AN5328
Application note

150 V - 150 W LED driver with the L6564H and L6699 transition mode PFC pre-regulator, half bridge LCC resonant converter

Introduction

The growing popularity of LEDs, thanks to their high efficiency and longer lifetime, are dramatically contributing to the reduction of energy consumption for internal and external lighting. Street lighting applications require a power supply specifically designed to power an LED lamp having high efficiency and long lifetime in order to guarantee maintenance-free operation during the LED lifetime.

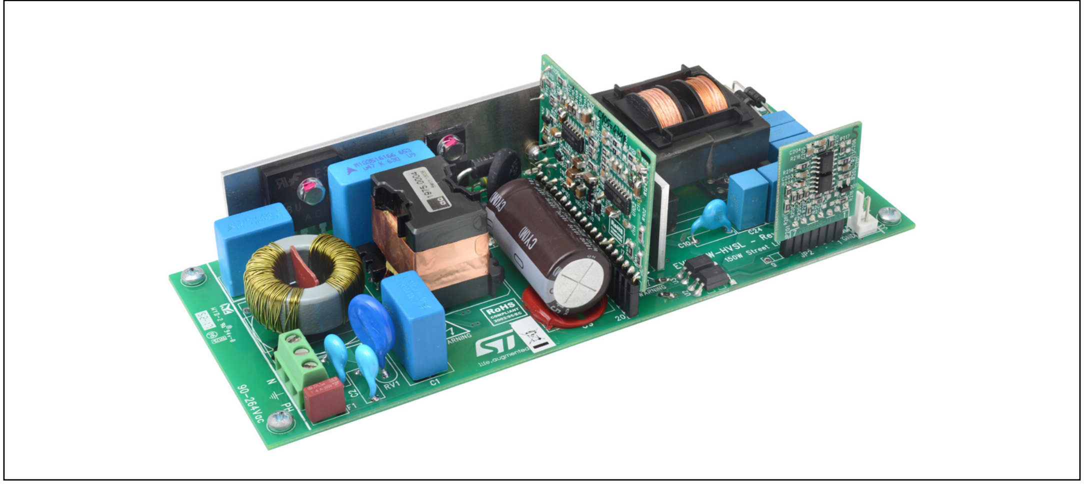
This application note describes the performance of a 150 W, wide-range mains, power-factor corrected, LED driver board. Its electrical specification is tailored on a typical high-power street lighting application.

The architecture is based on a two-stage approach: a front-end PFC pre-regulator, featuring the L6564H, and a downstream half-bridge LCC resonant converter, featuring the L6699. LCC topology has been chosen because it allows to build, in practice and in brief, a current source that is the natural choice to drive an LED string.

Overall, the main features of this design are high efficiency, low open load input power, reduced harmonics compliant with the EN61000-3-2 Class-C and conducted EMC within the relevant EN55022 limits. Another noticeable feature of this LED driver is the extremely wide dimming capability; the board can actually regulate the current from maximum level down to less than 10% with analog dimming and to 1% in PWM dimming. The PWM dimming is perfectly flicker free, because even in the case of very low current it is kept continuous (DC) in the LED and thus independent of the frequency of the PWM dimming signal.

The board also has protection features in case of overload, short-circuit, open loop by each section. For this particular application, all protections in case of intervention have an auto-restart functionality. The board is shown in the following *Figure 1*.

Figure 1. EVL6699-HVSL: wide input mains range 150 W LED driver



Contents

List of tables

List of figures

1 Main characteristics and circuit description

The main features of the LED driver are listed here below:

- Universal Input Mains Range: 90÷264 Vac - Frequency 45÷65 Hz
- Output voltage: 150 V at 1 A continuous operation
- Mains Harmonics: EN61000-3-2 Class-C and JEITA-MITI Class-C
- No Load Mains Consumption: < 500 mW (optimized board, see *1.1*)
- THD: < 10% at 230 Vac from 35% to 100% of full load
- Efficiency: > 91% @ full load
- Auxiliary stage: No need of aux SMSP (Viper or equivalent)
- Conducted EMC: Within EN55022-Class-B limits
- Safety: Meets EN60950
- Dimensions: 69x157 mm, 28 mm components maximum height
- PCB: Double side, 70 µm, FR-4, Mixed PTH/SMT
- Dimming: Analog, Resistive, PWM (open collector)
- Feedback loops: Constant Current and Constant Voltage
- Protections: LED short-circuit, LED string open, regulation loop failure
- Start-up time: < 400 ms, from main connection to steady-state

The circuit is composed of two stages: a front-end PFC based on the L6564H and a half-bridge LCC resonant converter based on the L6699 as resonant stage controller.

The L6564H embodies a transition mode (TM) PFC, a high voltage current source to manage the startup, a highly linear multiplier, along with a special correction circuit that reduces crossover distortion of the mains current and allows wide range mains operation with an extremely low THD even over a large load range. All protections such as OVP, feedback disconnection (FFP), OCP are embedded too, although FFP is foreseen but not implemented at schematic level.

The half-bridge (HB) controller L6699 provides two complementary outputs directly driving the high-side and low-side MOSFET 180° out-of-phase, with a self-adjustable deadtime to achieve the ZVS in all load conditions. Additionally, it embeds a fully programmable oscillator, protections to prevent ZVS lost, OCP and burst mode functionalities. The overload protection mechanism based on the DELAY pin is disabled since the LED driver is a current generator, so it is inherently protected against overload and/or short-circuit, at output.

PFC power stage

The PFC stage works as pre-regulator and feeds the resonant stage with constant voltage of 400 V. It is based on peak current mode control with an internal VFF and it includes also a complete set of protections: cycle-by-cycle overcurrent (OCP), an output overvoltage (OVP), feedback failure (FFP), AC brownout/in, boost inductor saturation. Actually, this LED driver includes two control loops, CC for output current control and CV for open load control, with dedicated optocouplers, so the feedback disconnection path is foreseen at schematic level, but disabled in the implementation (details hereinafter, paragraph *Protections*).

Resonant power stage

The L6699 is an advanced double-ended controller specific to the resonant half-bridge topology. It provides symmetrical complementary duty cycle: the high-side switch and the low-side switch are driven ON/OFF 180° out-of-phase for exactly the same time. Output voltage regulation is obtained by modulating the operating frequency. The deadtime inserted between the turn-off of one switch and the turn-on of the other one is automatically adjusted to best fit the transition times of the half-bridge midpoint.

To drive the high-side switch with the bootstrap approach, the L6699 incorporates a high voltage floating structure able to withstand more than 600 V with a synchronous-driven high voltage DMOS that replaces the external fast-recovery bootstrap diode.

The IC enables the user to set the operating frequency range of the converter by means of a high accuracy externally programmable oscillator.

At startup, in addition to the traditional frequency shift soft-start (the switching frequency starts from a preset maximum value and then decays as far as the steady-state value determined by the control loop), a proprietary circuit controls the half-bridge to prevent hard switching.

At light load the IC works in burst-mode operation minimizing the converter input consumption.

IC protection functions include a current sense input for OCP with frequency shift and delayed shutdown with automatic restart. Additionally, the IC prevents the converter from working in or too close to the capacitive mode, to guarantee soft-switching. Other functions include a not-latched active-low disable input with current hysteresis, useful for power sequencing or for brownout protection, and an interface with the PFC controller that enables the switching-off of the pre-regulator during fault conditions or during burst mode operation.

The transformer uses the integrated magnetic approach, incorporating the resonant series inductance. Thus, no external additional coil is needed for the resonance.

The transformer secondary winding configuration is full-bridge, and makes use of four rectifier diodes (STTH3R02Q). A small LC filter has been added on the output, to reduce the high frequency ripple current through the LED string. The output capacitors are film type, to increase the system lifetime and minimize the size.

LCC topology

For the resonant tank, the LCC topology has been selected: varying reasons led to this choice. First, it looks like a current source because when the frequency is changed, the output current is almost not dependent on the load. Second, at given resonant inductance and capacitance, considering the voltage gain, the peak is higher and the slope is steeper than in an LLC topology, giving wider voltage at both input and output of the resonant tank. On the one hand, the input voltage range is not so relevant in this case, because of the PFC pre-regulator stage; however, on the other hand, a wide output voltage range is a key feature in LED driving application because it allows to accommodate larger LED string values. Third, if the switching frequency tends to ∞, then the voltage gain quickly tends to 0, not depending on the load: this behaviour allows to regulate down to very light loads without the need for burst mode operation of the resonant converter that would impact the light emission by the LED string. Of course, the continuous switching operation down to very light loads brings to not minimized light load consumption. Lastly, there is no need of precise transformer integration, because there is no leakage inductance, and, furthermore, it is a capacitor ratio that has to be set, rather than an inductance ratio, and this usually simplifies the design.

Feedback loops

The EVL6699-HVSL implements two different feedback loops, one controlling the output voltage, the other dedicated to regulate the output current: they have dedicated optocouplers and they work alternately; the former when the LED string is not connected, the latter when the LED string is connected.

During normal operation, when the LED string is connected, an LED driver has to regulate the current flowing in the LED string according to the dimming voltage. This is achieved by the current control loop. It is mainly located on the smaller daughterboard, at secondary side. The dimming signal applied to the connector J3 is filtered and then inserted as the reference signal in the CC error amplifier, comparing this signal with the signal coming from the current sensing resistor. The output of the CC error amplifier drives the optocoupler U2, which modulates the current through the CC loop RFMAX resistor (R129), and thus the resonant converter frequency. In this case, to prevent the flickering in case of deep dimming, the burst mode is not implemented in the CC loop: only continuous switching operation is allowed.

When the LED string is not connected, the control voltage loop rules the LED driver as soon as the output voltage goes above the maximum allowed value (150 V), being the set point of the CV loop right above it. The circuit is simply done with a TLVH431 configured as error amplifier, sensing the output voltage through a resistive divider and modulating the current in the optocoupler U3. The RC branch in parallel to the upper resistor of the divider is to modulate the rise of the output voltage at turn-on. As the output voltage goes over 150 V, the CV loop pulls current in the optocoupler, increasing the switching frequency and decreasing the feedback voltage until burst mode operation is triggered. The components are mainly located on the motherboard: only the CV loop RFMAX resistor (R130) and the RC to STBY pin (R131, C118) are located on the primary daughterboard.

So, on the one hand, during normal operation with the LED string connected, the converter is not allowed to work in burst mode to avoid flicker on the LED string, since the STBY pin is not connected to the CC feedback path. In this case, the output current is controlled by the current flowing into the resistor R129 whose value is such that the CC loop can push up the switching frequency of the converter to the values necessary to dimming down at very low levels (even below 10%).

Conversely, on the other hand, when the LED string is not connected, the converter operates in burst mode, the STBY pin being connected to the CV feedback path, in order to limit and control the open load output voltage while obtaining low switching losses at no load operation. In this case, the output voltage is controlled by the current flowing into the resistor R130 and the voltage level at pin STBY: the resistor value sets the maximum current that can be pulled down by the CV loop and so the maximum switching frequency: correspondingly, the minimum voltage at the STBY pin is set as well.

When the signal at the STBY pin goes below 1.24 V (typ.), the switching activity is stopped while L6699 is driven to a low consumption state and a 30 mV (typ.) hysteresis is applied to the internal comparator. Since there is no more energy transfer, the CV loop reaction is the reduction of the pulled current through the optocoupler, to which corresponds an increase in the voltage at the STBY pin. When the signal at the STBY pin goes above 1.27 V (typ.), L6699 comes back to normal switching operation that lasts until the signal at the STBY pin goes again below 1.24 V, driven by the CV loop. The frequency of the switching packet is defined by the value of the limiting resistor R130, while the duration of the idle period depends on the open load consumption and the feedback path response.

Lastly, during light load operation in burst mode, the PFC_STOP pin of the L6699 enables and disables the PFC stage, thus lowering the circuit losses.

Eventually, in case the output voltage rises for any reason above the set point value of the CV loop (~155 V), like in case the LED string fails to open, where we could get very high and dangerous potential on the secondary side that would bring the board to catastrophic failures and safety issues, the CV loop keeps the output voltage regulated.

Protections

The LED driver is a current source so it is inherently limited in case of overcurrent. In case the CC loop fails with the LED string connected, the voltage loop cannot operate because the output voltage would be clamped by the LED string, below the CV set point, but the output current would be uncontrolled. In this case, the LED driver is protected by the second level OCP integrated in the L6699 that immediately shuts down the IC itself when the signal at pin ISEN reaches 1.5 V (typ.).

An additional protection, at primary side, for feedback failure disconnection, can be implemented by mounting the Zener diode D106 (Zener voltage about 43 V) on the L6564H & L6699 daughterboard (the other necessary components are already mounted). The voltage of the resonant transformer auxiliary winding is sensed and if it gets too high, then the Zener diode D106 is activated and consequently the NPN transistor Q102 is turned on, pulling down the PFC_OK pin of L6564H that shuts down the IC itself.

Secondary auxiliary voltage regulator

Because of the high output voltage of the LED string, the secondary side control circuitry cannot be directly power supplied. So, the resonant transformer is provided with a secondary auxiliary winding from which the power supply voltage is derived.

The secondary auxiliary winding follows the output voltage, whose range is from 150 V down to about 30 V, since it is well coupled to the secondary output winding. So, the variation of the secondary auxiliary voltage is not compatible with a traditional LDO biased on the collector side of the NPN transistor.

Consequently, the LDO has been built on a depletion MOSFET, Q4, biased on the source side by the regulated output voltage. The LDO is driven by the shunt regulator U1 to give a typical output voltage of 12 V.

The overall schematic of the LCC LED driver is shown in the following *Figure 2*.

1.1 Schematic update for board optimization

With respect to the proposed schematic, the LED driver can be optimized from the viewpoint of the open load consumption and of the total harmonic distortion. The variation allows to save about 100 mW on the input power in open load and some points on the total harmonic distortion at light loads. The schematic update consists of the following items:

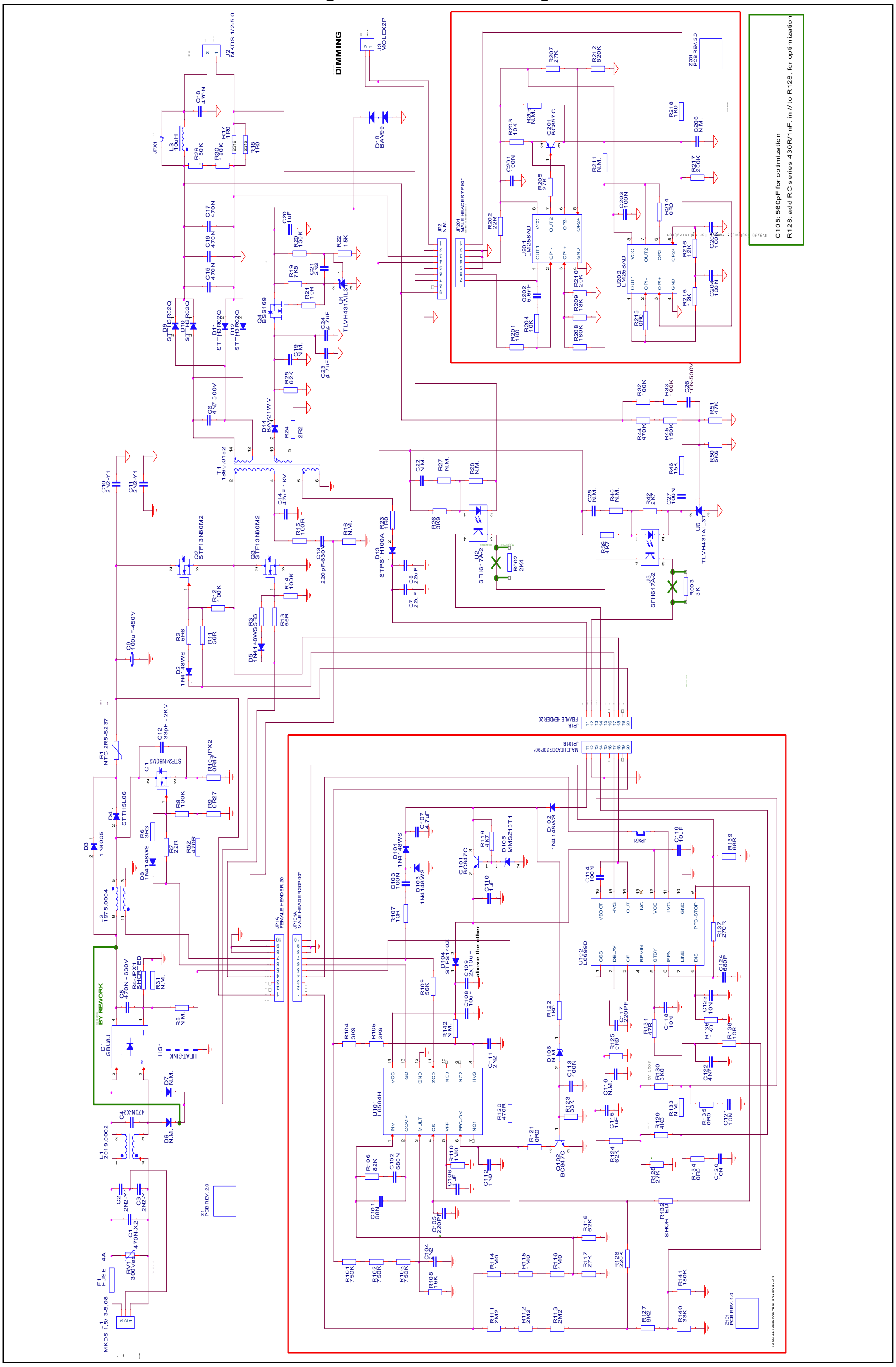
- R29 and R30 removed (output bleeder, on the motherboard)
- C105 from 220 pF to 560 pF (filter on pin CS of L6564H, on the primary daughterboard)

- RC series = 430 Ω / 1 nF added between pin RFMIN of L6699 and ground (on the primary daughterboard; at implementation level, the two extra components can be easily added near R128)

The board characterization and the application results have been carried on the optimized schematic.

