4.4 a) 50 Hz $\longrightarrow$ T (period) = 20 ms

Two "blips" per period $\longrightarrow$ full wave rectification

b) Peak diode current = 10 A = $C v_{max}\, \omega \sin\phi$

$$\phi = \underset{0.5\,ms}{\omega\delta} = \underbrace{2\pi \times 50}_{rad/s} \times 5 \times 10^{-4} = 0.157 \text{ rad}$$

$$= 9^\circ$$

$$v_{max} = \frac{10}{10 \times 10^{-3} \times 2\pi \times 50 \times 0.156} = 20.4\ V$$

But $\dfrac{v_{ripple}}{v_{max}} = 1 - \cos\phi = 0.123$

$\hookrightarrow$ $v_{ripple} = 0.25\ V$

c) maximum load current $= \dfrac{v_{max}}{R} = i_{Lm}$

But $\dfrac{v_{ripple}}{v_{max}} = \dfrac{T}{2RC}$

$\hookrightarrow$ $$R = \frac{1}{50 \times 2 \times 10^{-2} \times 0.123}$$

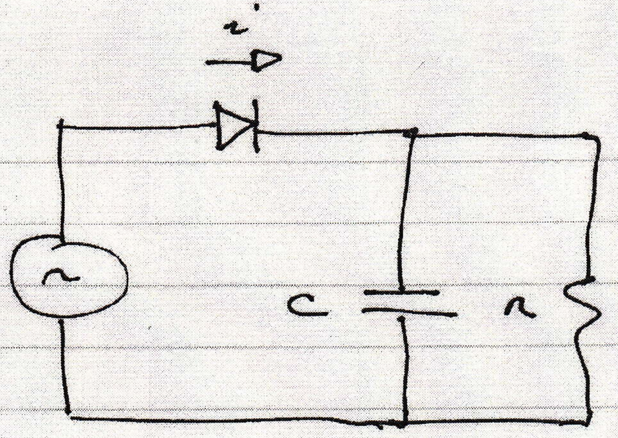
$$= 8.13\ \Omega$$

So $i_{Lm} = \dfrac{20.4}{8.13} = 2.5\ A$

4.7

60 Hz

stepped down to $10 \sin \omega t$ (transformer)



$R = 100\,\Omega$

$$v_{max} = 100\text{ mA} \times 0.1\text{ K} = 10\text{ V}$$

$$5\%\text{ ripple} = 0.5\text{ V}$$

$$\frac{v_{ripple}}{v_{max}} = \frac{1}{20} = \frac{T}{RC}$$

$$\rightarrow C = \frac{20}{60 \times 100} = 3.33\text{ mF}$$

$$\cos\phi = 1 - \frac{v_{ripple}}{v_{max}} = 0.95$$

$$\phi = 18.2^\circ$$

$$i_{max} = C v_{max}\, \omega \sin\phi$$

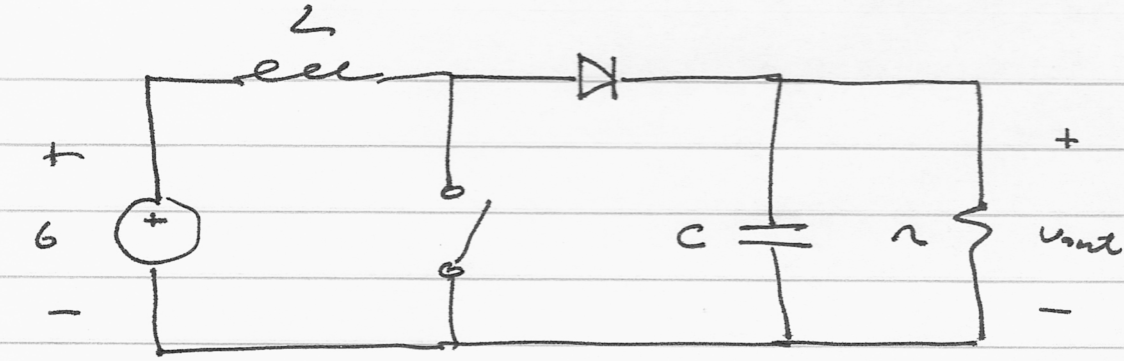
$$= 3.33 \times 10^{-3} \times 20 \times 2\pi \times 60 \sin\phi$$

$$= 7.84\text{ A}$$

Choose a 10-A diode rating.

