FROM LAST TIME...

Electronic Systems

- Why electronic systems?
- Passive electronic components
- Electronic system analysis

\[
R = 10k \quad C = 5\mu F
\]
UNIT 2:
ELECTRONIC SYSTEMS

PART B:
ACTIVE ELECTRONICS (DIODES)
**NOBEL GASES ARE INERT (DUE TO FULL ATOMIC SHELLS)**

<table>
<thead>
<tr>
<th>13</th>
<th>14</th>
<th>15</th>
<th>16</th>
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<tr>
<td>B</td>
<td>C</td>
<td>N</td>
<td>O</td>
<td>F</td>
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<tr>
<td>Al</td>
<td>Si</td>
<td>P</td>
<td>S</td>
<td>Cl</td>
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<tr>
<td>Cu</td>
<td>Zn</td>
<td>Ga</td>
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<tr>
<td>Ag</td>
<td>Cd</td>
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<td></td>
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<td></td>
<td>Te</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>I</td>
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He  | Ne  | Ar  | Kr  | Xe
CONDUCTORS NORMALLY HAVE 1-3 ELECTRONS IN OUTERMOST SHELL

<table>
<thead>
<tr>
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<tbody>
<tr>
<td>Cu</td>
<td>Zn</td>
<td>Ga</td>
<td>Ge</td>
<td>As</td>
<td>Se</td>
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<td>Si</td>
<td>P</td>
<td>S</td>
<td>Cl</td>
<td>Ar</td>
<td>He</td>
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<td>Ag</td>
<td>Cd</td>
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<td>Sn</td>
<td>Sb</td>
<td>Te</td>
<td>I</td>
<td>Xe</td>
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</table>
Semiconductors usually have 4 electrons in outermost shell.

<table>
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<td>Ag</td>
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<td>Sn</td>
<td>Sb</td>
<td>Te</td>
<td>I</td>
<td>Xe</td>
<td></td>
</tr>
</tbody>
</table>
SEMICONDUCTOR MATERIALS ARE POOR CONDUCTORS/INSULATORS

e.g. silicon (Si), germanium (Ge), and cadmium sulfide (CdS)

Image: http://www.howstuffworks.com/diode.htm
IN PURE SILICON CRYSTAL, EACH ATOM BONDS WITH FOUR OTHER ATOMS

Full set of covalent bonds are created, leaving behind no excess or shortage of electrons.
Adding energy (heat) to the crystal causes electrons to jump to a higher energy level, creating a "hole."
HOLES CAN BE VIEWED AS POSITIVE CHARGE CARRIERS

Net effect is electrons moving left, while holes move to the right
n-TYPE DOPING RESULTS IN A FREE ELECTRON

Silicon can be doped with donor elements (e.g. arsenic or phosphorus) having five electrons in their valence orbit. This frees an electron from the crystal lattice, thus producing an "n-type" semiconductor.
p-TYPE DOPING RESULTS IN AN OPEN HOLE

Silicon can be doped with acceptor elements (e.g. aluminum, boron, or gallium) that have 3 electrons in their valence orbit. This leaves a hole in the crystal structure, thus producing a "p-type" semiconductor.
JOINING p-TYPE AND n-TYPE MATERIALS FORMS A p-n JUNCTION
WE REFER TO A SINGLE p-n JUNCTION AS A **DIODE**

Diode Symbols:
DIODES

Image: http://www.protostack.com/semiconductors/1n5404-general-purpose-400v-3a-rectifier-diode
A DIODE IS THE ELECTRONIC EQUIVALENT OF A CHECK VALVE:

Fluid can flow this way...

but not this way!
CHECK-VALVE ANALOGY IS REVEALED IN V-I GRAPH

Forward Bias:

If $V_D > V_F$ ($\sim 0.6\text{--}0.7\text{ V for Si}$)

$\Rightarrow$ Diode conducts (short circuit)

Reverse Bias:

If $V_Z < V_D < V_F$

$\Rightarrow$ Diode does not conduct (open circuit)

- If you exceed the breakdown voltage, you will likely destroy the diode!
- Breakdown voltage also known as "peak reverse" or "peak inverse" voltage
DIODES: PRACTICAL CONSIDERATIONS

If the voltage across a diode is larger than $V_F$ (i.e., forward biased), then the diode can be modeled as a short circuit in series with a $V_F$ volt battery, e.g.

