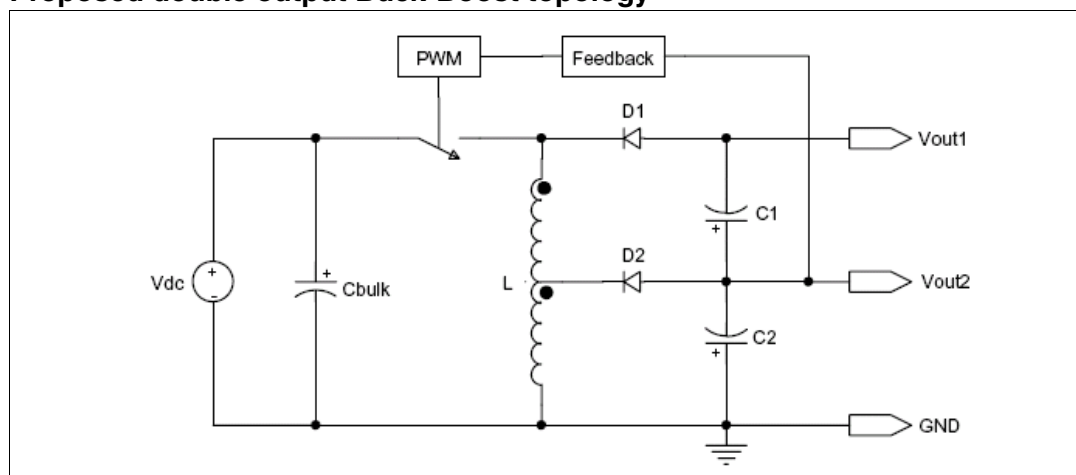


Double output Buck-Boost converter with VIPerX2A

Introduction

This paper introduces two off-line non-insulated SMPS double outputs in Buck–Boost configuration based on VIPerX2A family. The power supplies are operated in wide input voltage range, i.e. 88 to 265VAC. They can supply small loads, such as a microcontroller, triacs, display and peripherals in the industrial segment and home appliance. In the applications where a double output is required, two different solutions can be used. The first one regards an insulated converter topology, with second output generated by means of one winding on the magnetic core of the inductor with a proper turns ratio. Nevertheless, this solution is expensive in terms of transformer and can be used for medium and high current or insulated applications. For low power and low cost applications, a non-insulated converter topology can be used. The proposed topology, based on Buck-Boost converter, is used to supply negative output voltage referred to neutral in all those applications where the galvanic insulation is not required. The principle schematic is shown in figure below.

Proposed double output Buck-Boost topology



V_{OUT1} is provided using the classic Buck-Boost configurations, while V_{OUT2} is obtained thanks to an intermediate tap on the inductor.

Compared to other already proposed solutions, the second output is obtained thanks to an intermediate tap on a low cost inductor. This configuration limits the parasitic capacitive effect between the two winding and improves the regulation at open load.

Further advantage is related to the regulation feedback connected on V_{OUT2} . Thanks to this regulation, it is possible to cover those applications where a low tolerance and low voltage is required (i.e. a microcontroller) and a high tolerance and high voltage is required for the auxiliary circuit (drivers, relays...).

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1 VIPerX2 description

The proposed converters are based on The VIPerX2A family, which is a range of smart power devices with current mode PWM controller, start-up circuit and protections integrated in a monolithic chip using VIPower M0 Technology.

The VIPerX2A family includes:

- VIPer12, with a 0.4A peak drain current limitation and 730V breakdown voltage;
- VIPer22, with a 0.7A peak drain current limitation and 730V breakdown voltage.

The switching frequency is internally fixed at 60kHz by the integrated oscillator of the VIPerX2.

The internal control circuit offers the following benefits:

- Large input voltage range on the V_{DD} pin accommodates changes in supply voltage;
- Automatic burst mode in low load condition;
- Overload protection in hiccup mode.

The feedback pin FB is sensitive to current and controls the operation of the device.

2 Output voltage selection

Two converters with different output voltage are introduced in this paper. The main specifications are listed in [Table 1](#).

Table 1. Proposed converters

Output 1	Output 2	P _{OUT(MAX)}
-12V/150mA	-5V/300mA	3.3W
-24V/100mA	-5V/300mA	3.9W

As already discussed, V_{OUT2} is obtained by means of an intermediate tap on the inductor.

This imposes, for the two solutions, a different design of the output inductor in terms of turns ratio, i.e. n=1.4 for the -12V solution, against n=3.8 for the -24V solution (even if it could be necessary to tune the turn ratio for proper output voltage).

Some disadvantage are related to the -12V solution:

- The parasitic capacitance effect between the two windings is increased, compared to the second one. This will bring about higher switching losses in turn-on (see [Figure 10](#). and [Figure 11](#).) and, consequently, a worsening in terms of efficiency;
- A higher voltage diode is needed to supply the VIPer;
- The peak current is twice higher, giving less output power margin for a given I_{DLIM}.

Therefore, a -24V/-5V solution can be suitably used for all those applications where efficiency and cost are important and, in general, in all the designs where a -24V output voltage does not impact on the cost of the relays and drivers.

Instead, the -12V/-5V solution can be used all those times where it is not possible to change the auxiliary supply voltage.

3 Application example n° 1

The first application example is a 3.3W double output Buck-Boost converter. The specifications are listed in [Table 2](#).

The schematic of the circuit is shown in [Figure 1](#). and the component list is shown in [Table 3](#).

