CHAPTER 5

DESIGN SAMPLES

5.1 15W,25-100V, Self-Oscillating Converter

5.1.1 Design

Given P_{out} 15 W

V_{in} 25 V

V_{out} 100 V

$$I_C = \frac{P_{in}}{\eta V_{in}} = \frac{15}{0.8 \times 25} = 0.75 \text{ A}$$

$$I_{out} = \frac{P_{out}}{V_{out}} = \frac{15}{100} = 0.15 \text{ A}$$

Select 2N3740, silicon, pnp,transistor which is characterized by: $I_{Cmax} = 1$ A, $I_{Bmax} = 2$ A, $BV_{CBO} = 60$ V, $BV_{EBO} = 7$ V, $BV_{CEO} = 60$ V $h_{FE(min)} = 30$

$$I_B = \frac{2I_C}{h_{FE(min)}} = \frac{2 \times 0.75}{30} = 0.05 \text{ A}$$

Select TDK, H5B, 2616, ferrite pot core, which is characterized by: $A_{core} = 0.94$ cm^2, $W = 0.445$ cm^2, $B_{sat} = 4100$ gauss, mean diameter 2.0 cm, volume 3.54 cm^3

$$J = \left[\frac{2P_{out}\eta}{\rho l_w W K_w}\right]^{\frac{1}{2}} = \left[\frac{2 \times 15 \times 0.01}{1.72 \times 10^{-6} \times \pi \times 2.0 \times 0.445 \times 0.5}\right]^{\frac{1}{2}}$$

$$= 354 \text{ A/cm}^2$$

$$\frac{1}{J} = \frac{1}{354} \frac{1}{5.07 \times 10^{-6}} = 564 \text{ cir mils/A}$$

$$f = \frac{P_{out} \times 10^8}{2 K_w B_{max} J A_{core} W} = \frac{15 \times 10^8}{2 \times 0.5 \times 4100 \times 354 \times 0.94 \times 0.445}$$

$$= 2.75 \text{ kHz}$$

The value of V_{in} is not available in the Feedback Table, so, call eq. (6-10)

$$V_{FB} = \sqrt{V_{in} V_{BE(sat)}} + V_{BE(sat)}$$

$$= \sqrt{25 \times 0.7} + 0.7 = 4.9 \text{ V.}$$

$$N_1 = \frac{V_{in} \times 10^8}{4f B_{max} A_{core}} = \frac{25 \times 10^8}{4 \times 2.75 \times 10^3 \times 4100 \times 0.94}$$

$$= 59$$

$$N_2 = \frac{K_1 N_1 V_{out}}{V_{in}} = 1.05 \times 59 \times \frac{100}{25} = 248$$

$$N_{FB} = \frac{K_1 N_1 V_{FB}}{V_{in}} = 1.05 \times 59 \times \frac{4.9}{25} = 12.7$$

Select $N_{FB} = 13$ which gives $V_{FB} = 5.0$ V

wire size of $N_1 = \frac{1}{J} \times \frac{I_c}{2} = \frac{564 \times 0.75}{2} = 212$ cirmil

" $N_2 = \frac{1}{J} \times I_{out} = 564 \times 0.15 = 84$ "

" $N_{FB} = \frac{1}{J} \times I_B = 564 \times \frac{0.05}{2} = 14$ "

But the calculated wire size of N_{FB} is too small so a wire size of 84 cirmil is used instead.

$$R_1 = \frac{V_{FB} - V_{BE(sat)}}{I_B} = \frac{5.0 - 0.7}{0.05} = 88$$

$$R_2 = R_1 \left(\frac{V_{in}}{V_B} - 1 \right) = 88 \left(\frac{25}{0.7} - 1\right) = 3120$$

5.1.2 Result

The result is shown in Fig. 6

At rated load the following data are obtained

V_{in} = 25 V, I_{in} = 0.695 A

V_{out} = 100 V, I_{out} = 0.15 A

$V_{CE(sat)}$ = 0.15 V, $V_{BE(sat)}$ = 0.8 V

voltage drop across R_1 = 4.0 V

" " " R_2 = 29 V

resistance of N_2 = 6.4 ohms

" " N_1 = 0.5 ohms

voltage drop across diode when it is ON = 1.2 V

B - H loop of TDK, H 5 B core = 141×10^3 gauss-oersted

Input power, $P_{in} = V_{in} I_{in} = 25 \times 0.695 = 17.4$ W

Output power, $P_{out} = V_{out} I_{out} = 100 \times 0.15 = 15.0$ W

Efficiency, $\eta = \frac{P_{out}}{P_{in}} \times 100 = \frac{15.0}{17.4} \times 100 = 86.2$ %

