Lecture 1: Diode Basics

1. Diode Basics
2. Voltage Clamp
3. Circuit Simulation

Reading: Ch 3.1-3.5, 4.10

- HW 1 due next Tue

Course Website:
→ minerva.union.edu/bumat
1. Diode Basics

- **What is a diode?**
  Circuit element that conducts current in **only** one direction.

- **Made from a semiconductor** (usually silicon)

- **Applications**
  - AC-to-DC power supplies
  - Voltage limiting
  - Voltage multipliers
  - Voltage reference
  - AM detectors
  - RF mixers
  - Logarithmic amplifiers

**NO!**
- **Cathode**
- **Anode**

[www.digikey.com](http://www.digikey.com)
Example Benchtop Power Supply Transformer

1. Plug
2. Transformer
3. Diodes
4. Voltage Regulator

Graphs:
1. Sine wave
2. Sine wave
3. Sine wave
4. Sine wave
Another example: Battery backup

\[ V_{\text{MAIN}} > V_{\text{Battery}} \]

\[ V_{\text{MAIN}} < V_{\text{Battery}} \]
- Simple rules:
  1. When diode is ON, the diode voltage is 0.7 Volts (current flows)
  2. If the voltage drop is less than 0.7V, Diode is OFF (no current)

* A diode does NOT obey Ohm's law

- How to analyze a diode circuit?
  1. Assume the diode is ON (or OFF) and solve for voltages + currents

  **Step 2a:** If voltages and currents look OK, then you are done! 😊

  **2b:** Otherwise, the diode is OFF (or ON)
Example

Step 1
Let's "guess" that the diode is ON

\[ V_A - V_C = V_D = 0.7\text{V} \]

\[ \Rightarrow V_C = 5 - 0.7 = 4.3\text{V} \]

\[ \Rightarrow I = \frac{V_C - 0}{1\text{k}\Omega} = \frac{4.3\text{V}}{1\text{k}\Omega} = \frac{4.3\text{V}}{1000\Omega} = 0.0043\text{A} = 4.3\text{mA} \]

The voltages and currents make sense.

Done! 😊
What if we had assumed the diode is OFF?

\[ \text{Current } I = 0 \]

What about \( V_c \)?

\[ I = 0 = \frac{V_c - 0}{1K} \]

\[ \Rightarrow V_c = 0V \]

\[ \text{Anode voltage } \Rightarrow \text{Cathode voltage} \]

\( (5V) \Rightarrow (0V) \)

\[ \Rightarrow \text{Therefore, the diode must be ON!} \]

\[ V_D = +5V \text{ contradicts the diode being OFF!} \]

It is OK to "guess wrong", because your analysis will "self-correct"! 😄
Example 2: Compute load voltage, current, and dissipated power in diode.

**Method:** Use KCL ("Brute force") approach.

\[
I_1 = \frac{36 - V'}{6k}, \quad I_2 = \frac{V'}{3k}, \quad I_L = \frac{V_L}{1k} = \frac{V' - 0.7}{1k}
\]

**KCL:**
\[
I_1 = I_2 + I_L
\]
\[
\frac{36 - V'}{6k} = \frac{V'}{3k} + \frac{V'}{1k} - \frac{0.7V}{1k}
\]

\[
\frac{36V}{6k} + \frac{0.7V}{1k} = \left(\frac{1}{6k} + \frac{1}{3k} + \frac{1}{1k}\right)V' = \left(\frac{3}{2k}\right)V'
\]

\[
\frac{3V}{2} \times 6.7mA = 4.47V \rightarrow V_L = 4.47 - 0.7 = 3.77V
\]

\[
I_L = \frac{V_L}{1k} = 3.77mA
\]

Diode Power = \[
I \times (0.7V) = 2.64mW
\]
Method 2: use thevenin to simplify the circuit.

1. **Open circuit voltage**

   \[ V_{oc} = \frac{36 \times 3k}{9k} = 12V \]

2. **Equivalent resistance**

   \[ R_{th} = \frac{6k}{3k} = \frac{1}{\frac{1}{6k} + \frac{1}{3k}} = 2k \]

3. **KVL**

   \[ 12 - I \times 2k - 0.7 - I \times 1k = 0 \]

   \[ I = \frac{12 - 0.7}{3k} = 3.77mA \text{ } \checkmark \]

Everything else is the same...
Q: Is there a way to correctly guess if the diode is ON?

A: YES (sort of...)

1. Look at anode (+) connection
   ⇒ Any voltage sources nearby?

2. Look at cathode (-) connection
   ⇒ Is ground located nearby?
   AND/OR
   ⇒ Any voltage sources less than anode (+) side?

Example:

![Diode Circuit Diagram](image1.png)

Example:

![Diode Circuit Diagram](image2.png)

Example:

![Diode Circuit Diagram](image3.png)
2. Voltage Clamp or called "Voltage clipper"

- A voltage clamp prevents voltage from going above or below a certain value.

Example: CMOS Logic

NAND gate

Every input has the following:

- Keeps $V_{in} < 5.7V$
- Keeps $V_{in} > -0.7V$
Ideally, the clipping level is set by a fixed voltage source (e.g., battery).

NOTE: Voltage source must be able to handle the diode current during clipping.
A voltage divider is often OK, but there will be some voltage error.

