CLASS 8

p-n junction biasing, diode and piecewise linear diode models

TUTORS

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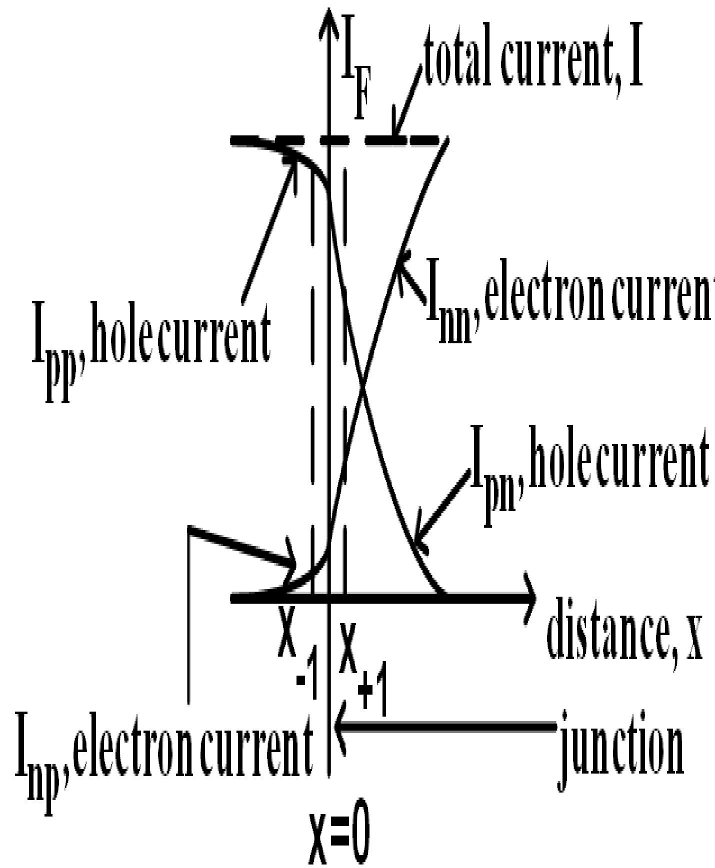
Hole current crosses the junction and enters the n as:

FORWARD CURRENT

$$I_{pn} = \frac{AqD_p p_n}{L_p}\left(e^{\left(V/V_T\right)} - 1\right)$$

Electron current crosses the junction and enters the p as:

$$I_{np} = \frac{AqD_n n_p}{L_n}\left(e^{\left(V/V_T\right)} - 1\right)$$



where A = cross section area

L_p , L_n = hole, electron diffusion length in n,p

p_n , n_p = hole, electron density in n, p (minority carriers)

q = electronic charge, 1.6 x 10^{-19} C

D_p , D_n =hole, electron diffusion coefficient

V = forward biasing voltage,

V_T = temperature equivalent voltage

= kT/q ≈ 26 mV at T = 300°K,

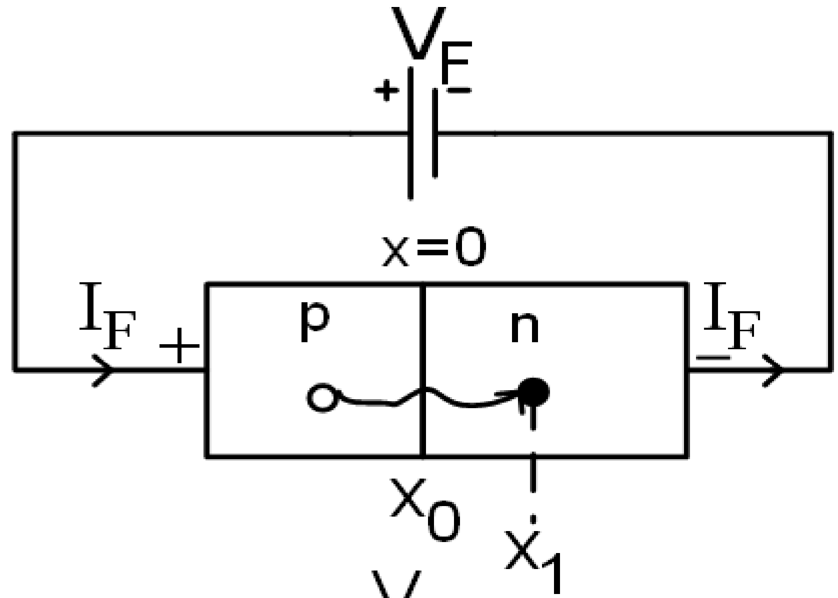
k = Boltzmann constant = 1.38x10^{-23} J/°K

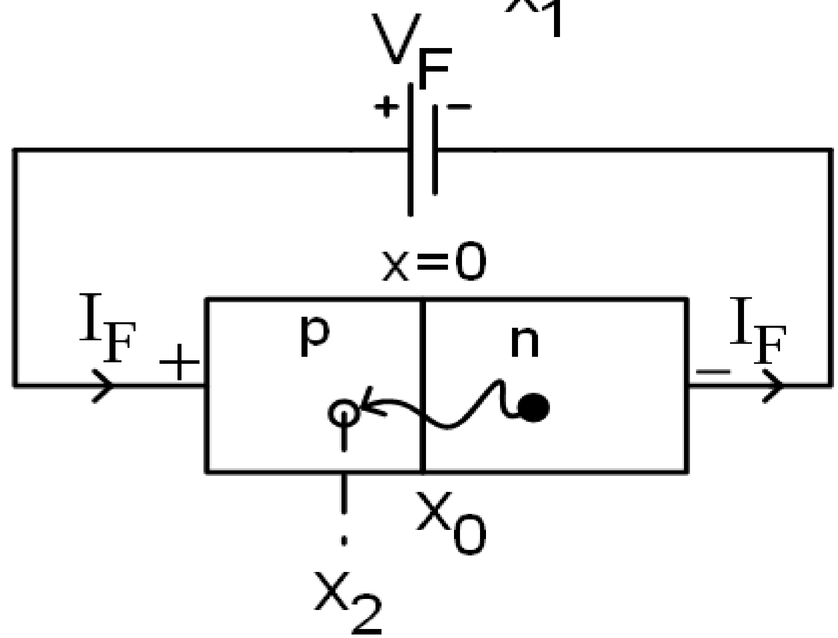
- **Hole diffusion length in n:**

  $L_p = |x_1 - x_0|$ is the distance into the n before the hole recombines with an electron.

