# Wave Shaping

**Text Books**

**1. Electronic Devices and Circuit Theory**

*by R Boylestad and L Nashelsky*

***2.* Op-Amps and Linear Integrated Circuits**

*by  Ramakant A. Gayakwad*

**3. Microelectronic Circuits Analysis and Design**

*by Muhammad H. Rashid*

**4. Electronic Principles 7th Edition**

*by Albert Malvino, David Bates*

***5.* Operational Amplifiers & Linear Integrated Circuits: Theory and Application**

*by James M. Fiore*

# Wave Shaping

- A Signal can also be called as a Wave.
- Every wave has a certain shape when it is represented in a graph.
- This shape can be of different types such as sinusoidal, square, triangular, etc. which vary with respect to time period or they may have some random shapes disregard of the time period.

## Types of Wave Shaping:

There are two main types of wave shaping. They are –

- Linear wave shaping
- Non-linear wave shaping

## Linear Wave Shaping:

- ✓ Linear elements such as resistors, capacitors and inductors are employed to shape a signal in this linear wave shaping.
- ✓ A Sine wave input has a sine wave output and hence the nonsinusoidal inputs are more prominently used to understand the linear wave shaping.

# Wave Shaping

## Nonlinear Wave Shaping

Along with resistors, the non-linear elements like diodes are used in nonlinear wave shaping circuits to get required altered outputs. Either the shape of the wave is attenuated or the dc level of the wave is altered in the Non-linear wave shaping.

The process of producing non-sinusoidal output wave forms from sinusoidal input, using non-linear elements is called as nonlinear wave shaping.

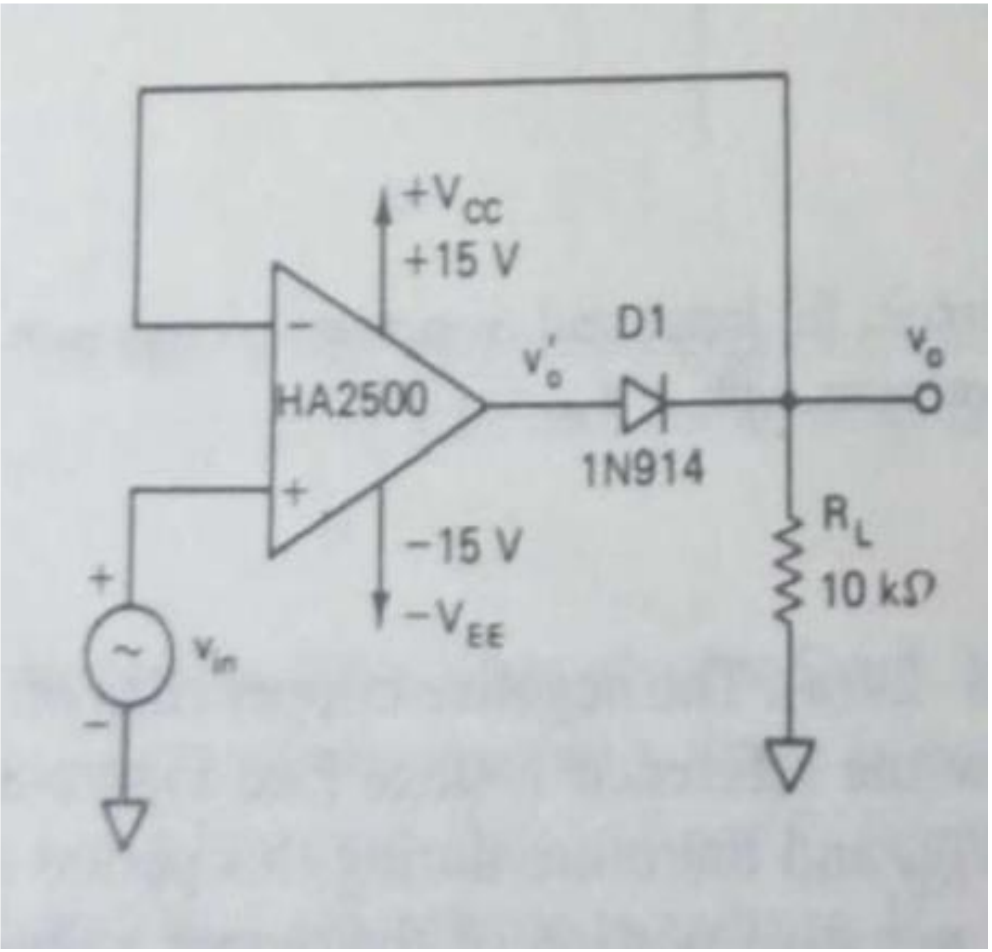
Clipper Circuits: A Clipper circuit is a circuit that rejects the part of the input wave specified while allowing the remaining portion.

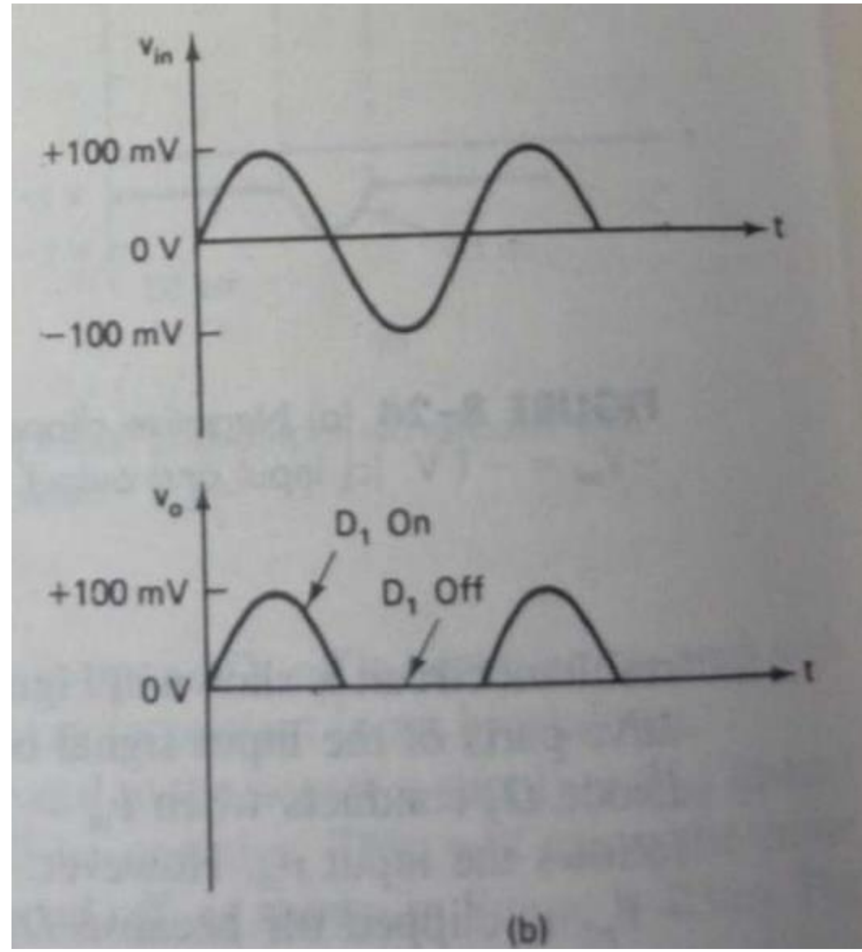
## Applications

- ✓ Wave shaping circuits are commonly used in digital computers and communication system
- ✓ Such as TV and FM receivers

# Rectifiers

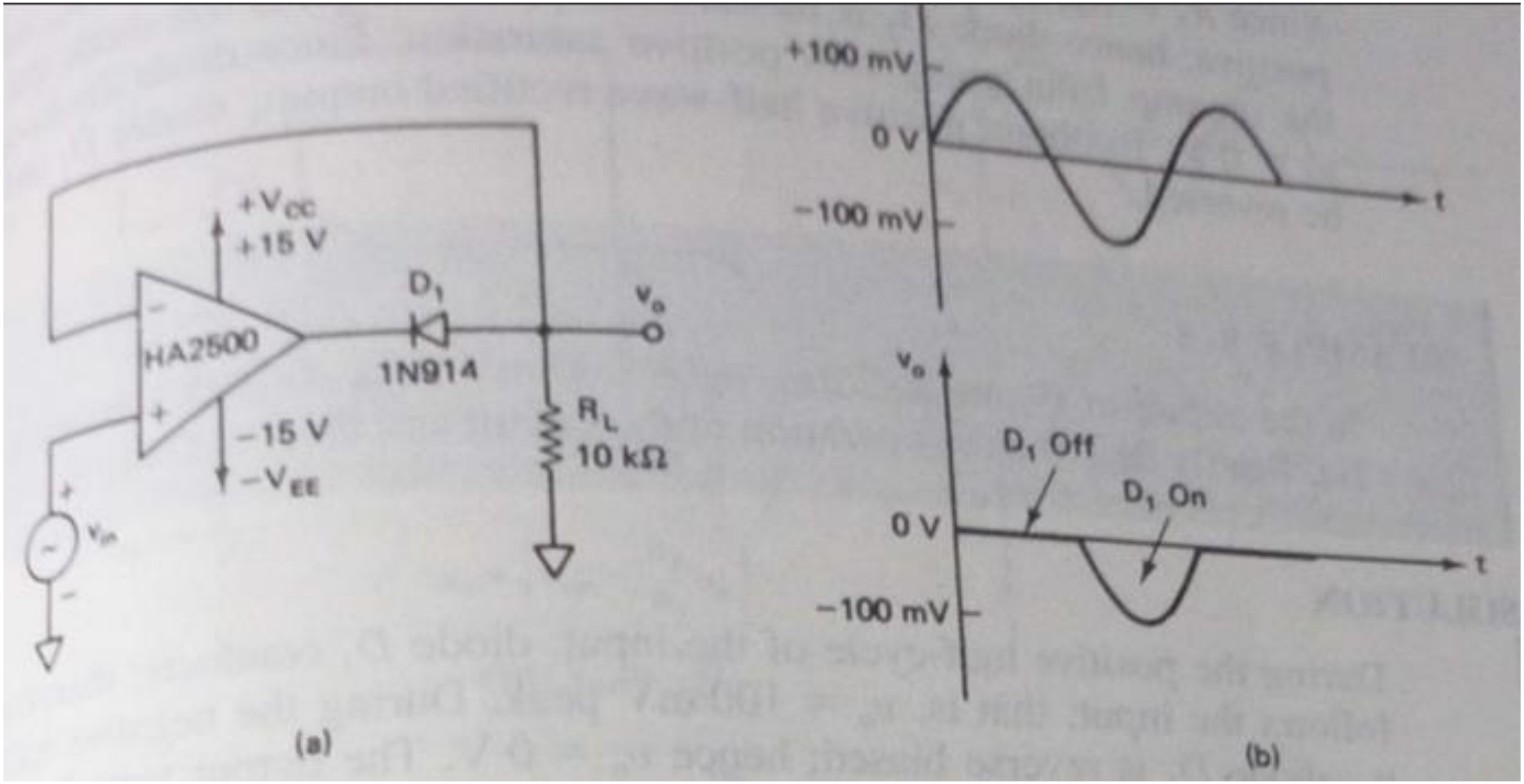
**Positive small signal half wave rectifier, its input, and its output response**



# Rectifiers

**Negative small signal half wave rectifier, its input, and its output response**



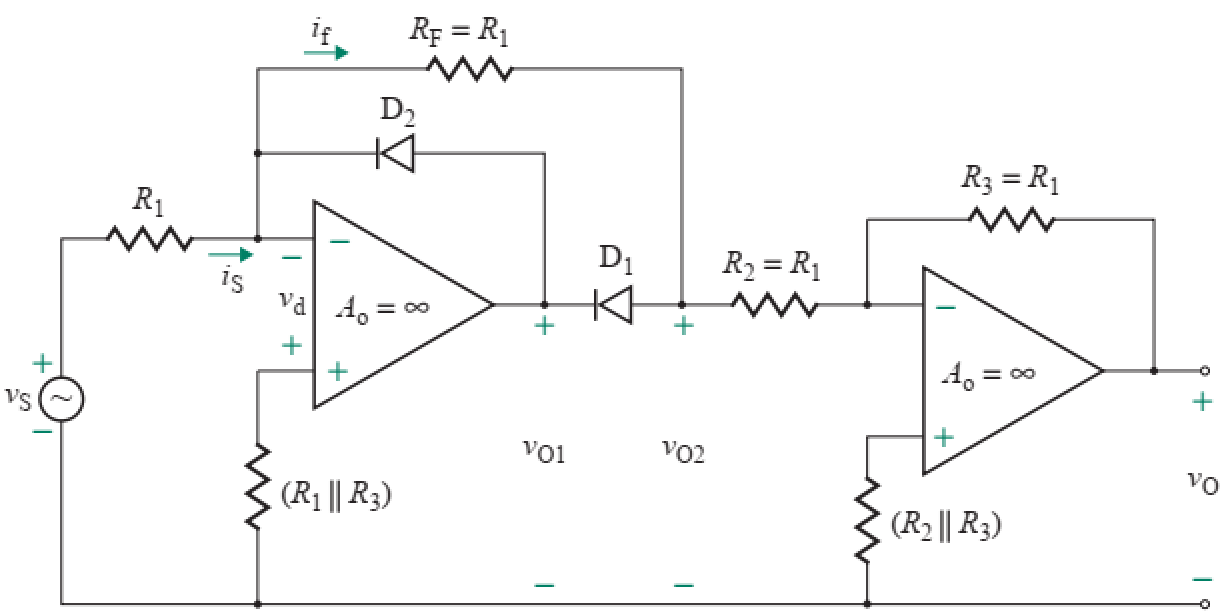
# Rectifiers

## Precision Half-Wave Rectifiers

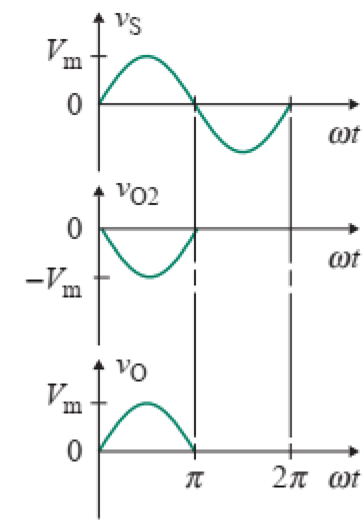
- Precision rectifiers, unlike normal (diode-based) rectifiers, can accurately rectify very small AC signals, even those below the typical 0.7V forward voltage drop of a diode.

