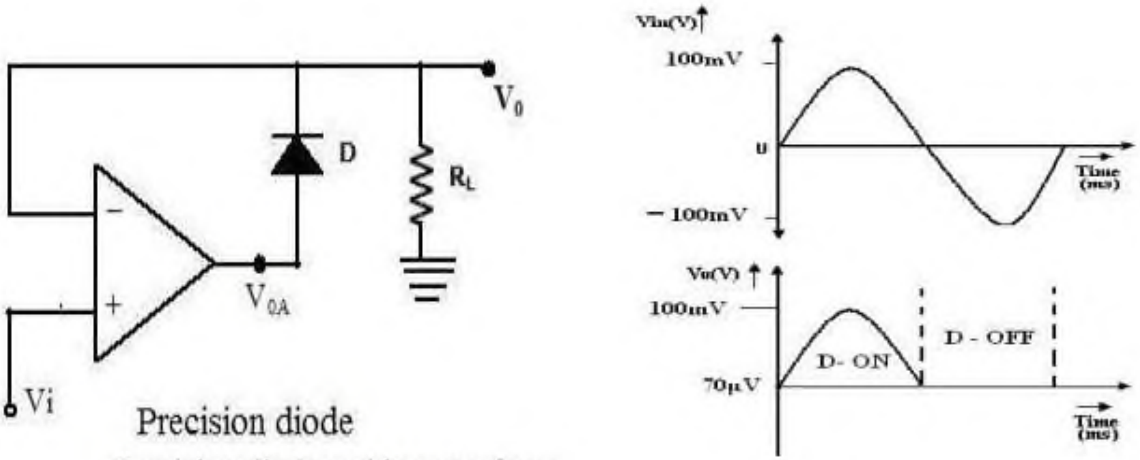
Precision Rectifier:

The ordinary diodes cannot rectify voltages below the cut-in -voltage of the diode. A circuit which can act as an ideal diode or precision signal – processing rectifier circuit for rectifying voltages which are below the level of cut-in voltage of the diode can be designed by placing the diode in the feedback loop of an op-amp.



Precision diode

Precision diode and its waveform

Precision diodes:

Figure shows the arrangement of a precision diode. It is a single diode arrangement and functions as a non-inverting precision half– wave rectifier circuit. If V_I in the circuit of figure is positive, the op-amp output V_{OA} also becomes positive. Then the closed loop condition is achieved for the op-amp and the output voltage $V_0 = Vi$. When $Vi < 0$, the voltage V_{0A} becomes negative and the diode is reverse biased. The loop is then broken and the output $V_0 = 0$.

Consider the open loop gain AOL of the op-amp is approximately 10^4 and the cut-in voltage Vγ for silicon diode is ≈ 0.7V. When the input voltage $Vi > V\gamma / AOL$, the output of the op-amp V_{OA} exceeds Vγ and the diode D conducts.

Then the circuit acts like a voltage follower for input voltage level $V_i > V_\gamma / AOL$,(i.e. when $V_i > 0.7/10^4 = 70\mu V$), and the output voltage V_0 follows the input voltage during the positive half cycle for input voltages higher than 70µV as shown in figure.

When Vi is negative or less than V_γ / A_{OL}, the output of op-amp V_{OA} becomes negative, and the diode becomes reverse biased. The loop is then broken, and the op-amp swings down to negative saturation. However, the output terminal is now isolated from both the input signal and the output of the op-amp terminal thus $V_0 =0$.

No current is then delivered to the load RL except for the small bias current of the op-amp and the reverse saturation current of the diode.

This circuit is an example of a non-linear circuit, in which linear operation is achieved over the remaining region ($V_i < 0$). Since the output swings to negative saturation level when $V_i < 0$, the circuit is basically of saturating form. Thus the frequency response is also limited.

Applications: The precision diodes are used in

- half wave rectifier,
- Full-wave rectifier,

- peak value detector,
- Clipper and clamper circuits.

