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AN5774

Application note

EVL012LED: 200W LED driver using the STNRG012

Introduction

LEDs changed the way we see light. Day by day, they are replacing old lighting methods in so many applications, from outdoor street and park lighting, horticulture, and floodlights to interior lighting of industrial, commercial, and home spaces, just to cite a few.

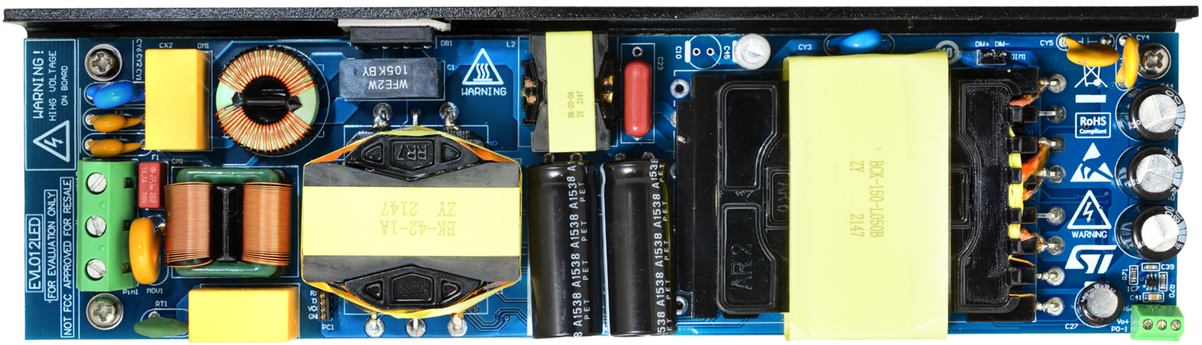
There are several reasons that drive this change: efficiency, endurance, quality of light, low maintenance, and cost.

But while LED luminaries establish new standards in terms of performance, they are also challenging their power supply units, from tight specifications to reliability and long life. This application note describes the performance of EVL012LED, a 200 W, wide input mains range, power-factor corrected, LED driver board, that can be tailored to several implementations in the above fields.

Its architecture is based on a two-stage approach: a front-end PFC pre-regulator and a downstream resonant half-bridge converter, using the new STNRG012 IC that embeds the controllers of both sections in the same device. Thanks to the STNRG012, the main features of this design are high efficiency, low power consumption at no load without an auxiliary supply, good Power Factor with low harmonic content, and reduced parts count.

The board also has a full set of protection features including output overload, short-circuit, and overvoltage; all of them can be easily defined as latched or auto-restart, simply changing a value in the non-volatile memory of the controller.

Figure 1. EVL012LED: 200 W wide input range LED driver



1 Main characteristics and circuit description

The main features of this LED driver demo board are listed hereafter:

Universal input mains range	90…277 Vac - frequency 45 ÷ 65 Hz
Maximum output power	200 W
Constant current output	3.6A max.
Output voltage range	36÷56 Vdc
Mains harmonics	According to EN61000-3-2 Class-C, JEITA-MITI Class-C
No load Mains Consumption	< 0.5 W
Auxiliary stage	No
Efficiency	> 93 % at full load
THD	< 7.5% at 230 Vac from 30% to 100% of full load
Conducted EMC	According to EN55022-Class-B limits
Safety	According to EN60950
Dimensions	210x55x15mm, (L x W x H)
PCB	Dual layer, 35 μm, FR-4, mixed PTH/SMT
Dimming	Analog from 100% to less than 10% with: • 100 Kohm potentiometer or: • 0-10 V external voltage
Feedback loops	Constant current and constant voltage
Protections	• Input brown-in/out • PFC saturation and PFC OVP • LLC capacitive mode, OCP • LED output overload and short-circuit, LED string open, feedback disconnections

The key component of this board is the STNRG012. This device embodies the controllers for a multi-mode transition mode (TM) PFC, and a time shift (TSC) LLC resonant converter; moreover, all the MOSFET drivers, an 800 V-rated high voltage section, and all the glue logic required to supervise the operations are included, reducing the overall part count to a real minimum. This device is a member of the STNRG01x family, and so it inherits almost all the features of that component, while it is especially intended for lighting applications.

In fact, a relevant aspect is its ability to work with DC input voltages, also allowing the implementation of special power supplies, i.e., for emergency lighting.

Refer to the datasheet for a complete description of all its characteristics.

The STNRG012, as a digital combo, provides a very high configurability by means of a set of parameters stored in its non-volatile memory (NVM), while remaining as simple to use as an equivalent analog device: no coding is needed at all.

A PC based, user-friendly, GUI is available to easily configure and fine-tune the system, without changing any components.

The communication board STEVAL-PCC020V2 provides an insulated link to connect the demo board to a Personal Computer.

1.1 PFC power stage

The PFC section uses a proprietary constant on-time control methodology that does not require a sinusoidal input reference, thereby reducing the external component count and overall system cost. In particular, the controller implements a multi-mode PFC that manages the Transition Mode, the (one to three) Valley Skipping, and the Discontinuous Conduction Mode (DCM).

