Chapter 1: PN junction diode

1. Introduction

The diode is the simplest semiconductor component. It is an element that allows the current to pass only in one direction. The current circulates from the anode to the cathode, therefore the diode is an oriented component.

In this chapter we will give the principle of operation of the diode, its characteristic curve, and its areas of applications.

2. Principle of PN junction diode

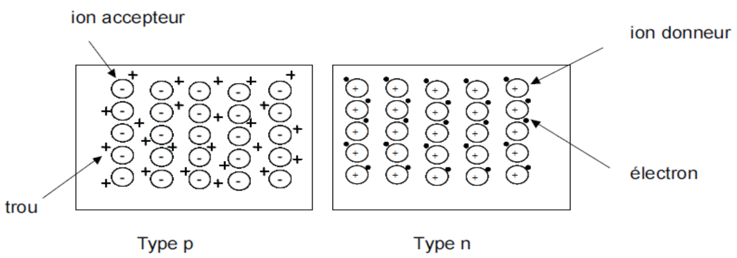
A PN junction is constituted by the juxtaposition of two regions of different types of the same semiconductor monocrystal.

When the two regions are combined, the concentration difference between the carriers of the P and N regions will cause the circulation of a diffusion current aimed at equalizing the concentrations in carriers from one region to another.

- In the zone P the majority carriers are holes, and the accepting atoms constitute a reservoir of negative ions

- In the N region the majority carriers are electrons, and the donor atoms constitute a set of positive ions

A schematic representation of each region is shown in Fig. 1. Fixed ionized impurities, majority and minority carriers are represented in each region.



3. Bias of PN junction

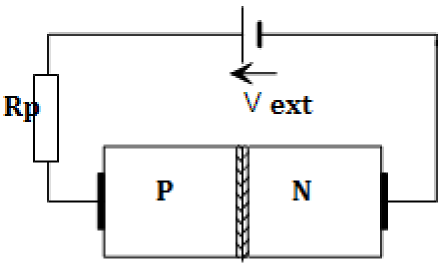
The polarization is obtained by applying, between its region P and its region N, an external tension, Vext. It can have two modes of connecting the external source, its plus on the P side, or its plus on the N side.

3.1. Zero bias

No external voltage is applied to the PN junction diode.

3.2. Forward bias of the PN junction

The negative borne of Vext is connected to the N region of the PN junction and the positive borne to the P region. A representation of direct polarization for a PN junction is illustrated in the figure below:



$$I = I_S(e^{V_D/U_T} - 1)$$

Is: reverse saturation current.
K: Boltzman constant.
T: temperature, at ambient temperature (300K) UT=KT/q=26mv.

Two cases may be occurring:

1) Vext>Vi

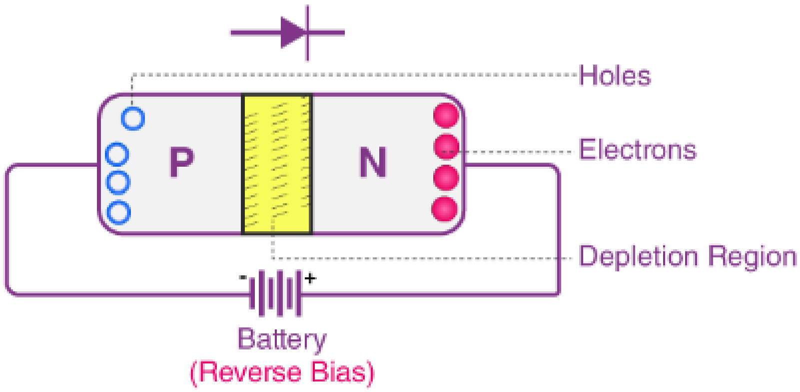
Since the forward voltage of the diode, V_D is greater than V_o, more majority carriers will be crossing the junction, and the forward current exponentially increases with the forward voltage V_D. The diode is in conducting state, or we can say the diode is in the ON state.

2) Vex<Vi

Barrier voltage (V_0) is dominating. Hence, no majority carrier will be crossing the junction. Thus, the forward current is Zero (practically, forward current is 10^{-12} to 10^{-15}A), and the diode is now forward biased and non-conducting, i.e., it is in an OFF state.