Table 2. SMPS specifications

Specification	Value
Input voltage range, V_{IN}	88 - 265V _{AC}
Output voltage V_{OUT1}	-12V
Output voltage V_{OUT2}	-5V
Maximum output current I_{OUT1}	150mA
Maximum output current I_{OUT2}	300mA
Maximum output power	3.3W

The input voltage can range from 88V_{AC} to 265V_{AC}. The input section consists in a resistor as a fuse, a single input rectifier diode and an input C-L-C filter. Such a filter provides both DC voltage stabilization and EMI filtering. The C_{SN} - R_{SN} leg across D_1 helps the further reducing of the conducted emissions.

The regulation feedback is connected to V_{OUT2} by means of the PNP transistor Q_1 and zener diode D_{Z2} , in order to provide an output voltage with tight regulation range (the output precision depends on D_{Z2} tolerance). V_{OUT1} is obtained thanks to the turns ratio of the transformer.

The output inductor is wound in a TDK drum ferrite core (SRW0913 type), with an intermediate tap for V_{OUT2} . The specifications are the following:

- $L_{1-3} = 420\mu\text{H}$;
- $N_{1-2} = 70$ turns;
- $N_{2-3} = 62$ turns.

Optional bleeder resistors, R_{b1} and R_{b2} , can be connected to the outputs in order to improve the regulation.

In particular, R_{b1} has to be chosen in order to avoid the overvoltage on V_{OUT1} when V_{OUT2} is full loaded and V_{OUT1} is in no load condition.

Figure 1. Converter schematic

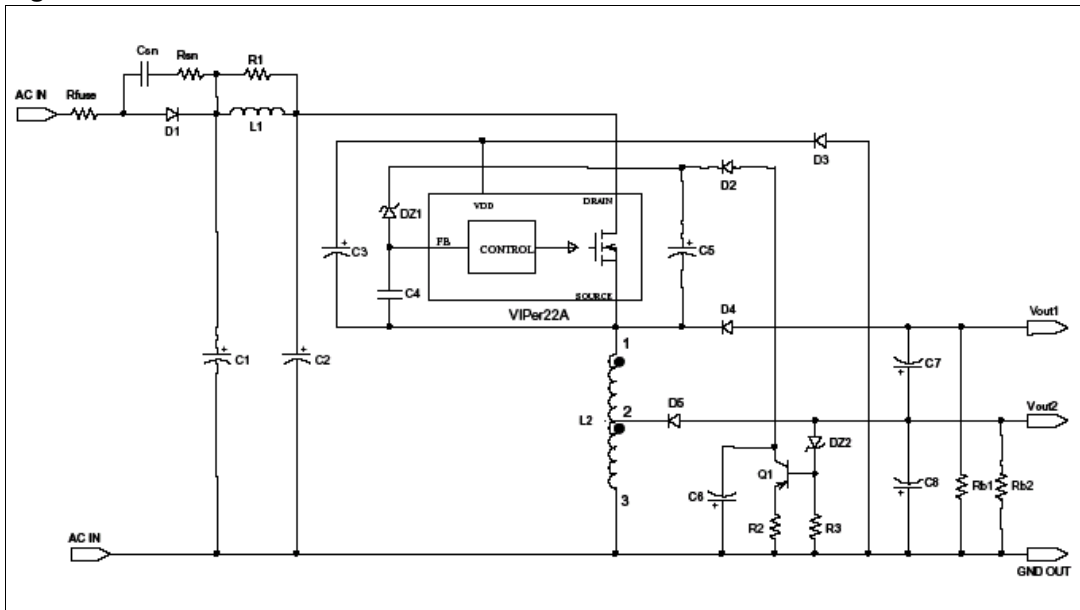


Table 3. Component list

Reference	Value	Description
R _{FUSE}	22Ω, 1/2W	Metallic oxide resistor
R _{SN} , R ₁	1.2KΩ, 1/4W	Resistor
R ₂	22Ω, 1/2W	Resistor
R ₃	68Ω, 1/4W	Resistor
R _{b1} , R _{b2}		Optional resistor
C _{SN}	0.1μF, 400V	Polyester capacitor
C ₁ , C ₂	10μF, 400V	Electrolytic capacitor
C ₃	10μF, 50V	Electrolytic capacitor
C ₄	22nF, 35V	Ceramic capacitor
C ₅	0.47μF, 50V	Electrolytic capacitor
C ₆	4.7μF, 50V	Electrolytic capacitor
C ₇	220μF, 16V	Electrolytic capacitor
C ₈	470μF, 16V	Electrolytic capacitor
D ₁		Diode 1N4007
D ₂ , D ₃		Diode BA157
D ₄ , D ₅		Diode STTH106 (ultrafast)
D _{Z1}		Diode Zener 6.8V
D _{Z2}		Diode Zener 4.3V
Q ₁		PNP transistor BC558
L ₁	470μH	Axial inductor

Table 3. Component list (continued)

Reference	Value	Description
L ₂	(Read sec. 5)	
IC		STMicroelectronics VIPer22ADIP

3.1 Experimental results

The power supply has been characterized in terms of line and load regulation. The efficiency measurements have been taken using a DC power source and a milliamperometer, in order to have higher accuracy than in AC measurements. In [Table 4.](#), [Table 5.](#) and [Table 6.](#) the experimental results are shown. It is then possible to observe the efficiency decreases, at same output power, when V_{OUT2} is more loaded. This can be explained with an increase of the parasitic capacitance effect between the windings. These measurements have been performed without bleeder resistors. Consequently, an overvoltage occurs on V_{OUT1} when it is in no load condition and V_{OUT2} is full loaded. This can be avoided adding a 3.3KW resistor as a bleeder, with only a slight reduction of the efficiency. In [Figure 2.](#), [Figure 3.](#), [Figure 4.](#), [Figure 5.](#), [Figure 6.](#), and [Figure 7.](#) typical waveforms at minimum and maximum input voltage are shown. [Figure 8.](#) and [Figure 9.](#) shows the output ripple voltage at full load at minimum and maximum input voltage. In [Figure 10.](#) and [Figure 11.](#) turn-on losses measurements are shown in the same previous conditions. It is important to point out that a lot of power is dissipated in turn-on, due to the parasitic capacitance of the inductor.