220 kHz

4.20



$50\ mA\ @\ 15\ V \longrightarrow R = 300\ \Omega$

$15 = \frac{6}{1-D} \longrightarrow D = 0.6$

$L > \frac{6\,(0.4)(0.6)}{220 \times 10^3 \times 2 \times 0.05} = 66\ \mu H$

dc load current

choose $L = 100\ \mu H$ (standard)

$v_{ripple} = \left(\frac{V_o}{1-D}\right)\left(\frac{DT}{RC}\right) \leq 0.1\ V$

$\hookrightarrow C > \frac{15\,(0.6)}{220 \times 10^3 \times 0.1 \times 300} = 1.4\ \mu F$

choose $C = 2.2\ \mu F$ (standard)

$i_L = \frac{V_o}{R(1-D)^2} \pm \frac{V_s DT}{2L}$

$\hookrightarrow i_{L\,p\text{-}p} = \frac{V_o DT}{L} = \frac{6\,(0.6)}{10^{-4} \times 220 \times 10^3} = 0.16 A$

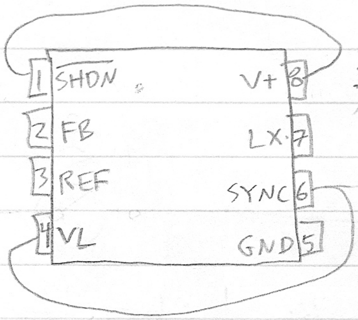
most flows through C

$v_{ripple} \approx ESR \times i_{L\,p\text{-}p} < 0.1\ V$

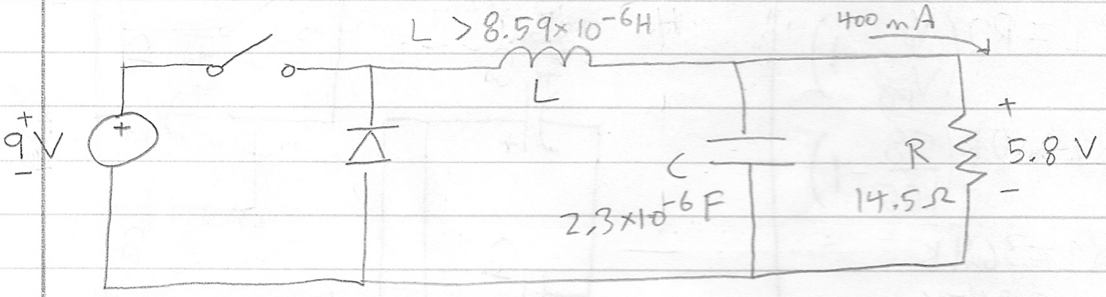
$\hookrightarrow ESR < 0.63\ \Omega$

choose $ESR \lesssim 0.25\ \Omega$ to be safe

$\boxed{4.23}$ a.)



*Tie Sync → VL for 300kHz



$V_{out} = DV_o \qquad 5.8 = 9(D) \qquad D = 0.644 \qquad T = 1/300k = 3.3\mu S$

$L > \dfrac{V_o(1-D)DT}{2\times \text{DC load current}} = \dfrac{9(1-0.644)(3.33\times10^{-6})(0.644)}{2(0.4)}$

$R = 5.8/0.400 = 14.5\,\Omega \qquad L > 8.59\times10^{-6}H$

$i_{p-p} = V_o(1-D)DT/L = 9(1-.644).644(3.33\times10^{-6})/8.59\times10^{-6}$

$= 0.799\text{ A}$

$Z_c = R + \dfrac{1}{j\omega C} \qquad |Z_c| = \sqrt{R^2 + \dfrac{1}{\omega^2 C^2}}$