The manufactured boards have not been updated, so they are according to the proposed schematic.

Figure 2. Electrical diagram



2 Efficiency and open load input power

Measurements carried out according to the following test bench and procedure: 1) Input power measured by power meter with voltage probe at the AC input of the LED driver, 2) Output voltage and current measured by a DMM without remote sensing, 3) Oscilloscope probes on the pin GD of L6564H, on the half-bridge node and on the output voltage connector, 4) Warm-up time about 1/2h at 230 Vac and preset current (VDIMM = open, IOUT ≈ 1.05A), then measurements from 100% dimming to minimum dimming, 5) Warm-up time about 1/2h at 115 Vac and preset current (VDIMM = open, IOUT ≈ 1.05A), then measurements from 100% dimming to minimum dimming.

Table 1 shows the overall efficiency measured at the nominal mains voltages, using an LED string, of about 135 V at 1A, as output load. ***The full load efficiency is 91% at 115 Vac, and 93% at 230 Vac***.

Table 1. Overall efficiency at nominal mains input voltage

Vin	Pin	VLED	ILED	Pout	Efficiency
[Vac]	[W]	[V]	[A]	[W]	%
230V-50Hz	152.48	135.15	1.050	141.91	93.07%
	144.67	134.48	1.000	134.48	92.96%
	129.28	133.15	0.900	119.84	92.69%
	114.26	131.64	0.800	105.33	92.18%
	99.58	130.17	0.700	91.14	91.52%
	85.08	128.52	0.600	77.16	90.70%
	71.09	126.83	0.500	63.45	89.26%
	57.26	124.85	0.400	49.95	87.24%
	43.77	122.51	0.300	36.75	83.97%
	29.86	119.73	0.200	23.95	80.19%
	16.07	115.82	0.100	11.58	72.07%
	11.28	113.43	0.060	6.81	60.34%

Table 1. Overall efficiency at nominal mains input voltage (continued)

Vin	Pin	VLED	ILED	Pout	Efficiency
[Vac]	[W]	[V]	[A]	[W]	%
115V-60Hz	154.49	134.33	1.050	141.05	91.30%
	146.48	133.61	1.000	133.61	91.21%
	130.68	132.22	0.900	119.00	91.06%
	115.22	130.82	0.800	104.66	90.83%
	99.98	129.32	0.700	90.52	90.54%
	85.29	127.73	0.600	76.64	89.86%
	70.97	125.99	0.500	63.00	88.76%
	56.91	124.05	0.400	49.62	87.19%
	43.25	121.75	0.300	36.57	84.56%
	30.03	118.92	0.200	23.81	79.28%
	17.33	115.03	0.100	11.51	66.41%
	13.06	112.94	0.060	6.78	51.89%

Measurements of efficiency versus output power are also reported in *Figure 3* while in *Figure 4* the efficiency is reported at different input mains voltage values: the measured efficiency is very high at full load, remaining above about 90% down to about half load and it still remains at good levels even decreasing the load down to about 8% of the nominal one. The measurement procedure has a warm-up time of about ¼ h at 90 Vac and given LED current, then the measurements have been taken at the different mains voltages.

Figure 3. Efficiency vs. output power

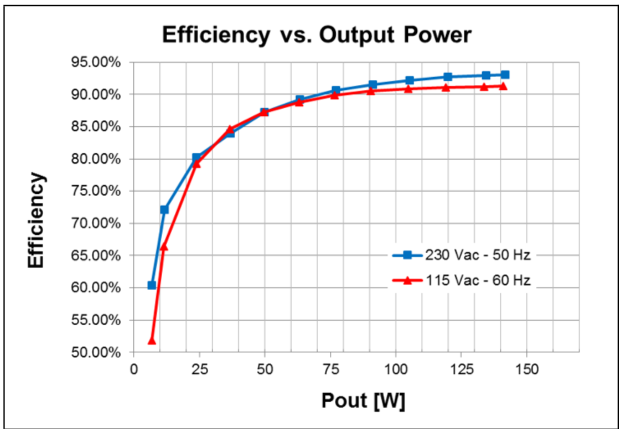
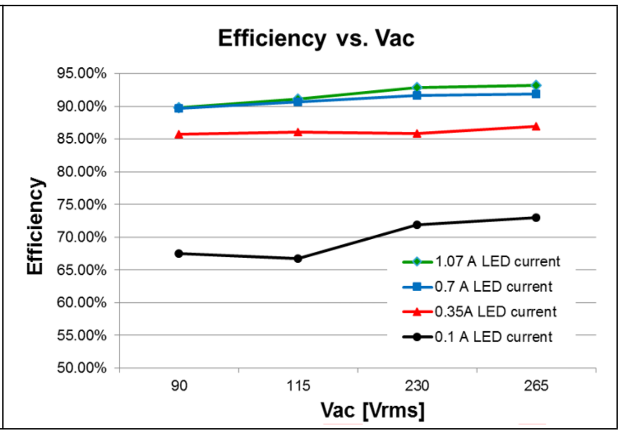


Figure 4. Efficiency vs. VAC



In order to measure the efficiency at the full load, given the unavailability of an LED string of about 150 V at 1 A, the LED driver has been loaded by an active load in CV mode. After a warm-up time of about ½ h at 230 Vac and preset current (1.05 A), the efficiency curve at high mains voltage, with respect to the output power, has been measured. Similarly, after a warm-up time of about ½ h at 115 Vac and preset current (1.05 A), the efficiency curve at low mains voltage, with respect to the output power has been measured. The results are synthesized in the following *Figure 5* and *Figure 6*, confirming the ones obtained with the LED string as load.

Figure 5. Efficiency vs. output power

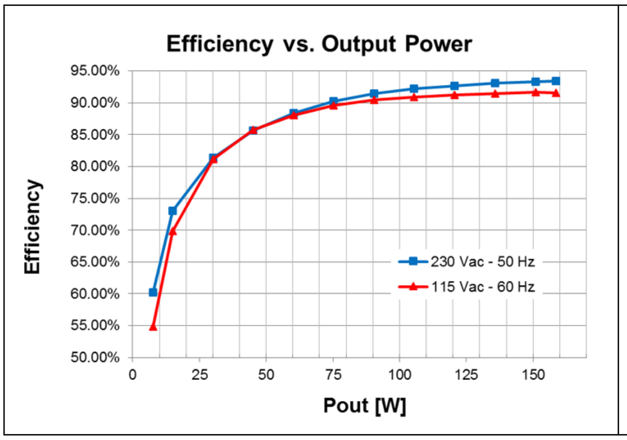
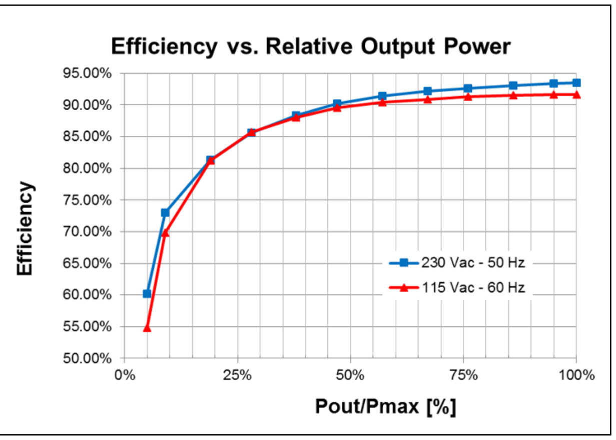


Figure 6. Efficiency vs. relative output power



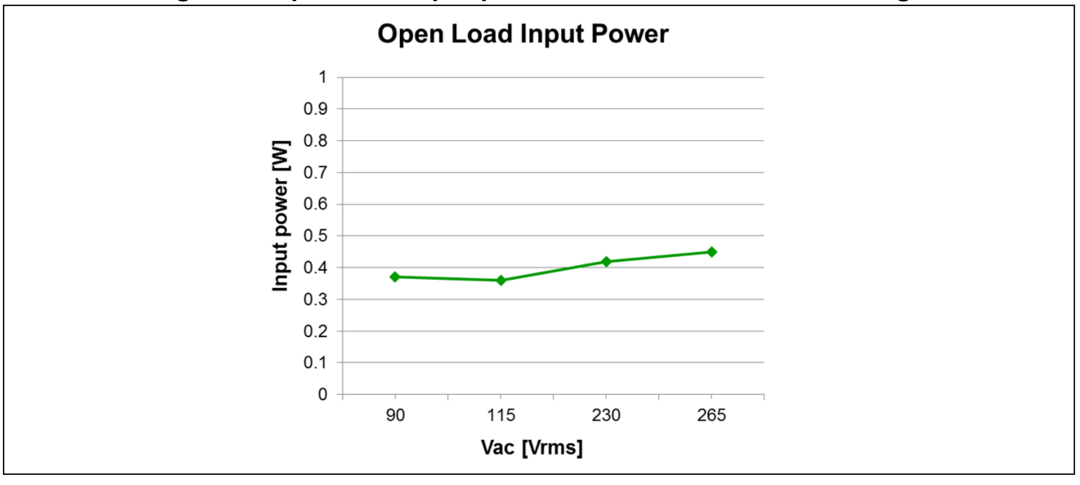
Open load input power consumption

Measurements during open load operation have been measured and reported in *Figure 7*. As can be seen, input power is below 500 mW at any input mains voltage.

Measurements have been done disconnecting the LED string from the board and measuring the input power by power meter integration. Input power doesn't change if the dimming circuitry is driven by an external dimming signal or the dimming input connector is open too.

Measurements have been done after a warm-up time of about 1/2h at 90 Vac (and open load), then 5 min. between each measurement point. The output voltage, the half-bridge node and the pin GD of L6564H have been probed on the oscilloscope during the test.

Figure 7. Open load input power as function of mains voltage

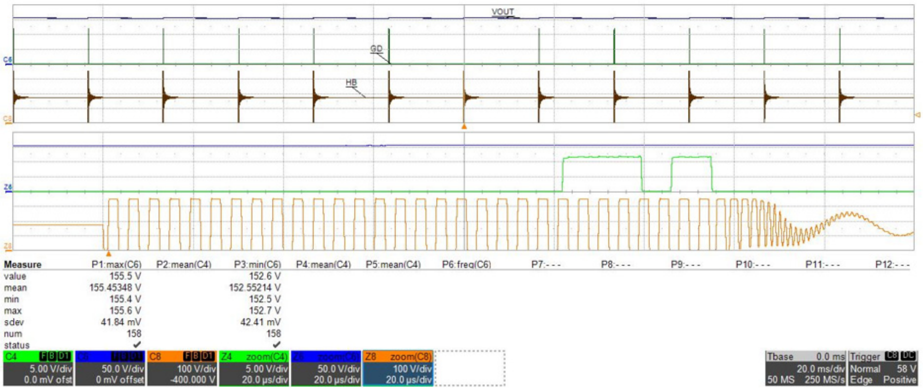


During open load operation (LED string unconnected), the LED driver is controlled by the CV loop that sets the output voltage just above the maximum LED voltage (150 V). The HBR stage operates in burst mode and it is master on the PFC stage. The resulting output voltage is sawtooth type, between 152 V and 156 V, while the bulk capacitor voltage is about 350 V at 90 Vac and 400 V at 265 Vac.

The single switching packet of the HBR stage lasts between about 110 usec and 140 usec, increasing with decreasing mains voltage but rather constant at given mains voltage. The switching frequency is between 220 kHz and 230 kHz. The period between adjacent packets is between 16 msec and 22 msec, increasing with increasing mains voltage, but rather stable at given mains voltage. The PFC stage generates one or two pulses, at low or high mains voltage, respectively, after about 100 usec from the beginning of the switching packet by the HBR stage. The PFC pulses are 10 to 20 usec wide at low mains voltage and 1 to 5 usec narrow at high mains voltage.

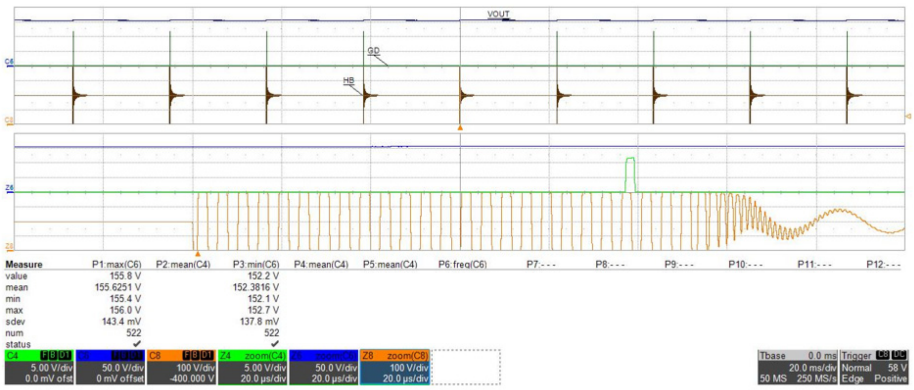
Waveforms of the operation during burst mode are reported in the following *Figure 8* and *Figure 9*, for the 90 Vac and the 265 Vac cases.

Figure 8. Burst mode @ 90 Vac / 60 Hz - open load



			CH4: GDPFC
	CH6: V_OUT		CH8: HB

Figure 9. Burst mode @ 265 Vac / 50 Hz - open load



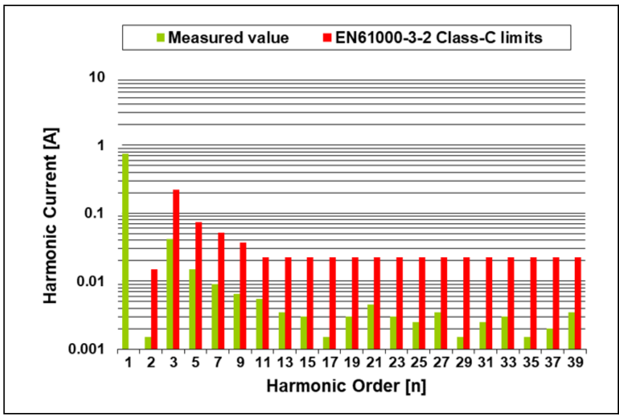
			CH4: GDPFC
	CH6: V_OUT		CH8: HB

3 AC current harmonic content and power factor

The board has been tested against the European norm EN61000-3-2 Class-C and Japanese norm JEITA-MITI Class-C compliance, at both the nominal input voltage mains. The test results are reported in the following *Figure 10*, *Figure 11*, *Figure 12*, *Figure 13*, *Figure 14* and *Figure 15*.

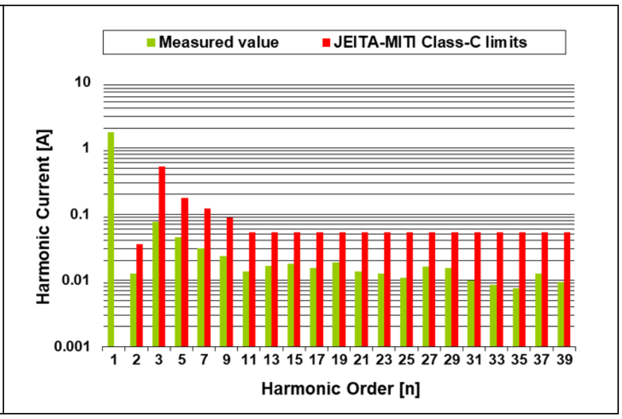
From *Figure 10* to *Figure 13*, the harmonics of the input mains current at both nominal mains input voltage, European and Japanese, have been reported at full load and half load: the harmonics of the LCC LED driver are well within the limits of both regulations.

Figure 10. EN61000-3-2 at 230 Vac / 50 Hz full load (Pout = 158.4 W)



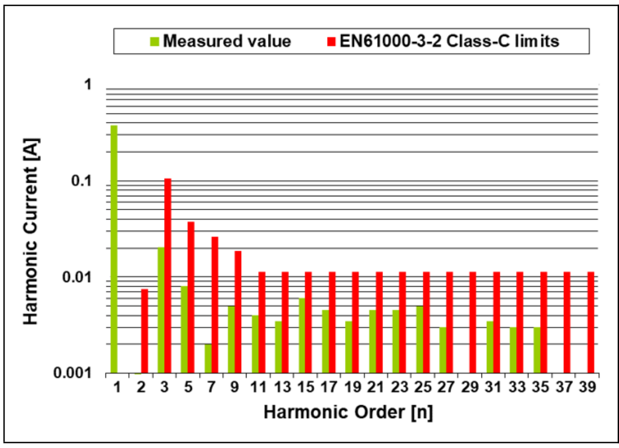
Pin = 169.4 W, PF = 0.981, THD = 6.2%

Figure 11. JEITA-MITI at 100 Vac / 60 Hz full load (Pout = 158.4 W)



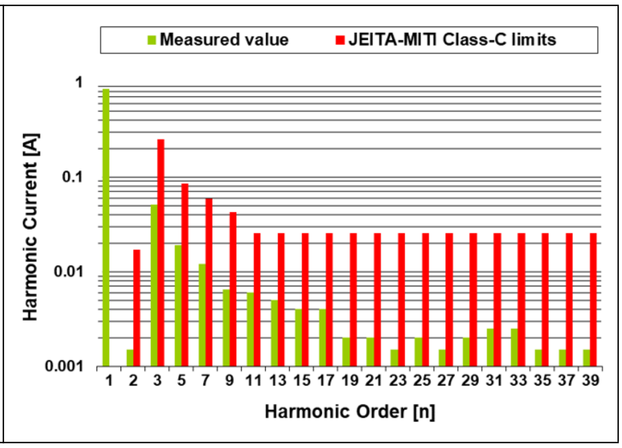
Pin = 174.3 W, PF = 0.994, THD = 5.8%

Figure 12. EN61000-3-2 at 230 Vac / 50 Hz half load (Pout = 75.3 W)



Pin = 83.5 W, PF = 0.938, THD = 6.8%

Figure 13. JEITA-MITI at 100 Vac / 60 Hz half load (Pout = 75.3 W)



Pin = 84.4 W, PF = 0.988, THD = 6.7%

Further decreasing the load, down to about 25 W, that is one sixth of full load, at 230 Vac, the PFC stage enters burst mode operation: the shaping of the input current is no longer exactly sinusoidal and the first harmonics, especially the second one, increases and can override the limit value. The following *Figure 14* and *Figure 15*, show the harmonic content in this condition, at both 230 Vac and 100 Vac.

