AN116

Buck-Boost Isolated Discontinuous Current Design
Using an LPT E2000Q Core

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The Buck-Boost Isolated Converter is shown in Figure 1.

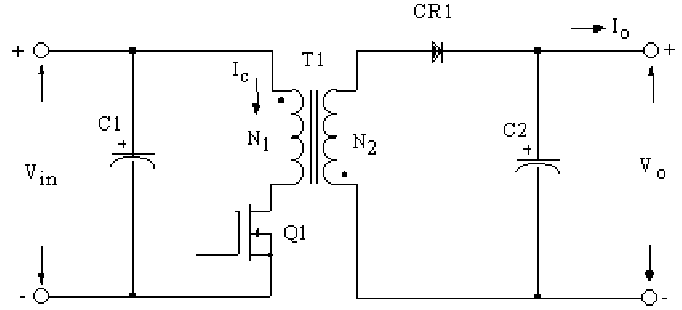

Figure 1. Buck-Boost isolated discontinuous current converter.

Buck-Boost Isolated Discontinuous Current 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 = 5 A
6.	Window utilization	K_U =0.4
7.	Frequency	f=100 kHz
8.	Converter efficiency	η = 90 %
9.	Maximum duty ratio	D_{max}=0.5
10.	Dwell time duty ratio	D_w=0.1
11.	Regulation	α = 1.0 %
12.	Operating flux density	ΔB = 0.4 T
13.	Diode voltage drop	V_d = 1 V

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:

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

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 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

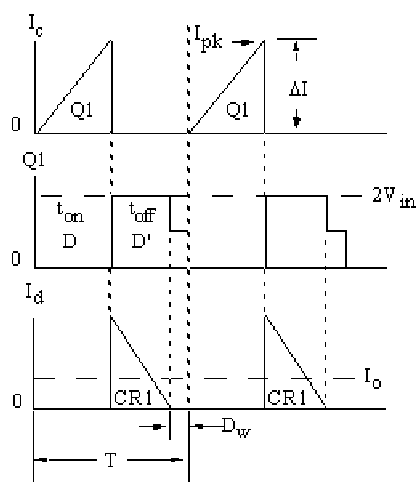

Figure 2. Voltage, current waveforms of a buck-boost isolated discontinuous current converter.

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 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 load power, P_O.

$$P_O = I_O \left(V_O + V_d\right)$$
$$P_O = 5 \cdot (5+1) = 30 \text{ [W]}$$

Step No. 4 Calculate the maximum input current, I_{max}.

$$I_{in(\max)} = \frac{P_o}{V_{\min} \cdot h}$$

$$I_{in(\max)} = \frac{30}{24 \cdot 0.9} = 1.39 \text{ [A]}$$

Step No. 5 Calculate the primary peak current, I_{ppk}.

$$I_{ppk} = \frac{2 \cdot T \cdot P_o}{h \cdot V_{in(\min)} \cdot t_{on(\max)}}$$

$$I_{ppk} = \frac{2 \cdot 10 \cdot 10^{-6} \cdot 30}{0.9 \cdot 24 \cdot 5 \cdot 10^{-6}} = 5.55 \text{ [A]}$$

Step No. 6 Calculate the primary rms current, I_{prms}.

$$I_{prms} = I_{ppk} \cdot \sqrt{\frac{t_{on}}{3 \cdot T}}$$

$$I_{prms} = 5.55 \cdot \sqrt{\frac{5}{3 \cdot 10}} = 2.27 \text{ [A]}$$

Step No. 7 Calculate the required primary inductance, L.

$$L = \frac{V_{in(\min)} \cdot t_{on(\max)}}{I_{ppk}}$$

$$L = \frac{24 \cdot 5 \cdot 10^{-6}}{5.55} = 21.6 \text{ [}m\text{H]}$$

Step No. 8 Calculate the energy-handling capability in watt-second.

$$ENG = \frac{L \cdot I_{ppk}^2}{2}$$

$$ENG = \frac{21.6 \cdot 10^{-6} \cdot 5.55^2}{2} = 0.000333 \text{ [W} \cdot \text{s]}$$

Step No. 9 Calculate the electrical conditions, Ke.

