EE 254

Electronic Instrumentation

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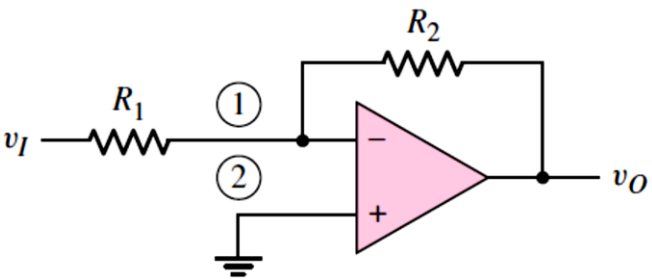
Lecture Note #05

Content (Brief)

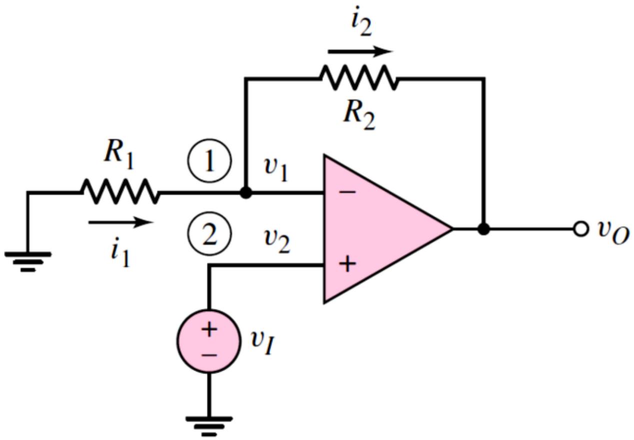
2. Op-Amp Applications

- Linear Applications
  - Inverting amplifiers
  - Noninverting amplifiers
  - Differential amplifiers
  - Summing amplifiers
  - Integrators
  - Differentiators
  - Low/ High pass filters
  - Instrumentational amplifiers
- Nonlinear Applications
  - Precision rectifiers
  - Peak detectors
  - Schmitt-trigger comparator
  - Logarithmic amplifiers

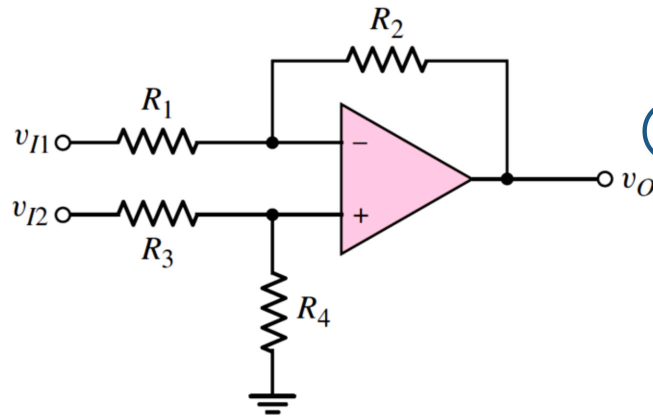
Linear Application (Discussed)



