Basic Electronic Circuits
(IEC-103)

Lecture-08

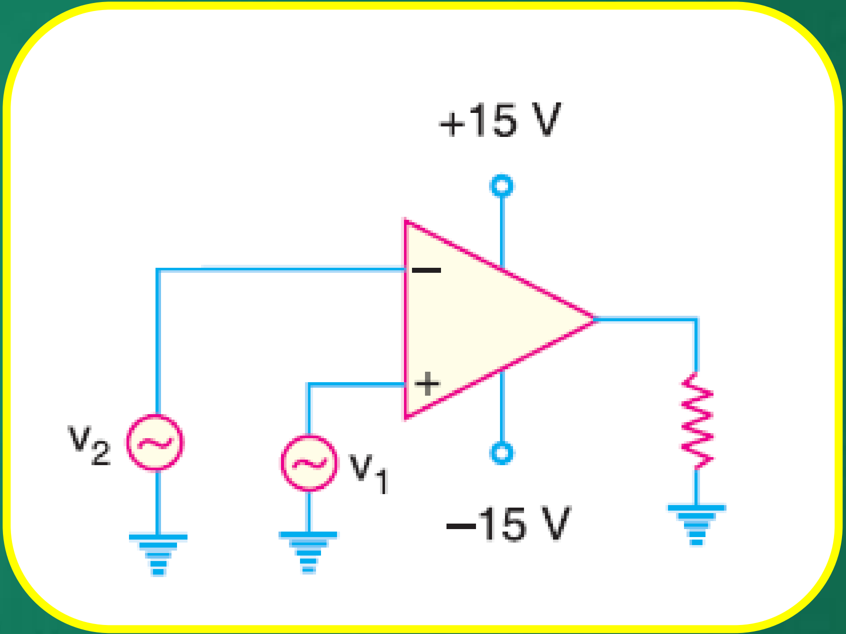
Nonlinear Applications of Operational Amplifiers

Non-Linear Op-Amp Applications

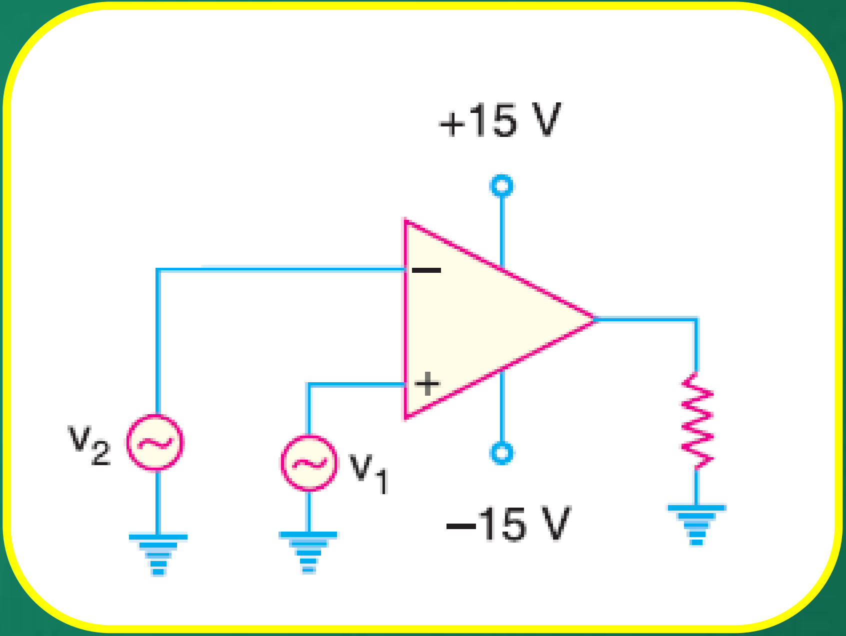
- Applications using saturation
  - Comparators
  - Comparator with hysteresis (Schmitt trigger)
  - Square wave and triangular wave generators

- Applications using active feedback components
  - Log, antilog, squaring etc. amplifiers
  - Precision rectifier

Comparators

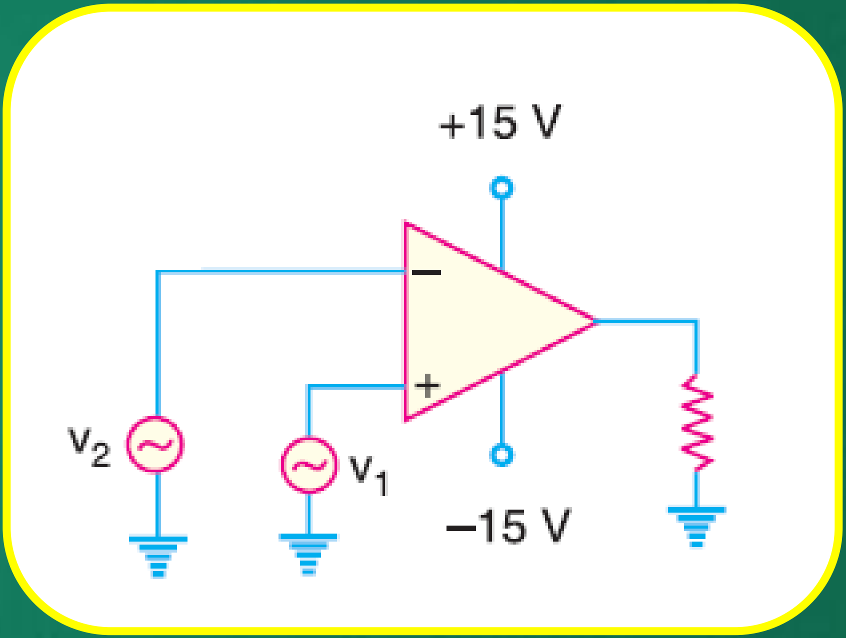


Comparators



- A comparator is an op-amp circuit without negative feedback and takes the advantage of very high open-loop gain.

Comparators



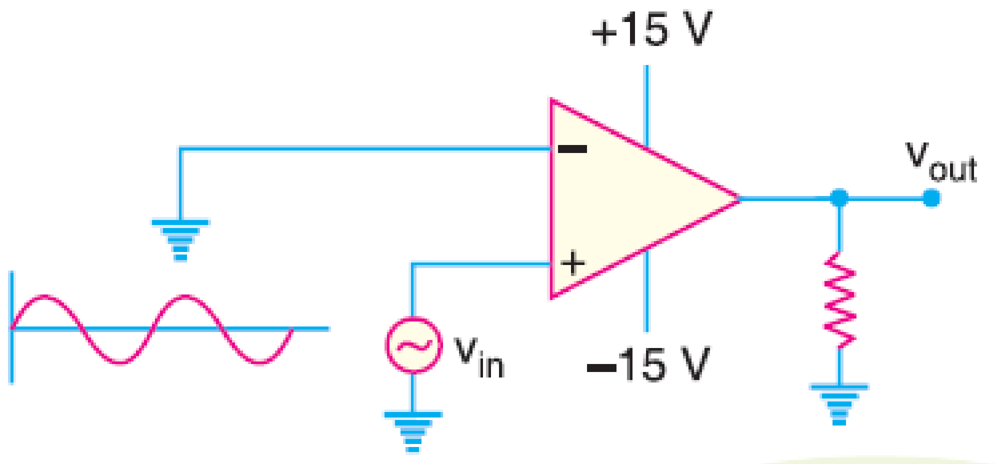
- A comparator is an op-amp circuit without negative feedback and takes the advantage of very high open-loop gain.
- It is operated in a non-linear mode.

Comparators

$$+V_{sat} = +V_{\text{supply}} - 2 = 15 - 2 = +13\text{ V}$$

$$-V_{sat} = -V_{\text{supply}} + 2 = -15 + 2 = -13\text{ V}$$

Comparator
(Square Wave Generator)



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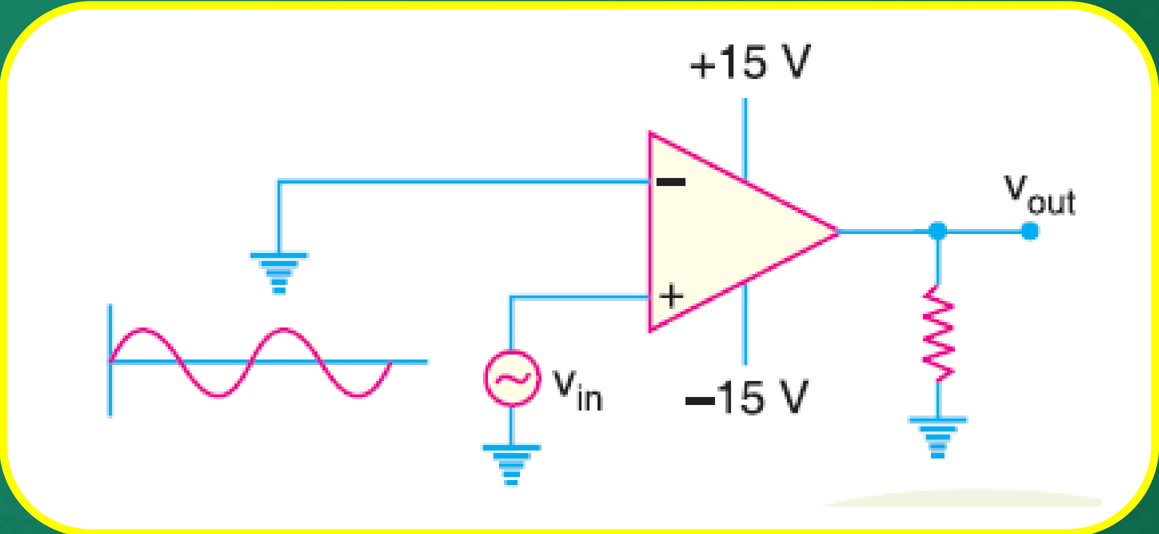
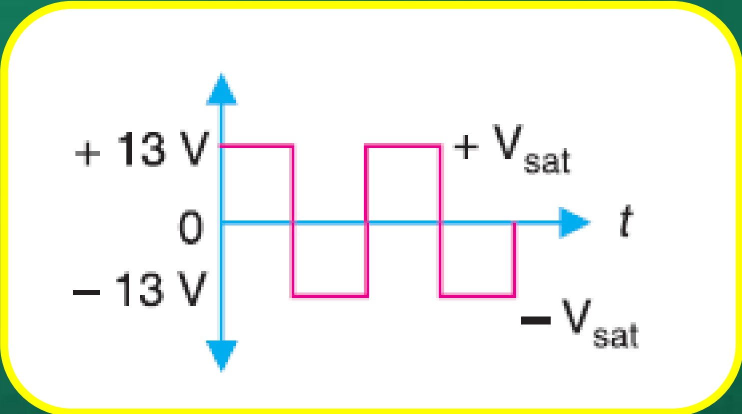
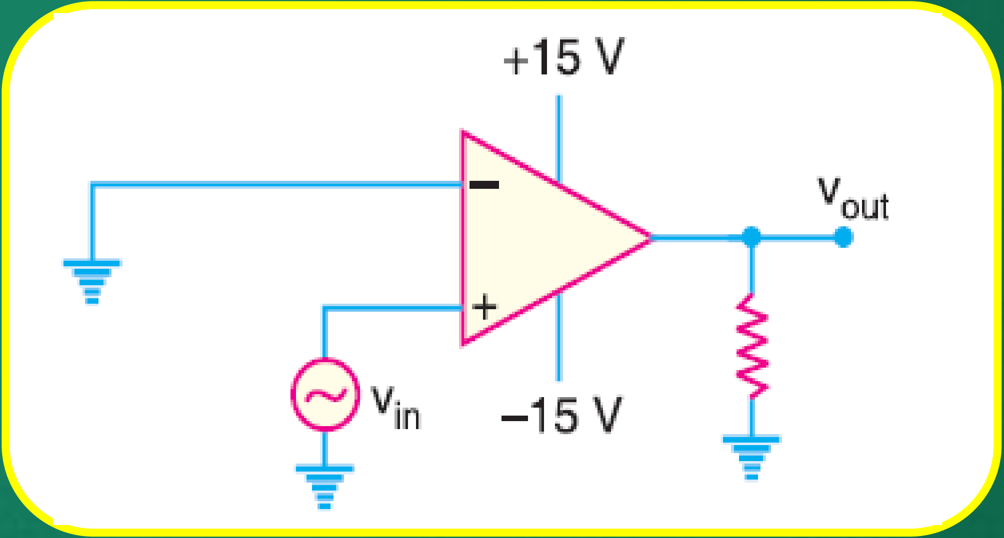




Comparator (Zero Crossing Detector)