Over all power loss $= P_{in} - P_{out} = 17.4 - 15.4 = 2.4$ W

Power loss in diodes $= 4\, V_{diode} \times \frac{I_{out}}{2} = 4 \times 1.2 \times \frac{0.15}{2}$

$= 0.360$ W

" output coil $= I_{out}^2 R_{N_2} = (0.15)^2 \times 6.4$

$= 0.144$ W

Power loss in input coil $= I_{in}^2 R_{N_1} = (0.695)^2 \times 0.5 = 0.216$ W

" R_1 $= \frac{V_{R_1}^2}{R_1} = \frac{(4.0)^2}{88} = 0.182$ W

" R_2 $= \frac{V_{R_2}^2}{R_2} = \frac{(29)^2}{3120} = 0.270$ W

" collector $= V_{CE(sat)} I_C = 0.15 \times 0.695 = 0.104$ W

" base $= V_{BE(sat)} I_B = 0.8 \times 0.05 = 0.040$ W

" core $= \frac{V f}{4\pi} \oint HdB \times 10^{-7}$

$$= \frac{3.54 \times 2.75 \times 10^3 \times 141 \times 10^3}{4\pi} = 1.092 \text{ W}$$

switching loss $= \frac{1}{T} \int VIdt \cong \frac{1}{400} \int_0^7 1.5 \times \frac{6}{7} t \, dt$

$= 0.079$ W

Total loss $= 2.487$ W

5.2 15 W, 25-100 V, Driven Converter

5.2.1 Design

Given $P_{out} = 15$ W

$V_{in} = 25$ V

$V_{out} = 100$ V

$$I_C = \frac{P_{in}}{\eta V_{in}} = \frac{15}{0.8 \times 25} = 0.75 \text{ A}$$

$$I_o = \frac{P_{out}}{V_{out}} = \frac{15}{100} = 0.15 \text{ A}$$

Select 2N 3740 transistor (its specifications are given in section 5.1 ; 1)

$$I_B = \frac{2 I_C}{h_{FE(min)}} = \frac{2 \times 0.75}{30} = 0.05 \text{ A}$$

Select H5B, 2616 ferrite core (its specifications are given in section 5.1.1)

$$J = \left(\frac{2 P_{out} n}{\rho l_w W K_w}\right)^{1/2} = \left(\frac{2 \times 15 \times 0.01}{1.72 \times 10^{-6} \times \pi \times 2.0 \times 0.445 \times 0.5}\right)^{1/2}$$

$$= 354 \quad A/cm^2$$

$$\frac{1}{J} = \frac{1}{354 \times 5.07 \times 10^{-6}} = 564 \quad \text{cir mil / A}$$

$$B_{max} = 0.8 B_{sat} = 0.8 \times 4100 = 3280 \quad \text{gauss}$$

$$f = \frac{P_{out} \times 10^8}{2K_w B_{max} J A_{core} W} = \frac{15 \times 10^8}{2 \times 0.5 \times 3280 \times 354 \times 0.94 \times 0.445}$$

$$= 3.44 \quad \text{kHz}$$

$$N_1 = \frac{V_{in} \times 10^8}{4f B_{max} A_{core}} = \frac{25 \times 10^8}{4 \times 3.44 \times 10^3 \times 3280 \times 0.94}$$

$$= 59$$

$$N_2 = K_1 N_1 \frac{V_{out}}{V_{in}} = 1.05 \times 59 \times \frac{100}{25} = 248$$

$$\text{wire size of } N_1 = \frac{1}{J} \times \frac{I_C}{2} = 564 \times \frac{0.75}{2} = 212 \quad \text{cirmil}$$

$$\text{" } N_2 = \frac{1}{J} \times \frac{I_{out}}{2} = 546 \times 0.15 = 84 \text{ cirmil}$$

The circuit of the driver that gives $I_B = 0.05$ A and $f = 3.3$ KHz is shown in Fig. 5

5.2.2 Result

At rated load the wave forms are shown in Fig. 7 and the following values are obtained

