AN5335
Application note

35W transition-mode flyback converter with ultra-low THD based on HVLED007

Introduction

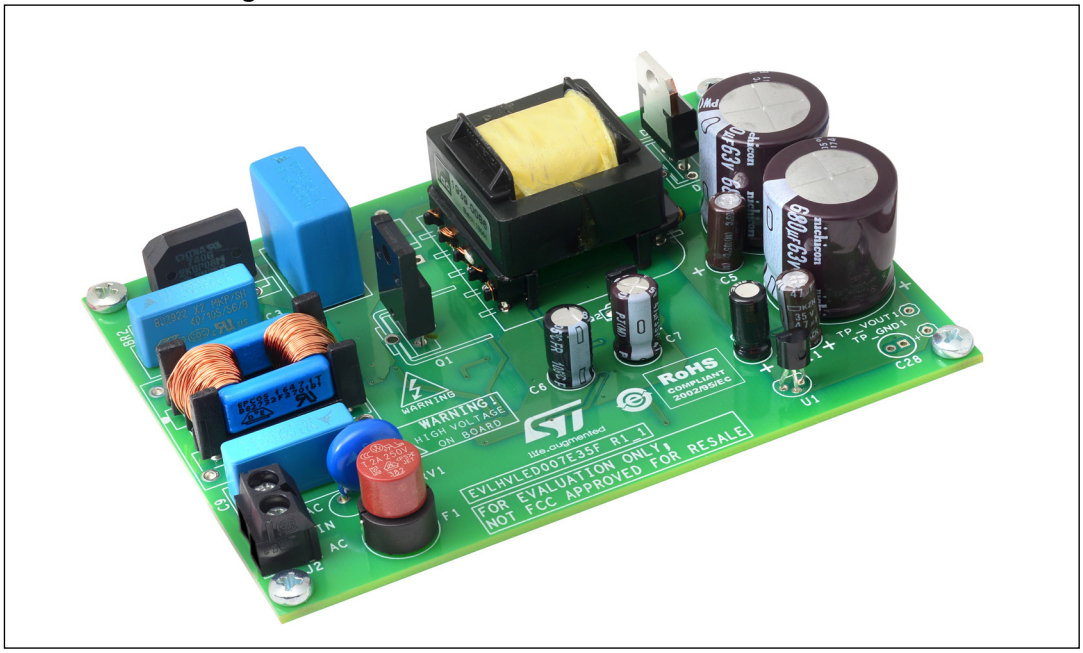
This application note describes the EVLHVLED007W35F demonstration board, based on the transition mode PFC controller dedicated to flyback topology, the HVLED007, and presents the main results of its bench evaluation.

The EVLHVLED007W35F supplies a stable and isolated 48 V voltage bus suitable for secondary side circuitry (e.g., LED current generators) for a total output power of 35 W when a wide range of input voltages is applied at its input. An auxiliary 12 V output is also present to supply small circuits which absorb a maximum current of 15 mA.

Thanks to an STMicroelectronics patented control embedded on the HVLED007, the main feature of this design is the very low input current distortion (THD) in a flyback converter operating in Transition mode (Quasi-Resonant).

Fast startup and protections with auto-restart are available for safe operation in lighting environments.

Figure 1. EVLHVLED007W35F demonstration board



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1 Main characteristics and circuit description

The main characteristics of the demonstration board are listed below:

- Input voltage: 90 Vac-265 Vac
- Maximum output power: 35 W
- Output Constant Voltage (CV): 48 V
- Output current range: 0 - 730 mA
- Input current distortion (THD): <5% at full-load; <20% at 30% full-load
- Power Factor (PF): >0.98 at full-load
- Converter efficiency: up to 90%
- Mains harmonics: meets EN61000-3-2 and JEITA-MITI Class-C
- EMI: according to EN55022 Class-B
- PCB: double-sided, 70 µm, CEM-1, 105 x 75 mm

The HVLED007 is a current-mode PFC controller specific to isolated High Power Factor, flyback converters operated in Transition Mode (aka Quasi-Resonant operation).

The main feature of the HVLED007 is a special circuit (Input Current Shaper [*1*]), that enables High-PF, Quasi-Resonant flyback converters to draw a theoretically sinusoidal input current from the power line [*2*], unlike the traditional control [*3*].

In practice, with little effort it is possible to achieve a total distortion of the input current (THD) lower than 10% at full-load and lower than 20% at 30% load over the entire input voltage range.

The IC is provided with a control input (COMP pin - #2) intended to be driven by the phototransistor of an optocoupler (ISO1) to close a secondary-regulated isolated control loop. The secondary control loop circuitry is mainly composed by the output voltage resistor divider (R41, R42, R43 and R47) and by the TL431 reference (U3) in a standard configuration. The compensation network, to define system bandwidth and stability, is comped by C10, R36 and C26 components.

To speed up the converter response in case of output overvoltage, a Zener diode (DZ6) is connected between output voltage and reference voltage feedback (REF pin - U3).

To achieve a fast startup, typically required in lighting applications, a high-voltage start-up circuitry (which is mainly composed by the high-voltage Mosfet Q2), charges the VCC pin voltage. Once the VCC pin voltage reaches the IC turn-on threshold (12.5 V typ.), the HVLED007 starts the operations. The high-voltage start-up circuitry is then turned off, to limit the power dissipation, once the output voltage reaches around 75% of the target.

To meet the EMC standards, the board is equipped with an input EMI filter (C9, T2BIS1, C3) cutting the switching noise coming from the flyback stage.