- **Electron diffusion length in p:**

  $L_n = |x_2 - x_0|$ is the distance into the p before the electron recombines with a hole.





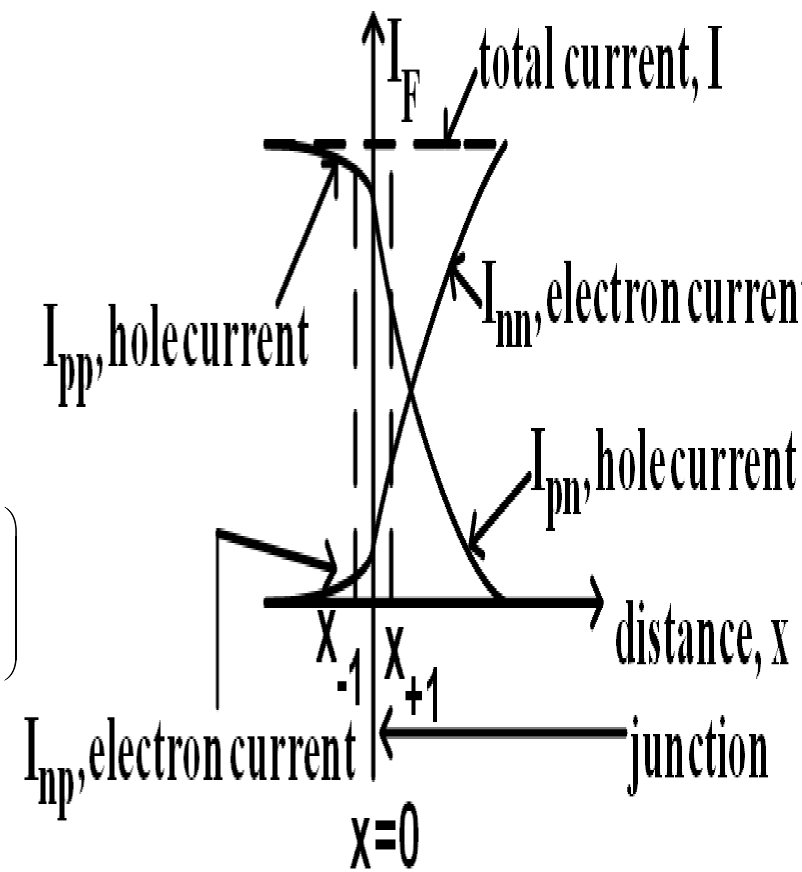
At x = 0, I = I_{pn} + I_{np}

$$I_{np} = \frac{AqD_n n_p}{L_n}\left(e^{\left(V/V_T\right)} - 1\right)$$

$$I_{pn} = \frac{AqD_p p_n}{L_p}\left(e^{\left(V/V_T\right)} - 1\right)$$

$$I = \left(\frac{AqD_p p_n}{L_p} + \frac{AqD_n n_p}{L_n}\right)\left(e^{\left(V/V_T\right)} - 1\right)$$

$$= I_S\left(e^{\left(V/V_T\right)} - 1\right)$$



where I_S is the reverse saturated current.

$$L_p = \sqrt{D_p \tau_p}$$

$$L_n = \sqrt{D_n \tau_n}$$

τ_p = Hole lifetime in n

τ_n = Electron lifetime in p

$\tau_p = |t_1 - t_0|$

$\tau_n = |t_2 - t_0|$

If l_p and l_n are the length of the p and n respectively, then

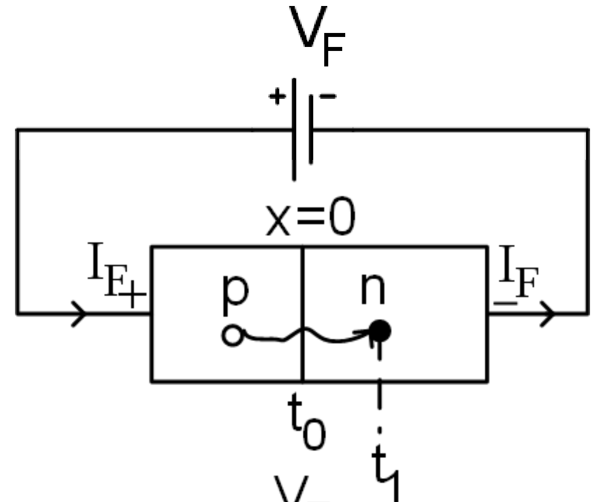
$$I = \left(\frac{AqD_p p_n}{L_p} + \frac{AqD_n n_p}{L_n} \right) \left(e^{\left(V/V_T \right)} - 1 \right)$$

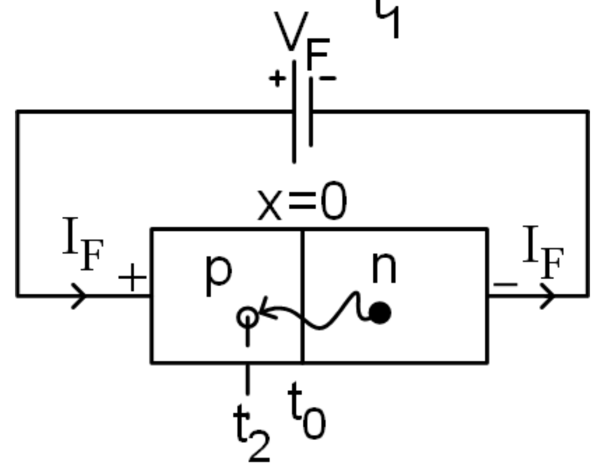
is for the condition when $l_p >> L_p$

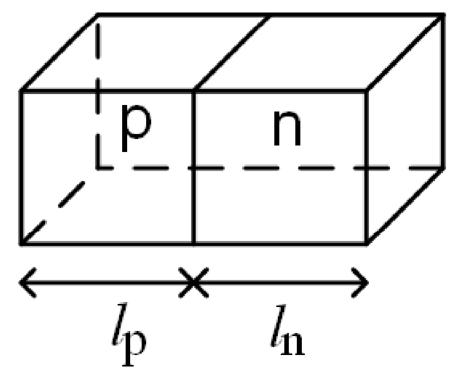
and $l_n >> L_n$.

