3B3 2016 PALMER

1 a) i) Half wave rectifier. Two diodes to split the higher off voltage requirement. to the
10% same as for a bridge. (Reduces EMI).

~~100Ω~~

ii) Full bridge, lower off state ~~on state~~ voltage diodes.
15 ~~20~~% Symmetrical ac waveform. 2 pulses per cycle so smaller smoothing capacitor

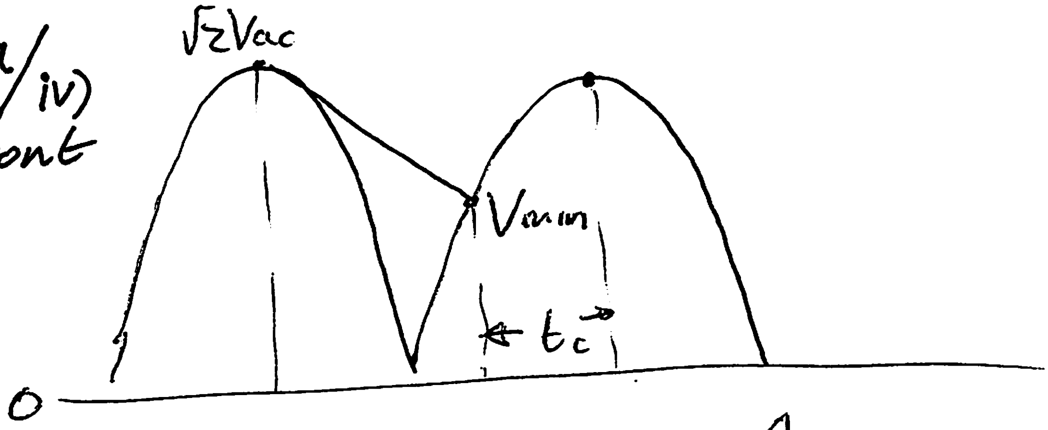
iii) $i = C\frac{dV}{dt}$ so surge current when diodes come on is reduced. L_{IN} (R_{F2} in 1(a)) and C_{IN1}, C_{IN2} also
10 ~~15~~% form a filter for the pulses of current drawn by the SMPS. So the high freq. current is kept out of C_{IN1}

iv) V_{ac} is rms. Stored energy is $\frac{1}{2}CV^2$

$$\frac{1}{2} C_{IN} V_{ac}^2 . \sqrt{2}^2 = C_{IN} V_{ac}^2$$

P_o is the overall output, so this circuit needs P_{IN}! $P_{IN} = \frac{P_o}{\eta}$. $\frac{1}{2f}$ is the period of $\frac{1}{2}$ a cycle.

1a/iv) cont



assume discharge from $\hat{V}$

V_{min} when it starts to charge again.

t_c diodes are on, so power from ac mains.

$\left(\frac{1}{2f} - t_c\right)$ is the discharge time.

Energy supplied by C_{in} = $\frac{C_{in} V_{ac}^2 - C_{in} V_{min}^2}{2}$

20%

= Energy used $\frac{P_o}{\eta}\left(\frac{1}{2f} - t_c\right)$

ignore diode losses.