This stage works as a pre-regulator and powers the resonant stage with a constant voltage of about 407 V (configurable with NVM parameters #40 "*PFC Vout Target*"). This voltage is regulated by means of a digital PI control loop, whose parameters are determined by NVM values (#22 "PFC Ki", and #23 "PFC Kp").

It also includes a complete set of protections:

- a cycle-by-cycle overcurrent (PFC OC1).
- a boost inductor saturation protection (PFC OC2).
- an output overvoltage (Software: PFC SW OVP, and Hardware: PFC HW OVP).
- an output undervoltage (PFC UVP).
- a feedback disconnection failure (on PFC CS current sense pin).
- an AC brown-in/out.

1.2 LLC resonant power stage

The STNRG012 incorporates an advanced controller, specific for the resonant half-bridge topology, with both high-side and low-side MOS drivers. It employs the ST proprietary "Symmetric Time Shift" algorithm that always guarantees 50% duty cycle, and allows a good supply ripple rejection, even with a simple loop compensation. Normally, in this converter the MOSFETs are alternately switched on and off (180° out-of-phase) for exactly the same time, with a deadtime TD where both MOSFETs are off, inserted between the turn-off of one MOSFET and the turn-on of the other one. This deadtime is essential for the converter to work correctly: it enables soft-switching and then, the high frequency operation with high efficiency and low EMI emissions. NVM parameter #47 "*LLC deadtime*" can be used to establish the correct value for this time.

Also, the LLC stage is equipped with several protections:

- an overload protection (LLC OLP)
- an overcurrent protection (LLC OC2)
- an anti-capacitive (Soft: LLC Soft ACP, and Hard: LLC Hard ACP)
- an output overvoltage (LLC OVP)
- a feedback disconnection failure (on LLC CS sense pin).

On the secondary side synchronous rectification is employed to increase the board efficiency. An SRK2001 drives the two (Q7 and Q9) 150 V rated MOS, while Q6 and Q10 signal MOSFETs have been introduced to scale the high transformer voltages to the SRK2001 DVS1 and DVS2 inputs.

1.3 Dimming and feedback loops

The EVL012LED implements two different feedback loops: the first regulates the LEDs current (CC), the other controls the output voltage (CV), both are handled on the secondary side by a TSM1014, (a dedicated IC with two operational amplifiers and a reference voltage).

With the configuration realized, in normal conditions, the current flowing in the LEDs string is regulated according to an external dimming voltage or resistor. This is achieved by the current control loop: the signal appearing on connector DIM1 is buffered, filtered, scaled, and fed, as reference signal, to the positive input (C+) of the CC error amplifier, which compares it to the voltage coming from the output of a current sense amplifier.

A TSC213 is used for the latter function, together with a 3 mOhm sense resistor, thus introducing low power losses, while maintaining a good precision.

The output of the error amplifier then drives an optocoupler (OP1) through diode D19. When in CC mode, with a correct LED string plugged in, the output of the voltage loop is high and does not sink any current through D18 and OP1: the unique regulation path involved is that of the current control loop.

Otherwise, if the LED string is "open", the output voltage is limited to a value that is determined by the Constant Voltage loop: the TSM1014 (CV) section compares its internal reference to the LEDs anode voltage, scaled down by a resistive divider, and regulates it in consequence, slightly above 56 V (56.7 V nom).

The TSM1014 CV output operates on the same (OP1) optocoupler of the CC loop then, if the output voltage rises too much, its output goes low, forcing a current through D18 and OP1, overriding the CC loop and reducing the output power.

To close both the Current and Voltage feedback loops, on the primary side, the phototransistor of the optocoupler is configured as a common emitter that sinks current from a central node of a voltage divider; this node is also connected to the LLC_FB pin of the STNRG012 IC, whose voltage is sampled and converted into a digital number that is used by the SMEDs as the time-shift value for LLC power stage control.

1.4 Protections

In case of CC loop failure with the LEDs string connected, the voltage loop cannot be activated because the output voltage is clamped by the LEDs, and the output current could go out of control. When the corresponding current on the primary side becomes excessive, the Overload Protection (OLP) integrated in the STNRG012 intervenes to protect the board: if the OLP is detected for a time interval longer than a value set by the NVM parameter #52: “LLC OLP Timeout”, the device shuts down the system.

In case of a short-circuit the Overcurrent Protection level_2 (OCP2) is triggered, and the device shuts down the board after a programmable number of OCP2 occurrences: NVM parameter #11 “*Max Number of LLC OC2*”.

To protect the board against a failure of the CV loop, an LLC OVP circuitry is implemented on the secondary side with IC3 (TL431ACL) and OP2 (EL1008). If the OVP function is enabled, “LLC OVP detection” parameter #6, and Vout exceeds 62 V, the TL431 sinks current. This causes a high current through R38 on the primary side and, consequently, the pin LLC_AUX goes above 2.5 V triggering the protection. This fault is set as “latched” to increase the safety of the system: if the LEDs string fails to open or is disconnected, the board enters the OVP latched condition, and stops working. When the LEDs are reconnected, no light is generated until the mains voltage is switched off and on again.

