Lecture 18: Diodes

Administrivia

New schedule for next week:
- LATELACE: Transform + Frequency
  - Chapter 12, 13 + Chapter 9
    - Reading: Skip 4-7 in Chap. 9
  - No BJT's 😞
- Next week is last lab week
- You all get 20% of BJT project grade
- Last homework problem set up!
- Scores are updated: Labs 1-4, HW 1-4, MT 2
- Extra credit will add to final exam points.
- Regrade deadlines:
  - HW 3: 08/11, 5:00 pm
  - HW 4, 5: 08/11, 5:00 pm
  - MT 2: 08/11, 5:00 pm

START KEEPING TRACK OF YOUR SCORES ONLINE!
Today: Diode

1. Highly nonlinear device.

2. Intuitively, a diode is a \textbf{Check-valve} because it allows current to flow in only one-way.

<table>
<thead>
<tr>
<th>Anode</th>
<th>$I &gt; 0$ \implies $V &gt; 0$</th>
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3. Algebraically, the IV graph can be written as (ignoring breakdown):

$$I \approx I_s \left(e^{\frac{V_{th}}{V_{th}}} - 1\right) - I_0 \approx 10^{-12} \text{ A}$$

$V_{th}$: Thermal voltage, temp. dependent, $\approx 25 \text{ mV}$ @ room temp.
Unfortunately, $\Phi$ is "highly nonlinear". It is difficult to solve circuits using $\Phi$.

**Example:**

\[ \begin{align*}
5V & \quad \text{(5V supply)} \\
\Phi & \quad \text{(Nonlinear diode)} \\
\text{(Q1)} & \quad \text{Find (V, I)} \\
\text{(KVL)} & \quad 5 = (1k) I + V \\
\Rightarrow & \quad 5 = (1k) \left[ 10^{-12} \left( \frac{V}{0.025} - 1 \right) \right] + V \\
\text{(Transcendental equation)} & \quad \Rightarrow \text{hard to solve,}
\end{align*} \]

\[
V \approx 0.56 \text{ V}
\]

**Mathematica**

\[
\text{Solve}[5 == 1000 \times 10^{-12} \left( 2.718281828 \frac{V}{0.025} - 1 \right) + V, V]
\]

We need a simple model for solving diode circuit quickly & accurately.
Model I: Ideal diode model (on) switch model

[open circuit] Open switch:

\[ V < 0 \Rightarrow I = 0 \]

[short circuit] Closed switch:

\[ I > 0 \Rightarrow V = 0 \]

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Step 3! Check to make sure assumption in Step 1) is correct by using the I-V values.

\[ I = 0, \quad V = 5V \]

\[ \text{[open circuit]} \quad \text{Open switch}: \quad x \quad x \quad V < 0 \Rightarrow I = 0 \]

\[ \text{[short circuit]} \quad \text{Closed switch}: \quad x \quad x \quad I > 0 \Rightarrow V = 0 \]

\[ \text{Incorrect: operation point} \quad (5, 0) \quad V \]

Our assumption is wrong:

Diode is on:

\[ \text{5V} \quad \text{I} = 5\text{mA} \]

\[ V = 0 \]

\[ \text{Note:} \]

There are other models we can use:

\[ \text{Model 2: Voltage-offset model}. \]

\[ \quad \text{V} \]

\[ \quad \text{I} \]

\[ \quad \text{0.6V} \]

\[ \quad V \]
Using model 2 in the circuit above:

\[ I = \frac{5 - 0.6}{1k} = 4.4 \text{ mA} \]

Model 3

We will use only model 1:

Forward diode model

\[ \text{Case 1:} \quad A = 0, B = 0 \]

Claim: \( Y = 0 \)

\[ \text{Case 2:} \quad A = 4, B = 6 \]

\[ Y = -5 \text{ V} \]
Con(iii): \( A = 0, \ B = 5\ V \)
\[
\begin{align*}
\frac{V}{A} &= 5\ V \\
\frac{V}{X} &= 1\ k\ \\
V &= 5\ V
\end{align*}
\]

Con(iv): \( A = 5, \ B = 0, \ Y = 5\ V \)
\[
\begin{align*}
5\ V &\xrightarrow{\text{Diode}} 5\ V
\end{align*}
\]

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**Example 2:**

Assume \( D_1, D_2 \) are ideal. Sketch \( V_{\text{out}} \) given \( V_S \) (Diagram).
coefficient: $V_s < 0$

\[ V_s(t) \]

Example: $V_s = -10 \text{ V}$

KVL: 
\[-10 - v_1 - 4 = 0\]

\[ v_1 = -14 \text{ V} \]
**KVL:** \( V_2 = 4 \text{ V} \rightarrow \text{op-amp diode can't be off.} \)

\[ \therefore \text{D2 is on.} \implies V_{out} = 0 \text{ V} \]

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**Consider:** \( V_8 > 0 \)

\[ E_x: V_5 = 10 \text{ V} \]

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**KVL:** \( V_1 = 6 \text{ V} \times \)

**Turn D1 on:** \( V_2 = 10 \text{ V} \times \)

---

\[ 10 \text{ V} \]

**D2 is off again:** \( 10 \text{ V} \neq 0 \text{ V} \)
Answer: oops, problem is screwed up.

we will do more examples on Monday