AN1344
Application note

VIPower: 108 W power supply using VIPer100A-E

Introduction

The VIPer100A-E is designed to deliver 100 W for the upper voltage range or 50 W for universal input. This application note describes a power supply that delivers over 100 W for both voltage ranges using a voltage doubler in the front end. The VIPer100A-E combines a state-of-the-art PWM circuit along with an optimized 700 V avalanche rugged Vertical Power MOSFET. It is part of STMicroelectronics' proprietary VIPower, (Vertical Intelligent Power). It uses a fabrication process, which allows the integration of analog control circuits with vertical power device on the same chip.

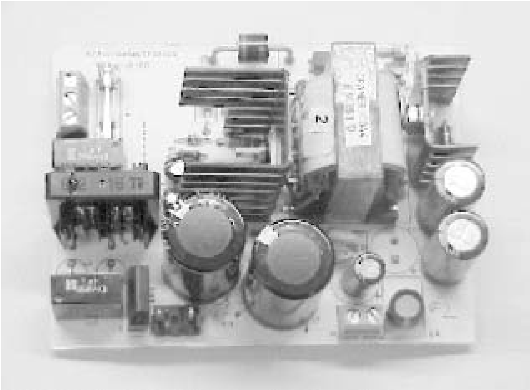
This document covers the implementation and results for achieving 18 V at 6 A power supply that runs from both European and domestic mains. (90-132 V_{ac} and 180- 264 V_{ac}, 47-63 Hz).

Contents

1 Key features of the VIPer100A-E

- Adjustable switching frequency up to 20 kHz
- Current mode control
- Burst mode operation in standby mode, meets "Blue Angel"
- Undervoltage lock-out with hysteresis
- Integrated start-up supply
- Avalanche rugged
- Overtemperature protection
- Primary or secondary regulation

Figure 1. Board layout



The power supply has low ripple voltage, good transient response, and be able to current limit by power limiting and cycling on and off during a hard short. One use of this application is to replace a bulky 60 Hz transformer with a lighter, better regulated, more efficient alternative for an audio or entertainment system.

2 General circuit description

The power supply has been designed for the upper voltage range. The lower voltage range utilizes a voltage doubler to raise the bulk voltage to 2 times the peak of the input line voltage. In the doubling mode, the current charges one capacitor for each phase of the line, therefore doubling the voltage. When SW1 is open, both capacitors are charged in series resulting in a bulk voltage equal to the peak of the line input.

A wire jumper can be installed at production for units destined for countries using the lower range. The switching frequency operates at 100 kHz. The output can deliver 18 V from no load to 6 A continuous. The mode of operation ranges from discontinuous at high line minimum load to continuous at low line max load. This mode of operation was chosen to minimize the high peak currents of the discontinuous mode of operation.

The VIPer100A-E can be regulated in secondary mode with an optocoupler giving excellent regulation or in the primary mode. Primary regulation works by regulating the V_{dd} pin at the output of the auxiliary winding. Depending on the coupling of the transformer, a 15% regulation can be achieved. In this application, by taking advantage of the dual regulation, a current limit scheme is obtained. This VIPer100A-E advantage, along with the transformer design, constitutes the overcurrent circuit. The transformer is designed for a turn ratio of operation for a universal input and an inductance to run in continuous conduction mode at one-half the output load. The coupling between the secondary to auxiliary winding along with the VIPer100A-E dual regulation plays an important part in the current limit.

Under typical operation, the output is tightly regulated through U2 and U3, the optocoupler and TL431 respectively. As the output current increases, it causes the voltage at the auxiliary output to increase. R4 is selected to trim the voltage at V_{dd} to reach 13 V when the output current exceeds the maximum limit. At this point, primary regulation takes over and the output starts to fold-back.

The output uses an STMicroelectronics 100 V Schottky diode for better efficiency. C9 and C10 are low ESR capacitors which manage the ripple current. U3 provides the reference and the feedback to tightly regulate the output. C7, C8, and R6 form the feed back loop compensation to optimize stability during transients.