If $l_p < L_p$ and $l_n < L_n$, then

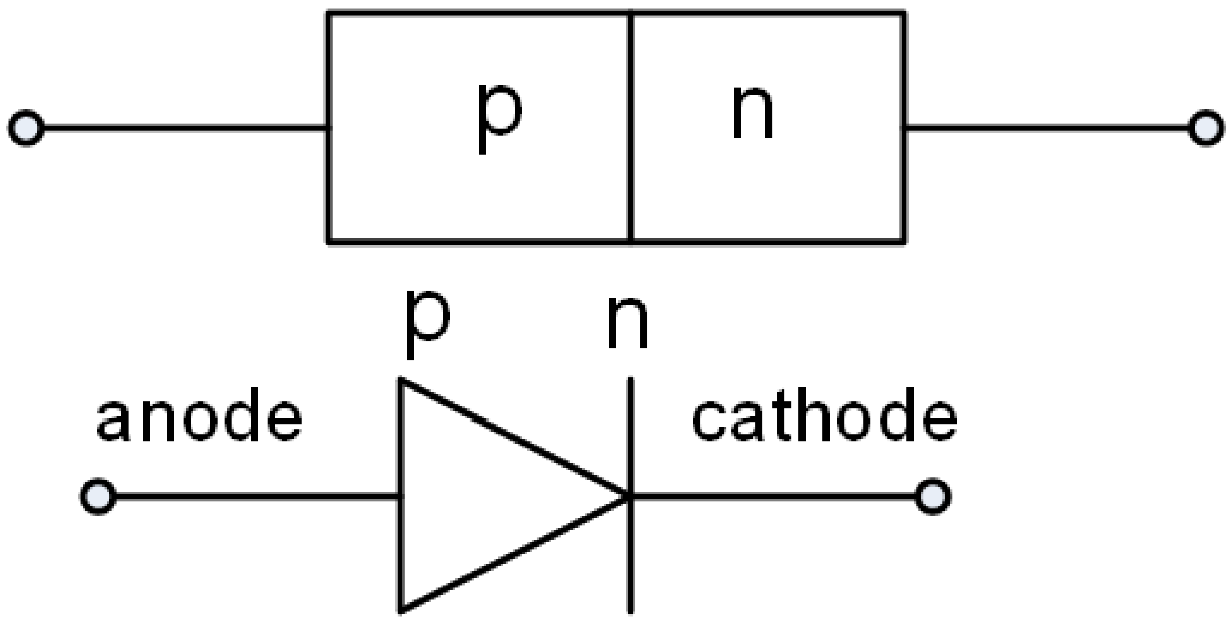
$$I = \left(\frac{AqD_p p_n}{l_p} + \frac{AqD_n n_p}{l_n} \right) \left(e^{\left(V/V_T \right)} - 1 \right)$$





