Midterm this Week

- Midterm in lab.
- Duration: 1 hour (2-3pm).
- Material on midterm:
  - Everything from first 4 weeks of class.
  - Thévenin’s Theorem & Source Impedance.
  - Impedance of resistors, capacitors, and inductors.
  - Filters (RC, RL, RLC, low-pass, high-pass, bandpass, notch, Chebyshev, Butterworth, etc ...).
  - Basic oscilloscope use, resistor code, etc...
- Midterm will cover design exercises and lab exercises.
- The purpose of the midterm is to consolidate passive analog linear circuitry before we move onto non-linear devices.
Diodes

2-terminal quantum device

A diode only conducts in one direction !!!

Non-linear → **Ohm’s Law** doesn’t apply!

→ There is no simple $Z_{\text{diode}}$ formula!

→ **Thevenin’s theorem** doesn’t apply!

Calculus: you can linearize a function/system in the vicinity of some $V_0$ or $I_0$.

→ **Ohm’s law**, $Z_{\text{diode}}$, and **Thevenin’s theorem** can only be used locally around some value of $V_0$ and $I_0$.

→ i.e. you can still write down a differential equation for your circuit (i.e. Kirchhoff’s loop and junction laws are still valid).
Semiconductors have a modest resistivity:

Normally we think of electrons moving in a circuit

In a semiconductor things are a little different

- We think of either holes or electrons.
  - Holes (+ charge)
  - Electrons (- charge)

<table>
<thead>
<tr>
<th>Material</th>
<th>Resistivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Copper</td>
<td>1.70x10^-8 Ω.m</td>
</tr>
<tr>
<td>Silicon</td>
<td>6400 Ω.m</td>
</tr>
<tr>
<td>Rubber</td>
<td>~10^{13} Ω.m</td>
</tr>
</tbody>
</table>
The PN junction

- Made from differently doped silicon
  - N region has more electrons
  - P region had more holes
- At the **PN junction** the holes & electrons recombine to form a small insulating **depletion region**.

\[ \Delta \text{Energy} \approx 0.6 \text{ V} \]
How a diode works

Depletion E-field

Depletion Region

Fermi Level

Conduction band

Valence band

p-n junction

Applied E-field

Reverse Bias

Depletion Region

is larger

Valence band

Conduction band

p-n junction

Forward Bias

Depletion E-field

Applied E-field

slight

Depletion Region

is smaller

Combination of electrons and holes occurs near the junction.

Holes move to junction from the positive side.

Electrons move to junction from the negative side.
How a diode works

Depletion
E-field
Depletion Region

Applied E-field

Reverse Bias

Depletion Region

slight
Forward Bias

Depletion Region

Applied E-field

is smaller

Combination of electrons and holes occurs near the junction.

Holes move to junction from the positive side.

Electrons move to junction from the negative side.
Diode: I-V characteristic curve

- Reverse bias $V_d$
- Forward bias $V\rightarrow$
- Real Diode

- Standard diode symbol
- P-type end
- N-type end
- Forward bias
- Reverse bias

- 'Ideal' Diode

$V_d \approx 0.6 \text{ V}$

[Image from www.mtmi.vu.lt]
Simple model

- Current can only flow in one direction.
- A 0.6V “diode drop” when conducting.
- \( IR = V_{IN} - 0.6 \) V
- Useful for designing circuits.

More complete model: Ebers-Moll equation.

- Not so useful for designing circuits.

A little negative is OK

A lot is “bad” → smoke!!!!
Diode Spec Sheet

1N/FDLL 914/A/B / 916/A/B / 4148 / 4448
Small Signal Diode

Absolute Maximum Ratings

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Parameter</th>
<th>Values</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>VA</td>
<td>Maximum Allowable Reverse Voltage</td>
<td>100</td>
<td>V</td>
</tr>
<tr>
<td>IO</td>
<td>Average Rectified Forward Current</td>
<td>200</td>
<td>mA</td>
</tr>
<tr>
<td>IR</td>
<td>Reverse-Mode Leakage Current</td>
<td>500</td>
<td>mA</td>
</tr>
<tr>
<td>TP</td>
<td>Non-operating Peak Forward Current</td>
<td>400</td>
<td>mA</td>
</tr>
<tr>
<td>T80</td>
<td>Storage Temperature Range</td>
<td>-65 to 125°C</td>
<td></td>
</tr>
<tr>
<td>TdJ</td>
<td>Operating Junction Temperature</td>
<td>175°C</td>
<td></td>
</tr>
</tbody>
</table>

Thermal Characteristics

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Parameter</th>
<th>Max. 1N/FDLL 91448 / 4148</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>PD</td>
<td>Power Dissipation</td>
<td>930</td>
<td>mW</td>
</tr>
<tr>
<td>PMAX</td>
<td>Thermal Resistance, Junction to Ambient</td>
<td>930</td>
<td>°C/W</td>
</tr>
</tbody>
</table>
Diode Spec Sheet