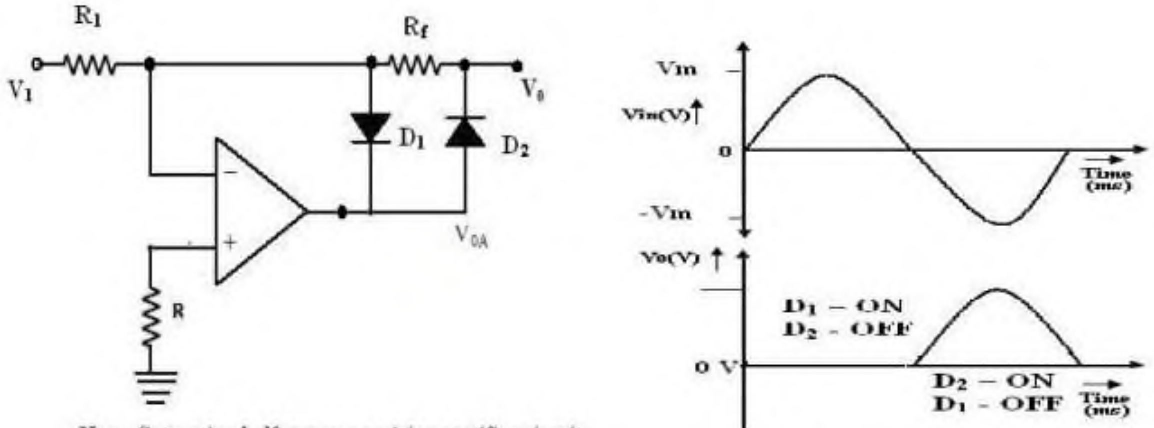
Disadvantage:

It can be observed that the precision diode as shown in figure operated in the first quadrant with Vi > 0 and $V_0 > 0$. The operation in third quadrant can be achieved by connecting the diode in reverse direction.

Half – wave Rectifier:

A non-saturating half wave precision rectifier circuit is shown in figure. When $V_i > 0V$, the voltage at the inverting input becomes positive, forcing the output V_{OA} to go negative. This results in forward biasing the diode D_1 and the op-amp output drops only by ≈ 0.7V below the inverting input voltage. Diode D_2 becomes reverse biased. The output voltage V_0 is zero when the input is positive.

When $V_i > 0$, the op-amp output V_{OA} becomes positive, forward biasing the diode $D_2$and reverse biasing the diode D_1. The circuit then acts like an inverting amplifier circuit with a non-linear diode in the forward path. The gain of the circuit is unity when $R_f = R_i$.



Non - Saturating half - wave precision rectifier circuit

Input and Output Waveforms

Half wave rectifier and its operation

The circuit operation can mathematically be expressed as

$V_0 = 0$ when $V_i > 0$ and

$V_0 = R_f/R_iV_1$ for$V_i < 0$

The voltage V_{oA} at the op amp output is $V_{OA} = - 0.7V$ for $V_i>0$

$V_{OA}= R_f/R_i\ V_1 + 0.7V$ for$V_i<0$

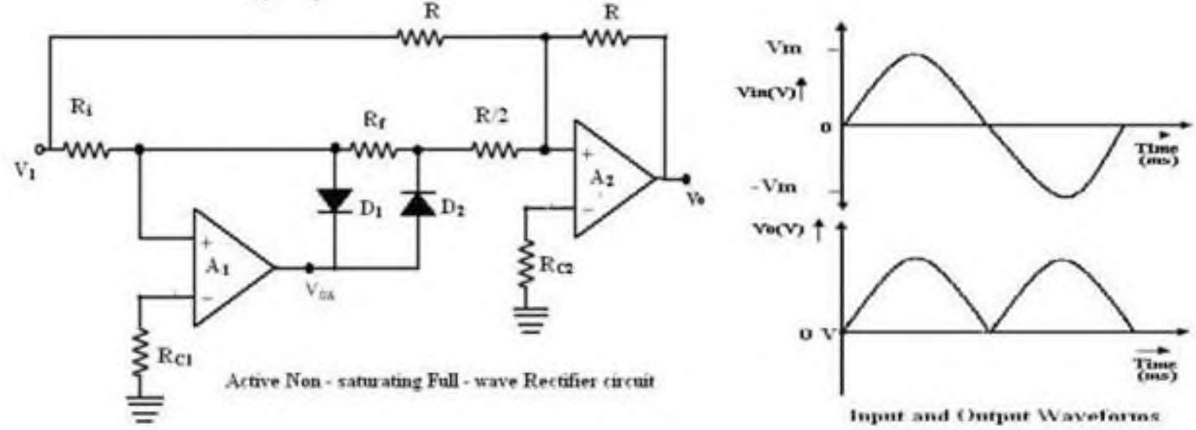
Advantages:

- It is a precision half wave rectifier and
- It is a non saturating one.

The inverting characteristics of the output V0 can be circumvented by the use of an additional inversion for achieving a positive output.

Full wave Rectifier:

The first part of the Full wave circuit is a half wave rectifier circuit. The second part of the circuit is an inverting amplifier.



Full wave rectifier and its operation

For positive input voltage $V_i > 0V$ and assuming that $R_F = R_i = R$, the output voltage $V_{OA} = V_i$. The voltage V_0 appears as (-) input to the summing op-amp circuit formed by A_2, The is R/(R/2), as shown in figure.

