AN109

Push-Pull Converter Design Using a
CoreMaster E2000Q Core

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The single output push-pull converter is shown in Fig.1.

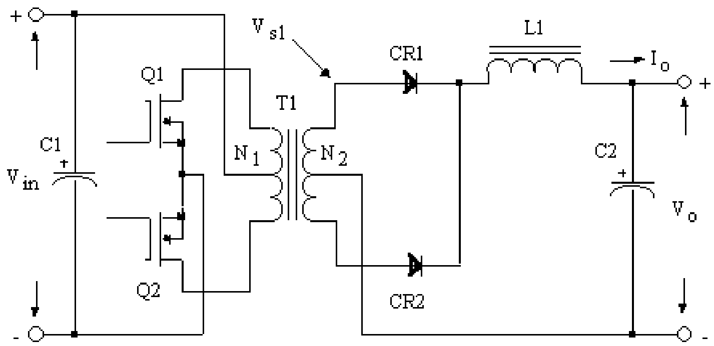

Figure 1 Single output push-pull converter.

Push-Pull 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.	Output circuitry	Center tapped
7.	Frequency	f=100 kHz
8.	Regulation	$\alpha = 0.5$ %
9.	Efficiency	$\eta = 98$ %
10.	Operating flux density	$B_m = 0.1$T
11.	Window utilization	$K_U = 0.4$
12.	Diode voltage drop	$V_d = 1$ V
13.	Duty ratio	$D_{max} = 0.5$
14.	Temperature rise	$T_r = 25°C$

At this point, 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 = 2*d*
Wire diameter = 2·0.0209= 0.0418 [cm]

Then, the bare wire area A_W is:

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

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

From the Wire Table, number 26 has a bare wire area of 0.001280 centimeters. 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 transformer output power, P_O.

$$P_O = I_O (V_O + V_d)$$

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

Step No. 2. Calculate the total apparent power, P_t.

$$P_t = P_O \left(\frac{\sqrt{2}}{h} + \sqrt{2} \right)$$

$$P_t = 60 \left(\frac{1.41}{0.98} + 1.41 \right) = 171\ [\text{W}]$$

Step No. 3. Calculate the electrical conditions, K_e

$$K_e = 0.145 \cdot K_f^2 \cdot f^{2}\, B_m^2 \cdot 10^{-4}$$

$$K_f = 4 \text{ for square wave}$$

$$K_e = 0.145 \cdot 4^2 \cdot 100{,}000^2 \cdot 0.1^2 \cdot 10^{-4} = 23200$$

Step No. 4. Calculate the core geometry, K_g.

$$K_g = \frac{P_t}{2 \cdot a \cdot K_e}$$

$$K_g = \frac{171}{2 \cdot 23{,}200 \cdot 1} = 0.00369\ [\text{cm}^5]$$

Step No. 5. Select from the data sheet a E2000Q core comparable in core geometry, K_g

Core number	TEA0112Q
Manufacturer	CMI
Magnetic material	E 2000Q
Magnetic path length, MPL	5.11 cm
Core weight, W_{tfe}	9.5 g
Mean length turn, MLT	3.4 cm
Iron area, A_c	0.24 cm^2
Window area, W_a	0.866 cm^2
Area product, A_p	0.208 cm^4
Core geometry, K_g	0.00594 cm^5
Surface area, A_t	24.9 cm^2

Step No. 6. Calculate the number of primary turns N_P using Faradays Law.

$$N_p = \frac{V_{P(MIN)} \cdot 10^4}{f \cdot A_c \cdot B_{AC} \cdot K_f}$$

$$N_P = \frac{12 \cdot 10^4}{100{,}000 \cdot 0.24 \cdot 0.1 \cdot 4.0} = 25 \text{ [turns]}$$

Step No. 7. Calculate the current density J using a window utilization, $K_u = 0.4$.

$$J = \frac{P_t \cdot 10^4}{f \cdot A_P \cdot B_{AC} \cdot K_u \cdot K_f}$$

$$J = \frac{171 \cdot 10^4}{100{,}000 \cdot 0.208 \cdot 0.1 \cdot 0.4 \cdot 4.0} = 514 \text{ [A/cm}^2\text{]}$$

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

$$I_{IN} = \frac{P_O}{V_{IN} \cdot h}$$

$$I_{IN} = \frac{60}{24 \cdot 0.98} = 2.55 \text{ [A]}$$

Step No. 9. Calculate the primary bare wire area, $A_{wp(B)}$

$$A_{wp(B)} = \frac{I_{IN} \cdot \sqrt{D_{MAX}}}{J}$$

$$A_{wp(B)} = \frac{2.55 \cdot 0.707}{514} = 0.00351 \text{ [cm}^2\text{]}$$

Step No. 10. Calculate the required number of primary S_{np}. Using the area of a #26 wire.

