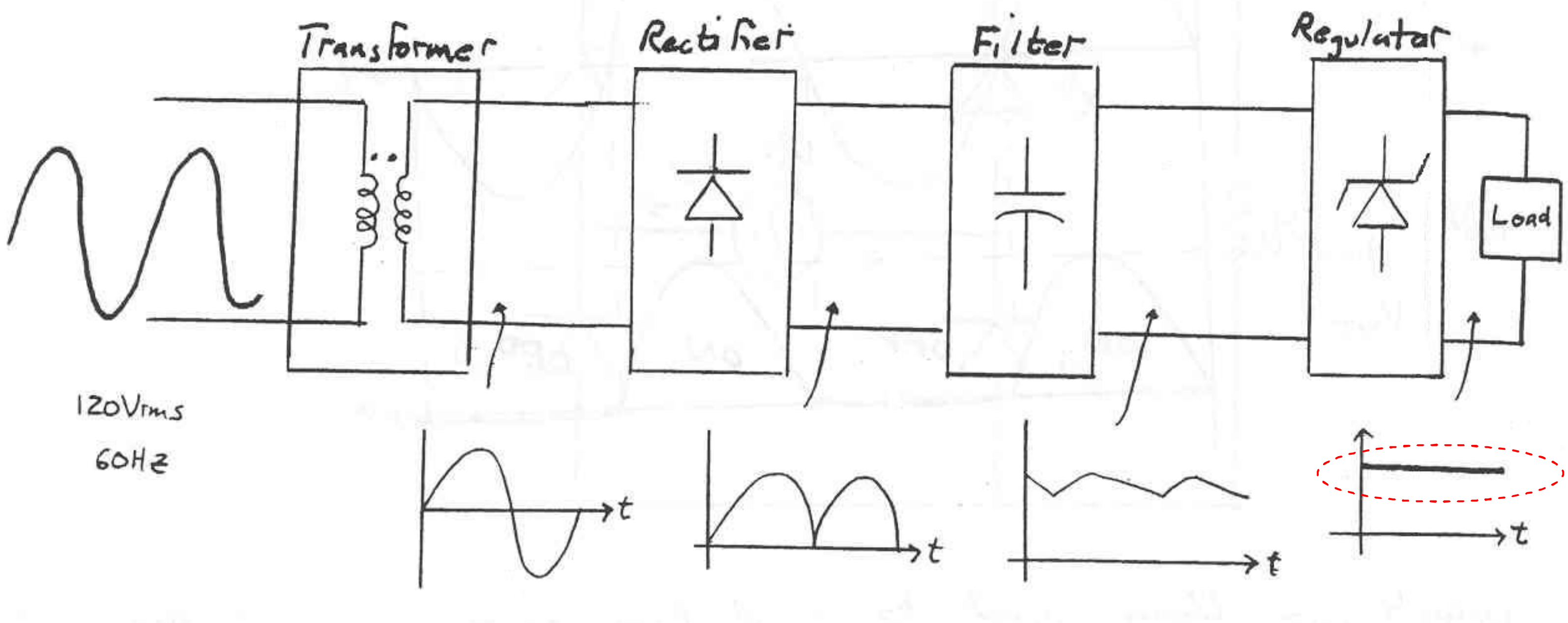
Lesson 36:
Power supply design

Overview

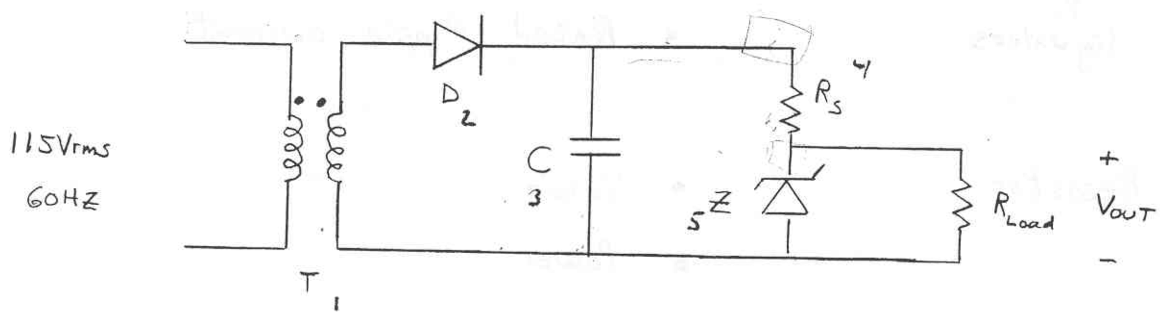
- Now that we have analyzed all the elements, we are ready to design a simple power supply.



