STRING OF LED'S

D1 + C1 FORM A RECTIFIER/FILTER TO GET A DC LEVEL.

THE IDEA SEEMS TO BE TO LIGHT UP MORE LEDs AS THE INPUT VOLTAGE INCREASES.

HOWEVER, THE VOLTAGE AT A NODE OF D2 IS ALMOST CONSTANT (2 DIODE DROPS) SO D2-D4-D24 WILL PROBABLY NEVER TURN ON (OR ONLY RARELY)

D28 WILL CERTAINLY NEVER LIGHT.
Chapter 4-23

Lowest output voltage = 8.83 V

Line Regulation = \frac{r_Z}{R + r_Z} = \frac{30}{300 + 30}

= 90 \text{ mV/V}

Load Regulation = -(r_Z \parallel R) = -29.1 \text{ mV/mA}

4.64

(a) \( V_{ZT} = V_{ZO} + r_T I_{ZT} \)

\( 10 = V_{ZO} + 7(0.025) \)

\( \Rightarrow V_{ZO} = 9.825 \text{ V} \)

(b) The minimum zener current of 5 mA occurs when \( I_L = 20 \text{ mA} \) and \( V_Z \) is at its minimum of \( 20(1 - 0.25) = 15 \text{ V} \), see the circuit below:

\[
R = \frac{15 - (V_{ZO} + r_Z I_Z)}{20 + 5}
\]

\[
\leq \frac{15 - (9.825 + 7(0.005))}{25}
\]

\[
\leq 205.6 \Omega.
\]

\( \therefore \) use \( R = 205 \Omega \)

(c) Line regulation = \( \frac{7}{205 + 7} = 33 \text{ mV/V} \)

\( \pm 25\% \) change in \( V_Z = \pm 5 \text{ V} \)

\( V_o \) changes by \( \pm 5 \times 33 = \pm 165 \text{ mV} \)

corresponding to \( \frac{\pm 165}{10} \times 100 = \pm 1.65\% \)

(d) Load Regulation = \( -(r_Z \parallel R) \)

\( = -(7 \parallel 205) = -6.77 \text{ \Omega} \)

or \(-6.77 \text{ V/A} \)

\( \Delta V_o = -6.77 \times 20 \text{ mA} = -135.4 \text{ mV} \)

corresponding to \( \frac{0.1354}{10} \times 100 = -1.35\% \)

(e) The maximum zener current occurs at no load = \( I_L = 0 \) and the supply at \( 20 + \frac{1}{4}(20) = 25 \text{ V} \).

\( V_Z = V_{ZO} + r_Z I_Z \)

\[
25 V
\]

\[
205 \Omega
\]

\( 205 \Omega \)

\( I_L = 0 \)

\( V_Z = 9.825 + 7 \times \frac{25 - V_Z}{205} \)

\( 205 V_Z = 205(9.825) + 7(25) - 7V_Z \)

\( \Rightarrow V_Z = 10.326 \text{ V} \)

\( P_Z = 10.326 \times \left( \frac{25 - 10.326}{205} \right) \)

\( = 739.4 \text{ mW} \)

Alternate circuit to calculate \( V_Z \)
\[ I_z = \frac{25 - V_{zo}}{250 + 7} \]
\[ = \frac{25 - 9.825}{250 + 7} \]
\[ = 71.6 \text{ mA} \]

\[ V_z = V_{zo} + I_z \cdot r_z \]
\[ = 9.825 + 0.0716 \times 7 \]
\[ = 10.326 \text{ V} \]
as above!

4.65

using the constant voltage drop model:

\[ v_0 = v_s + 0.7 \text{ V} \], For \( v_s \leq -0.7 \text{ V} \)
\[ v_0 = 0 \], for \( v_s \geq -0.7 \text{ V} \)

\[ V_{p0} = 0.7 \text{ V} \]
\[ r_0 = 0 \]

(a) \( v_0 = v_s + 0.7 \text{ V} \), For \( v_s \leq -0.7 \text{ V} \)
\[ v_0 = 0 \], for \( v_s \geq -0.7 \text{ V} \)

