AERO ASTRO

16.682 - Prototyping Avionics
Spring 2006

LECTURE 5

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DEPARTMENT OF AERONAUTICS AND ASTRONAUTICS

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Outline

- **Power Regulation**
  - **Transformers**
  - **Rectifiers**
  - **Linear Regulators**
  - **Switching Regulators**
- **How much power?**

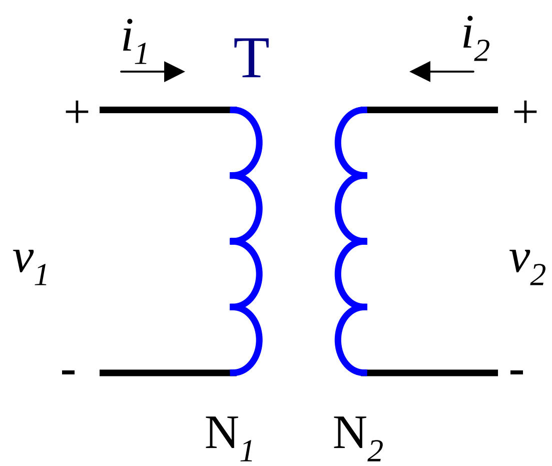
Transformers

- **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**

$$\frac{v_1}{v_2} = \frac{N_1}{N_2}$$

$$\frac{i_1}{i_2} = -\frac{N_2}{N_1}$$

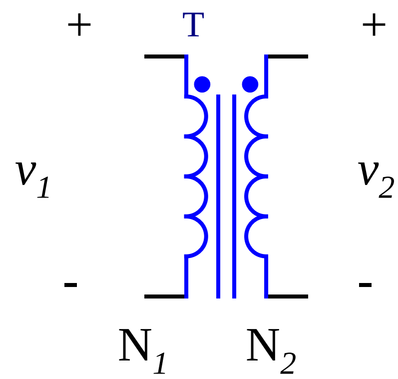
$$\frac{v_1}{v_2} = -\frac{i_2}{i_1}$$



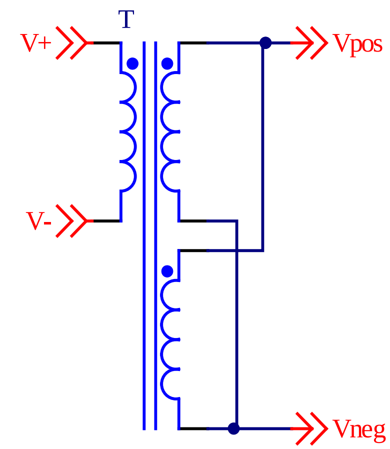
  - **Note: no *conductive* element between v_1 and v_2!**