3.3. Reverse Bias of the PN junction

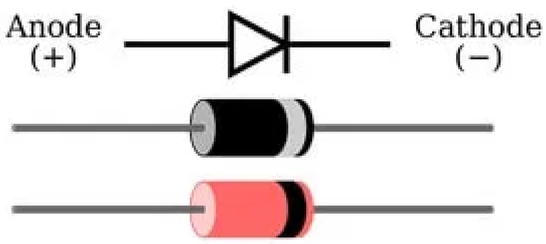
The figure below illustrates a voltage source connected to provide reverse bias of diode. Note that the positive borne of Vext is connected to the N region of the junction and the negative borne to the P region.



The reverse-bias voltage causes the depletion region of the diode to widen, creating a high resistance barrier that prevents the flow of current. and the diode is now revese biased and non-conducting, i.e., it is in an OFF state.

4. Symbol

The schematic symbol for the general-purpose diode is illustrated in Figure 4. The region N is the cathode (K) and the region P is called the anode (A).



Note: The ring indicates the cathode.

5. Diode equivalent scheme

5.1. The ideal diode

In this case the diode is a switch controlled by the Anode-Cathode voltage.

1) VAK>0 ⇒ The diode is “on” ⇒ The switch is closed.
2) VAK<0 ⇒ The diode is “off” ⇒ The switch is open.

5.2. The real diode

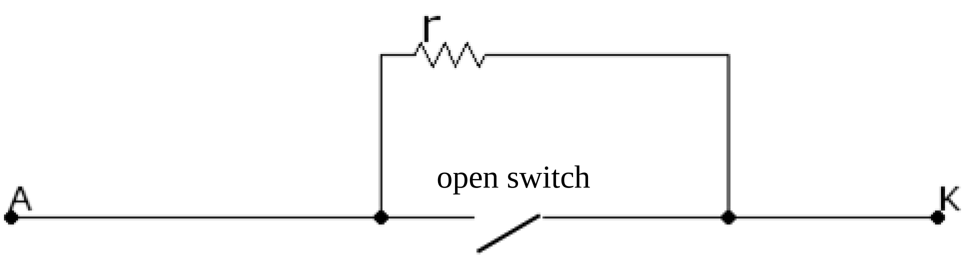
The real diode model takes into account the potential barrier, the low dynamic resistance and the high reverse resistance.

When the diode is under direct polarization, it acts as a closed serial switch with the potential barrier and dynamic resistance rd.

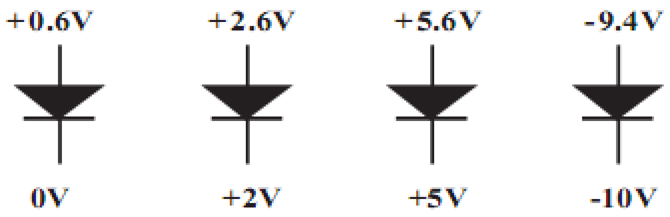
V0 : threshold voltage (potential barrier) from which the diode begins to drive.

rd: dynamic resistance of the diode

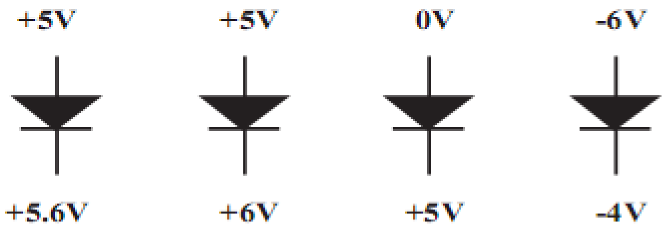
When the diode is under reverse polarization, it acts as an open switch in parallel with the strong internal reverse resistance r.