The input Vi also appears as an input to the summing amplifier. Then, the net output is $V_0 = -V_i - 2V_0 = -V_i - 2(-V_i) = Vi$. Since $V_i > 0V$, V_0 will be positive, with its input output characteristics in first quadrant. For negative input $Vi < 0V$, the output V_0 of the first part of rectifier circuit is zero. Thus, one input of the summing circuit has a value of zero. However, Vi is also applied as an input to the summer circuit formed by the op-amp A2.

The gain for this input id (-R/R) = -1, and hence the output is $V_0 = -Vi$. Since Vi is negative, V_0 will be inverted and will thus be positive. This corresponds to the second quadrant of the circuit.

To summarize the operation of the circuit,

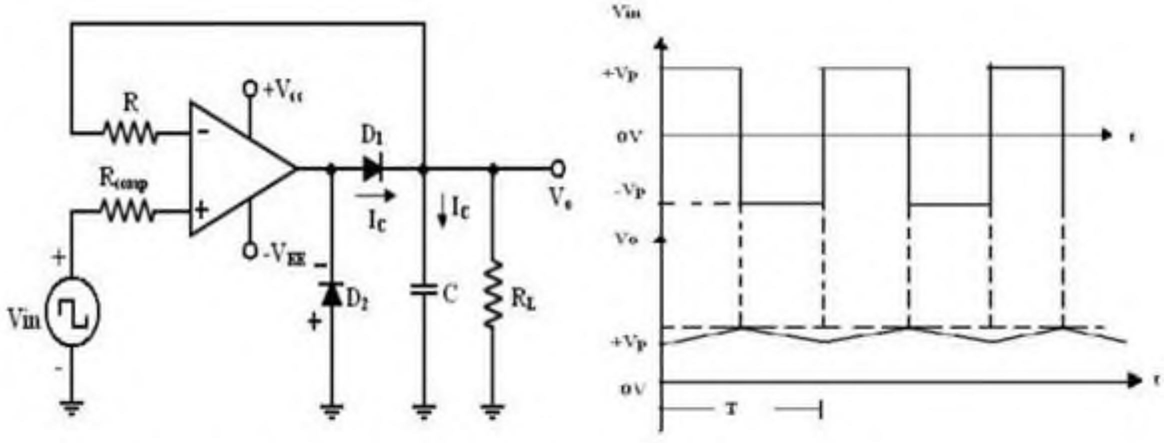
$V_0 = V_i$ when $V_i < 0V$ and

$V_0 = V_i$ for $V_i > 0V$, and hence

$V_0 = |V_i|$

Peak Detector

Square, Triangular, Saw tooth and pulse waves are typical examples of non-sinusoidal waveforms. A conventional AC voltmeter cannot be used to measure these sinusoidal waveforms because it is designed to measure the RMS value of the pure sine wave. One possible solution to this problem is to measure the peak values of the non-sinusoidal waveforms. Peak detector measures the +ve peak value of the square wave input.



Peak detector circuit and input and output waveforms

i) During the positive half cycle of Vin: the o/p of the op-amp drives D_1 on. (Forward biased) Charging capacitor C to the positive peak value Vp of the input volt Vin.

ii) During the negative half cycle of Vin:D_1 is reverse biased and voltage across C is retained. The only discharge path for C is through R_L since the input bias IB is negligible.

For proper operation of the circuit, the charging time constant (CR_d) and discharging time constant (CR_L) must satisfy the following condition.

$$CR_d <= T/10$$

Where R_d = Resistance of the forward-biased diode.

T = time period of the input waveform.

$$CRL >= 10T \qquad (2)$$

Where R_L = load resistor.

If R_L is very small so that eqn. (2) cannot be satisfied.

- Use a (buffer) voltage follower circuit between capacitor C and R_L load resistor.
- R is used to protect the op-amp against the excessive discharge currents.
- Rcomp = minimizes the offset problems caused by input current
- D_2 conducts during the –ve half cycle of Vin and prevents the op-amp from going into negative saturation.

Clipper and clipper

Applications:

Wave shaping circuits are commonly used in digital computers and communication such as TV and FM receiver. Wave shaping technique include clipping and clamping.

In op-amp clipper circuits a rectifier diode may be used to clip off a certain portion of the input signal to obtain a desired o/p waveform. The diode works as an ideal diode (switch) because when on, the voltage drop across the diode is divided by the open loop gain of the op-amp. When off (reverse biased) the diode is an open circuit. In an op-amp clamper circuits, however a predetermined dc level is deliberately inserted in the o/p volt. For this reason, the clamper is sometimes called a dc inverter.