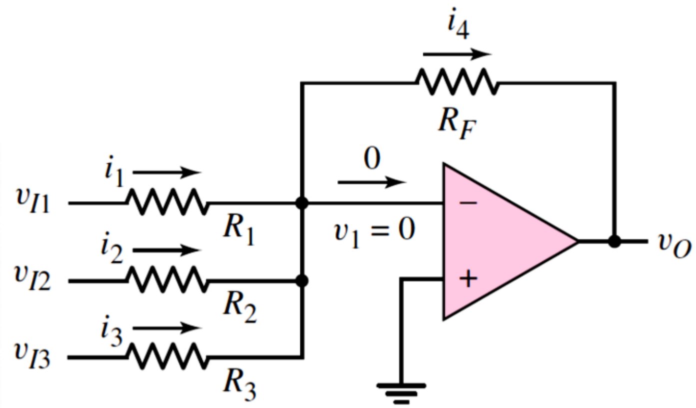
① Inverting Amplifier



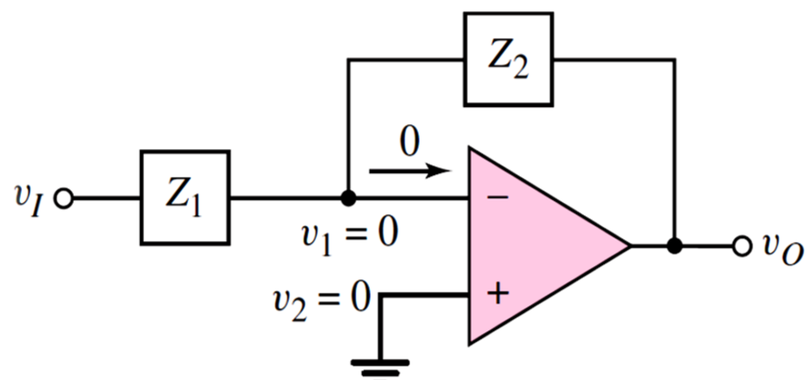
② Non-Inverting Amplifier



③ Differential Amplifier



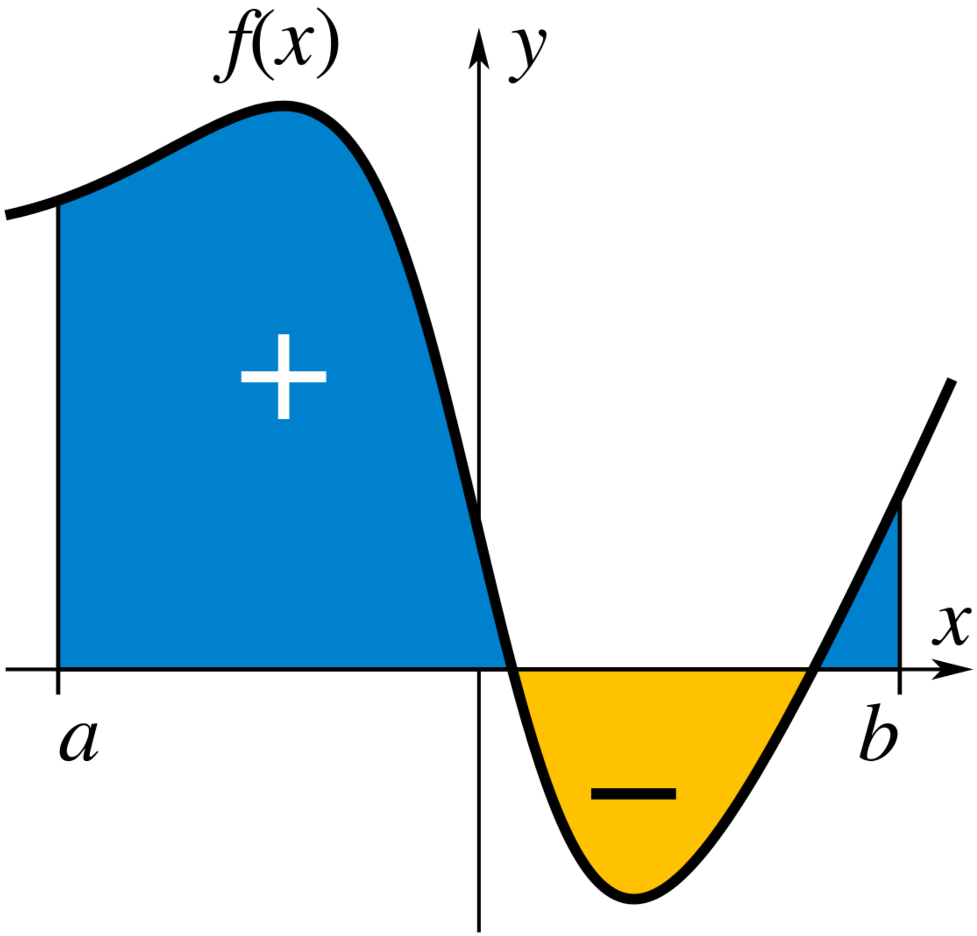
④ Summing Amplifier



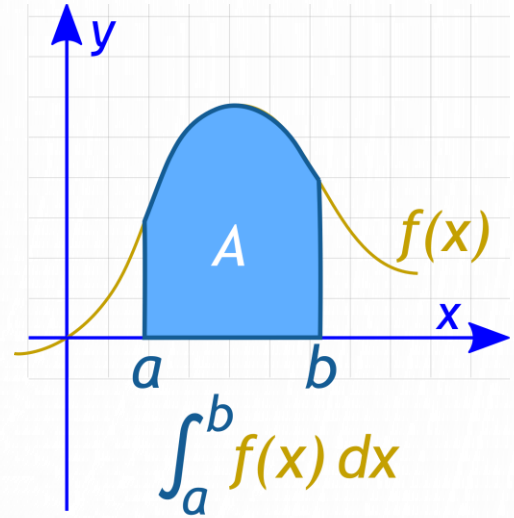
Generalized Inverting Amplifier

Integrators

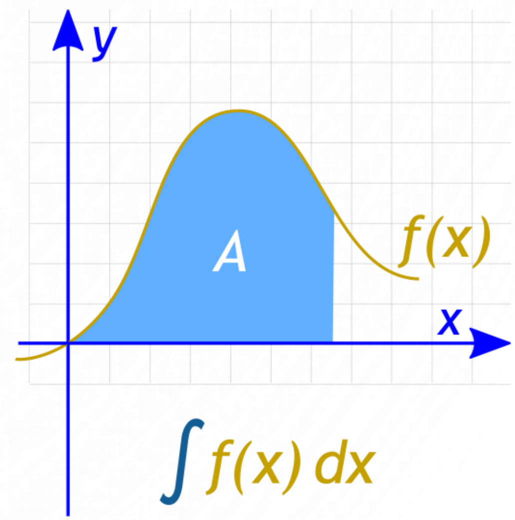
Mathematical Integrator



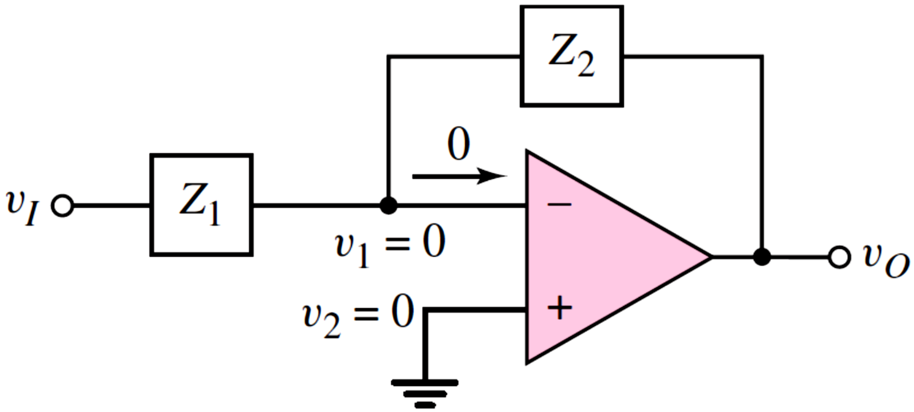
- **Definite** Integral



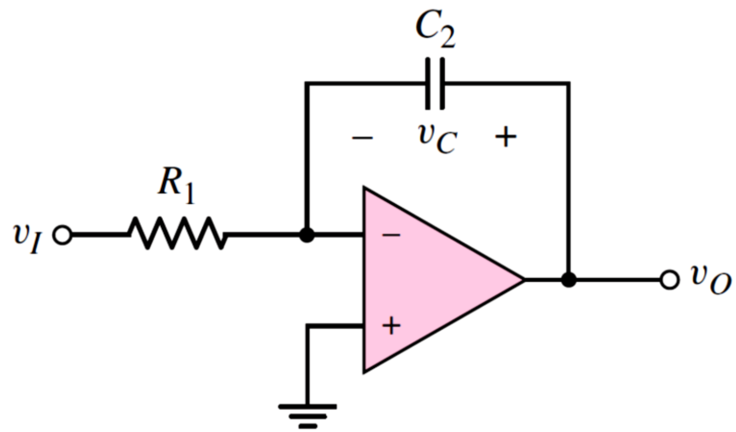
- **Indefinite** Integral



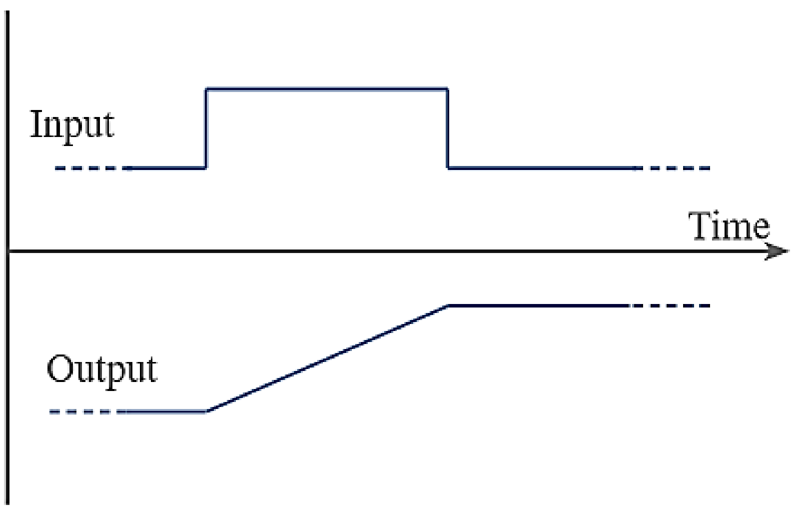
Integrator



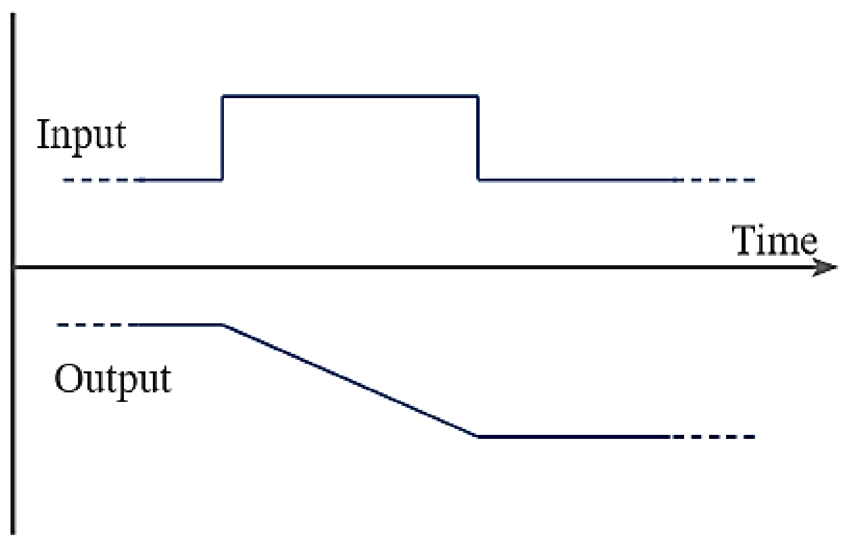
Z_2
0
v_I
Z_1
$v_1 = 0$
$v_2 = 0$
$-$
$+$
v_O



