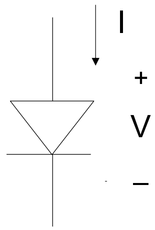
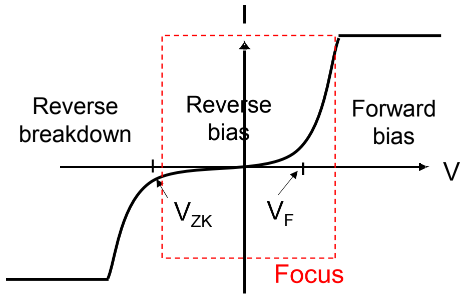
Last time…





we introduced the **diode**

and its (complicated) **I-V relationship**.

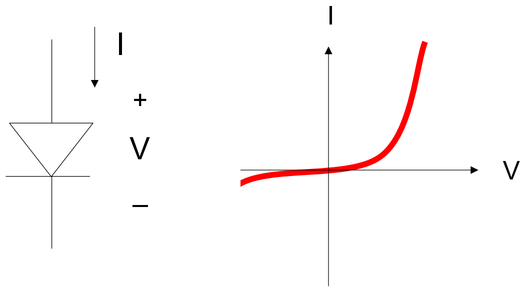
Today we will…

- 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

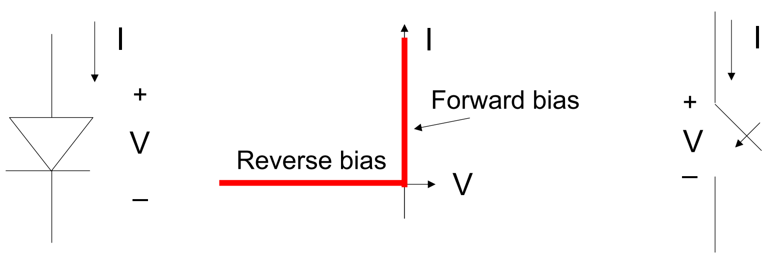
REALISTIC DIODE MODEL



$$I = I_0\left(e^{\frac{V}{V_T}} - 1\right)$$

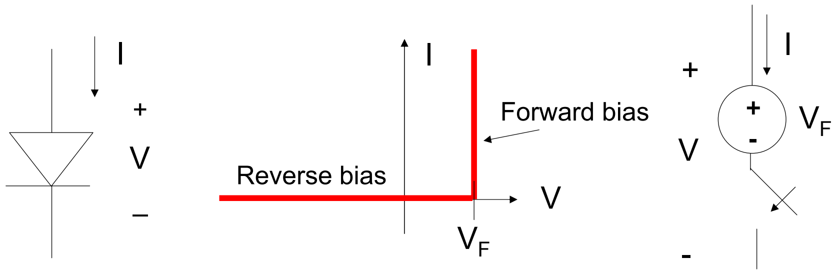
- Here, V_T is "thermal voltage": $V_T = (kT)/q \approx 0.026$ V @ 300°K (q is electron charge in C, k is Boltzmann's constant, and T is the operating temperature in °K)
- Equation is valid for all modes of operation considered
- You might need a computer to solve the nonlinear equation this model can create

IDEAL DIODE MODEL



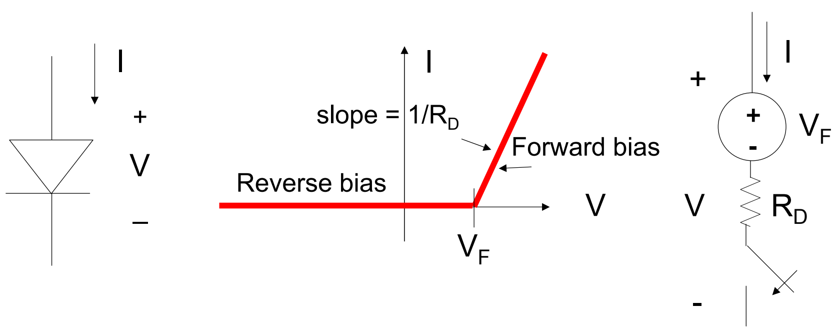
- Diode either has negative voltage and zero current, or zero voltage and positive current
- Diode behaves like a switch: open in reverse bias mode, closed (short circuit) in forward bias mode
- Guess which situation diode is in, see if answer makes sense