Figure 14. EN61000-3-2 at 230 Vac / 50 Hz 1/6 of full load (Pout = 25.3 W)

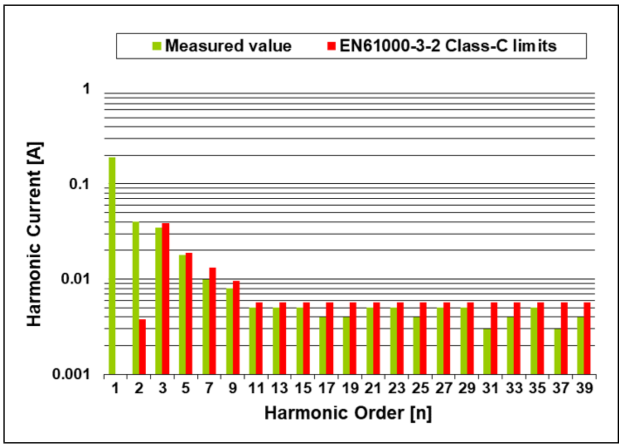
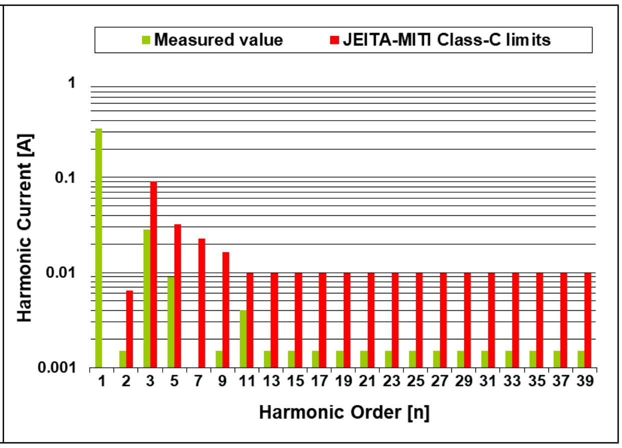


Figure 15. JEITA-MITI at 100 Vac / 60 Hz 1/6 of full load (Pout = 25.3 W)



Pin = 31.9 W, PF = 0.675, THD = 40% - 60%

Pin = 32.0 W, PF = 0.938, THD = 9.2%

Eventually, in *Figure 16* and *Figure 17*, the power factor measurements are reported, as function of the output current and input mains voltage. The power factor is high as expected and it tends to decrease when the LED driver begins to work in burst mode.

Figure 16. Power factor vs. input power

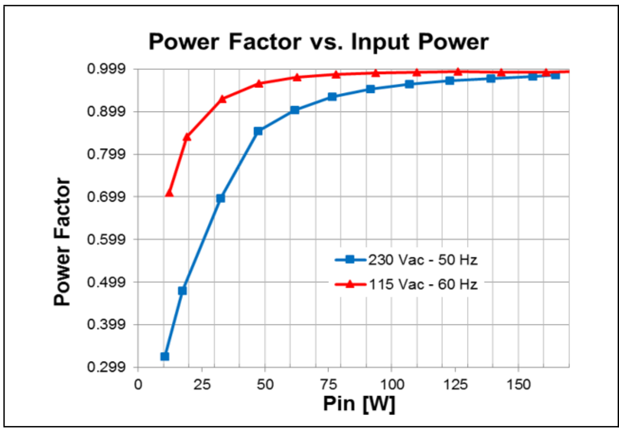
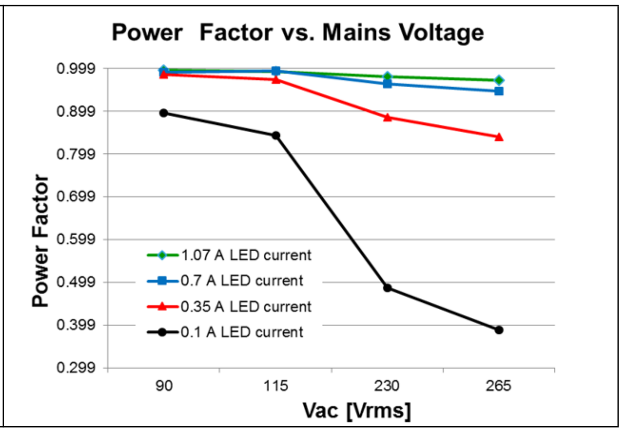


Figure 17. Power factor vs. mains voltage



Lastly, in the following figures, the total harmonic distortion, THD, is reported as function of the input power (see *Figure 18*), of the relative output power (see *Figure 19*) and of the mains voltage at different current levels (see *Figure 20*).

The THD at full load is high and decreases as the load is decreased, as expected. However, at high mains voltage, when the PFC stage starts to operate in burst mode because of the reduced load, the THD shows an abrupt increase (and, usually, the power meter reading usually becomes unstable). So, in the following figures, the curves at high mains voltage are stopped at the measurement point before the burst mode operation of the PFC stage. The output power at which the PFC stage starts burst mode operation is about 50 W and 30 W, at 265 Vac and 230 Vac, respectively.

Nevertheless, it is worth underlining that the regulations about mains current, including the IEC61000-3-2 or the JEITA-MITI, do not limit the THD value but the limit is for each single harmonic peak as represented from *Figure 10* to *Figure 15*. The THD is therefore just an index, giving a rough idea regarding the shape of the input current, but its value is not representative that the unit is within or out of the regulation limits.

Figure 18. THD vs. input power

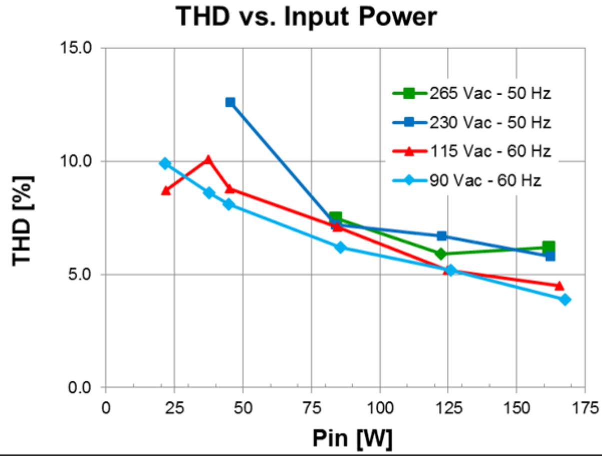


Figure 19. THD vs. relative output power

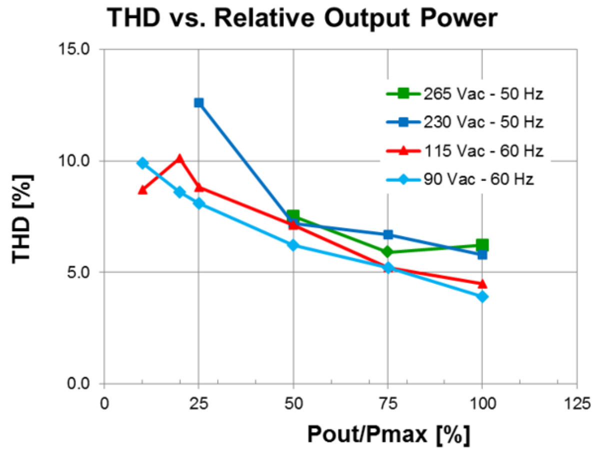
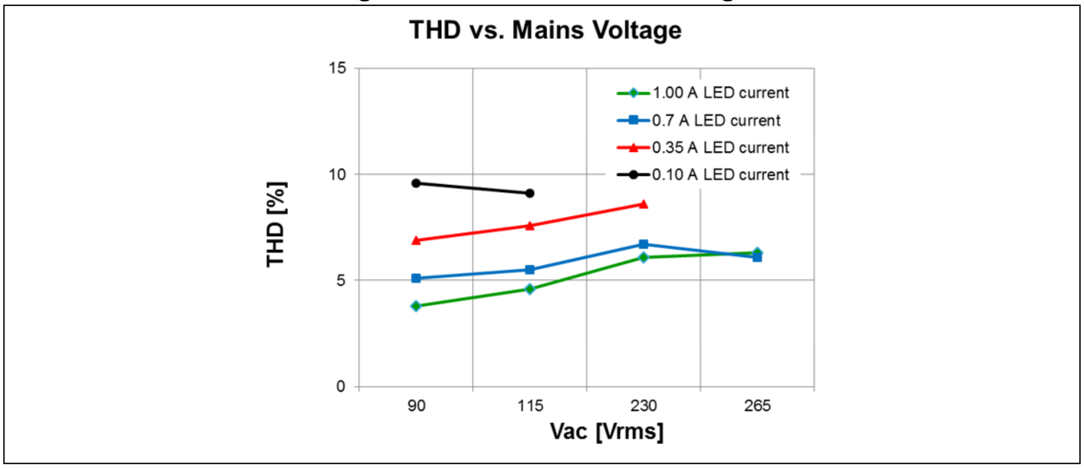


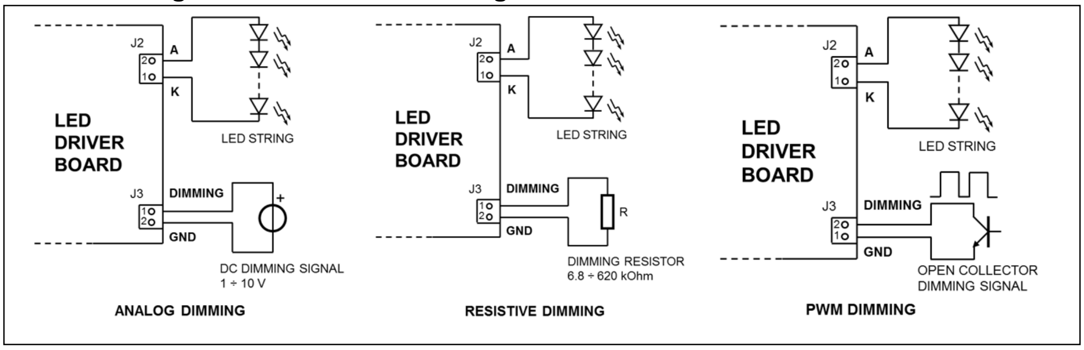
Figure 20. THD vs. mains voltage



4 LED current dimming

The board accepts different dimming signals for controlling the current flowing in the LED: analog, resistive and PWM. The board provides a dedicated connector (J3) for all dimming types. The dimming signals have to be supplied referred to secondary ground (note that there is no insulation between the dimming input connector and the secondary ground). Connections of different dimming types to the boards are shown in the following *Figure 21*.

Figure 21. Different dimming connections at board connectors



When no dimming signal is provided (dimming connector open), the maximum current, that is a few percent higher than the nominal current, 1 A, is delivered to the LED string. Features of different dimming types, especially the analog one, are exploited hereinafter (in the following, the LED driver has been loaded by an active load in CV).

- **Analog dimming**

The board accepts as analog dimming signal a voltage in the range 1 ÷ 10 V, with an input impedance of 200 kΩ. The LED current proportionally changes with the dimming voltage and the relationship is very linear, as can be seen in the diagram of *Figure 22*. Applying 10 V at the dimming connector, the nominal current is delivered (1 A), then the relationship among the dimming voltage and LED current is 0.1 A/V, from 10 V to 1 V.

For LED voltage around 150 V, the dimming depth is about 5% while for LED voltages from 100 V to 50 V, the dimming depth moves from 10% to 20%. At LED voltage around 30 V, the dimming depth is between 25% and 30%.

The operating area of the converter is represented in *Figure 23*: note the wide dimming capability of the converter, allowing a perfect current regulation from 100 % to below 30% of the nominal output current and from 100% to about 30% of the maximum output voltage.

- **Resistive dimming**

The LED current can be changed also by connecting a suitable resistor to the pins of connector J3. Current changes proportionally with the resistor value, as we can see in the diagram of *Figure 24*. This dimming mode is used for low-cost applications needing a selectable fixed preset of the LED current by the user. A potentiometer could be used in case a variable LED current setting is needed instead of a fixed resistor preset.

- **PWM dimming**

Another popular control signal for LED current is the so called PWM dimming: the board accepts this kind of driving signal, still applied to the connector J3 by an open collector/drain output. The open collector/drain has to sustain a 12 V maximum voltage, and has to pull down a current of 0.1 mA.

The input dimming signal is averaged by the board circuitry, therefore any dimming frequency and duty cycle can be fed into the connector J3 and the board does not show any light flickering due to the PWM modulating signal because the current flowing in the LED string is a DC current, proportional to the average value of the PWM signal multiplied for the maximum (preset) current. The diagram of *Figure 25* shows the output current flowing into the LED string as a function of the duty cycle of the PWM dimming signal.

At rated output voltage (150 V), the PWM dimming circuit allows to regulate the LED current with good linearity down to very small duty cycles in the range of 1%, making this board also suitable not only for street lighting but also for applications like indoor lighting where the PWM dimming is usually required.