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

$$K_e = 0.145 \cdot 30 \cdot 0.4^2 \cdot 10^{-4} = 0.0000696$$

Step No. 10 Calculate the core geometry, K_g.

$$K_g = \frac{(ENERGY)^2}{K_e \cdot a}$$

$$K_g = \frac{0.000333^2}{0.0000696 \cdot 1.0} = 0.00159 \text{[cm}^5\text{]}$$

Step No. 11. 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. 12 Calculate the number of primary turns, N_p.

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

$$N = 1000 \cdot \sqrt{\frac{0.0216}{39.4}} = 23.4 \text{ use } 23 \text{ [turns]}$$

Step No. 13 Calculate the current density, J, using a window utilization $K_u = 0.4$.

$$J = \frac{2 \cdot (ENERGY) \cdot 10^4}{B_m \cdot A_p \cdot K_u}$$

$$J = \frac{2 \cdot 0.000333 \cdot 10^4}{0.4 \cdot 0.112 \cdot 0.4} = 372 \text{ [A/cm}^2\text{]}$$

Step No. 14 Calculate the required incremental permeability, Δμ.

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

$$\Delta m = \frac{0.4 \cdot 4.7 \cdot 10^4}{0.4 \cdot 3.14 \cdot 0.95 \cdot 372 \cdot 0.4} = 106 \text{ use } 125$$

Step No. 15 Calculate the ac flux density in Tl, B_{ac}, $\Delta I = I_{ppk}$.

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

$$B_{ac} = \frac{0.4 \cdot 3.14 \cdot 23 \cdot 2.775 \cdot 125 \cdot 10^{-4}}{4.7} = 0.213 \text{ [T]}$$

Step No. 16 Calculate the primary wire area, $A_{pw(B)}$.

$$A_{pw(B)} = \frac{I_{prms}}{J}$$

$$A_{pw(B)} = \frac{2.27}{372} = 0.0061 \text{ [cm}^2\text{]}$$

Step No. 17 Calculate the required number of primary strands, S_{np}.

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

$$S_{np} = \frac{0.0061}{0.00128} = 4.77 \text{ use } 5$$

Step No. 18 Calculate the primary the new μΩ/cm.

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

$$(new) m\Omega / cm = \frac{1345}{5} = 269$$

Step No. 19 Calculate the primary winding resistance, R_p.

$$R_p = MLT \cdot N_p \cdot \frac{m\Omega}{cm} \cdot 10^{-6}$$

$$R_p = 2.8 \cdot 23 \cdot 269 \cdot 10^{-6} = 0.0173\ [\Omega]$$

Step No. 20 Calculate the primary copper loss, P_p.

$$P_p = I_p^2 \cdot R_p$$

$$P_p = 2.27^2 \cdot 0.0173 = 0.0891\ [\text{W}]$$

Step No. 21 Calculate the secondary turns, N_s.

$$N_s = \frac{N_p \cdot (V_o + V_d) \cdot (1 - D_{\max} - D_w)}{V_p \cdot D_{\max}}$$

$$N_s = \frac{23 \cdot (5+1) \cdot (1 - 0.5 - 0.1)}{24 \cdot 0.5} = 6.9 \text{ use } 7\ [\text{turns}]$$

Step No. 22 Calculate the secondary peak current, I_{spk}.

$$I_{spk} = \frac{2 \cdot I_o}{1 - D_{\max} - D_w}$$

$$I_{spk} = \frac{2 \cdot 5}{1 - 0.5 - 0.1} = 16.7\ [\text{A}]$$

Step No. 23 Calculate the secondary rms current, I_{srms}.