Table 4. Circuit characterization - $V_{IN} = 120V_{DC}$

I _{OUT1} [mA]	I _{OUT2} [mA]	V _{OUT1} [V]	V _{OUT2} [V]	I _{IN} [mA]	P _{IN} [W]	P _{OUT} [W]	η[%]
0	0	12.00	5.01	1.08	0.129	0	0
0	150	14.73	4.99	9.71	1.16	0.784	67.58
0	300	16.04	4.97	18.33	2.20	1.49	67.70
75	0	10.51	5.00	8.86	1.06	0.788	74.30
75	150	11.15	4.97	17.60	2.11	1.58	74.80
75	300	11.32	4.95	27.10	3.25	2.33	71.70
150	0	10.40	4.99	16.81	2.02	1.56	77.20
150	150	10.95	4.95	26.40	3.17	2.38	75.00
150	300	11.14	4.92	36.60	4.40	3.15	71.50

Table 5. Circuit characterization - $V_{IN} = 320V_{DC}$

I _{OUT1} [mA]	I _{OUT2} [mA]	V _{OUT1} [V]	V _{OUT2} [V]	I _{IN} [mA]	P _{IN} [W]	P _{OUT} [W]	η[%]
0	0	11.77	5.04	0.47	0.15	0.00	0.00
0	150	15.56	5.02	3.89	1.24	0.75	60.49
0	300	16.26	5.01	7.25	2.32	1.50	64.78
75	0	10.55	5.02	3.55	1.14	0.79	69.65

Table 5. Circuit characterization - $V_{IN} = 320V_{DC}$

I_{OUT1} [mA]	I_{OUT2} [mA]	V_{OUT1} [V]	V_{OUT2} [V]	I_{IN} [mA]	P_{IN} [W]	P_{OUT} [W]	η [%]
75	150	11.23	5.01	7.01	2.24	1.59	71.05
75	300	11.37	4.99	10.53	3.37	2.35	69.73
150	0	10.4	5.01	6.7	2.14	1.56	72.76
150	150	11.01	5	10.38	3.32	2.40	72.30
150	300	12.21	4.98	14.44	4.62	3.33	71.97

Table 6. Circuit characterization - $V_{IN} = 374V_{DC}$

I_{OUT1} [mA]	I_{OUT2} [mA]	V_{OUT1} [V]	V_{OUT2} [V]	I_{IN} [mA]	P_{IN} [W]	P_{OUT} [W]	η [%]
0	0	11.74	5.06	0.44	0.16	0.00	0.00
0	150	15.77	5.02	3.39	1.27	0.75	59.39
0	300	16.51	5	6.38	2.39	1.50	62.86
75	0	10.54	5.02	3.09	1.16	0.79	68.40
75	150	11.26	5.01	6.18	2.31	1.60	69.05
75	300	11.41	5	9.36	3.50	2.36	67.29
150	0	10.4	5.01	5.92	2.21	1.56	70.46
150	150	11.05	5.01	9.26	3.46	2.41	69.56
150	300	11.2	4.98	12.74	4.76	3.17	66.61