1.5 Auxiliary voltage supplies

To power the control circuitry at the secondary side, an auxiliary voltage is derived from an additional winding of the LLC transformer, and is regulated to 12 V by Q8, driven by IC6.

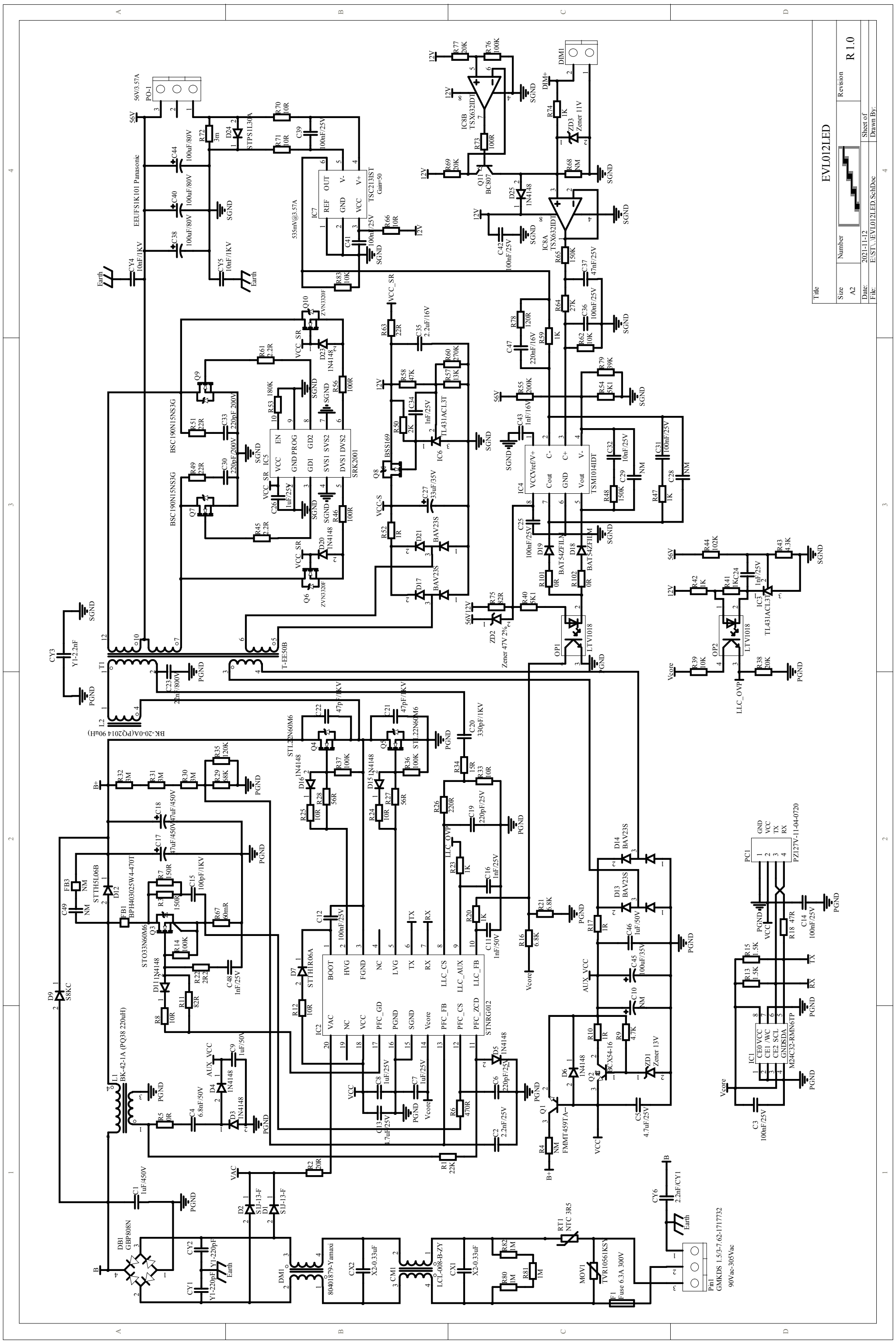
On the same transformer, another winding provides the auxiliary supply to the primary side (AUX_VCC) by means of a bridge rectifier (D13 and D14), and to the STNRG012 IC through the simple regulator formed by Q2 and ZD1. To speed up the start-up phase and reduce the time to light, the high voltage transistor Q1, can be connected to the bulk voltage through R4 (please read the DT0138 for more information).

Finally, a charge pump is connected between a winding on the PFC coil and the unregulated AUX_VCC to sustain VCC while the PFC is activated, but the resonant converter is not yet turned on.

In this way, the usual Flyback supply can be avoided.

1.5.1 Electrical diagram

Figure 2. Electrical diagram



2 Efficiency and open load input power

Normal operation efficiency measurement

Table 1 shows the overall efficiency measured at the nominal mains voltages, powering an active load set to emulate an LED string. At 120 Vac the full load efficiency is 93.11%, at 230 Vac it is 94.53%. and at 277 Vac it is 94.78%. And over 90% for output power higher than 40% whatever the input voltage.