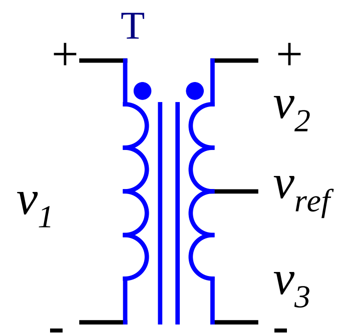
Transformers: Multiple Types

- **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**

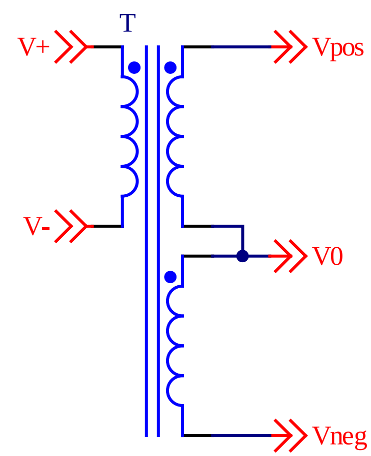


Single Tap





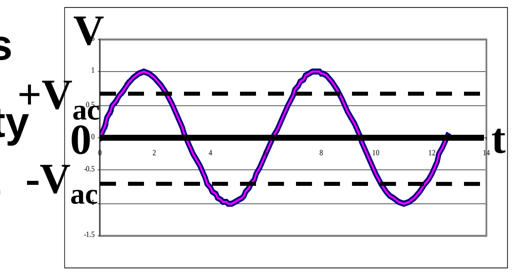
Center Tap
configured for +V & -V



Two Windings

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**

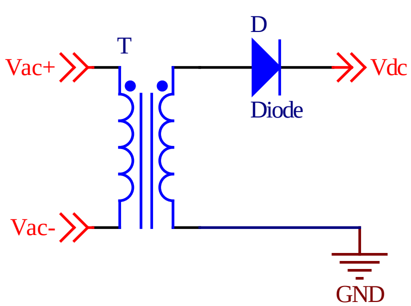


Note: Volts AC is given in RMS value, which means the peak is at

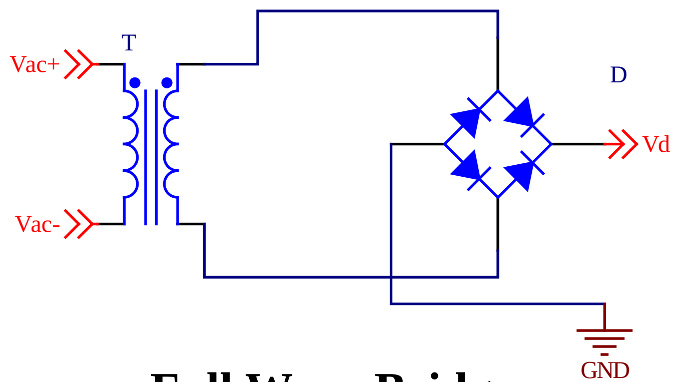
$$V_{pp} = \frac{1}{0.707} V_{ac}$$

AC Voltage Plot

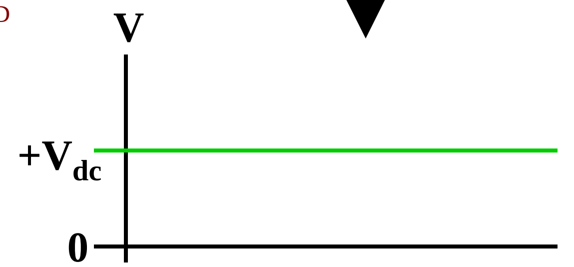
- **For DC projects must convert AC to DC: use rectifiers**



