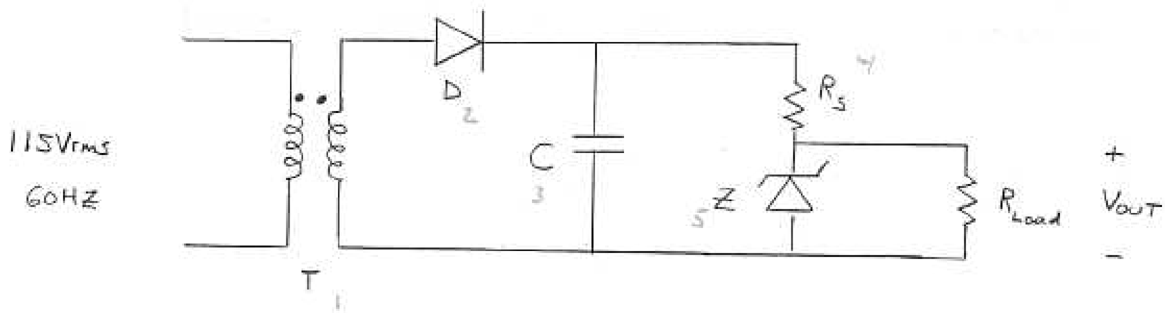
POWER SUPPLY DESIGN

(*) We can at best "tease" the topic -- especially since the zener regulator would most likely be replaced by either

1. Linear IC voltage regulator
2. Switchmode voltage regulator

(*) In our most basic topology



we have 5 components to specify. If we assume that our INPUT is wall-outlet power (115Vrms at 60Hz), then the starting point is what we want

DESIRED OUTPUT : $V_{OUT,min} < V_{OUT} < V_{OUT,max}$

For $R_{Load,min} < R_{Load} < R_{Load,max}$

with the load voltage variation being as small as possible

MAIN COMPONENT SPECIFICATIONS

1. Transformer
   - Rated Primary Voltage
   - Rated Secondary Voltage
   - Rated Secondary Current (or apparent power)

2. Rectifier Diode
   - Blocking voltage (Peak Inverse Voltage)
   - Average current

3. Capacitor (Electrolytic) ↑ big values
   - Rated working voltage
   - Value
   - Rated Ripple current

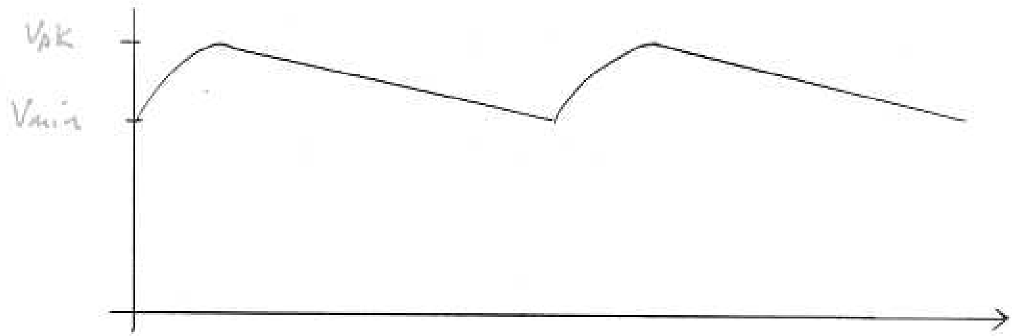
4. Resistor
   - Value
   - Power

5. Zener Diode
   - Zener voltage
   - Power

(*) Let's assume that our goal is to create a 6.1 V reference voltage where the attached load is anticipated to vary between $250\,\Omega < R_{Load} < \infty$. The starting point is choosing the transformer

Step 1: Choosing the transformer secondary voltage

(*) Recall, the filtered half-wave rectifier voltage will appear as follows



where

$$V_{pk} \approx \left(V_{sec,pk,NL} - 0.7\ V\right) \frac{R_{Load}}{R_{Load} + R_{TRAN}}$$

1 diode drop

transformer output resistance

With the zener regulator in the circuit, we no longer simply have an R_{Load} value to use here. Further, we generally don't know R_{TRAN} a priori, so let's ballpark this ratio as 0.96

(*) The transformer secondary voltages are given in RMS and are no-load values

(*) We know that we need $V_{min} > 6.1\ V$ and $V_{pK} > V_{min}$ with the difference related to the amount of capacitance

$(12 \times \sqrt{2} - 0.7)(.96)$

Transformer

Rated Voltage (Secondary)	Rated Current (secondary)	(Digikey) Cost	V_{pk}
12V	250mA	\$3.60	15.62
11V	270mA	\$3.60	14.26
10V	250mA	\$11.44	12.90
9V	330mA	\$3.60	11.55
8V	300mA	\$10.27	10.19
7V	230mA	\$2.98	8.83

