# AN4007
# Application note

## EVLVIP37LE5V3A: 15 W (5 V - 3 A) wide range single-output demonstration board

**By Fabio Cacciotto**

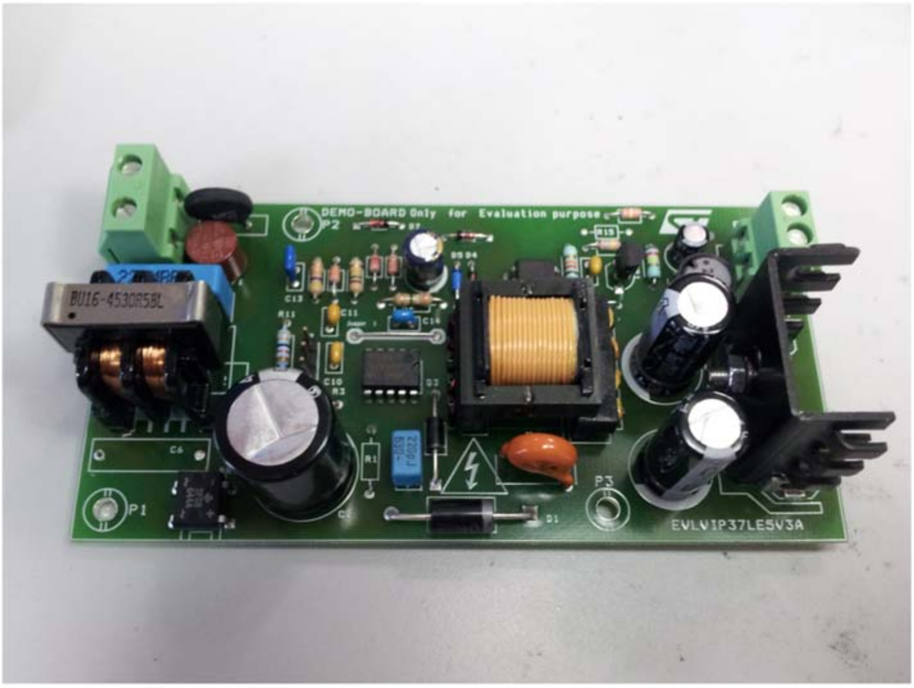
## Introduction

In several applications, such as LCD or plasma TVs, desktop computers, etc., the power supply that converts the energy from the main, often includes two modules: the main power supply that provides most of the power and is OFF when the application is OFF or in standby mode, and the auxiliary power supply that provides energy only to some specific parts of the equipment such as USB ports, remote receivers, or modems but is still ON when the application is in standby mode.

It is often required that, in standby condition, the equipment input power is as low as possible which means the input power of the auxiliary power supply in no load or light load condition is reduced as low as possible.

This application note introduces a new offline high voltage converter from the VIPerPlus family, the VIPER37LE and the presented demonstration board meets the specifications of a wide range of auxiliary power supplies for said applications. Furthermore, it is optimized for very low standby consumption, therefore helping to meet the most stringent energy saving requirements.

**Figure 1. Demonstration board image: power supply board**




AM11340v1

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*Table 1* summarizes the electrical specifications of the power supply, *Table 2* provides the bom list and *Table 3* lists the transformer characteristics. The electrical schematic is shown in *Figure 1* and the PCB layout in *Figure 4*.

**Table 1. VIPER37LE power supply: electrical specifications**

| Parameter | Min. | Typ. | Max. |
|---|---|---|---|
| AC main input voltage | 85 $V_{AC}$ | | 265 $V_{AC}$ |
| Mains frequency ($f_L$) | 50 Hz | | 60 Hz |
| Output voltage | 4.75 V | 5 V | 5.25 V |
| Output current | | | 3 A |
| Output ripple voltage | | | 50 mV |
| Rated output power | | 15 W | |
| Input power in standby | | | 30 mW |
| Active mode efficiency | 70% | | |
| Ambient operating temperature | | | 60 °C |

**Table 2. VIPER37LE demonstration board: bom list**

| Reference | Part | Description | Note |
|---|---|---|---|
| R1 | | 2.2 MΩ | 1% tolerance |
| R2 | | 3.9 MΩ | 1% tolerance |
| R3 | | 2 MΩ | 1% tolerance |
| R4 | | 150 kΩ | 1% tolerance |
| R5 | | 3.3 Ω | |
| R6 | | 330 Ω | |
| R7 | | 220 Ω | |
| R8 | | 12 kΩ | |
| R9 | | 120 kΩ | 1% tolerance |
| R10 | | 10 kΩ | |
| R11 | | 33 kΩ | 1% tolerance |
| R12 | | 33 kΩ | 1% tolerance |
| R13 | | 47 kΩ | |
| R14 | | 39 kΩ | 1% tolerance |
| C1 | | 220 pF - 630 V film capacitor | |
| C2 | | 33 µF - 400 V electrolytic | |
| C3, C4 | ZLK series | 1200 µF - 16 V electrolytic | Rubycon |

**Table 2. VIPER37LE demonstration board: bom list (continued)**

| Reference | Part | Description | Note |
|---|---|---|---|
| C5 | ZLH series | 100 µF - 16 V electrolytic | Rubycon |
| C6 | B81133C1223M | 22 nF - X2 | EPCOS |
| C7 | | 2.2 nF Y-CAP | |
| C9, C10 | | 10 nF ceramic – 25 V | |
| C11 | | 33 nF ceramic – 25 V | |
| C12 | | 22 µF - 35 V electrolytic | |
| C13 | | 2.2 nF ceramic – 25 V | |
| C14 | | 22 nF ceramic – 25 V | |
| D1 | 1.5KE220A | Transil™ | ST |
| D2 | STPS30L40CT | Power Schottky diode | ST |
| D3 | STTH1L06A | Ultra-fast high voltage diode | ST |
| D5 | BAT46RL | Signal Schottky diode | ST |
| D4, D7 | 1N4148 | Signal diode | NXP |
| D6 | BZX79-C18 | 18 V Zener diode | NXP |
| L1 | ELC09D2R2F | 2.2 H power inductor | Panasonic |
| CM | BU16-2530R7BL | CM choke | Coilcraft |
| BR | DF08M-E3 | Bridge diode | Vishay |
| IC1 | VIPER37LE | Primary switching regulator | ST |
| OPT | KB817A | Optoisolator | Kingbright |
| TF | 1715.0038 | Flyback transformer | Magnetica |
| Fs | | 1.6 A fuse | Wickmann |
| NTC | B57236S0160M | NTC inrush current limiter | EPCOS |

*Note: If not otherwise specified, all resistors are ±5%, ¼ W.*

**Figure 2. Electrical schematic**

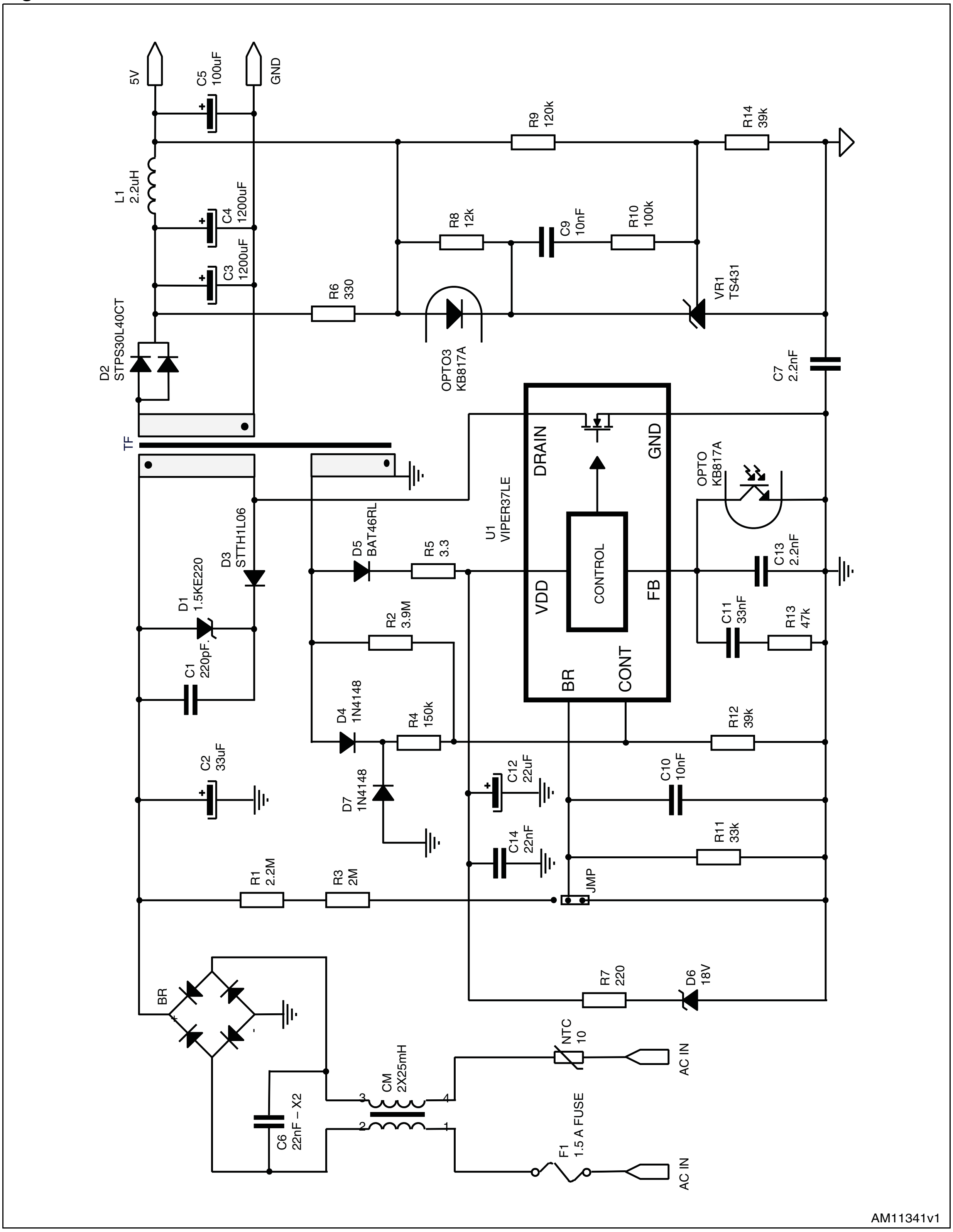
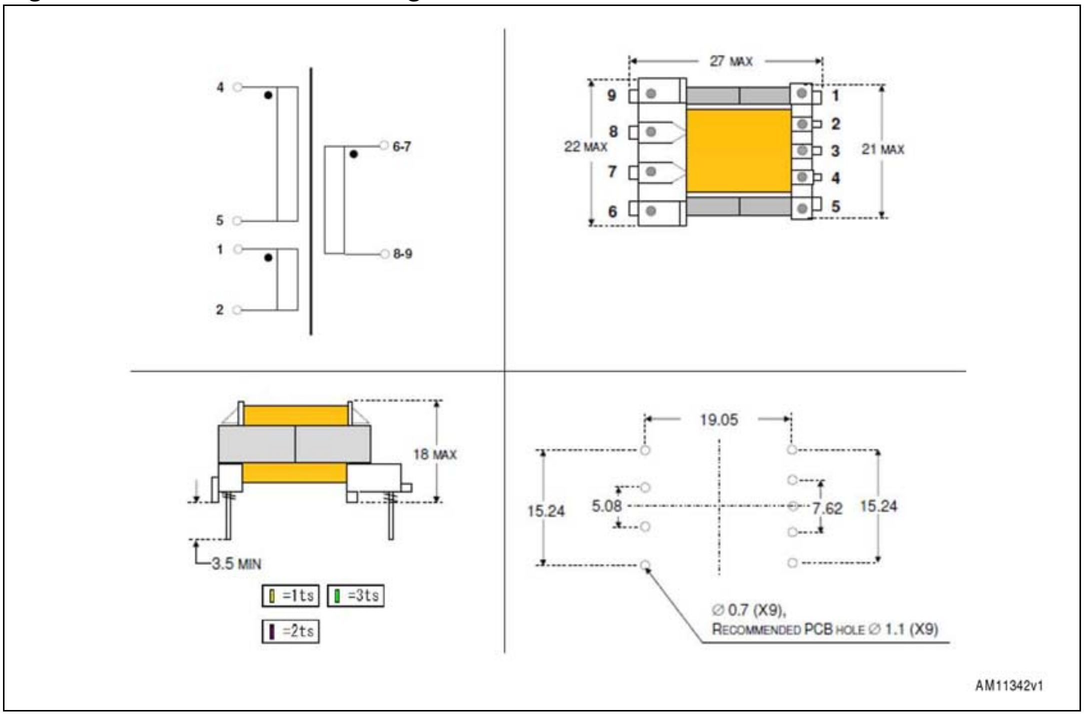