$ESR = 0.08\,\Omega = \dfrac{1}{\omega C} = \dfrac{1}{2\pi(300{,}00)C} = 6.62\mu F$

-closest we can get is 6.8 μF from Digikey

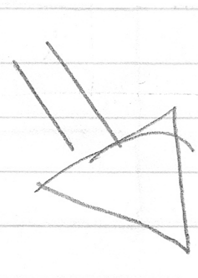
$|Z_c| = 0.08\sqrt{2} = 0.113\,\Omega$

$V_{ripple} = (i_{Lp-p})(Z_c) = (0.113)(.799) = 0.09\ V_{\text{o}}Hz$

$i_{Lmax} = \dfrac{DV_o}{R} + \dfrac{V_o(1-D)DT}{2L} = \dfrac{(0.644)9}{14.5} + \dfrac{9(1-.644)(.644)3.3\times10^{-6}}{2(8.59\times10^{-6})}$

$i_{Lmax} = .796$ amps

$L = 8.6\mu H$
$C = 6.62\mu F$
$R = 14.5\Omega$



Circuit for part A:

$R2 = 10k\Omega$

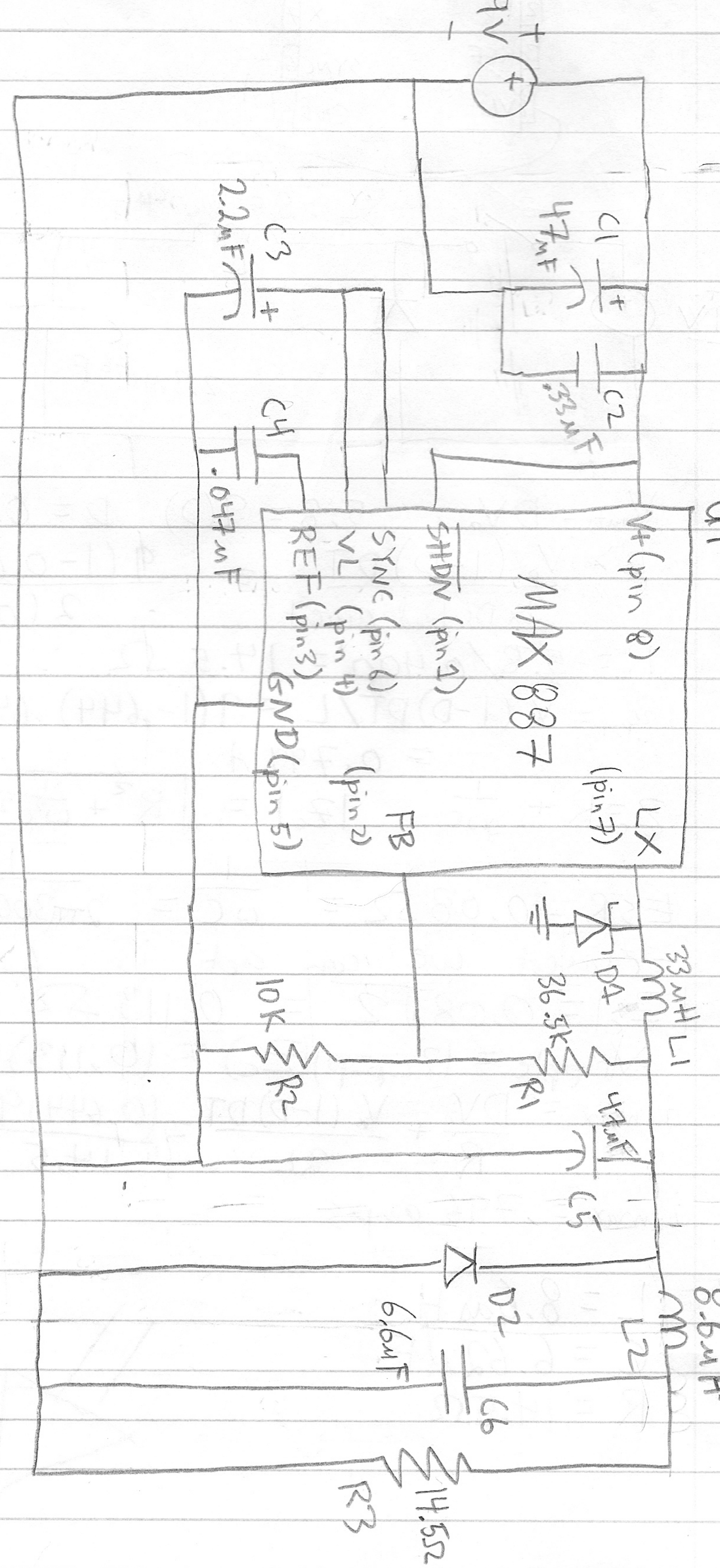
$R1 = R2\left(\frac{V_o}{V_{FB}} - 1\right)$

