Diode Resistance

When some external voltage is applied across a diode, some current flows. Therefore, the diode can be imagined to have some resistive behavior. This resistive behavior of diode is generally called diode resistance. On the basis of type of applied voltage, diode resistance can be divided into two parts.

1) Static resistance or DC resistance. 2) Dynamic resistance or AC resistance.

Static Resistance- The resistive behavior of diode in presence of DC source is called static resistance or DC resistance. It can be defined as the ratio of applied DC voltage across diode and its respective current.

i.e $r_{DC}= V_{DC}/I_{DC}$

For example, for a typical forward biased Si diode, the voltage across the diode = 0.7 V and let the current flowing be = 100 mA.

The static resistance of the diode (in forward direction)

$$=0.7V/100mA =7\Omega$$

If the diode is reverse biased with reverse voltage of 10V and if the reverse current is 1µA, then the static resistance (in the reverse direction)

$$=10V/1\mu A=10M\ \Omega$$

From the above values of static resistances in the forward and the reverse directions, it can be understood that the diode offers very low resistance in the forward direction and very high resistance (practically open circuit) in the reverse direction. This property becomes very useful in rectifier applications where the diode conducts freely in one direction and does not conduct in the other direction.

Example- Find DC resistance of a diode, if voltage applied across a Si diode at room temperature (300^0K) is 0.3V. I0 at this temperature is 2µA.

From diode equation,

$$I = I_0\ (e^{V/\eta\ V_T} - 1) = 2\times10^{-6}(e^{\frac{0.3}{2\times26mV}} - 1) = 2\times10^{-6}\times(e^{5.769} - 1) = 2\times10^{-6}\times5768 = 0.0115\ A$$

r_{DC}=0.3V/.0115A=26.09Ω.

Above example shows way to calculate r_{DC} by diode equation. Static resistance can also be calculated by diode characteristics.

Same procedure can be applied for reverse bias voltage-

Example- Find r_{DC} of diode in last example at -0.3V at same temperature.

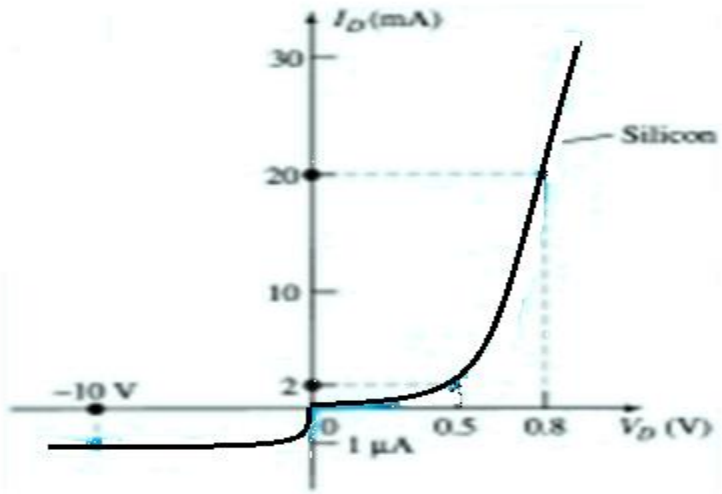
From diode equation,

$$I = I_0\ (e^{V/\eta\ V_T} - 1) = 2\times10^{-6}(e^{\frac{-0.3}{2\times26mV}} - 1) = 2\times10^{-6}\times(e^{-5.769} - 1) = 2\times10^{-6}\times12 = 2.4\ \mu A$$