Figure 2. EVLHVLED007W35F demonstration board schematic

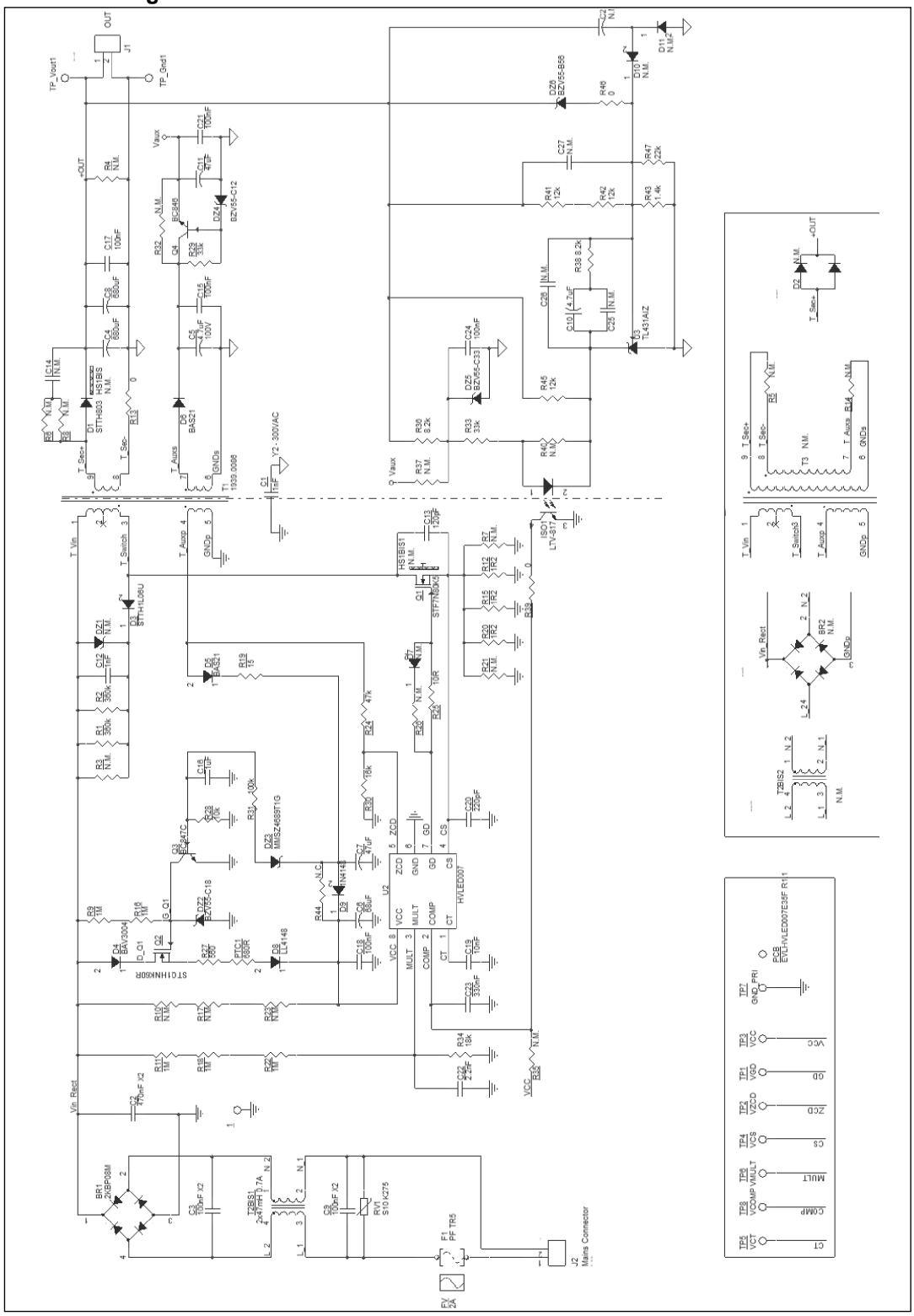
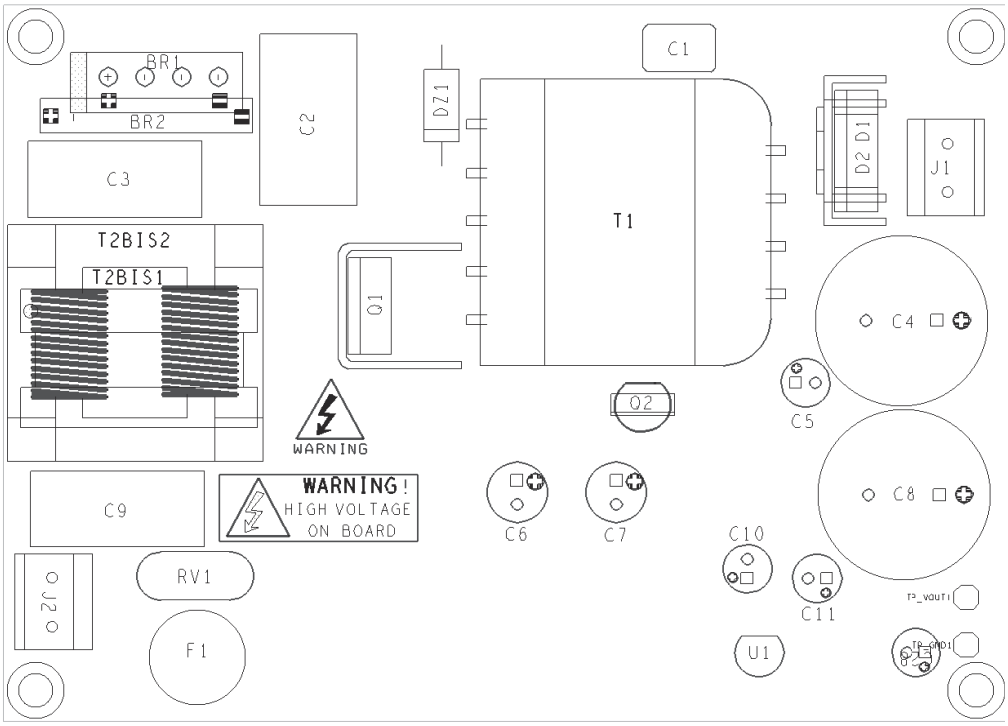


Figure 3. EVLHVLED007W35F PCB component placement

TOP-SIDE



BOTTOM-SIDE

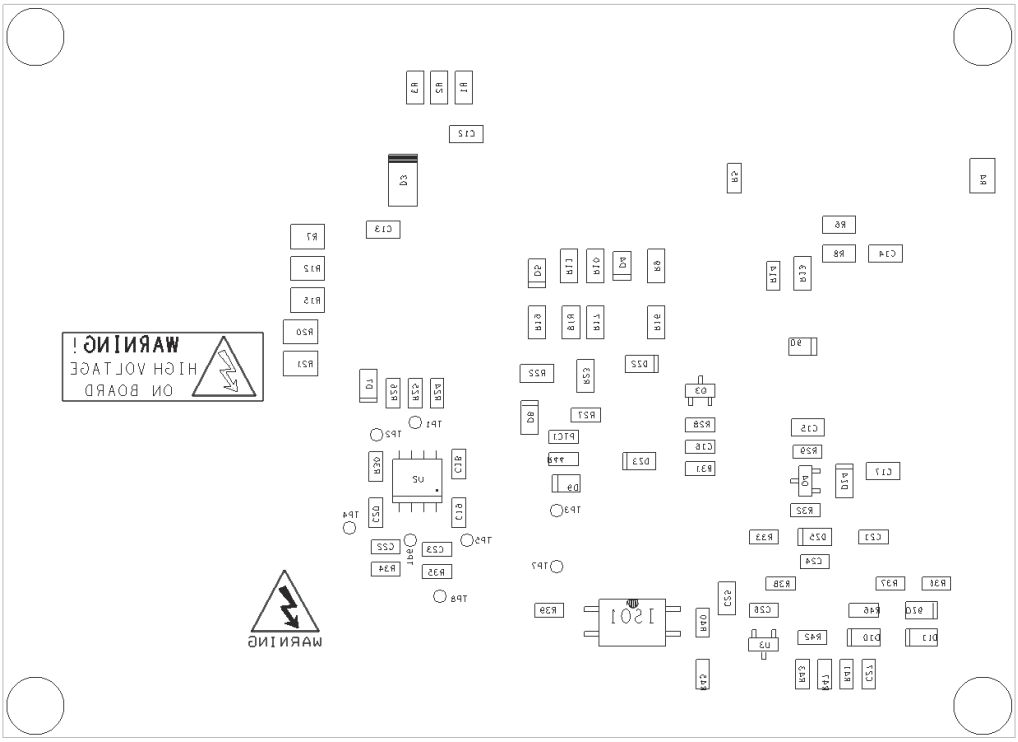
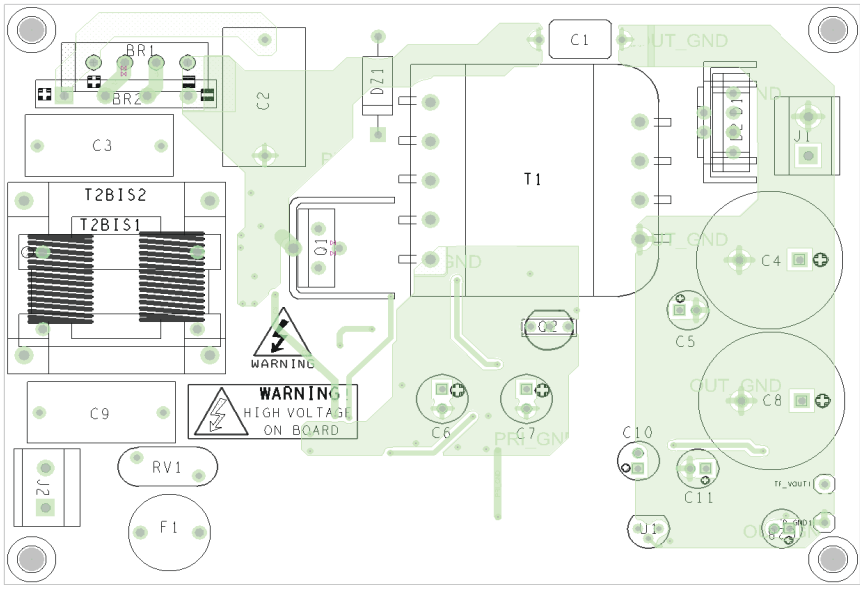
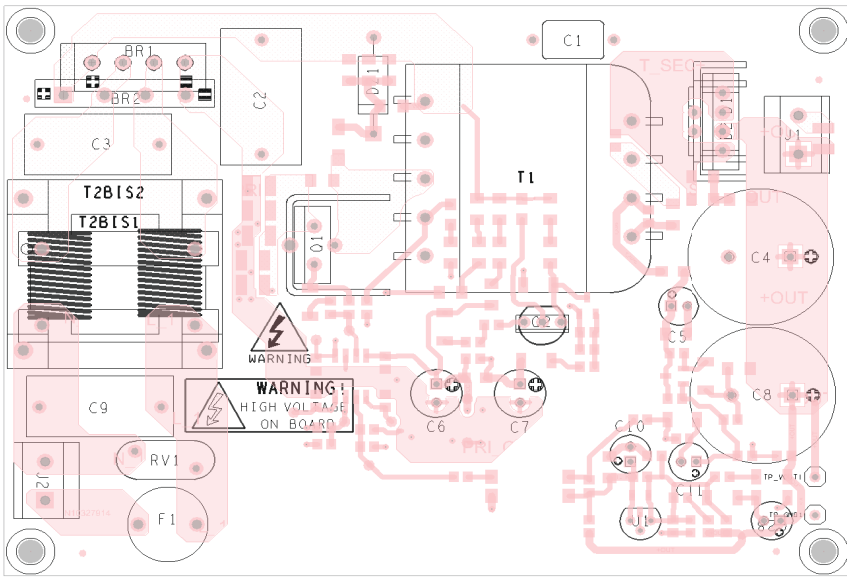


