AN1489
Application note

VIPower: non isolated power supply using VIPer20 with secondary regulation

Introduction

Output voltage regulation with adjustable feedback compensation loop is very simple when a VIPer device is used in low cost non-isolated applications. In this paper such a simple regulation circuit is introduced and analyzed in Buck and Buck-boost converter based on VIPer20, a monolithic smart power with an integrated PWM controller. The device is suitable for off-line applications and features integrated protection circuits such as over-temperature and over-current protection.

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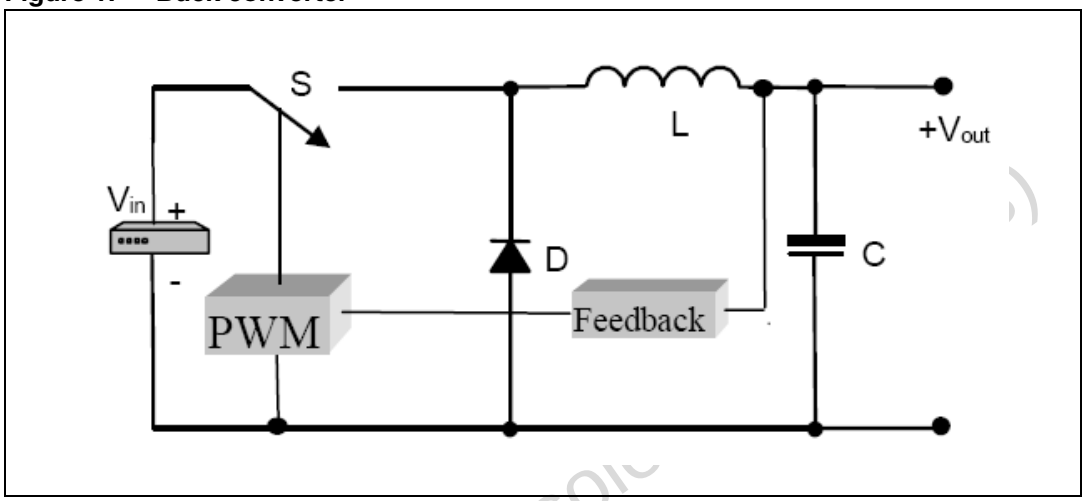
1 Non isolated power supply

1.1 Buck converter

In the basic circuit, shown in *Figure 1.*, when the switch is closed current flows through the inductor L producing an output voltage. When the switch opens the magnetic field in L changes polarity and the freewheeling diode provides a return path for the current to circulate through the load.

Varying the diode voltage waveform duty-cycle can control the output voltage.

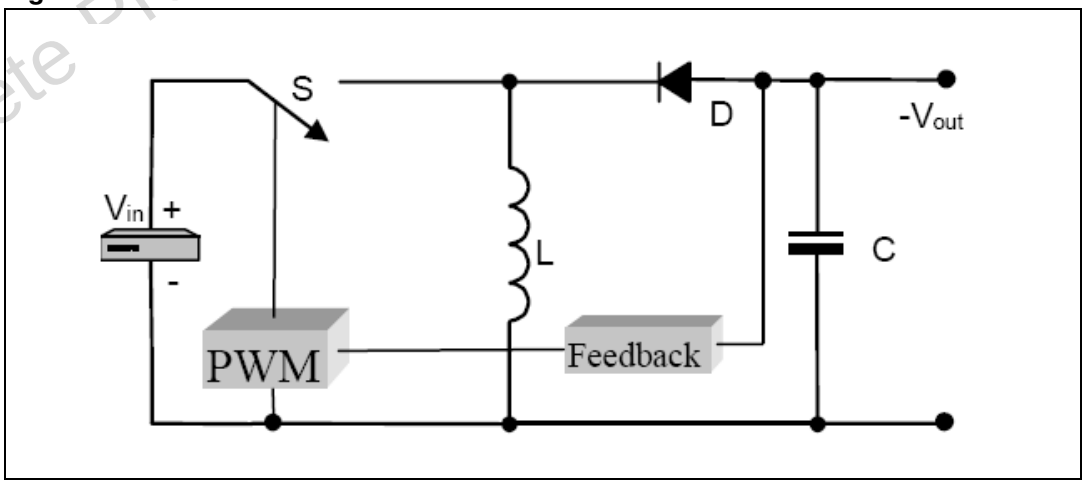
Figure 1. Buck converter



1.2 Buck-boost converter

In this configuration the energy is stored in the inductor L during the on time of the switch, when the switch is off the voltage across L reverses as the inductor transfers the stored energy to the smoothing capacitor and to the load. The output voltage is the opposite polarity to the input.