C_2
$-$ v_C $+$
R_1
v_I
$-$
$+$
v_O

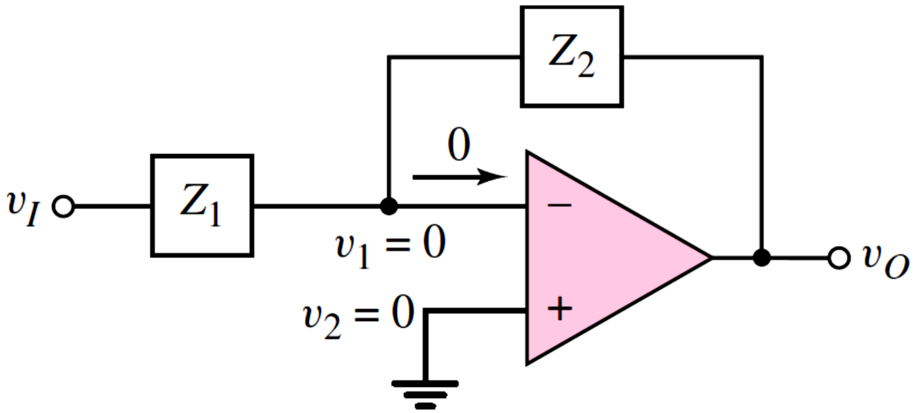


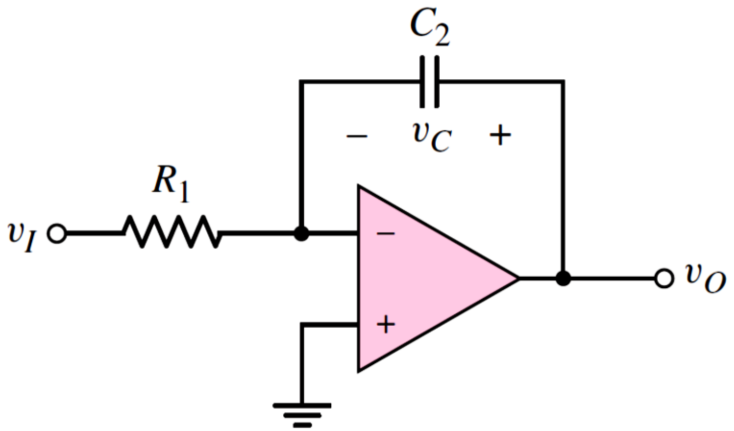
Input
Time
Output



Input
Time
Output

Generalized Inverting Amplifier



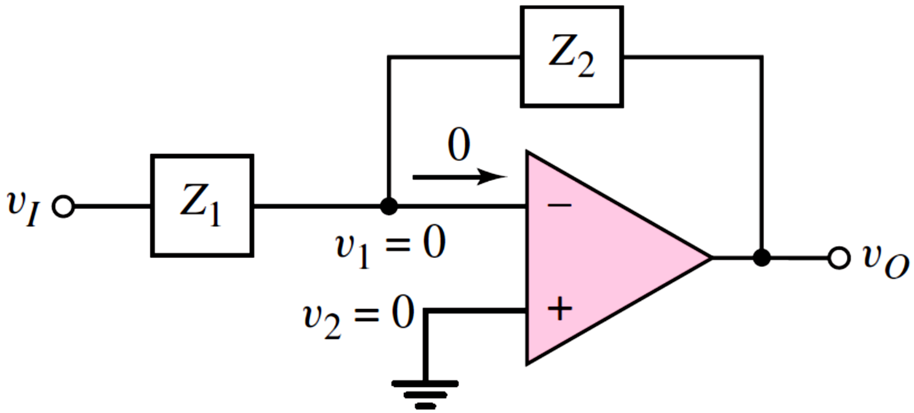


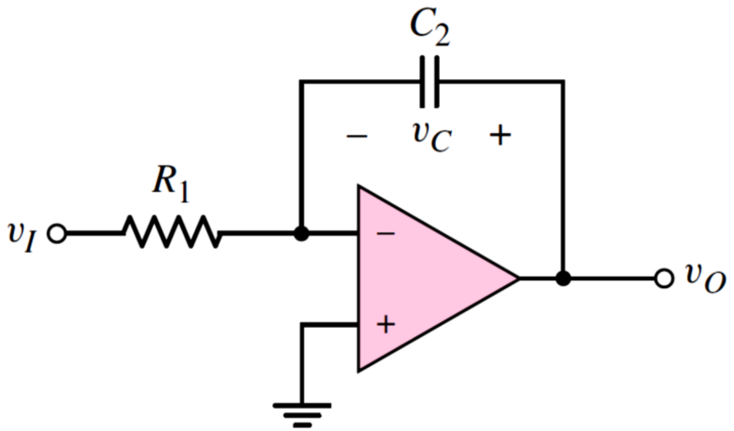
- Let's set Z_1 as a resistor and Z_2 to a capacitor.
- The impedances are then $Z_1 = R_1$ and $Z_2 = 1/sC_2$, where s again is the complex frequency