$V_{IN} > V_F$

$V_Z < V_{IN} < V_F$

[Diagrams of a diode in different voltage scenarios]
DIODES: PRACTICAL CONSIDERATIONS

In addition to watching out for the maximum permissible reverse bias voltage, one has to ensure that the maximum allowable current ($I_O$) is not exceeded. Placing a *current limiting* resistor in series with the diode can alleviate this problem.

\[
\text{Current: } \frac{V_S - V_F}{R_S}
\]
# Diodes: Practical Considerations

**1N4148**

Vishay Semiconductors

## Electrical Characteristics

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Test Condition</th>
<th>Symbol</th>
<th>Min.</th>
<th>Typ.</th>
<th>Max.</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forward Voltage</td>
<td>$I_F = 10 , mA$</td>
<td>$V_F$</td>
<td>1</td>
<td>1</td>
<td>V</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$V_R = 20 , V$</td>
<td>$I_R$</td>
<td>25</td>
<td>25</td>
<td>nA</td>
<td></td>
</tr>
<tr>
<td>Reverse Current</td>
<td>$I_R = 100 , \mu A$</td>
<td>$V_{(BR)}$</td>
<td>100</td>
<td></td>
<td>V</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$V_R = 20 , V$, $T_j = 150 , ^\circ C$</td>
<td>$I_R$</td>
<td>50</td>
<td>50</td>
<td>\mu A</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$V_R = 75 , V$</td>
<td>$I_R$</td>
<td>5</td>
<td>5</td>
<td>\mu A</td>
<td></td>
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<tr>
<td>Breakdown Voltage</td>
<td>$I_R = 100 , \mu A$, $t_p/T = 0.01$, $t_p = 0.3 , ms$</td>
<td>$V_{(BR)}$</td>
<td>100</td>
<td></td>
<td>V</td>
<td></td>
</tr>
<tr>
<td>Diode Capacitance</td>
<td>$V_R = 0 , V$, $f = 1 , MHz$, $V_{HF} = 50 , mV$</td>
<td>$C_D$</td>
<td>4</td>
<td>4</td>
<td>pF</td>
<td></td>
</tr>
<tr>
<td>Rectification effiency</td>
<td>$V_{HF} = 2 , V$, $f = 100 , MHz$</td>
<td>$\eta_r$</td>
<td>45</td>
<td></td>
<td>%</td>
<td></td>
</tr>
<tr>
<td>Reverse recovery time</td>
<td>$I_F = I_R = 10 , mA$, $i_R = 1 , mA$</td>
<td>$t_{rr}$</td>
<td>8</td>
<td>8</td>
<td>ns</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$I_F = 10 , mA$, $V_R = 6 , V$, $i_R = 0.1 \times i_R$, $R_L = 100 , \Omega$</td>
<td>$t_{rr}$</td>
<td>4</td>
<td>4</td>
<td>ns</td>
<td></td>
</tr>
</tbody>
</table>

[Tamb = 25 °C, unless otherwise specified]

[http://www.vishay.com/docs/81857/1n4148.pdf]
DIODES: PRACTICAL CONSIDERATIONS

Datasheet for Vishay Semiconductor 1N4148 Diode

### PARTS TABLE

<table>
<thead>
<tr>
<th>PART</th>
<th>ORDERING CODE</th>
<th>TYPE MARKING</th>
<th>INTERNAL CONSTRUCTION</th>
<th>REMARKS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1N4148</td>
<td>1N4148-TAP or 1N4148TR</td>
<td>V4148</td>
<td>Single diode</td>
<td>Tape and reel/ammpack</td>
</tr>
</tbody>
</table>