r_{DC}=0.3V/2.4μA=0.125MΩ

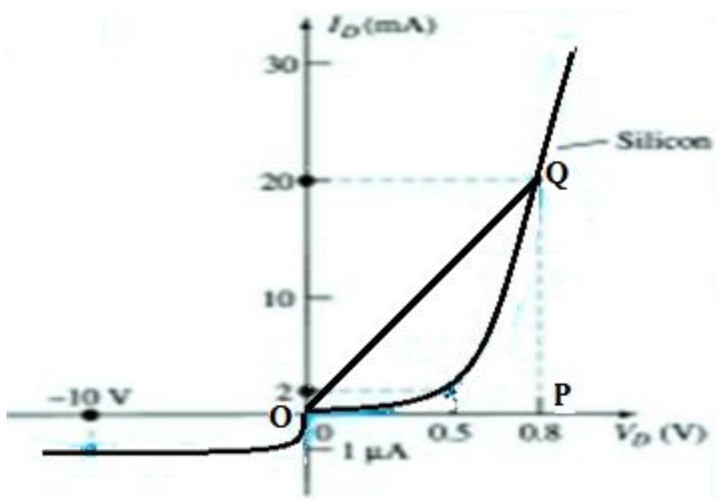
Example- Find DC resistance of following diode at 0.8V.

In this type of problem characteristics of diode will be given. We have to find DC resistance graphically. From given characteristic first of all we find current for 0.8V. It is 20mA from characteristic. So **r_{DC}=0.8/20mA=40Ω.**



One more method can be used to calculate diode resistance. The steps for this method are as follows-

1- Find operating point at diode characteristic for given voltage (0.8 for this example). This is point Q on characteristics.
2- Now connect operating point to origin by a connecting line OQ.
3- Find slope of line OQ. Slope of this line will be ratio of current and voltage operating point i.e, PQ/OP
4- Find r_{DC}= 1/slope of OQ=1/(20mA/0.8V)=0.8V/20mA=40Ω



r_{DC} =1/(20mA/0.8V)=0.8V/20mA=40Ω

All methods discussed above to calculate static resistance of diode in forward bias condition can also be applied for reverse bias condition.

Example- Calculate static resistance of diode in last example at -10V (characteristic of last example).

From characteristic we can see current through diode at -10V is 1μA. **So r_{DC} =10V/1 μA=10MΩ**

Dynamic Resistance- The resistive behavior of diode in presence of ac source is called dynamic resistance or ac resistance. On the basis voltage range of applied signal, dynamic resistance can be of two types.

1- $r_{ac(avg)}$- It is applicable for large ac signal applied across diode.

2- r_{ac}- It is applicable for small ac source applied across diode.

$r_{ac\ (avg)}$ ⇒ It is a dynamic resistance of a diode in the presence of large applied signal. It can be defined as

$r_{ac(avg)} = \frac{\Delta V}{\Delta I}$,

ΔV- is change in voltage across diode in presence of ac source. ΔI- is change in current through diode in presence of ac source.

Example- Find $r_{ac(avg)}$ of a Si diode at 0.3V, if ac signal across this diode at 0.3 V is v(t)=Sin100πt at room temperature(300^0K).I_0 at this temperature is 2μA.

The voltage applied across diode in this example is 0.3V DC and 0.2Sin100πt ac signals. So maximum voltage across diode will be V_1=0.5V and minimum voltage will be V_2= 0.1V. So, Change in voltage $\Delta V=V_1-V_2=0.4V$.

Current through diode atV_1 =0.5V,

$$I_1=I_0(e^{V/\eta V_T}-1)=2\times10^{-6}(e^{\frac{0.5}{2\times26mV}}-1)=2\times10^{-6}\times(e^{9.61}-1)=2\times10^{-6}\times9614=0.0192 \text{ A}$$

Current through diode at V_2=0.1V,

$$I_2=I_0(e^{V/\eta V_T}-1)=2\times10^{-6}(e^{\frac{0.1}{2\times26mV}}-1)=2\times10^{-6}\times(e^{8.33}-1)=2\times10^{-6}\times8332=0.016 \text{ A}$$

