AN3011
Application note

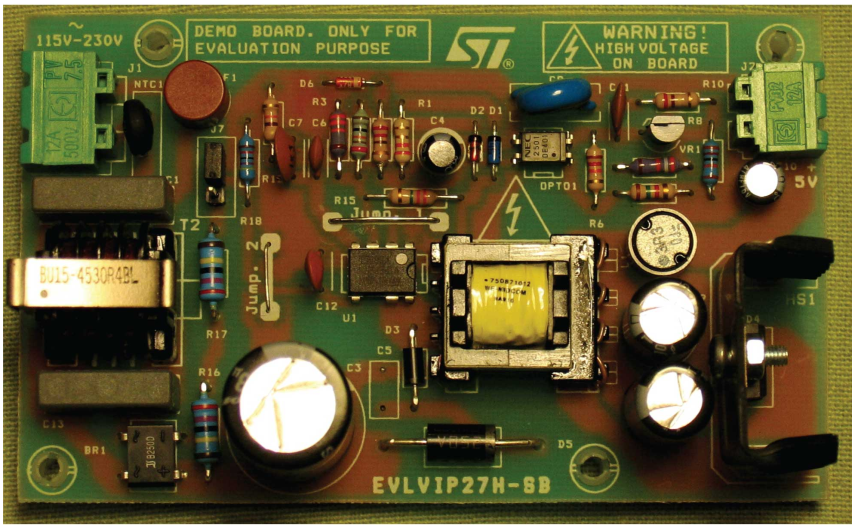
Wide range input (90 - 265), single output (5 V-11 W) EVLVIP27H-12SB, VIPer27 demonstration board

Introduction

In certain applications such as LCD or plasma TVs, desk top computers, etc., the power supply that converts the energy from the mains often includes two modules: the main power supply that provides most of the power which is off when the application is off or in standby mode, and the auxiliary power supply that only provides energy to specific parts of the equipment, like the USB ports, remote receivers, or modems, but stays on when the application is in standby mode.

In standby mode it is often required that the equipment input power is as low as possible, which means reducing the input power of the auxiliary power supply, in no-load or light-load conditions, as low as possible. This demonstration board meets the specifications of a wide range of auxiliary power supplies for the above mentioned applications. Furthermore, it is optimized for very low standby consumption which helps to meet the most stringent energy saving requirements. Using the VIPer27, which has a switching frequency of 115 kHz, helps to reduce the transformer size.

Figure 1. Demonstration board image



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1 Board descriptions

1.1 Electrical specifications

The electrical specifications of the demonstration board are listed in *Table 1*.

Table 1. Electrical specifications

Parameter	Symbol	Value
Input voltage range	V_{IN}	[90 V_{RMS}; 265 V_{RMS}]
Nameplate output voltage	V_{OUTn}	5 V
Max output current	I_{OUT}	2.2 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	60 °C

1.2 Schematic and bill of materials

The schematic of the board is shown in *Figure 2*, and the bill of materials is shown in *Table 2*.

Figure 2. Schematic

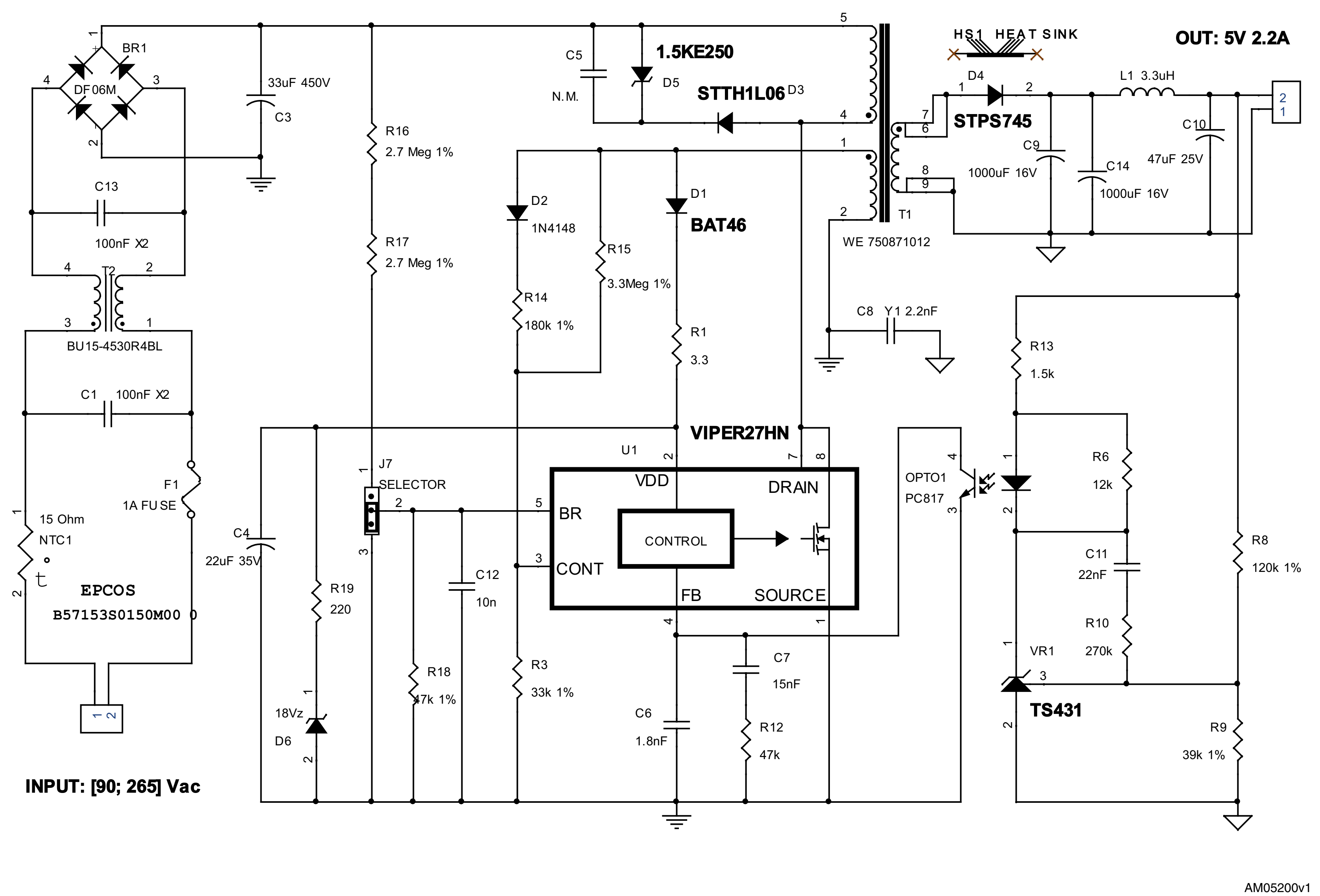


Table 2. BOM

Part reference	Description	Part name	Manufacturer
BR1	Bridge diodes	DF06M	Fairchild/ Vishay
C1,C13	100 nF X2 capacitor		
C3	33 µF 450 V electrolytic cap.		
C4	22 µF 35 V electrolytic cap.		
C5	N.M		
C6	1.8 nF ceramic cap		
C7	15 nF		
C8	2.2 nF Y1 capacitor		
C9, C14	ZL 1000 µF 16 V electrolytic cap.		RUBYCON
C10	YXF 47 µF 25 V electrolytic cap.	YXF 47 µF 25 V	RUBYCON
C11	22 nF ceramic cap	22 nF	
C12	10 nF ceramic cap	10 nF	
D1	100 V small signal Schottky diode	BAT46	STMicroelectronics
D2	100 V small signal fast diode	1N4148	
D3	600 V 1 A ultra-fast diode	STTH1L06	STMicroelectronics
D4	Power Schottky diode	STPS745	STMicroelectronics
D5	250 V Transil	1.5KE250	STMicroelectronics
D6	18 V Zener		
F1	1 A Fuse		
HS1	Heat sink		
J7	Selector		
L1	3.3 µH 3 A inductor		
NTC1	15 Ω		EPCOS
OPTO1	Opto-coupler	PC817	SHARP
R1	3.3 Ω resistor		
R3	33 kΩ 1% precision resistor		
R6	1 2kΩ 1% precision resistor		
R8	120 kΩ 1% precision resistor		
R9	39 kΩ 1% precision resistor		
R10	270 kΩ		
R12	47 kΩ		
R13	1.5 kΩ		
R14	180 kΩ 1% precision resistor		
R15	3.3 Meg 1% precision resistor		

Table 2. BOM (continued)

Part reference	Description	Part name	Manufacturer
R16, R17	2.7 Meg 1% precision resistor		
R18	47 kΩ 1% precision resistor		
R19	220 Ω		
T1	Switch mode transformer	WE - 750871012	Würth Elektronik
T2	Common mode line filter	BU15-4530R4BL	Coilcraft
U1	Offline switching regulator	VIPER27HN	STMicroelectronics
VR1	Voltage reference	TS431	STMicroelectronics

1.3 Transformer

Transformer characteristics are listed in *Table 3*:

Table 3. Transformer characteristics

Properties	Value	Test condition
Manufacturer	Würth Elektronik	
Part number	750871012	
Primary inductance	900 µH ±10 %	Measured at 10 kHz 0.1 V
Leakage inductance	25 µH max	Measured at 100 kHz 0.1 V (primary and secondary windings shorted)
Primary to secondary turn ratio (4 - 5) / (6, 7 – 8, 9)	14.75 ±1 %	Measured at 10 kHz 0.1 V
Primary to auxiliary turn ratio (6 - 4) / (3 - 1)	5.36 ±1 %	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 - top view