(c) The diode conducts at an angle
\[ \theta = \sin^{-1}\left(\frac{0.7}{12}\right) \approx 3.34^\circ \& \text{ stops} \]
at \( \pi - \theta = 176.65^\circ \)
Thus the conduction angle is \( \pi - 2\theta \)
\[ = 173.31^\circ \text{ or } 3.025 \text{ rad.} \]

\[ v_{o,\text{avg}} = \frac{1}{2\pi} \int_{\theta}^{\pi-\theta} (12\sin\phi - 0.7) \, d\phi \]
\[ = \frac{1}{2\pi} \left[ -12\cos\phi - 0.7\phi \right]_{\theta}^{\pi-\theta} \]
\[ = \frac{1}{2\pi} \left[ 12\cos\theta - 0.7(\pi - \theta) \right] \]
\[ = -4.572 \text{ V} \]

(d) Peak current in diode is:
\[ \frac{12 - 0.7}{1.5 \times 10^3} = 2.53 \text{ mA} \]

(e) PIV occurs when \( v_s \) is at its peak and \( v_o = 0 \).
\[ \text{PIV} = 12 \text{ V} \]
(b) For \( v_{o,\text{avg}} = 100 \text{ V} \)
\[
V_S = \frac{\pi}{2} \times 101.4 = 159.3 \text{ V}
\]

Turns Ratio = \( \frac{120.\sqrt{2}}{159.3} = 1.065 \) to 1

4.72
Refer to Fig. 4.23
For \( 2V_{D0} << V_S \)
\[
V_{o,\text{avg}} = \frac{2}{\pi} V_s - 2V_{D0} = \frac{2}{\pi} V_s - 1.4
\]

(a) For \( V_{o,\text{avg}} = 10 \text{ V} \)
\[
10 \text{ V} = \frac{2}{\pi} \cdot V_s - 1.4
\]
\[
\therefore V_s = 11.4\left(\frac{\pi}{2}\right) = 17.9 \text{ V}
\]

Turns ratio = \( \frac{120.\sqrt{2}}{17.9} = 9.5 \) to 1

(b) For \( V_{o,\text{avg}} = 100 \text{ V} \)
\[
100 \text{ V} = \frac{2}{\pi} \cdot V_s - 1.4
\]
\[
\Rightarrow V_s = 101.4\left(\frac{\pi}{2}\right) = 159 \text{ V}
\]

Turns ratio = \( \frac{120.\sqrt{2}}{159} = 1.07 \) to 1

4.73
\[
120.\sqrt{2} \pm 10\% : 24.\sqrt{2} \pm 10\%
\]
\[
\Rightarrow \text{turns Ratio} = 5:1
\]
\[
v_s = \frac{24.\sqrt{2}}{2} \pm 10\%
\]

\[
\text{PIV} = 2V_{S\text{max}} - V_{D0}
\]
\[
= 2 \times \frac{24.\sqrt{2}}{2} \times 1.1 - 0.7
\]
\[
= 36.6 \text{ V}
\]

using a factor of 1.5 for safety we select a diode having a PIV rating of 55 V

4.74
The circuit is a full wave rectifier with centre tapped secondary winding. The circuit can be analyzed by looking at \( v_o^+ \) and \( v_o^- \) separately.

\[
v_{o,\text{avg}} = \frac{1}{2\pi} \int (V_S \sin \phi - 0.7) d\phi = 15
\]
\[
= \frac{2V_S}{\pi} - 0.7 = 15
\]

assumed \( V_S >> 0.7 \text{ V} \)
\[
V_S = \frac{15 + 0.7}{2} = 24.66 \text{ V}
\]

Thus voltage across secondary winding
\[
= 2V_S = 49.32 \text{ V}
\]

Looking at \( D_4 \)
\[
\text{PIV} = V_S - V_o^-
\]
\[
= V_S + (V_S - 0.7)
\]
\[
= 2V_S - 0.7
\]
\[
= 48.6 \text{ V}
\]

If choosing a diode, allow a safety margin of
\[ 1.5\text{PIV} = 73 \text{ V} \]

4.75
(i) \( v_r = (V_p - V_{DO}) \frac{T}{CR} \) \text{  Eq. (4.28)}

\[ 0.1(V_p - V_{DO}) = (V_p - V_{DO}) \frac{T}{CR} \]

\[ C = \frac{1}{0.1 \times 60 \times 10^{-6}} = 166.7 \mu\text{F} \]

(ii) for

\[ v_r = 0.01(V_p - V_{DO}) = \frac{(V_p - V_{DO})T}{CR} \]

(a) \( v_{o,avg} = V_p - V_{DO} - \frac{1}{2} V_r \)

\[ = 12.\sqrt{2} - 0.7 - \frac{1}{2}(12.\sqrt{2} - 0.7) \times 0.1 \]

\[ = (12.\sqrt{2} - 0.7)(1 - 0.1) \]

\[ = 15.5 \text{ V} \]