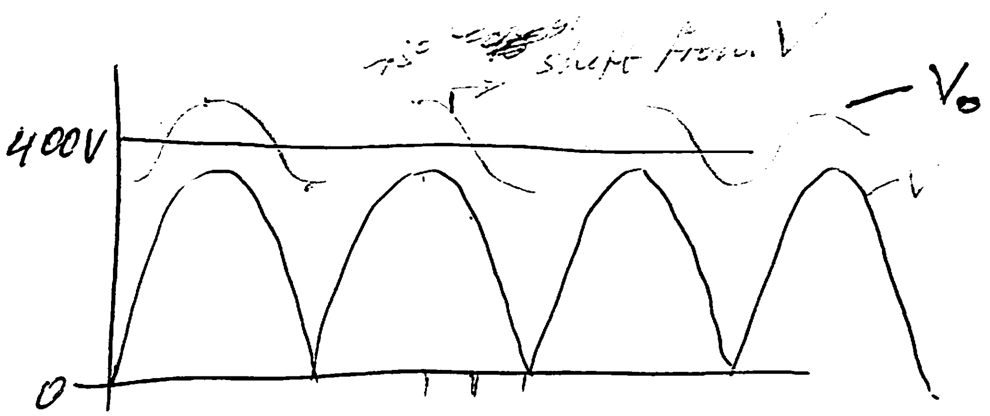
1 b) i) It operates as a step-up converter such that the current in L_1 is sinusoidal. Depending on the polarity of V_{ac}, D_3 or D_4 conduct and S_2 & D_1 alternate or S_1 & D_2.

15% So cts

$D_4 D_1, D_4 S_1, D_4 D_1 \ldots$

ii) D_4 is slow – rectifier type (or even MOSFET)

10% D_1 must be fast



Higher harmonics are attenuated so 2nd dominates.

iii) F.S. $\frac{2}{\pi} - \frac{4}{3\pi}\cos 2\omega t - \frac{4}{15\pi}\cos 4\omega t \ldots$

20% 6·25A ≈ small

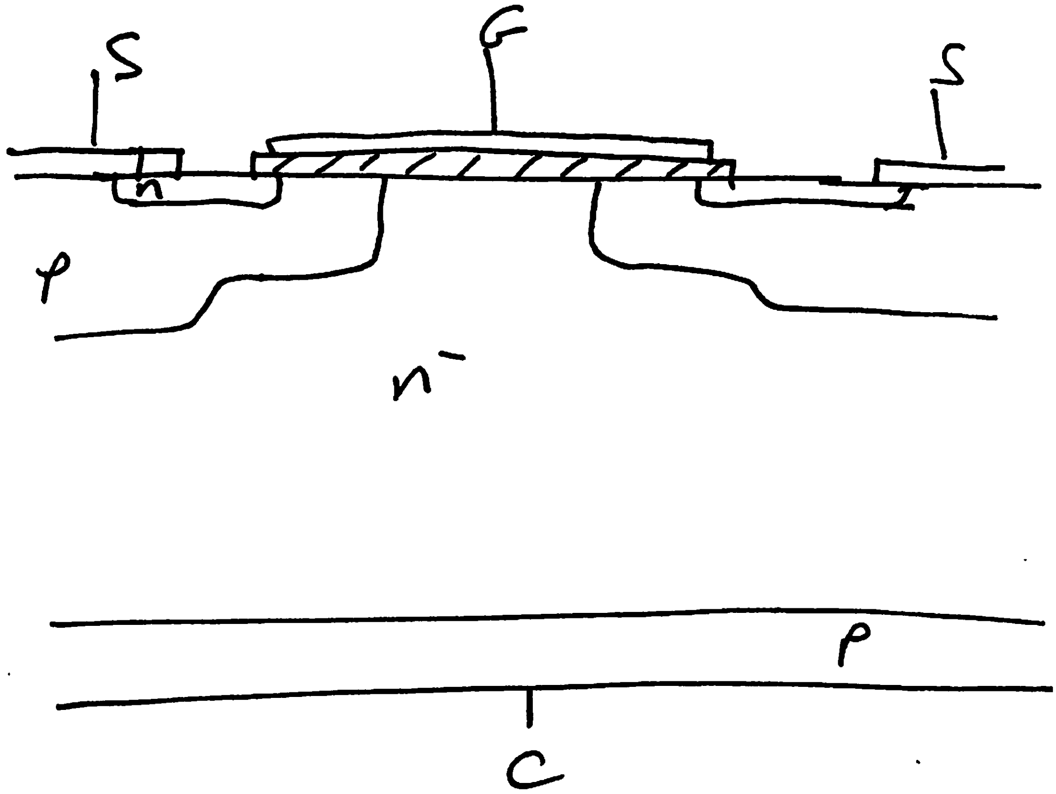
$I_2 = 6{\cdot}25 \times \frac{2}{3} = 4{\cdot}17A$ peak. $\hat{V}_{o_2} = 40V$