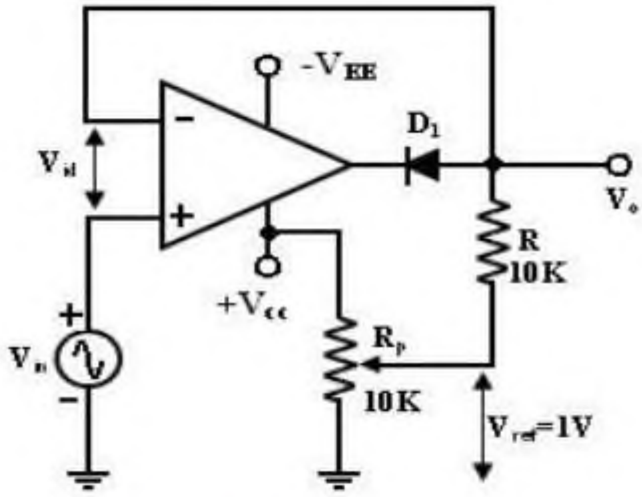
Clipper: Positive Clipper:

A circuit that removes positive parts of the input signal can be formed by using an op-amp with a rectifier diode. T he clipping level is determined by the reference voltage V_{ref}, which should less than the i/p range of the op-amp ($V_{ref} < V_{in}$). The Output voltage has the portions of the positive half cycles above Vref clipped off.

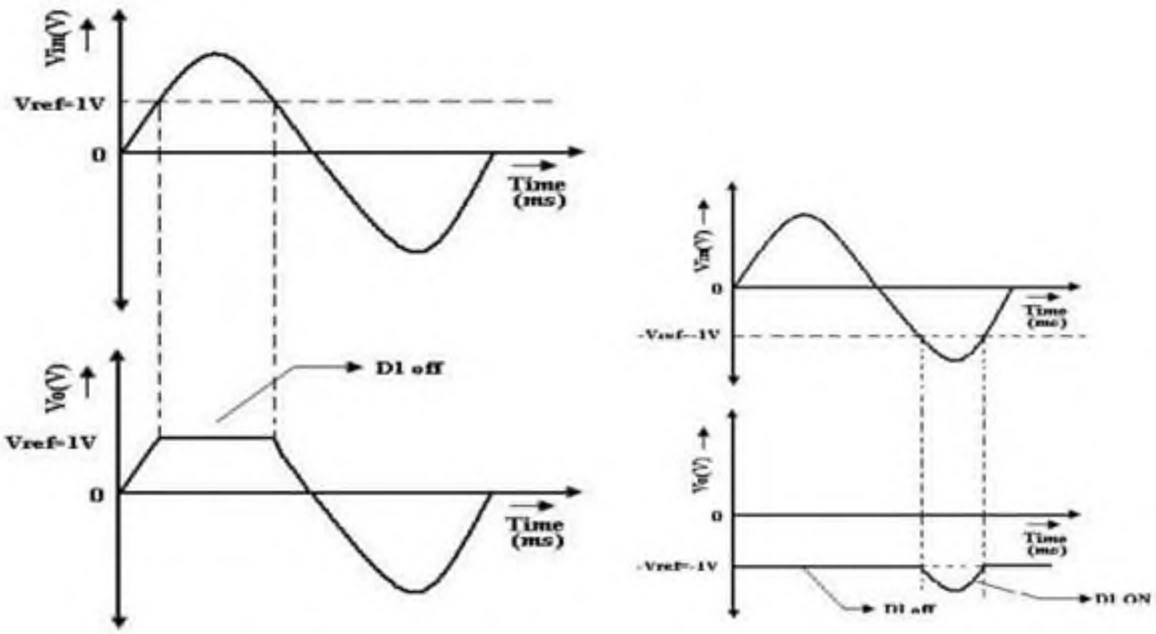
The circuit works as follows:During the positive half cycle of the input, the diode D_1 conducts only until $V_{in} = V_{ref}$. This happens because when $V_{in} < V_{ref}$, the output volts V_0 of the op-amp becomes negative to device D_1 into conduction when D_1 conducts it closes feedback loop and op-amp operates as a voltage follower. (i.e.) Output V0 follows input until $V_{in} = V_{ref}$.

When $V_{in} > V_{ref}$ => the V_0 becomes +ve to derive D_1 into off. It opens the feedback loop and op- amp operates open loop. When V_{in} drops below V_{ref} ($V_{in} < V_{ref}$) the o/p of the op-amp V_0 again becomes –ve to device D_1 into conduction. It closes the feedback path. (o/p follows the i/p).