- This is achieved by using operational amplifiers (op-amps) in conjunction with diodes to create a circuit that behaves like an ideal diode, minimizing the voltage drop and maximizing accuracy

$$0 \le \omega t \le \pi.$$
$$v_{O2} = -v_S.$$



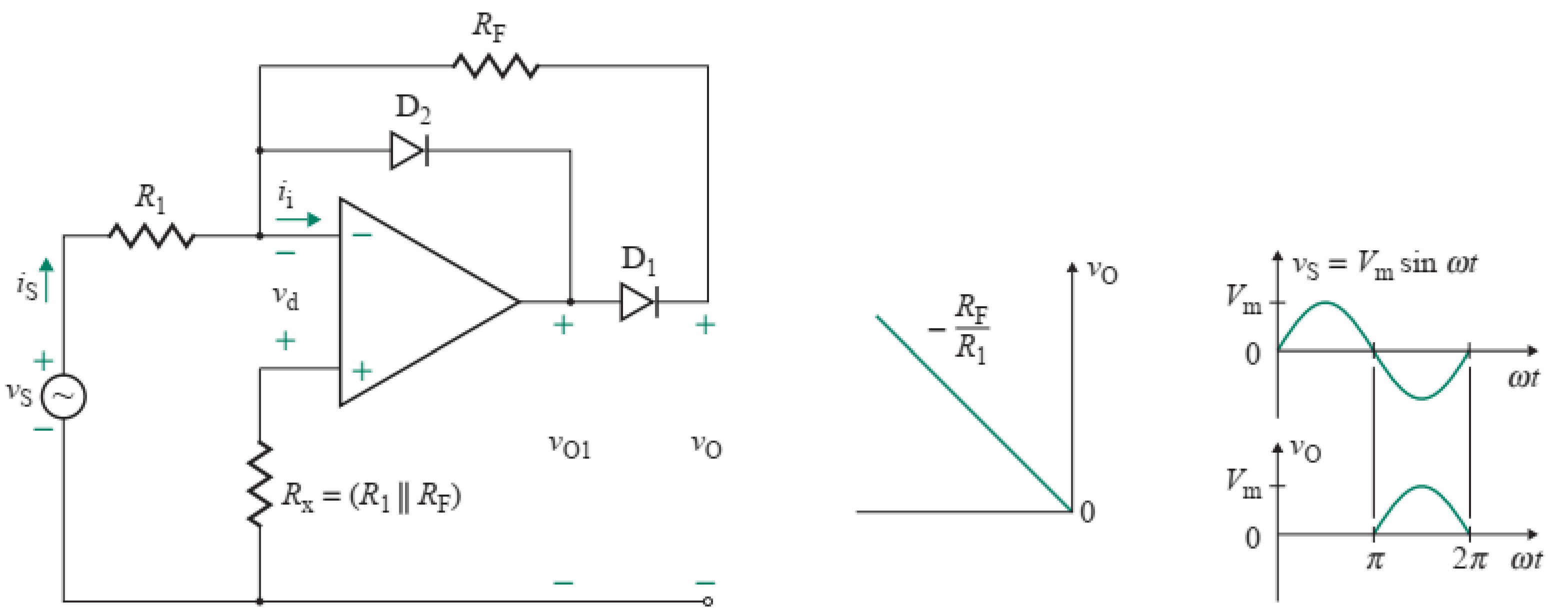

(a) Circuit




(b) Waveforms

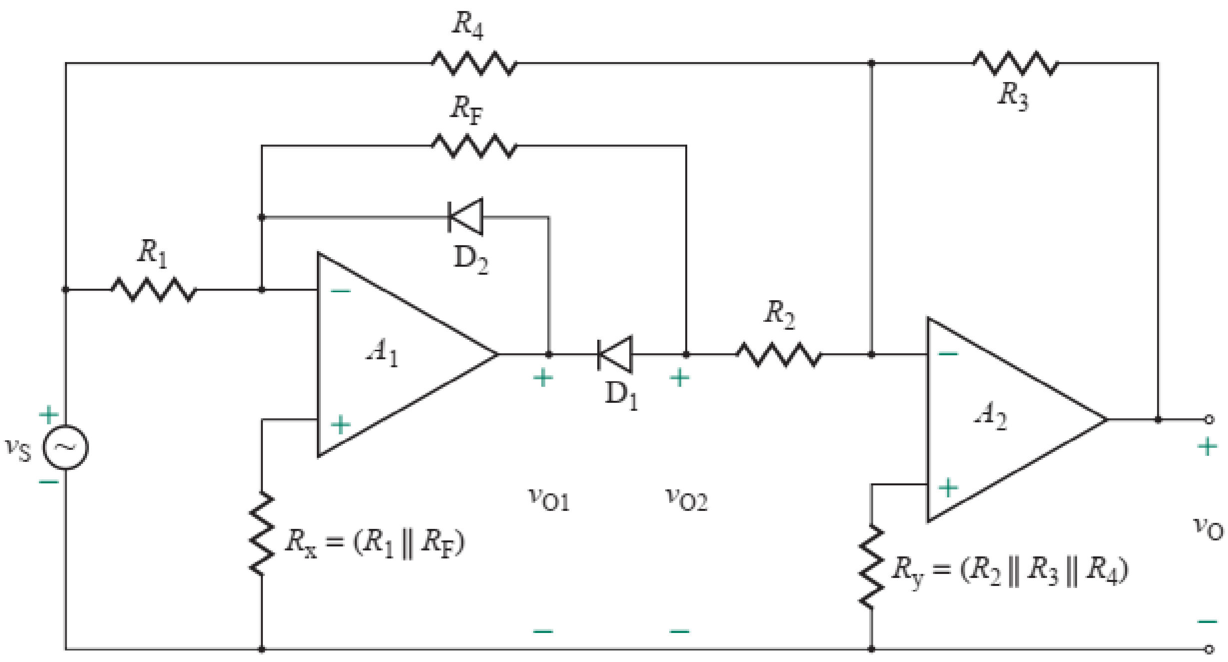
# Rectifiers

## Precision Half-Wave Rectifiers

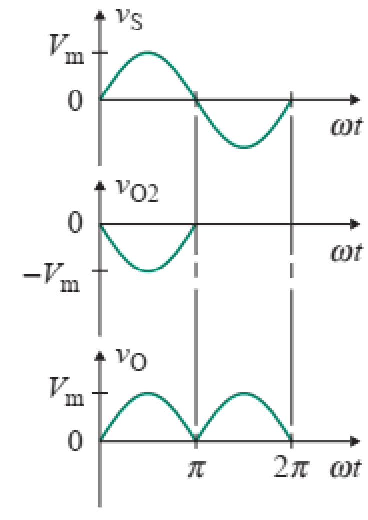



(a) Circuit (b) Transfer characteristic (c) Waveforms

## Precision Full-Wave Rectifiers




**(a) Circuit**




**(b) Waveforms**

$0 \le \omega t \le \pi.$

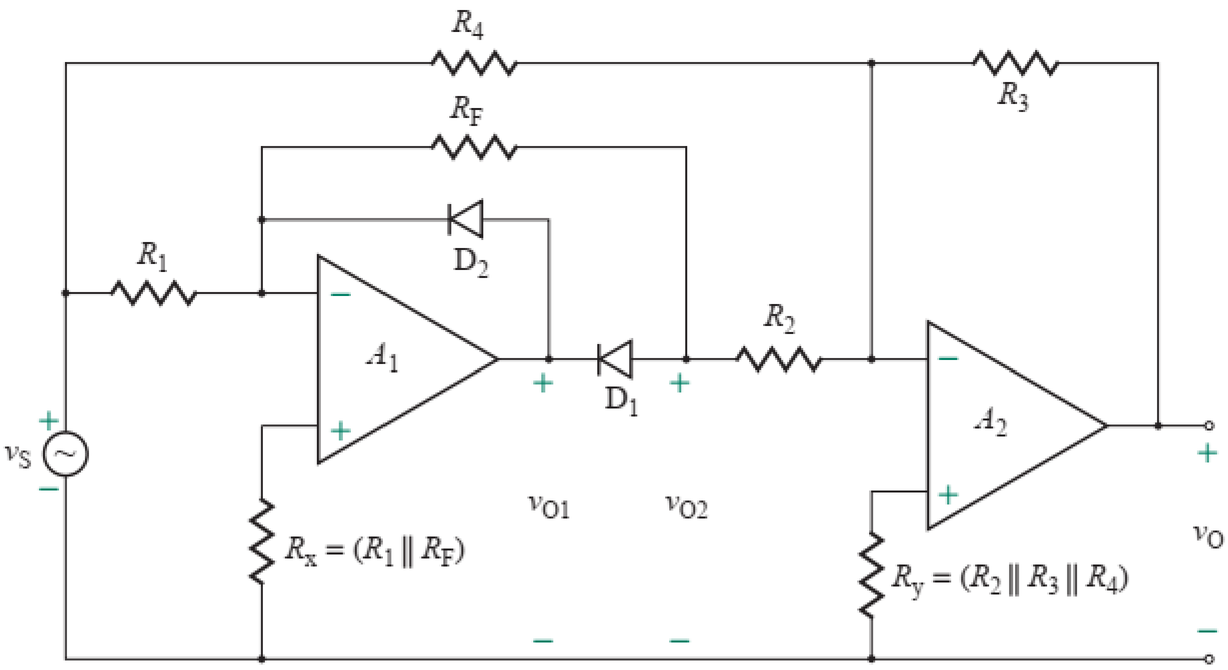
$v_{O2} = -v_S.$

$$v_O = -\left(\frac{R_3}{R_2} v_{O2} + \frac{R_3}{R_4} v_S\right) \qquad \because R_3 = R_4 = 2R \text{ and } R_2 = R,$$

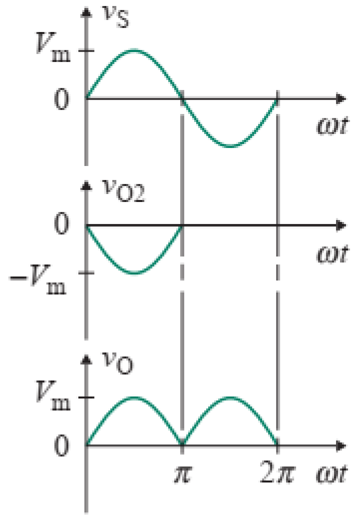
$$v_O = -2v_{O2} - v_S = -2(-v_S) - v_S = v_S \quad (\text{for } v_S \ge 0)$$

# Rectifiers

## Precision Full-Wave Rectifiers




(a) Circuit




(b) Waveforms

$\pi \leq \omega t \leq 2\pi$.