power supply block diagram

Topology

- The power supply consists of 5 components.

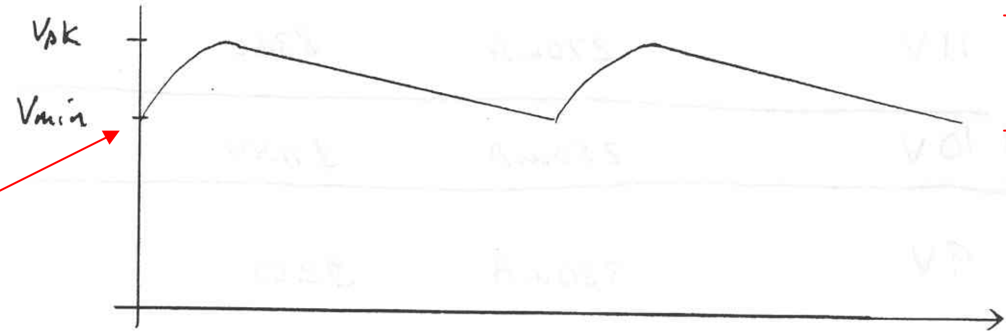


power supply components

- Desired output
  - $V_{\text{out,min}} < V_{\text{out}} < V_{\text{out,max}}$ for $R_{\text{load,min}} < R_{\text{load}} < R_{\text{load,max}}$
  - For our example, the goal is to create a 6.1 V reference voltage with a load in the range $250\ \Omega < R_{\text{load}} < \infty$

Step 1: Choose a transformer

- Recall the output of a filtered half wave rectifier



$V_{min} > 6.1\ \text{V}$

ΔV related to capacitance

where

$$v_{pk} \approx \left(v_{sec,pk,NL} - 0.7\right)\frac{R_{load}}{R_{load} + R_{tran}}$$

