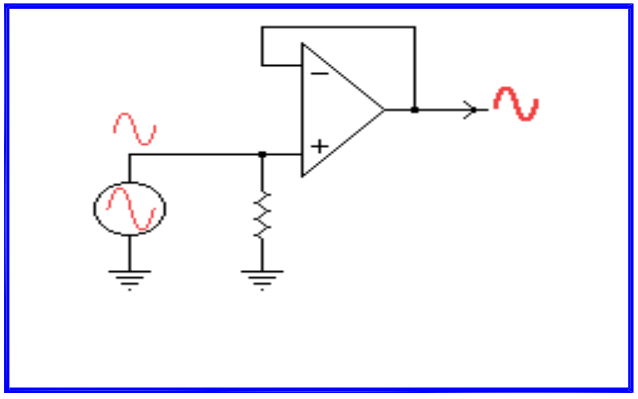
	Ideal Op Amp	Typical Op Amp
Open-loop voltage gain A	∞	$10^5 – 10^9$
Common mode voltage gain	0	10^{-5}
Frequency response f	∞	1- 20 MHz
Input impedance Z_{in}	∞	10^6 Ω (bipolar) 10^9–10^{12} Ω (FET)
Output impedance Z_{out}	0	50 – 1000 Ω

Output signal shape of Op-amp

- Inverting mode:
  - Invert the input signal.
  - $V_o = -AV_{in}$.



- Non-inverting mode (follower):
  - Input signal dose not change.
  - $V_o = +1V_{in}$

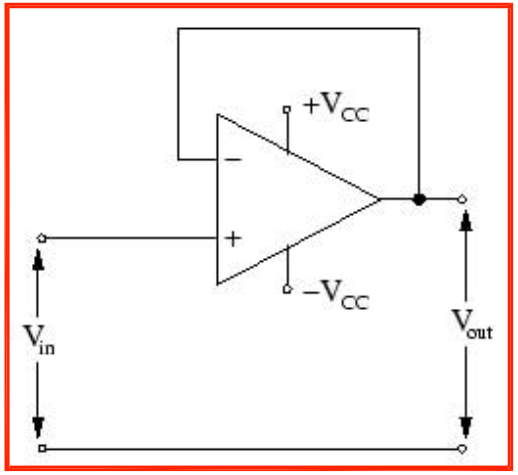


Unity gain non-inverting amplifier (follower)

- A special case of the non-inverting amplifier
- The resistor network is not used in this circuit
- The output is connected directly to the inverting input
- Used in output buffering and impedance matching bw. a high source impedance and low-impedance input circuit

