AN114

Push-Pull Output Inductor Design Using a
LPT E2000Q Core

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The Push-Pull converter with a single output shown in Fig.1.

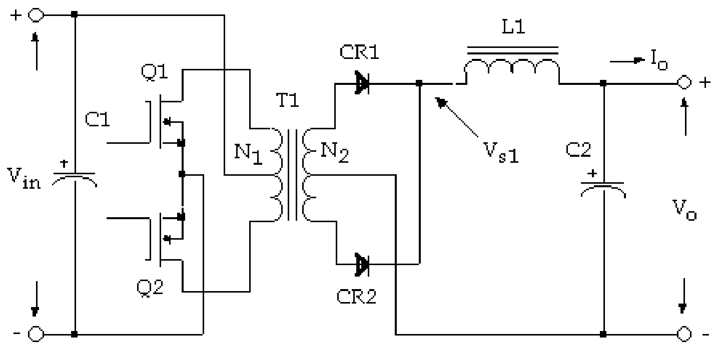

Figure 1 Push-Pull converter with a single output.

Push-Pull Output Inductor Design specification

1.	Frequency	f=100 kHz
2.	Output voltage	$V_O = 5$ V
3.	Output current max	$I_{Omax} = 10$ A
4.	Output current min	$I_{Omin} = 2$ A
5.	Delta current	$\Delta I = 4$ A
6.	Input voltage maximum	$V_{slmax} = 9$ V
7.	Input voltage minimum	$V_{slmin} = 6$ V
8.	Regulation	$\alpha = 1.0\%$
9.	Output power	$P_O = 50$ W
10.	Operating flux density	$B_M = 0.8$ T
11.	Window utilization	$K_U = 0.4$
12.	Diode voltage drop	$V_d = 1$ V

Step No. 1 Calculate the total period, T.

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

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

Step No. 2 Calculate the minimum duty ratio, D_{min}.

$$D_{min} = \frac{V_o}{V_{max}}$$

$$D\min = \frac{5}{9} = 0.555$$

Step No. 3 Calculate the required inductance, L.

$$L = \frac{T \cdot (V_O + V_d) \cdot (1 - D_{min})}{\Delta I}$$

$$L = \frac{10 \cdot 10^{-6} \cdot 6 \cdot (1 - 0.555)}{4} = 6.675 \text{ use } 7\ [m\text{H}]$$

Step No. 4 Calculate the peak current, I_{pk}.

$$I_{pk} = I_{o(\max)} + \frac{\Delta I}{2}$$

$$I_{pk} = 10 + \frac{4}{2} = 12\ [\text{A}]$$

Step No. 5 Calculate the energy-handling capability in watt-seconds, w-s.

$$Energy = \frac{L \cdot I_{pk}^2}{2}$$

$$Energy = \frac{7 \cdot 10^{-6} \cdot 12^2}{2} = 0.000504\ [\text{W} \cdot \text{s}]$$

Step No. 6 Calculate the electrical conditions, K_e.

$$K_e = 0.145 \cdot P_o \cdot B_m^2 \cdot 10^{-4}$$

$$K_e = 0.145 \cdot 50 \cdot 0.8^2 \cdot 10^{-4} = 0.000464$$

Step No. 7 Calculate the core geometry, K_g.

$$K_g = \frac{Energy^2}{K_e \cdot a}$$

$$K_g = \frac{0.000504^2}{0.000464 \cdot 1.0} = 0.000547\ [\text{cm}^5]$$

Step No. 8 Select from the LPT data sheet a E2000Q core comparable in core geometry, K_g.

Core number	GC70111
Manufacturer	CMI
Magnetic path length, MPL	4.1 cm
Core weight, W_{tfe}	4.3 g
Copper weight, W_{tcu}	5.6 g
Mean length turn, MLT	2.7 cm
Iron area, A_c	0.14 cm^2
Window area, W_a	0.581 cm^2
Area product, A_p	0.08132 cm^4
Core geometry, K_g	0.00168 cm^5
Surface area, A_t	16.3 cm^2
Permeability	μ=300
MilliHenries per 1000 turns	mH=129

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

$$I_{rms} = \sqrt{I_{\max}^2 + \left(\frac{\Delta I}{2}\right)^2}$$

$$I_{rms} = \sqrt{10^2 + 2^2} = 10.2 \text{ [A]}$$

Step No. 10 Calculate the current density, J, using a window utilization $K_u = 0.4$.

$$J = \frac{2 \cdot Energy \cdot 10^4}{A_p \cdot B_m \cdot K_u}$$

$$J = \frac{2 \cdot 0.000504 \cdot 10^4}{0.08132 \cdot 0.8 \cdot 0.4} = 387 \text{ [A/cm}^2\text{]}$$

Step No. 11 Calculate the required permeability, Δμ.

$$\Delta m = \frac{B_m \cdot MPL \cdot 10^4}{0.4 \cdot p \cdot W_a \cdot J \cdot K_u}$$

$$\Delta m = \frac{0.8 \cdot 4.1 \cdot 10^4}{0.4 \cdot 3.14 \cdot 0.581 \cdot 387 \cdot 0.4} = 290 \text{ use } 300$$

Step No. 12 Calculate the number of turns, N.