### ABSOLUTE MAXIMUM RATINGS \( T_{amb} = 25 \, ^\circ\text{C}, \text{unless otherwise specified} \)

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>TEST CONDITION</th>
<th>SYMBOL</th>
<th>VALUE</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Repetitive peak reverse voltage</td>
<td></td>
<td>( V_{RRM} )</td>
<td>100</td>
<td>V</td>
</tr>
<tr>
<td>Reverse voltage</td>
<td></td>
<td>( V_R )</td>
<td>75</td>
<td>V</td>
</tr>
<tr>
<td>Peak forward surge current</td>
<td>( t_p = 1 , \mu\text{s} )</td>
<td>( I_{FSM} )</td>
<td>2</td>
<td>A</td>
</tr>
<tr>
<td>Repetitive peak forward current</td>
<td></td>
<td>( I_{FRM} )</td>
<td>500</td>
<td>mA</td>
</tr>
<tr>
<td>Forward continuous current</td>
<td></td>
<td>( I_F )</td>
<td>300</td>
<td>mA</td>
</tr>
<tr>
<td>Average forward current</td>
<td>( V_R = 0 )</td>
<td>( I_{FAV} )</td>
<td>150</td>
<td>mA</td>
</tr>
<tr>
<td>Power dissipation</td>
<td>( I = 4 , \text{mm}, , T_L = 45 , ^\circ\text{C} )</td>
<td>( P_{tot} )</td>
<td>440</td>
<td>mW</td>
</tr>
<tr>
<td></td>
<td>( I = 4 , \text{mm}, , T_L \leq 25 , ^\circ\text{C} )</td>
<td>( P_{tot} )</td>
<td>500</td>
<td>mW</td>
</tr>
</tbody>
</table>

### THERMAL CHARACTERISTICS \( T_{amb} = 25 \, ^\circ\text{C}, \text{unless otherwise specified} \)

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>TEST CONDITION</th>
<th>SYMBOL</th>
<th>VALUE</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermal resistance junction to ambient air</td>
<td>( I = 4 , \text{mm}, , T_L = \text{constant} )</td>
<td>( R_{thJA} )</td>
<td>350</td>
<td>K/W</td>
</tr>
<tr>
<td>Junction temperature</td>
<td></td>
<td>( T_j )</td>
<td>175</td>
<td>°C</td>
</tr>
<tr>
<td>Storage temperature range</td>
<td></td>
<td>( T_{stg} )</td>
<td>-65 to +150</td>
<td>°C</td>
</tr>
</tbody>
</table>
WHY DO WE NEED DIODES?

- Signal processing
  - Rectification
  - Clipping
  - Peak detection
- Voltage regulation (Zener diode)
- Signal indication (LED)
- System isolation (LED + photodiode)
DIODE APPLICATION: RECTIFICATION

Rectification of AC Signals

- Half-wave rectifier

![Diagram of half-wave rectifier with BA157GP diode and voltage waveform]
DIODE APPLICATION: RECTIFICATION

Rectification of AC Signals

- Bridge rectifier

![Diagram of bridge rectifier with Vac and Rload labels]
**DIODE APPLICATION: RECTIFICATION**

**KBL005, KBL01B, KBL02, KBBL04, KBL06, KBL08, KBL10**

www.vishay.com

Vishay General Semiconductor

**Single-Phase Bridge Rectifier**

- **Features**
  - UL recognition, file number E54214
  - Ideal for printed circuit boards
  - High surge current capability
  - High case dielectric strength of 1500 Vrms
  - Solder dip 275 °C max. 10 s, per JESD 22-B106
  - Material categorization: For definitions of compliance please see [www.vishay.com/doc?99912](http://www.vishay.com/doc?99912)

**Typical Applications**

General purpose use in AC/DC bridge full wave rectification for monitor, TV, printer, SMPS, adapter, audio equipment, and home appliances applications.

**Mechanical Data**

- **Case:** KBL
- Molding compound meets UL 94 V-0 flammability rating
- Base P/N-E4 - RoHS-compliant, commercial grade
- **Terminals:** Silver plated leads, solderable per J-STD-002 and JESD22-B102
- **Polarity:** As marked on body
- **Mounting Torque:** 10 cm-km (8.8 inches-lbs) max.
- **Recommended Torque:** 5.7 cm-km (5 inches-lbs)