At $f = 3.3$ kHz $\quad I_{in} = 0.685$ A

$V_{in} = 25$ V

$I_{out} = 0.15$

$V_{out} = 100\ V$

$P_{in} = I_{in}V_{in} = 0.685x25 = 17.1\ W$

$P_{out} = I_{out}V_{out} = 0.15x100 = 15.0\ W$

$$\eta = \frac{P_{out}x100}{P_{in}} = \frac{15.0x100}{17.1} = 87.8\ \%$$

But the driver circuit draws a power of 2.8 W

$$\text{Thus over-all efficiency} = \frac{15.0x100}{17.1+2.8} = 75.4\ \%$$

By varying the frequency of the driver, it is observed (in Fig. 11) that the maximum efficiency occurred when the frequency is 3.3 kHz, that is, when B_{max} is approximately $0.8B_{sat}$. At higher frequency the efficiency is decreased due to transistor switching loss. At lower frequency, V_{in} is greater than $4fB_{max}A_{core}Nx10^{-8}$ because B_{max} can not be greater than B_{sat} , so the waveforms are as shown in Fig. 7-D and Fig. 7-E and the transistor is operating in active region in some portion of a cycle, and a large amount of collector dissipation loss occurred.

5.3 30W, 25-200V, Self-Oscillating Converter

5.3.1 Design

Given : $P_{out} = 30\ W$

$V_{in} = 25\ V$

$V_{out} = 100\ V$

$$I_C = \frac{P_{in}}{\eta V_{in}} = \frac{30}{0.8x25} = 1.5\ A$$

$$I_{out} = \frac{P_{out}}{V_{in}} = \frac{30}{200} = 0.15\ A$$

Select 2N148N, silicon, npn transistor, which is characterized by: $I_{Cmax} = 3.5$ A, $I_{Bmax} = 1.5$ A, $BV_{EBO} = 12$ V,

$BV_{CEO} = 100$ V, $h_{FE(min)} = 20$

$$I_B = \frac{2I_C}{h_{FE(min)}} = \frac{2x1.5}{20} = 0.15 \text{ A}$$

Select TDK, H5B, 6726, ferrite, EE core, which is characterized by: $A_{core} = 1.09 \text{ cm}^2$, $W = 0.445 \text{ cm}^2$, $B_{sat} = 4100$ gauss, mean length for one turn = 6.4 cm.

$$J = \left(\frac{2P_{out}\,n}{\rho\, l_w W K_w}\right)^{\frac{1}{2}} = \left(\frac{2x30x0.005}{1.72x10^{-6}x6.4x0.445x0.4}\right)^{\frac{1}{2}}$$

$$= 392$$

$$\frac{1}{J} = \frac{1}{392x5.07x10^{-6}} = 510 \text{ cir mils/ A}$$

$$f = \frac{P_{out} x\, 10^8}{2K_w B_{max} J A_{core} W} = \frac{30x10^8}{2x0.4x4100x392x1.09x0.445}$$

$$= 4.7 \text{ kHz}$$

$$V_{FB} = (V_{in} V_{BE(sat)})^{\frac{1}{2}} + V_{BE(sat)}$$

$$= (25x0.7)^{\frac{1}{2}} + 0.7 = 4.9 \text{ V}$$

$$N_1 = \frac{V_{in} x\, 10^8}{4fB_{max} A_{core}} = \frac{25x10^8}{4x4.7x10^3x4100x1.09} = 29$$

$$N_2 = \frac{K_1 N_1 V_{out}}{V_{in}} = \frac{1.05x29x200}{25} = 244$$

$$N_{FB} = \frac{K_1 N_1 V_{FB}}{V_{in}} = \frac{1.05x29x4.9}{25} = 6$$

wire size of $N_1 = \frac{1}{J}\frac{I_C}{2} = 510x\frac{1.5}{2} = 382$ cirmils

wire size of $N_2 = \frac{1}{J} I_{out} = 510x\,0.15 = 76.4$ cirmils wire size of N_{FB} use 76.4 cirmil

$$R_1 = \frac{V_{FB} - V_{BE(sat)}}{I_B} = \frac{4.9 - 0.7}{0.15} = 30 \text{ ohms}$$

$$R_2 = R_1\left(\frac{V_{in}}{V_B} - 1\right) = 30\left(\frac{25}{0.7} - 1\right) = 1030 \text{ ohms}$$

5.3.2 Result

At rated load :

$V_{in} = 25$ V

$I_{in} = 1.4$ A

$V_{out} = 202$ V

$I_{out} = 0.148$ A

$P_{in} = V_{in} I_{in} = 25 \times 1.4 = 35.0$ W

$P_{out} = V_{out} I_{out} = 202 \times 0.148 = 29.9$ W

$$\text{Efficiency} = \frac{P_{out}}{P_{in}} \times 100 = \frac{29.9 \times 100}{35.0} = 85.5\ \%$$