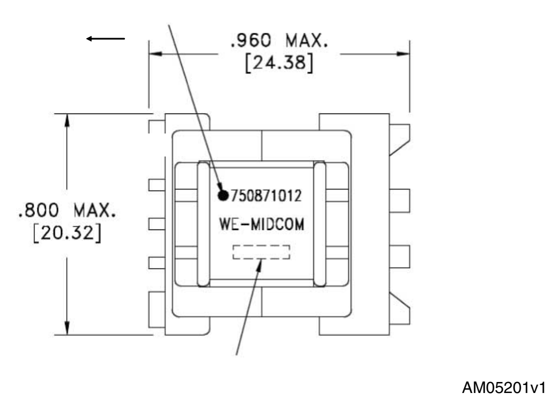


Figure 4. Transformer size - side view

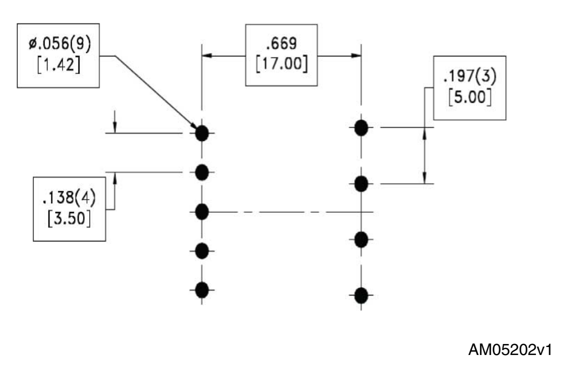


Figure 5. Pin placement diagram - bottom view

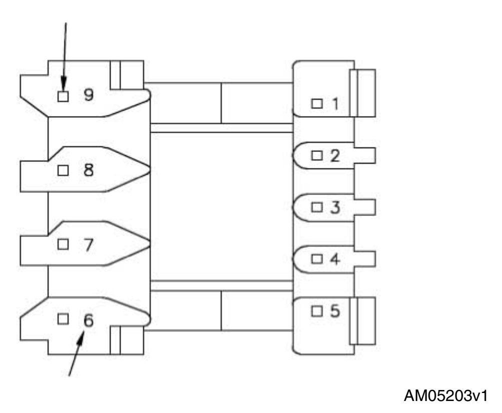
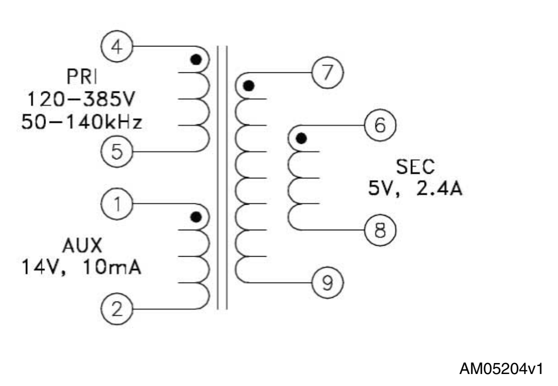


Figure 6. Pin placement diagram - electrical diagram



2 Testing the board

2.1 Typical board waveforms

Figure 7 and *8* show the drain current and the drain voltage waveforms at the nominal input voltages, which are 115 V_{AC} and 230 V_{AC} when at maximum load (2.2 A). *Figure 9* and *10* show the same waveforms for the same load condition, but with the input voltages at the minimum 90 V_{AC} and the maximum 265 V_{AC}.

The converter is designed to operate in continuous conduction mode (in full-load condition) at low-line. CCM (continuous conduction mode) allows the reducing 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 (D4) and in the output capacitors (C9 and C14). Reducing RMS currents means reducing the power dissipation (mainly in the VIPer) and the stress on the above mentioned components.

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

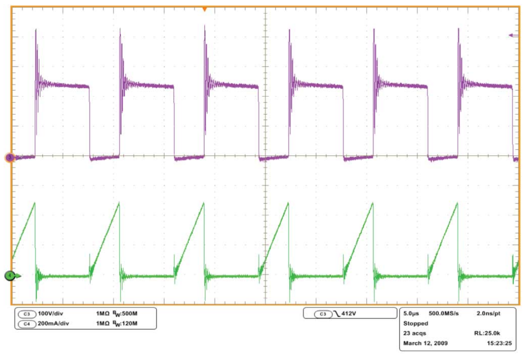


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Figure 8. Drain current and voltage at full-load 230 V_{AC}

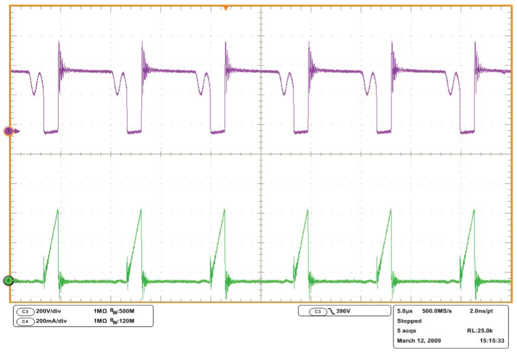

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Figure 9. Drain current and voltage at full-load 90 V_{AC}

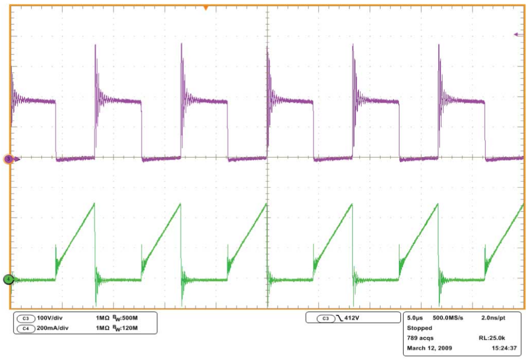

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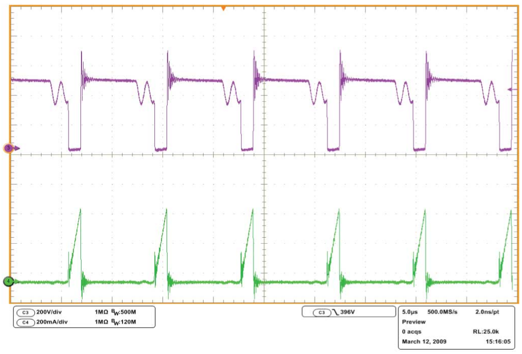
Figure 10. Drain current and voltage at full-load 265 V_{AC}



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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*. The output voltage is practically not affected by the line condition and only slightly affected by load condition (a difference of 10 mV between max and minimum V_{OUT}, see *Table 4*). The V_{DD} voltage was also measured.

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

V_{INAC} (V)	Full load		Half load		No load	
	V_{OUT} (V)	V_{DD} (v)	V_{OUT} (V)	V_{DD} (V)	V_{OUT} (V)	V_{DD} (V)
90	5.073	21.1	5.078	20.00	5.083	9.98
115	5.073	20.98	5.078	20.02	5.083	9.83
230	5.073	20.94	5.077	20.08	5.083	9.30
265	5.073	20.98	5.077	20.04	5.083	9.17

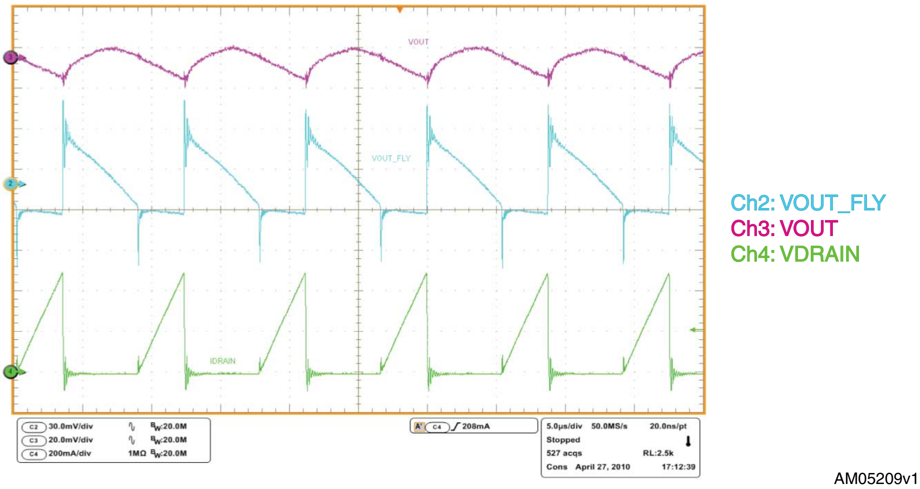
In a two-output flyback converter, when just one output is regulated, the unregulated output does not rigorously respect the turn ratio. The unregulated output voltage value depends not only by the turn ratio but also, approximately, from the output currents ratio (output current at the regulated output divided by output current of the unregulated output).

As confirmed from the results reported in *Table 4*, the V_{DD} voltage (unregulated auxiliary output) increases as the load on the regulated output increases. In order to avoid the V_{DD} voltage exceeding the VIPer27 operating range, an external clamp was used (D6, R19, see schematic).

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 capacitors C9 and C14 (VOUT_FLY), that is the output capacitors of the flyback converter before the LC filter (see schematic in *Figure 2*), was also measured to verify the effectiveness of the LC filter.

