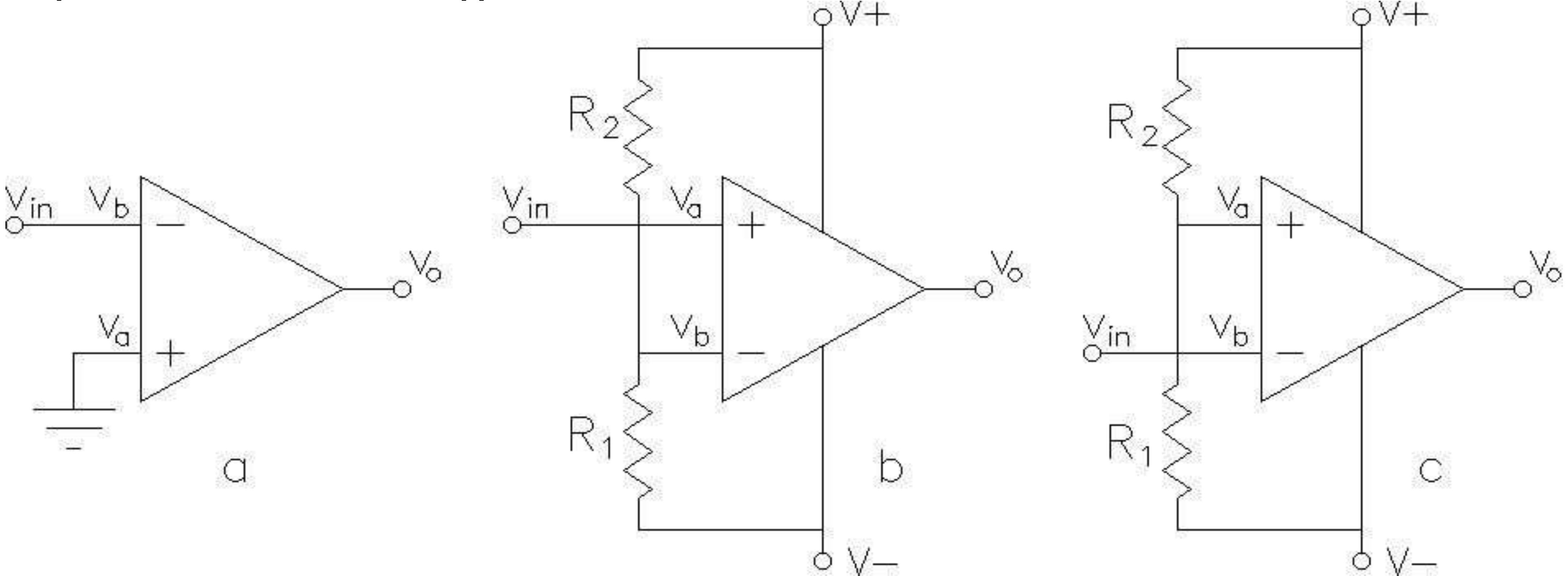
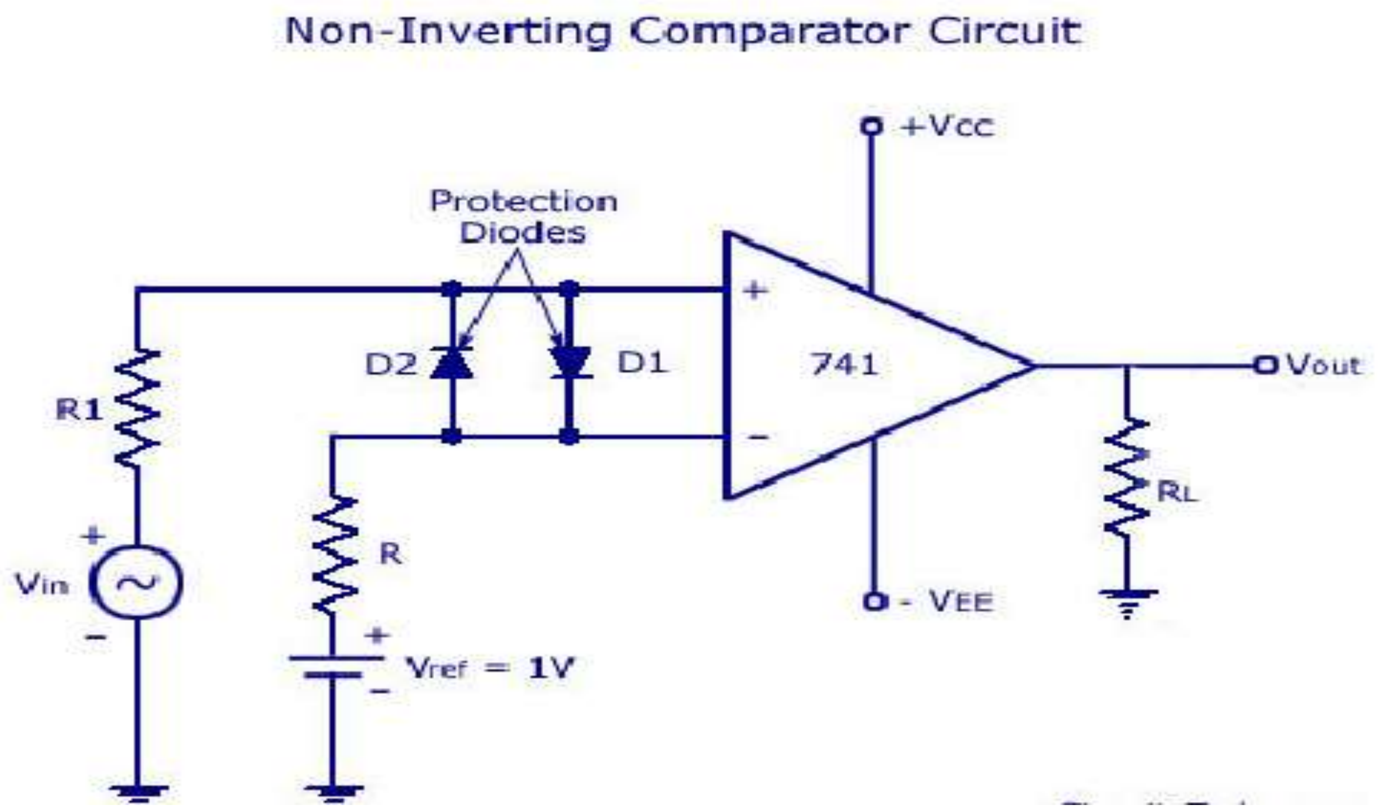
- **Module 3 : Non-Linear Applications of Op-amp**

  3.1 Comparators :

  A Voltage comparator circuit : A Voltage comparator is a circuit which compares two voltages and switches the output to either high or low state depending upon which voltage is higher.

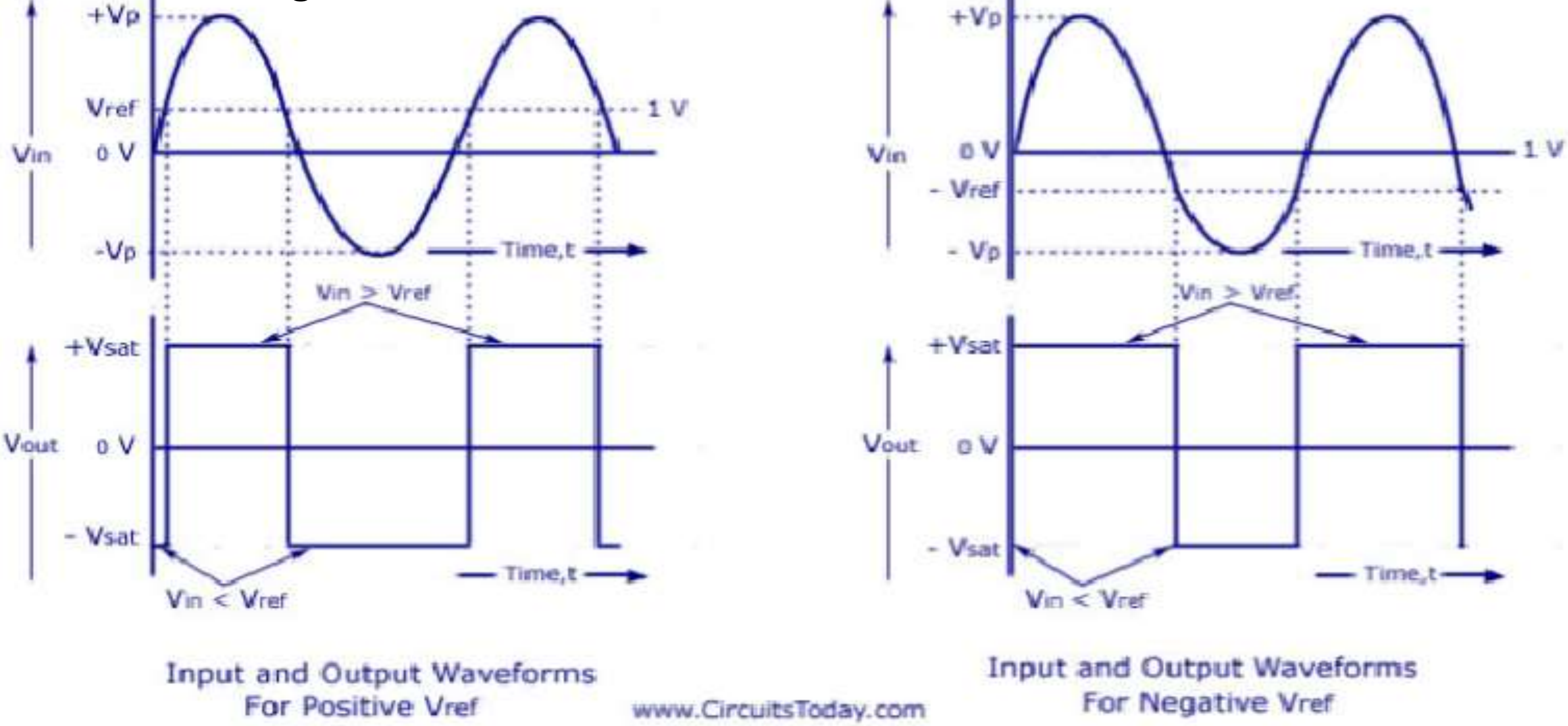
  A voltage comparator based on op-amp is shown in fig a. Fig b shows a voltage comparator in non- inverting mode and Fig c. shows a voltage comparator in inverting mode.