(b) \[ v_{o,avg} = (12.\sqrt{2} - 0.7)(1 - 0.01) \]

\[ = 16.19 \text{ V} \]

(c)\( i_{d, avg} = I_c \frac{2(V_p - V_{DO})}{\sqrt{1 + \pi \frac{2}{\sqrt{0.1(V_p - V_{DO})}}}} \)

\[ = \frac{V_{o,avg}}{R} \frac{2(V_p - V_{DO})}{\sqrt{1 + \pi \frac{2}{\sqrt{0.1(V_p - V_{DO})}}}} \]

\[ = 15.5 \left(1 + \pi \frac{2}{\sqrt{0.1}}\right) \]

\[ = 233 \text{ mA} \]

(ii) \[ i_{d, avg} = \frac{16.19}{10^3} \left(1 + \pi \sqrt{200}\right) \]

\[ = 735 \text{ mA} \]

NB next user \( I_L = \frac{V_p - V_{DO}}{R} \)

but here are used \( i_{d, avg} = \frac{V_p - V_{DO} - \frac{1}{2} V_r}{R} \)

which is more accurate.

(d) \( i_{d, peak} = I_c \left(1 + 2\pi \sqrt{\frac{2(V_p - V_{DO})}{V_r}}\right) \)

\[ = \frac{15.42}{10^3} \left(1 + 2\pi \sqrt{\frac{2}{\sqrt{0.1}}}\right) \]

\[ = 449 \text{ mA} \]

(ii) \[ i_{d, peak} = \frac{16.19}{10^3} \left(1 + 2\pi \sqrt{\frac{2}{\sqrt{0.01}}}\right) \]

\[ = 1455 \text{ mA} \]

4.76

(i) \( v_r = 0.1(V_p - V_{DO}) = (V_p - V_{DO}) \frac{T}{2fCR} \)

The factor of 2 accounts for discharge occurring only half of the period \( T/2 = \frac{1}{2f} \)

\[ C = \frac{1}{2(60) \times 10^3 \times 0.1} = 83.3 \mu\text{F} \]

(ii) \[ C = \frac{1}{2(60) \times 10^3 \times 0.01} = 833 \mu\text{F} \]

(a) \( V_o = V_p - V_{DO} - \frac{1}{2} V_r \)

\[ = (V_p - V_{DO})\left(1 - \frac{0.1}{2}\right) \]

\[ = (16.27)\left(1 - \frac{0.1}{2}\right) \]

\[ = 15.5 \text{ V} \]

(ii) \( V_o = (16.27)\left(1 - \frac{0.01}{2}\right) = 16.19 \text{ V} \)
(b) (i) Fraction of cycle $= \frac{2\omega \Delta t}{2\pi} \times 100$

$= \sqrt{\frac{2V_J(V_P - V_{DO})}{\pi}} \times 100$

$= \frac{1}{\pi} \sqrt{2(0.1)} \times 100 = 14.2\%$

(ii) Fraction of cycle $= \frac{2\sqrt{2(0.01)}}{2\pi} \times 100$

$= 4.5\%$

(c) use eq (4.34)

(i) $i_{D,avg} = I_L \left(1 + \pi \frac{V_P - V_{DO}}{2V_f}\right)$

$= 15.5 \left(1 + \pi \frac{1}{\sqrt{2(0.1)}}\right) = 124.4\ mA$

(ii) $i_{D,avg} = 16.19 \left(1 + \pi \frac{1}{\sqrt{2(0.01)}}\right) = 376\ mA$

(d) use eq (4.35)