Table 1. Electrical specification

Parameter	Results
Input voltage	90-132 V_{AC} with jumper in, 180 - 264 V_{AC} no jumper
Output voltage J2	
Load regulation (0.6 to 6 A) from set point	+/- 0.6%
Line regulation (at max load)	+/- 0.05%
Efficiency	86% @120 V_{DC} and 87% @ 375 V_{DC}
Output ripple voltage	15 mV max
Input power at no load	1.5 W typical
Transient response, 50% load step	+/- 350 mV, +/- 1.9%, 200 µs settling time
EMI	EN55022 and FCC class B

Figure 2. Electrical schematic

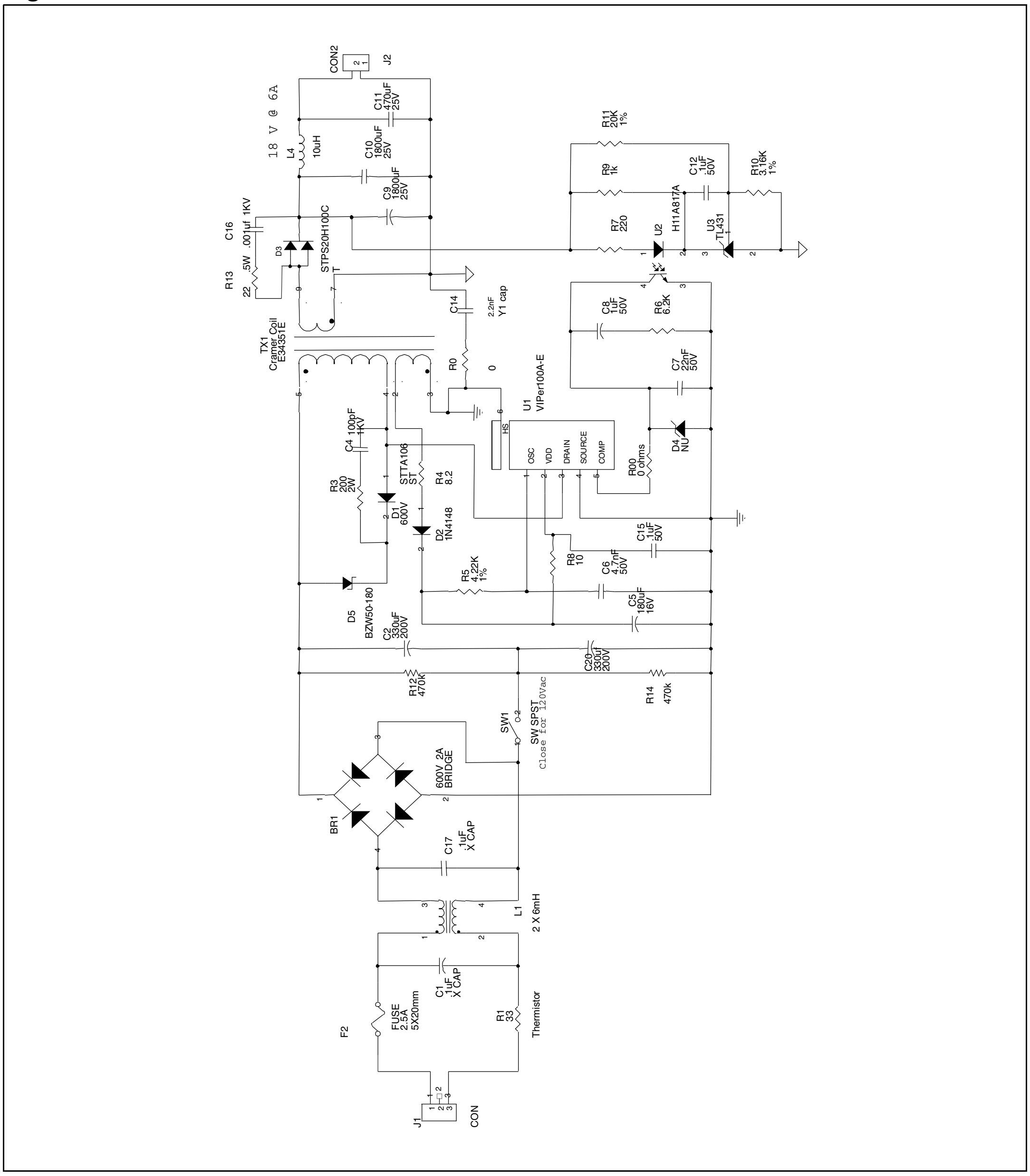
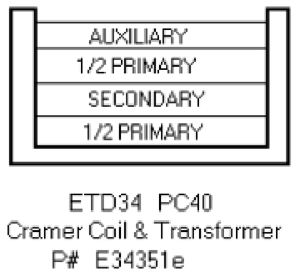