$$v_O = -\frac{Z_2}{Z_1}v_I = \frac{-1}{sR_1C_2}v_I$$

Integrator

Generalized Inverting Amplifier



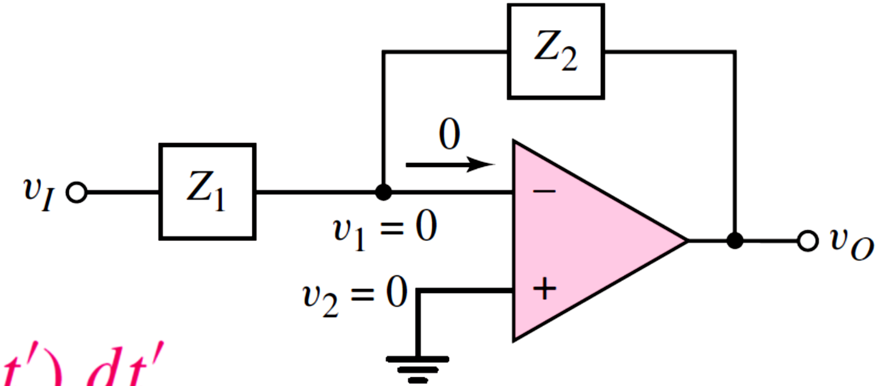


$$v_O = -\frac{Z_2}{Z_1} v_I = \frac{-1}{sR_1C_2} v_I$$

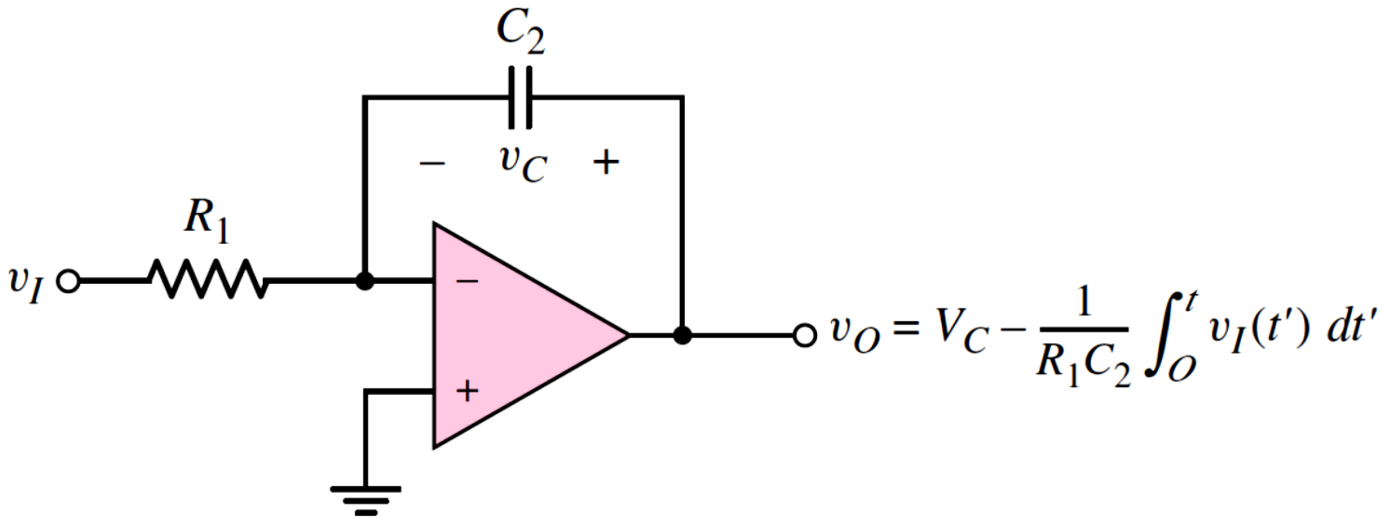
If V_C is the voltage across the capacitor at $t = 0$, the output voltage

$$v_O = V_C - \frac{1}{R_1C_2}\int_0^t v_I(t')\,dt'$$

Integrator



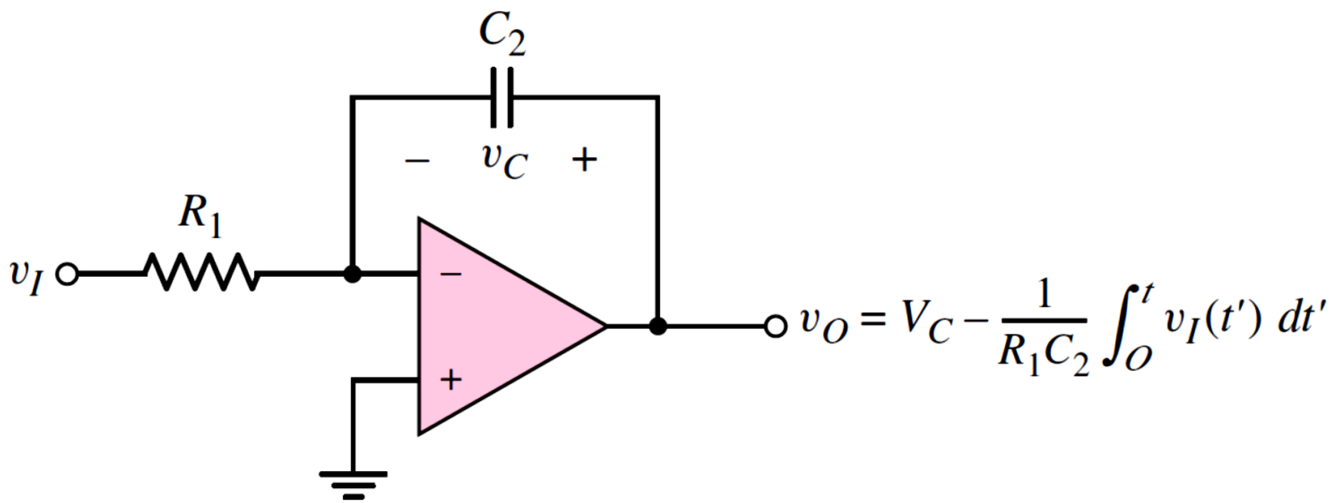
$$v_O = V_C - \frac{1}{R_1 C_2} \int_0^t v_I(t')\, dt'$$



In many applications, a **transistor switch** needs to be added in parallel with the capacitor to periodically **set the capacitor voltage to zero**.

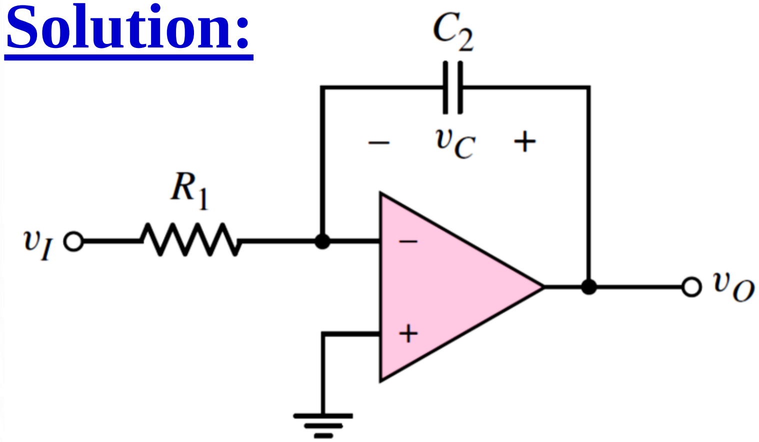
Ex.01: Integrator

Consider the integrator shown in Figure. Assume that voltage V_C across the capacitor is **zero** at $t = 0$. A step input voltage of $v_I = -1\,V$ is applied at $t = 0$. Determine the time constant required such that the output reaches $+10\,V$ at $t = 1\,ms$.



Ex.01: Integrator

Solution:



The output voltage of the integrator

$$v_O = V_C - \frac{1}{R_1C_2}\int_0^t v_I(t')dt'$$

Given that $V_C = 0$ at $t = 0$. $v_I = -1\,V$, at $t = 0$. The expected output voltage is $v_O = +10\,V$ at $t = 1\,ms$.