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

$$S_{np} = \frac{0.00351}{0.00128} = 2.74 \text{ use } 3$$

Step No. 11. Calculate the primary new μΩ/cm from the number 26AWG.

$$new m\Omega / cm = \frac{m\Omega / cm}{S_{np}}$$

$$new m\Omega / cm = \frac{1345}{3} = 448$$

Step No. 12. Calculate the primary winding resistance, R_p.

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

$$R_P = 3.4 \cdot 25 \cdot 448 \cdot 10^{-6} = 0.0381 \ [\Omega]$$

Step No. 13. Calculate the primary copper loss, P_P.

$$P_P = I_{P\,rms}{}^2 R_P$$

$$P_P = 2.55^2 \cdot 0.0381 = 0.247 \ [W]$$

Step No. 14. Calculate the number of secondary turns, N_S.

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

$$V_S = V_O + V_d$$

$$V_S = 5 + 1 = 6 \ [V]$$

$$N_S = \frac{25 \cdot 6}{24}\left(1 + \frac{1.0}{100}\right) = 6.31 \text{ use } 6 \ [\text{turns}]$$

Step No. 15. Calculate the secondary bare wire area, A_{ws}.

$$A_{ws} = \frac{I_O \cdot \sqrt{D_{MAX}}}{J}$$

$$A_{ws(B)} = \frac{10 \cdot 0.707}{514} = 0.0138 \ [cm^2]$$

Step No. 16. Calculate the required number of secondary strands, S_{ns}.

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

$$S_{ns} = \frac{0.0138}{0.00128} = 10.78 \text{ use } 10$$

Step No. 17. Calculate the secondary new mW per centimeter using number 26 AWG.

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

$$(new)m\Omega / cm = \frac{1345}{10} = 134.5$$

Step No. 18. Calculate the secondary resistance, R_s.

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

$$R_s = 3.4 \cdot 6 \cdot 134.5 \cdot 10^{-6} = 0.0027 \ [\Omega]$$

Step No. 19. Calculate the secondary copper loss, P_S.

$$P_S = I_S{}^2 R_S$$

$$P_P = 10^2 \cdot 0.00274 = 0.274 \ [W]$$

Step No. 20. Calculate the total copper loss, P_{cu}.

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

$$P_{CU} = 0.247 + 0.274 = 0.521 \ [W]$$

Step No. 21. Calculate the transformer regulation, α.

$$a = \frac{P_{CU}}{P_O} \cdot 100\%$$

$$a = \frac{0.521}{60} \cdot 100 = 0.868\%$$

Step No. 22. Calculate the milliwatts per gram, mW/g.

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

$$mW/g = 8.64 \cdot 10^{-7} \cdot 100{,}000^{1.834} \cdot 0.1^{2.1122} = 9.875$$

Step No. 23. Calculate the core loss, P_{Fe}.

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

$$P_{Fe} = 9.875 \cdot 9.4 \cdot 10^{-3} = 0.0928 \text{ [W]}$$

Step No. 24. Calculate the total loss, P_{Σ}.

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

$$P_{\Sigma} = 0.521 + 0.0928 = 0.614 \text{ [W]}$$

Step No. 25. Calculate the watt density, Ψ.

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

$$\Psi = \frac{0.614}{24.9} = 0.0247 \text{ [W/cm}^2\text{]}$$

Step No. 26. Calculate the temperature rise, T_r.

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

$$T_r = 450 \cdot 0.0247^{0.826} = 21 \text{ [}^{\circ}\text{C]}$$

Step No. 27. Calculate the total window utilization K_U.

$$K_U = K_{uP} + K_{uS}$$

$$K_{uS} = \frac{2 \cdot N_S \cdot S_N \cdot A_{ws}}{W_a}$$

$$K_{us} = \frac{2 \cdot 6 \cdot 10 \cdot 0.00128}{0.866} = 0.154$$

$$K_{uP} = \frac{2 \cdot N_P \cdot S_{nP} \cdot A_{wP}}{W_a}$$

$$K_{uP} = \frac{2 \cdot 25 \cdot 3 \cdot 0.00128}{0.866} = 0.222$$

$$K_u = 0.222 + 0.154 = 0.376$$

BIBLIOGRAPHY

Colonel William T. McLyman, Transformer and Inductor Design Handbook, Second Edition, Marcel Dekker Inc., New York, 1988.
Colonel William T. McLyman, Magnetic Core Selection for Transformers and Inductors, Second Edition, Marcel Dekker Inc., 1997
Colonel William T. McLyman, Designing Magnetic Components for High Frequency, dc-dc Converters, Kg Magnetics, Inc., 1993.

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