AN112

Single Ended Regulation only, Mag-Amp Design
Using a CoreMaster E1000S Core

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The Single Ended Forward Converter and Mag-Amp are shown in Figure 1.

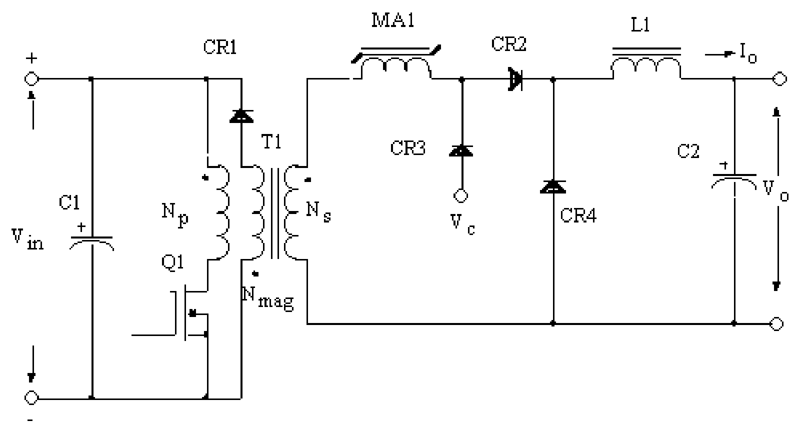
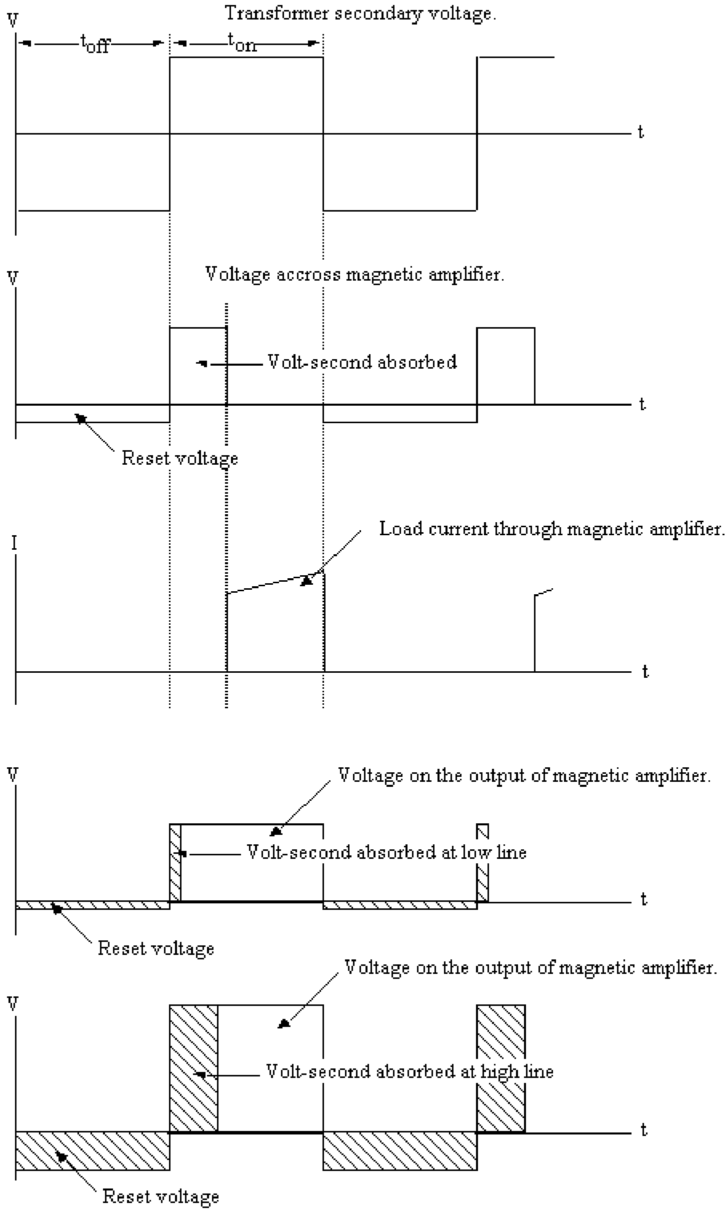


Figure 1. Single ended forward converter with mag-amp.

Single Ended Forward Converter Mag-Amp Design Output Specification

1.	Secondary voltage maximum	V_{Smax} = 16 V
2.	Output voltage	V_O = 5 V
3.	Output current	I_O = 2.5 A
4.	Overwind	O_W=20%
5.	Frequency	f=100 kHz
6.	Maximum duty ratio	D_{max} = 0.5
7.	Operating flux density @100°C	B_{AC} = 0.25 T
8.	Window utilization	K_U =0.2
9.	Current density	J=300 A/cm^2
10.	Control	Regulation only
11.	Magnetic material	E1000S
12.	Diode voltage drop	V_d = 1 V

Ideal Mag-Amp Waveforms



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 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 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 required pulse width, t_{pw}.

$$t_{pw} = \left(V_O + V_d\right) \cdot \frac{t_{on}}{V_{MAX}}$$

$$t_{pw} = \left(5+1\right) \cdot \frac{5}{16} = 1.875\ [ms]$$

Step No. 4 Calculate the mag-amp required micro-seconds, t_{ma}.

$$t_{ma} = \left(t_{on} - t_{pw}\right)$$

$$t_{ma} = \left(5 - 1.875\right) = 3.125\ [ms]$$

Step No. 5 Calculate the mag-amp control and clamp voltage, V_c.

$$t_{off} = \frac{T}{2} = \frac{10}{2} = 5\ [ms]$$

$$V_C = \frac{V_{s\max} \cdot t_{ma}}{t_{off}}$$

$$V_C = \frac{16 \cdot 3.125}{5} = 10\ [\text{V}]$$

Step No. 6 Calculate the rms gate current, $I_{g(rms)}$.

$$I_{g(rms)} = I_O \cdot \sqrt{D_{MAX}}$$

$$I_{g(rms)} = 2.5 \cdot \sqrt{0.5} = 1.77 \text{ [A]}$$

Step No. 7 Calculate the gate wire area, $A_{w(B)}$.