$v_{O2} = 0$

$$v_O = -\left(\frac{R_3}{R_2} v_{O2} + \frac{R_3}{R_4} v_S\right)$$

: $R_3 = R_4 = 2R$ and $R_2 = R$,

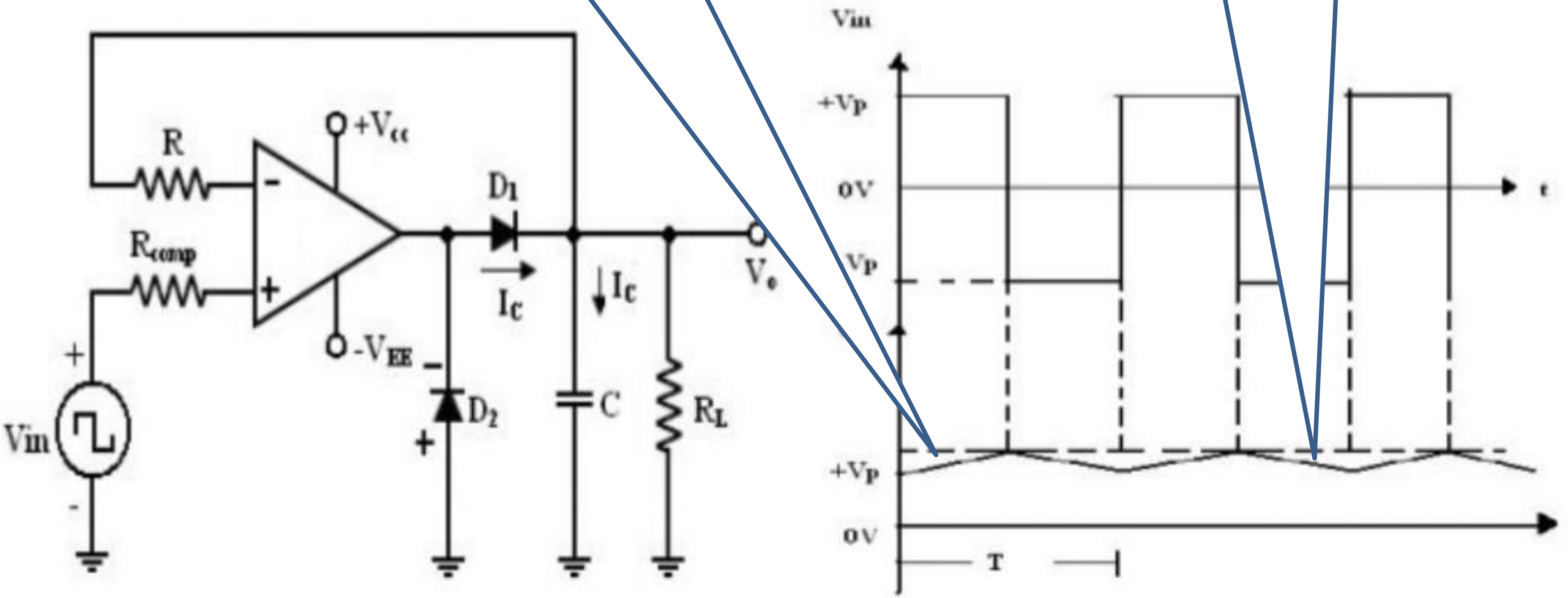
$$v_0 = -(0 + 1 \times (-v_m)) = v_m$$

# Peak Detector

## Peak detector circuit

Charging time constant = $CR_d \leq T/10$

Discharging time constant = $CR_L \geq 10T$

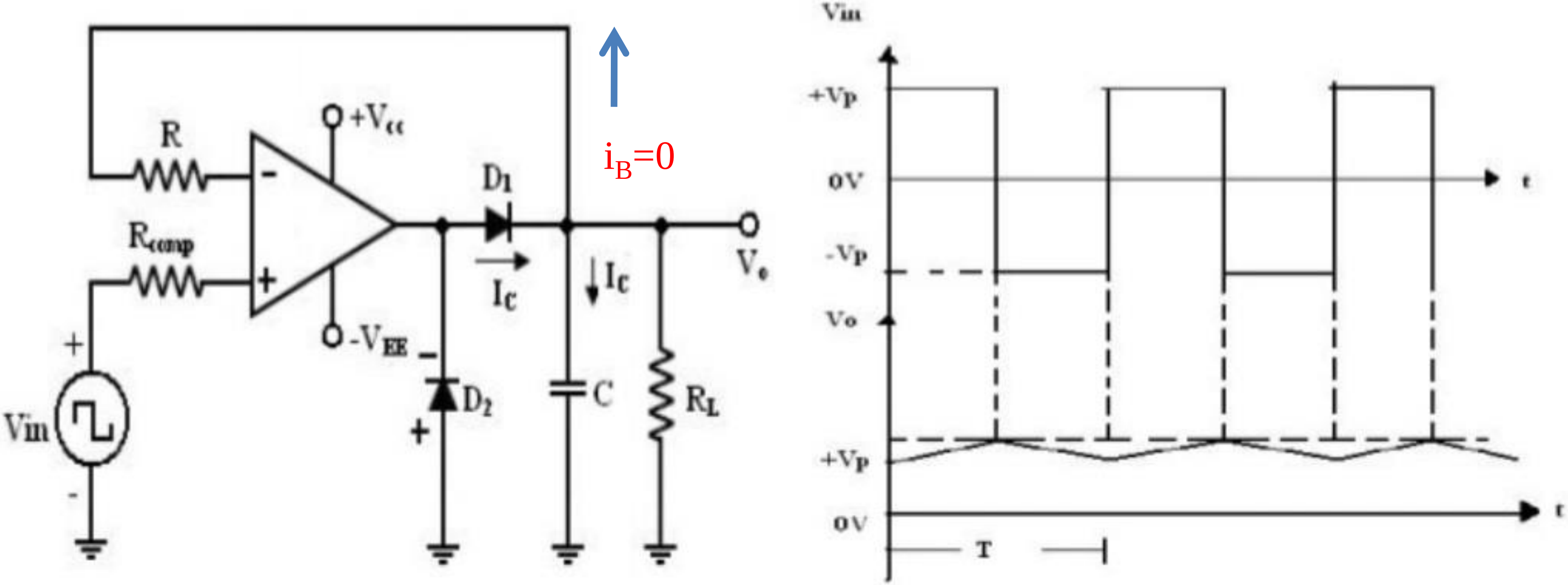



- Conventional ac voltmeter is unable to measure non-sinusoidal waveform because it measures rms value

**$R_{comp}$ = R minimises offset problem of the circuit**
**R protects the op amp against excessive discharge current**
**$R_d$ = Resistance of the forward bias diode**

# Peak Detector

## Peak detector circuit

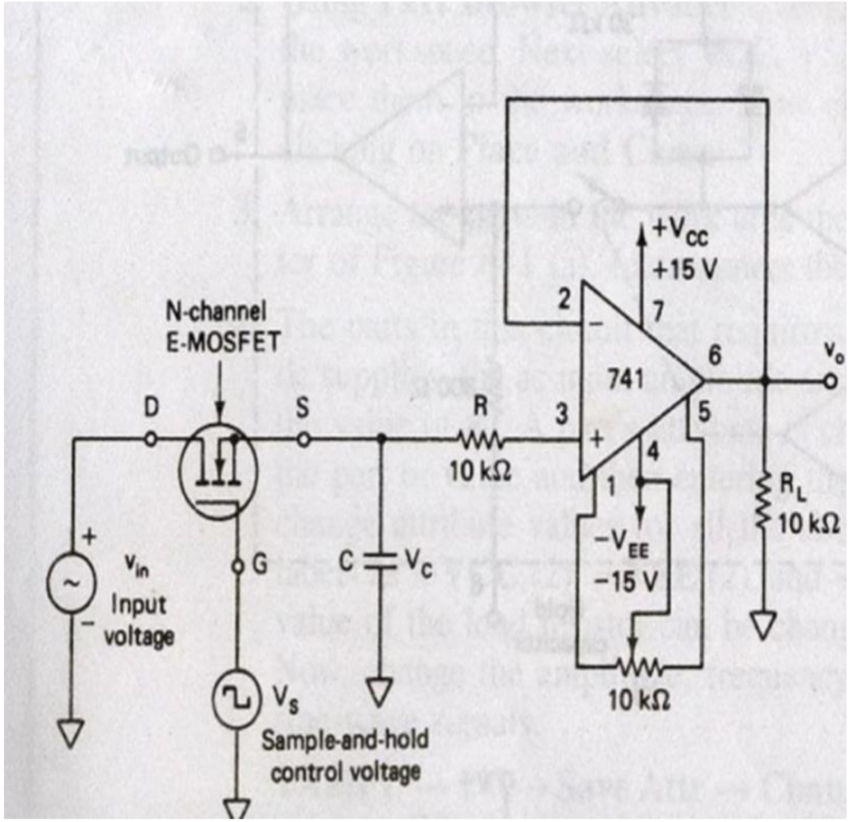


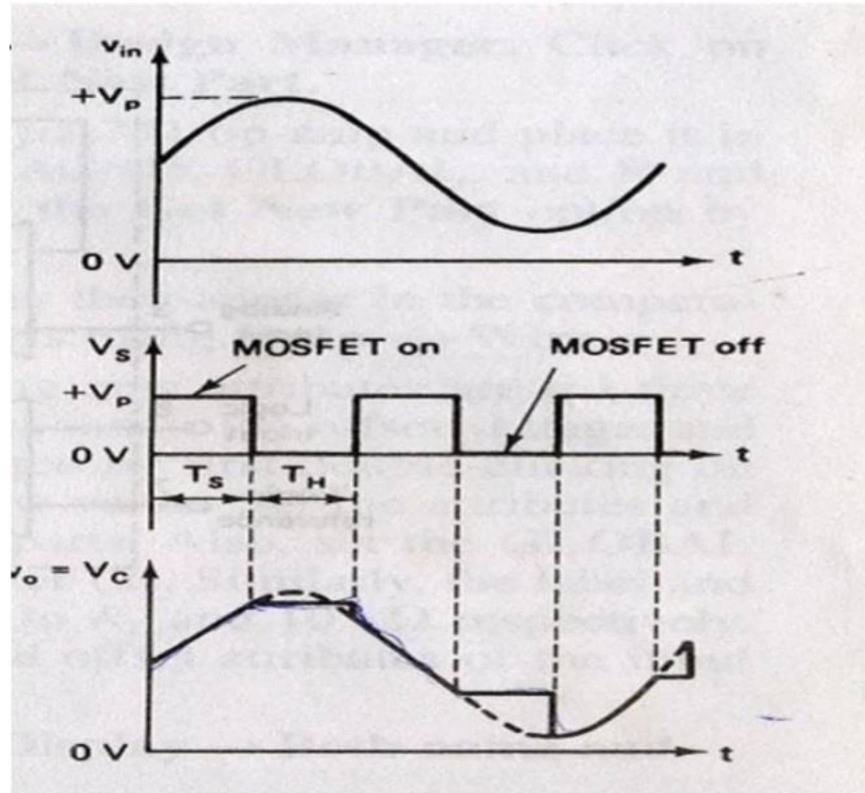

**Diode $D_2$ is on for the negative cycle. Thus, op amp can not go to negative saturation. This helps to improve recovery time of op amp.**

**In spite of $R_L$, a buffer can be used.**

# Sample and Hold Circuit

## Sample and hold circuit, its input, and its output waveform




- ✓ As its name implies, this circuit samples an input signal and holds on to its last sampled value until the input is sampled again.
- ✓ The input resistance of the op-amp follower is high , hence, voltage across C is retained like no discharging i.e., holding the charge when MOSFET is off

Applications: (i) digital interfacing (ii) communications
Such as analog-to-digital and pulse modulation system