$R1 = 10k\left(\frac{5.8}{1.25} - 1\right)$

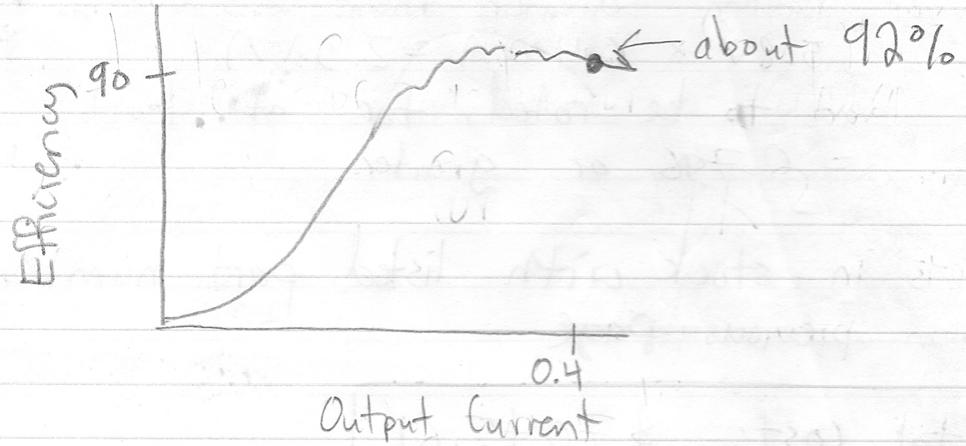
$R1 \approx 36.4K$
$\approx 36.5K$

for 300 kHz,
$L = 33\,\mu H$

*D1 is a 1A Shottky Diode that prevents the slow internal diode of the N-channel MOSFET from turning on.



b.) The operating efficency of my design will be based on the efficency of the MAX 887, which for our circuit looks like this.



$\boxed{\text{The operating efficency is about 92\%}}$

c.) Ordering Information from Digikey for 1000 of each part. (continued on next page)