Figure 22. LED current vs. analog dimming signal at different V_{LED}

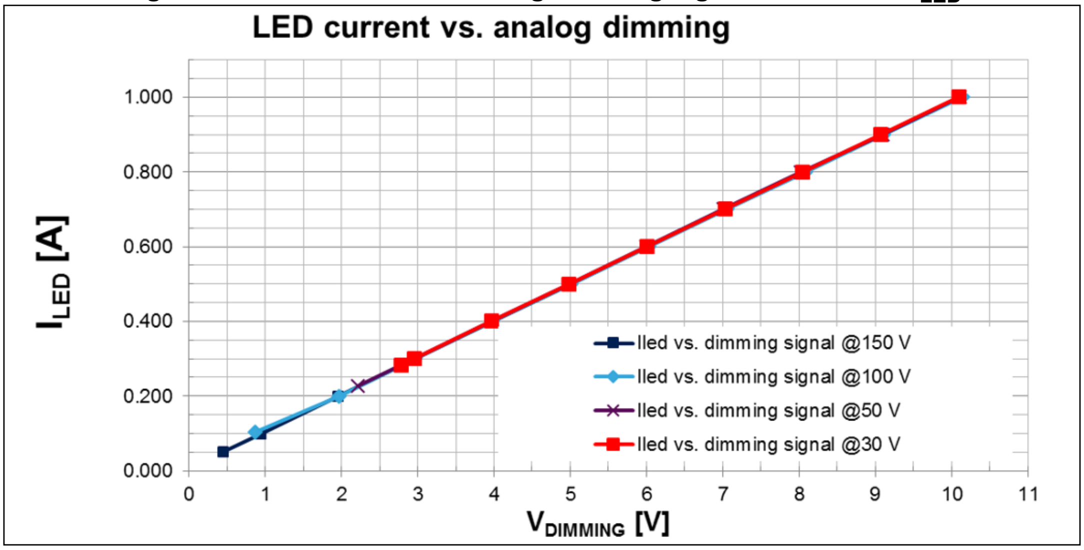


Figure 23. Converter operating area, I_{LED} vs. V_{LED}

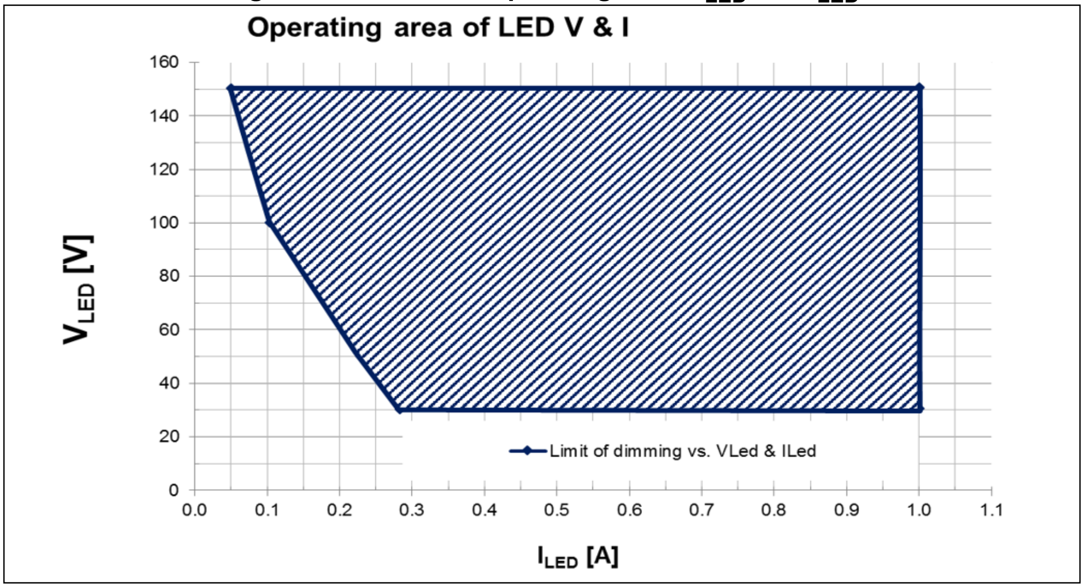


Figure 24. LED current vs. dimming resistance at different V_{LED}

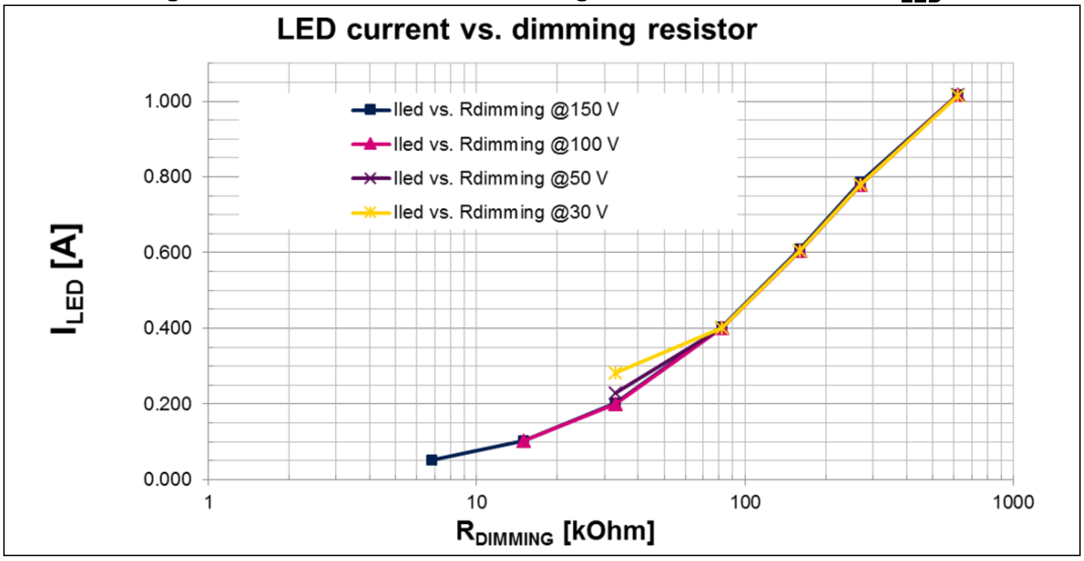
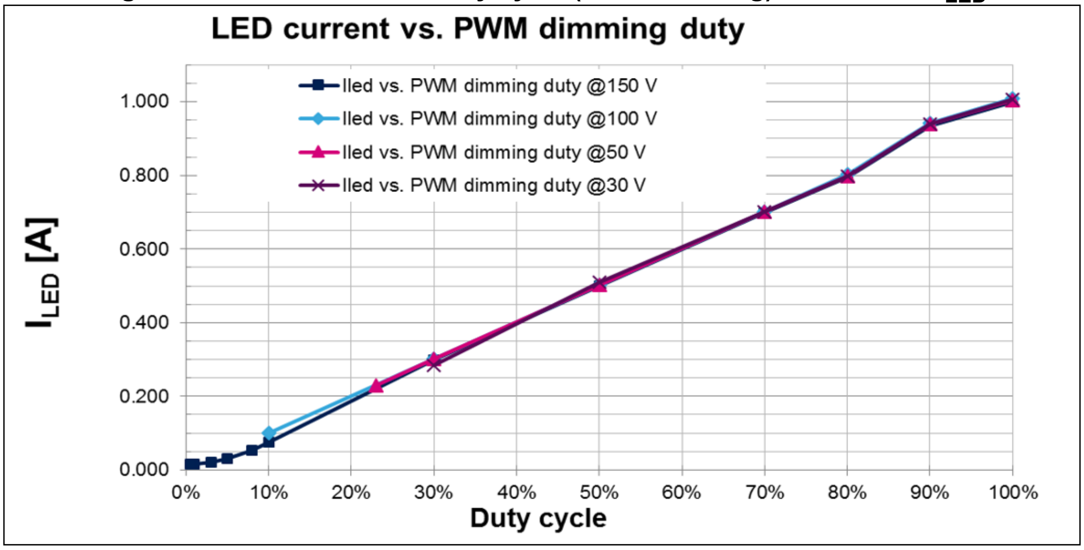


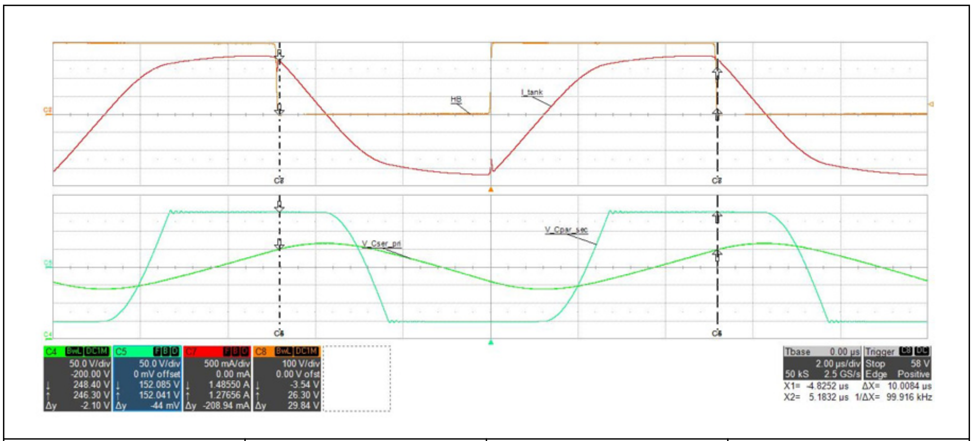
Figure 25. LED current vs. duty cycle (PWM dimming) at different V_{LED}



5 LCC topology: main waveforms of the tank

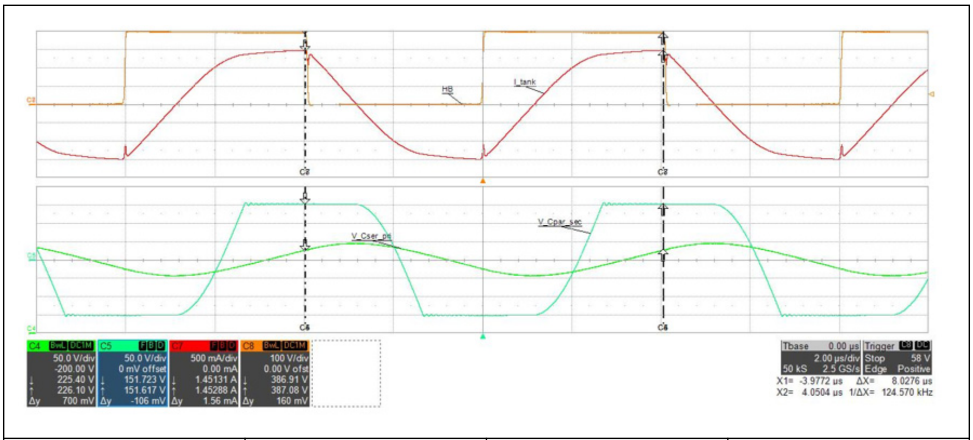
In this section, typical waveforms of the LCC resonant tank are shown. Referring to the schematic of the board, reported in *Figure 2*, the half-bridge node, the series capacitor voltage at primary (C14), the parallel capacitor voltage at secondary (C6) and the primary current entering into the resonant tank have been captured at some steady-state conditions at 230 Vac / 50 Hz (active load in CV set at 150 V).

Figure 26. LCC typical waveforms, 150V - 1A (full load, 100% dimming)



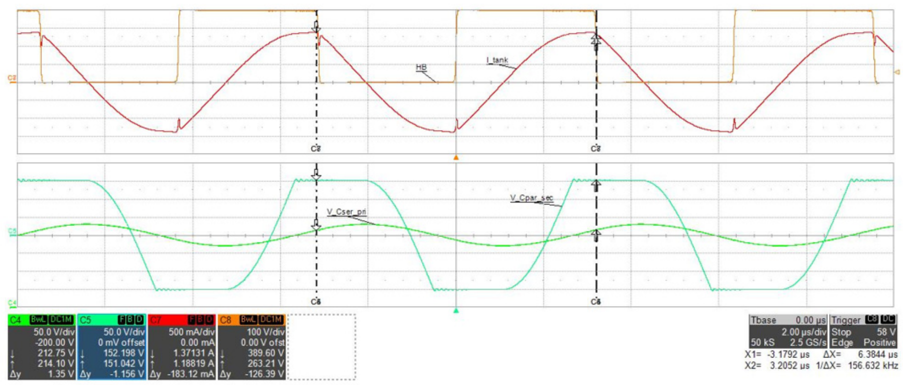
CH4: V_C14	CH5: V_C6 (diff)	CH7: I_tank	CH8: HB

Figure 27. LCC typical waveforms, 150V - 0.75A (75% dimming)



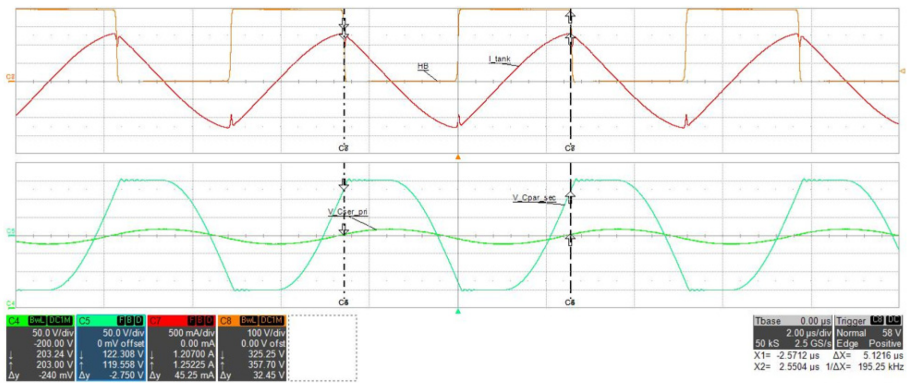
CH4: V_C14	CH5: V_C6 (diff)	CH7: I_tank	CH8: HB

Figure 28. LCC typical waveforms, 150V - 0.5A (half load, 50% dimming)



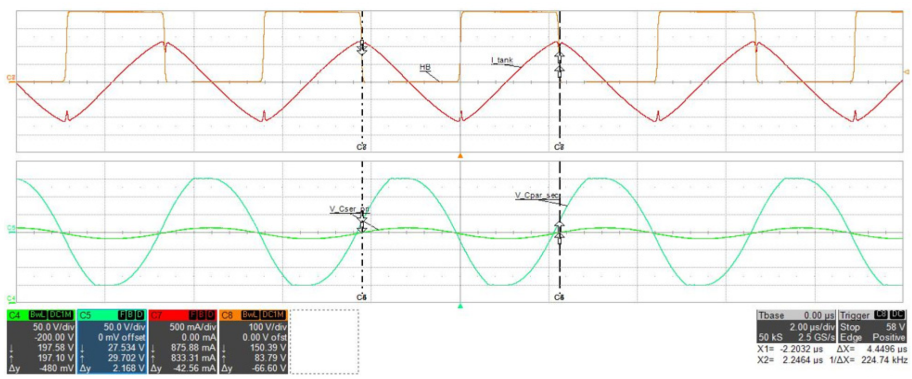
CH4: V_C14	CH5: V_C6 (diff)	CH7: I_tank	CH8: HB

Figure 29. LCC typical waveforms, 150V - 0.25A (25% dimming)



CH4: V_C14	CH5: V_C6 (diff)	CH7: I_tank	CH8: HB

Figure 30. LCC typical waveforms, 150V

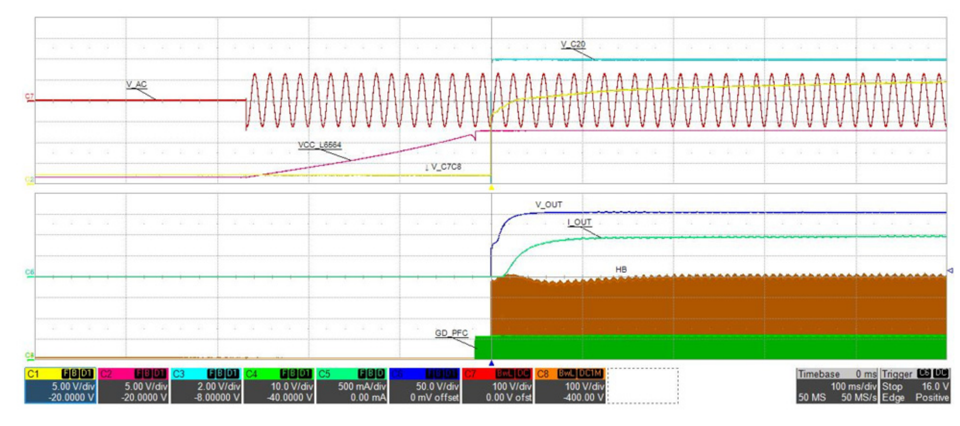


CH4: V_C14	CH5: V_C6 (diff)	CH7: I_tank	CH8: HB

6 Startup

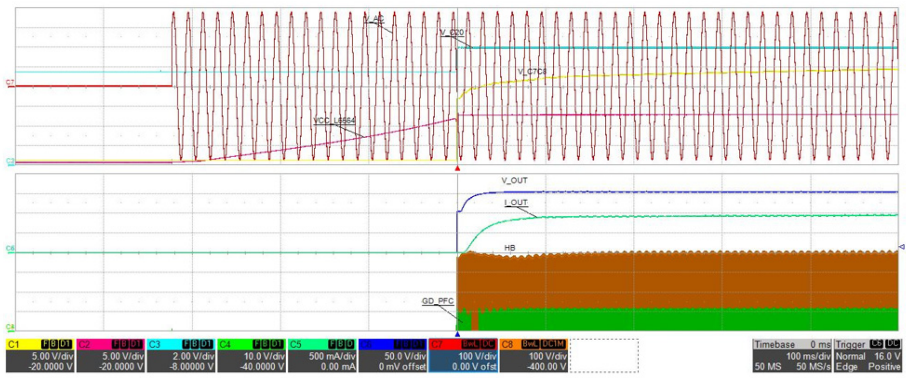
The L6564H is equipped with internal HV start-up circuitry dedicated to supplying the IC during the start-up phase, before the self-supply winding is operating. As the mains voltage is connected, an internal current source (1 mA) charges the capacitors connected to the VCC pin up to the turn-on threshold, then it is shut down. Normally, the high voltage startup is re-enabled when the VCC voltage falls below 6 V to ensure a low power throughput during short-circuit. Once the turn-on threshold is reached, the L6564H starts operating and the GD starts driving the PFC MOSFET. The resonant stage begins operating once the PFC voltage reaches the LINE pin threshold sensing the PFC voltage, thus ensuring that the resonant HB stage starts after the PFC has started up, and PFC output voltage is close to the nominal level. Several tests have been done at different mains voltage, dimming level and output load (50/100/150 V LED strings or open load): in all the cases, there is no output voltage overshoot and the rise is usually smooth and monotonic. In some cases, when the reduced voltage LED string is connected, the output voltage rise is not monotonic. The turn-on time, from mains connection to steady-state is rather fast: in the case of full load, the output current takes about 400 ms to reach its nominal value (from mains connection). *Figure 31*, *Figure 32*, *Figure 33*, *Figure 34* and *Figure 35* show some start-up events.