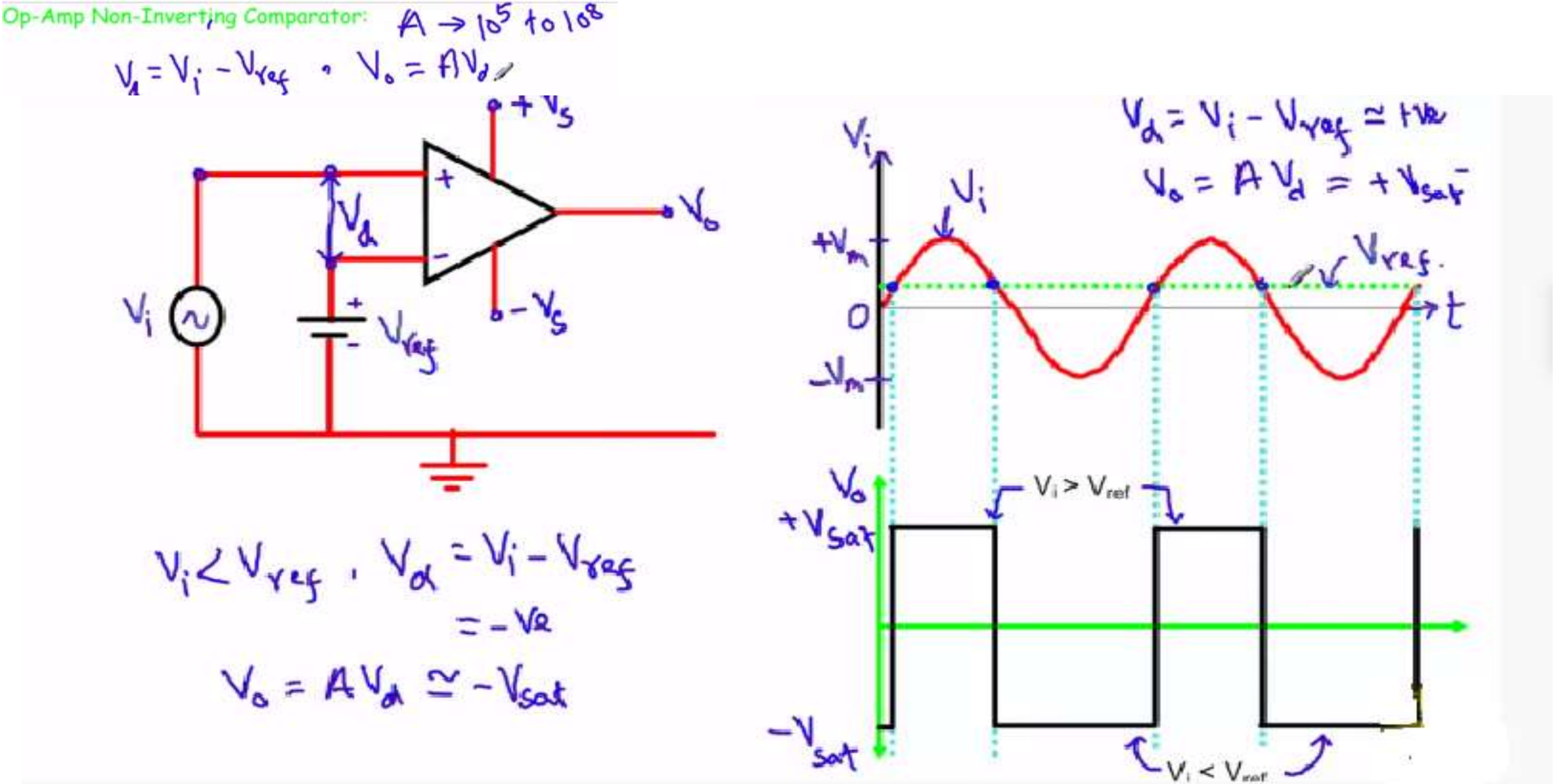


- In non-inverting comparator the reference voltage is applied to the inverting input and the voltage to be compared is applied to the non-inverting input. Whenever the voltage to be compared (Vin) goes above the reference voltage, the output of the op-amp swings to positive saturation (V+) and vice versa. Actually what happens is that, the difference between Vin and Vref, (Vin **–** Vref) will be a positive value and is amplified to infinity by the op-amp.

- Since there is no feedback resistor Rf, the op-amp is in open loop mode and so the voltage gain (Av) will be close to infinity. So the output voltage swings to the maximum possible value ie; V+.
- When the Vin goes below Vref, the reverse occurs.



741 IC Op-Amp Non-Inverting Comparator Waveform



Op-Amp as Non-Inverting Comparator

Applications of a Comparator

- Zero crossing detector (ZCD), Window detector.
- Time marker generator, Phase detector.

❖ MCQ: If the input to the circuit of figure is a sine wave the output will be

Options are: A) A Half-wave rectified sine wave B) A Full-wave rectified sine wave

C) Triangular wave D) Square wave

Comparator Characteristics :

1. **Operation Speed** – According to change of conditions in the input, a comparator circuit switches at a good speed between the saturation levels and the response is instantaneous.

2. **Accuracy** – Accuracy of the comparator circuit causes the following characteristics:-

(a) **High Voltage Gain** – The comparator circuit is said to have a high voltage gain characteristic that results in the requirement of smaller hysteresis voltage. As a result the comparator output voltage switches between the upper and lower saturation levels.

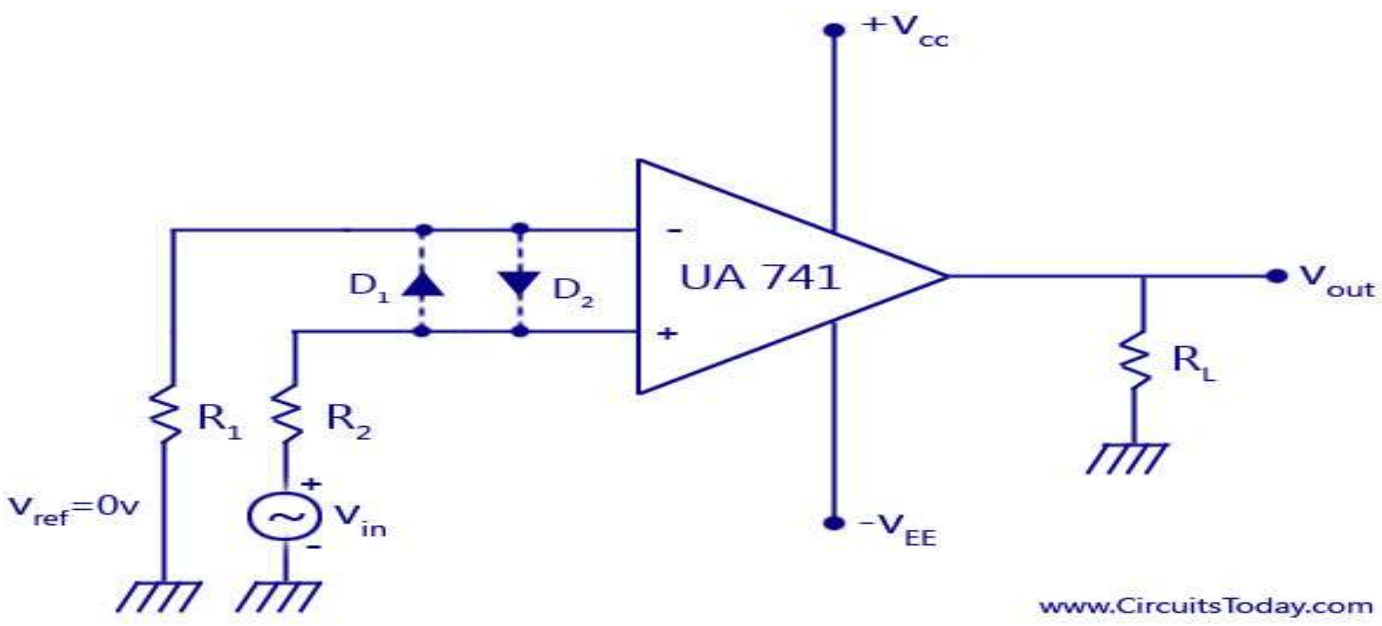
b) **High Common Mode Rejection Ratio (CMRR)** – The common mode input voltage parameters such a noise is rejcted with the help of a high CMRR.

