

48 V - 130 W high efficiency converter with PFC for LED street lighting applications - European version

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Introduction

Nowadays, LEDs are becoming ever more popular, thanks to their particular characteristics, such as high efficiency and long life, and therefore they are pushing the innovation of current lamp types and strongly contributing to reducing the energy consumption for internal or external lighting. This is also the case in street lighting applications, where higher efficiency and long life are vital for reducing costs.

For these reasons a street lighting power supply designed to power an LED lamp must have high efficiency and at least a similar lifetime, in order to guarantee the maintenance free operation required by these kinds of applications.

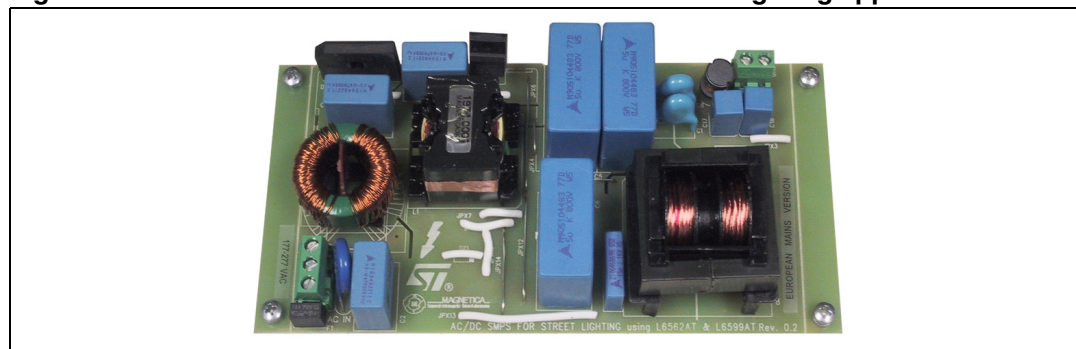
This application note describes the characteristics and features of a 130 W demonstration board (EVL130W-SL-EU), tailored on an LED power supply specification for street lighting. The circuit is composed of two stages; a front-end PFC using the L6562AT and an LLC resonant converter based on the L6599AT.

The peculiarities of this design are; very high efficiency, extended European input mains range (177-277 V_{AC}) operation, and long term reliability.

Because reliability (MTBF - "Mean Time Between Failures") in power supplies is typically affected by electrolytic capacitors and their typical high failure rate, unless using very expensive types, this board offers a very innovative design approach as the board doesn't implement any electrolytic capacitors, which are replaced by film capacitors from EPCOS. Component de-rating has also been carefully applied during the design phase, decreasing the component stress as recommended by MIL-HDBK-217D. The number of components, thanks to the use of the new L6562AT and L6599AT devices, has also been minimized, therefore increasing the MTBF and optimizing the total component cost. Thanks to the high efficiency achieved no heatsinks are required. The resonant stage power components are SMT, like most of the passive components, therefore decreasing production costs.

The board also has protections in case of overload or short-circuit, open-loop by each stage, or input overvoltage. Because of the particular application, all protections, in the case of intervention, are auto-restart.

Figure 1. EVL130W-SL-EU: 130 W SMPS for LED street lighting applications



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1 Main characteristics and circuit description

The main features of the SMPS are:

- Extended European input mains range: 177 to 277 V_{AC} - frequency 45 to 55 Hz
- Output voltage: 48 V at 2.7 A
- Long-life electrolytic capacitors are not used
- Mains harmonics: acc. to EN61000-3-2 Class-C
- Efficiency at full load: better than 90%
- EMI: according to EN55022-Class-B
- Safety: double insulation, according to EN60950, SELV
- Dimensions: 75 x 135 mm, 30 mm components maximum height
- No heatsinks needed
- PCB: single side, 35 µm, FR-4, mixed PTH/SMT

1.1 Power Factor corrector

The PFC stage, working in transition mode, acts as a pre-regulator and powers the resonant stage with the output voltage of 450 V. The PFC power topology is a conventional boost converter, connected to the output of the rectifier bridge D3. It is completed by the coil L1, manufactured by MAGNETICA, the diode D2 and the capacitors C5, C6, and C7 in parallel. The PFC output capacitors are film type, 5 µF - 800 V, manufactured by EPCOS. Using film capacitors to replace the typical electrolytic capacitors considerably increases the MTBF of the board.

The boost switch is represented by the Power MOSFET Q2. The board is equipped with an input EMI filter necessary to filter the commutation noise coming from the boost stage. The PFC implements the L6562AT controller, a small and inexpensive controller which is guaranteed for operation over a wide temperature range.

At startup, the L6562AT is supplied by the startup resistors R5, R8, and R13 charging the capacitor C13; once the PFC begins switching, a charge pump connected to the auxiliary winding of the PFC inductor L1 supplies both PFC and resonant controllers via a small linear regulator realized by Q1. Once both stages have been activated, the controllers are also supplied by the auxiliary winding of the resonant transformer, assuring correct supply voltage during all load condition operations. The L1 auxiliary winding is also connected to the L6562AT pin #5 (ZCD) through the resistor R18. Its purpose is to provide the information that L1 has demagnetized, needed by the internal logic to trigger a new switching cycle. The PFC boost peak current is sensed by resistor R34 in series to the MOSFET source; the signal is fed into pin #4 (CS) of the L6562AT, via the filter R27 and C16.

The dividers R7, R12, R14, and R22 provide the information on the instantaneous mains voltage to the L6562AT multiplier which is used to modulate the peak current of the boost.

The resistors R2, R6, R9 with R15 and R16 are dedicated to sensing the output voltage and feed, to the L6562AT, the feedback information necessary to keep the output voltage regulated. The components C11 and R20 (C12 is shorted) make up the error amplifier compensation network necessary to keep the required loop stability.

1.2 Resonant power stage

The down-stream converter is a resonant LLC half-bridge stage working with 50 percent fixed duty cycle and variable frequency. It implements the ST L6599AT, integrating all functions necessary to properly control the resonant topology.

The resonant transformer, manufactured by MAGNETICA, uses the integrated magnetic approach, so the leakage inductance is used for resonant operation of the circuit. Therefore, no external, additional coil is needed for the resonance. The transformer secondary winding configuration is the typical centre tap, using a couple of type STPS10150CG power Schottky rectifiers. The output capacitors are film type, 4.7 μ F - 63 V from EPCOS. Like for the PFC stage, using film capacitors allows to increase considerably the MTBF of the board.

A small LC filter has been added on the output, in order to filter the high frequency ripple. D21, D22, and R55 implement a voltage controlled bleeder; in the case of no-load operation of the SMPS, this circuit provides a bleeder limiting the increase of output voltage, but not affecting efficiency during normal operation. Please note that the converter has not been designed to work in this condition and therefore its mains consumption is not optimized (~3 W).

1.3 Startup sequence

The PFC acts as master and therefore starts first; the resonant stage operates only if the PFC is delivering the nominal output voltage to prevent the resonant converter from working with a too low input voltage which can cause incorrect capacitive mode operation. Therefore both stages are designed to work according to this sequence.

For correct sequencing, the L6599AT makes use of the LINE pin (#7) to sense the PFC output voltage via a resistor divider. The L6599AT LINE pin (#7) has an internal comparator which has a hysteresis allowing the turn-on and turn-off voltage to be set independently. At startup, the LLC stage starts once the PFC output voltage reaches ~ 430 V, while the turn-off threshold has been set to ~ 330 V.

1.4 Output voltage feedback loop

The output voltage is kept stable by means of a feedback loop implementing a typical circuit using a TS2431 to modulate the current in the optocoupler diode.

On the primary side, R43 - connecting pin RF_{MIN} (#4) to the optocoupler's phototransistor - allows the L6599AT oscillator frequency to be modulated, therefore keeping the output voltage regulated. It also sets the maximum switching frequency at about 130 kHz. R42, which connects the same pin to ground, sets the minimum switching frequency. The R-C series R37 and C24 sets both soft-start maximum frequency and duration.

All demonstration boards implement the voltage loop circuitry described above but in case a current loop is also required it can be achieved by implementing the following modifications:

- Replace R30 and R31 0R0 Ω resistors with sensing resistors, 0R033 and 0R039 respectively, both 0805
- Populate on PCB U4 and the relevant components reported on the schematic as N.M.: C36 = 1N0-0805; C37 = 100NF-0805; R51 = 15R-0805; R56 = 1K0-0805; R61 = 22K-1206; C41 = 2N2-0805; U5 = SEA05TR
- Remove the TS2431A1LT

With these modifications the circuit is able to keep the output current constant at 2.7 A down to an output voltage value of around 30 V. This function can be used to optimize the voltage drop and power dissipation in case current linear regulators are used to regulate the current flowing in each LED strip. In case the output current is lower than the current loop setpoint, the voltage loop takes over the operation regulating the output voltage at its nominal value, like using the TS2431AILT.

1.5 L6599AT overload and short-circuit protection

The current flowing into the primary winding, proportional to the output load, is sensed by the lossless circuit C34, R53, D19, D18, R57, and C35 and it is fed into the ISEN pin (#6) of L6599AT. In the case of overcurrent, the voltage on the pin overpasses an internal threshold (0.8 V), triggering a protection sequence. The capacitor (C21) connected to the DELAY pin (#2) is charged by an internal 150 μ A current generator. If the voltage on the pin reaches 2 V, the soft-start capacitor is completely discharged so that the switching frequency is pushed to its maximum value. As the voltage on the pin exceeds 3.5 V the IC stops switching and the internal generator is turned off, so that the voltage on the DELAY pin decays because of the external resistor connected between the pin and GND. The L6599AT is soft-restarted as the voltage drops below 0.3 V. In this way, under short-circuit conditions, the converter works intermittently with low input average power, limiting the stress of components during shorts.