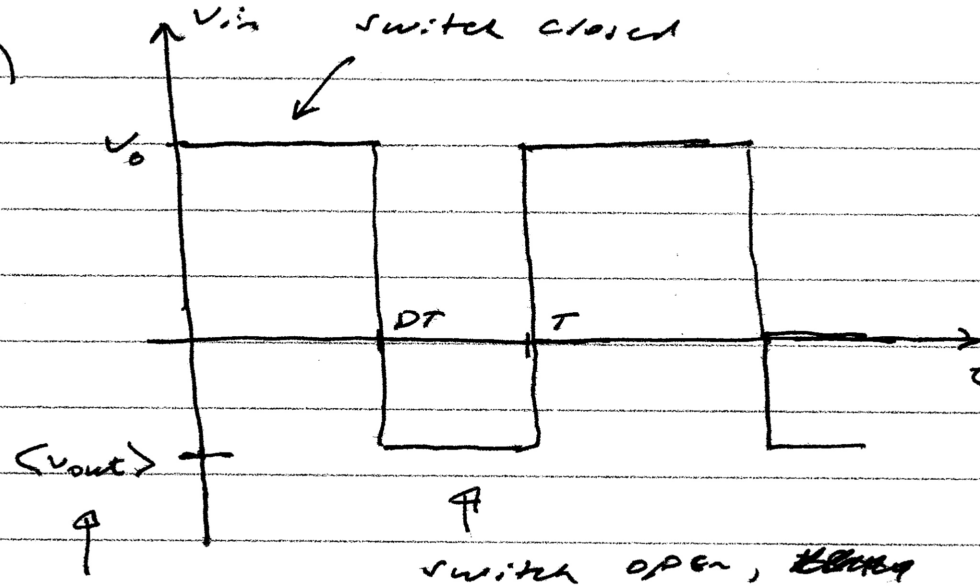
Part	Digikey #	Notes	Price for 1000
C1	2-1879291-2-ND	47 µF, Aluminum, 16 V rated	$265.73
C2	PCC1876TR-ND	0.33 µF, Ceramic, 16 V rated	$132.16
C3	PCE3169DKR-ND	2.2 µF, Aluminum, 16 V rated	$693.63
C4	PCC1729TR-ND	0.047 µF, Ceramic, 16 V rated	$63.42
C5	2-1879291-2-ND	47 µF, Aluminum, 16 V rated	$265.73
C6	PCE3171DKR-ND	6.8 µF, Aluminum, 16 V rated	$693.63
R1	P36.5KHDKR-ND	36.5K, Thick Film, 1/10 W rated	$4.16
R2	P10KGDKR-ND	10k, Thick Film, 1/10 W rated	$2.88
R3	SM6227FT14R7-ND	14.7 Ω, Wirewound Surface Mount, 3W	$761.26
L1	811-1138-2-ND	33 µH, rated for 1A	$494.00
L2	SRR6028-8R6YTR-ND	8.6 µH, rated for 2.1 A	$380.00
D1	568-4138-6-ND	Schottky, 1A fwd current, 60V reverse	$122.20
D2	MA2YD2100LCT-ND	Rectifier, 1A fwd, 15V DC reverse	$166.31
U1	MAX887HESA+-ND	MAX887 switching DC-DC converter	$3000.00

- For C6, we chose a part with an ESR that fit with our part A calculations.
- For R3, we need a resistor with a power rating greater than 2.3 Watts.
  ($5.8V \times 0.400A = 2.3W$)
- L2 had to be rated for at least $i_{Lmax} = 0.796$ or greater.

* Parts in stock with listed part numbers from previous page

- $\boxed{\text{Total cost: \$7045.61 for 1000 of each part.}}$

4.29 a)



switch open, zero diode voltage if $i_L > 0$

negative

Prove shortly

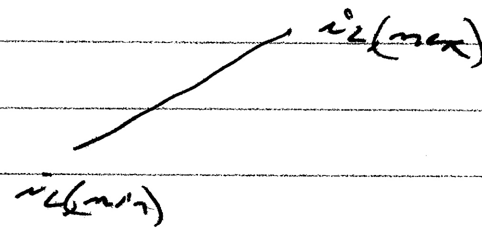
b) $\langle V_L \rangle = \langle V_{in} \rangle = 0$

$$0 = \frac{1}{T}\left[V_0 DT + \langle V_{out} \rangle (1-D)T \right]$$

$$\rightarrow V_{out} = \frac{-DV_0}{1-D}$$

c) switch closed

$$L \frac{di_L}{dt} = V_0$$



$$i_L(max) - i_L(min) = \frac{V_0 DT}{L}$$

4.29 (cont.)