1. Example of forward bias



2. Example of reverse bias:



6. $I_D(V_D)$ characteristic of PN junction diode

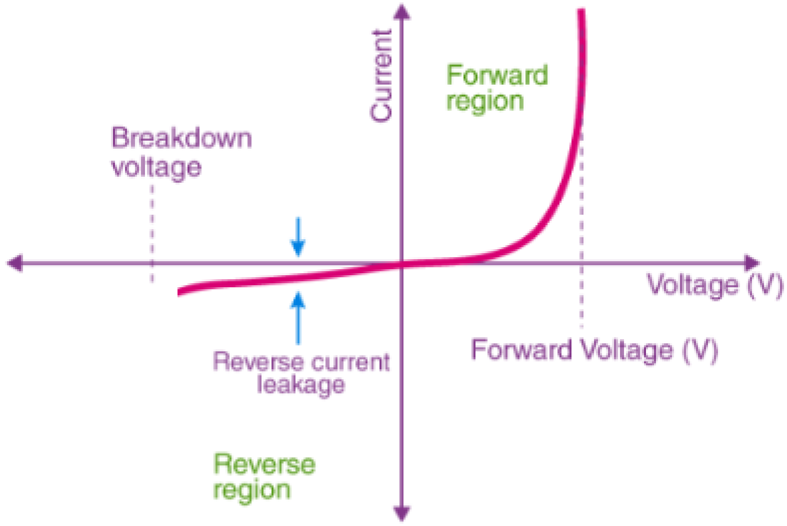
The characteristic of a diode is the curve representing the variation of the current I passing through the diode depending on the voltage V applied to it.

The characteristic in the direct direction relative to the diode is defined using the following equation : $I = I_S(e^{V_D/U_T} - 1)$

I_s : reverse saturation current.

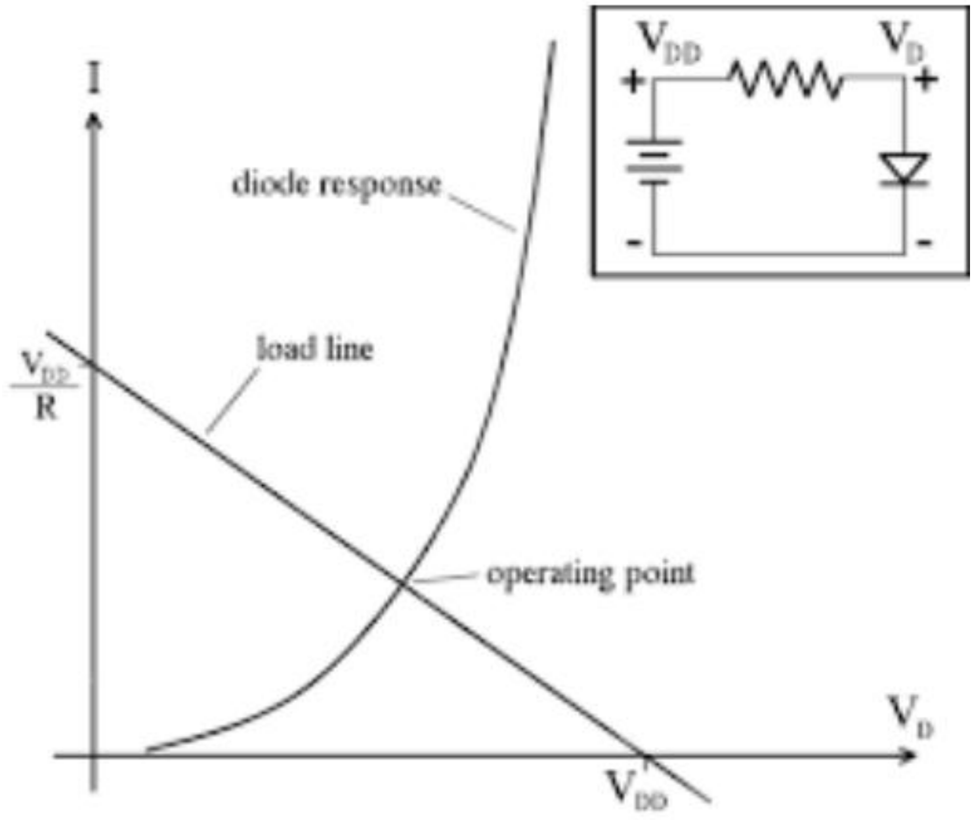
K_B : Boltzman constant.