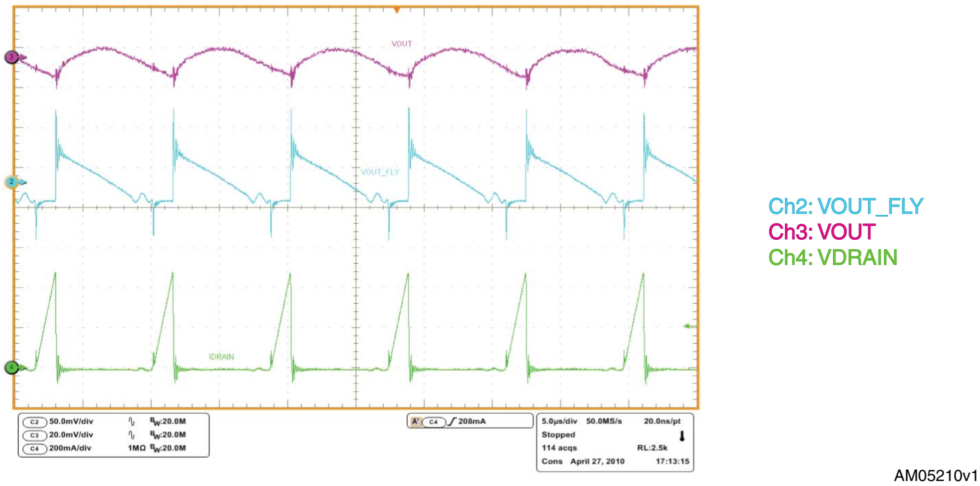
The waveforms of the two voltages (VOUT and VOUT_FLY) are reported in *Figure 11* and *12*. The output voltage ripple when the converter input voltage is 115 V_{AC} is shown in *Figure 11*, and the output voltage ripple when the converter input voltage is 230 V_{AC} is shown in *Figure 12*.

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



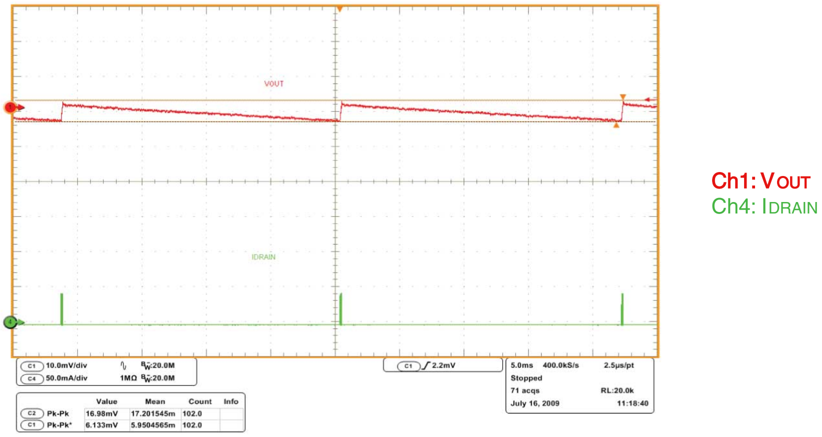
The measured output voltage ripple is around 20 mV, well below the maximum admitted value (50 mV, see electrical specification in *Table 1*).

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



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 when the power MOSFET is kept off, and no power is processed by the converter, and periods when the power MOSFET is switching and power flows towards the converter output. Even no-load is present at the output of the converter, during no switching periods 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 and the feedback voltage when the converter is no-loaded. In *Figure 13* the converter is supplied with 115 V_{AC}, and with 230 V_{AC} in *Figure 14*.

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



	Value	Mean	Count	Info
C2 Pk-Pk	16.98mV	17.201545m	102.0	
C1 Pk-Pk*	6.133mV	5.9504565m	102.0	

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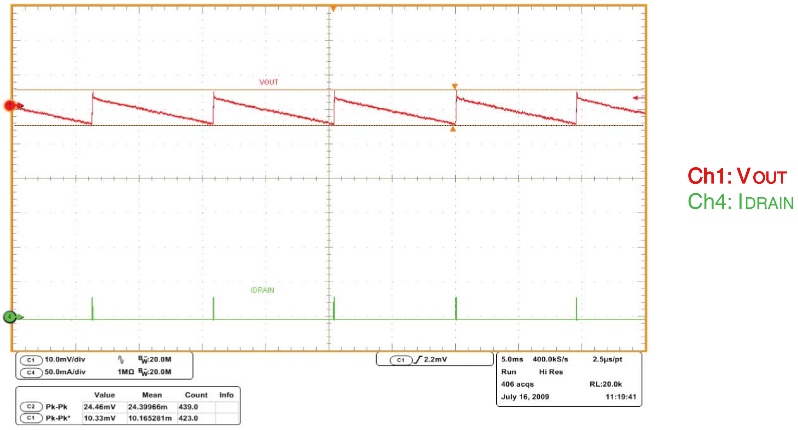
Figure 14. Output voltage ripple 230 V_{INAC} 50 mA load (burst mode)



	Value	Mean	Count	Info
C2 Pk-Pk	24.46mV	24.39966m	439.0	
C1 Pk-Pk*	10.33mV	10.165281m	423.0	

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3 Efficiency

The efficiency of the converter was measured in different load and line voltage conditions. In accordance with the ENERGY STAR® active mode testing efficiency method, the measurements are done with different load values (full-load, 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 (2.2 A)	75 % load (1.65 A)	50 % load (1.1 A)	25 % load (0.55 A)
90	73.0	75.1	76.9	77.9
115	75.3	76.5	77.9	78.1
132	75.9	76.9	77.8	77.7
175	76.8	77.3	77.6	76.4
230	77.4	77.6	77.3	75.4
265	76.8	76.9	76.3	74.2

For better visibility the results are plotted in the diagrams below. In *Figure 15*, efficiency versus converter AC input voltage (V_{IN}), for four different load values, is plotted. In *Figure 16*, the value of efficiency versus load for different input voltages is plotted.

Figure 15. Efficiency vs V_{IN}

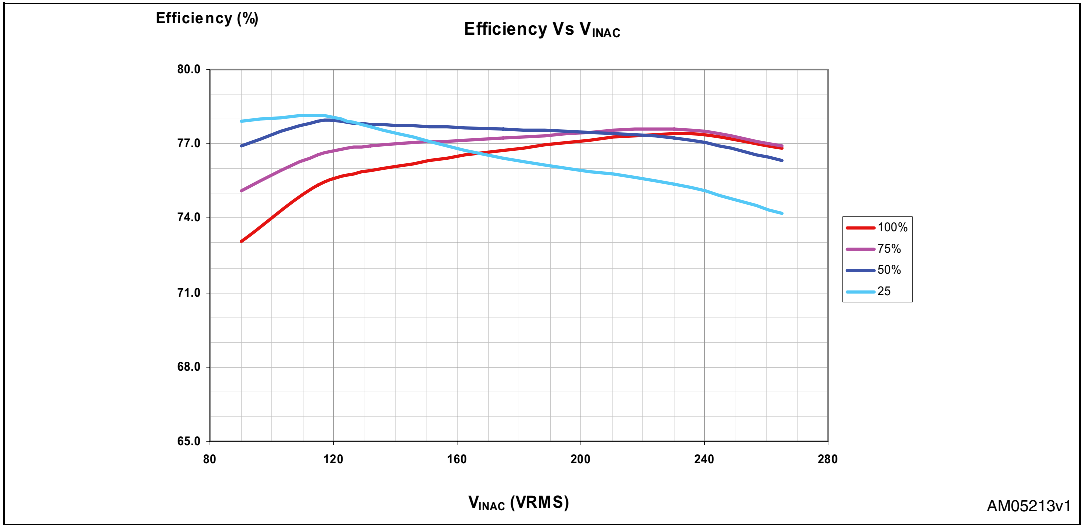
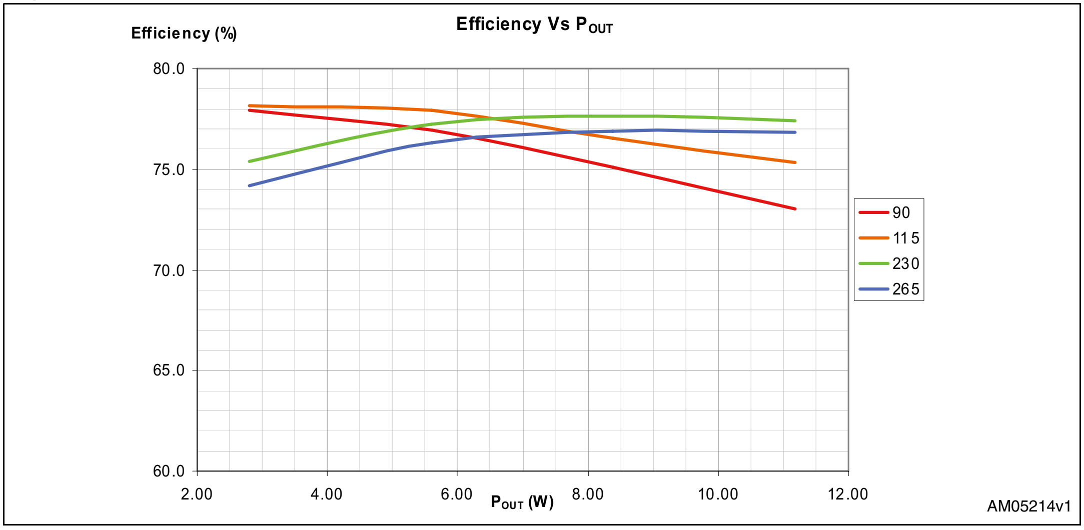


Figure 16. Efficiency vs load



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* shows the active mode efficiency calculated from the measured value of *Table 5*. The values in *Table 6* are plotted in *Figure 17*. In *Figure 18* the average value of the efficiency versus load is shown (the average was obtained considering efficiency at different input voltages).