Half Wave Rectifier



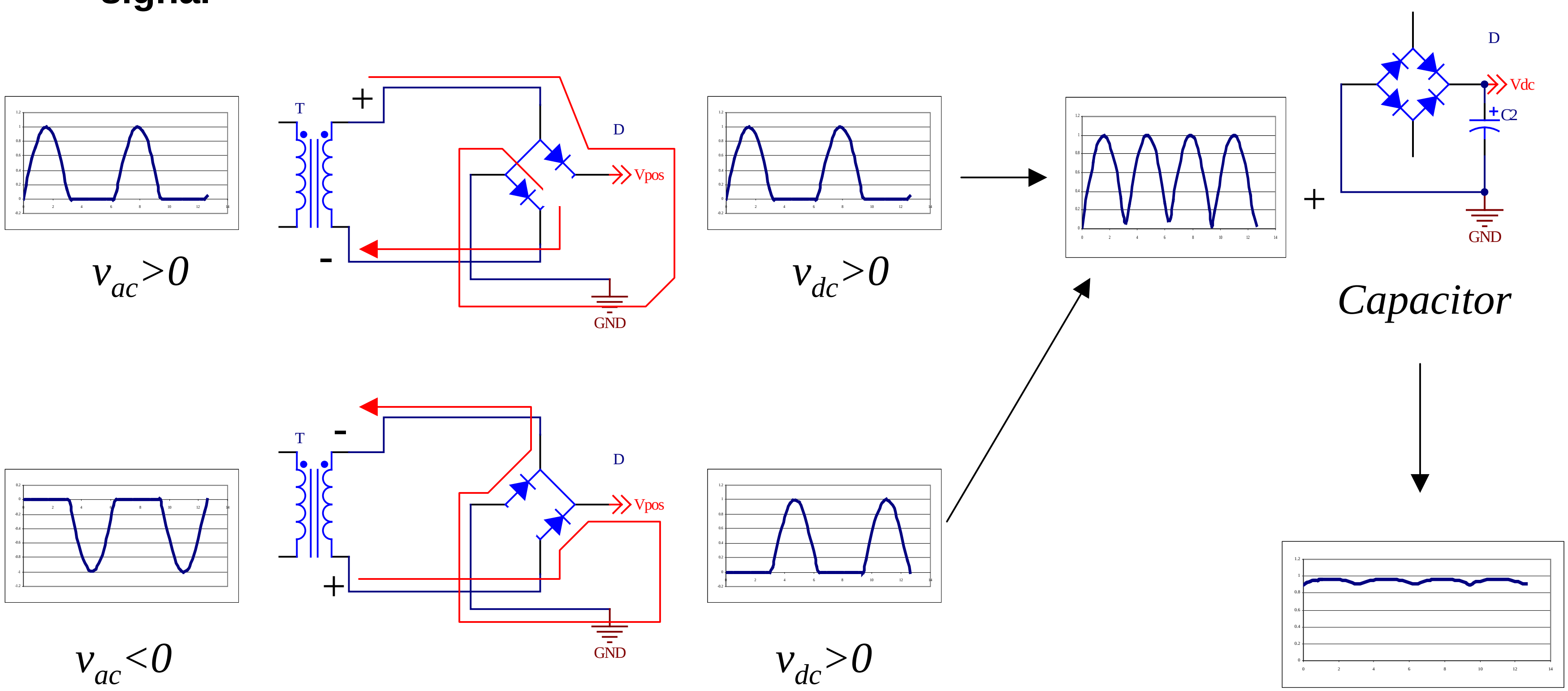
Full Wave Bridge



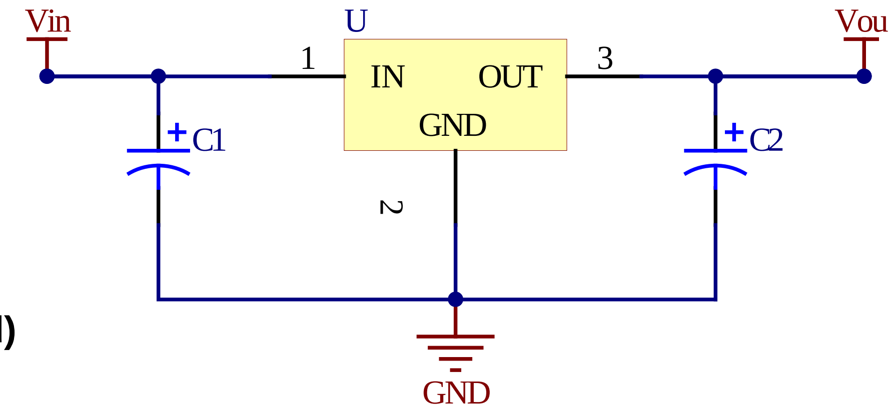
  - **Many types:**
    - **Most common: half wave and full wave**

Full Wave Rectifier

- **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**



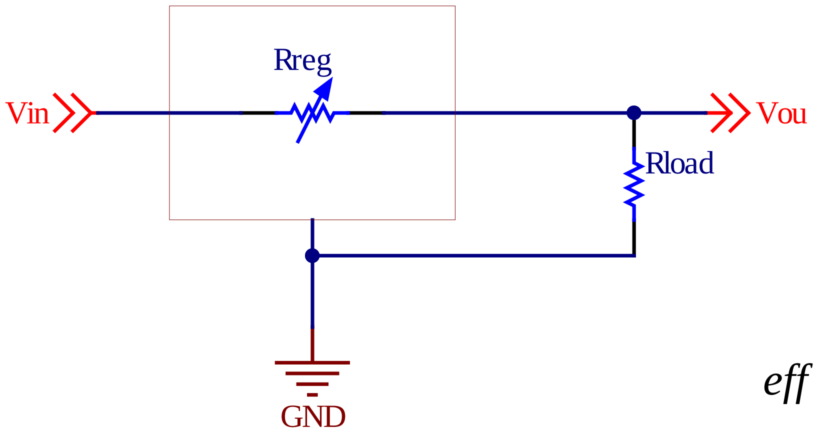
Linear Regulators



- 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 <u>linear</u> WRT the voltage drop (V_{in}-V_{out})
  - Most efficient with small voltage drop...