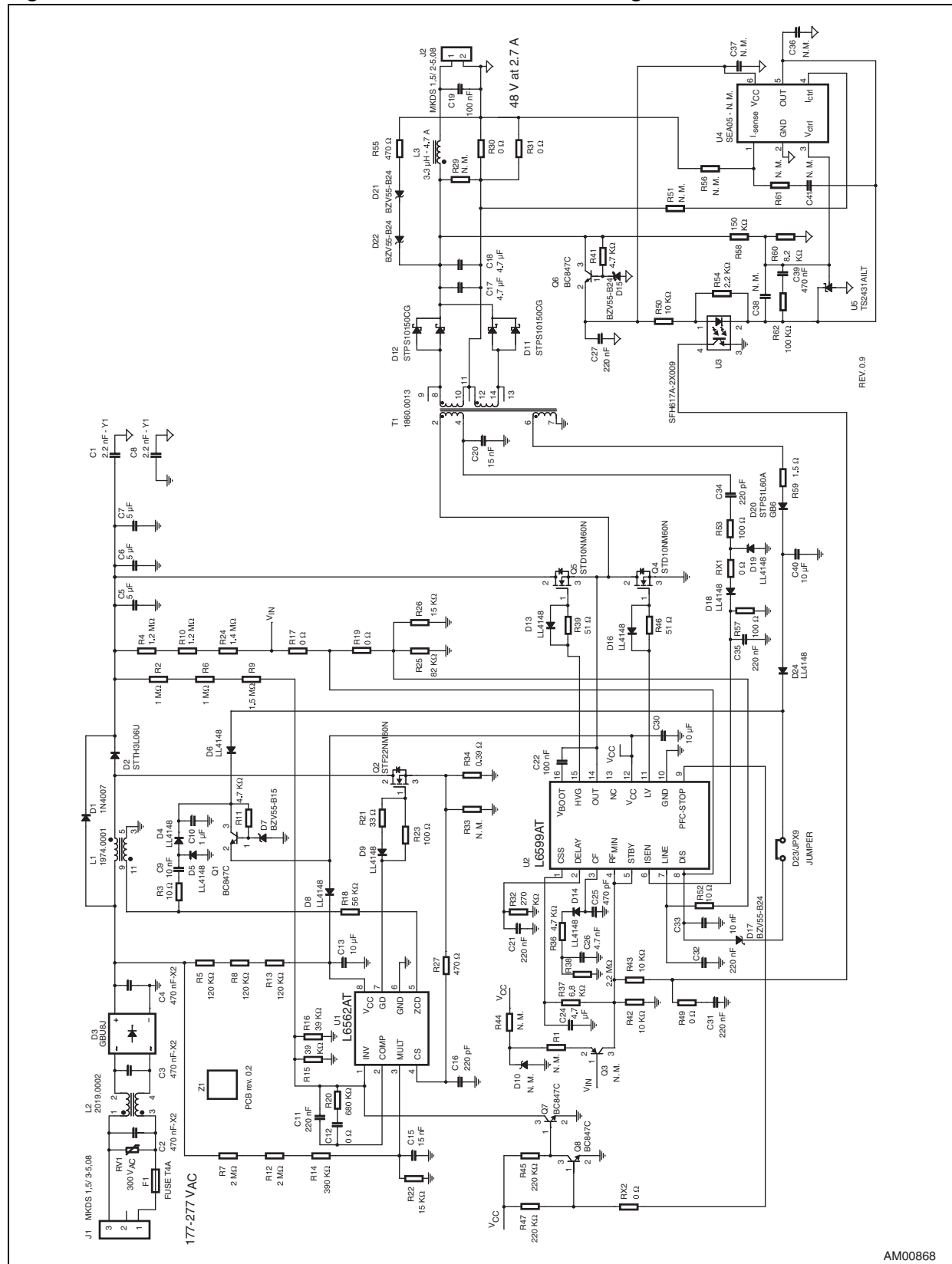
1.6 Overvoltage and open-loop protection

Both circuit stages, PFC and resonant, are equipped with their own overvoltage protections.

The L6562AT PFC controller implements an overvoltage protection against the output voltage variation due to the poor bandwidth of the error amplifier, happening in the case of transients. Unfortunately it cannot protect the circuit in the case of a feedback loop failure such as disconnection or deviation from the nominal value of the feedback loop divider. In the case where a similar failure condition is detected, the L6599AT pin DIS (#8) stops the operation and also stops the PFC operation by means of the L6599AT pin PFC_STOP (#9) connected to the L6562AT pin INV (#1). The converter operation is latched until the V_{CC} capacitors are discharged, then a new startup sequence takes place automatically and the converter resumes operation if the failure is removed or a new sequence is triggered. The same sequence occurs also in the case of input voltage transients which may damage the converter.

The DIS pin is also used to protect the resonant stage against loop failures. The Zener diode D17 detects the auxiliary voltage generated by the LLC transformer. In the case of loop failure, it conducts, and voltage on the DIS pin exceeds the internal threshold, latching off the device. The L6562AT operation is also stopped by the PFC_STOP pin as in the previous case, and after some time has elapsed the circuit restarts.

Figure 2. EVL130W-SL-EU demonstration board: electrical diagram



2 Efficiency measurement

[Table 1](#) shows the overall efficiency, measured at 230 V_{AC} - 50 Hz with different loads.

At 230 V_{AC} and full load the overall efficiency is 93.85%, making this design suitable for high efficiency power supplies. The efficiency has been measured at 25%, 50%, 75%, and 100%, the average efficiency calculated according to the ES-2 standard is 91.56%.

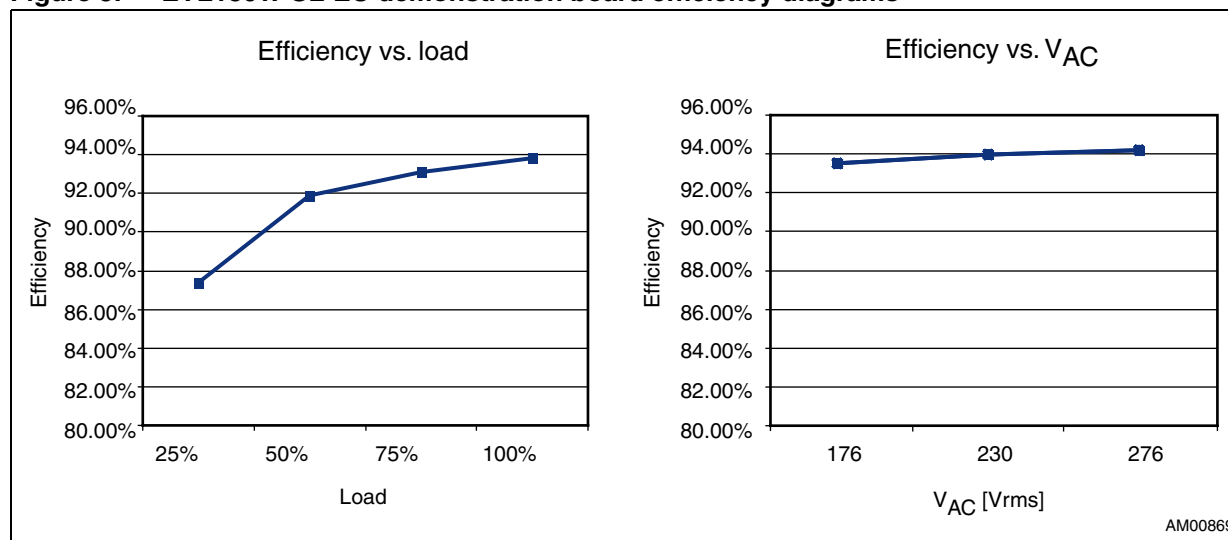
Table 1. EVL130W-SL-EU demonstration board: overall efficiency vs. load

Load	230 V-50 Hz				
	V _{OUT} [V]	I _{OUT} [A]	P _{OUT} [W]	P _{IN} [W]	Efficiency [%]
25% load	47.59	0.682	32.46	37.14	87.39%
50% load	47.55	1.37	65.14	70.89	91.89%
75% load	47.54	2.00	95.08	102.1	93.12%
100% load	47.54	2.74	130.26	138.8	93.85%
Average efficiency					91.56%

The measured output voltage at different load conditions is reported in [Table 1](#). As seen, the voltage is very stable over all the output load range.

The measured efficiency is shown on the lefthand side of the graph in [Figure 3](#), while on the righthand side of [Figure 3](#) the efficiency, at maximum load and at minimum, nominal, and maximum AC input voltage, is reported.

Figure 3. EVL130W-SL-EU demonstration board efficiency diagrams

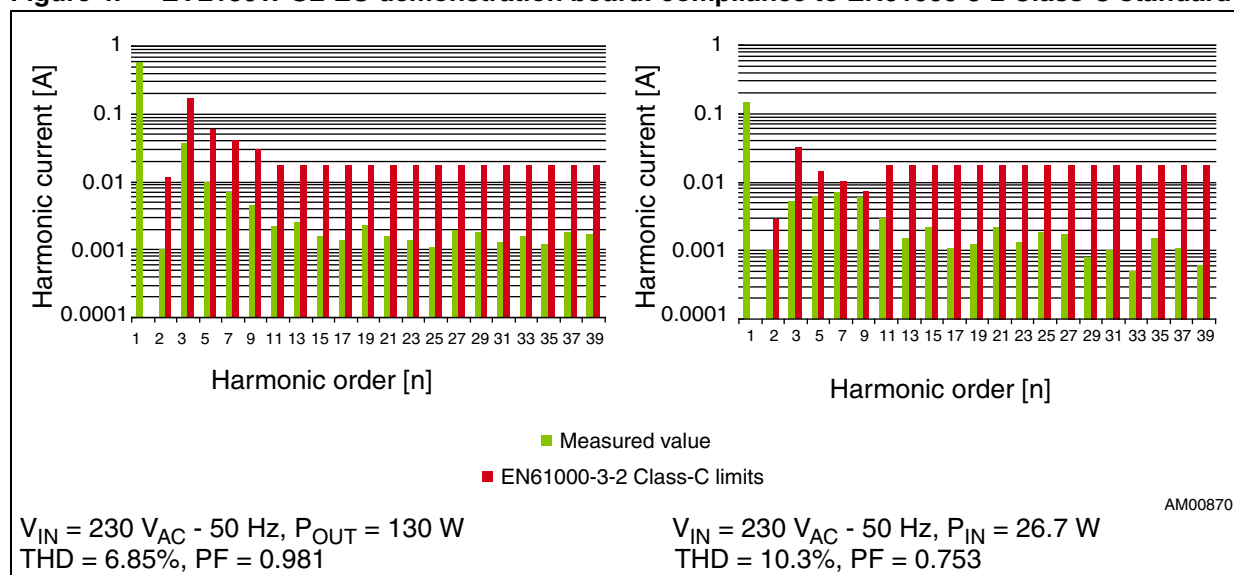


3 Input current harmonics measurement

One of the main purposes of a PFC pre-conditioner is the correction of input current distortion, decreasing the harmonic contents below the limits of the relevant regulations. Therefore, this demonstration board has been tested according to the European standard EN61000-3-2 Class-C relevant to lighting equipment, at full load and nominal input voltage mains. Measurement results are in [Figure 4](#) - on the lefthand side.