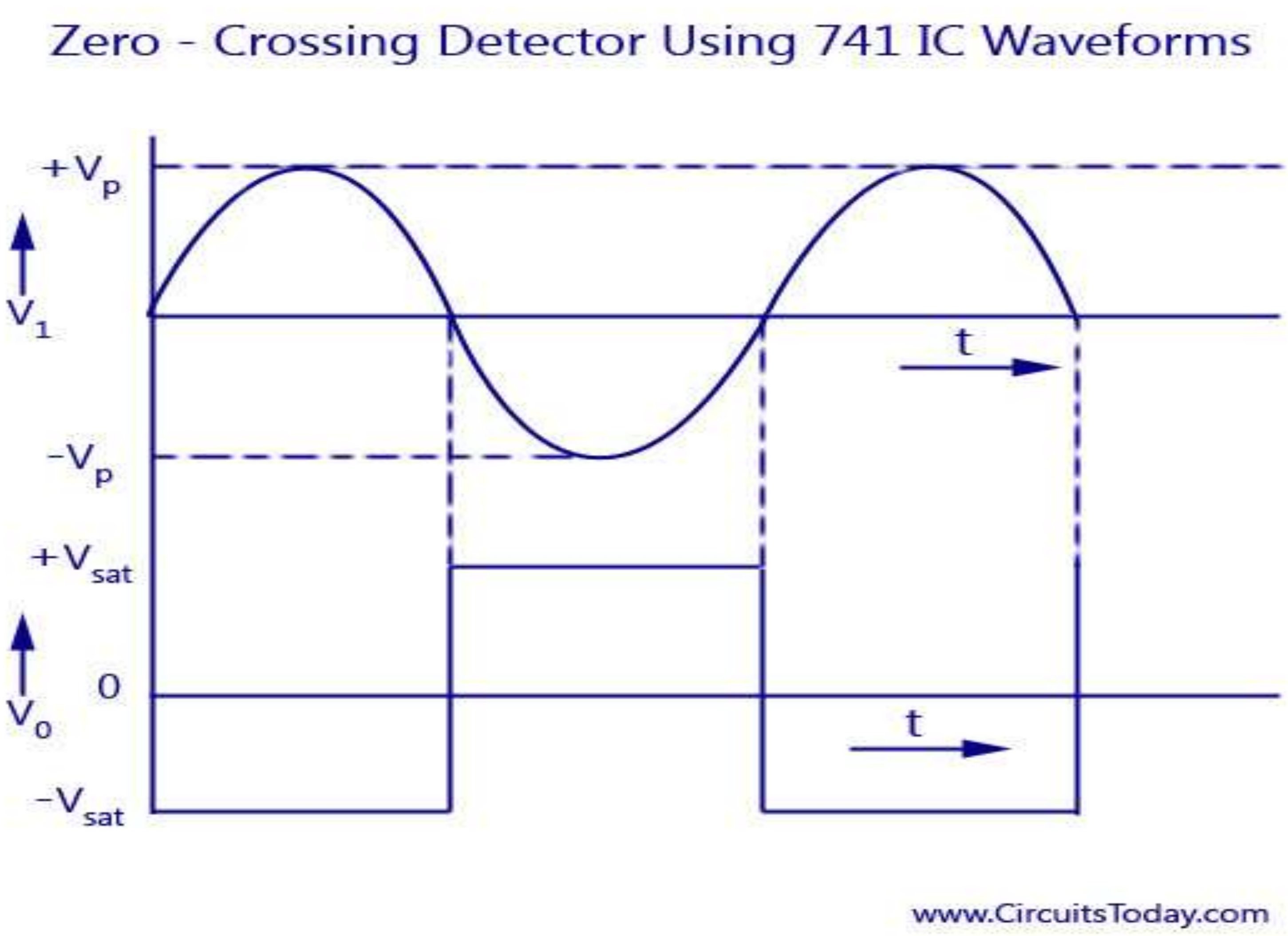
(c) **Very Small Input Offset Current and Input Offset Voltage** – A negligible amount of Input Offset Current and Input Offset Voltage causes a lesser amount of offset problems.

1. Zero crossing detector

- The zero crossing detector circuit is an important application of the **op-amp comparator circuit**.
- It can also be called as the sine to square wave converter.
- Anyone of the inverting or non-inverting comparators can be used as a zero-crossing detector.
- The only change to be brought in is the reference voltage with which the input voltage is to be compared, must be made zero (Vref = 0V).
- An input sine wave is given as Vin. These are shown in the circuit diagram and input and output waveforms of an inverting comparator with a 0V reference voltage.

Zero Crossing Detector Using UA 741 op-amp IC





❖ **MCQ** The zero crossing detector circuit plays a crucial role in conversion of input sine wave into a perfect --------- at its output.

Options are : A) Triangular wave B) Square wave C) Saw-tooth wave D) Pulse wave .

Schmitt trigger or squaring circuit.

Figure shows an Inverting comparator with positive feedback.

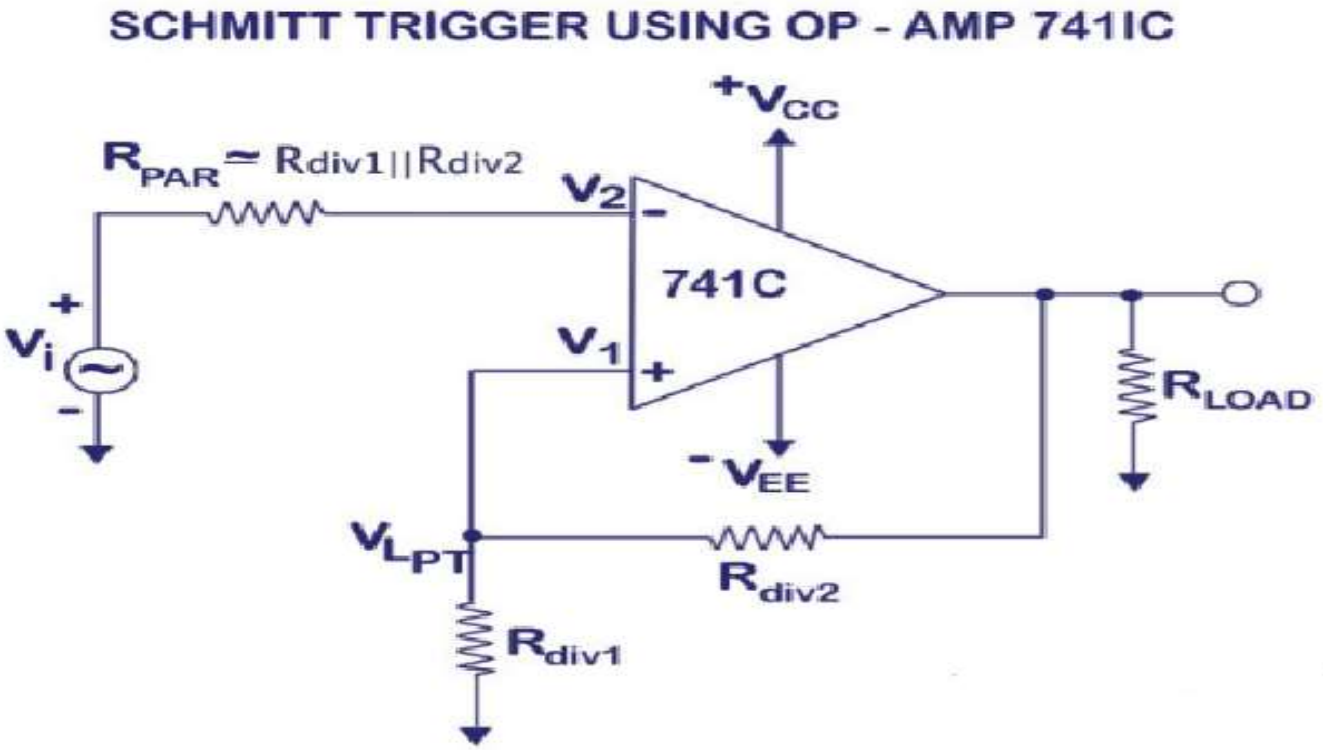
This circuit converts an irregular-shaped waveform to a square wave.