Figure 2. Buck-boost converter



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2 VIPer20 in non isolated secondary regulation

VIPer20 is an integrated device with: 620V breakdown voltage Power MOSFET (700V VIPer20A), PWM controller, start up circuit and protections.

The start up of the power supply is provided through the DRAIN pin by means of an integrated high voltage current source, which is switched off during normal operation. The VDD pin provides two functions. The first one is to supply the control section of the power IC; in fact if VDD goes below 8V, the start-up current source is turned on and the Power MOSFET is switched off until the VDD voltage reaches 11V. During the start up the internal current consumption is reduced, the VDD pin provides a current of about 2mA and the COMP pin is shorted to ground. After that (VDD=11V), the current source is switched off, and the device starts switching. The second function is related to the control of the device since this pin is also connected to the error amplifier, in order to allow primary as well as secondary regulation configurations. In case of primary regulation, an internal 13V trimmed reference voltage is used to maintain VDD at 13V. For secondary regulation, a voltage between 8.5V and 12.5V will be put on VDD pin, in order to stick the error amplifier output transconductance to the high state. The COMP pin behaves as a constant current source, and can easily be connected to the output of an optocoupler. Note that any over-voltage due to regulation loop failure is still detected by the error amplifier through the VDD voltage, which cannot overpass 13V. The output voltage will be somewhat higher than the nominal one, but still under control.

The COMP pin provides two functions: it is the output of the error amplifier, and allows the connection of a compensation network to provide the desired transfer function of the regulation loop (R3, C2). Its bandwidth can be easily adjusted using usual component values. As stated above, secondary regulation configurations are also implemented through the COMP pin. When the COMP voltage goes below 0.5V, the shutdown of the circuit occurs, with a zero duty cycle for the Power MOSFET. This feature can be used to switch off the converter, and is automatically activated by the regulation loop (whatever is the configuration) to provide a burst mode operation in case of negligible output power or open load condition.

The switching frequency is set by an RC network connected to the OSC pin, regardless VDD value in the range from 8V to 15V. This pin also provides a synchronization capability, when connected to an external frequency source.

2.1 Comp pin control

In order to perform secondary regulation a suitable control circuit is applied to COMP pin, as shown in *Figure 3.* Since the output voltage supplies directly the VIPer20 by means of a high voltage diode, it has to be in the range 8V ÷ 12.5V, in order to guarantee the minimum supply voltage and to avoid the primary regulation.

The control circuit consists in an npn transistor Q1, a Zener diode Dz, a high voltage decoupling diode D2 and a bias network (C1, R1 and R2). The feedback circuit (D2,Dz) works during the off state of the power switch, charging the capacitor C1.

During the on state, the voltage across C1 drives Q1 base, through R1 and R2, drawing current from the COMP pin and performing the regulation. The capacitor value is selected considering both the feedback precision and stability, thus it depends on the desired output precision and the switching frequency. In steady state condition the voltage across C1 is