Table 3. VIPER37LE power supply: transformer characteristics

| Manufacturer Magnetica | Values |
|---|---|
| Part number | 1715.0038 |
| Primary inductance | 1.3 mH |
| Leakage inductance | 3% nom |
| Primary to secondary turn ratio | 16.2 ± 5% |
| Primary to auxiliary turn ratio | 5.90 ± 5% |
| Insulation primary-secondary | AC 4 kV (1 s – 2 mA) |

Figure 3. Dimensional drawing

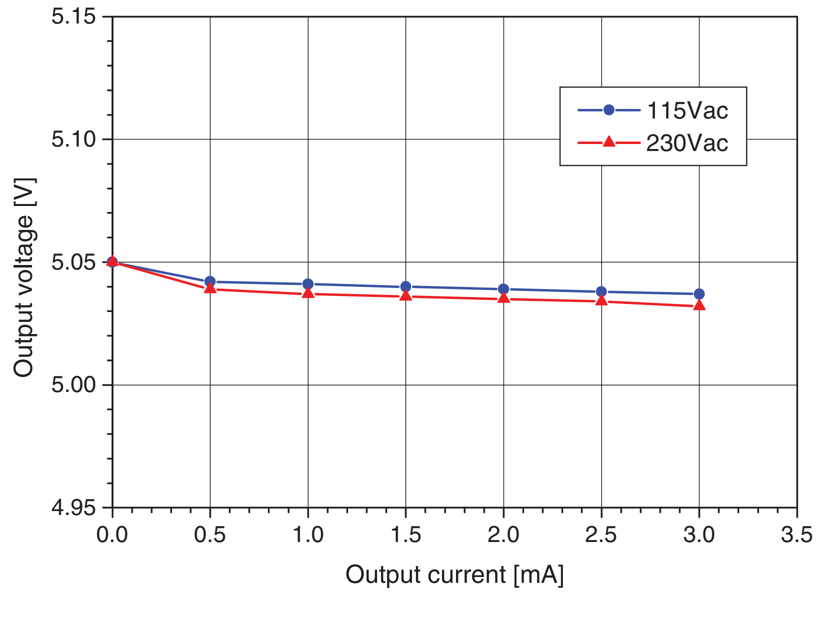



## 1.1 Output voltage characteristics

The output voltage of the board is measured in different line and load conditions. *Figure 4* shows the results: the output voltage variation range is a few tens of mV for all the tested conditions.

All output voltages have been measured on the output connector of the board.

**Figure 4. Line and load regulation**




## 1.2 Efficiency and light load measurements

Any external power supply (EPS) must be capable to meet the international regulation agency limits. The european code of conduct (EC CoC) and US department of energy (DoE-US EISA 2007) limits are taken as reference. EPS limits are fixed up to 76.4%, when the average efficiency is measured. The average efficiency measures the average value at 25%, 50%, 75% and 100% of the rated output power, at both 115 Vac and 230 Vac. *Table 4* and *Table 5* show the results:

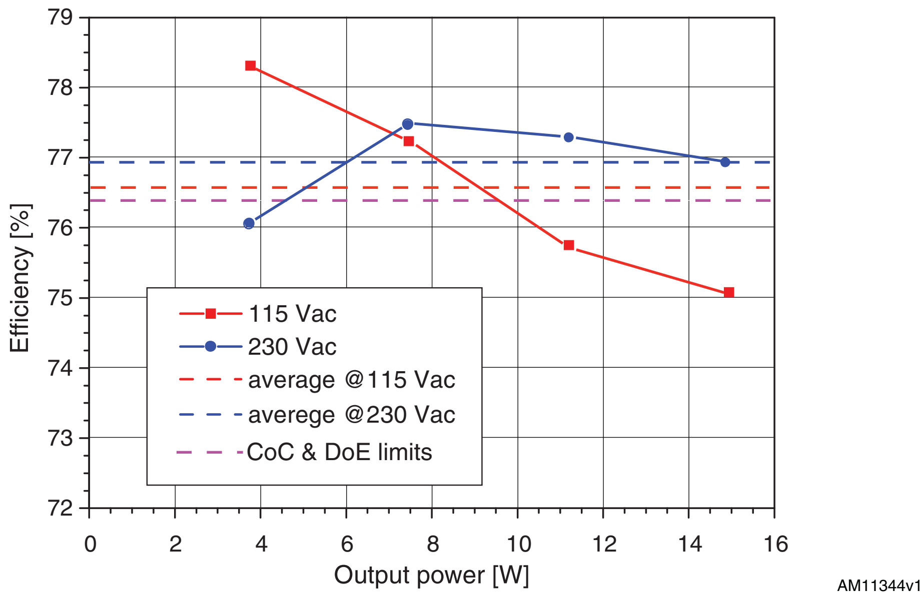
**Table 4. Efficiency at 115 $V_{AC}$**

| Load | $I_{OUT}$ | $V_{OUT}$ | $P_{OUT}$ | $P_{IN}$ | Efficiency |
|---|---|---|---|---|---|
| 25% | 0.75 | 4.97 | 3.73 | 4.76 | 78.31% |
| 50% | 1.5 | 4.97 | 7.46 | 9.65 | 77.25% |
| 75% | 2.25 | 4.97 | 11.17 | 14.75 | 75.74% |
| 100% | 3 | 4.97 | 14.91 | 19.86 | 75.08% |
| Average efficiency | | | | | 76.59% |

Table 5. Efficiency at 230 $V_{AC}$

| Load | $I_{OUT}$ | $V_{OUT}$ | $P_{OUT}$ | $P_{IN}$ | Efficiency |
|---|---|---|---|---|---|
| 25% | 0.75 | 4.97 | 3.73 | 4.9 | 76.07% |
| 50% | 1.5 | 4.965 | 7.45 | 9.61 | 77.50% |
| 75% | 2.25 | 4.965 | 11.17 | 14.45 | 77.31% |
| 100% | 3 | 4.95 | 14.85 | 19.3 | 76.94% |
| Average efficiency | | | | | 76.96% |

Figure 5. Efficiency vs. output power



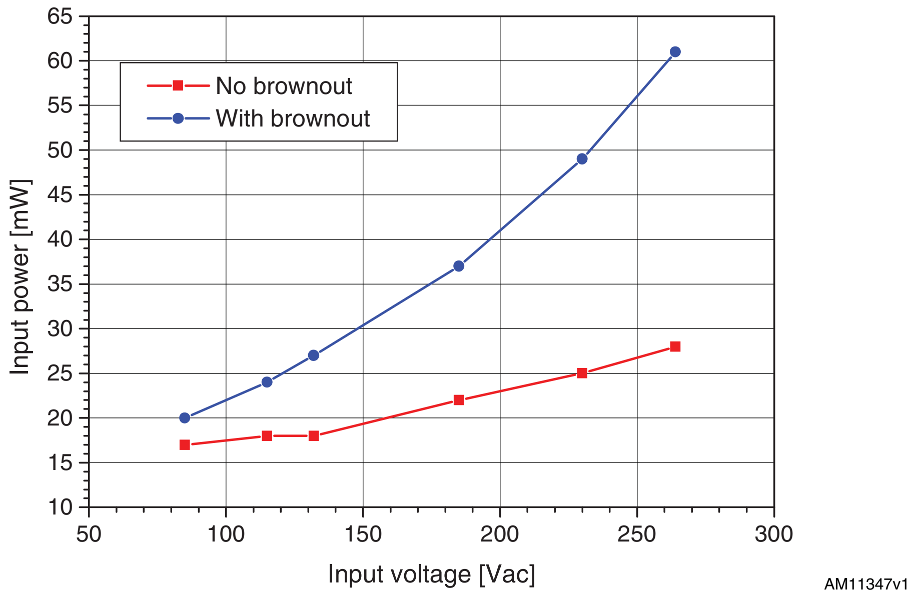

## 1.3 No-load consumption

The input power of the converter was measured in no load condition, with brownout protection disabled (see relevant *Section 2.4: Brownout protection*) and brownout protection enabled in the entire input voltage range.

The converter in the no load condition works always in burst mode so that the average switching frequency is reduced. The presence of the brownout resistor divider (R16, R17 and R18, see schematic in *Figure 2*) does not affect the average switching frequency but increases the input power consumption due to the power dissipated across it.

It is worth noting that often, if the converter is used as the standby power supply for LCD TVs, PDPs or other applications, the EMI line filter often coincides with the main power supply line filter that heavily contributes to standby consumption even if the power needed by the auxiliary power supply is very low.

Figure 6. No load consumption vs. input voltage




## 1.4 Light load consumption

Even though the EC CoC and DoE-US EISA 2007 programs don't have other requirements regarding light load performance, except no load consumption, the user very often requires the input power consumption when the output is loaded with a few tens of mW output power. Such measurements were performed at different loads with brownout protection both enabled and disabled, the results are reported below. The application meets the new EuP Lot 6 requirements.

Figure 7. Light load consumption at different output power without brownout

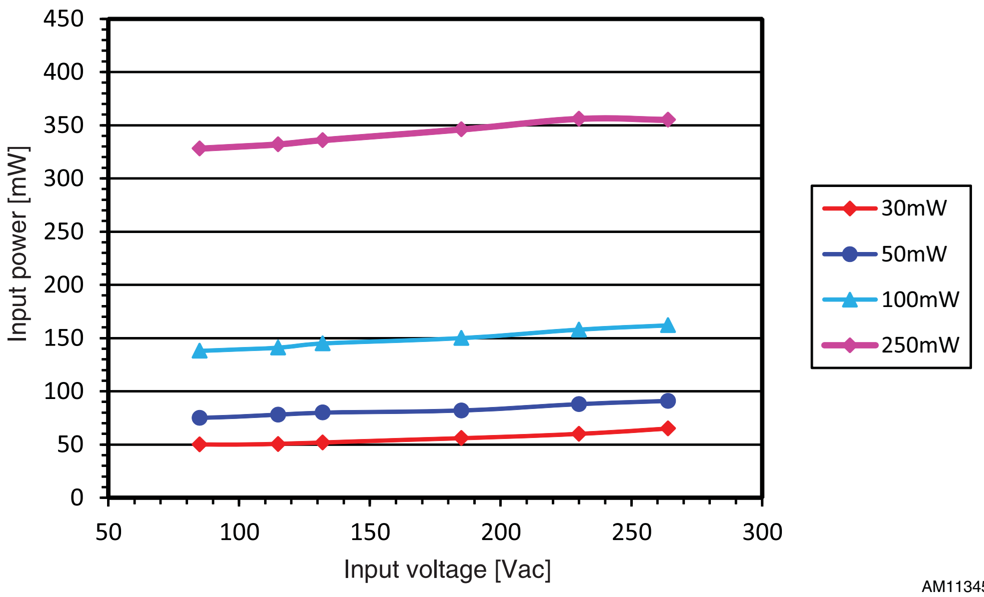
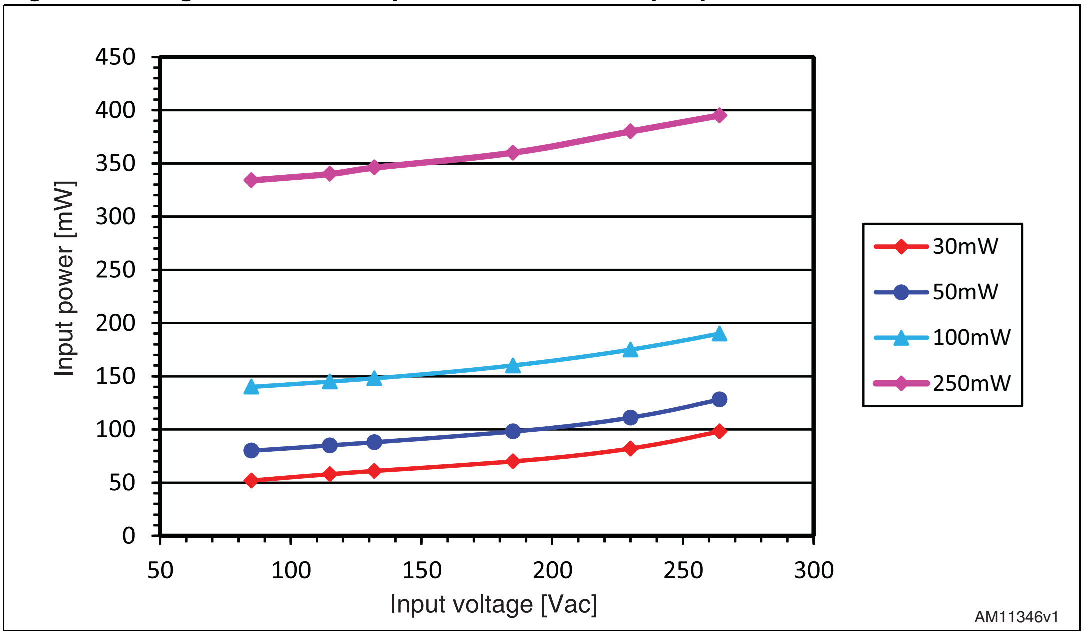


**Figure 8. Light load consumption at different output power with brownout**




## 1.5 Typical board waveforms

Drain voltage and current waveforms were reported at nominal input voltages and for the minimum and the maximum voltage of the converter input operating range. *Figure 10* and *11* show the drain current and the drain voltage waveforms at the two nominal input voltages and full load, while *Figure 9* and *12* show the same waveforms at the minimum and maximum input voltage range respectively.