approximated as 0.96

transformer secondary voltages are specified in RMS

Step 1: Choose a transformer

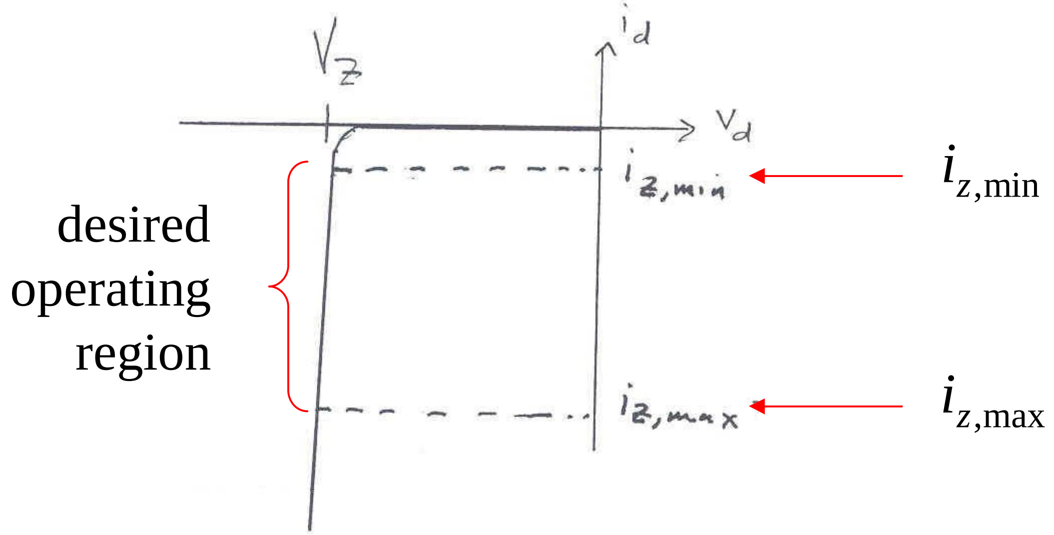
- Transformer choices from Digikey

Rated voltage (sec,rms)	Rated current (sec)	Cost	V_{pk}
12 V	250 mA	$3.60	15.62
11 V	270 mA	$3.60	14.26
10 V	250 mA	$11.44	12.90
9 V	330 mA	$3.60	11.55
8 V	300 mA	$10.27	10.19
7 V	230 mA	2.98	8.83

$$v_{pk} = \left(\sqrt{2} \times v_{sec,rms} - 0.7\right)(0.96)$$

Step 2: Specify the Zener diode

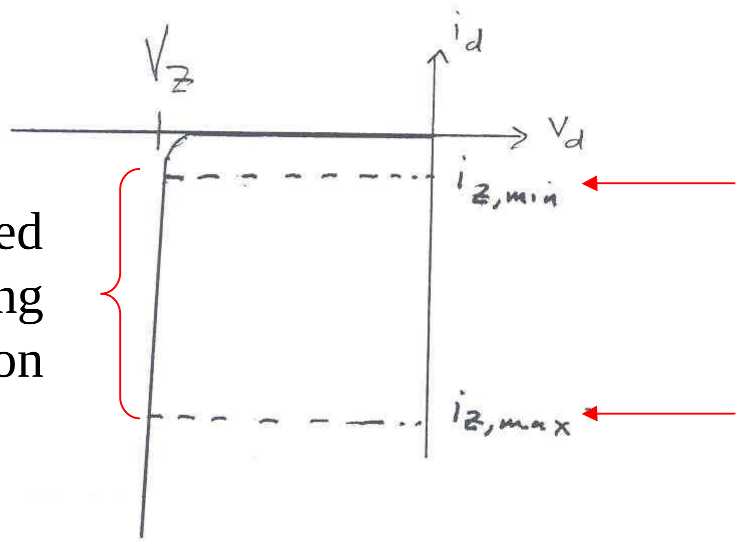
- We will use a 6.1 V zener diode rated for 0.5 W.
- How do we determine $i_{z,max}$ and $i_{z,min}$?



Step 2: Specify the Zener diode

- We will use a 6.1 V zener diode rated for 0.5 W.
- How do we determine $i_{z,\max}$ and $i_{z,\min}$?

desired
operating
region



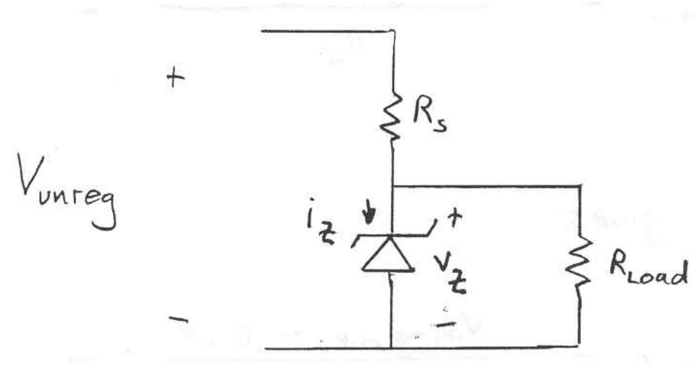
$$i_{z,\min} = \frac{i_{z,\max}}{50} = \frac{65.6}{50} = 1.31 \text{ mA}$$

$$i_{z,\max} = 0.8\frac{P_z}{V_z} = 0.8\frac{0.5}{6.1} = 65.6 \text{ mA}$$

Step 3: Specify R_s

- Recall that

$$i_{z,\max} = \frac{V_{\text{unreg,max}} - V_z}{R_s} - \frac{V_z}{R_{\text{load,max}}}$$



therefore $i_{z,\max} = 65.6 = \frac{12.9 - 6.1}{R_s} - \frac{6.1}{\infty}$

solving for $R_s = 103.9\ \Omega$

- Because $103.8\ \Omega$ isn't a standard value, we choose $R_s = 120\ \Omega$
  - Why choose the next larger value?