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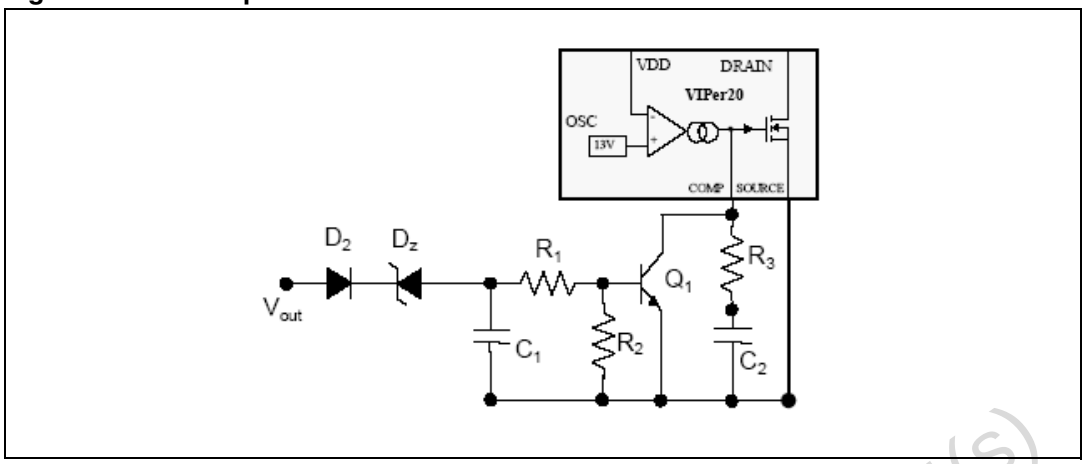
constant. As an output voltage change is detected by the feedback network (D2, Dz), the voltage across C1 changes driving the base current of the transistor Q1 and consequently the comp pin voltage. Thus the regulation loop sets the output voltage to the proper value.

Figure 3. COMP pin control scheme



2.2 Inductor and frequency selection

The Inductor and frequency value are based to maximum output current and mode of operation, besides the peak drain current has not to overcome 0.5A. It suitably works in discontinuous mode in which the inductor current never goes to zero, in fact it is better to avoid the continuous mode because of several reasons:

- higher switching losses in the switch and in the free wheeling diode
- the inductor size and price would increase
- regulators operating in the discontinuous are very stable and have a very good closed loop response
- higher EMI

The interaction between inductor and switching frequency in order to have the maximum output current with limited drain current peak lower (for VIPer20 is 0.5A), can be calculate by means of following formula:

Equation 1

$$L = \frac{2 \bullet V_{out} \bullet I_{out}}{I_{dmax}^{2} \bullet f_{sw}}$$

We can do two considerations

- fixed inductor, the maximum output current increased with the switching frequency
- fixed switching frequency, the maximum output current increased with the inductor value

The following relation shows interaction between inductor value and switching frequency in order to work in discontinuous mode:

Equation 2

$$f < \frac{V_{out}}{I_{out} \bullet 2 \bullet L}$$

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3 Application examples

3.1 Buck converter

The schematic of the circuit is shown in *Figure 4.* The specifications of the power supplies are listed in *Table 1.* Due to the basic operation of the power supply a Zener diode, Dzo, is connected across the output in order to allow voltage regulation in open load condition and to avoid voltage spike due to slow input voltage transients (see AN1317).

The maximum output current is related to the drain current limitation of the VIPer. The typical value for VIPer20 is 0.67A with a minimum guaranteed value of 0.5A. As the output current increases over the current limitation the output voltage drops down to the minimum supply voltage (8V) shutting down the device.

Table 1. Buck converter specifications

Parameter	Value
AC input voltage Vinac	85 - 265Vac
Output current Iout	300mA
Output voltage Vout	+12V
Switching frequency	20kHz
Output voltage ripple	5%