Electrical Characteristics

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Parameter</th>
<th>Test Conditions</th>
<th>Min.</th>
<th>Max.</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>V&lt;sub&gt;B&lt;/sub&gt;</td>
<td>Breakdown Voltage</td>
<td>T&lt;sub&gt;22&lt;/sub&gt; = 125°C, I&lt;sub&gt;B&lt;/sub&gt; = 100mA</td>
<td>350</td>
<td>700</td>
<td>V</td>
</tr>
<tr>
<td>V&lt;sub&gt;F&lt;/sub&gt;</td>
<td>Forward Voltage</td>
<td>T&lt;sub&gt;22&lt;/sub&gt; = 125°C, I&lt;sub&gt;B&lt;/sub&gt; = 100mA</td>
<td>55</td>
<td>700</td>
<td>mV</td>
</tr>
<tr>
<td></td>
<td>Reverse Leakage</td>
<td>T&lt;sub&gt;22&lt;/sub&gt; = 125°C, I&lt;sub&gt;B&lt;/sub&gt; = 100mA</td>
<td>50</td>
<td>700</td>
<td>μA</td>
</tr>
<tr>
<td>C&lt;sub&gt;B&lt;/sub&gt;</td>
<td>Transit Capacitance</td>
<td>T&lt;sub&gt;22&lt;/sub&gt; = 125°C, I&lt;sub&gt;B&lt;/sub&gt; = 100mA</td>
<td>2.0</td>
<td>10</td>
<td>pF</td>
</tr>
<tr>
<td>I&lt;sub&gt;PD&lt;/sub&gt;</td>
<td>Reverse Recovery Time</td>
<td>T&lt;sub&gt;22&lt;/sub&gt; = 125°C, V&lt;sub&gt;D&lt;/sub&gt; = 6.5V, T&lt;sub&gt;22&lt;/sub&gt; = 100mA</td>
<td>1.0</td>
<td>4.0</td>
<td>ns</td>
</tr>
</tbody>
</table>

Typical Characteristics

- Figure 1: Reverse voltage vs. reverse current (V<sub>R</sub> vs. I<sub>R</sub>)
- Figure 2: Reverse current vs. reverse voltage (I<sub>R</sub> vs. V<sub>R</sub>)
- Figure 3: Forward voltage vs. forward current (V<sub>F</sub> vs. I<sub>F</sub>)
- Figure 4: Forward current vs. forward voltage (I<sub>F</sub> vs. V<sub>F</sub>)
Diode Spec Sheet

Typical Characteristics (continued)

Figure 5: Forward Voltage vs. Forward Current
$V_F = 1516 \times I_{F, \text{max}}$

Figure 6: Forward Voltage vs. Ambient Temperature
$V_F = 9.61 + 23.5T_A (-40 \text{ to } +85^\circ C)$

Figure 7: Total Capacitance

Figure 8: Reverse Recovery Time vs. Reverse Recovery Current

Figure 9: Average Rectified Current ($I_{R, \text{avg}}$) vs. Ambient Temperature ($T_A$)

Figure 10: Power Dissipation ($P_D$) vs. Temperature ($T_J$)
Diode Spec Sheet

**FAIRCHILD SEMICONDUCTOR TRADEMARKS**

The following are registered and unregistered trademarks of Fairchild Semiconductor owned or licensed to use and are not intended to be an exhaustive list of all such trademarks:

- ACE™
- ADVANTAGE™
- BOSS™
- QTY™
- Built In™
- QFAB™
- CROSSVOL™
- QFP™
- DIGITAL™
- ESDMAX™
- ESDMAX™
- ESDMAX™
- ELECTRIC™
- ECG™
- FAST™
- FAST™
- FASTER™
- FAST™
- FLEX™
- FLEX™
- FLEX™
- FLEX™
- FLEX™
- FLEX™
- FLEX™
- FLEX™
- FLEX™
- FLEX™
- FLEX™
- FLEX™

**DISCLAIMER**

Fairchild Semiconductor reserves the right to make changes without further notice to any products herein to improve reliability, performance, or design.

**LIFE SUPPORT POLICY**

Fairchild products are not authorized for use as critical components in life support systems without the express written approval of Fairchild Semiconductor Corporation.

**PRODUCT STATUS DEFINITIONS**

**Definition of Terms**

<table>
<thead>
<tr>
<th>Status Identification</th>
<th>Product Status</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Advance Information</td>
<td>Formative or in Design</td>
<td>This status contains the design specifications for product development. Specifications may change in any manner without notice.</td>
</tr>
<tr>
<td>Preliminary</td>
<td>Pre-production</td>
<td>This status contains preliminary data and specifications, which are subject to change at any time without notice in order to improve design.</td>
</tr>
<tr>
<td>Announced</td>
<td>Full Production</td>
<td>This status contains final specifications. Fairchild Semiconductor reserves the right to make design changes at any time without notice to improve design.</td>
</tr>
<tr>
<td>Discontinued</td>
<td>Post-production</td>
<td>This status contains specifications on a product that has been discontinued by Fairchild Semiconductor. The datasheet is printed for reference information only.</td>
</tr>
</tbody>
</table>

www.fairchildsemi.com
Applications

- Circuit Protection
- Rectification
  - half wave rectifier
  - full wave rectifier
  - Power Supplies
- Frequency manipulation
  - Frequency multiplier
  - Mixers
Fourier Transform (FFT) of Full Wave Rectifier

Fourier space representation of rectified output

- 120 Hz
- 240 Hz
- 360 Hz
- 480 Hz