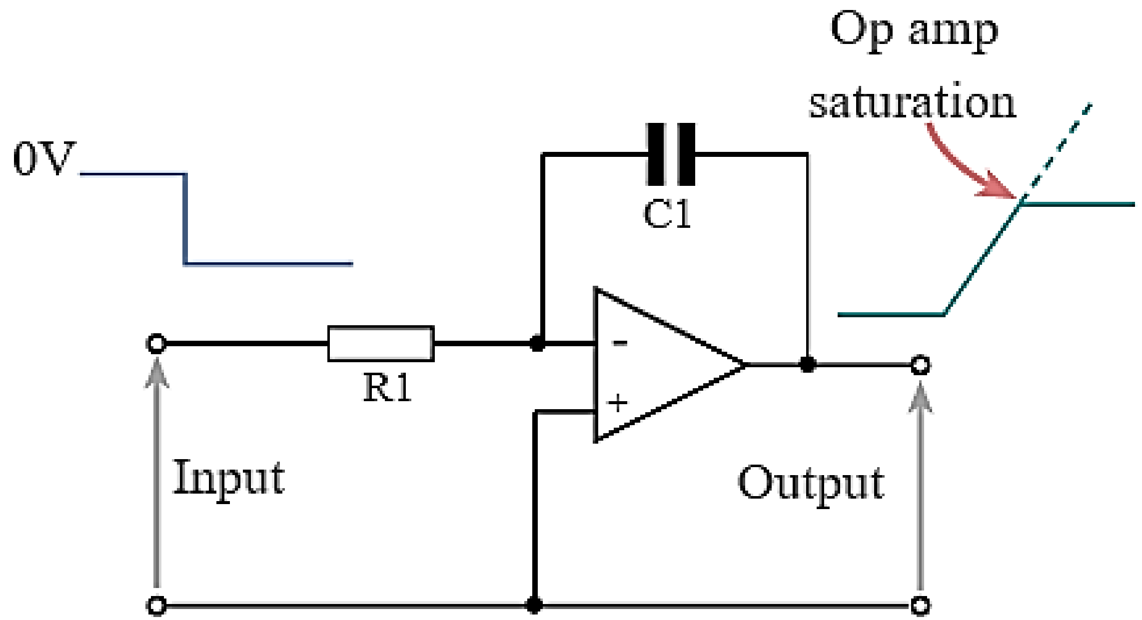
Then, $$v_O = -\frac{1}{R_1C_2}\int_0^t (-1)dt' = \frac{1}{R_1C_2}t'\Big|_0^t = \frac{t}{R_1C_2}$$

At $t = 1\,ms$ $$10 = \frac{10^{-3}}{R_1C_2}$$

Which means the time constant is $R_1C_2 = 0.1\,ms$

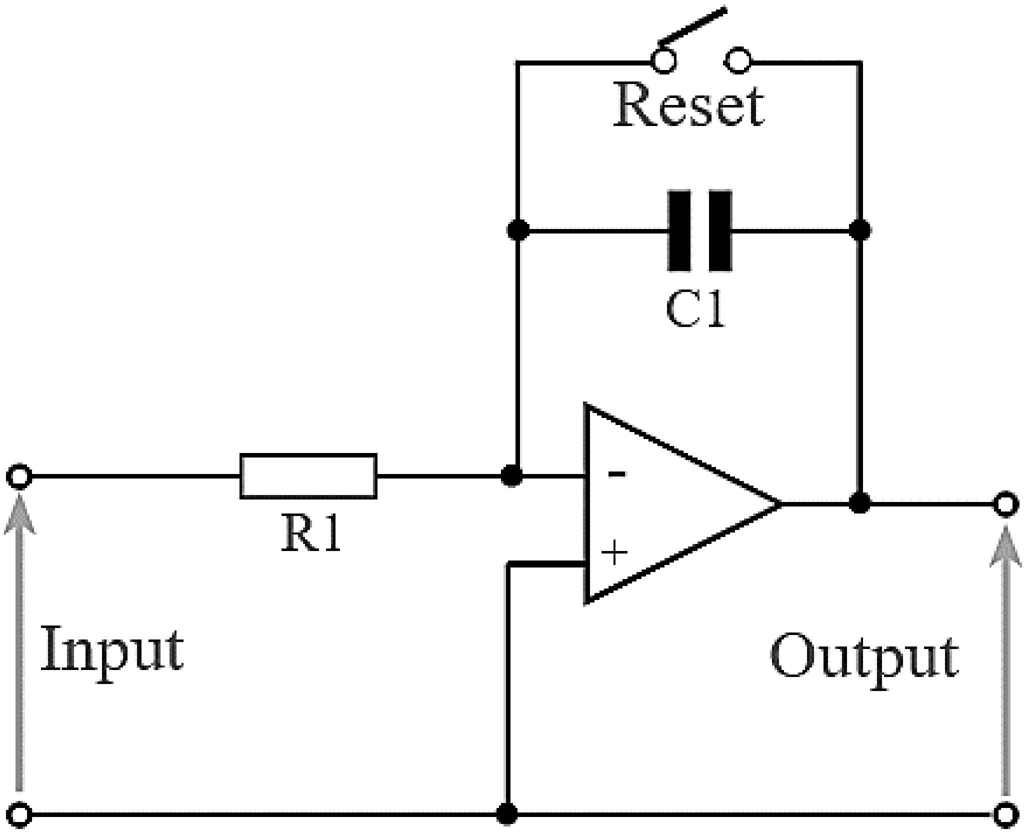
Op-Amp Saturation

- The output of the integrator cannot rise indefinitely as the output will be limited.
- The output of the op amp integrator will be limited by supply voltage.
- When designing one of these circuits, it may be necessary to limit the gain or increase the supply voltage to accommodate the likely output voltage swings.