$V_{o_2} = I_2 \cdot \frac{1}{j\omega C} \Rightarrow C = \frac{4{\cdot}17}{2 \times 100\pi \times 40} = 0{\cdot}166mF$

$0{\cdot}22mF \Rightarrow 30V$

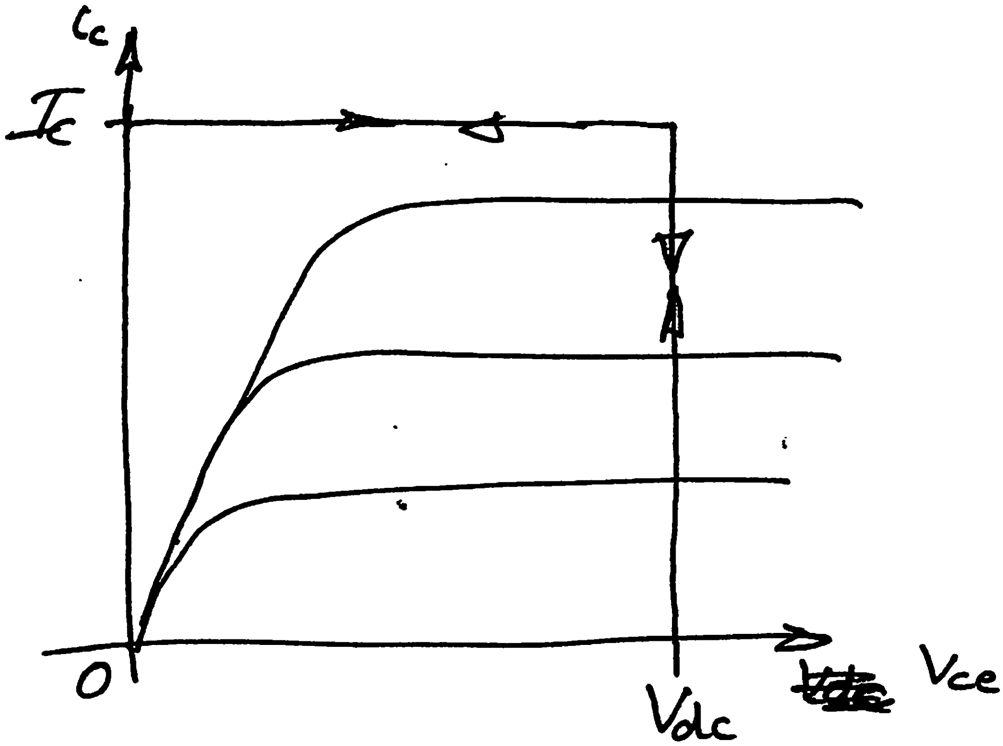
2/a) Base current replaces majority carriers lost by recombination in the base & extended base and lost across the b-e junction. 10%

b)



The bipolar is pnp so electrons are needed. These are provided by the MOS Channel formed in the p at the top 20%

