AN1357
APPLICATION NOTE

VIPower: LOW COST POWER SUPPLIES USING VIPer12A IN NON ISOLATED APPLICATIONS

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INTRODUCTION

The industrial field is asking for an increasing number of low power low voltage applications both in isolated and non isolated topology. The main specification is related to the cost of the power converter, which has to be operated in off-line mode. VIPer12A is a low cost monolithic smart power device with an integrated PWM controller that is suitable for such applications. In this paper a detailed analysis of VIPer12A in non isolated applications is performed, exploiting the main features of such a device, in Buck and Buck-boost configuration.

1. OFF-LINE NON ISOLATED CONVERTERS

Off-line non isolated topologies convert the mains to regulated DC voltage with no need of any isolation transformer, adjusting the duty cycle of a power switch. The energy is transferred from input to output by a low cost inductor.

Two main topologies are used to generate either positive or negative voltage with respect to the common terminal of the input voltage, "step down" (or "buck") and "step-down/up" (or "buck-boost") topology respectively, shown in figure 1.

Both topologies use an inductor for energy storage, charged during the turn-on of the power switch. The inductor current waveform defines the mode of operation of the converter, i.e. "continuous" and "discontinuous". In the continuous mode, the inductor current never goes to zero, while in the discontinuous mode such a current is zero for a given time period. A "boundary mode" is also defined, referring to a single zero point of the inductor current.

In continuous mode, both converters operate like a transformer with a voltage ratio continuously controlled electronically by means of duty cycle of the switch, D, defined by the ratio between the turn on time, t_{on}, and the switching period T_s, according to (1) and (2):

$$\frac{V_o}{V_i} = D \qquad\qquad \text{buck converter} \qquad\qquad (1)$$

$$\frac{V_o}{V_i} = \frac{D}{1-D} \qquad\qquad \text{buck-boost converter} \qquad\qquad (2)$$

When the switch is on, there is a constant voltage across the output inductor (V_i-V_o), making the current in it rising linearly at a rate, di/dt, given by (3).

$$\frac{di}{dt} = \frac{V_i - V_o}{L} \qquad\qquad (3)$$

As the switch is turned off, the voltage polarity across the inductor immediately reverses trying to maintain the same current as just before turn off. The diode turns on and clamps the inductor voltage to ideally zero. The voltage across L is V_o and its current ramps down linearly at a rate given by (4).

$$\frac{di}{dt} = -\frac{V_o}{L} \qquad\qquad (4)$$

Once the switch turns on again the current in L is diverted from D to the switch S, back biasing the diode. The current in L consists in the switch current when it is on and in the diode current when the switch is off. The inductor current ramps up and down around the DC value I_o with a ripple determined by the L value.

Figure 1: Not isolated power converters

Buck configuration

Buck-boost configuration
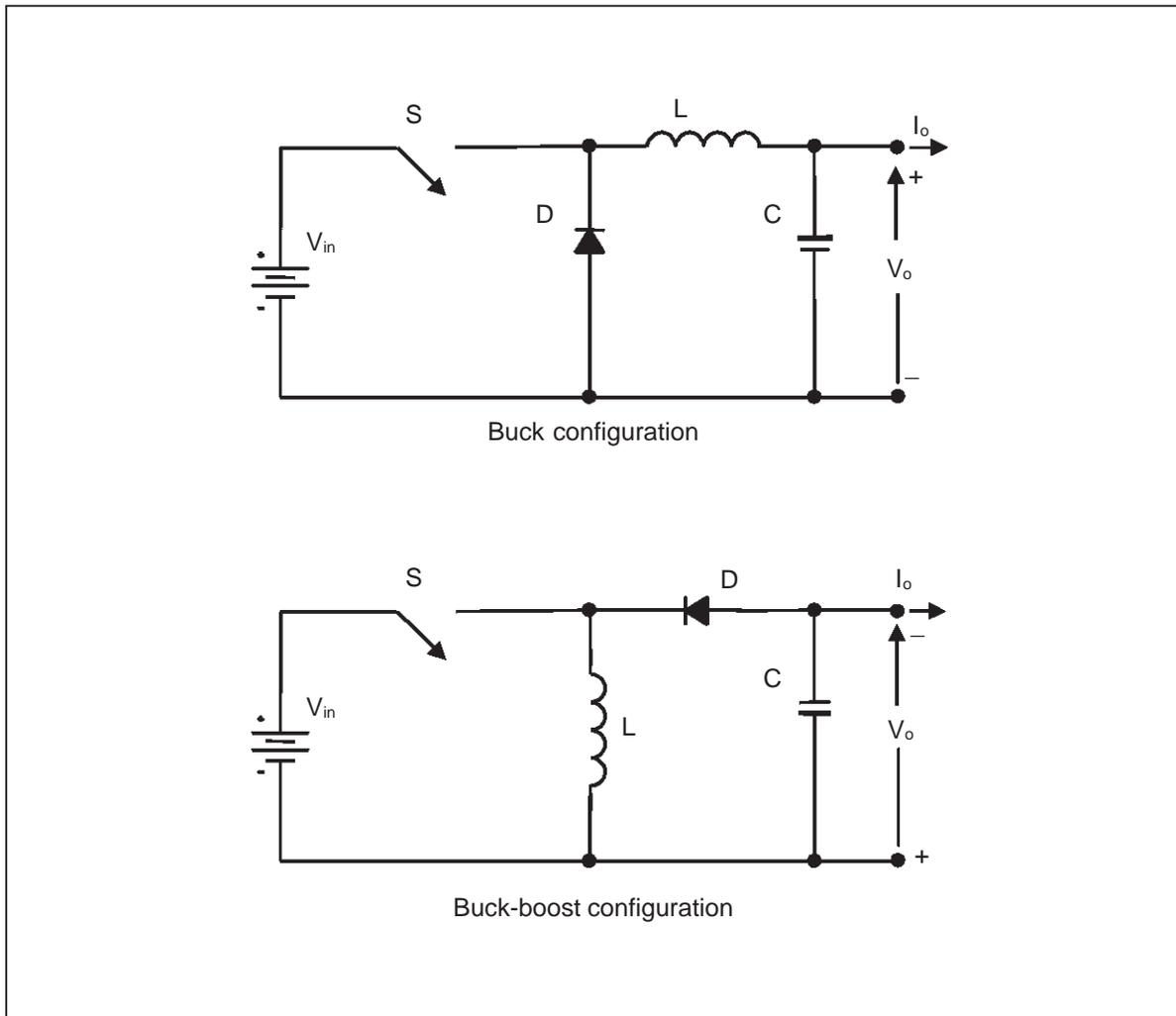
2. FRONT-END RECTIFIER

Single wave or bridge rectifiers could be used for mains rectification. However, if the neutral connection is required as ground, the single wave rectifier has to be used. Such a choice determines the minimum input filter capacitance value.

The rectifier diode is rated for 800V to 1000V of reverse voltage with a 1A current since the power level of the considered application is low.

The input bulk capacitor is determined on the basis of the minimum input voltage (that depends on the power supply specifications, i.e. single or wide range) and on the maximum voltage ripple acceptable in the input voltage. The rectifier topology, i.e. single wave or full bridge, affects the value of the minimum input capacitance as well.

A basic consideration has to be taken about the value of the bulk capacitor: although larger values mean low peak and rms current through the power device and less duty cycle adjustment for regulation, a higher peak current is drawn from the mains, leading to higher power dissipation in the rectifier and poorer harmonic behavior.

For low power applications a good compromise is given by the peak-to-peak voltage ripple of 25-30% related to the peak mains voltage. If hold-up capability is required, a larger capacitor is needed.

When a VIPer12A is used as a power switch, a minimum DC input voltage (i.e. 50V) is needed to perform a proper start-up operation, thus a higher voltage ripple is allowed. In conclusion, the input bulk capacitor is selected to provide the minimum DC voltage with the lower input AC voltage and the maximum load, in order to enable VIPer12A control circuit. In such a way, a better power quality performance is obtained with no effect on the output voltage regulation, thanks to the high switching frequency and the current mode control of VIPer12A.

Single wave rectification has been chosen to have the output ground connected to one of the mains lines, as is required in most of non isolated applications.

High-grade electrolytic capacitors with high ripple current capacity and low ESR are usually used with a rated voltage of 400Vdc minimum. Referring to Fig. 2, for a given output power P_{out} and voltage ripple $\Delta V (= V_{inpeak} - V_{inlow})$, the input capacitor C_{in} can be calculated using eq. (5).

$$C_{in} = \frac{I \cdot t}{\Delta V} = \frac{\dfrac{P_{out}}{\eta \cdot V_{indc}} \cdot t}{\Delta V} \tag{5}$$
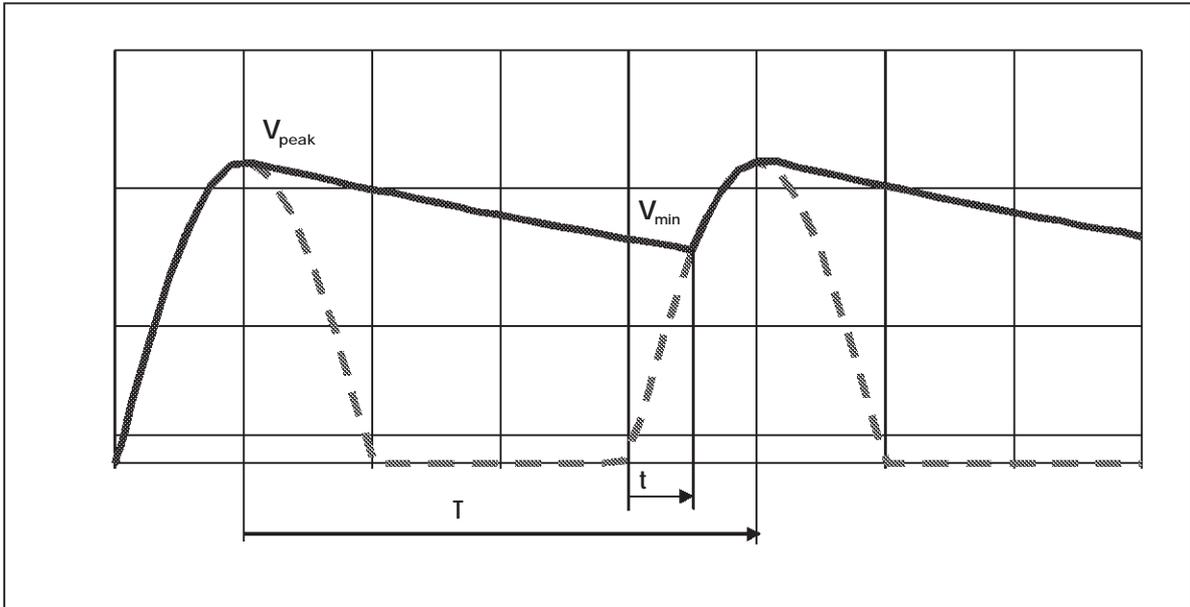
where "I" is the discharging current, η is the efficiency, V_{indc} is the DC input voltage and "t" is the time during which the capacitor must supply current, given by (6).

$$t = 0.75 \cdot T + \Delta T = 0.75 \cdot T + \frac{T}{2\pi} \cdot \arcsin \frac{V_{inlow}}{V_{peak}} \tag{6}$$

The DC input voltage is given by:

$$V_{indc} = \sqrt{2} \cdot V_{inac} \tag{7}$$

Figure 2: DC bus voltage

3. EMI INPUT FILTER

EMI is an issue for SMPS since it is a requirement for CE certification. Some applications may require a decoupling input filter to limit the conducted emission to the mains. The limits established by EU depend on the classification of the power supply, whether industrial or domestic appliances. In order to comply with standard requirements, simple filters can be used in low cost applications, as shown in figure 3, reducing the common-mode emissions. The most common filter topology is the CLC π filter, however for very noisy high performance circuits the multistage approach is a mandatory solution.

Figure 3: Basic EMI filter
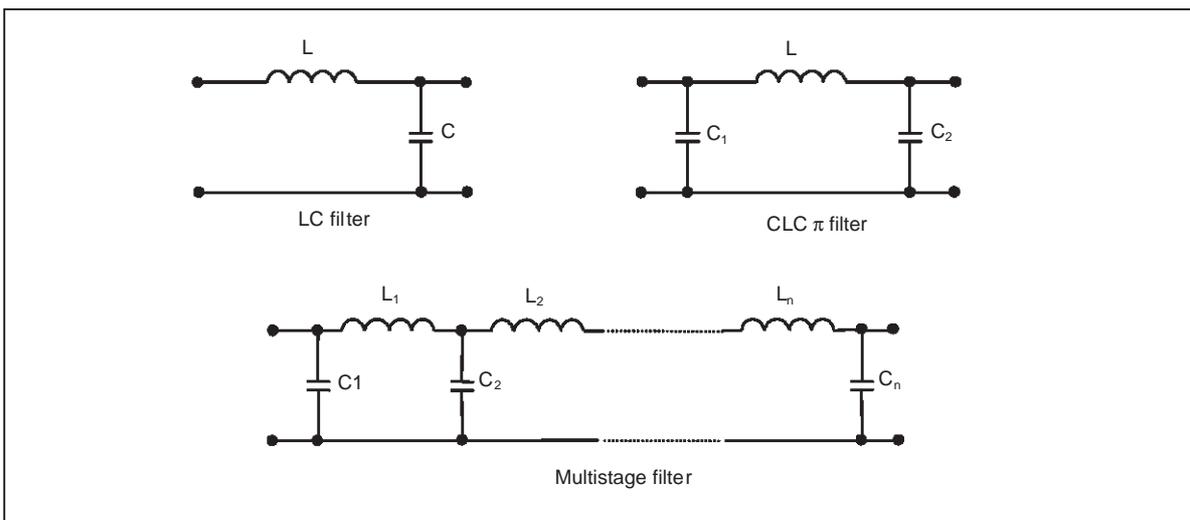
Considering a CLC π filter, a simplified design method is given, based on the corner frequency of the 2nd order filter, providing a dumping factor ζ higher than 0.5 and a corner frequency much lower than the switching frequency.