Thus diode D_1 is on for $v_{in} < V_{ref}$ (o/p follows the i/p) and D_1 is off for $V_{in} > V_{ref}$.The op-amp alternates between open loop (off) and closed loop operation as the D_1 is turned off and on respectively. For this reason the op-amp used must be high speed and preferably compensated for unity gain.



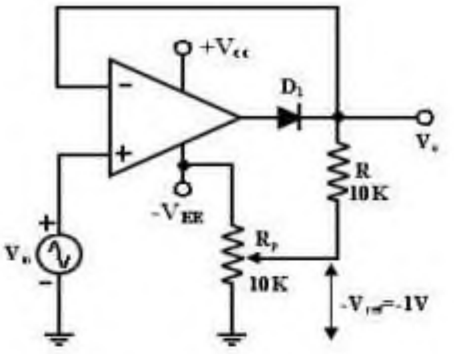
Positive Clipper



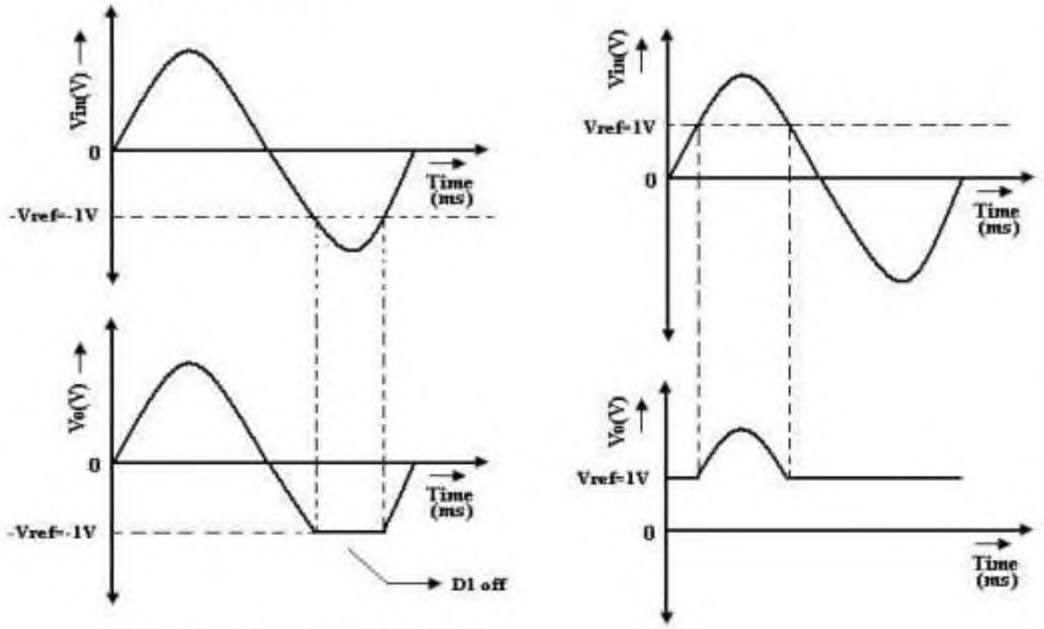
Positive clipper input output waveforms

Ex: for high speed op-amp HA 2500, LM310, μA 318. In addition the difference input voltage (Vid=high) is high during the time when the feedback loop is open (D_1 is off) hence an op-amp with a high difference input voltage is necessary to prevent input breakdown. If Rp (pot) is connected to –VEE instead of +Vcc, the ref voltage Vref will be negative (Vref = -ve). This will cause the entire o/p waveform above –Vref to be clipped off.

Negative Clipper:



Negative clipper



Input output waveforms

The positive clipper is converted into a –ve clipper by simply reversing diode D_1 and changing the polarity of V_{ref} voltage. The negative clipper clips off the –ve parts of the input signal below the reference voltage. Diode D_1 conducts -> when $V_{in} > -V_{ref}$ and therefore during this period o/p volt V0 follows the i/p volt Vin. The –Ve portion of the output volt below –Vref is clipped off because (D_1 is off) $V_{in} < -V_{ref}$. If $-V_{ref}$ is changed to $-V_{ref}$ by connecting the potentiometer R_p to the $+V_{cc}$, the V_0 below $+V_{ref}$ will be clipped off. The diode D1 must be on for $V_{in} > V_{ref}$ and off for V_{in}.