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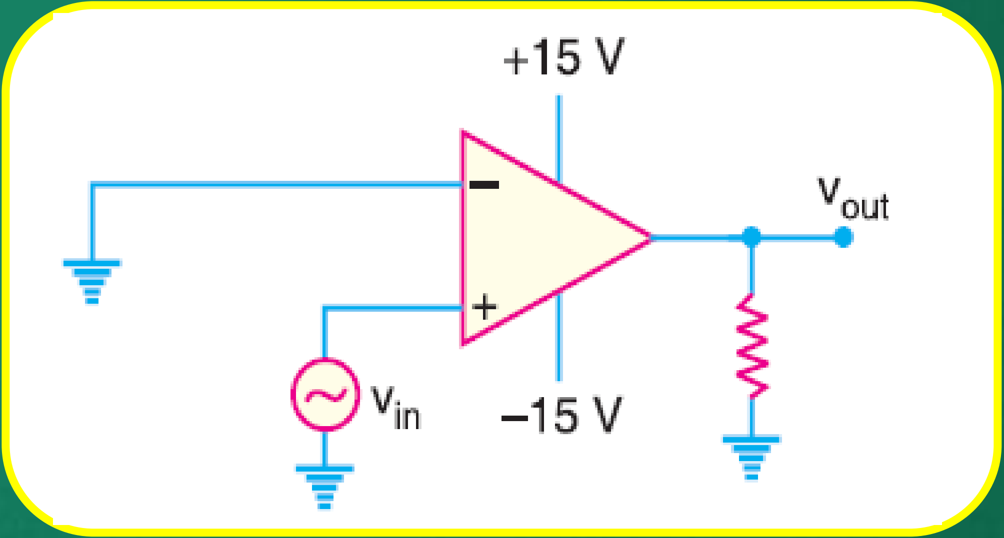

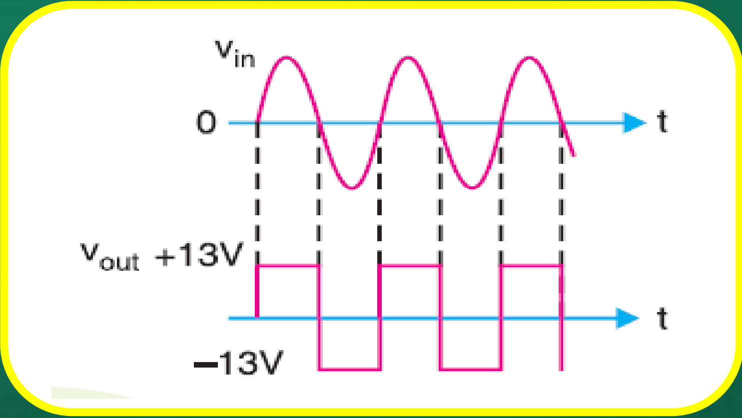

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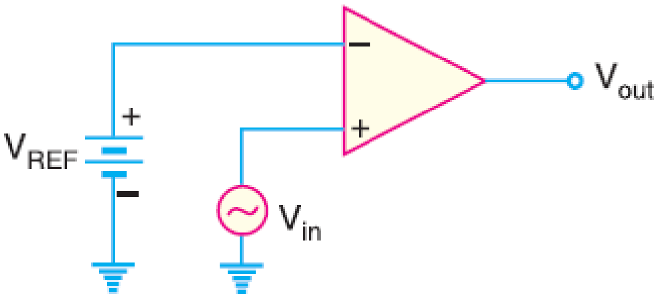
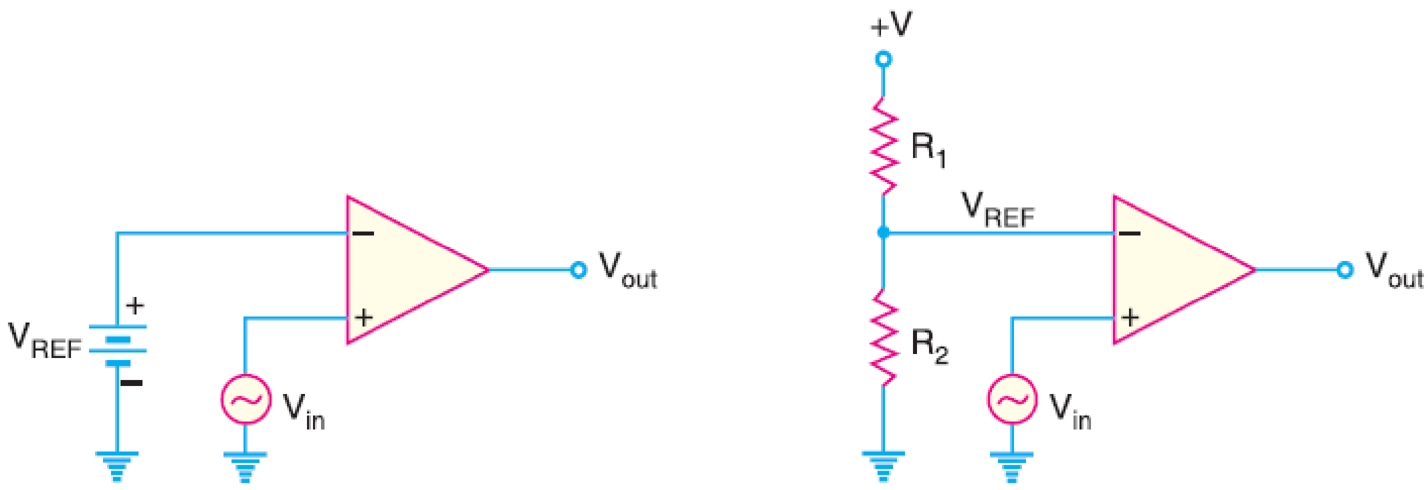


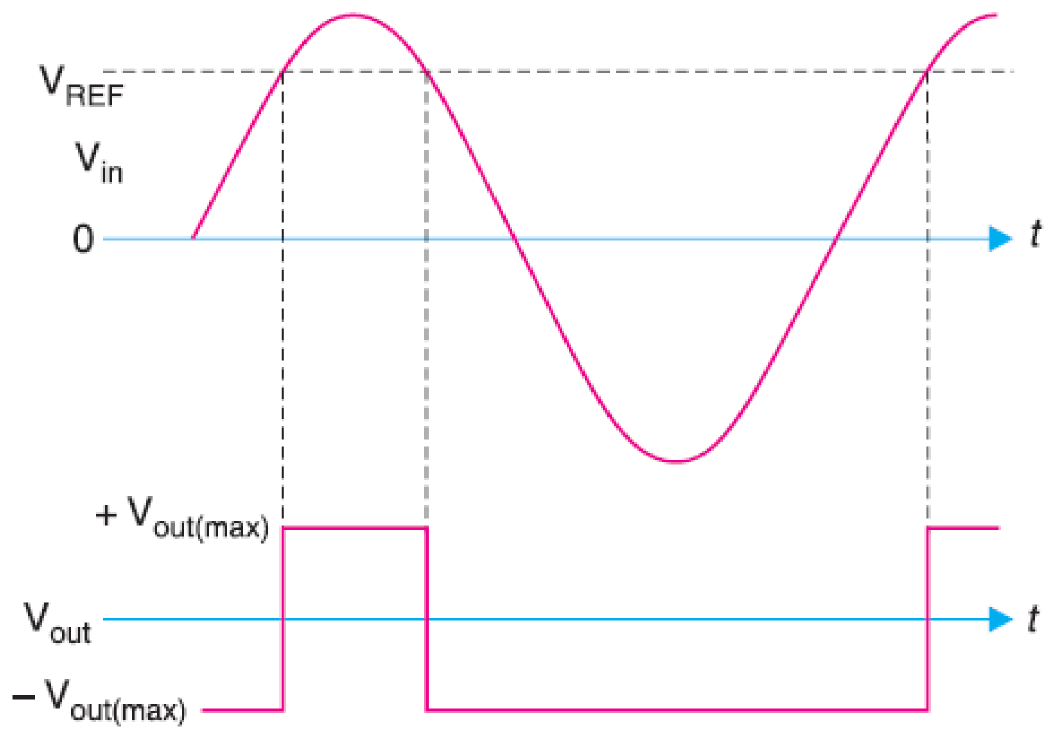
(*i*) Battery reference

Comparator (Level Detector)



(*i*) Battery reference (*ii*) Voltage-divider reference

Comparator (Level Detector)



Hysteresis

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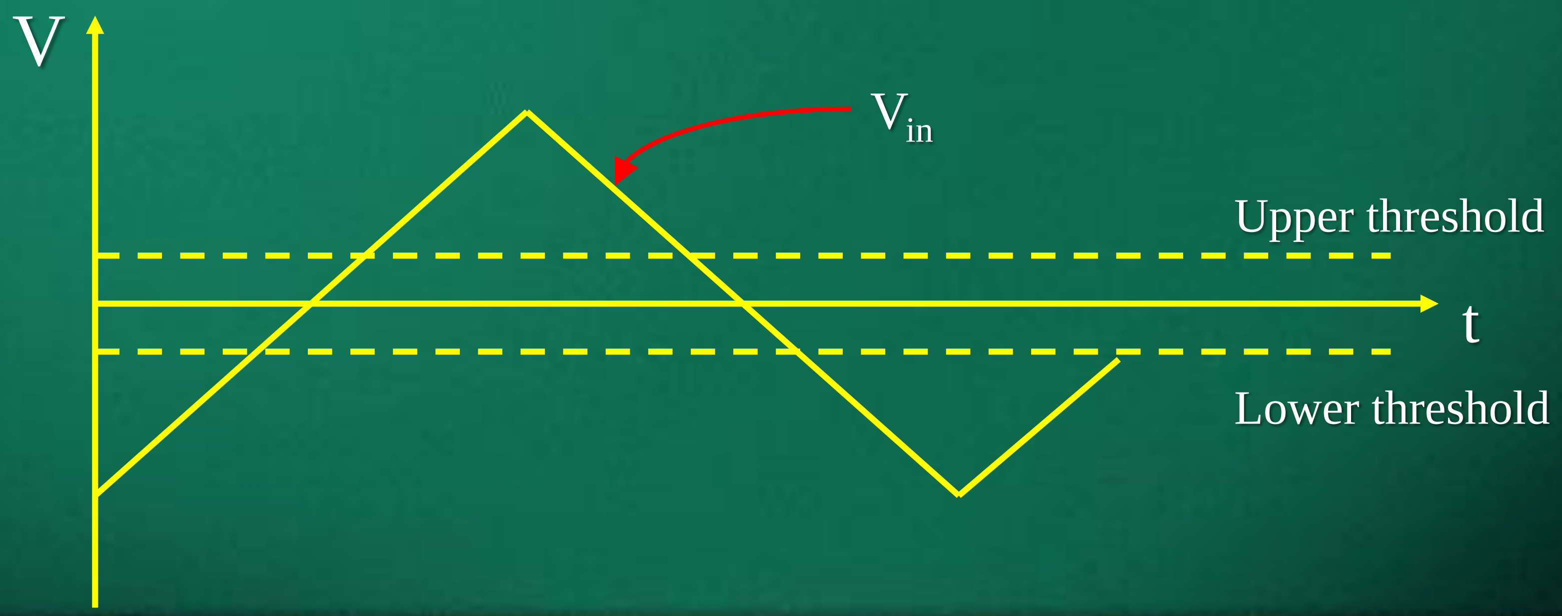

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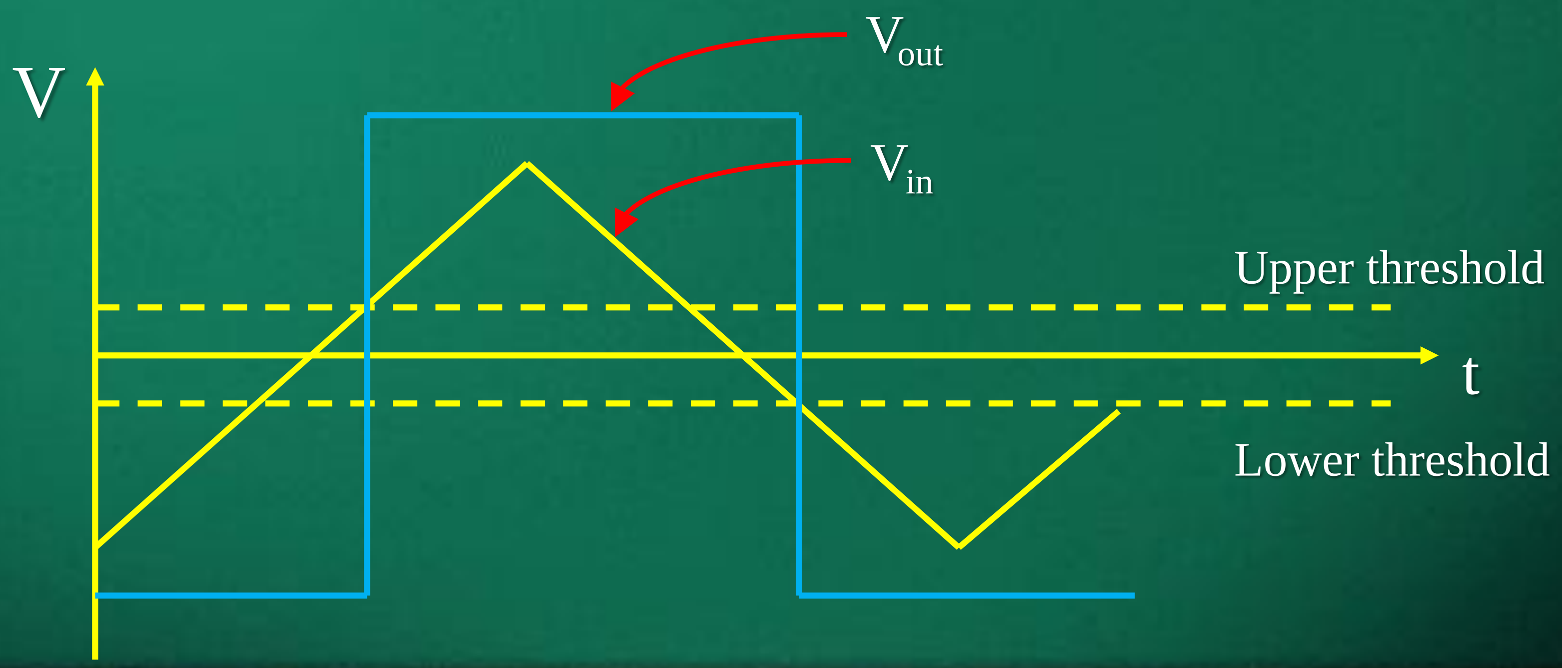