Table 6. Active-mode efficiency

Active mode efficiency	
V_{INAC} (V_{RMS})	Efficiency (%)
90	75.8
115	77.0
230	76.9
265	76.1

Figure 17. Active mode efficiency vs V_{IN}

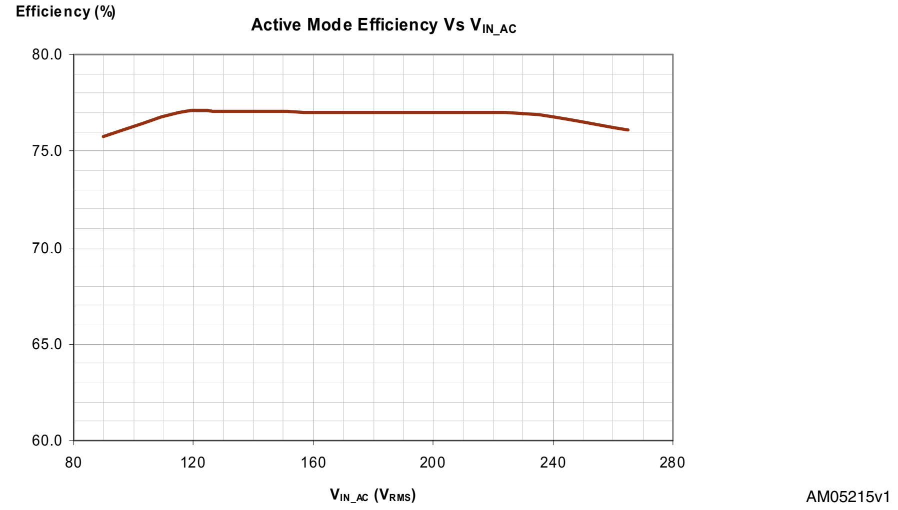


Figure 18. Input voltage average efficiency vs load

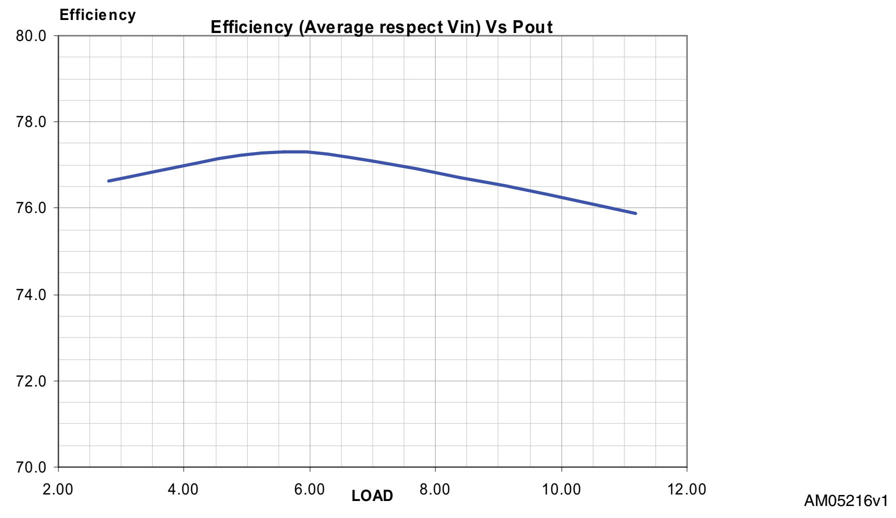


Table 7. Line voltage average efficiency vs load

Load (% of full load)	Efficiency (%)
100	75.7
75	76.5
50	77.1
25	76.4

In version 2.0 of the ENERGY STAR® program requirement for single voltage external AC/DC power supplies (see References 2), the power supplies are divided into two categories: low voltage power supplies and standard power supply, with respect to the nameplate output voltage and current. An external power supply, in order to be considered a low voltage power supply, must 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* show the EPA energy efficiency criteria for AC/DC power supplies in active mode for standard models and for low voltage models respectively.

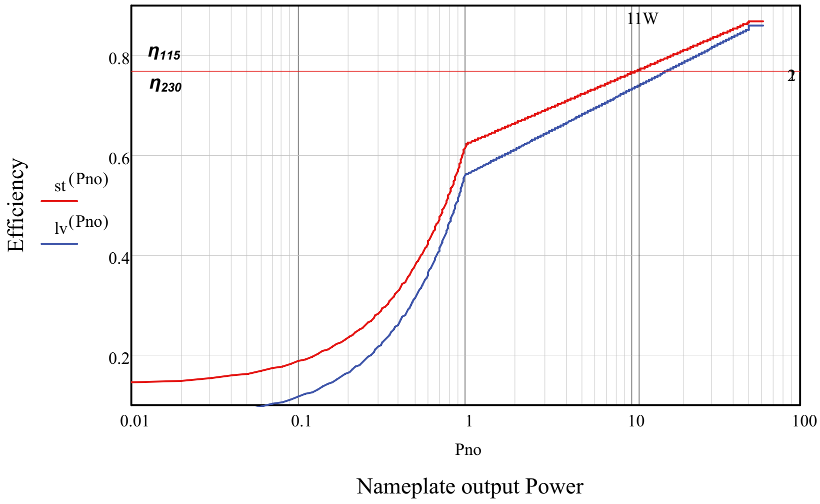
Table 8. Energy efficiency criteria for standard models

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



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The criteria are plotted in *Figure 19* above where the red line is the criteria for the standard model and the blue line is the criteria for the low voltage model. The PNO axe is in the logarithmic scale.

The presented power supply belongs to the low voltage power supply category and, in order to be compliant with ENERGY STAR requirements, must have an efficiency higher than 74.1 % when the converter input voltage is at the nominal value (115 V_{AC} or 230 V_{AC} in this case). For all the considered input voltages the efficiency (see *Table 6*) results are higher than the required value.

3.1 Light load performance

3.1.1 No-load condition

The input power of the converter was measured in no-load condition, with brown-out protection disabled (see relevant section) and brown-out protection enabled for different applied input voltages (see *Table 10*). The converter in no-load condition always works in burst mode so that the average switching frequency is strongly reduced. The average switching frequency values were also measured. The presence of the resistor dividers (R16, R17 and R18, see schematic of *Figure 2*) to sense the flyback input voltage, when brown-out protection is enabled, does not affect the average switching frequency, but obviously affects the input power due to the power dissipated in the resistor divider itself.

Table 10. No-load input power

Vin AC (V_{RMS})	Pin (mW) (BR enabled)	Pin (mW) (No BR)	f_{SW_AVG} (kHz)
90	19.20	16.80	1.0816
115	22.90	17.50	0.9706
132	25.00	18.60	0.9139
175	33.00	23.00	0.7552
230	48.00	29.00	0.6923
265	62.00	37.00	0.6561

In the ENERGY STAR program version, the power consumption of the power supply when it is no-loaded is also considered. The compliance criteria is shown in *Table 11*:

Table 11. Energy consumption criteria for no-load

Nameplate output power (P_{no})	Maximum power in no-load for AC/DC EPS
0 to = 50 W	< 0.3 W
> 50 watts < 250 W	< 0.5 W

The performance of the demonstration board is far better then required, but it is worth noting that often the AC/DC adapter or battery charger manufacturer have stricter requirements regarding no-load consumption, compared to ENERGY STAR requirements, due also to other standards or recommendations which they want to be compliant with. In cases where the converter is used as the standby power supply for LCD TVs, PDPs or other applications, the line filter is often the big line filter of the main power supply which heavily contributes to the standby consumption, even though the power needed to the auxiliary power supply is very low.

The ENERGY STAR program does not have other requirements regarding light-load performance, however the input power and efficiency of the demonstration board, also in other low load cases, is given in order to supply more complete information.

3.1.2 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 30 mW, 50 mW, 100 mW and 200 mW with brown-out protection enabled and with brown-out protection disabled

- P_{OUT} = 30 mW

Table 12. Low-load performance. P_{OUT} = 30 mW (brown-out disabled)

V_{IN_AC}	P_{OUT} (mW)	P_{IN} (mW)	Eff. (%)	P_{IN}-P_{OUT} (mW)	f_{SW_AVG} (kHz)
90	29.48	51.60	57.13	22.12	3.731
115	29.48	54.40	54.19	24.92	3.375
132	29.48	55.00	53.60	25.52	3.155
175	29.48	59.60	49.47	30.12	2.814
230	29.48	69.00	42.73	39.52	2.876
265	29.48	74.00	39.84	44.52	2.534

Table 13. Low-load performance. P_{OUT} = 30 mW (brown-out enabled)

V_{IN_AC}	P_{OUT} (mW)	P_{IN} (mW)	Eff. (%)	P_{IN}-P_{OUT} (mW)
90	29.48	54.80	53.80	25.32
115	29.48	57.90	50.92	28.42
132	29.48	62.30	47.32	32.82
175	29.48	69.80	42.24	40.32
230	29.48	87.00	33.89	57.52
265	29.48	101.00	29.19	71.52

- P_{OUT} = 50 mW

Table 14. Low-load performance. P_{OUT} = 50 mW (brown-out disabled)

V_{IN_AC}	P_{OUT} (mW)	P_{IN} (mW)	Eff. (%)	P_{IN}-P_{OUT} (mW)	f_{SW_AVG} (kHz)
90	54.39	85.90	63.32	31.51	6.248
115	54.39	87.40	62.23	33.01	5.663
132	54.39	88.20	61.66	33.81	5.314
175	54.39	94.80	57.37	40.41	5.259
230	54.39	104.00	52.30	49.61	4.845
265	54.39	111.00	49.00	56.61	4.299

