AN3160
Application note

Wide range [90 - 265] input, single output [12 V-6 W] VIPer15 demonstration board (STEVALVIP15L-6W)

Introduction

The new VIPer15 device integrates two components in the same package: an advanced BCD6 technology PWM controller and an 800 V avalanche rugged vertical power MOSFET. The device is suitable for realizing an offline power converter using flyback topologies with variable frequency control strategies, commonly known as quasi-resonant flyback. The device is able to handle up to about 6 W in wide input voltage range (88 V_{AC} 264 V_{AC}) converters and up to about 10 W in European input voltage range converters. The main advantage of using a QR (quasi-resonant) approach is that it makes use of the otherwise undesirable parasitic drain capacitance to generate a zero-voltage condition that minimizes turn-on losses of the MOSFET.

In mains operated applications, due to the ripple appearing across the input bulk capacitor, the switching frequency is modulated at twice the mains frequency and this causes the EMI spectrum to be spread over frequency bands, rather than being concentrated on single frequency values. Especially when measuring conducted emissions with the average detection method, the level reduction can be of several dBµV.

The way the system processes power does not change, therefore the designer's experience with a standard flyback can be fully exploited and there is very little additional know-how needed.

The proposed solution has the advantage of using few external components providing several protections and very low standby consumption.

Figure 1. Demonstration board image

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1 Board description

1.1 Electrical specifications

The electrical specifications for this demonstration board are listed in *Table 1* below.

Table 1. Electrical specifications

Parameter	Symbol	Value
Input voltage range	V_{IN}	[90V_{RMS}; 265V_{RMS}]
Nameplate output voltage	V_{OUTn}	12 V
Max. output current	I_{OUT}	0.5 A
Precision of output regulation	$\frac{V_{OUT} - V_{OUTn}}{V_{OUTn}}$	±5 %
High frequency output voltage ripple	Δ_{VOUT_HF}	50 mV
Max. ambient operating temperature	T_A	85 °C

1.2 Schematic and bom list

The schematic of the board is given in *Figure 2*, and the BOM list is shown in *Table 2*.

Figure 2. Schematic

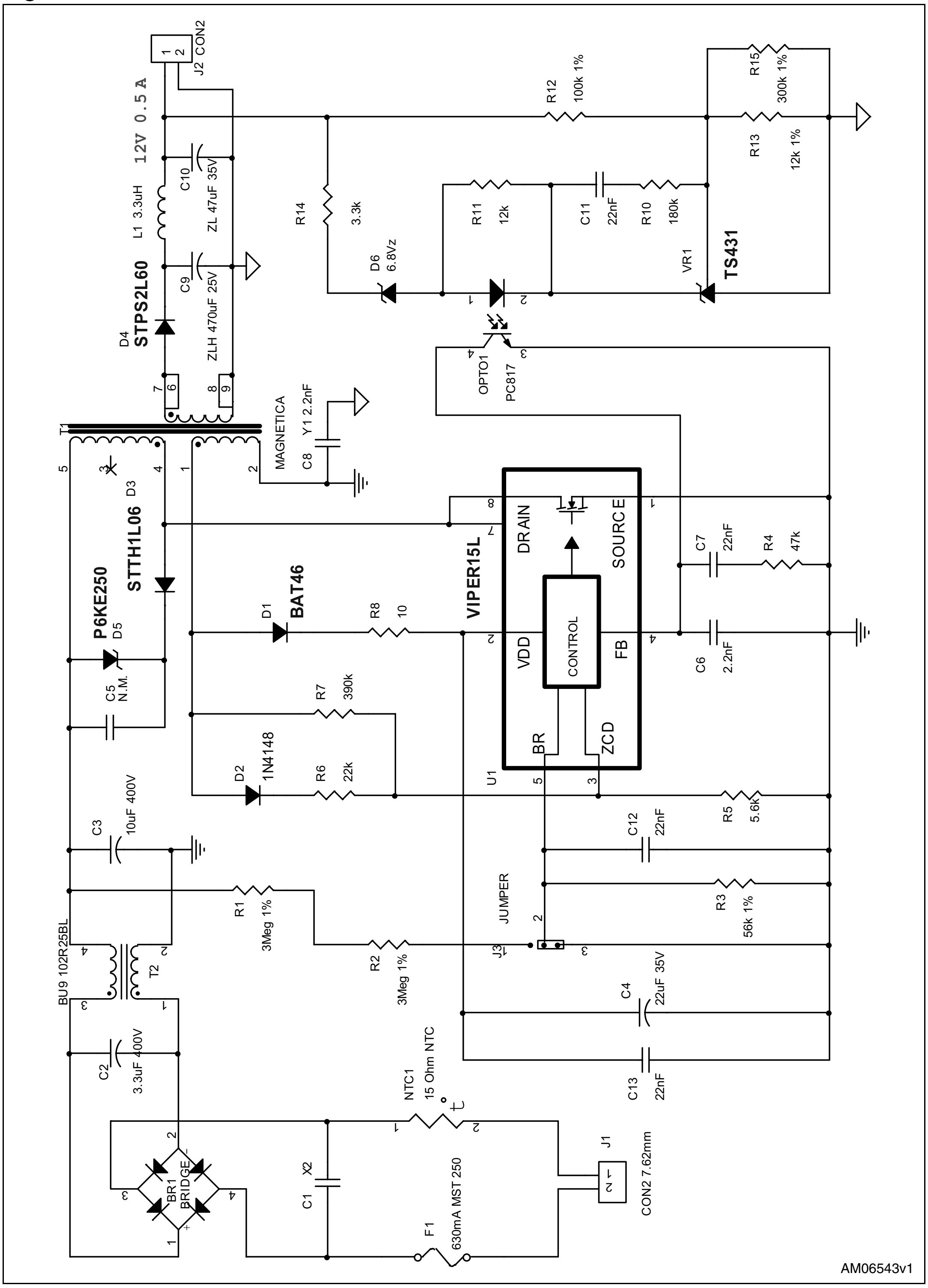


Table 2. BOM list

Reference	Description	Value	Part number	Manufacturer
BR1	Bridge diodes		DF06M	
C1	X2 type capacitor	100 nF		
C2	400 V electrolytic cap.	3.3 µF		
C3	400 V electrolytic cap.	10 µF		
C4	35 V electrolytic cap.	22 µF		
C5	N.M.			
C6	25 V ceramic ca.	2.2 nF		
C7, C11, C12, C13	25 V ceramic ca.	22 nF		
C8	Y1 type cap.	2.2 nF		
C9	25 V electrolytic cap.	330 µF	ZL	Rubycon
C10	25 V electrolytic cap.	47 µF	ZLH	Rubycon
D1	Schottky diode		BAT46	STMicroelectronics
D2	100 V small signal fast diode		1N4148	
D3	Diode		STTH1L06	STMicroelectronics
D4	Diode		STPS2L60	STMicroelectronics
D5	Transil		P6KE250	STMicroelectronics
D6	Zener diode		BZX55C 6V8	
F1	Fuse	630 mA		
NTC1	15 Ω NTC		B57153S0150M	EPCOS
OPTO1	Opto-coupler		PC817	Sharp
R1, R2	Resistor 1 % precision	3 MΩ		
R3	Resistor 1 % precision	56 kΩ		
R4	Resistor	47 kΩ		
R5	Resistor 1 % precision	5.6 kΩ		
R6	Resistor 1 % precision	22 kΩ		
R7	Resistor 1 % precision	390 kΩ		
R8	Resistor	10 Ω		
R10	Resistor	180 kΩ		
R11	Resistor	12 kΩ		
R12	Resistor 1 % precision	100 kΩ		
R13	Resistor 1 % precision	12 kΩ		
R14	Resistor	3.3 kΩ		
R15	Resistor 1 % precision	300 kΩ		
U1	High voltage converter		VIPer15LN	STMicroelectronics

Table 2. BOM list (continued)

Reference	Description	Value	Part number	Manufacturer
VR1	Voltage reference		TS431	STMicroelectronics
T1	Transformer		1335.0082 Rev. 1	MAGNETICA
T2	CMC for line filter		BU9-103R25BL	Coilcraft

1.3 Transformer

Transformer characteristics are listed in *Table 3* below.

Table 3. Transformer characteristic

Properties	Value	Test Condition
Manufacturer	MAGNETICA	
Part number	1335.0082	
Primary inductance	1650 µH ±15 %	Measured at 10 kHz 0.1 V
Leakage inductance	50 µH max	Measured at 10 kHz 0.1 V (auxiliary and secondary windings shorted)
Primary to secondary turn ratio (4 - 5)/(6, 7 – 8, 9)	12 ±5 %	Measured at 10 kHz 0.1 V
Primary to auxiliary turn ratio (6 - 4)/(3 - 1)	10 ±5 %	Measured at 10 kHz 0.1 V
Insulation	4 kV	Primary to secondary

Figure 3, *4*, *5*, and *6* show the size and pin distances (inches and [mm]) of the transformer.