# Clipper

Wave shaping techniques include limiting, clipping and clamping

## Op amp Positive Clipper

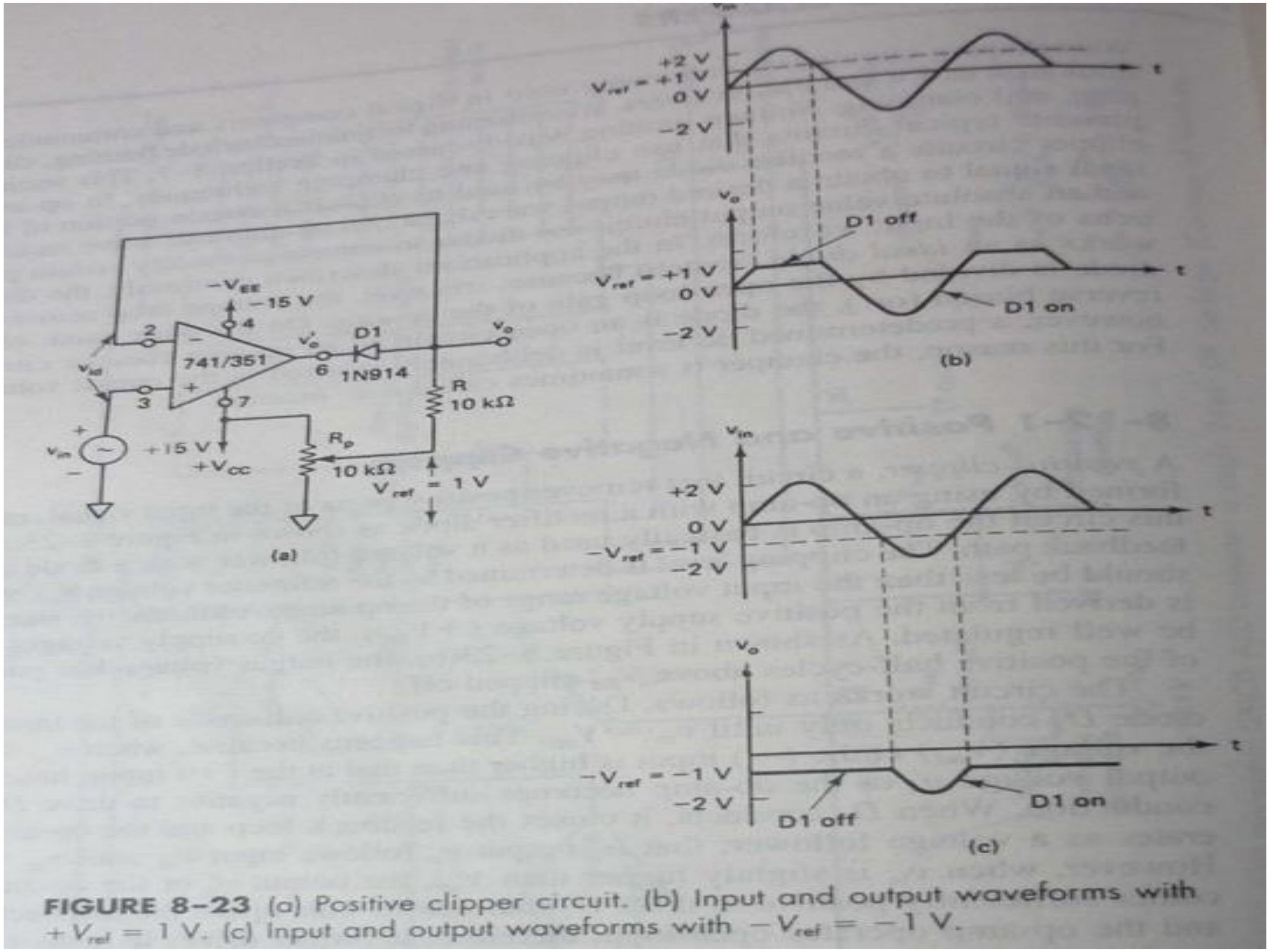



FIGURE 8–23 (a) Positive clipper circuit. (b) Input and output waveforms with $+V_{ref} = 1$ V. (c) Input and output waveforms with $-V_{ref} = -1$ V.

**Chapter 8, Page 368** of **Op-Amps and Linear Integrated Circuits** *by Ramakant A. Gayakwad*

# Clipper

## Op amp Negative Clipper

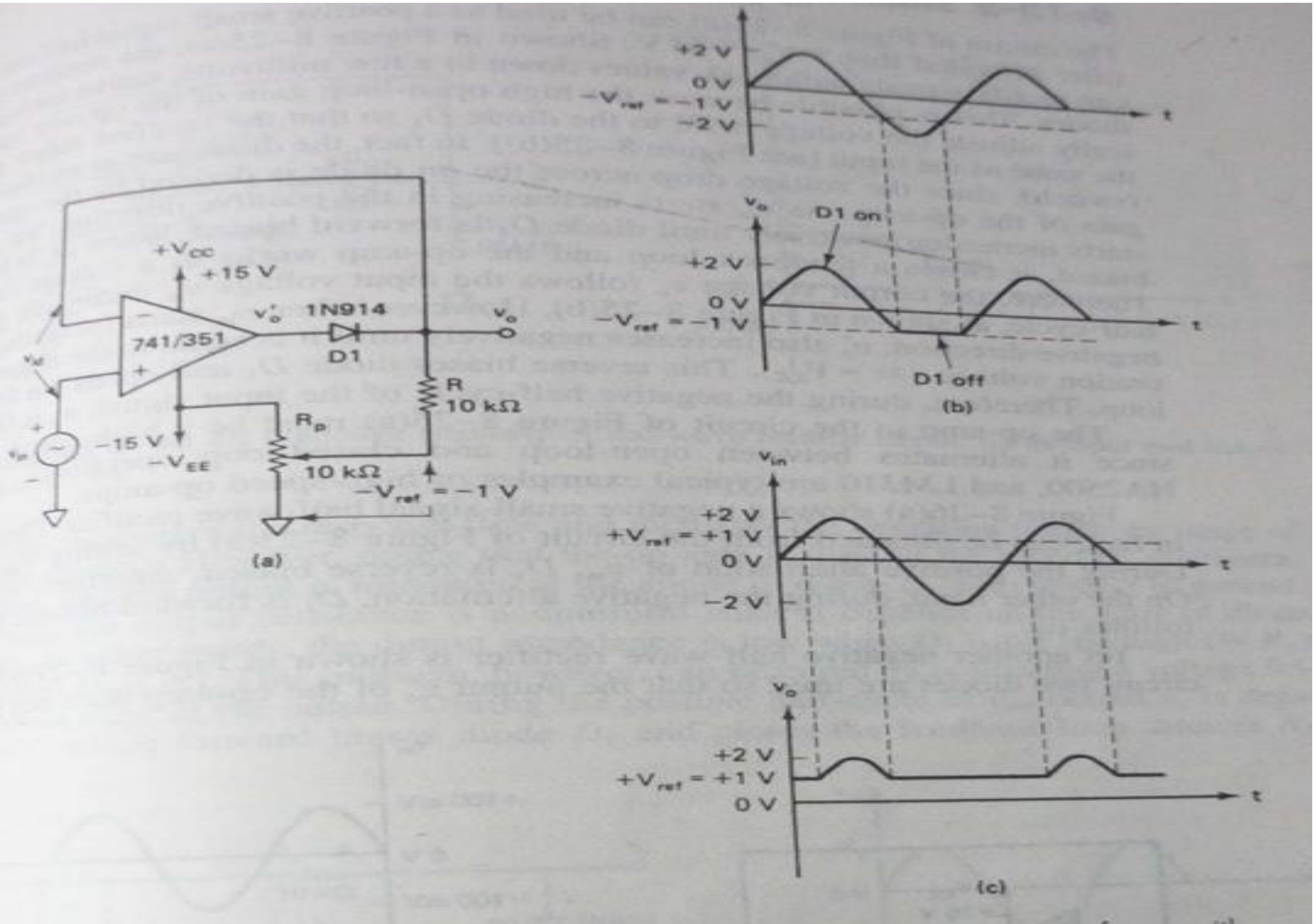


FIGURE 8–24 (a) Negative clipper circuit. (b) Input and output waveforms with $-V_{ref} = -1$ V. (c) Input and output waveforms with $+V_{ref} = +1$ V.



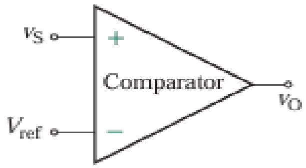
**Chapter 8, Page 369** of **Op-Amps and Linear Integrated Circuits** *by Ramakant A. Gayakwad*

# Comparator

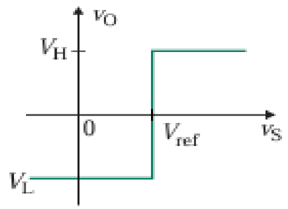
A comparator compares a signal voltage $v_S$ on one input terminal with a known voltage, called the *reference voltage* $V_{ref}$, on the other input terminal. The symbol of a comparator, which is similar to that of an op-amp, is shown in Fig. 16.19(a). A comparator gives a digital output voltage $v_O$. Thus, it can be considered a simple one-bit analog-to-digital (A/D) converter, which produces a digital 1 output ($v_O = V_H$) if the input voltage $v_S$ is above the reference level $V_{ref}$ and a digital 0 output ($v_O = V_L$) if the input voltage $v_S$ falls below the reference level $V_{ref}$. The output levels $V_L$ and $V_H$ may be of opposite polarity (i.e., $V_H$ positive and $V_L$ negative or vice versa), or both $V_L$ and $V_H$ may be either positive or negative. The transfer characteristic of an ideal comparator is shown in Fig. 16.19(b). The output may be symmetric or asymmetric.

A practical comparator has a finite voltage gain in the range from 3000 to 200,000 and takes a finite amount of time (in the range from 10 ns to 1 μs) to make a transition from one level to another (e.g., $V_L$ to $V_H$). The transfer characteristic of a practical comparator is shown in Fig. 16.19(c). The input voltage swing required to produce the output voltage transition is in the range of about 0.1 mV to 4 mV. The output of a comparator must switch rapidly between the levels. The bandwidth must be wide because the wider the bandwidth, the faster the switching speed will be. Some typical parameters (listed here for the LM111 comparator) are as follows:

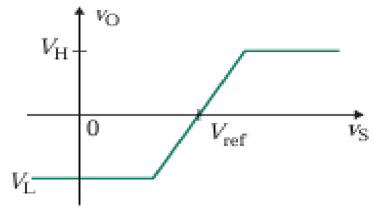
- Operates from a single 5-V power supply
- Input current: 150 nA (maximum)
- Offset current: 20 nA (maximum)
- Differential input voltage: ±30 V
- Voltage gain: 200 V/mV (typical)




(a) Symbol




(b) Ideal transfer characteristic



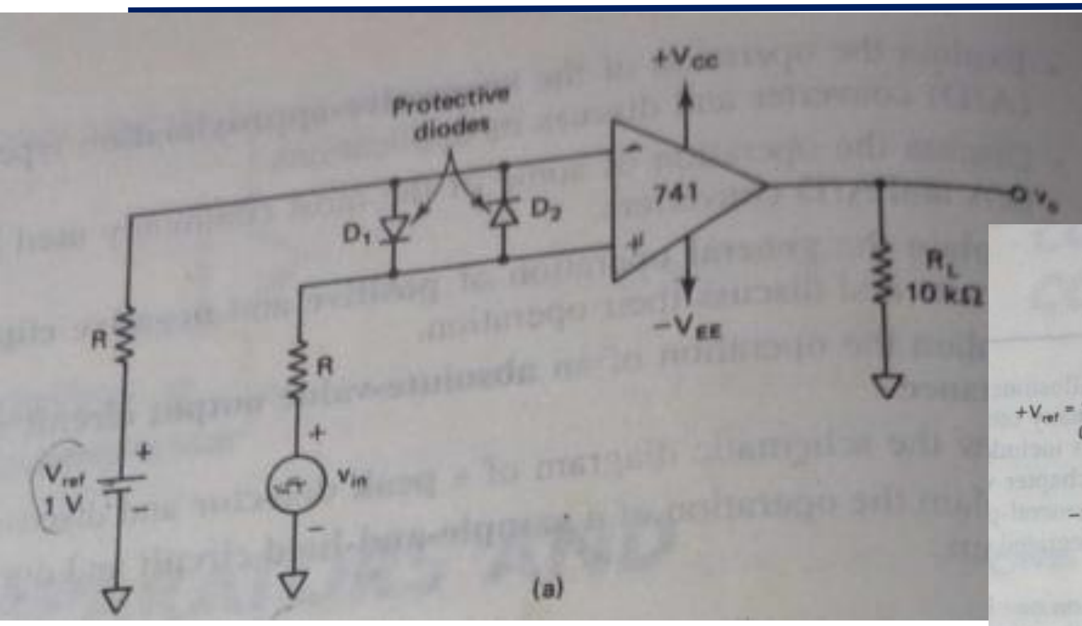

(c) Practical transfer characteristic

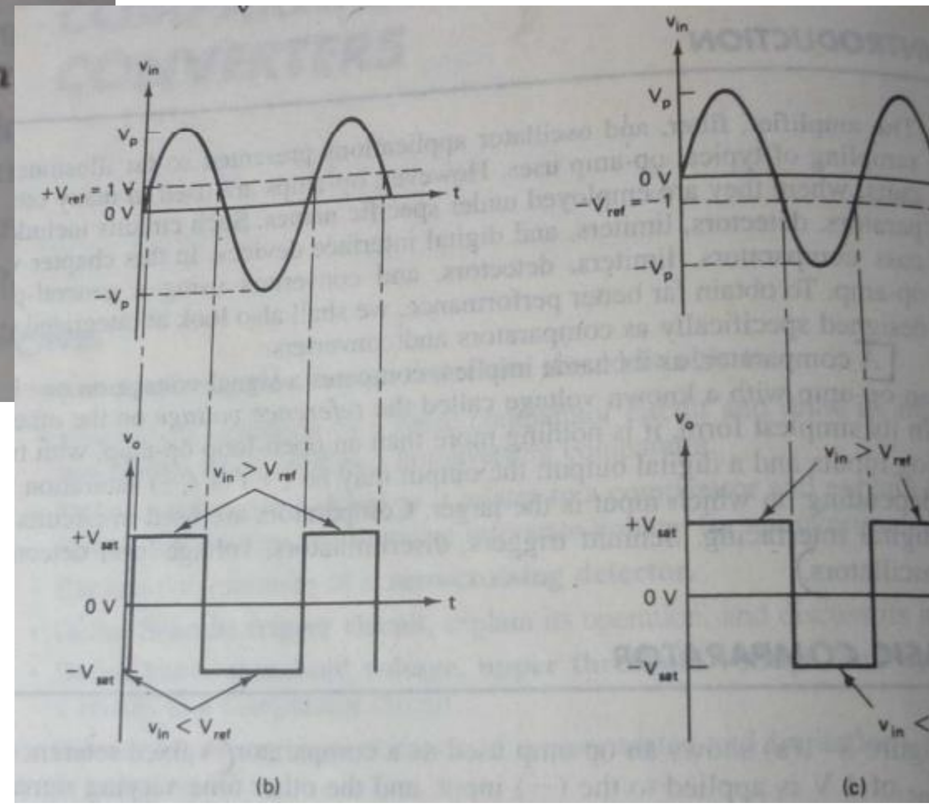
**FIGURE 16.19** Symbol and transfer characteristics of a comparator