4. OUTPUT INDUCTOR

The design of the output inductor depends on the converter topology as described hereafter for the Buck and Buck-boost converter respectively.

4.1. BUCK CONVERTER

As described in Section 1, the energy is stored in the inductor L during the on-time and then released to the load during the off-time of the power device. Thus the load is fed both during the on-time and off-time of the power switch. Since the energy related to the free-wheeling period is negligible compared to the energy transferred during the on-time -considering only the power transferred to the load during on-time- the inductor value is given by (8) with a good approximation.

$$L \cong \frac{2 \cdot P_{out}}{I_{dpeak}^2 \cdot f_{sw}} \tag{8}$$

where: "I_{dpeak}" is the maximum allowable peak drain current and "f_{sw}" is the switching frequency.

The value of L determines whether the circuit operates in continuous mode or discontinuous mode for a given output current. Regulators operating in the discontinuous mode are very stable and have a very good closed loop response; therefore, the discontinuous mode is preferred. However, in discontinuous mode the current stress is higher for a given output power, increasing the ratings of power devices and decreasing the reliability of the system.

The boundary condition between continuous and discontinuous modes of operation is given by (9), thus to operate in discontinuous mode, the inductor value has to be lower than such a value.

$$L_b = \frac{1}{2} \cdot R \cdot T \cdot (1 - D) \tag{9}$$

where "R" is the load resistance and "T" is the switching period.

Finally, it is better to avoid the continuous mode because of several reasons:

 - Higher switching losses in the switch and free-wheeling diode;
 - The inductor size and price would increase
 - Regulators operating in the discontinuous mode are very stable and have a very good closed loop response.

4.2. BUCK-BOOST CONVERTER

In the Buck-boost converter the load is supplied only during off-time. Neglecting the power consumption of VIPer12, the inductor value is still given by (8).

The boundary condition between continuous and discontinuous mode of operation in a buck-boost regulator is given by (10).

$$L = \frac{1}{2} \cdot R \cdot T \cdot D \cdot (1 - D)^2 \tag{10}$$

The considerations taken about the inductor value in Buck topology apply to Buck-boost topology as well.

5. OUTPUT CAPACITOR

5.1. BUCK CONVERTER

The filter capacitor is not an ideal capacitor, but it has a series resistance (ESR-Equivalent Series Resistance) and a series inductance (ESL-Equivalent series inductance). Below about 300KHz, ESL can be neglected and the output ripple is only determined by ESR and the capacitor value.

The voltage ripple consists in two components related to ESR and the capacitance value: the first one is proportional to the slope of the inductor current; the second one is proportional to the integral of that current. For a worst-case comparison it can be assumed that they are in phase.

The output capacitor filter value is chosen to minimize the output ripple voltage component, according to (11).

$$C_{out} = \frac{T^2 \cdot V_{out}}{8 \cdot \Delta V_{out} \cdot L} \cdot (1 - D) \tag{11}$$

where: "ΔV_{out}" is the required voltage ripple, "D" is the duty-cycle and "L" is the output inductor value.

In the frequency domain, the output voltage ripple due to the switching frequency is controlled by the second order LC low-pass filter, which corner frequency f_c is given by (12).

$$f_c = \frac{1}{2\pi \cdot \sqrt{L \cdot C}} \tag{12}$$

To minimize the voltage ripple a proper corner frequency has to be chosen, according to (13).

$$f_c \ll f_{switching} \tag{13}$$

The peak-to-peak ripple voltage ESR component is given by (14).

$$\Delta V_{out} = \Delta I \cdot ESR \tag{14}$$

where:

$$\Delta I = \frac{t_{on} \cdot (V_i - V_{out})}{L} \tag{15}$$

Thus, it is important to choose a capacitor with a low ESR since it is the most important parameter affecting the voltage ripple. A figure of merit for capacitors is the product "$R_o \cdot C_o$", with a typical value for aluminum electrolytic capacitor about 50-80$\Omega\mu$F.

5.2. BUCK-BOOST CONVERTER

In the Buck-boost regulator the output capacitor supplies the load only during the on time t_{on} of the switch, thus the capacitor value can be determined by (16):

$$C_{out} = \frac{D \cdot T \cdot I_{out}}{\Delta V_{out}} \tag{16}$$

As in the Buck regulator, an important parameter affecting the output voltage ripple is the capacitor ESR. Moreover, since the capacitor in the Buck-boost regulator supplies the current during the ton of the power switch, the capacitor voltage has a much higher current ripple, making the ESR requirement more stringent.

6. DESIGNING A STEP DOWN CONVERTER USING A VIPer12A

The design of a Buck converter using a VIPer12A is straightforward thanks to the device features, e.g. start-up capability, integrated PWM controller and thermal and overcurrent protection. Moreover the PWM controller is very simple and does not require any external feed-back compensation network.

The circuit schematic is shown in figure 4 for single wave rectification. The power circuit consists in input rectifier D_r, bulk capacitor for DC bus filtering, C_{bulk}, power switch VIPer12A, free-wheeling diode D, and output LC filter.

6.1. VIPer12A SUPPLY CIRCUIT

The supply voltage for VIPer12A can be easily obtained through the output of the converter by means of a diode and a capacitor on V_{dd} pin, D_1 and C_1 in figure 4. The diode voltage rating depends on the input voltage, while the current rating is not an issue. For example, for the European voltage range 185-265Vac a 400V diode can be used.

The capacitor value is chosen according to the start-up time and the short circuit behavior of the converter. In fact, during a short circuit the V_{dd} voltage falls down below the minimum required value, enabling the internal high voltage current generator for a new start-up sequence. The charging and discharging time of the capacitor depends on its value, thus the time period during which the power switch is properly supplied changes accordingly. Moreover, if current pulses heat considerably the device, the over temperature protection shuts off the circuit.

Typical values range from 300nF to 10uF, while the voltage rating is at least 40-50V.

6.2. VIPer12A REGULATION CIRCUIT

The output voltage regulation circuit simply consists of a zener diode D_z across FB and V_{dd} pins, as shown in figure 4. To perform a better regulation, a filter capacitor C_2 can be connected across FB and S pins. The C_2 value is in the order of some tens of nF.

If the output voltage is lower than 15V the circuit has to be slightly modified in order to allow the start up of VIPer12A. In such a case the regulation circuit has to be decoupled from the supply circuit, using a separate diode and capacitor to supply the zener diode on FB pin, D_2 and C_3 in figure 5. The diode D_2 is a low voltage diode, e.g. 1N4148, and allows the voltage on V_{dd} to reach the start-up value. Since D_2 and C_3 realize a peak detector of the output voltage, C_3 value influences the precision of the regulation circuit. If high precision is not an issue it can be as low as 100nF. To prevent disturbance resulting in possible output overvoltage or incorrect start-up, a zener diode D_o is connected across the output. The value must be 2 or 3 volts higher than the output voltage. For further details please refer to the A.N. 1317 (NON ISOLATED POWER SUPPLIES IN BUCK AND INVERTER CONFIGURATION USING VIPer20 DEVICE -A. Bailly - S. Luciano).
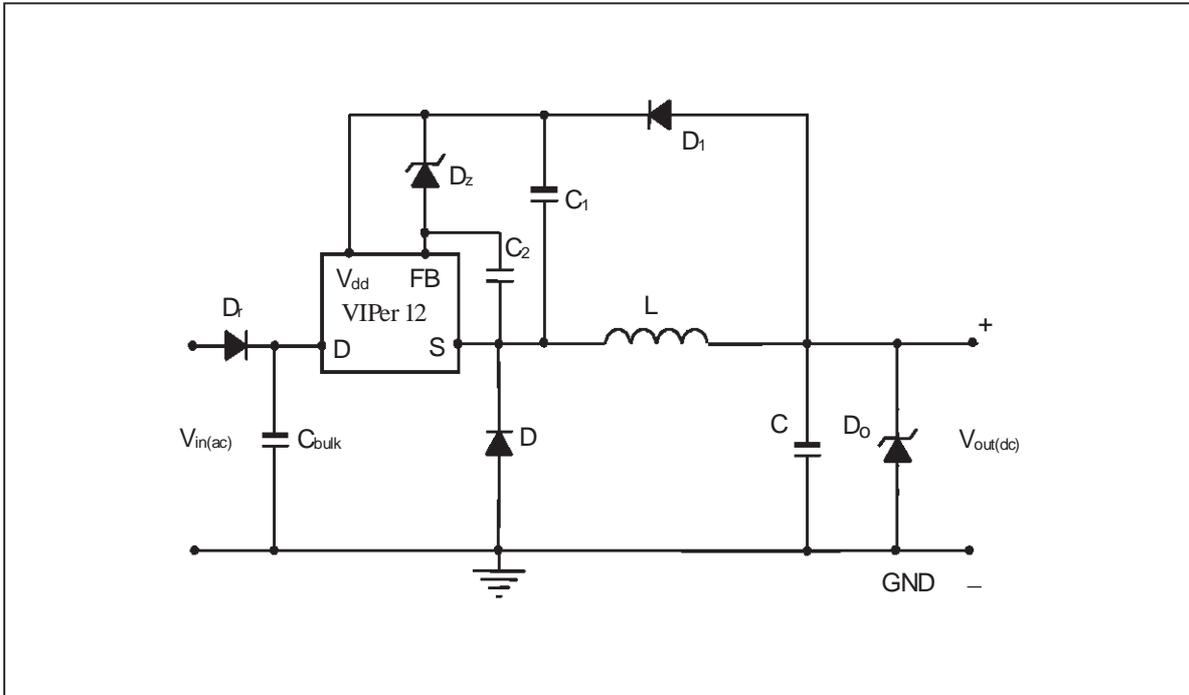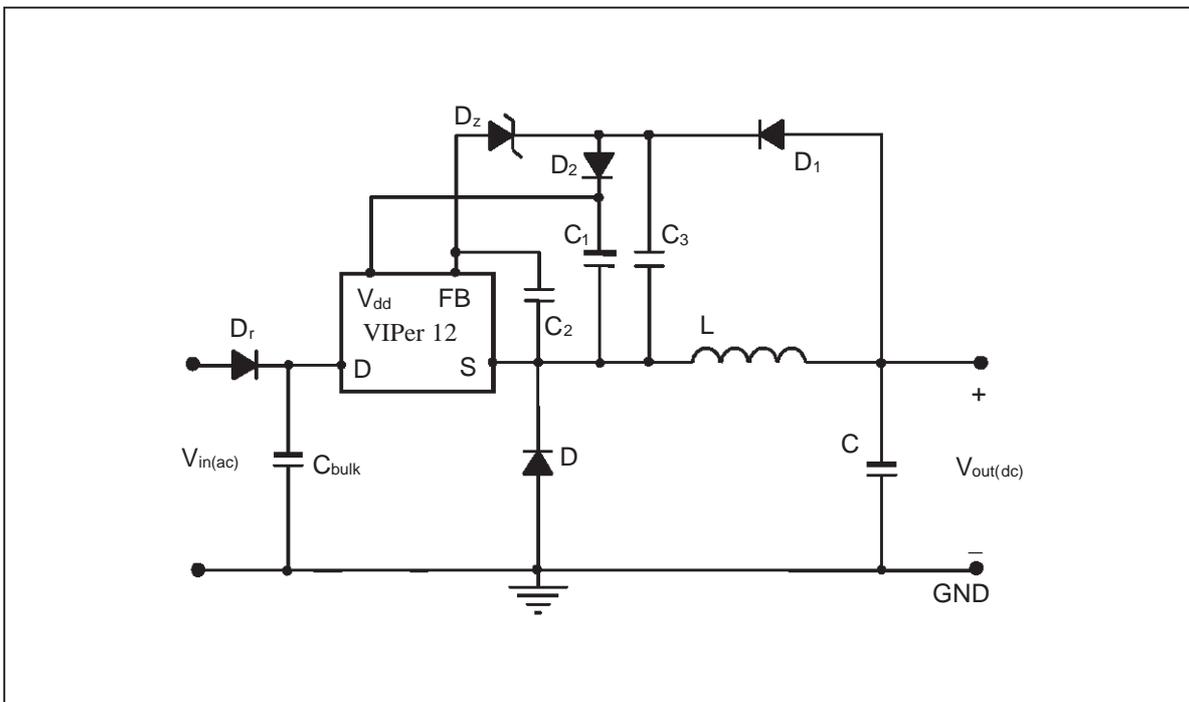
Figure 4: Buck converter with $V_{out}>15V$

Figure 5: Buck converter with $V_{out}<15V$

If the required output voltage is lower than 8V, a different solution has to be used. In fact, although the control feedback path and supply circuit are separated, since the output voltage is lower than the minimum voltage on V_{dd} pin, the device will not start anyway and will work in start up mode with no voltage regulation and high peak current. A patented approach is introduced that allows supplying the power IC. As shown in figure 6 the proposed circuit needs one more inductor compared to the standard Buck topology to generate the supply voltage. It stores the required energy in an auxiliary capacitor through a low voltage diode by means of a voltage divider. The capacitor C_4 is charged during the turn-on time of the power switch through D_3 and then is discharged during the turn-off time through D_1 transferring energy to C_1. D_3 is a low voltage diode, i.e. 1N4148, and C_4 is a low voltage capacitor which value ranges from 10nF to 1uF. In particular, such a capacitor has to be calculated in order to store the charge required by the VIPer12A and supply the proper voltage depending on output inductors ratio L_1/L_2 and AC input voltage. Due to inductor ESR, the voltage across C_4 may depend on the output current too. The capacitor C_1 is calculated following the standard procedure.