Figure 4. Buck converter using VIPer20 in secondary regulation

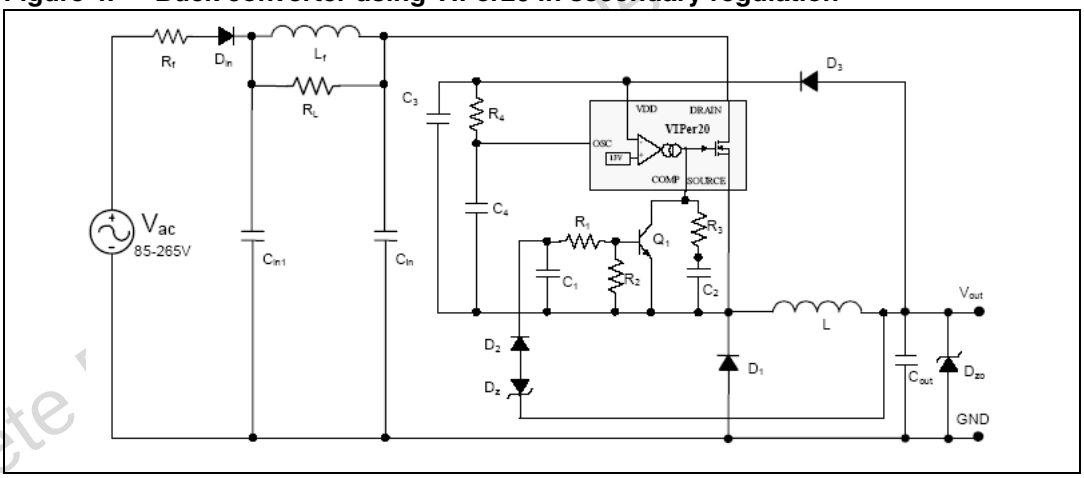

Table 2. Components list

Reference	Value	Part number
R_f	10Ω/ 1/2W 5%	
R_L	10KΩ / 1/2W 5%	
R_1	10KΩ / 1/4W 5%	
R_2	47KΩ / 1/4W 5%	
R_3	8.2KΩ/ 1/4W 5%	

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Table 2. Components list (continued)

Reference	Value	Part number
R_4	10KΩ / 1/4W 5%	
C_{in}	10µF / 400V Electrolytic	
C_{in1}	3.3µF / 400V Electrolytic	
C_{out}	100µF / 25V Electrolytic	
C_1	470nF / 25V Ceramic	
C_2	100nF / 25V Ceramic	
C_3	10µF / 25V Electrolytic	
C_4	10nF / 25V Ceramic	
D_r		Diode 1N4007
D_1		Diode STTA106
D_2		Diode 1N4005
D_3		Diode 1N4005
D_Z	9.1V Zener	
D_{Z0}	13V Zener	
L	2.1mH Inductor	
L_f	470µH Inductor	
Q_1		Transistor BC547B
I_{C1}		STMicroelectronics VIPer20DIP

Figure 5. PCB layout using VIPer20 in secondary regulation (not in scale)

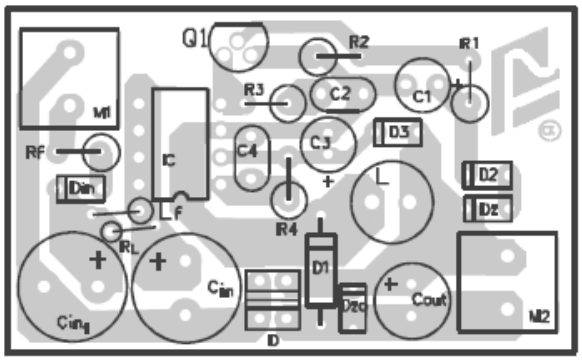

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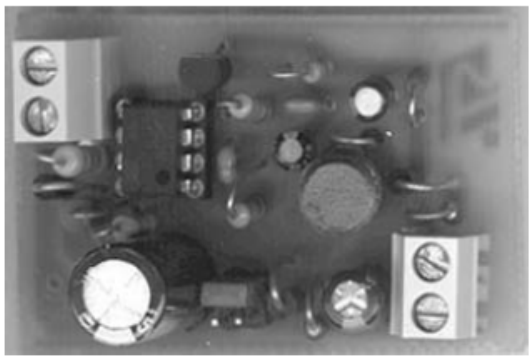
Figure 6. VIPer20 board in secondary regulation



3.2 Experimental results

In this section some experimental waveforms are shown and a performance evaluation is carried out in terms of line and load regulation as well as efficiency.

The output voltage is almost independent of input voltage, featuring a horizontal line as the input voltage changes from 80V to 265V, confirming the superior regulation behavior.

Load regulation is performed as well, ranging from 10.8V to 12V as the load increases from no load to 300mA.

The efficiency has been evaluated and it is shown in the figure as function of output current. The circuit works with a good efficiency that is always over 55% with peak over 75%.