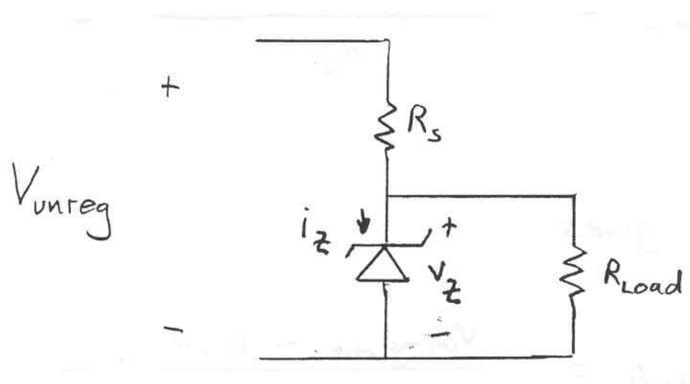
Step 3: Specify R_s

- We can now determine the minimum voltage to ensure the diode remains in breakdown.

$$i_{z,\min} = \frac{V_{\text{unreg,min}} - V_z}{R_s} - \frac{V_z}{R_{\text{load,min}}}$$

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

which yields $V_{\text{unreg,min}} = 9.185\text{ V}$

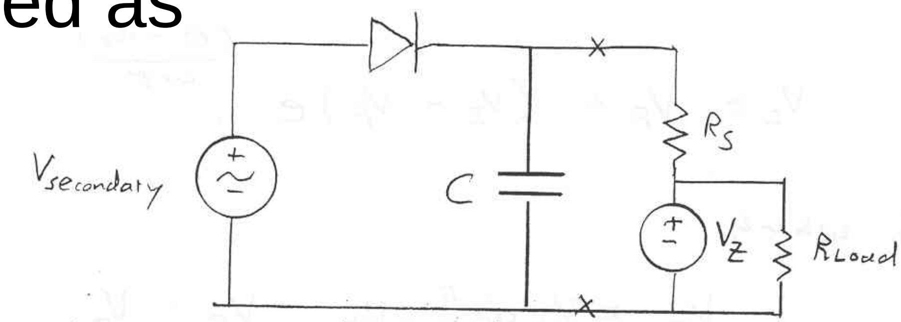


- Therefore, $9.185 < V_{\text{unreg,min}} < 12.9\text{ V}$

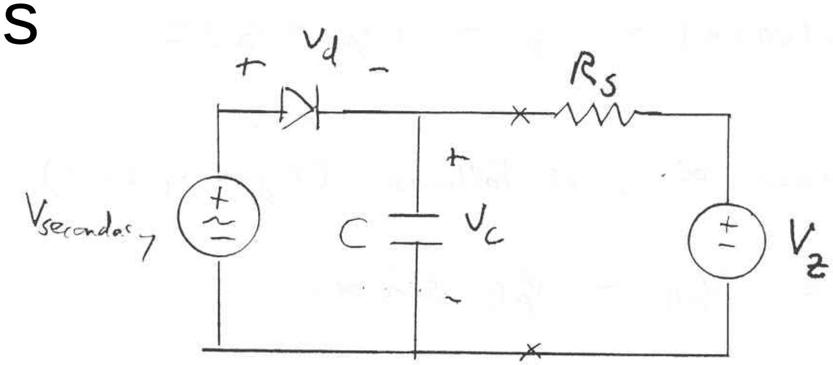
  so our capacitor voltage must achieve a peak-to-peak ripple of < 3.71 V, so we'll choose ΔV = 3 V