The converter is designed to operate in continuous conduction mode (in full load condition) at low line. CCM (continuous conduction mode) allows the reduction of the root mean square currents value, at the primary side, in the power switch inside the VIPer and in the primary winding of the transformer; at the secondary side in the output diode (D2) and in the output capacitors (C3 and C4). Reducing RMS currents means reducing the power dissipation in the VIPer™ and the stress of the secondary side components.

**Figure 9. Drain current and voltage at full load 85 $V_{AC}$**

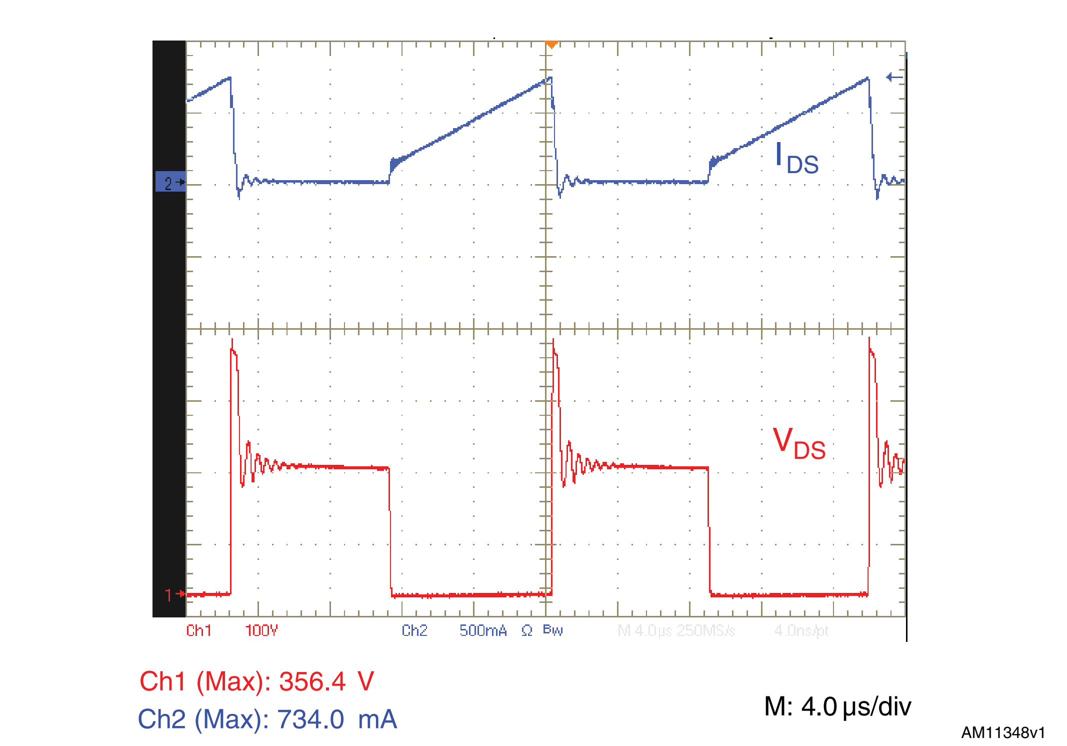



**Figure 10. Drain current and voltage at full load 115 $V_{AC}$**

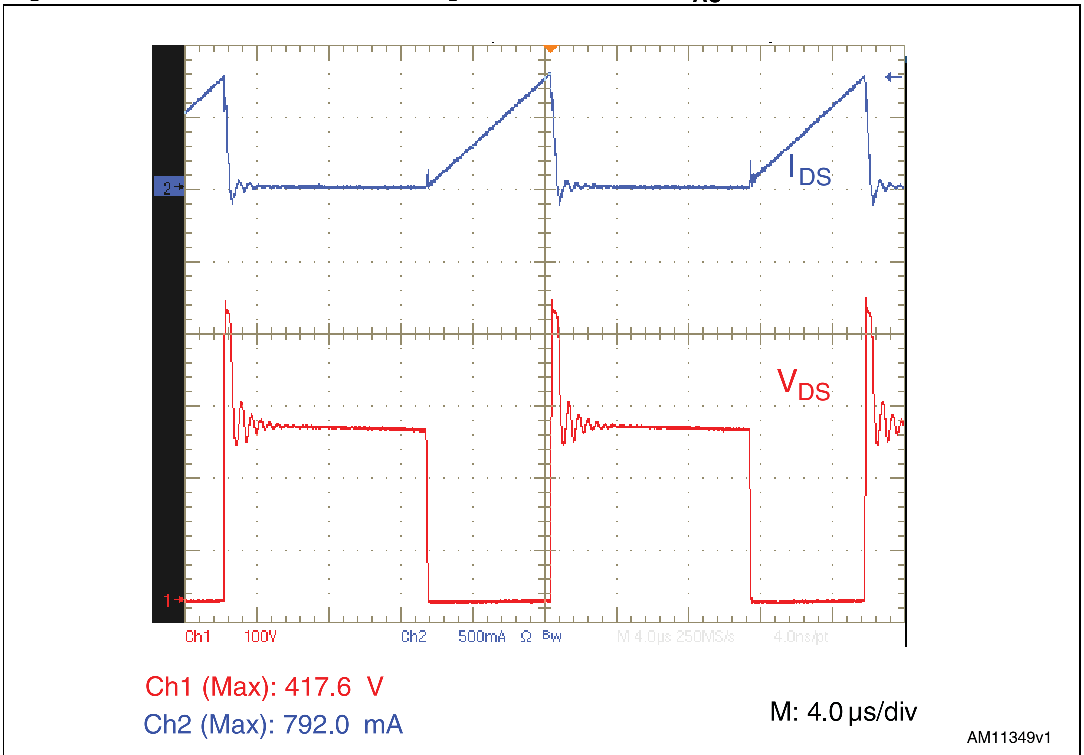


Figure 11. Drain current and voltage at full load 230 $V_{AC}$

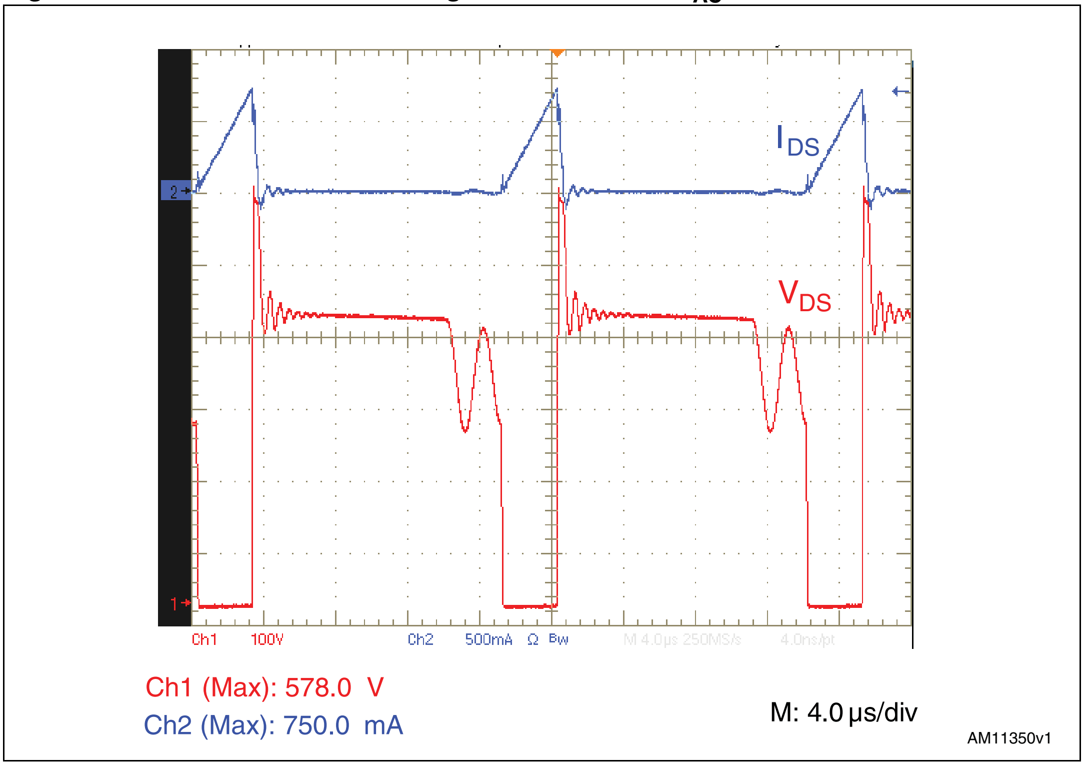
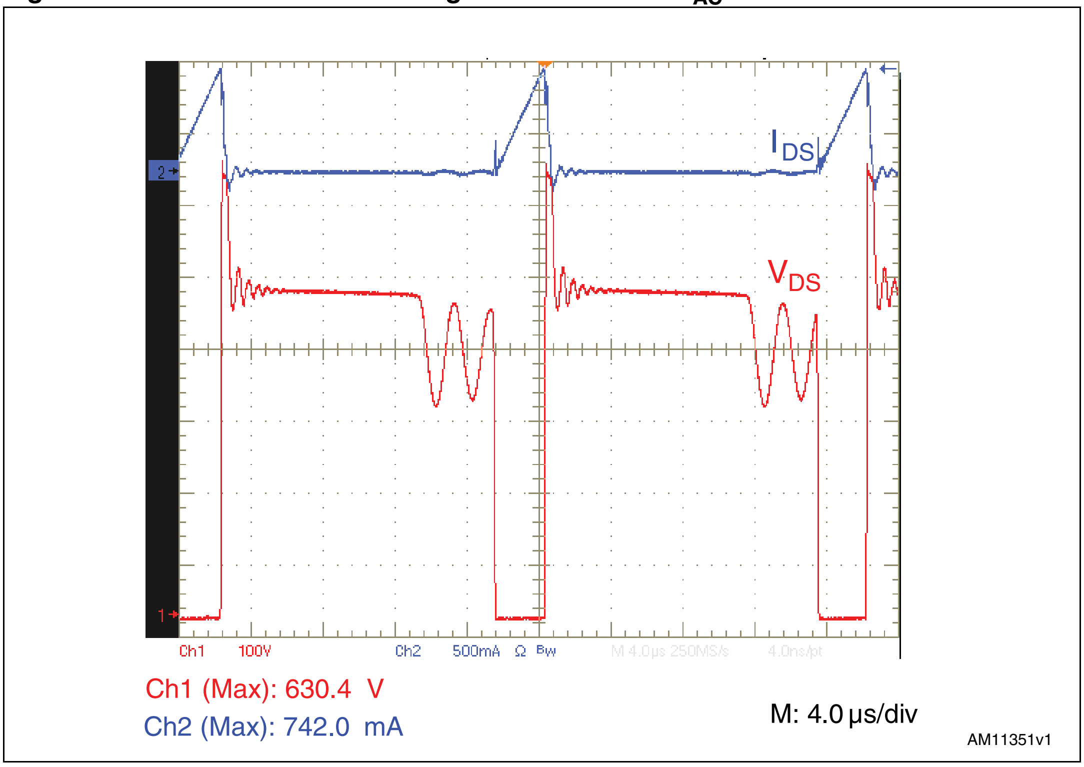



Figure 12. Drain current and voltage at full load 264 $V_{AC}$



The ripple at the switching frequency superimposed at the output voltage was also measured. The board is provided with an LC filter to further reduce the ripple without reducing the overall output capacitor's ESR.

The voltage ripple across the output connector ($V_{OUT}$) and before the LC filter ($V_{OUT\_PRE}$) were measured in order to verify the effectiveness of the LC filter: *Figure 13* shows the output voltage ripple at full load when the converter input voltage is 115 $V_{AC}$; while *Figure 14* shows the output voltage ripple at full load when the converter input voltage is 230 $V_{AC}$.