Figure 4. EVLHVLED007W35F PCB layout

TOP-SIDE



BOTTOM-SIDE

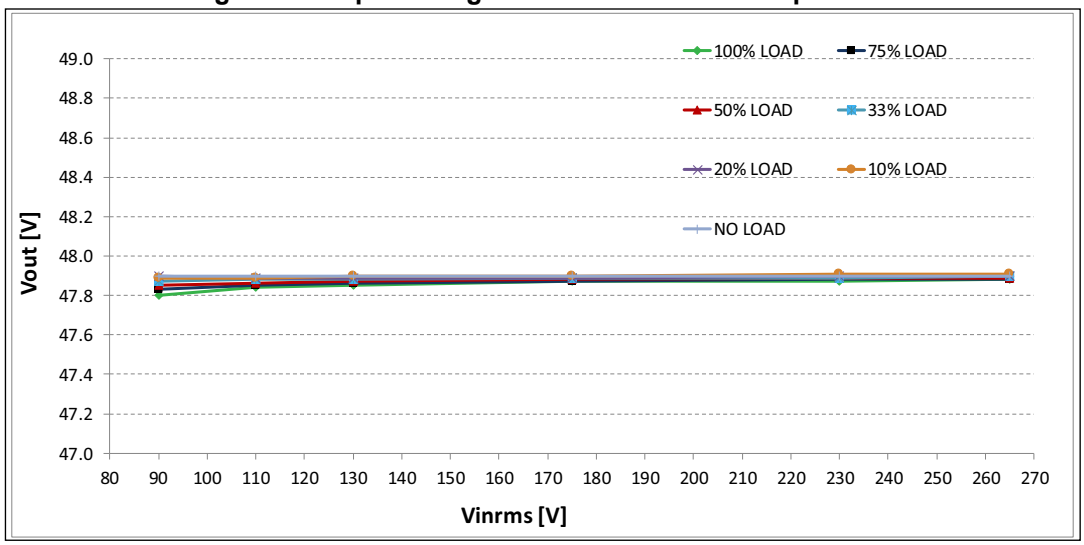


2 Test results and main waveforms

2.1 Line and load regulation

Figure 5 shows the measured average output voltage versus the input voltage at different load conditions. The results show that the output voltage is well regulated regardless of the input and output load conditions.

Figure 5. Output voltage versus AC line and output load



2.2 Power Factor and Total Harmonic Distortion

In *Figure 6* and *Figure 7* the Total Harmonic Distortion of the input current (THD) and the Power Factor (PF) is reported, respectively, versus the input voltage at different load conditions.

The results show that the HVLED007 is able to achieve THD lower than 5% at full-load and lower than 20% at around 30% of the maximum load.

Figure 6. Total Harmonic Distortion (THD) versus load

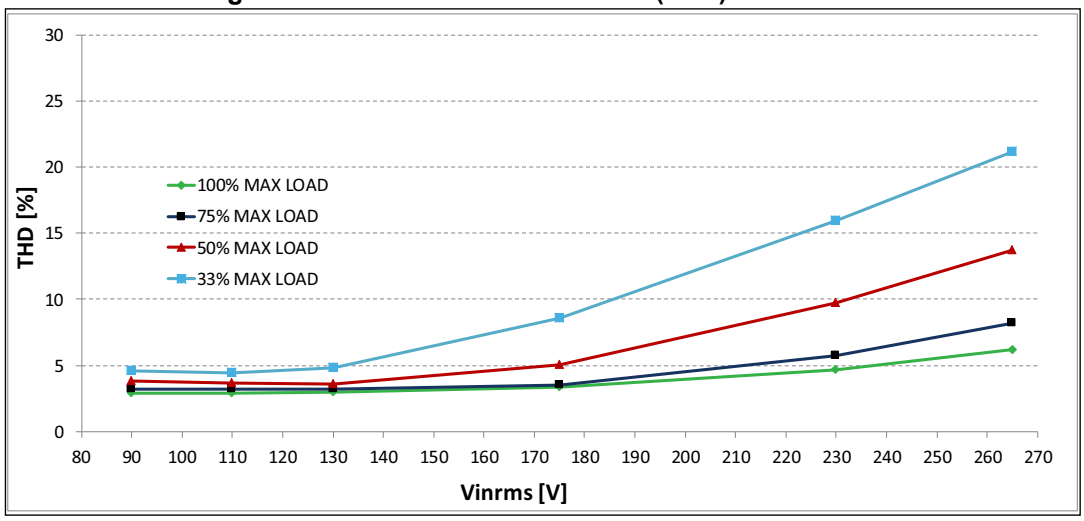
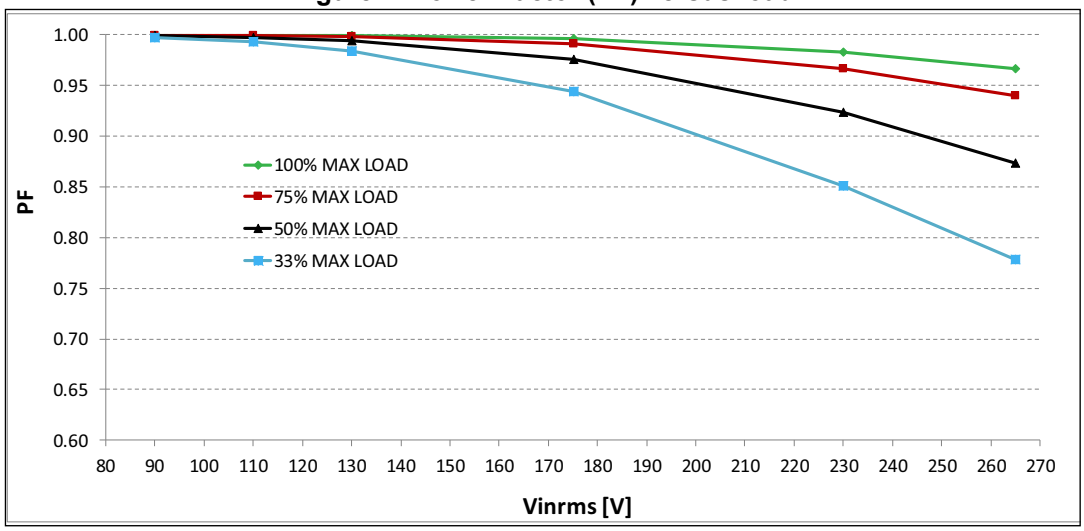


Figure 7. Power Factor (PF) versus load



2.3 Converter efficiency and no-load power consumption

Figure 8 shows the efficiency of the converter at the nominal input voltages mains. At full-load, the converter's efficiency reaches around 90%.

