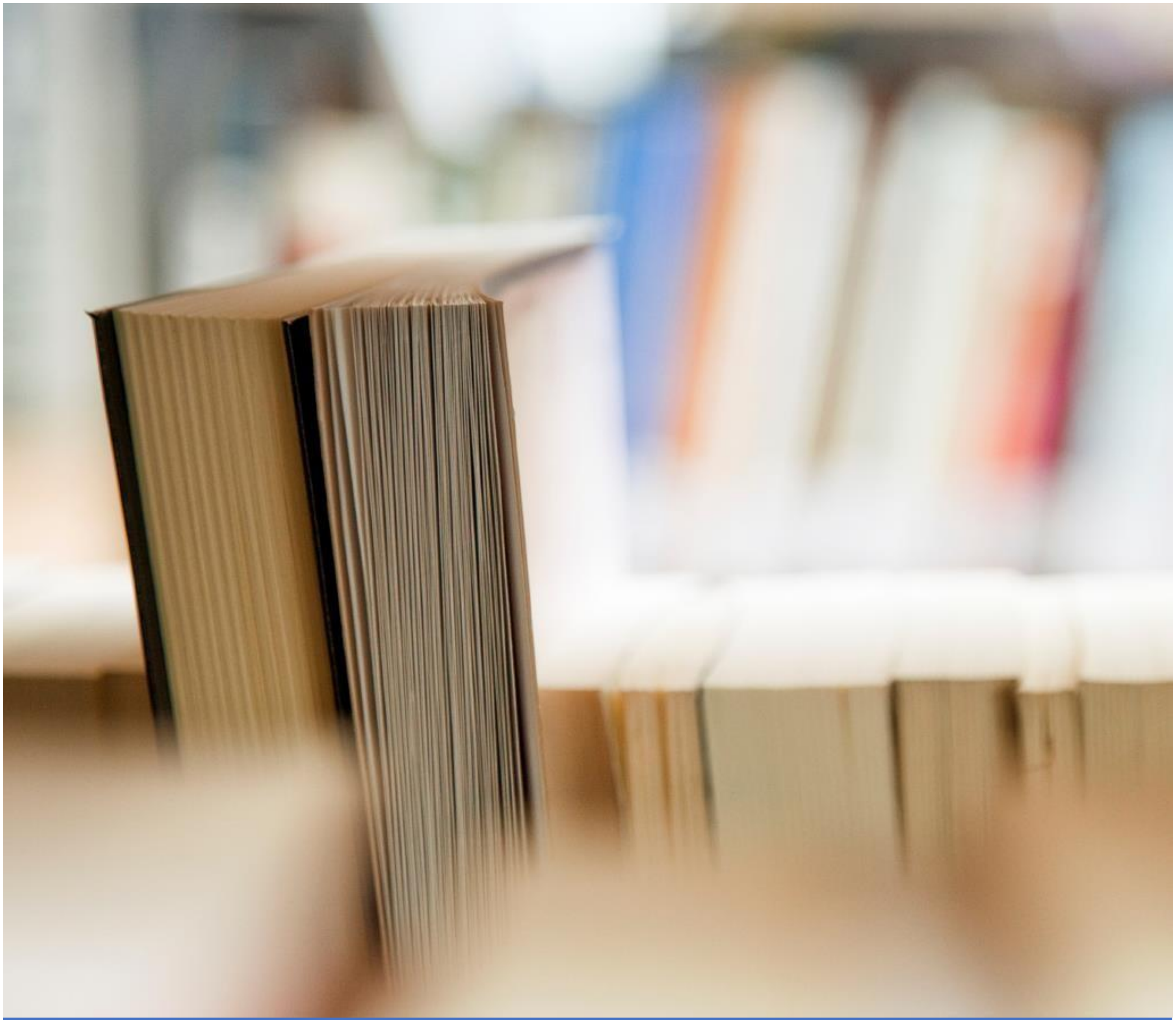

Electronic devices & circuit

Second Stage

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Lecture Three

First Course

Lecture Three

Resistance levels

1. Introduction

As the operating point of a diode moves from one region to another the resistance of the diode will also change due to the nonlinear shape of the characteristic curve. The type of applied voltage or signal will define the resistance level of interest.