Figure 2. Typical waveforms at 88V_{AC}: open load

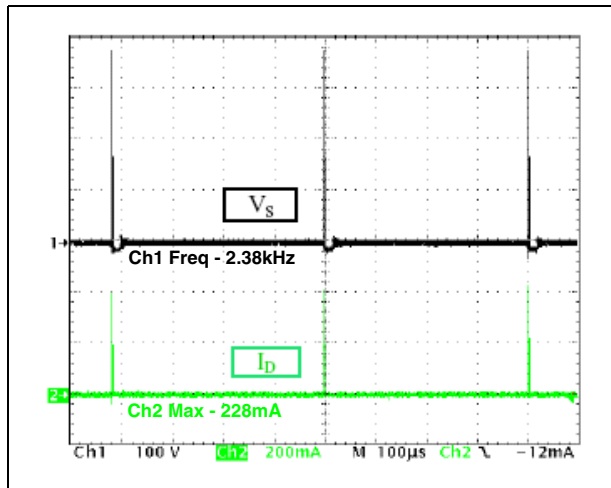


Figure 3. Typical waveforms at 88V_{AC}: full load

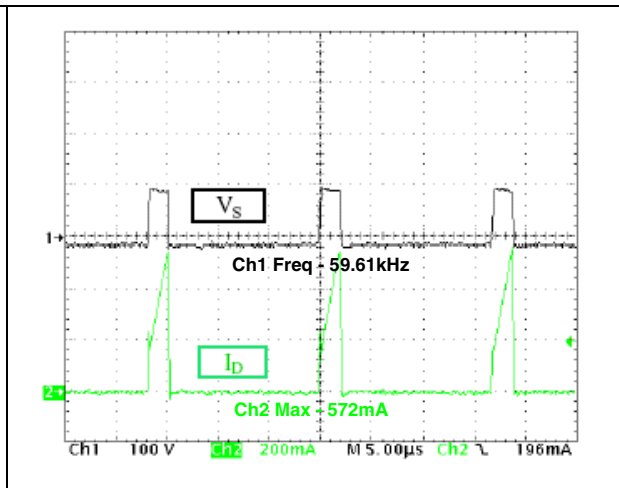


Figure 4. Typical waveforms at 265V_{AC}: open load

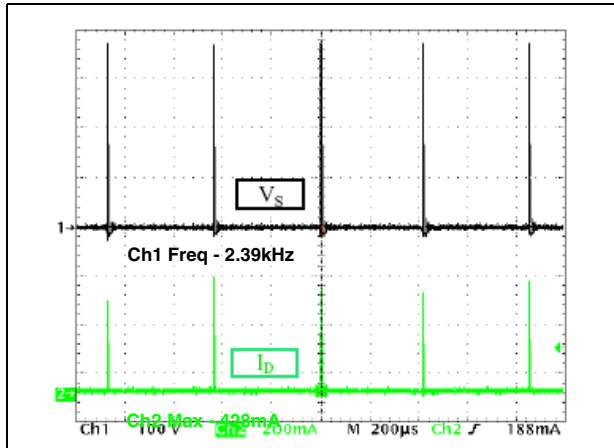


Figure 5. Typical waveforms at 265V_{AC}: full load

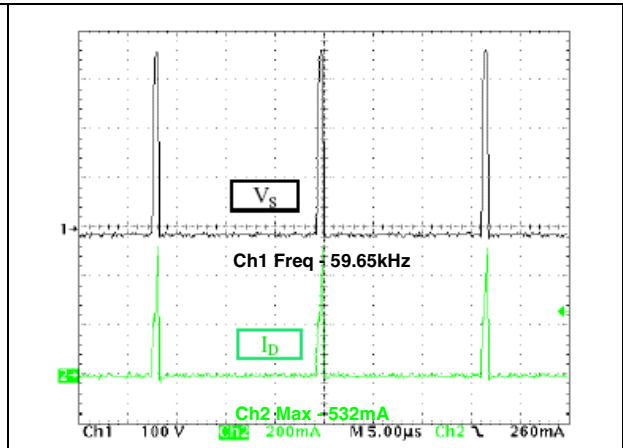


Figure 6. Commutation at full load: 88V_{AC}

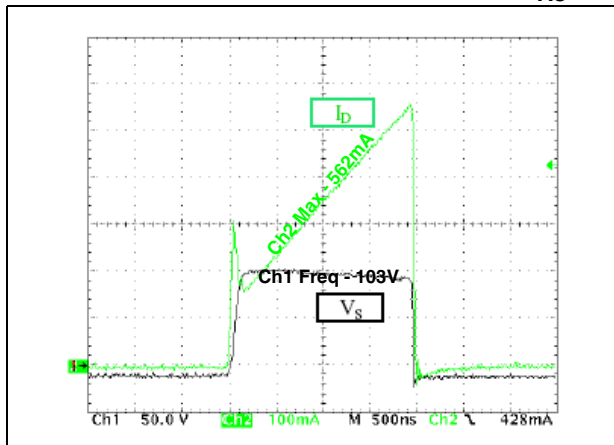


Figure 7. Commutation at full load: 265V_{AC}

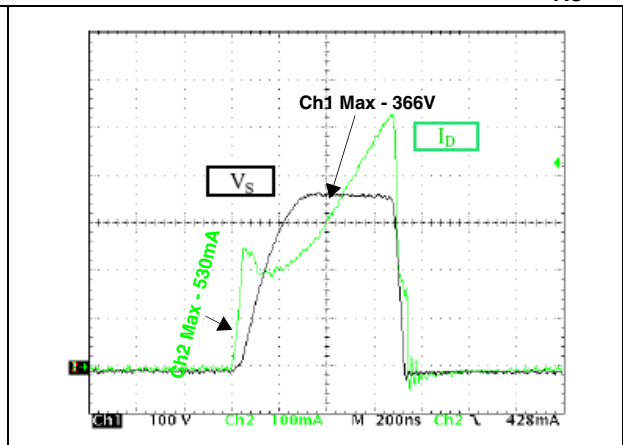


Figure 8. Output ripple voltage at full load: 88V_{AC}

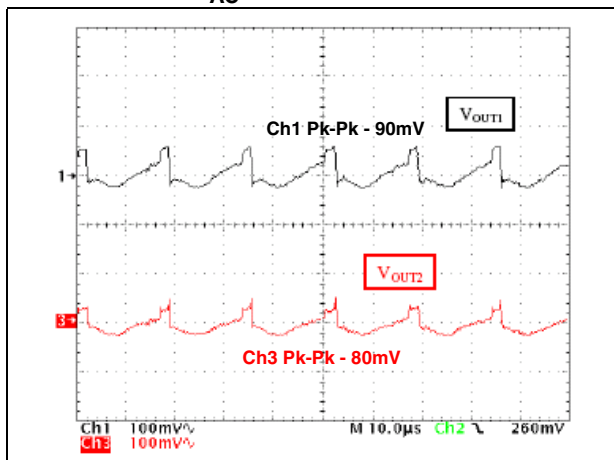


Figure 9. Output ripple voltage at full load: 265V_{AC}

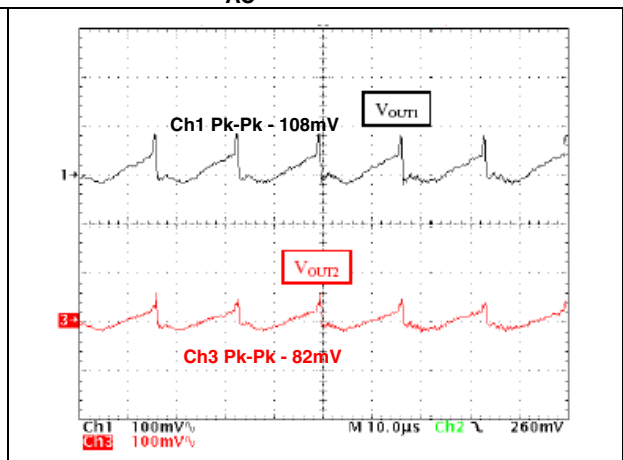


Figure 10. Turn on losses measurement at full load: 88V_{AC}

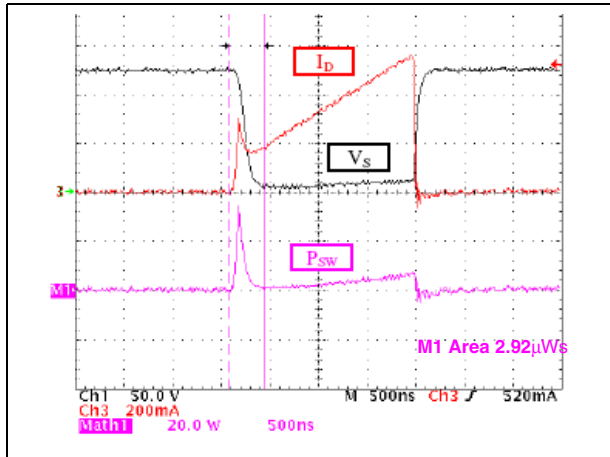