Table 1. Overall efficiency at nominal mains input voltage.

Vin [Vac]	Pin [W]	VLED [V]	ILED [A]	POUT [W]	Load [%]	PF	THD [%]	EFF. [%]
90V / 60Hz	219.19	56.339	3.5475	199.86	100	0.9962	3.1	91.18
	198.49	56.333	3.2250	181.67	90	0.998	3.1	91.53
	176.01	56.333	2.8612	161.18	80	0.9984	3.2	91.57
	153.80	56.335	2.5012	140.91	70	0.9985	3.5	91.62
	132.05	56.337	2.1450	120.84	60	0.9983	3.6	91.51
	110.34	56.34	1.7812	100.35	50	0.9977	4	90.95
	89.03	56.344	1.4212	80.08	40	0.9967	4.7	89.94
	67.78	56.348	1.0612	59.80	30	0.9949	5.3	88.22
	46.33	56.352	0.7012	39.51	20	0.9896	5.3	85.29
	25.40	56.357	0.3750	21.13	10	0.7955	11	83.20
120V / 60Hz	214.56	56.312	3.5475	199.77	100	0.9985	2.9	93.11
	194.84	56.314	3.2212	181.40	90	0.9983	3	93.10
	173.24	56.316	2.8612	161.13	80	0.998	3.2	93.01
	151.80	56.32	2.5012	140.87	70	0.9974	3.5	92.80
	128.61	56.324	2.1075	118.70	60	0.9965	3.9	92.30
	109.39	56.331	1.7850	100.55	50	0.9952	4.2	91.92
	88.50	56.337	1.4212	80.07	40	0.9928	4.5	90.47
	67.39	56.342	1.0612	59.79	30	0.9887	4.5	88.72
	46.00	56.347	0.7012	39.51	20	0.9767	5	85.89
	25.20	56.351	0.3750	21.13	10	0.7668	10	83.87
230V / 50Hz	211.34	56.317	3.5475	199.78	100	0.9914	2.5	94.53
	192.26	56.318	3.2212	181.41	90	0.9898	2.6	94.36
	171.33	56.32	2.8612	161.14	80	0.9873	3	94.05
	150.47	56.323	2.5012	140.88	70	0.9838	3.3	93.62
	129.80	56.327	2.1450	120.82	60	0.9788	3.7	93.08
	109.08	56.333	1.7812	100.34	50	0.9709	4.3	91.99
	88.60	56.336	1.4212	80.06	40	0.9577	5.3	90.37
	67.45	56.343	1.0612	59.79	30	0.9331	7.3	88.65
	46.05	56.347	0.7012	39.51	20	0.8744	12	85.80
	25.15	56.352	0.3750	21.13	10	0.71	20	84.02
277V /	210.77	56.311	3.5475	199.76	100	0.9817	3.3	94.78
	191.74	56.313	3.2212	181.40	90	0.979	3.7	94.60

Vin [Vac]	Pin [W]	VLED [V]	ILED [A]	POUT [W]	Load [%]	PF	THD [%]	EFF. [%]
50Hz	170.93	56.316	2.8600	161.06	80	0.9745	4.2	94.23
	150.23	56.326	2.5012	140.88	70	0.9678	4.9	93.78
	127.73	56.33	2.1075	118.72	60	0.9569	5.8	92.94
	108.96	56.335	1.7812	100.34	50	0.943	6.7	92.09
	87.53	56.338	1.4212	80.07	40	0.9163	12.2	91.47
	66.72	56.344	1.0612	59.79	30	0.8624	15	89.62
	45.43	56.349	0.7012	39.51	20	0.7811	22	86.97
	24.90	56.373	0.3712	20.93	10	0.5511	52	84.04
277V / 60Hz	210.76	56.31	3.5475	199.76	100	0.9753	3.8	94.78
	191.78	56.312	3.2212	181.39	90	0.9712	4.3	94.58
	170.96	56.318	2.8612	161.14	80	0.9649	4.8	94.25
	150.25	56.325	2.5012	140.88	70	0.9556	5.5	93.76
	127.72	56.33	2.1075	118.72	60	0.9413	6.7	92.95
	109.00	56.334	1.7812	100.34	50	0.9228	8	92.06
	87.57	56.339	1.4212	80.07	40	0.8907	13.5	91.43
	66.75	56.342	1.0612	59.79	30	0.8388	16.7	89.57
	45.42	56.35	0.7012	39.51	20	0.7391	23	86.99
	20.95	56.37	0.3712	20.92	10	0.5133	46	83.87

The same measurements are reported in Figure 4 at different input mains voltages.