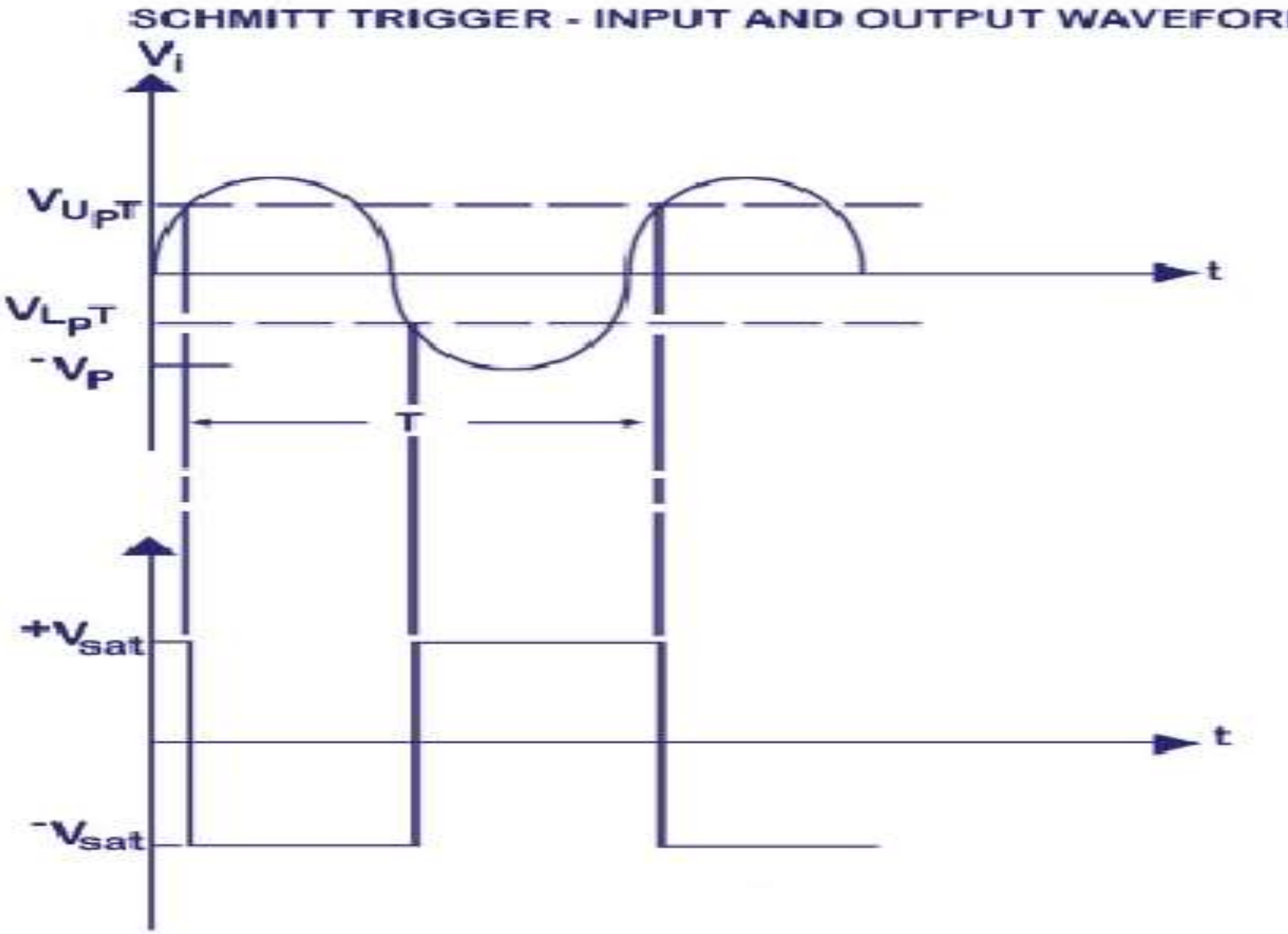
The circuit is known as **Schmitt trigger or squaring circuit.**

The input voltage Vin triggers the output Vo every time it exceeds certain voltage levels called the **upper threshold voltage Vut & lower threshold voltage Vlt**.

Where, $Vut = [R_1 / (R_1 + R_2)] * (+Vsat)$ = **upper threshold voltage Vut**

$Vlt = [R_1 / (R_1 + R_2)] * (^{-}Vsat)$ = **lower threshold voltage Vlt**.



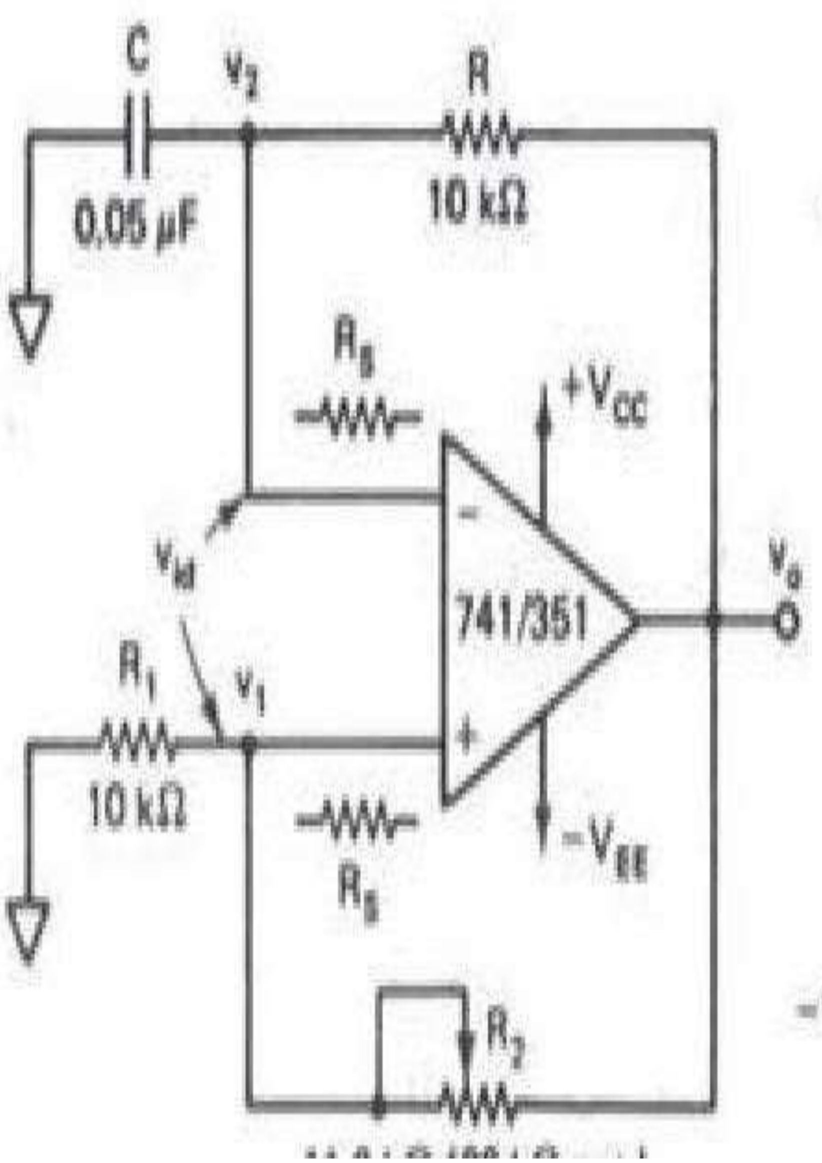


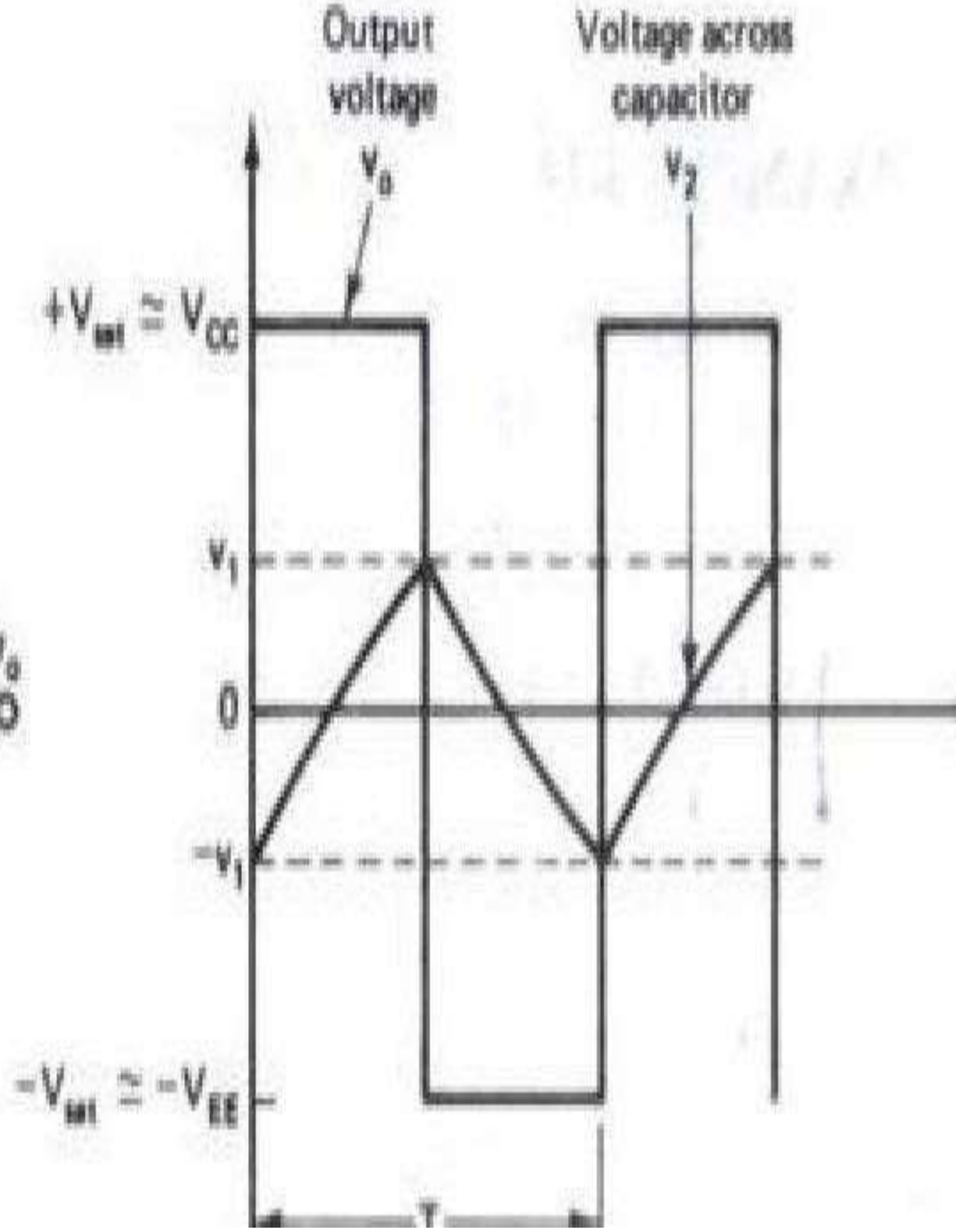
❖ MCQ : Which circuit converts irregularly shaped waveform to regular shaped waveforms? Options are : A) Schmitt trigger B) Voltage limiter C) Comparator D) Subtractor