Figure 6: Buck converter with V_{out}<8V
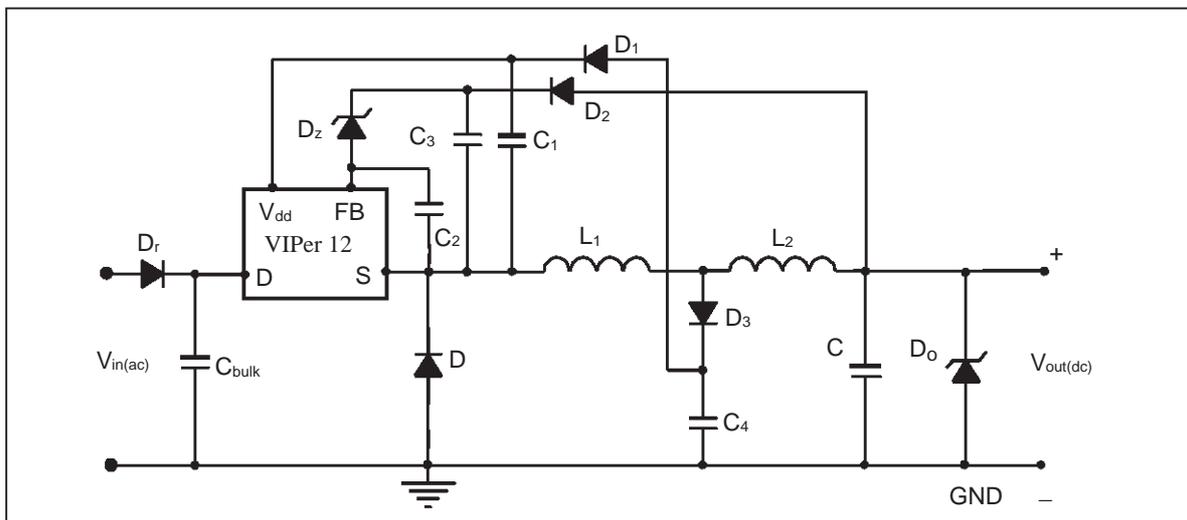
6.3. INDUCTOR CONSIDERATIONS

Inductor selection is done according to (8), where "I_{dpeak}" is the VIPer12A peak drain current, i.e. 360mA, and "f_{sw}" is the fixed 50kHz switching frequency. The maximum peak current limits the power delivered by these topologies using VIPer12A. In the discontinuous mode the maximum output current is half of the peak current, i.e 180mA. However, if a higher output current is required the continuous mode can be entered without affecting voltage regulation.

For low output power an axial insulated inductor can be used. Such a kind of inductor meets low cost considerations but features a high series resistance that affects the efficiency of the converter. The current capability of this kind of inductor is determined, for a given package, by its series resistance. For example, a 1.5mH inductor has a current capability of about 100mA since its series resistance is about 30Ω. If the inductor current is higher, a custom ferrite inductor has to be used.

6.4. APPLICATION EXAMPLES

The first application example is a 16V-100mA off-line power supply. Converter specifications are given in table 1. The schematic of the circuit is shown in figure 7.

A single wave rectification is performed in order to have the ground connected to the neutral of the mains. In this case to improve the reverse voltage robustness a series connection of two high voltage diodes can be used for rectification. The bulk capacitor can be selected according to table 2, that lists the minimum input capacitor for a given input voltage range and output current. Such a minimum value results in DC voltage ripple that is beneficial in terms of power quality and efficiency. A higher voltage ripple means that the capacitor draws current for a longer period reducing the current peak and thus reducing the low frequency harmonic content of the input current. On the other hand, for a given minimum duty cycle the current in the switch is lower because of a lower input voltage, reducing power losses and thus increasing the efficiency. Of course, in the case of a bridge rectifier the values can be considerably reduced. As shown in figure 7, the input bulk capacitor is split in two capacitors and an inductor is inserted in between, realizing an EMI filter as described in Section 3. The components list is given in table 3.

Table 1: Buck converter specifications

AC input voltage	185 - 265Vac
Output power	1.5W
Output voltage	+16V

Table 2: Input capacitor selection table

Input Capacitor Cin	Maximum Output current	
	90Vac Minimum input voltage (Wide range)	180Vac Minimum input voltage (Single range)
1µF	15mA	80mA
2.2µF	40mA	100mA
3.3µF	60mA	120mA
4.7µF	80mA	150mA

Figure 7: Application example: 16V-100mA power supply
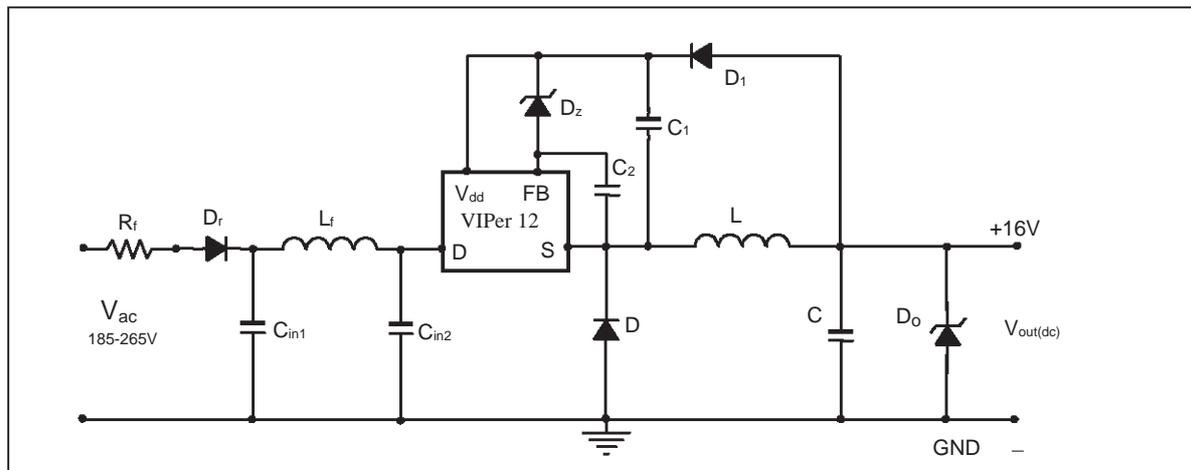
Table 3: Components list

REFERENCE	VALUE	PART NUMBER
R_f	10Ω / 1/2W	
C_{in1}	1μF / 400V Electrolytic	
C_{in2}	1μF / 400V Electrolytic	
C_1	10μF / 25V Electrolytic	
C_2	22nF / 25V Ceramic	
C_{out}	10μF / 25V Electrolytic	
D_o	18V Zener	BZX55C18V
D_1	1A - 600V	STTA106
D_2	1A - 600V	STTA106
D_r	1A - 1000V	1N4007
D_z	15 V Zener	
L	1.8mH	
L_f	680μH	
I_{C1}		VIPer12ADIP

The proposed power supply can be successfully applied in microcontroller-based low power motor drive systems. Such an application requires two regulated output voltage: 15V for power switch gate driver and 5V for microcontroller. In figure 8 the circuit schematic is shown, using a 5V linear regulator with reset for proper system operation. This circuit assures good performance in terms of size and performances at very low cost.

Figure 8: Application example: double output converter for microcontroller supply
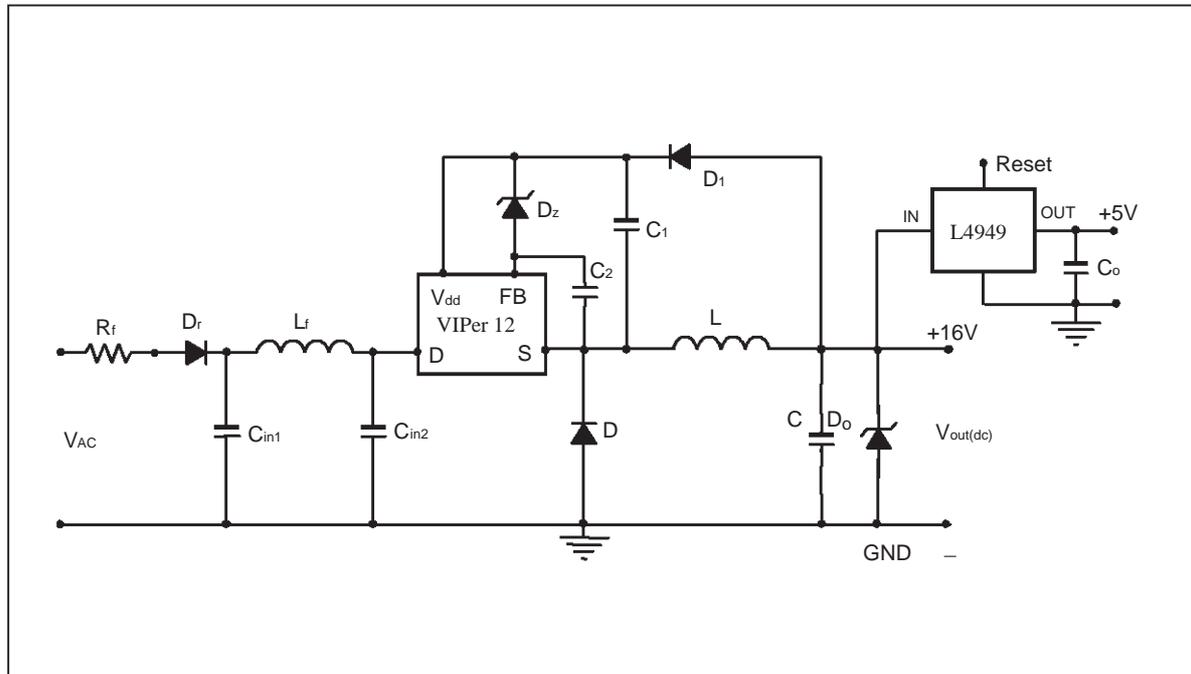
6.5. LAYOUT CONSIDERATIONS

The circuit layout is shown in figure 9 for all the proposed configurations, with single and full wave rectification. The size of the board is 3.5x4 mm and could be further reduced if SMD components were used. However, in such a case the board is more expensive and does not fit the low cost requirements.

The design of a PCB layout is not an easy task. Component placing and trace routing strongly affect the functionality and EMI behavior of the board. Moreover, adequate clearance is required for insulation issues between high and low voltage circuits.

In doing so, power traces have to be as short and wide as possible, minimizing resistive and inductive effects in order to improve efficiency and reduce the EMI noise.