Table 15. Low-load performance. P_{OUT} = 50 mW (brown-out enabled)

V_{IN_AC}	P_{OUT} (mW)	P_{IN} (mW)	Eff. (%)	P_{IN}-P_{OUT} (mW)
90	54.39	87.20	62.37	32.81
115	54.39	93.80	57.98	39.41
132	54.39	94.00	57.86	39.61
175	54.39	104.20	52.20	49.81
230	54.39	125.00	43.51	70.61
265	54.39	139.00	39.13	84.61

- P_{OUT} = 100 mW

Table 16. Low-load performance. P_{OUT} = 100 mW (brown-out disabled)

V_{IN_AC}	P_{OUT} (mW)	P_{IN} (mW)	Eff. (%)	P_{IN}-P_{OUT} (mW)	f_{SW_AVG} (kHz)
90	106	152	69.5	46	11.3
115	106	157	67.3	51	10.2
132	106	157	67.3	51	9.6
175	106	162	65.3	56	8.5
230	106	177	59.7	71	8.7
265	106	181	58.4	75	7.8

Table 17. Low-load performance. P_{OUT} = 100 mW (brown-out enabled)

V_{IN_AC}	P_{OUT} (mW)	P_{IN} (mW)	Eff. (%)	P_{IN}-P_{OUT} (mW)
90	106	155	68.2	49
115	106	159	66.5	53
132	106	166	63.7	60
175	106	174	60.8	68
230	106	195	54.2	89
265	106	206	51.3	100

- P_{OUT} = 200 mW

Table 18. Low-load performance. P_{OUT} = 200 mW (brown-out disabled)

V_{IN_AC}	P_{OUT} (mW)	P_{IN} (mW)	Eff. (%)	P_{IN}-P_{OUT} (mW)	f_{SW_AVG} (kHz)
90	208.403	286	72.87	77.597	21.3115
115	208.403	293	71.13	84.597	19.2462
132	208.403	294	70.89	85.597	18.1681
175	208.403	296	70.41	87.597	16.0584
230	208.403	313	66.58	104.597	16.4671
265	208.403	328	63.54	119.597	14.7167

Low-load performance. P_{OUT} = 200 mW (brown-out enabled)

V_{IN_AC}	P_{OUT} (mW)	P_{IN} (mW)	Eff. (%)	P_{IN}-P_{OUT} (mW)
90	208.403	289	72.11	80.60
115	208.403	296	70.41	87.60
132	208.403	299	69.70	90.60
175	208.403	313	66.58	104.60
230	208.403	336	62.02	127.60
265	208.403	349	59.71	140.60

Figure 20. Converter input power vs Vin_ac in light-load condition

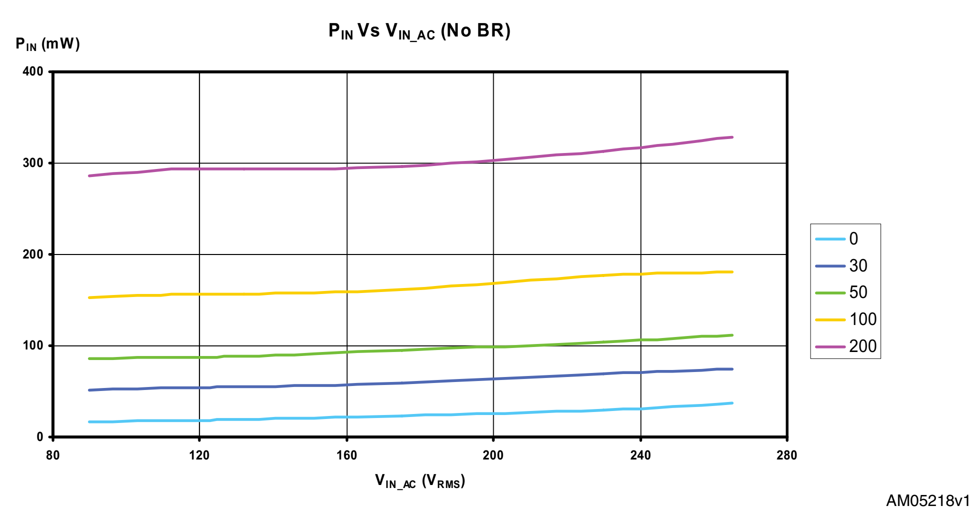
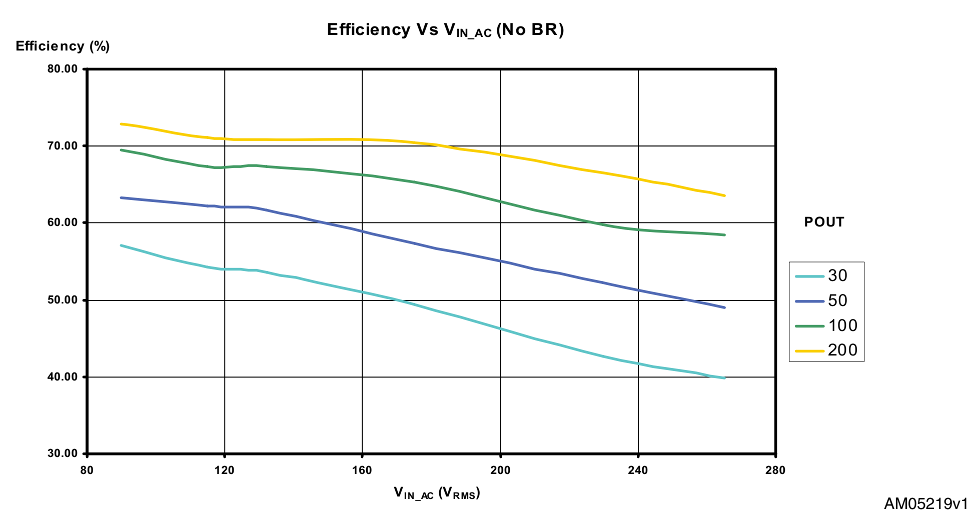


Figure 21. Converter efficiency vs Vin_ac in light-load condition



Depending on the equipment supplied, it’s possible to have several criteria to measure the standby or light-load performance of a converter. One of these is the measurement of the output power when the input power is equal to 1 watt. In *Table 19* and *20*, the output power needed to have 1 W of input power in different line conditions is shown, with BR disabled and with BR enabled respectively. *Figure 22* shows the diagram of the efficiency (proportional to the output power) versus the input voltage when the input power is 1 W.

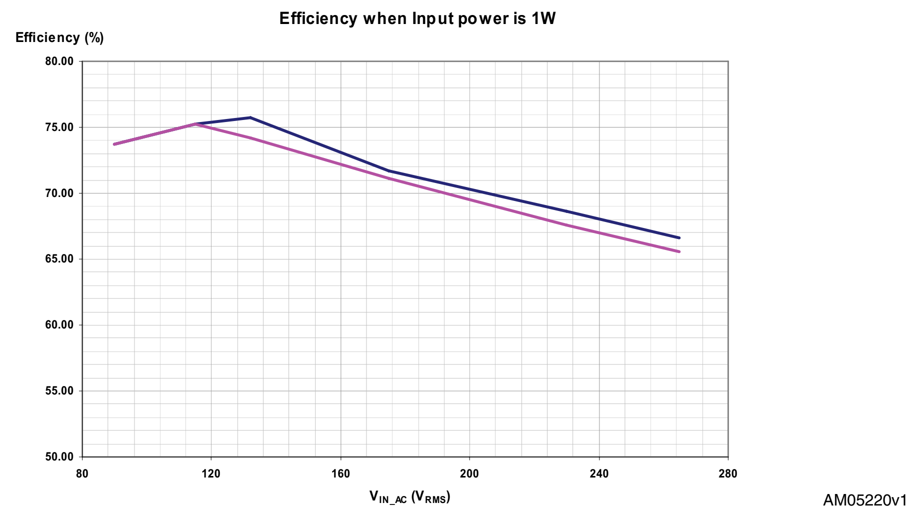
Table 19. Output power when the input power is 1 W (BR disabled)

V_{IN} (V_{RMS})	P_{IN} (mW)	P_{OUT} (mW)	Efficiency (%)	Pin-Pout (mW)
90	1000	737	73.70	263
115	1000	752	75.23	248
132	1000	757	74.74	243
175	1000	717	71.67	283
230	1000	686	68.62	314
265	1000	666	66.59	334

Table 20. Output power 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	737	73.70	263
115	1000	752	75.23	248
132	1000	742	74.21	258
175	1000	712	71.16	288
230	1000	676	67.60	324
265	1000	656	65.57	344

Figure 22. Efficiency vs AC input voltage when the input power is 1 W



3.2 Test equipment and measurement of efficiency and input power

The converter input power was measured using a wattmeter. The wattmeter contemporaneously measures converted input current (using its internal ammeter) and voltage (using its internal voltmeter). The wattmeter is a digital instrument, therefore, it samples the current and voltage and converts them into digital form. The digital samples are then multiplied giving the instantaneous measured power. The sampling frequency is 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. A voltmeter was used in order to measure the output voltage of the power converter.