Step 4: Establish the capacitance

- When the zener is in breakdown, the circuit can be modeled as

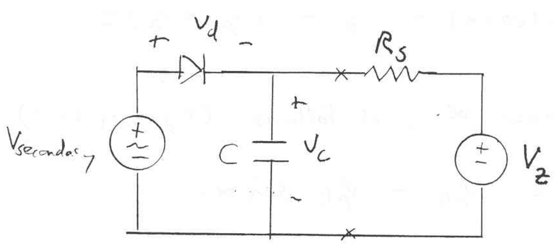


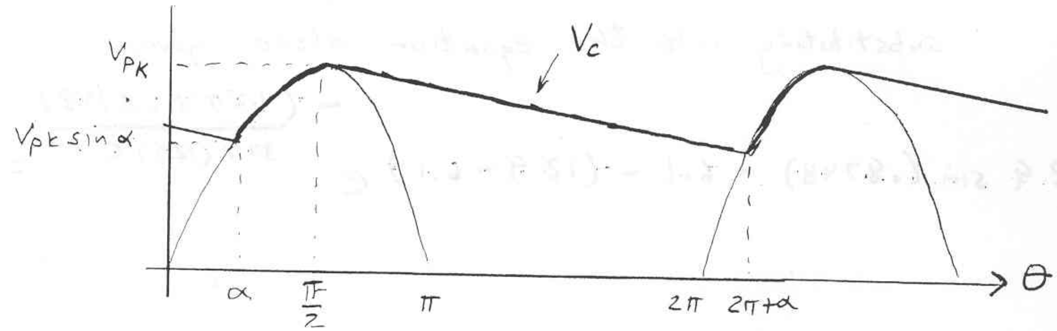
- The Thévenin circuit seen to the right of the capacitor is



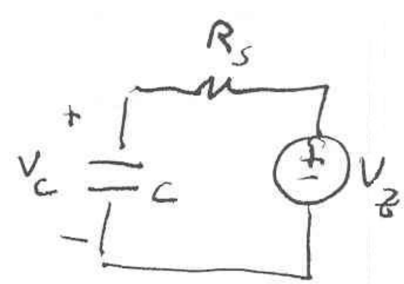
Step 4: Establish the capacitance

- To simplify, consider we'll assume that the diode conducts until $\theta = \pi/2$.





- The diode remains off until $v_d = v_{\text{secondary}} - v_c > 0$
- How do we express the capacitor voltage v_c ?

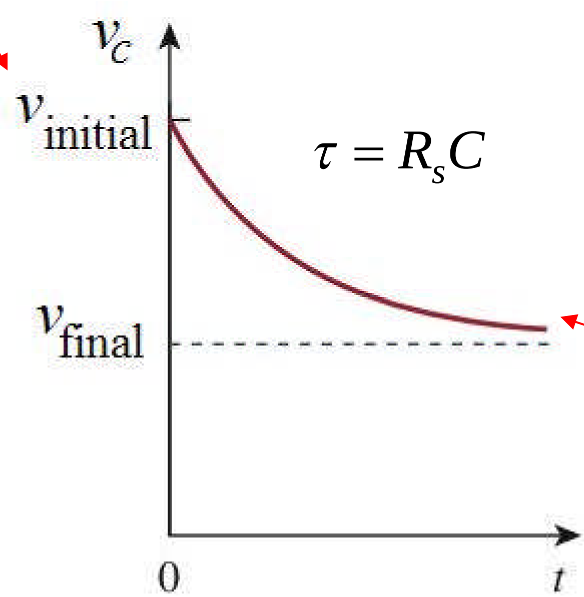


Step 4: Establish the capacitance

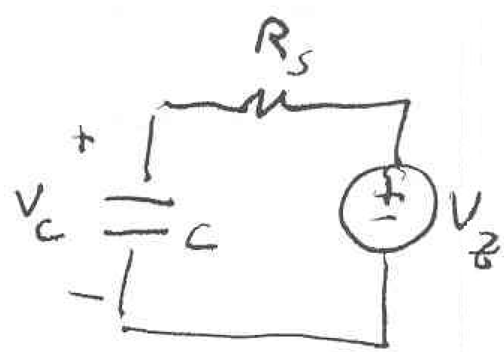
- Recall for a capacitor, voltage is given

$$v_c = v_{\text{final}} - (v_{\text{initial}} - v_{\text{final}})e^{\frac{-(\theta - \pi/2)}{\omega\tau}}$$