Inductor energy gained $= \frac{1}{2} L i_{L(max)}^2 - \frac{1}{2} L i_{L(min)}^2$

$$= \underbrace{\frac{1}{R}\left[\frac{-DV_o}{1-D}\right]^2}_{\text{Load Power}} DT$$

↑ switch ~~closed~~ closure time

$$\left(\tfrac{1}{2} L\right)\underbrace{\left(i_{L(max)} - i_{L(min)}\right)}_{\frac{V_o DT}{2}}\left(i_{L(max)} + i_{L(min)}\right)$$

$$= \frac{DT}{R}\,\frac{D^2 V_o^2}{(1-D)^2}$$

$$i_{L(max)} + i_{L(min)} = \frac{2 V_o D^2}{R(1-D)^2}$$

$$i_{L(max)} - i_{L(min)} = \frac{V_o DT}{2}$$

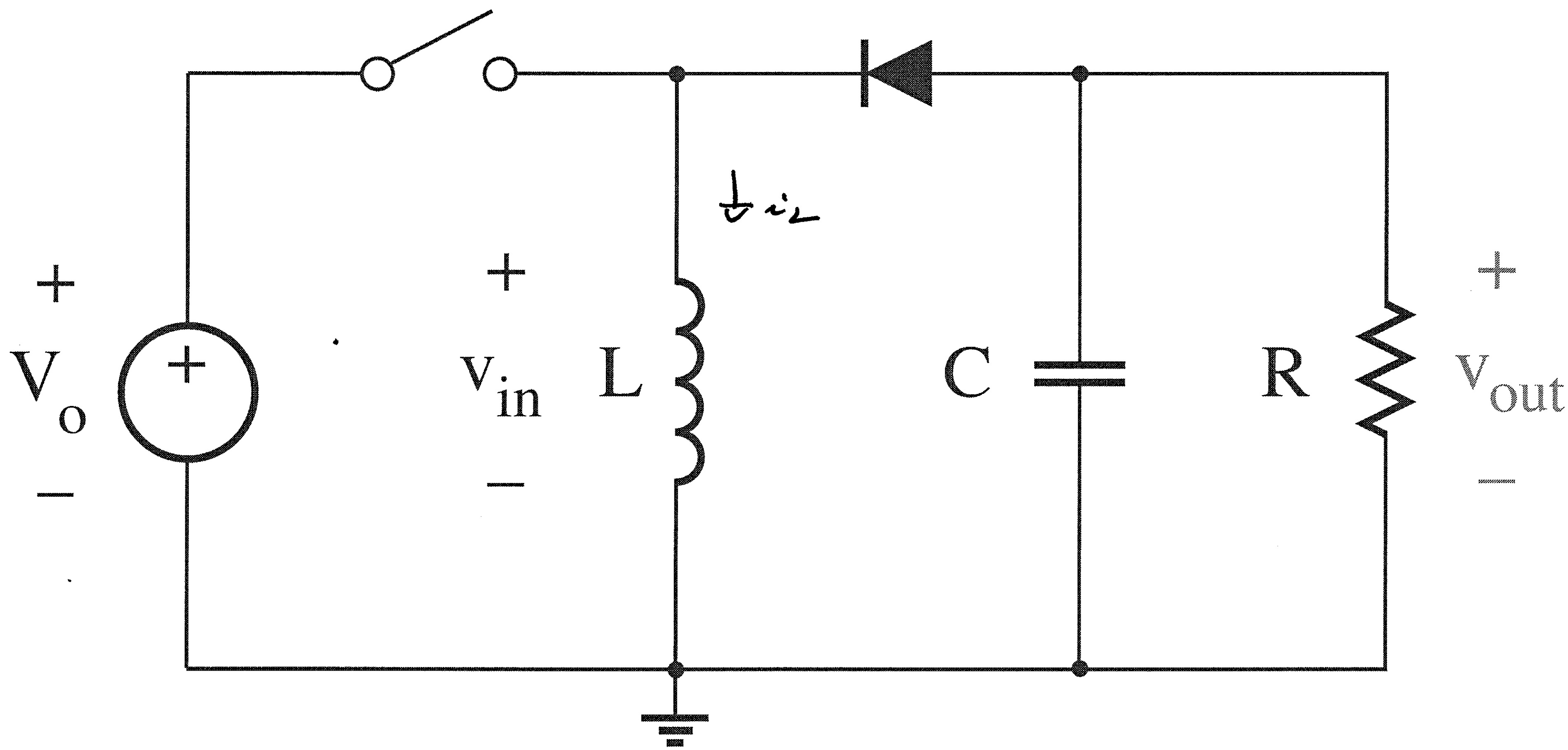
$$i_L\begin{pmatrix} max \\ min \end{pmatrix} = \frac{V_o D^2}{R(1-D)^2} \pm \frac{V_o DT}{2L}$$