Figure 31. Startup at 90 Vac - full load - dimming connector open



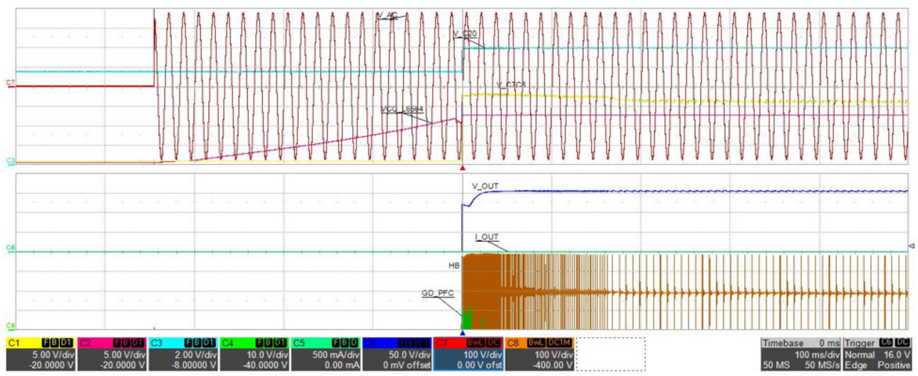
CH1: V_C7C8	CH2: VCC_6564	CH3: V_C20	CH4: GDPFC
CH5: I_OUT	CH6: V_OUT	CH7: V_AC	CH8: HB

Figure 32. Startup at 265Vac - full load - V_DIMM = 10 V



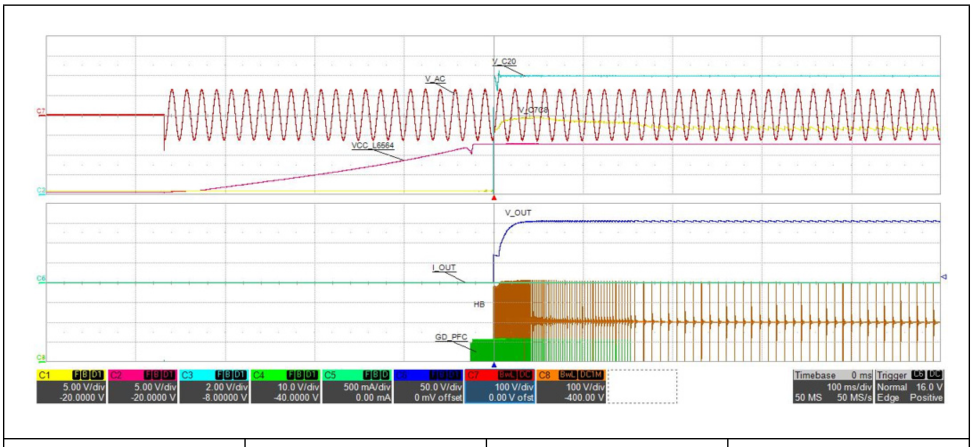
CH1: V_C7C8	CH2: VCC_6564	CH3: V_C20	CH4: GDPFC
CH5: I_OUT	CH6: V_OUT	CH7: V_AC	CH8: HB

Figure 33. Startup at 265Vac - open load - V_DIMM = 10 V



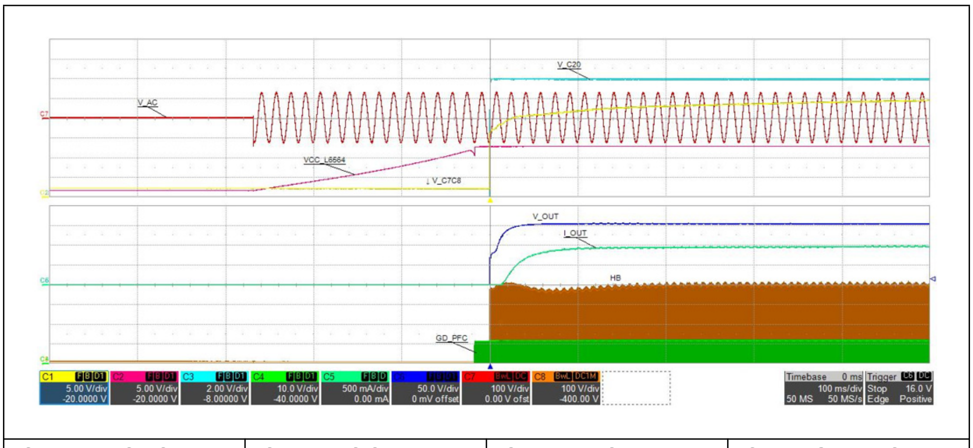
CH1: V_C7C8	CH2: VCC_6564	CH3: V_C20	CH4: GDPFC
CH5: I_OUT	CH6: V_OUT	CH7: V_AC	CH8: HB

Figure 34. Startup at 90Vac - open load - V_DIMM = 0 V



CH1: V_C7C8	CH2: VCC_6564	CH3: V_C20	CH4: GDPFC
CH5: I_OUT	CH6: V_OUT	CH7: V_AC	CH8: HB

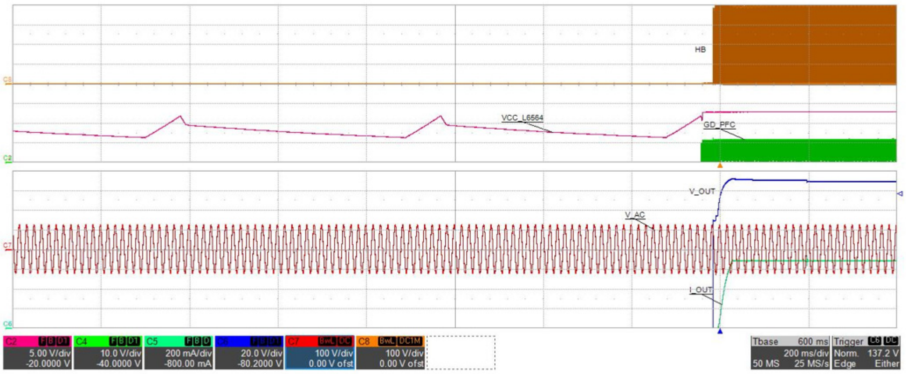
Figure 35. Startup at 90Vac - full load - dimming connector open



CH1: V_C7C8	CH2: VCC_6564	CH3: V_C20	CH4: GDPFC
CH5: I_OUT	CH6: V_OUT	CH7: V_AC	CH8: HB

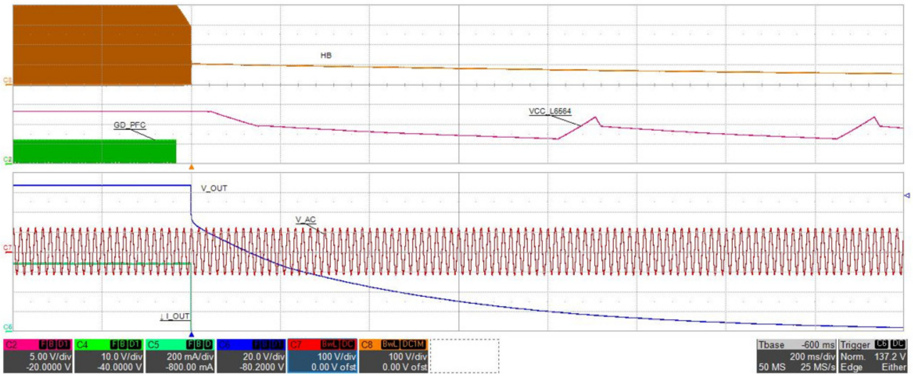
The L6564H is equipped with brown-in and brownout protection to prevent the operation at too low AC input voltage: if the voltage at pin VFF goes below 800 mV (typ.), then the system goes into brownout that is a not latched shutdown; as the voltage at pin VFF goes above 880 mV (typ.), the system restarts normal operation. In detail, at mains plug, if the voltage is below the brown-in threshold, the high voltage start-up generator charges the VCC capacitors until VCC reaches the turn-on threshold, but PFC operation is prevented until the voltage reaches the brown-in threshold. An example of brown-in is reported in *Figure 36*: the mains voltage is slowly increased from a value below the brown-in threshold. As long as the threshold is not triggered, the high voltage start-up generator periodically charges VCC up to Vccon, but converter turn on is inhibited. Then, as soon as the threshold is triggered, because of the increased mains voltage, the converter turn-on is allowed. If, during normal operation, the mains voltage drops below the brownout threshold, then the PFC is turned off and the switching activity restarts once the mains voltage is back above the brown-in threshold. An example of brownout event is reported in *Figure 37*: test done by slowly decreasing the mains voltage until the PFC turn-off is observed.

Figure 36. AC brown-in at 87 Vac - V_OUT = 150V, I_OUT = 0.70A



	CH2: VCC_6564		CH4: GDPFC
CH5: I_OUT	CH6: V_OUT	CH7: V_AC	CH8: HB

Figure 37. AC brownout at 83 Vac - V_OUT = 150V, I_OUT = 0.70 A

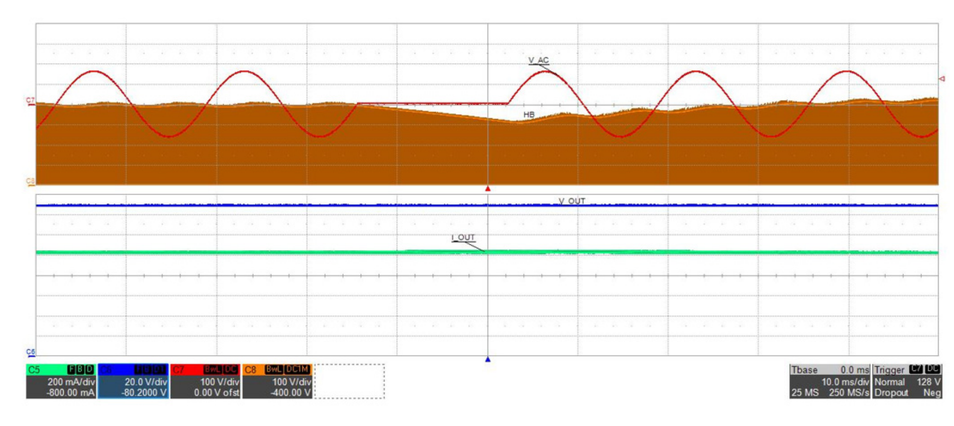


	CH2: VCC_6564		CH4: GDPFC
CH5: I_OUT	CH6: V_OUT	CH7: V_AC	CH8: HB

7 Mains voltage short interruptions (0% dips)

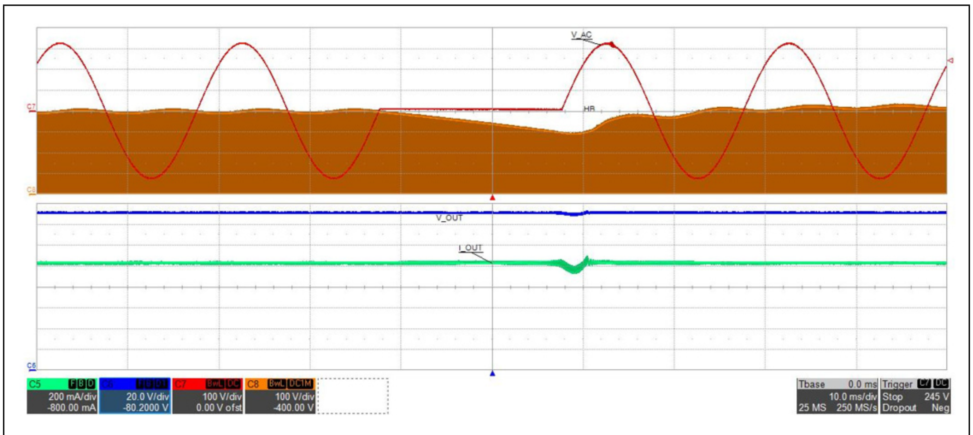
In order to validate the design, the LED driver has been submitted to the partial test compliance against the EN61000-4-11. Short interruptions, that are 0% dips, of mains voltage, at both 115 Vac and 230 Vac, from single-cycle to some tens, have been applied at full load (150 V LED string and dimming connector open): at the single-cycle interruption, a variation of about 50 mA can be observed on the output current; when longer interruptions are applied, the LED string properly turns off and then restarts as the mains voltage reappears. No missing or uncertain restart observed. Hereinafter, some images captured during the tests are reported (see *Figure 38*, *Figure 39*, *Figure 40*, *Figure 41* and *Figure 42*).

Figure 38. 115 Vac / 60 Hz - full load, single cycle (16.67 ms) 0% dip



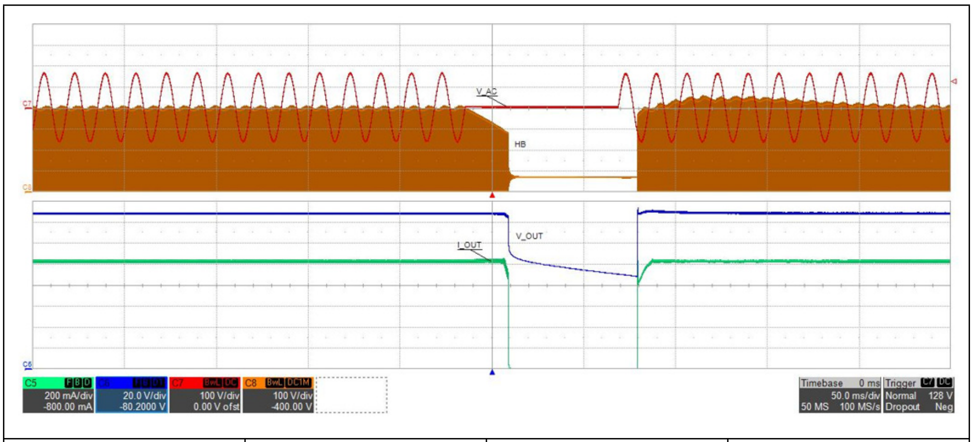
CH1: HB			CH4: Vac
CH5: I_OUT	CH6: V_OUT		

Figure 39. 230 Vac / 50 Hz - full load, single cycle (20 ms) 0% dip



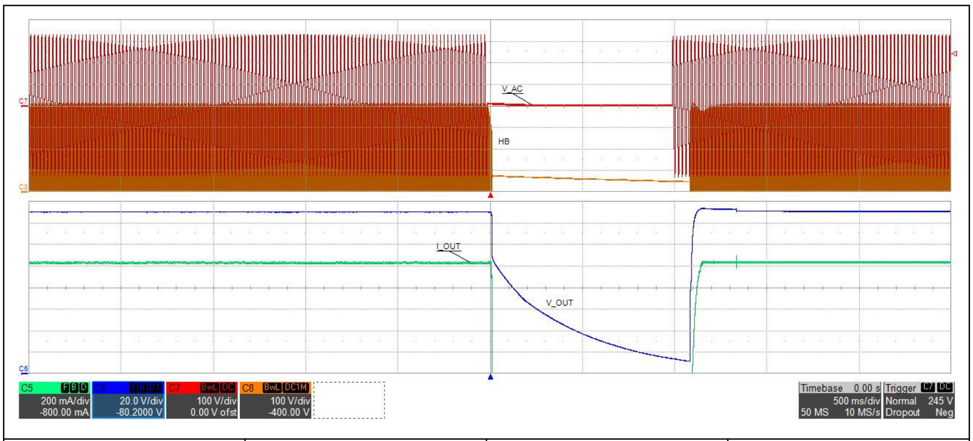
CH1: HB			CH4: Vac
CH5: I_OUT	CH6: V_OUT		

Figure 40. 115 Vac / 60 Hz - full load, 5 cycles (83.35ms) 0% dip



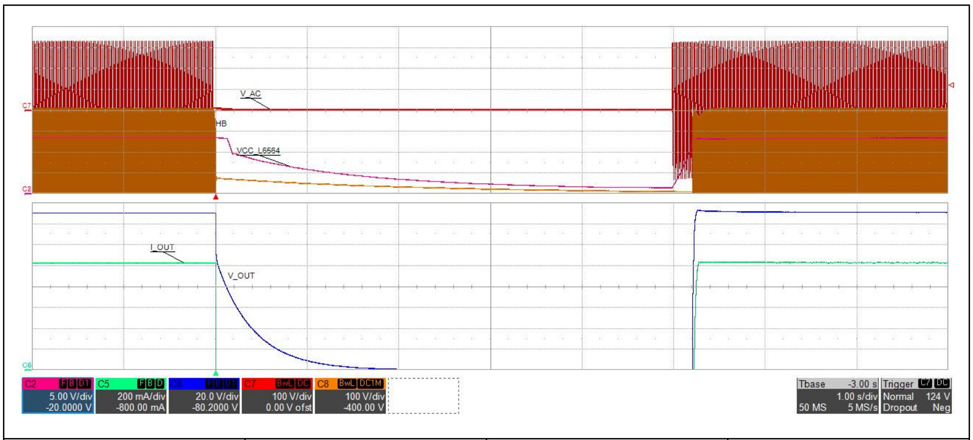
CH1: HB			CH4: Vac
CH5: I_OUT	CH6: V_OUT		

Figure 41. 230 Vac / 50 Hz - full load, 50 cycles (1.00s) 0% dip



CH1: HB			CH4: Vac
CH5: I_OUT	CH6: V_OUT		

Figure 42. 230 Vac / 50 Hz - full load, 250 cycles (5.00s) 0% dip



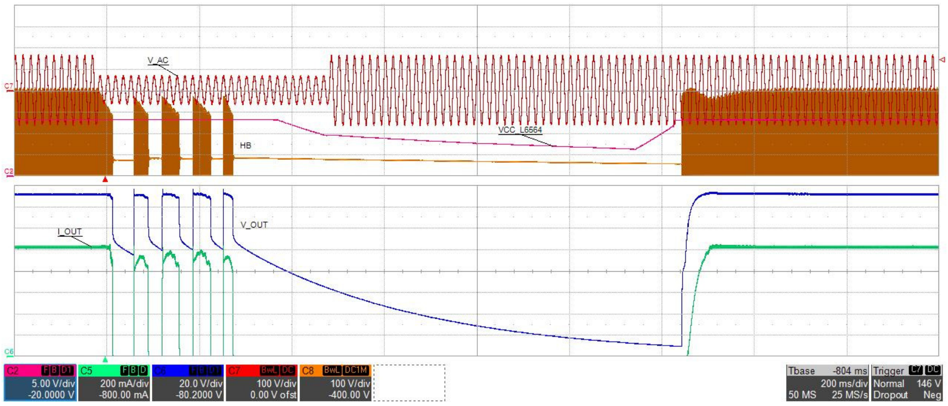
CH1: HB	CH2: VCC_6564		CH4: Vac
CH5: I_OUT	CH6: V_OUT		

8 Mains voltage dips (> 0% dips)

In order to extend the partial test compliance against the EN61000-4-11, the LED driver has also been submitted to mains voltage dips (reduction of the RMS voltage of mains, for a given time), at full load (150 V LED string and dimming connector open). In this case, the behaviour of the LED driver depends on the occurrence of two factors that are the voltage dip is below the AC brownout threshold and the trigger of the DC brownout threshold.