Figure 3. Efficiency vs. output power

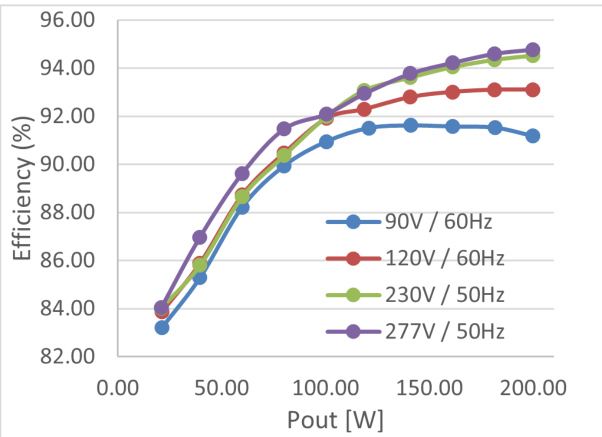
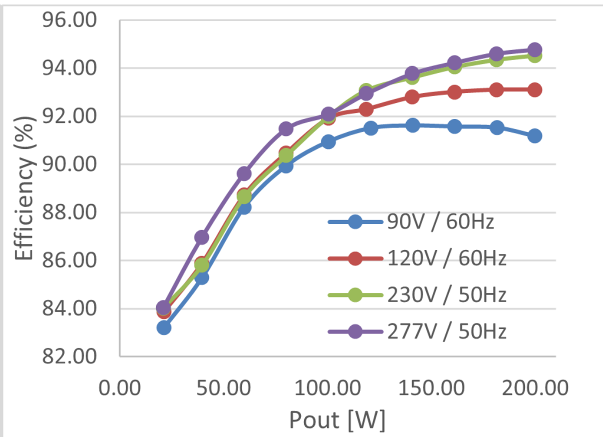


Figure 4. Efficiency vs. vin_ac

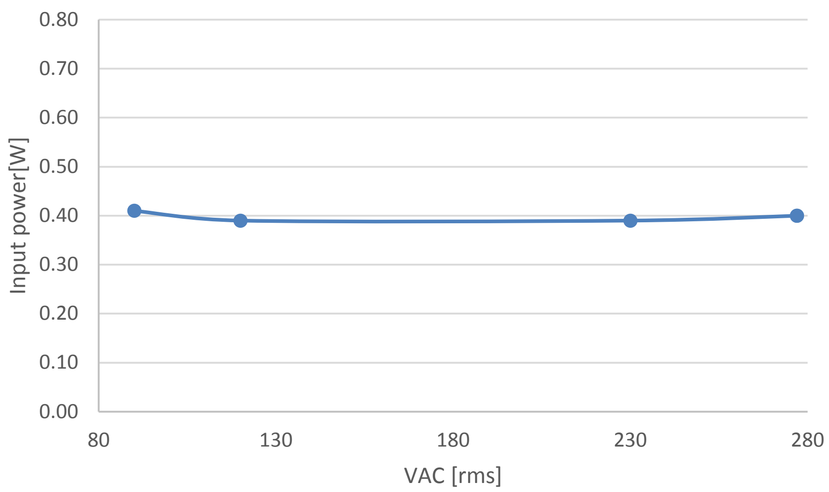


2.1 Open load input power consumption

Measurements during open load operation have been performed and reported in Figure 5. As can be seen, input power is below 500 mW, and almost constant for all mains voltages.

The tests have been done disconnecting the LED string from the board, measuring the input power by a power meter set in integration mode with 36s period. Input power does not change even if the dimming circuitry is driven by an external signal or the dimming input connector is left open.

Figure 5. **Open load input power vs. Vac**



3 Mains 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 the nominal mains input voltages. As reported in the following images, the harmonics content is below the limits both at full load and at 10% of the rated power. All tests below follow IEC61000-3-2(2020).