Figure 8. Converter efficiency

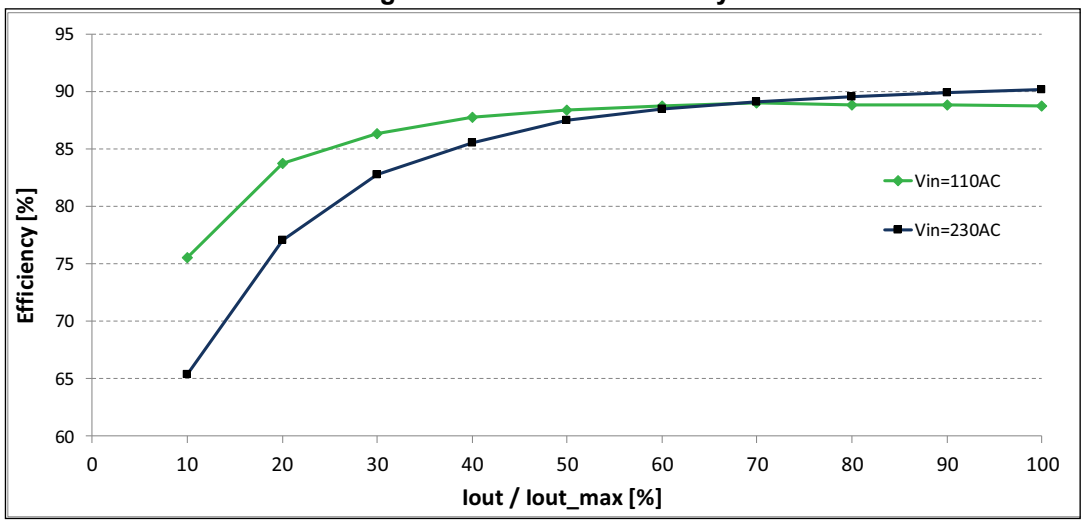
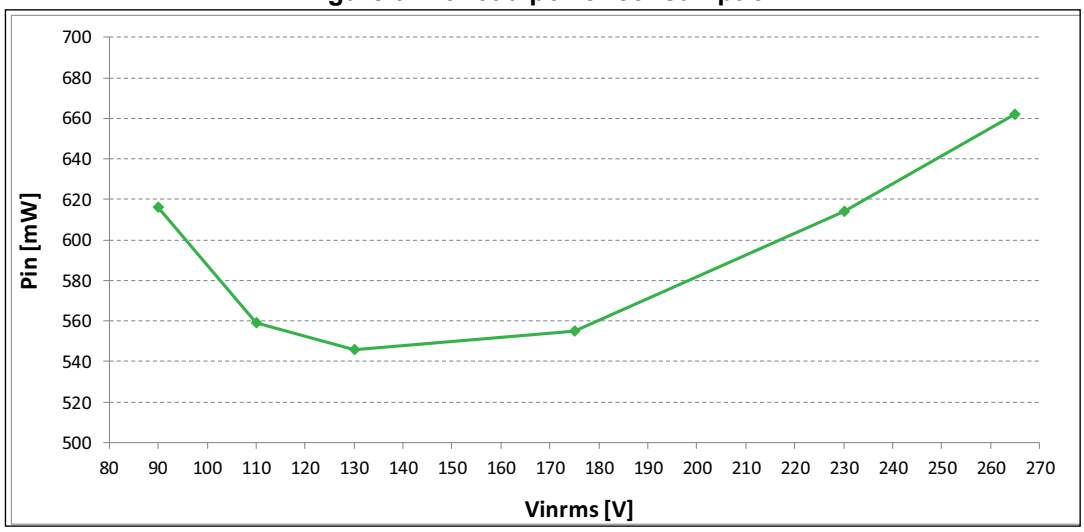


Figure 9 below shows the power consumption of the converter in no-load condition, versus the input voltage.

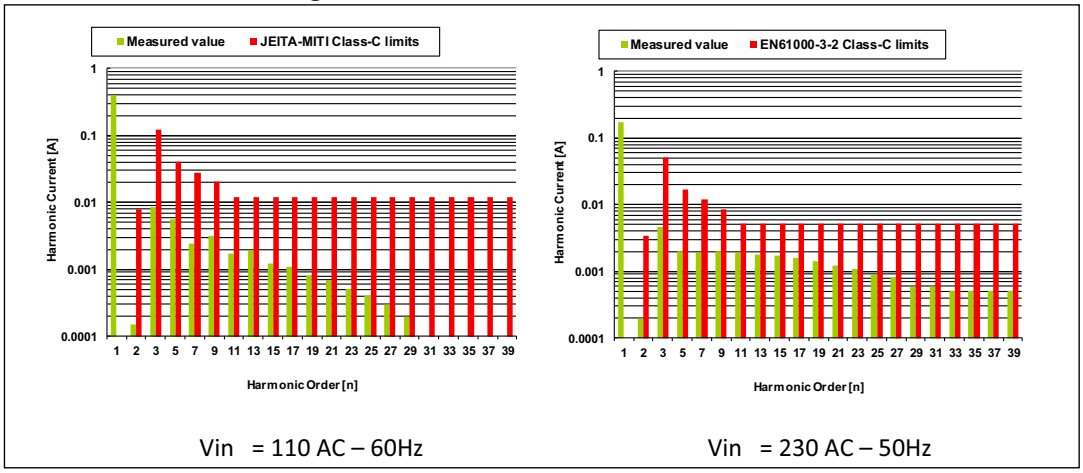
Figure 9. No-load power consumption



2.4 Harmonics content

The demonstration board meets the European norm EN61000-3-2 Class-C and Japanese norm JEITA_MITI Class-C both relevant to lighting equipment, at full-load and nominal input voltage mains. The measurements are shown in *Figure 10*.

Figure 10. Harmonics content at full-load



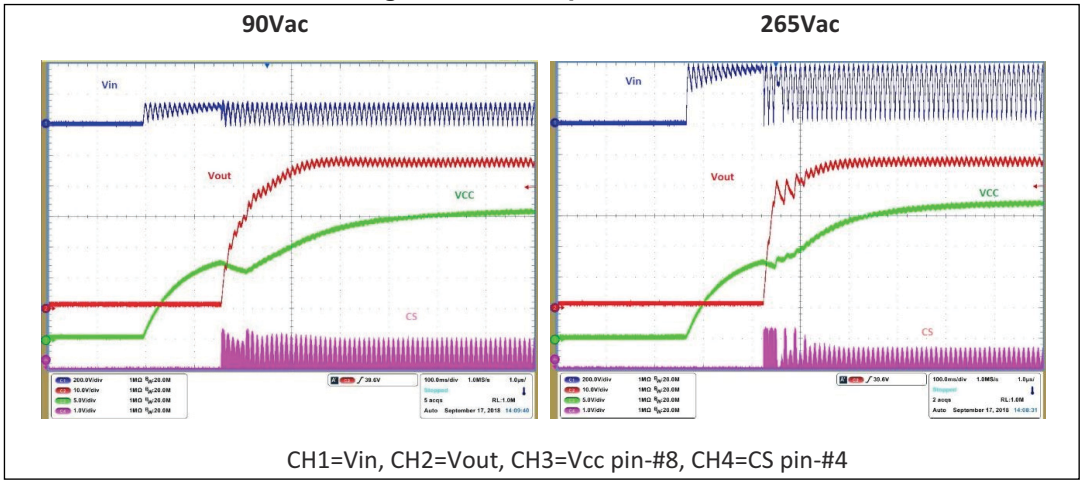
Vin = 110 AC – 60Hz

Vin = 230 AC – 50Hz

2.5 Startup

Figure 11 and *Figure 12* show the main voltage waveforms during the system startup when the mains is plugged, for different load conditions.