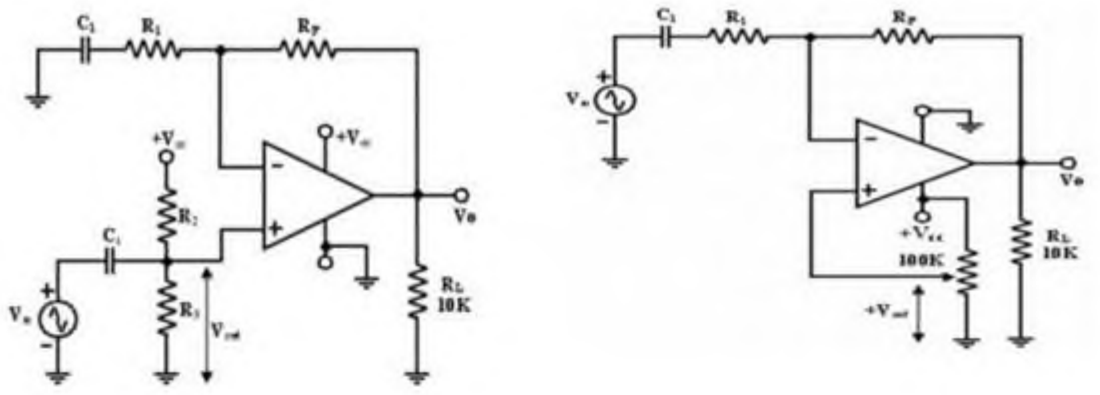
CLAMPERS

Positive and Negative Clampers:

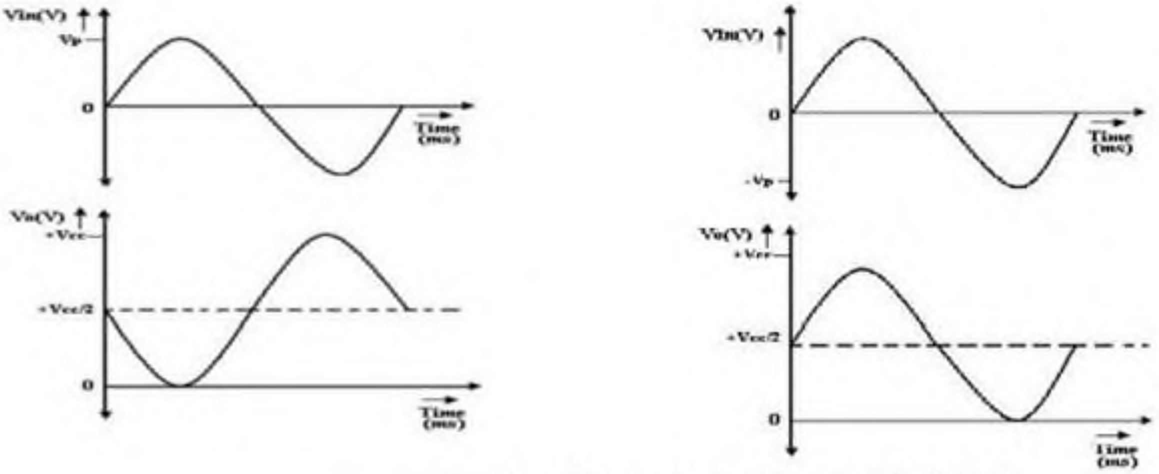
In clamper circuits a predetermined dc level is added to the output voltage. (or) The output is clamped to a desired dc level.

1. If the clamped dc level is +ve, the clamper is positive clamper
2. If the clamped dc level is –ve, the clamper is negative clamper.

Other equivalent terms used for clamper are dc inserter or restorer. Inverting and Non-Inverting that uses this technique.



Positive –Negative campers



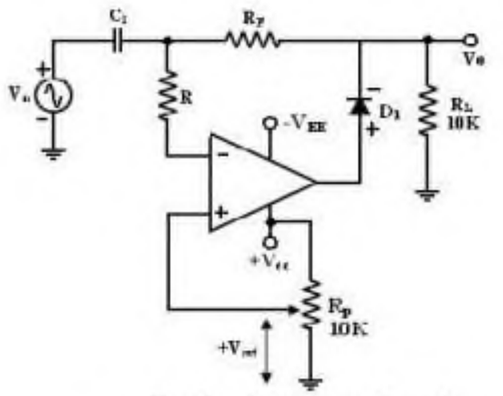
Input and output waveform with +Vref

Capacitor:

The Value of the capacitors in these circuits depends on different input rates and pulse widths.