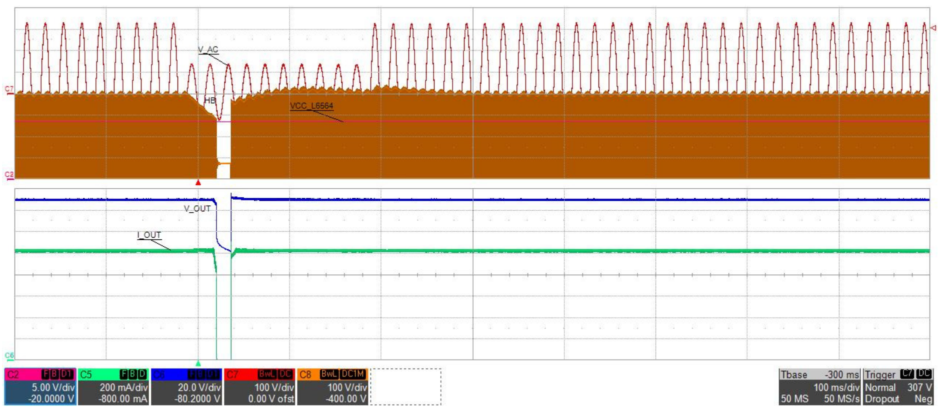
The following *Figure 43* and *Figure 44* show two examples: at low mains where the dip is below AC brownout threshold and at high mains where the dip is above AC brownout. In the first case, entering the dip, repeated turn-off and on is observed, before AC brownout detection, because of DC brownout. In the second case, entering the dip, a single turn-off and on is observed because of DC brownout, while AC brownout is not triggered. In both cases, the restart, as the voltage dip is removed, is without uncertainty.

Figure 43. 115 Vac / 60 Hz - full load 30 cycles (500.1 ms) 40% mains dip (46 Vac)



CH1: HB	CH2: VCC_6564		CH4: Vac
CH5: I_OUT	CH6: V_OUT		

Figure 44. 230 Vac / 50 Hz - full load 10 cycles (200 ms) 40% mains dip (92 Vac)



CH1: HB	CH2: VCC_6564		CH4: Vac
CH5: I_OUT	CH6: V_OUT		

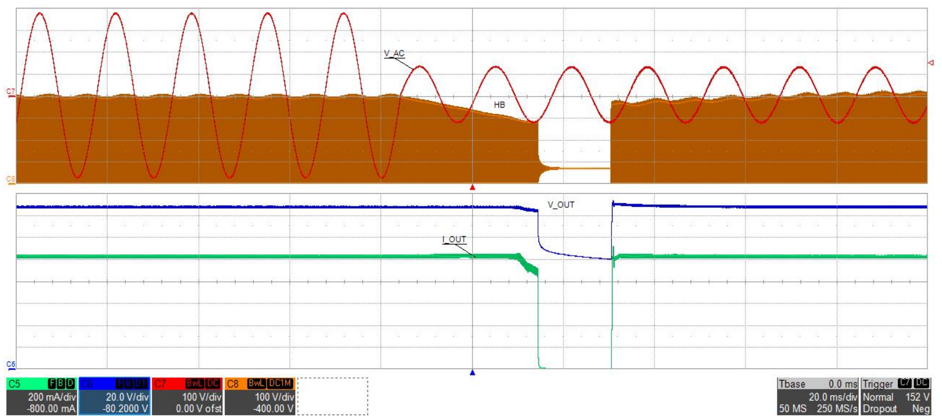
9 Mains voltage transitions

Eventually, the LED driver has been also stressed, at full load (150 V LED string and dimming connector open), by zero phase line transitions, from maximum high mains voltage to minimum low mains voltage and vice versa.

On one side, see *Figure 45*, for the high to low transition, a turn-off followed by proper restart is observed. The turn-off occurs at DC brownout and it is due to the limited speed of the voltage feed-forward function of the L6564H. Such behaviour can be removed by adjusting (reducing) the RC filter on the pin VFF, although a trade-off has to be found with the ripple on the pin VFF itself. Otherwise, the bulk capacitor can be increased in order to sustain the resonant converter for a longer time.

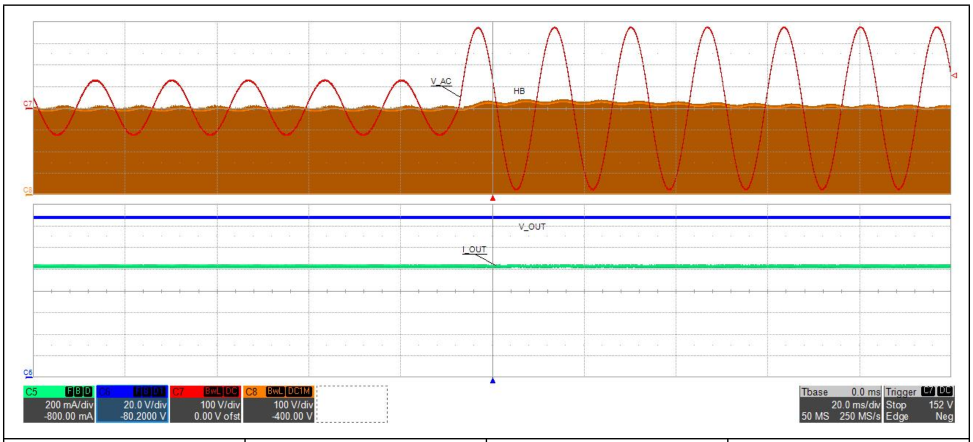
Conversely, see *Figure 46*, for the opposite transition, from low to high; the update of the voltage at the pin VFF is practically instantaneous with respect to the transition and there is no effect on the output of the LED driver.

Figure 45. Full load, mains transition, 265 → 90 Vac (50 Hz)



CH1: HB			CH4: Vac
CH5: I_OUT	CH6: V_OUT		

Figure 46. Full load, mains transition, 90 → 265 Vac (60 Hz)



CH1: HB			CH4: Vac
CH5: I_OUT	CH6: V_OUT		

10 Thermal map

In order to check the design reliability, a thermal mapping by means of an IR Camera was done. Here below, in Figure 47 and Figure 48, the thermal measurements of the board, component side, at nominal input voltage are shown. Some pointers, visible in the images, have been placed across key components or showing high temperature (see Table 2). The ambient temperature during both measurements was 27°C. All components are working within their operating temperature range with margin.

Figure 47. Thermal map at 115 Vac - 60 Hz - full load

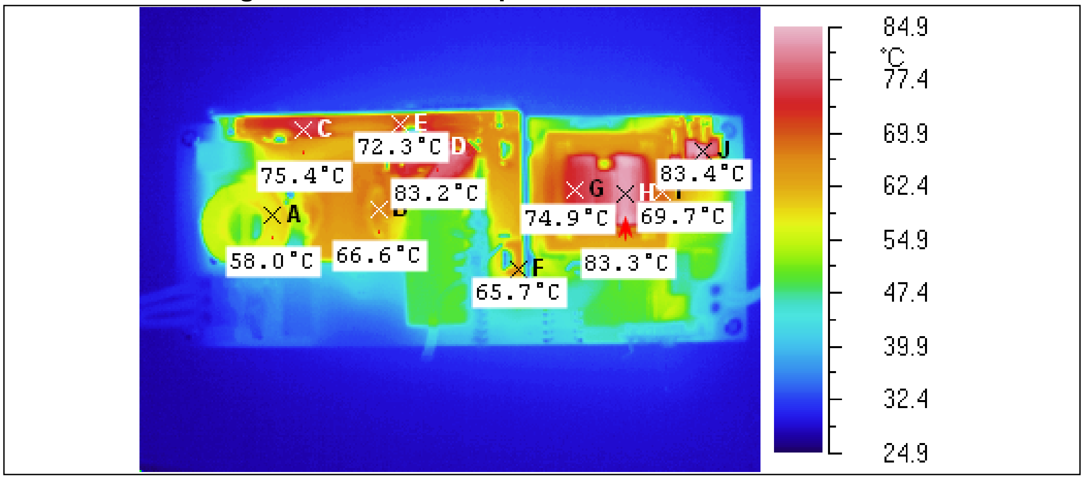


Figure 48. Thermal map at 230 Vac - 50 Hz - full load

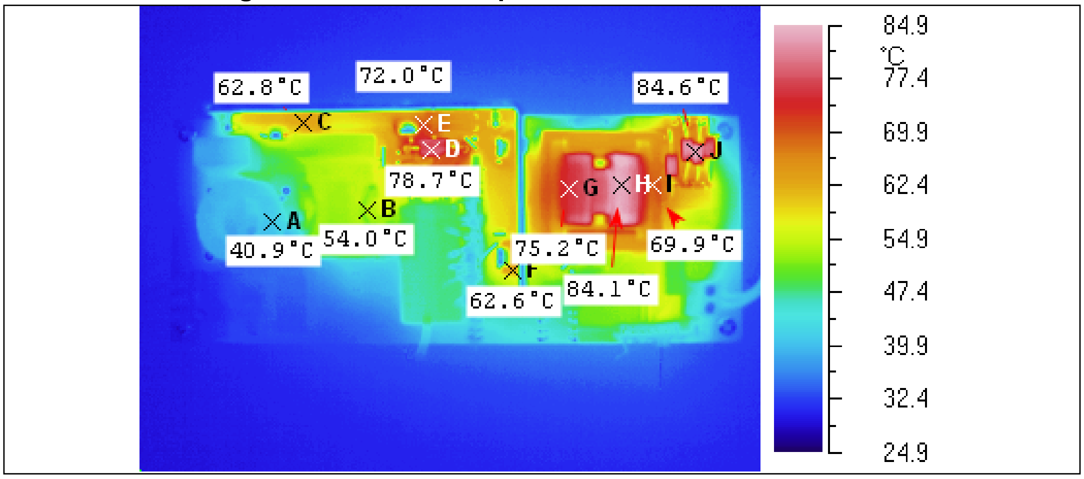


Table 2. Thermal maps reference points

Point	Reference	Description
A	L1	EMI filtering inductor
B	L2	PFC inductor - hottest point
C	D1	Bridge rectifier
D	D4	PFC output diode

Table 2. Thermal maps reference points (continued)

Point	Reference	Description
E	Q1	PFC MOSFET
F	Q2	Resonant HB MOSFET
G - H - I	T1	Resonant power transformer
J	D10	Output rectifier (hottest one)

11 Conducted emission pre-compliance test

Pre-compliance measurements of the conducted emission in average detection, at full load (dimming connector open) and nominal mains voltages, have been done. The LISN is fed by a Variac connected to the line voltage, while the load is an LED string (150 V nominal voltage). The LED driver under test is connected to the LISN and the load by unshielded and ungrounded wire (about 1m long, at each side). The LED driver and the LED string are placed on a wooden table with a grounded shield at about 1m.

As a reference, the CE test has been done on the test bench with the DUT not connected but the nominal mains voltage given to the LISN and on the test bench with the DUT connected to the LISN but zero mains voltage applied: results are shown in *Figure 49* and *Figure 50*.

Figure 49. Average CE measurement: no DUT to LISN, Vac = 115 V

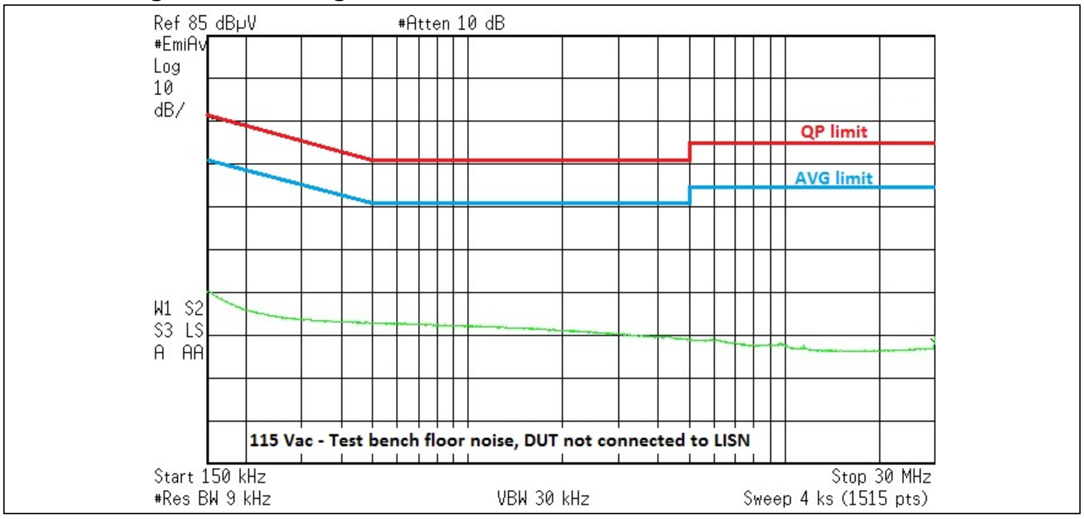
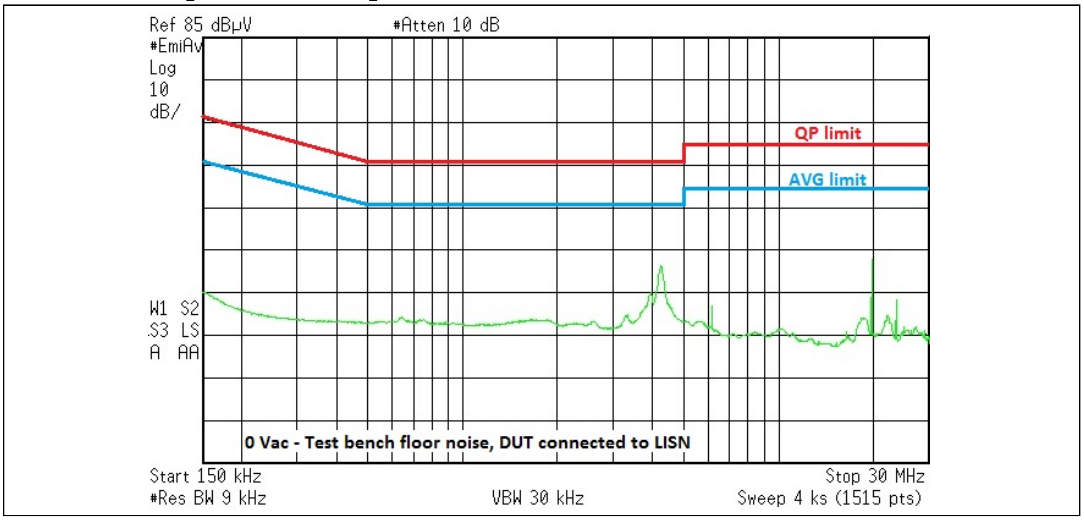


Figure 50. Average CE measurement: DUT to LISN, Vac = 0 V



Pre-compliance results are then shown in *Figure 51* and *Figure 52*. The limits shown in the diagrams are from EN55022 Class-B that are the same as EN55015, typical of lighting equipment. As can be seen in the diagrams, in all test conditions the measurements are well below the limits.

