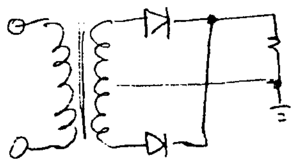
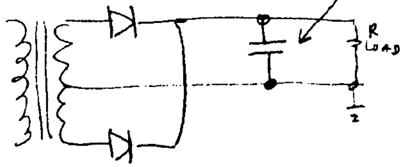
Power supply filters (2.1.3)

Recall ---
A rectifier puts out something like this:

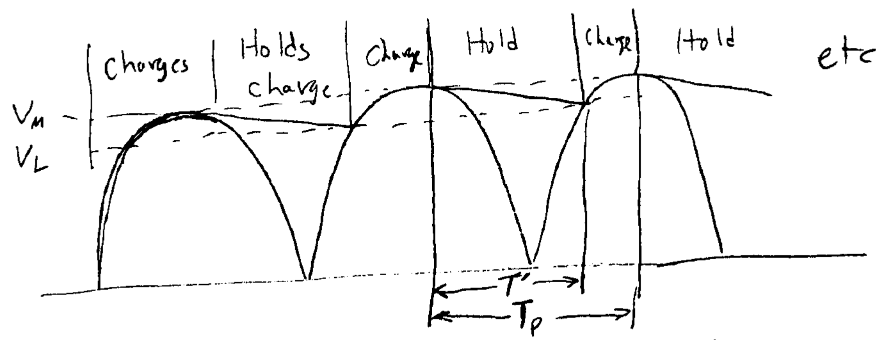


We want DC, without ripple.

Idea: Add a capacitor



It charges when the diode is on, then holds the charge.



etc.

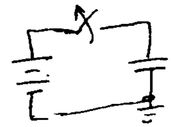
The capacitor holds the voltage to nearly the peak voltage.

The diode is only on for a short period at the peak (marked "charge" here).
The output has a small (?) ripple.

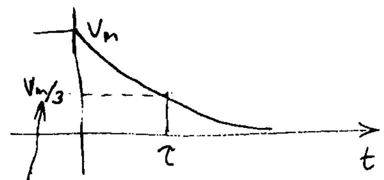
Recall --- The formula for a capacitor voltage decaying --

$$V_0(t) = V_M e^{\frac{-t}{\tau}}$$

t = time s/n
τ = time constant = RC



(It is like the input dropping so the diode turns off)



approximately
(Actually -- $.368 V_M$
$.368 = e^{-1} \approx \frac{1}{3}$)

For power supply filters, we can only tolerate a little ripple, so τ is much longer than the ripple period. (T_P)
(time between peaks)

The smallest output voltage is when the diode turns back on -- after time T'

$$V_L = V_M e^{\frac{-T'}{\tau}}$$

Ripple voltage is the difference ..

$$V_r = V_M - V_L = V_M \left(1 - e^{-\frac{T'}{\tau}}\right)$$

Replace (3A 3)

Simpler analysis ---

We need to supply a current (I).

We can tolerate some ripple (V_R).

Recall .... $I = C \frac{dv}{dt}$ $\quad Q = CV$

Basic capacitor equations ..

$$I = \frac{dQ}{dt}$$ ← definition of current

For half wave -- $dt = \frac{1}{f}$

full wave -- $dt = \frac{1}{2f}$

So $I = C \frac{dv}{dt}$

- I ← DC Load current
- C ← Capacitor needed
- dv ← Ripple voltage — peak-to-peak
- dt ← Time between peaks.

⇘ $I = C\, V_R\, f$ (where $f = \frac{1}{dt}$)

Rearrange:

$$C = \frac{I}{V_R f}$$

Replace (3A 4)

Example

A power supply must deliver 100 volts at 100 mA with less than 10 volts (peak to peak) ripple. What is C?