❖ MCQ : When a large sine wave drives a Schmitt trigger, the output is a Rectangular wave Options are : A) Rectangular wave B) Triangular wave B) Rectified sine wave C) Series of ramps

Square Wave Generator using OP-AMP 741 IC :

This square wave generator is also called a **free-running** or **a stable multi vibrator**. The output of the op-amp in this circuit will be in positive or negative saturation, depending on whether the differential voltage **vid** is negative Or positive, respectively





- **Working of the Circuit :**
- Assume that the voltage across capacitor C is zero volts at the instant the dc supply voltages +VCC and -VEE are applied.
- This means that the voltage at the **Inverting terminal** is zero initially. At the same instant, however, the voltage V1 at then **Non-inverting terminal** is a very small finite value that is a function of the output offset voltage VOOT and the values of R1 and R2 resistors.
- Thus the differential input voltage Vid is equal to the voltage V1 at the Non-inverting terminal. Although very small, voltageV1 will start to drive the op-amp into saturation.
- For example, suppose that the output offset voltage VOOT is positive and that, therefore, voltage V1 is also positive.
- Since initially the capacitor C acts as a short circuit, the gain of the op-amp is very large (A); hence V1 drives the output of the op-amp to its positive saturation **+Vsat**.
- With the output voltage of the op-amp at +Vsat, the capacitor C starts charging toward +Vsat through resistor R.
- However, as soon as the voltage V**2** across capacitor C is slightly more positive than V1, the output of the op-amp is forced to switch to a negative saturation, -Vsat. With the op-**amp's** output voltage at negative saturation, -Vsat, the voltage v1 across R1 is also negative, since

Working of circuit:

- For generation of square wave the OPAMP is forced to operate in its saturation region.
- The voltage available at **Non-inverting input of OP-AMP** is obtained by potential-divider action.

$V_1 = (R_1/R_1 + R_2)\ V_o$ --------- Vo = +Vsat initially

Now , $V_1 = \beta * V_o$, where $\beta = R_1/(R_1 + R_2)$ = feedback factor

- The o/p Vo, is also feedback to Inverting I/p terminal where I/p voltage obtained is given by

$V_c = V2 = (1/RC) \int V_o\, dt.$

- Whenever Vc > V1 > $\beta\ V_o$ Switching takes place and square wave output is available from comparator developed by op-amp.
- Theoretically: $\mathbf{f_o = 1/ 2RC}$ ------ (Assuming, $\mathbf{R_2 = 2R_1}$)
- Practically: $\mathbf{f_o = 1 /T}$

- **MCQ** : **Q1)** How are the square wave output generated in op-amp?

Options are: A) Op-amp is forced to operate in the positive saturation region

B) Op-amp is forced to operate in the negative saturation region

C) Op-amp is forced to operate in the positive and negative saturation region

D) None of the mentioned

Q2) An Astable multivibrator using op-amp has f_o =1kHz. Assume the resistor value to be 10kΩ, find the capacitor value. Use R2=1.16 R1

Options are: A) 3.9 uF B) 0.3 uF C) 2uF D) 0.05 uF

Q3) To design a square wave generator using OP-AMP 741 IC for f=700Hz.

Derivation for frequency of Square wave

The frequency is determined by the time it takes the capacitor to charge from $-\beta V_{sat}$ to $+\beta V_{sat}$ and vice versa. The voltage across the capacitor as a function of time is given by,

$$v_c(t) = V_f + (V_i - V_f)e^{-t/RC} \tag{5.4}$$

where, the final value, $V_f = +V_{sat}$

and the initial value, $V_i = -\beta V_{sat}$

Therefore,

$$v_c(t) = V_{sat} + (-\beta V_{sat} - V_{sat})\, e^{-t/RC}$$

or

$$v_c(t) = V_{sat} - V_{sat}\,(1 + \beta)\, e^{-t/RC} \tag{5.5}$$

At $t = T_1$, voltage across the capacitor reaches βV_{sat} and switching takes place. Therefore,

$$v_c(T_1) = \beta V_{sat} = V_{sat} - V_{sat}\,(1 + \beta)\, e^{-T_1/RC} \tag{5.6}$$

After algebraic manipulation, we get,

$$T_1 = RC \ln \frac{1+\beta}{1-\beta} \tag{5.7}$$

This give only one half of the period.

Total time period

$$T = 2T_1 = 2RC \ln \frac{1+\beta}{1-\beta} \tag{5.8}$$

and the output wave form is symmetrical.

If $R_1 = R_2$, then $\beta = 0.5$, and $T = 2RC \ln 3$. And for $R_1 = 1.16R_2$, it can be seen that $T = 2\,RC$

or

$$f_0 = \frac{1}{2RC} \tag{5.9}$$

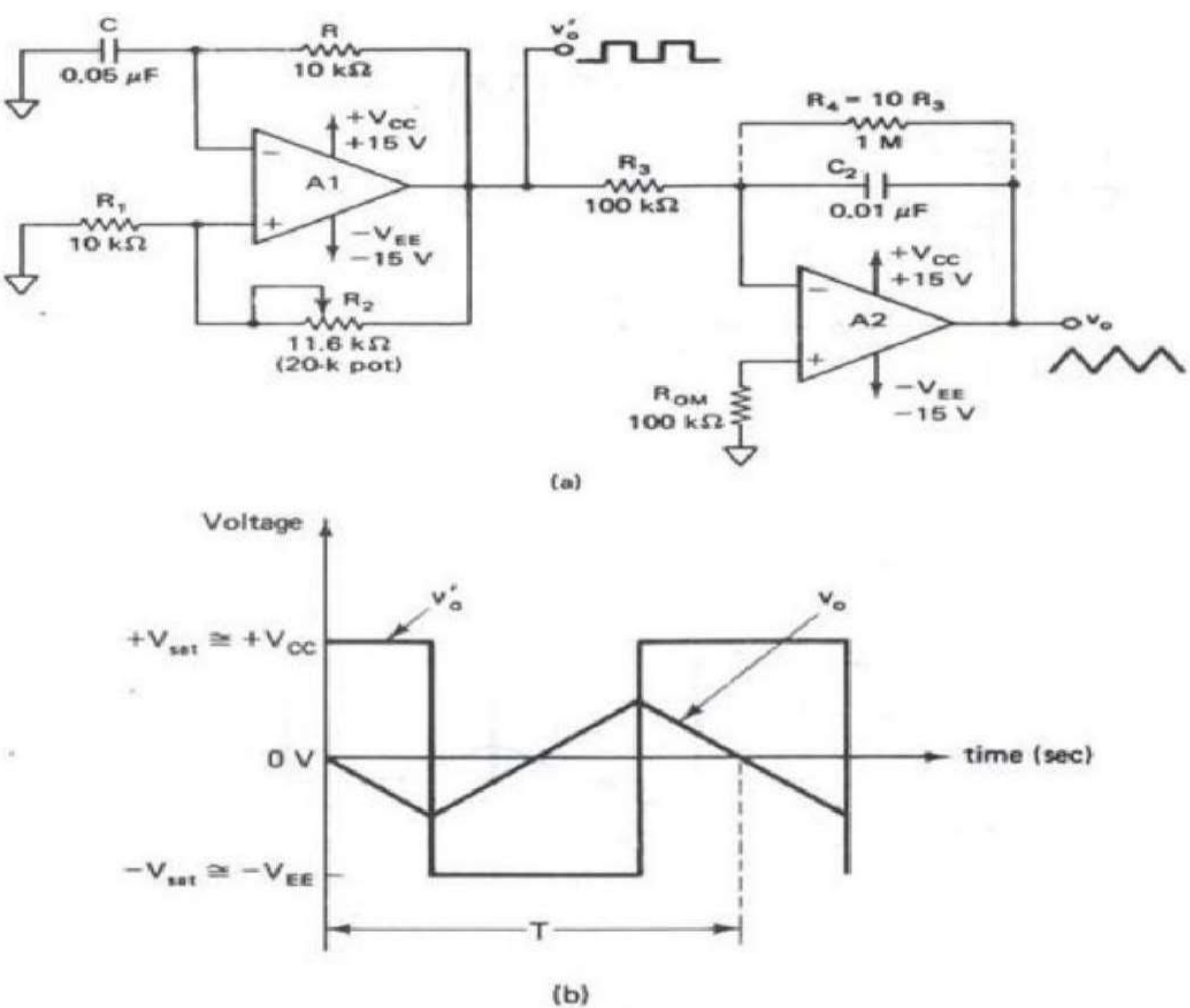
The output swings from $+V_{sat}$ to $-V_{sat}$, so,