**Figure 13. Output voltage ripple at full load and 230 $V_{AC}$**

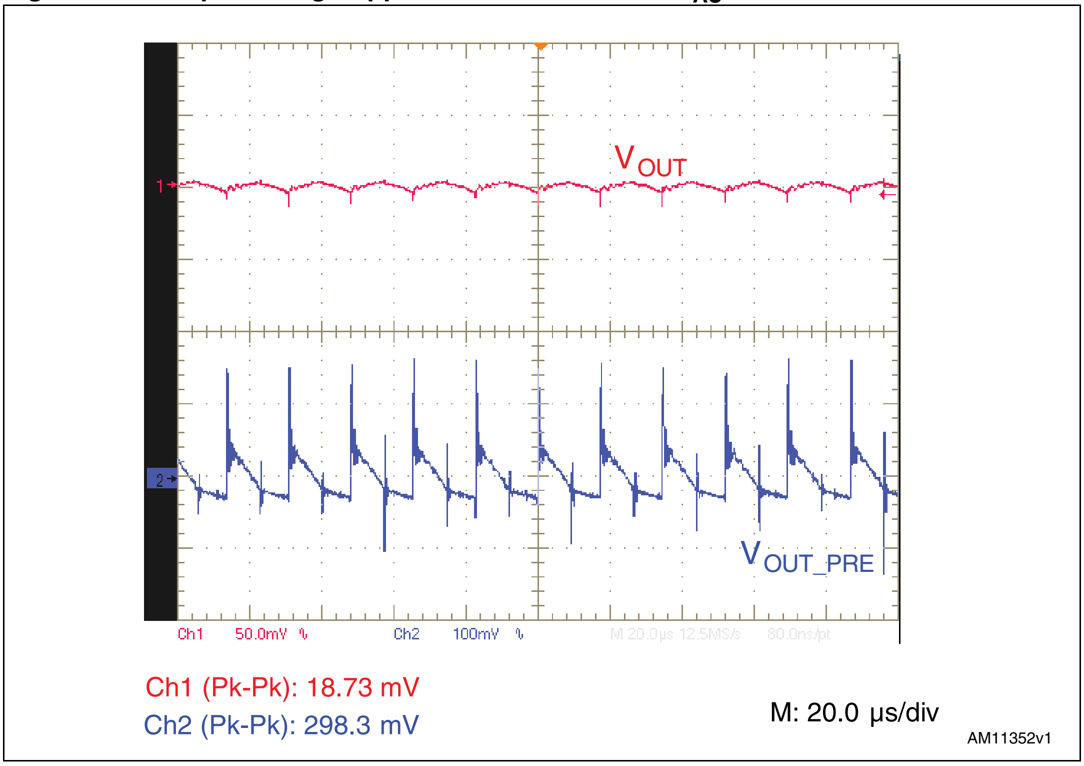


**Figure 14. Output voltage ripple at full load and 115 $V_{AC}$**

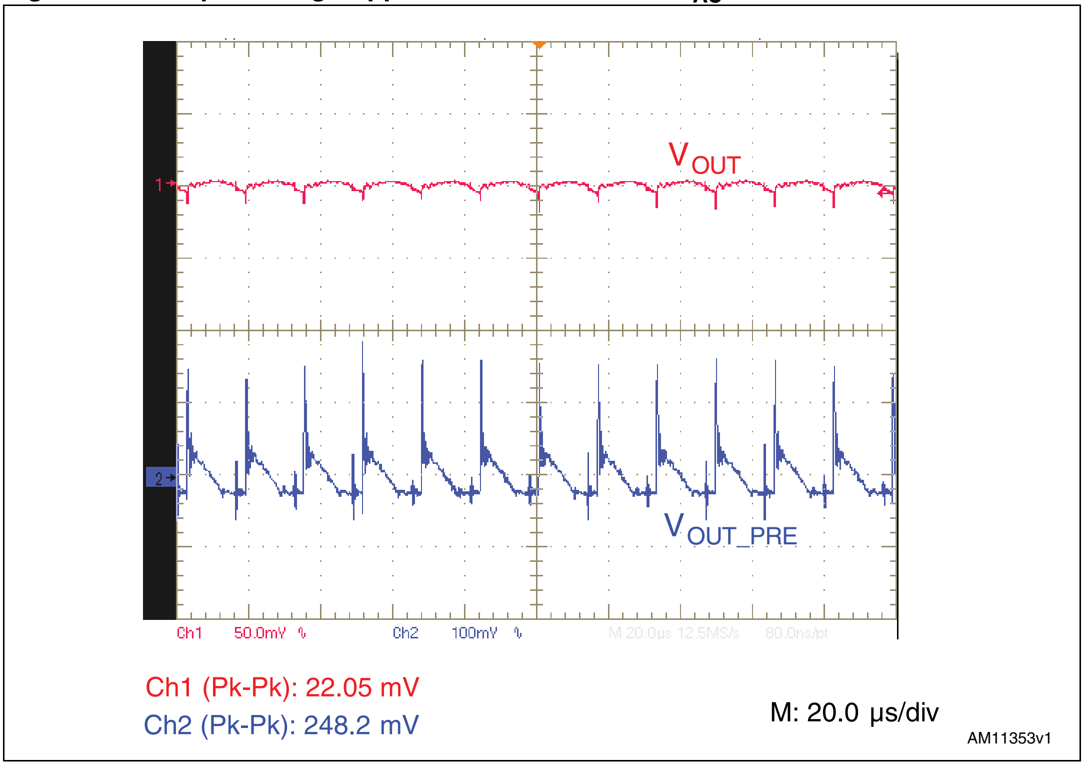



**Figure 15. Output voltage ripple during burst mode and 115 $V_{AC}$**

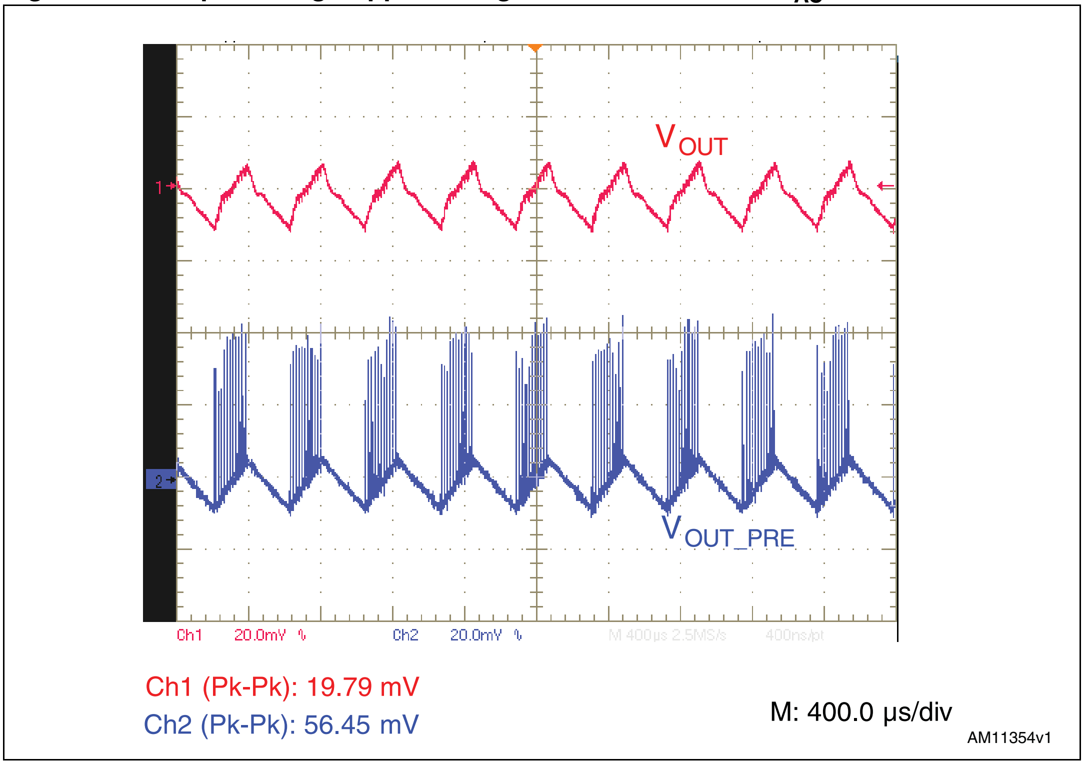
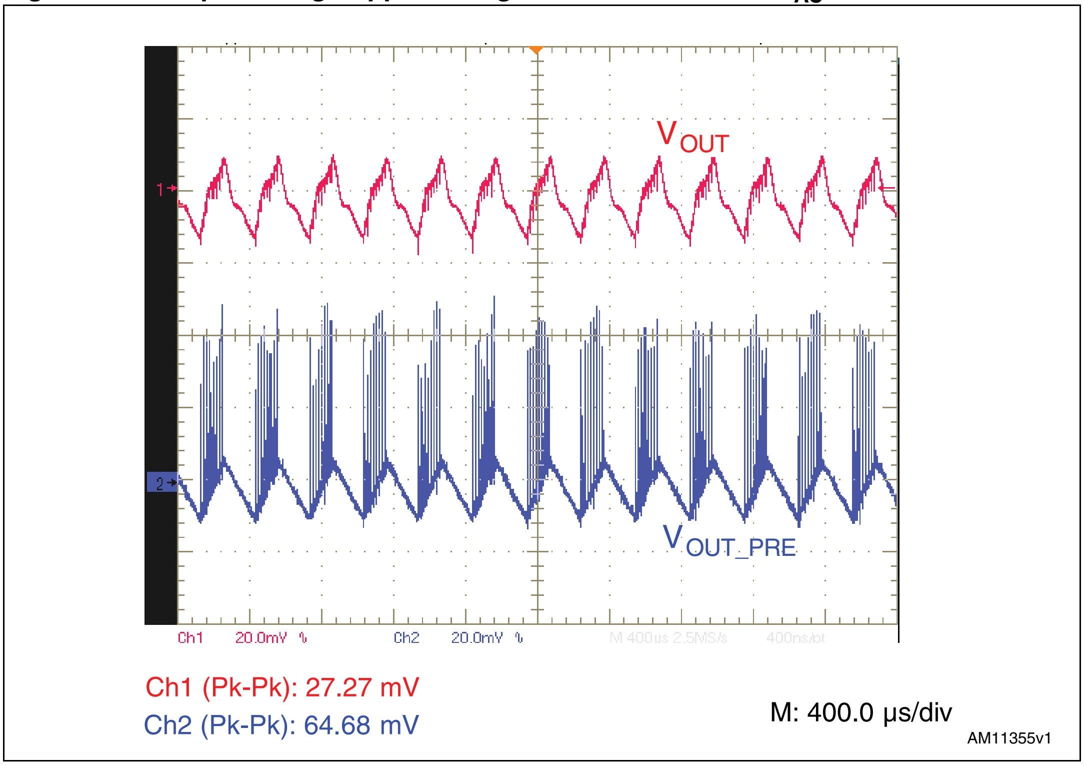


**Figure 16. Output voltage ripple during burst mode and 230 $V_{AC}$**




## 1.6 Dynamic step load regulation

In any power supply it is important to measure the output voltage when the converter is submitted to dynamic load variations, in order to be sure that good stability is ensured and no overvoltage on undervoltage occurs.

The board under evaluation was submitted to dynamic load variations from 0 to 50% loads (*Figure 17*), from 50% to 100% loads (*Figure 18*) and from 0 to 100% loads (*Figure 19*).

In any tested condition, no abnormal oscillations were noticed on the output and the over/undershoot were well within acceptable values.