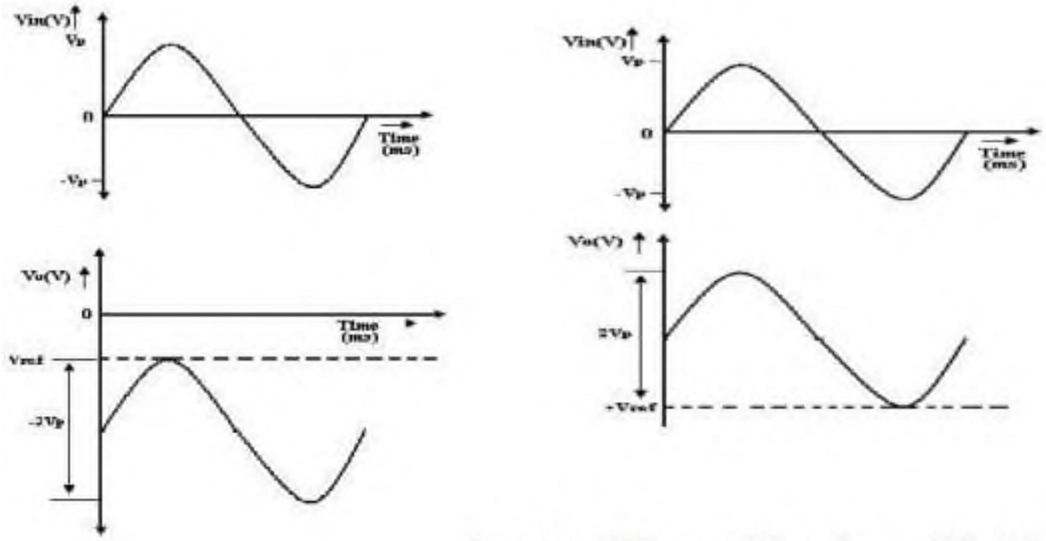
1. In both circuits the dc level added to the o/p voltage is approximately equal to $V_{cc}/2$.
2. This +ve fixed dc level is needed to obtain a maximum undistorted symmetrical sine wave.

Peak clamper circuit:



Peak clamper circuit

In this circuit, the input waveform peak is clamped at Vref. For this reason, the circuit is called the peak clamper.First consider the input voltage Vref at the (+) input: since this volt is +ve, V‘0 is also +ve which forward biases D_1. This closed the feedback loop.
Voltage V_{in} at the (-) input: During its –ve half cycle, diode D_1 conducts, charging c; to the –ve peak value of V_p. During the +ve half cycle, diode D1 in reverse biased. Since this voltage Vp is in series with the +ve peak volt Vp the o/p volt V0 = 2 Vp. Thus the nett o/p is Vref plus 2 Vp. So the – ve peak of 2 Vp is at Vref. For precision clamping, $C_iR_d << T/2$



Input and Output Waveform with –Vref

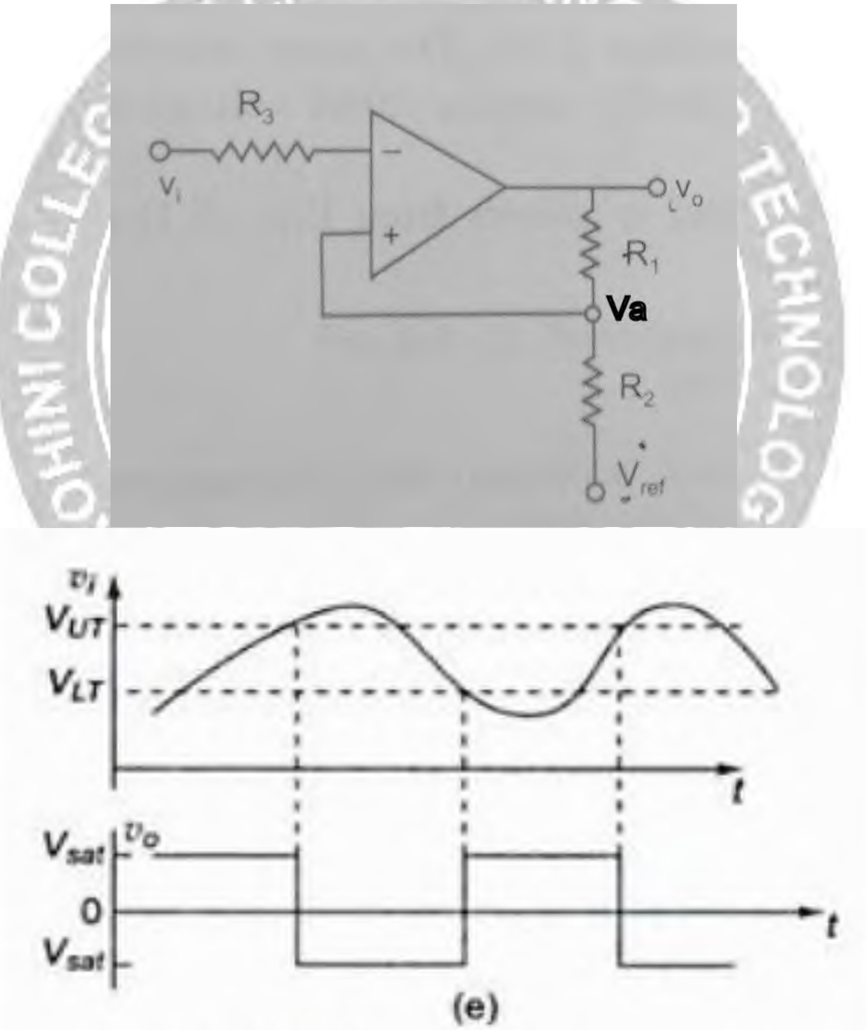
Where R_d = resistance of diode D_1 when it is forward biased.
T = time period of the input waveform.