Figure 51. Average CE measurement: 115 Vac / full Load

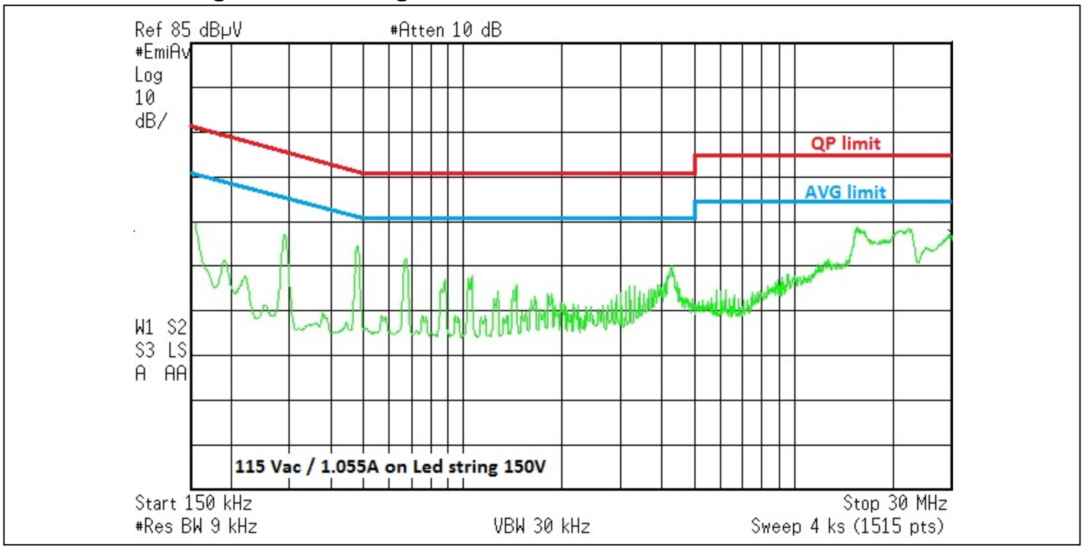
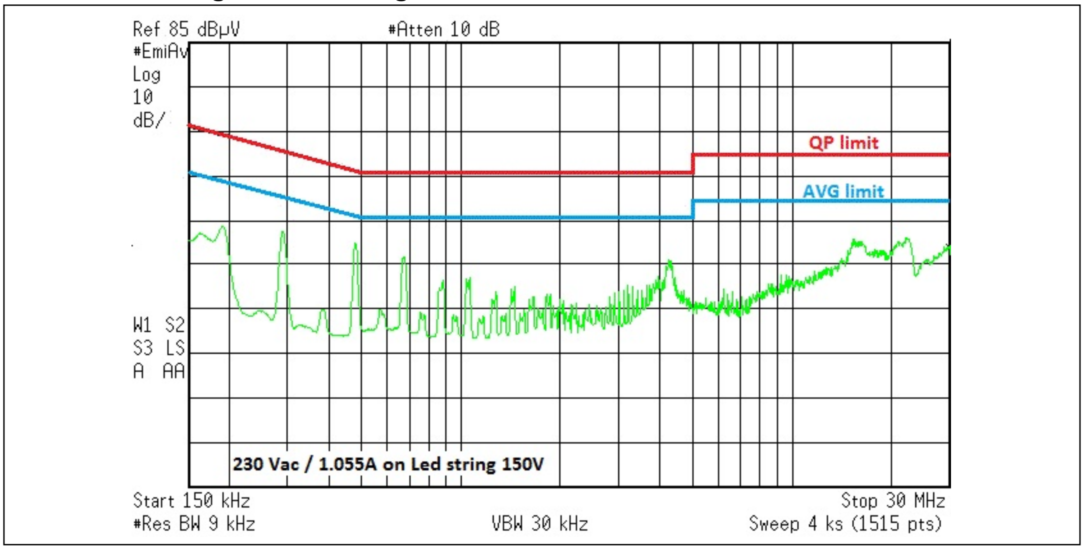


Figure 52. Average CE measurement: 230 Vac / full Load



12 Bill of material

Table 3. EVL6699-HVSL Evaluation board: bill of material

Ref	Value/PN	Case	Description	Supplier
C1	470N-X2	9.0 × 18.0 p15mm	X2 - film cap - B32922C3474K	EPCOS
C2	2N2-Y1	p10mm	Y1 safety cap. DE1E3KX222M	MURATA
C3	2N2-Y1	p10mm	Y1 safety cap. DE1E3KX222M	MURATA
C4	470N-X2	9.0 × 18.0 p15mm	X2 - film cap - B32922C3474K	EPCOS
C5	470N - 630V	8.5 x 26.5 p22.5mm	630V - film cap - B32673Z6474K	EPCOS
C6	4N7	5.0 x 13.0 p10mm	450VAC - film cap - B32651A7472K	EPCOS
C7	22uF	2220	CERCAP - 50V - X7R - 20%	TDK
C8	22uF	2220	CERCAP - 50V - X7R - 20%	TDK
C9	100uF-450V	DIA 18 x 35.5 mm	Aluminium ELCAP - CY SERIES - 105°C	NICHICON
C10	2N2-Y1	p10mm	Y1 safety cap. DE1E3KX222M	MURATA
C11	2N2-Y1	p10mm	Y1 safety cap. DE1E3KX222M	MURATA
C12	33pF - 1KV	1206	1KV CERCAP - X7R - 10%	MURATA
C13	220pF	1206	630V CERCAP - GRM31A7U2J220JW31	MURATA
C14	47nF 1KV	7.0 x 18.0 p15mm	1KV - film cap - B32652A0473K	EPCOS
C15	470N	6.0x13 p10 mm	MKT film cap - B32521C3474M - 250V - 20%	EPCOS
C16	470N	6.0x13 p10 mm	MKT film cap - B32521C3474M - 250V - 20%	EPCOS
C17	470N	6.0x13 p10 mm	MKT film cap - B32521C3474M - 250V - 20%	EPCOS
C18	470N	6.0x13 p10 mm	MKT film cap - B32521C3474M - 250V - 20%	EPCOS
C19	N.M.	1210	CERCAP - 50V - X7R - 20%	TDK
C20	1uF	1206	CERCAP - 50V - X7R - 20%	TDK
C21	2N2	0805	50V CERCAP - C0G - 10%	AVX
C22	N.M.	0805	Not mounted	
C23	4.7uF	8.5x7.2 p5 mm	MKS2 film cap - MKS2C044701M00 - 63V - 5%	WIMA
C24	4.7uF	8.5x7.2 p5 mm	MKS2 film cap - MKS2C044701M00 - 63V - 5%	WIMA
C25	N.M.	0805	Not mounted	

Table 3. EVL6699-HVSL Evaluation board: bill of material (continued)

Ref	Value/PN	Case	Description	Supplier
C26	10N-500V	1206	CERCAP - 500V - X7R - 10%	KEMET
C27	100N	0805	CERCAP - 50V - X7R - 10%	KEMET
C101	68N	0805	CERCAP - 25V - C0G - 10%	AVX
C102	5.6N	1206	CERCAP - 25V - X7R - 20%	AVX
C103	100N	1206	CERCAP - 50V - X7R - 10%	AVX
C104	2N2	0805	CERCAP - 50V - C0G - 10%	AVX
C105	220PF	0805	CERCAP - 50V - C0G - 5%	AVX
	Replace with 560pF for optimization (see paragraph *1.1*)			
C106	1uF	0805	CERCAP - 25V - X7R - 10%	AVX
C107	4.7uF	1206	CERCAP - 50V - X7R - 20%	AVX
C108	10uF	1206	CERCAP - 25V - X7R - 20%	TDK
C109	2x 10uF	1206	CERCAP - 25V - X7R - 20%	TDK
C110	1uF	1206	CERCAP - 50V - X7R - 10%	AVX
C111	2N2	1206	2 KV CERCAP - X7R - 10%	AVX
C112	1N0	0805	CERCAP - 50V - X7R - 10%	AVX
C113	100N	0805	CERCAP - 50V - X7R - 10%	AVX
C114	100N	0805	CERCAP - 50V - X7R - 10%	KEMET
C115	1.0uF	1206	CERCAP - 25V - X7R - 20%	AVX
C116	DNM	0805	CERCAP - 50V - X7R - 10%	AVX
C117	220PF	0805	CERCAP - 50V - C0G - 5%	AVX
C118	10N	0805	CERCAP - 50V - C0G - 5%	AVX
C119	10uF	1206	CERCAP - 25V - X7R - 20%	TDK
C120	10N	0805	CERCAP - 50V - X7R - 10%	AVX
C121	10N	0805	CERCAP - 50V - X7R - 10%	AVX
C122	4N7	0805	CERCAP - 50V - C0G - 10%	AVX
C123	10N	0805	CERCAP - 50V - X7R - 10%	AVX
C124	680P	0805	CERCAP - 50V - C0G - 10%	AVX
C201	100N	0805	CERCAP - 50V - X7R - 10%	KEMET
C202	5.6N	0805	CERCAP - 50V - X7R - 10%	KEMET
C203	100N	0805	CERCAP - 50V - X7R - 10%	KEMET
C204	100N	0805	CERCAP - 50V - X7R - 10%	KEMET
C205	100N	0805	CERCAP - 50V - X7R - 10%	KEMET
C206	N.M.	0805	Not mounted	
D1	GBU8J	STYLE GBU	Single phase bridge rectifier	VISHAY
D2	1N4148WS	SOD-323	High speed signal diode	VISHAY

Table 3. EVL6699-HVSL Evaluation board: bill of material (continued)

Ref	Value/PN	Case	Description	Supplier
D3	1N4005	DO-41 DO - 41	General purpose rectifier	VISHAY
D4	STTH5L06	DO-201	Ultrafast high voltage rectifier	STMicroelectronics
D5	1N4148WS	SOD-323	High speed signal diode	VISHAY
D6	N.M.	DO214AC	Not mounted	
D7	N.M.	DO214AC	Not mounted	
D8	1N4148WS	SOD-323	High speed signal diode	VISHAY
D9	STTH3R02Q	DO-15	Ultrafast rectifier	STMicroelectronics
D10	STTH3R02Q	DO-15	Ultrafast rectifier	STMicroelectronics
D11	STTH3R02Q	DO-15	Ultrafast rectifier	STMicroelectronics
D12	STTH3R02Q	DO-15	Ultrafast rectifier	STMicroelectronics
D13	STPS1H100A	SMA	Power SCHOTTKY diode	STMicroelectronics
D14	BAV21W-V	SOD-123	Small signal diode high voltage	VISHAY
D18	BAV99	SOT-23	Dual small signal diode	VISHAY
D101	1N4148WS	SOD-323	High speed signal diode	VISHAY
D102	1N4148WS	SOD-323	High speed signal diode	VISHAY
D103	1N4148WS	SOD-323	High speed signal diode	VISHAY
D104	STPS140Z	SOD-123	Power SCHOTTKY diode	STMicroelectronics
D105	MMSZ13T1	SOD-123	13V ZENER diode	ONSEMI
D106	DNM	SOD-123	39V ZENER diode	ONSEMI
F1	FUSE T4A	8.5x4 p.5.08mm	FUSE 4A - TIME LAG - 3921400	LITTLEFUSE
HS1	HEAT-SINK	DWG	Heatsink FOR D1, Q1, Q2, Q3	
J1	MKDS 1,5/ 3-5,08	DWG	PCB TERM. BLOCK, SCREW CONN., PITCH 5MM - 3 W.	PHOENIX CONTACT
J2	MKDS 1/2-5.0	DWG	PCB TERM. BLOCK, SCREW CONN., PITCH 5MM - 2 W.	PHOENIX CONTACT
J3	MOLEX2P	HEADER 2.54	Male header 2.54mm - 2P	MOLEX
JP1	FEMALE HEADER 20	DWG	Female header p.2,54mm PRECI-DIP	
JP2	FEMALE HEADER 9	DWG	Female header p.2,54mm PRECI-DIP	
JP101	MALE HEADER 20P 90°	DWG	Male header p.2,54mm 90°	
JP201	MALE HEADER 7P 90°	DWG	Male header p.2,54mm 90°	
JPX1	JUMPER			
JPX51	SHORTED		Wire jumper (See mech part)	
L1	2019.0002	DWG	Input EMI filter	MAGNETICA

Table 3. EVL6699-HVSL Evaluation board: bill of material (continued)

Ref	Value/PN	Case	Description	Supplier
L2	1975.0004	DWG	PFC inductor - 0.31mH - PQ26/25	MAGNETICA
L3	10uH	dia 8.8, p 5 mm	Drim coil RFB0807-100	COILCRAFT
Q1	STF24N60M2	TO-220FP	N-channel Power MOSFET	STMicroelectronics
Q2	STF13N60M2	TO-220FP	N-channel Power MOSFET	STMicroelectronics
Q3	STF13N60M2	TO-220FP	N-channel Power MOSFET	STMicroelectronics
Q4	BSS169	SOT-23	N-CH depletion MOSFET	INFINEON
Q101	BC847C	SOT-23	NPN small signal BJT	VISHAY
Q102	BC847C	SOT-23	NPN small signal BJT	VISHAY
Q201	BC857C	SOT-23	PNP small signal BJT	VISHAY
R002	2.4K	0805	SMD standard film RES - 1/8W - 5% - 250ppm/°C	VISHAY
R003	3.0K	0805	SMD standard film RES - 1/8W - 5% - 250ppm/°C	VISHAY
R1	NTC 2R5-S237	DWG	NTC RESISTOR P/N B57237S0259M000	EPCOS
R2	5R6	0805	SMD standard film RES - 1/8W - 5% - 250ppm/°C	VISHAY
R3	5R6	0805	SMD standard film RES - 1/8W - 5% - 250ppm/°C	VISHAY
R4-JPX1	SHORTED	PTH	SHORT BY WIRE	
R5	N.M.	0805	Not mounted	
R6	3R3	0805	SMD standard film RES - 1/8W - 5% - 250ppm/°C	VISHAY
R7	22R	0805	SMD standard film RES - 1/8W - 5% - 250ppm/°C	VISHAY
R8	100K	0805	SMD standard film RES - 1/8W - 5% - 250ppm/°C	VISHAY
R9	0R27	PTH	RSMF1TB - METAL FILM RES - 1W - 2% - 200ppm/°C	AKANEOHM
R10-JPX2	0R47	PTH	RSMF1TB - METAL FILM RES - 1W - 2% - 200ppm/°C	AKANEOHM
R11	56R	0805	SMD standard film RES - 1/8W - 5% - 250ppm/°C	VISHAY
R12	100K	0805	SMD standard film RES - 1/8W - 5% - 250ppm/°C	VISHAY
R13	56R	0805	SMD standard film RES - 1/8W - 5% - 250ppm/°C	VISHAY
R14	100K	0805	SMD standard film RES - 1/8W - 5% - 250ppm/°C	VISHAY

Table 3. EVL6699-HVSL Evaluation board: bill of material (continued)

Ref	Value/PN	Case	Description	Supplier
R15	100R	1206	SMD standard film RES - 1/4W - 1% - 100ppm/°C	VISHAY
R16	N.M.	0805	Not mounted	
R17	1R0	2512	SMD CURRENT SENSE RESISTOR - 1W - 1%	PANASONIC
R18	1R0	2512	SMD CURRENT SENSE RESISTOR - 1W - 1%	PANASONIC
R19	7K5	0805	SMD standard film RES - 1/8W - 5% - 200ppm/°C	VISHAY
R20	130K	0805	SMD standard film RES - 1/8W - 1% - 100ppm/°C	VISHAY
R21	10R	0805	SMD standard film RES - 1/8W - 5% - 200ppm/°C	VISHAY
R22	15K	0805	SMD standard film RES - 1/8W - 1% - 100ppm/°C	VISHAY
R23	1R0	1206	SMD standard film RES - 1/4W - 5% - 250ppm/°C	VISHAY
R24	2R2	0805	SMD standard film RES - 1/8W - 5% - 250ppm/°C	VISHAY
R25	62K	0805	SMD standard film RES - 1/8W - 5% - 200ppm/°C	VISHAY
R26	3K9	0805	SMD standard film RES - 1/8W - 5% - 250ppm/°C	VISHAY
R27	N.M.	0805	Not mounted	
R28	N.M.	0805	Not mounted	
R29	150K	1206	SMD standard film RES - 1/4W - 5% - 250ppm/°C	VISHAY
	Remove for optimization (see paragraph 1.1)			
R30	180K	1206	SMD standard film RES - 1/4W - 5% - 250ppm/°C	VISHAY
	Remove for optimization (see paragraph 1.1)			
R31	N.M.	PTH	Not mounted	
R32	100K	0805	SMD standard film RES - 1/8W - 5% - 250ppm/°C	VISHAY
R33	100K	0805	SMD standard film RES - 1/8W - 5% - 250ppm/°C	VISHAY
R39	4K7	0805	SMD standard film RES - 1/8W - 5% - 250ppm/°C	VISHAY
R40	N.M.	0805	Not mounted	
R42	2K7	0805	SMD standard film RES - 1/8W - 5% - 250ppm/°C	VISHAY

Table 3. EVL6699-HVSL Evaluation board: bill of material (continued)

Ref	Value/PN	Case	Description	Supplier
R44	470K	0805	SMD standard film RES - 1/8W - 1% - 100ppm/°C	VISHAY
R45	150K	0805	SMD standard film RES - 1/8W - 1% - 100ppm/°C	VISHAY
R46	15K	0805	SMD standard film RES - 1/8W - 5% - 250ppm/°C	VISHAY
R50	5K6	0805	SMD standard film RES - 1/8W - 1% - 100ppm/°C	VISHAY
R51	47K	0805	SMD standard film RES - 1/8W - 1% - 100ppm/°C	VISHAY
R52	470R	0805	SMD standard film RES - 1/8W - 5% - 250ppm/°C	VISHAY
R101	750K	1206	SMD standard film RES - 1/4W - 1% - 100ppm/°C	VISHAY
R102	750K	1206	SMD standard film RES - 1/4W - 1% - 100ppm/°C	VISHAY
R103	750K	1206	SMD standard film RES - 1/4W - 1% - 100ppm/°C	VISHAY
R104	3K9	1206	SMD standard film RES - 1/4W - 1% - 100ppm/°C	VISHAY
R105	3K9	PTH	standard film RES - 1/8W - 1% - 100ppm/°C	VISHAY
R106	82K	0805	SMD standard film RES - 1/8W - 5% - 250ppm/°C	VISHAY
R107	10R	0805	SMD standard film RES - 1/8W - 1% - 100ppm/°C	VISHAY
R108	16K	0805	SMD standard film RES - 1/8W - 5% - 250ppm/°C	VISHAY
R109	56K	0805	SMD standard film RES - 1/8W - 5% - 250ppm/°C	VISHAY
R110	1M0	0805	SMD standard film RES - 1/8W - 1% - 100ppm/°C	VISHAY
R111	2M2	PTH	standard film RES - 1/8W - 1% - 100ppm/°C	VISHAY
R112	2M2	1206	SMD standard film RES - 1/4W - 1% - 100ppm/°C	VISHAY
R113	2M2	1206	SMD standard film RES - 1/4W - 1% - 100ppm/°C	VISHAY
R114	1M0	PTH	standard film RES - 1/8W - 1% - 100ppm/°C	VISHAY
R115	1M0	1206	SMD standard film RES - 1/4W - 1% - 100ppm/°C	VISHAY

Table 3. EVL6699-HVSL Evaluation board: bill of material (continued)