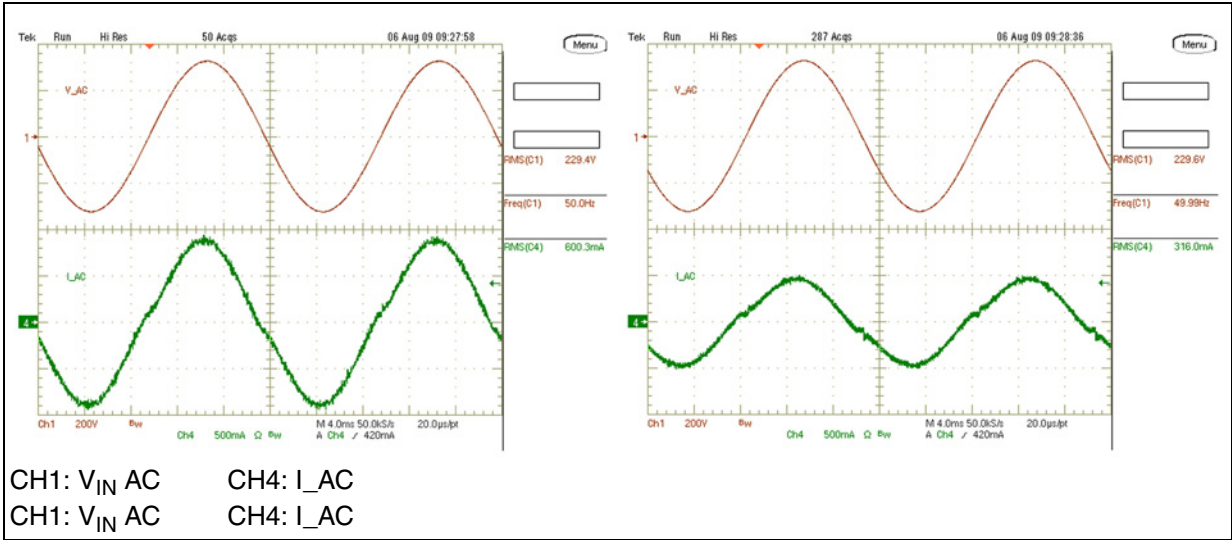
The circuit shows its ability to reduce the harmonics, also well below the limits of EN61000-3-2 Class-C regulation, not only at full load but also at significant lower load; on the righthand side of [Figure 4](#) the input current harmonics measurement at light load (minimum input power to be compliant with the above mentioned rule is 25 W) shows that even if the power supply is working out of its typical operating region it is still compliant with the EN61000-3-2 Class-C limits.

Figure 4. EVL130W-SL-EU demonstration board: compliance to EN61000-3-2 Class-C standard



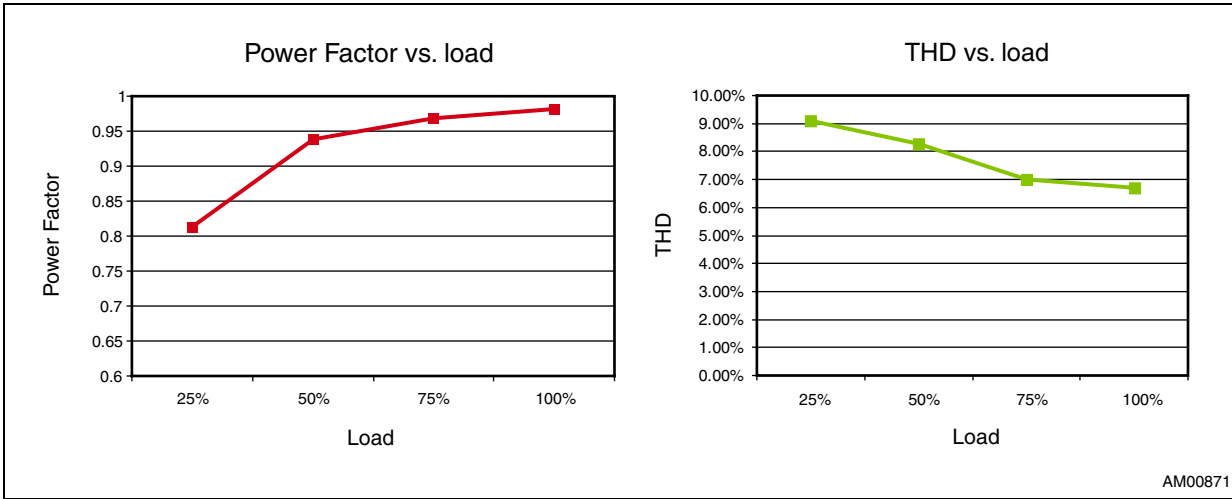
For user reference, waveforms of the input current and voltage at nominal input voltage mains full load and 50% load conditions are given in [Figure 5](#).

Figure 5. EVL130W-SL-EU demonstration board: input current waveform at 230 V - 50 Hz - 130 W load and 65 W load



The “Power Factor” (PF) and the “Total Harmonic Distortion” (THD) versus load variations have also been measured and the results are given in [Figure 6](#). As seen, the Power Factor remains close to unity and the Total Harmonic Distortion is very low.

Figure 6. EVL130W-SL-EU demonstration board: Power Factor and Total Harmonic Distortion vs. load



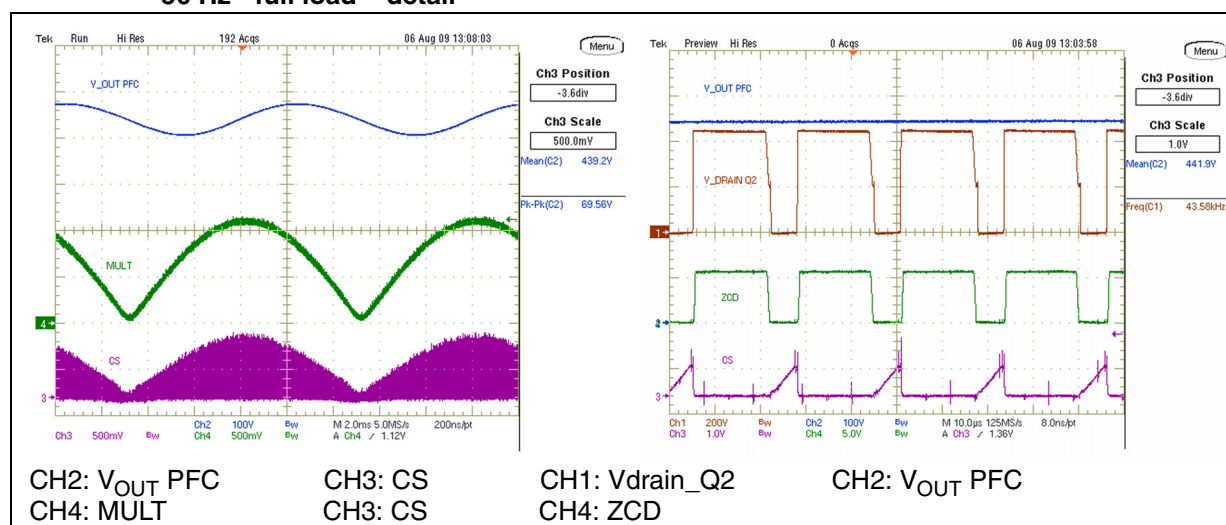
4 Functional check

4.1 PFC circuit

On the lefthand side of [Figure 7](#), some waveforms relevant to the PFC stage have been captured; the envelope of CS pin (#4) waveforms of the L6562AT is in phase with the MULT pin (3#) and has the same sinusoidal shape, demonstrating the correct functioning of the PFC stage. It is also possible to measure the peak-to-peak value of voltage ripple over imposed to the PFC output voltage; this is due to the low value of the PFC output capacitors.

On the righthand side of [Figure 7](#) the details of some waveforms at switching frequency are given.

Figure 7. EVL130W-SL-EU demonstration board: PFC stage and L6562AT waveforms at 230 V - 50 Hz - full load – detail



4.2 Half-bridge resonant LLC circuit

Some waveforms relevant to the resonant stage during steady-state operation are given in the following pages. The resonant stage switching frequency is about 100 kHz, in order to have a good trade off between transformer losses and dimensions.

The LLC converter has been designed to operate at nominal voltage and full load at the resonance frequency, but due to the PFC output voltage ripple at twice the mains frequency it is driven slightly above and below the resonant tank frequency, according to the instantaneous value of PFC output voltage.

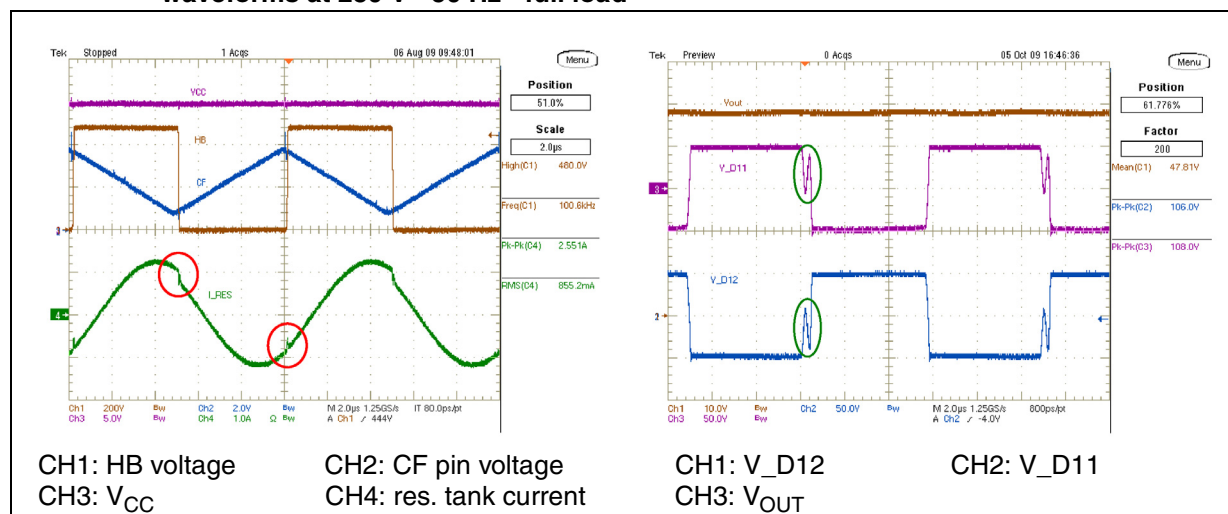
In [Figure 8](#) (on the lefthand side) some waveforms relevant to the resonant stage ZVS operation are shown; it is possible to see that both MOSFETs are turned on when resonant current is flowing through their body diodes and therefore drain-source voltage is almost zero, achieving good efficiency because the turn-on losses are negligible. The HB MOSFET voltage de-rating and low operating temperature allow the board MTBF to be increased.

The current flowing in the resonant tank is sinusoidal; in [Figure 8](#) it is possible to appreciate a slight asymmetry of operating modes by each half portion of the sinewave; half cycle is working at resonant frequency while the other is working above the resonant frequency. This

is due to a small difference between each half-secondary leakage inductance of the transformer reflected to the primary side, providing the two slightly different resonant frequencies. This phenomenon is typically due to a different coupling of transformer secondary windings and in this case it is not an issue. The slight asymmetry can also be appreciated in [Figure 8](#) (on the righthand side); the small ringing appearing on both secondary rectifiers anode voltage indicates that for a short time the rectifiers are not conducting; it demonstrates that during half cycle the circuit is working below the resonant frequency while during the following half cycle it is working at resonance frequency.