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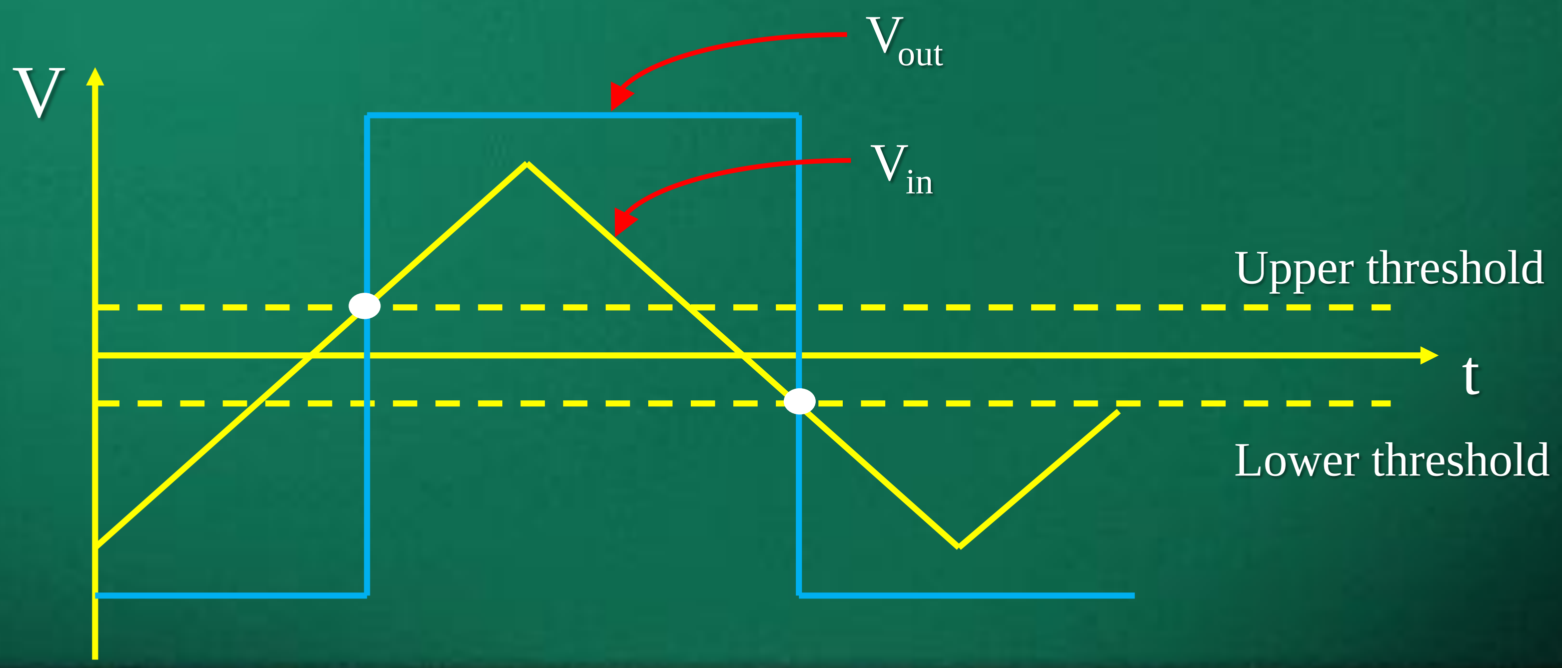

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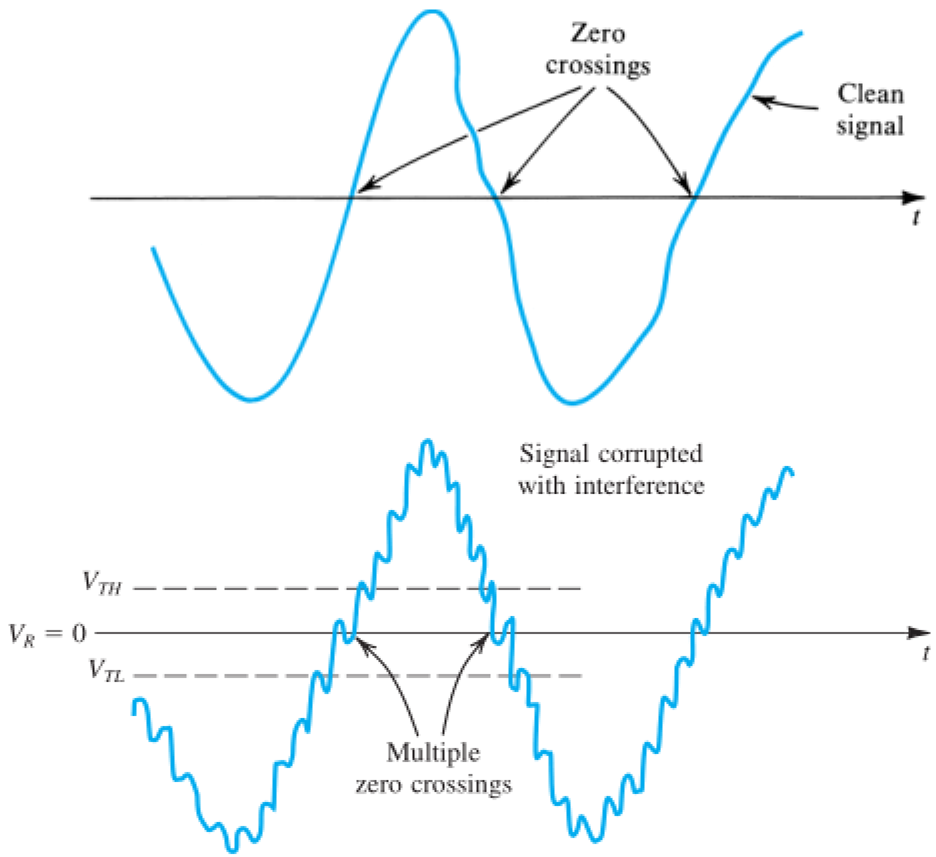
- The advantage is immunity against small noise spikes.
- It takes at minimum the hysteresis range to make it switch.

Rejecting Interference



Schmitt Trigger

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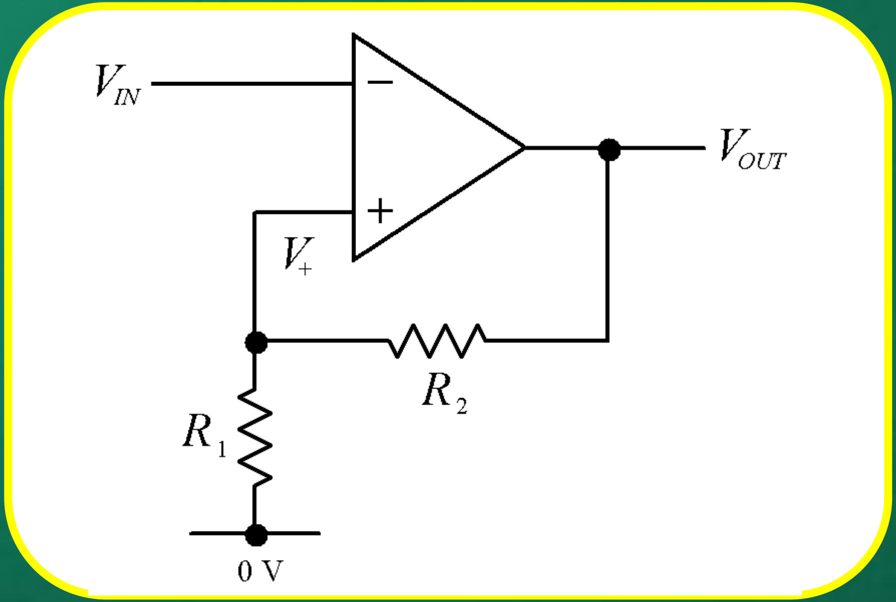
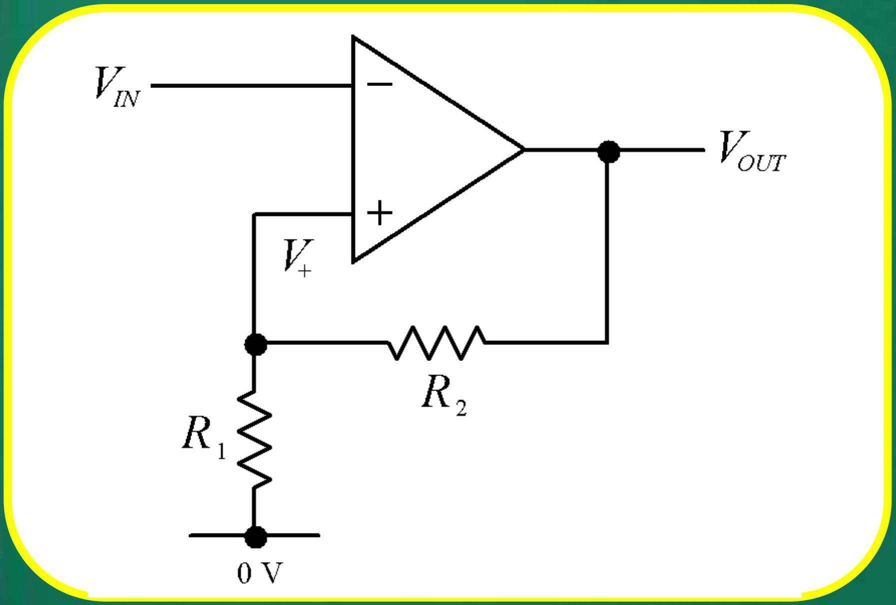
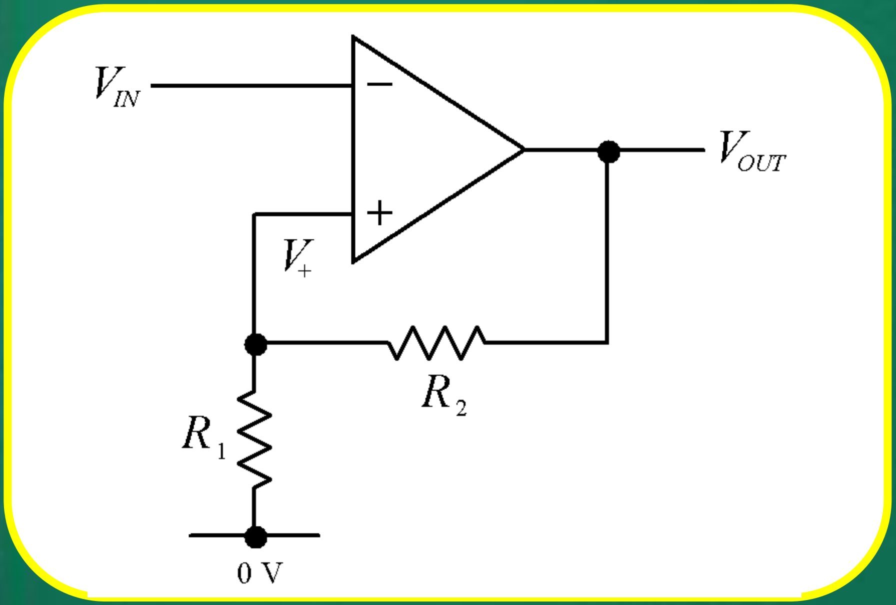


Schmitt Trigger Analysis



Schmitt Trigger Analysis

Switching occurs when:



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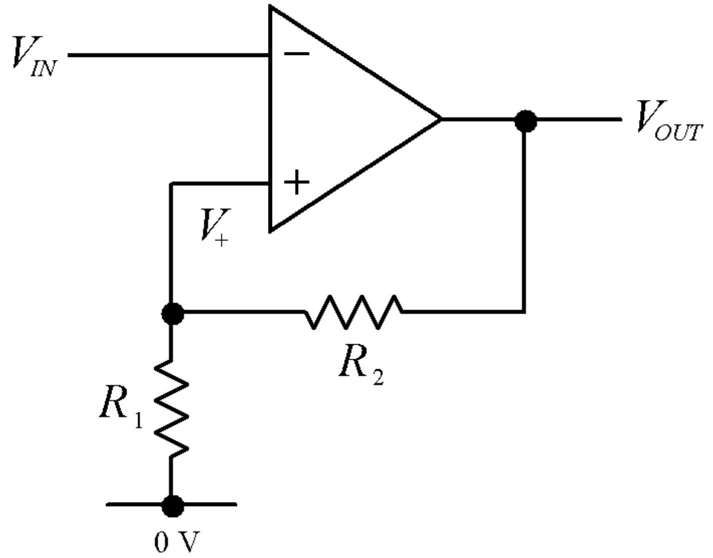
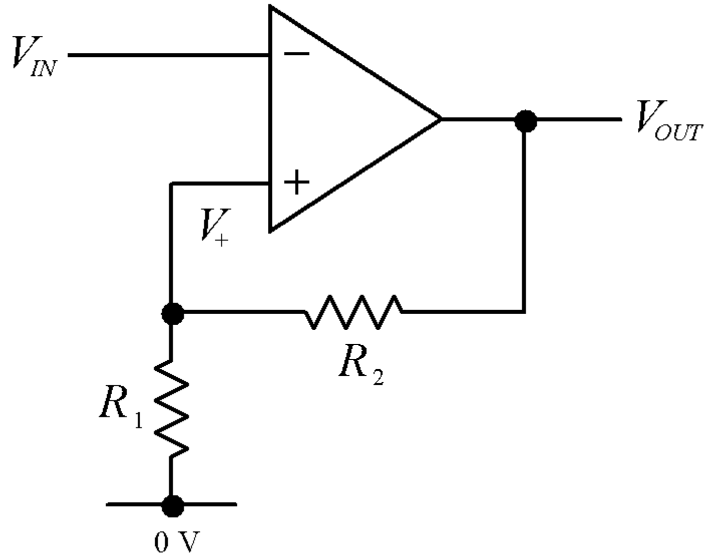


Switching occurs when:

$$V_{IN} = V_- = V_+ = V_{OUT}\,\frac{R_1}{R_1 + R_2}$$

Schmitt Trigger Analysis



Switching occurs when:

$$V_{IN} = V_- = V_+ = V_{OUT}\frac{R_1}{R_1 + R_2}$$

But,

$$V_{OUT} = \pm V_{SAT}$$

$$\therefore V_{THRESH} = \pm V_{SAT}\frac{R_1}{R_1 + R_2}$$

Input-Output Relationship

–

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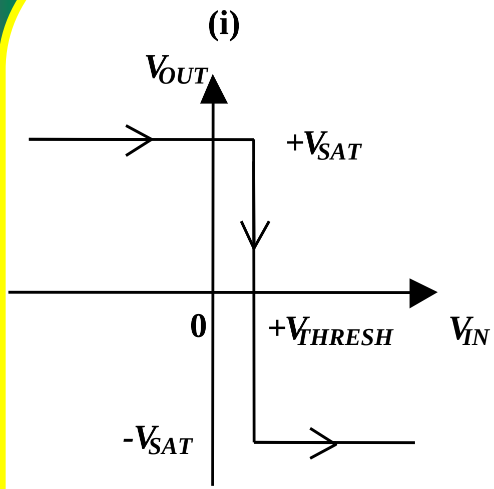
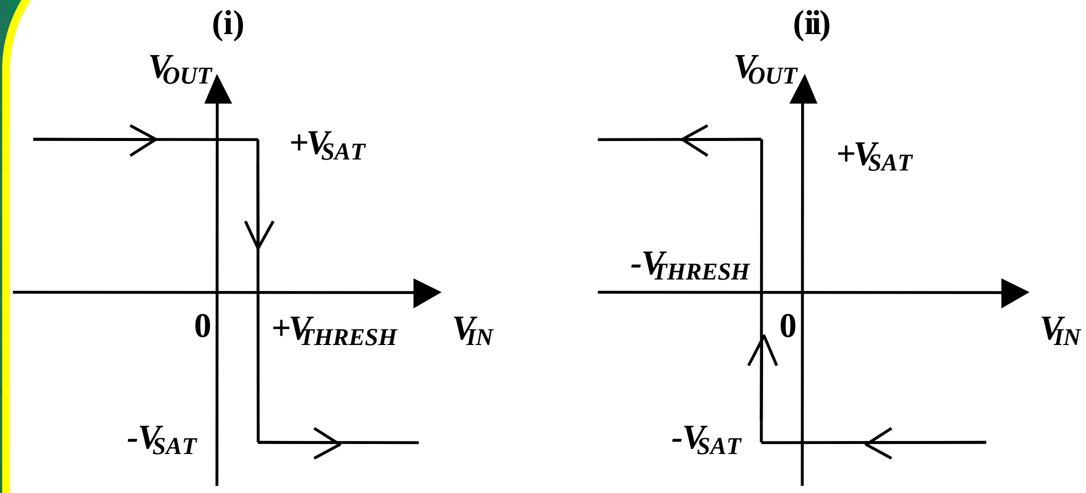


V_{IN} increasing

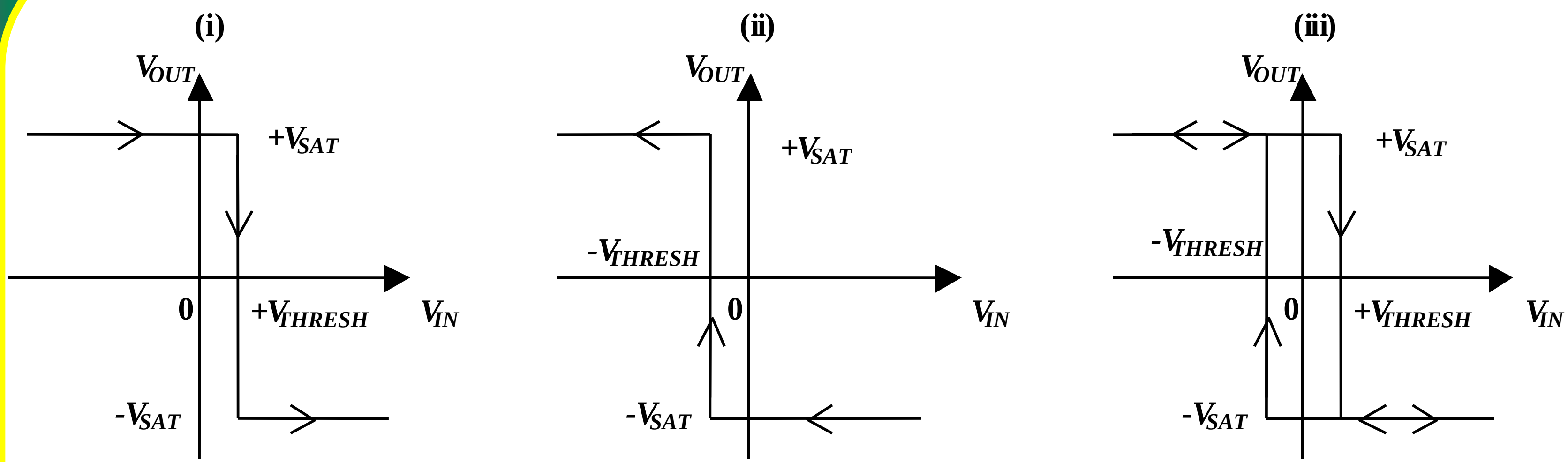
Input-Output Relationship



V_{IN} increasing

V_{IN} decreasing

Input-Output Relationship



V_{IN} increasing

V_{IN} decreasing

(i) & (ii) combined

Square Wave Generator

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- Square waves are generally used in digital switching circuits.

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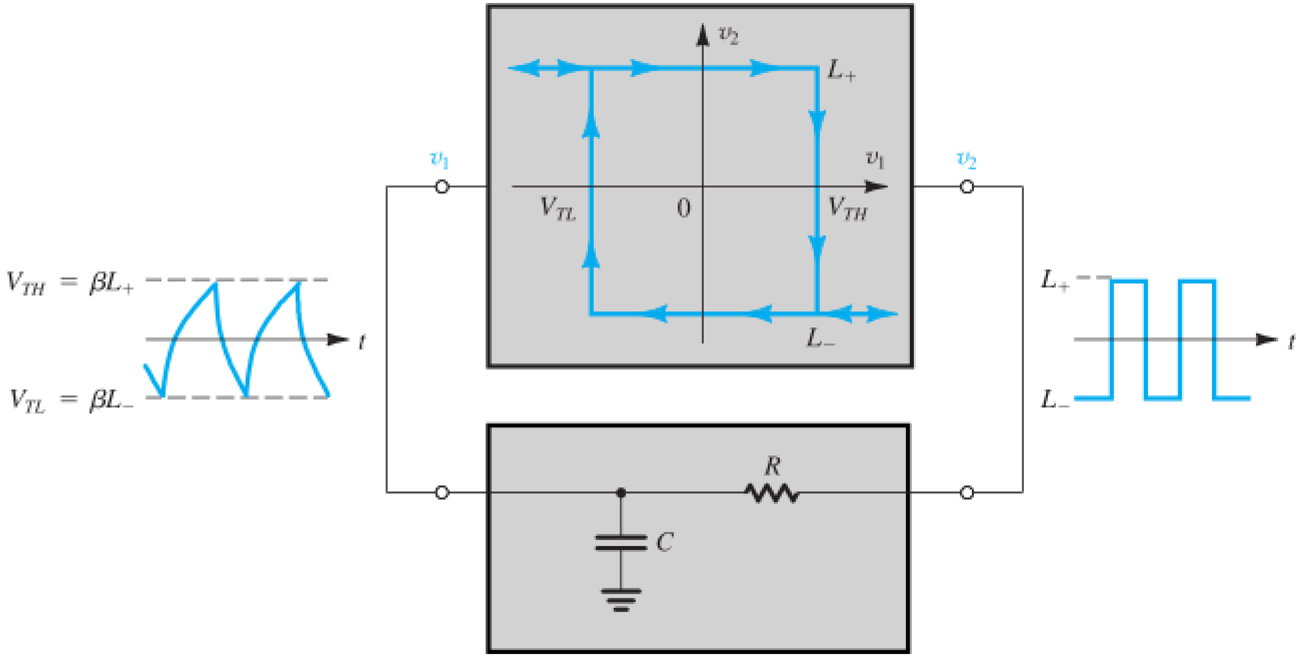
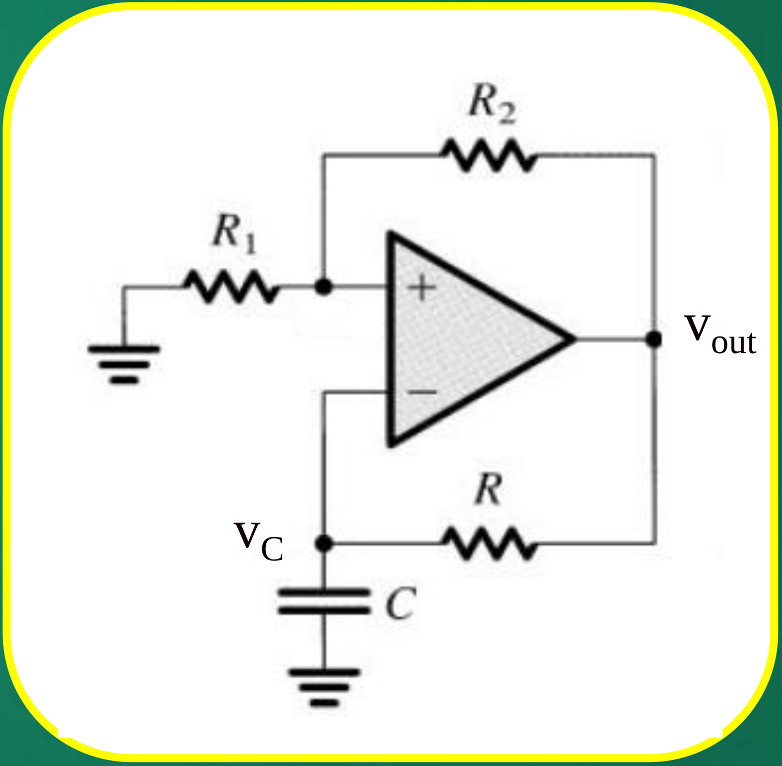
- Square wave can be generated using op-amp in positive feedback configuration without the need of an external input.
- The circuits generating a square wave can be called as relaxation oscillator or astable multi vibrator.