Figure 9: PCB Layout (not in scale)
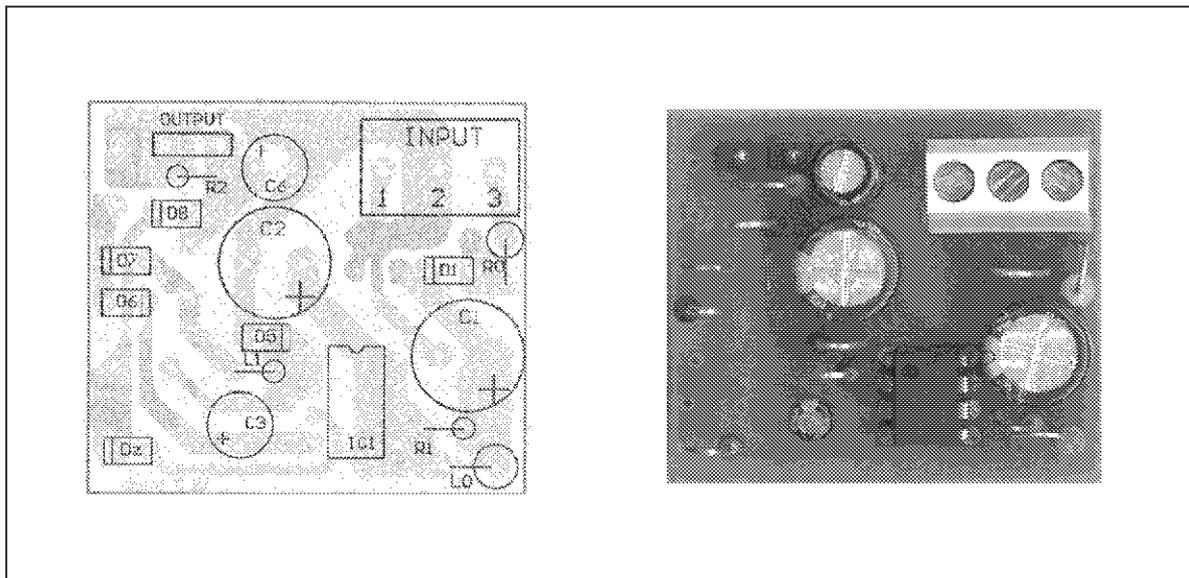
6.6. EXPERIMENTAL RESULTS

Typical waveforms of the 16V power supply are shown in figure 10 and figure 11, with I_{out}=50mA and I_{out}=100mA respectively. In particular, as shown in figure 11, the converter is in boundary condition for I_{out}=100mA. In figure 12 the output voltage and the source voltage in open load condition are shown. In such a case the VIPer12A operates in burst mode, decreasing the effective switching frequency and reducing the power consumption to less the 100mW.

Figure 10: Buck converter with V_{out}=16V: normal operation with I_{out}=50mA
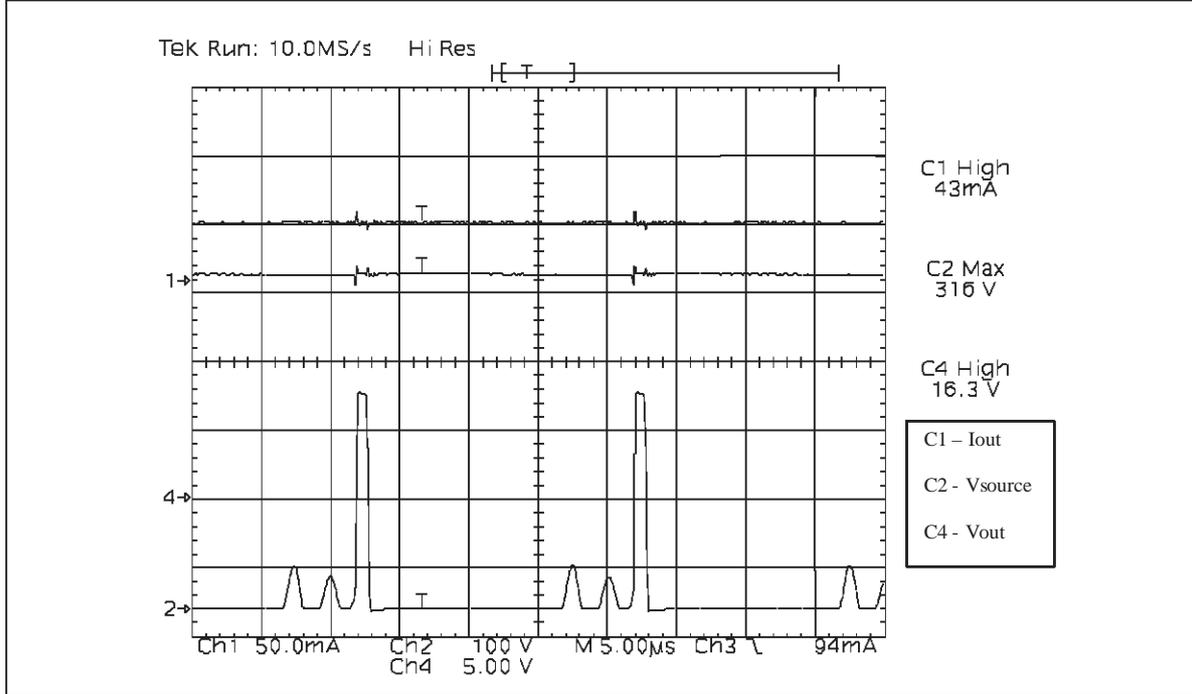
Figure 11: Buck converter with V_{out}=16V: normal operation with I_{out}=100mA
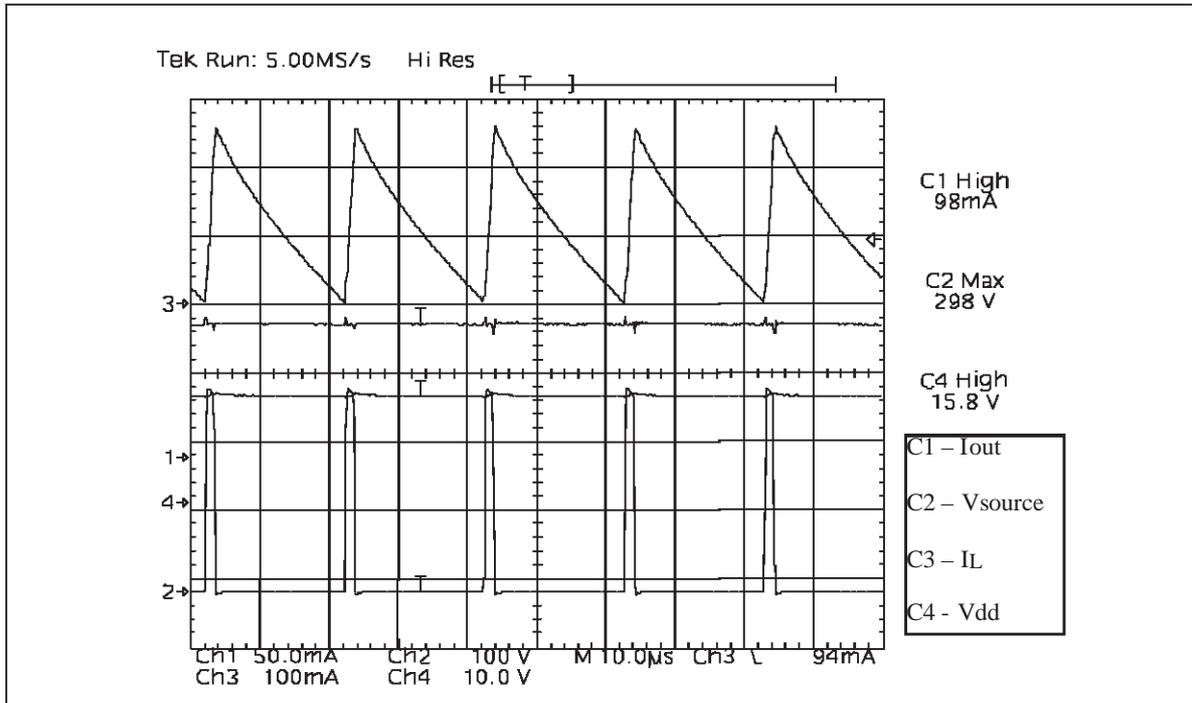
Figure 12: Buck converter with V~out~=16V: open load condition
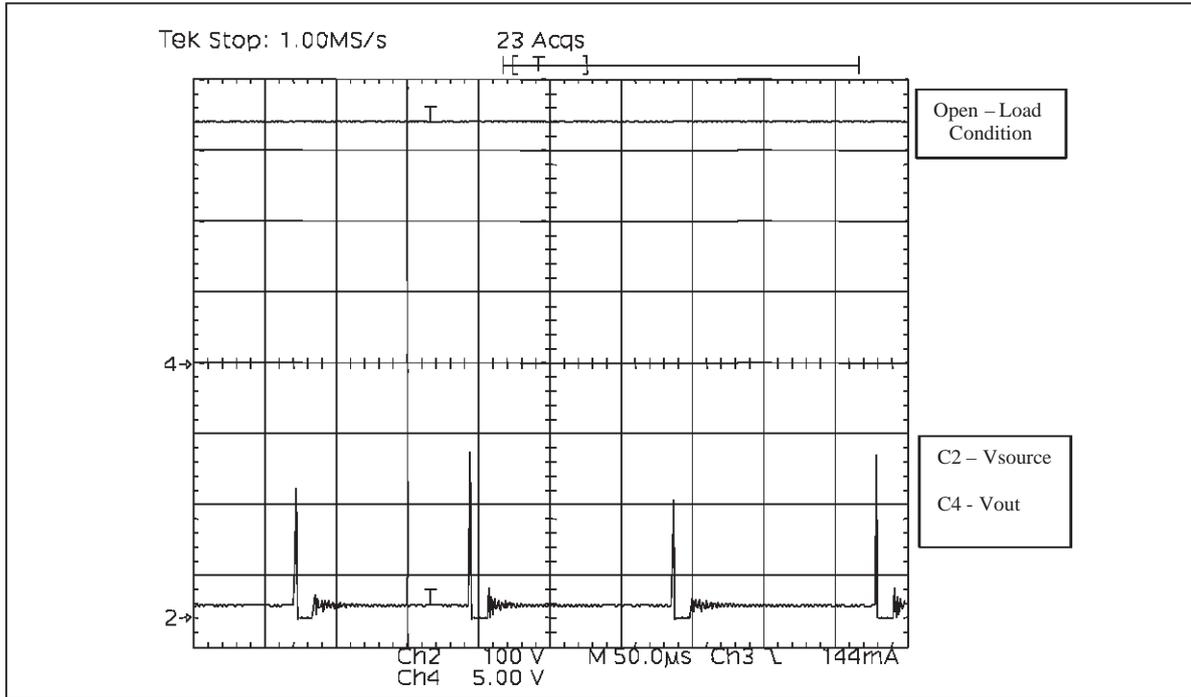
Figure 13: Buck converter with V~out~=16V: short circuit condition
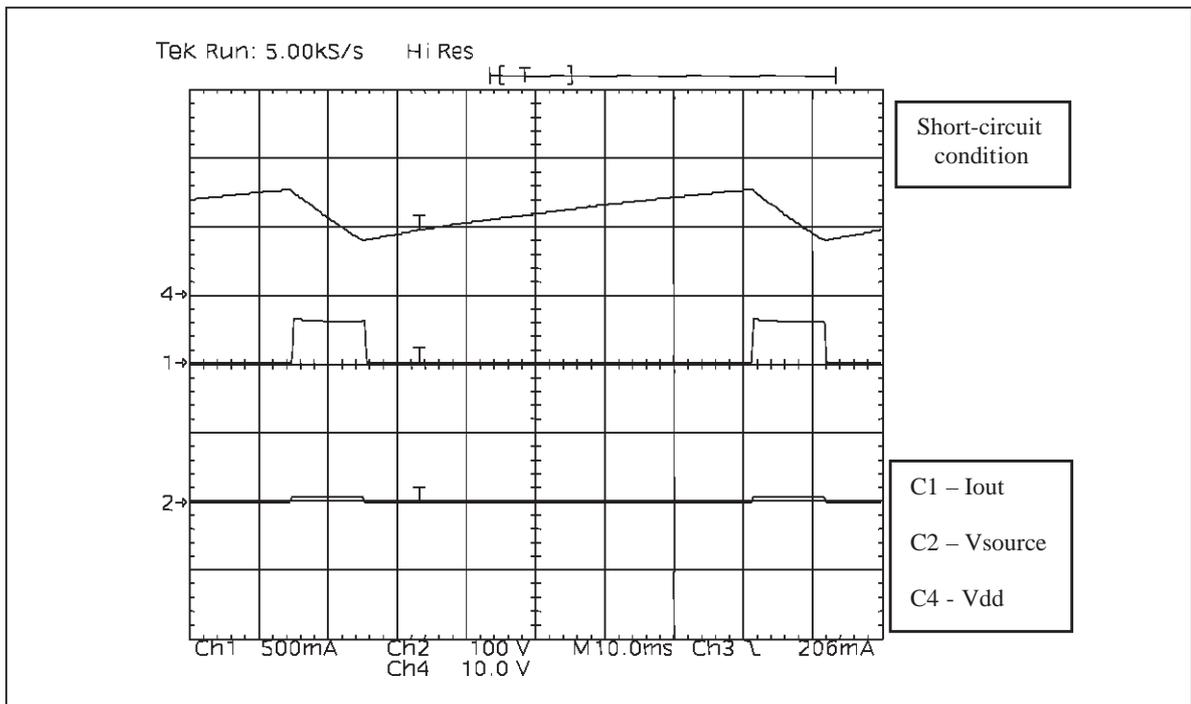
In short circuit condition VIPer12A limits the short circuit current thanks to three main features: start-up sequence due to low V_{dd} voltage, current limit function and thermal shut down. This way the power dissipation is strongly reduced and the converter is safely protected. It is worth noting that the input resistor and the series resistance of the output inductor also limit the short circuit current . A typical short circuit operation is shown in figure 13.