(*) Let's choose the 115V / 10 V transformer as our first design swipe

Step 2: Specify the zener diode

(*) We find a 6.1V zener diode rated for 0.5 W

Thus

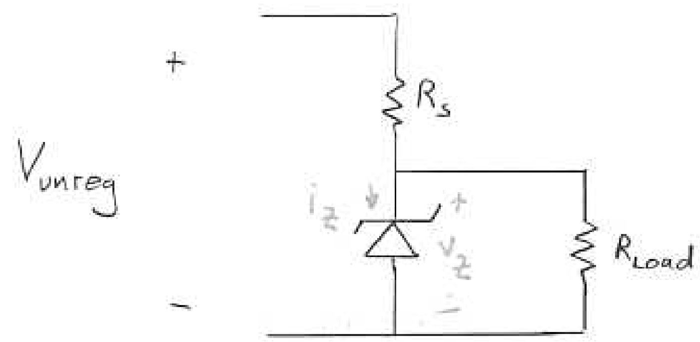
$$i_{z,max} = \underset{\text{safety}}{0.8}\,\frac{P_z}{V_z} = 0.8\,\frac{0.5}{6.1} = 65.5\,mA$$

$$i_{z,min} \approx \frac{i_{zmax}}{50} = \frac{65.5\,mA}{50} = 1.31\,mA$$

Step 3: Specify R_s

(*) Recall from last time that

$$i_{z,max} = \frac{(V_{unreg,max} - V_Z)}{R_S} - \frac{V_Z}{R_{Load,max}}$$



so

$$i_{z,max} = 65.5 \text{ mA} = \frac{12.9 - 6.1V}{R_S} - \frac{6.1V}{\infty}$$

solving for $R_s = 103.8\Omega$

This is not a standard value so we might choose $R_s = 120\Omega$

(*) To get the max power $P_{RS,max} = \frac{(V_{unreg,max} - V_Z)^2}{R_S}$

which in our case gives 0.385 W and so we would choose at least a 0.5 W resistor

(*) We can now calculate the minimum capacitor voltage to ensure that the zener diode stays in breakdown

Recall

$$i_{Z,min} = \frac{V_{unreg,min} - V_Z}{R_S} - \frac{V_Z}{R_{Load,min}}$$

Substituting gives

$$1.31 \text{ mA} = \frac{V_{unreg,min} - 6.1V}{120} - \frac{6.1V}{250}$$

which yields $V_{unreg,min} = 9.1852$ (> 6.1V ok)

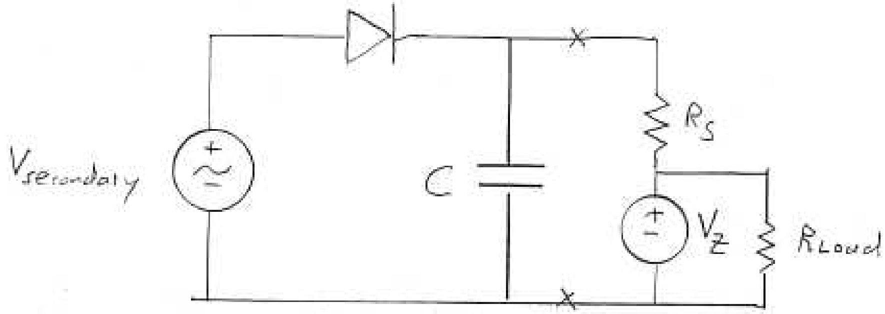
(*) Therefore

$$9.1852V < V_c < 12.9 \quad V$$

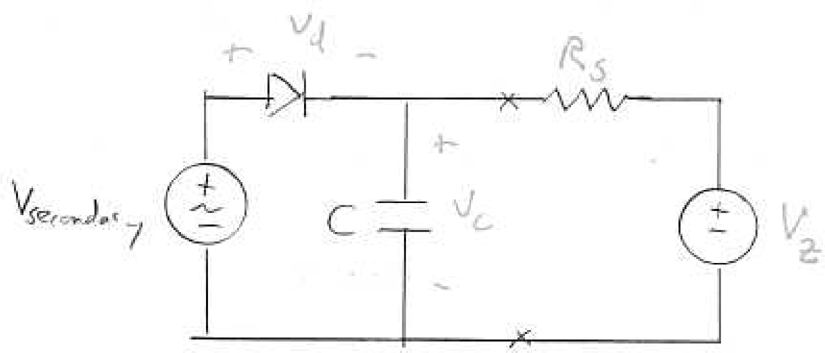
and so our capacitor must achieve a peak-to-peak ripple of no more than 3.71 V, so let's be conservative and choose $\Delta V = 3V$