Figure 6. Compliance to EN61000-3-2 at 230 Vac – Vac – 50 Hz, full load

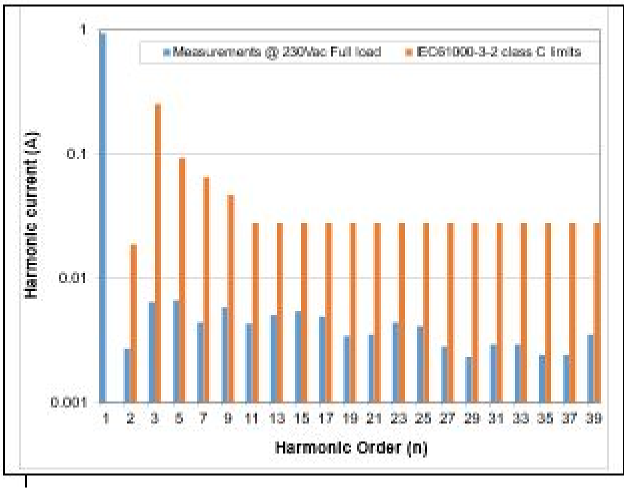


Figure 7. Compliance to EN61000-3-2 at 230 Vac – 50 Hz, 10% load

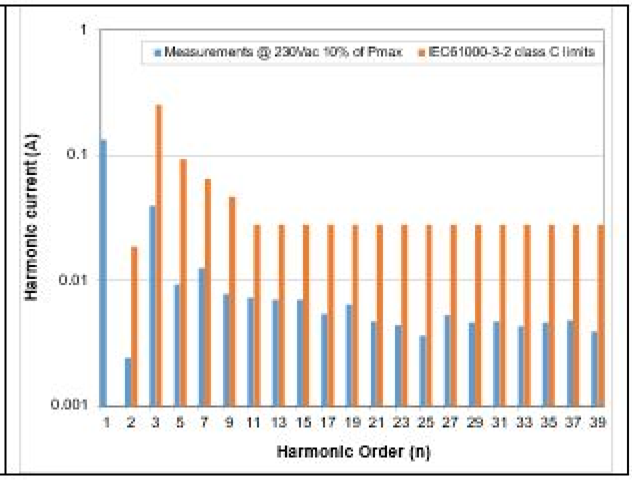


Figure 8. Compliance to EN61000-3-2 at 100 Vac – 60 Hz, full load

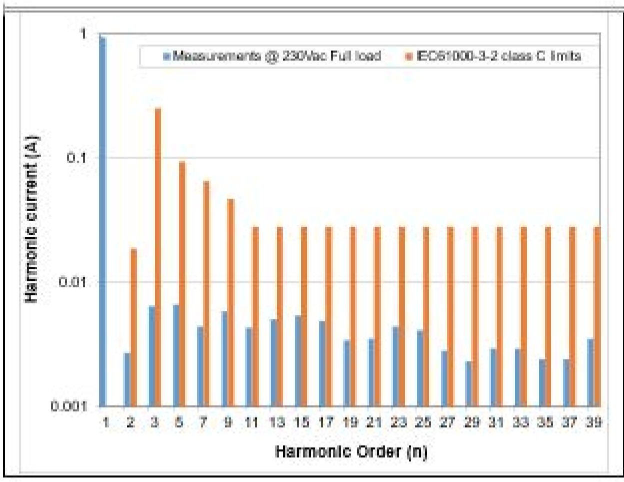
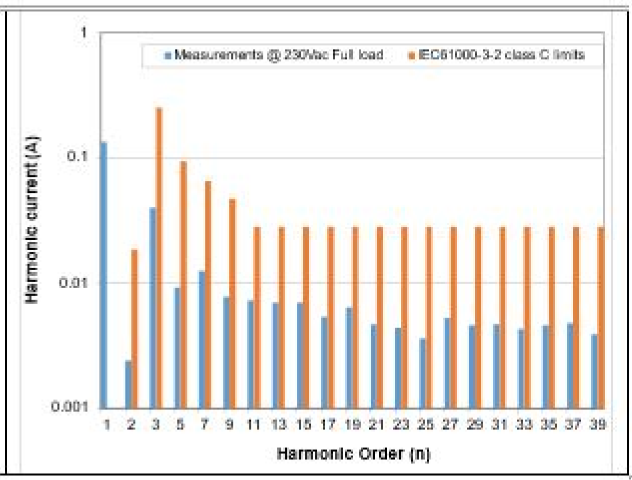


Figure 9. Compliance to EN61000-3-2 at 100 Vac – 60 Hz, 10% load



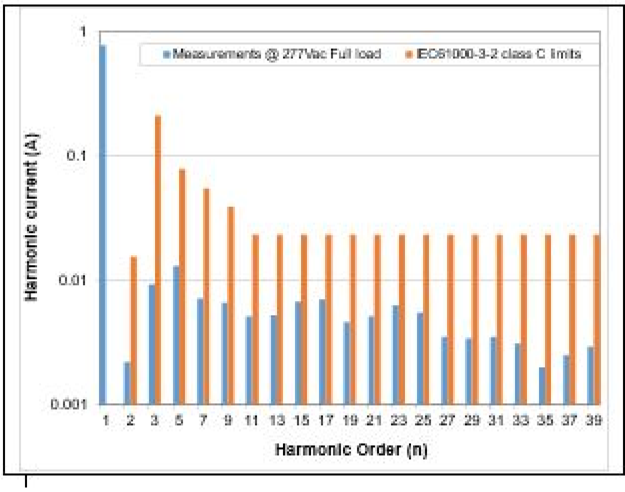


Figure 10. Compliance to EN61000-3-2 at 277 Vac - 50 Hz; full load

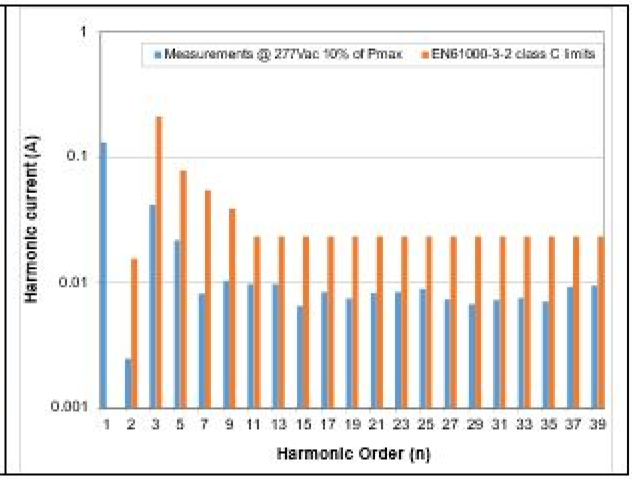


Figure 11. Compliance to EN61000-3-2 at 277 Vac - 50 Hz; 10% load

In Figure 12 and Figure 13 the power factor measurements are reported, as a function of the output LEDs current and input mains voltage. The power factor is quite good at high loads for all input voltages and decreases at low loads and high Vin as usual.