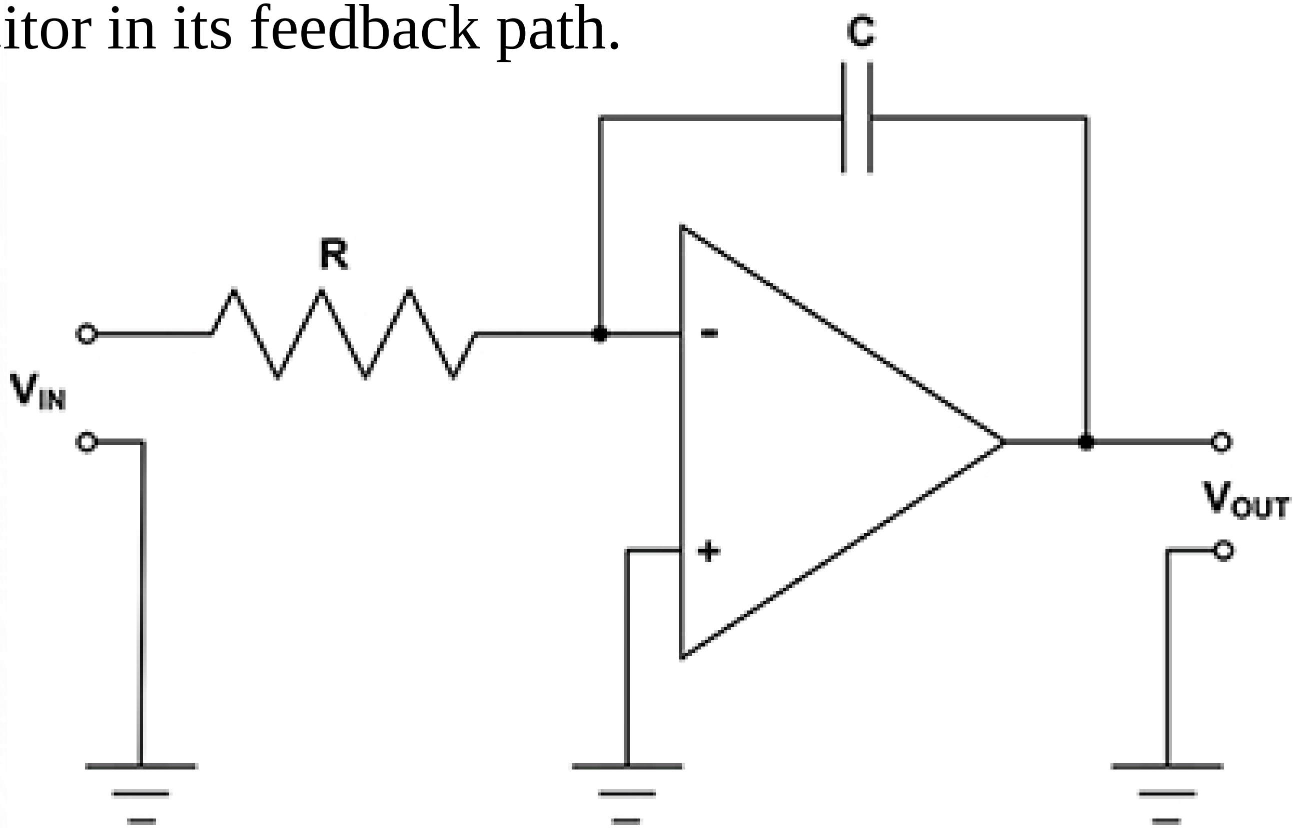
Integrator Reset Capability

- It is sometimes necessary to reset the integrator to zero.



Different Analog Integrators

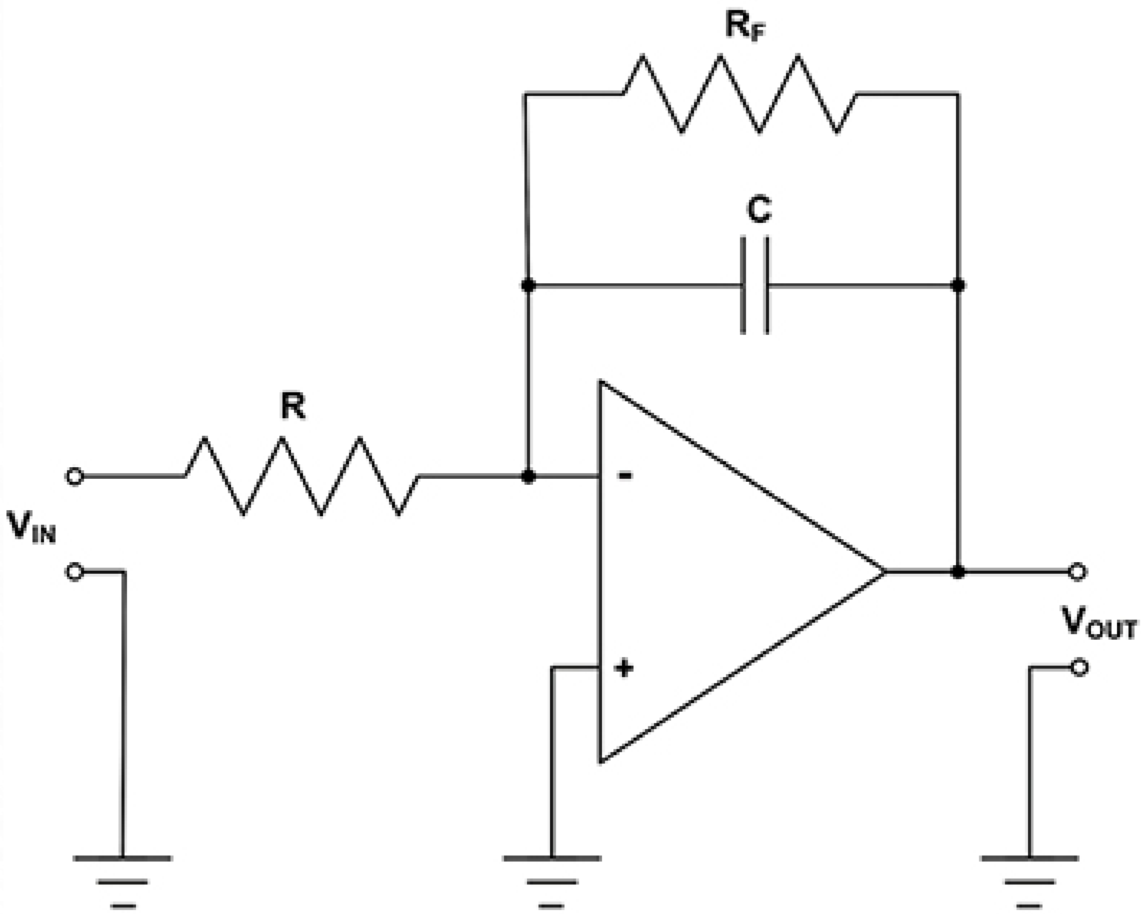
- The basic inverting analog integrator consists of an op-amp with a capacitor in its feedback path.



