Outline

• Power Regulation
  – Transformers
  – Rectifiers
  – Linear Regulators
  – Switching Regulators

• How much power?
Transformers

- Exchange voltage for current to reduce potential difference (voltage) across two points
  - The difference in number of turns between the two windings determines the ratio of voltage input to voltage output

\[
\frac{v_1}{v_2} = \frac{N_1}{N_2} \quad \frac{i_1}{i_2} = -\frac{N_2}{N_1} \\
\frac{v_1}{v_2} = -\frac{i_2}{i_1}
\]

- **Note:** no conductive element between \( v_1 \) and \( v_2 \)!
Transformers: Multiple Types

- **Single-tap**
  - One voltage output

- **Multiple-taps/windings**
  - Provide multiple voltage outputs
  - Multiple taps
    - Must share common point
  - Multiple windings
    - Can use in series (like a tap) to get multiple voltages or in parallel to increase current output
Rectifiers

- **DC vs AC**
  - DC = Direct Current: used in most electronics & batteries
  - AC = Alternating Current: used during common electricity generation (power plants, motors with rotating magnets)
    - Preferred method to transmit over long distances
- **For DC projects must convert AC to DC: use rectifiers**

  Half Wave Rectifier
  - Many types:
    - Most common: half wave and full wave

  Full Wave Bridge

  Note: Volts AC is given in RMS value, which means the peak is at

  \[ V_{pp} = \frac{1}{0.707} V_{ac} \]
A full-wave bridge rectifier effectively provides abs(Vac) at the output

- A capacitor “flattens” the sinusoidal AC signal for a relatively flat DC output
- The output will always have some *ripple*, must use a regulator to fully flatten the signal
Linear Regulators

- Regulate an input voltage to:
  - Reduce voltage to exact needs
  - Provide constant output
    - No ripple
    - Regardless of load (even changing load)

- Simplest design of all regulators
  - Only needs capacitors as external components, no high-frequency elements

- Input voltage (abs) MUST be higher than output voltage (abs)
  - Linear regulators cannot increase or invert voltage

- Power lost in regulator is linear WRT current pull and voltage drop ($V_{in} - V_{out}$)
  - Useful for small current and/or small voltage drop

- Efficiency is linear WRT the voltage drop ($V_{in} - V_{out}$)
  - Most efficient with small voltage drop...
The simplest model of a linear regulator is a **variable resistor**:

\[
i_{\text{out}} = \frac{v_{\text{out}}}{R_{\text{load}}} \\
i_{\text{in}} = i_{\text{out}} \\
P_{\text{reg}} = i_{\text{out}} (v_{\text{in}} - v_{\text{out}}) \\
eff = \frac{P_{\text{out}}}{P_{\text{reg}} + P_{\text{out}}} = \frac{i_{\text{out}} v_{\text{out}}}{i_{\text{out}} v_{\text{out}} (v_{\text{in}} - v_{\text{out}}) + i_{\text{out}} v_{\text{out}}} = \frac{v_{\text{out}}}{v_{\text{in}}}
\]

- The effective resistance of the circuit, \( R_{\text{load}} \), determines the necessary current
  - The input current must be the same as the output current

**Example:**

- \( V_{\text{in}} = 7\text{V}, V_{\text{out}} = 5\text{V}, i = 100\text{mA} \)
  - \( P_{\text{reg}} = 0.2\text{W}, P_{\text{tot}} = 0.7\text{W}, \text{eff} = 71\% \) reasonable use, no heatsink
- \( V_{\text{in}} = 7\text{V}, V_{\text{out}} = 5\text{V}, i = 1\text{A} \)
  - \( P_{\text{reg}} = 2\text{W}, P_{\text{tot}} = 7\text{W}, \text{eff} = 71\% \) NEED heatsink to dissipate 2W!
- \( V_{\text{in}} = 20\text{V}, V_{\text{out}} = 5\text{V}, i = 100\text{mA} \)
  - \( P_{\text{reg}} = 1.5\text{W}, P_{\text{tot}} = 2\text{W}, \text{eff} = 25\% \) UNreasonable use, a lot of power wasted, low efficiency!
Switching Regulators

- Regulate an input voltage to:
  - Decrease, increase, and/or invert a voltage
    - Allow for large input/output voltage differentials
    - Can only increase or decrease voltage, not both
      - Practically get rid of ripple
  - Complex design
    - Uses many external components

- Design uses an inductor to create the necessary voltage by driving current through it at high frequencies (~100-500kHz)
  - Utilizes feedback of both current (through sense resistor) and voltage (at output)
  - Output voltage has small noise at operating frequency, usually insignificant

- Usually 80-95% efficiency, dependent on current pull
  - Driving the high-frequency signal requires a minimum constant power input, even if the output is disconnected (no current)
Switching Regulator Model

- No simple model
  - It is a feedback loop where the sensor drives the “current switch” as necessary
- For design purposes can assume that power in equals power out, plus the efficiency factor
  - For design one *must* know the necessary current supply for $V_{in}$

\[
\begin{align*}
  v_{in} i_{in} &= P_{in} = P_{out} = v_{out} i_{out} \\
  i_{in} &= \frac{v_{out} i_{out}}{v_{in}} \cdot \frac{1}{\text{eff}}
\end{align*}
\]

- Example: from datasheet, since the model of a switching regulator is not always the same
  - Note different curves for different input voltages
  - Note very low efficiency for low output currents
How much power do you need?

• Remember it is very simple:
  – $P = IV$, always as far as we’re concerned
  – Power can be added
    • If you know the power of individual components, and are given the voltage & current for others, add the power together!
  – Account for regulator efficiency
    • Select the best type of regulator for your needs, consider both design (linear is simple) and efficiency/power dissipation (usually switching is better)
  – Allow for at least 20% margin
    • After considering regulator efficiency