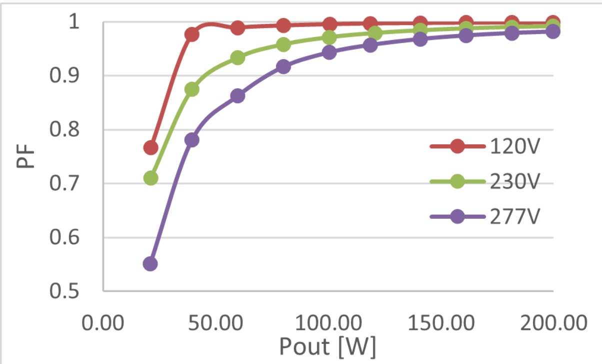


Figure 12. Power factor vs. output power

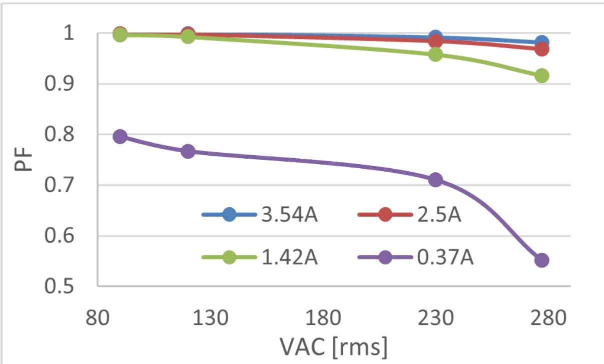
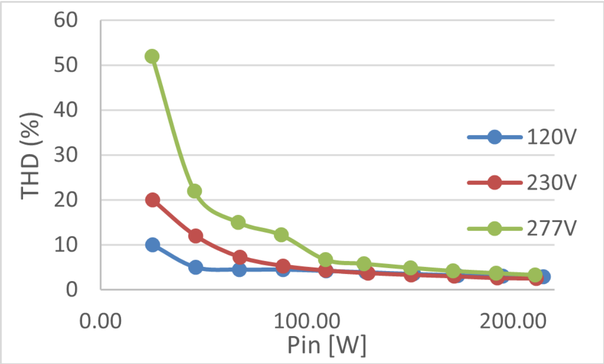


Figure 13. Power factor vs. Vac and LEDs current

Figure 14. THD vs. input power



In Figure 14 the THD measurements versus the input power at the nominal mains voltage are reported. At high loads, the THD is quite good, and as expected, worsens when reducing the output current. It is worth noting that the current regulations, including the IEC61000-3-2 and the JEITA-MITI, do not fix a limit for the THD value itself, instead the requirement is relative to each single harmonic peak, as represented in Figure 6 to Figure 11. The THD is therefore just an index, that gives a rough idea about the shape of the input current.

4 LEDs current dimming

Depending on the application, the LEDs current dimming approach can be quite different, leading to very specific solutions. For this reason, a very simple circuit is proposed on the demo board, leaving to the final customer the introduction of his own specific configuration. Our goal here is to show how immediate a basic circuit could be and provide a straightforward interface between the STNRG012 power section and the dimming control unit.

Therefore, analog dimming has been chosen, with a well-established topology: a (100uA) constant current source, implemented with IC8B and Q11, is placed between the aux supply (12V) and the (DIM+) line.

A variable resistor, with a value of 0 ... 100kohm, can be placed externally between the (DIM1) inputs, thus obtaining a voltage at these pins in the 0 to 10V range.

Otherwise, an external voltage source, with a current sink capability of at least 100uA, can be directly connected to the (DIM1) connector, obtaining the same behaviour.

In any case, the voltage at DIM1 is buffered by IC8A, filtered and scaled (R65, C37, R64, C36, R62), and then fed to the (C+) non-inverting input of the TSM1014 (CC) error amplifier. The (C-) inverting input of the same op_amp is driven by the output of IC7, the TSC213 current sense amplifier.

With a 3m ohm Rsense resistor, and with the gain Av = 50 of the TSC213, a sensitivity of:

$$(V\_sense / I\_led) = (Av * R\_sense) = (50 * 0.003) = 0.15V/A \tag{1}$$

is achieved.

This is equivalent to a V_sense voltage of 535mV at the full-scale output current of 3.57A, while, with the TSC213 offset of (+/- 100uV), the error is less than +/- 1%.

