Chapter 9: Diodes and Diode Circuits

9.1 Diode Characteristics

- A diode is simply a pn junction, but its applications are extensive in electronic circuits.
- Three important characteristics of a diode are:
  - Forward voltage drop
    - Forward Bias, about .7 volts
  - Reverse voltage drop.
    - Depletion layer widens, usually the applied voltage
  - Reverse breakdown voltage.
    - Reverse voltage drop that will force current flow and in most cases destroy the diode.

Diode Elements

- A diode has two leads connected to the external circuit.
- Since a diode behaves differently depending upon forward or reverse bias, it is critical to be able to distinguish the leads.
- The anode connects to the p-type material, the cathode to the n-type material of the diode.
Ideal Diodes

- In an ideal diode, current flows freely through the device when forward biased, having no resistance.
- In an ideal diode, there would be no voltage drop across it when forward biased. All of the source voltage would be dropped across circuit resistors.
- In an ideal diode, when reverse biased, it would have infinite resistance, causing zero current flow.

Practical Diodes

- A practical diode does offer some resistance to current flow when forward biased.
- Since there is some resistance, there will be some power dissipated when current flows through a forward biased diode. Therefore, there is a practical limit to the amount of current a diode can conduct without damage.
- A reverse biased diode has very high resistance.
- Excessive reverse bias can cause the diode to conduct.

Practical Diode Forward Bias
Practical Diode Forward Bias

(b)

Practical Diode Forward Bias

(c)

Reverse Bias

(a)
Current versus Voltage

- In a practical diode, there is very little forward current until the barrier voltage is reached.
- When reverse biased, only a small amount of current flows as long as the reverse voltage is less than the breakdown voltage of the device.
9.2 Power Supply Applications

- Nearly all computers have some sort of power supply.
- Power supply circuits must:
  - Convert the ac line voltage into a dc voltage required by the circuit.
  - Reduce the ac voltage to a lower value.
  - Continuously adjust the dc output voltage to keep it constant under varying load conditions.

Half-wave Rectifier

- The term *rectify* is used to describe the conversion of ac into dc.
- In the circuit shown, only one-half of the input waveform is allowed to pass through to the output.
- This is called *half-wave rectification*.

Circuit Operation

- During the positive alternation, the diode is forward biased and the full applied voltage is dropped across the load resistor.
- During the negative alternation, the diode is reverse biased and acts like an open circuit. No voltage is present across the load resistor.
- The output voltage is actually pulsating dc.
- An application for a half-wave rectifier is shown on the following slide.
Circuit Operation

12:1 ratio, about 10 volts rms or 14.1 VP
Pulsating DC = \( \frac{V_p}{\pi} \), or \(.318 \times V_p\) in this case 4.48 VDC average (formula not in text)

Full-wave Rectifier

- A full-wave rectifier applies both halves of an ac waveform to the output.
- The circuit shown is called a biphase half-wave rectifier and sometimes a center-tapped rectifier circuit.
- Operation of a full-wave rectifier is demonstrated in the figure shown on the following slide.
**Bridge Rectifier**

- A bridge rectifier is more widely used than the center-tapped rectifier.
- Circuit operation is best understood by examining the current paths of the forward and reverse biased diodes during each half-cycle of the input waveform.

**Filter Networks**

- Most electronic applications require smooth dc current to operate properly. Filtering pulsating dc circuits accomplishes this.
- Adding a capacitor to the output of a half-wave rectifier filters the pulsating dc into smooth dc.
- Ripple-----

**Full-wave Rectifier with Filter**

- A capacitive filter added to the output of a full-wave bridge rectifier is shown at the right.
- One drawback of a half-wave rectifier is the higher level of ripple voltage after filtering. Full-wave rectification reduces this ripple voltage.
Other Types of Filtering

- Simple capacitor filtering is adequate for many electronic applications.
- In more critical applications, more complex filter networks are required to reduce or eliminate ripple voltage.
- Examples of more complex filters are:
  - L filters.
    - Shape of L
  - Pi filters.
    - Shape of π

9.3 Miscellaneous Diode Applications

- There are many practical applications for diodes beyond power supplies.
- Some of these applications include:
  - Clipper circuits that serve to protect circuits from damage as a result of over-voltage conditions.
  - Clippers are common in computer circuits.
Industrial application of a Clipper
Protection from high voltage input

The clipper here will limit the input to 5.7 volts
Miscellaneous Diode Applications

- Isolation diodes are used to isolate various sections of circuits from another.
- An example of this is the battery backup for computer memory.

- Diodes can be used to create an RC circuit that has different time constants for charge and discharge.
  - This principle is called *asymmetrical time constants*.

- Diodes can also be used as AM (amplitude modulation) detector circuits in radio receivers.
  - See simulation in Multisim Fig09_26.msm.
9.4 Special Diodes

- There are many diodes that have special properties that are useful in electronic circuits.
- A zener diode is much like a standard diode in many respects, except it is designed to operate in the reverse breakdown region of its operating curve.
- Fig09-31.msm

Basic Zener Characteristics

- Zener diodes are operated in their reverse breakdown mode to provide voltage regulation in a circuit.
- The point where the reverse current begins to increase is called the knee voltage. The current at this point is the knee current.