**Figure 17. Dynamic step load: 0 to 50% load**

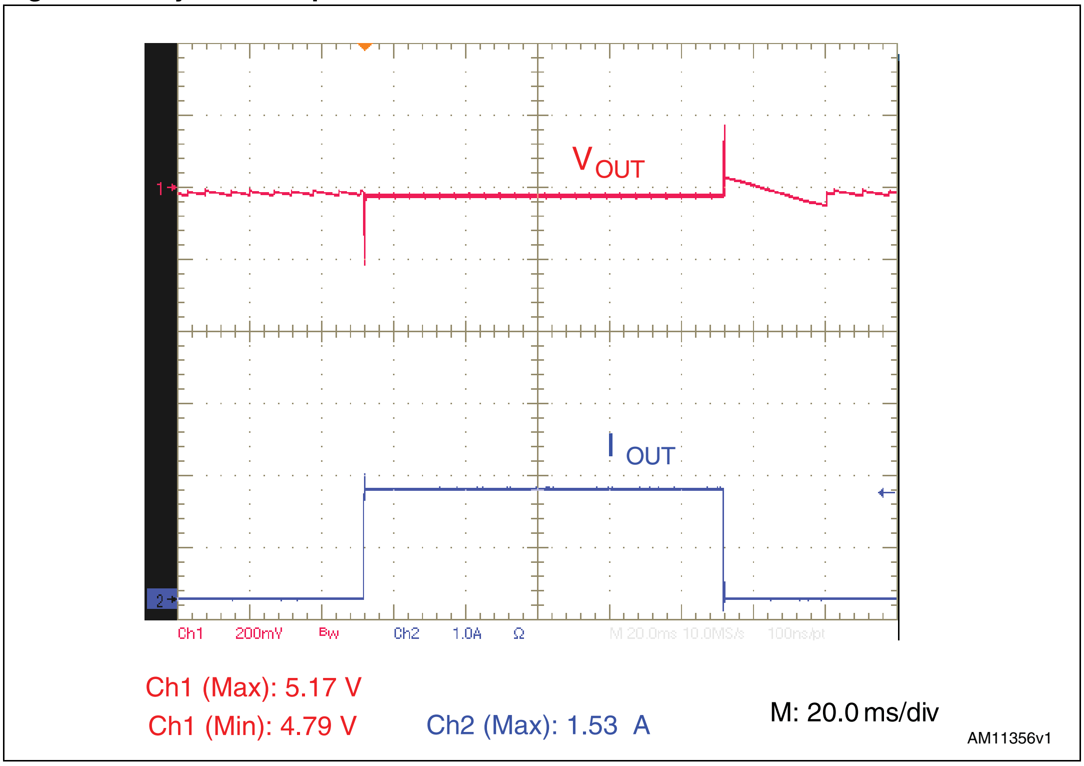



**Figure 18. Dynamic step load: 50 to 100% load**

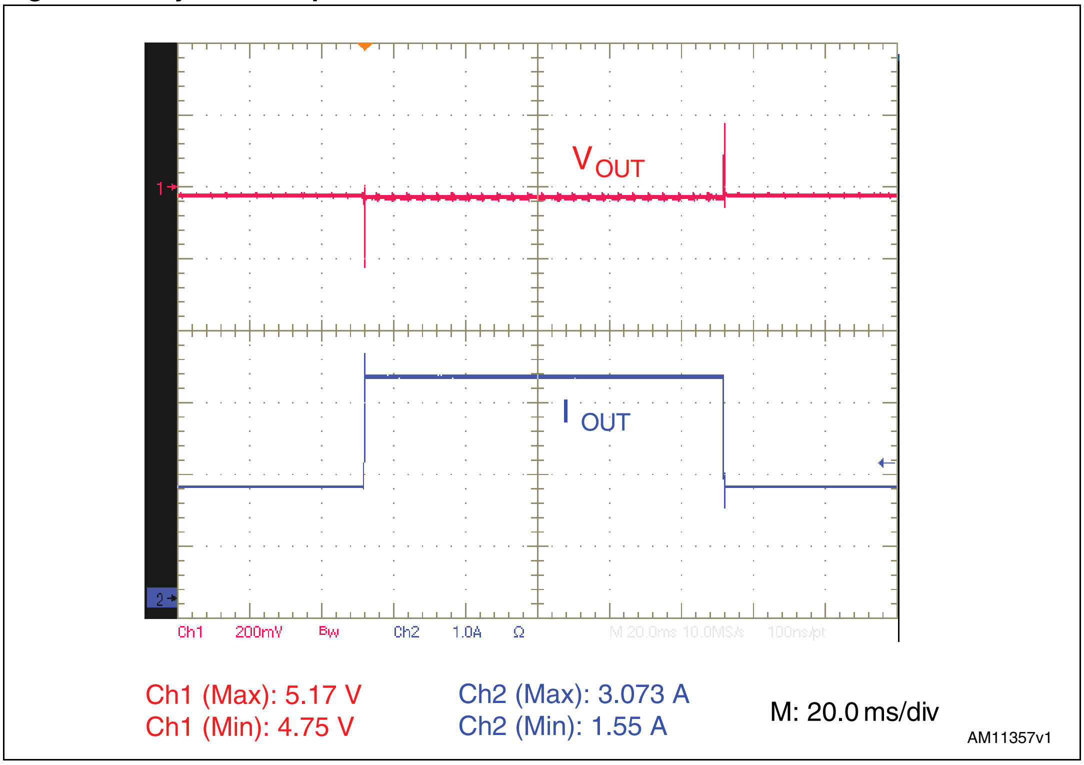
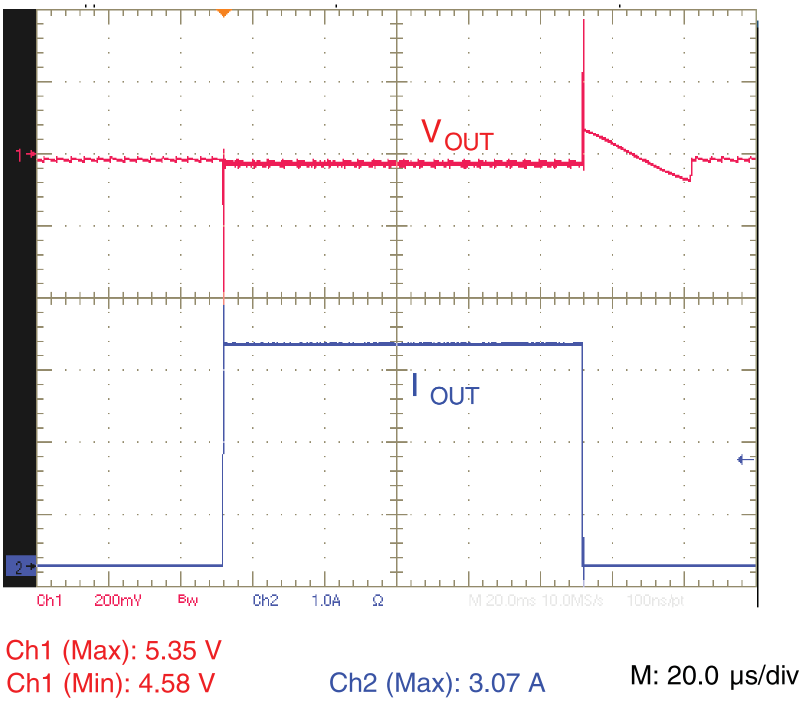


**Figure 19. Dynamic step load: 0 to 100% load**




## 1.7 Soft-start

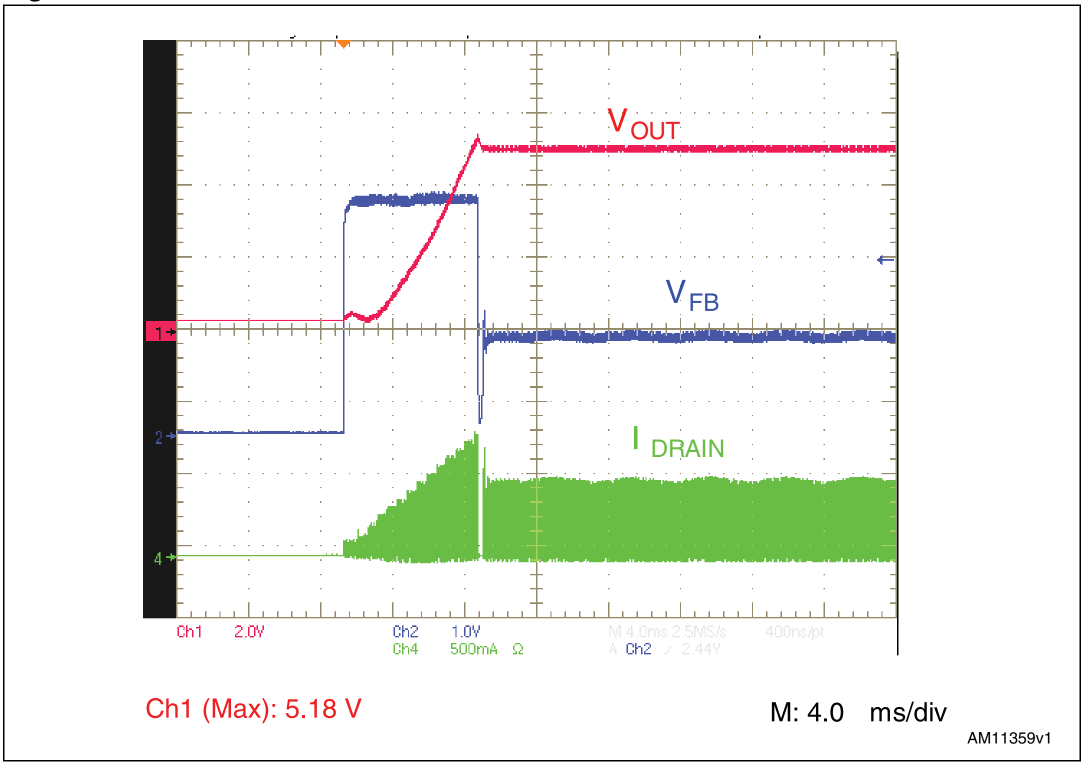
When the converter starts, the output capacitor is discharged and needs some time to reach the steady-state condition. During this time the power demand from the control loop is the maximum while the reflected voltage is low. These two conditions could lead to a deep continuous operating mode of the converter.

When the MOSFET is switched on, it cannot be switched off immediately as the minimum on-time ($T_{ON\_MIN}$) must elapse. Because of the deep continuous working mode of the converter, during this $T_{ON\_MIN}$, an excess of drain current can overstress the component of the converter as well as the device itself, the output diode, and the transformer. Transformer saturation is also possible under these conditions.

To avoid all the described negative effects, the VIPER37LE implements an internal soft-start feature. As the device starts to work, no matter what the control loop requests, the drain current is allowed to increase from zero to the maximum value gradually.

The drain current limit is incremented in steps, and the values range from 0 to the fixed drain current limitation value (values that can be adjusted through an external resistor) which is divided into 16 steps. Each step length is 64 switching cycles. The total length of the soft-start phase is about 8.5 ms. *Figure 20* shows the soft-start phase of the presented converter when it is operating at minimum line voltage and maximum load.

**Figure 20. Soft-start feature**



# 2 Protection features

The VIPER37LE has several protection features that considerably increase end-product safety and reliability: overload protection, overvoltage protection, shorted secondary rectifier detection and transformer saturation protection. In the following paragraphs all protections are tested and the results are presented.

## 2.1 Overload and short-circuit protection

If the load power demand increases, the output voltage decreases and consequently the feedback loop reacts, increasing the voltage on the FEEDBACK pin.

The FEEDBACK pin voltage increase leads to the PWM current set point increase, with the rise of the power delivered to the output. This process ends when the delivered power equals the load power requested.

If the load power demand exceeds the power capability (that can be adjusted using $R_{LIM}$), the voltage on the FEEDBACK pin continuously rises, but the drain current is limited to the fixed current limitation value.

When the FEEDBACK pin voltage exceeds $V_{FB\_lin}$ (3.3 V typ), the VIPER37LE takes it as a warning status of an output overload condition. Before stopping the system, the device waits for a time fixed by the FB capacitor. When the voltage on the FEEDBACK pin exceeds $V_{FB\_lin}$, an internal pull-up circuit is disconnected and the pin starts sourcing a 3 A current that charges the capacitor connected to the FEEDBACK pin itself. As the FEEDBACK pin's voltage reaches the $V_{FB\_olp}$ threshold (4.8 V typ.), the power MOSFET stops switching and is not allowed to switch again until the $V_{DD}$ voltage falls below $V_{DD\_RESTART}$ (4.5 V typ.).

If the short-circuit is not removed, the system starts to work in auto-restart mode: in this case the MOSFET switches for a short period of time and the converter tries to deliver to the output as much power as it can, and for a longer period where the device is not switching and no power is processed.

As the duty cycle of power delivery is very low (around 4%), the average power throughput is also very low, resulting in a very safe operation.

*Figure 21* and *22* show the triggering of the overload and the operation with continuous overload.