Linear Regulator Model

- The simplest model of a linear regulator is a *variable resistor:*



$$i_{out} = \frac{v_{out}}{R_{load}}$$

$$i_{in} = i_{out}$$

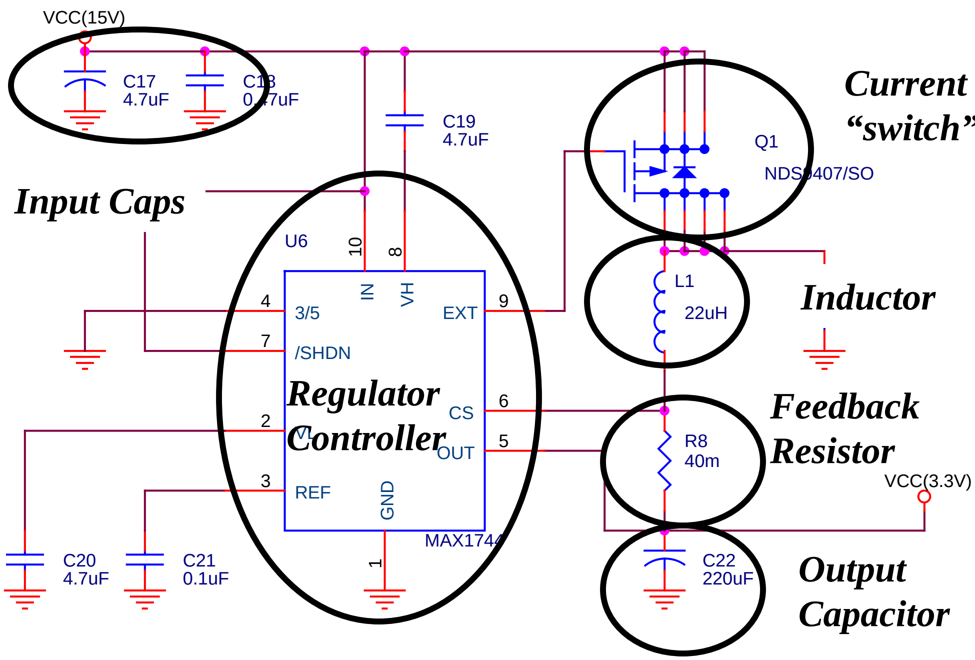
$$P_{reg} = i_{out}\left(v_{in} - v_{out}\right)$$

$$eff = \frac{P_{out}}{P_{reg} + P_{out}} = \frac{i_{out} v_{out}}{i_{out}\left(v_{in} - v_{out}\right) + i_{out} v_{out}} = \frac{v_{out}}{v_{in}}$$

- The effective resistance of the circuit, R_{load}, determines the necessary current
  - The input current must be the same as the output current
- Example:
  - V_{in}=7V, V_{out}=5V, i=100mA
    - P_{reg} = 0.2W, P_{tot} = 0.7W, eff=71% reasonable use, no heatsink
  - V_{in}=7V, V_{out}=5V, i=1A
    - P_{reg}= 2W, P_{tot}= 7W, eff=71% NEED heatsink to dissipate 2W!
  - V_{in}=20V, V_{out} =5V, i=100mA
    - P_{reg}= 1.5W, P_{tot} = 2W, 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, <u>dependent on current pull</u>
  - 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 equal power out, plus the efficiency factor**
  - **For design one *must* know the necessary current supply for V_{in}**

$$v_{in} i_{in} = P_{in} = P_{out} = v_{out} i_{out}$$

$$i_{in} = \frac{v_{out} i_{out}}{v_{in}} \cdot \frac{1}{eff}$$

- **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**