Table 2. Transformer specification

Parameter	Value
Primary inductance	525 µH
Primary leakage inductance	7.9 µH
Core	ETD34
Inductance rating (al factor)	329 nH/T
Note	Split primary - gapped core

2.1 Transformer construction

Figure 3. Cross section of the transformer



The transformer is wound with a split primary to reduce leakage inductance and minimize the snubbing needed. The auxiliary winding is placed on the outside to achieve the coupling needed for the current limiting function.

Figure 4. PC board top legend and bottom foil (112 mm X 83 mm single sided)

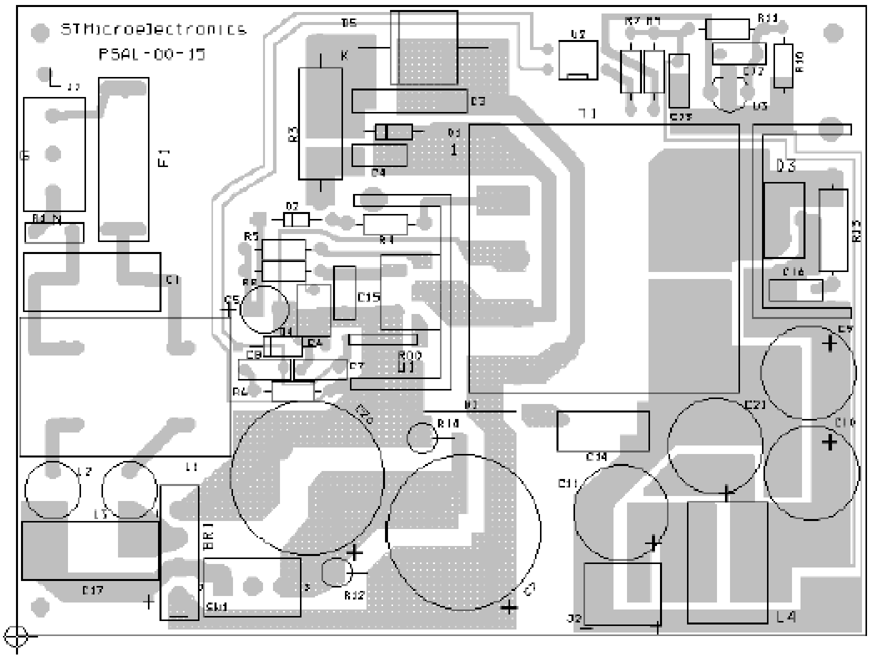


Figure 5. Voltage and current waveforms

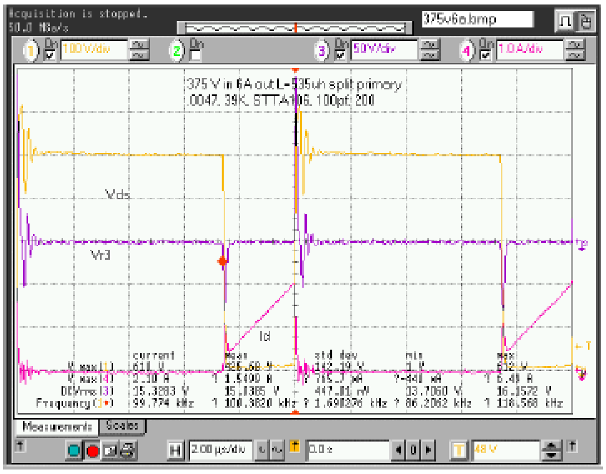


Figure 5 illustrates the voltage drain to source, and the current through the VIPer100A-E.