Figure 3. Transformer size - bottom view

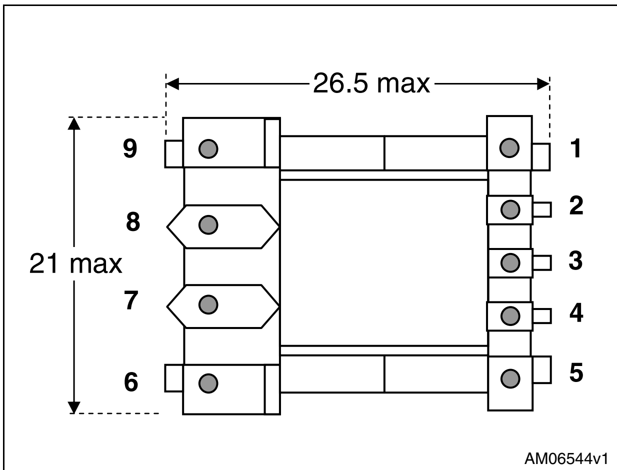


Figure 4. Transformer size - side view

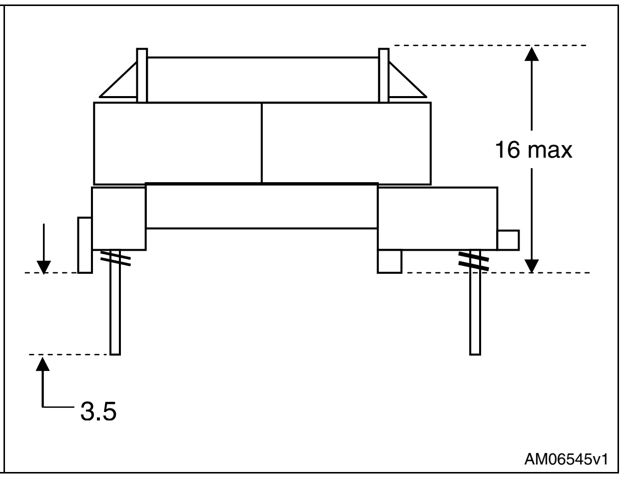


Figure 5. Pin placement diagram - bottom view

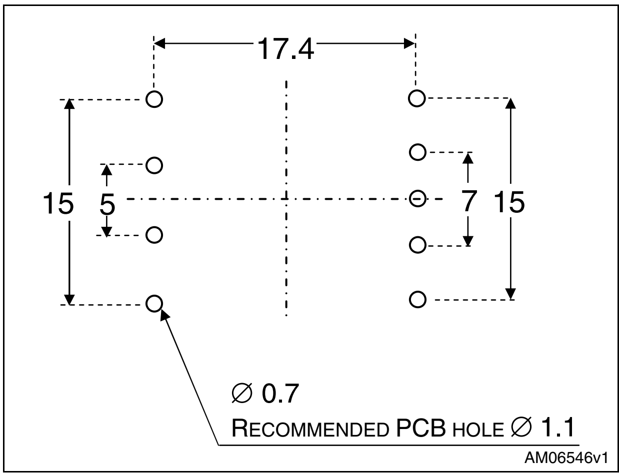
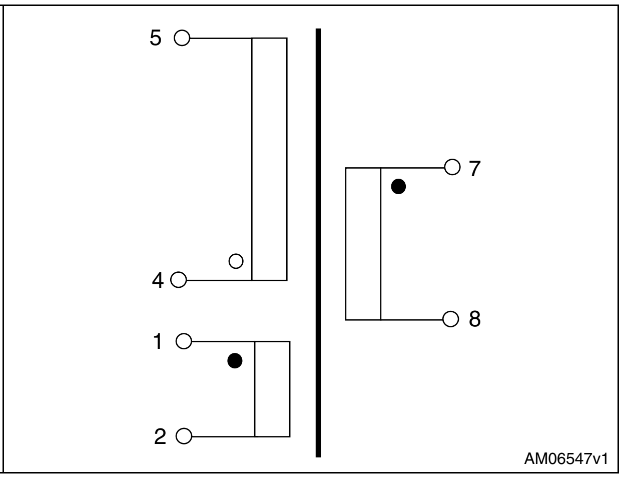


Figure 6. Pin placement diagram - electrical diagram



2 Testing the board

2.1 Typical board waveforms

The VIPer15 operates in quasi-resonant mode. Thanks to the ZCD pin (zero-current detect) it is able to sense the transformer demagnetization and switch on the MOSFET on the valley of the drain voltage ringing that follows the transformer demagnetization. *Figure 7* and *8* show the drain current and the drain voltage waveforms at the nominal input voltages of 115 V_{AC} and 230 V_{AC} in full load condition. *Figure 9* and *10* show the same waveforms for the same load condition, but at minimum (90 V_{AC}) and maximum (265 V_{AC}) input voltages, respectively.

Figure 7. Drain current and voltage at full load 115 V_{AC}

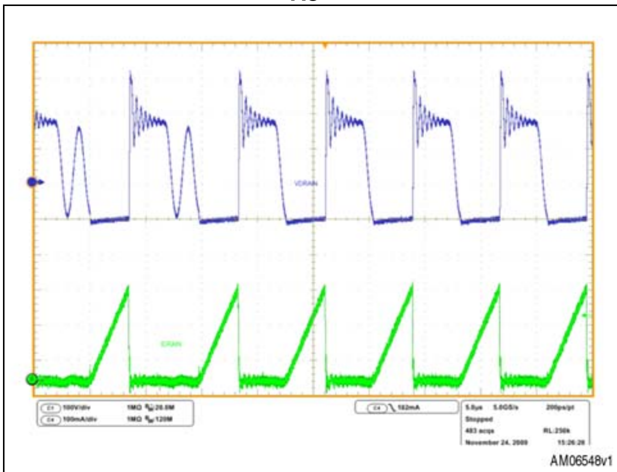


Figure 8. Drain current and voltage at full load 230 V_{AC}

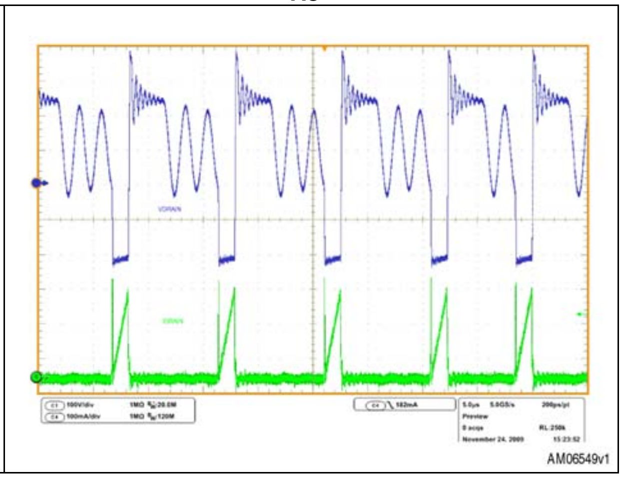


Figure 9. Drain current and voltage at full load 90 V_{AC}

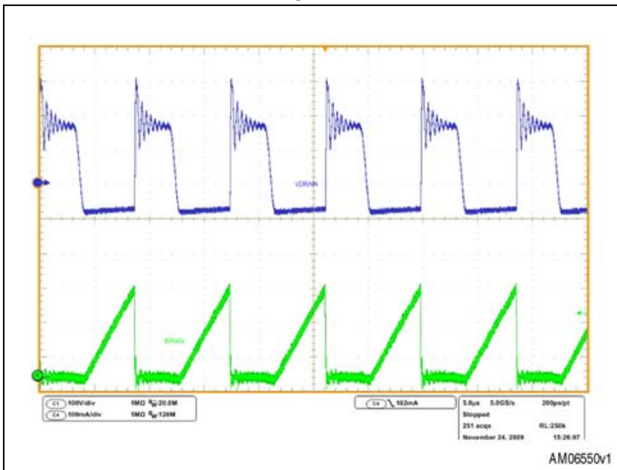
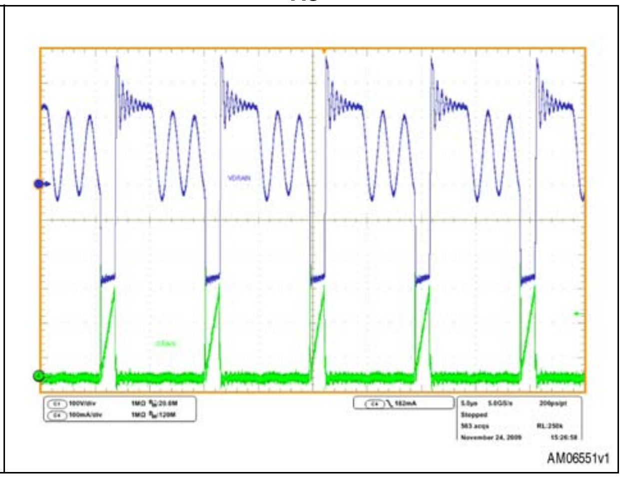


Figure 10. Drain current and voltage at full load 265 V_{AC}



The switching frequency of a flyback converter operating in quasi-resonant mode is not fixed but depends on its input voltage and on the load. As the load decreases, the switching frequency increases as a consequence of the drain peak current reduction and also the required on-time and the demagnetization time reduction. As the input voltage increases, the on-time is reduced and so the switching frequency increases. From previous considerations, in light load and at high input voltage, the switching frequency can be very high. To avoid excessive frequency switching, the device has the frequency fold-back feature which inhibits the MOSFET from turning on if the last switch-on is too recent. The frequency fold-back feature practically limits the maximum switching frequency. In the VIPer15L device this limit is set at 136 kHz while in VIPer15H this frequency limit is 225 kHz. The VIPer15L was used on the present board. The Converter was designed so that the minimum switching frequency (around 100 kHz) is not much lower then the maximum (136 kHz in VIPer15L) in order not to have a large transformer size. As a consequence of this choice, (see *Figure 7*), even with 115 V_{AC} the frequency fold-back feature is active.

While the frequency fold-back feature is active, uneven switching cycles may be observed due to the fact that the off-time of the MOSFET is allowed to change with discrete steps (the MOSFET is always switched on in the valley, so the off-time length increases by one drain voltage ringing period (T_{RING}) each time one valley is skipped), while the off-time needed for the cycle-by-cycle energy balance may fall between two consecutive steps. One or more longer switching cycles are then compensated by one or more shorter ones, and vice versa. This phenomenon (see *Figure 7*) is absolutely normal and there is no appreciable effect on the performance of the converter and its output voltage.

2.2 Precision of the regulation and output voltage ripple

The output voltage of the board was measured in different line and load conditions. The results are given in *Table 4* below. The output voltage is practically not affected by the line condition and by the load contition.

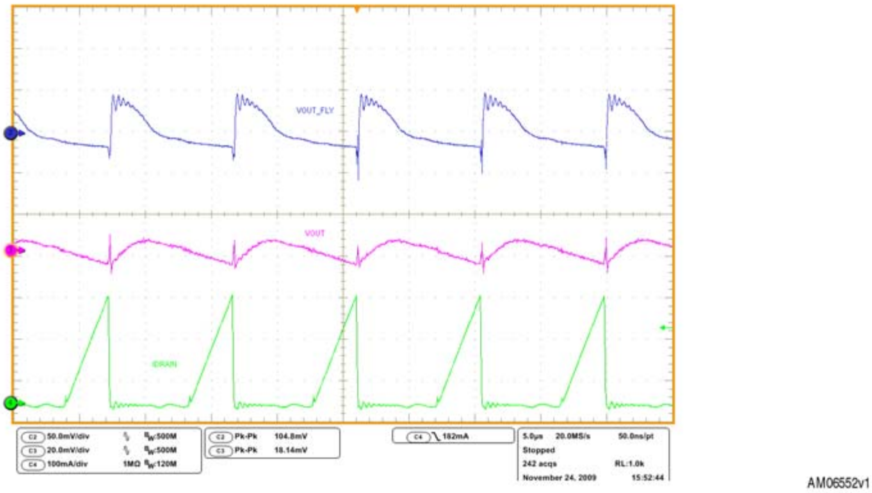
Table 4. Output voltage and V_{DD} line-load regulation

V_{INAC} (V)	Full load	Half load	No-load
	V_{OUT} (V)	V_{OUT} (V)	V_{OUT} (V)
90	12.14	12.15	12.16
115	12.14	12.15	12.16
230	12.14	12.15	12.16
265	12.14	12.15	12.16

The ripple at the switching frequency superimposed at the output voltage was also measured. The board is provided with an LC filter for cleaner output voltage. The high frequency voltage ripple across capacitor C9 (V_{OUT_FLY}), which is the output capacitor of the flyback converter before the LC filter, was also measured to verify the effectiveness of the filter and for more thorough results.