Power frequency = 60 Hz

Solution: (half wave)

$$C = \frac{I}{V_R f} = \frac{.1\,A}{(10\text{ volts})(60\text{ Hz})} = 166.7 \times 10^{-6}\text{ Farads}$$

$$= 166.7\ \mu f$$

Full wave -- $f = \underline{120\text{ Hz}}$

$$C = \frac{I}{V_R f} = \frac{.1}{(10)(120)} = 83.3\ \mu f$$

3A-5

Variants of the formula..

$$C = \frac{V_m}{V_r} \frac{T_p}{R}$$

with current... $V_m = IR$

$$C = \frac{IR}{V_r} \frac{T_p}{R} = \frac{I T_p}{V_r}$$ ← Usually, this is the easiest form to use

or $$C = \frac{I}{V_r f}$$

Half wave: $$C = \frac{.1}{(10)(60)} = 167 \mu f$$

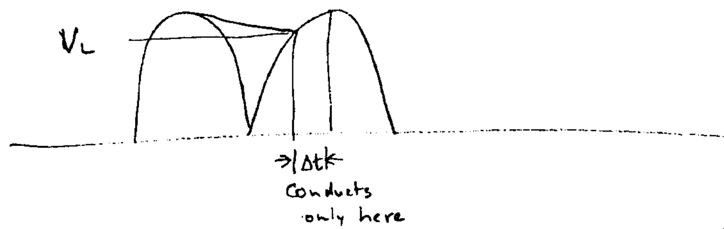
Full wave: $$C = \frac{.1}{(10)(120)} = 83.3 \mu f$$

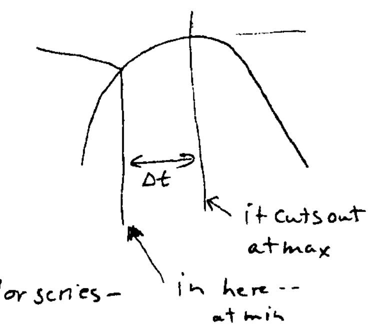
3A-6

Diode current and Capacitor current

Diode current flows only in a small part of the cycle, yet load current flows continuously. It comes from the capacitor.

Peak current is much higher than average current.





To calculate Δt ....

$$V_L = V_M \cos(\omega \Delta t)$$

Taking the first 2 terms of the taylor series -

$$\cos(x) \approx 1 - \frac{1}{2} x^2$$

$$V_L = V_M \left(1 - \frac{1}{2}(\omega \Delta t)^2\right)$$

$$V_M - V_r = V_M \left(1 - \frac{1}{2}(\omega \Delta t)^2\right)$$

$$V_M - V_r = V_M - \frac{V_M}{2}(\omega \Delta t)^2$$

$$V_r = \frac{V_M}{2}(\omega \Delta t)^2$$

$$\frac{2V_r}{V_M} = (\omega \Delta t)^2$$

→ $$\omega \Delta t = \sqrt{\frac{2V_r}{V_M}}$$

example: $\sqrt{\frac{2(10)}{100}} = .44$ rad $= 25$ deg.

$$\Delta t = \frac{\sqrt{\frac{2V_r}{V_M}}}{\omega}$$

Example:

$$\Delta t = \frac{\sqrt{\frac{2(10)}{100}}}{2\pi 60} = 1.18 \times 10^{-3}$$

(3A 7)

Charge lost by capacitor to load:

$Q = CV_r$ also $Q = I\,T_p$ $\left(q = \frac{di}{dt}\right)$

This charge must be restored when the diode is on..

$Q = i_{cap.}\,\Delta t$

$i_{cap.}$: avg. current during charge. Δt: charge time

Example:

$Q = (167\,\mu F)(10)$

$= 1.67 \times 10^{-3}$ coul.

$i_{cap} = \frac{Q}{\Delta t}$

Example:

$i_{cap} = \frac{1.67 \times 10^{-3}}{1.18 \times 10^{-3}}$

$= 1.415$ Amp.

Diode current = cap current + load current

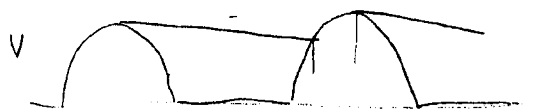
$i_{Diode} = i_{cap} + i_{LOAD}$

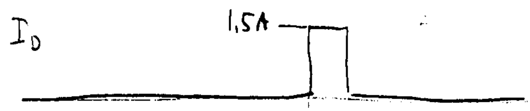
$i_D = 1.415 + .1$

$= 1.515$

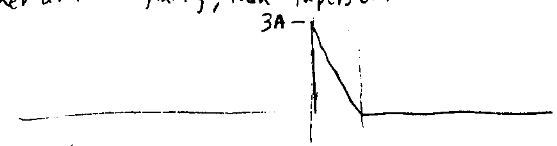
But that assumes it is uniform:

It isn't.





Actual is higher at the beginning, then tapers off.



It is roughly triangular,

so the peak is about twice the average.

(3A for this example.)

(3A 8)

Exercises!

