AN108

Designing a Half Bridge Converter
Using a CoreMaster E2000Q Core

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The half bridge converter is shown in Figure 1.

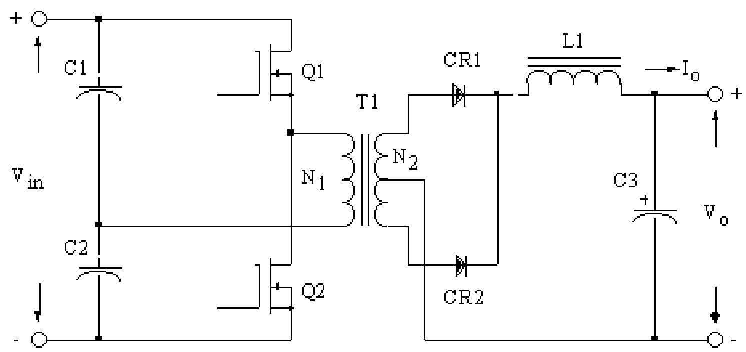

Figure 1. Half bridge converter

The dynamic BH loop for a half bridge push-pull converter is shown in Figure 2.

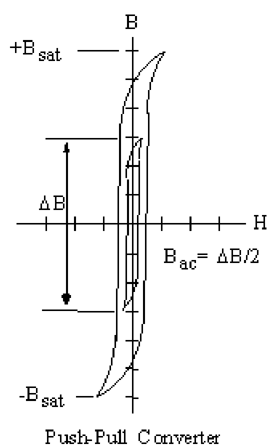

Figure 2 The dynamic BH loop of a push-pull converter.

Half Bridge 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.	Maximum duty ratio	$D_{max} = 0.5$
9.	Regulation	$\alpha = 0.5$ %
10.	Operating flux density	$B_{AC} = 0.2$ T
11.	Diode voltage drop	$V_d = 1$ V
12.	Window utilization	$K_U = 0.4$*
13.	Waveform factor	$K_F = 4.0$
14.	Temperature rise	$T_r = 30°C$

* Note – window utilization will be re-calculated.

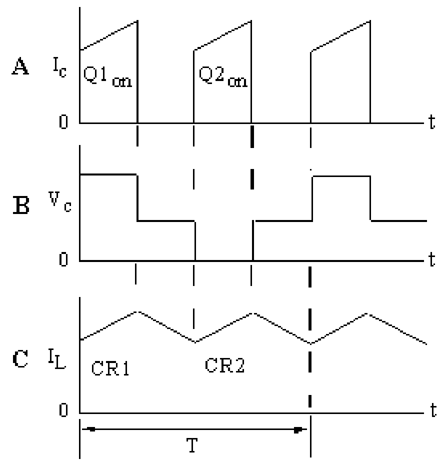

Figure 3. Typical half bridge converter waveforms.

The waveforms shown in Figure 3, are typical waveforms of the half bridge converter. The collector current Ic is shown in Figure 3-A. The collector voltage, Vc is shown in figure 3-B. The inductor L1 current, IL, made up from the rectifier CR2 and CR4 are shown in Figure 3-C.

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 = $2 \cdot 0.0209 = 0.0418$ [cm]

Then, the bare wire area A_W is:

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

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

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

When operating at high frequencies, the engineer has to review the window utilization factor, K_u. Operating at 100kHz and having to use a #26 wire, because of the skin effect, the ratio of the bare copper area to the total area is 0.79. The window utilization factor was developed using a #20 wire, with a bare copper area to the total area ratio of 0.86. Therefore, the overall window utilization K_u is reduced. To return the design back to the norm, the core geometry K_g is to be multiplied by 1.1, and the current density J is calculated, using a window utilization factor of 0.367.

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 output power, P_O.