$$v_o \text{ peak-to-peak} = 2\,V_{sat}$$

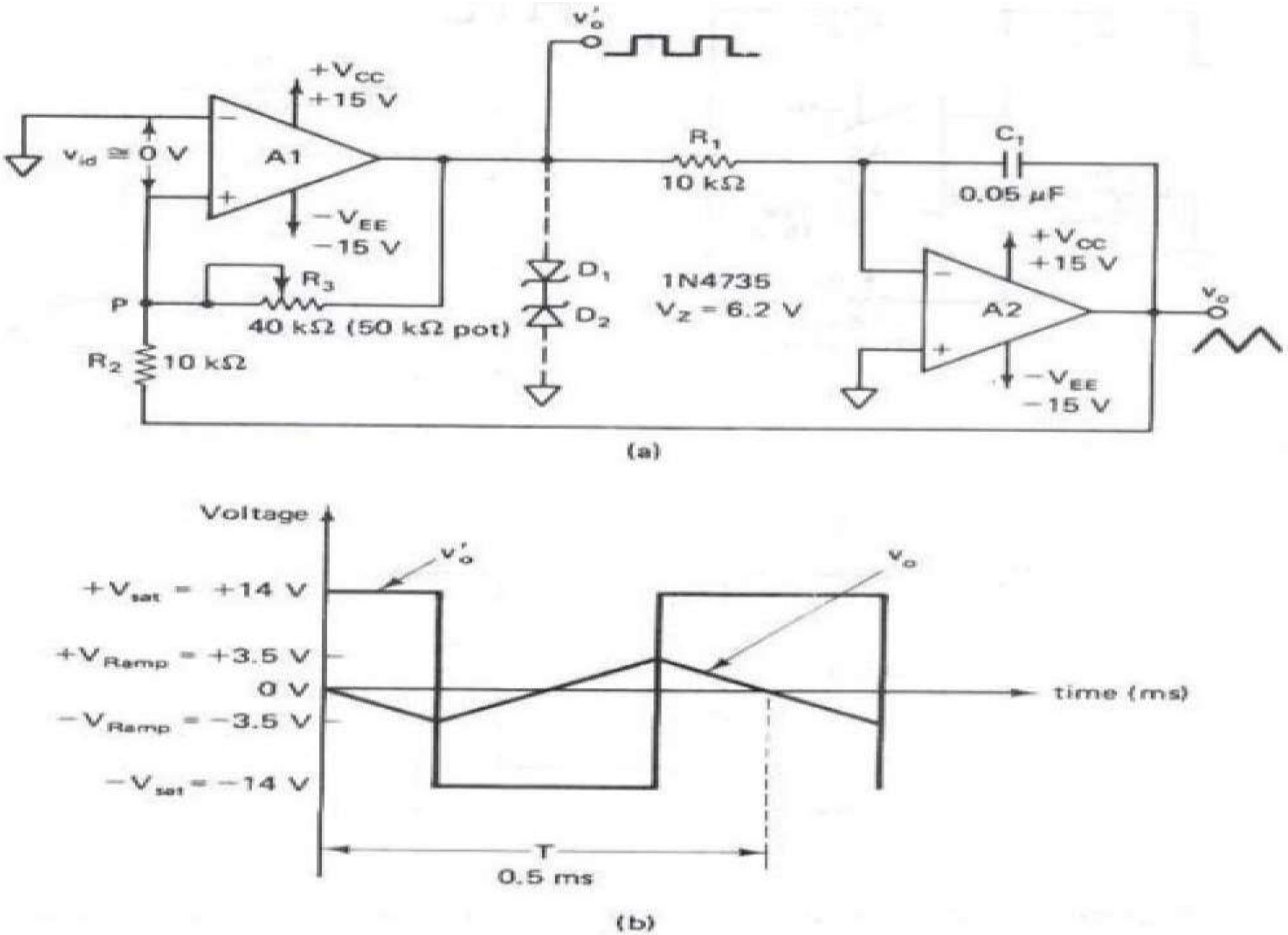
Triangular Wave Generator using Square wave generator and Integrator

Recall that the output waveform of the integrator is triangular if its input is a square wave. This means that a triangular wave generator can be formed by simply connecting an integrator to the square wave generator. The resultant circuit is shown in Figure. This circuit requires a dual op-amp, two capacitors, and at least five resistors.

The frequencies of the square wave and triangular wave are the same. For fixed R1, R2, and C values, the frequency of the square wave as well as the triangular wave depends on the resistance R.

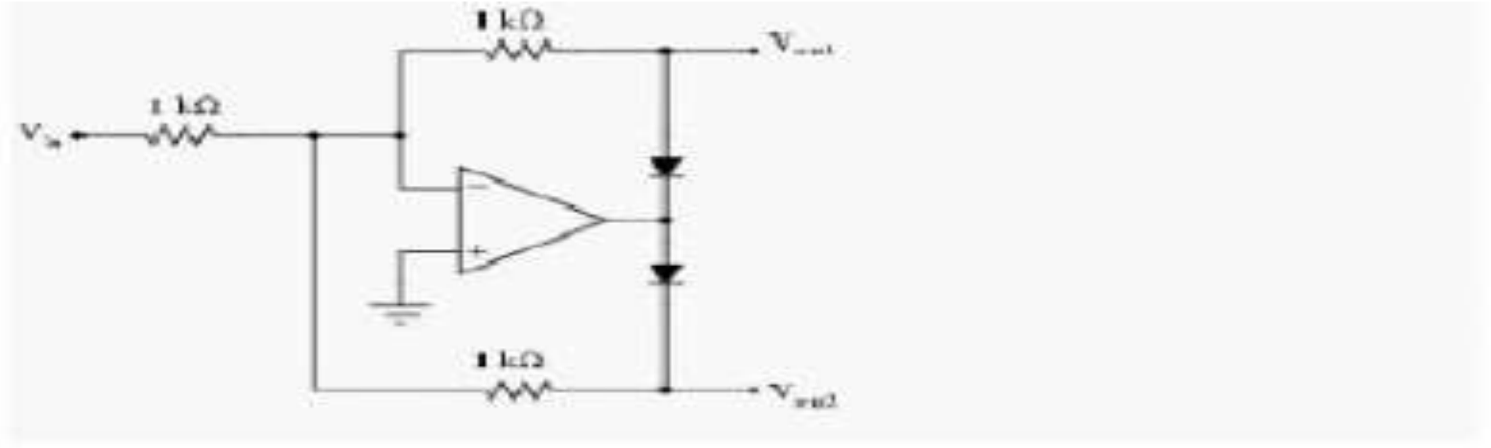


Triangular Wave Generator using Comparator and Integrator



Precision Rectifiers types : 1) Full wave Rectifier

MCQ. Select the following option for following circuit, if Diodes are ideal and Vin = + Vp



Options are: A) Vout1= -2Vp, Vout2= 0 Vp

B) Vout1= 2Vp, Vout2= -2 Vp

C) Vout1= 0 Vp , Vout2= -2 Vp

D) Vout1= 0 Vp, Vout2= 2 Vp

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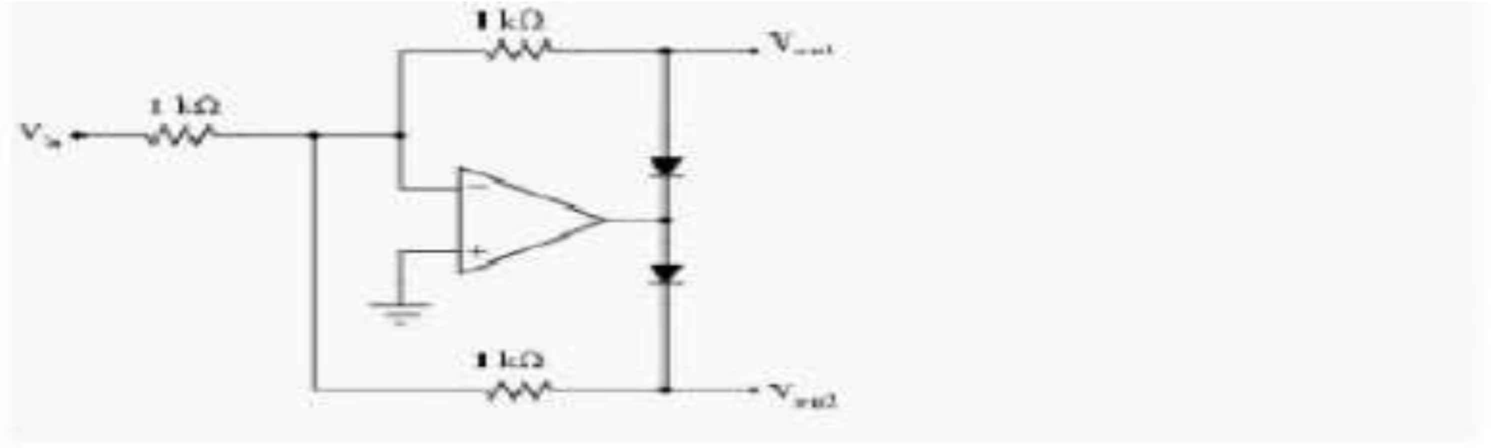