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

$$A_{w(B)} = \frac{1.77}{300} = 0.0059 \text{ [cm}^2\text{]}$$

Step No. 8 Calculate the mag-amp apparent power, P_t.

$$P_t = I_{g(rms)} \cdot V_{s(\max)} \cdot O_w$$

$$P_t = 1.77 \cdot 16 \cdot 1.2 = 34 \text{ [W]}$$

Step No. 9 Calculate the required mag-amp core area product, A_p.

$$A_P = \frac{P_t \cdot t_{ma} \cdot 10^4}{2 \cdot B_{ac} \cdot J \cdot K_u}$$

$$A_P = \frac{34 \cdot 3.125 \cdot 10^{-6} \cdot 10^4}{2 \cdot 0.25 \cdot 300 \cdot 0.2} = 0.0354 \text{ [cm}^4\text{]}$$

Step No. 10 Select from the data sheet a mag-amp core comparable in area product A_p.

Core number	TCM0232
Manufacturer	CMI
Magnetic material	E 1000S
Magnetic path length, MPL	3.5 cm
Core weight, W_{tfe}	2.9 g
Copper weight, W_{tcu}	2.4 g
Mean length turn, MLT	2.0 cm
Iron area, A_c	0.108 cm^2
Window area, W_a	0.232 cm^2
Area product, A_p	0.03584 cm^4
Core geometry, K_g	0.000777 cm^5
Surface area, A_t	10.4 cm^2

Step No. 11 Calculate the number of gate turns, N_g.

$$N_g = \frac{V_{S(\max)} \cdot O_w \cdot t_{ma} \cdot 10^4}{2 \cdot A_c \cdot B_m}$$

$$N_g = \frac{16 \cdot 1.2 \cdot 3.125 \cdot 10^{-6} \cdot 10^4}{2 \cdot 0.108 \cdot 0.25} = 11 \text{ [turns]}$$

Step No. 12 Calculate the required number of gate strands, S_g, and the new μΩ/cm

$$NS_g = \frac{A_{wg}}{\#26}$$

$$NSg_P = \frac{0.0059}{0.00128} = 4.61 \text{ use } 4$$

$$new m\Omega / cm = \frac{m\Omega / cm}{S_g} = \frac{1345}{4} = 336$$

Step No. 13 Calculate the gate winding resistance, R_g.

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

$$R_p = 2.0 \cdot 11 \cdot 336 \cdot 10^{-6} = 0.00739 \ [\Omega]$$

Step No. 14 Calculate the gate copper loss, P_g.

$$P_g = I_g{}^2 R_g$$

$$P_g = 1.77^2 \cdot 0.00739 = 0.0231 \ [\text{W}]$$

Step No. 15 Calculate the window utilization, K_U.

$$K_u = \frac{N_g \cdot A_{w(B)} \cdot NS_g}{W_a}$$

$$K_u = \frac{11 \cdot 0.00128 \cdot 4}{0.332} = 0.169$$

Step No. 16 Calculate the watts per kilogram, WK .

$$WK = 4.154 \cdot 10^{-7} \cdot f^{1.934} \cdot B_{ac} \cdot^{2.249}$$

$$WK = 4.154 \cdot 10^{-7} \cdot 100{,}000^{1.934} \cdot 0.25^{2.249} = 84.9 \ [\text{W/kg}] \text{ or } [\text{mW/g}]$$

Step No. 17 Calculate the core loss, P_{Fe}.

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

$$P_{Fe} = 84.9 \cdot 2.9 \cdot 10^{-3} = 0.246 \ [\text{W}]$$

Step No. 18 Calculate the total loss, P_Σ.

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

$$P_\Sigma = 0.246 + 0.0231 = 0.269 \ [\text{W}]$$

Step No. 19 Calculate the watt density, Ψ.

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

$$\Psi = \frac{0.269}{10.4} = 0.0259 \ [\text{W/cm}^2]$$

Step No. 20 Calculate the temperature rise, T_r.

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

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

Step No. 21 Calculate the magnetizing force in Oersteds, H_c.

$$H_c = \frac{\frac{WK}{2.2}}{0.019 \cdot B_m \cdot f}$$

$$H_c = \frac{\frac{84.9}{2.2}}{0.019 \cdot 0.25 \cdot 100{,}000} = 0.0818 \ [\text{Oe}]$$

Step No. 22 Calculate the control or magnetizing current, I_c.

$$I_m = \frac{H_c \cdot MPL}{1.256 \cdot N_g}$$

$$I_m = \frac{0.0808 \cdot 2.0}{1.256 \cdot 11} = 0.0117 \text{ [A]}$$

BIBLIOGRAPHY

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