AN107

Designing a 2 Transistor Forward Converter Using a CoreMaster E2000Q Core

By
Colonel Wm. T. McLyman

The two transistor forward converter is shown in Figure 1. This type of converter topology is used for powers under 200W.

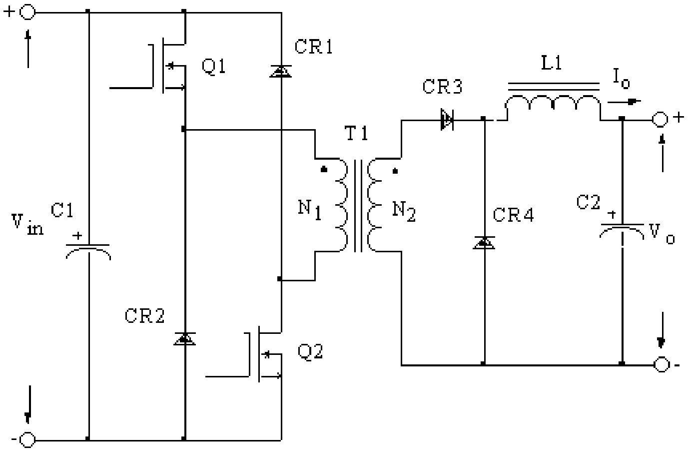

Figure 1. Two transistor forward converter

The dynamic BH loops for the single-ended, forward converter and the push-pull converter are shown in Figure 2

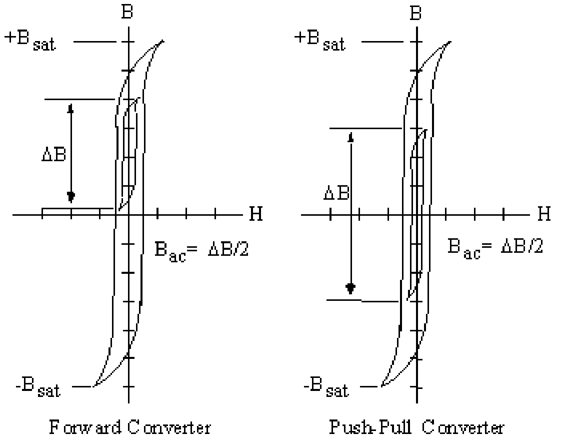

Figure 2. The dynamic BH loop comparison between a single-ended, forward converter and a push-pull converter.

Two Transistor Forward Converter Transformer Design Specification

1.	Input voltage nominal	$V_{nom} = 28$ V
2.	Input voltage minimum	$V_{min} = 24$ V
3.	Input voltage maximum	$V_{max} = 32$ V
4.	Output voltage	$V_O = 5$ V
5.	Output current	$I_O = 10$ A
6.	Frequency	f=100 kHz
7.	Efficiency	$\eta = 98$ %
8.	Regulation	$\alpha = 1.0$ %
9.	Diode voltage drop	$V_d = 1$ V
10.	Design flux density	$\Delta B = 0.1$ T
11.	Use window utilization	$D_{max} = 0.5$
12.	Window utilization	$K_U = 0.4$

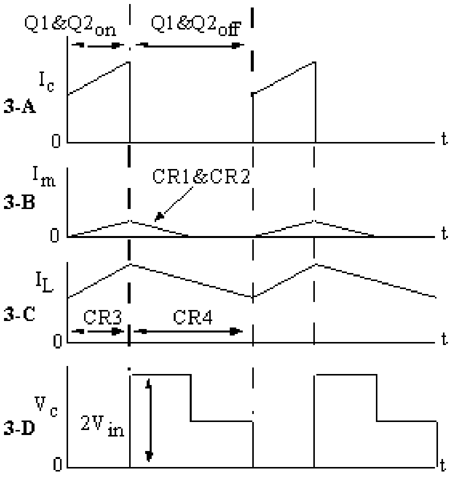

Figure 3. Typical single-ended forward, converter waveforms

The waveforms shown in Figure 3, are typical waveforms of the single-ended forward converter. The collector current Ic is shown in Figure 3-A, and the magnetizing, Im, is shown in Figure 3-B. The inductor L1 current, IL, made up from the rectifier CR3, and the commutating rectifier, CR4, are shown in Figure 3-C. The collector voltage, Vc is shown in figure 3-D.

Select a wire so that the relationship between the AC resistance and the DC resistance is 1:

$$\frac{R_{AC}}{R_{DC}} = 1$$

The skin depth in cm is:

$$d = \frac{6.62}{\sqrt{f}}$$

$$d = \frac{6.62}{\sqrt{100{,}000}} = 0.0209 \text{ [cm]}$$

Then, the wire diameter is:

Wire diameter = 2d
Wire diameter = $2 \cdot 0.0209 = 0.0418$ [cm]

Then, the bare wire area A_W is:

$$A_W = \frac{p D^2}{4}$$

$$A_W = \frac{3.1416 \cdot 0.0418^2}{4} = 0.00137[\mathrm{cm}^2]$$

From the Wire Table, number 26 has a bare wire area of 0.001280 cm^2. This will be the minimum wire size used in this design. If the design requires more wire area to meet the specification, then, the design will use a multifilar of #26. Listed below are #27 and #28, just in case #26 requires too much rounding off.