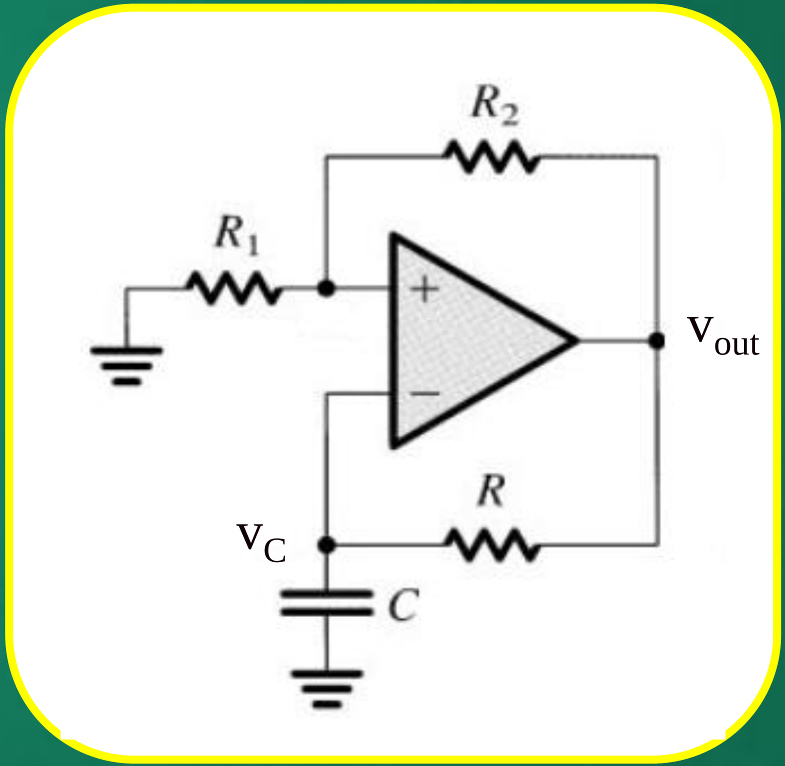
Square Wave Generator



Square Wave Generator

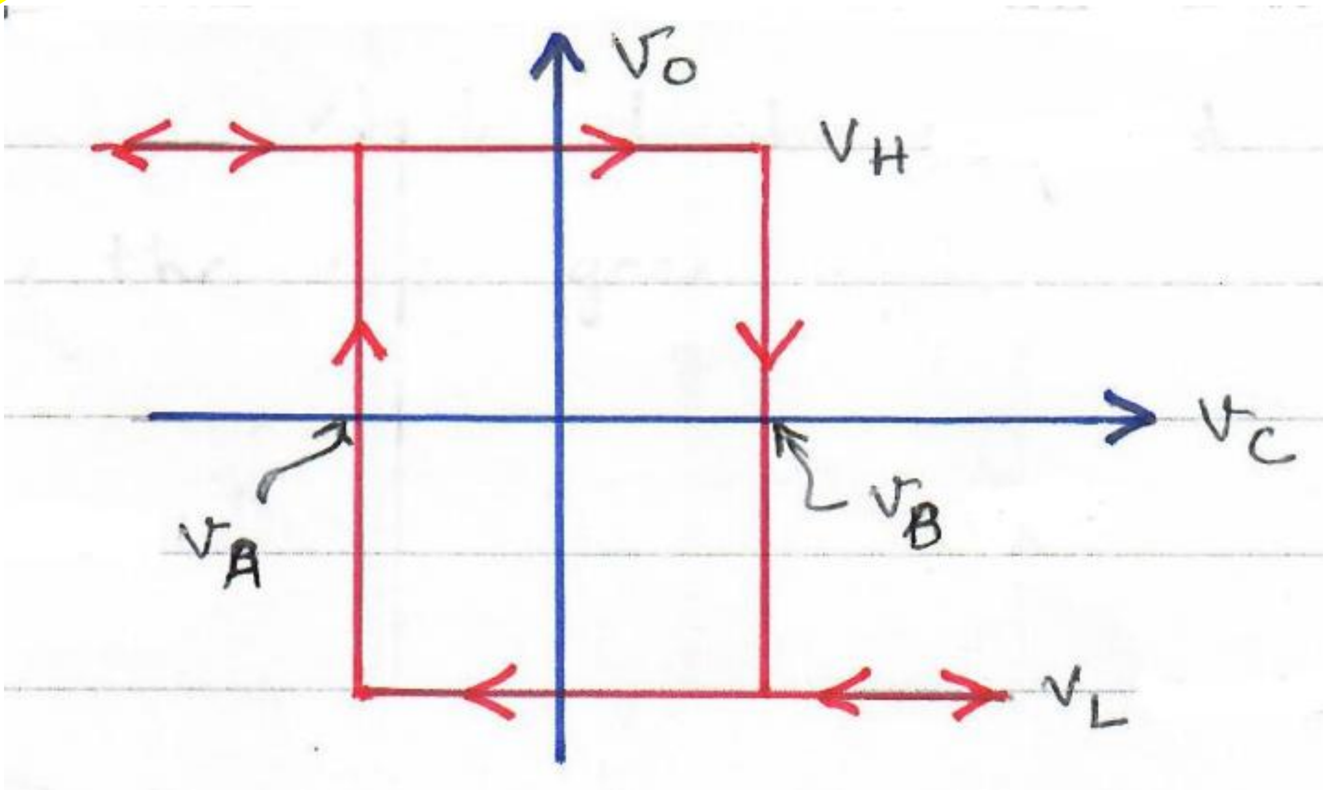


Square Wave Generator

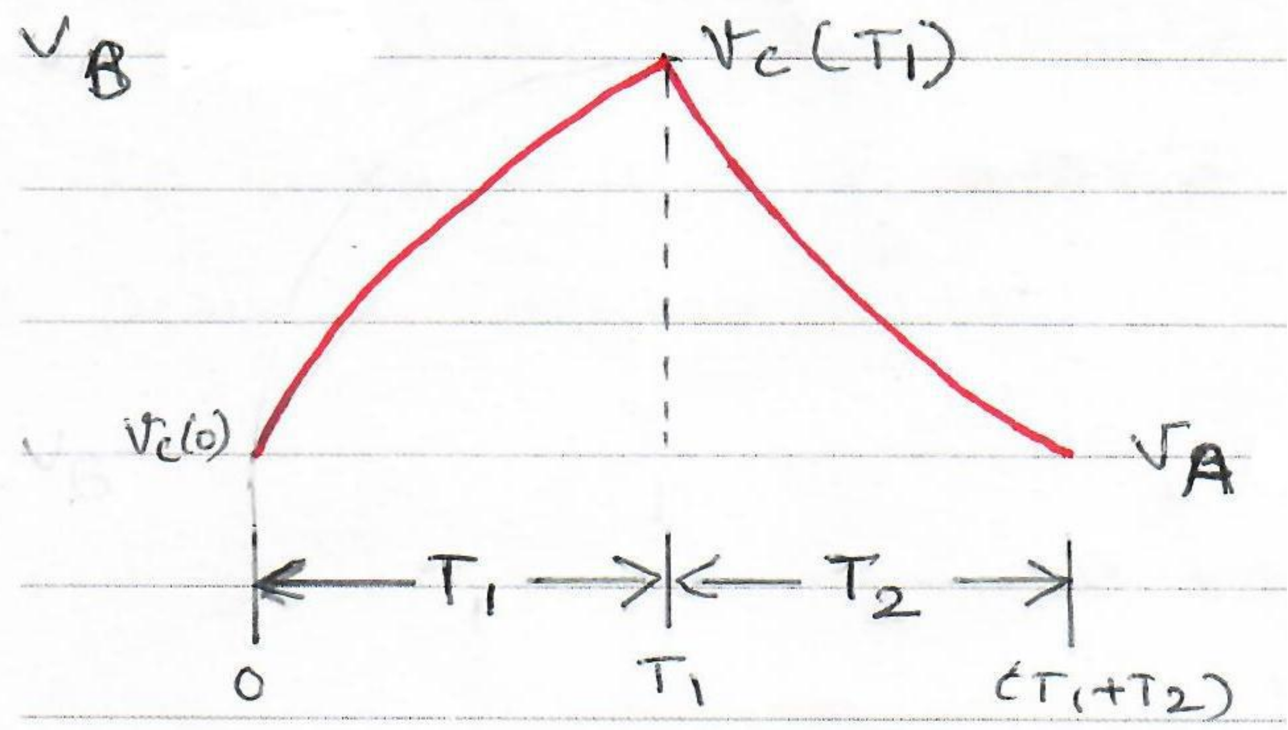


The circuit's frequency of oscillation will depend on the charging and discharging of capacitor C through feedback resistor R.

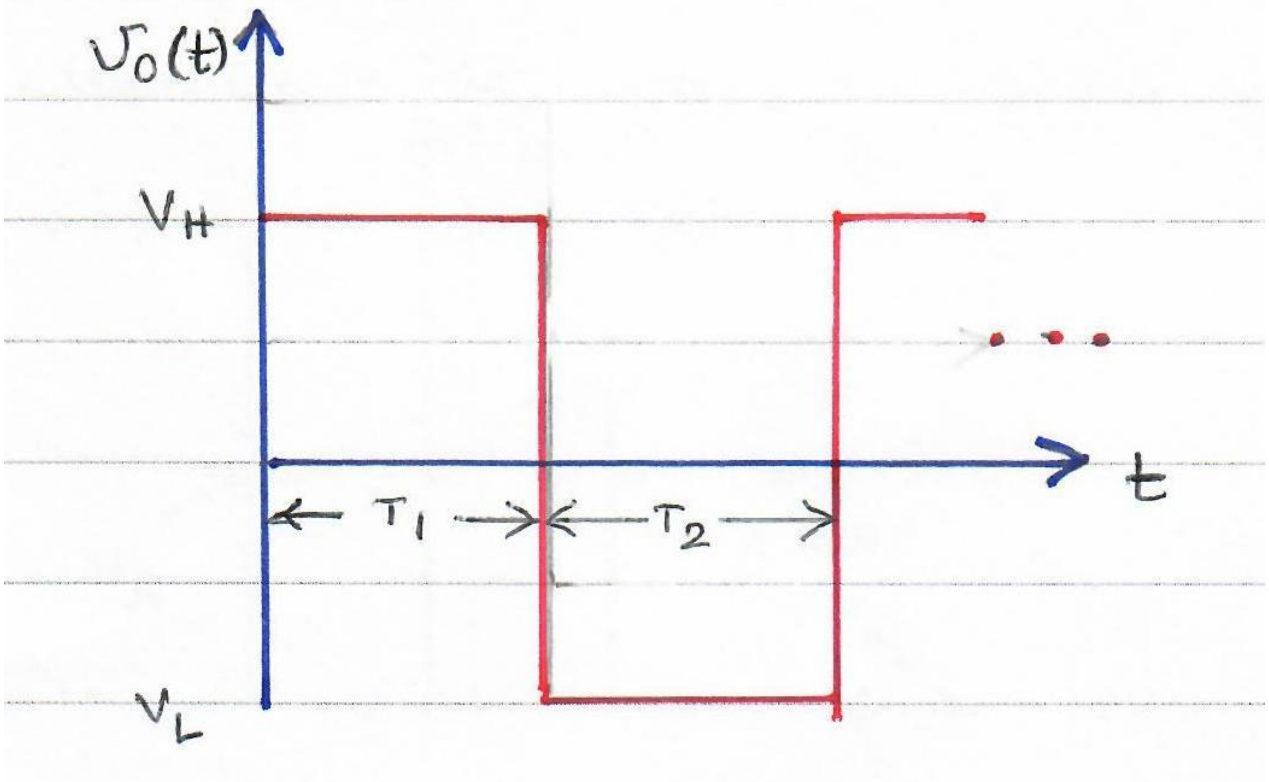
Hysteresis Loop



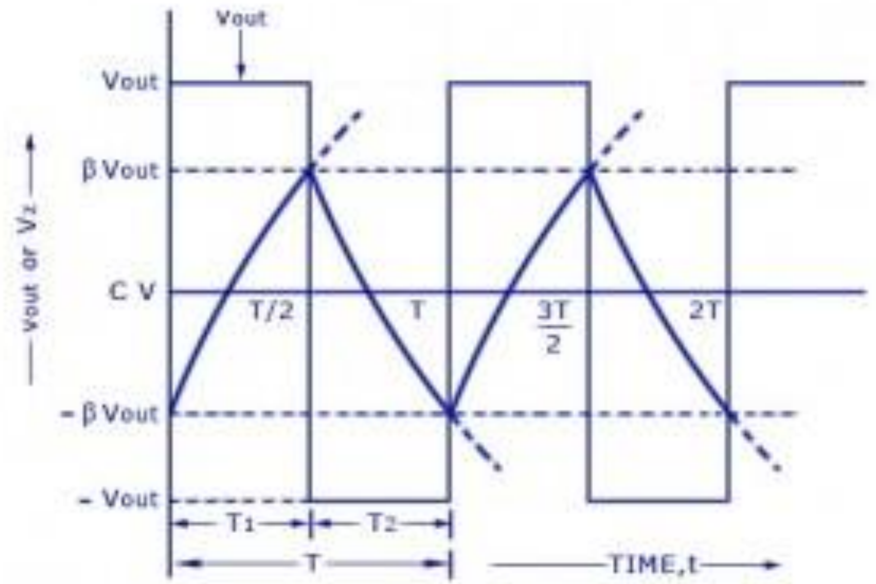
Capacitor Voltage



Output Voltage

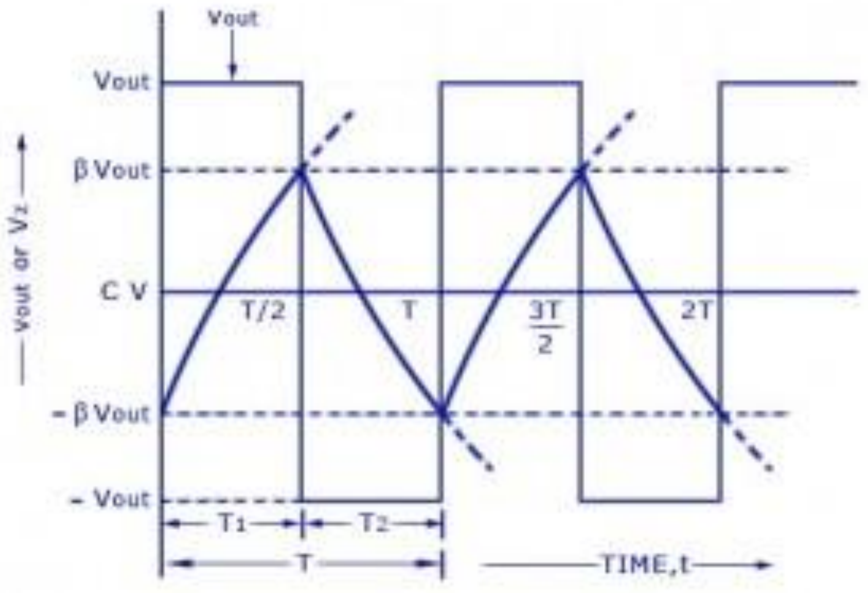


Analysis



Output and Capacitor Voltage Waveforms

Analysis



Output and Capacitor Voltage Waveforms

$$T_1 = RC\ln\left(\frac{1+\beta}{1-\beta}\right) \text{ where } \beta = \frac{R_1}{R_1+R_2}$$