Zener Voltage Regulator

See circuit Fig09_30(a).msm
9.4B Varactor Diodes

- Junction capacitance is present in all reverse biased diodes because of the depletion region.
- Junction capacitance is optimized in a varactor diode and is used for high frequencies and switching applications.
- Varactor diodes are often used for electronic tuning applications in FM radios and televisions.
- They are also called voltage-variable capacitance diodes.
- Values vary from 2 pf to more than 1000 pf.

Schottky Diodes

- While varactor diodes are designed to optimize the effect of junction capacitance, Schottky diodes are designed to minimize the junction capacitance.
- Junction is made of gold or aluminum and n type silicon. This configuration eliminates capacitance and therefore gives them their high frequency ability.
- Schottky diodes are able to switch between conducting and nonconducting states much faster than conventional diodes.
- This fast switching speed is the identifying characteristic of a Schottky diode. They are also referred to as hot-carrier diodes.

Current Regulator Diodes

- Current regulator diodes are designed to provide a relatively constant forward current over a wide range of voltages.
- The diode functions as a constant-current source.
- The forward resistance of a current regulator diode is very high, from 250 kΩ to over 20 MΩ.
**Step-recovery Diodes**

- Step-recovery diodes are characterized by extremely fast switching times.
- They are primarily used in communication circuits above 1 GHz.
  - Suitable for microwave use
- Step-recovery diodes are doped differently than other types of diodes, with less doping at the pn junction than away from it.

**Tunnel Diodes**

- Tunnel diodes are another device designed to be operated at very high frequencies.
- The pn junction is doped much more heavily than other types of diodes.
- Tunnel diodes are used in the forward-biased state and exhibits what is known as negative resistance.
  - A portion of the characteristic curve actually has decreased current as voltage across it increases.
  - Your text has a picture of this curve
  - This is called the negative resistance portion of the curve.
  - This contradicts Ohm's law

**PIN Diodes**

- PIN diodes are another device intended for use at extreme frequencies (100 MHz–100 GHz).
- A layer of p-type material is separated from a layer of n-type material by a layer of intrinsic or very lightly doped silicon.
  - 3 layers, see picture in text
- This semiconductor sandwich of p-type, intrinsic, and n-type materials gives this diode its name.
**PIN Diodes**

- Because of the intrinsic semiconductor material in between the p and n material the capacitance when reverse biased is very low.
  - The MPN3404 has only 1.3pF over a wide range of reverse voltages.
  - This makes it well suited for use at very high frequencies.
- The rf resistance can vary from less than one ohm with a high forward current to well over one thousand ohms for lesser currents.
  - This makes them well suited to acting as a current controlled resistance.

**Partial Data Sheet for MPN3404**

**Silicon Pin Diode**

This device is designed primarily for VHF band switching applications but is also suitable for use in general-purpose switching circuits. It is applied in a non-evaluated TO-92 type plastic package for low insertion, high-voltage consumer and industrial requirements.

- Emitter-Base Junction with Trenchless Construction for Optimum Reliability
- Low Series Resistance: 10 kΩ
- Rp = 0.7 Ohm (Typ); Rp = 0.3 kΩ
- Neat TO-92 Style Package for Handling Ease

**MAXIMUM RATINGS**

<table>
<thead>
<tr>
<th>Rating</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reverse Voltage</td>
<td>50 V</td>
</tr>
<tr>
<td>Forward Voltage</td>
<td>25 V</td>
</tr>
<tr>
<td>Forward Current</td>
<td>4 A</td>
</tr>
<tr>
<td>Reverse Power Dissipation @ Ta = 25°C</td>
<td>2 W</td>
</tr>
<tr>
<td>Reverse Power Dissipation @ Ta = 125°C</td>
<td>0.5 W</td>
</tr>
<tr>
<td>Reverse Temperature</td>
<td>+125 °C</td>
</tr>
<tr>
<td>Storage Temperature Range</td>
<td>−40°C to +85°C</td>
</tr>
</tbody>
</table>

**9.5 Troubleshooting Diode Circuits**

- Because diodes are so common in the electronics industry, it is important to be able to troubleshoot and repair systems that employ diodes.
- Diode defects include:
  - Anode-to-cathode short.
  - Anode-to-cathode open.
  - Low front-to-back ratio.
  - Out-of-tolerance parameters.
Troubleshooting Diode Circuits

- Tests that can performed on diodes to check for their operation are:
  - Voltage measurements.
  - Ohmmeter tests.
  - Diode testers.

- Rectifier diode defects fall into one of two classes:
  - Power supply is defective, but no visible damage and no fuses are blown.
  - The rectifier circuit shows damage or a fuse is blown.