Vr3 is the V_{rms} across R3 to snub the diode. The maximum voltage drain to source measured 609 V out of the 700 V, specified maximum. The current shows the power supply being in continuous conduction mode with a peak of 2 A. The snubber R3-C4 reduces ringing thus lowering the maximum peak voltage on the Power MOSFET and reducing the EMI. In these waveforms the transil, D3, was replaced by an RC clamp, (R2=39 K, 2 W and C3=4700 pF). The clamp circuit worked the same under normal operation, but during start up or during short circuit operation, the voltage on the drain of VIPer100A-E reached as high as 750 V. The device is avalanche rugged and was able to withstand the momentary energy. Using the Transil at this power level is preferred in order to reduce the stresses.

Table 3. Component list

Quantity	Reference	Value	Part number
1	BR1	600 V, 1.5 A	Bridge 2KBP06M
2	C1, C17	0.1 µF, X CAP	P4610
2	C2, C20	330 µF, 200 V	P6116
1	C4	100 pF, 1 KV	P4116
1	C5	180 µF, 16 V	P10245
1	C6	4.7 nF, 50 V	P4793
1	C7	22 nF, 50 V	P4517
1	C8	1 µF, 50 V	P10312
1	C9	1800 µF, 25 V	PANASONIC FC
1	C10	1800 µF, 25 V	P10283
1	C11	470 µF, 25 V	P6242C
2	C12, C15	0.1 µF, 50 V	P4923
1	C14	2.2 nF, Y1 CAP	P10463

Table 3. Component list (continued)

Quantity	Reference	Value	Part number
1	C16	0.001 µF, 1 KV	P4128
1	D1	600 V	STMicroelectronics STTA106
1	D2		1N4148
1	D3	2x10 A, 100 V	STMicroelectronics STPS20H100CT
1	D4	3.3NZ	NU
1	D5		STMicroelectronics BZW50-180
1	F2	2.5 A, 5x20 mm	FUSE
1	J1		CON
1	J2		CON2
1	L1	2x6 mH	PLK1084
1	L4	10 µH	M6007
1	R0	0	WIRE
1	R00	0 Ω	WIRE
1	R1	33 Ω Thermistor	NW 96F3302
1	R3	200 Ω, 2 W	
1	R4	8.2 Ω	
1	R5	4.22 KΩ, 1%	
1	R6	6.2 KΩ	
1	R7	220 Ω	
1	R8	10 Ω	
1	R9	1 KΩ	
1	R10	3.16 KΩ, 1%	
1	R11	20 KΩ, 1%	
2	R12, R14	470 KΩ, 1/4 W	
1	R13	22 Ω, 1/2 W	
1	SW1		SW SPST
1	TX1	Cramer Coil	E34351E
1	U1	VIPer100A-E	STMicroelectronics VIPer100A-E
1	U2		H11A817A
1	U3	TL431	STMicroelectronics TL431Z

3 Layout considerations

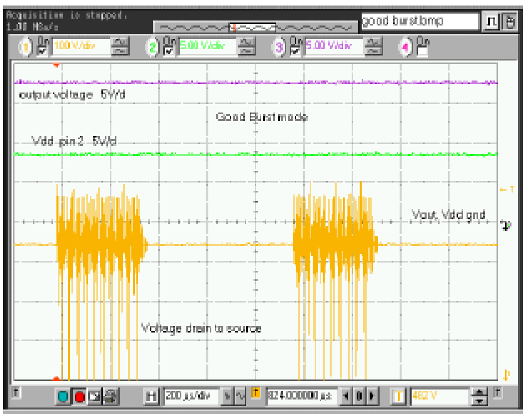
Some simple rules to improve the performance and minimize noise should be followed:

1. Minimize power loops. Switched power current paths inner loop area must be as small as possible. This can be achieved by careful layout of the printed circuit board. This avoids radiated and conducted EMI noise, and improves efficiency by eliminating parasitic inductance, thus reducing or eliminating the need for snubbers and EMI filtering.
2. Use separate tracks for low level signal and power traces carrying fast switching pulses. This can be seen on the VIPer100A-E pin 4. Ground is split between power and signal traces on the printed circuit lay out. When signal paths share the same trace as a power path, instabilities may result. The compensation components, C7, R6, and C9 are on a separate trace connected directly to the source of the device.