The performance of the circuit has been evaluated and fully characterized, as shown from figure 14 to figure 19. In particular, the circuit features a good line and load regulation, as shown in figure 14 and figure 15 respectively. The worst regulation at low input voltage and high output current is basically related to the value of the input capacitors, a trade off between performance, size and cost.

The efficiency of the power supply is higher than 50%, as shown in figure 16 and figure 17 as a function of output current and input voltage respectively, and is considerably affected by the parasitic resistance of the components. High quality components could be used to improve the efficiency, but a trade off between cost and performance has to be done for such a low cost application.

Figure 14: Buck converter with V_{out}=16V: line regulation
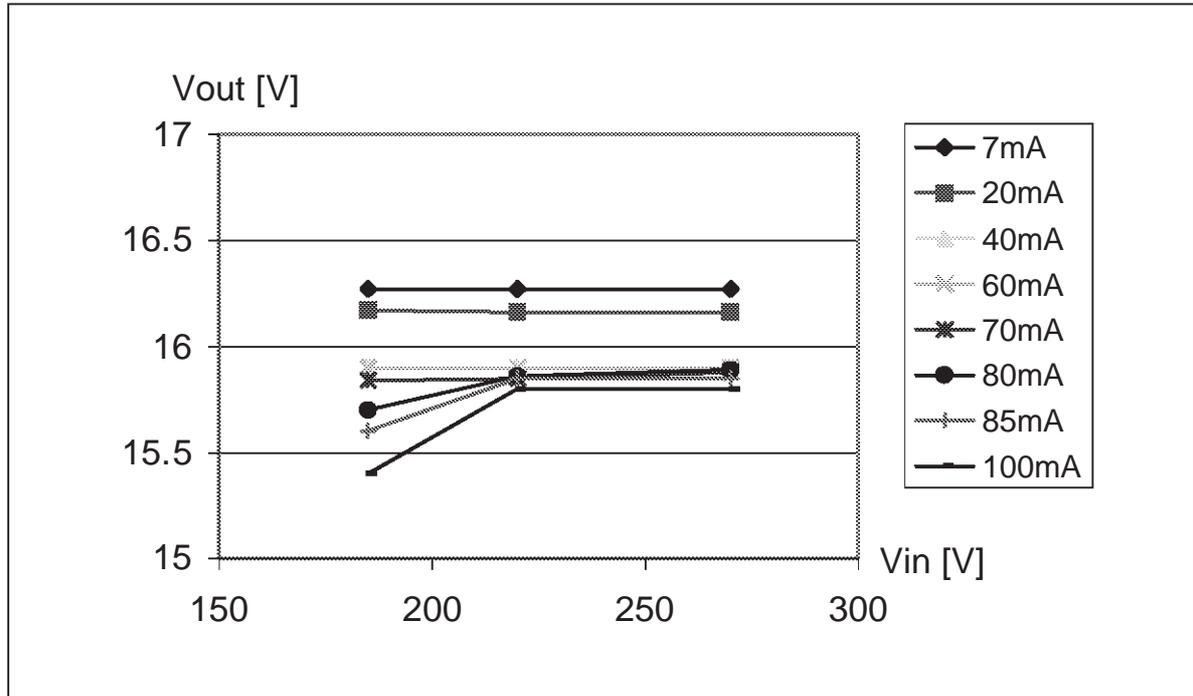
The EMI behavior of VIPer12A-based power supply is shown in figure 18 and figure 19. Conducted emission measurements have been performed according to the standard EN55022 using a 50Ω LISN (Line Impedance Stabilization Network), with a peak detector, in the frequency range 0.15-30 MHz. As shown in figure 18, the power supply features low conducted emissions even with no input EMI filter, taking into account that the limit lines are related to Quasi-peak and Average detector and the experimental traces have been measured with a peak detector. In figure 19 the effect of the input EMI filter on the conducted emissions is shown.

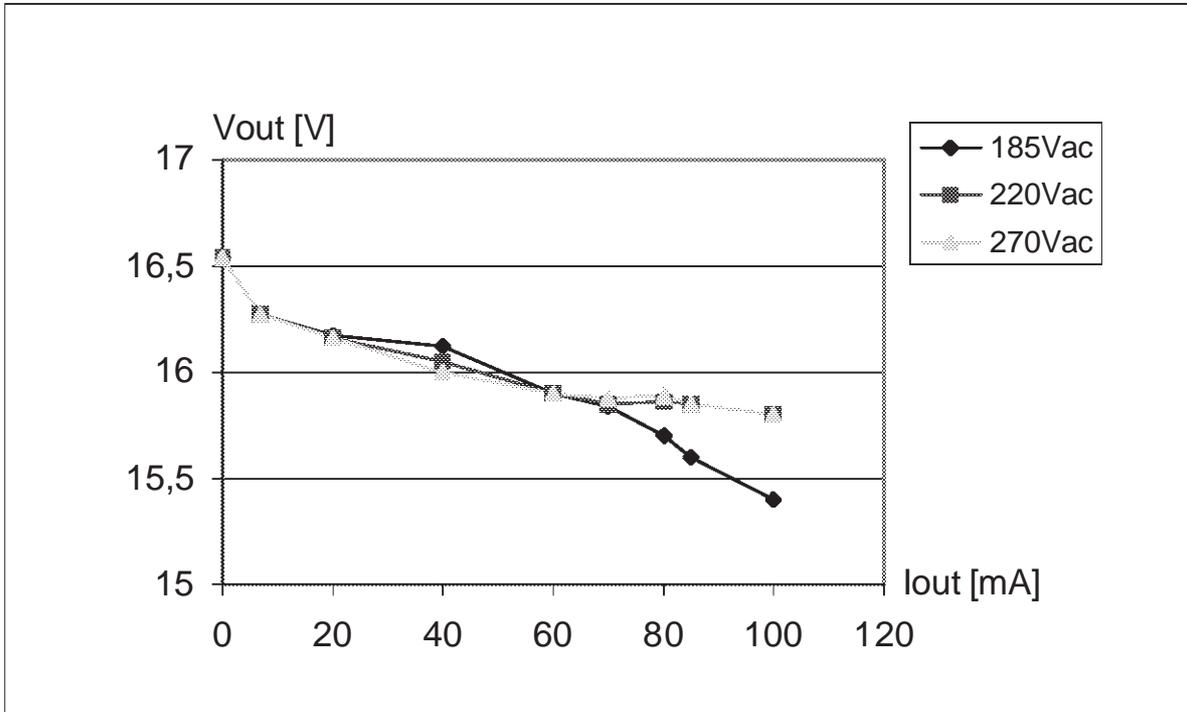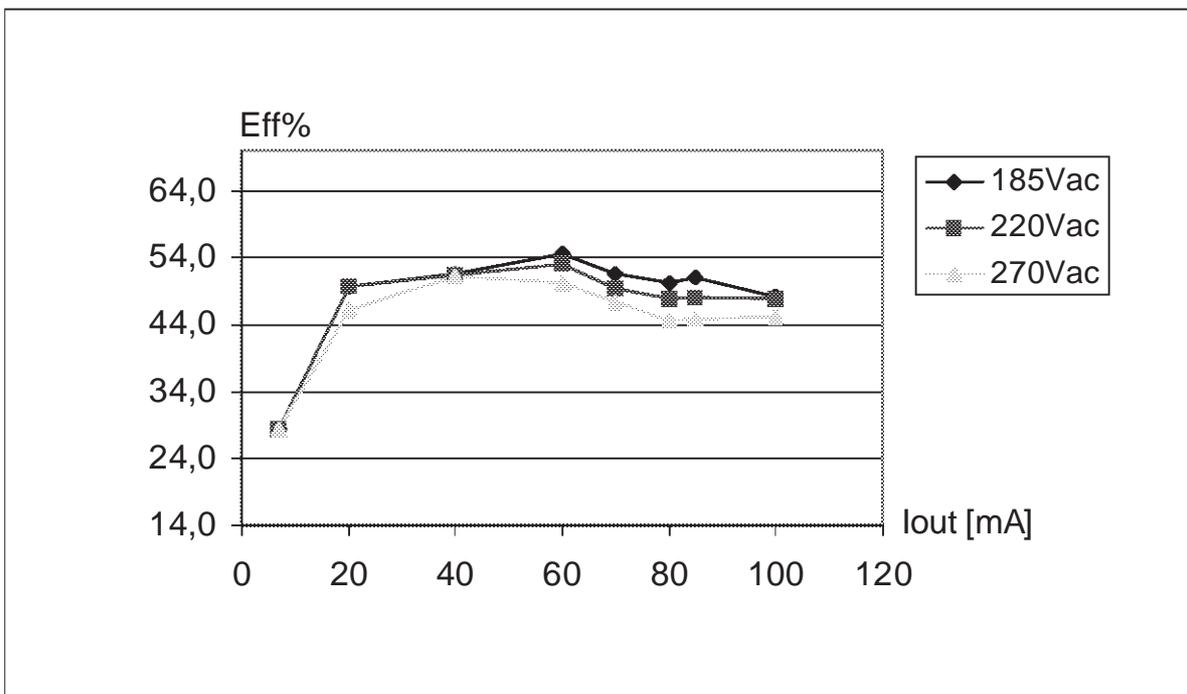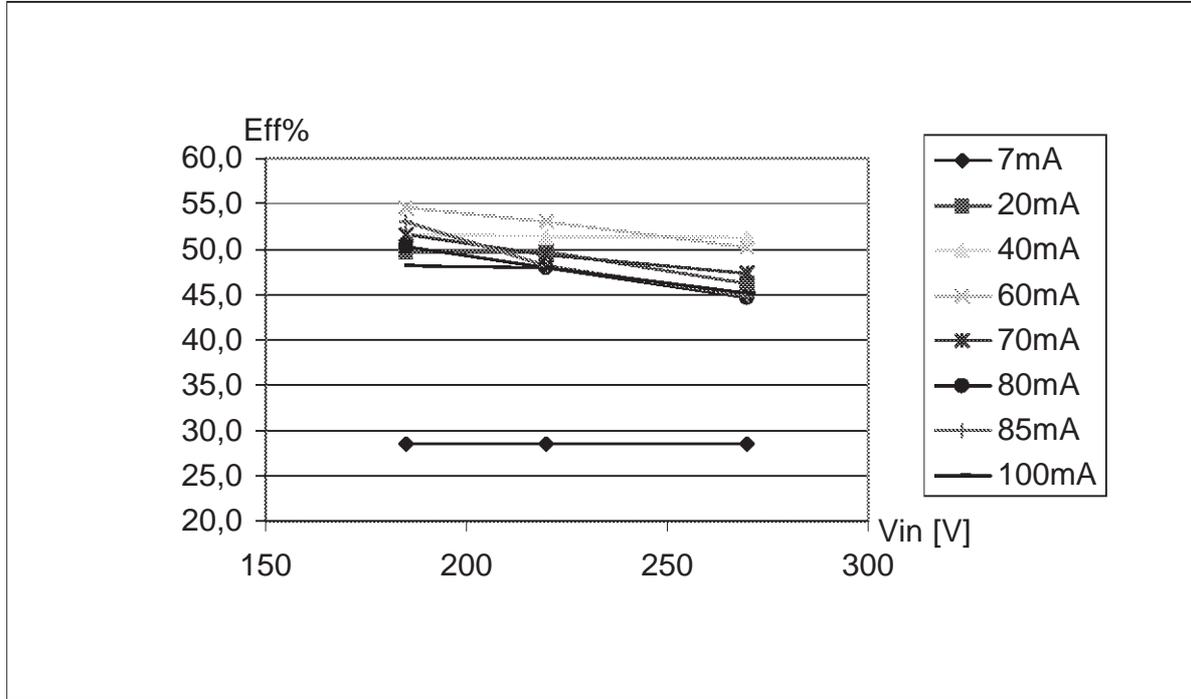**Figure 15:** Buck converter with V_{out}=16V: load regulation