(i) $i_D = I_L \left(1 + 2\pi - \frac{1}{\sqrt{2(0.1)}}\right) = 233\ mA$

(ii) $i_D = I_L \left(1 + 2\pi - \frac{1}{\sqrt{0.02}}\right) = 735\ mA$

4.77

1) $V_r = 0.1(V_P - V_{DO} \times 2) = \frac{V_P 2V_{DO}}{2fCR}$

discharge occurs only over $\frac{1}{2} T = \frac{1}{2f}$

$C = \frac{(V_P - 2V_{DO})}{(V_P - 2V_{DO})} \frac{1}{(2(0.1))fR} = 83.3\ \mu F$

(ii) $C = \frac{1}{(2(0.01))fR} = 833\ \mu F$

(b) (i) Fraction of cycle $= \frac{2\omega \Delta t}{2\pi} \times 100$

$= \sqrt{\frac{2(0.1)}{\pi}} \times 100 = 14.2\%$

(ii) Fraction of cycle $= \sqrt{\frac{2(0.01)}{\pi}} \times 100 = 4.5\%$

(c) i) $i_{D,avg} = 14.79 \left(1 + \pi \frac{1}{\sqrt{0.2}}\right) = 119\ mA$

(ii) $i_{D,avg} = 15.49 \left(1 + \pi \frac{1}{\sqrt{0.02}}\right) = 356\ mA$

(d) (i) $i_D = 14.79 \left(1 + 2\pi \frac{1}{\sqrt{0.2}}\right) = 223\ mA$

(ii) $i_D = 15.49 \left(1 + 2\pi \frac{1}{\sqrt{0.02}}\right) = 704\ mA$

4.78

\[ \text{PIV} = V_P - V_{DO} - \sqrt{2} + V_P \]

\[ = V_{0,peak} + V_P \]

\[ = 15 + 16.7 \]

\[ = 31.7 \ V \]

For a 50% safety margin PIV $= 1.5 \times 31.7 = 47.6 \ V$

(d) $i_{D,avg} = I_L \left(1 + \pi \sqrt{\frac{2(V_P - V_{DO})}{V_r}}\right)$

using $I_L = \frac{\nu_{0,avg}}{R} = \frac{15}{R}$ we have

\[ i_{D,avg} = 15 \left(1 + \pi \sqrt{\frac{2(16)}{2}}\right) \]

\[ = 1.36 \ A \]

(c) $i_{D,peak} = I_L \left(1 + 2\pi \sqrt{\frac{2(V_P - V_{DO})}{V_r}}\right)$

\[ = 15 \left(1 + 2\pi \sqrt{\frac{2(16)}{2}}\right) \]

\[ = 2.61 \ A \]
Each diode has 0.7 V drop when conducting. The Zener has 8.2 V drop when conducting. So the limiter thresholds are:

\[ \pm (2 \times 0.7 + 8.2) = \pm 9.6 \text{ V} \]

Diodes have 0.7 V drop at 1 mA current.

\[ i_D = \frac{e^{(v_D - 0.7)/V_T}}{1 \text{ mA}} \]

\[ i_D = 1 \times 10^{-3} e^{(v_D - 0.7)/V_T} \]
Solution: Problem B) What does the portion of the circuit shown below do? Assume a 1W zener (19mA max), so that we want at least 1.9mA flowing through the zener at all times. You also know that the resistor can dissipate a maximum of 1W before overheating.

This circuit creates a lower voltage (5.2V) regulated power supply from the much higher voltage (24V) battery – also battery voltages change with load, so the 24V is only nominal.

1. How much current goes through the Zener when $I_{LOAD}=0$?

$I_{500\Omega} = \frac{24 - 5.2}{500} = 37.6mA$

$I_{Zener} + I_{Load} = I_{500\Omega}$

$I_{Zener, no load} = I_{500\Omega} = 37.6mA$

Note – this would destroy the zener, so some current must be flowing in load.

2. What is the maximum value for $I_{LOAD}$ before the power supplies fails?

$I_{Zener, min} + I_{Load, max} = I_{500\Omega} = 37.6mA$

$I_{Load, max} = I_{500\Omega} - I_{Zener, min} = 37.6mA - 1.9mA = 35.7mA$

3. For this maximum current compare the power dissipated in the load ("useful power") to the power dissipated in the 500Ω resistor ("wasted power") and calculate the efficiency, $\eta = \text{useful power/total power}$.

$P_{Load, max} = I_{Load, max} \cdot 5.2V = 35.7mA \cdot 5.2V = 186mW$

$P_{500\Omega} = I_{500\Omega} \cdot 24 - 5.2 = 37.6mA \cdot 18.8V = 707mW$

$P_{Zener} = I_{Zener, min} \cdot 5.2V = 1.9mA \cdot 5.2V = 10mW$

$\eta = \frac{P_{Load, max}}{P_{Load, max} + P_{500\Omega} + P_{Zener}} = \frac{186}{186 + 707 + 10}$

$= \frac{186}{903} = 0.206 \approx 21\%$

Note that this is the maximum efficiency. If the load current drops, so does the efficiency.

Also – it is OK if you didn’t include $P_{Zener}$, I didn’t include it in the original problem statement (but it doesn’t change the answer much).