Figure 11. Startup at full-load



CH1=Vin, CH2=Vout, CH3=Vcc pin-#8, CH4=CS pin-#4

Figure 12. Startup at no-load

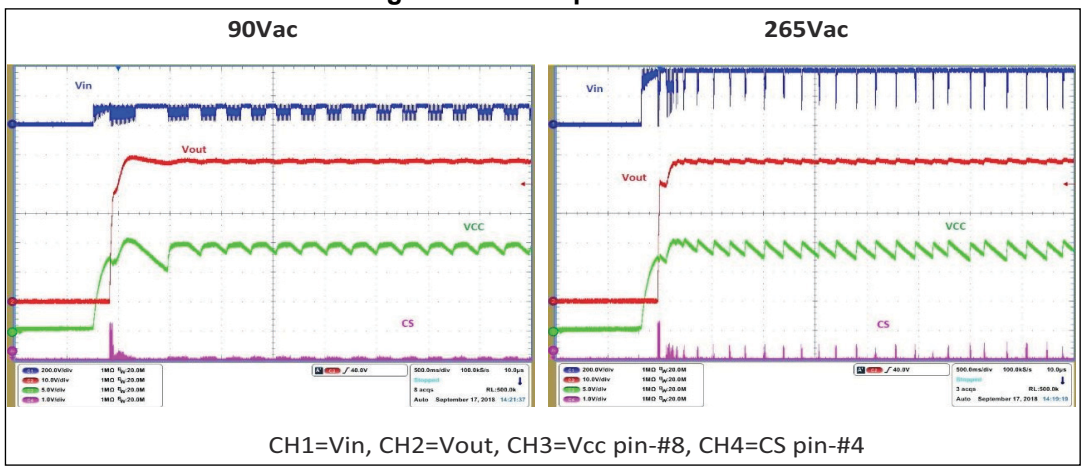
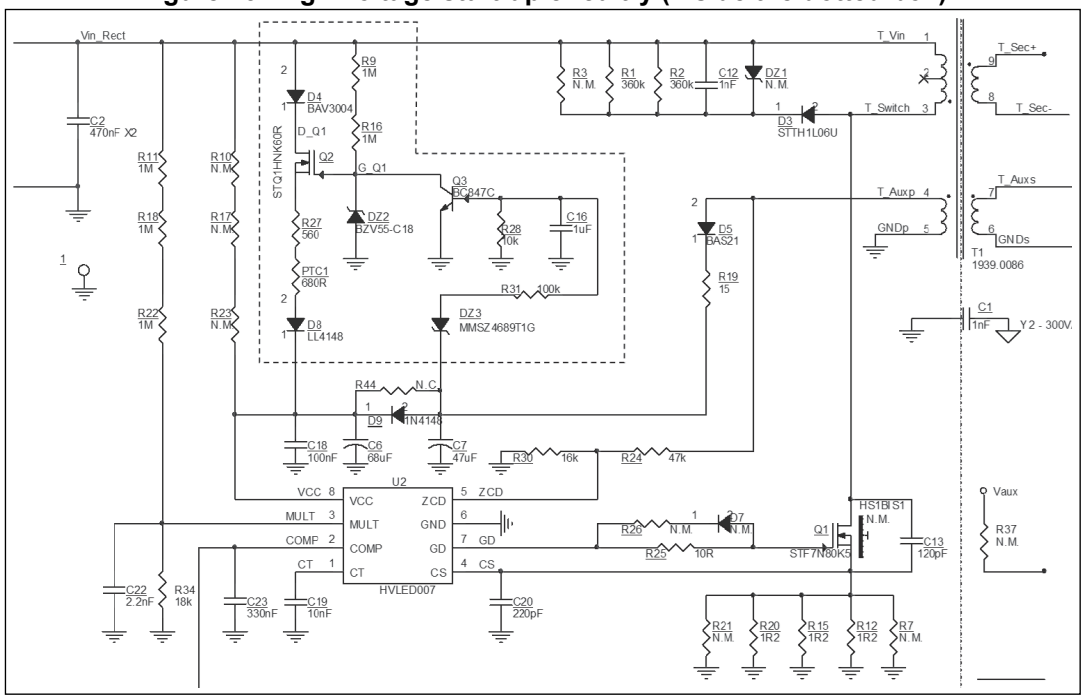


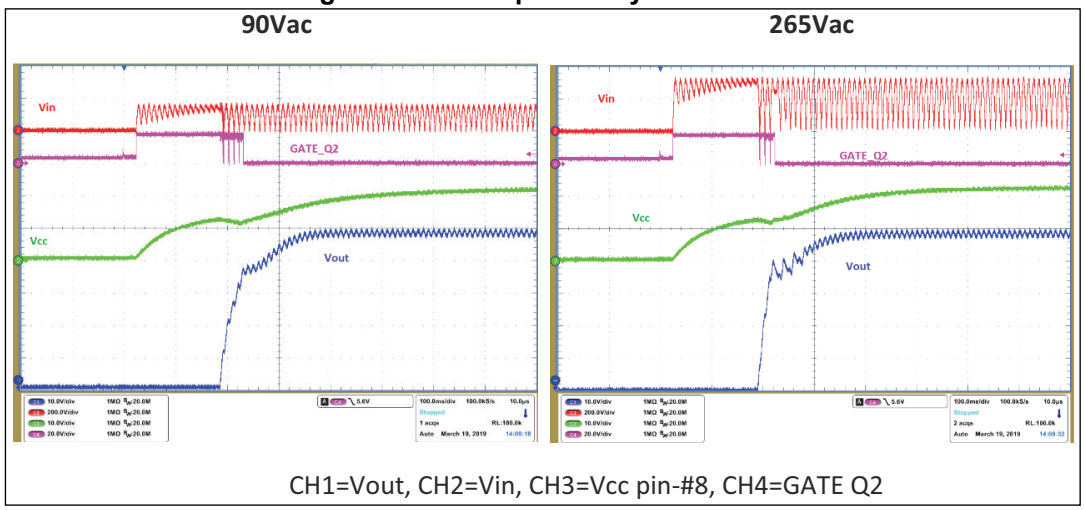
Figure 13 the high-voltage start-up circuitry, which is mainly composed by the high-voltage Q2 Mosfet, that charges the VCC pin voltage, is highlighted. Once the VCC pin voltage reaches the IC turn-on threshold (12.5 V typ.), the HVLED007 starts the operations.

Figure 13. High-voltage start-up circuitry (inside the dotted box)



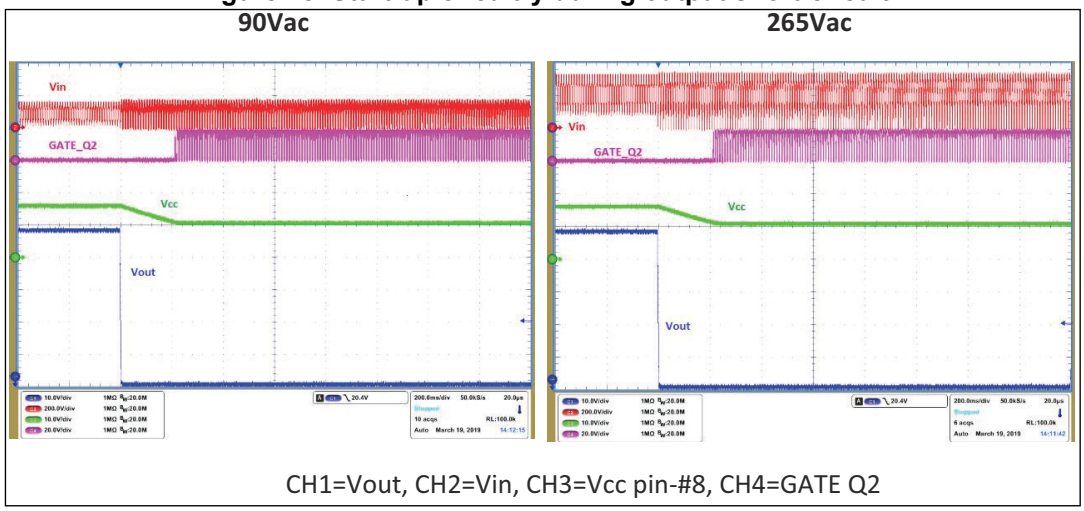
Once the output voltage reaches around 75% of the desired output voltage the Q2 Mosfet is turned off by Q3 bjt $\left(Vbe = Vaux \frac{Naux}{Ns} \frac{R28}{R28 + R100}\right)$ in order to reduce the power consumption, as shown in *Figure 14*.

Figure 14. Start-up circuitry waveforms



In case of output short-circuit, the auxiliary voltage drops turning off the Q3 bjt: as a result6, the high-voltage Q2 Mosfet is turned on, as shown in *Figure 15*. In order to protect the Q2 Mosfet from excessive power dissipation, the PTC1 resistor limits the current flowing into the Q2 Mosfet.

