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Nonisolated Negative Output Buck/Boost AC/DC Converter

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APPLICATION NOTE

This application note describes the way, how to easily design the simple, nonisolated AC/DC converter for powering low voltage control part of mains applications with triac, or SCR power switch. Some examples are: dishwashers, microwave ovens, coffee machines, night illumination and so on. In comparison with resistive, or capacitive dropper is this solution more comfortable and features some advantages such as:

- Wide Input Voltage range 85 VAC – 265 VAC
- Smaller Size, Lower Weight, Lower Total Cost
- Good Line and Load Regulation, No Need of Additional Linear Regulators
- Efficient Design with Up to 80% Efficiency
- Overload, Short−Circuit and Thermal Protected
- Simple for Low Cost Mass Production
- Universal Design for Wide Range of Output Currents and Voltages

The monolithic power switcher, used in this application, greatly simplifies the total design and reduces time to production. The new line of the Power Switchers, NCP1010 through NCP1014, is ideal for this purpose. This IC in the SOT−223 package reduces size and is suitable for mass production. The design consists of input filter, rectifier with filtering capacitor, power stage with switcher and inductor, output ultrafast rectifier, output filtering capacitor, feedback loop with zener diode and optocoupler and indicating LED. The only component necessary for proper powering of the IC is the V_{CC} capacitor. The IC is directly powered from the HV Drain circuit via internal voltage regulator. To eliminate the noise at the feedback input, some small ceramic capacitor with value of around 1.0 nF is necessary to be connected as close to the FB pin, as possible.

Schematic diagram

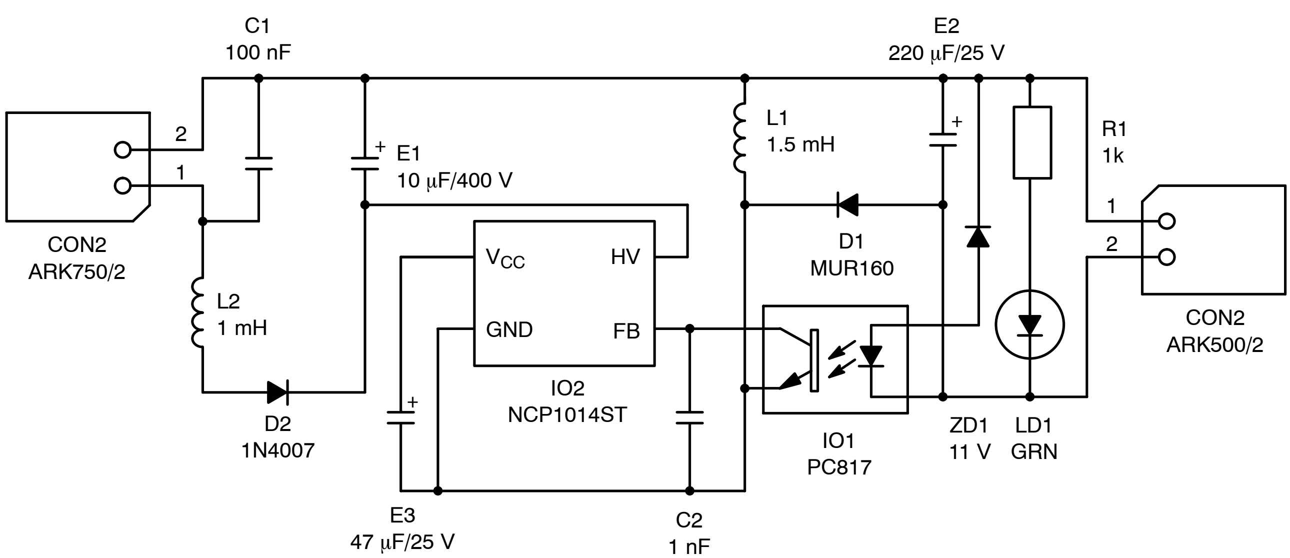

Figure 1. Complete Schematic Diagram of the 12 V/0.2 A Converter

SELECTION OF CRITICAL COMPONENTS

Inductor selection

For the selected output power need to be selected certain minimum value of the inductance. This value is dependent on the mode of operation. Reduced value results in Discontinuous Conduction Mode of operation (DCM). Practically was found, that the borderline between Continuous Conduction Mode of operation (CCM) and DCM is commonly set slightly below maximum output power. The result is low cost of the inductor, freewheeling diode (t_{rr} > 35 ns), higher efficiency and lower cost. The negative result is in lower output power and higher cost of the NCP101x Power Switcher.