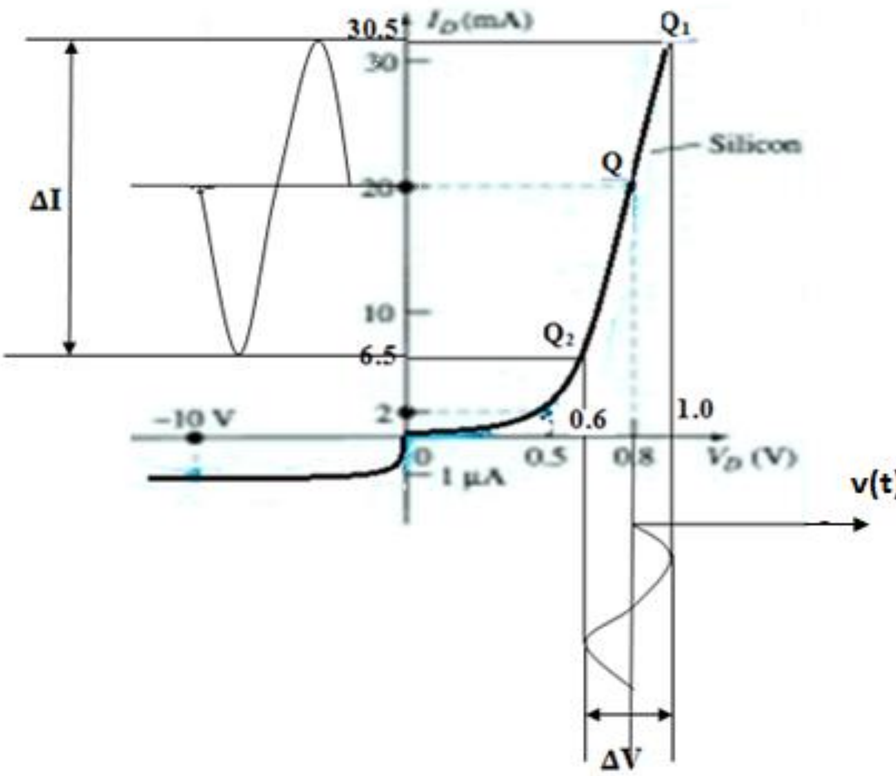
So, change in current $\Delta I=I_1-I_2$=0.019-0.016=0.003A

So, $r_{ac(avg)}=\frac{\Delta V}{\Delta I}=\frac{0.4V}{0.003A}$=133Ω

Dynamic resistance can also be calculated by graphical analysis based on diode characteristic.

Example- Find $r_{ac(avg)}$ of a Si diode by graphical analysis using given characteristics. If an ac signal v(t)=0.2Sin100πt is applied across diode at 0.8V.

From given characteristic we can see current at 0.8V is 20mA. If we apply ac signal, $v(t)=0.2\sin 100\pi t$,then voltage across diode will vary around 0.8V and current through diode will vary around 20mA.



In above figure ac signal v(t) is applied on V_D axix of diode characteristic. On application of ac signal, voltage across diode is varying from 0.6V to 1.0V and in respect of this operating point is varying from Q_1 to Q_2. Then current is varying from 6.5mA to 30.5mA. So change in voltage ΔV=0.4V and change in current ΔI=24mA.

$$\mathbf{r_{ac(avg)}} = \frac{\Delta V}{\Delta I} = \frac{0.4V}{0.024A} = \mathbf{16.66\Omega}$$

Graphical analysis of $r_{ac(avg)}$ can also be possible in other way. In above figure connect points Q_1 and Q_2 by a connecting line, then find out slope of line Q_1Q_2.