4 Burst mode

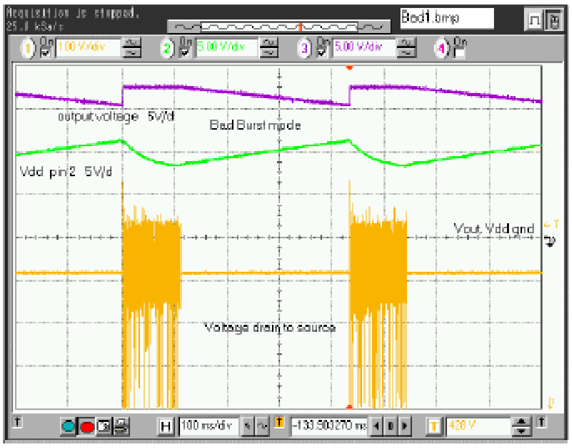
When the output current is too low, the minimum on time, fixed by the internal blanking time, is too high to control the output voltage. In this case the burst mode operation takes over automatically. The VIPer100A-E switch stays off when the voltage on the compensation pin goes below 0.5 V. This results in missing cycles as shown in *Figure 6*. V_{in} is 115 V_{AC}, minimum output current is at 40 mA.

Figure 6. Good burst mode



As can be seen, there is a burst of pulses followed by a pause of 600 ms. This repetitive burst reduces power consumption while maintaining a negligible ripple on the output. The V_{dd} voltage is stable, just above the low threshold of 8 V of the internal under voltage lock out. The under voltage lock out can be reached by further reducing the output current. As the current decreases, the V_{dd} voltage on the primary side also decreases. When V_{dd} falls below the under voltage lock out of 8 V, another type of burst mode appears which is controlled by the V_{dd} voltage. This is called “bad” burst mode (see *Figure 7*) because it has drawbacks, but the output voltage is still under control.

Figure 7. Bad burst mode



At lighter load, the V_{dd} voltage drops below the under voltage threshold, the start up circuit is reset, and the V_{dd} capacitor charges back up to the high threshold of 11 V through the start up current source.

As shown in *Figure 7* the reoccurrence of this cycle is about 300ms. The worst output voltage swing is 2.4 V, which occurs at 20mA. At no-load condition, the output voltage swing becomes negligible (45 mV).

This mode of operation leads to the following drawbacks:

1. Because the start up current source is turned on to supply the capacitor from a high voltage rail, efficiency is dramatically reduced.
2. The recurring period leads to as much as 13% variation in the output voltage. For this audio application it does not matter, but the designer should review all aspects of operation.
3. Below the minimum current of 40 mA, the dynamic behavior is very poor which is typical of all power supplies. If the demand of current occurs during the recharging phase, the output capacitor is discharged and normal operation returns only at the next starting phase.

In conclusion for this design a 40 mA minimum load is needed, 0.6% of maximum load, to keep the unit in optimal performance. However, below this range, the output voltage is still under control and no stresses are applied to the unit.

Table 4. Stand-by input power

Input voltage	Input wattage at no-load	Input wattage at 40 mA
90 V_{ac}	0.85 W	1.77 W
115 V_{ac}	1.1 W	1.8 W
132 V_{ac}	1.3 W	1.86 W

The transformer was optimized for the current scheme and not for Blue Angel.

5 Thermal consideration

Temperature measurement was taken at room ambient of 24 °C, convection air-cooled resulted in the VIPer100A-E tab temperature of 91.1 °C at 115 V_{ac} input with a 6 A output. Results may vary depending on final application.

6 Overcurrent limiting

This power supply was designed for an audio application where music peaks can exceed the maximum current of the power supply. In a sound entertainment system it is imperative for the power supply to not shut down during such peaks. It is acceptable for the voltage to decrease as the current increases. This maintains constant power for the unit. Under a short circuit condition, this unit cycles on and off or "hiccup mode". In *Figure 8* the output voltage versus the output current is shown. Maximum output power reached is 163 W. The VIPer100A-E also has thermal shutdown with hysteresis that is located close to the Power MOSFET portion of the die, which protects it from exceeding the temperature limit of the I.C.