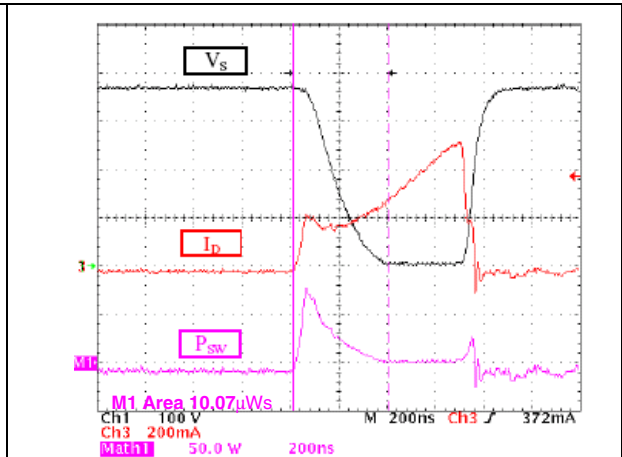


Figure 11. Turn on losses measurement at full load: 265V_{AC}



3.2 Thermal measurements

In this application, the main thermal issues are related to parasitic capacitance effects that can lead to higher power dissipation in the device and then higher working temperature. In order to evaluate the case temperature of the VIPer in the entire input voltage range, a thermal mapping by means of an IR Camera was done at ambient temperature and full load. In [Figure 12](#) and [Figure 13](#) the thermal profile of the device at minimum and maximum input voltage range respectively is shown. It is important to highlight that at low line the conduction losses are predominant, instead at high input voltage the switch losses became not negligible, due to parasitic capacitance of the inductor. This is point out in [Figure 14](#).