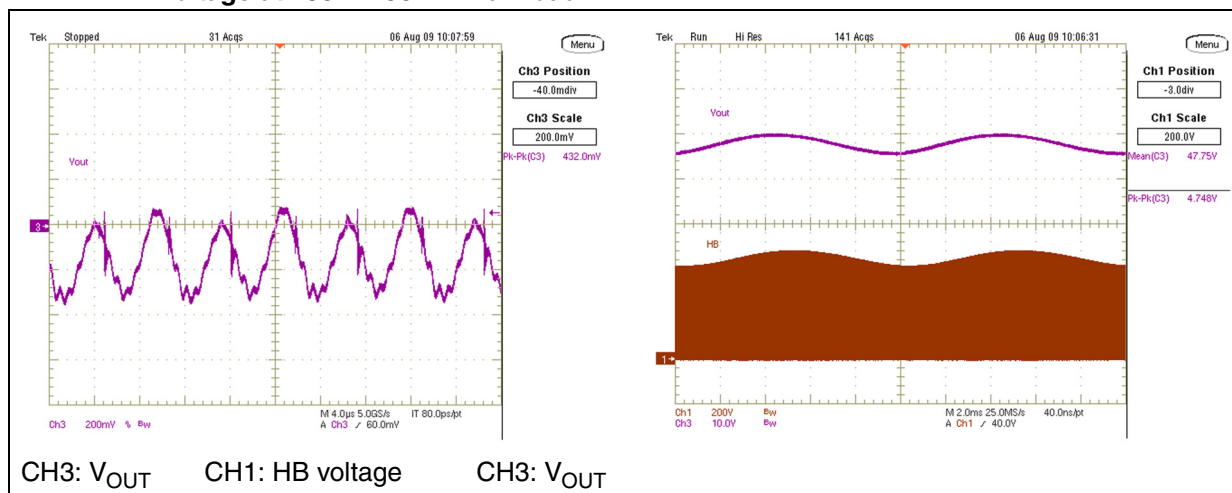
In [Figure 8](#) it is also possible to appreciate the rectifier operating voltage and its margin with respect to the maximum reverse voltage (V_{RRM}). This de-rating with respect to the rectifiers V_{RRM} guarantees good reliability of the output rectifiers increasing the board total MTBF.

Figure 8. EVL130W-SL-EU demonstration board: primary and secondary side resonant stage waveforms at 230 V - 50 Hz - full load



On the lefthand side of [Figure 9](#) the high frequency ripple has been measured; as seen the ripple and noise at switching frequency is very limited, thanks to the low EMI generated by both stages. On the righthand side of [Figure 9](#) the low frequency ripple has also been measured. It is possible to note that the peak-to-peak value is not so low but it doesn't affect the application, in fact the converters regulating the current flowing in each LED strip can reject the ripple without any problem.

Figure 9. EVL130W-SL-EU demonstration board: high and low frequency ripple on output voltage at 230 V - 50 Hz - full load



4.3 Dynamic load operation

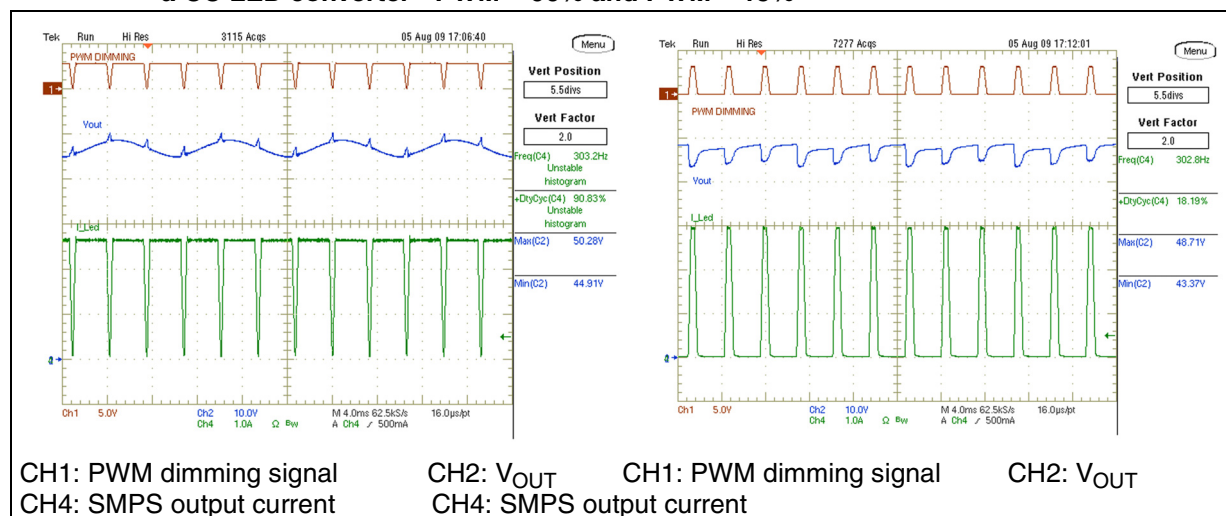
Waveforms reported in [Figure 10](#) are relevant to the demonstration board during operation, supplying converters dedicated to power LED strips with constant current.

In both figures it is possible to see the output voltage modulation during operation with variable load due to the dimming of the LED current by PWM. For both measurements, a dimming frequency of 300 Hz has been chosen.

On the lefthand side of [Figure 10](#) the converter output current was 2.6 A and dimming duty cycle was 90%, therefore very close to the converter nominal output power. The output voltage in the image has two modulations; one is due to the rejection of the PFC output voltage ripple already measured in [Figure 9](#), on the righthand side. Over imposed there is the voltage variation due to the LED current dimming. The peak-to-peak variation is 5.37 V, this doesn't create any problems for the load as the converters reject the modulation.

Whereas on the righthand side of [Figure 10](#) the converter has been checked at light load, so the peak output current was 3 A and dimming duty cycle was 15%, for an output power of 21 W. Even in this case the peak-to-peak modulation doesn't give any trouble to the downstream current regulators and the board still works correctly.

Figure 10. EVL130W-SL-EU demonstration board: output voltage variation driving a CC LED converter - PWM = 90% and PWM = 15%



It is worth clarifying that, for correct operation with LED strips, the board needs some additional capacitors connected on the +48 V output bus. It has not been equipped with all the capacitors necessary for correct operation with LEDs but only with minimum capacitance to allow board operation, in order to optimize the system cost and reliability. The additional capacitors needed are intended to be placed close to each LED strip current regulator, therefore filtering the EMI generated by these. In several cases, in fact, the power supply is placed at the base of the lighting pole while the LED current regulators are located on top, in the lamp. The long wiring connection between the power supply and the converters can act as an antenna radiating EMI. Therefore local filtering minimizes the radiated EMI.

The capacitance to be added to the 48 V bus, for correct operation with LEDs, is around 40 μ F. In order to not affect the board MTBF, using the same capacitor type already used on the power supply board is suggested.

4.4 Overcurrent and overvoltage protection

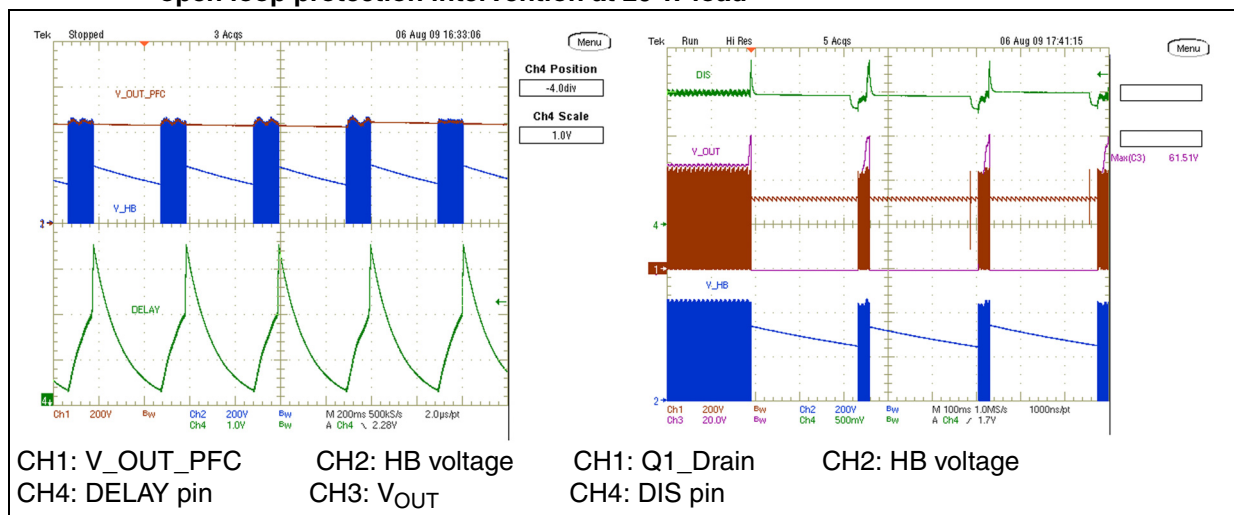
The L6599AT is equipped with a current sensing input (pin #6, ISEN) and a dedicated overcurrent management system. The current flowing in the resonant tank is detected and the signal is fed into the ISEN pin. It is internally connected to a first comparator, referenced to 0.8 V, and to a second comparator referenced to 1.5 V. If the voltage externally applied to the pin exceeds 0.8 V, the first comparator is tripped causing an internal switch to be turned on and discharging the soft-start capacitor C24 (CSS). Under output short-circuit, this operation results in a nearly constant peak primary current.

With the L6599AT the designer can program externally the maximum time that the converter is allowed to run overloaded or under short-circuit conditions. Overloads or short-circuits lasting less than the set time do not cause any other action, and so provide the system with immunity to short duration phenomena. If, instead, an overload condition continues, a protection procedure is activated which shuts down the L6599AT. In the case of continuous overload or short-circuit, it results in continuous intermittent operation with a user defined duty cycle.

This function is realized with the DELAY pin (#2), by means of a capacitor C21 and the parallel resistor R32 connected to ground. As the voltage on the ISEN pin exceeds 0.8 V the first OCP comparator, in addition to discharging CSS, turns on an internal 150 μ A current generator that via the DELAY pin charges C21. When the voltage on C21 is 3.5 V, the L6599AT stops switching and the PFC_STOP pin (#9) is pulled low, also turning off the PFC stage via the L6562AT pin #1 (INV). Also the internal generator is turned off, so that C21 is now slowly discharged by R32. The IC restarts once the voltage on C21 is less than 0.3 V. Additionally, if the voltage on the ISEN pin reaches 1.5 V for any reason (e.g. transformer saturation), the second comparator is triggered, the L6599AT shuts down and the operation is resumed after recycling the V_{CC} . In this demonstration board the intervention of the second level comparator latches the operation of the L6599AT and the PFC_STOP pin (#9) stops the PFC. Both controllers are no longer powered by V_{CC} and the latch is removed, then a new startup cycle takes place. This sequence lasts until the short is removed.