d) $i_{L(min)} > 0$

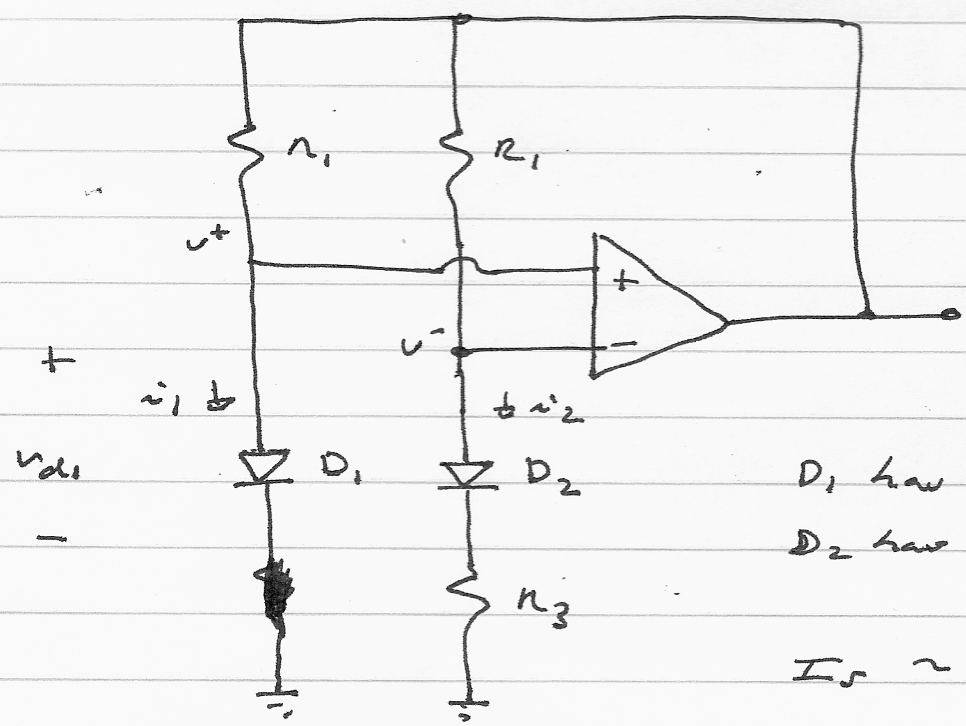
$$\hookrightarrow \quad L > \frac{RT(1-D)^2}{2D} = \frac{R}{2} DT \left(\frac{V_o}{V_{out}}\right)^2$$

e) $RC >> T$

4.29



4.41



D_1 has area XA

D_2 has area A

$I_s \sim \text{Area} * I_s'$

$$v^+ = v^- \longrightarrow i_1 = i_2$$

$$\frac{kT}{q}\ln\left(\frac{i_1}{XAI_s'}\right) = \frac{kT}{q}\ln\left(\frac{i_2}{AI_s'}\right) + i_2 R_3$$

$$i_2 = \frac{1}{R_3}\left(\frac{kT}{q}\right)\ln\left(\frac{1}{X}\right) \qquad \text{PTAT current}$$

$$= i_1$$

$$v_{out} = v_{d1} + \left(\frac{R_1}{R_3}\right)\left(\frac{kT}{q}\right)\ln\left(\frac{1}{X}\right)$$

This has the form needed to cancel out the linear dependence on temperature

As $T \uparrow$ $v_{d1} \downarrow$

so $\ln\left(\frac{1}{X}\right) > 0$ is required

$\hookrightarrow$ $\underline{X < 1}$