Figure 15. Start-up circuitry during output short-circuit

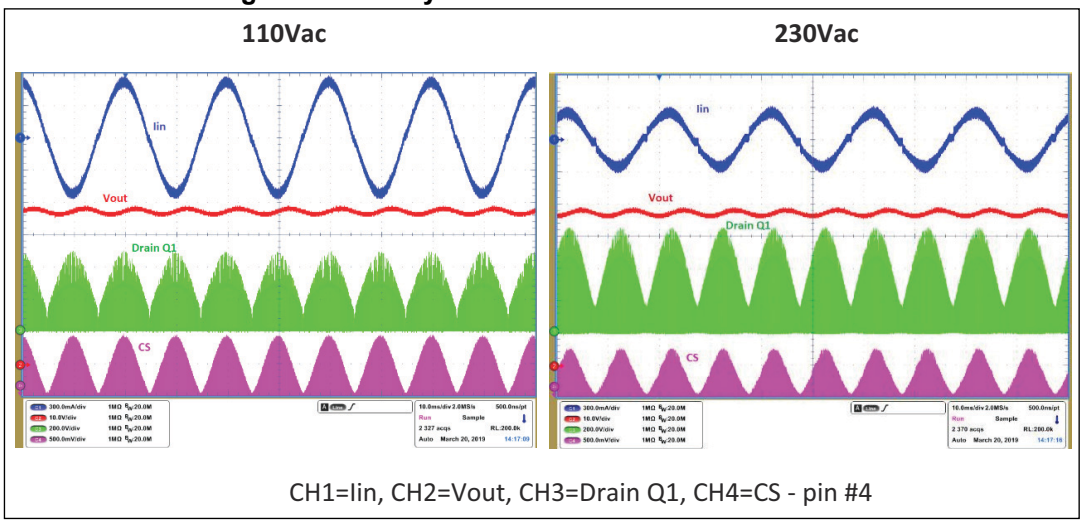


2.6 Steady-state operation

In *Figure 16* and *Figure 17* the main waveforms of the converter at full-load and half-load are reported, respectively.

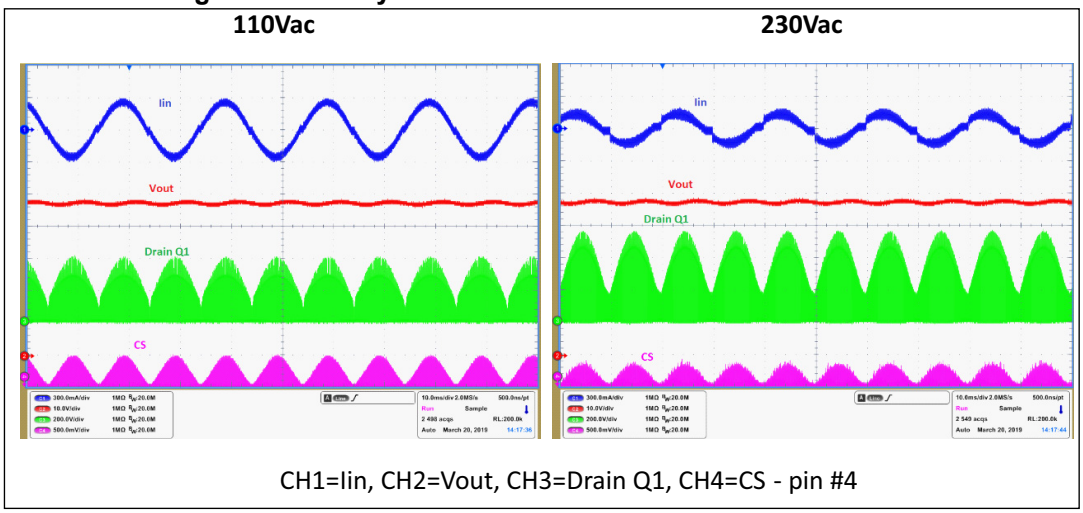
The waveforms confirm that the patented HVLED007 input current shaper (ICS) is able to achieve sinusoidal input current (extremely low THD) regardless of the operating conditions (e.g. input or output load).

Figure 16. Steady-state main waveforms at full-load



CH1=Iin, CH2=Vout, CH3=Drain Q1, CH4=CS - pin #4

Figure 17. Steady-state main waveforms at 50% of full-load



CH1=Iin, CH2=Vout, CH3=Drain Q1, CH4=CS - pin #4

3 Thermal measurements

In order to check the design reliability, a thermal mapping by means of an IR camera was done. *Figure 18* and *Figure 19* show thermal measurements of the on-board components at nominal input voltages and full-load. Some pointers, visible in the images, placed across key components show the relevant temperature. *Table 1* and *Table 2* provide the correlation between the measured points and components, for both thermal maps. The ambient temperature during both measurements was 25 °C.

Figure 18. Thermal measurements at 115 Vac - full-load

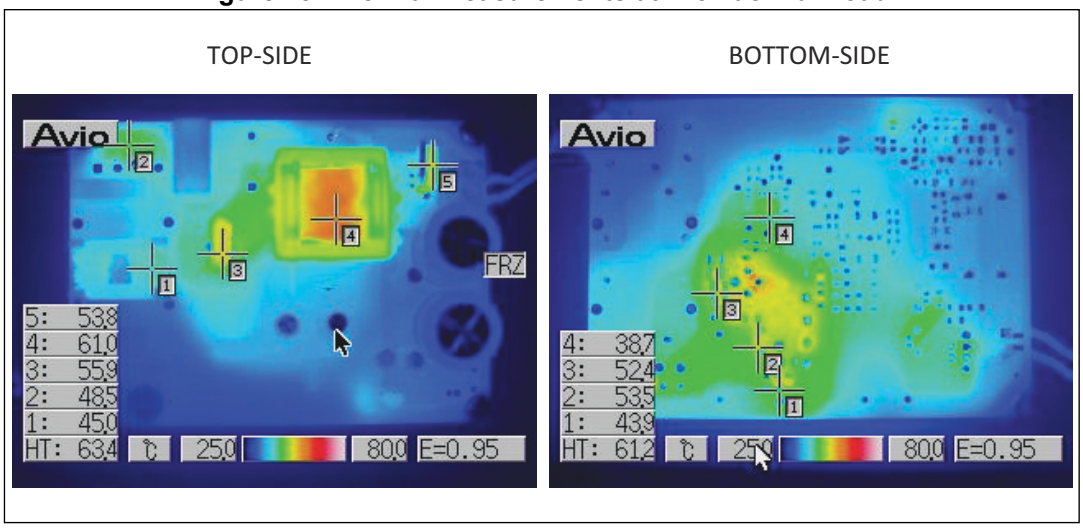


Figure 19. Thermal measurements at 230 Vac - full-load

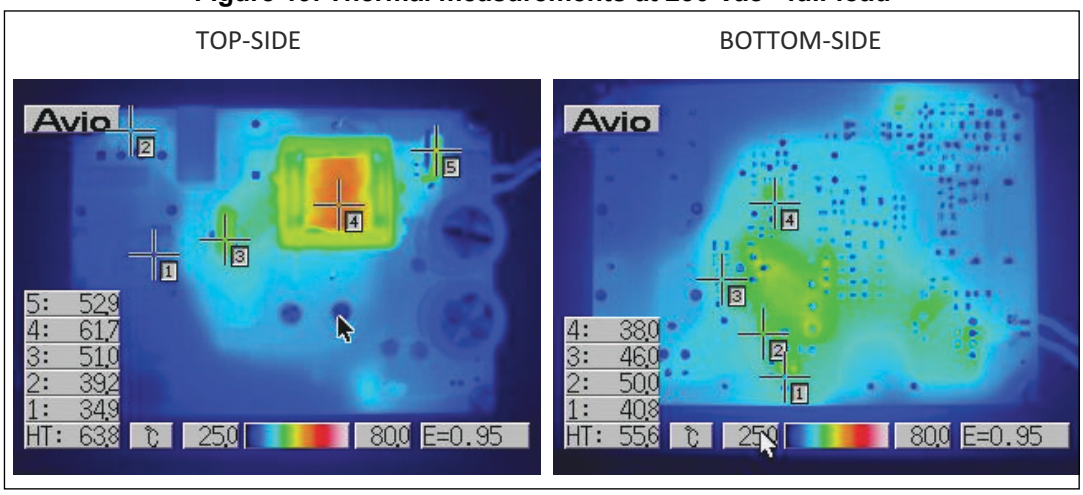


Table 1. Measured temperature - PCB TOP side

Point	Part no.	Component	Temperature at 115Vac	Temperature at 230Vac
1	T2BIS1	Input common choke	45.0	34.9
2	BR1	Input bridge	48.5	39.2
3	Q1	Flyback power switch	55.9	51.0
4	T1	Flyback transformer	61.0	61.7
5	D1	Output diode	53.8	52.9