(Not to hand in)

p	#
61	1
62-63	2,3,4,5
87	4,8,11

To hand in:

P. 95 D 2.53

It doesn't come out exact.

Get as close as you can.

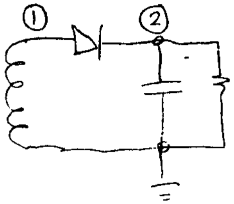
Assume $V_D = .7$

What is peak diode current?

Peak inverse diode voltage?

Reverse voltage across diodes — with filter

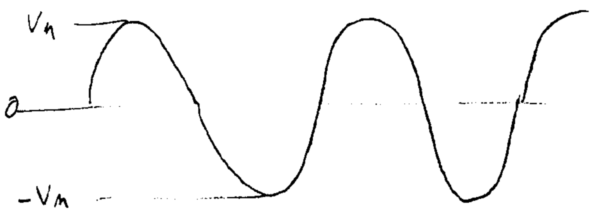
Here's a circuit



Recall ...

The output voltage is: (node ②)

The voltage at node ① is:



The voltage across the diode is: (V② − V①)

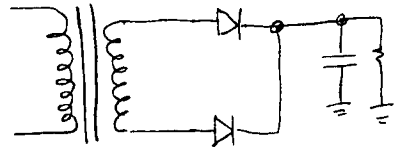
The peak voltage across the diode is twice the max delivered voltage. → $\approx -2V_M$

Twice what it was with no capacitor.

What about full wave? ______

bridge? ______

Designing a power supply



① Pick a topology

② Determine V_M, V_L from specs.

③ Take V_M. Add voltage lost in diodes.

④ Add transformer loss. (like a resistance)

→ This is peak secondary voltage

⑤ Convert to RMS if needed. (depends on specs)

⑥ Calculate turns ratio $\frac{V_{sec}}{V_{pri}}$ or $\frac{V_{pri}}{V_{sec}}$

Express as $n:1$ (step down) or $1:n$ (step up)

⑦ Determine capacitor value

⑧ Determine voltage, power, current ratings of components.

3B
3

Example

You are designing a power supply for the high voltage on a cathode ray tube.

Your power source is 7 volts AC (10 volts peak)
20 KHz

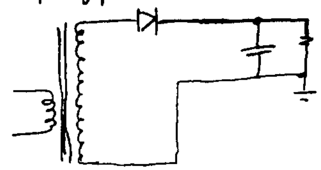
The supply must deliver 20-25 KV.
(25 KV max, 20 KV min, 5 KV max ripple)
with a load current of 1 ma.

Assume a 10 volt drop in the diode.
(It is really 16 diodes in series.)

Choose a topology.

Then find:
- Turns ratio (pri : sec)
- Capacitor
- Voltage rating of diode
- Peak diode current
- Average primary current
- Power delivered to load

Topology: half wave.



Power delivered to load:

$(25 KV)(1 ma)$

$= 25$ watts

Average primary current

$(1 ma)(2500) = 2.5 A.$

Peak diode current:

$Q = CV = (10^{-11})(5 \times 10^3)$

$= 50 \times 10^{-9}$

$= I T_p = (10^{-3})(50 \times 10^{-6})$

$= 50 \times 10^{-9}$

$$\Delta t = \frac{\sqrt{\frac{2V_r}{V_M}}}{\omega} = \frac{\sqrt{\frac{(2)(5)}{25}}}{2\pi(20K)}$$

$$= \frac{\sqrt{\frac{10}{25}}}{126 \times 10^3} = \frac{.632}{126 \times 10^3}$$

$= 5 \times 10^{-6} = 5 \mu S$

$$i_{cap} = \frac{Q}{\Delta t} = \frac{50 \times 10^{-9}}{5 \times 10^{-6}} =$$

$= 10$ ma (avg when on)

$i_{cap\ peak} \approx 20$ ma.

3B
4

Ignore 10 volt diode loss.

$V_M = 25$ KV
$V_L = 20$ KV
$V_r = 5$ KV.

Ignore transformer resistance

Turns ratio $= \frac{25000}{10} = 2500$

1 : 2500

Capacitor:

$$C = \frac{I}{V_r f}$$

$$= \frac{1 \times 10^{-3}}{(5 \times 10^3)(2 \times 10^4)}$$

$= 10 \times 10^{-12}$

$= 10$ pf

Voltage rating of diode:
50 KV.
(10 5 KV diodes)