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

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

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

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

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

Step No. 5 Calculate the apparent power, P_t.

$$P_t = P_O\left(\frac{1}{h} + \sqrt{2}\right)$$

$$P_t = 60\left(\frac{1}{0.98} + 1.41\right) = 146 \text{ [W]}$$

Step No. 6 Calculate the electrical conditions, K_e

$$K_e = 0.145 \cdot K_f^2 \cdot f^{\cdot 2}\ \Delta B_{AC}^2 \cdot 10^{-4}$$

$$K_e = 0.145 \cdot 4^2 \cdot 100{,}000^2 \cdot 0.2^2 \cdot 10^{-4} = 92800$$

Step No. 7 Calculate the core geometry, Kg .

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

$$K_g = \frac{146}{2 \cdot 92800 \cdot 0.5} = 0.00157\ [\mathrm{cm}^5]$$

The core geometry K_g in the data table is calculated using a window utilization of 0.4. Operating at 100kHz and using a #26 AWG the window utilization K_u has to be multiplied 1.1 to bring it back to the norm.

$$K_g = 1.1 \cdot K_g$$

$$K_g = 1.1 \cdot 0.00157 = 0.00173\ [\mathrm{cm}^5]$$

Step No. 8 Select from the data sheet a E 2000Q core comparable in core geometry, K_g.

Core number	TEA0111Q
Manufacturer	CMI
Magnetic material	E 2000Q
Magnetic path length, MPL	4.06 cm
Core weight, W_{tfe}	4.6 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	0.541 cm^2
Area product, A_p	0.0757 cm^4
Core geometry, K_g	0.00158 cm^5
Surface area, A_t	15.9 cm^2

Step No. 9 Calculate the low line input current, I_{in}.

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

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

Step No. 10 Calculate the primary rms current, I_{prms}. When using a half bridge the input current is multiplied by 2 to calculate the primary current.

$$I_{\Pr ms} = \frac{2 \cdot I_{IN}}{\sqrt{2 \cdot D_{MAX}}}$$

$$I_P = \frac{2 \cdot 2.55}{1} = 5.1\ [\mathrm{A}]$$

Step No. 11 Calculate the number of primary turns, N_p. Because this is a half bridge the input voltage is divided by 2.

$$N_p = \frac{V_{in(\min}}{2}$$

$$N_p = \frac{24}{2} = 12[V]$$

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

$$N_P = \frac{12 \cdot 10^4}{100{,}000 \cdot 0.14 \cdot 0.2 \cdot 4.0} = 10.7 \text{ use 10, [turns]}$$

Step No. 12 Calculate the current density J using a window utilization $K_u = 0.367$.

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

$$J = \frac{146 \cdot 10^4}{100{,}000 \cdot 0.0757 \cdot 0.2 \cdot 0.367 \cdot 4.0} = 657 \text{ [A/cm}^2\text{]}$$

Step No. 13 Calculate the required primary bare wire area, A_{wp}.

$$A_{wp} = \frac{I_{Prms}}{J}$$

$$A_{wp} = \frac{5.1}{657} = 0.00776 \text{ [cm}^2\text{]}$$

Step No. 14 Calculate the required number of strands NS_p. Using the area of a #26 wire.

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

$$NS_P = \frac{0.00776}{0.00128} = 6.06 \text{ use 6}$$

Step No. 15 Calculate the primary new μΩ/cm from the number 26AWG.

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

$$new m\Omega / cm = \frac{1345}{6} = 224$$

Step No. 16 Calculate the primary winding resistance, R_p.

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

$$R_P = 2.7 \cdot 10 \cdot 224 \cdot 10^{-6} = 0.00605 \text{ [}\Omega\text{]}$$

Step No. 17 Calculate the primary copper loss, P_P.

$$P_P = {I_{Prms}}^2 R_P$$

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

Step No. 18 Calculate the transformer secondary voltage, V_s.

$$V_S = V_O + V_d$$

$$V_S = 5 + 1 = 6 \text{ [V]}$$

Step No. 19 Calculate the number of secondary turns, N_S.