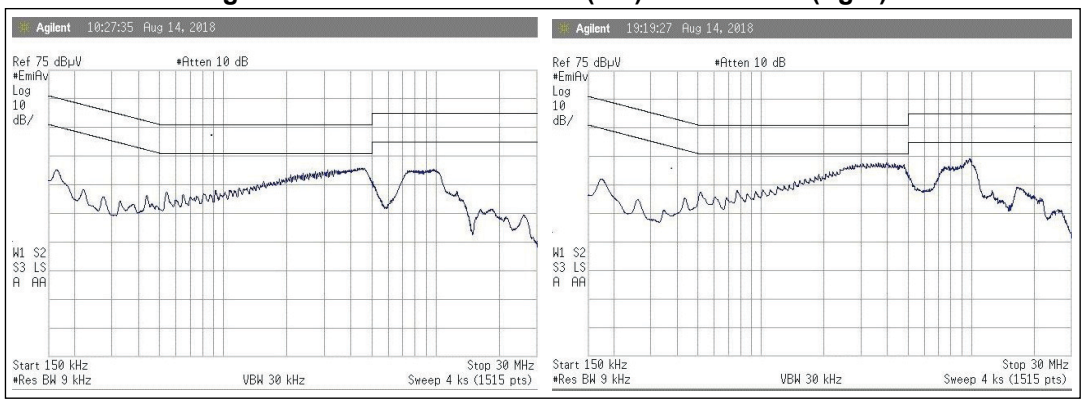
Table 2. Measured temperature - PCB BOTTOM side

Point	Part no.	Component	Temperature at 115Vac	Temperature at 230Vac
1	R1, R2	Snubber resistor	43.9	40.8
2	D3	Snubber diode	53.5	50.0
3	R12, R15, R20	Current sense resistors	52.4	46.0
4	U2	Flyback controller	38.7	38.0

4 Conducted emission pre-compliance test

Figure 20 shows the measurements of the conducted noise at full-load and nominal mains voltages, with the “average” setup. The limits shown in the diagrams are relevant to the EN55022 Class-B, the most popular standard for European equipment using a two-wire mains connection.

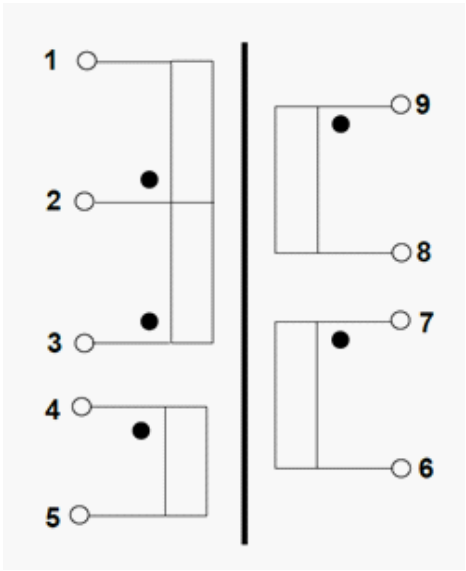
Figure 20. Full-load at 115 Vac (left) and 230 Vac (right)



5 Flyback transformer specification

Figure 21 shows the electrical diagram and the pins function of the transformer. In *Figure 22* and *Figure 23* the electrical and mechanical specifications are reported, respectively.

Figure 21. Flyback transformer - electrical diagram and pins function



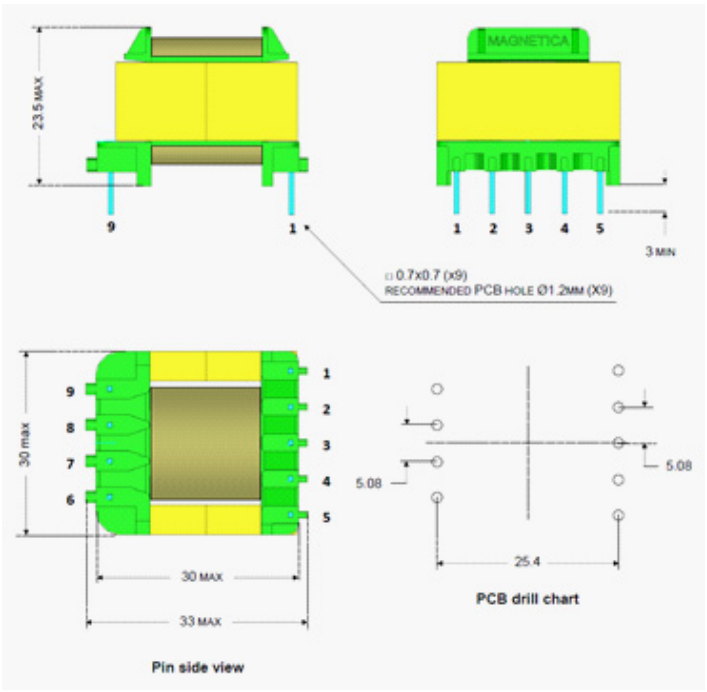
PIN FUNCTIONS					
PIN (*)	*FUNCTION*		*PIN(*)*	*FUNCTION*	
1	PRIMARY +VB (125÷430VDC)		6	SECONDARY GROUND	16V 20mA
2	PRIMARY CENTER TAP		7	SECONDARY	
3	PRIMARY DRAIN		8	SECONDARY GROUND	50V 700mA
4	AUXILIARY	+16V 20mA	9	SECONDARY	
5	AUXILIARY GROUND				
(*) PIN WITH THE SAME SUBSCRIPT MUST BE CONNECTED TOGETHER IN PCB					

Figure 22. Flyback transformer - electrical specifications

TECHNICAL SPECIFICATIONS

INDUCTANCE	
(MEASURE 1KHZ, TA 20°C)	
PIN 3-1	500 µH ± 15%
PIN 4-5	10.0 µH ± 15%
PIN 9-8	77.6 µH ± 15%
PIN 7-6	9.82 µH ± 15%
RESISTANCE	
(MEASURE D.C, TA 20°C)	
PIN 3-1	573 mΩ MAX
PIN 4-5	192 mΩ MAX
PIN 9-8	185 mΩ MAX
PIN 7-6	147 mΩ MAX
TURN RATIO	
(MEASURE 10KHZ, WITH TOLERANCE ±0.5, *TA 20°C)*	
PIN 3-1 ⇔ 4-5	7.33 NOM
PIN 3-1 ⇔ 9-8	2.54 NOM
PIN 3-1 ⇔ 7-6	7.33 NOM
LEAKAGE INDUCTANCE *(MEASURE 3-1,4-5-6-7-8-9 C.C, F10KHZ, TA 20°C)*	7µH MAX
PARASITIC CAPACITANCE *(MEASURE 3-1, F 1.20MHZ, TA 20°C)*	35 pF MAX
SATURATION CURRENT *(MEASURE 3-1, B_{SAT} 0.3T , TA 20°C)*	3 A_P MAX
OPERATING CURRENT *(MEASURE 3-1, PMAX 35W ,F 40KHZ, TA 20°C)*	1.7 A_P MAX
WORKING FREQUENCY *(P_{MAX} 35W , TA 20°C)*	40 KHZ MIN
AMBIENT TEMPERATURE RANGE (P_{MAX} 50W, WITH SELF TRISE 45°C)	-20°C÷+85°C
THERMAL CLASS	B
STORAGE TEMPERATURE RANGE	-20°C÷+85°C
PRIMARY TO SECONDARY INSULATION *(F 50HZ, DURATION 2", TA 20°C)*	4KV
MAXIMUM DIMENSIONS	33x30 H23.5mm
WEIGHT	33 g APPROX