Wire AWG	Bare Area	Area Ins.	Bare/Ins.	μΩ/cm
#26	0.00128	0.001603	0.798	1345
#27	0.001021	0.001313	0.778	1687
#28	0.000804	0.000105	0.765	2142

Step No. 1 Calculate the total period, T.

$$T = \frac{1}{f}$$

$$T = \frac{1}{100{,}000} = 10 \cdot 10^{-6} \ [\mathrm{s}]$$

Step No. 2 Calculate the maximum transistor on time, $t_{on.}$

$$t_{on} = TD_{MAX}$$

$$t_{on} = 10 \cdot 10^{-6} \cdot 0.5 = \ 5 \ [ms]$$

Step No. 3 Calculate the secondary output power, P_O.

$$P_O = I_O \left(V_O + V_d\right)$$

$$P_O = 10 \cdot (5+1) = 60 \ [\mathrm{W}]$$

Step No. 4 Calculate the total input power, P_{in}

$$P_{in} = \frac{P_O}{h}$$

$$P_{in} = \frac{60}{0.98} = 61.2 \ [\mathrm{W}]$$

Step No. 5 Calculate the electrical coefficient, K_e

$$K_e = 0.145 f^2 \Delta B^2 \cdot 10^{-4}$$

$$K_e = 0.145 \cdot 100{,}000^2 \cdot 0.1^2 \cdot 10^{-4} = 1450$$

Step No. 6 Calculate the core geometry, Kg .

$$K_g = \frac{P_{in} D_{MAX}}{a K_e}$$

$$K_g = \frac{61.2 \cdot 0.5}{1 \cdot 1450} = 0.0211 \ [\mathrm{cm}^5]$$

Step No. 7 Select from the data sheet a E 2000Q core comparable in core geometry, Kg.

Core number	TEA0113Q
Manufacturer	CMI
Magnetic material	E 2000Q

Magnetic path length, MPL	6.44 cm
Core weight, W_{tfe}	18.0 g
Copper weight, W_{tcu}	22.3 g
Mean length turn, MLT	4.1 cm
Iron area, A_c	0.36 cm^2
Window area, W_a	1.539 cm^2
Area product, A_p	0.554 cm^4
Core geometry, K_g	0.0196 cm^5
Surface area, A_t	38.5 cm^2

Step No. 8 Calculate the low line input current, I_{in}.

$$I_{IN} = \frac{P_{IN}}{V_{INMIN}}$$

$$I_{IN} = \frac{61.2}{24} = 2.55\ [\text{A}]$$

Step No. 9 Calculate the primary rms current, I_{Prms}.

$$I_{\Pr ms} = \frac{I_{IN}}{\sqrt{D_{MAX}}}$$

$$I_{\Pr ms} = \frac{2.55}{0.707} = 3.607\ [\text{A}]$$

Step No. 10 Calculate the number of primary turns, N_p.

$$N_p = \frac{V_{IN(MIN)} D_{MAX} \cdot 10^4}{f A_c \Delta B}$$

$$N_P = \frac{24 \cdot 0.5 \cdot 10^4}{100{,}000 \cdot 0.36 \cdot 0.1} = 33\ [\text{turns}]$$

Step No. 11 Calculate the current density J using a window utilization, $K_u = 0.4$.

$$J = \frac{2 P_{IN} \sqrt{D_{\max}} \cdot 10^4}{f A_P \Delta B K_u}$$

$$J = \frac{2 \cdot 61.2 \cdot 0.707 \cdot 10^4}{100{,}000 \cdot 0.554 \cdot 0.1 \cdot 0.4} = 391\ [\text{A/cm}^2]$$

Step No. 12 Calculate the primary bare wire area, A_{wp}.

$$A_{wp} = \frac{I_{\Pr ms}}{J}$$

$$A_{wp} = \frac{3.607}{391} = 0.00923\ [\text{cm}^2]$$

Step No. 13 Calculate the required number of primary strands, NS_p.

$$NS_P = \frac{A_{wp(B)}}{\#26}$$

$$NS_P = \frac{0.00923}{0.00128} = 7.2 \text{ use } 7$$

Step No. 14 Calculate the primary new μΩ/cm.

$$new m\Omega / cm = \frac{m\Omega / cm}{NS_p}$$

$$new m\Omega / cm = \frac{1345}{7} = 192$$

Step No. 15 Calculate the primary winding resistance, R_p.

$$R_P = MLT \cdot N_P \left(\frac{m\Omega}{cm} \right) \cdot 10^{-6}$$

$$R_P = 4.1 \cdot 33 \cdot 192 \cdot 10^{-6} = 0.026 \; [\Omega]$$

Step No. 16 Calculate the primary copper loss, P_P.

