

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.

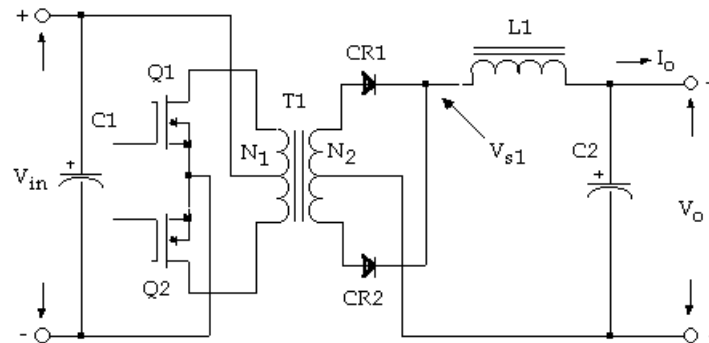


Figure 1 Push-Pull converter with a single output.

Push-Pull Output Inductor Design specification

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

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.

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

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

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 .

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

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

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	$\mu=300$
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 $K_u = 0.4$.

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

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

Step No. 11 Calculate the required permeability, Δm .

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

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

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:

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

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

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

$$D_n = D - 2e$$

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

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

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

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 .

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

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

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 .

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Step No. 25 Calculate the watt density, Ψ .

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

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

Step No. 26 Calculate the temperature rise T_r .

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

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

Step No. 27 Calculate the window utilization, K_u .

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

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

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