$$V_{out} = -\frac{1}{RC}\int V_{IN}\,dt$$

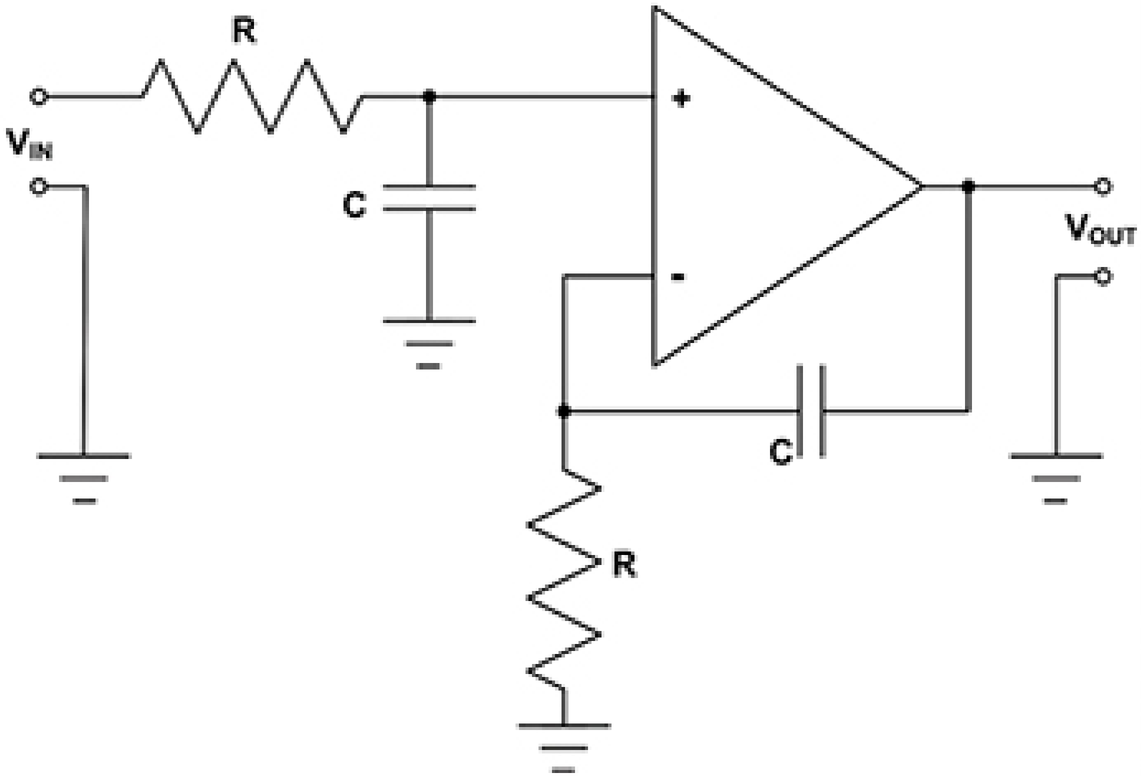
Different Analog Integrators

- Adding a large resistor in parallel with the feedback capacitor limits the DC gain and results in a practical integrator.



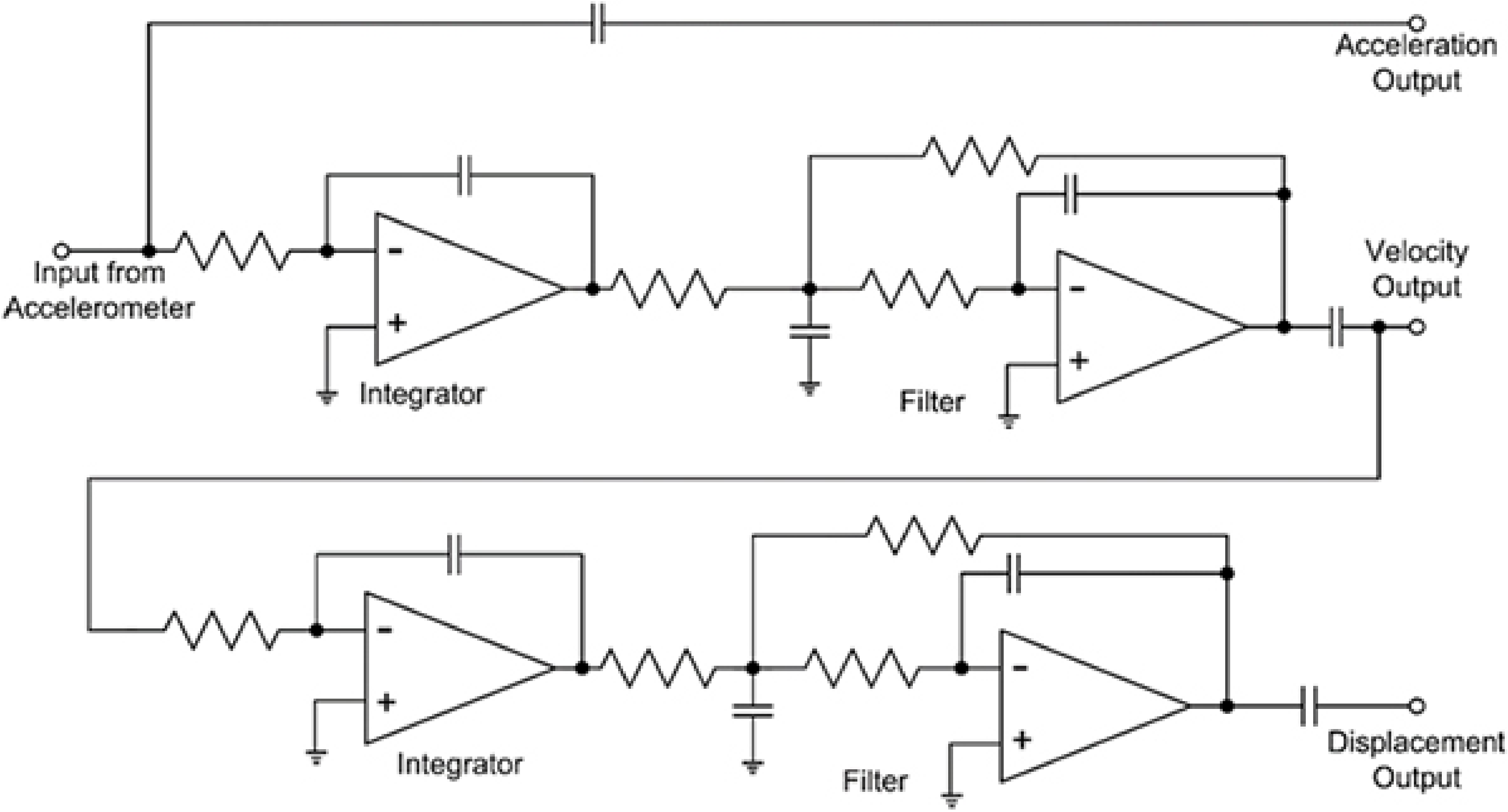
Non-inverting integrator

- A non-inverting integrator based on a difference amplifier op amp configuration can ensure the output phase matches that of the input.