T : temperature, at ambient temperature KT/q=26mv.



7. Load line and operating point

The purpose of this study is to determine the current and voltage of the Q(ID,VD) diode called the resting point or operating point.



For this, there are two methods for determining these two parameters.

7.1. The analytical method

It consists of solving the following system of equations:

$$\begin{cases} I = I_S\left(e^{V_D/U_T} - 1\right) \; diode\ current - voltage\ equation \\ \quad VD\ (ID)\ circuit\ load\ line\ equation \end{cases}$$

7.2. Graphical method

This method consists of determining the intersection point of the static charge line with the diode's voltage-current characteristic VD(ID).

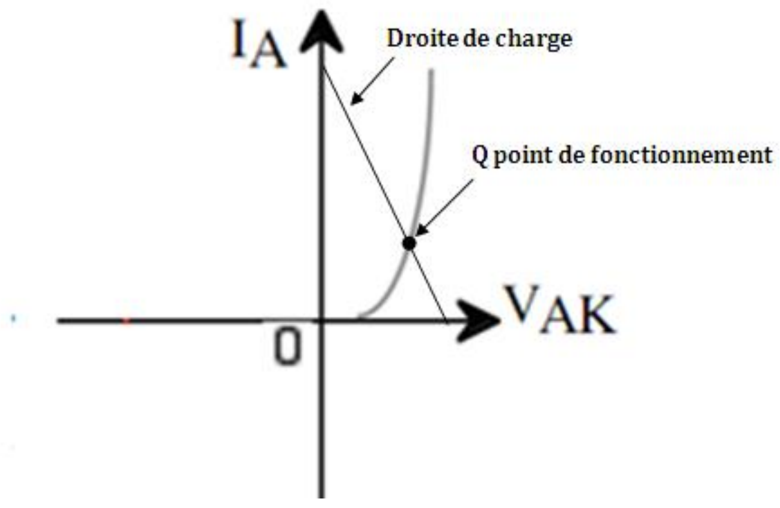
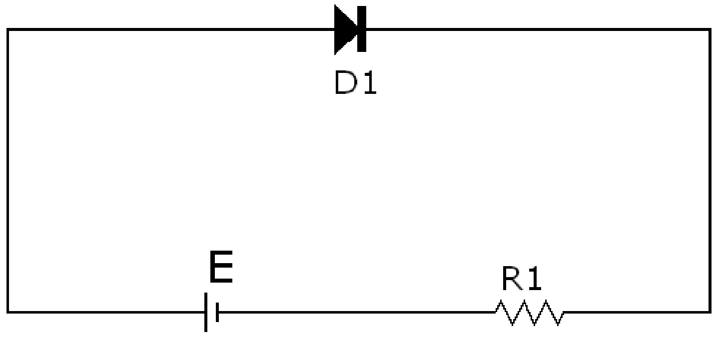


Figure 1

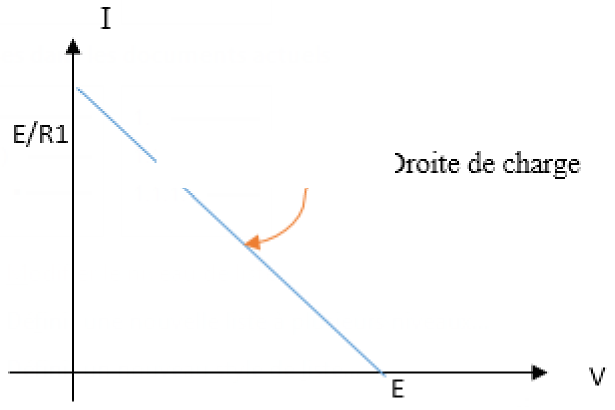
Example: Consider the circuit of the figure below:



1) Draw the load line equation

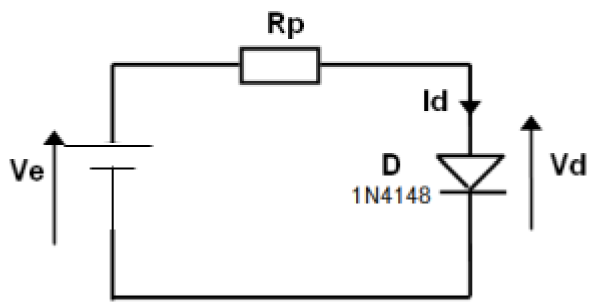
The equation of the charge line is:

$$V_D = E - R_1 I_D \Rightarrow I_D = \frac{E}{R_1} - \frac{V_D}{R_1}$$



Example

Consider the circuit of the figure below:



Given Ve=+5V, Rp=1KΩ et V0=0.6V.

1) Determine the current Id.

ID= ?

VD+RpID-Ve=0→ID=(Ve-VD)/Rp

NA:ID=(5-0.6)/1000=4.4mA

8. Diode in circuits

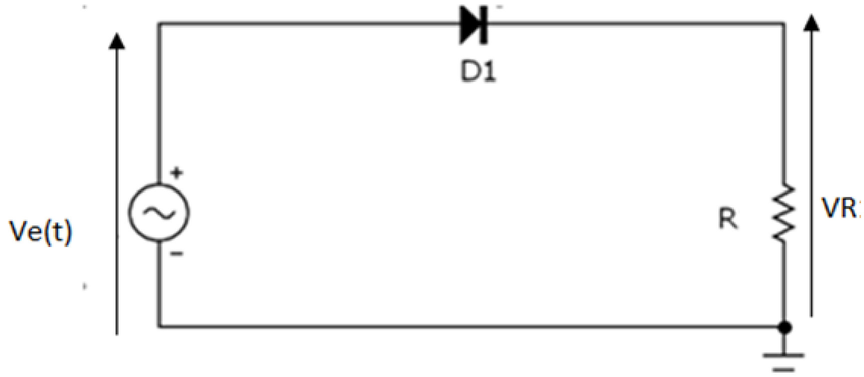
In all of the following circuits the diode is considered ideal, and $Ven(t) = Vmsin(wt)$.

8.1. Diode as rectifiers

The main application of PN junction diode is in rectification circuits. Diode rectifier circuits allow alternating (AC) current to be converted into one-way current (DC). Rectifiers are used in AC to DC power supplies

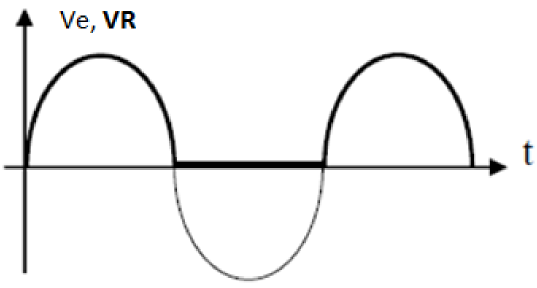
8.1.1. Half wave rectifier

We consider Ve(t)=Vmsin(wt), draw the output signal VR(t).



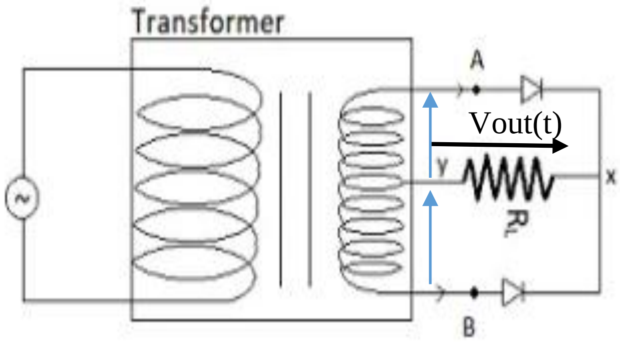
Work: Analyze the circuit and draw Vin(t) and VR(t) in the same graph.

- ✓ During the positive wave of Ve(t)⇒the diode is forward biased⇒VR=Ve(t).
- ✓ During the negative wave of Ve(t)⇒the diode is reverse biased⇒VR=0.