Analysis

$$T_2 = RC\ln\left(\frac{1+\beta}{1-\beta}\right) \text{ where } \beta = \frac{R_1}{R_1+R_2}$$

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$$\therefore T_1 = T_2$$

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$$T = T_1 + T_2 = 2RC\ln\left(\frac{1+\beta}{1-\beta}\right)$$

Analysis

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$$T = T_1 + T_2 = 2RC\ln\left(\frac{1+\beta}{1-\beta}\right)$$

$$\text{If } R_1 = R_2 = R \text{ then } \beta = 0.5$$

Analysis

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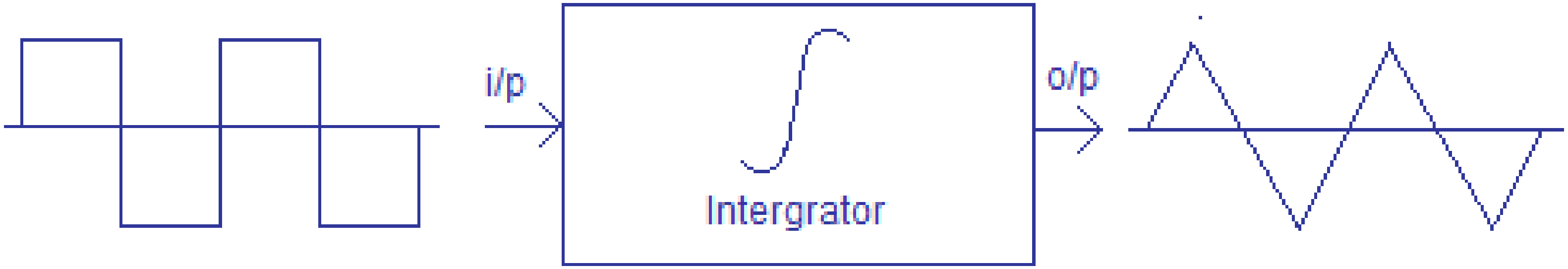
$$T = T_1 + T_2 = 2RC\ln\left(\frac{1+\beta}{1-\beta}\right)$$

If $R_1 = R_2 = R$ then $\beta = 0.5$

$$\Rightarrow T = 2RC\ln\left(\frac{1+0.5}{1-0.5}\right) = 2RC\ln(3) = 2.197RC$$

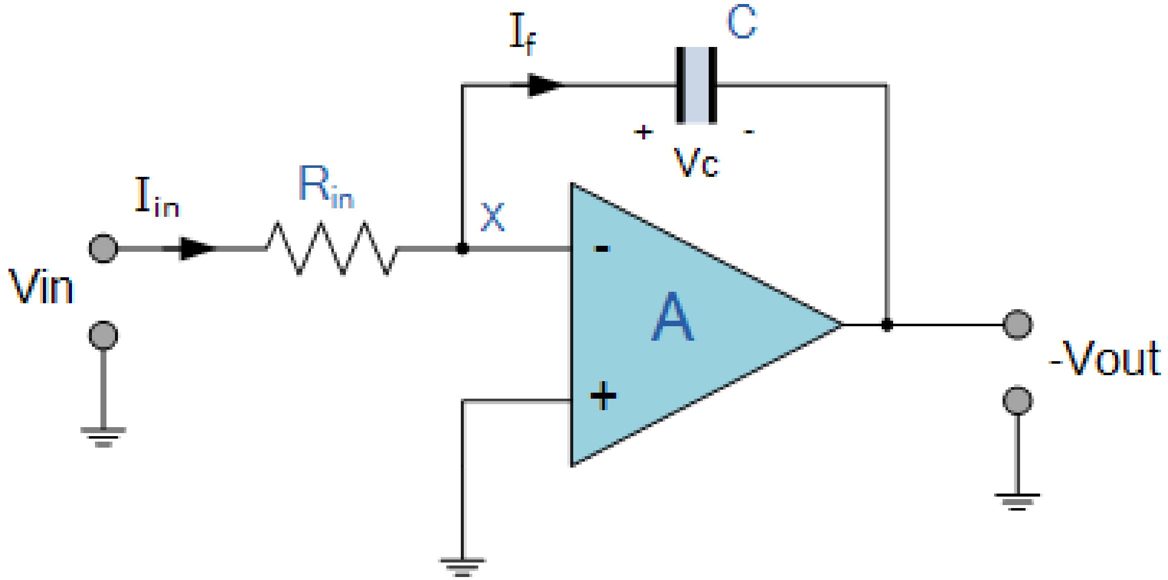
Triangular Wave Generator

Triangular Wave Generator



Generating triangular wave from a square wave

Integrator Circuit



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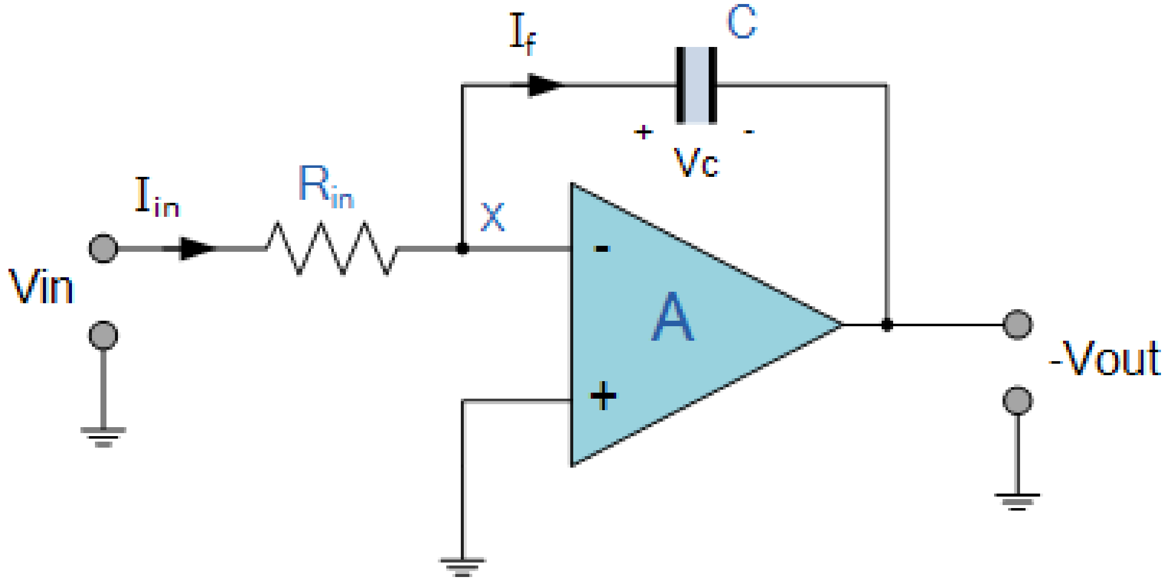
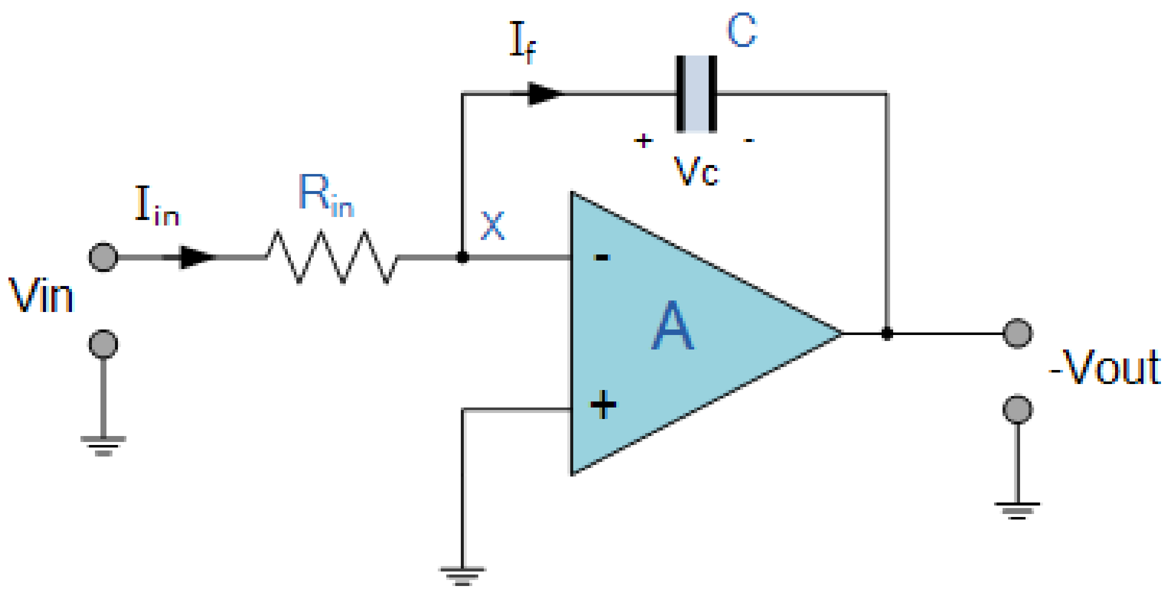