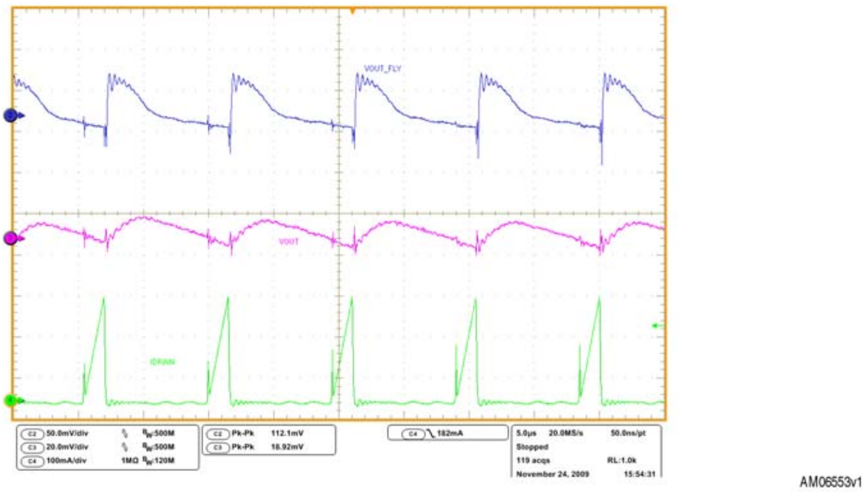
Waveforms of the two voltages (V_{OUT} and V_{OUT_FLY}) are shown in *Figure 11* and *12*.

Figure 11. Output voltage ripple 115 V_{INAC} full load



Ch2: V_{OUT_FLY} (blue)
Ch3: V_{OUT} (purple)
Ch4: I_{DRAIN} (green)

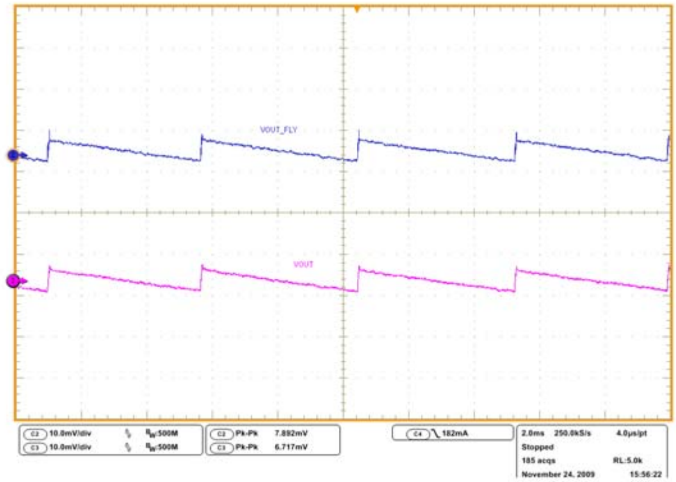
Figure 12. Output voltage ripple 230 V_{INAC} full load



Ch2: V_{OUT_FLY} (blue)
Ch3: V_{OUT} (purple)
Ch4: I_{DRAIN} (green)

When the device is working in burst mode, a lower frequency ripple is present. In this operation mode the converter does not supply continuous power to its output. It alternates periods where the power MOSFET is kept off and no power is processed by the converter, and periods where the power MOSFET is switching and power flows towards the converter output. Even if no load is present at the output of the converter, during periods of no switching, the output capacitors are discharged by their leakage currents and by the currents needed to supply the circuitry of the feedback loop present at the secondary side. During the switching period the output capacitance is recharged. *Figure 13* and *14* show the output voltage when the converter has no load.

Figure 13. Output voltage ripple 115 V_{INAC} no-load (burst mode)



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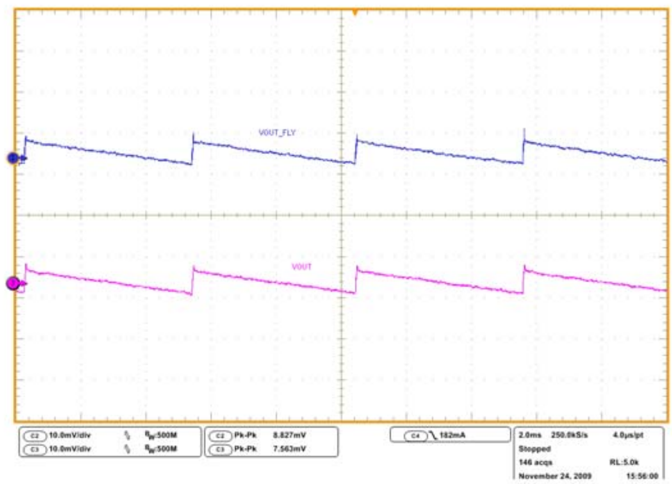
Ch1: V_{OUT_FLY} (blue)
Ch3: V_{OUT} (purple)

Figure 14. Output voltage ripple 230 V_{INAC} no-load (burst mode)



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Ch2: V_{OUT_FLY} (blue)
Ch3: V_{OUT} (purple)

2.3 Efficiency

The efficiency of the converter was measured in different load and line conditions according to the ENERGY STAR® average active mode testing efficiency method. The measurements were carried out with full load and with 75 %, 50 %, and 25 % of the full load for different input voltages. The results are given in *Table 5* below.

Table 5. Efficiency

V_{INAC} (VRMS)	Efficiency (%)			
	Full load (500 mA)	75 % load (375 mA)	50 % load (250 mA)	25 % load (125 mA)
90	76.5	77.8	79.8	81.1
115	78.7	79.5	80.3	81.5
132	79.4	79.9	80.7	81.1
175	80.4	80.1	80.7	79.8
230	79.9	79.7	79.0	76.2
265	79.4	78.8	77.8	73.7

For better visibility the results were plotted in *Figure 15* and *16*. *Figure 15* below shows the efficiency versus converter AC input voltage (V_{IN}) for the four different load values. *Figure 16* shows the values of the efficiency for different input voltages.

Figure 15. Efficiency vs V_{IN}

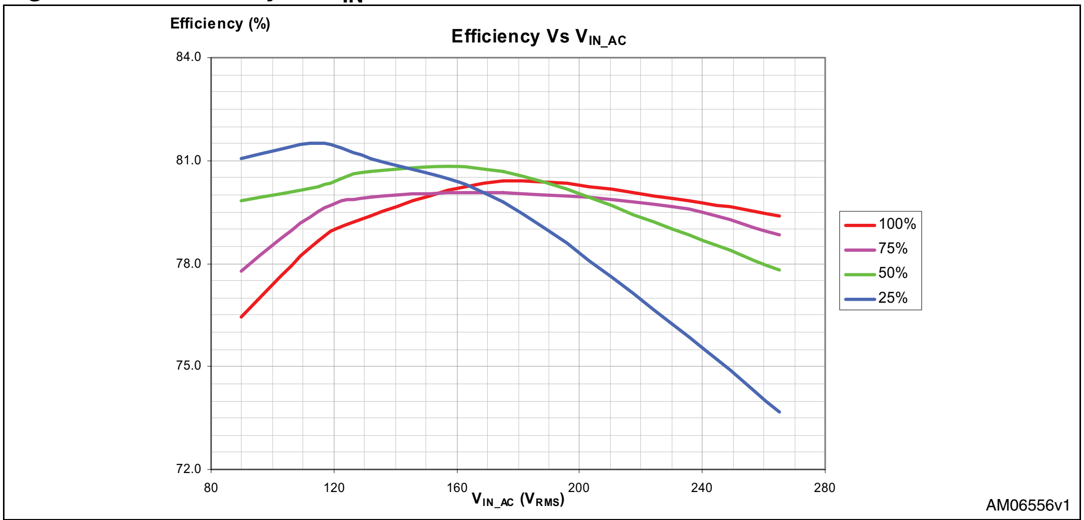
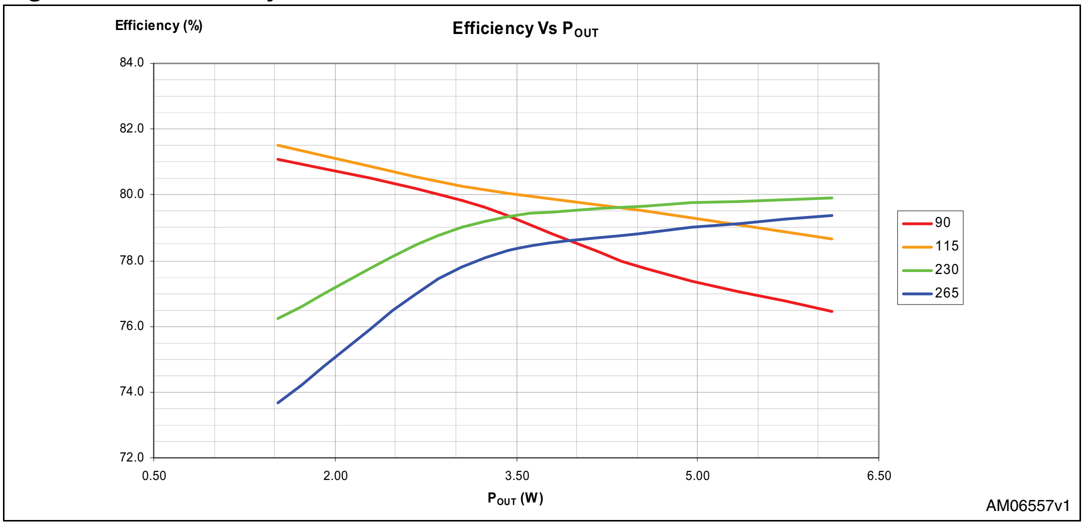


Figure 16. Efficiency vs load



The active mode efficiency is defined as the average of the efficiencies measured at 25 %, 50 % and 75 % of maximum load and the maximum load itself. *Table 6* below gives the active mode efficiency calculated from the measured values in *Table 5*. For clarity the values from *Table 6* are plotted in *Figure 22*. In *Figure 23* the average value (average was taken considering the efficiency at different input voltages) of the efficiency versus load are shown.