The current ripple in the inductor during the T_{on} time may be expressed by Equation 1.

$$\Delta I_{ripple}(T_{on}) = T_{on} \cdot \left(\frac{(V_{min} - V_{ds})}{L_{min}}\right) \qquad \text{(eq. 1)}$$

Where:
T_{on} = ON Time, Internal Power Switch in ON,
V_{min} = Minimum Rectified Input Voltage,
V_{ds} = Drain−to−Source Voltage Drop,
L_{min} = Minimum Inductor Value.

The current ripple in the inductor during the T_{off} time may be expressed by Equation 2.

$$\Delta I_{ripple}(T_{off}) = T_{off} \cdot \frac{V_O}{L_{min}} \qquad \text{(eq. 2)}$$

Where:
T_{off} = OFF Time, Internal Power Switch in OFF,
V_O = Output Voltage.

The current through the inductor at the beginning of the T_{on} time is;

$$I_{init} = I_{set} - \Delta I_{ripple} \qquad \text{(eq. 3)}$$

Where:
I_{set} = Peak Switching Current set by the FB Loop.

The average current through the inductor over one switching cycle can be expressed by Equation 4.

$$I_c = f_{op\_min} \cdot \left(\left(\frac{\Delta I_{ripple}}{2 + I_{init}}\right) \cdot T_{on} + \left(\frac{\Delta I_{ripple}}{2 + I_{init}}\right) \cdot T_{off}\right) \qquad \text{(eq. 4)}$$

Where:
I_c = Inductor Operating Current,
f_{op_min} = Minimum Operating Frequency.

The theoretical minimum inductor value corresponds to Equation 5.

$$L_{min} = \frac{(2 \cdot (V_O \cdot I_O))}{(\Delta I_{ripple}^2 \cdot f_{op\_min})} \qquad \text{(eq. 5)}$$

Where
I_o = Output DC Current.

The theoretical maximum output power in DCM mode will be as shown in Equation 6.

$$P_{out\_max} = L_{min} \cdot \Delta I_{ripple}^2 \cdot \frac{f_{op\_min}}{2} \qquad \text{(eq. 6)}$$

The theoretical maximum output power in CCM mode will be as shown in Equation 7.

$$P_{out\_max} = L_{min} \cdot I_{set} \cdot \Delta I_{ripple} \cdot f_{op\_min} - L_{min} \cdot \Delta I_{ripple}^2 \cdot \frac{f_{op\_min}}{2} \qquad \text{(eq. 7)}$$

The current ripple in the inductor during the normal operation in the DCM, or CCM mode will be as shown in Equation 8.

$$\Delta I_{ripple} = \frac{(V_{min} \cdot V_O)}{((V_{min} + V_O) \cdot f_{op\_min} \cdot L_{min})} \qquad \text{(eq. 8)}$$

TABLE OF PRESELECTED INDUCTORS (V_{min} = 120 V, V_O = 12 V, f_{op_min} = 59 kHz)

Inductance (μH)	Coilcraft Part Number (see appendix for address)	ΔI_{ripple} (A)	Output Current (A)
470	RFB0810−471	0.39	0.18
680	RFB0810−681	0.27	0.24
820	RFB0810−821	0.23	0.26
1000	RFB0810−102	0.18	0.27
1500	RFB0810−152	0.12	0.30

NOTE: The output current is the theoretical value and need to be multiplied by the efficiency (~0.7).

Freewheeling diode selection

The freewheeling diode needs to be selected accordingly to the mode of operation. For the CCM operation needs to be used the ultra fast diode with t_{rr} < 35 ns. For the DCM operation the standard ultra fast diode with t_{rr} < 75 ns is enough.

TABLE OF PRESELECTED FREEWHEELING DIODES

Part number	V_{RRM} (V)	$I_{F(AV)}$ (A)	t_{rr} (ns)	Package
MUR160	600	1.0	75	Axial Lead
MURA160T3	600	1.0	75	SMD SMA
MURS160T3	600	1.0	75	SMD SMB
MURS260T3	600	2.0	75	SMD SMB

Electrical Specification of the Example in Figure 1:
Input: 85 VAC – 265 VAC
Output: + 12 V / 200 mA

NOTE: The polarity is proportional to the common line.