**Chapter 16, Page 1097** of **Microelectronic Circuits Analysis and Design** *by Muhammad H. Rashid*

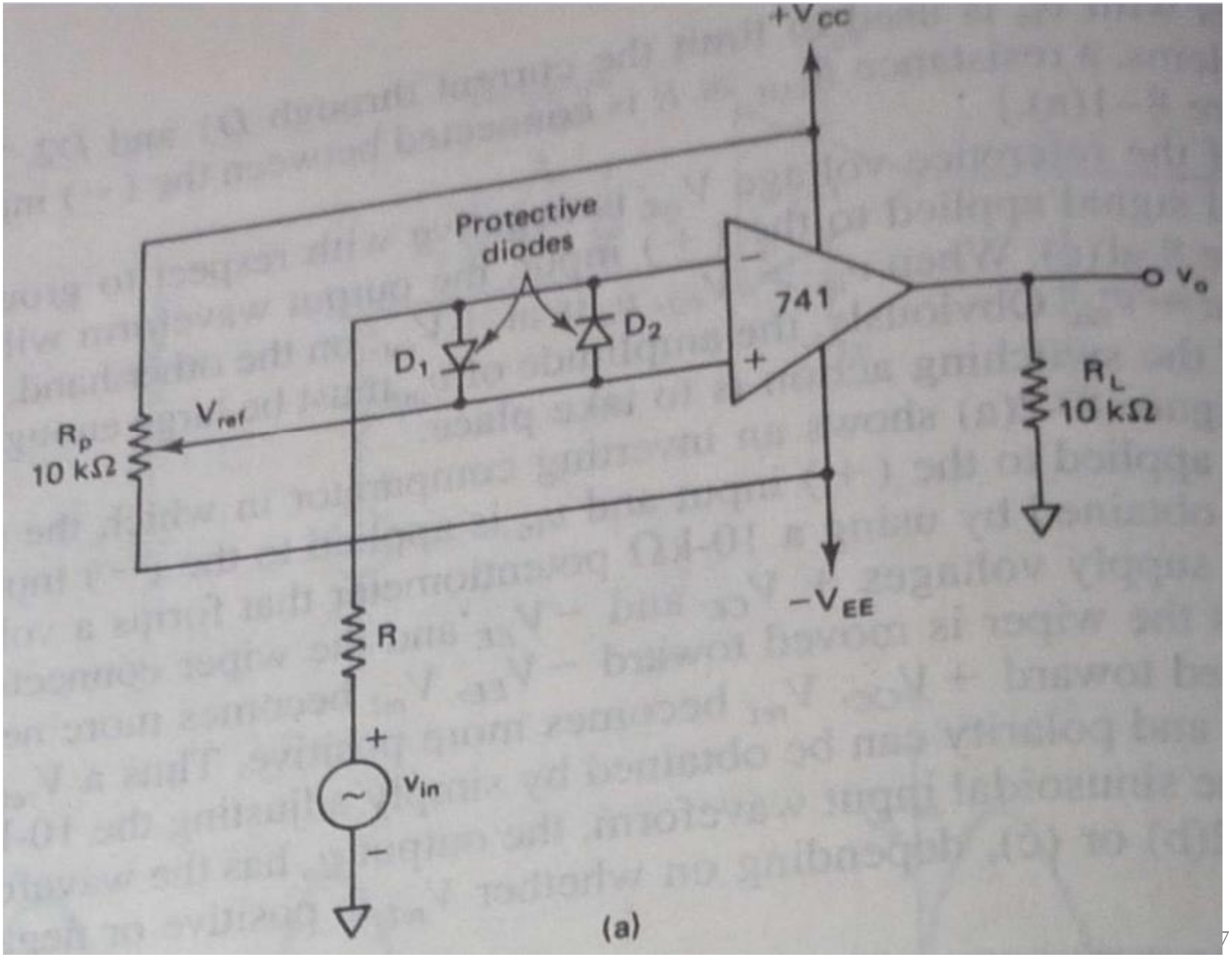
# Non-Inverting Comparator




In Figure 8–1(a) the diodes $D1$ and $D2$ protect the op-amp from damage due to excessive input voltage $v_{in}$. Because of these diodes, the difference input voltage $v_{id}$ of the op-amp is clamped to either 0.7 V or −0.7 V; hence the diodes are called *clamp diodes.* There are some op-amps with built-in input protection; in such op-amps the input diodes $D1$ and $D2$ are unnecessary. The resistance $R$ in

Inverting Comparator



# Inverting Comparator

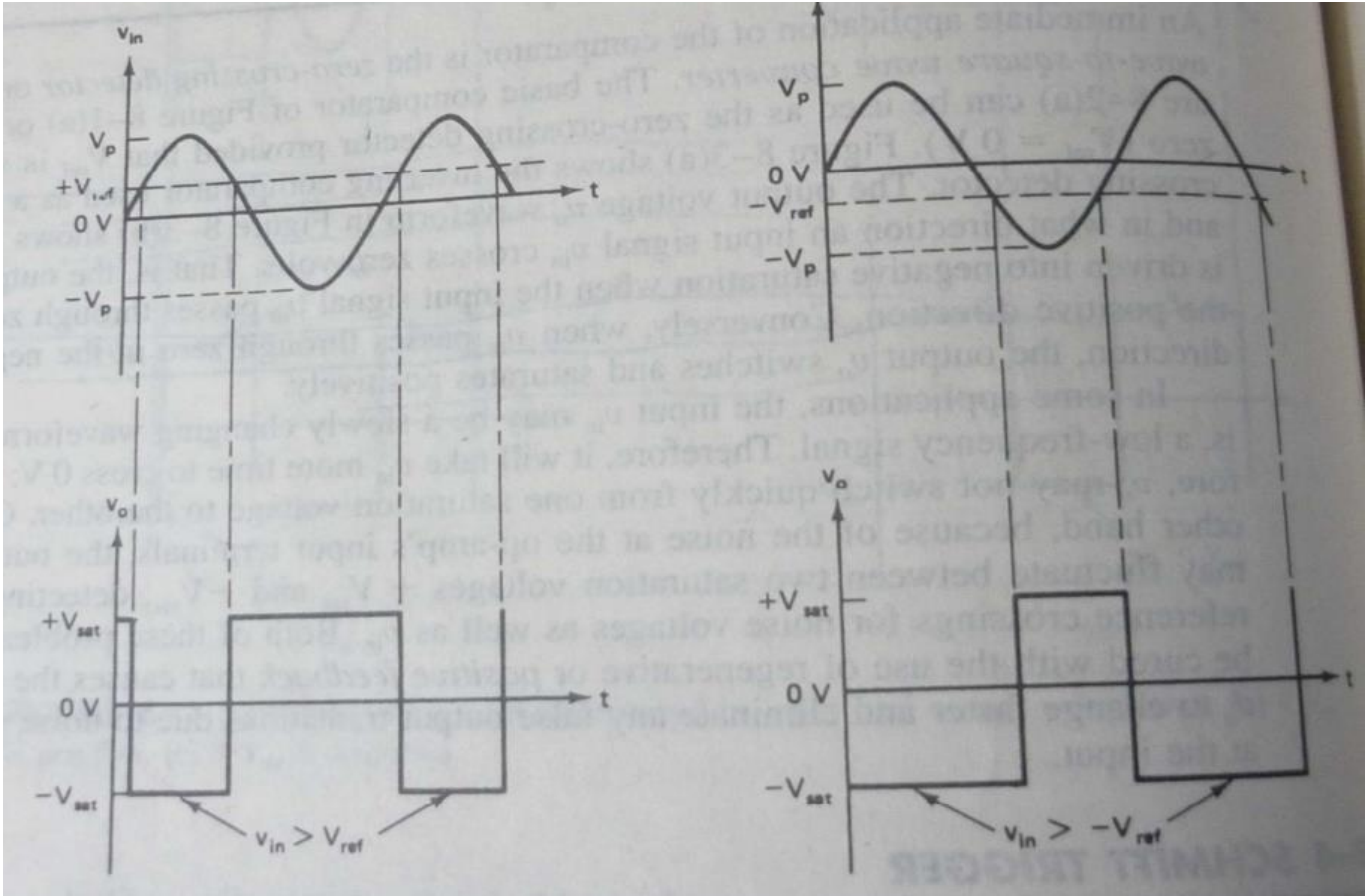
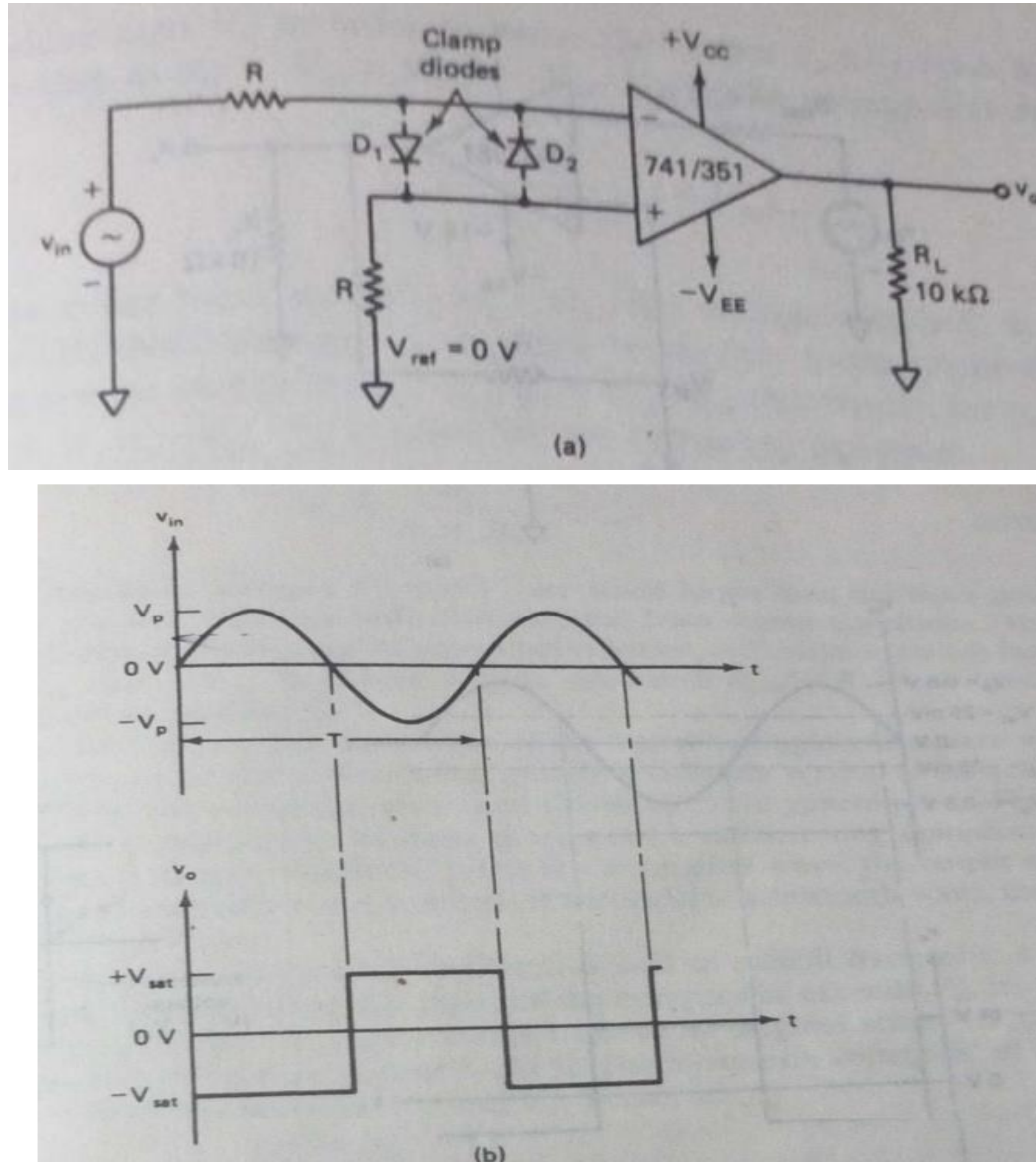



**FIGURE 8–2** (a) Inverting comparator with input and output waveforms. (b) If $V_{ref}$ is positive. (c) If $V_{ref}$ is negative.