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

3.2.1 Measuring input power notes

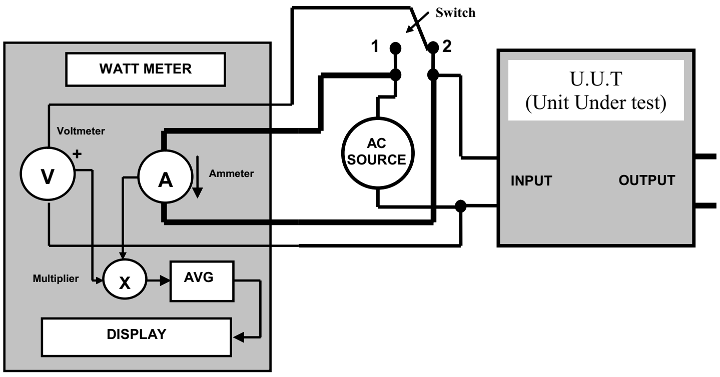
With reference to *Figure 23*, the UUT input current causes a voltage drop across the ammeter internal shunt resistance (the ammeter is not ideal so it has an internal resistance higher than zero) and across the cables that connect the wattmeter to the UUT.

If the switch of *Figure 23* is in position 1 (see also the simplified scheme of *Figure 24*) this voltage drop causes an input measured voltage higher than the input voltage at the UUT input which, 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 UUT in low-load condition). In the case of high UUT input current the voltage drop can be relevant (compared to the UUT real input voltage) and therefore, if this is the case, the switch in *Figure 23* can be changed to position 2 (see simplified scheme of *Figure 25*) 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 (which is not ideal and which doesn't have infinite input resistance). If the switch in *Figure 23* is in position 2 (see simplified scheme of *Figure 25*) the voltmeter leakage current is measured by the ammeter, together with the UUT input current, causing a measurement error. The error is negligible in a case where the UUT input current is much higher than the voltmeter leakage. If the UUT input current is low, and not much higher than the voltmeter leakage current, it is probably better to set the switch (in *Figure 23*) to position 1.

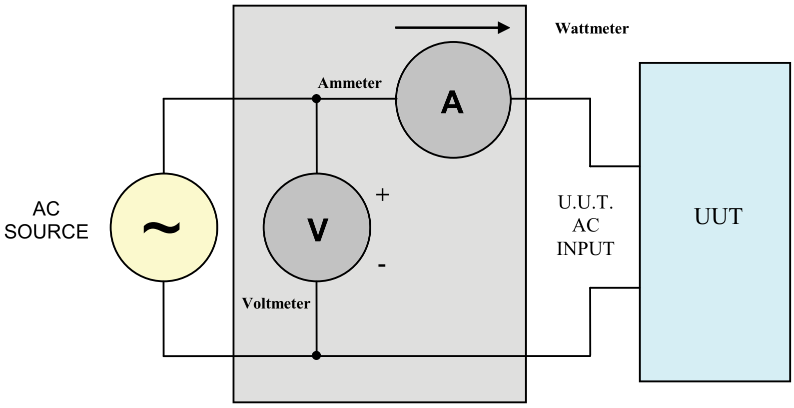
In a case where it is not certain which measurement scheme least affects the results, it is possible to try with both and register the input power lower value.

Figure 23. Wattmeter possible connections with the U.U.T. (unit under test)



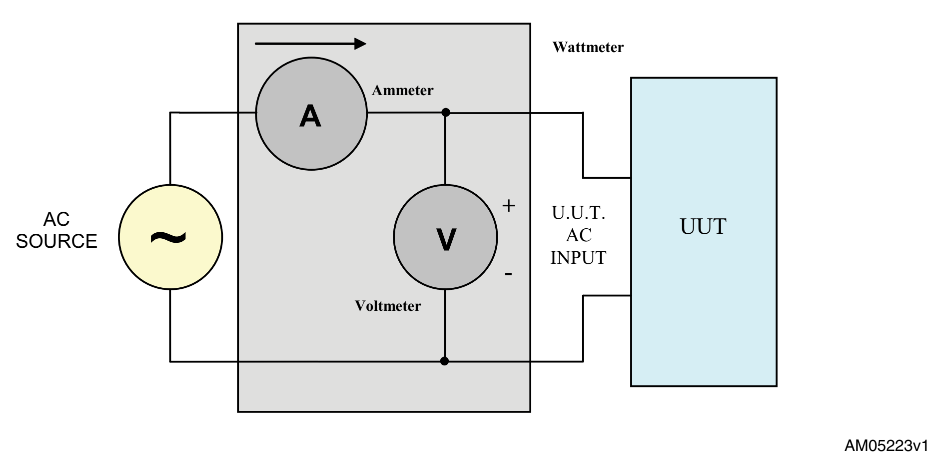
AM05221v1

Figure 24. Wattmeter connection scheme for low input current



AM05222v1

Figure 25. Wattmeter connection scheme for high input current



As noted in IEC 62301, instantaneous measurements are appropriate when power readings are stable. The UUT is to be operated at 100% of the nameplate output current 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 the 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.

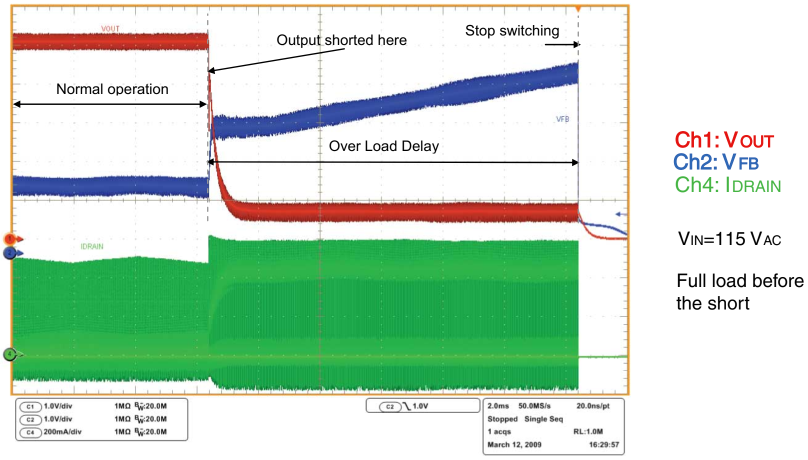
Some wattmeter models allow the integration of the measured input power in a time range, and then measures the energy absorbed by the UUT during the integration time. Dividing this by the integration time itself gives the average input power.

3.3 Overload protection

VIPer27 is protected against 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 PWM current set point is increased, leading to higher power delivered to the output until this power equals the load power demands. If the load power demand exceeds the converter power capability (fixed by the R_{LIM} value) the voltage on the feedback pin continuously rises, but the power delivered does not rise further. When the feedback pin voltage exceeds V_{FB_lin} (3.3 V typ), VIPer27 logic assumes it is a warning for an overload event. Before shutting-down the system, the device waits for a period, fixed by the capacitor present on the feedback pin. In fact, if the voltage on the feedback pin exceeds V_{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 V_{FB_olp} threshold (4.8 V typ.), VIPer27 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 waveforms show the behavior of the converter when the output is shorted.

Figure 26. Output short-circuit

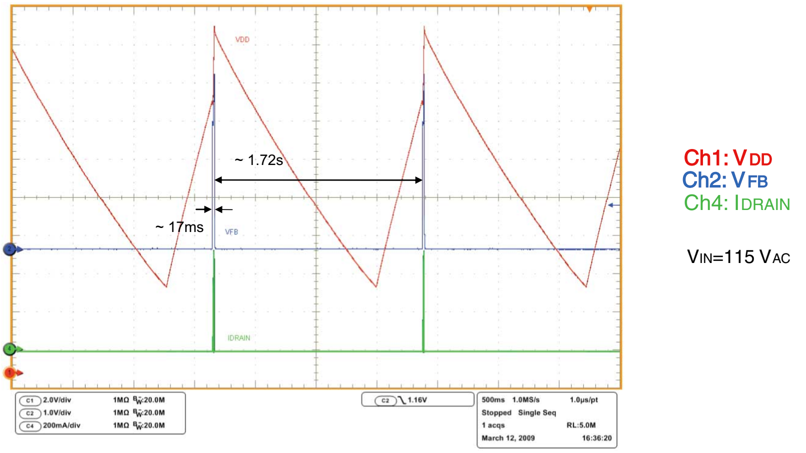


AM05224v1

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.

The duty cycle of power delivery is very low (around 1 %), therefore, the average power throughput is then very low (see *Figure 27*).

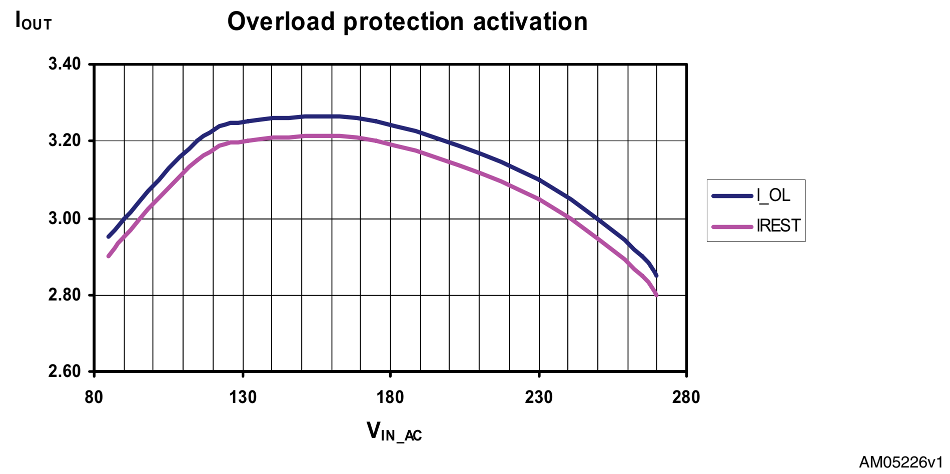
Figure 27. Operation with output shorted



AM05225v1

The power capability of the converter was also tested, verifying the minimum value of the output current needed to activate the overload protection (IOL) and the maximum value of the output current that allows the system to restart (I_REST). Results are given in *Figure 28*.