On the lefthand side of [Figure 11](#) the operation of the DELAY pin and the consequent hiccup mode operation of the board during short-circuit operation can be seen. Thanks to the narrow operating time, with respect to the off time, the average output current, as well as the average primary current, are limited. This avoids converter overheating and consequent failures. At short removal the board resumes normal operation.

Figure 11. EVL130W-SL-EU demonstration board: short-circuit at 230 V_{AC} - 50 Hz - full load and open loop protection intervention at 20 W load

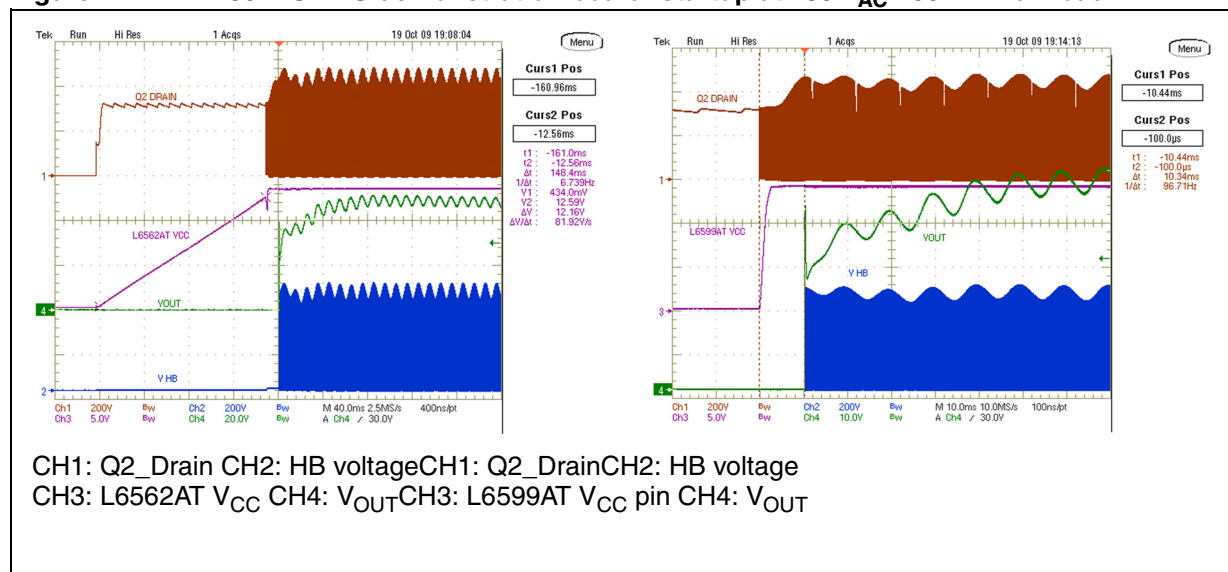


On the righthand side of [Figure 11](#) the operation of the demonstration board during “open-loop” operation by the LLC stage is shown. The open-loop operation also provides an increase of the auxiliary voltage which triggers the L6599AT pin #9 (DIS) protection pin via the Zener diode D17. As a consequence, the L6599AT shuts down, stopping the operation. The L6599AT also activates the PFC_STOP pin (#9) which also stops the PFC, therefore both controllers are no longer powered by V_{CC} . Once V_{CC} drops below the UVLO the latch is removed and a new startup cycle takes place. This sequence lasts until the open-loop is removed.

4.5 Converter startup

On the lefthand side of [Figure 12](#) the converter startup is shown. It is possible to note that at nominal input voltage the converter begins operation in ~150 ms. This is the time needed to charge the V_{CC} to the L6562AT turn-on voltage. Therefore the L6562AT starts switching and the PFC output voltage starts increasing. Once the PFC output voltage reaches the enable level set via the L6599AT LINE pin (~430 V), even the LLC stage starts switching and the output voltage rises up to the nominal level. The V_{CC} is initially supplied by the PFC coil charge pump, and then, once the L6599AT starts operating, the V_{CC} is also provided by the LLC transformer auxiliary winding. Details of converter sequencing can be found on the righthand side of [Figure 12](#).

Figure 12. EVL130W-SL-EU demonstration board: startup at 230 V_{AC} - 50 Hz - full load



[Figure 12](#) shows a correct startup of the board using an active load, with only the capacitors for the 48 V populating the board. When powering current regulators with LEDs it is possible that the board may show an incorrect startup, with output voltage going up and down and the LEDs flashing. As already explained in [Section 4.3: Dynamic load operation](#), the board needs an additional 40 μ F capacitance on the +48 V.

4.6 Thermal map

In order to check the design reliability, a thermal mapping by means of an IR camera was done. In [Figure 13](#) and [14](#) the thermal measurements of the board, both sides, at nominal input voltage are shown. Some pointers visible on the images have been placed across key components. The ambient temperature during both measurements was 27 °C.

Figure 13. Thermal map at 230 V_{AC} - 50 Hz - full load - PCB top side

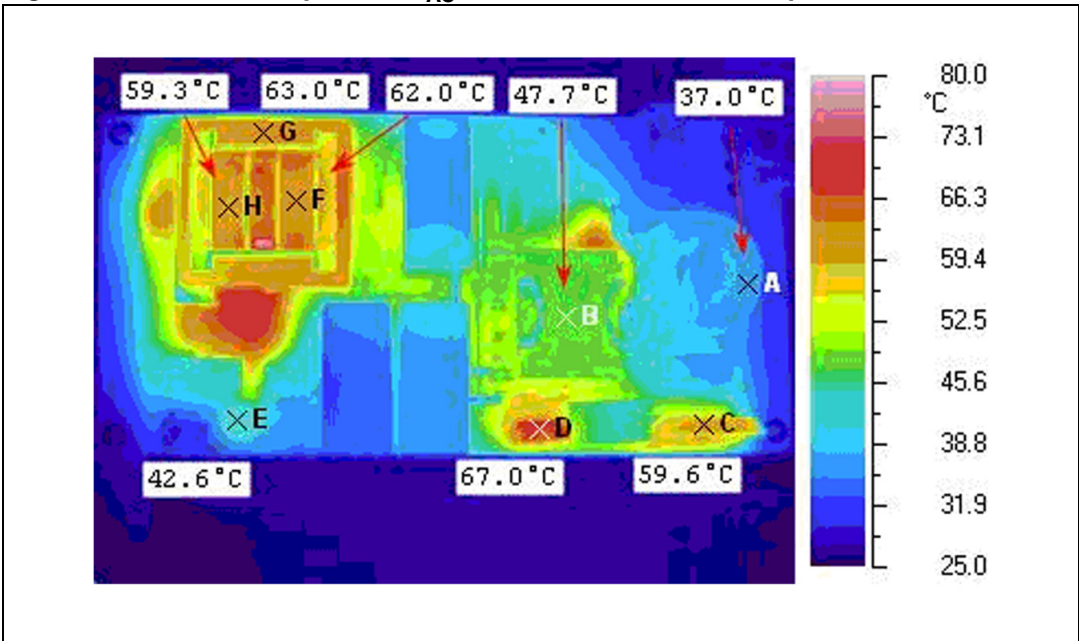


Table 2. Thermal maps reference points - PCB top side

Point	Reference	Description
A	L2	EMI filtering inductor
B	L1	PFC inductor
C	D3	Bridge rectifier
D	Q2	PFC MOSFET
E	L3	Output filter inductor
F	T1	Resonant power transformer - primary winding
G	T1	Resonant power transformer - ferrite core
H	T1	Resonant power transformer - secondary winding

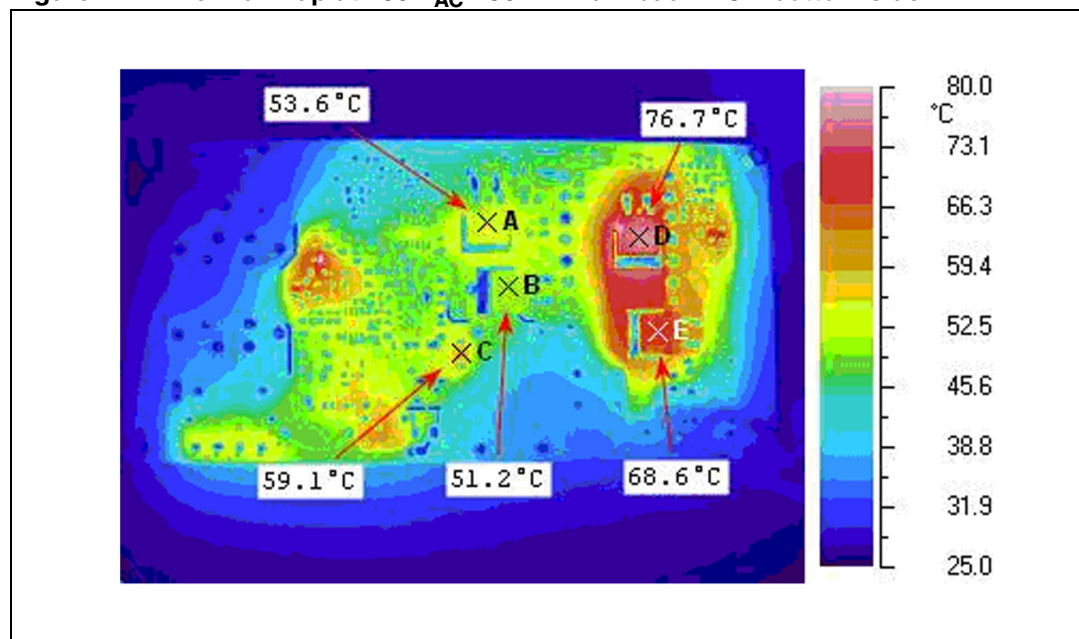
Figure 14. Thermal map at 230 V_{AC} - 50 Hz - full load - PCB bottom side

Table 3. Thermal maps reference points - PCB bottom side

Point	Reference	Description
A	Q4	LLC resonant HB MOSFET
B	Q5	LLC resonant HB MOSFET
C	D2	PFC output diode
D	D12	Output rectifier
E	D11	Output rectifier

5 Conducted emission pre-compliance test: peak measurement

Figure 15 and 16 show the peak measurement of the conducted noise at full load and nominal mains voltage. The limits on the diagrams are the EN55022 Class-B. As seen in the diagrams, for both input wires the measurements are well below the limits.