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

$$N_S = \frac{10 \cdot 6}{12} \left(1 + \frac{1.0}{100} \right) = 5.05 \text{ use 5 [turns]}$$

Step No. 20 Calculate the secondary rms current, I_{Srms}.

$$I_{Srms} = I_S \sqrt{D_{MAX}}$$
$$I_{Srms} = 10 \cdot 0.707 = 7.07 \text{ [A]}$$

Step No. 21 Calculate the secondary bare wire area, A_{ws}.

$$A_{ws(B)} = \frac{I_{S\,rms}}{J}$$
$$A_{ws(B)} = \frac{7.07}{657} = 0.0108 \text{ [cm}^2\text{]}$$

Step No. 22 Calculate the required number of secondary strands, NS_s.

$$NS_S = \frac{A_{ws(B)}}{\#26}$$
$$NS_S = \frac{0.0108}{0.00128} = 8.4 \text{ use } 8$$

Step No. 23 Calculate the secondary new mW per centimeter using number 26 AWG.

$$(new)m\Omega / cm = \frac{m\Omega / cm}{NS_S}$$
$$(new)m\Omega / cm = \frac{1345}{8} = 168$$

Step No. 24 Calculate the winding resistance, R_s.

$$R_S = MLT \cdot N_S \left(\frac{m\Omega}{cm}\right) \cdot 10^{-6}$$
$$R_S = 2.7 \cdot 5 \cdot 168 \cdot 10^{-6} = 0.0227 \text{ [}\Omega\text{]}$$

Step No. 25 Calculate the secondary copper loss, P_S.

$$P_S = I_{Srms}{}^2 R_S$$
$$P_S = 10^2 \cdot 0.00227 = 0.227 \text{ [W]}$$

Step No. 26 Calculate the total copper loss, P_{cu}.

$$P_{CU} = P_P + P_S$$
$$P_{CU} = 0.157 + 0.227 = 0.384 \text{ [W]}$$

Step No. 27 Calculate the regulation, α.

$$a = \frac{P_{CU}}{P_O} \cdot 100\%$$
$$a = \frac{0.384}{60} \cdot 100 = 0.64\%$$

Step No. 28 Calculate the window utilization K_U.

$$N = N_P \cdot NS_P + 2 \cdot N_S \cdot NS_S$$
$$N = 10 \cdot 6 + 2 \cdot 5 \cdot 8 = 140$$
$$K_U = \frac{NA_{W(\#26)}}{W_a}$$
$$K_U = \frac{140 \cdot 0.00128}{0.541} = 0.331$$

Step No. 29 Calculate the true flux density, B_{AC}.

$$B_{AC} = \frac{V_{P\min} \cdot 10^4}{f \cdot A_C \cdot N_P \cdot K_f}$$

$$B_{AC} = \frac{12 \cdot 10^4}{100{,}000 \cdot 0.14 \cdot 10 \cdot 4} = 0.214 \text{ [Tl]}$$

Step No. 30 Calculate mW/g.

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

$$mW/g = 8.64 \cdot 10^{-7} \cdot 100{,}000^{1.834} \cdot 0.214^{2.1122} = 49.2$$

Step No. 31 Calculate the core loss, P_{Fe}.

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

$$P_{Fe} = 49.2 \cdot 4.6 \cdot 10^{-3} = 0.226 \text{ [W]}$$

Step No. 32 Calculate the total loss, P_{Σ}.

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

$$P_{\Sigma} = 0.384 + 0.226 = 0.61 \text{ [W]}$$

Step No. 33 Calculate the watt density, Ψ.

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

$$\Psi = \frac{0.61}{15.9} = 0.0384 \text{ [W/cm}^2\text{]}$$

Step No. 34 Calculate the temperature rise, T_r.

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

$$T_r = 450 \cdot 0.0384^{0.826} = 30.5 \text{ [}^{\circ}\text{C]}$$

Step No. 35 Calculate the transformer efficiency, η

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

$$h = \frac{60}{60 + 0.61} \cdot 100 = 99 \text{ [\%]}$$

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