$$I_{srms} = I_{spk} \cdot \sqrt{\frac{1 - D_{\max} - D_w}{3}}$$

$$I_{srms} = 16.7 \cdot \sqrt{\frac{1 - 0.5 - 0.1}{3}} = 7.47\ [\text{A}]$$

Step No. 24 Calculate the secondary wire area, $A_{sw(B)}$.

$$A_{sw(B)} = \frac{I_{srms}}{J}$$

$$A_{sw(B)} = \frac{7.47}{372} = 0.0201\ [\text{cm}^2]$$

Step No. 25 Calculate the required number of secondary strands, S_{ns}.

$$S_{ns} = \frac{A_{ws}}{wire_A}$$

$$S_{ns} = \frac{0.0201}{0.00128} 15.7 \text{ use } 16$$

Step No. 26 Calculate the secondary the $\mu\Omega$/cm.

$$(new)\, m\Omega / cm = \frac{m\Omega / cm}{S_{ns}}$$

$$(new)\, m\Omega / cm = \frac{1345}{16} = 84$$

Step No. 27 Calculate the winding resistance, R_s.

$$R_s = MLT \cdot N_s \cdot \frac{m\Omega}{cm} \cdot 10^{-6}$$

$$R_s = 2.8 \cdot 7 \cdot 84 \cdot 10^{-6} = 0.00165\ [\Omega]$$

Step No. 28 Calculate the secondary copper loss, P_s.

$$P_s = I_s^2 \cdot R_s$$

$$P_s = 7.47^2 \cdot 0.00165 = 0.0921 \text{ [W]}$$

Step No. 29 Calculate the window utilization, K_u.

$$[turns] = N_p \cdot S_{np} \text{ [primary]}$$

$$[turns] = 23 \cdot 7 = 161 \text{ [primary]}$$

$$[turns] = N_s \cdot S_{ns} \text{ [secondary]}$$

$$[turns] = 7 \cdot 16 = 112 \text{ [secondary]}$$

$$N_t = 273 \text{ turns \# 26}$$

$$K_u = \frac{N_t \cdot A_w}{W_a}$$

$$K_u = \frac{273 \cdot 0.00128}{0.95} = 0.368$$

Step No. 30 Calculate the total copper loss, P_{cu}.

$$P_{cu} = P_p + P_s$$

$$P_{cu} = 0.0891 + 0.0921 = 0.181 \text{ [W]}$$

Step No. 31 Calculate the regulation, α, for this design.

$$a = \frac{P_{cu}}{P_o} \cdot 100\%$$

$$a = \frac{0.181}{30} \cdot 100 = 0.603 \text{ [\%]}$$

Step No. 32 Calculate the magnetizing force in Oersteds, H.

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

$$H = \frac{0.4 \cdot 3.14 \cdot 23 \cdot 5.55}{4.7} = 34.1 \text{ [Oe]}$$

Step No. 33 Calculate the Watts per kilogramm, WK.

$$W/K = 8.64 \cdot 10^{-7} \cdot f^{1.28} \cdot B_{ac}^{2.112}$$

$$W/K = 8.64 \cdot 10^{-7} \cdot 100{,}000^{1.28} \cdot 0.213^{2.112} = 48.5 \text{ [W/kg] or [mW/g]}$$

Step No. 34 Calculate the core loss, P_{fe}.

$$P_{fe} = \frac{mW}{g} \cdot W_{tfe} \cdot 10^3$$

$$P_{fe} = 48.5 \cdot 4.1 \cdot 10^{-3} = 0.199 \text{ [W]}$$

Step No. 35 Calculate the total loss, core P_{fe} and copper P_{cu}, in watts P_Σ.

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

$$P_\Sigma = 0.119 + 0.181 = 0.38 \text{ [W]}$$

Step No. 36 Calculate the watt density, Ψ.

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

$$\Psi = \frac{0.38}{19.8} = 0.0192 \text{ [W/cm}^2\text{]}$$

Step No. 37 Calculate the temperature rise T_r, in degrees °C.

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

$$T_r = 450 \cdot 0.0259^{0.826} = 22\ [^\circ C]$$

BIBLIOGRAPHY

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