Figure 12. VIPer22A Thermal profile: at VIN= 88V_{AC}

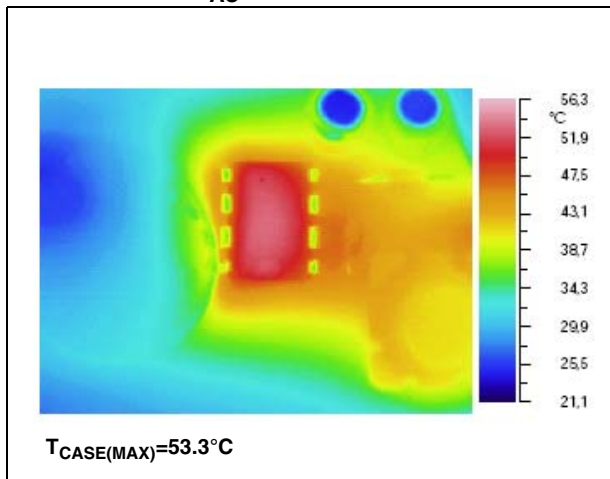


Figure 13. VIPer22A Thermal profile: at VIN= 265V_{AC}

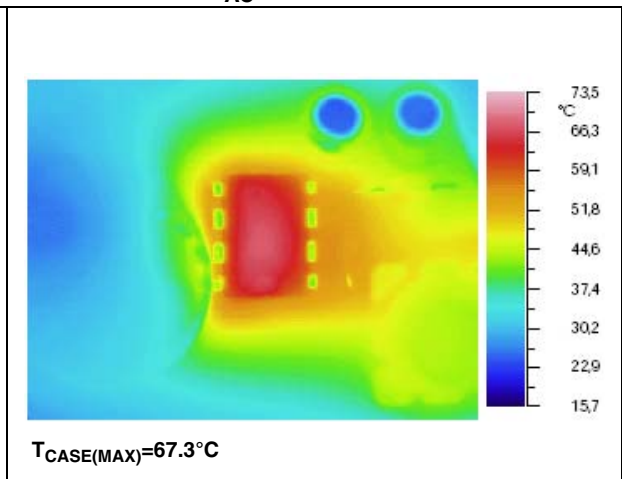
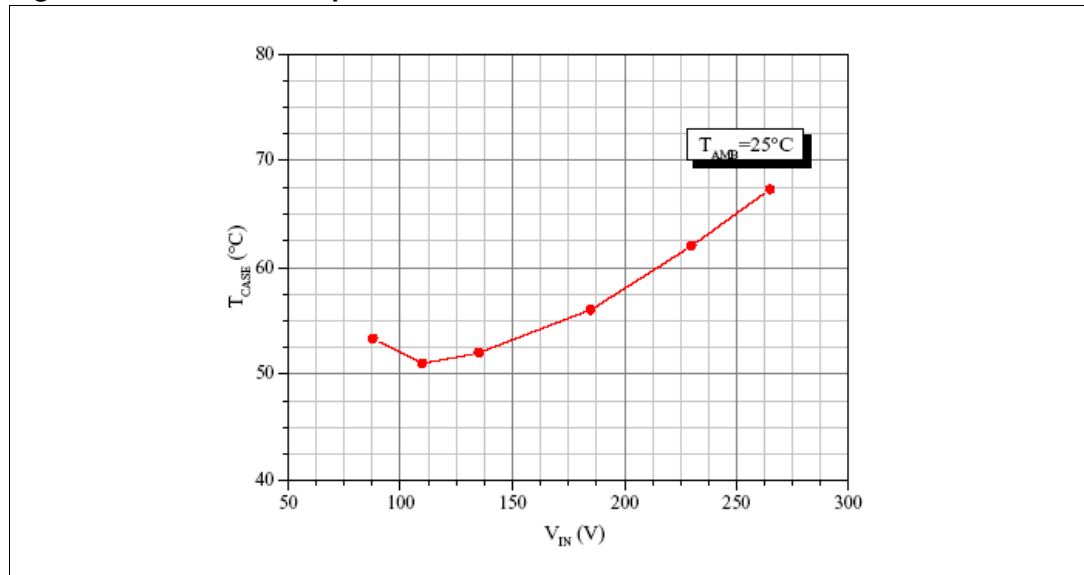


Figure 14. VIPer22A temperature at maximum load



4 Application example nº 2

In this second example, the Buck-Boost is modified in order to have -24V/-5V outputs voltages in a 4W application. In [Table 7](#), the main specifications of the power supply are listed. The schematic of the circuit and the component list are shown in [Figure 15](#), and in [Table 8](#), respectively.

Table 7. SMPS specifications

Specification	Value
Input voltage range, V _{IN}	88 - 265V _{AC}
Output voltage V _{OUT1}	-24V
Output voltage V _{OUT2}	-5V
Maximum output current I _{OUT1}	100mA
Maximum output current I _{OUT2}	300mA
Maximum output power	4W

The -24V output voltage allows to supply the VIPer directly from the feedback path, saving the cost of a high voltage diode. Even in this case, the feedback regulation is connected to V_{OUT2} by means of Q₁ transistor and D_{Z1} zener diode. The output inductor, with intermediate tap for V_{OUT2}, is provided by PULSE (PFM0250 type) with the following features:

- L₁₋₃ = 510µH ±10%;
- N₁₋₃ / N₂₋₃ = 3.81 ± 2%;
- R₁₋₂ = 560mW (max);
- R₂₋₃ 260ΩW (max).

Also bleeder resistors or zener diodes may be mandatory at no load in order to improve the regulation and avoid output overvoltage.