$$N = 1000\sqrt{\frac{L_{(new)}}{L_{1000}}}$$

$$N = 1000 \cdot \sqrt{\frac{0.007}{129}} = 7.37 \text{ use } 7 \text{ [turns]}$$

Step No. 13 Calculate the peak flux density, B_m.

$$B_m = \frac{0.4 \cdot p \cdot N \cdot I_{pk} \cdot m_\Sigma \cdot 10^4}{MPL}$$

$$B_m = \frac{0.4 \cdot 3.14 \cdot 7 \cdot 12 \cdot 300 \cdot 10^4}{4.06} = 0.779 \text{ [T]}$$

Step No. 14 Calculate the required bare wire area, $A_{w(B)}$.

$$A_{w(B)} = \frac{I_{rms}}{J}$$

$$A_{w(B)} = \frac{10.2}{387} = 0.0264 \text{ [cm}^2\text{]}$$

Step No. 15 Select a wire size with the required area from the Wire Table. If the area is not within 10% of the required area, then go to the next smallest size.

$$AWG = \#13$$

$$A_{w(B)} = 0.0263 \text{ [cm}^2\text{]}$$

$$m\Omega / cm = 65.5$$

Step No. 16 Check the ΔI current density using the skin effect ε.

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

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

Calculate the diameter of a #13 AWG:

$$D = \sqrt{\frac{4 \cdot A_{w(B)}}{p}}$$

$$D = \sqrt{\frac{4 \cdot 0.0263}{3.14}} = 0.183 \text{ [cm]}$$

Subtract 2 times the skin depth from the diameter and calculate the new area.

$$D_n = D - 2e$$

$$D_n = 0.183 - 2 \cdot 0.0209 = 0.141 \text{ [cm]}$$

$$A_n = \frac{p \cdot D_n^2}{4}$$

$$A_n = \frac{3.14 \cdot 0.141^2}{4} = 0.0156 \text{ [cm}^2\text{]}$$

Take the difference between A_w and A_n. This will be the area for the ΔI current.

$$A_{\Delta I} = A_{w(B)} - A_n$$

$$A_{\Delta I} = 0.0263 - 0.0156 = 0.0107 \text{ [cm}^2\text{]}$$

Check the current density to see if it is close to the design current density J.

$$J = \frac{\Delta I}{A_{\Delta I}}$$

$$J = \frac{4}{0.0107} = 374 \text{ [A/cm}^2\text{]}$$

ΔI current density J =374
dc current density J = 387

Step No. 17 Calculate the winding resistance, R.

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

$$R_p = 2.7 \cdot 7 \cdot 65.6 \cdot 10^{-6} = 0.00124 \text{ [}\Omega\text{]}$$

Step No. 18 Calculate the copper loss, P_{cu}.

$$P_{cu} = I_{rms}^{\;2} R$$

$$P_{cu} = 10.2^2 \cdot 0.00124 = 0.129 \text{ [W]}$$

Step No. 19 Calculate the magnetizing force in Oersteds, H.

$$H = \frac{0.4 \cdot p \cdot N \cdot I_{pk}}{MPL}$$

$$H = \frac{0.4 \cdot 3.14 \cdot 7 \cdot 12}{4.06} = 25.98 \text{ [Oe]}$$

Step No. 20 Calculate the ac flux density in T, B_{ac}.

$$B_{ac} = \frac{0.4 \cdot p \cdot N \cdot \frac{\Delta I}{2} \cdot m_r \cdot 10^{-4}}{MPL}$$

$$B_{ac} = \frac{0.4 \cdot p \cdot 7 \cdot 2 \cdot 300 \cdot 10^{-4}}{4.06} = 0.13 \text{ [T]}$$

Step No. 21 Calculate the regulation, α, for this design.

$$\text{New Regulation}=\frac{K_{g(required)}}{K_{g(used)}}=\frac{0.000547}{0.00168}=0.326$$

Step No. 22 Calculate the Watts per kilogramm, W/K.

$$W/K=8.64\cdot 10^{-7}\cdot f^{1.834}\cdot B_{ac}^{2.112}$$

$$W/K=8.64\cdot 10^{-7}\cdot 100{,}000^{1.834}\cdot 0.13^{2.112}=17.0\ [\mathrm{W}]$$

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

$$P_{fe}=\left(\frac{mW}{g}\right)\cdot W_{tfe}\cdot 10^{-3}$$

$$P_{fe}=17\cdot 4.3\cdot 10^{-3}=0.0738\ [\mathrm{W}]$$

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

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

$$P_{\Sigma}=0.129+0.0731=0.202\ [\mathrm{W}]$$

Step No. 25 Calculate the watt density, Ψ.

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

$$\Psi=\frac{0.202}{16.3}=0.0124\ [\mathrm{W/cm^2}]$$

Step No. 26 Calculate the temperature rise T_r.

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

$$T_r=450\cdot 0.0124^{0.826}=11.98\ [^{\circ}\mathrm{C}]$$

Step No. 27 Calculate the window utilization, K_U.

$$K_u=\frac{N\cdot S_N\cdot A_{w(\mathbf{B})}}{W_a}$$

$$K_{us}=\frac{7\cdot 1\cdot 0.0263}{0.581}=0.317$$

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