Figure 15. CE peak measure at 230 V_{AC} and full load - phase wire

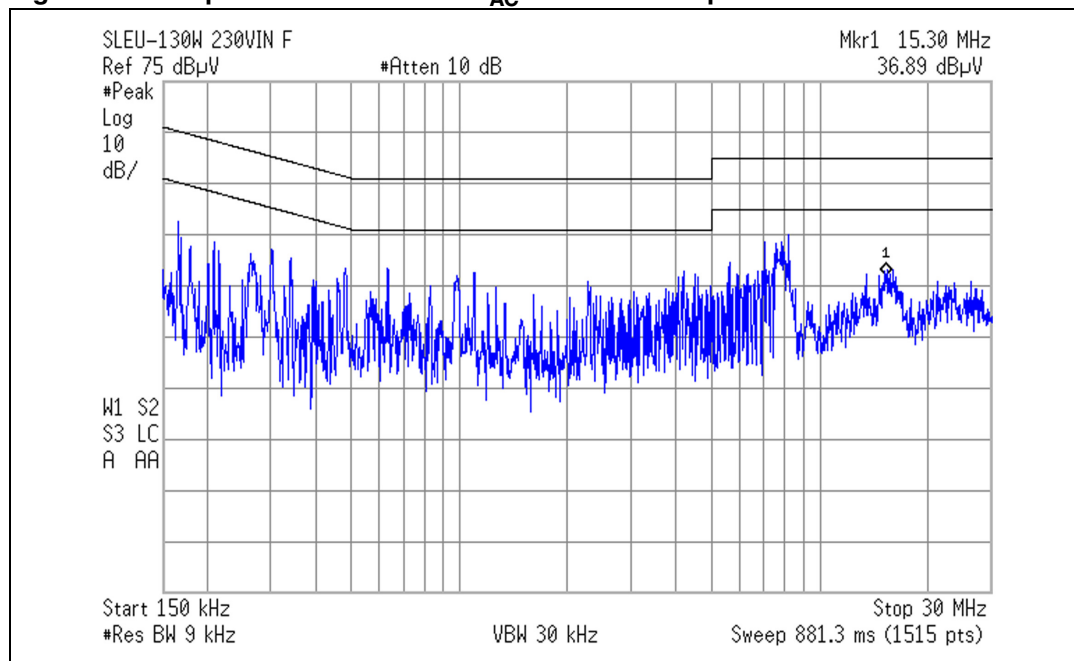
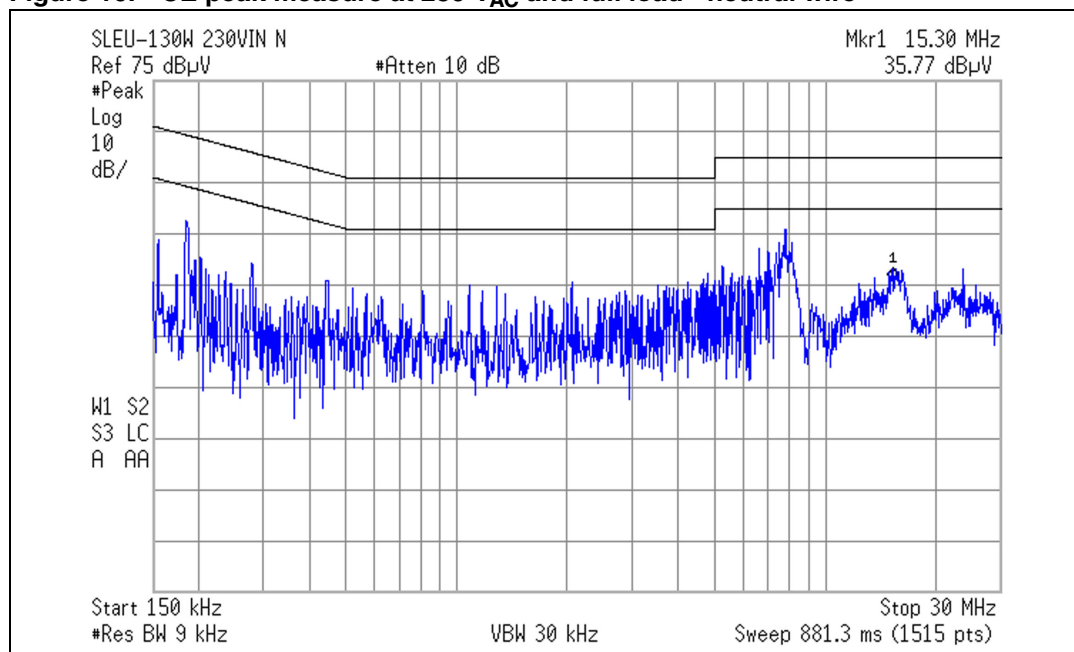


Figure 16. CE peak measure at 230 V_{AC} and full load - neutral wire



6 Bill of material

Table 4. EVL130W-SL-EU demonstration board: bill of material

Des.	Part type/ part value	Case style/ package	Description	Supplier
C1	2N2-Y1	4.5 x 12.0 p.10 mm	Y1 safety cap. DE1E3KX222M	Murata
C10	1 μ F	1206	50 V CERCAP - general purpose - X7R - 10%	TDK®
C11	220 nF	0805	16 V CERCAP - general purpose - X7R - 10%	Murata
C12	0R0	0805	SMD standard film res. - 1/8 W - 1% - 100 ppm/°C	VISHAY®
C13	10 μ F	1210	25 V CERCAP - general purpose - X7R - 20%	TDK
C15	15 nF	0805	50 V CERCAP - general purpose - X7R - 10%	KEMET
C16	220 pF	0805	50 V CERCAP - general purpose - COG - 5%	KEMET
C17	4.7 μ F	7.8 x 7.8 p. 5	63 V - MKT film cap. - B32529D0475M000	EPCOS
C18	4.7 μ F	7.8 x 7.8 p. 5	63 V - MKT film cap. - B32529D0475M000	EPCOS
C19	100 nF	0805	100 V CERCAP - general purpose - X7R - 10%	AVX
C2	470 nF - X2	9.0 x 18.0 p.15 mm	X2 - MKP film cap. - B32922C3474K	EPCOS
C20	15 nF	DWG - 5 x 18 p.15 mm	1000 V - MKP film cap. - B32652A0153K000	EPCOS
C21	220 nF	0805	16 V CERCAP - general purpose - X7R - 10%	Murata
C22	100 nF	1206	50 V CERCAP - general purpose - X7R - 10%	KEMET
C24	4.7 μ F	0805	6.3 V CERCAP - general purpose - X5R - 10%	EPCOS
C25	470 pF	0805	50 V CERCAP - general purpose - COG - 5%	EPCOS
C26	4.7 nF	0805	50 V CERCAP - general purpose - X7R - 10%	KEMET
C27	220 nF	0805	50 V CERCAP - general purpose - X7R - 10%	Murata
C3	470 nF - X2	9.0 x 18.0 p. 15 mm	X2 - MKP film cap. - B32922C3474K	EPCOS
C30	10 μ F	1210	25 V CERCAP - general purpose - X7R - 20%	TDK
C31	220 nF	0805	16 V CERCAP - general purpose - X7R - 10%	Murata
C32	220 nF	0805	16 V CERCAP - general purpose - X7R - 10%	Murata
C33	10 nF	0805	50 V CERCAP - general purpose - X7R - 10%	KEMET
C34	220 pF	1206	1 KV high voltage CERCAP - X7R - 10%	AVX
C35	220 nF	0805	16 V CERCAP - general purpose - X7R - 10%	Murata
C36	N. M.	0805	Not mounted	
C37	N. M.	0805	Not mounted	
C38	N. M.	0805	Not mounted	

Table 4. EVL130W-SL-EU demonstration board: bill of material (continued)

Des.	Part type/ part value	Case style/ package	Description	Supplier
C39	470 nF	0805	25 V CERCAP - general purpose - X7R - 10%	KEMET
C4	470 nF - X2	9.0 × 18.0 p.15 mm	X2 - MKP film cap. - B32922C3474K	EPCOS
C40	10 µF	2220	50 V - CERCAP - general purpose - X7R - 20%	TDK
C41	N. M.	0805	Not mounted	
C5	5 µF	14 × 31.5 p.27.5 mm	800 V - MKP film cap. - B32774D8505K000	EPCOS
C6	5 µF	14 × 31.5 p. 27.5 mm	800 V - MKP film cap. - B32774D8505K000	EPCOS
C7	5 µF	14 × 31.5 p. 27.5 mm	800 V - MKP film cap. - B32774D8505K000	EPCOS
C8	2.2 nF - Y1	4.5 × 12 p.10 mm	Y1 safety cap. DE1E3KX222M	Murata
C9	10 nF	1206	100 V CERCAP - general purpose - X7R - 10%	KEMET
D1	1.4007 nF	DO-41	General purpose rectifier	VISHAY
D10	N. M.	SOD-80	Not mounted	
D11	STPS10150CG	D2PAK	Power Schottky rectifier	STMicroelectronics™
D12	STPS10150CG	D2PAK	Power Schottky rectifier	STMicroelectronics
D13	LL4148	SOD-80	Fast switching diode	VISHAY
D14	LL4148	SOD-80	Fast switching diode	VISHAY
D15	BZV55-B24	SOD-80	Zener diode	VISHAY
D16	LL4148	SOD-80	Fast switching diode	VISHAY
D17	BZV55-B24	SOD-80	Zener diode	VISHAY
D18	LL4148	SOD-80	Fast switching diode	VISHAY
D19	LL4148	SOD-80	Fast switching diode	VISHAY
D2	STTH3L06U	SMB	Ultrafast high voltage rectifier	STMicroelectronics
D20	STPS1L60A	SMA	Fast switching diode	STMicroelectronics
D21	BZV55-B24	SOD-80	Zener diode	VISHAY
D22	BZV55-B24	SOD-80	Zener diode	VISHAY
JPX9 /D23	JUMPER		Wire jumper	
D24	LL4148	SOD-80	Fast switching diode	VISHAY
D3	GBU8J	STYLE GBU - DWG	Single-phase bridge rectifier	VISHAY
D4	LL4148	SOD-80	Fast switching diode	VISHAY
D5	LL4148	SOD-80	Fast switching diode	VISHAY
D6	LL4148	SOD-80	Fast switching diode	VISHAY

Table 4. EVL130W-SL-EU demonstration board: bill of material (continued)