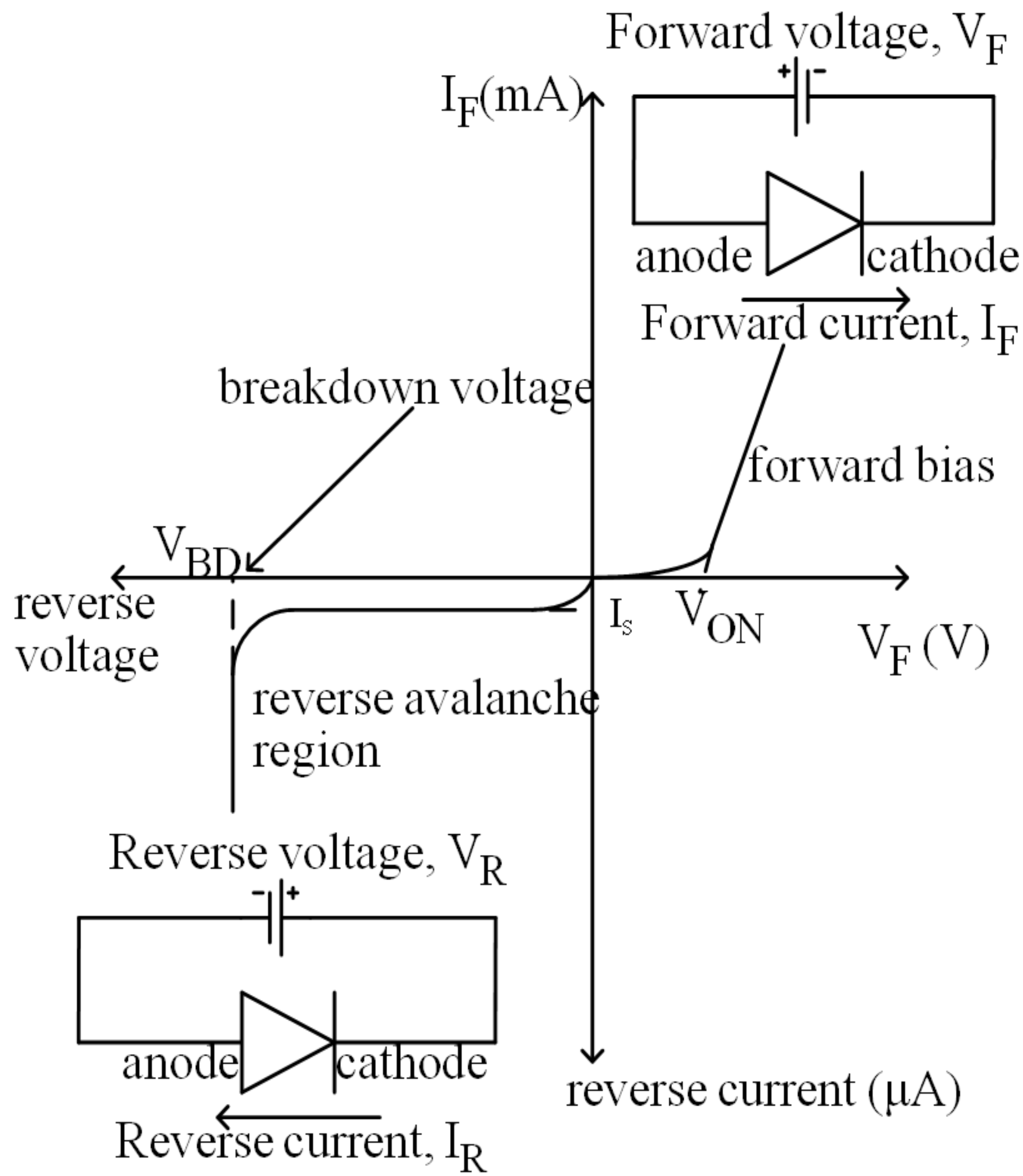


DIODE



symbol for the diode

- **In the fb region, the diode is a conductor and has low resistance towards current (provided V_F > V_{ON}). Diode can be replaced by a short.**
- **In the rb region, the diode is a weak conductor and has very high resistance towards current (condition before avalanche). Diode can be replaced by an open.**
- **The reverse avalanche region should be avoided as the diode may be damaged under this condition.**



DIODE CURRENT

$$I = I_S\left(e^{\left(V/\eta V_T\right)} - 1\right)$$

where I_S is the saturated current. For a small signal diode (small size diode for low power application), I_S is in the vicinity of 10^{-15} A. I_S is very dependent on temperature. For example, I_S in Ge may double for every 10°C increase in temperature.

η = 1→2 depending on the material and the physical structure of the diode.

Diode fabricated through typical IC process has η = 1 when operated under normal condition.

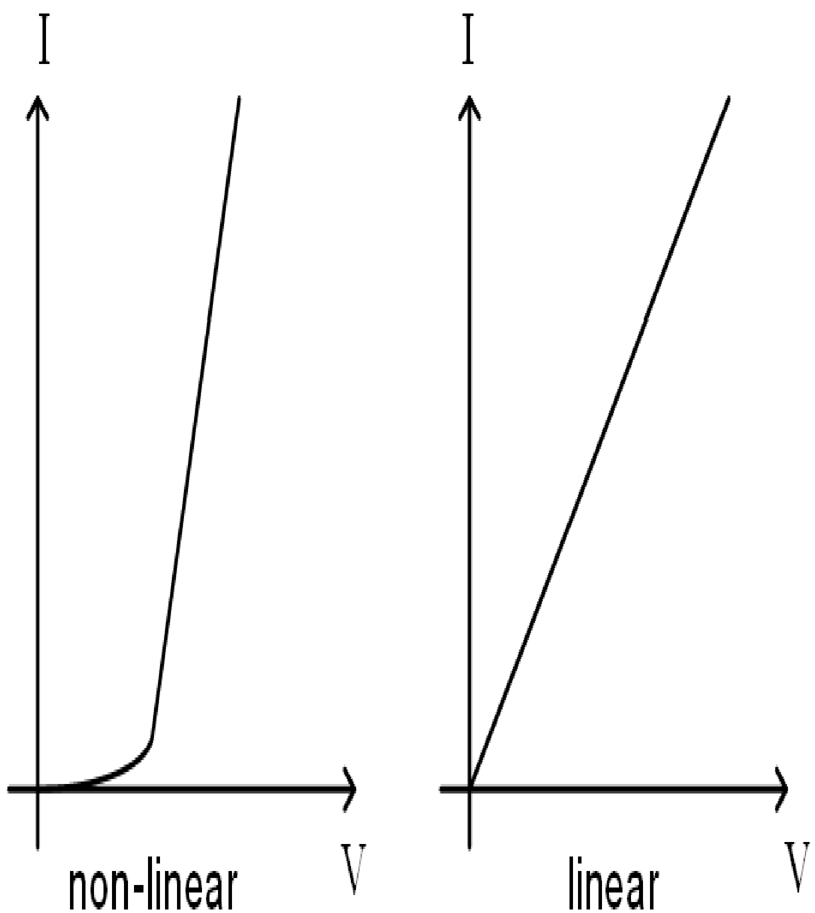
DIODE CIRCUITS

<u>Piecewise linear diode model</u>

Transistors are used in electronic circuits. Transistors are active devices that have non-linear characteristics.

A transistor is constructed of 2 p-n junctions. The p-n junction is having non-linear characteristics.

Typical technique used in analyzing non-linear circuits is the graph technique. However, this technique is inappropriate if the circuit is complex, contains capacitors and inductors whose whose dynamic characteristic is more important than its static characteristic.