Common Integrator Applications

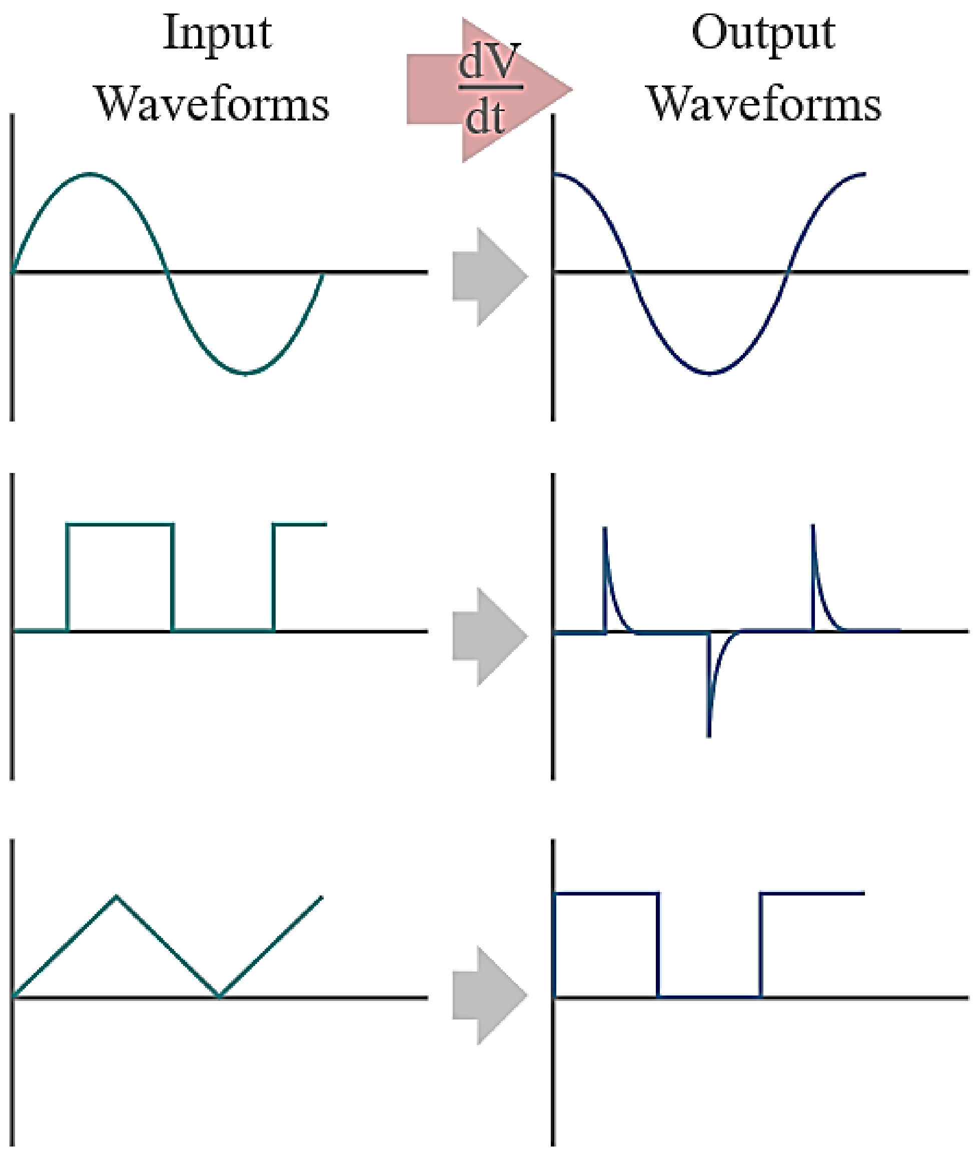
- Using dual integrators, a designer can produce **acceleration, velocity, and displacement** readouts from an accelerometer.



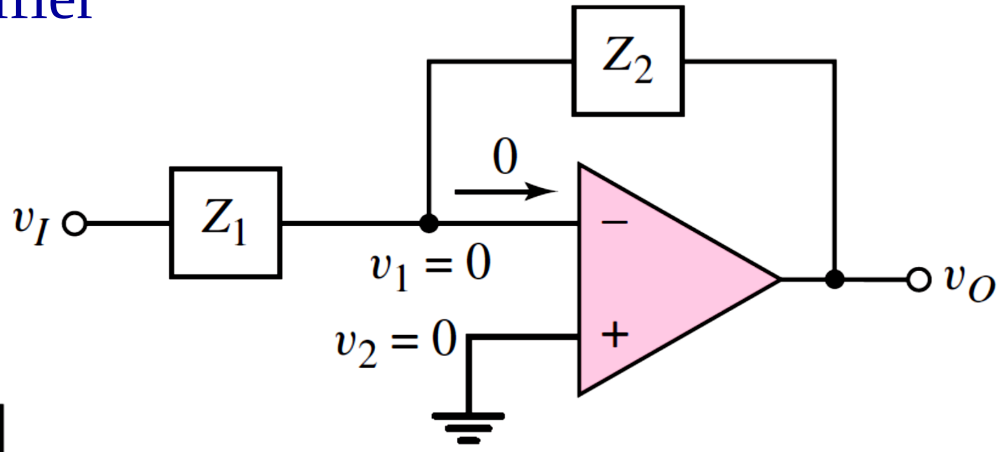
Differentiator

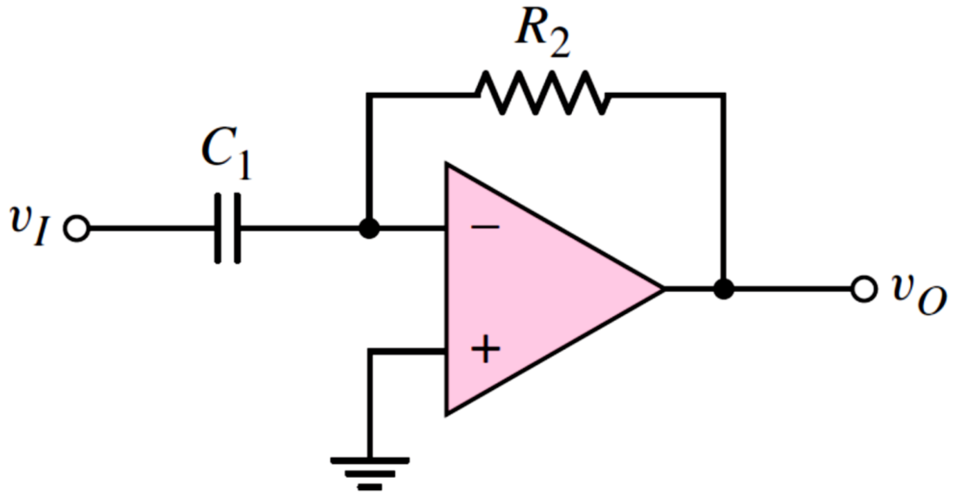
Differentiator

- A differentiator circuit is one in which the voltage output is directly proportional to the rate of change of the input voltage with respect to time.



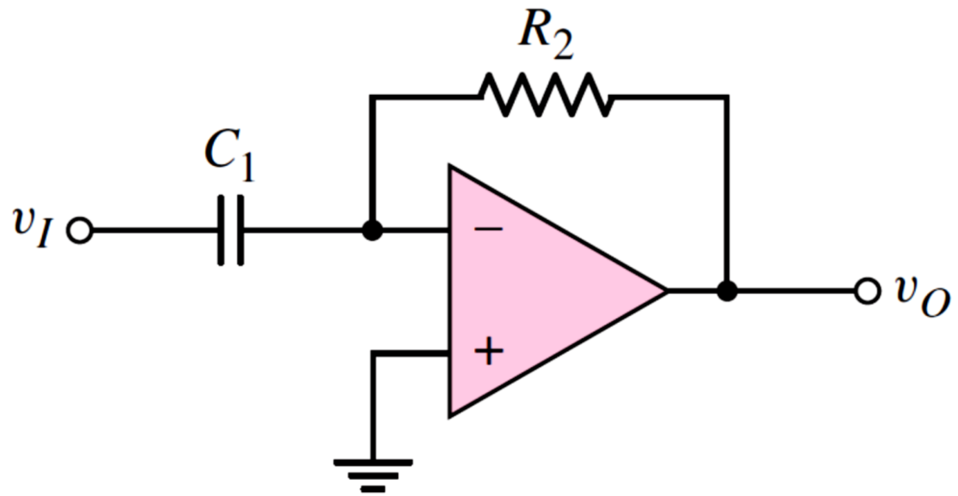
Generalized Inverting Amplifier





The impedances are $Z_1 = 1/sC_1$ and $Z_2 = R_2$

Differentiator



Voltage transfer function

$$\frac{v_O}{v_I} = -\frac{Z_2}{Z_1} = -sR_2C_1$$

Output voltage

$$v_O = -sR_2C_1v_I$$

$$v_O(t) = -R_2C_1\frac{dv_I(t)}{dt}$$