$$v_{\text{initial}} = v_{\text{pk}} \sin\frac{\pi}{2} = v_{\text{pk}}$$



$$\tau = R_s C$$



$$v_{\text{final}} = v_z$$

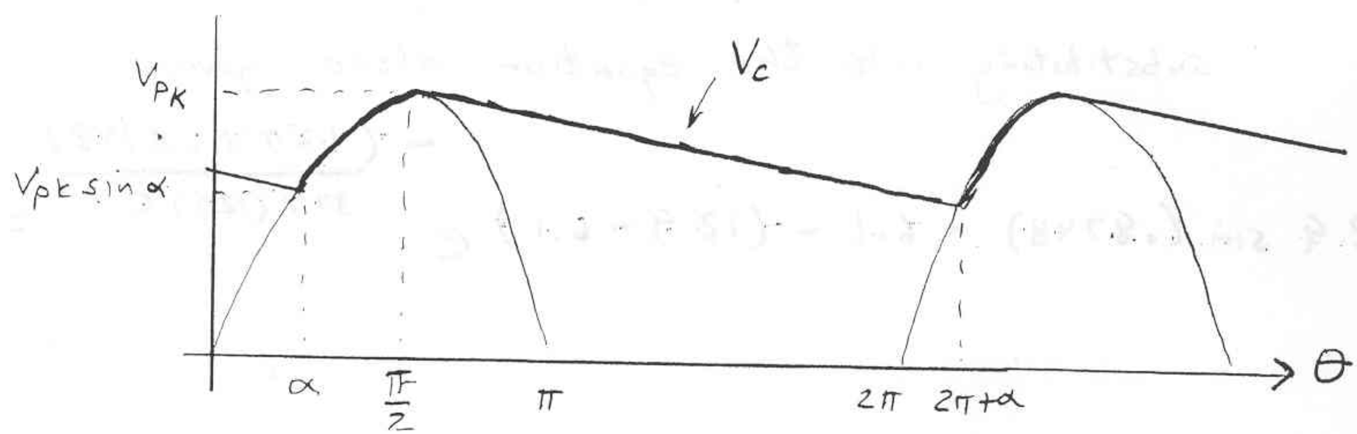
Step 4: Establish the capacitance

- With an expression for v_c we now have to solve

$$v_{\text{secondary}} - v_c = 0$$

$$v_{\text{pk}} \sin(2\pi + \alpha) - v_{\text{z}} - (v_{\text{pk}} - v_{\text{z}}) e^{-\left(\frac{2\pi + \alpha - \pi/2}{\omega R_s C}\right)} = 0$$