---

**Primary Characteristics**

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Package</td>
<td>KBL</td>
</tr>
<tr>
<td>$I_{F(AV)}$</td>
<td>4 A</td>
</tr>
<tr>
<td>$V_{RRM}$</td>
<td>50 V, 100 V, 200 V, 400 V, 600 V, 800 V, 1000 V</td>
</tr>
<tr>
<td>$I_{FSM}$</td>
<td>200 A</td>
</tr>
<tr>
<td>$I_R$</td>
<td>5 μA</td>
</tr>
<tr>
<td>$V_F$ at $I_F=4$ A</td>
<td>1.1 V</td>
</tr>
<tr>
<td>$T_J$ max.</td>
<td>150 °C</td>
</tr>
<tr>
<td>Diode variations</td>
<td>In-Line</td>
</tr>
</tbody>
</table>
DIODE APPLICATION: DC POWER SUPPLY

AC Regulator Load

Step-Down Transformer

Bridge Rectifier

Low-Pass Filter

Load
DIODES CAN BE USED TO CLIP A SIGNAL AT SPECIFIED LIMITS

Where might you use this?
A diode with a capacitor can be used as a peak detector.

Where might you use this?
ZENER DIODES OPERATE IN THE REVERSE BREAKDOWN REGION

- Steep breakdown curve with well defined breakdown voltage $V_Z$
- Can maintain nearly constant voltage for a wide range of currents
ZENER DIODE MODELED AS HAVING TWO PARALLEL BRANCHES:

Forward biased: $V_D > V_F$

Reverse biased: $V_D \leq V_Z$
**ZENER DIODE APPLICATION: VOLTAGE REGULATOR**

- Load voltage equals $V_Z$ if the Zener diode is in the reverse breakdown region: $i_L = \frac{V_Z}{R_L}$
- Load current comes from KCL: $i_L = i_S - i_Z$
- Source current is: $i_S = \frac{V_S - V_Z}{R_S}$
- Zener diode is usually rated by its maximum allowable power dissipation: $P_{Z,\text{max}} = i_{Z,\text{max}} \cdot V_Z$
  
  ⇒ Need to make sure that $i_Z$ will not become too large
VOLTAGE REGULATION: PRACTICAL CONSIDERATION

IC Voltage Regulator:

Image: https://www.sparkfun.com/products/107
VOLTAGE REGULATION: PRACTICAL CONSIDERATION

- Zener regulators are usually smaller, cheaper, and easier to implement, and are suitable for low power voltage regulation.
- IC voltage regulators are generally more efficient, especially for widely varying current loads, and at higher power levels.
- Zener diode performance varies with temperature, while IC voltage regulators are compensated for thermal variations.
- Since the zener diode splits current with the load, the voltage drop across the zener diode can be influenced by the load current. In comparison, an IC voltage regulator is designed to draw a nearly constant bias current, regardless of fluctuations in load voltage and current.
LIGHT-EMITTING DIODES (LEDs)

LEDS EMIT PHOTONS WHEN FORWARD BIASED

Light intensity is related to the amount of current flowing through the diode.
LEDS CAN BE USED TO INDICATE A SIGNAL VALUE

LEDs exhibit a voltage drop of 1.5 to 2.5 volts when forward biased

A series current-limiting resistor (≈330Ω for a 5 volt source) is needed to prevent excess forward current
PHOTODIODES

Image: http://www.pacer-usa.com/Assets/Pacer/User/Photodiodes.jpg
PHOTODIODES ARE LIGHT-SENSITIVE p-n JUNCTIONS

Optimized to generate reverse (leakage) current in the presence of light. As the light intensity increases, additional electrons are kicked into the conduction band, allowing for greater current flow.

A photodiode can be used as a light sensor.
LED/PHOTODIODE PAIRING MAKES AN OPTOCOUPLER

- Couples two circuits while maintaining electronic isolation
- Extremely useful when connecting high-power circuits to low-power control circuits
- Not suited for analog signals

SCHOTTKY DIODES ALLOW FOR FASTER SWITCHING

At high frequencies (> 1MHz), ordinary diodes cannot shut off quick enough to avoid noticeable current. This is corrected by a Schottky diode, which uses a precious metal on one side of the p-n junction, and doped silicon on the other.
COMING UP...

Electronic Systems

- Switching and amplifying with transistors
- Interfacing active electronic components

Computer Systems

- Why do Computer Systems matter?
- Combinational logic
- Sequential logic
- Finite state machines
ACTION ITEMS

1. First lab report due: Thursday 1/22 or Friday 1/23, by 5 pm