Figure 21. Overload event: OLP triggering

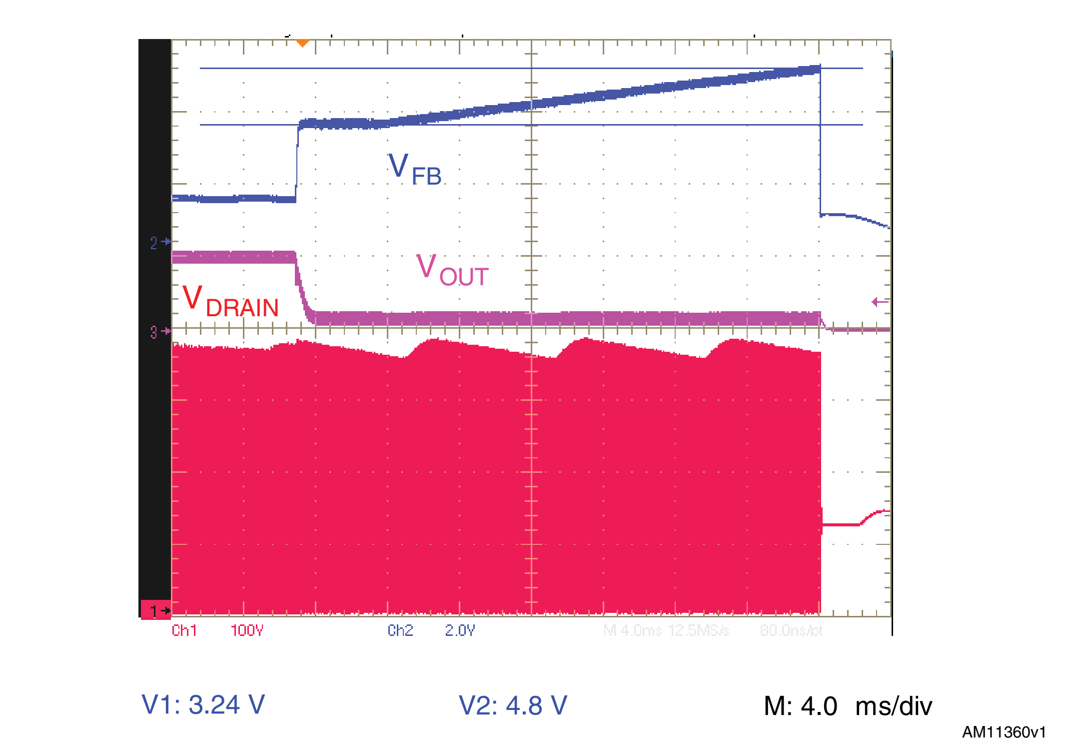
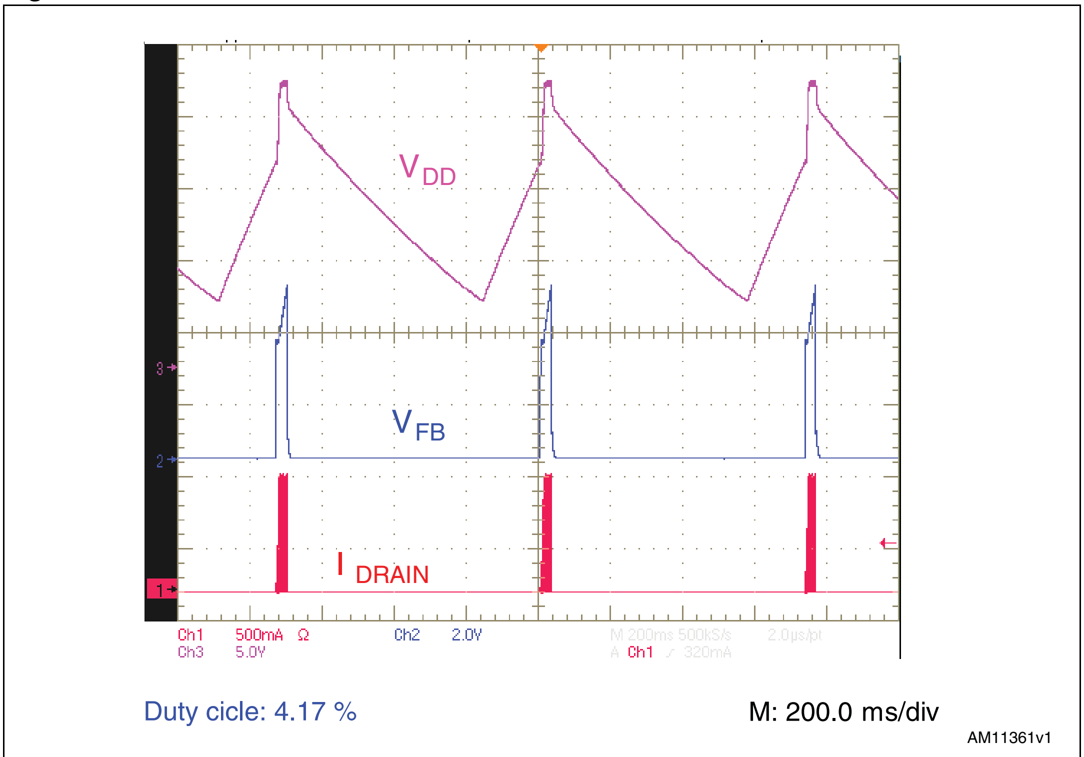



Figure 22. Overload event: continuous overload



## 2.2 Overvoltage protection

An output overvoltage protection is implemented monitoring the voltage across the auxiliary winding during the MOSFET turn-off time, through the diode D4 and the resistor dividers R4 and R12 connected on the CONT pin of the VIPER37LE. If this voltage exceeds the $V_{OVP}$ threshold (3 V typ.), an overvoltage event is assumed and the device is no longer allowed to switch.

To re-enable operation, the $V_{DD}$ voltage must be recycled. In order to provide high noise immunity and avoid that spikes erroneously trip the protection, a digital filter was implemented so the CONT pin must sense a voltage higher than $V_{OVP}$ for four consecutive cycles before stopping operation.

The protection can be tested by opening the resistor R9. In this way the converter operates in open loop and the excess of power with respect to the load charges the output capacitance, increasing the output voltage as the OVP is tripped and the converter stops switching.

In *Figure 23* and *24* it is possible to see that output voltage increases and as it reaches the value of 6.5 V the converter stops switching. In the same figure the CONT pin voltage is reported. The crest value of the CONT pin voltage tracks the output voltage.

**Figure 23. Overvoltage event: OVP triggering**

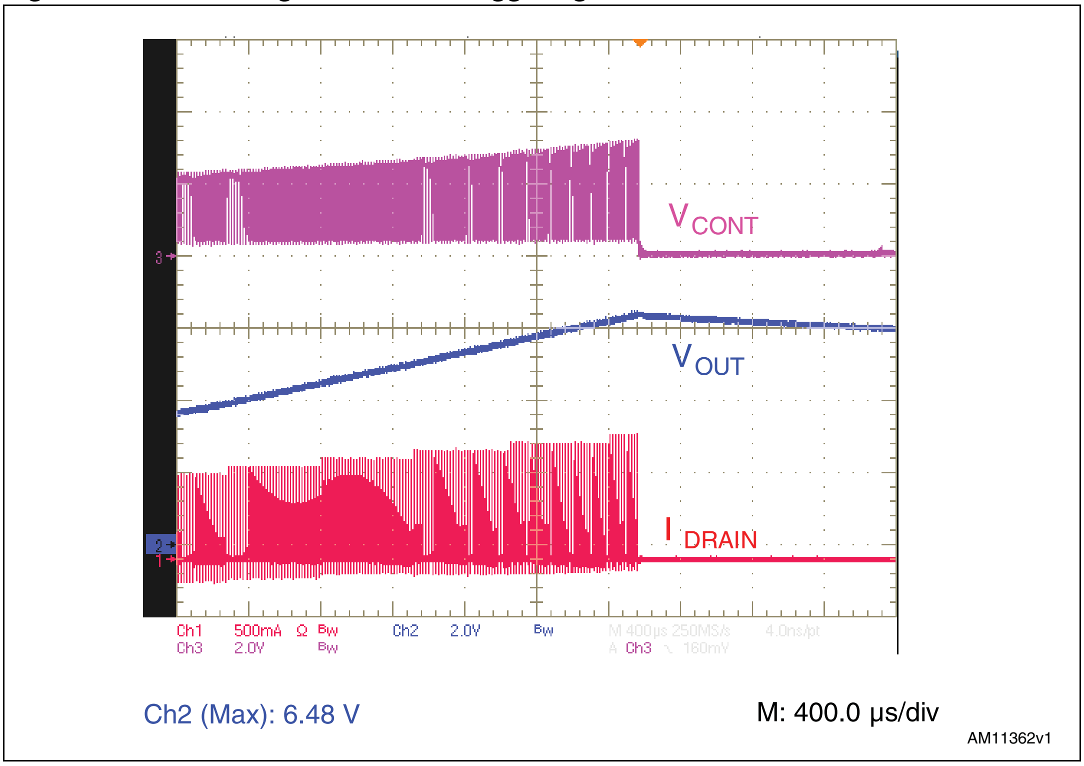
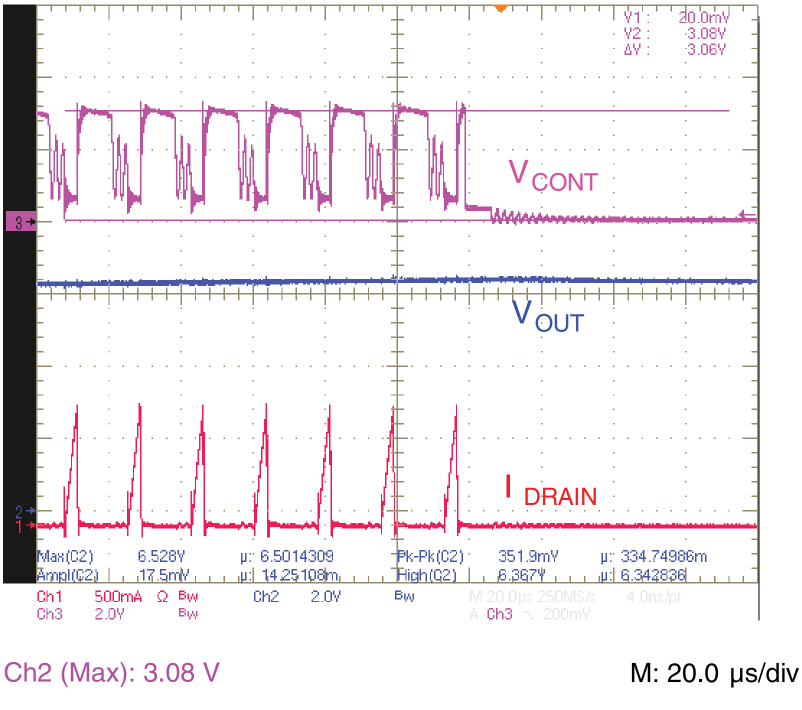


**Figure 24. Overvoltage event: OVP triggering (magnification)**




## 2.3 Secondary winding short-circuit and transformer saturation protection

The VIPER37LE is equipped with a hiccup mode overcurrent protection level.

If the drain current exceeds the second overcurrent threshold, the device enters a warning state, at the next switching cycle, if the hiccup mode level is exceeded again, the device assumes that a secondary winding short-circuit or a hard saturation of the transformer has occurred, so the device stops operating and the MOSFET is no longer allowed to switch on.

In order to enable the MOSFET to switch on again, the $V_{CC}$ voltage must be recycled down to $V_{CCrestart}$ and then up to $V_{CCon}$. If the cause of the hiccup mode overcurrent protection activation is not removed, the device again enters auto-restart mode. The extremely low repetition rate ensures safe and reliable operation.

This protection was tested on the demonstration board. The secondary winding of the transformer was shorted in different operating conditions. *Figure 25* and *26* show the behavior of the system during fault.

Figure 25. 2nd level OCP: protection tripping

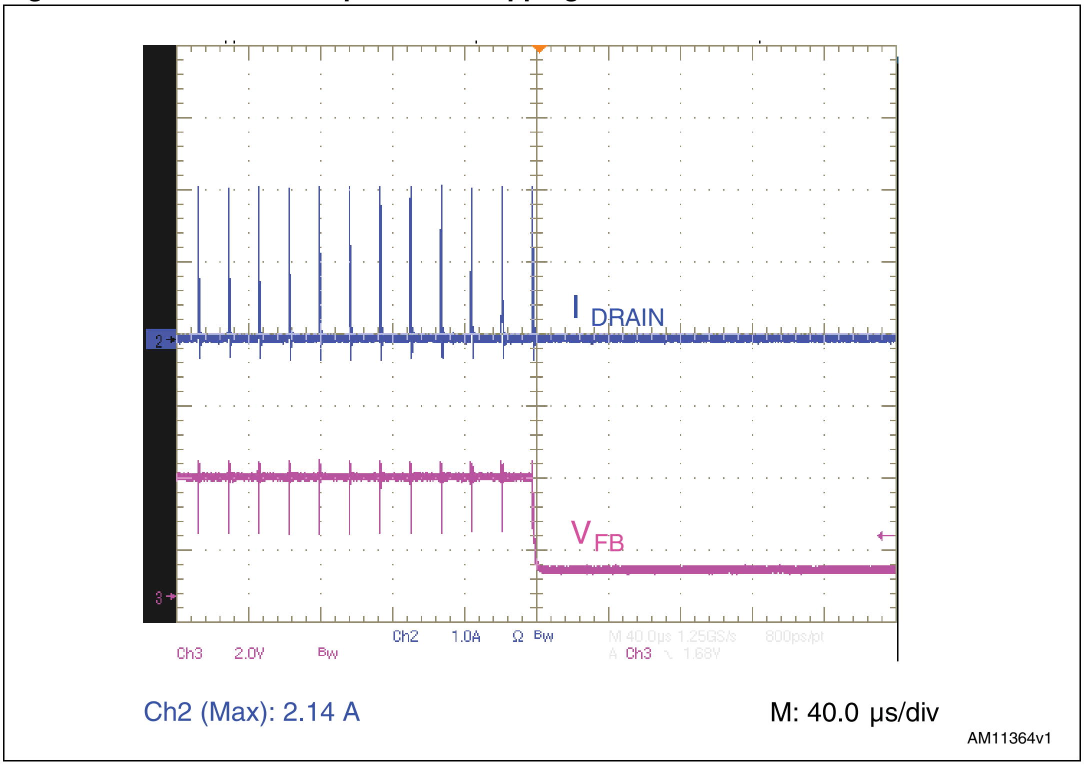
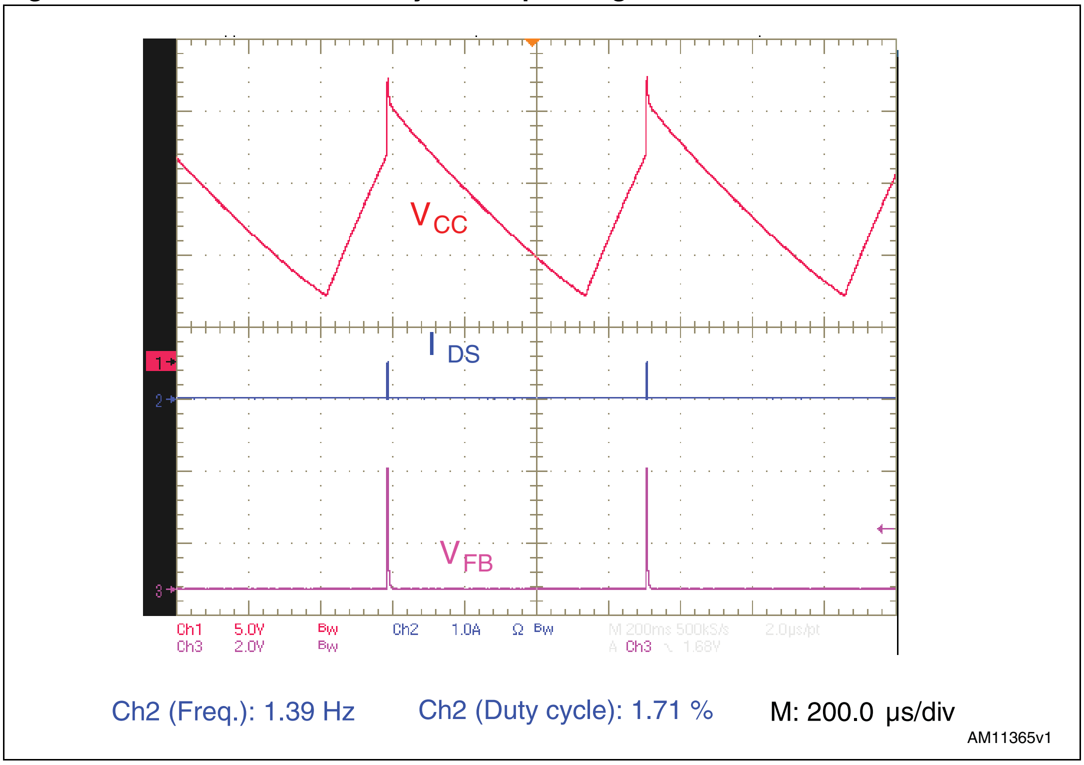