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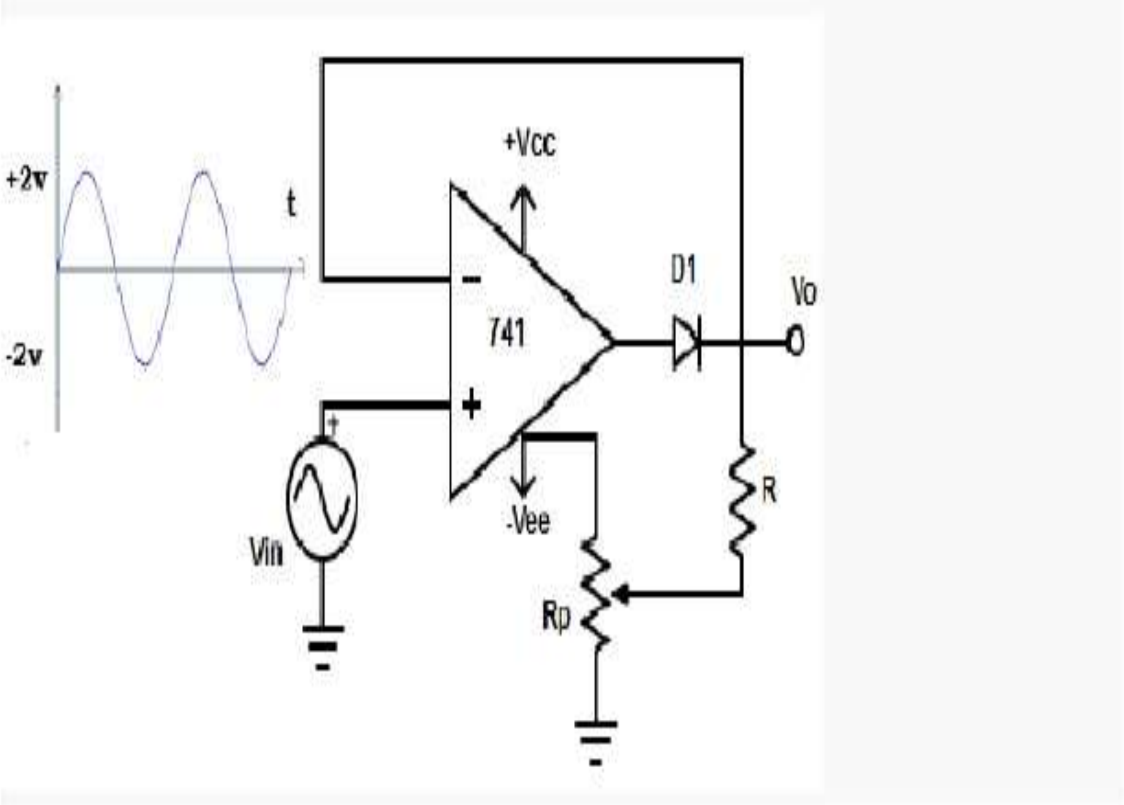
C) Vout1= 0 Vp , Vout2= -2 Vp

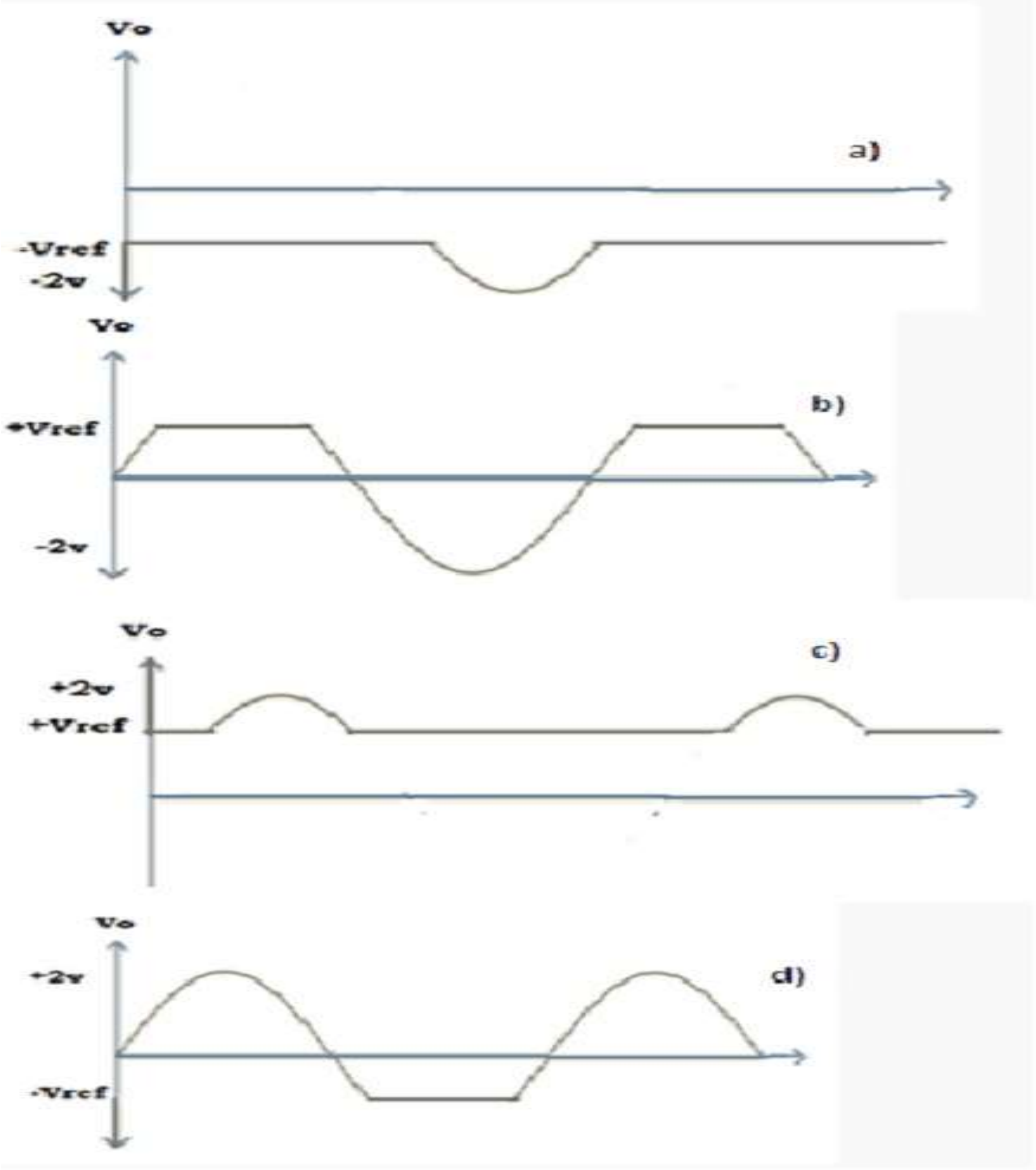
D) Vout1= 0 Vp, Vout2= 2 Vp

Precision Rectifier:

2) Half wave rectifier

MCQ: For the circuit shown below Find the output Waveforms.





Ans : d

Sample and Hold Circuits :

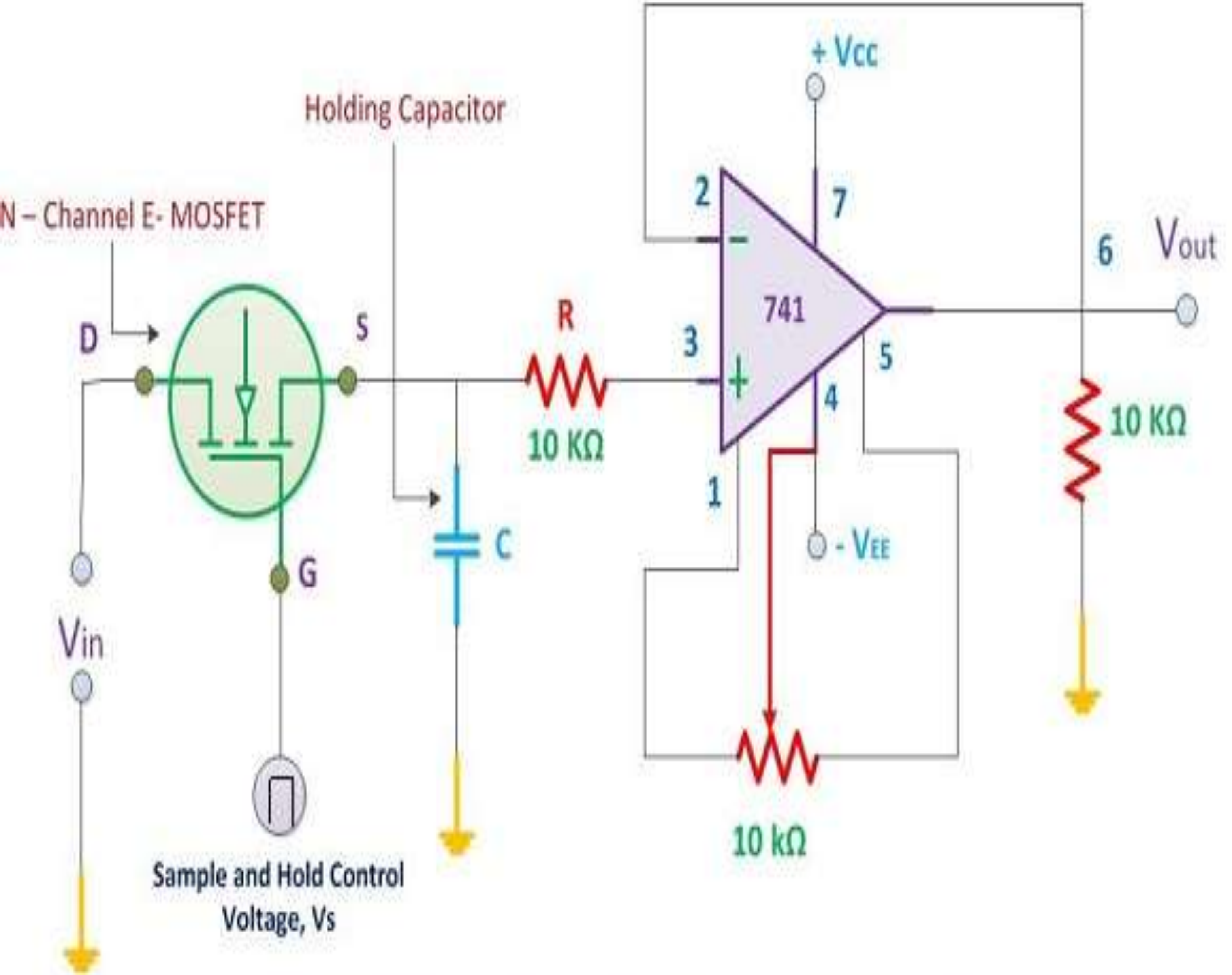
The sample and hold circuit, as its name implies samples an i/p signal and holds on to it last sampled value until the i/p is sampled again.