Figure 7. Buck converter: line regulation

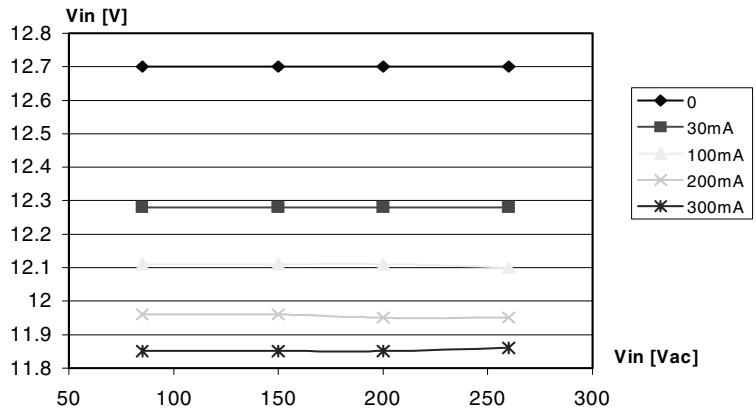


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Figure 8. Buck converter: load regulation

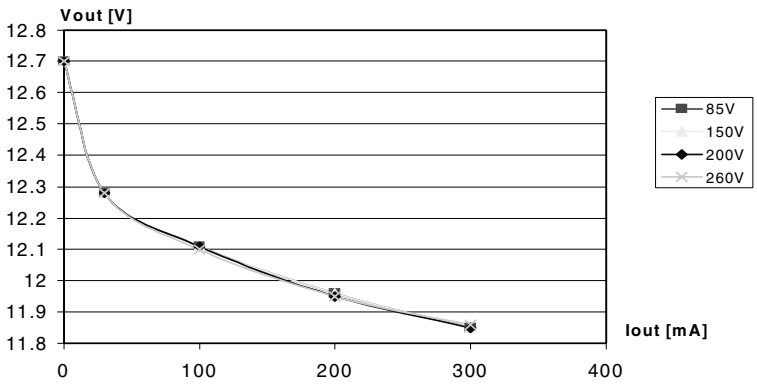
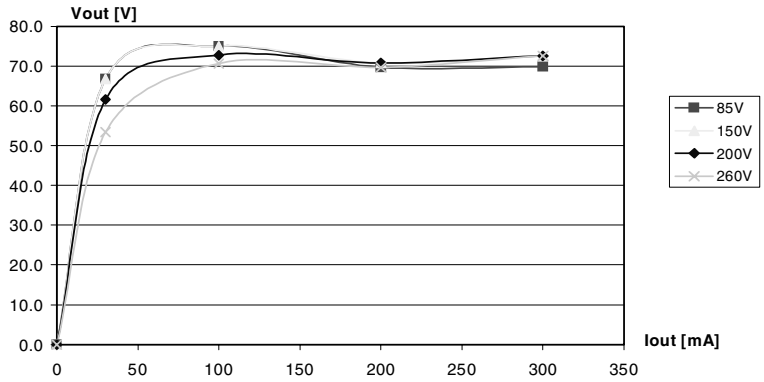


Figure 9. Buck converter: efficiency



3.3 EMI behavior

In this session the circuit EMI behavior has been analyzed, both with an LC filter and without, in the following conditions:

- Vin = 185Vac
- Vout = 9.34Vdc
- Pin = 1.5W
- Rout = 100Ω
- Iout = 100mA

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Figure 10. EMI behavior without filter