2/c) i



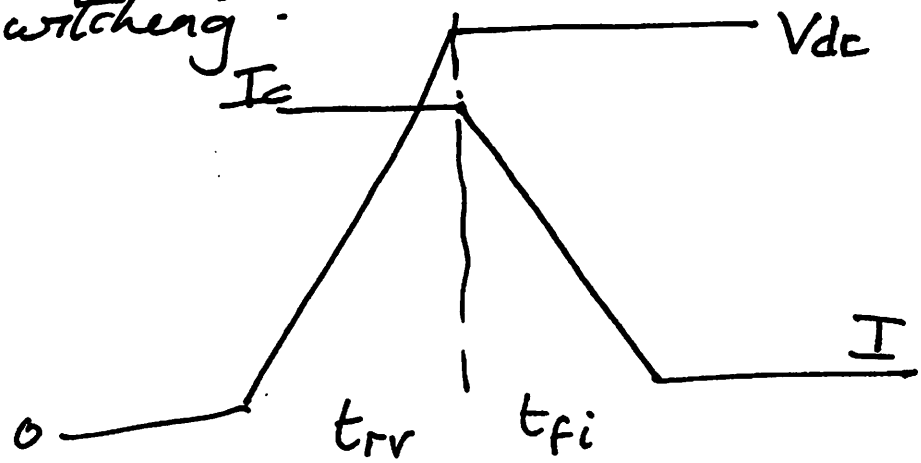
15%

2/c) ii) $f = 40kHz$ $D = 50\%$ $25\mu s$.

On-state $1.5 \times 2 \times 0.5 = 1.5W$.

Base losses $0.3 \times 1 \times 0.5 = 0.15W$.

Switching:



Energy $I_c \cdot V_{dc} \cdot \frac{t_{rv}}{2} + V_{dc} \cdot I_c \cdot \frac{t_{fi}}{2}$.

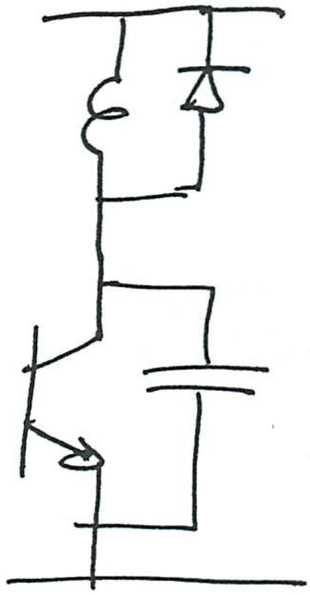
$$= \frac{I_c V_{dc}}{2}(t_{rv} + t_{fi})$$

$$\Rightarrow 300 \times 1.5 \times \left[\frac{1.5\mu}{2} + \frac{3.5\mu}{2}\right] \times 40k = 45W.$$

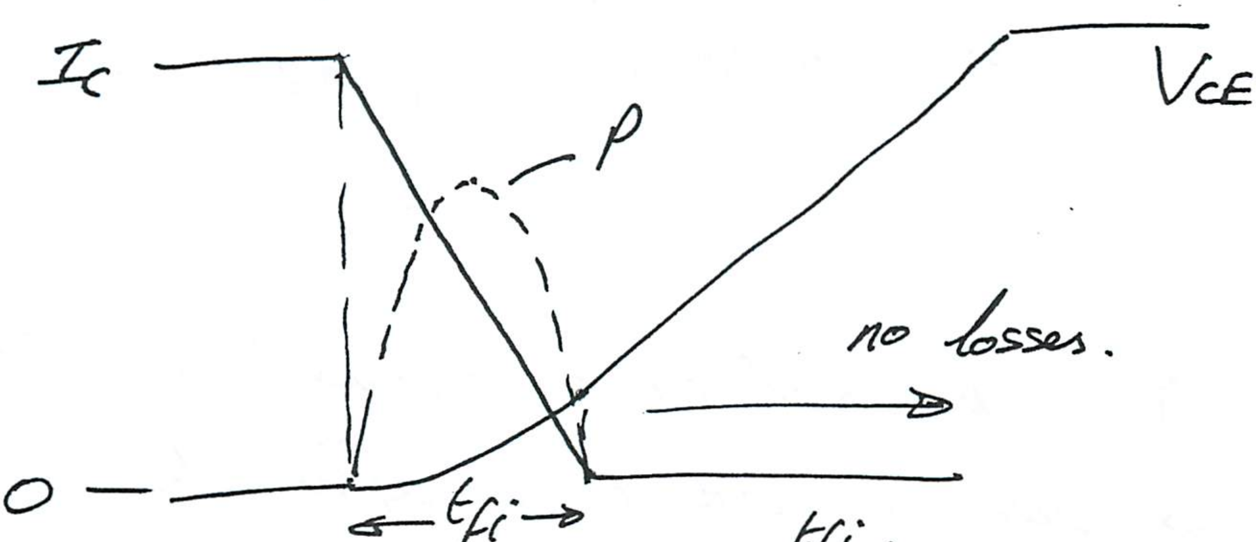
30% Its a lot! Switching is slow.

