Nonlinear Modeling

- Nonlinear problems are difficult to solve
- The diode is a nonlinear device

- Picewise linear models can simplifying the solution of non linear circuits problems.

The purpose of modeling

- Nonlinear problems are much more difficult than linear ones. These problems could be impossible to solve manually and could require huge amount of time if solved on a computer.

- One possible solution of the above mentioned problem is to approximate the nonlinear relationship with a model that has a linear relationship.
- The trust of nonlinear modeling is direct towards this end.
- The modeling not only simplifies the solution, it also allows the designer to understand how the circuit behaves. Modeling often increases the conceptual understanding of the circuit operation.

Demonstration of the difficulty in solving nonlinear problems

- Consider a linear circuit (a) and nonlinear circuit (b). Determine *I* and *V_{out}*?

- Solution: In circuit (a):

By simple ohm's law we can find current I as,

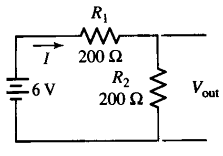
$I = V_1/R_1 + R_2 = 6 /(200 + 300) = 0.012A$

The output voltage is then
$V_{out} = IR_2 = 0.012 \times 300 = 3.6V$

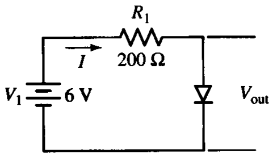
Circuit (b):

The current I can be determine by using diode equation as
$I = I_s(e^{qV}/kT-1) = 10^{-10}(e^{Vout}/0.026 - 1)$

There is no close form solution of the above equation.



(a)



(b)

Demonstration of the difficulty in solving nonlinear problems (cont.)

In order to determine V_{out} we have to solve another equation which can be written as by Kirchhoff's law,

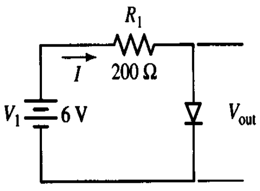
$V_1 = IR_1 + V_{out}$

$\Rightarrow V_1 = 200 \times 10^{-8}(e^{Vout}/0.026-1) + V_{out}$

Again, there is no close form solution of the above equation.

Perhaps the quickest method for solving this problems is a trial and error iterative method.

If we guess many time, finally we will be able to show that, when $V_{out} = 0.505215 \sim 0.5V$, the right side of the above equation is 5.99V, which is essentially equal to the value of the left side of the equation.
Finally ,I =0.02747≅0.027A.



(b)

Possible model of the problem (constant voltage drop model)

- One possible model for the forward bias diode is a simple 0.6V voltage source.
- When this model replaces the diode, the circuit appear as shown in the figure and is very easy to analyze.
- For this circuit the current is calculated to be
- $I=(V_1-0.6)/200 = 0.027A$
- And the $V_{out} = 0.6V$
- These values compare well to the results calculated from the exact equations, but much easier to obtained.
- The above example demonstrate that how model simplifies the solution.

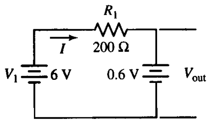


Figure 5.12
The circuit of Fig. 5.11 with a simplified diode model.

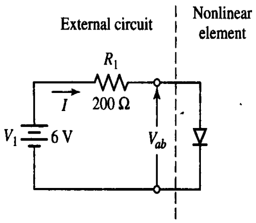
A load line approach

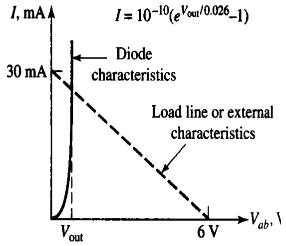
- An alternate and more traditional graphical method to analyze a circuit containing a nonlinear element is that of using a load line.
- The load line can yield accurate results and used extensively in the evaluation of the electronic circuits.

Load line analysis

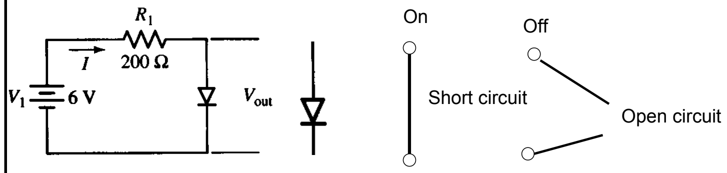
- In this approach the series circuit shown here can be split into a non linear element and the remaining external circuit.

Load line equation: $V_{ab}=V_1-IR_1$





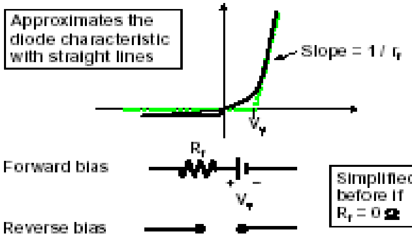
Ideal diode model



I_D = (6-0)/200=0.03A
V_{OUT}=0V

Piecewise Linear Diode Model

Approximates the diode characteristic with straight lines



Simplified to before if $R_f = 0\ \Omega$

Conductor-to-Semiconductor Contact

- Must have some way of making electrical connections to semiconductors.
- If metal (Al, Pt, Au, Ag, Cu, etc.) deposited on clean semiconductor surface (Ge, Si, GaAs, etc.), the resulting contact:
  - Rectifying
  - Ohmic

Metal-to-Semiconductor Contacts

- With contact between metal and semiconductor (let's assume Si),
  - Some path exists for electron flow from one material to the other.

Metal-to-Semiconductor Contacts

- At the contact, the energy level of electrons within both materials must be the same.
  - This energy level is also termed the "Fermi" level.
- To equalize energy, momentary movement of electrons from silicon and metal and vice versa.
  - Flow equalization depends on the metal type and the doping of silicon.

Rectifying Contacts

- Consider an n-type semiconductor.
- Semiconductor doping level can result in fewer mobile electrons near the metal-silicon interface
- Thus, donor impurities (atoms) exist that do not have mobile electrons nearby to compensate their positive charge.

Other Diode Types

- Conductor-to-Semiconductor Contacts
  - Schottky Diodes
- Junction Capacitance
  - Varactors
- Breakdown Region
  - Zener Diodes
- Photodiodes and Solar Cells
- Light-Emitting Diodes