$$V_{out}(t) = -\frac{1}{R_{in}C}\int_0^t V_{in}(t)dt$$

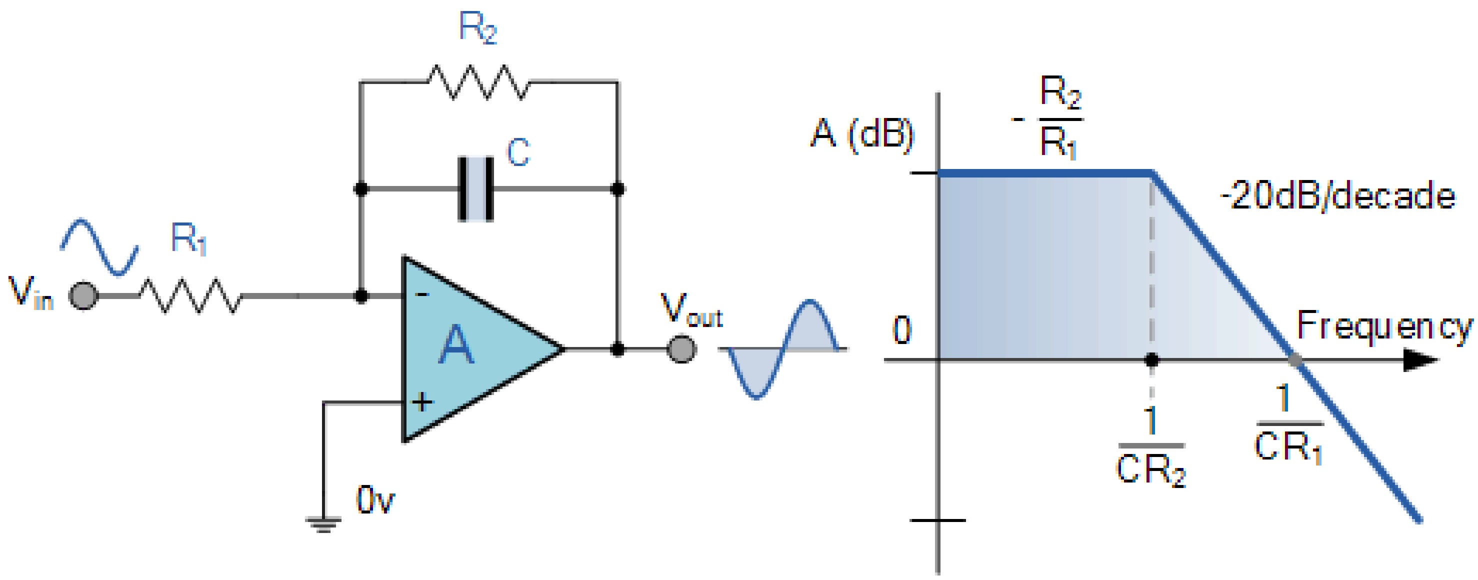
Integrator Circuit



$$V_{out}(t) = -\frac{1}{R_{in}C}\int_0^t V_{in}(t)dt$$

$$V_{out}(\omega) = -\frac{1}{j\omega R_{in}C}V_{in}(\omega)$$

Practical Integrator Circuit



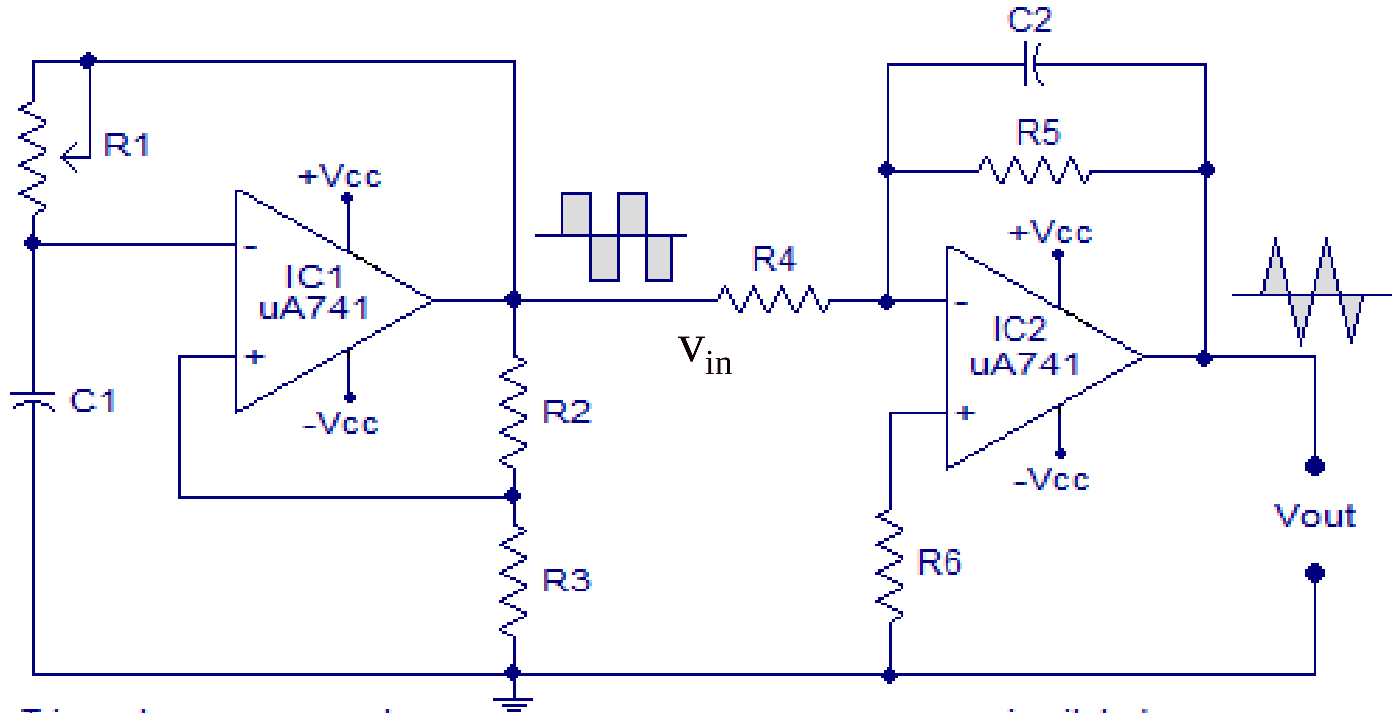
Practical Integrator Circuit

$$\text{DC Voltage Gain } (A_{v0}) = -\frac{R_2}{R_1}$$

$$\text{AC Voltage Gain } (A_v) = -\frac{R_2}{R_1} \times \frac{1}{(1+\omega C R_2)}$$

$$\text{Corner Frequency } (\omega_0) = \frac{1}{C R_2}$$

Triangular Wave Generator



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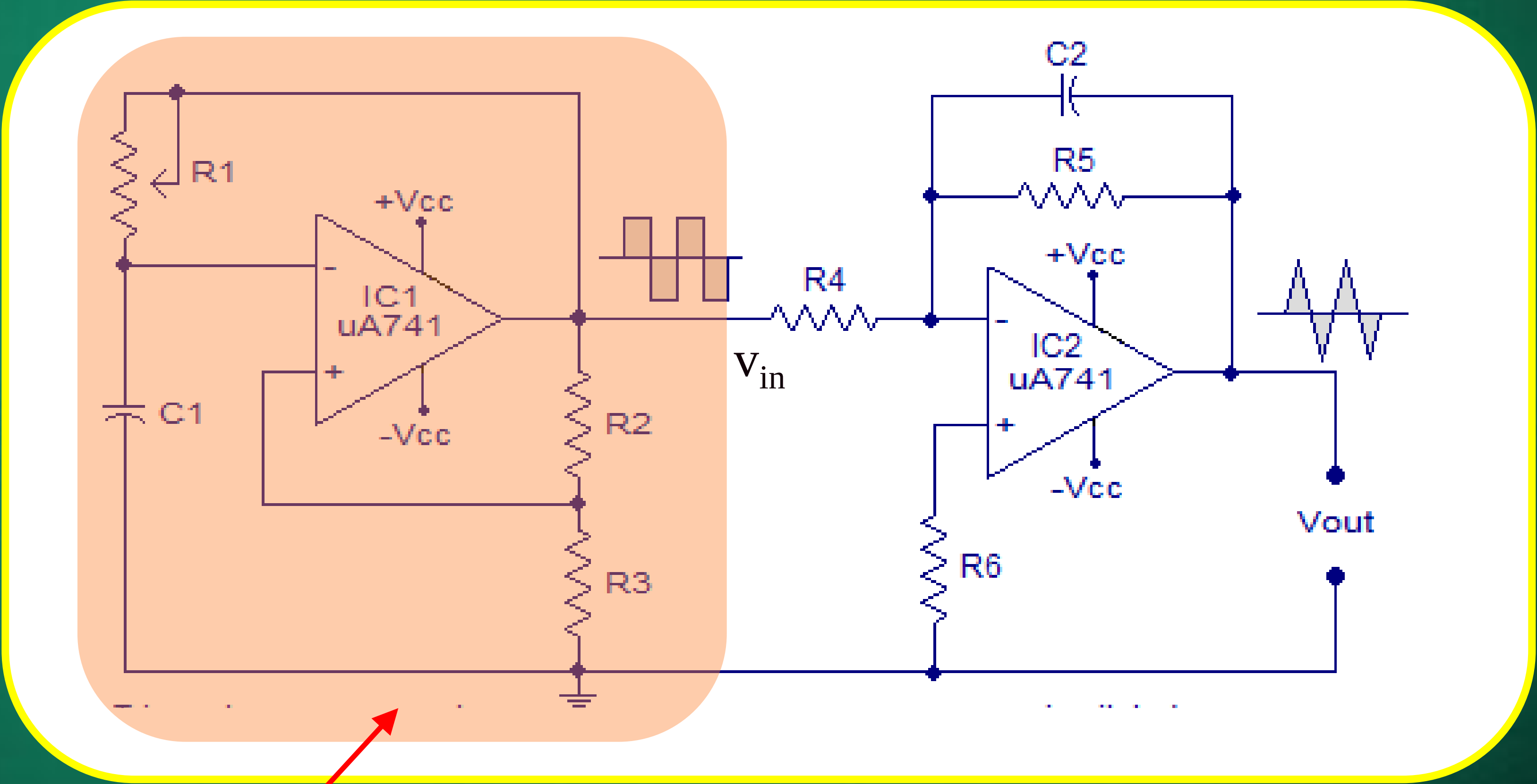
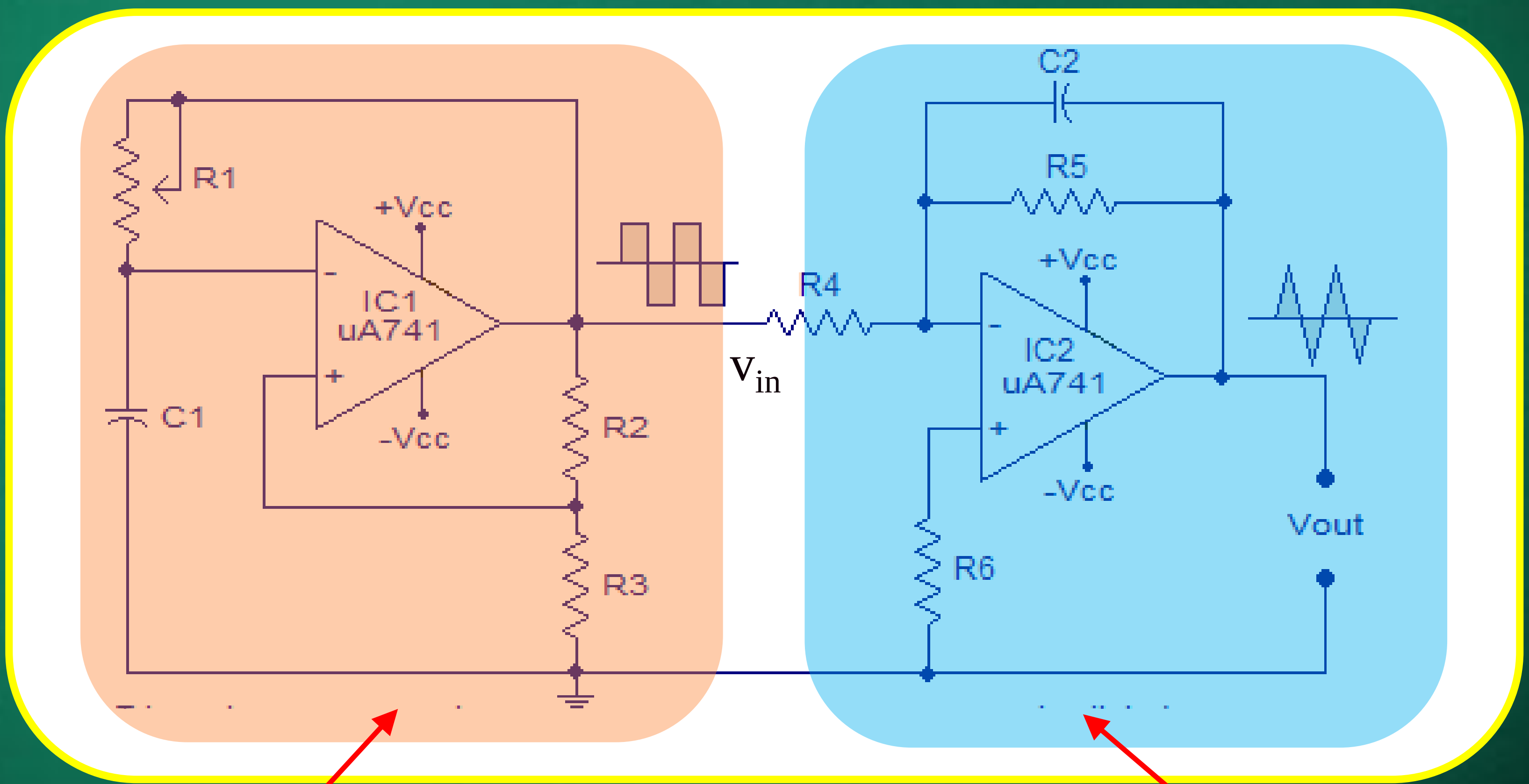