Total 46.65W

c iii) Inductive load



As soon as V_{CE} rises the current in the BJT falls. — rate the same.



$$V_{CE} = \frac{1}{C}\int i\,dt = \frac{1}{C}\int_0^{t_{fi}} \frac{I_C\,t}{t_{fi}}\,dt$$

$$= \frac{1}{C}\,\frac{I_C}{2}\,\frac{t^2}{t_{fi}}\Big|_0^{t_{fi}} = \frac{1}{C}\,\frac{I_C t_{fi}}{2}$$

$V_{CE} = \frac{1}{~~0.2\mu~~\ 0.02\mu} \times \frac{1.5}{2} \times 2\mu$ ~~7.5~~ 75V

$=$ ~~15V~~

15%

~~$P = \frac{15}{2} \times \frac{1.5}{2} \times 2\mu \times 40k = 0.45\,kW$~~

2ciii cont. / Its a quadratic.

$$\text{Energy} = \int_0^{t_{fi}} \frac{I_c}{C}\frac{t^2}{2t_{fi}} \times I_c\left(1 - \frac{t}{t_{fi}}\right) dt$$

$$= \frac{I_c^2}{2Ct_{fi}}\left(\frac{t^3}{3} - \frac{t^4}{4t_{fi}}\right)\Bigg|_0^{t_{fi}} = \frac{I_c^2}{2Ct_{fi}} t_{fi}^3\left(\frac{1}{3} - \frac{1}{4}\right)$$

$$= \frac{I_c^2 \, t_{fi}^2}{24.C}$$

$$= \frac{1.5^2}{24 \times 0.2\mu} . (2\mu)^2$$

$$\text{Power} = \text{Energy} \times f = \frac{9 \, . \, \mu^2}{24 \times 0.2\mu} \times 40\text{k m}$$

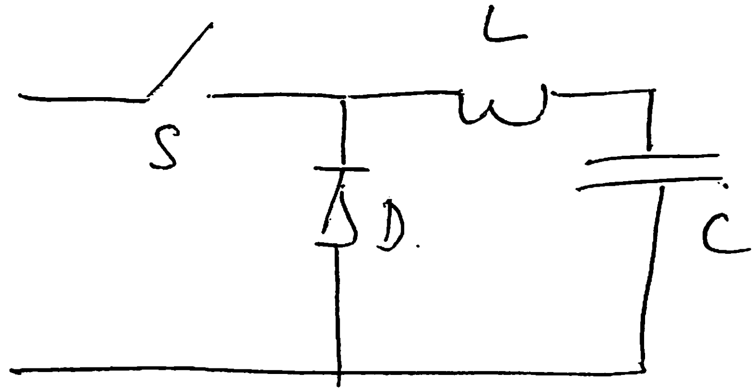
$$= \underline{75\,\text{mW}}\,!$$

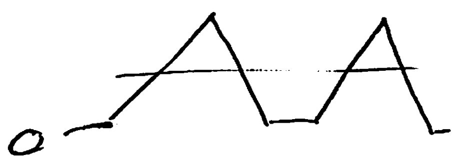
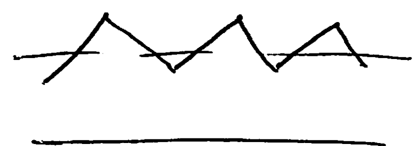
iv) Must be used in a resonant converter as turn on needs to be after the capacitor has discharged, or the transistor will blow up!