Table 6. Active mode efficiencies

Active mode efficiency	
V_{INAC} (V_{RMS})	Efficiency (%)
90	78.8
115	80.0
132	80.3
175	80.2
230	78.7
265	77.4

Figure 17. Active mode efficiency vs V_{IN}

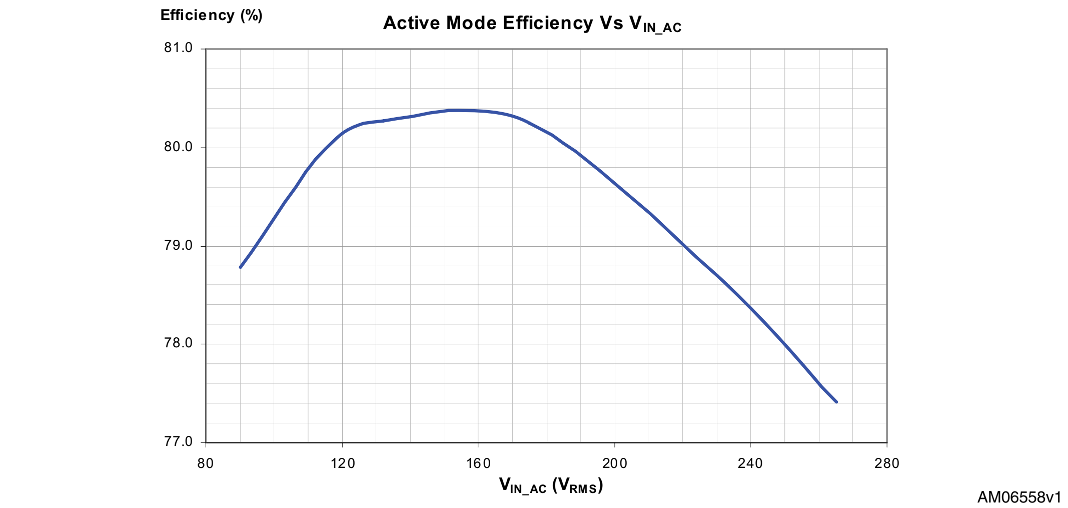


Figure 18. Input voltage average efficiency vs load

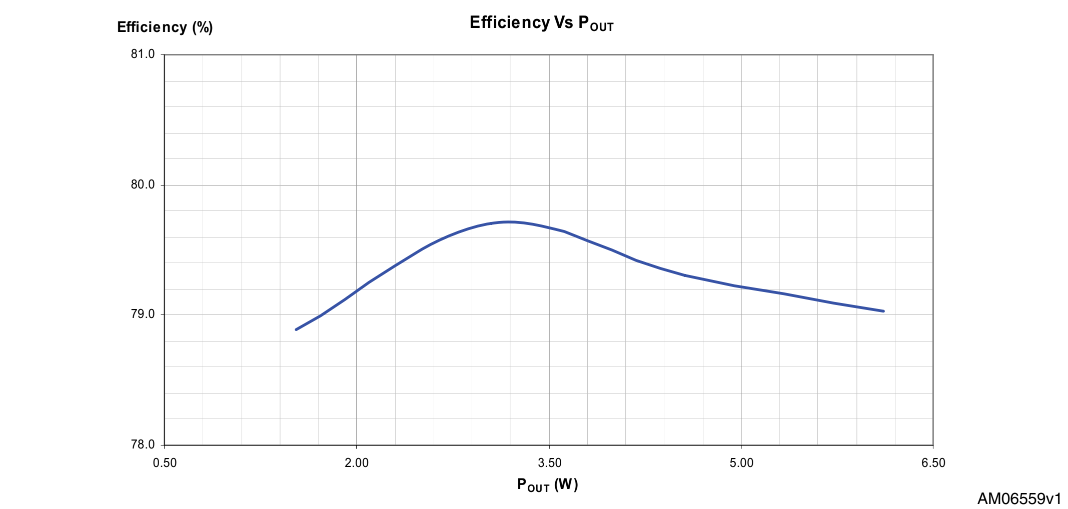


Table 7. Line voltage average efficiency vs load

Load (% of full load)	Efficiency (%)
100	79.0
75	79.3
50	79.7
25	78.9

In version 2.0 of the ENERGY STAR program requirement for single voltage external AC-DC power supplies (see *Section 4*), the power supplies are divided into two categories: low-voltage power supplies and standard power supplies with respect to the nameplate output voltage and current. An external power supply, in order to be considered a low-voltage power supply, needs to have a nameplate output voltage lower than 6 V and a nameplate output current greater than or equal to 550 mA. *Table 8* and *9* give the EPA energy efficiency criteria for AC-DC power supplies in active mode for standard models and for low-voltage models.

Table 8. Energy efficiency criteria for standard models

Nameplate output power (P_{no})	Minimum average efficiency in active mode (expressed as a decimal)
0 to = 1 W	= 0.48*Pno+0.140
> 1 to = 49 W	= [0.0626 * ln (P_{no})] + 0.622
> 49 W	= 0.870

Table 9. Energy efficiency criteria for low voltage models

Nameplate output power (P_{no})	Minimum average efficiency in active mode (expressed as a decimal)
0 to = 1 W	= 0.497 *Pno+0.067
> 1 to = 49 W	= [0.075 * ln (P_{no})] + 0.561
> 49 W	= 0.860

Figure 19. ENERGY STAR efficiency criteria

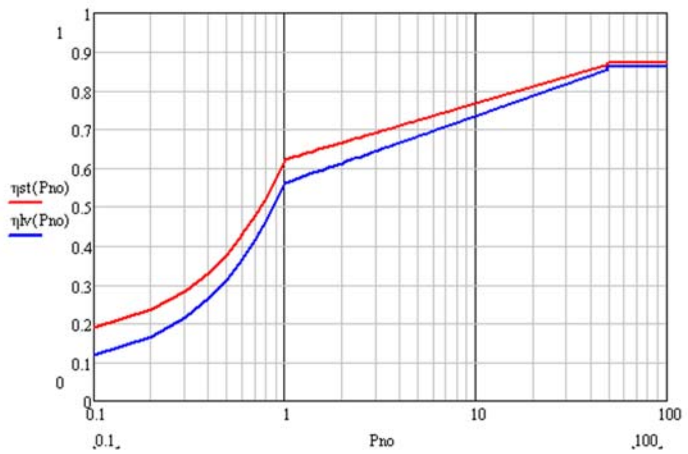


Figure 19 above shows the efficiency criteria for the standard model (red line) and for the low voltage model (blue line). The Pno (nameplate output power) is in logarithmic scale. The presented power supply belongs to the standard model power supply category and, in order to be compliant with ENERGY STAR requirements, needs to have an efficiency higher than 73.4 %. For all the considered input voltages the efficiency results (see *Table 6*) are higher than required.

2.4 Light load performance

2.4.1 No-load condition

The input power of the converter was measured in no-load condition, with brownout protection disabled and brownout protection enabled for different input voltages, the results are given in *Table 10*. The converter in no-load condition works always in burst mode so that the average switching frequency is strongly reduced. The average switching frequency values were also measured.

Table 10. No-load input power

Vin AC (V_{RMS})	Pin (mW) (BR enabled)	Pin (mW) (no BR)	f_{SW_AVG} (kHz)
90	23.54	20.83	2.0628
115	26.24	23.30	1.9247
132	28.30	24.30	1.8221
175	34.63	25.80	1.6113
230	46.88	31.10	1.3725
265	56.87	37.50	1.2694

2.4.2 Low load performance

The demonstration board was tested not only in no-load condition but also with a low load applied. The tests were performed with, 50 mW, 100 mW, 200 mW, 500 mW and 1 W with brownout protection enabled and with brownout protection disabled.

Measurement results with brownout protection disabled are given in *Table 11*. *Figure 20* shows the efficiency vs Pout diagram for 115 V_{AC} and 230 V_{AC} input voltage.

Table 12 and *Figure 21* give the results of the same measurements, but, in this case brownout protection is enabled.

Table 11. AC adapter efficiency at light load (brownout protection disabled)

AC input voltage	Output power (W)	Input power (W)	Efficiency (%)
115 V / 60 Hz (US standard)	0.050	84.57	59.1
	0.100	145.6	68.7
	0.200	267.0	74.9
	0.500	631.3	79.2
	1.0	1242	80.5
	1.5	1.841	81.5
	3.0	3.736	80.3
	4.5	5.660	79.5
	6.0	7.624	78.7

Table 11. AC adapter efficiency at light load (brownout protection disabled)

AC input voltage	Output power (W)	Input power (W)	Efficiency (%)
230 V / 50 Hz (European standard)	0.050	0.0997	50.2
	0.100	0.164	60.8
	0.200	0.295	67.9
	0.500	0.682	73.3
	1.0	1.329	75.3
	1.5	1.969	76.2
	3.0	3.797	79.0
	4.5	5.646	79.7
	6.0	7.509	79.9

Figure 20. Efficiency vs load (brownout protection disabled)

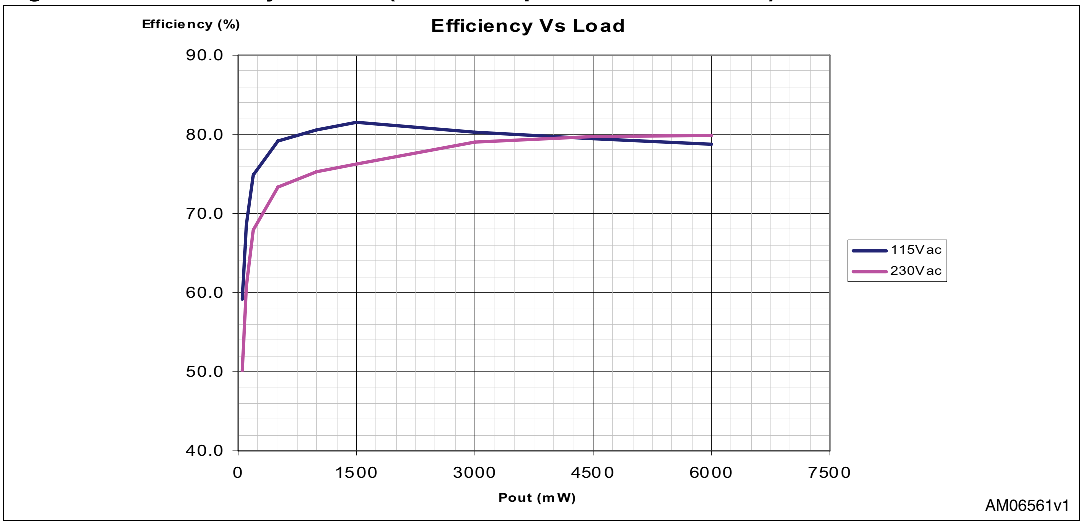


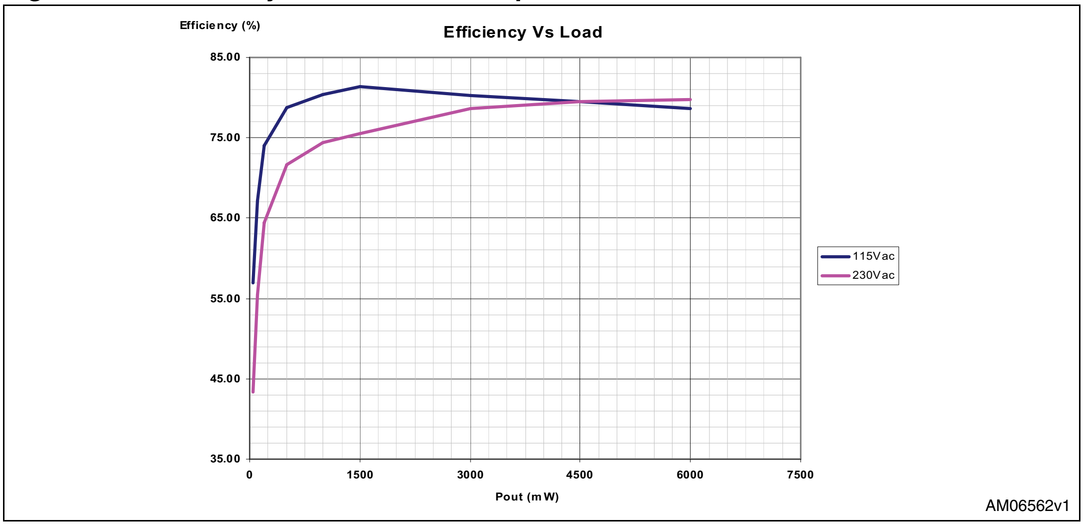
Table 12. AC adapter efficiency at light load (brownout enabled)