8.1.2. Full-wave rectifier with a transformer

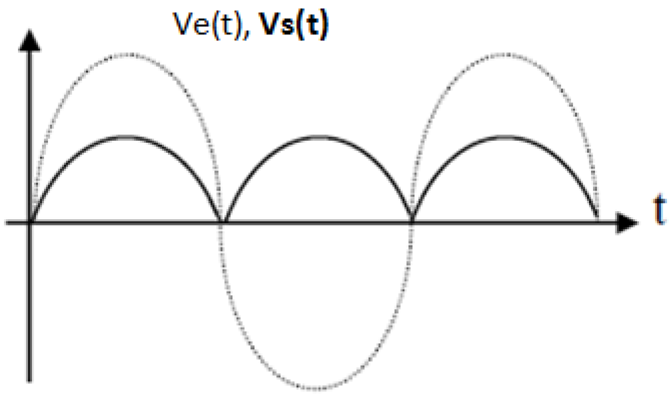
Consider the circuit below:



Work: Analyze the operation and plot the shape of the output signal Vin(t) and Vout(t) in the same graph.

During the positive half cycle, diode D_1 is forward biased as it is connected to the top of the secondary winding while diode D_2 is reverse biased as it is connected to the bottom of the secondary winding. Due to this, diode D_1 will conduct acting as a short circuit and D_2 will not conduct acting as an open circuit.

During the negative half cycle, the diode D_1 is reverse biased and the diode D_2 is forward biased because the top half of the secondary circuit becomes negative and the bottom half of the circuit becomes positive. Thus in a full wave rectifier, DC voltage is obtained for both positive and negative half cycle.



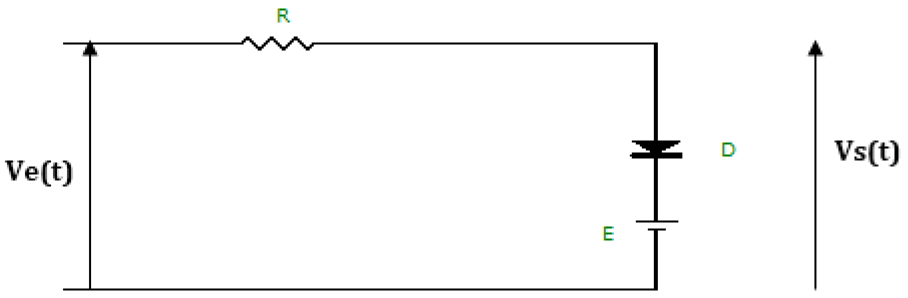
8.2. Clipping circuits

These clipping circuits (also called limiters) aim to modify the amplitude of a voltage or more precisely to eliminate part of it.

A clipper is a device that removes either the positive half (top half) or negative half (bottom half), or both positive and negative halves of the input AC signal.

8.2.1. Positive clipper

Consider the circuit below :Ve(t)=VmSin(wt) ; Vm>E



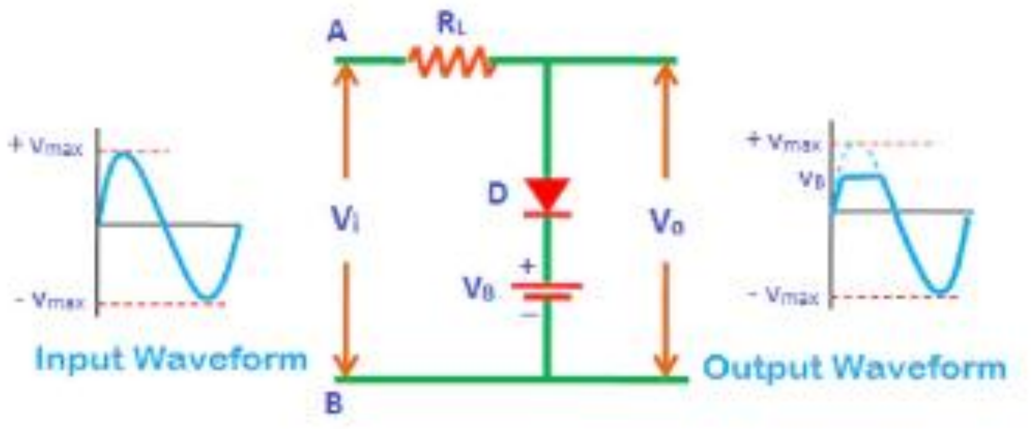
Work : Analyze the circuit and draw the shape of Ve(t) and Vs(t) in the same graphe.