Figure 28. Converter power capability

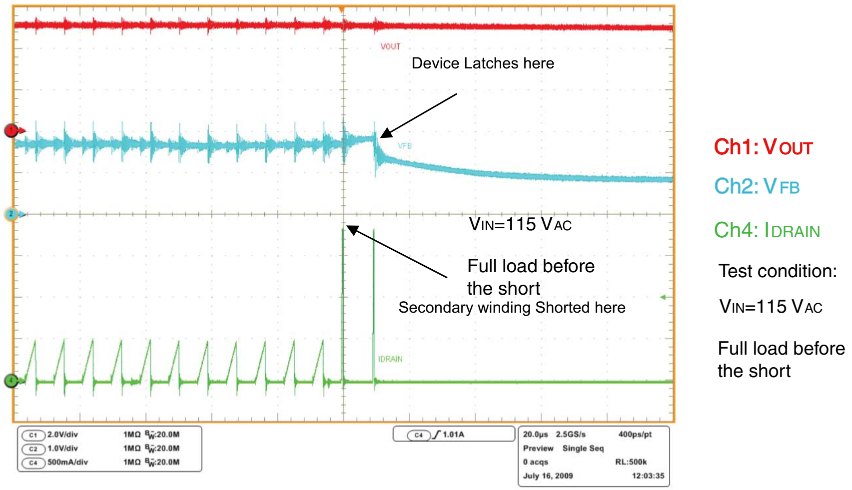


3.4 Secondary winding short-circuit protection

VIPer27 is provided with an adjustable first level of primary overcurrent limitation that switches off the power MOSFET if this level is exceeded. This limitation acts cycle by cycle and its main purpose is to limit the maximum deliverable output power. A second level of primary overcurrent protection is also present but in this case it is not adjustable, it is fixed to 1 A (typical value). If the drain current exceeds this second overcurrent protection threshold, the device enters a warning state. In the next cycle the MOSFET is switched on, and if the second level of overcurrent protection is exceeded again, the device assumes that a secondary winding short-circuit or a hard saturation of the transformer is happening and stops the operation. In order to re-enable the operation, V_{DD} voltage must be recycled, that means: V_{DD} must go down, up to $V_{DD\_RESTART}$, then rise up to V_{DD_ON}. When the VIPer27 is switched on again (V_{DD} equals V_{DD_ON}), the MOSFET can start to switch again. If the cause of the second overcurrent protection activation is not removed, the device goes into auto-restart mode.

This protection was tested on the demonstration board. The secondary winding of the transformer was shorted, in different operating conditions. *Figure 29* and *30* show the behavior of the system during these tests.

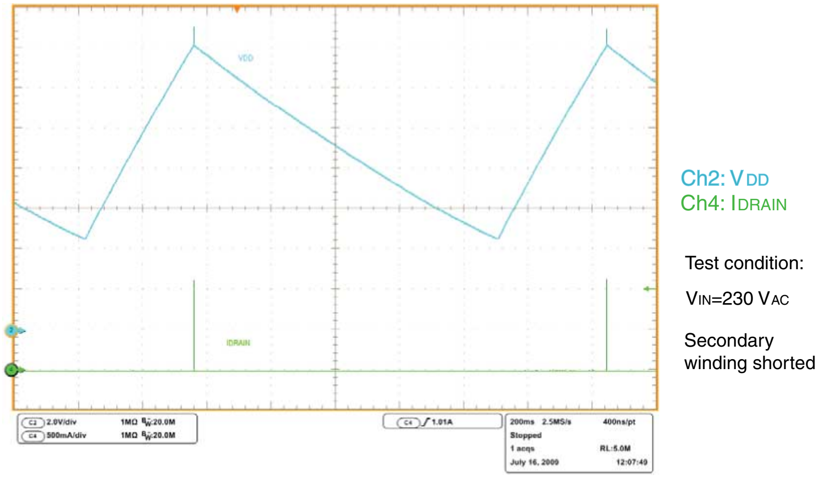
Figure 29. Second overcurrent protection - protection tripping



AM05227v1

In *Figure 29*, when the board is working in full-load condition with an input voltage of 115 V_{AC}, the secondary winding is shorted. If the converter runs with the secondary winding shorted, there is a very high current flowing through the transformer windings, the secondary diode, and the VIPer power section. The second over-current protection, which stops the converter operation after two switching cycles, prevents the flow of these high currents. *Figure 30* shows the situation when a permanent short-circuit is applied on the secondary winding. Most of the time the power section of the VIPer is off, eliminating any risk of overheating.

Figure 30. Operating with the secondary winding shorted. Restart mode

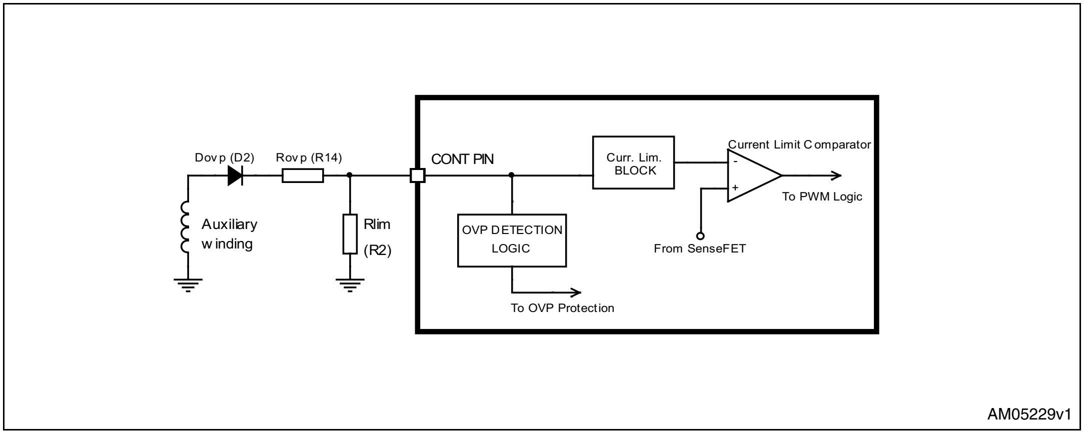


AM05228v1

3.5 Output overvoltage protection

Output overvoltage protection is implemented, monitoring the voltage across the auxiliary winding during the MOSFET off time, through the D2 diode and the R3 and R14 resistor dividers (see schematic of *Figure 31*) connected to the CONT pin of the VIPer27. If the voltage on the CONT pin exceeds the V_{OVP} thresholds (3 V typ.), VIPer assumes an overvoltage event and the power section is no longer allowed to be switched-on. To re-enable 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 CONT pin must sense a voltage higher than V_{OVP} for four consecutive cycles before it stops operation (see device datasheet for details).

Figure 31. OVP circuit



The value of the output voltage when the protection must be tripped can be properly fixed by selecting the R3 and R14 resistor dividers. When R3 is selected, considering the maximum power that the converter must manage, R14 output must be selected, according to the formula:

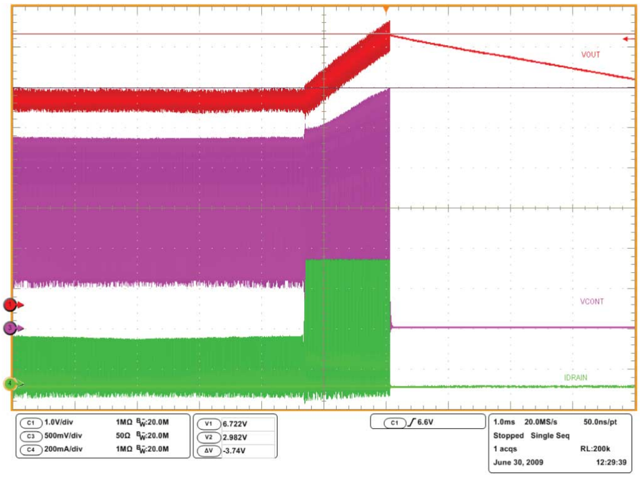
Equation 1

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

The protection was tested by shorting the voltage reference pin of the TS431 device (pin 3 of VR1 in the schematic) with pin 2 of the same device during converter operation. In this way the converter operates in open loop and delivers the maximum power possible to output. The excess of power, in respect to the maximum 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 5.58 V the converter stops switching. In the same figure the CONT pin voltage (Ch3, fuchsia waveform) and the drain current (Ch4 green waveform) are shown (see *Figure 32* and *33*). The crest value of the CONT pin voltage tracks the output voltage.

Figure 32. OVP protection



Ch1: I_{DRAIN}
Ch3: V_{DD}
Ch4: I_{DRAIN}

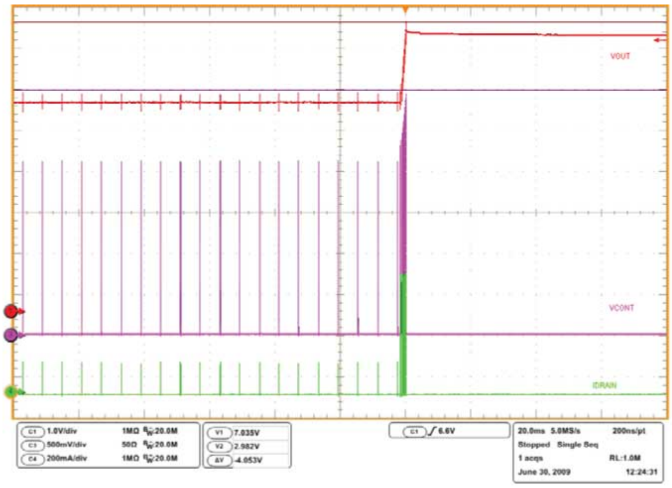
Working condition:

Input voltage:
115 VAC
1.1 A of load

Shorting TL431
reference to signal GND

AM05230v1

Figure 33. OVP protection



Ch1: I_{DRAIN}
Ch3: V_{DD}
Ch4: I_{DRAIN}

Working condition:

Input voltage:
115 VAC
No load

Shorting TL431
reference to signal GND

AM05231v1

The test was performed in different line and load conditions to check the dependence of the output voltage value, when protection is activated, from the converter input voltage and load.

