0. Review
1. Zener Diode
2. Zener Regulator
3. Light Emitting Diode

- Lab 1 report due Fri (Apr 8)
  ⇒ see course website for template
- HW2 due next Tue
  + Quiz
- PreLab2 due at beginning of lab session
1. Full Wave Rectifier

2. Bridge Rectifier

\[ \frac{1}{2} V_{sec, p} \]

\[ V_{sec, p} - 0.7 \]

\[ V_{sec, p} - 1.4 \]
Voltage Ripple

Half-Wave

\[
V_{\text{ripple}} = \frac{V_p}{R_L C} \frac{1}{f}
\]

Full-Wave Bridge

\[
V_{\text{ripple}} = \frac{V_p}{R_L C} \frac{1}{2f}
\]
Quiz #1 Recap

Determine $V_{LOAD}$, $P_{LOAD}$, $P_{D1}$, $P_{D2}$
Intro to Voltage Regulators

- Most DC power supplies have the following:

Previous Lecture

Transformer \[\rightarrow\text{Rectifier} \rightarrow\text{Filter}\] \[\rightarrow\text{Regulator}\]

120V rms 60Hz (AC input)

1. Ripple
2. Drift

Regulated Voltage

Stable DC output

\[\uparrow\]

Unregulated voltage

\[\downarrow\]
Another example: Power supply for Arduino

Serial COM + 5V power → USB Port

IN: +7 to 12V
OUT: +5V

Voltage Regulator IC

Microcontroller (AVR)

(7 to 12V) DC

"V_IN"

unregulated is OK → (wire carrying 7 to 12V)

e.g. 9V battery
1. Zener Diodes

- Any voltage regulator requires a voltage reference.

Q: How to make a voltage reference?

Recall that any diode can experience reverse breakdown: $-V_{zK}$, the "knee" or "zener" point.

$\Rightarrow$ Want to avoid breakdown in rectifier applications

$\Rightarrow$ Large $\Delta I$ causes tiny $\Delta V$

**However**, breakdown is useful for voltage reference applications.
- A rectifier diode (e.g. 1N4002) has very large $-V_{zk}$.
  ⇒ not very useful for voltage regulation.

- A **zener diode** has a deliberately low $-V_{zk}$.
  ⇒ Available in a variety of $V_z$!

<table>
<thead>
<tr>
<th>Part #</th>
<th>$V_z$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1N4730A</td>
<td>3.9V</td>
</tr>
<tr>
<td>1N4734A</td>
<td>5.6V</td>
</tr>
<tr>
<td>1N4742A</td>
<td>12V</td>
</tr>
</tbody>
</table>

Ex: $V_D = -V_z$
How to use a zener diode?

- Usually want at least 10 mA of current for good voltage regulation.

\[ I_z = 10 \text{mA} \]

\[ V_2 = +5.6 \text{V} \]

\[ I_D = -10 \text{mA} \]

\[ V_D = -5.6 \text{V} \]

Ex:

\[ V_{out} \]

\[ 14 \text{V} \]

\[ I \]

\[ 5.6 \text{V} \]

\[ I = \frac{14 - 5.6}{R} > 10 \text{mA} \rightarrow R < \frac{540}{2} \Omega \Rightarrow \text{Choose } R = 820 \Omega \quad (\text{standard 5\% resistor}) \]
2. Zener Regulator

- A Zener diode works properly if:
  1. It is in the breakdown region
  2. Enough current (typically 10 mA or more)

**Example** Is this a good Zener circuit?

Assume zener is ON and compute zener current.

\[ I_z = I_s + I_L \]

\[ I_z = I_s - I_L \]

\[ I_z = \frac{18 - 10}{0.27\Omega} - \frac{10}{1k} = 19.6\,mA \]

\[ \Rightarrow \text{zener is in breakdown} \checkmark \]
\[ \Rightarrow \text{current is } > 10\,mA \]

\[ \{ \text{Answer = YES} \} \]
Zener Drop-Out

In practical applications, the source voltage $V_s$ and load $R_L$ change.

The zener "drops out" of voltage regulation if $V_s$ is too low or $R_L$ is too low.

Why?

$I_z = I_s - I_L = \frac{V_s}{R_s} - \frac{V_z}{R_L}$

$I_z$ can drop to zero if:

1. $V_s$ is too small
2. $R_L$ is too small
3. $R_s$ is too large

So, we must analyze the worst case scenario that may cause $I_z = 0$:

$0 = \frac{V_{s_{\text{min}}}}{R_{s_{\text{max}}}} - \frac{V_z}{R_{L_{\text{min}}}}$
Example: Max allowable $R_s$?

$I_2 = I_s - I_L$

$O = \frac{12 - 12}{R_{s,\text{max}}} - \frac{\frac{12}{140}}{\text{largest} \ I_L}$

$R_{s,\text{max}} = \frac{10}{12/140} = 117 \Omega$

Example: Max allowable $R_s$?

$I_2 = I_s - I_L$

$O = \frac{15 - 6.8}{R_{s,\text{max}}} - 2.0 \text{ mA}$

$R_{s,\text{max}} = \frac{8.2}{20 \text{ mA}} = 0.41 \text{ V} = 410 \Omega$
Zener resistance

The I-V curve for a zener is not perfectly vertical in the breakdown region.

This imperfection can be modeled as a series resistance $R_z$.

$\Rightarrow R_z$ changes the load voltage.

Example: If $R_z = 8 \, \Omega$ and $V_z = 10 \, V$, what is $V_L$?

KCL:

\[
30 - V_L = \frac{V_L - 10}{8} + \frac{V_L}{1000}
\]

\[
\frac{30}{470} + \frac{10}{8} = \left(\frac{1}{8} + \frac{1}{1000} + \frac{1}{470}\right) V_L
\]

$V_L = 10.25 \, V$
3. Light Emitting Diodes (LEDs)

- Many sizes and shapes.
  Common package for discrete LED is the "T-1" and "T-1 3/4" style.
- Shorter wavelength LEDs have larger $V_F$.
  - Blue: $\sim 3.5 \text{ V}$
  - Green: $\sim 2.2 \text{ V}$
  - Red: $\sim 2 \text{ V}$
  - Infrared: $\sim 1.5 \text{ V}$

LEDs are fragile $\Rightarrow$ reverse breakdown voltage only $\sim 5 \text{ V}$?
$\uparrow$ damage
• LEDs are **current-driven** devices. 10-20 mA is common. Usually rated at a recommended current for a certain $V_f$.

**Ex:** Let $I = 10 \text{ mA} @ V_f = 1.2 \text{ V}$

$$\Rightarrow \frac{5 - 1.2}{R} = 0.01 \text{ A} \Rightarrow R \approx 380 \Omega$$

• Optical communications require modulating the LED current.

$\Rightarrow$ usually use a transistor

Next week.
Lab 2: Adjustable voltage supply (0-12V) for DC motor

- Power Transformer
- Full-Wave Rectifier
- IN4002
- LM317
- Adjustable voltage regulator
- DC Motor