Square Wave Generator

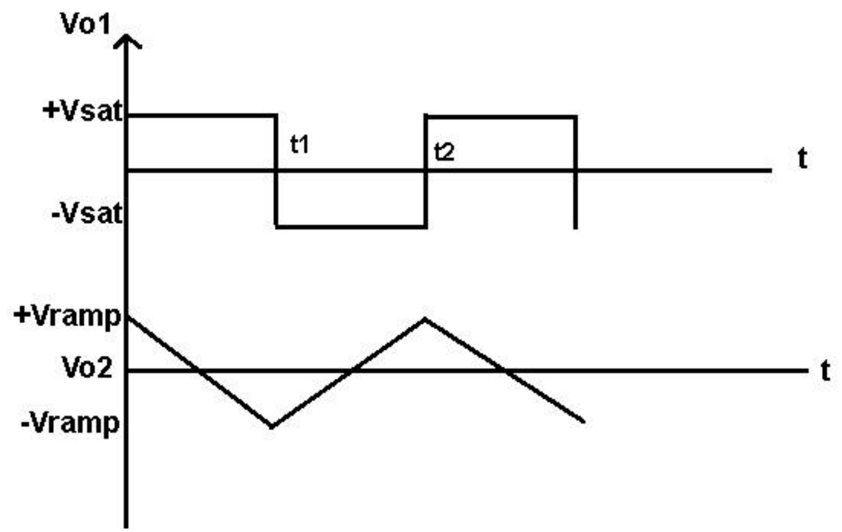
Triangular Wave Generator



Square Wave Generator

Integrator

Triangular Wave Generator



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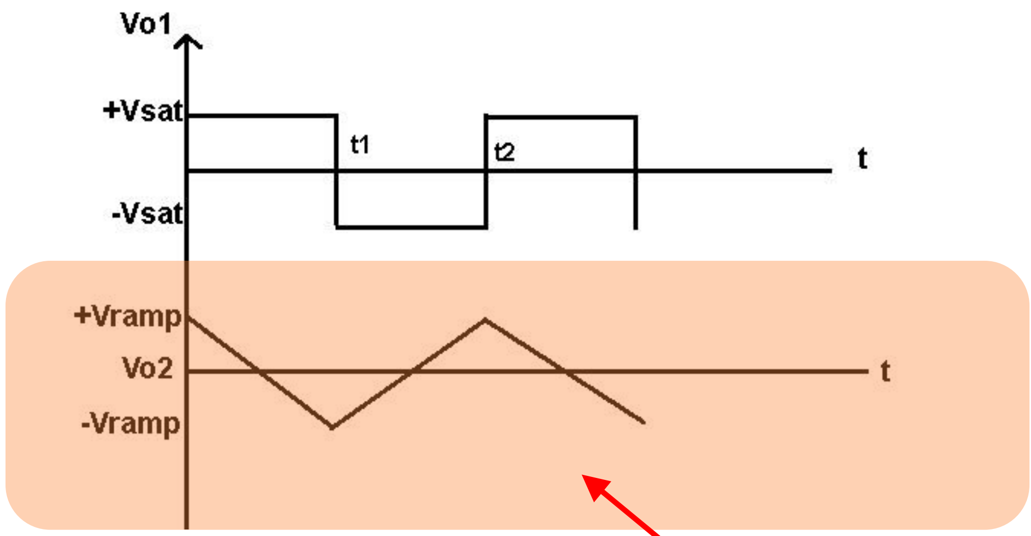
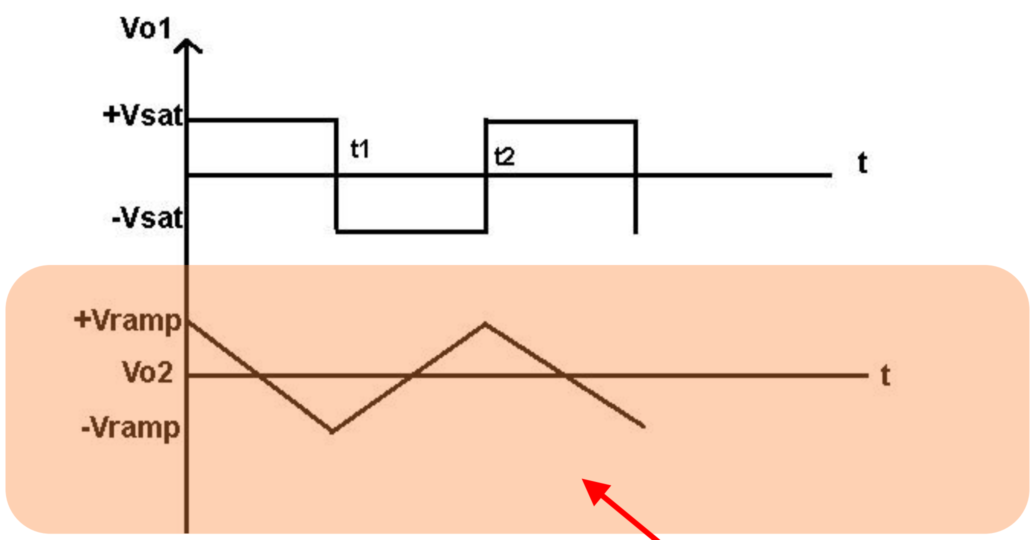


V_{out}

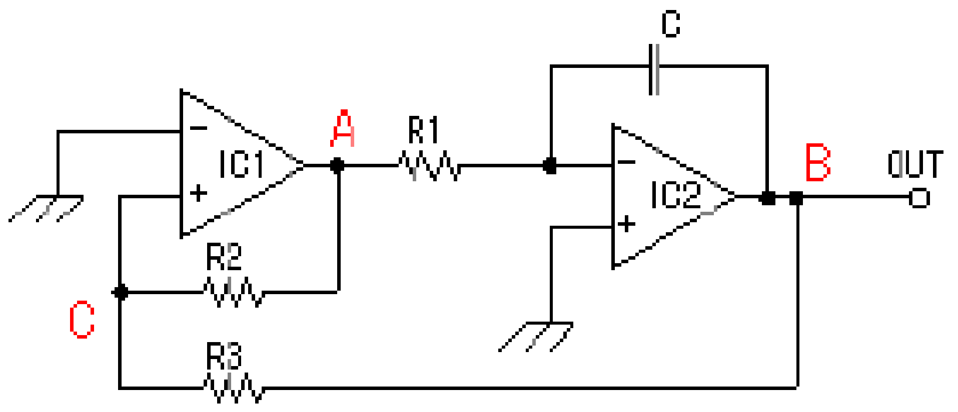
Triangular Wave Generator



$$V_{out} = \left(\frac{-R_5 / R_4}{R_5 C_2 s + 1} \right) V_{in}$$

V_{out}

Triangular Wave Generator



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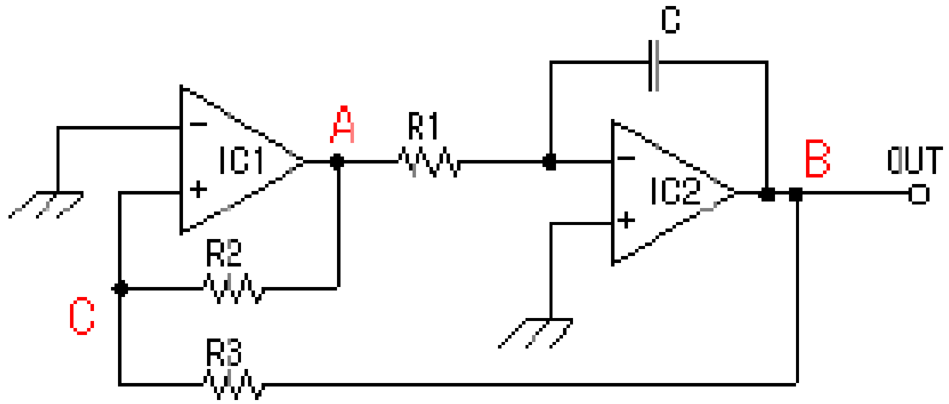
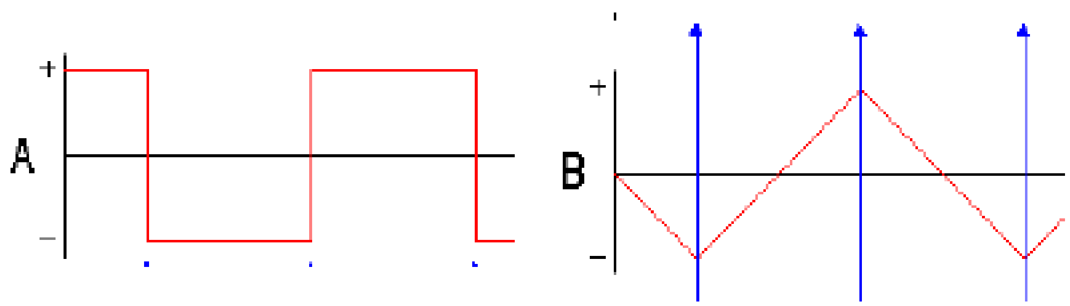
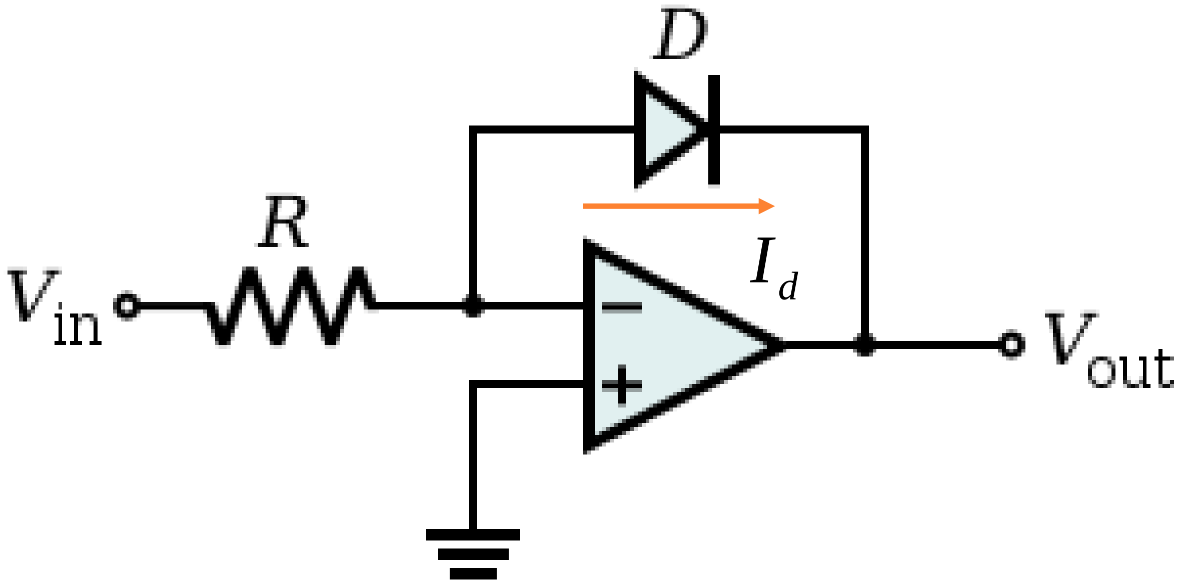




Log and Antilog Amplifier

Logarithmic Amplifier



Diode Equation

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i_D = the net current flowing through the diode;
I_0 = "dark saturation current", the diode leakage current in the absence of light;
v_D = applied voltage across the terminals of the diode;
q = absolute value of electron charge (1.6×10^{-19} C);
k = Boltzmann's constant (1.38×10^{-23} J/K);
T = absolute temperature in Kelvin (K); and
n = empirical constant, 1 for Ge and 2 for Si diode.

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At 300 K, kT/q = 26 mV, the thermal voltage.

Diode Equation

$$i_D = I_0\left(e^{\left(\frac{v_D}{0.026}\right)} - 1\right)$$

where v_D is the voltage applied across diode in volts.

If diode is forward biased

$$i_D \cong I_0 e^{\left(\frac{v_D}{0.026}\right)}$$

Analysis

Applying KCL at inverting input

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$$\frac{0 - \mathrm{V_{in}}}{R} + I_d = 0 \Rightarrow I_d = \frac{\mathrm{V_{in}}}{R}$$

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But

$$I_d=I_0\left(e^{(v_d/v_T)}-1\right)$$

Analysis

Applying KCL at inverting input

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But

$$I_d = I_0(e^{(v_d/v_T)}-1)$$

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$$I_0 e^{(-v_{out}/v_T)} = \frac{V_{in}}{R}$$

Analysis

Here $v_d = -v_{out}$

$$\therefore I_d = I_0 e^{(-v_{out}/v_T)}$$

$$I_0 e^{(-v_{out}/v_T)} = \frac{V_{in}}{R}$$

$$e^{(-v_{out}/v_T)} = \frac{V_{in}}{I_0 R}$$

Analysis

Here $v_d = -v_{out}$

$$\therefore I_d = I_0 e^{(-v_{out}/v_T)}$$

$$I_0 e^{(-v_{out}/v_T)} = \frac{V_{in}}{R}$$

$$e^{(-v_{out}/v_T)} = \frac{V_{in}}{I_0 R}$$

$$v_{out} = -v_T \ln\left(\frac{V_{in}}{I_0 R}\right) = k_1 \ln\left(\frac{V_{in}}{k_2}\right)$$

Analysis

Here $v_d = -v_{out}$

$$\therefore I_d = I_0 e^{(-v_{out}/v_T)}$$

$$I_0 e^{(-v_{out}/v_T)} = \frac{V_{in}}{R}$$

$$e^{(-v_{out}/v_T)} = \frac{V_{in}}{I_0 R}$$

$$v_{out} = -v_T \ln\left(\frac{V_{in}}{I_0 R}\right) = k_1 \ln\left(\frac{V_{in}}{k_2}\right)$$

where $k_1 = -v_T$ and $k_2 = I_0 R$