- **Diode is not an active device, but it has non-linear characteristics. Hence, the diode can be used as a model to analyze non-linear circuits.**
- **Piecewise linear diode model is in the form of a network that contains linear elements such as the resistor.**
- **The diode model technique can be used for other non-linear components. This is to simplify the analysis of non-linear circuits.**

Replacing junction diodes with piecewise linear diodes will:

1. **reduce the problem of analyzing non-linear network as the network is converted to become linear. Consequently, typical method of analysis can be implemented.**
2. **provide combined linear I-V relationships to give an approximation of the overall non-linear I-V characteristic.**

Diode characteristics:

1. **Enable large current to flow in one direction (during forward bias) and only a very small current to flow in the opposite direction (during reverse bias).**
2. **Enable large voltage drop across the diode terminals during reverse bias but a very small voltage during forward bias. The reverse voltage can reach hundreds of volts.**

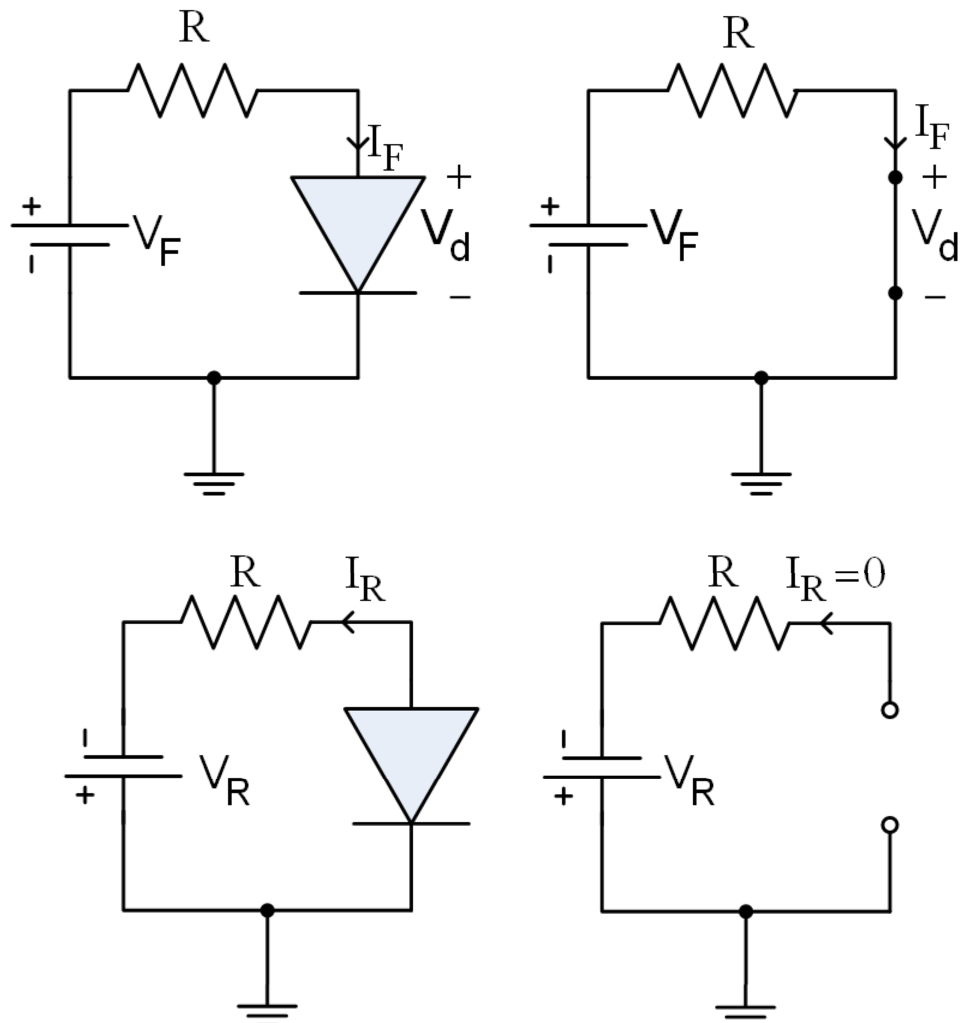
IDEAL PIECEWISE LINEAR DIODE MODEL

$I_F >> I_R$

$V_R >> V_d$

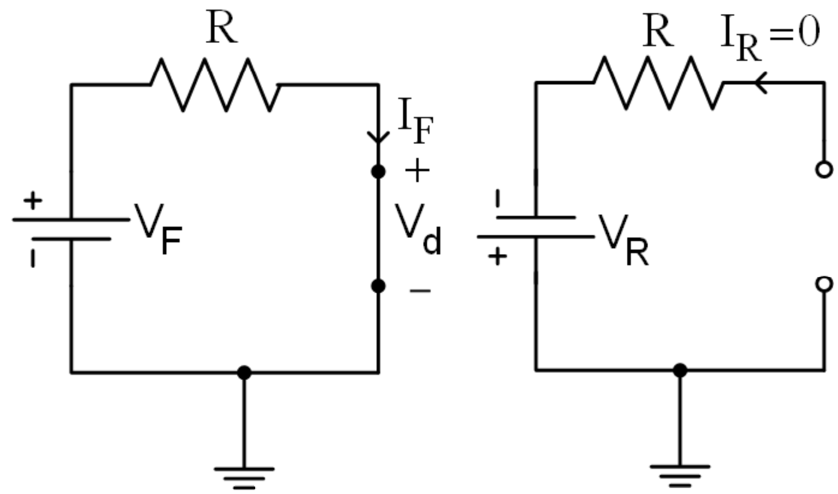
Ideal piecewise linear diode model:

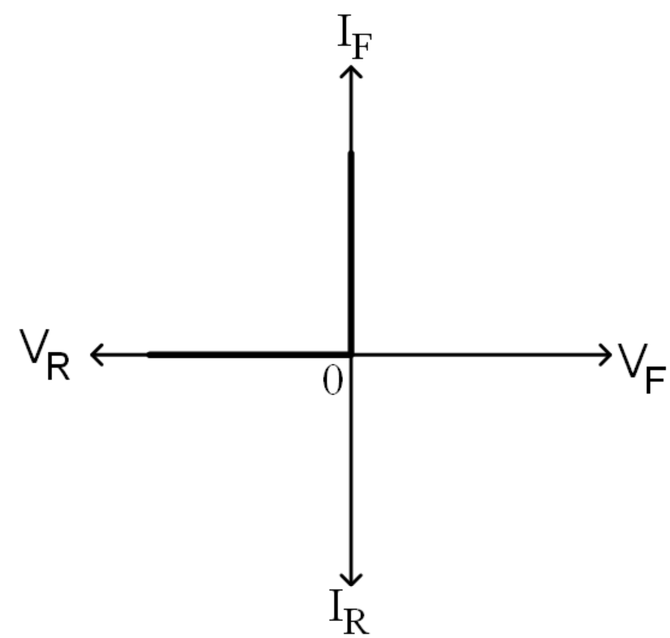
1. **Under the forward bias condition, $I_F > 0$ and $V_d = 0$. Diode is a s/c.**
2. **Under the reverse bias condition, $I_R = 0$ and $V_d < 0$. Diode is an o/c.**
3. **Potential barrier and reverse leakage current is neglected.**