AC input voltage	Output power (W)	Input power (W)	Efficiency (%)
115 V / 60 Hz (US standard)	0.050	84.57	59.1
	0.100	145.6	68.7
	0.200	267.0	74.9
	0.500	631.3	79.2
	1.0	1242	80.5
	1.5	1.841	81.5
	3.0	3.736	80.3
	4.5	5.660	79.5
	6.0	7.624	78.7

Table 12. AC adapter efficiency at light load (brownout enabled) (continued)

AC input voltage	Output power (W)	Input power (W)	Efficiency (%)
230 V / 50 Hz (European standard)	0.050	0.0997	50.2
	0.100	0.164	60.8
	0.200	0.295	67.9
	0.500	0.682	73.3
	1.0	1.329	75.3
	1.5	1.969	76.2
	3.0	3.797	79.0
	4.5	5.646	79.7
	6.0	7.509	79.9

Figure 21. Efficiency vs load brownout protection enabled



Depending on the equipment supplied, there are several criteria to measure the standby or light load performance of a converter. One criterion is the measurement of the output power when the input power is equal to 1 W. *Table 13* below shows the output power needed to have 1 W of input power in different line conditions and *Figure 26* shows a graph of these values.

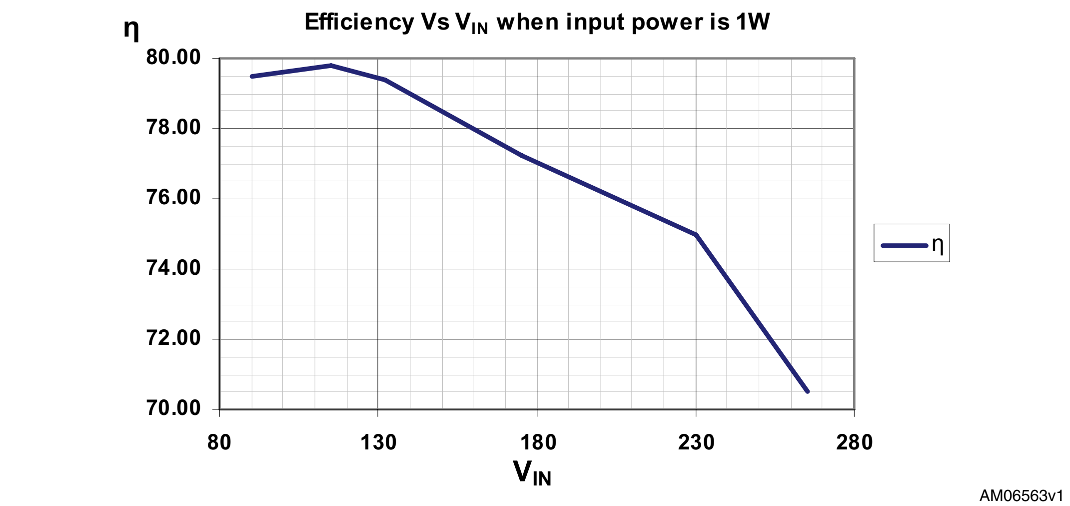
Table 13. Output powers when the input power is 1 W (NO BR)

V_{IN} (V_{RMS})	P_{IN} (mW)	P_{OUT} (mW)	Efficiency (%)	Pin-Pout (mW)
90	1000	796	79.6	203
115	1000	801	80.1	199
132	1000	797	79.7	204
175	1000	778	77.8	221
230	1000	746	74.6	257
265	1000	722	72.2	281

Table 14. Output powers when the input power is 1 W (BR enabled)

V_{IN} (V_{RMS})	P_{IN} (mW)	P_{OUT} (mW)	Efficiency (%)	Pin-Pout (mW)
90	1000	795.01	79.5	205
115	1000	797.77	79.8	202
132	1000	793.83	79.4	206
175	1000	772.46	77.2	228
230	1000	749.64	75.0	250
265	1000	705.09	70.5	295

Figure 22. Efficiency at 1 W as input power Vs AC converter input voltage



2.5 Test equipment and measurement of efficiency and input power

The converter input power was measured using a wattmeter. The wattmeter measures contemporary convert input current (using its internal ammeter) and voltage (using its internal voltmeter). Modern wattmeters are digital instruments, it means that they sample the current and voltage and convert them into digital forms. The digital samples are then multiplied giving the instantaneous measured power. The sampling frequency is generally in the range of 20 kHz (or higher depending on the instrument used). The display provides the average measured power, averaging the instantaneous measured power.

Figure 23 shows how the wattmeter is connected to the UUT (unit under test) and to the AC source and the wattmeter internal block diagram.

An electronic load was connected to the output of the power converter (UUT), sinking the load current. The electronic load also measures the load current. In order to measure the output voltage of the power converter a voltmeter was used.

Once the input power and the output power can be measured, the efficiency can be calculated in different operating conditions by properly setting the AC source and the current sourced by the electronic load.

2.5.1 Measuring input power notes

The UUT input current causes a voltage drop across the ammeter internal shunt resistance (the ammeter is not ideal so it has an internal resistance higher than zero) and across the cables that connect the wattmeter to the UUT (see *Figure 23* below).

If the switch in *Figure 23* is in position 1 (see also the simplified scheme of *Figure 25*) this voltage drop causes an input measured voltage higher than the input voltage at the UUT input that, of course, affects the measured power. The voltage drop is generally negligible if the UUT input current is low (for example when measuring the input power of the UUT in low load condition). In case of high UUT input current the voltage drop can be relevant (compared to the UUT real input voltage) so, in such a case, the switch in *Figure 23* can be changed to position 2 (see simplified scheme of *Figure 26*) where the UUT input voltage is measured directly to the UUT input terminal and the input current does not affect the measured input voltage.

The voltage across the voltmeter causes a leakage current inside the voltmeter itself (that is not ideal and that does not have infinite input resistance). If the switch in *Figure 23* is in position 2 (see simplified scheme of *Figure 26*) the voltmeter leakage current is measured by the ammeter together with the UUT input current, causing a measurement error. The error is negligible in the case where the UUT input current is much higher than the voltmeter leakage. If the UUT input current is low and not much bigger than the voltmeter leakage current it is probably better to set the switch in *Figure 23* to position 1.

In case it is not clear which measurement scheme least affects the result, both can be tried and the input power lower value registered.

Figure 23. Converter input power measurement: instrument connection scheme

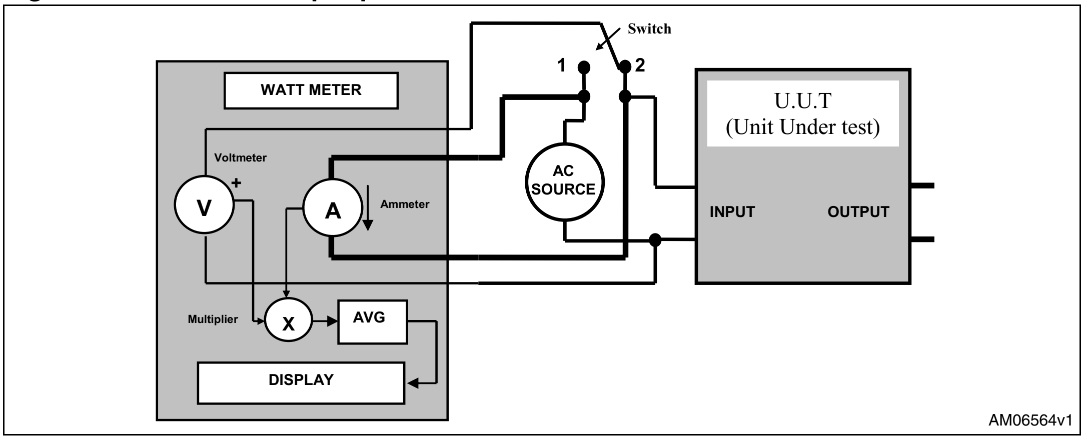


Figure 24. Converter input power measurement: simplified connection scheme for low input current

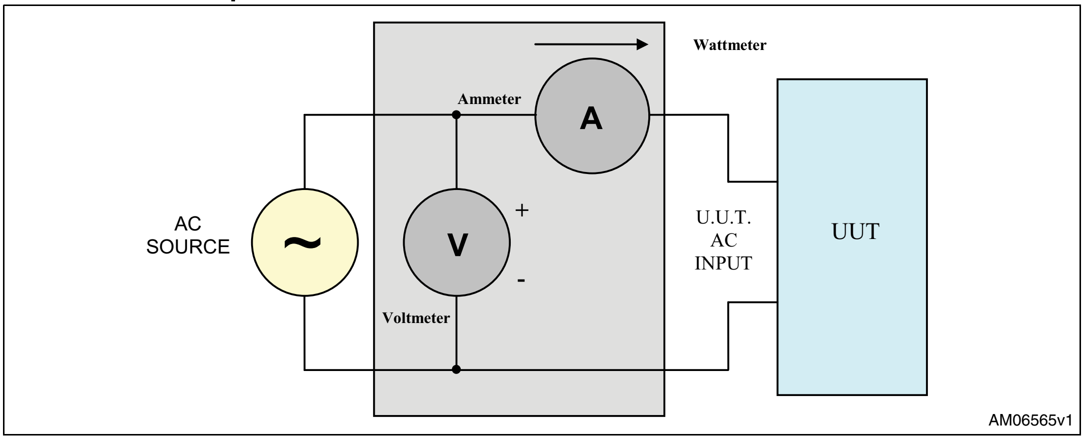
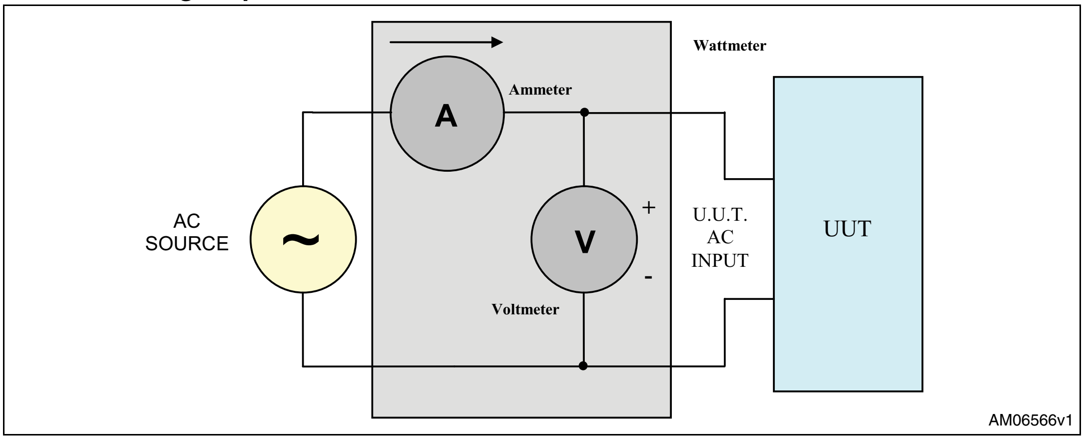


Figure 25. Converter input power measurement: simplified connection scheme for high input current



As noted in IEC 62301, instantaneous measurements are appropriate when power readings are stable. The UUT is operated at 100 % of nameplate output current output for at least 30 minutes (warm up period) immediately prior to conducting efficiency measurements.