COMPONENT LAYOUT

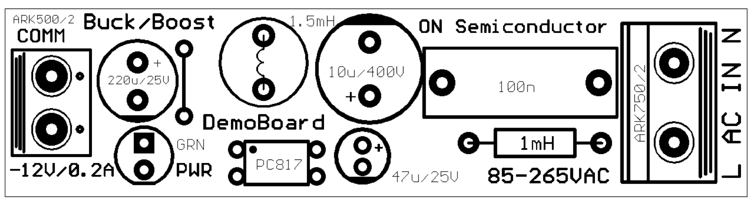

Figure 2. Component Layout – Top Side

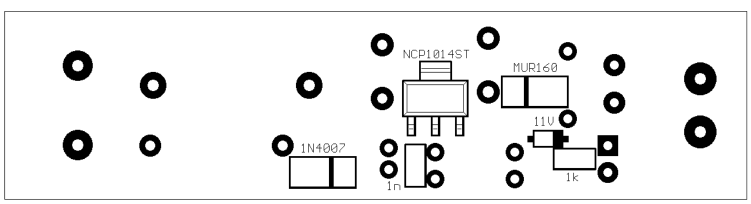

Figure 3. Component Layout – Bottom Side

PCB LAYOUT

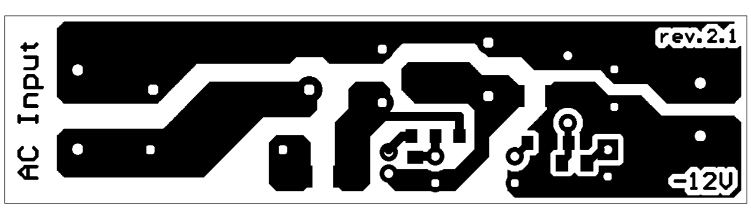

Figure 4. PCB Layout

EMI TEST RESULTS

Test Conditions:
Input: 230 VAC
Output: 11.7 VDC
Load: Resistive 68 R

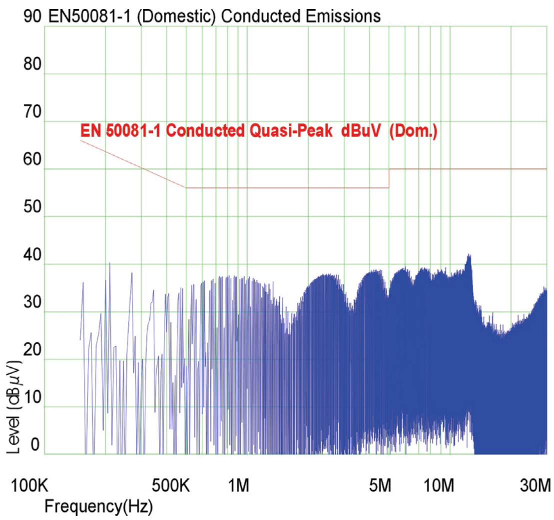

Figure 5. Conducted EMI

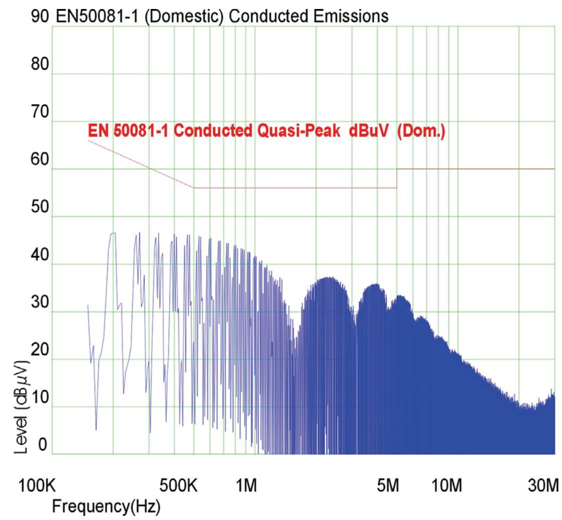

Figure 6. Magnetic Radiation

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