15%

3 a) Step-down.

i)



	DCM	CCM
Waveform	 current reaches zero	 current never zero.
L	small.	bigger
D	cheap	fast recovery expensive.
S	high $\hat{I}$	lower $\hat{I}$
C	larger C	smaller C
η	low switching losses.	higher sw losses.

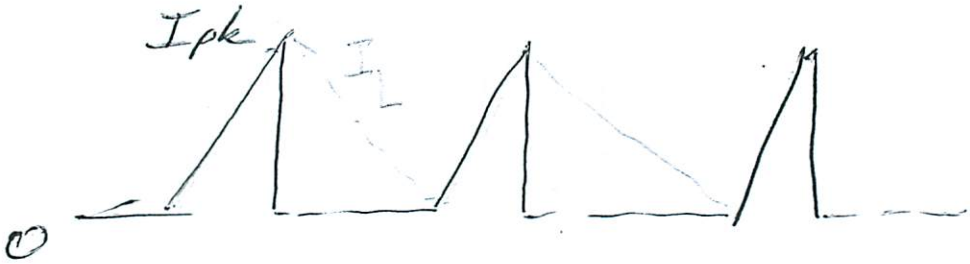
35%
40%

ii.) Step down is more efficient as some energy is delivered directly to the load. Also no transformer is needed.

10%

3a iii) LinkSwitch-TN current

15%



iv). RMS of a triangle.

Current rise - $\hat{I}\frac{t}{DT}\Big|_0^{DT}$; current fall $\hat{I}t$

$\hat{I}\left[1 - t'/T(1-D)\right]_0^{T(1-D)}$

squared. & mean

$$\frac{1}{T}\int_0^{DT}\hat{I}^2\frac{t^2}{(DT)^2}\,dt + \frac{1}{T}\int_0^{(1-D)T}\hat{I}^2\left[1-\frac{t'}{(1-D)T}\right]^2 dt'$$

$$\Rightarrow \frac{\hat{I}^2}{T}\frac{DT}{3} + \frac{\hat{I}^2}{T}\frac{(1-D)T}{3} = \frac{\hat{I}^2}{3}$$

$$RMS = \frac{\hat{I}}{\sqrt{3}}$$

The average is $\frac{\hat{I}}{2}$ so the RMS is worse

25% for heating. As the inductor gets smaller $\hat{I}$ goes up, but an off time starts to appear: so the RMS does not run away too fast. But $\hat{I}$ stresses the switch device, but L has less resistance! DCM more efficient

~~3a~~ v) Duty cycle. $\delta = \frac{V_o}{V_{IN}} = \frac{15}{325}$.

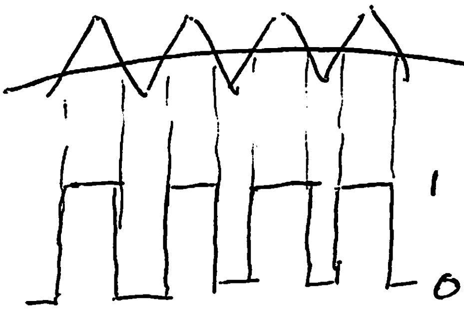
This is a very small δ and small

15% errors would lead to massive voltage movement in V_o. Much better just to skip cycles and keep δ fixed.

4 a) "Two level" as output is either '0' or '1' or '0' or 'V_{dc}'. No middle state even if the voltages are $-V_{dc}$ and V_{dc}. So it is a good description.

Sine reference + triangular carrier.