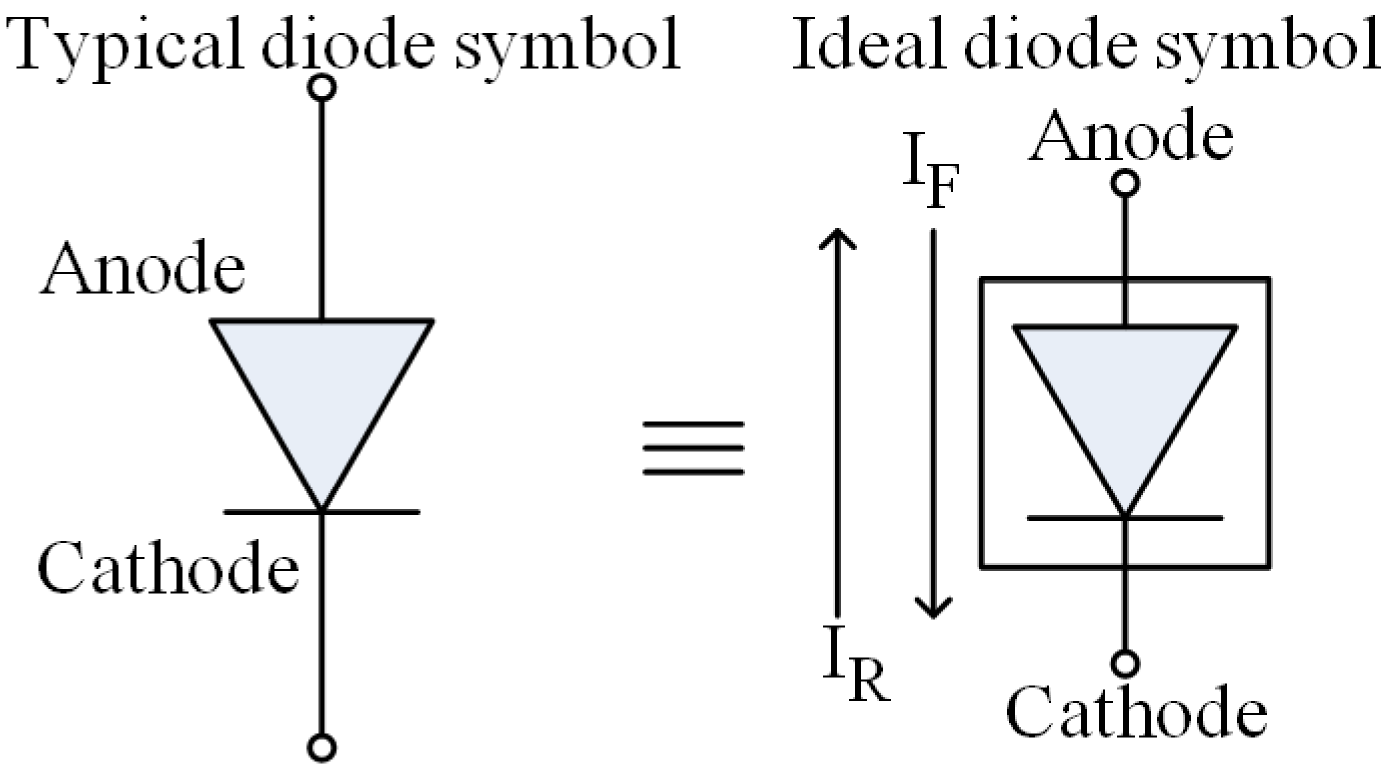
- **Conclusions:**

1. **s/c when the current is +ve (as V_d=0). Under the fb condition, diode can be represented by a s/c.**
2. **o/c when the voltage is –ve (as I_R=0). Under the rb condition, diode can be represented by an o/c.**
3. **The ideal piecewise linear diode model is a rough approximation of the characteristics of a p-n junction diode but the precision is sufficient.**
4. **The ideal piecewise linear diode model is a 1st order model to estimate the general behavior of an unknown diode circuit.**

