SO FAR:
- Complex Impedance
- Passive & Active Filters
- Spectral (Fourier) Analysis

TODAY:
- Power Supplies
  - Transformers
  - Rectifiers
  - Filtering
  - Linear Regulators

NEXT TIME: START DIGITAL ELECTRONICS!

Today's objective is to start with 120V AC from the wall and end up with a well-regulated DC power source.

It is not unusual in physics experiments for power supply stability to be the limiting factor in a precision measurement.
First, step voltage down.

Transformer — Turn Ratio $N_2:N_1$

$$V_{\text{IN}} \quad N_1 \quad || \quad N_2 \quad R_{\text{LOAD}} (V_{\text{OUT}})$$

$$V_{\text{OUT}} = \frac{N_2}{N_1} V_{\text{IN}}$$

$$i_{\text{OUT}} = \frac{N_1}{N_2} i_{\text{IN}}$$

$$P_{\text{OUT}} = P_{\text{IN}} \, \text{( Ideality)}$$
SECOND, CONVERT FROM AC TO DC.

BRIDGE RECTIFIER

\[ V_{\text{IN}} \]

\[ R_{\text{LOAD}} \] (\( V_{\text{OUT}} \))

DIODE DROP = \( V_t \)

\[ V_{\text{OUT}} \]

\[ V_{\text{OUT}} = H \left[ \frac{1}{4} \left( \frac{N_2}{N_1} V_{\text{IN}} \right) - V_t \right] \]

HEAVISIDE FUNCTION \( H(x) = \begin{cases} 1, & x \geq 0 \\ 0, & x < 0 \end{cases} \)

\[ V_{\text{OUT MAX}} = \frac{N_2}{N_1} V_{\text{IN MAX}} - 2V_t \]
THIRD STEP: SMOOTH OUT THE BUMPS

FILTER CAPACITOR

\[ V_{in} \]

\[ @f \]

\[ \frac{\Delta V}{\Delta t} \]

\[ t \]

WE CALL THIS A BRUTE FORCE POWER SUPPLY. SIMILAR SUPPLIES ARE COMMON FOR MODEL RAILROAD EQUIPMENT AND OTHER APPLICATIONS THAT ARE INSENSITIVE TO NOISE.

RIPPLE VOLTAGE:

\[ q = CV \]

\[ V = iR \]

\[ i = \frac{dq}{dt} = \frac{V}{R} = C \frac{dV}{dt} \]

So \[ \frac{dV}{dt} = \frac{V}{RC} \] (THIS SHOULD LOOK FAMILIAR)

NOW, THE CAPACITOR DISCHARGES FROM \[ V_{out, max} \] FOR A TIME OF \[ \Delta t = T/2 = 1/2f \].

ASSUMING \[ \Delta t \ll RC \],

\[ \Delta V \approx \frac{dV}{dt} \Delta t = \frac{V_{out, max}}{2fRC} \]
LOAD AND LINE REGULATION

LOAD REGULATION:
"CHANGE IN OUTPUT VOLTAGE OR CURRENT FOR ANY LOAD CHANGE WITHIN RATINGS"

LINE REGULATION:
"CHANGE IN OUTPUT VOLTAGE OR CURRENT FOR ANY LINE CHANGE WITHIN RATINGS"

Q: WHAT ARE THE LOAD AND LINE REGULATION CHARACTERISTICS OF THE BFPS?
BFPS LOAD REGULATION:

\[ \Delta V = \frac{V_{\text{out max}}}{2fR_{\text{load}}C} \]

The smaller \( R_{\text{load}} \), the greater the current loading the supply, and the greater the ripple voltage, the mean output voltage is roughly

\[ \overline{V_{\text{out}}} = \left(1 - \frac{1}{4fR_{\text{load}}C}\right)V_{\text{out max}}. \]

BFPS LINE REGULATION:

\[ V_{\text{out max}} = \frac{N_2}{N_1} V_{\text{in max}} - V_t \]

\[ \Delta V_{\text{out}} = \frac{N_2}{N_1} \Delta V_{\text{in}} \]

So, the BFPS has essentially no line regulation. The output voltage is essentially proportional to line voltage.
SIMPLIFIED LINEAR REGULATOR

HOW IT WORKS:

- ZENER DIODE PROVIDES A VOLTAGE REFERENCE.
- OP AMP STABILIZES OUTPUT VOLTAGE AT 
  \[
  \left[\frac{(R_1+R_2)}{R_2}\right] V_{REF}.
  \]
- PASS TRANSISTOR CAN SOURCE LOTS OF CURRENT, SO IT
  ACTS AS A LINE DRIVER FOR THE OP AMP.
- FILTER CAPACITOR SMOOTH OUT REMAINING RIPPLE.

ISSUES:

- INRUSH AT TURN-ON TIME CAN DAMAGE PASS TRANSISTOR.
- VARYING CURRENT THROUGH ZENER CAUSES SMALL FLUCTUATIONS
  OF REFERENCE VOLTAGE.

*I.E.: WHILE CAPACITOR IS CHARGING INITIALLY.*
CURRENT LIMITING
(PROTECTS THE PASS TRANSISTOR)

- $R_{CL}$ is a small value, chosen so that $V = iR_{CL} = 0.7V$ for some maximum desired current. When this threshold is exceeded, the lower transistor turns on and reduces the base current to the pass transistor.

(CRIBBED FROM THE LM723 DATA SHEET)
**Precision Voltage Reference**

- This is intended to improve **line regulation**.
- The 723 regulator uses an amplifier and a current source to accomplish the same thing.