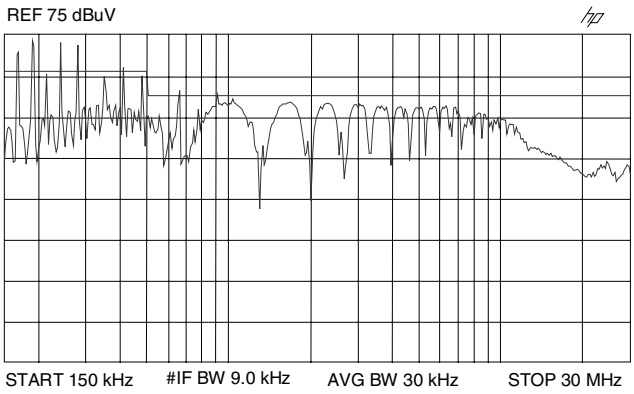
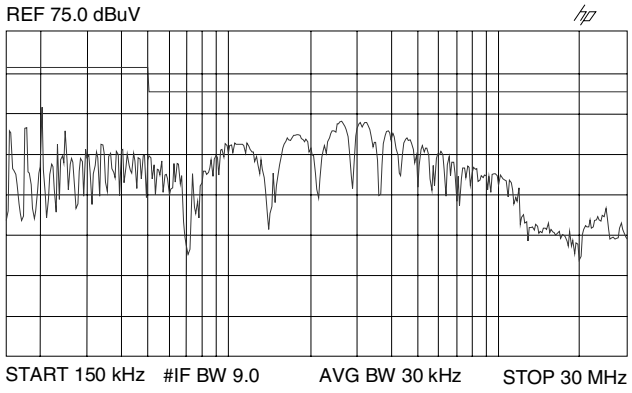


Figure 11. EMI behavior with filter LC



The *Figure 11.* shows a good EMI behavior for the circuit with a LC filter.

3.4 3Buck-boost converter

The schematic of the circuit is shown in *Figure 12.* The specifications of the power supplies are listed in *Table 3.* The output voltage supplies directly the VIPer20, then it has to range from 8V to 12.5V, in order to keep on the VIPer and hold the error amplifier in saturation allowing voltage regulation through the COMP pin. The control circuit consists in a BC547B transistor and a 10V Zener diode.

Table 3. Buck-boost converter specifications

Parameter	Value
AC input voltage Vinac	85 - 265Vac
Output current Iout	300mA
Output voltage Vout	-11V

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Table 3. Buck-boost converter specifications (continued)