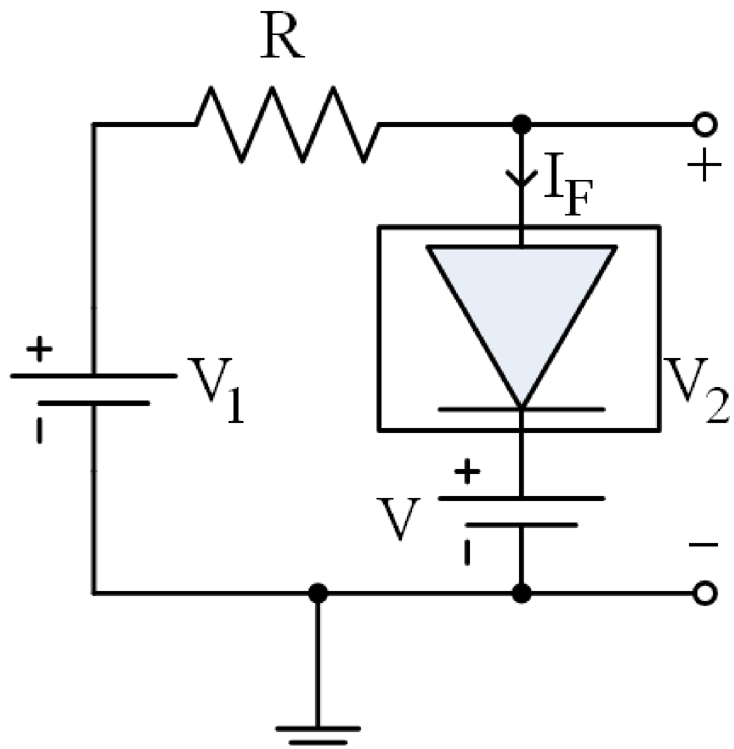




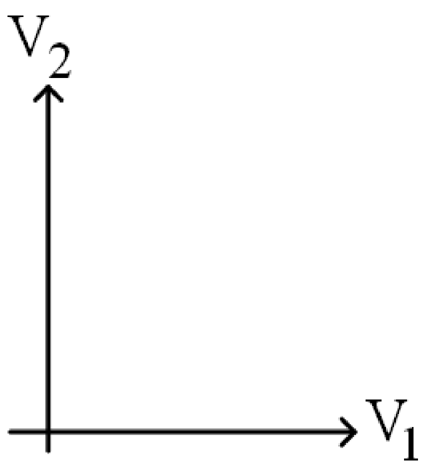
Equivalent circuit for the diode in an ideal piecewise linear diode model.

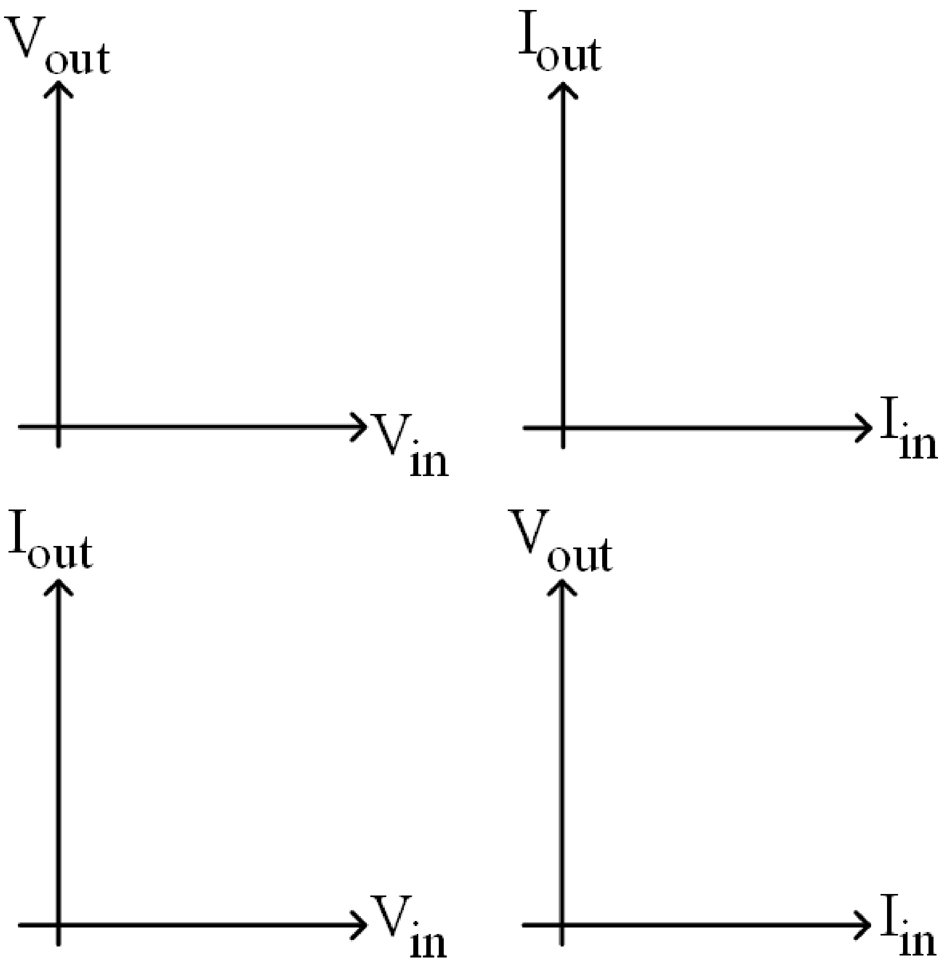


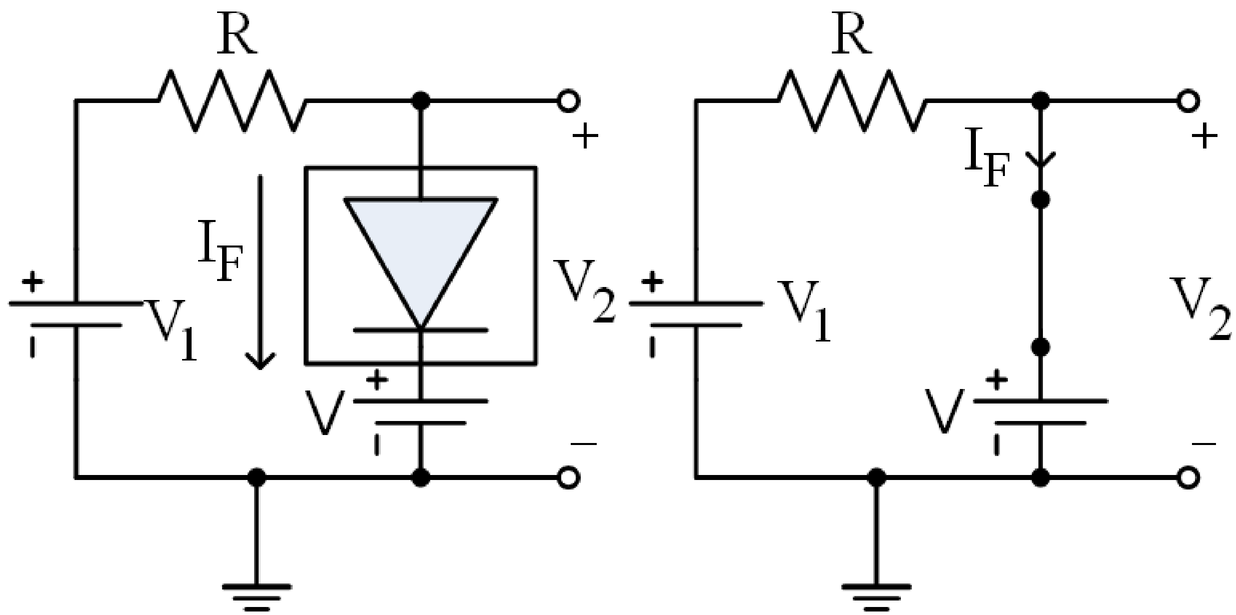
Example 1: **Draw the transfer characteristic of the following circuit using the ideal piecewise linear diode model.**