Figure 8. Output voltage versus the output current

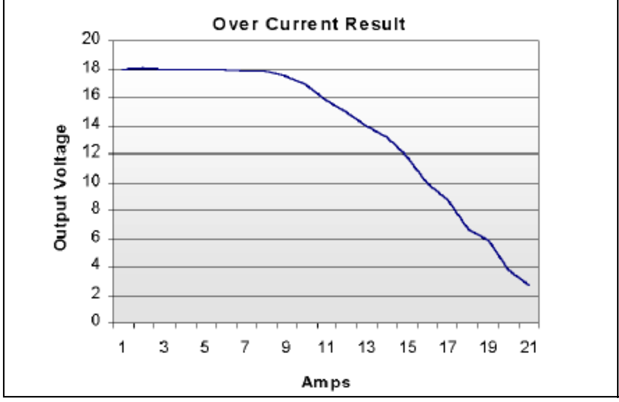


Figure 9. Transient Response 50% step change

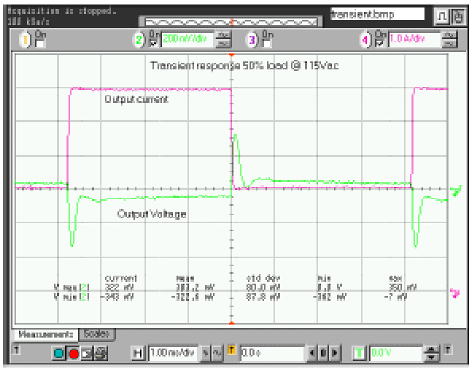


Figure 10. Output Ripple

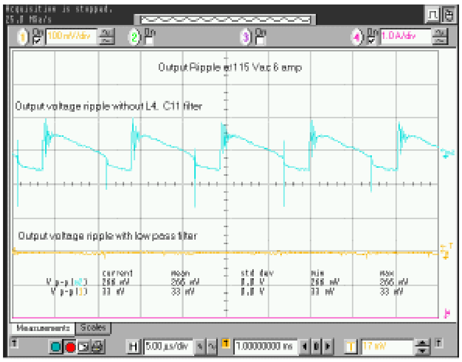
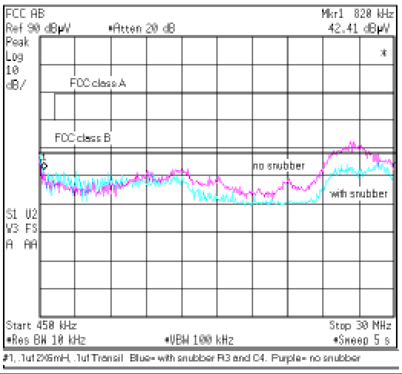


Figure 11. EMI measurement



7 Transient response 50% step change

The output current is modulated from 3 A to 6 A, 50% duty cycle at a line input of 115 V_{AC}. The result is 322 mV or 1.8% dynamic regulation with a settling time of 500 microseconds.

8 Output ripple

The ripple was measured using an HP probe socket attached after the output connector. This minimizes stray noise being picked up by the scope probe ground lead, which shows up as high frequency noise.

The top trace shows the reduction in cost from eliminating L4 and C11. This gives a ripple, at 6 A load, of 125 mV peak to peak. With the low pass filter the ripple is reduced to about 13 mV excluding voltage spikes.

9 EMI consideration

When dealing with EMI, it is always best to reduce noise at its source. *Figure 11* shows FCC class B plots comparing EMI at 6 amps load with snubber R3 and C4 in and out. The blue trace, or lower trace, has the RC snubber across the diode. The EMI is reduced by 4 to 8 db. Adding a 2W resistor and a capacitor here is much less expensive than adding across the line capacitors and inductors in the EMI filter. This unit passed both EN55022 class B and FCC class B.

10 Performance and cost consideration

This design has been optimized for performance. Cost can be reduced by substituting a 17V zener for the TL431. The output regulation falls to the +/- 5% voltage set point, plus a +0.084/°C temperature drift of the zener. The cost of the TL431 and 3 other passive components can then be eliminated. If more output ripple voltage can be tolerated, than L4 and C11 can be eliminated.

11 Conclusion

This design delivers over 100 W for both voltage ranges by utilizing the VIPer100A-E with a voltage doubler in the front end. The power supply has excellent regulation, current limiting, short circuit protection, meets both EN55022 and FCC class B and best of all is from STMicroelectronics.

12 Revision history

Table 5. Document revision history

Date	Revision	Changes
04-Jan-2005	1	Minor text changes
18-Oct-2007	2	– Document reformatted no content change – VIPer100A replaced by VIPer100A-E