Des.	Part type/ part value	Case style/ package	Description	Supplier
D7	BZV55-B15	SOD-80	Zener diode	VISHAY
D8	LL4148	SOD-80	Fast switching diode	VISHAY
D9	LL4148	SOD-80	Fast switching diode	VISHAY
F1	FUSE T4A	8.5 x 4 p. 5.08 mm	Fuse 4 A - time lag - 3921400	Littlefuse
J1	MKDS 1,5/ 3-5,08	p. 5.08 mm	PCB term. block, screw conn., pitch 5 mm - 3 W.	PHOENIX CONTACT
J2	MKDS 1,5/ 2-5,08	p. 5. 08 mm	PCB term. block, screw conn., pitch 5 mm - 2 W.	PHOENIX CONTACT
L1	1974.0001	DWG	PFC choke - 520 μ H PQ26/20	MAGNETICA
L2	12 mH	DWG	CM filter 2019.0002	MAGNETICA
L3	3.3 μ H - 4.7 A	Dia. 7.7 p. 5 mm	Inductor 1071.0080	MAGNETICA
Q1	BC846C	SOT-23	NPN small signal BJT	VISHAY
Q2	STF22NM60N	TO220	N-channel Power MOSFET	STMicroelectronics
Q3	N. M.	SOT-23	Not mounted	
Q4	STD10NM60N	DPAK	N-channel Power MOSFET	STMicroelectronics
Q5	STD10NM60N	DPAK	N-channel Power MOSFET	STMicroelectronics
Q6	BC846C	SOT-23	NPN small signal BJT	VISHAY
Q7	BC846C	SOT-23	NPN small signal BJT	VISHAY
Q8	BC846C	SOT-23	NPN small signal BJT	VISHAY
R1	N. M.	0805	Not mounted	
R10	1.2 M Ω	1206	SMD standard film res. - 1/4 W - 1% - 100 ppm/ $^{\circ}$ C	VISHAY
R11	4.7 K Ω	1206	SMD standard film res. - 1/4 W - 5% - 250 ppm/ $^{\circ}$ C	VISHAY
R12	2.0 M Ω	1206	SMD standard film res. - 1/4 W - 5% - 250 ppm/ $^{\circ}$ C	VISHAY
R13	120 K Ω	1206	SMD standard film res. - 1/4 W - 5% - 250 ppm/ $^{\circ}$ C	VISHAY
R14	390 K Ω	1206	SMD standard film res. - 1/4 W - 5% - 250 ppm/ $^{\circ}$ C	VISHAY
R15	39 K Ω	0805	SMD standard film res. - 1/8 W - 1% - 100 ppm/ $^{\circ}$ C	VISHAY
R16	39 K Ω	0805	SMD standard film res. - 1/8 W - 1% - 100 ppm/ $^{\circ}$ C	VISHAY
R17	0 Ω	1206	SMD standard film res. - 1/4 W - 1% - 100 ppm/ $^{\circ}$ C	VISHAY
R18	56 K Ω	1206	SMD standard film res. - 1/4 W - 5% - 250 ppm/ $^{\circ}$ C	VISHAY
R19	0 Ω	0805	SMD standard film res. - 1/8 W - 1% - 100 ppm/ $^{\circ}$ C	VISHAY
R2	1.0 M Ω	1206	SMD standard film res. - 1/4 W - 1% - 100 ppm/ $^{\circ}$ C	VISHAY
R20	680 K Ω	0805	SMD standard film res. - 1/8 W - 5% - 250 ppm/ $^{\circ}$ C	VISHAY
R21	33 Ω	0805	SMD standard film res. - 1/8 W - 5% - 250 ppm/ $^{\circ}$ C	VISHAY

Table 4. EVL130W-SL-EU demonstration board: bill of material (continued)

Des.	Part type/ part value	Case style/ package	Description	Supplier
R22	15 K Ω	0805	SMD standard film res. - 1/8 W - 5% - 250 ppm/ $^{\circ}$ C	VISHAY
R23	100 Ω	0805	SMD standard film res. - 1/8 W - 5% - 250 ppm/ $^{\circ}$ C	VISHAY
R24	1.4 M Ω	1206	SMD standard film res. - 1/4 W - 1% - 100 ppm/ $^{\circ}$ C	VISHAY
R25	82 K Ω	0805	SMD standard film res. - 1/8 W - 1% - 100 ppm/ $^{\circ}$ C	VISHAY
R26	15 K Ω	0805	SMD standard film res. - 1/8 W - 1% - 100 ppm/ $^{\circ}$ C	VISHAY
R27	470 Ω	0805	SMD standard film res. - 1/8 W - 5% - 250 ppm/ $^{\circ}$ C	VISHAY
R29	N. M.	1206	Not mounted	
R3	10 Ω	1206	SMD standard film res. - 1/4 W - 5% - 250 ppm/ $^{\circ}$ C	VISHAY
R30	0 Ω	1206	SMD standard film res. - 1/4 W - 1% - 100 ppm/ $^{\circ}$ C	VISHAY
R31	0 Ω	1206	SMD standard film res. - 1/4 W - 1% - 100 ppm/ $^{\circ}$ C	VISHAY
R32	270 K Ω	0805	SMD standard film res. - 1/8 W - 5% - 250 ppm/ $^{\circ}$ C	VISHAY
R33	N. M.	2010	Not mounted	
R34	0.39 Ω	2010	SMD standard film res. - 1/2 W - 5% - 250 ppm/ $^{\circ}$ C	VISHAY
R36	4.7 K Ω	0805	SMD standard film res. - 1/8 W - 5% - 250 ppm/ $^{\circ}$ C	VISHAY
R37	6.8 K Ω	1206	SMD standard film res. - 1/4 W - 5% - 250 ppm/ $^{\circ}$ C	VISHAY
R38	2.2 M Ω	0805	SMD standard film res. - 1/8 W - 5% - 250 ppm/ $^{\circ}$ C	VISHAY
R39	51 Ω	0805	SMD standard film res. - 1/8 W - 5% - 250 ppm/ $^{\circ}$ C	VISHAY
R4	1.2 M Ω	1206	SMD standard film res. - 1/4 W - 1% - 100 ppm/ $^{\circ}$ C	VISHAY
R41	4.7 K Ω	1206	SMD standard film res. - 1/4 W - 5% - 250 ppm/ $^{\circ}$ C	VISHAY
R42	10 K Ω	0805	SMD standard film res. - 1/8 W - 1% - 100 ppm/ $^{\circ}$ C	VISHAY
R43	10 K Ω	1206	SMD standard film res. - 1/4 W - 5% - 250 ppm/ $^{\circ}$ C	VISHAY
R44	N. M.	0805	Not mounted	
R45	220 K Ω	1206	SMD standard film res. - 1/4 W - 5% - 250 ppm/ $^{\circ}$ C	VISHAY
R46	51 Ω	1206	SMD standard film res. - 1/4 W - 5% - 250 ppm/ $^{\circ}$ C	VISHAY
R47	220 K Ω	1206	SMD standard film res. - 1/4 W - 5% - 250 ppm/ $^{\circ}$ C	VISHAY
R49	0 Ω	0805	SMD standard film res. - 1/8 W - 5% - 250 ppm/ $^{\circ}$ C	VISHAY
R5	120 K Ω	1206	SMD standard film res. - 1/4 W - 5% - 250 ppm/ $^{\circ}$ C	VISHAY
R50	10 K Ω	0805	SMD standard film res. - 1/8 W - 5% - 250 ppm/ $^{\circ}$ C	VISHAY
R51	N. M.	0805	Not mounted	
R52	10 Ω	0805	SMD standard film res. - 1/8 W - 5% - 250 ppm/ $^{\circ}$ C	VISHAY
R53	100 Ω	1206	SMD standard film res. - 1/4 W - 5% - 250 ppm/ $^{\circ}$ C	VISHAY
R54	2.2 K Ω	0805	SMD standard film res. - 1/8 W - 5% - 250 ppm/ $^{\circ}$ C	VISHAY
R55	470 Ω	0805	SMD standard film res. - 1/8 W - 5% - 250 ppm/ $^{\circ}$ C	VISHAY
R56	N. M.	0805	Not mounted	

Table 4. EVL130W-SL-EU demonstration board: bill of material (continued)

Des.	Part type/ part value	Case style/ package	Description	Supplier
R57	100 Ω	0805	SMD standard film res. - 1/8 W - 5% - 250 ppm/°C	VISHAY
R58	150 K Ω	0805	SMD standard film res. - 1/8 W - 1% - 100 ppm/°C	VISHAY
R59	1.5 Ω	1206	SMD standard film res. - 1/4 W - 5% - 250 ppm/°C	VISHAY
R6	1.0 M Ω	1206	SMD standard film res. - 1/4 W - 1% - 100 ppm/°C	VISHAY
R60	8.2 K Ω	0805	SMD standard film res. - 1/8 W - 1% - 100 ppm/°C	VISHAY
R61	N. M.	1206	Not mounted	
R62	100 K Ω	0805	SMD standard film res. - 1/8 W - 5% - 250 ppm/°C	VISHAY
R7	2.0 M Ω	1206	SMD standard film res. - 1/4 W - 5% - 250 ppm/°C	VISHAY
R8	120 K Ω	1206	SMD standard film res. - 1/4 W - 5% - 250 ppm/°C	VISHAY
R9	1.5 M Ω	1206	SMD standard film res. - 1/4 W - 1% - 100 ppm/°C	VISHAY
RV1	300 V _{AC}	dia. 15 x 5 p. 7.5 mm	300 V metal oxide varistor - B72214S0301K101	EPCOS
RX1	0 Ω	1206	SMD standard film res. - 1/4 W - 5% - 250 ppm/°C	VISHAY
RX2	0 Ω	1206	SMD standard film res. - 1/4 W - 5% - 250 ppm/°C	VISHAY
T1	1860.0013	DWG - ETD34	Resonant power transformer	MAGNETICA
U1	L6562ATD	SO-8	TM PFC controller	STMicroelectronics
U2	L6599ATD	SO-16	Improved HV resonant controller	STMicroelectronics
U3	SFH617A-2X009	SMD4 - 10.16 MM	Optocoupler	VISHAY
U4	SEA05 - N. M.	SOT-23-6L	CC/CV controller – not mounted	STMicroelectronics
U5	TS2431AILT	SOT-23	Programmable shunt voltage reference	STMicroelectronics
Z1	PCB REV. 0.2			

7 PFC coil specifications

General description and characteristics

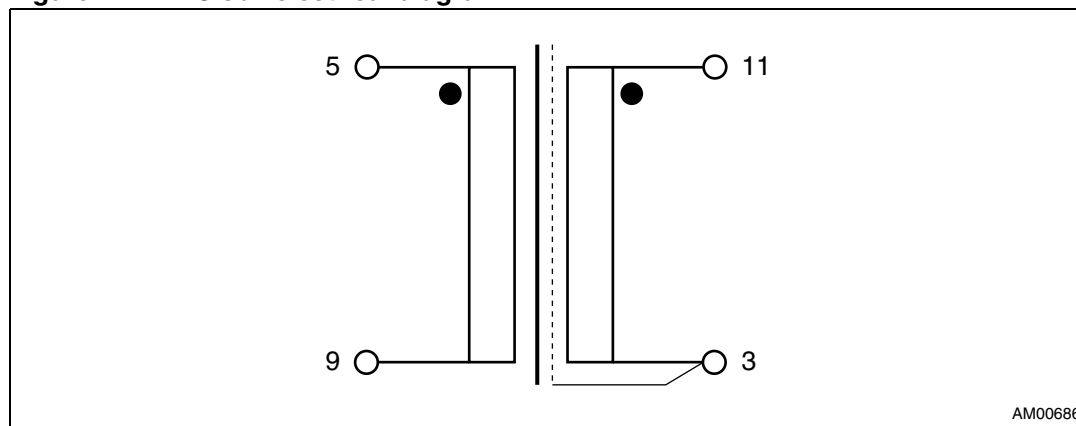
- Application type: consumer, home appliance
- Transformer type: open
- Coil former: vertical type, 6 + 6 pins
- Max. temp. rise: 45 °C
- Max. operating ambient temperature: 60 °C
- Mains insulation: N. A.
- Unit finishing: varnished

Electrical characteristics

- Converter topology: boost, transition mode
- Core type: PQ26/20-PC44 or equivalent
- Min. operating frequency: 40 kHz
- Typical operating frequency: 120 kHz
- Primary inductance: 1 mH $\pm$ 10% at 1 kHz-0.25 V^(a)
- Peak primary current: 2.1 Apk
- RMS primary current: 0.85 A_{RMS}

Electrical diagram and winding characteristics

Figure 17. PFC coil electrical diagram



a. Measured between pins #5 and #9.