Figure 15. Converter schematic

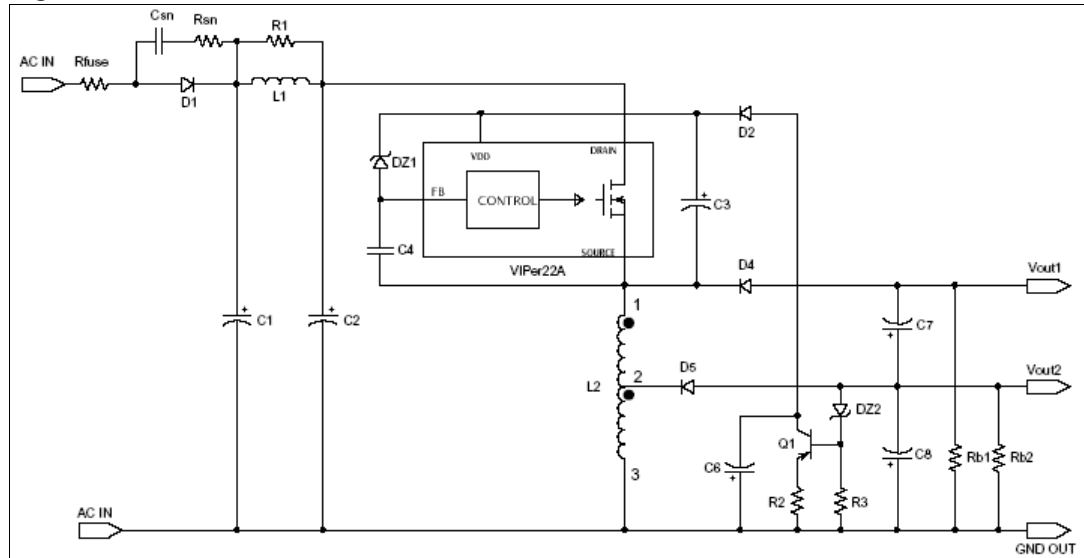


Table 8. Component list

Reference	Value	Description
R _{FUSE}	22Ω, 1/2W	Metallic oxide resistor
R _{SN} , R ₁	1.2KΩ, 1/4W	Resistor
R ₂	22Ω, 1/4W	Resistor
R ₃	100Ω, 1/4W	Resistor
R _{b1} , R _{b2}		Optional resistor
C _{SN}	0.1μF, 400V	Polyester capacitor
C ₁ , C ₂	10μF, 400V	Electrolytic capacitor
C ₃	33μF, 25V	Electrolytic capacitor
C ₄	47nF, 35V	Ceramic capacitor
C ₆	22μF, 16V	Electrolytic capacitor
C ₇	470μF, 25V	Electrolytic capacitor
C ₈	100μF, 16V	Electrolytic capacitor
D ₁		Diode 1N4007
D ₂ , D ₄ , D ₅		Diode BYT11-400 (ultrafast)
D _{Z1}		Diode Zener 18V
D _{Z2}		Diode Zener 4.3V
Q ₁		PNP transistor BC327
L ₁	470μH	Axial inductor

Table 8. Component list (continued)

Reference	Value	Description
L ₂	(Read sec. 6)	Pulse PFM0250
IC		STMicroelectronics

4.1 Experimental results

In [Table 9.](#), [Table 10.](#) and [Table 11.](#) the measures performed on the proposed converter are listed. In [Figure 16.](#) and [Figure 17.](#) typical waveforms at 300V_{DC} are shown.

The converter performs well in terms of line and load regulation. The -5V output shows a ±5% of precision. V_{OUT1}, obtained by means of the turns ratio of the inductor, shows good performance too, even if an overvoltage occurs on V_{OUT1} when it is in no load condition and V_{OUT2} is full loaded. This can be avoided connecting an appropriate bleeder resistor on V_{OUT1}. The efficiency measurements show a better behavior compared to the -12V solution. This can be explained because, in this configuration, the turn-on losses are lower compared to the -12V solution.

Table 9. Experimental results - V_{IN}=120V_{DC}

I _{OUT1} [mA]	I _{OUT2} [mA]	V _{OUT1} [V]	V _{OUT2} [V]	I _{IN} [mA]	P _{IN} [W]	P _{OUT} [W]	η[%]
0	0	24.09	5.096	0.986	0.1972	0	0.00
10	30	23.87	5.098	3.643	0.7286	0.39164	53.75
50	150	23.97	5.087	13.33	2.666	1.96155	73.58
80	240	24.05	5.075	20.5	4.1	3.142	76.63
100	300	24.06	5.069	25.68	5.136	3.9267	76.45
0	300	41.54	5.02	12.74	2.55	1.51	59.11
100	0	21.82	5.083	13.74	2.75	2.18	79.40

Table 10. Experimental results - V_{IN}=320V_{DC}

I _{OUT1} [mA]	I _{OUT2} [mA]	V _{OUT1} [V]	V _{OUT2} [V]	I _{IN} [mA]	P _{IN} [W]	P _{OUT} [W]	η[%]
0	0	24.1	5.098	0.666	0.20	0.00	0.00
10	30	23.9	5.094	2.435	0.73	0.39	53.64
50	150	23.96	5.091	9.182	2.75	1.96	71.21
80	240	24.03	5.079	13.85	4.16	3.14	75.60
100	300	24.03	5.068	17.17	5.15	3.92	76.17
0	300	41.14	5.025	8.684	2.61	1.51	57.87
100	0	21.89	5.096	9.41	2.82	2.19	77.54

Table 11. Experimental results - $V_{IN}=374V_{DC}$

$I_{OUT1}[mA]$	$I_{OUT2}[mA]$	$V_{OUT1}[V]$	$V_{OUT2}[V]$	$I_{IN}[mA]$	$P_{IN}[W]$	$P_{OUT}[W]$	$\eta[\%]$
0	0	24.16	5.098	0.513	0.21	0.00	0.00
10	30	23.99	5.094	1.852	0.74	0.39	53.01
50	150	24	5.094	7.04	2.82	1.96	69.75
80	240	24.03	5.085	10.66	4.26	3.14	73.71
100	300	24.028	5.071	13.14	5.26	3.92	74.66
0	300	41	5.03	6.68	2.67	1.51	56.47
100	0	21.93	5.1	7.221	2.89	2.19	75.92

Figure 16. Typical waveforms at 300V_{DC} and full load: commutation

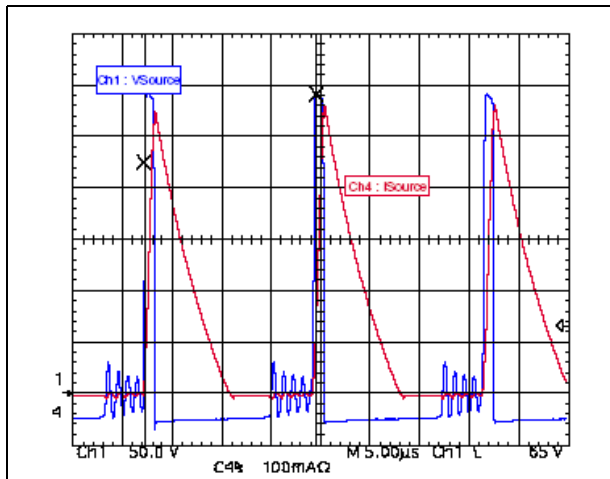
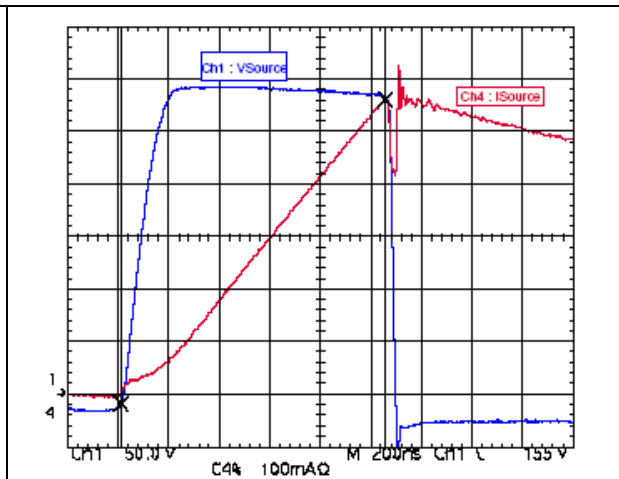