Figure 23. Flyback transformer - mechanical aspect



6 Bill of material

Table 3. EVLHVLED007W35F demonstration board bill of material

Reference	Part no.	Case	Description	Supplier
BR1	2KBP08M	KBPM	Bridge rectifier - 800V / 2A	VISHAY
BR2	N.M.	GBU		
C1	1nF	RAD 5x7 p10	Y2 - 300Vac	VISHAY
C2	470nF X2	9x18 p15	X2 / 305Vac	TDK
C3	100nF X2	5x18 p15	X2 / 305Vac	TDK
C4	680uF	RAD d18 p7.5	Electrolytic 105°C - 63V	Nichicon
C5	4.7uF	RAD d5 p2	Electrolytic 105°C - 100V	United Chemi-Con
C6	68uF	RAD d6.3 p2.5	Electrolytic 105°C - 35V	Panasonic
C7	47uF	RAD d6.3 p2.5	Electrolytic 105°C - 35V	Nichicon
C8	680uF	RAD d18 p7.5	Electrolytic 105°C - 63V	Nichicon
C9	100nF X2	5x18 p15	X2 / 305Vac	TDK
C10	4.7uF	RAD d5 p2	Electrolytic 105°C - 50V	Panasonic
C11	47uF	RAD d5 p2	Electrolytic 105°C - 35V	Nippon Ch.
C12	1nF	SMD 1206	Ceramic X7R - 630V	TDK
C13	120pF	SMD 1206	Ceramic COG - 1kV	
C14	N.M.	SMD 1206	Ceramic X7R - 50V	
C15	100nF	SMD 1206	Ceramic X7R - 100V	
C16	1uF	SMD 0805	Ceramic X7R - 50V	
C17	100nF	SMD 1206	Ceramic X7R - 100V	
C18	100nF	SMD 0805	Ceramic X7R - 50V	
C19	10nF	SMD 0805	Ceramic X7R - 50V	
C20	220pF	SMD 0805	Ceramic X7R - 50V	
C21	100nF	SMD 0805	Ceramic X7R - 50V	
C22	2.2nF	SMD 0805	Ceramic X7R - 50V	
C23	330nF	SMD 0805	Ceramic X7R - 50V	
C24	100nF	SMD 0805	Ceramic X7R - 50V	
C25	N.M.	SMD1206	Ceramic X7R - 50V	
C26	N.M.	SMD 0805	Ceramic X7R - 50V	
C27				
N.M.	SMD 0805	Ceramic X7R - 50V		
C28	N.M.	RAD d5 p2	Electrolytic 105°C - 100V	
DZ1	N.M.	DO-15	Transil 300V / 600W	

Table 3. EVLHVLED007W35F demonstration board bill of material (continued)

Reference	Part no.	Case	Description	Supplier
DZ2	BZV55C18	SMD MINI-MELF	Zener diode 18V / 500mW - +/-5%	Taiwan S.
DZ3	MMSZ4689T1G	SMD MINI-MELF	Zener diode 5.1V / 500mW - +/-5%	On Semiconductor
DZ4	BZV55C12	SMD MINI-MELF	Zener diode 12V / 500mW - +/-5%	Taiwan S.
DZ5	BZV55C33	SMD MINI-MELF	Zener diode 33V / 500mW - +/-5%	Taiwan S.
DZ6	BZV55B56	SMD MINI-MELF	Zener diode 56V / 500mW - +/-2%	Taiwan S.
D1	STTH803	TO-220AC	Ultrafast Rectifier 300V / 8A	STMicroelectronics
D2	N.M.	TO-220AB		
D3	STTH1L06U	SMD SMA	Ultrafast Rectifier 600V / 1A	STMicroelectronics
D4	BAV3004	SMD SOD-323	Small signal Diode 300V / 225mA	Diode
D5	BAS21	SMD SOD-323	Fast Rectifier 250V / 200mA	ON-SEMI
D6	BAS21	SMD SOD-323	Fast Rectifier 250V / 200mA	ON-SEMI
D7	N.M.	SMD MINI-MELF		
D8	LL4148	SMD MINI-MELF	Fast Rectifier 75V / 150mA	FAIRCHILD
D9	LL4148	SMD MINI-MELF	Fast Rectifier 75V / 150mA	FAIRCHILD
D10	N.M.	SMD MINI-MELF		
D11	N.M.	SMD MINI-MELF		
FV	2A	TR5	TR5 Fuse - 250Vac	Littlefuse
F1	PF TR5	TR5	TR5 Fuse Holder -250Vac	Littlefuse
ISO1	LTV-817	DIL 4PIN	Optocoupler	Lite-ON
J1	LED out	SIP 2P p5.08	PCB screw terminal -10A	Weidmuller
J2	Mains Connector	SIP 2P p5.08	PCB screw terminal - 10A	Weidmuller
Q1	STF7N80K5	TO-220FP	N-MOSFET 800V / 6A	STMicroelectronics
Q2	STQ1HNK60R	TO-92	N-MOSFET 600V / 400mA	STMicroelectronics
Q3	BC847C	SMD SOT-23	NPN BJT 50V / 100mA	Nexperia
Q4	BC846	SMD SOT-23	NPN BJT 65V/100mA	Nexperia
RV1	S10 K275	RAD 5x12 p15	Varistor 275Vac	EPCOS
R1	360k	SMD1206	Resistor - 1/4W +/-1%	
R2	360k	SMD1206	Resistor - 1/4W +/-1%	
R3	N.M.	SMD1206		
R4	N.M.	SMD1210		
R5	N.M.	SMD 0805		

Table 3. EVLHVLED007W35F demonstration board bill of material (continued)

Reference	Part no.	Case	Description	Supplier
R6	N.M.	SMD1206		
R7	N.M.	SMD1206		
R8	N.M.	SMD1206		
R9	1M	SMD1206	Resistor - 1/4W +/-1%	
R10	N.M.	SMD1206		
R11	1M	SMD1206	Resistor - 1/4W +/-1%	
R12	1R2	SMD1206	Resistor - 1/4W +/-1%	
R13	0	SMD1206	Resistor - 1/8W +/-1%	
R14	N.M.	SMD 0805		
R15	1R2	SMD1206	Resistor - 1/4W +/-1%	
R16	1M	SMD1206	Resistor - 1/4W +/-1%	
R17	N.M.	SMD1206		
R18	1M	SMD1206	Resistor - 1/4W +/-1%	
R19	15	SMD1206	Resistor - 1/4W +/-1%	
R20	1R2	SMD1206	Resistor - 1/4W +/-1%	
R21	N.M.	SMD1206		
R22	1M	SMD1206	Resistor - 1/4W +/-1%	
R23	N.M.	SMD1206		
R24	47k	SMD 0805	Resistor - 1/8W +/-1%	
R25	10	SMD 0805	Resistor - 1/8W +/-1%	
R26	N.M.	SMD 0805		
R27	560	SMD 0805	Resistor - 1/8W +/-1%	
R28	10k	SMD 0805	Resistor - 1/8W +/-1%	
R29	33k	SMD 0805	Resistor - 1/8W +/-1%	
R30	16k	SMD 0805	Resistor - 1/8W +/-1%	
R31	100k	SMD 0805	Resistor - 1/8W +/-1%	
R32	N.M.	SMD 0805		
R33	33k	SMD 0805	Resistor - 1/8W +/-1%	
R34	18k	SMD 0805	Resistor - 1/8W +/-1%	
R35	N.M.	SMD 0805		
R36	8.2k	SMD 0805	Resistor - 1/8W +/-1%	
R37	N.M.	SMD 0805	Resistor - 1/8W +/-1%	
R38	8.2k	SMD 0805	Resistor - 1/8W +/-1%	
R39	0	SMD 0805	Resistor - 1/8W +/-1%	
R40	N.M.	SMD 0805		

Table 3. EVLHVLED007W35F demonstration board bill of material (continued)

Reference	Part no.	Case	Description	Supplier
R41	12k	SMD 0805	Resistor - 1/8W +/-1%	
R42	12k	SMD 0805	Resistor - 1/8W +/-1%	
R43	1.4k	SMD 0805	Resistor - 1/8W +/-1%	
R44	N.M.	SMD 0805		
R45	12k	SMD 0805	Resistor - 1/8W +/-1%	
R46	0	SMD 0805	Resistor - 1/8W +/-1%	
R47	22k	SMD 0805	Resistor - 1/8W +/-1%	
PTC1	680ohm - 90deg	SMD0805	PTC resistor	TDK
T1	1939.0086	TRAFO DIL 9P 26x32	35W Flyback Transformer	MAGNETICA
T3	N.M.	TRAFO DIL 9P 30x33		
T2BIS1	2x47mH	DIL 4P 24x15	Current compensated choke - 0.7A	TDK
T2BIS2	N.M.	DIL 4P 26x25		
U2	HVLED007	SMD SO-8	Hi-PF Flyback controller	STMicroelectronics
U3	TL431 1% 105deg	TO-92	Reference Voltage	STMicroelectronics
HS1BIS	N.M.	Heatsink TO-220		
HS1BIS1	N.M.	Heatsink TO-220		

7 References

1. HVLED007 datasheet.
2. C. Adragna, G. Gritti, “High-power-factor Quasi-Resonant Flyback converters draw sinusoidal input current”, Applied Power Electronics Conference and Exposition, 2015. APEC '15, Conference Proceedings 2015, pp. 498-505, March 2015.
3. C. Adragna, “Design Equations of High-Power-Factor Flyback Converters based on the L6561”, STMicroelectronics Application Note, AN1059.

8 Revision history

Table 4. Revision history

Date	Revision	Changes
18-Sept-2019	1	Initial release.