1) During the positive wave (+) of Ve(t)

- Ve<E⇒ D is reverse biased by ve(t) (i=0) ⇒ D ⇔ Open switch ⇒V_S=Ve(t).
- Ve>E⇒ D is forward biased by ve(t) ⇒ D ⇔ Closed switch ⇒ V_s=E.

2) During the negative wave (-) of Ve(t)

D is reverse biased by ve(t) (i=0) ⇒ D ⇔ Open switch ⇒V_S=Ve(t).



8.2.2. Dual clipper

Sometimes it is desired to remove a small portion of both positive and negative half cycles. In such cases, the dual clippers are used.

The dual clippers are made by combining the biased shunt positive clipper and biased shunt negative clipper.

1) We clip the positive part and the negative part. Both levels are adjustable.
2) It is necessary that the amplitude of the signal to be clipped is greater than E1 and E2, so that the circuit can correctly fulfill the function for which it was designed.

3) $Ve(t) = Vm \sin wt$ et $Vm > E1\ et\ E2$.

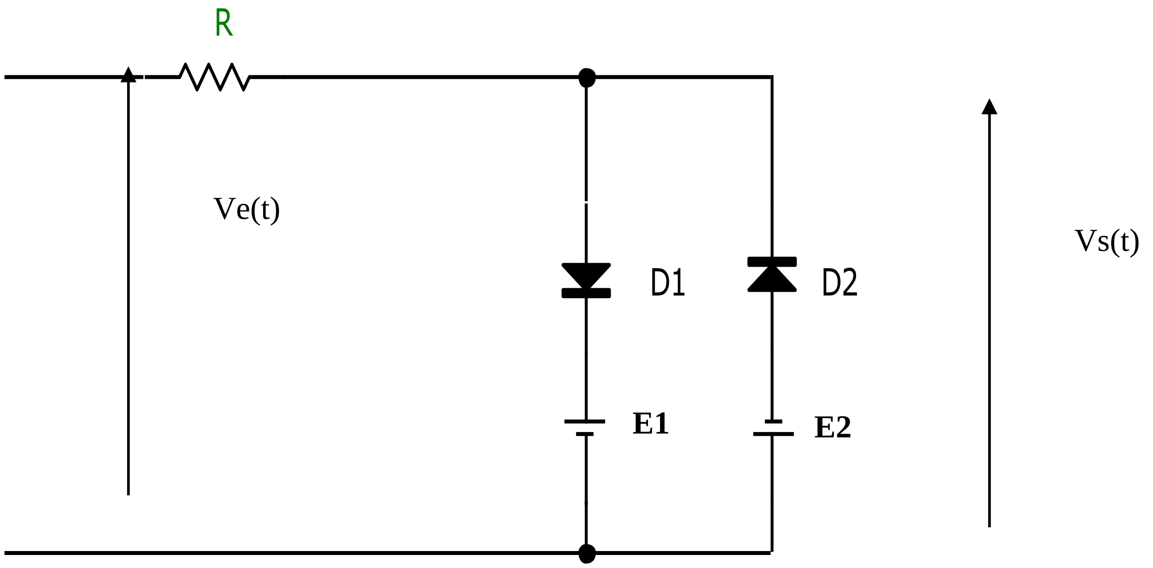


Figure 2

Work: Draw the shape of the output signal.

Analysis:

✓ During the (+) wave of Ve(t) : D2 is always off

1) Ve(t)>E1 ➔D1 on ➔ VS=E1
2) Ve(t)<E1 ➔D1 off➔ VS=Ve(t)

✓ During the (-) wave of Ve(t) : D1 is always off

1) Ve(t)>E2 ➔D2 off ➔ VS=Ve(t)
2) Ve(t)<E2 ➔D2 on ➔ VS=-E2