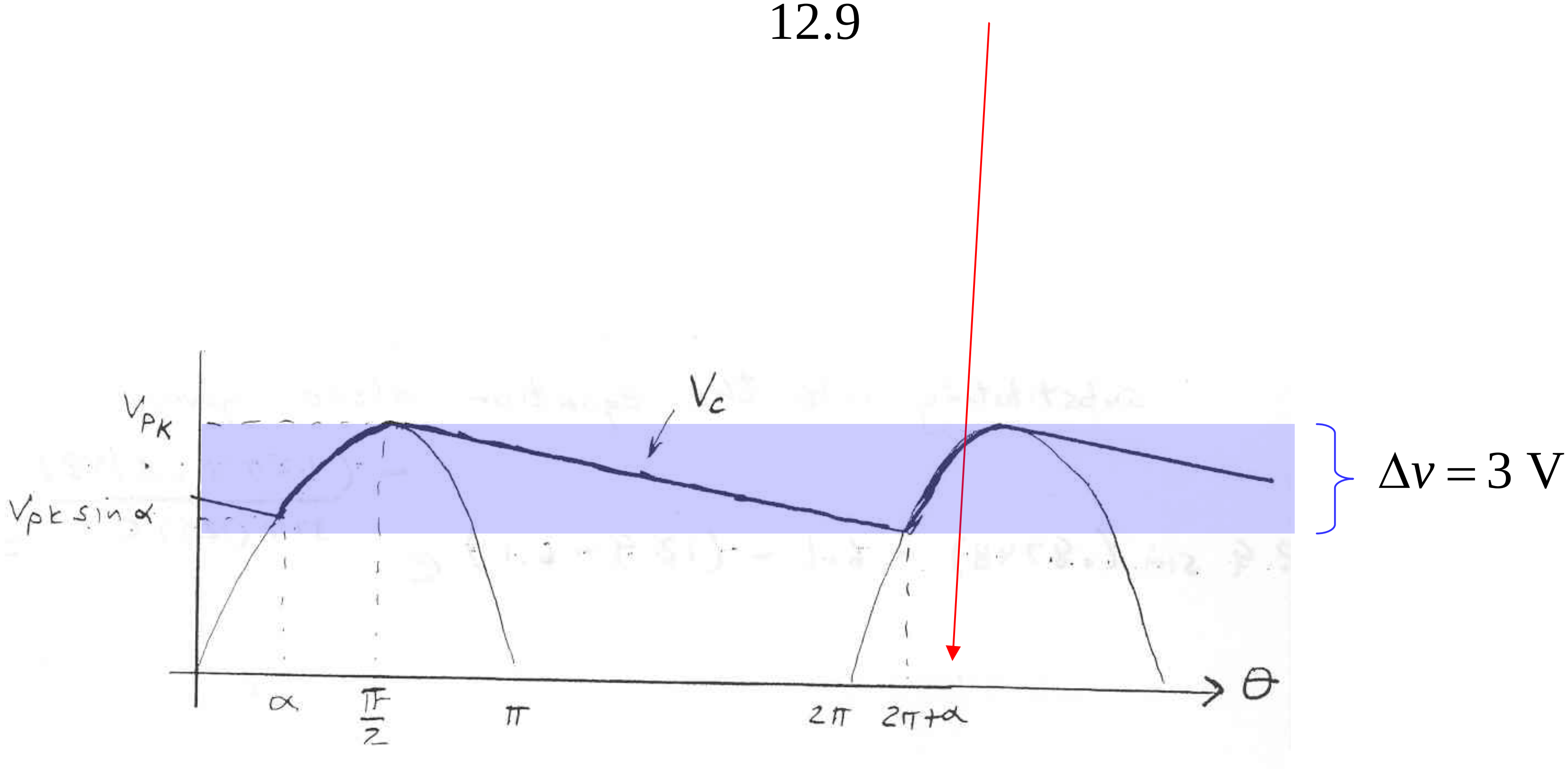
which is a function of α and C.



Step 4: Establish the capacitance

- Recall that $\Delta v_{\text{out}} = v_{\text{pk}} - v_{\text{pk}} \sin\alpha$ and we set $\Delta v = 3\ \text{V}$

  so we know that $\sin\alpha = \dfrac{12.9 - 3}{12.9} \rightarrow \alpha = 0.8748\ \text{rad}$