After this warm-up period, the AC input power is monitored for a period of 5 minutes to assess the stability of the UUT. If the power level does not drift by more than 5 % from the maximum value observed, the UUT can be considered stable and the measurements can be recorded at the end of the 5 minute period.

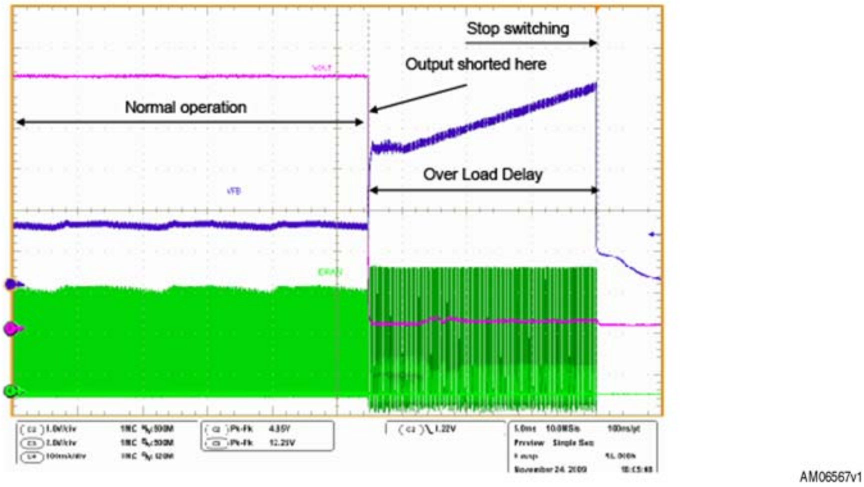
If AC input power is not stable over a 5 minute period, the average power or accumulated energy is measured over time for both AC input and DC output.

Some wattmeter models allow the measured input power to be integrated in a time range, resulting in the energy absorbed by the UUT during the integration time. By dividing by the integration time itself, the average input power is given.

2.6 Overload protection

The VIPer15 has several protections, one of which prevents damage to the board in case of overload or output short-circuit. If the load power demand increases, the output voltage decreases and the feedback loop reacts by increasing the voltage on the feedback pin. The feedback pin voltage increase leads to the PWM current set point increase, increasing the power delivered to the output until this power equals the load power. If the load power demand exceeds the converter power capability, the voltage on the feedback pin continuously rises but the power delivered does not additionally rise. When the feedback pin voltage exceeds V_{FB_lin} (3.3 V typ.), VIPer15 logic assumes that it is a warning of an overload event. Before shutting down the system, the device waits for a time set by the capacitor present on the feedback pin. In fact, if the voltage on the feedback pin exceeds FB_lin, the internal pull-up is disconnected and the pin starts sourcing a 3 µA current that charges the capacitor connected to it. As the voltage on the feedback pin reaches the VFB_olp threshold (4.8 V typ.), VIPer15 stops switching and is not allowed to switch again until the V_{DD} voltage goes below $V_{DD\_RESTART}$ (4.5 V typ.) and rises again up to V_{DD_ON} (14 V typ.). The following waveform shows the behavior of the converter when the output is shorted.

Figure 26. Output short-circuit



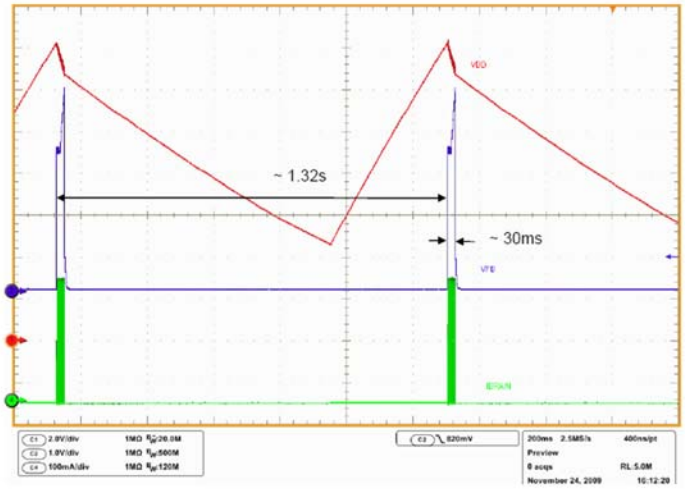
Ch1: V_{OUT} (purple)
Ch2: V_{FB} (blue)
Ch4: I_{DRAIN} (green)

full load
before the short

V_{IN} =115 V_{AC}

If the short-circuit is not removed, the system starts to work in auto-restart mode. The behavior, when a short-circuit is permanently applied on the output, is a short period of time where the MOSFET is switching and the converter tries to deliver as much power as it can to the output, and a longer period where the device is not switching and no power is processed. As shown in *Figure 27*, the duty cycle of power delivery is very low (around 2.27 %), so the average power throughput is very low.

Figure 27. Operation with output shorted



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Ch1: V_{DD} (red)
Ch2: V_{FB} (blue)
Ch4: I_{DRAIN} (green)

V_{IN} =115 V_{AC}

2.7 Voltage feed-forward function

According to *Equation 1*, for a fixed value of the maximum peak primary current, the transformer input power is proportional to the switching frequency as well as the maximum output power which is called converter power capability.

Equation 1

$$P_{IN-TRAFO\_Max} = \frac{1}{2} \cdot L_P \cdot I^2_{PK\_Max} \cdot f_{SW}$$

Generally, in a quasi-resonant converter, the power capability, if the maximum drain peak current is kept constant, increases as the input voltage increases because of the increasing of the switching frequency.

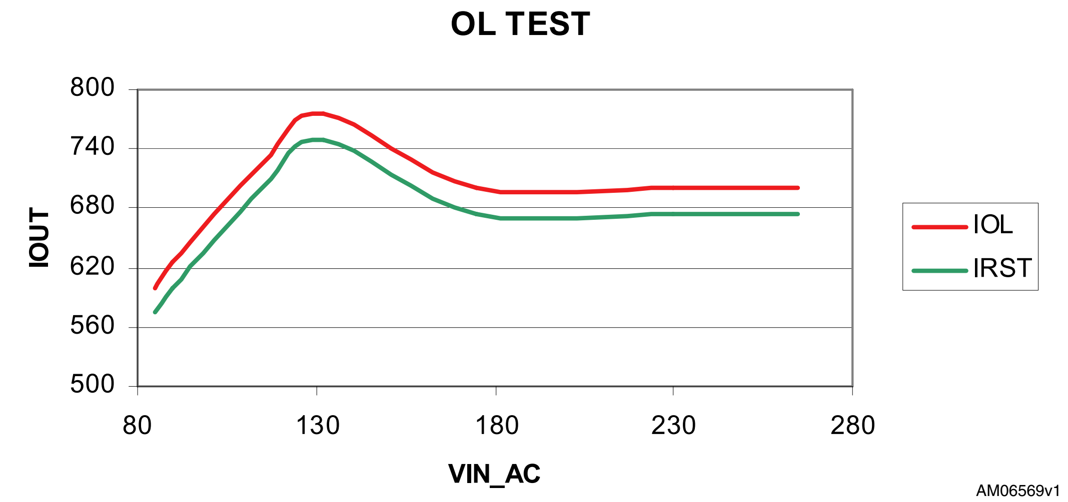
The VIPer15 voltage feed-forward function lowers the maximum drain current as the input voltage increases, by simply connecting a resistor between the auxiliary winding and the ZCD pin (RFF resistor in *Figure 29*). When the MOSFET is on, the auxiliary winding voltage is negative and proportional to the flyback input voltage. Through the RFF resistor a current almost proportional to the input voltage is sunk by the ZCD pin. Thanks to the adjustable current limitation function of the VIPer15, the maximum peak drain current is reduced according to the value of the input voltage (the current is reduced as the input voltage increases).

In this case, being a converter designed in order to work with a not-wide switching frequency range, the RFF resistance value was selected quite high. So the maximum drain peak current value is just slightly reduced as the converter input voltage increases.

Figure 30 shows the output current when the overload protection is tripped (IOLP, red line) and it is the converter power capability in terms of current.

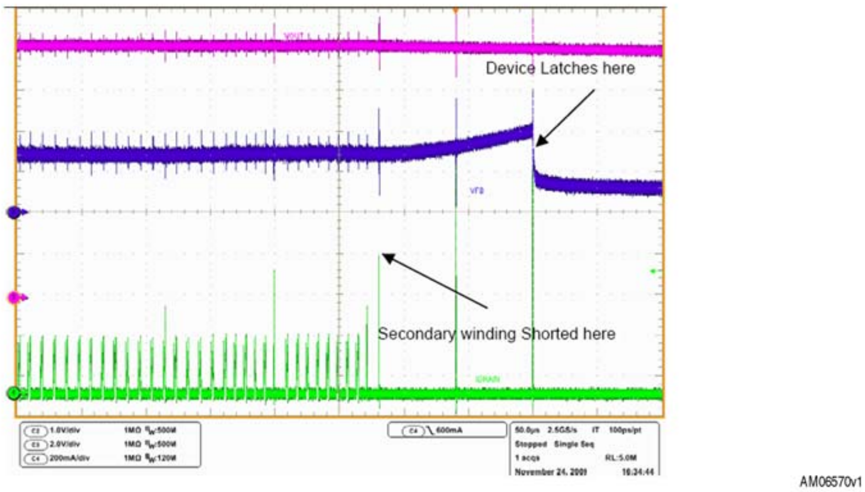
IOUT_REST is the output current value when the converter starts working again (after the overload protection has been tripped and the output current has been gradually reduced).