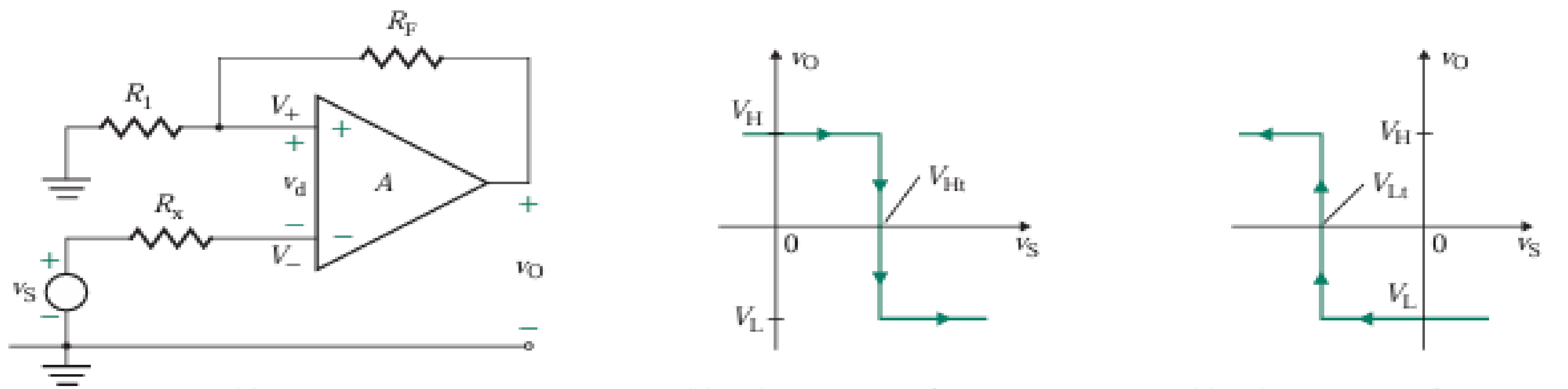
# Zero-crossing Detector

An immediate application of the comparator is the Zero-crossing detector or sine wave to square wave converter.




(a) Zero-crossing detector. (b) Its typical input and output waveforms.

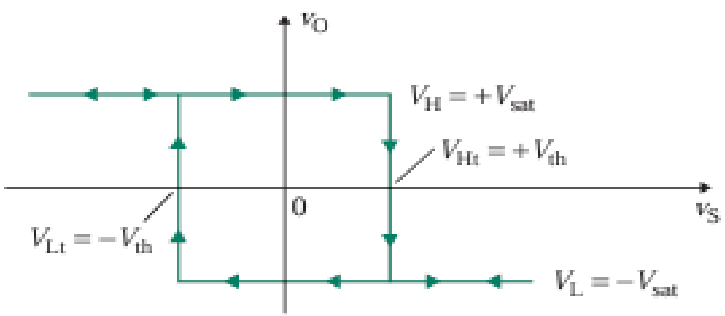
## 16.5.1 Inverting Schmitt Trigger



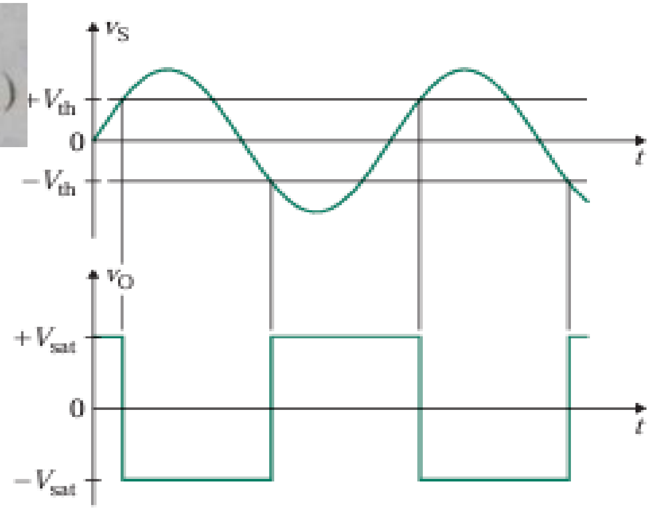

(a) Circuit (b) Characteristic for $v_S > V_{Ht}$ (c) Characteristic for $v_S > V_{Lt}$

$$V_{ut} = \frac{R_1}{R_1 + R_2}(+V_{sat})$$

$$V_{lt} = \frac{R_1}{R_1 + R_2}(-V_{sat})$$




(d) Complete transfer characteristics



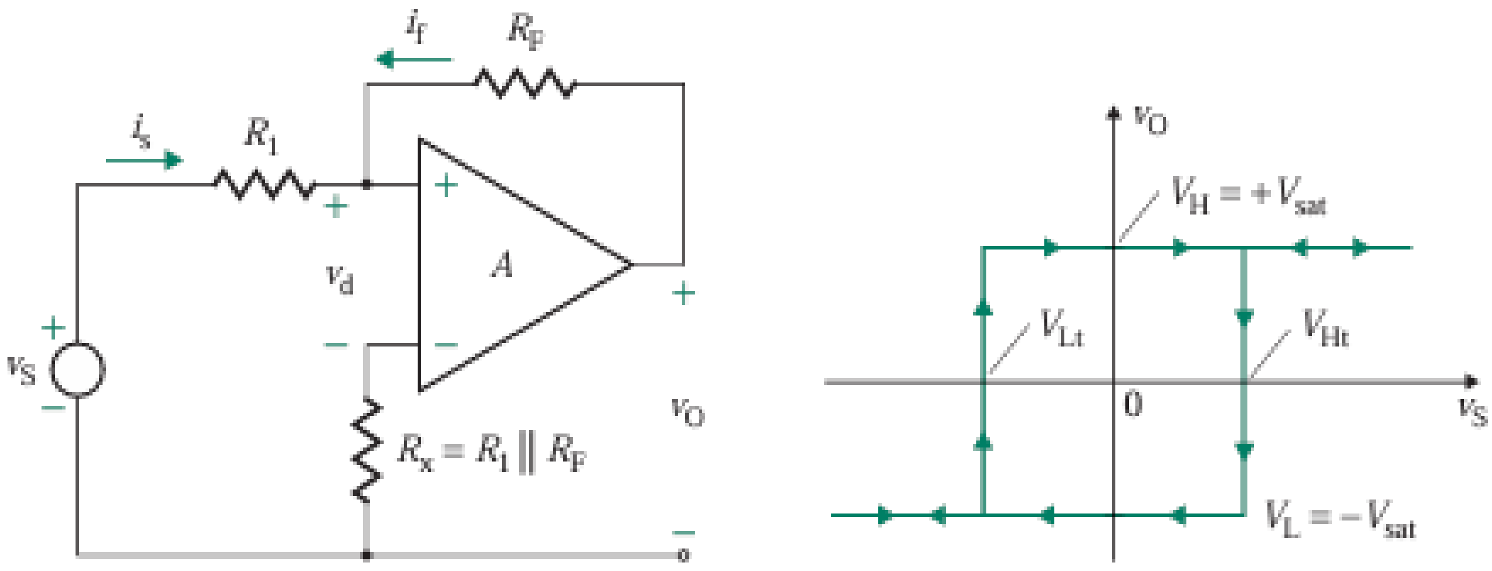

(e) Input and output voltages

**FIGURE 16.25** Schmitt trigger



**Chapter 16, Page 1102** of **Microelectronic Circuits Analysis and Design** *by Muhammad H. Rashid*

## 16.5.2 Noninverting Schmitt Trigger




(a) Circuit

(b) Transfer characteristics

**FIGURE 16.28** Noninverting Schmitt trigger

# Square-Wave Generators

- ❖ It is also called free running or astable multivibrator

- ❖ Assume that voltage across C is zero at the instate of the dc voltages (+Vcc and -$V_{EE}$) are supplied

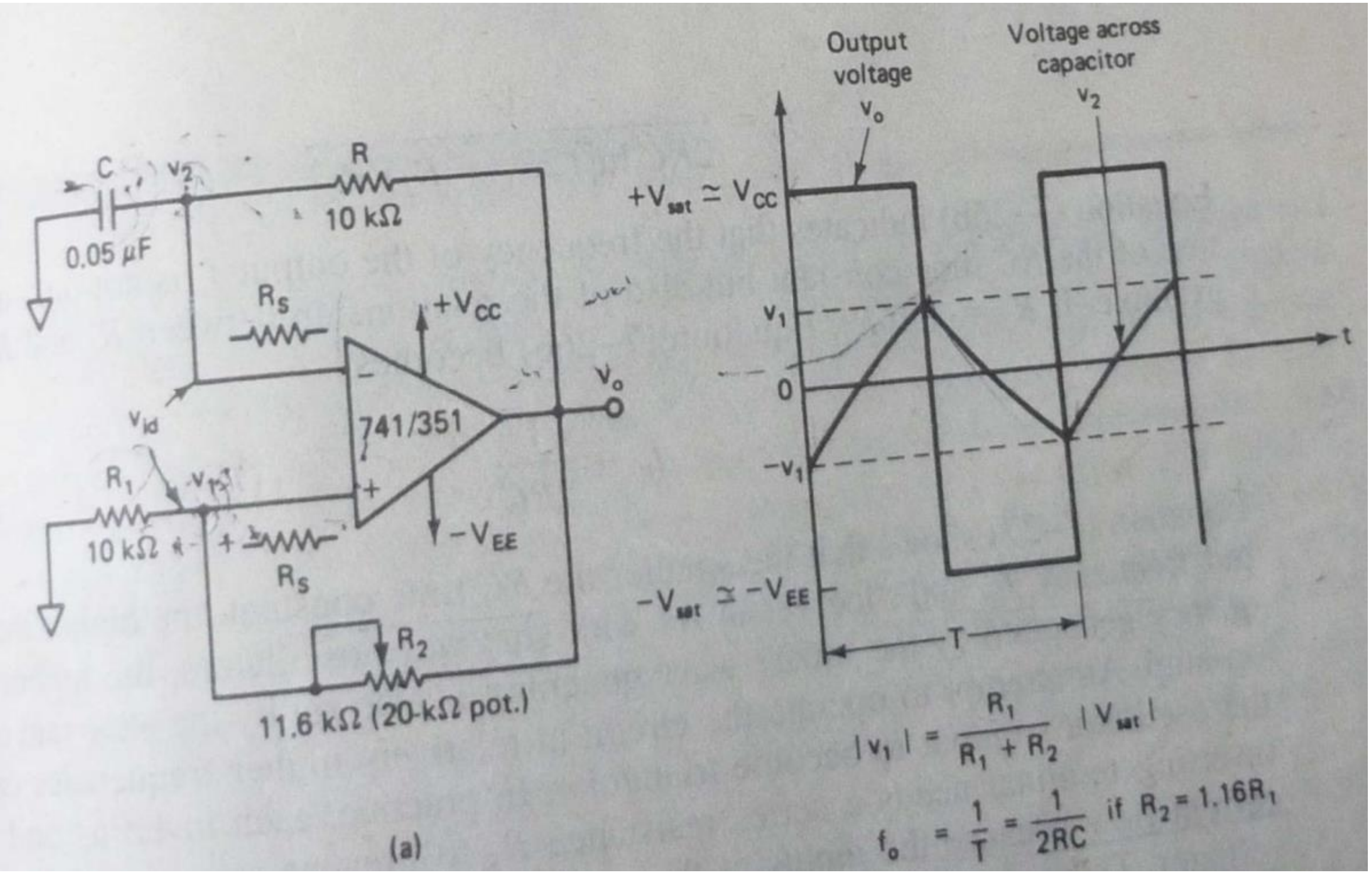



Fig. 7-21: (a) Square wave generator (b) waveform of the output voltage and capacitor voltage

- ❖ Offset voltage at v1 will drive the op-amp to positive saturation
- ❖ Then C will start to charge