Parameter	Value
Switching frequency	20kHz
Output voltage ripple	5%

Figure 12. Buck-boost converter using VIPer20 in secondary regulation

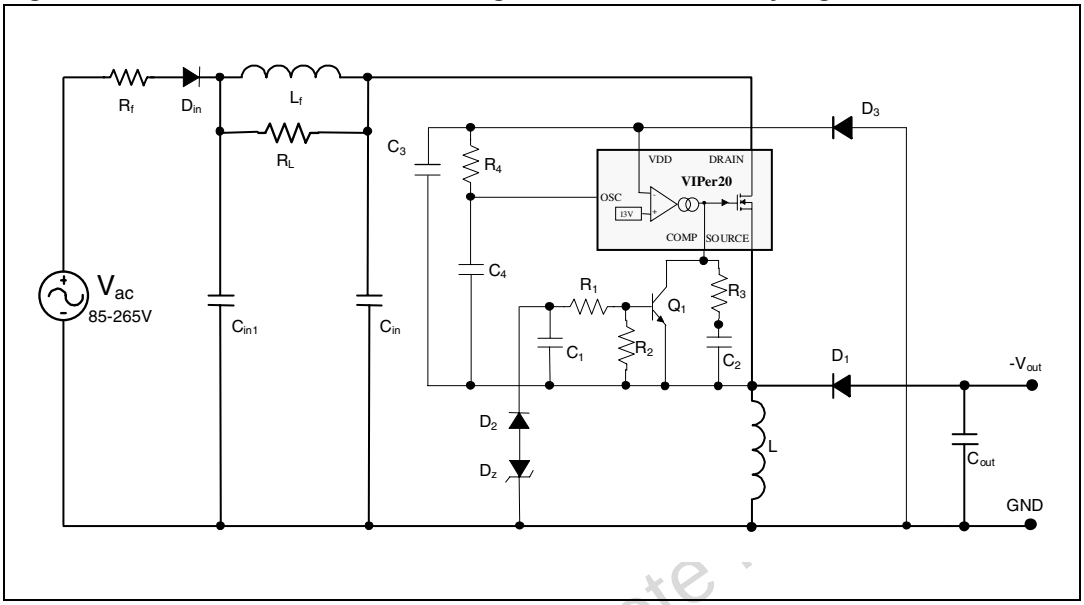

Table 4. Buck-boost converter component list

Reference	Value	Part number
R_f	10Ω/ 1/2W 5%	
R_L	10KΩ / 1/2W 5%	
R_1	10KΩ / 1/4W 5%	
R_2	47KΩ / 1/4W 5%	
R_3	8.2KΩ/ 1/4W 5%	
R_4	10kΩ1/4W, 5%	
C_{in}	3.3µF, 400V Electrolytic	
C_{in1}	3.3µF, 400V Electrolytic	
C_{out}	100µF, 25V Electrolytic	
C_1	470nF, 25V Ceramic	
C_2	100nF, 25V Ceramic	
C_3	10µF, 25V Electrolytic	
C_4	10nF, 25V Ceramic	
D_r		Diode 1N4007
D_1		Diode STTA106

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Table 4. Buck-boost converter component list (continued)

Reference	Value	Part number
D_2		Diode 1N4005
D_3		Diode 1N4005
D_Z	10V Zener	
D_{Z1}	13V Zener	
L	2.1mH Inductor	
L_f	470µHInductor	
Q_1		Transistor BC547B
I_{C1}		STMicroelectronics VIPer20DIP

Figure 13. Buck-boost converter: line regulation

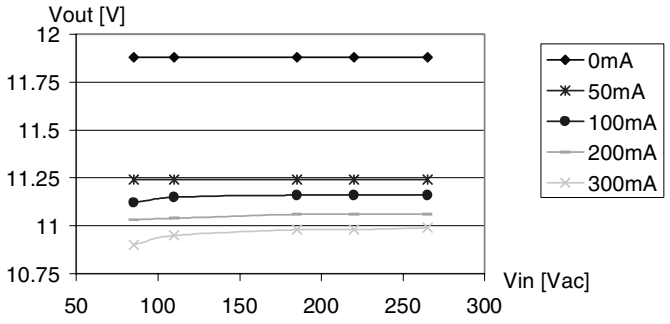


Figure 14. Buck-boost converter: line regulation

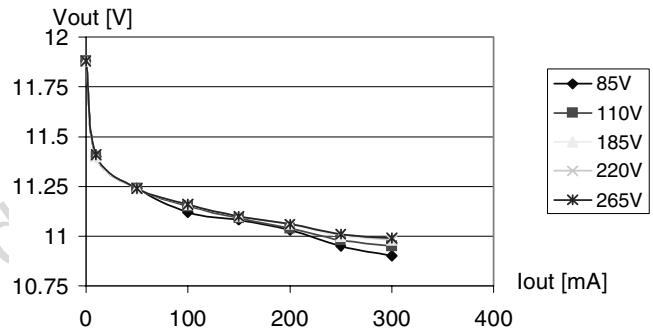
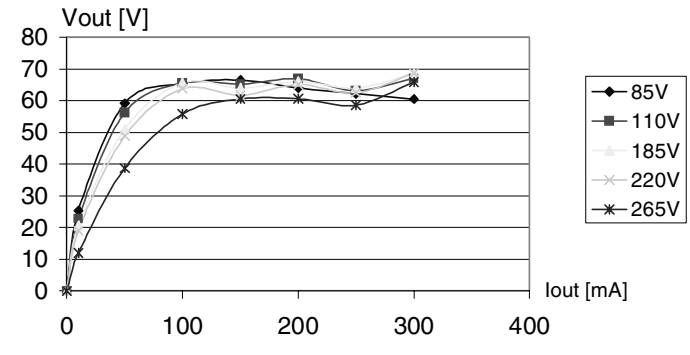


Figure 15. Buck-boost converter: line regulation



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4 Conclusion

A simple way to obtain secondary regulation in an off-line power supplies based on VIPer20 family has been introduced. The circuit features high efficiency and good overall performance in terms of load and line regulation. In such a way there is no need of any linear post regulator improving efficiency and reducing the size and cost of the supply. The considered topology can be realized with other devices of the VIPer family for higher power level.

For further information about SMPS PWM controller ICs please consult the VIPower web pages at: http://www.st.com/vipower.

5 Revision history

Table 5. Revision history

Date	Revision	Changes
04-Jan-2005	1	First issue
18-Dec-2006	2	The document has been reformatted Updated text on *Chapter 2*

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