Figure 26. 2nd level OCP: steady-state operating conditions



## 2.4 Brownout protection

Brownout protection is basically an unlatched device shutdown functionality whose typical use is to sense mains undervoltage or unplugged mains. The VIPER37LE has a BR pin dedicated to this function which must be connected to the DC HV bus through a voltage divider.

If the protection is not required, it can be disabled by connecting the pin to ground. In the presented converter, brownout protection is implemented but can be disabled by changing the jumper JMP.

The converter's shutdown is accomplished by means of an internal comparator internally referenced to 450 mV that disables the PWM if the voltage applied at the BR pin is below the internal reference.

PWM operation is re-enabled as the BR pin voltage is more than 450 mV plus 50 mV of voltage hysteresis that ensures noise immunity. The brownout comparator is also provided with current hysteresis. An internal 10 A current generator is ON as long as the voltage applied at the BROWNOUT pin is below 450 mV and is OFF if the voltage exceeds 450 mV plus the voltage hysteresis.

In *Figure 27* the converter's power-down is shown: once the main is disconnected and the bulk capacitor is discharged, the IC stops switching when the DC bus voltage falls below 78 V. This reduces the RMS input current and ensures monotonic output voltage decay.

*Figure 28* and *29* show brownout protection during the wake-up phase: once the DC bus reaches 100 V, as the voltage on $V_{DD}$ pin is higher than $V_{DDoff}$, the IC starts switching.

**Figure 27. Brownout protection: converter's power-down phase**

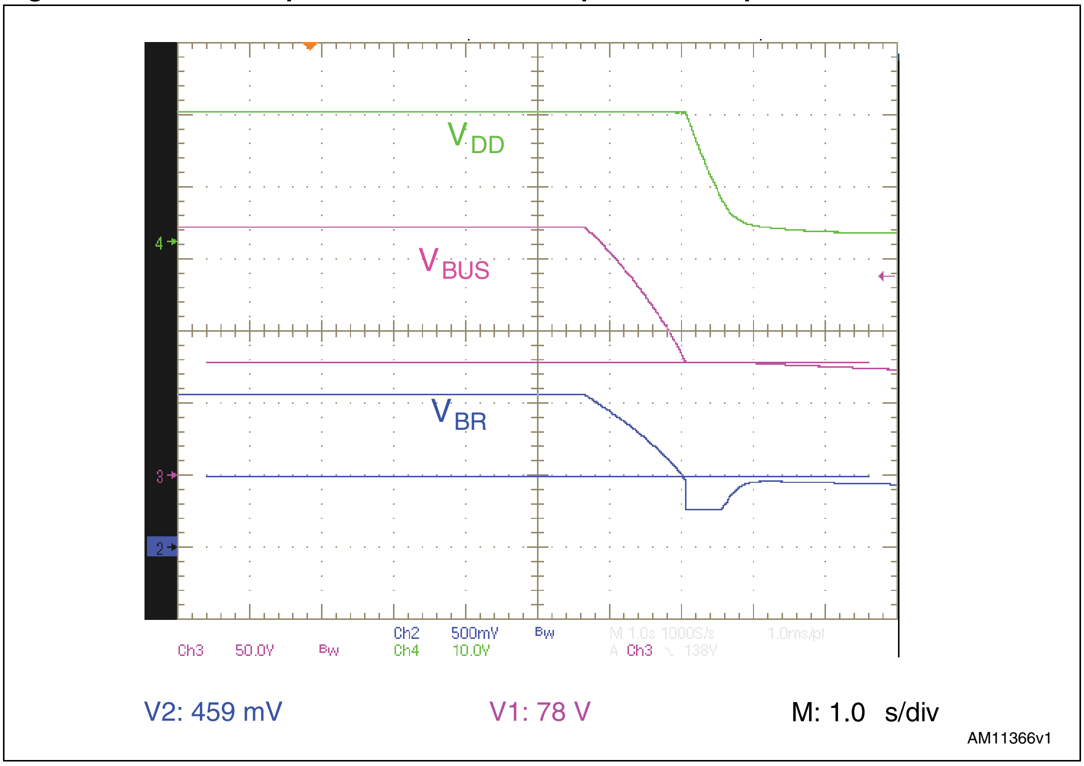


Figure 28. Brownout protection: converter's wake-up

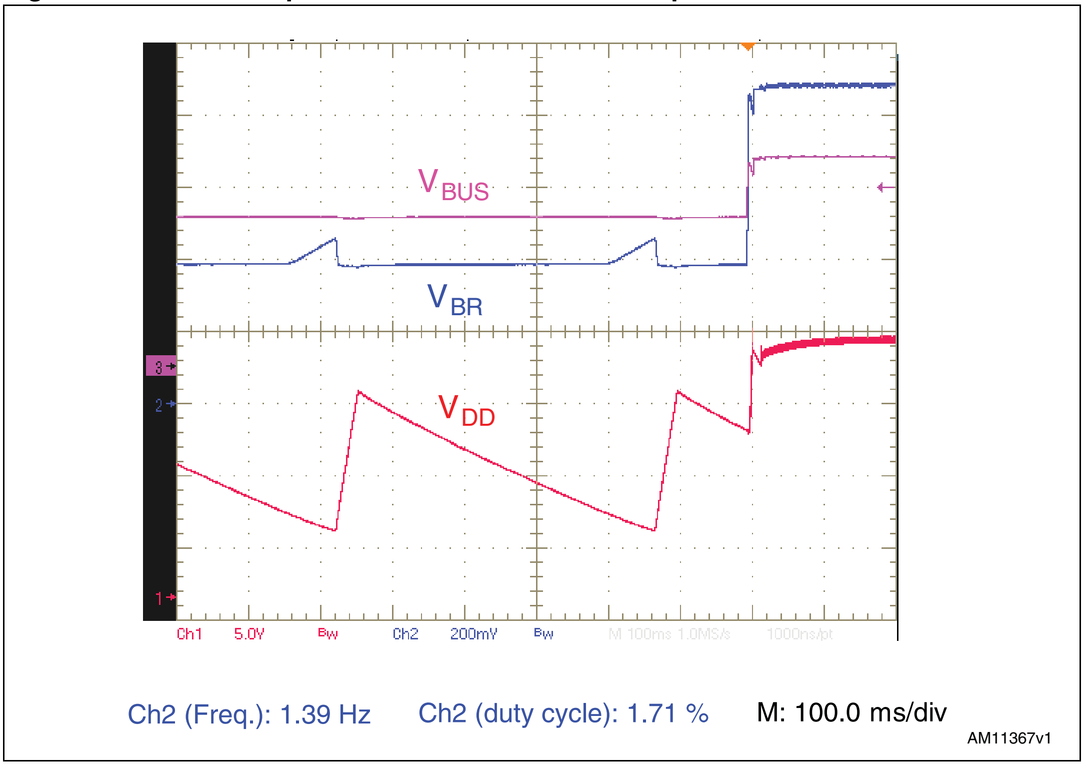
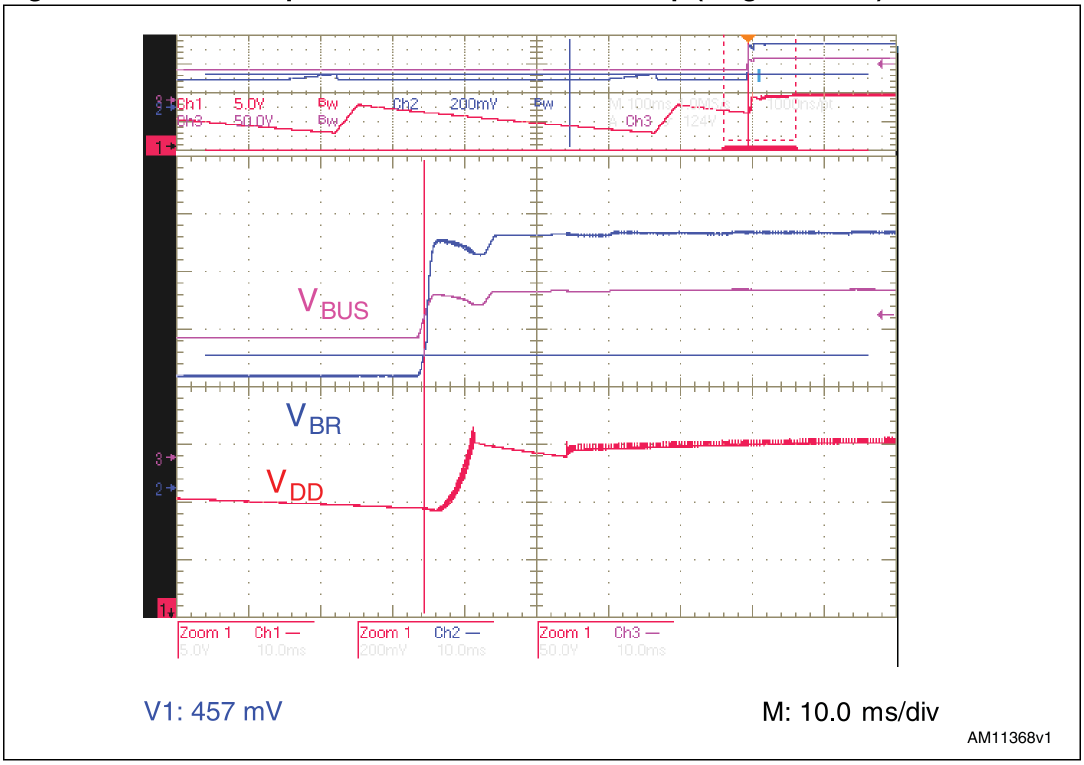



Figure 29. Brownout protection: converter's wake-up (magnification)



# 3 Conducted noise measurements

A pre-compliance test for the EN55022 (Class B) European normative was also performed on both average and peak measurements of the conducted noise emissions at full load and nominal mains voltages. Figure 30 to 33 show the results. As seen in the diagrams, in all test conditions there is a good margin for the measurements with respect to the limits, also using the peak detector.