20%

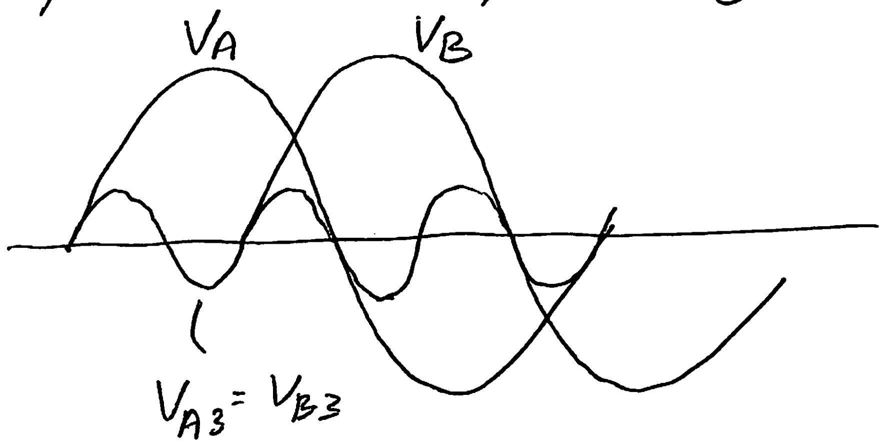


'1' → T_1 on T_2 off
'0' → T_1 off T_2 on.

20%

b) i) No third, ninth, fifteenth as there are three legs and the third harmonics are in phase in a 3 phase system.

10%



Since any output is across any two legs eg. $V_A - V_B = V_{AB}$ then the third harmonics have no contribution to V_{AB} as they cancel.

15%

~~b~~) ii) In the Fourier series of a squarewave the 3rd harmonic is at a magnitude of $\frac{1}{3}$. With just fundamental and $\frac{1}{3}$ of third the sum will exceed the peak level of the fundamental so overmodulation will occur. (Gibbs phenomenon)

$$\frac{d}{d\theta}\left(\sin\theta + \frac{1}{6}\sin 3\theta\right) = 0 = \cos\theta + \frac{3}{6}\cos 3\theta = 0$$

$\theta \simeq 30^\circ$ $\quad 0.866 + \frac{3}{6}0 = 0$ ✗ $\quad 60^\circ \quad 0.5 - \frac{3}{6}\times 1 = 0$

20% also $\sin\theta + \frac{1}{6}\sin 3\theta = 1$ max value. **20%**

check
With $\frac{1}{6}$ th. New value is $1 - \frac{1}{6} = 0.833$.
at 90°

iii) at 30° $\quad 0.5 + \frac{1}{6} = 0.666$.

at 60° $\quad 0.866 + 0 = 0.866$. ← max.

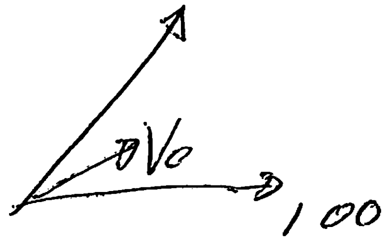
10% at 50° $\quad 0.766 + 0.0833 = 0.849$

at 70° $\quad 0.939 - 0.0833 = 0.855$

4c) i) There are two zero states 000, 111

To optimise switching losses move from one state to the next with as few changes as possible. → careful use of V_0 & V_7

Also switch between adjacent vectors eg.



as there is only one change 100 to 110.

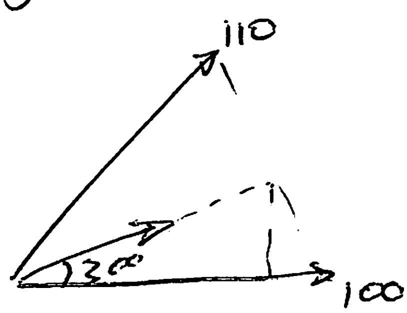
Then the order matters

000 – 100 → 110 → 111 → 110 – 100 – 000

10% 000 – 100 → 110 → 111 → 110 – 100 – 000

This is direct inverse. This reduces ripple.

ii) At 30° magnitude of $\frac{1}{2}$ relative to the maximum



Duty ratio is $\frac{1}{4}$ in 110, $\frac{1}{4}$ in 100, $\frac{1}{4}$ in 111, $\frac{1}{4}$ in 000