Ref	Value/PN	Case	Description	Supplier
R116	1M0	1206	SMD standard film RES - 1/4W - 1% - 100ppm/°C	VISHAY
R117	27K	0805	SMD standard film RES - 1/8W - 1% - 100ppm/°C	VISHAY
R118	62K	0805	SMD standard film RES - 1/8W - 1% - 100ppm/°C	VISHAY
R119	4K7	0805	SMD standard film RES - 1/8W - 5% - 250ppm/°C	VISHAY
R120	470R	0805	SMD standard film RES - 1/8W - 1% - 100ppm/°C	VISHAY
R121	0R0	0805	SMD standard film RES - 1/8W - 5% - 250ppm/°C	VISHAY
R122	1K0	0805	SMD standard film RES - 1/8W - 5% - 250ppm/°C	VISHAY
R123	33K	0805	SMD standard film RES - 1/8W - 5% - 250ppm/°C	VISHAY
R124	62K	0805	SMD standard film RES - 1/8W - 1% - 100ppm/°C	VISHAY
R125	0R0	0805	SMD standard film RES - 1/8W - 5% - 250ppm/°C	VISHAY
R126	220K	0805	SMD standard film RES - 1/8W - 1% - 100ppm/°C	VISHAY
R127	8K2	0805	SMD standard film RES - 1/8W - 1% - 100ppm/°C	VISHAY
R128	27K	0805	SMD standard film RES - 1/8W - 1% - 100ppm/°C	VISHAY
	Add RC series = 430R / 1nF between RFMIN pin and GND (in // to R128), for optimization (see paragraph *1.1*)			
R129	4K3	0805	SMD standard film RES - 1/8W - 5% - 250ppm/°C	VISHAY
R130	3K0	0805	SMD standard film RES - 1/8W - 5% - 250ppm/°C	VISHAY
R131	47R	0805	SMD standard film RES - 1/8W - 5% - 250ppm/°C	VISHAY
R132	SHORTED	PTH	Wire jumper	
R133	N.M.	0805	Not mounted	
R134	0R0	0805	SMD standard film RES - 1/8W - 5% - 250ppm/°C	VISHAY
R135	0R0	0805	SMD standard film RES - 1/8W - 5% - 250ppm/°C	VISHAY
R136	1K0	0805	SMD standard film RES - 1/8W - 5% - 250ppm/°C	VISHAY

Table 3. EVL6699-HVSL Evaluation board: bill of material (continued)

Ref	Value/PN	Case	Description	Supplier
R137	270R	0805	SMD standard film RES - 1/8W - 1% - 100ppm/°C	VISHAY
R138	10R	1206	SMD standard film RES - 1/4W - 1% - 100ppm/°C	VISHAY
R139	68R	0805	SMD standard film RES - 1/8W - 1% - 100ppm/°C	VISHAY
R140	33K	0805	SMD standard film RES - 1/8W - 1% - 100ppm/°C	VISHAY
R141	180K	0805	SMD standard film RES - 1/8W - 1% - 100ppm/°C	VISHAY
R142	N.M.	PTH	Not mounted	
R201	1K0	0805	SMD standard film RES - 1/8W - 1% - 100ppm/°C	VISHAY
R202	22R	0805	SMD standard film RES - 1/8W - 5% - 250ppm/°C	VISHAY
R203	10K	0805	SMD standard film RES - 1/8W - 1% - 100ppm/°C	VISHAY
R204	10K	0805	SMD standard film RES - 1/8W - 5% - 250ppm/°C	VISHAY
R205	27K	0805	SMD standard film RES - 1/8W - 5% - 250ppm/°C	VISHAY
R206	N.M.	0805	Not mounted	
R207	27K	0805	SMD standard film RES - 1/8W - 1% - 100ppm/°C	VISHAY
R208	180K	0805	SMD standard film RES - 1/8W - 1% - 100ppm/°C	VISHAY
R209	18K	0805	SMD standard film RES - 1/8W - 1% - 100ppm/°C	VISHAY
R210	20K	0805	SMD standard film RES - 1/8W - 1% - 100ppm/°C	VISHAY
R211	N.M.	0805	Not mounted	
R212	620K	0805	SMD standard film RES - 1/8W - 1% - 100ppm/°C	VISHAY
R213	0R0	0805	SMD standard film RES - 1/8W - 5% - 200ppm/°C	VISHAY
R214	0R0	0805	SMD standard film RES - 1/8W - 5% - 200ppm/°C	VISHAY
R215	12K	0805	SMD standard film RES - 1/8W - 1% - 100ppm/°C	VISHAY
R216	12K	0805	SMD standard film RES - 1/8W - 1% - 100ppm/°C	VISHAY

Table 3. EVL6699-HVSL Evaluation board: bill of material (continued)

Ref	Value/PN	Case	Description	Supplier
R217	200K	0805	SMD standard film RES - 1/8W - 1% - 100ppm/°C	VISHAY
R218	1K0	0805	SMD standard film RES - 1/8W - 1% - 100ppm/°C	VISHAY
RV1	300Vac	dia.15x5 p7.5 mm	300V metal oxide varistor - B72214S0301K101	EPCOS
T1	1860.0152	DWG	Resonant transformer	MAGNETICA
U1	TLVH431AIL3T	SOT23-3L	1.24V programmable shunt voltage reference	STMicroelectronics
U2	SFH617A-2	DIP-4 - 10.16MM	Optocoupler	VISHAY
U3	SFH617A-2	DIP-4 - 10.16MM	Optocoupler	VISHAY
U6	TLVH431AIL3T	SOT23-3L	1.24V programmable shunt voltage reference	STMicroelectronics
U101	L6564H	SO-14	HV startup transition mode PFC	STMicroelectronics
U102	L6699D	SO-16	Improved HV resonant controller	STMicroelectronics
U201	LM258AD	SO-8	Low power dual OP AMP	STMicroelectronics
U202	LM258AD	SO-8	Low power dual OP AMP	STMicroelectronics
Z1	PCB REV. 2.0		STCMB1 power board	
Z101	PCB REV. 1.0		PFC & LLC control daughterboard	
Z201	PCB REV. 1.0		CC control daughterboard	

13 PFC coil specification

General description and characteristics:

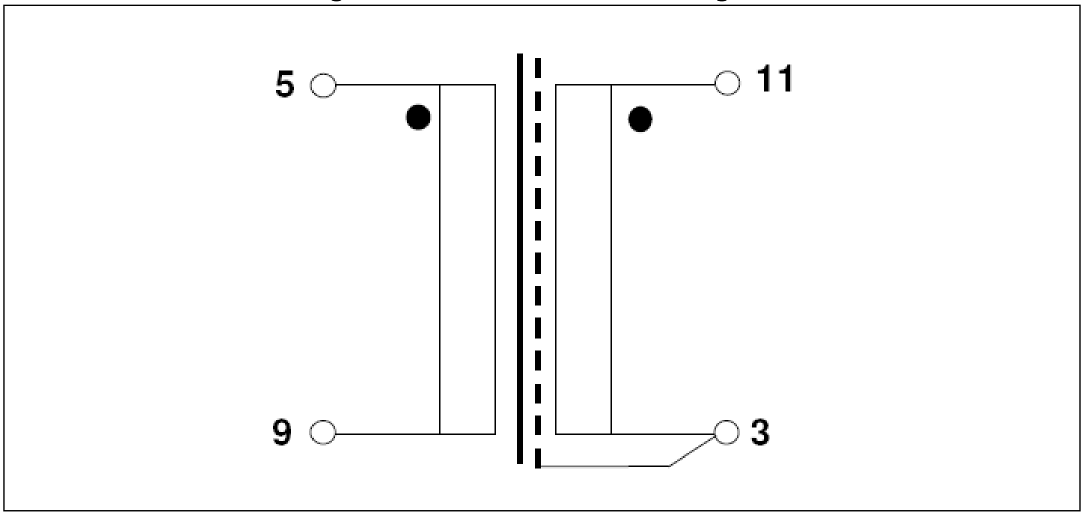
- Application type: consumer, home appliance
- Transformer type: open
- Coil former: vertical type, 6+6 pins
- Max. temp. rise: 45ºC
- Max. operating ambient temperature: 60ºC
- Mains insulation: n.a.
- Unit finishing: varnished

Electrical characteristics:

- Converter topology: boost, transition mode
- Core type: PQ26/25-PC44 or equivalent
- Min. operating frequency: 40 kHz
- Typical operating frequency: 120 kHz
- Primary inductance: 310 µH±10% at 1 kHz-0.25 V[(a)]
- Peak current: 5.6 Apk

Electrical diagram and winding characteristics:

Figure 53. PFC coil electrical diagram



a. Measured between pins #5 and #9.

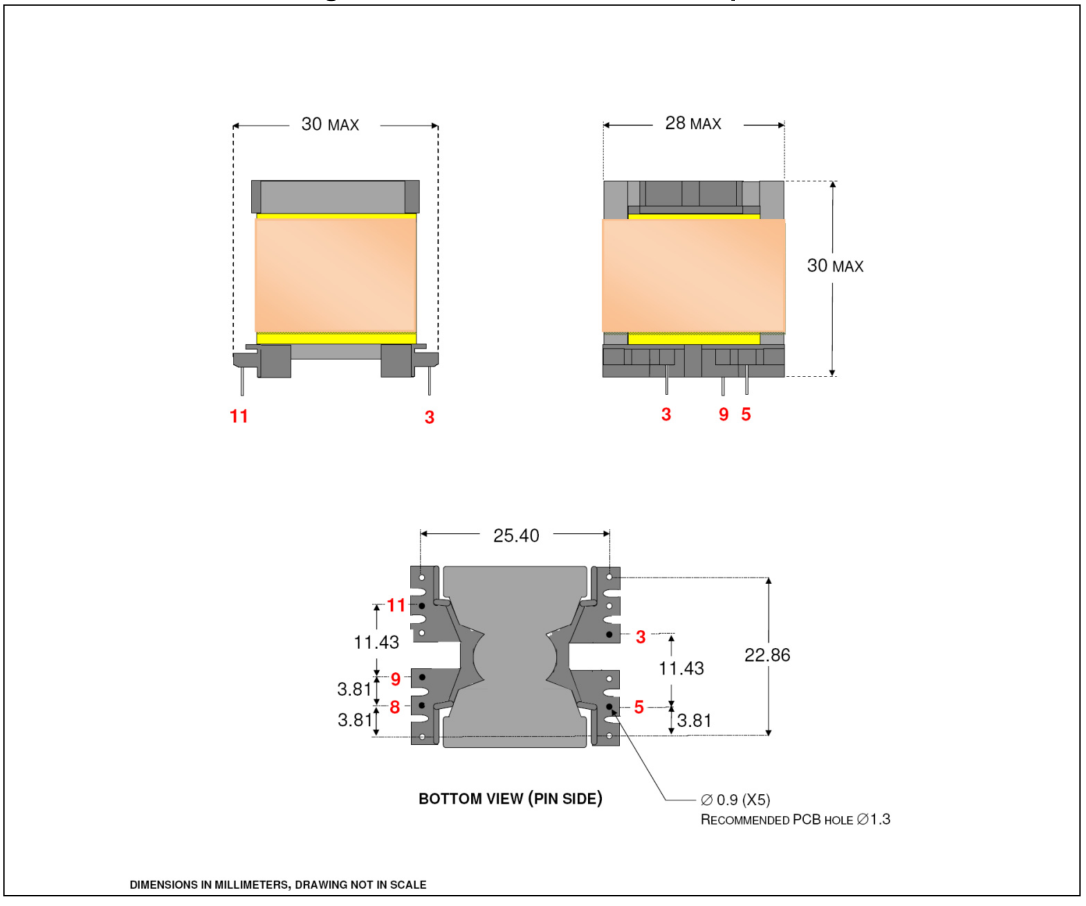
Table 4. PFC coil winding data

Pins	Windings	RMS current	Number of turns	Wire type
11 - 3	AUX	0.05 A_{RMS}	5	ϕ 0.28 mm - G2
5 - 8/9	PRIMARY	2.3 A_{RMS}	50	50xϕ 0.1 mm - G1

Mechanical aspect and pin numbering

- Maximum height from PCB: 30 mm
- Coil former type: vertical, 6+6 pins (pins 1, 2, 4, 6, 7, 10, 12 are removed)
- Pin distance: 3.81 mm
- Row distance: 25.4 mm
- External copper shield: not insulated, wound around the ferrite core and including the coil former. Height is 8mm. Connected to pin #3 by a soldered solid wire.

Figure 54. PFC coil mechanical aspect



Manufacturer

- MAGNETICA di R. Volpini - Italy - www.magnetica.eu
- Inductor P/N: 1975.0004

14 Transformer specification

General description and characteristics

- Application type: industrial, lighting
- Transformer type: open
- Coil Former: horizontal type, 7+7 pins, two slots
- Max. temp. rise: 45ºC
- Max. operating ambient temperature: 60ºC
- Mains insulation: Acc. with EN60950

Electrical characteristics

- Converter topology: half-bridge, resonant
- Core type: ETD34-PC44 or equivalent
- Min. operating frequency: 56 kHz
- Typical operating frequency: 90 kHz
- Primary inductance: 3.00 mH ± 20% at 10 kHz-0.25 V[b]
- Leakage inductance: 300 µH ± 10% at 100 kHz-0.25 V[c]

Figure 55. Transformer electrical diagram

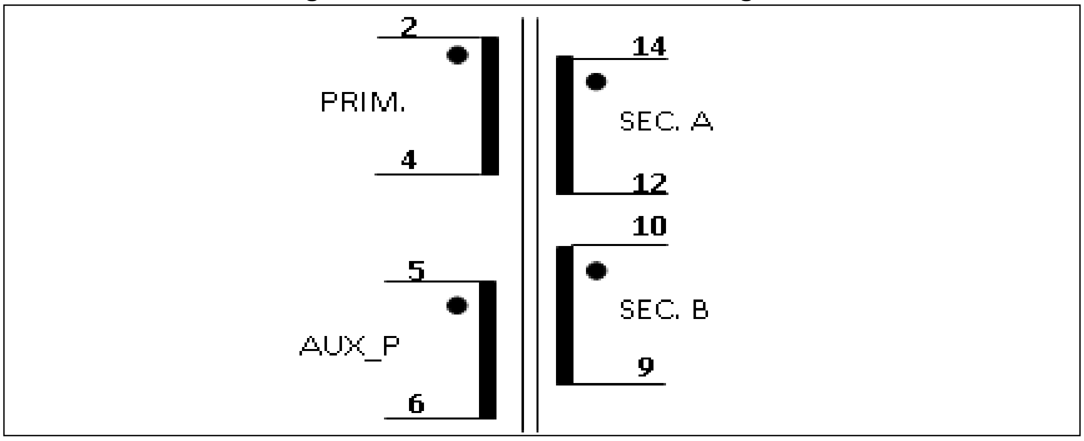


Table 5. Transformer winding data

Pins	Winding	DC resistance	Number of turns	Wire type
2 - 4	PRIMARY	1.6 A_{RMS}	60	TBD
5 - 6	AUX_P[(1)]	0.05 A_{RMS}	5	TBD
14 - 12	SEC. A	1.6 A_{RMS}	54	TBD
10 - 9	SEC. B[(2)]	0.05 A_{RMS}	17	TBD

b. Measured between pins 2-4.

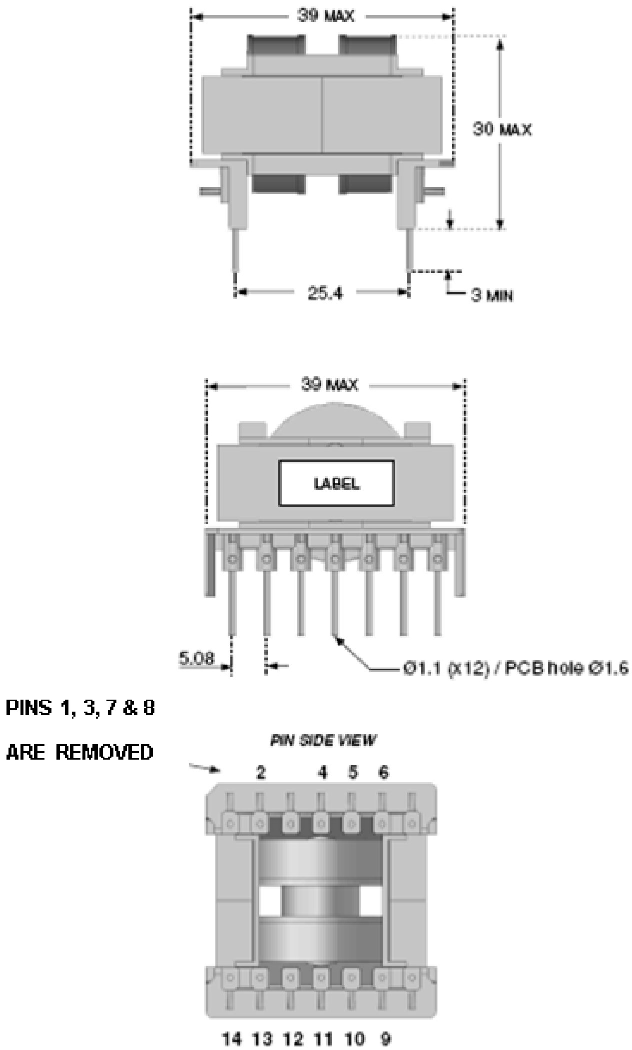
c. Measured between pins 2-4 with all secondary windings shorted.

1. Aux winding primary side is wound on top of primary winding, turns are close to each other, placed on external side of the coil former.
2. Secondary B winding on secondary side is wound on top of Secondary A winding, turns are spaced on whole coil former secondary side slot.

Mechanical aspect and pin numbering

- Maximum height from PCB: 30mm
- Coil former type: horizontal, 7+7 pins (pins #1, 3, 7 and 8 are removed)
- Pin distance: 5.08mm
- Row distance: 25.4mm

Figure 56. Transformer overall drawing



Manufacturer

- MAGNETICA di R. Volpini - Italy - www.magnetica.eu
- Transformer P/N: 1860.0152

15 Revision history

Table 6. Document revision history

Date	Revision	Changes
25-July-2019	1	Initial release.