Section B4: Diode Equivalent Circuit Models

If we keep the diode operation away from the breakdown region, the curve of Figure 3.18 may be approximated as piecewise linear and we can model the diode as a simple circuit element or combination of standard circuit elements (We do love to model things and analyze circuits, don’t we?). However, just like in circuits composed of resistors, inductors and capacitors, we must look at dc and ac separately.

DC Diode Model

To define the dc diode model, we look at the characteristics of an ideal diode and the modifications that were required due to practical considerations. To review:

- **Ideal diode**: $V_{ON} = 0$, $R_r = \infty$ and $R_f = 0$. In other words, the ideal diode is a short in the forward bias region and an open in the reverse bias region.
- **Practical diode** (silicon): $V_{ON} = 0.7V$, $R_r < \infty$ (typically several $M\Omega$), $R_f \approx r_d$ (typically < 50 $\Omega$).

The general representation for a practical diode under dc operating conditions is shown below. Recall the diode is a two-terminal device, which simply means that it connects to other circuit elements at connection points labeled $a$ and $b$ in the circuit below with the voltage $V_{ab}$ applied across the diode. Note that the terminal voltage $V_{ab}$ is the same as the voltage applied across the diode, $v_D$ – same animal, different notation.

![Diode Circuit Diagram]

This model may be simplified if we can define the operating region as forward or reverse bias. For the forward bias region ($v_D \geq 0.7$ V for silicon), the ideal diode is a short and the terminal characteristics of the model above reduce to the parallel combination of $R_r$ and $R_f$. Since $R_r >> R_f$, $R_r || R_f \approx R_f$. Likewise, when the voltage applied to the diode is less than $V_{ON}$ ($v_D < 0.7$ V
for silicon), the ideal diode is an open and the resistance between terminals \(a\) and \(b\) is \(R_r\). These two cases are illustrated below for reference – keep them in mind; it makes analyzing diode circuits much easier!!

\[ \begin{align*}
&\text{Forward Biased dc Diode Model} & & \text{Reverse Biased dc Diode Model} \\
&\bullet \quad I_D \quad R_f \quad \bullet & & \bullet \quad I_D \quad R_f \quad \bullet \\
+a \quad + \quad V_{ab} (=V_D) > V_{ON} & & a \quad + \quad V_{ab} (=V_D) < V_{ON} \\
\end{align*} \]

Now, just a beware... even though the models above look the same, they behave very differently! Remember the values of the resistances in the different regions and you can see that diode characteristics in the forward and reverse bias regions are quite distinct.

**AC Diode Model**

The diode model under ac conditions is quite a bit more complicated. For now, keep in mind that whenever you have a charge separation there is a capacitive effect. This charge separation comes about in the diode due to the depletion region, which is in turn dependent on the applied bias. For the reverse bias case, this introduces a junction capacitance (\(C_j\)) in parallel with the reverse bias resistance (\(R_r\)) as shown below and in Figure 3.20b of your text.

\[ \begin{align*}
&\text{Reverse Biased ac Diode Model} \\
&\bullet \quad I_D \quad R_f \quad \bullet \\
+a \quad + \quad V_{ab} (=V_D) < V_{ON} \\
\end{align*} \]

To add insult to injury, it turns out that the frequency of operation introduces an additional consideration for forward bias operation. We’re going to get into the effects of frequency in the next course, but what essentially happens is that the current flows in different directions under ac operation. Since current flow is moving charge, we’ve got charges moving in the semiconductor material. Charges cannot move instantaneously, so there
is a “charge storage” effect that leads to a diffusion capacitance ($C_D$). The forward bias resistance is also a function of frequency, so the dynamic resistance, $r_d$, of Equation 3.31, replaces the constant $R_f$ term. Put this all together and the ac diode model under forward bias conditions is represented below (and in Figure 3.20c) of your text.

So... the plot thickens. Not only is a diode a nonlinear device, which means we can’t use standard circuit techniques (KVL, KCL, etc.) to analyze circuits containing diodes, we’ve got this whole ac/dc/temperature thing going!

Don’t worry – there is hope. If we can restrict the operational conditions (and we generally can), there are tried-and-true methods for getting the information we need. We’ll discuss three of the most popular in the next part of this section.