Chapter 3: Solid State Switching

1 Lecture 8: Introduction to Diodes

1.1 Diode Fundamentals and IV Characteristics

A diode is a two-terminal device that allows current to flow primarily in one direction. Its operation is based on the properties of a **PN junction**, formed by joining p-type and n-type semiconductors.

1.1.1 Forward Bias

When the p-side is connected to a positive voltage and the n-side to a negative voltage:

- The depletion region narrows as electrons and holes recombine.
- A forward current flows if the applied voltage exceeds the **threshold voltage** (approximately 0.7 V for silicon diodes and 0.3 V for germanium diodes).

1.1.2 Reverse Bias

When the p-side is connected to a negative voltage and the n-side to a positive voltage:

- The depletion region widens, inhibiting current flow.
- A small **reverse saturation current** flows due to minority carriers.
- If the reverse voltage exceeds the **breakdown voltage**, significant current can flow, potentially damaging the diode (unless designed as a Zener diode).

1.1.3 IV Characteristics

The relationship between current (I) and voltage (V) for a diode is given by:

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

where:

- I_s: Saturation current (typically very small).
- V_T: Thermal voltage ($\sim 26\,\text{mV}$ at room temperature).
- n: Ideality factor ($n \approx 1$ for ideal diodes).

1.2 Rectification and Applications

1.2.1 Half-Wave Rectifier

- Consists of a single diode.
- Converts AC to pulsating DC by allowing only the positive half-cycle of the AC waveform to pass.
- Output RMS voltage is approximately $V_{\text{peak}}/\sqrt{2}$.

1.2.2 Full-Wave Bridge Rectifier

- Utilizes four diodes in a bridge configuration.
- Converts both halves of the AC waveform into pulsating DC.
- Often paired with a capacitor to smooth the output, reducing ripple voltage.

1.3 Zener Diodes and Voltage Regulation

Zener diodes are designed to operate in the reverse breakdown region. They are used in circuits to:

- Provide a stable reference voltage.
- Regulate voltage by clamping excess voltage in a circuit.

1.4 Example Problems

1.4.1 Problem 1: IV Characteristics

Problem: Plot the IV curve of a silicon diode with:

- $V = 0.8\,\text{V}$, $I_s = 10^{-12}\,\text{A}$.
- $n = 1.2$, $V_T = 26\,\text{mV}$.

Solution: Using the diode equation:

$$I = 10^{-12}\left(e^{\frac{0.8}{1.2\cdot 0.026}} - 1\right)$$

1.4.2 Problem 2: Full-Wave Rectifier

Problem: For an AC input voltage of $V_{\text{in}} = 10\,\text{V}_{\text{peak}}$:

- Calculate the RMS output voltage.
- Determine the frequency of the rectified signal ($f_{\text{in}} = 60\,\text{Hz}$).

Solution:

- RMS Output Voltage: $V_{\text{out,RMS}} = V_{\text{peak}}/\sqrt{2}$.
- Frequency: $f_{\text{out}} = 2 \cdot f_{\text{in}}$.

1.4.3 Problem 3: Zener Voltage Regulation

Problem: A 6.2 V Zener diode regulates a 12 V supply with a 1 kΩ resistor:

- Calculate the current through the Zener diode.
- Determine the maximum load resistance maintaining regulation.

Solution:

- Zener current: $I_Z = (12 - 6.2)/1000$.
- Maximum load current: $I_{\text{load}} = I_Z - I_{\text{min}}$.

1.5 Summary

- Diodes are essential components enabling unidirectional current flow.
- Applications include rectification, clamping, and voltage regulation.
- Zener diodes are critical for maintaining a stable reference voltage in circuits.