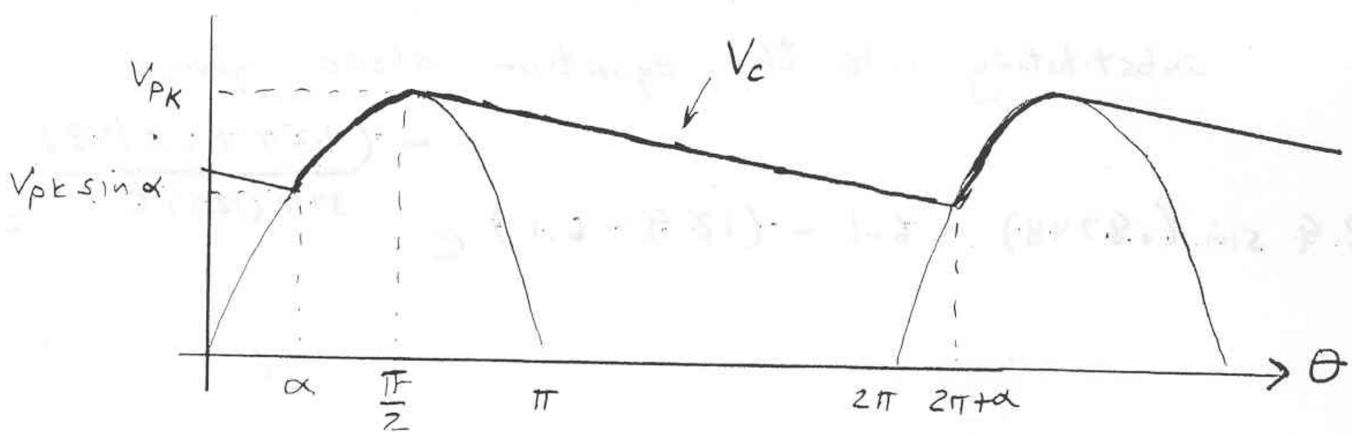
Step 4: Establish the capacitance

- Now we can solve

$$v_{\text{pk}}\sin(2\pi+\alpha)-v_{\text{z}}-(v_{\text{pk}}-v_{\text{z}})e^{-\left(\frac{2\pi+\alpha-\pi/2}{\omega R_s C}\right)}=0$$

$$12.9\sin(0.8748)-6.1-(12.9-6.1)e^{\frac{-(2\pi+0.8748-\pi/2)}{377(120)C}}=0$$

- What is C ?

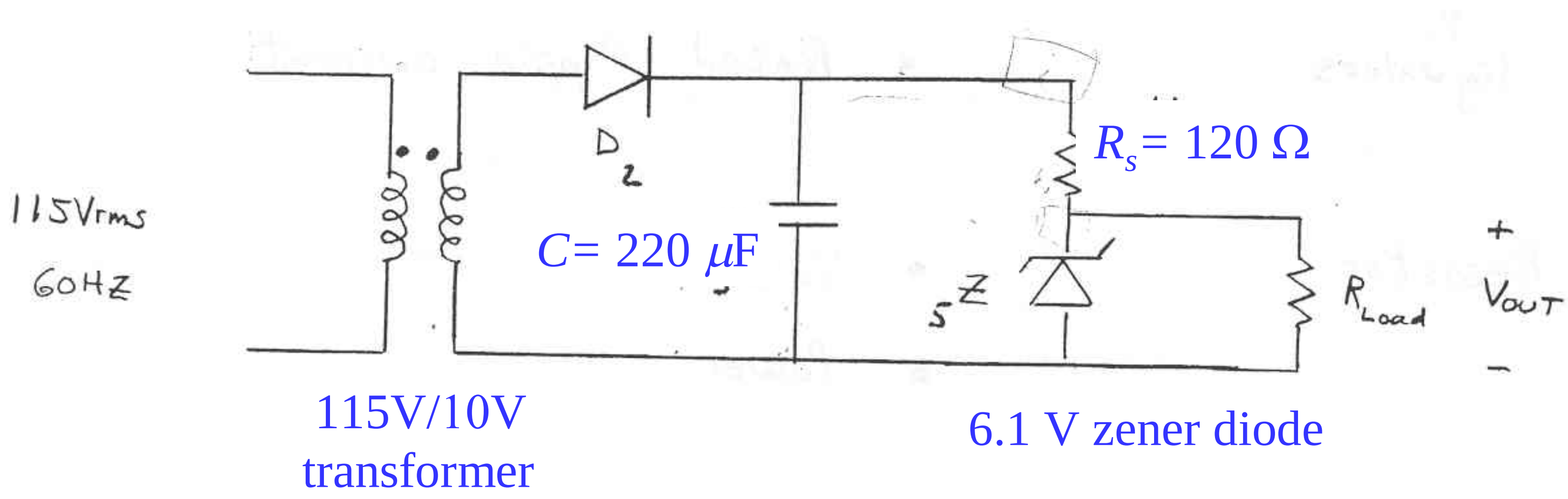


Step 4: Establish the capacitance

- We find that $C = 212\ \mu\mathrm{F}$, so we choose the next larger standard value $220\ \mu\mathrm{F}$.

Final circuit

- Thus, our 6.1 V_{dc} power supply handling $250\ \Omega < R_{load} < \infty$ is given



power supply components