$r_{ac(avg)}$= 1/slope of line Q_1Q_2

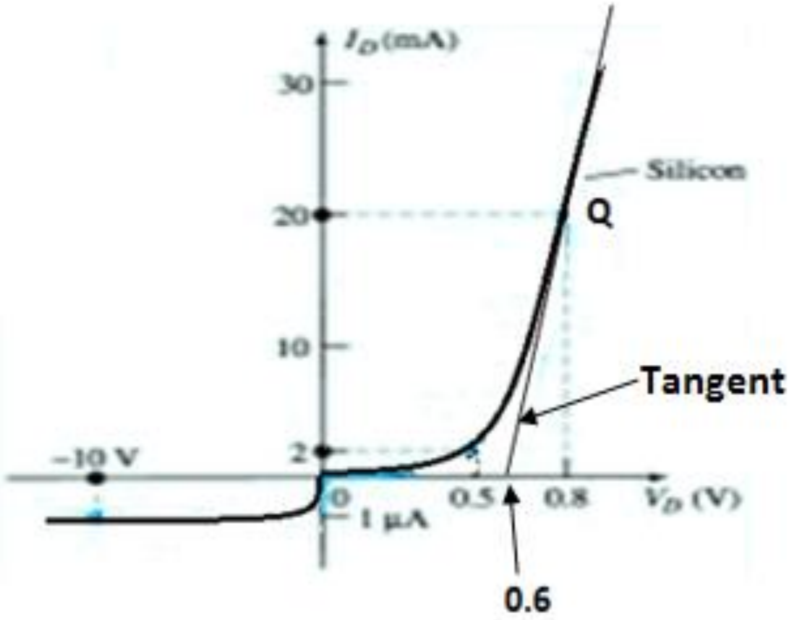
Dynamic resistance (r_{ac}) - This is a resistive behavior of diode in presence of small ac source. For small ac source change in voltage and current will be very small. So r_{ac} can be defined in terms of $r_{ac(avg)}$will be

$$r_{ac} = \lim_{\Delta V \text{ and } \Delta I \to 0} r_{ac(avg)} = \lim_{\Delta V \text{ and } \Delta I \to 0} \frac{\Delta V}{\Delta I} = \frac{\partial V}{\partial I}$$

Graphical analysis

For very small signal, points Q_1 and Q_2 on characteristics will shifted toward point Q and line between Q_1 and Q_2 will be converted into a tangent at point Q (see above figure).

To calculate r_{ac} first of all find operating point (suppose it is at 0.8V in characteristics), then draw a tangent on diode characteristic at operating point. Now calculate slope of tangent at operating point. Dynamic resistance rac=1/slope of tangent at operating point.



In above figure slope of tangent will be 20mA/0.2V. So r_{ac} will be 0.2V/20mA=10Ω.

Mathematical analysis

Dynamic resistance of diode can also be calculated by mathematical equation. As we discussed that to calculate dynamic resistance slope of tangent at operating point is required. Slope of tangent at operating point $=\frac{dI}{dV}$.

We know $I = I_0 \left(e^{V/\eta V_T} - 1\right)$

So $\frac{dI}{dV} = \frac{(I_0 e^{V/\eta V_T})}{\eta V_T}$

So $r_{ac} = \frac{dV}{dI} = \frac{\eta V_T}{(I_0 e^{V/\eta V_T})} = \frac{\eta V_T}{(I + I_0)}$

For Forward bias condition

$r_{ac} = \frac{\eta V_T}{(I_0 e^{V/\eta V_T})} = \frac{\eta V_T}{(I + I_0)}$

For Reverse bias condition

$$r_{ac} = \frac{\eta V_T}{(I_0 e^{-V/\eta V_T})} = \frac{\eta V_T}{(I + I_0)}$$

If the magnitude of reverse bias voltage is more than 0.5v, then the reverse current

$I \cong I_0$

So $r_{ac} = \frac{\eta V_T}{(I_0)}$ = very high

For a forward bias diode, if $I >> I_0$ the $r_{ac} = \frac{\eta V_T}{(I\ )}$

For example, if the forward current I = 52 mA, then the dynamic resistance

$r_{ac} = \frac{\eta V_T}{(52\ )}$ for Ge $\eta = 1$, $V_T = 26$ mv at room temperature

Then $r_{ac} = \frac{26}{(52)} = 0.5\Omega$