Last time…

we introduced the diode and its (complicated) I-V relationship.

Today we will…

• focus on the relevant area of the diode I-V graph
• develop simpler models for the diode I-V relationship
• learn how to solve circuits with nonlinear elements

DIFFERENT MODELS, DIFFERENT USES

• We will consider 4 different diode I-V models with varying degrees of detail.
• Use most realistic model only for very precise calculations
• Use simpler models to find basic operation, gain intuition
• Sometimes one model may lead to an “impossible” situation: use a different (more realistic) model in this case
REALISTIC DIODE MODEL

\[ I = I_0 \left( \frac{V}{V_T} - 1 \right) \]

- Here, \( V_T \) is “thermal voltage”: \( V_T = \frac{(kT)}{q} \approx 0.026 \text{ V} \) at 300°K (q is electron charge in C, k is Boltzmann’s constant, and T is the operating temperature in °K)

- Equation is valid for all modes of operation considered

- You might need a computer to solve the nonlinear equation this model can create

IDEAL DIODE MODEL

- Diode either has negative voltage and zero current, or zero voltage and positive current

- Diode behaves like a switch: open in reverse bias mode, closed (short circuit) in forward bias mode

- Guess which situation diode is in, see if answer makes sense
LARGE-SIGNAL DIODE MODEL

- Diode either has voltage less than $V_F$ and zero current, or voltage equal to $V_F$ and positive current
- Diode behaves like a voltage source and switch: open in reverse bias mode, closed in forward bias mode
- Guess which situation diode is in, see if answer makes sense

SMALL-SIGNAL DIODE MODEL

- Diode either has voltage less than $V_F$ and zero current, or voltage greater than $V_F$ and positive current depending on $V$
- Diode behaves like a voltage source, resistor and switch: open in reverse bias mode, closed in forward bias mode
- Guess which situation diode is in, see if answer makes sense
Look at circuits with a nonlinear element like this:

A nonlinear element with its own I-V relationship, attached to a linear circuit with its own I-V relationship.

Equations we get:

1. \( I_L = f_L(V_L) \) (linear circuit I-V relationship)
2. \( I_{NL} = f_{NL}(V_{NL}) \) (nonlinear element I-V relationship)
3. \( I_{NL} = -I_L \)
4. \( V_{NL} = V_L \)

Our 4 equations

1. \( I_L = f(V_L) \) (linear circuit I-V relationship)
2. \( I_{NL} = g(V_{NL}) \) (nonlinear element I-V relationship)
3. \( I_{NL} = -I_L \)
4. \( V_{NL} = V_L \)

can easily become just 2 equations in \( I_{NL} \) and \( V_{NL} \)

1. \( I_{NL} = -f_L(V_{NL}) \)
2. \( I_{NL} = f_{NL}(V_{NL}) \)

which we can equate and solve for \( V_{NL} \), or…

graph the two equations and solve for the intersection.
LOAD LINE ANALYSIS

To find the solution graphically,

- graph the nonlinear I-V relationship,
- graph the linear I-V relationship in terms of $I_{NL}$ and $V_{NL}$ (reflect over y-axis),

and find the intersection: the voltage across and current through the nonlinear element.

EXAMPLE

Find $V_{NL}$.

Assume realistic diode model with $I_0 = 10^{-15}$ A.

1. $I_L = (V_L - 2) / 1000$
2. $I_{NL} = 10^{-15} (e^{V_{NL}/0.026} - 1)$
3. $I_{NL} = -I_L$
4. $V_{NL} = V_L$

Either substitute into 3. and solve

$$10^{-15} (e^{V_{NL}/0.026} - 1) = -[(V_{NL} - 2)/1000]$$

or determine graphically that $V_{NL} = 0.725$ V
EXAMPLE REVISITED

Find $V_{NL}$.
Assume small-signal diode model with $V_F = 0.7 \, \text{V}$ and $R_D = 20 \, \Omega$.

1. $I_L = (V_L - 2) / 1000$
2. $I_{NL} = (V_{NL} - 0.7) / 20$
   or $I_{NL} = 0$
3. $I_{NL} = -I_L$
4. $V_{NL} = V_L$
   Either substitute into 3. and solve
   $$(V_{NL} - 0.7) / 20 = -(V_{NL} - 2) / 1000$$
   or determine graphically that $V_{NL} = 0.725 \, \text{V}$
Find $V_{NL}$.

Assume small-signal diode model with $V_F = 0.7$ V and $R_D = 20 \, \Omega$.

1. $I_L = \frac{(V_L - 2)}{1000}$
2. $I_{NL} = \frac{(V_{NL} - 0.7)}{20}$
   or $I_{NL} = 0$
3. $I_{NL} = -I_L$
4. $V_{NL} = V_L$

Either substitute into 3. and solve

or determine graphically that $V_{NL} = -2$ V