# Triangular-Wave Generators

## 16.7 Triangular-Wave Generators

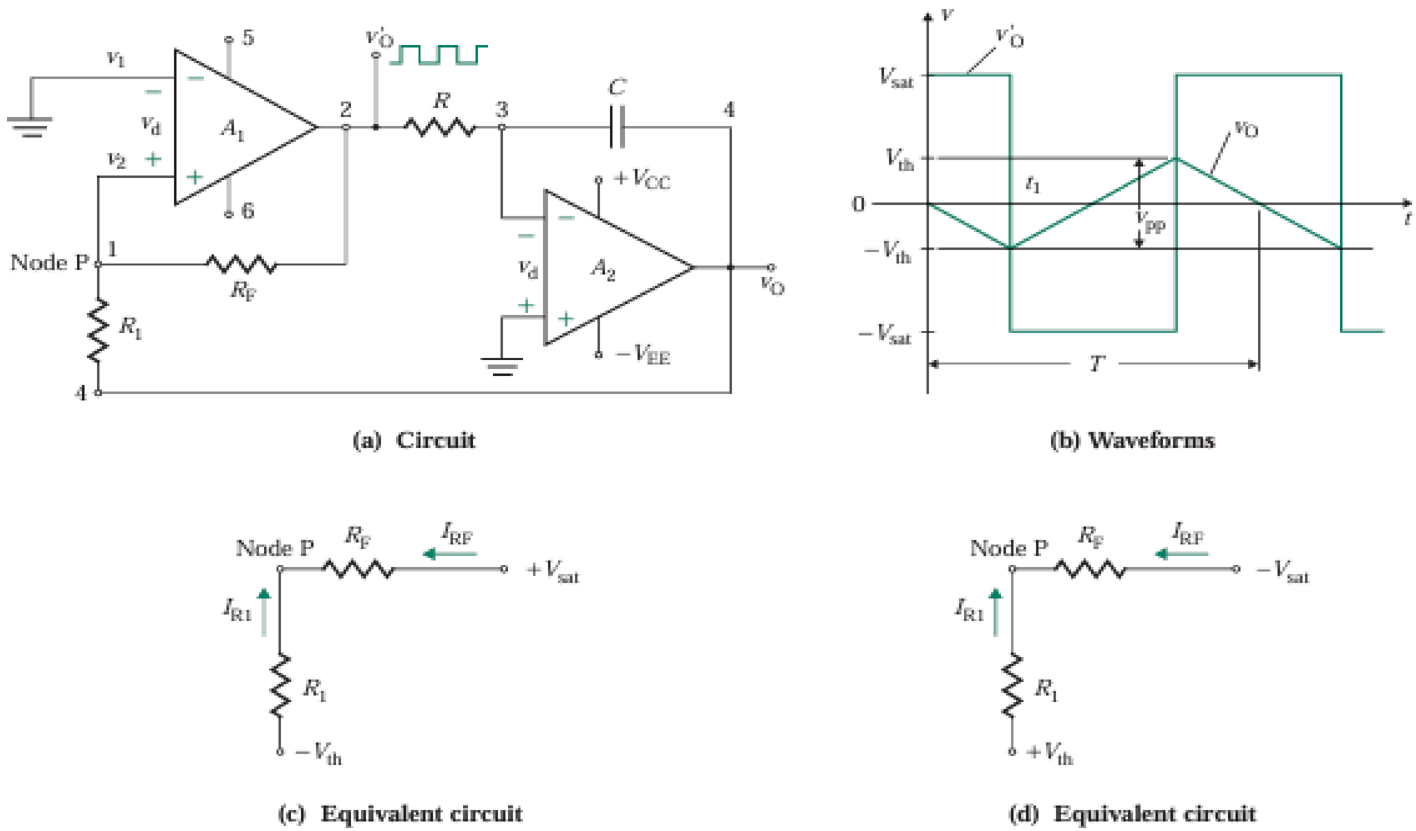
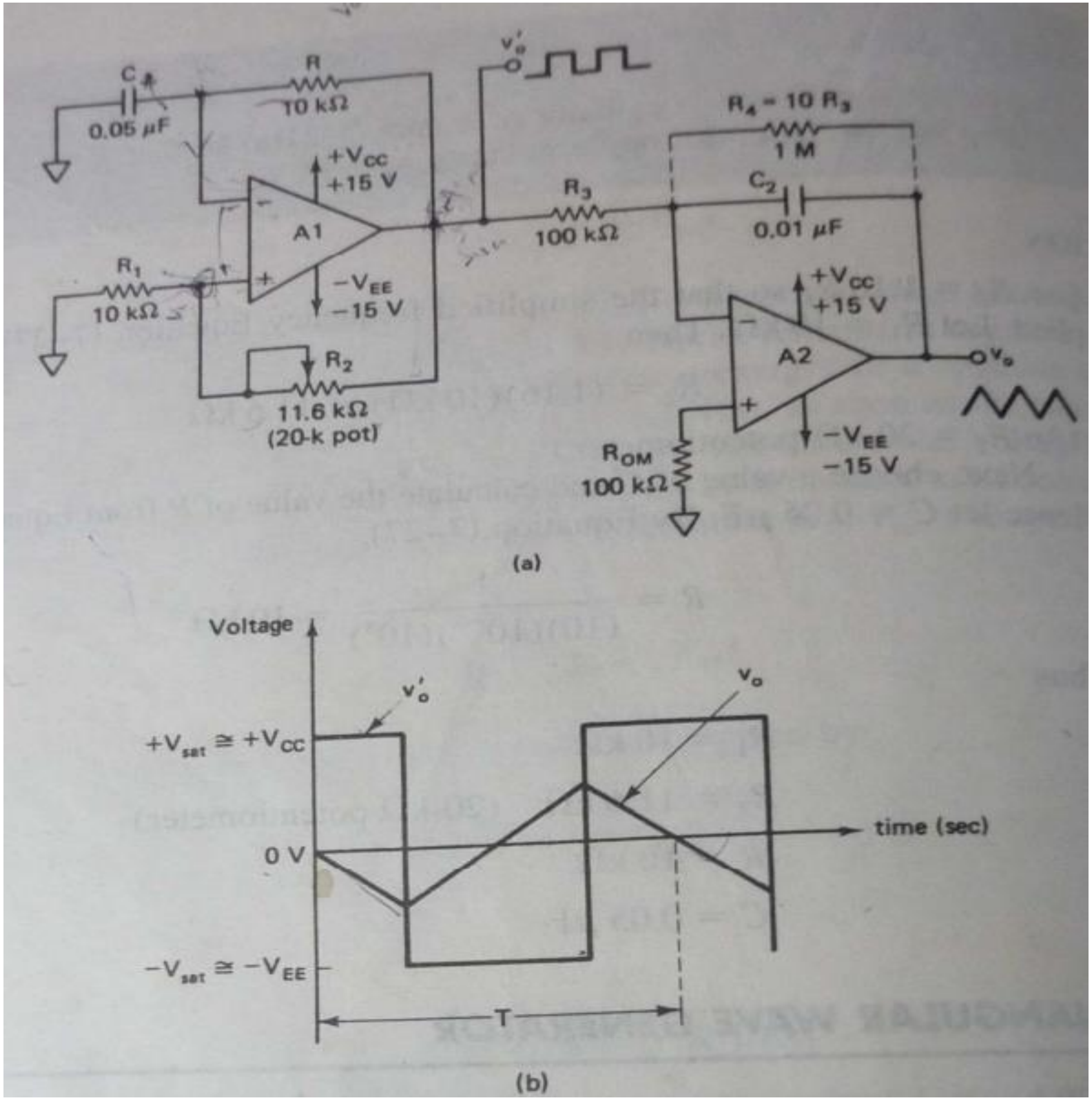



**FIGURE 16.37** Triangular-wave generator

# Triangular-Wave Generators



## 16.8 Sawtooth-Wave Generators

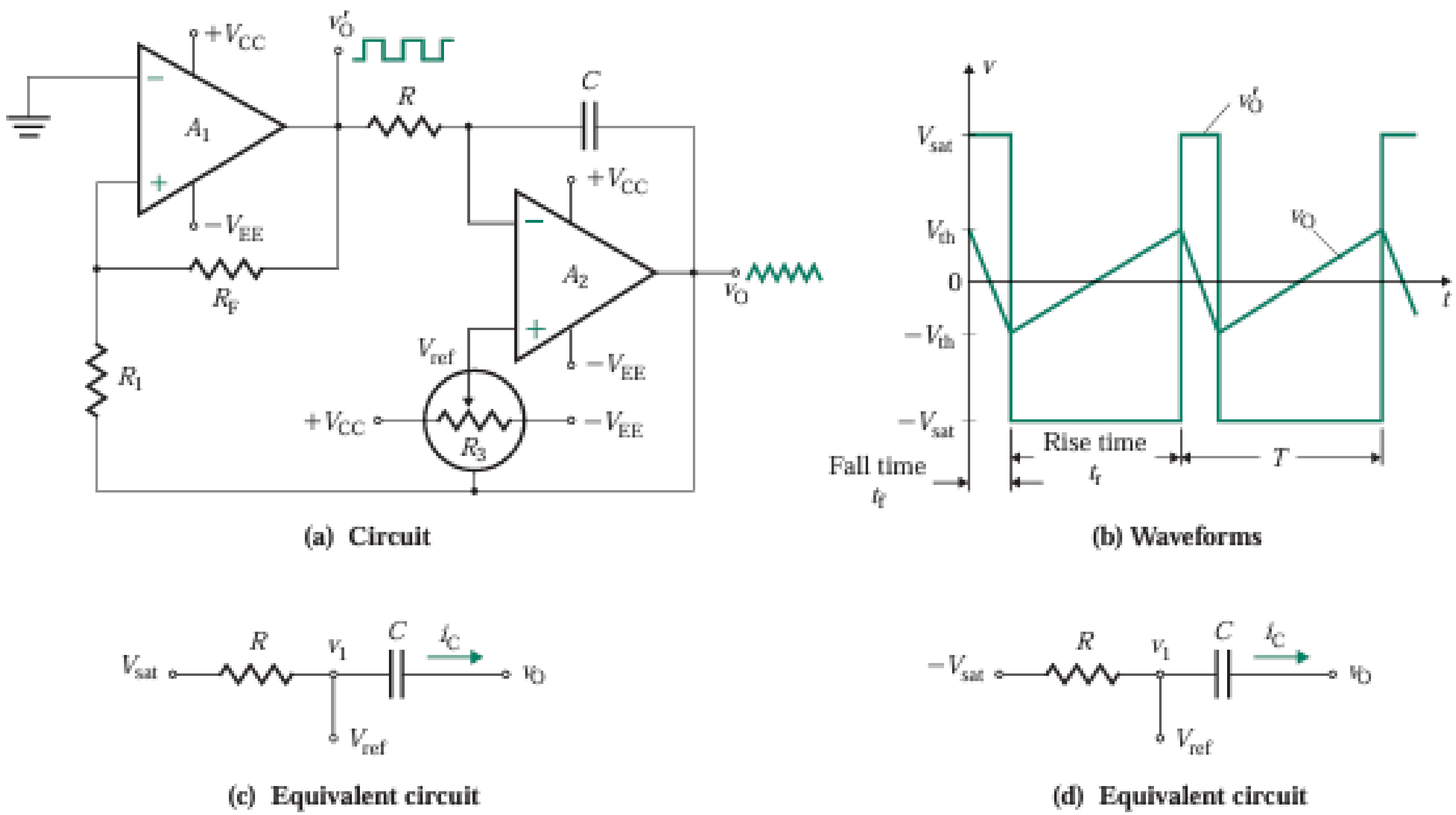
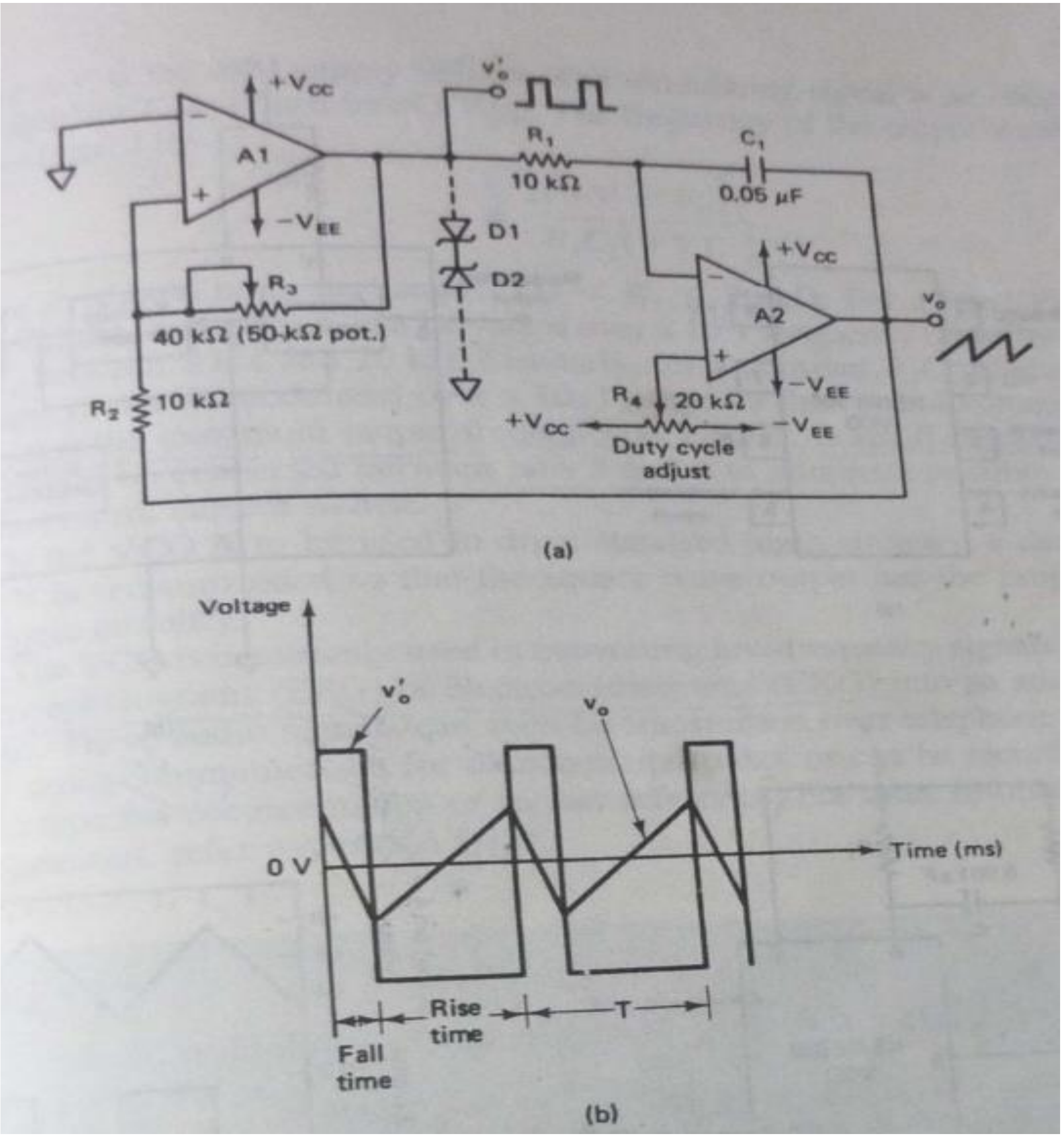