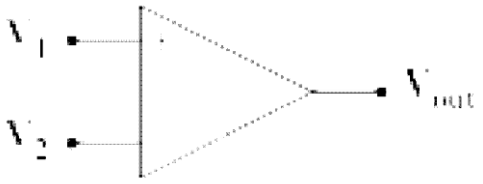
$$A = \frac{V_{out}}{V_{in}} = +1$$

$V_{out}=V_{in}$



Comparator

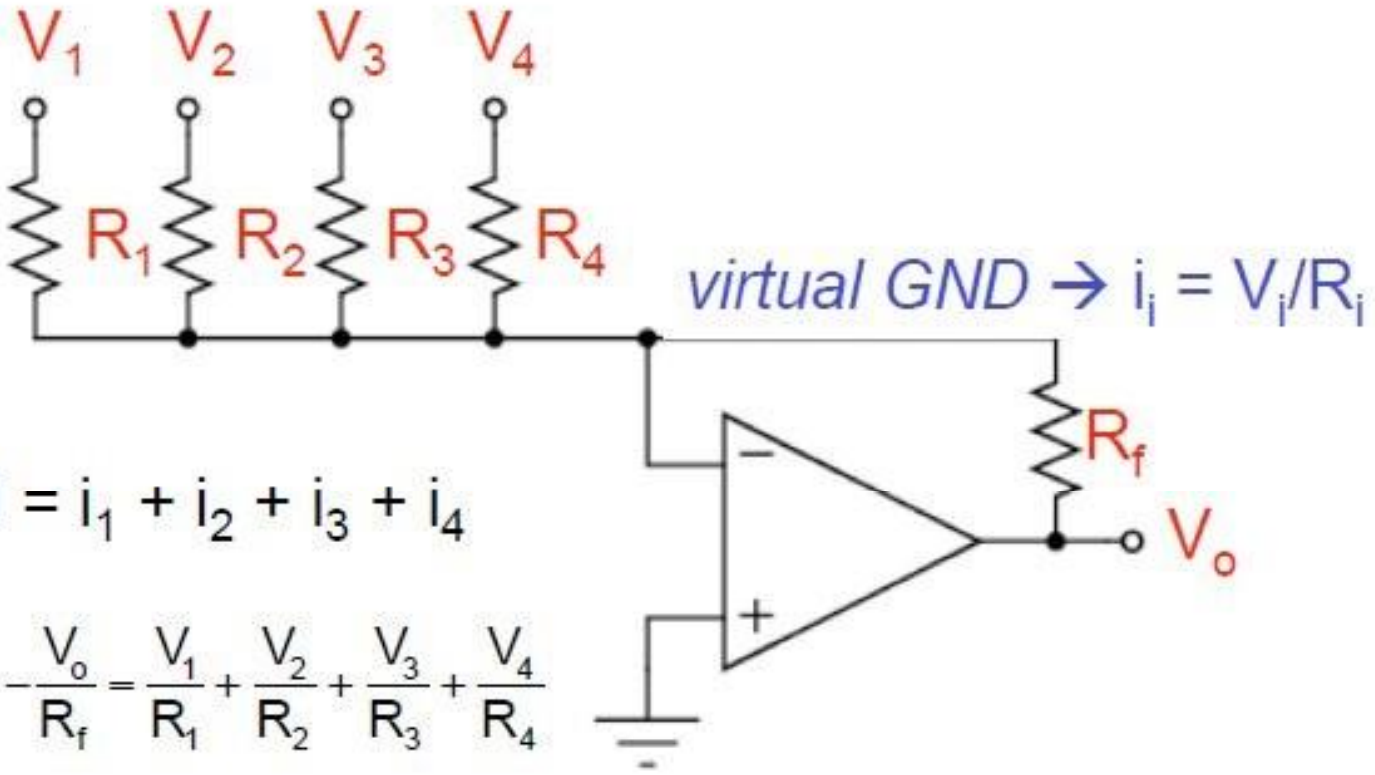
- a comparator is a device which compares two voltages or currents and switches its output to indicate which is larger (one is reference)
- Very useful for comparing signals and working with sensors
- Comparator circuits can be built with op-amps, but there are also comparator ICs with large slew rates and short propagation delays - good for high speed switching



$$V_{\text{out}} = \begin{cases} V_{S+} & V_1 > V_2 \\ V_{S-} & V_1 < V_2 \end{cases}$$

Where V_s is the supply voltage

Inverting Adder:



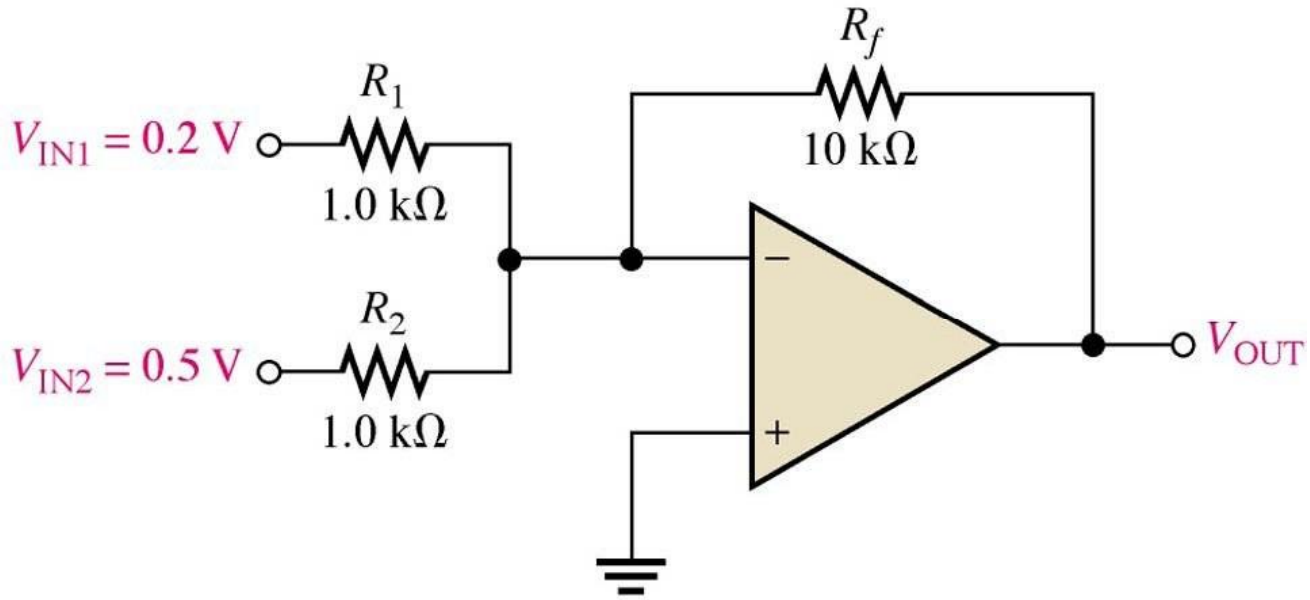
$$I = i_1 + i_2 + i_3 + i_4$$

$$-\frac{V_o}{R_f} = \frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3} + \frac{V_4}{R_4}$$

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

Example

Determine the output of the following summing amplifier



Solution

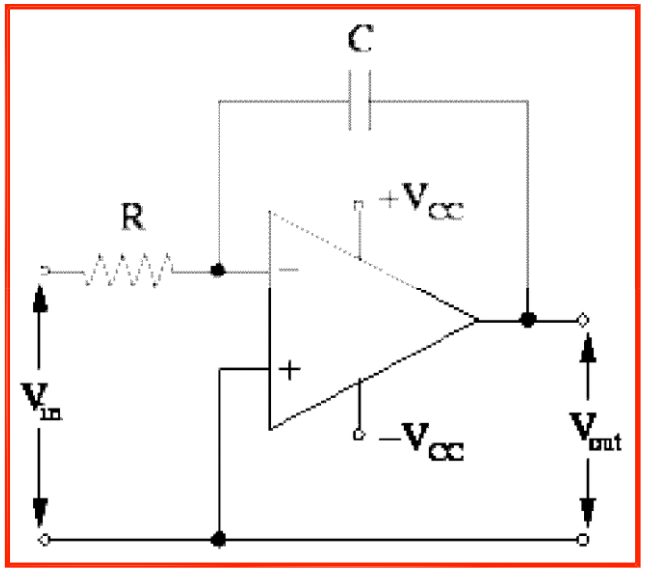
Rf = 10 kΩ and R = R1 = R2 = 1.0 kΩ. Thus,

VOUT = -Rf/R(VIN1 + VIN2) = -10 kΩ/1 kΩ (0.2 + 0.5) = **-7V**

integrator

- The integrator is a circuit that produce a voltage output proportional to the area under a curve defined by a time depended function (time average of the input signal)
- The output is: $V_{out} = -\frac{1}{RC}\int V_{in}\,dt$

  where:
  - V_{out} output potential in [V]
  - V_{in} input signal potential in [V]
  - Rinput resistance in [W]
  - Cfeedback capacitance in [F]
  - t the time in [sec]



- The integrator functions as low- pass filter

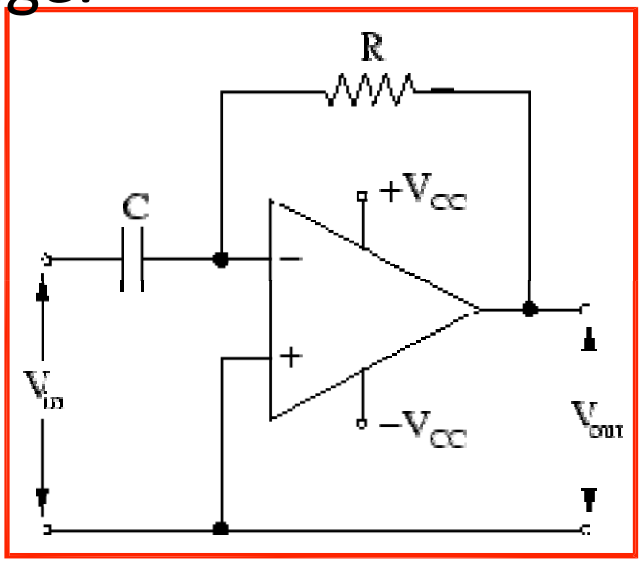
Differentiator

- The differentiator circuit produce a voltage output proportional to the time rate change of the input signal voltage.
- The output is:

$$V_{out} = -RC\frac{dv}{dt}$$

where:

- V_{out} output potential in [V]
- V_{in} input signal potential in [V]
- R feedback resistance in [W]
- C input capacitance in [F]
- t the time in [sec]



- *RC* is time constant and must be *very short* compared to time constant or period of the input signal
- The differentiator functions as a *high-pass filter*