- **In general, transfer characteristic is the characterization of the o/p vs the i/p.**
- **In this Example 1, transfer characteristic is V_2 vs V_1.**



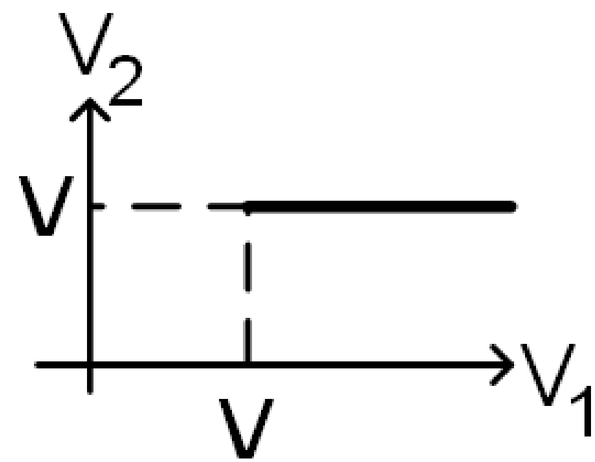




Solution:

Case 1 – What is the condition that will fb the diode?

Case 2 – What is the condition that will rb the diode?

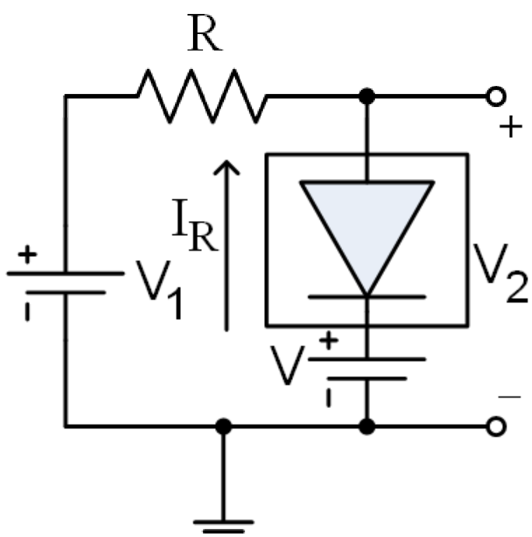


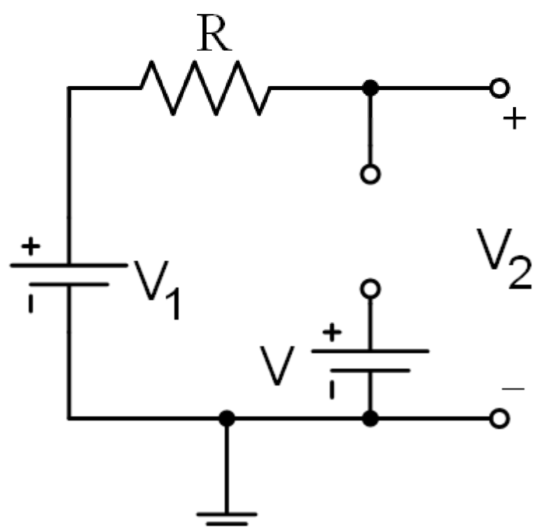
Case 1

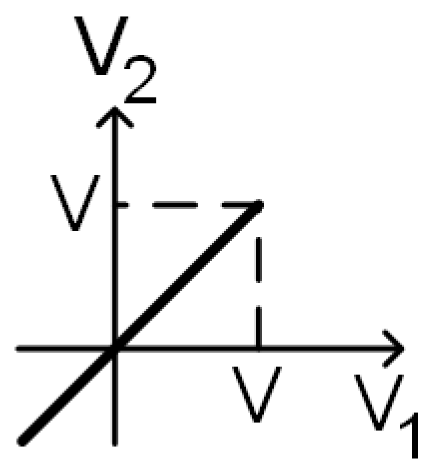
To fb the diode, $V_1 > V$. If the diode is ideal, it can be represented by a s/c. Hence, $V_2 > V$.

Case 2

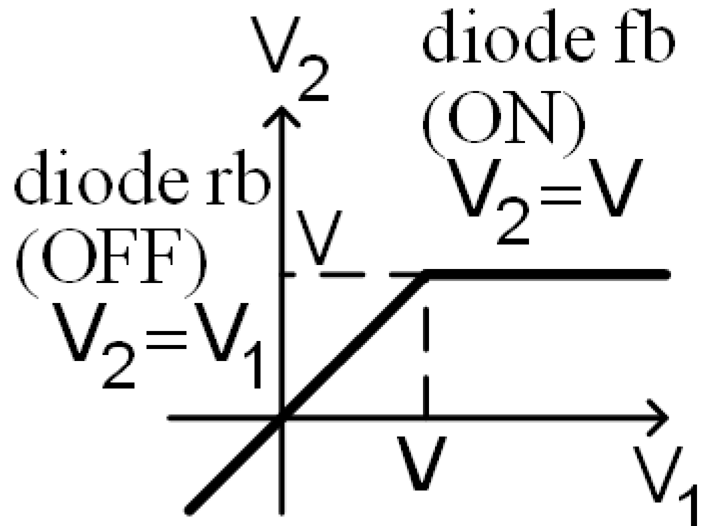
To rb the diode, $V_1 < V$. The ideal diode is represented by an o/c. Hence, $V_2 = V_1$.







The overall transfer characteristic of the diode circuit:



More accurate piecewise linear diode model

A more accurate representation of the diode's characteristic can be obtained by considering the forward voltage drop and resistance.