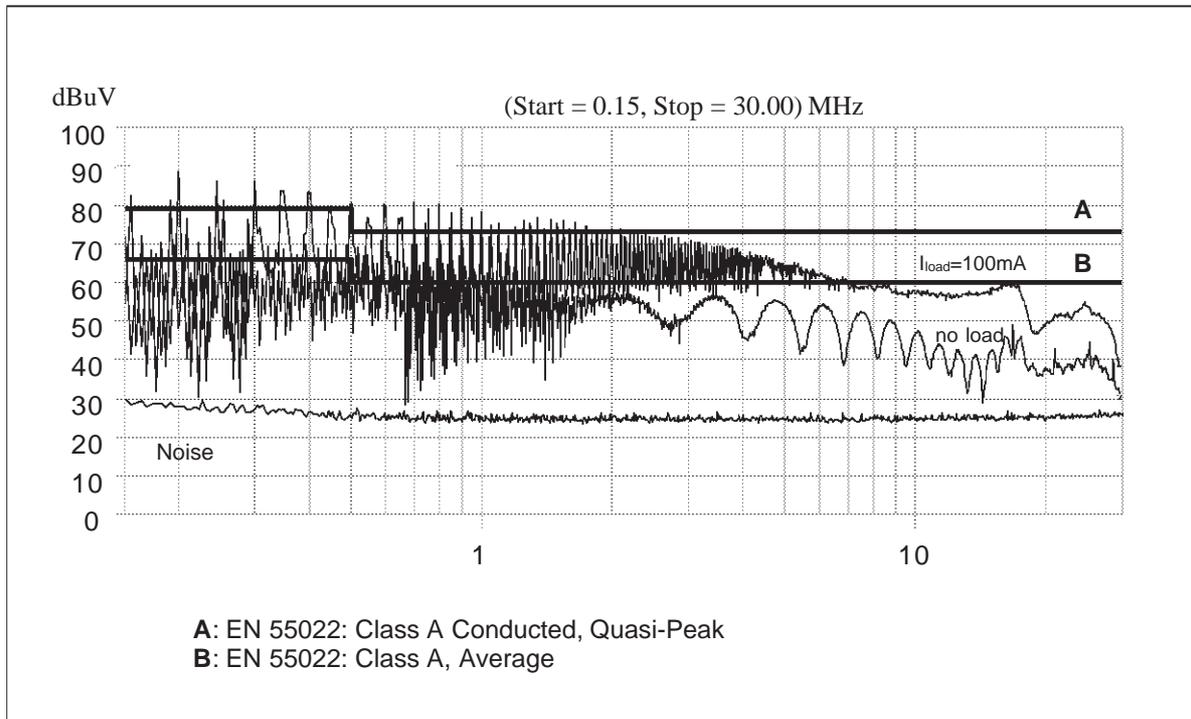**Figure 16:** Buck converter with V_{out}=16V: efficiency Vs. output current

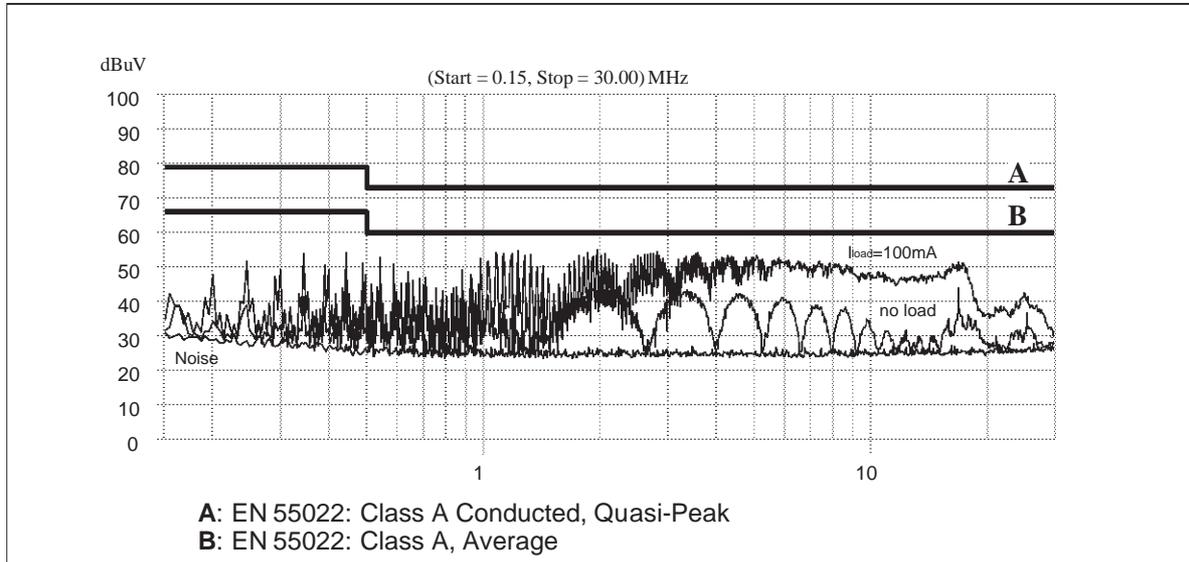**Figure 17:** Buck converter with V_{out}=16V: efficiency Vs. input ac voltage

Figure 18: Buck converter with V_{out} =16V: EMI behavior with no input filter

A: EN 55022: Class A Conducted, Quasi-Peak
B: EN 55022: Class A, Average

Figure 19: Buck converter with V_{out} =16V: EMI behavior with EMI input filter

A: EN 55022: Class A Conducted, Quasi-Peak
B: EN 55022: Class A, Average

6.7. 5V-60mA BUCK CONVERTER

The second application example is related to a 5V-60mA power supply. The schematic of the circuit is shown in figure 20. In this application a suitable circuit has been developed to properly supply the device since the output voltage is lower than the minimum V_{dd} voltage, i.e. 8V. Such a circuit consists in standard low cost components L_2, D_3 and C_4, as described in table 4. The selection of L_2 value depends on the input ac voltage range, since the voltage provided to V_{dd} is function of L_1/L_2 ratio. For the European voltage range, i.e. 185-265V, a ratio of 3-4 is the right choice. If low cost inductors with high series resistance were used, the voltage across C_4 would be influenced by the output current as well. The C_4 value is about 80-100nF with a voltage rating given by the inductor ratio. Basically, C_4 has to store the energy needed by the VIPer12A and then transfer it to C_1.

Figure 20: Buck converter with V_{out} = 5V - I_{out} = 60mA
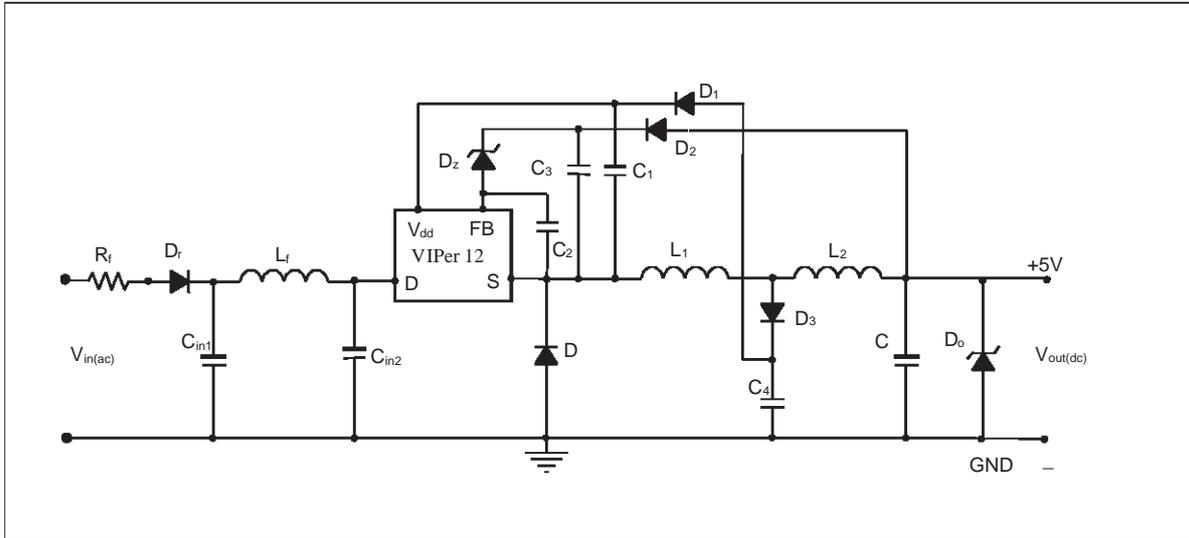
Table 4: Components list

REFERENCE	VALUE	PART NUMBER
R_f	10Ω / 1/2W	
C_{in1}	1µF / 385V Electrolytic	
C_{in2}	1µF / 385V Electrolytic	
C	100µF / 16V Electrolytic	
C_1	470nF Ceramic	
C_2	100nF Ceramic	
C_3	10µF Electrolytic	
C_4	100nF Ceramic	
L_f	470uH	
L_1	1.5mH	
L_2	470µH	
D_r	1A - 1000V	1N4007
D_z	5.1V Zener	
D	1A - 600V	STTA106
D_o	7.5V Zener	
D_1	1A - 600V	STTA106
D_2	1A - 600V	STTA106
D_3		1N4148
I_{C1}		VIPer12ADIP

The power supply features a good line and load regulation up to 120mA, as shown in figure 21 and figure 22. The efficiency is about 40% and is strongly affected by the series resistance of the output inductors.

The EMI behavior is shown in figure 23. A small input CLC EMI filter has been realized with two 1uF capacitors and a 470µH inductor. The measurements have been performed using a peak detector. The procedure is described in Section 6.6.

Figure 21: Buck converter with V_{out} = 5V: line regulation
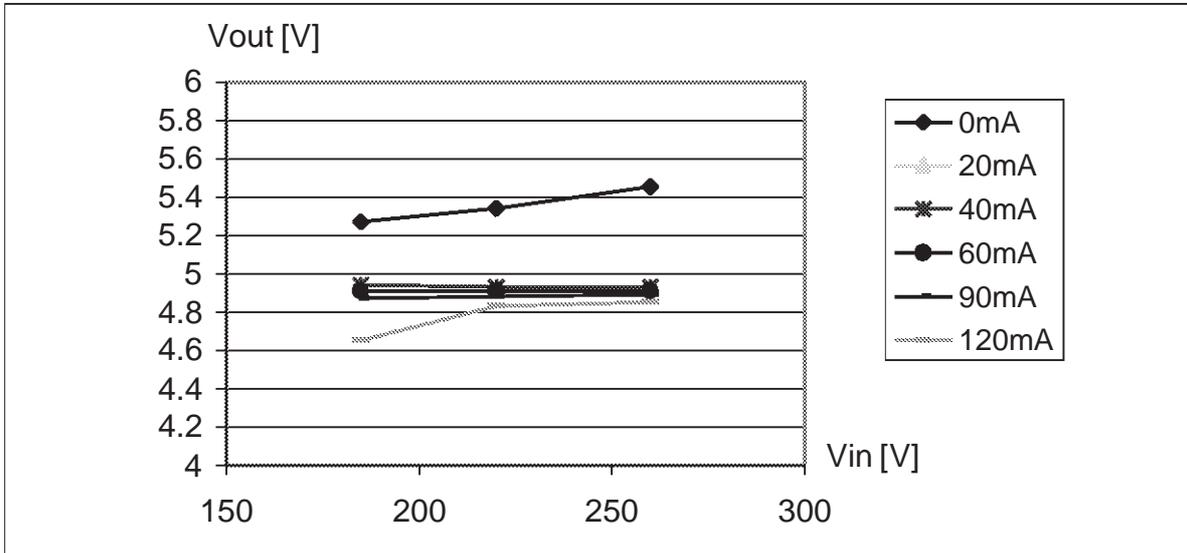
Figure 22: Buck converter with V_{out} = 5V: load regulation
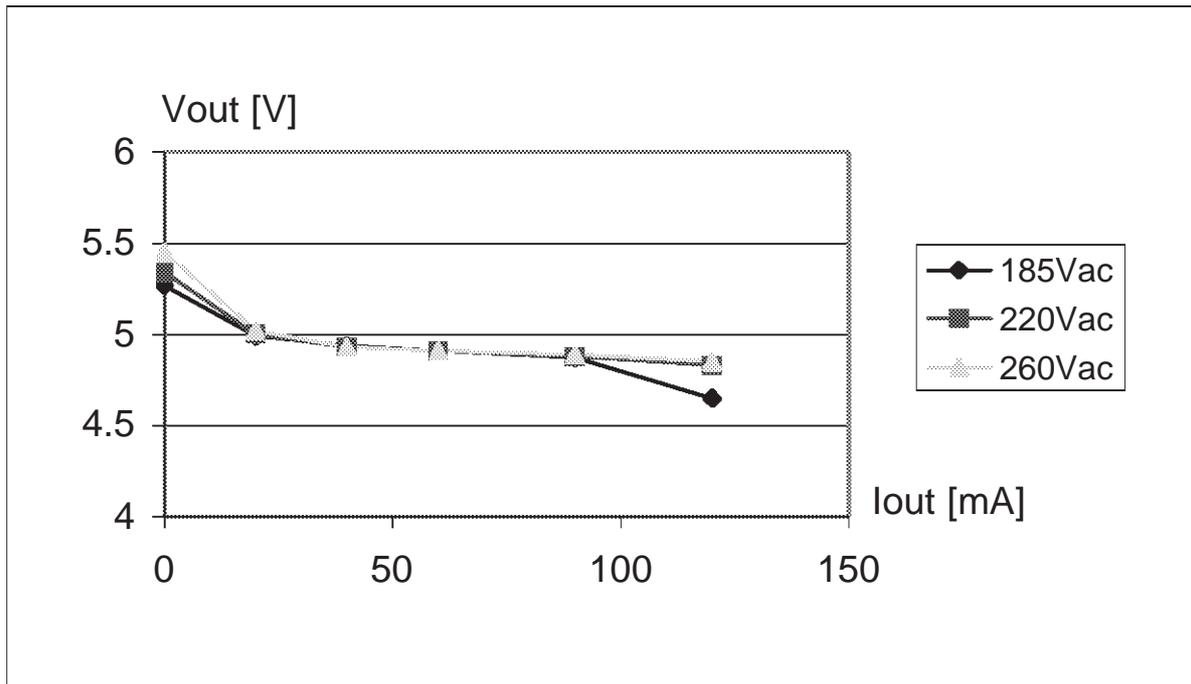
Figure 23: Buck converter with V_{out} = 5V: EMI behavior with CLC input filter
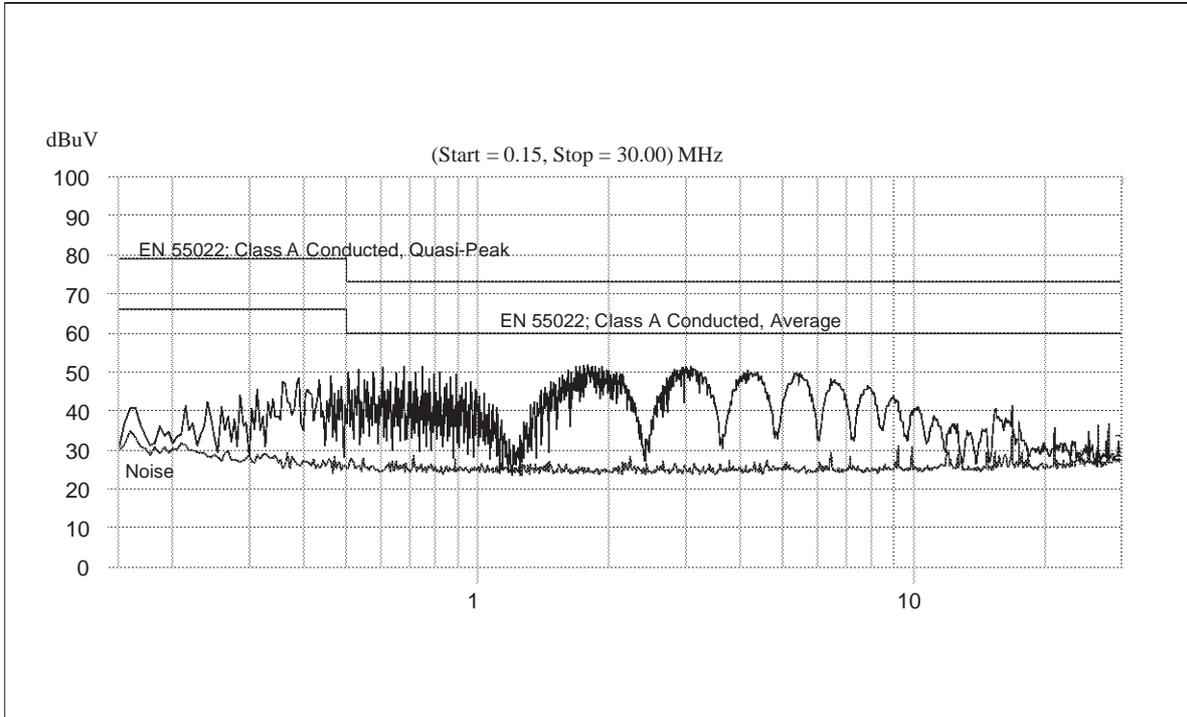
7. DESIGNING A BUCK-BOOST CONVERTER USING A VIPer12A