Step 4 : Establish the capacitance

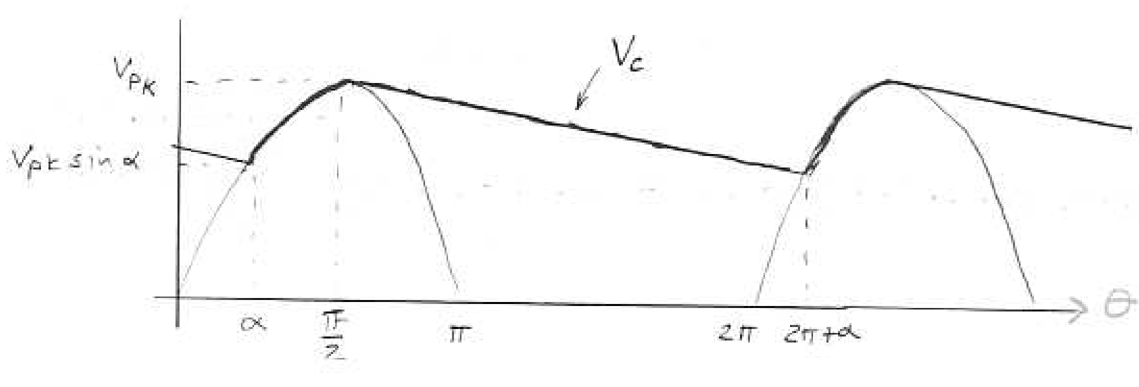
(*) When the zener is in breakdown, the circuit can be modeled as



The Thevenin Circuit "seen" to the right of the capacitor is

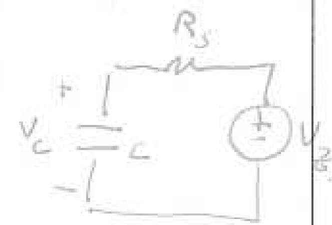


(*) To simplify our life, consider that the diode conducts until $\theta = \pi/2$



(*) The diode remains OFF until

$$V_d = V_{secondary} - V_C > 0$$



where

$$V_C = V_F + (V_I - V_F)\, e^{-\frac{(\theta - \pi/2)}{\omega \tau}}$$

in which

$$V_I = V_{pk} \sin\tfrac{\pi}{2} = V_{pk} \qquad V_F = V_z \qquad \tau = R_s C$$

so

$$V_{pk} \sin(2\pi + \alpha) - V_z - (V_{pk} - V_z)\, e^{-\frac{(2\pi + \alpha - \pi/2)}{\omega R_s C}} = 0$$

once we know α, it follows (Figure pg 35-7)

$$\Delta V = V_{pk} - V_{pk} \sin\alpha$$

(*) so let's work this problem in reverse.
Assume we want $\Delta V = 3V$, thus

$$\sin\alpha = \frac{12.9 - 3}{12.9} \rightarrow \alpha = 0.8748 \text{ rad}$$

substituting into the equation above gives

$$12.9 \sin(.8748) - 6.1 - (12.9 - 6.1)\, e^{-\frac{(1.5\pi + .8748)}{377\,(120)\,C}} = 0$$

which has an analytical solution of

$$C = 212\mu F$$

(*) This is not a standard value so choose

$$C = 220\mu F$$

Step 5: Housekeeping

a. We must also specify the rated capacitor voltage. A good rule of thumb is that it should be at least 20% higher than $V_{unreg,max}$

so $$V_{CRAT} > 1.2 \times 12.9V = 15.48V$$

too close

standard capacitor ratings are 16V, 25V, 63V, 100V

	220 μF
25V	\$0.3 per
63V	\$0.64 per
100V	\$1.74 per

b. Rectifier Diode

(*) When the diode is OFF the max voltage it "sees" is

$$V_{d,max} \approx -V_{pk} - V_{unreg,max}$$

in our case

$$V_{d,max} \approx -12.9V - 12.9V = -25.8V$$

The rated voltage should be 20 % higher or 31 V. A standard voltage value is 50V

(*) The capacitor carries zero average current in the steady state so

$$i_{D,ave} = i_{Rs,ave}$$

where

$$i_{Rs,ave} \approx \frac{\frac{(V_{unreg\,max} + V_{unreg,min})}{2} - V_Z}{R_S}$$

$$i_{Rs,ave} \approx \frac{(12.9V + 9.19V)/2 - 6.1V}{120} = 41.2mA$$

a standard rated diode current is 1A

c. Transformer secondary current

(*) This rms value should be about twice the average diode current. In our case, ~ 83mA Anything higher (which our transformer is) is fine!

Final Comments

(*) An actual power supply will need

- Fuse protection
- input cord
- output terminals
- enclosure
- mounting board

but this gets us in the game! A "better" design would incorporate a linear voltage regulator. If we need high efficiency, we go to a switchmode regulator.