Results are shown in *Table 21*.

Table 21. Overvoltage protection activation level test results

V_{OUT_OVP} (V)				
V_{IN} (V_{RMS})	Load			
	No-load	25% of load	Half-load (1.1 A)	Full-load
90	7.019	6.754	6.749	6.731
115	7.022	6.722	6.754	6.740

Table 21. Overvoltage protection activation level test results (continued)

V_{IN} (V_{RMS})	V_{OUT_OVP} (V) Load			
	No-load	25% of load	Half-load (1.1 A)	Full-load
230	7.029	6.735	6.760	6.752
265	7.035	6.786	6.765	6.762

Except for the no-load condition, the variation with load and line is very low ([6.731 V; 6.786 V], ΔV_{OUT_OVP} = 55 mV less then 1% of variation); including the values in the no-load condition ([6.731 V; 7.035 V], ΔV_{OUT_OVP} = 304 mV less then 5% of variation).

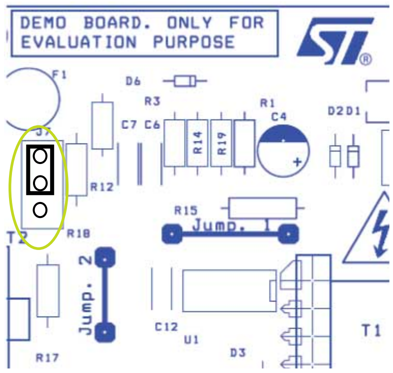
Considering a 10% precision of the OVP threshold in the CONT pin ([2.7 V; 3.3 V]), using as ROVP and R_{LIM} 1% precision resistances and with a turn ratio between the secondary and auxiliary windings which has a precision of 5%, and considering a large production, it is possible to fix the output overvoltage at 25% over the nominal output voltage, making sure that the OVP protection is not erroneously activated.

It is possible to not implement this protection, if it is not necessary, by not mounting the D2 diode and the R14 resistor. Therefore if OVP protection is not required, the total number of components can be reduced.

3.6 Brown-out protection

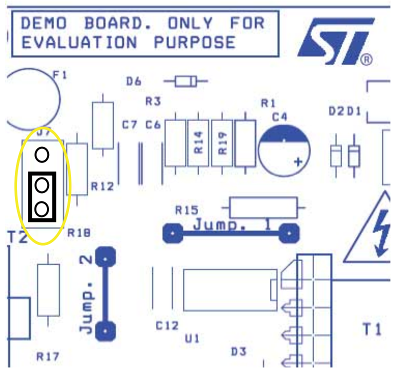
Brown-out protection is basically an unlatched device shutdown function with a typical use of sensing mains undervoltage or the main unplug. The VIPer27 has a dedicated pin (BR, pin 5) for this function, which must be connected to the DC HV bus. If protection is not required, it can be disabled by connecting the pin to ground. In the converter presented here, brown-out protection is implemented but can be disabled by changing the J7 jumper setting (see schematic in *Figure 2*). The settings of the J7 jumper 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, VBRth), which 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 that ensures noise immunity. The brown-out comparator is also provided with current hysteresis. An internal 10 µA current generator is ON as long as the voltage applied at the brown-out pin is below 450 mV and OFF if the voltage exceeds 450 mV plus the voltage hysteresis.

Figure 34. J7 jumper setting. Brown-out disabled



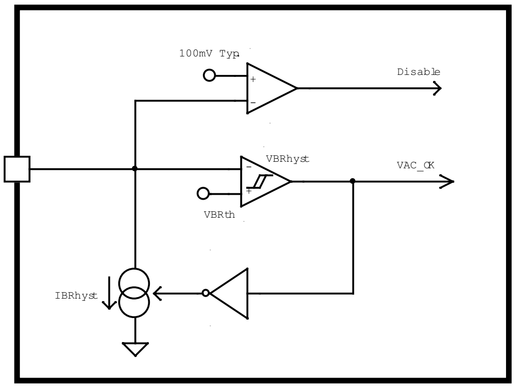
AM05232v1

Figure 35. J7 jumper setting. Brown-out enabled



AM05233v1

Figure 36. Brown-out protection, internal block diagram



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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 external divider resistors. The following relationships can be established for the ON (V_{IN_ON}) and OFF (V_{IN_OFF}) thresholds of the input voltage:

Equation 2

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

Equation 3

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

Where I_{BRhyst}=10 µA (typ.) is the current hysteresis, V_{BRhyst}=50 mV (typ.) is the voltage hysteresis and V_{BRth}=450 mV (typ.) is the brown-out comparator internal reference.

One purpose of this protection is to stop operation of the converter when the line voltage is too low, avoiding too high root mean square current value flowing inside the main switch an then its 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 mains. A typical situation, in most cases for converters designed for the European range (230 V_{AC}), could 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 full power), but the voltage on the Bulk capacitor is higher than $V_{DRAIN\ RESTART}$, so the device starts again and the output voltage rises again. This situation could be dangerous for some loads, and in many applications is best avoided.

Figures *37* and *38* show how brown-out 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 75 V_{AC} with full-load applied. The system stops switching and the output load, no longer supplied, decays monotonically to zero. *Figure 38* shows the system behavior when the input voltage changes from 75 V_{AC} to 90 V_{AC}.

Figure 37. Input AC voltage steps from 90 V_{AC} to 65 V_{AC}

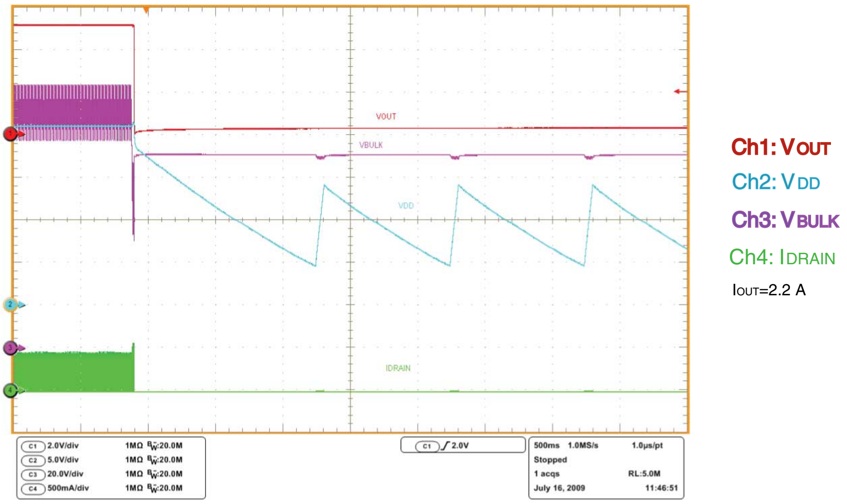

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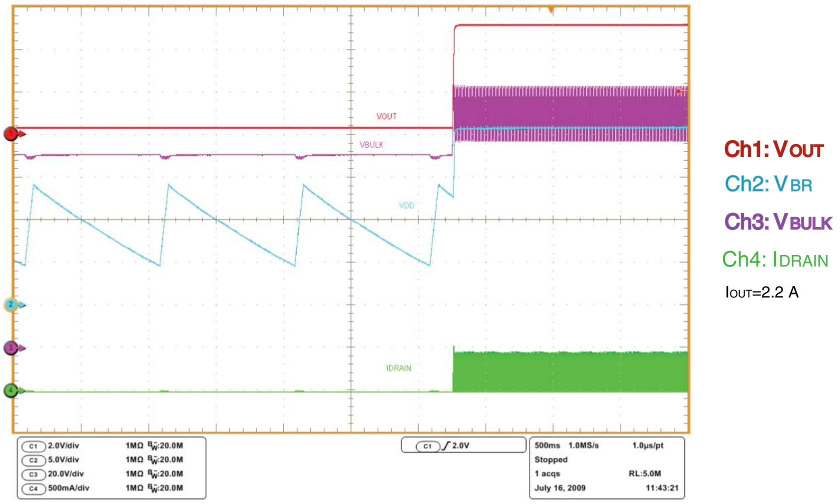
Figure 38. Input voltage steps from 90 V_{AC} to 0 V_{AC}



AM05236v1

4 Conclusions

The flyback converter is suitable for different applications and can be used as an external adapter or as an auxiliary power supply in consumer equipment. Special focus was put on low-load performance and the bench results are good with a very low input power in light-load conditions. The efficiency performance was compared with the requirements of the ENERGY STAR program for external AC/DC adapters with very good results, as the measured active mode efficiency is always higher with respect to the minimum required.

5 References

1. ENERGY STAR® Program requirements for single voltage external AC/DC adapter (Version 2.0)
2. VIPER27 datasheets

6 Revision history

Table 22. Document revision history

Date	Revision	Changes
13-Jan-2011	1	Initial release.

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