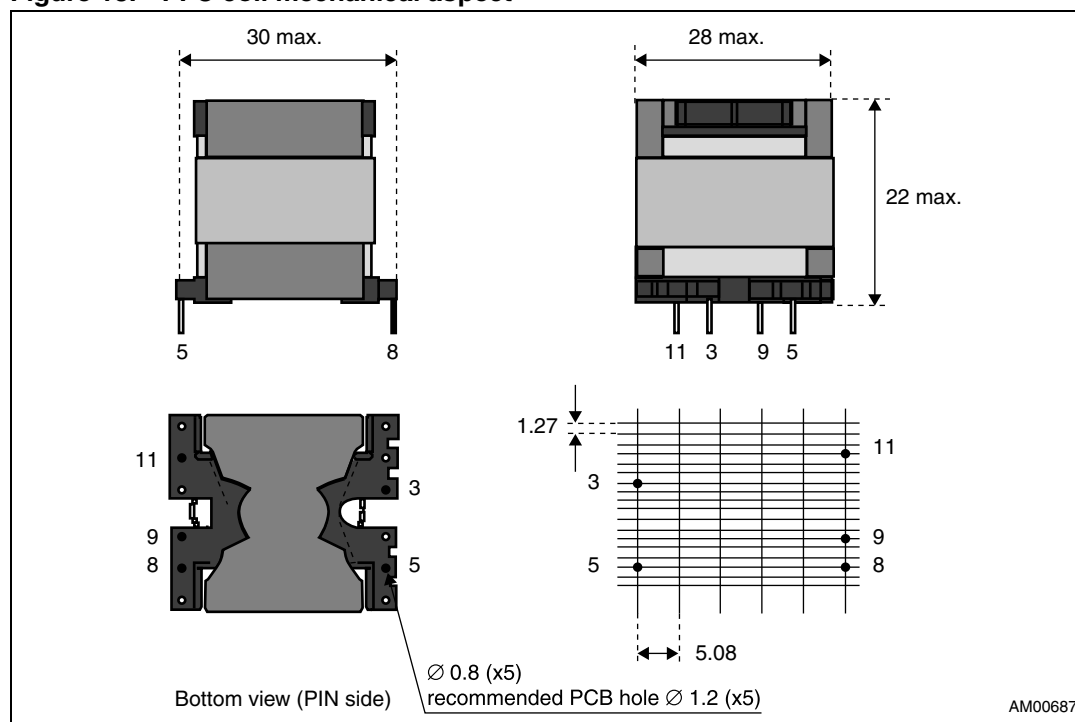
Table 5. PFC coil winding data

Pins	Windings	Number of turns	Wire type
11 - 3	Aux.	7	0.28 mm - G2
5 - 9	Primary	71	Multistrand #6 x 0.20 mm - G2

- Primary winding external insulation: 2 layers of polyester tape.
- Aux. winding is wound on top of primary winding.
- External insulation: 2 layers of polyester tape
- Wire connected to pin 5 is insulated by sleeve.

Mechanical aspect and pin numbering

- Maximum height from PCB: 22 mm
- Coil former type: vertical, 6+6 pins (pins #1, 2, 4, 6, 7, 10, and 12 are removed)
- Pin distance: 3.81 mm
- Row distance: 25 mm
- Coil former P/N: TDK BPQ26/20-1112CP
- External copper shield: Not insulated, wound around the ferrite core and including the coil former. Height is 8 mm. Connected to pin #3 by a soldered solid wire.

Figure 18. PFC coil mechanical aspect⁽¹⁾

1. Dimensions are in millimeters, drawing is not to scale.

Manufacturer

- MAGNETICA, R. Volpini - Italy (www.magnetica.it)
- Inductor P/N: 1974.0001.

8 Transformer specification

General description and characteristics

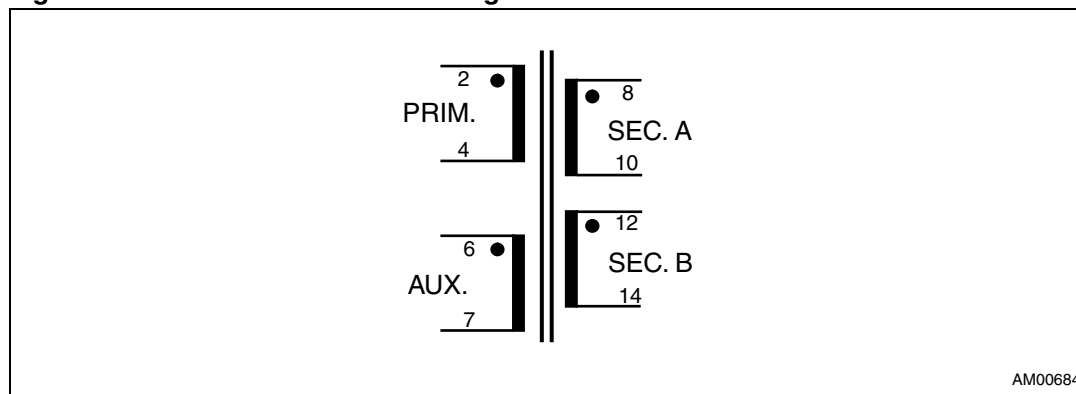
- Application type: consumer, home appliance
- Transformer type: open
- Coil former: horizontal type, 7 + 7 pins, two slots
- Max. temp. rise: 45 °C
- Max. operating ambient temperature: 60 °C
- Mains insulation: acc. With EN60950

Electrical characteristics

- Converter topology: half-bridge, resonant
- Core type: ETD34-PC44 or equivalent
- Min. operating frequency: 70 kHz
- Typical operating frequency: 100 kHz
- Primary inductance: 770 $\mu\text{H} \pm 15\%$ at 1 kHz - 0.25 V^(b)
- Leakage inductance: 170 μH at 100 kHz - 0.25 V^(c)

Electrical diagram and winding characteristics

Figure 19. Transformer electrical diagram



b. Measured between pins 2-4.

c. Measured between pins 2-4 with only one secondary winding shorted. The difference between the two measured leakage inductances must be < 10%.

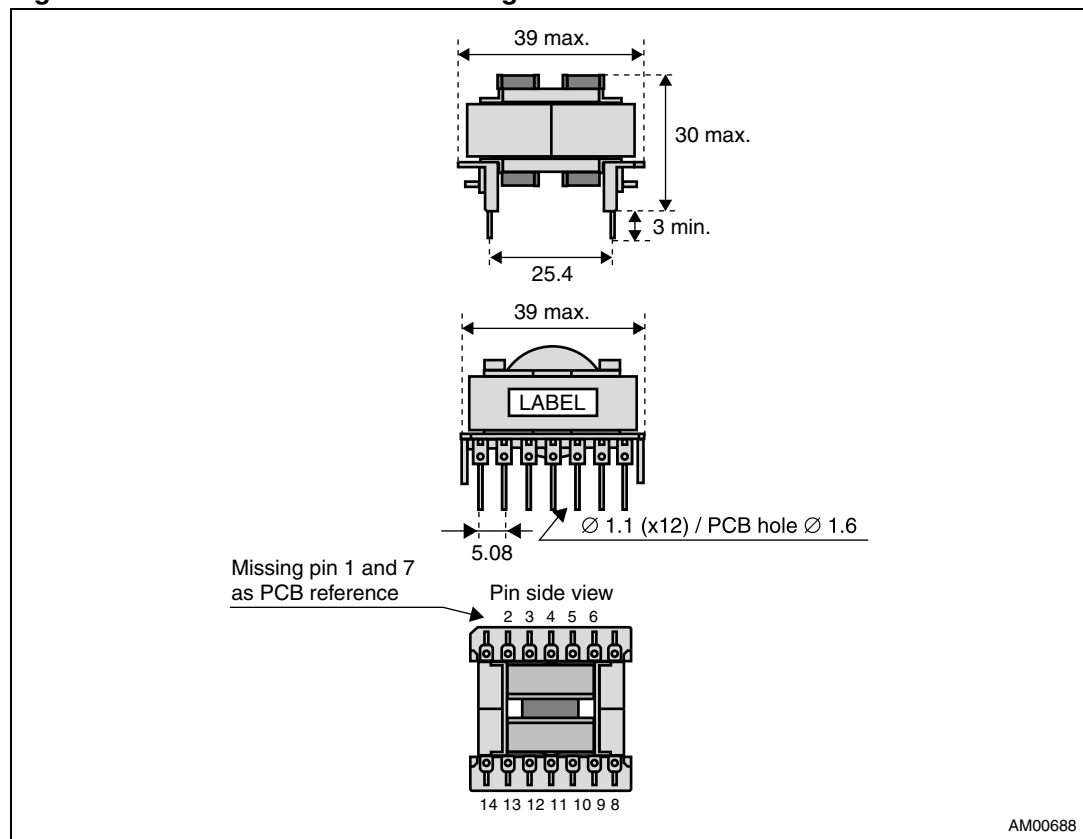
Table 6. Transformer winding data

Pins	Winding	RMS current	Number of turns	Wire type
2-4	Primary	1 A _{RMS}	47	#30 x 0.1 mm - G2
8-10	SEC - A ⁽¹⁾	0.05 A _{RMS}	9	#60 x 0.1 mm - G2
12-14	SEC - B4 ⁽¹⁾	2.2 A _{RMS}	9	#60 x 0.1 mm - G2
6-7	Aux. ⁽²⁾	2.2 A _{RMS}	3	0.28 mm - G2

1. Secondary windings A and B must be wound in parallel.
2. Aux. winding is wound on top of primary winding, turns are close to each other, placed on external side of the coil former.

Mechanical aspect and pin numbering

- Maximum height from PCB: 30 mm
- Coil former type: horizontal, 7 + 7 pins (pins #1, #3 and #5 removed for PCB reference)
- Pin distance: 5.08 mm
- Row distance: 25.4 mm.

Figure 20. Transformer overall drawing

1. Quotes are in millimeters, drawing is not to scale.

Manufacturer

- MAGNETICA, R. Volpini - Italy (www.magneticait.it)
- Transformer P/N: 1860.0013.

9 Revision history

Table 7. Document revision history

Date	Revision	Changes
01-Mar-2010	1	Initial release.
28-Sep-2012	2	– Modified: Table 4 – Modified: Figure 2 – Minor text changes to improve readability

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