$\Rightarrow D_A = \frac{3}{4}$, $D_B = \frac{1}{2}$, $D_C = \frac{1}{4}$

~~4(c)~~ (ii) To stay there we could add a $\frac{1}{4}$ to each.

$$\Rightarrow D_A = 1, \quad D_B = \frac{3}{4}, \quad D_C = \frac{1}{2}.$$

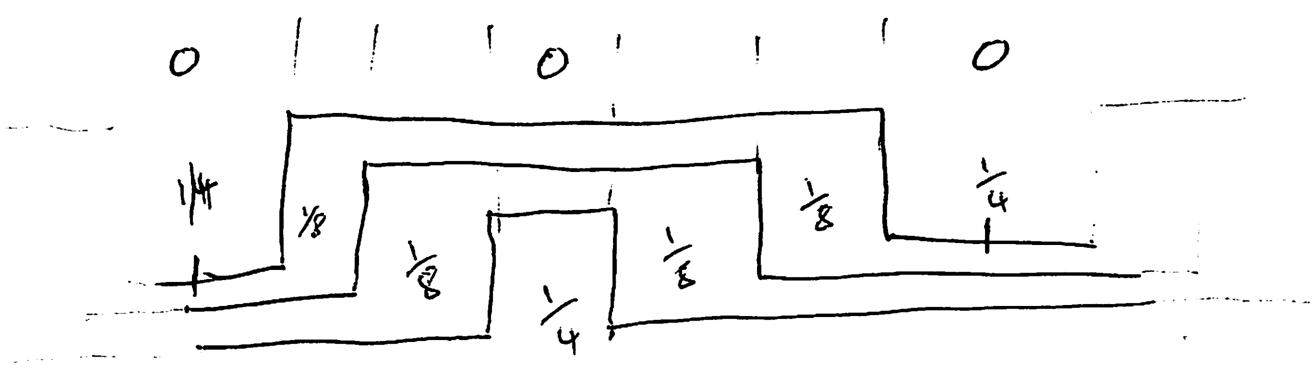
So now we have the same conditions for optimal BUT no switching in A!

Drawback is calculating how much to add!

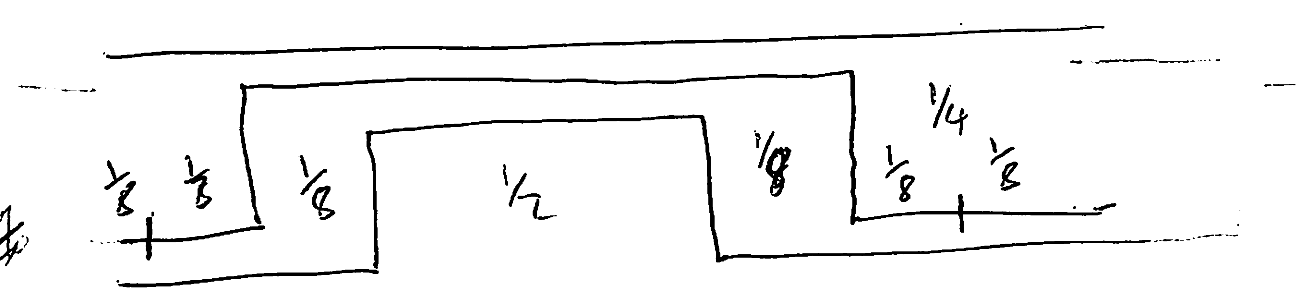
Adding $\frac{1}{4}$ to each is making 111 bigger by a $\frac{1}{4}$ so gets rid of $\frac{1}{4}$ of 000. unnecessary.

30%

In wave forms is easy to show!



$\Rightarrow$



iii) ~~[illegible]~~

~~20% Higher ripple, also bootstrap may not work, asymmetrical losses...~~