**FIGURE 16.40** Sawtooth-wave generator

# Sawtooth-Wave Generators



# Oscillator Circuits

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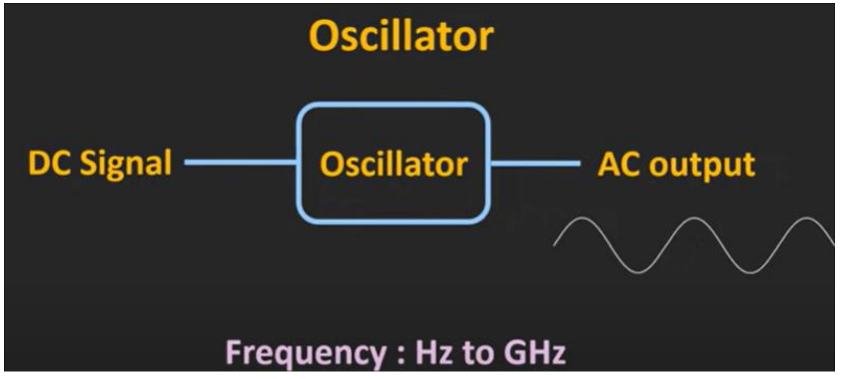
*by James M. Fiore*

# Oscillator Operation

- The use of positive feedback that results in a feedback amplifier having closed-loop gain $|A_f|$ greater than 1 and satisfies the phase conditions will result in operation as an oscillator circuit.
- An oscillator circuit then provides a varying output signal (sinusoidal oscillator, pulse or square-wave oscillator).




- When the switch at the amplifier input is open, no oscillation occurs. Consider that we have a fictitious voltage at the amplifier input $V_i$.
- This results in an output voltage $V_o = AV_i$ after the amplifier stage and in a voltage $V_f = \beta(AV_i)$ after the feedback stage.
- Thus, we have a feedback voltage $V_f = \beta AV_i$, where $\beta A$ is referred to as the loop gain.
- If the circuits of the base amplifier and feedback network provide $\beta A$ of a correct magnitude and phase, $V_f$ can be made equal to Vi. (It must be required for stable Oscillation)

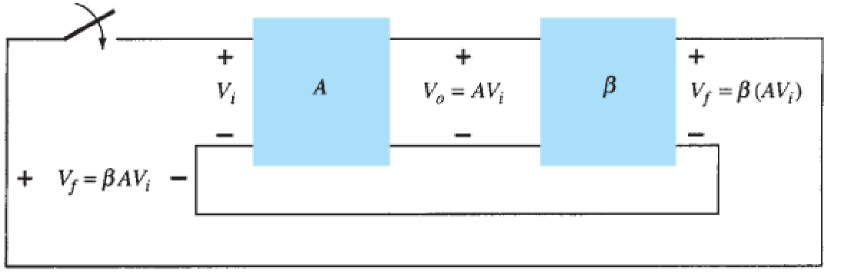



**FIG. 14.18**
*Feedback circuit used as an oscillator.*

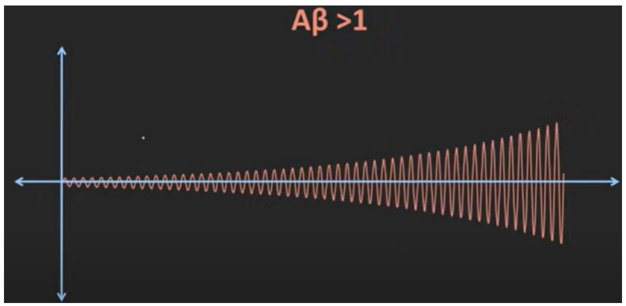
- Then, when the switch is closed and the fictitious voltage $V_i$ is removed, the circuit will continue operating since the feedback voltage is sufficient to drive the amplifier and feedback circuits, resulting in a proper input voltage to sustain the loop operation.
- The output waveform will still exist after the switch is closed if the condition $\beta A = 1$ is met. This is known as the Barkhausen criterion for oscillation.

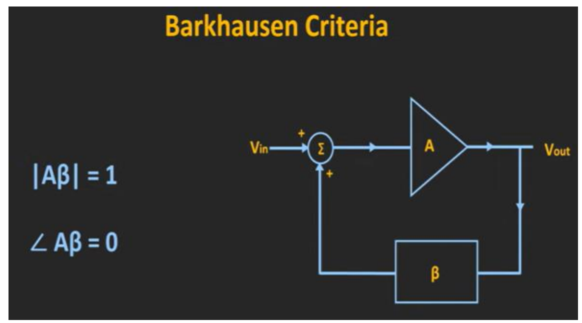


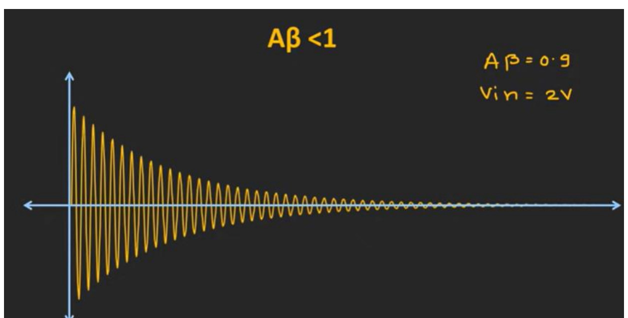
**Chapter 14, Page 766** of **Electronic Devices and Circuit Theory** *by R Boylestad and L Nashelsky*

# Oscillator Operation

- In reality, no input signal is needed to start the oscillator going.
- Only the condition βA = 1 must be satisfied for self-sustained oscillations to result.
- In practice, βA is made greater than 1 and the system is started oscillating by amplifying noise voltage, which is always present.
- Saturation factors in the practical circuit provide an “average” value of βA of 1.
- The resulting waveforms are never exactly sinusoidal.
- However, the closer the value βA is to exactly 1, the more nearly sinusoidal is the waveform.
- Figure 14.19 shows how the noise signal results in a buildup of a steady-state oscillation condition.



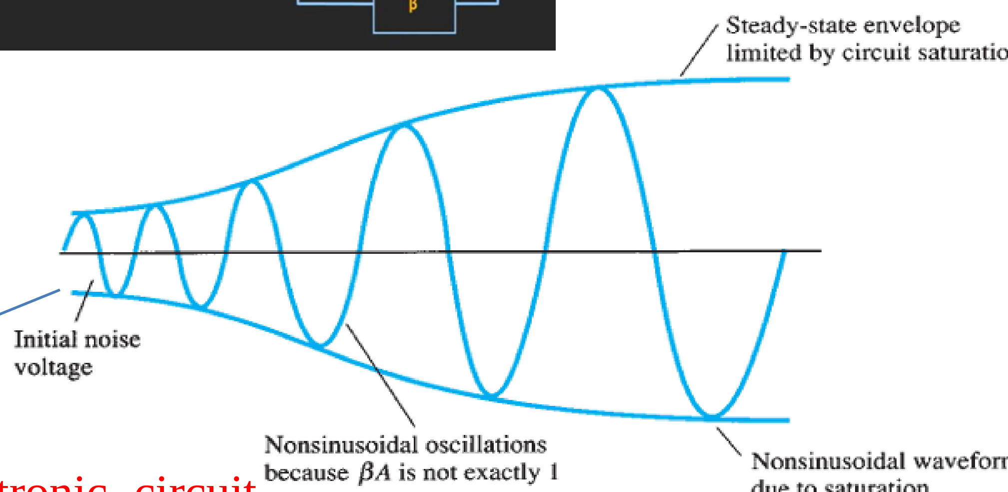



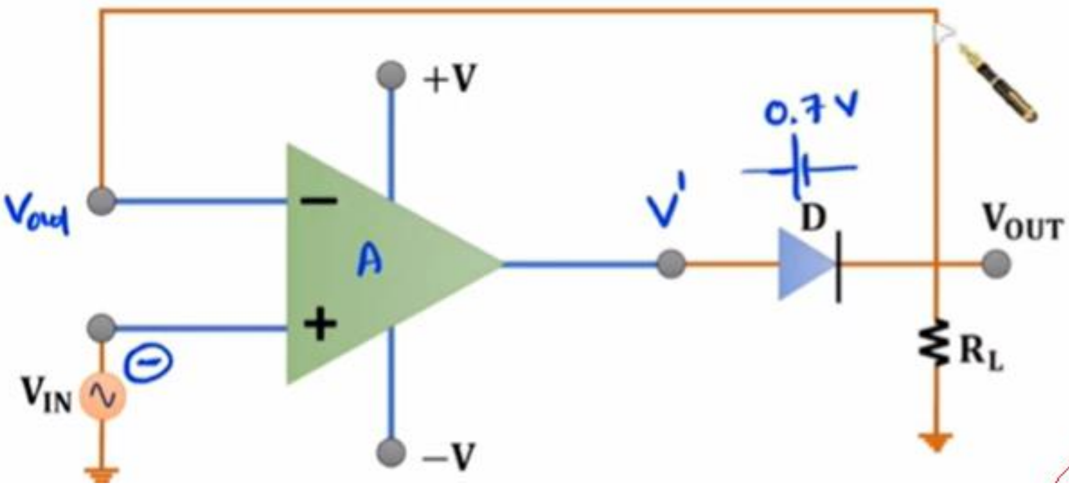

**FIG. 14.19**
*Buildup of steady-state oscillations.*

This is thermal noise exist in all electronic circuit without any input, frequency ranging from few Hz to GHz. Only one frequency is selected by feedback

Please solve Examples and Exercise problems of related topics

Practice yourself and send me your feedback, if any.

# Half wave Precision Rectifier using Operational Amplifier




Output of OpAmp

$$\Rightarrow V' = A\,(V_{in} - V_{out})$$

$$\Rightarrow 0.7 + V_{out} = A\,(V_{in} - V_{out})$$

$$\Rightarrow \frac{0.7 + V_{out}}{A} = V_{in} - V_{out}$$

$$A = 10^6$$

$$\Rightarrow 0 = V_{in} - V_{out}$$

$$\Rightarrow V_{in} = V_{out}$$