The design of a Buck-boost converter for negative output voltage is as easy as described in Section 6 for the Buck topology. The circuit schematic with output voltage lower than (-15V) is shown in figure 24 for single wave rectification. In figure 25 and figure 26 the circuit schematics for -15V< V_{out} < -8V and -8V < V_{out} are respectively shown.

7.1 VIPer12A SUPPLY CIRCUIT

In this topology the supply circuit for VIPer12A is implemented connecting a diode D_1 between the ground of the converter and a capacitor C_1 on V_{dd} pin, as shown in figure 24. In such a way the voltage on V_{dd} is positive and the VIPer12A can be properly fed. In particular, the capacitor C_1 receives energy during the off time t_{off} and supplies the VIPer12A during the on time t_{on}. The diode selection is based on the input voltage while the capacitor value is determined by the start-up time, as discussed in section 6.1.

7.2 VIPer12A REGULATION CIRCUIT

The output voltage regulation circuit consists of a zener diode across FB and V_{dd} pins, as described in Section 6.2 for Buck topology. If the required output voltage is higher than (-8V), i.e. (-5V), a different solution has to be used, as shown in figure 26. The diode D_4 is a low voltage diode, e.g. 1N4148, and the value of C_4 is about 100nF in order to store the energy required by the VIPer12A. The capacitor C_1 is calculated following the standard procedure. The capacitor C_2 is connected between FB and S pins to improve the regulation.

7.3 INDUCTOR CONSIDERATIONS

The considerations done about the inductor value in Buck topology apply to Buck-boost topology as well.

7.4. APPLICATION EXAMPLE

The considered circuit provides regulated 16V negative voltage output using the buck-boost non isolated configuration. Converter specifications are listed in table 5. Table 6 shows the components list of the power supply shown in figure 24.

As shown in figure 27 and figure 28, the circuit performs good voltage and line regulation. The efficiency of the circuit is as higher as more than 60%, as shown in figure 29 and figure 30. This power supply features higher efficiency than the positive counterpart only because of the lower series resistance of the inductor.

Table 5: Buck-boost converter specifications

AC input voltage	185 - 265VAC
Output power	3.5W
DC Output voltage	-16V

Figure 24: Buck-boost converter with V_{out}< -15V
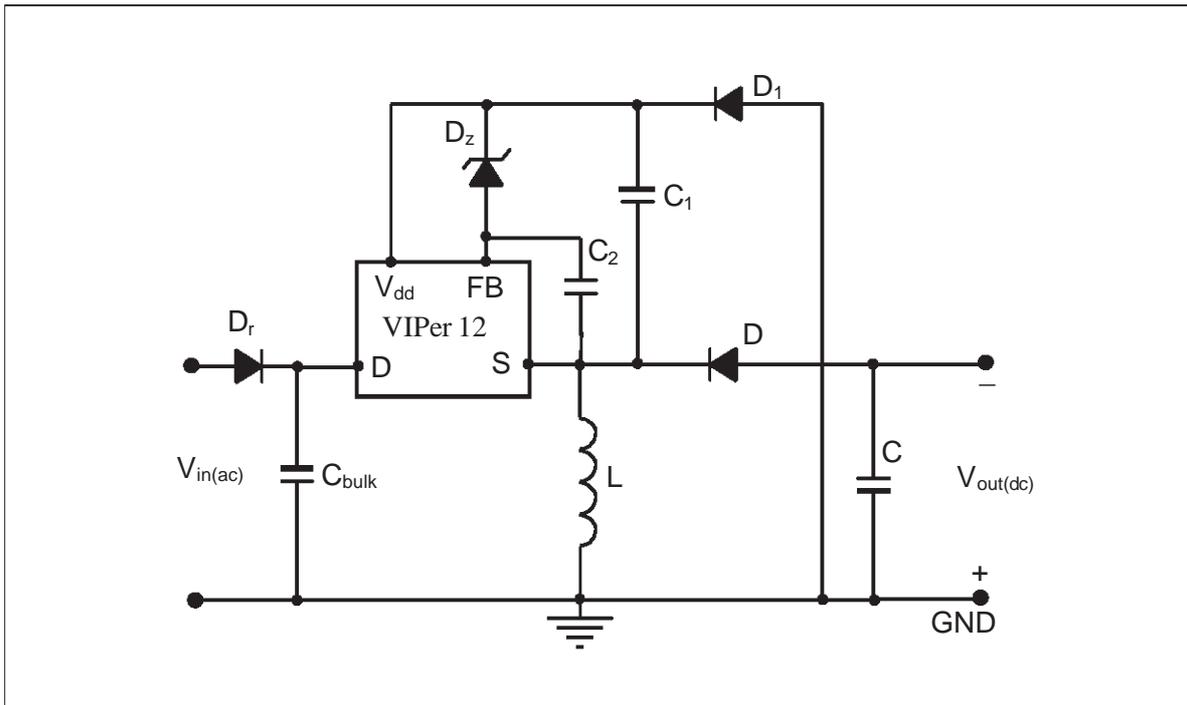
Figure 25: Buck-boost converter with -15V<V_{out}<-8V
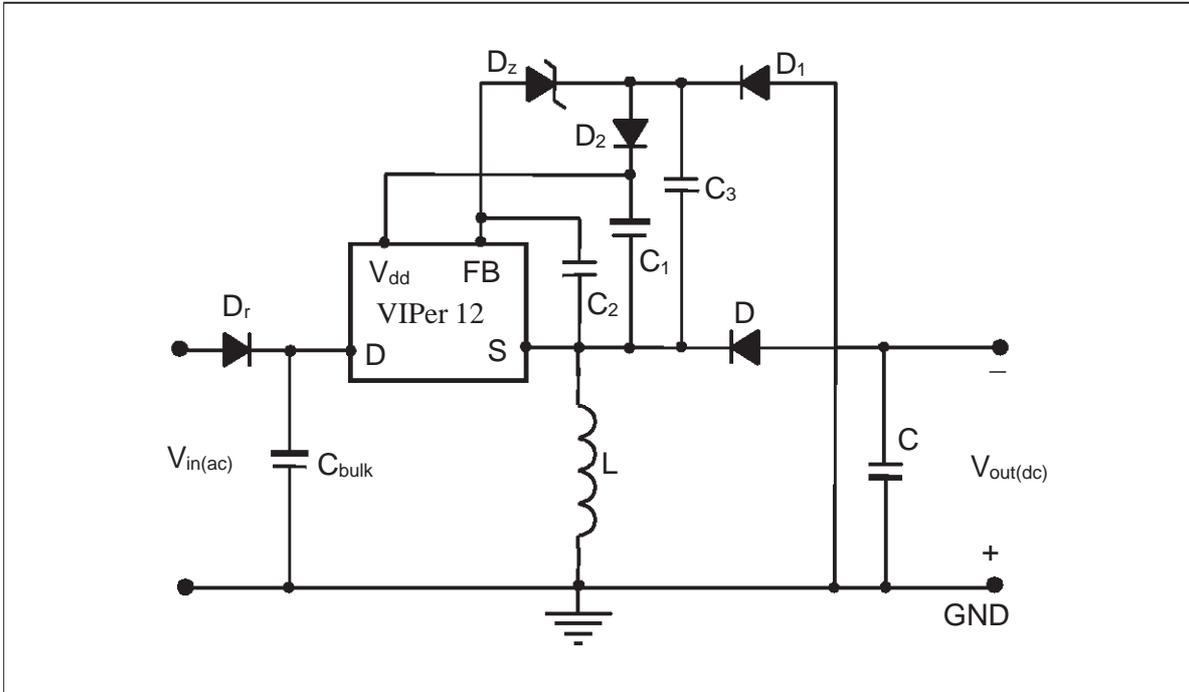
Figure 26: Buck-boost converter with -8V<V_{out}<0
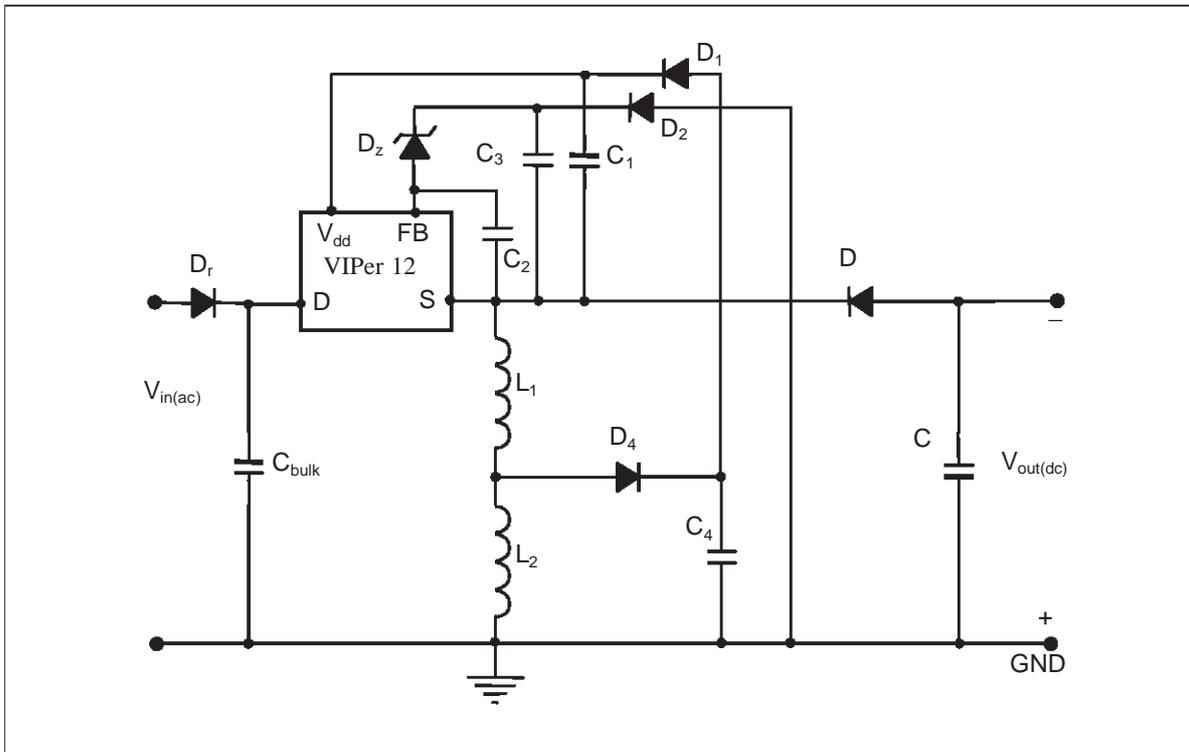
Table 6: Components list