Below fig shows a sample and hold circuit using an op-amp with an E- MOSFET. In this circuit the E-MOSFET works as a switch that is controlled by the sample and control voltage Vs, and the capacitor C serves as a storage element.

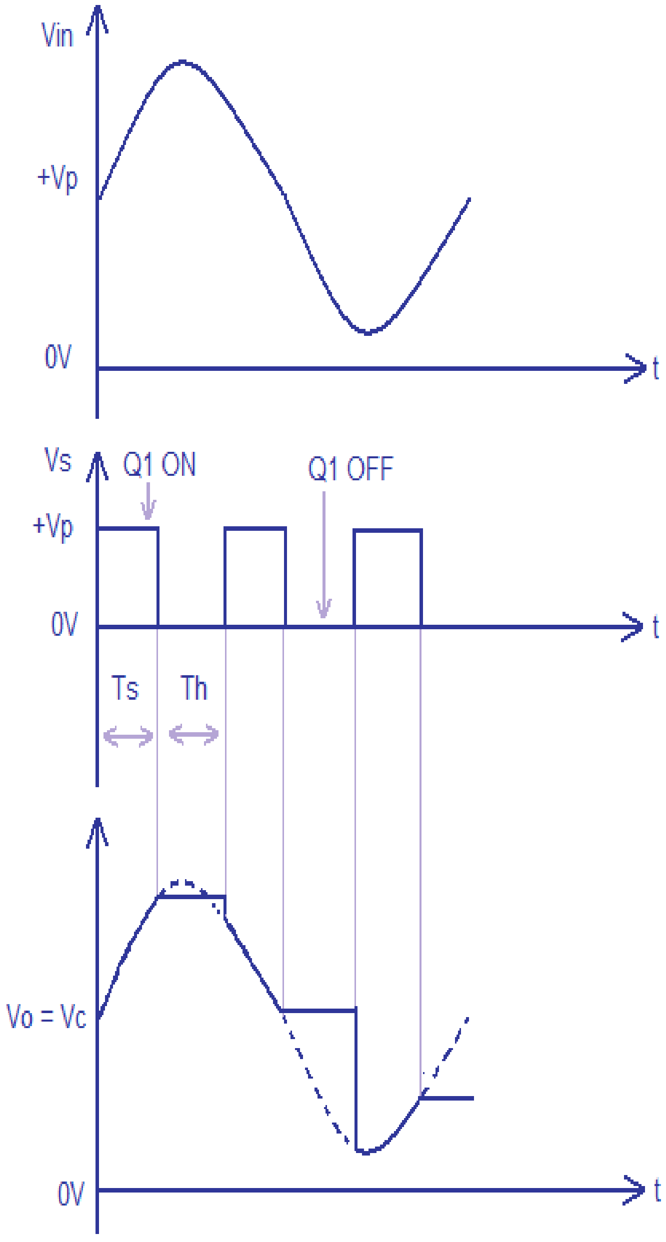
The analog signal Vin to be sampled is applied to the drain, and sample and hold control voltage Vs is applied to the gate of the E-MOSFET. During the positive portion of the Vs, the EMOSFET conducts and acts as a closed switch. This allows i/p voltage to charge capacitor C. In other words input voltage appears across C and in turn at the o/p as shown in above fig.

On the other hand, when Vs is zero, the EMOSFET is off and acts as open switch. The only discharge path for C is, through the op-amp. However the i/p resistance of the op-amp voltage follower is also very high; hence the voltage across C is retained.

The time periods Ts of the sample-and-hold control voltage Vs during which the voltage across the capacitor is equal to the i/p voltage are called sample periods. The time periods TH of Vs during which the voltage across the capacitor is constant are called hold periods. The o/p of the op-amp is usually processed/ observed during hold periods. To obtain the close approximation of the i/p waveform, the frequency of the sample-and-hold control voltage must be significantly higher than that of the i/p.

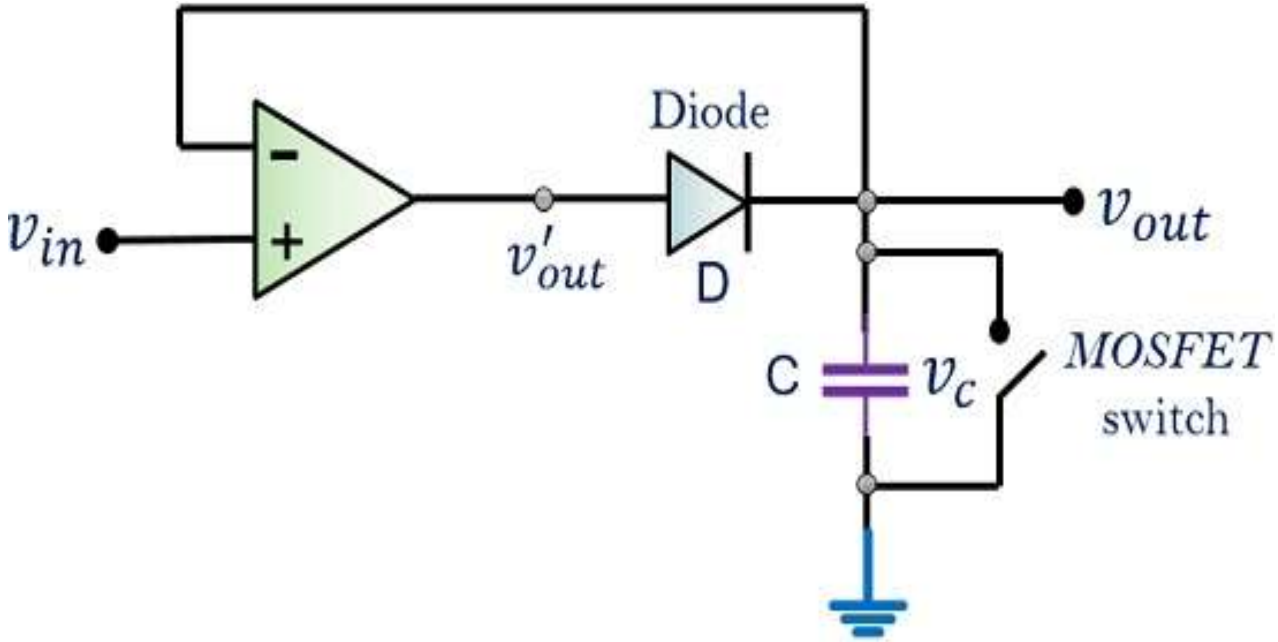


Practical Circuit of Sample and Hold Circuit



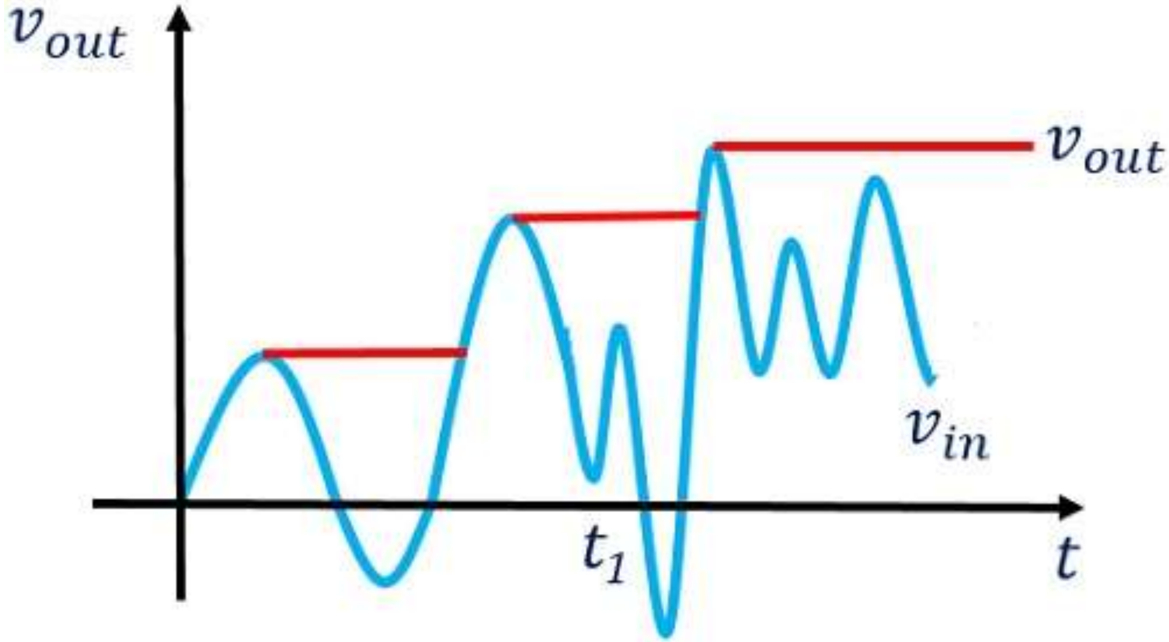
input and output waveforms

Peak detector circuit:



Peak detector circuit

Electronics Coach



Output waveform for an applied input waveform

Electronics Coach

MCQ: Q1) Among which of the following factors do the operation of sample and hold mode depend?

A) Input B) Output C)Position of switch D) TIME

Q2) In a peak detector circuit, which component holds the peak value till a higher peak value is detected ?

Options are : A) Diode B) Inductor C) Capacitor D) MOSFET switch

Q3. The most commonly used amplifier in sample and hold circuit is
A) a unity gain inverting amplifier
B) a unity gain non-inverting amplifier
C) an inverting amplifier with a gain of 10
D) an inverting amplifier with a gain of 100