$$P_P = I_{\Pr ms}{}^2 R_P$$

$$P_P = 3.607^2 \cdot 0.026 = 0.338 \; [\mathrm{W}]$$

Step No. 17 Calculate the transformer secondary voltage, V_s.

$$V_S = \frac{V_O + V_d}{D_{MAX}}$$

$$V_S = \frac{5+1}{0.5} = 12 \; [\mathrm{V}]$$

Step No. 18 Calculate the secondary turns, N_S.

$$N_S = \frac{N_P \cdot VS}{V_{PMIN}} \left(1 + \frac{a}{100} \right)$$

$$N_S = \frac{33 \cdot 12}{24} \left(1 + \frac{1.0}{100} \right) = 17 \; [\text{turns}]$$

Step No. 19 Calculate the secondary rms current, I_{Srms}.

$$I_{Srms} = I_S \sqrt{D_{MAX}}$$

$$I_{Srms} = 10 \cdot 0.707 = 7.07 \; [\mathrm{A}]$$

Step No. 20 Calculate the secondary bare wire area, A_{ws}.

$$A_{ws(B)} = \frac{I_{S\,rms}}{J}$$

$$A_{ws(B)} = \frac{7.07}{391} = 0.0181 \; [\mathrm{cm}^2]$$

Step No. 21 Calculate the required number of secondary strands, NS_s.

$$NS_S = \frac{A_{ws(B)}}{\#26}$$

$$NS_S = \frac{0.0181}{0.00128} = 14.1 \text{ use } 14$$

Step No. 22 Calculate the secondary, new μΩ/cm.

$$(new) m\Omega / cm = \frac{m\Omega / cm}{NS_S}$$

$$(new) m\Omega / cm = \frac{1345}{14} = 96.1$$

Step No. 23 Calculate the secondary winding resistance, R_S.

$$R_S = MLT \cdot N_S \left(\frac{m\Omega}{cm}\right) \cdot 10^{-6}$$

$$R_P = 3.4 \cdot 25 \cdot 336 \cdot 10^{-6} = 0.0252\ [\Omega]$$

Step No. 24 Calculate the secondary copper loss, P_S.

$$P_S = I_{Srms}{}^2 R_S$$

$$P_P = 7.07^2 \cdot 0.0067 = 0.335\ [\mathrm{W}]$$

Step No. 25 Calculate the total primary and secondary copper loss, P_{cu}.

$$P_{CU} = P_P + P_S$$

$$P_{CU} = 0.338 + 0.335 = 0.673\ [\mathrm{W}]$$

Step No. 26 Calculate the regulation, α.

$$a = \frac{P_{CU}}{P_O}$$

$$a = \frac{0.673}{60} \cdot 100 = 1.12\%$$

Step No. 27 Calculate the window utilization K_U.

$$K_U = \frac{NA_{W(\#26)}}{W_a}$$

$$N = N_P \cdot NS_P + N_S \cdot NS_S$$

$$N = 33 \cdot 7 + 17 \cdot 14 = 469$$

$$K_U = \frac{469 \cdot 0.00128}{1.539} = 0.39$$

Step No. 28 Calculate the mW/g.

$$mW/g = 8.64 \cdot 10^{-7} \cdot f^{1.834} \cdot B_{AC}^{2.1122}$$

$$mW/g = 8.64 \cdot 10^{-7} \cdot 100{,}000^{1.834} \cdot 0.05^{2.1122} = 2.28$$

Step No. 29 Calculate the core loss, P_{Fe}.

$$P_{Fe} = (mW/g) \cdot W_{tfe} \cdot 10^{-3}$$

$$P_{Fe} = 2.28 \cdot 18 \cdot 10^{-3} = 0.041\ [\mathrm{W}]$$

Step No. 30 Calculate the total loss, P_Σ.

$$P_\Sigma = P_{Cu} + P_{Fe}$$

$$P_\Sigma = 0.673 + 0.041 = 0.714\ [\mathrm{W}]$$

Step No. 31 Calculate the Watts density, Ψ.

$$\Psi = \frac{P_\Sigma}{A_t}$$

$$\Psi = \frac{0.714}{38.5} = 0.0185\ [\mathrm{W/cm^2}]$$

Step No. 32 Calculate the temperature rise, T_r.

$$T_r = 450 \cdot \Psi^{0.826}$$

$$T_r = 450 \cdot 0.0185^{0.826} = 16.6\ [^\circ\mathrm{C}]$$

Step No. 33 Calculate the transformer efficiency, η

$$h = \frac{P_O}{P_O + P_\Sigma}$$

$$h = \frac{60}{60 + 0.714} \cdot 100 = 98.8 \text{ [\%]}$$

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For information regarding the above Books and Companion Software for Windows 95', 98' and NT, contact:

Kg Magnetics, Inc.
38 West Sierra Madre Blvd, Suite J
Sierra Madre, Ca. 91024
Phone: (626) 836-7233, Fax: (626) 836-7263
Web Page: www.kgmagnetics.com
Email: sheassoc@pacbell.net