1.1 DC or static resistance

The application of a dc voltage to a circuit containing a semiconductor diode will result in an operating point on the characteristic curve that will not change with time. The resistance of the diode at the operating point can be found simply by finding the corresponding levels of VD and ID as shown in Fig. (10) and applying the following equation:

$$R_D = \frac{VD}{ID}$$

In general, therefore, the lower the current through a diode the higher the dc resistance level.

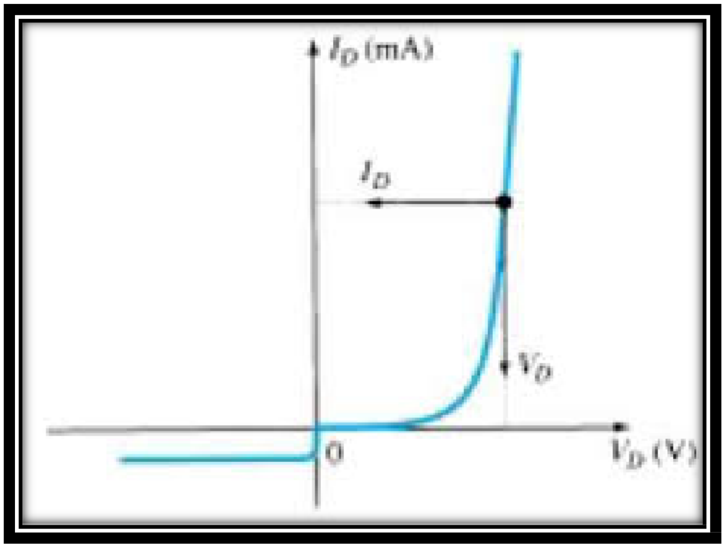


Figure (10) Determining the dc resistance of a diode at a particular operating point.

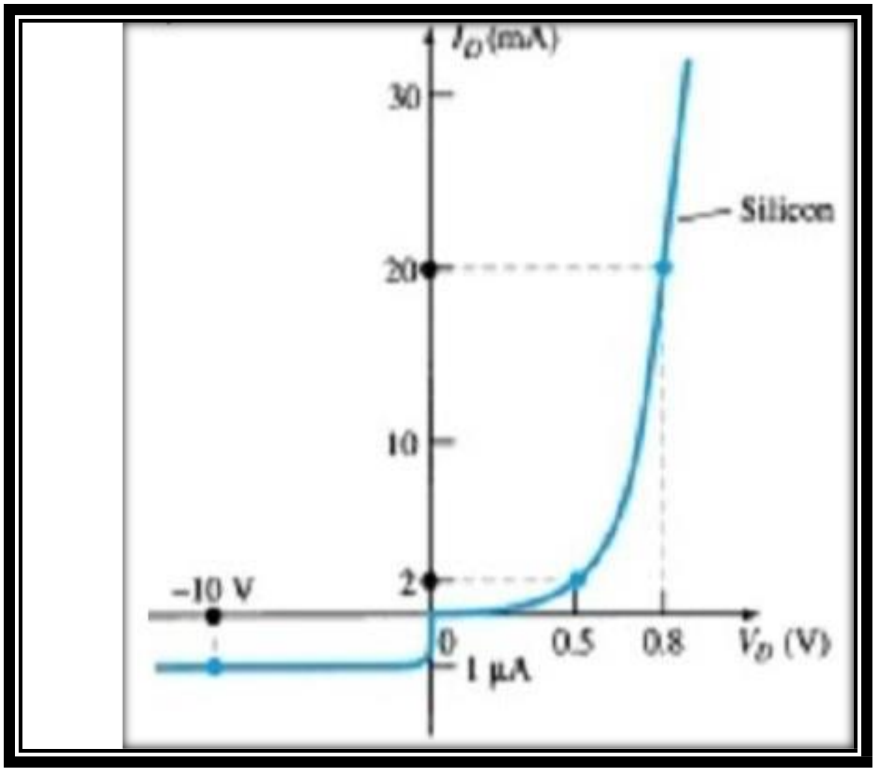
Example 1

Determine the dc resistance levels for the diode of Figure below:

(a) ID = 2 mA

(b) ID = 20 mA

(c) VD = -10 V



Solution:

(a) At $I_D = 2$ mA, $V_D = 0.5$ V (from the curve) and

$$R_D = \frac{V_D}{I_D} = \frac{0.5\text{ V}}{2\text{ mA}} = \mathbf{250\ \Omega}$$

(b) At $I_D = 20$ mA, $V_D = 0.8$ V (from the curve) and

$$R_D = \frac{V_D}{I_D} = \frac{0.8\text{ V}}{20\text{ mA}} = \mathbf{40\ \Omega}$$

(c) At $V_D = -10$ V, $I_D = -I_s = -1\ \mu$A (from the curve) and

$$R_D = \frac{V_D}{I_D} = \frac{10\text{ V}}{1\ \mu\text{A}} = \mathbf{10\ M\Omega}$$

1.2 AC Dynamic Resistance

If a sinusoidal rather than dc input is applied, the situation will change completely. The varying input will move the instantaneous operating point up and down a region of the characteristics and thus defines a specific change in current and voltage as shown in Fig. (11). With no applied varying signal, the point of operation would be the Q-point appearing on Fig. (11) determined by the applied dc levels. The designation Q-point is derived from the word quiescent, which means still or unvarying.

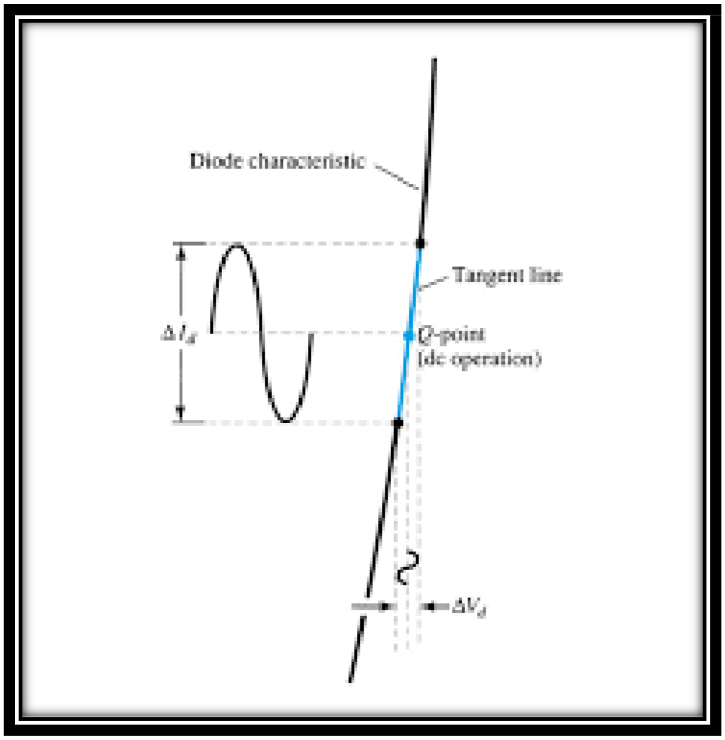


Figure (11) Defining the dynamic or AC resistance

A straight-line drawn tangent to the curve through the Q-point as shown in Fig. (12) will define a particular change in voltage and current that can be used to determine the ac or dynamic resistance for this region of the diode characteristics. An effort should be made to keep the change in voltage and current as small as possible and equidistant to either side of the Q-point. In equation form.