Resistor R is used to protect the op-amp against excessive discharge currents from capacitor Ci especially when the dc supply voltages are switched off. A +ve peak clamping is accomplished by reversing D1 and using –ve reference voltage ($-V_{ref}$).

Schmitt Trigger: [Square Circuit]

This circuit converts an irregular shaped waveform to a square wave or pulse. The circuit is known as Schmitt Trigger or squaring circuit. The input voltage Vin triggers (changes the state of) the o/p V_0 every time it exceeds certain voltage levels called the upper threshold V_{ut} and lower threshold voltage.

These threshold voltages are obtained by using the voltage divider $R_1 – R_2$, where the voltage across R_1 is feedback to the (+) input. The voltage across $R_1$is variable reference threshold voltage that depends on the value of the output voltage. When $V_0 = +V_{sat}$, the voltage across R1 is called upper threshold voltage V_{ut}.



Schmitt Trigger as squarer

When $V_0 = +V_{sat}$, the voltage across R1 is called upper threshold voltage V_{UT}.

$$□_□ = \frac{□_{□□}□_1}{□_1+□_2} + \frac{□_2□_{□□}}{□_1+□_2}$$

- As long as $V_i < V_{UT}$, the output remains constant at $+V_{sat}$.
- When $V_i > V_{UT}$, the o/p regeneratively switches to $-V_{sat}$.

- When $V_0 = -V_{sat}$, the voltage across R1 is called lower threshold voltage V_{LT}.

$$V_{LT} = \frac{V_{ref} R_1}{R_1+R_2} - \frac{R_2 V_{sat}}{R_1+R_2}$$

- The difference between the two threshold voltages are called hysteresis width .

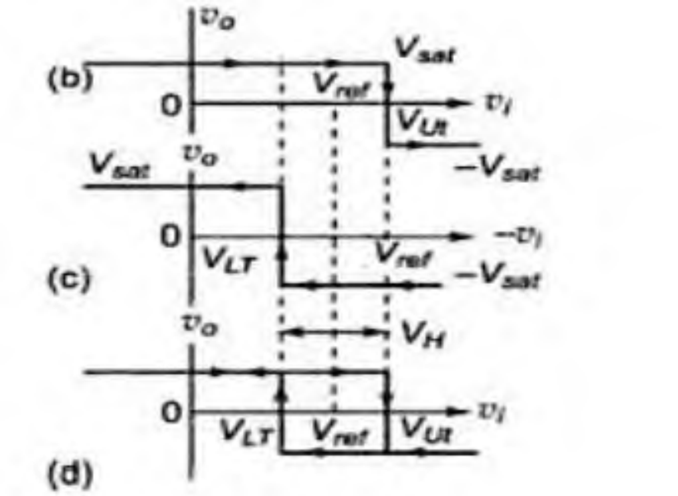
$$V_H = V_{UT} - V_{LT}$$

$$V_H = \frac{2 R_2 V_{sat}}{R_1+R_2}$$

- If V_{ref} is chosen as zero ,then

$$V_{UT} = - V_{LT} = \frac{2 R_2 V_{sat}}{R_1+R_2}$$

- If the threshold voltages V_{UT} and V_{LT} are made larger than the input noise voltages, the positive feedback will eliminate the false o/p transitions.
- Also the positive feedback, because of its regenerative action, will make V_0 switch faster between $+V_{sat}$ and $-V_{sat}$.
- Resistance $R_{comp}=R_1 \| R_2$ is used to minimize the offset problems.
- The comparator with positive feedback is said to exhibit hysteresis, a dead band condition. (i.e) when the input of the comparator exceeds V_{ut} its output switches from $+V_{sat}$ to $-V_{sat}$ and reverts to its original state, $+V_{sat}$ when the input goes below V_{LT}. The hysteresis voltage is equal to the difference between V_{UT} and V_{LT}. Therefore $V_H = V_{UT} - V_{LT}$.



Fig(b,c). Transfer characteristics of Vi increasing & decreasing
d) composite i/p –o/p curve