Ex: Suppose we want $V_{out}$ to be clipped at 3.2V.

Use KVL:

$6 - i \times 10K - 0.7 - i \times 0.5K - 2.5 = 0$

$2.8 - i \times (10K + 0.5K) = 0$

$\Rightarrow i = \frac{2.8V}{10K + 0.5K}$

$\Rightarrow V_{out} = 3.2 + 2.8 \times \frac{0.5K}{10K + 0.5K} = 3.2 + 0.13V$

Thevenized Voltage Divider

$V_{out} = 2.5 + i \times 0.5K + 0.7$

$= 3.2 + i \times 0.5K$

$= 3.2 + 0.13V$

$= 3.33V \leq 4\% \text{ error (not bad)}$
Stiff divider requires
\[ R_{TH} < \frac{R_s // R_L}{100} \]

For this example,
\[ R_{TH} = 0.5\,K \]
\[ R_s = 10\,K \]
\[ R_L = \infty \]
\[ R_s // R_L = 10\,K \Rightarrow 0.5\,K < 0.1\,K? \quad \text{No!} \quad \text{Not a stiff divider.} \]

Firm divider requires
\[ R_{TH} < \frac{R_s // R_L}{10} \Rightarrow 0.5\,K < 1\,K? \quad \text{YES!} \quad \text{This is a firm divider.} \]
3. Circuit Simulation

- Circuit designers almost always simulate their circuits before actual construction.

- There are many circuit simulators (e.g., PSpice). We'll use Multisim (N100, 102, 106 computers).
Start MultiSim ...

To place components, you can either:

1) Click on the appropriate icon ...

2) ... or click on Place >> Component

3) ... or use CTRL+W
For this example, we want to use a 1N4148 "switching diode".

1) Click on the "diode" icon
   - Group = Diode
   - Family = Switching Diode
   - Component = 1N4148

2) ... or Select Place >> Component
   - Group = Diode
   - Family = Switching Diode
   - Component = 1N4148

NOTE: The "Select a Component" window stays open after you place a component. If you want to close the window, you must click "Close" or the "X" button (top right).

NOTE: To rotate a component, press CTRL+R.
To place a resistor you can either:

1) Click on “resistor” icon
   - Select “RESISTOR” in “Family” menu
   - Type in the desired value in “Component” box
   - Press “Enter”

2) ... or Select Place >> Component
   - Group = Basic
   - Family = RESISTOR
   - Type in the desired value in “Component” box
   - Press “Enter”

NOTE: To rotate a component, press CTRL+R
To place grounds, you can either:

1) Click on “Sources” icon
   - Select “POWER_SOURCES” in “Family” menu
   - Select “GROUND” in “Component” box
   - Press “Enter”

2) … or Select Place >> Component
   - Select “Sources” in the “Group” menu
   - Select “POWER_SOURCES”
   - Select “GROUND”
   - Press “Enter”
To place a sine wave signal source you can either:

1) Click on “Sources” icon
   - Select “SIGNAL_VOLTAGE_SOURCES”
   - Select “AC_VOLTAGE”
   - Press “Enter”

2) … or Select Place >> Component
   - Select “Sources”
   - Select “SIGNAL_VOLTAGE_SOURCES”
   - Select “AC_VOLTAGE”
   - Press “Enter”

After placing the source on the schematic, double-click on it and adjust the following:
   - Frequency = 1 kHz
   - Voltage (pk) = 6V
To place a DC voltage source you can either:

1) Click on “Sources” icon
   - Select “POWER_SOURCES”
   - Select “DC_POWER”
   - Press “Enter”

2) ... or Select Place >> Component
   - Select “Sources”
   - Select “POWER_SOURCES”
   - Select “DC_POWER”
   - Press “Enter”

After placement, double-click on the source and set “Voltage (V)” to 5V
Wiring the components together is easy!

To make a wire, just click on the start and end points.
Use File >> Print to print the schematic (full page printout with nice border)

However, for prelab and lab reports you can save paper by doing the following:

1) CTRL+A (select all)
2) CTRL+C (copy)
3) Paste the figure into Word or PowerPoint or Paint ...
4) Re-size/rearrange multiple schematics to fit on a page.
We want the simulation to produce waveforms for the input and output voltage (above the diode).

One way to do this is to place a "voltage probe" on the desired location in the circuit.

This is easily done by clicking "Place >> Probe >> Voltage".

Double-click on the voltage probe to change its name.
Now we need to configure the simulation! We’ll use a “ transient” simulation to make plots that resemble an oscilloscope waveform:

1) Simulate >> Analyses and Simulation  
2) Select “Transient” from left side menu  
3) Set the “End Time (STOP)” = .002 s  
4) Click on “Output” tab  
5) You should see “V(vin)” and “V(vout)” appear in the right-side list.  
6) Press “Run”
The “Grapher View” should pop up with a plot of the input and output voltages.

1. If you want, you can edit the plot titles by double-clicking on them.
2. To save printer toner, change the plot background from black to white by clicking on the icon just below the “Cursor” menu.
3. You can copy and paste the graph into Word, PowerPoint, etc.
You can measure the actual voltage by using the “Cursors”. Two ways to do this:

1. Cursors >> Show cursors
2. Or click the “Show cursors” icon.

Then you can drag one of the cursor lines to the desired location. The little pop-up window will show you the x and y value of each cursor.