Figure 17. Typical waveforms at 300V_{DC} and full load: detail



5 Layout considerations

A proper PCB layout is essential for correct operation of any switch-mode converter and the same basic rules have to be taken into account in order to optimize the current path, especially in high current path routing.

Since EMI issues are related to layout, the current loop area has to be minimized. Moreover, the control ground path has to be separated from power ground, in order to avoid any noise interference between the control section and the power section.

All the traces carrying high currents have to be as short as possible, in order to minimize the resistive and inductive effect.

A particular care has to be taken into account regarding the optimal routing of the input EMI filter path and the correct placement of any single component ($L_1 - R_1$ very close to input bulk capacitors, trace as short as possible...).

Finally, dissipating copper area on the VIPer drain and diodes pins have to be provided, in order to increase the power dissipation capability and, consequently, reduce the devices temperature.

The circuit layout is shown in figure 12 for the -12V configuration and in figure 13 for the -24V configuration. The PCB is the same and includes the options for the two configurations.

Figure 18. PCB Layout (not in scale). Option n° 1: -12V output voltage

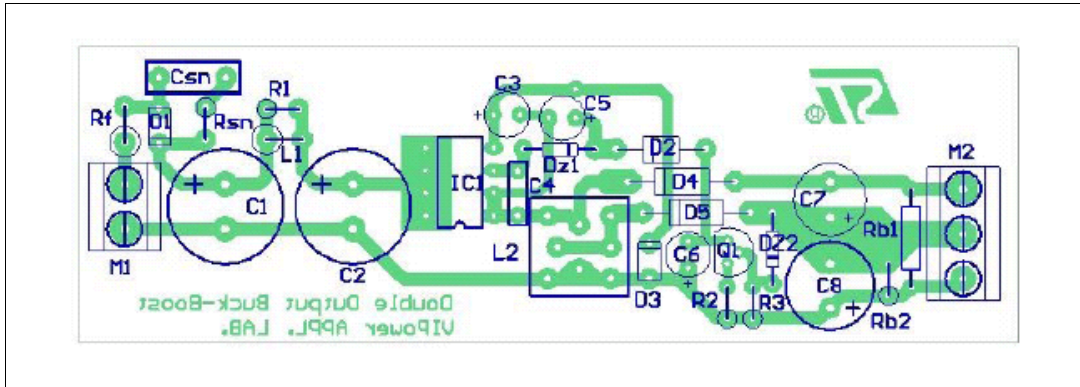
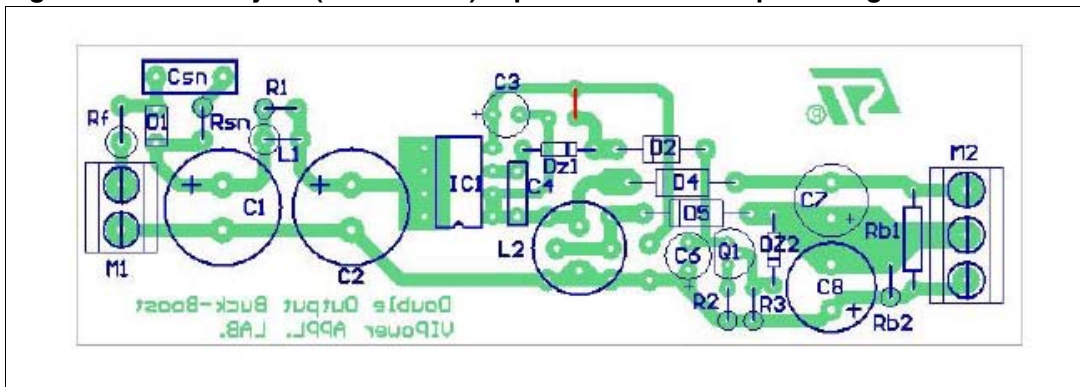


Figure 19. PCB Layout (not in scale). Option n° 2: -24V output voltage



6 Conclusions

Two low cost double outputs Buck-Boost converters have been proposed based on STMicroelectronics VIPer22A.

Thanks to the regulation feedback connected to $-5V$ output, the converters can be suitably used to supply a microcontroller or applications where a high output voltage tolerance is required.

Instead, the $-12V$ or $-24V$ output voltage, achieved by the output inductor turns ratio, can be used for the auxiliary circuits where a lower tolerance can be accepted.

In particular, the $-24V$ option can be preferred because it guarantees a higher efficiency (due to lower turn- on losses) and allows to save the cost of a high voltage diode compared to the $-12V$ solution.

On the other side, the $-12V$ solution has to be used in many applications when it is not possible to change the auxiliary supply voltage from $-12V$ to $-24V$.

The same topology can be used for lower power range, replacing the VIPer22 with the VIPer12.

In this case the device can deliver up to about 2.2W.

7 Revision history

Table 12. Revision history

Date	Revision	Changes
04-Dec-2006	1	Initial release

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