REFERENCE	VALUE	PART NUMBER
R_1	2KΩ / 1/4W	
C_1	10μF / 25V Electrolytic	
C_2	22nF / 25V Ceramic	
C_{bulk}	4.7μF / 400V Electrolytic	
C	100μF / 25V Electrolytic	
D_1	1A - 600V	STTA106
D_2	1A - 600V	STTA106
D_r	1A -1000V	1N4007
D_z	15V Zener	
L	1.6mH	
I_{C1}		VIPer12ADIP

Figure 27: Buck-boost converter with V_{out}= -16V: line regulation
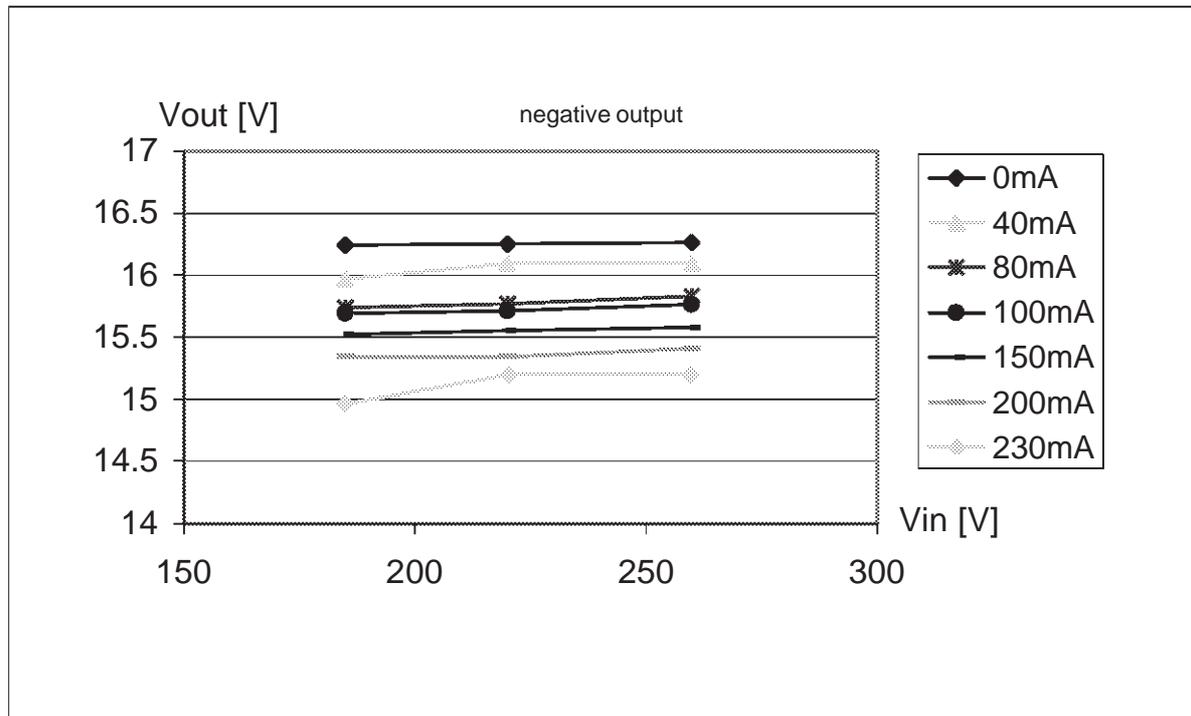
Figure 28: Buck-boost converter with V_{out}= -16V: load regulation
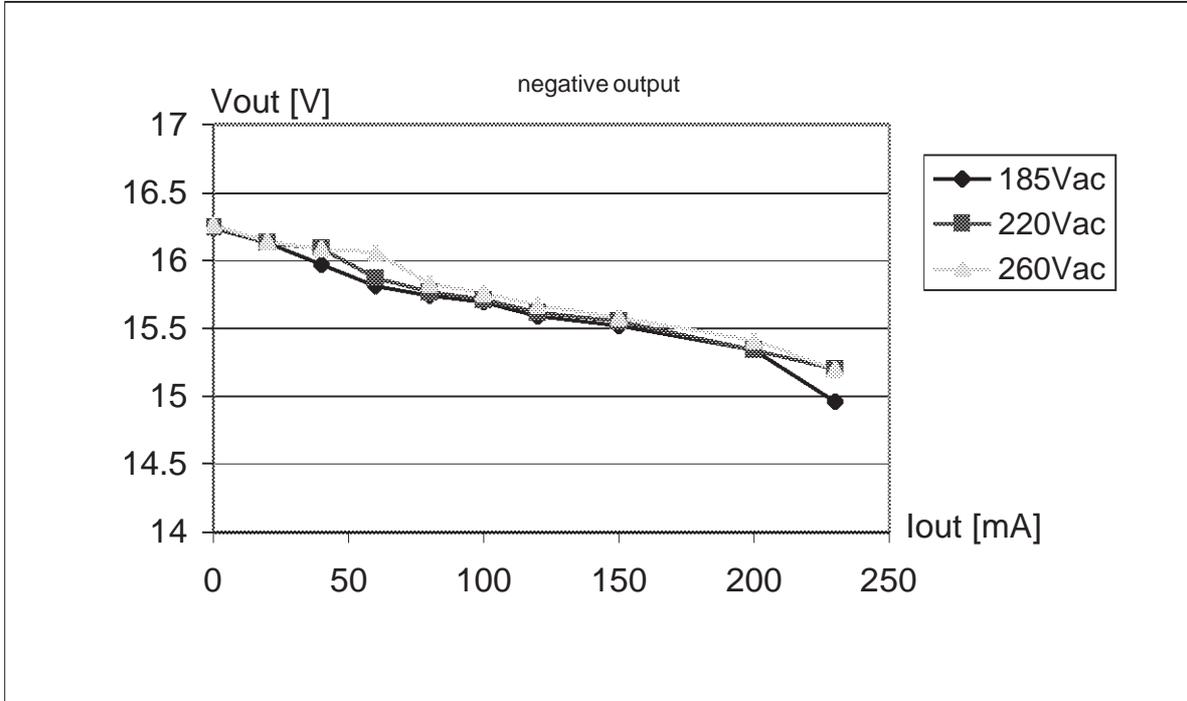
Figure 29: Buck-boost converter with V_{out}= -16V: efficiency Vs. output current
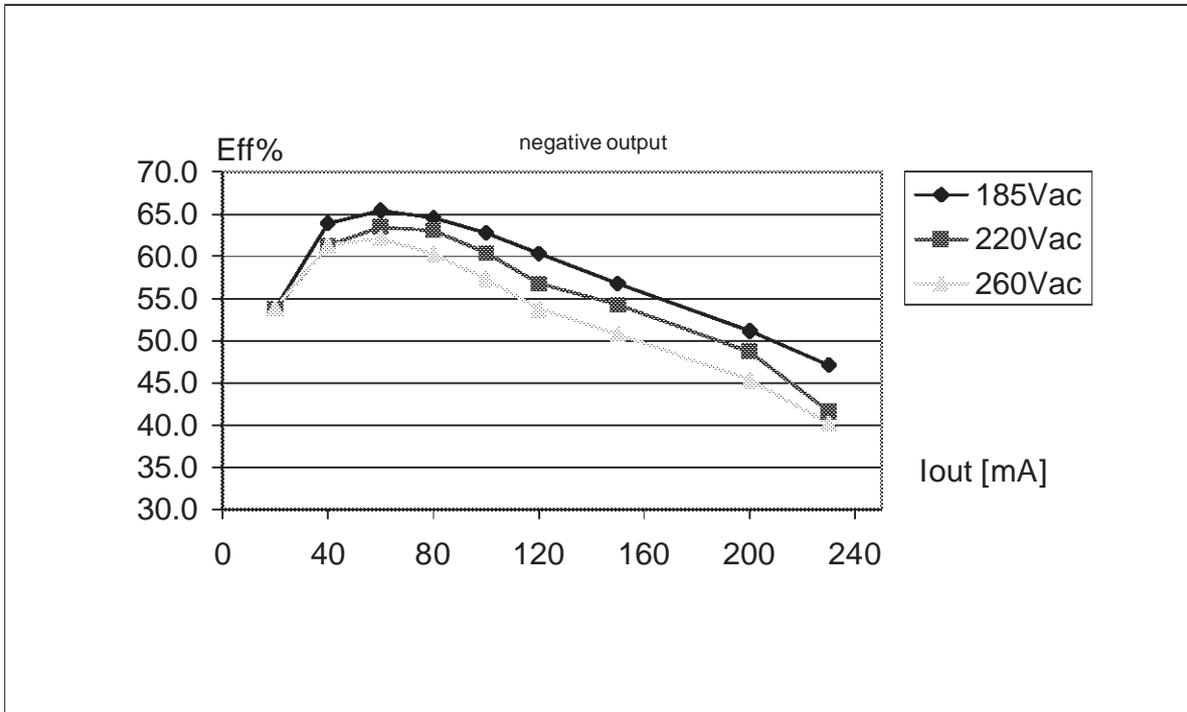
Figure 30: Buck-boost converter with V_{out}= -16V: efficiency Vs input voltage
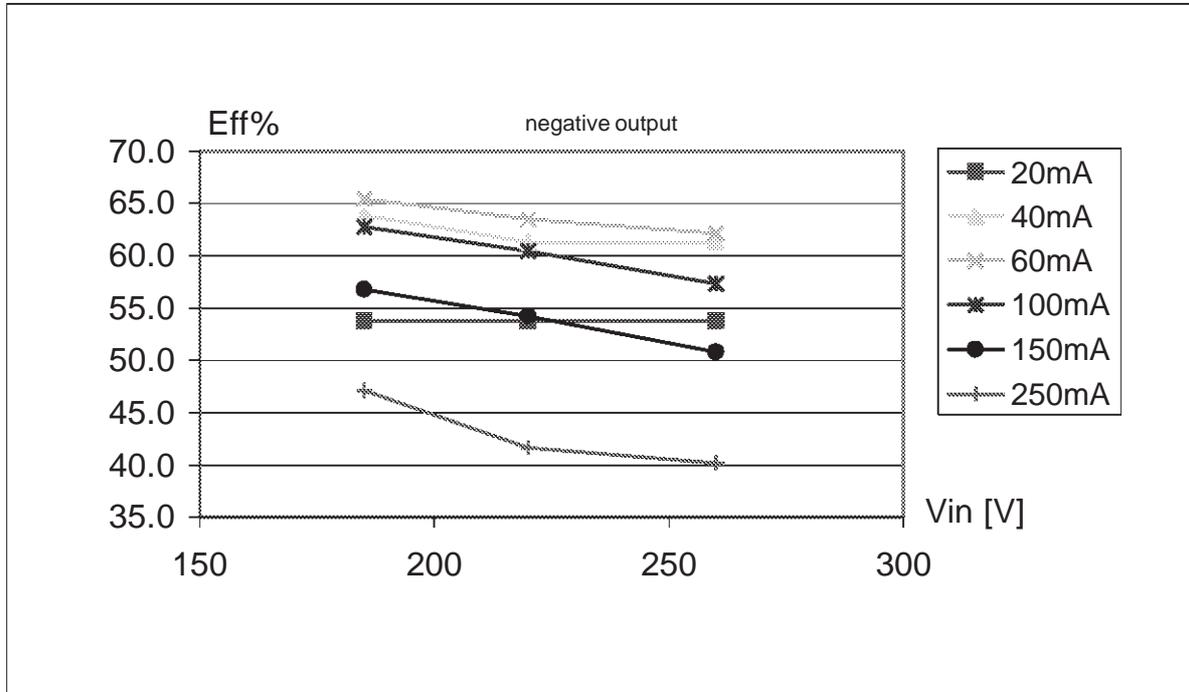
CONCLUSION

Several configurations have been introduced in Buck and Buck-boost configuration exploiting the main features of VIPer12A so as to realize low power and low cost non isolated power supplies for industrial applications. The inherent advantages of high frequency switched mode power conversion, allow off-line power supplies to operate with high efficiency and reduced cost and size. Viper12A, integrating a PWM controller and a power device in a single chip, maximizes such advantages in the power range up to few watts.

For further information about VIPer12A please consult the official datasheet on the VIPower web page: http://www.st.com/vipower.