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

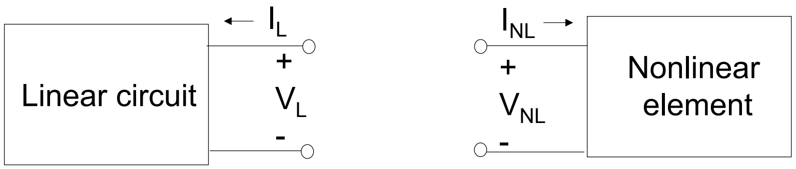
SMALL-SIGNAL DIODE MODEL



- 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

SOLVING CIRCUITS WITH NONLINEAR ELEMENTS

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. $V_{NL} = V_L$

SOLVING CIRCUITS WITH NONLINEAR ELEMENTS

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}

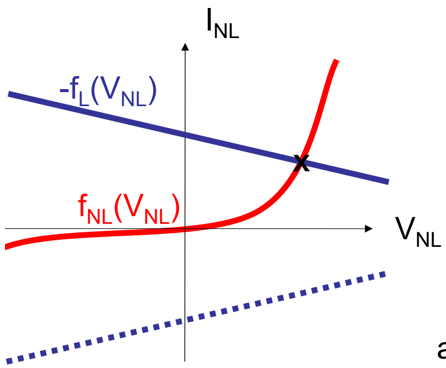
1. $I_{NL} = -f_L(V_{NL})$
2. $I_{NL} = f_{NL}(V_{NL})$

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.

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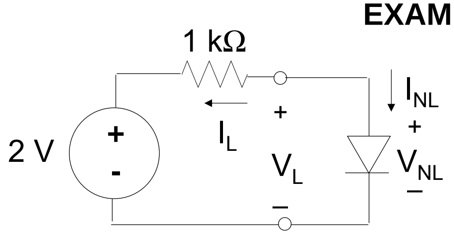
EXAMPLE



Find V_{NL}.

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

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

Either substitute into 3. and solve

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

or determine graphically that V_{NL} = 0.725 V

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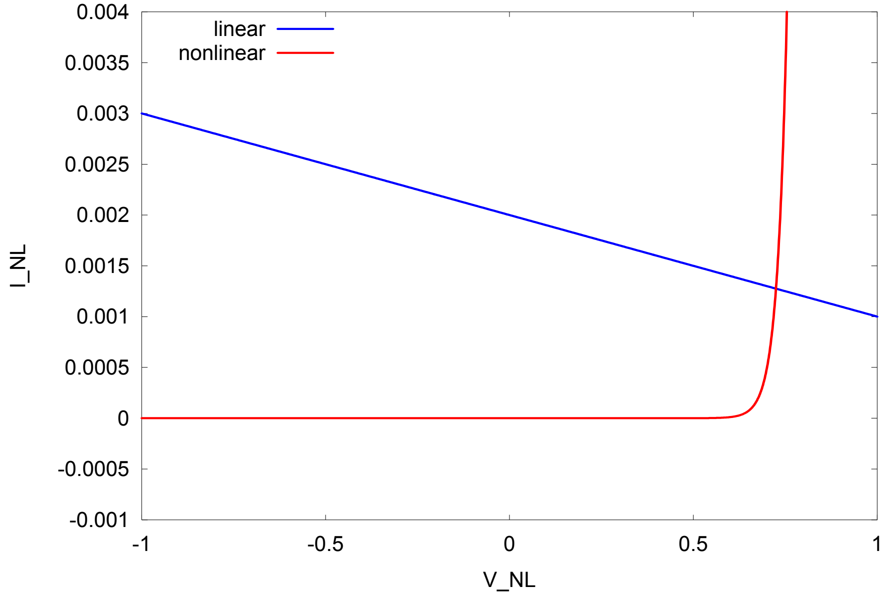
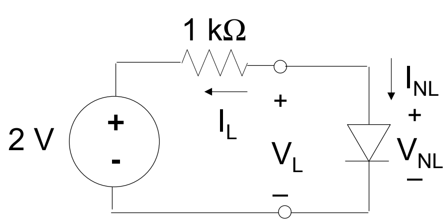


EXAMPLE REVISITED



Find V_{NL}.