Figure 28. Overload activation and converter restart vs V_{IN}



2.8 Secondary winding short-circuit protection

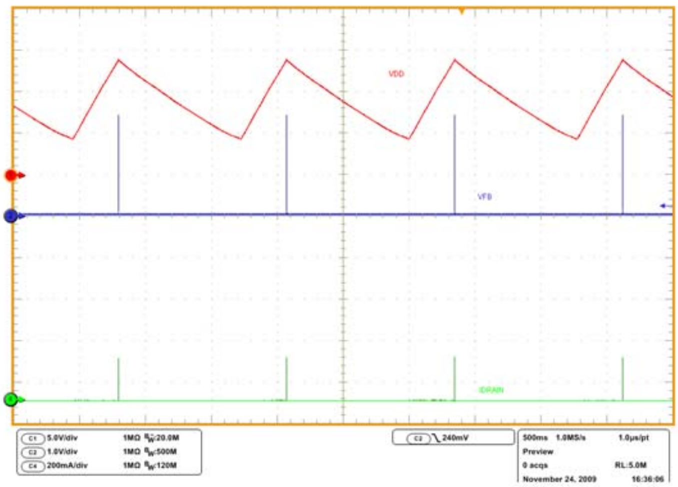
Figure 29. 2nd OCP protection tripping



Ch2 = V_{FB} (blue)
Ch3 = V_{OUT} (purple)
Ch4 = I_{DRAIN} (green)

Test condition:
Vin = 230 V_{AC}
Full load before short

Figure 30. Operating with secondary winding shorted. Restart mode



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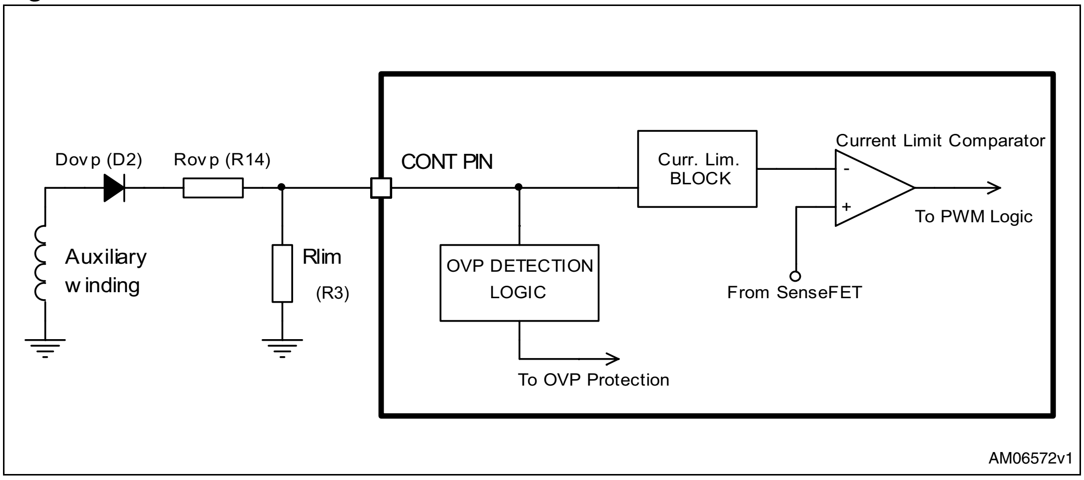
Ch1 = V_{DD} (red)
Ch2 = V_{FB} (blue)
Ch4 = I_{DRAIN} (green)

Test condition:
Vin=230 V_{AC}
Secondary winding shorted

2.9 Output overvoltage protection

The output overvoltage protection can be implemented by monitoring the voltage across the auxiliary winding during the MOSFET off-time. The monitoring is done through the D2 diode and the resistor divider R5 and R6 connected to the ZCD pin of the VIPer15 (see the complete schematic of *Figure 2* or the schematic of *Figure 29*). If the voltage on the pin exceeds the V_{OVP} threshold (4.2 V typ.), an overvoltage event is assumed and the power section is no longer allowed to switch on. To re-enable device operation, the V_{DD} voltage has to be recycled. In order to provide high noise immunity and avoid spikes erroneously tripping the protection, a digital filter was implemented, so the ZCD pin has to sense a voltage higher than V_{OVP} for four consecutive cycles before stopping device operation. Moreover, the voltage on the auxiliary winding is read in a time window which has a width of around 500 ns and it starts 2.3 µs after MOSFET switch off (T_{STROBE}). The T_{STROBE} helps to avoid that noise caused by leakage inductance at MOSFET switch-off is read.

Figure 31. OVP circuit



The threshold value of the output voltage for triggering overvoltage protection can be set by selecting the resistor R6 of the resistor divider connected.

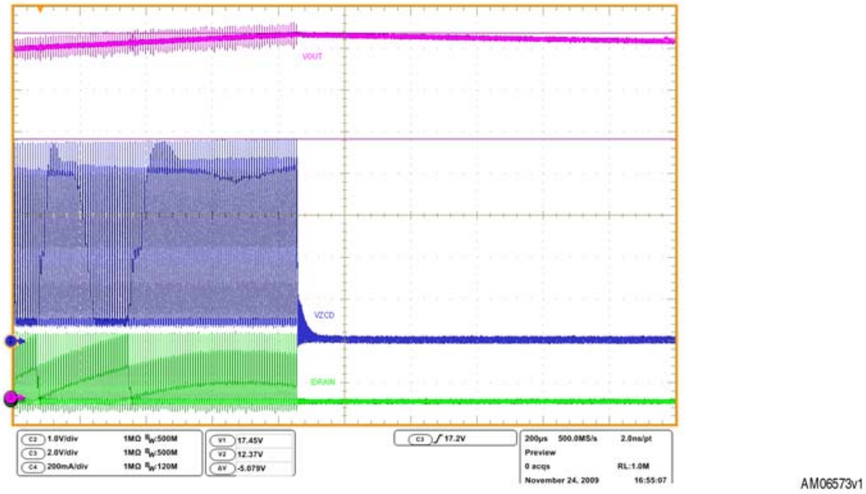
Equation 2

$$R_{OVP\_(R14)} = \frac{R_{LIM\_(R2)}}{3V} \cdot \left(\frac{N_{AUX}}{N_s} \cdot V_{OUT\_OVP} - V_{drop\_D_{ovp\_(D2)}} - 3V \right)$$

The protection was tested by disconnecting the opto-coupler from the feedback pin and supplying the converter. In this way the converter operates in open loop and delivers maximum power to the output. 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 working.

In *Figure 32* it is possible to see that the output voltage increases and as it reaches the value of 17.45 V, the converter stops switching. Also in *Figure 32* , the CONT pin voltage (Ch3, purple waveform) is shown. The crest value of the CONT pin voltage tracks the output voltage.

Figure 32. OVP protection

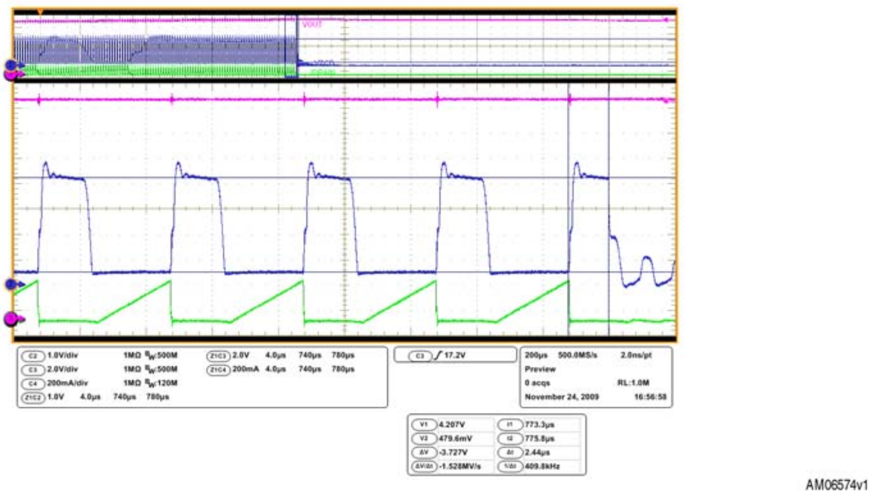


Ch2: V_{ZCD} (blue)
Ch3: V_{OUT} (purple)
CH4: I_{DRAIN} (green)

Working condition:
Input voltage: 115 V_{AC}
1.1 A of load

Figure 33 shows the protection tripping in more detail.

Figure 33. OVP protection: detail



Ch2: V_{ZCD} (blue)
Ch3: V_{OUT} (purple)
CH4: I_{DRAIN} (green)

Working condition:

Input voltage: 115 V_{AC}
Half load

2.10 Brownout protection

Brownout protection is basically an unlatched device shutdown function with a typical use of sensing mains undervoltage or the mains unplug. The VIPer15 has a pin (BR, pin 5) dedicated to this function which must be connected to the DC HV bus through a resistor 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 J3 (see schematic in *Figure 2*) setting. The settings of the jumper J3 are shown in *Figure 34* and *35*. The converter's shutdown is accomplished by means of an internal comparator internally referenced to 450 mV (typ, V_{BRth}) that disables the PWM if the voltage applied at the BR pin is below the internal reference, as shown in *Figure 36*. PWM operation is re-enabled as the BR pin voltage is more than 450 mV plus 50 mV of voltage hysteresis which ensures noise immunity. The brownout comparator is also provided with current hysteresis. An internal 8.5 µA 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.