**Figure 30. CE average measurement at 115 $V_{AC}$ and full load: average measurement**

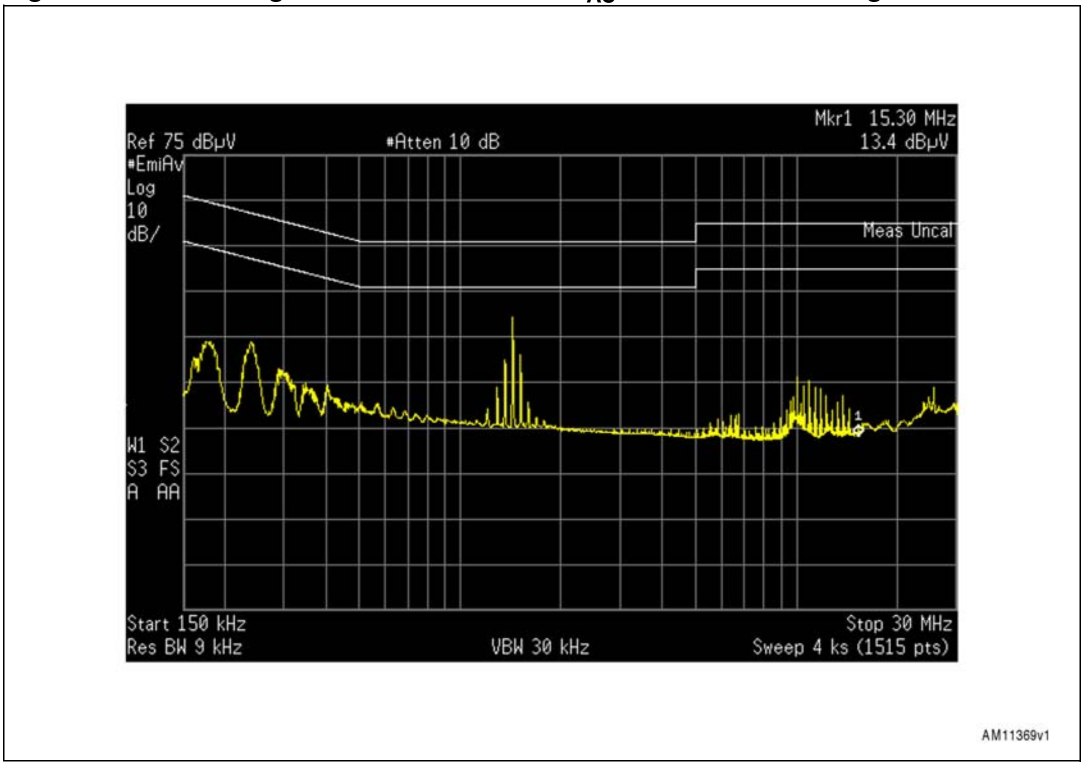


Figure 31. CE average measurement at 230 $V_{AC}$ and full load: average measurement

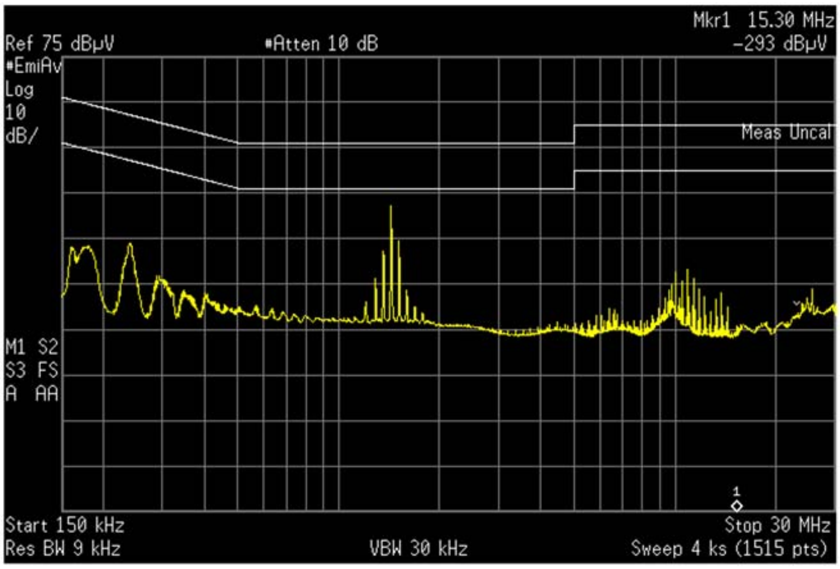



Figure 32. CE average measurement at 115 $V_{AC}$ and full load: peak measurement

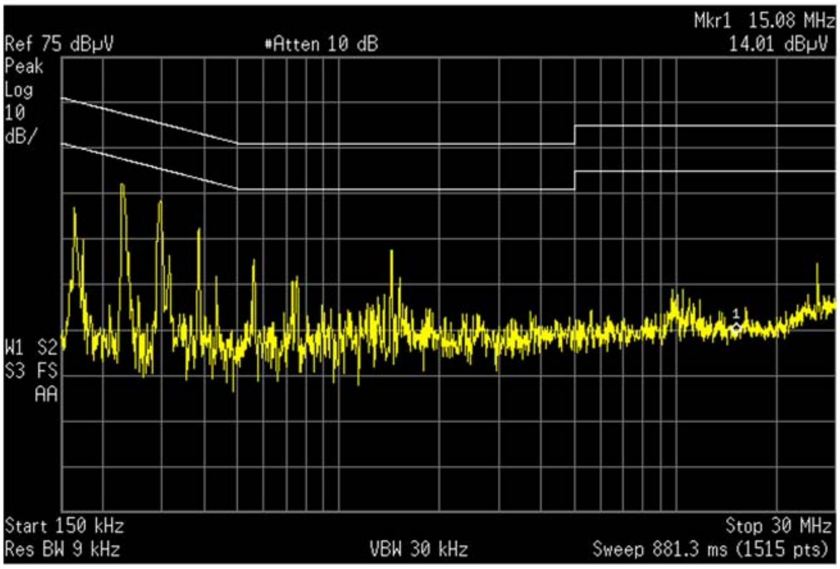
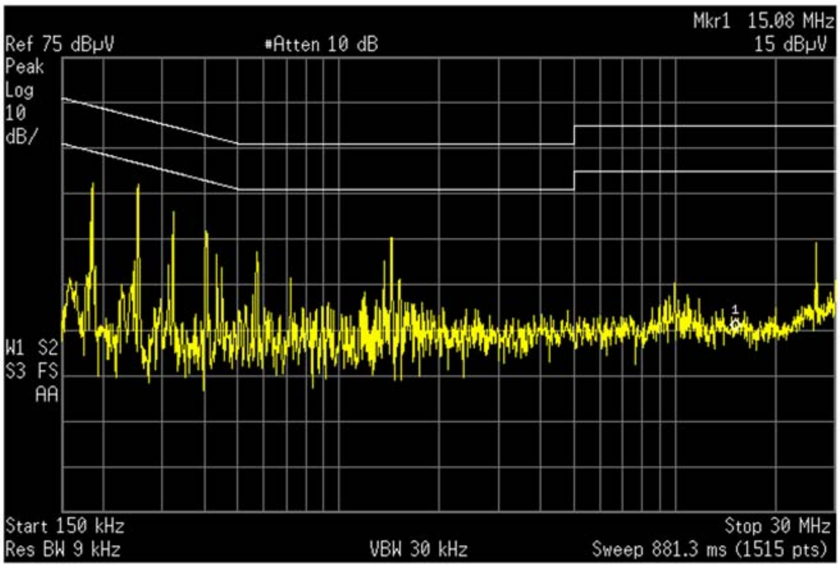


Figure 33. CE average measurement at 230 $V_{AC}$ and full load: peak measurement



# 4 Thermal measurements

A thermal analysis of the board was performed using an IR camera.

The board was submitted to full load at nominal input voltage and the thermal map was taken 15 min. after the power-on at ambient temperature (25 °C).

*Figure 34* and *35* show the results.

**Figure 34. Thermal map at 115 $V_{AC}$ and full load**

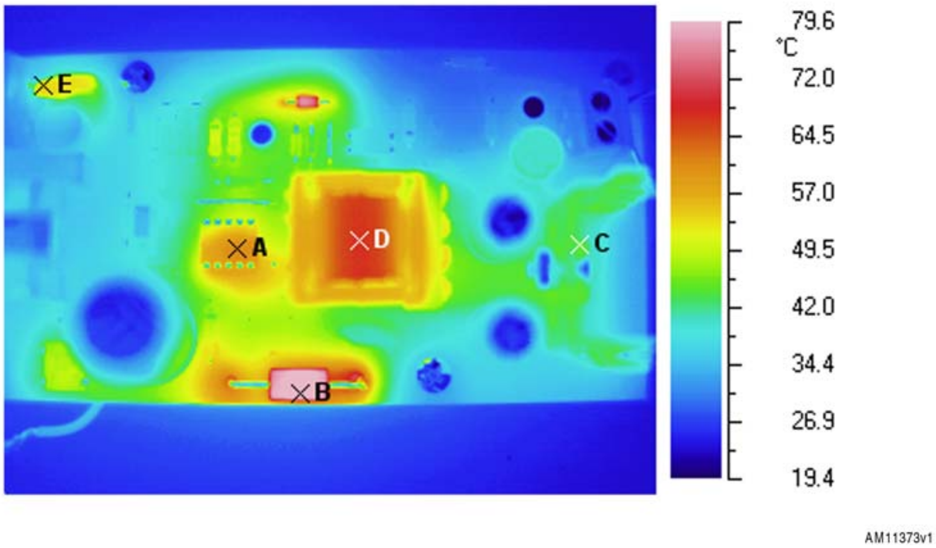



**Figure 35. Thermal map at 230 $V_{AC}$ and full load**

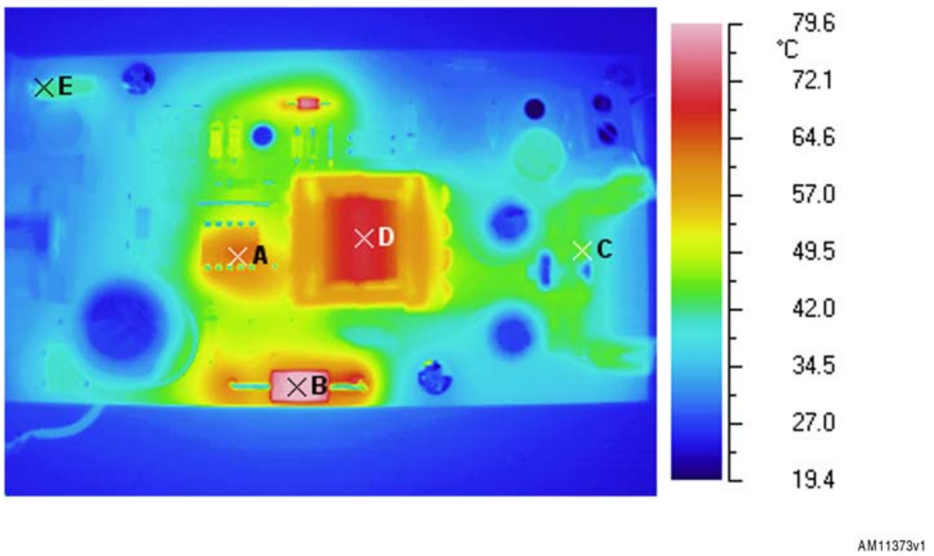


**Table 6. Temperature of key components ($T_{amb}$=25 °C, emissivity=0.95 for all points)**

| Point | Reference | T [°C] at 115 $V_{AC}$ | T [°C] at 230 $V_{AC}$ |
|---|---|---|---|
| A | IC (VIPER37LE) | 61.2 | 63.4 |
| B | D1 (Transil clamp) | 82.8 | 81.6 |
| C | D2 (output diode) | 44.1 | 45.0 |
| D | TF (flyback transformer) | 67.3 | 70.0 |
| E | NTC (inrush limiter) | 54.1 | 41.6 |

# 5 Conclusions

A 15 W wide range single-output flyback converter using the new VIPER37LE has been introduced and the results given.

The presented flyback converter is suitable as an external adapter or as an auxiliary power supply in consumer equipment. Special attention was paid to low load performance and the bench results are good with very low input power in light load condition.

The efficiency performances were compared with the requirements fixed by both EC CoC and DoE US EISA 2007 programs for external AC/DC adapters with very good results, the measured Active mode efficiency is always higher with respect to the minimum required.

# 6 Demonstration tools and documentation

The VIPER37LE demonstration board order code is: EVLVIP37LE5V3A.

Further information about this product is available in the VIPER37 datasheet at www.st.com.

# 7 Revision history

**Table 7. Document revision history**

| Date | Revision | Changes |
|---|---|---|
| 16-May-2012 | 1 | Initial release. |
| 12-Dec-2012 | 2 | Modified caption in *Table 1: VIPER37LE power supply: electrical specifications* and *Table 2: VIPER37LE demonstration board: bom list*.<br>Modified R12 value on *Table 2: VIPER37LE demonstration board: bom list*.<br>Modified *Section 1.2: Efficiency and light load measurements*.<br>Updated *Figure 5*, *Figure 7* and *Figure 8*.<br>Minor text changes. |