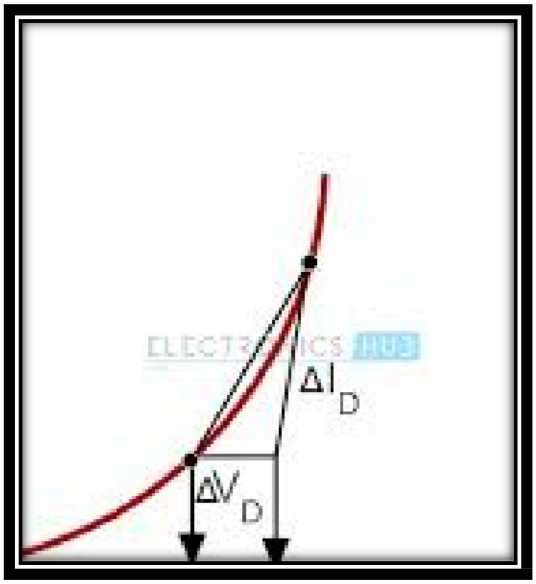


Figure (12) Determining the AC resistance at a Q-point.

$$r_d = \frac{\Delta V_d}{\Delta I_d} \text{ , where } \Delta \text{ a finite change in quintity}$$

In general, therefore, the lower the Q-point of operation (smaller current or lower voltage) the higher the ac resistance.

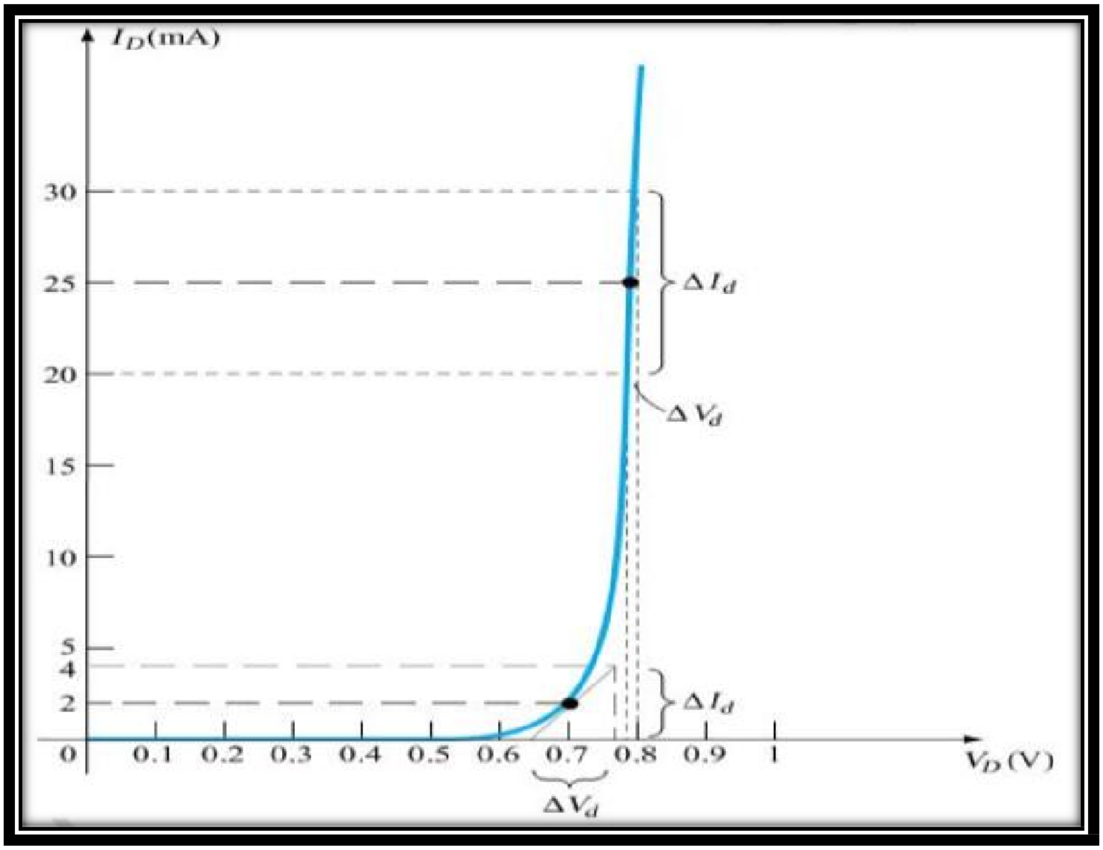
Example 2

For the characteristics of Figure below:

(a) Determine the ac resistance at ID = 2 mA.