Figure 34. J3 jumper setting. Brownout disabled

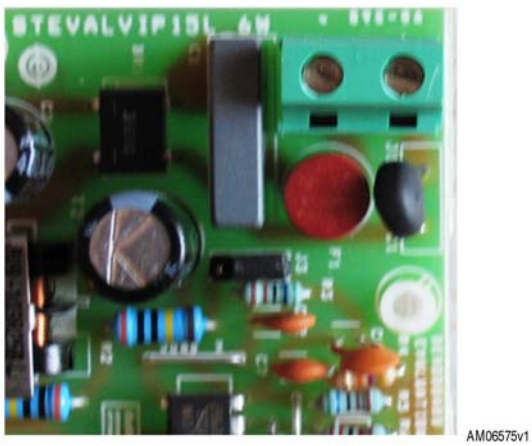


Figure 35. J3 jumper setting. Brownout enabled

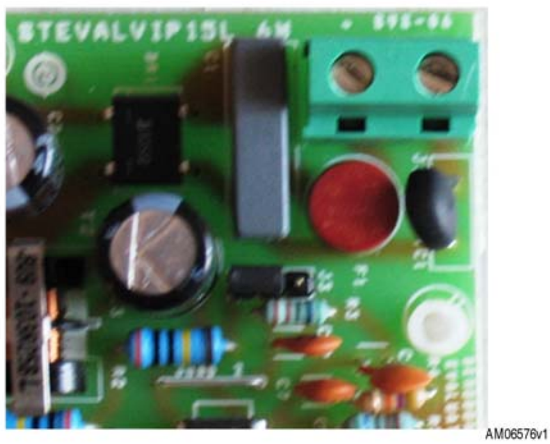
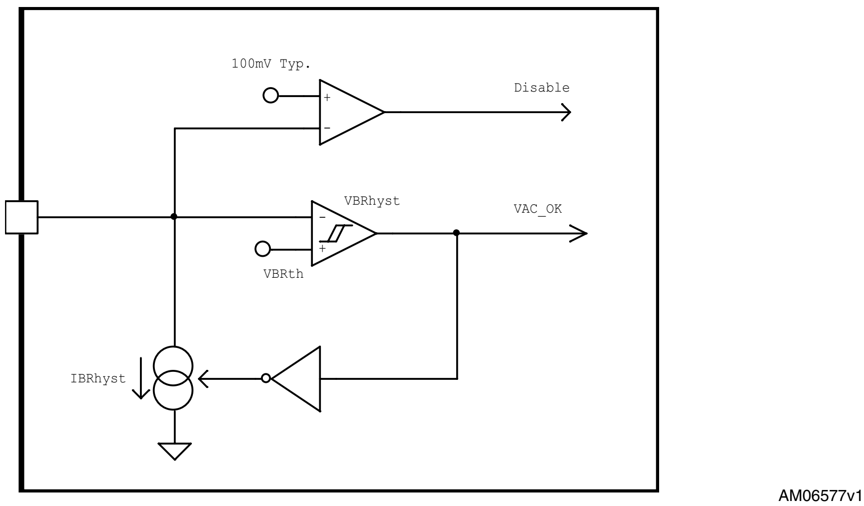


Figure 36. Brownout circuit block diagram



The current hysteresis provides an additional degree of freedom. It is possible to set the ON threshold and the OFF threshold for the flyback input voltage separately by properly choosing the resistors of the external divider. The following relationships can be established for the ON (V_{IN_ON}) and OFF (V_{IN_OFF}) thresholds of the input voltage:

Equation 3

$$V_{IN\_OFF} = V_{BRth} \cdot \left(\frac{R_H + R_L}{R_L} \right)$$

Equation 4

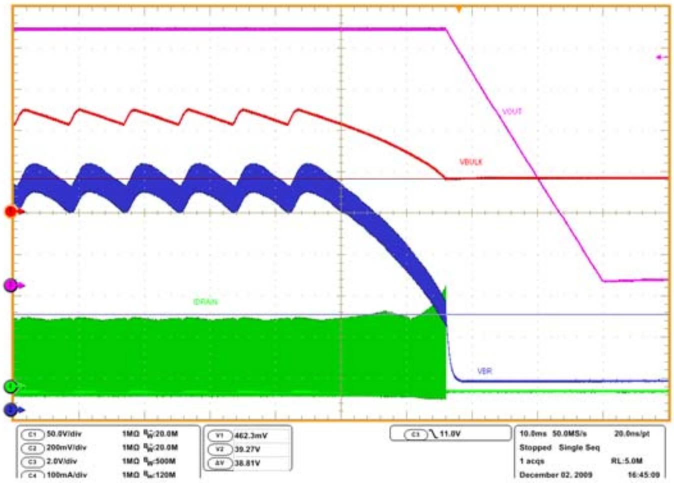
$$V_{IN\_ON} = \left(V_{BRth} + V_{BRhyst} \right) \cdot \left(\frac{R_H + R_L}{R_L} \right) + R_H \cdot I_{BRhyst}$$

where: I_{BRhyst}=8.50 µA (typ.) is the current hysteresis, V_{BRhyst}=50 mV (typ.) is the voltage hysteresis and V_{BRth}=450 mV (typ.) is the brownout comparator internal reference.

One purpose of this protection is to stop operation of the converter when the line voltage is too low, avoiding a too high root mean square current value flowing inside the main switch and so avoiding overheating. Another purpose is to avoid a false restart of the converter and then having a monotonically decay to zero of the output voltage when the converter itself is unplugged from the main. A typical situation, in most cases for converters designed for the European range (230 V_{AC}), may be a converter that, when unplugged, shuts down due to the overload protection (due to the low input voltage the converter is not able to supply the full power) but the voltage on the bulk capacitor is higher then $V_{DRAIN\ RESTART}$ so the device starts again and the output voltage rises again. This situation may be dangerous for some loads, and in many applications is best avoided.

Figure 37 and *38* show how brownout protection works in the VIPer27 board when used. *Figure 37* shows the behavior of the board when the input voltage is changed from 90 V_{AC} to 0 V_{AC} with half load applied. The system stops switching and the output load, no longer supplied, decays monotonically to zero. *Figure 38* shows the same situation but in this case the converter is full loaded.

Figure 37. Input AC voltage steps from 90 V_{AC} to 0 V_{AC} half load



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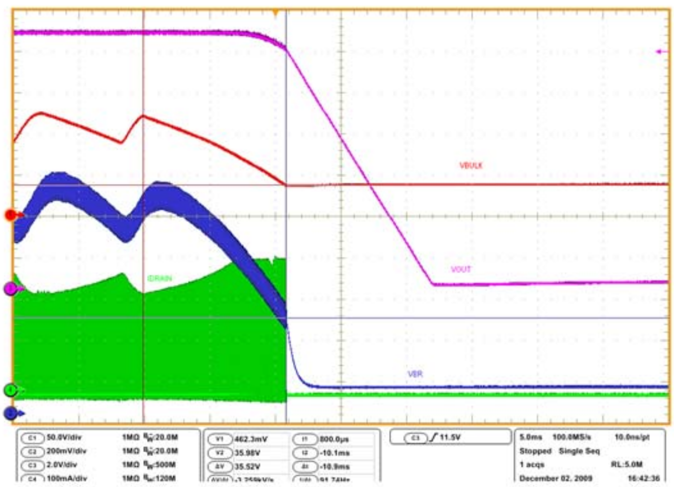
Ch1: V_{BULK} (red)
Ch2: V_{BR} (blue)
Ch3: V_{OUT} (purple)
Ch4: I_{DRAIN} (green)

Figure 38. Input AC voltage steps from 90 V_{AC} to 0 full load



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Ch1: V_{BULK} (red)
Ch2: V_{BR} (blue)
Ch3: V_{OUT} (purple)
Ch4: I_{DRAIN} (green)

2.11 EMI measurements

Pre-compliant tests to European standard EN55022 (class B) were also performed and results are shown in *Figure 39* and *40* below.

Figure 39. 115 V_{AC}

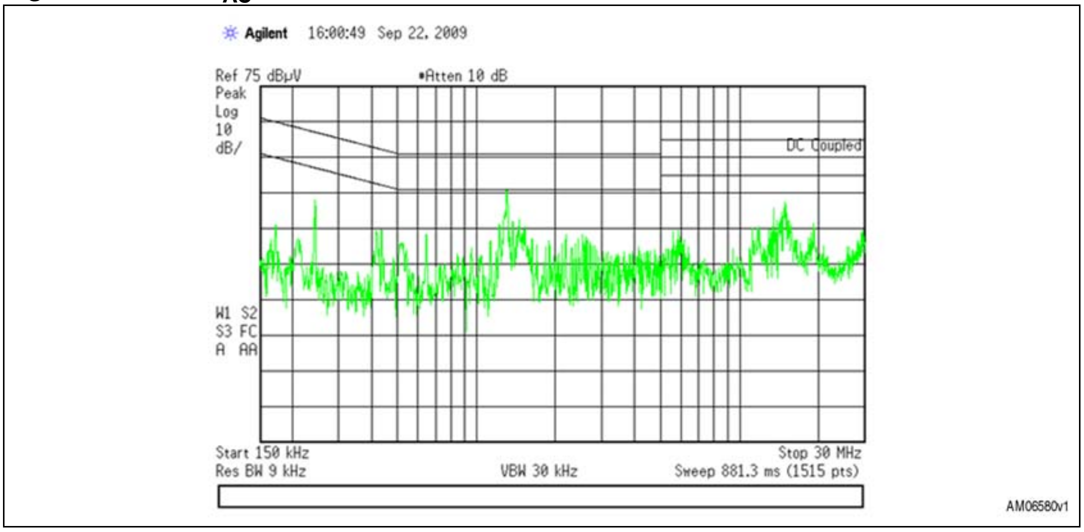
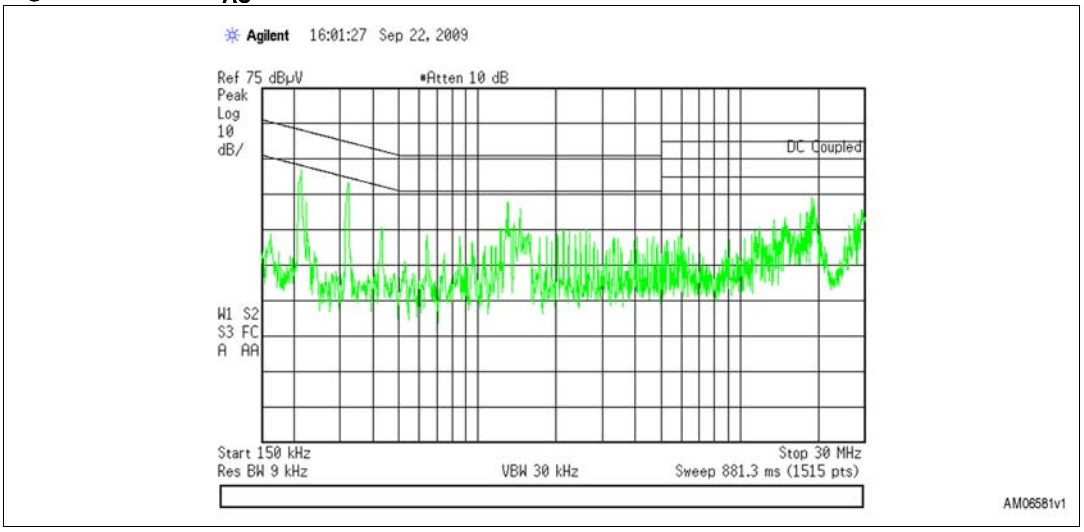


Figure 40. 230 V_{AC}



3 Conclusions

The presented flyback converter is suitable for different applications. The efficiency performance was compared with requirements of the ENERGY STAR program (version 2.0) for external AC-DC adapters with very good results, having the measured active mode efficiency always higher with respect to the minimum required.

4 References

1. ENERGY STAR Program Requirements for Single Voltage External AC-DC adapters (Version 2.0)
2. VIPer15; *Offline high voltage converters,* datasheet

5 Revision history

Table 15. Document revision history

Date	Revision	Changes
11-Mar-2011	1	Initial release.