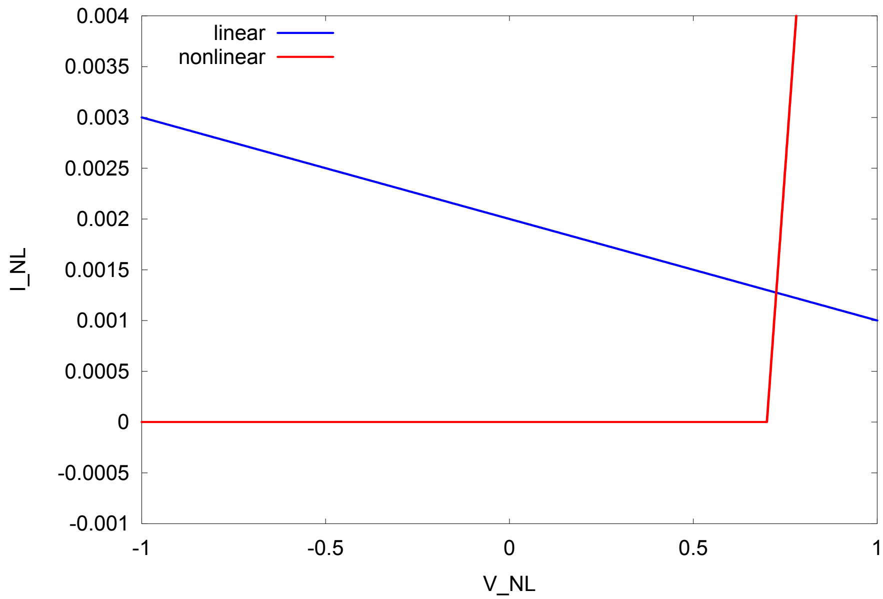
Assume small-signal diode model with $V_F = 0.7$ V and $R_D = 20\ \Omega$.

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. $V_{NL} = V_L$

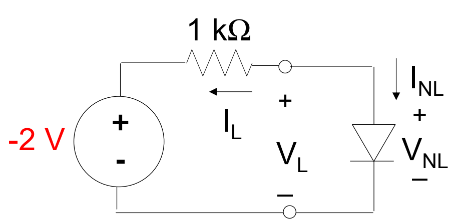
Either substitute into 3. and solve

$(V_{NL} - 0.7) / 20 = -(V_{NL} - 2) / 1000$

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



ONE MORE TIME



Find V_{NL}.

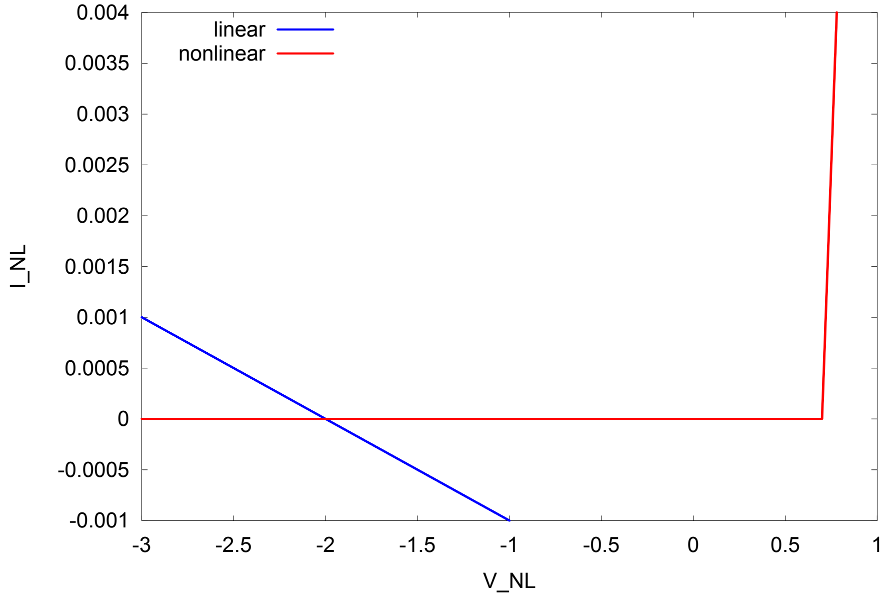
Assume small-signal diode model with $V_F = 0.7$ V and $R_D = 20\ \Omega$.

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

$0 = -(V_{NL} - -2) / 1000$

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



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