(b) Determine the ac resistance at ID = 25 mA.

(c) Compare the results of parts (a) and (b) to the dc resistances at each current level.



Solution:

(a:)

$$\Delta I_d = 4\text{ mA} - 0\text{ mA} = 4\text{ mA}$$

and $$\Delta V_d = 0.76\text{ V} - 0.65\text{ V} = 0.11\text{ V}$$

and the ac resistance:

$$r_d = \frac{\Delta V_d}{\Delta I_d} = \frac{0.11\text{ V}}{4\text{ mA}} = \mathbf{27.5\ \Omega}$$

$$\Delta I_d = 30\text{ mA} - 20\text{ mA} = 10\text{ mA}$$

and $$\Delta V_d = 0.8\text{ V} - 0.78\text{ V} = 0.02\text{ V}$$

and the ac resistance is

$$r_d = \frac{\Delta V_d}{\Delta I_d} = \frac{0.02\text{ V}}{10\text{ mA}} = \mathbf{2\ \Omega}$$

(b:)

(c:)

(c) For $I_D = 2$ mA, $V_D = 0.7$ V and

$$R_D = \frac{V_D}{I_D} = \frac{0.7\text{ V}}{2\text{ mA}} = \mathbf{350\ \Omega}$$

which far exceeds the r_d of 27.5 Ω.

For $I_D = 25$ mA, $V_D = 0.79$ V and

$$R_D = \frac{V_D}{I_D} = \frac{0.79\text{ V}}{25\text{ mA}} = \mathbf{31.62\ \Omega}$$

which far exceeds the r_d of 2 Ω.

We have found the dynamic resistance graphically, but there is a basic definition in differential calculus which states: The derivative of a function at a point is equal to the slope of the tangent line drawn at that point. If we find the derivative of the general equation for the semiconductor diode with respect to the applied forward bias and then invert the result, we will have an equation for the dynamic or ac resistance in that region.

$$\frac{d}{dV_D}(I_D) = \frac{d}{dV}[I_s(e^{kV_D/T_K} - 1)]$$

and

$$\frac{dI_D}{dV_D} = \frac{k}{T_K}(I_D + I_s)$$

If $I_D >> I_S$

$$then \ \frac{dI_D}{dV_D} \cong \frac{k}{T_K} \ I_D$$

Substituting $\eta = 1$ for Ge and Si in the vertical-rise section of the characteristics, we obtain

$$k = \frac{11{,}600}{\eta} = \frac{11{,}600}{1} = 11{,}600$$

and at room temperature,

$$T_K = T_C + 273^\circ = 25^\circ + 273^\circ = 298^\circ$$

so that $$\frac{k}{T_K} = \frac{11{,}600}{298} \cong 38.93$$

and $$\frac{dI_D}{dV_D} = 38.93 I_D$$

Flipping the result to define a resistance ratio ($R = V/I$) gives us

$$\frac{dV_D}{dI_D} \cong \frac{0.026}{I_D}$$

$$\boxed{r_d = \frac{26\text{ mV}}{I_D}}_{\text{Ge,Si}}$$

All the resistance levels determined thus far have been defined by the p-n junction and do not include the resistance of the semiconductor material itself (called **body resistance**).

The resistance introduced by the connection between the semiconductor material and the external metallic conductor (called **contact resistance**).

$$\boxed{r'_d = \frac{26\text{ mV}}{I_D} + r_B} \qquad \text{ohms}$$

The factor $\boldsymbol{r_B}$ can range from typically **0.1 Ω** for high-power devices to **2 Ω** for some low-power, general-purpose diodes. If the input signal is sufficiently large to produce a broad swing, the resistance associated with the device for this region is called the **average AC resistance**.