On the other hand, the max power dissipation on R_sense is limited to:

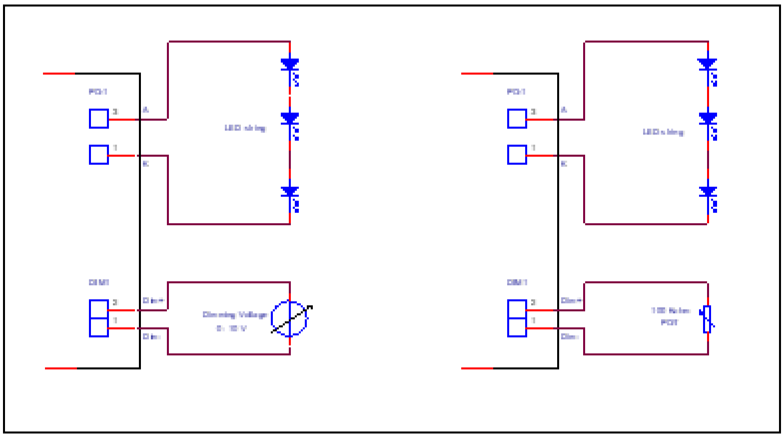
$$Pr_{\_sense} = (I\_led\_\max)^2 * R_{\_sense} = 38.2mW. \tag{2}$$

One point that has to be taken in account is that the (DIM-) input is directly connected to the secondary ground of the board, and then NO INSULATION is provided between the dimming circuitry and the board output.

Moreover, even though the PO-1_K connection (return of the LED string) is almost at ground potential, it should not be confused / interchanged with (DIM-), the risk is of shorting the current sense resistor or cause malfunctions.

The typical connection of analog dimming to the board is indicated in Figure 15:

Figure 15. Analog dimming connection at board connectors



In case the board connector (DIM1) is left floating, a current will be delivered to the LEDs string that is a little bit higher than the maximum value. If a greater accuracy is needed, a fixed resistor can be placed between DIM1 pins to define the required LEDs current.

Whith (Iout_max) = 3.57A.

$$Iout = \left(Iout\_max * \left(\frac{Vdim}{Vim\_max}\right)\right) = \left(Iout\_max\right) * \left(\frac{100uA * Rdim}{10V}\right) \quad (3)$$

$$Iout = \left(Iout\_max\right) * \left(10^{-5}\right) * \left(Rdim\right) \quad (4)$$

The LED current changes proportionally to the dimming voltage with a very good linearity, while it’s not too much sensitive to the LEDs voltage, as can be seen in Table 2 and Figure 16 hereafter.

Table 2. LED current vs. analog dimming signal at different V_{LED}

Dim voltage [V]	I_Led (A) at Vout= 36V	I_Led (A) at Vout= 48V	I_Led (A) at Vout= 56V
0	0.0397	0.0402	0.0401
1	0.3944	0.3946	0.3952
2	0.7474	0.7468	0.7465
3	1.1037	1.1029	1.1026
4	1.4598	1.4591	1.4587
5	1.817	1.8165	1.817
6	2.1687	2.1689	2.1686
7	2.5253	2.5235	2.5245
8	2.8901	2.8886	2.8899
9	3.2382	3.2385	3.238
10	3.5589	3.5593	3.5608

Figure 16. LED current vs. analog dimming signal at different V_{LED}

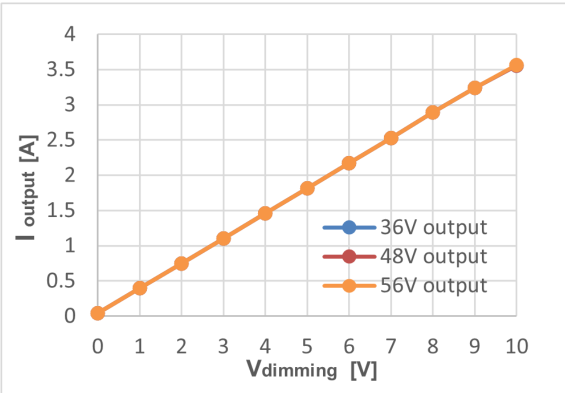
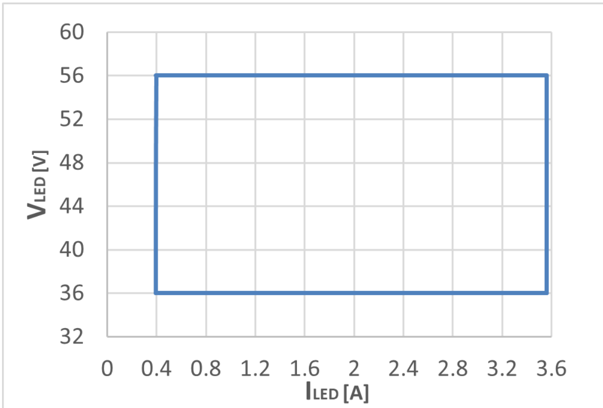


Figure 17. Converter operating area, I_{LED} vs V_{LED}



For LEDs voltage from 56V to 36V the current can be dimmed in the range <10% ÷ 100%, as visible in Section 4 . Considering that the lower limit is fixed more by the LEDs current ripple than by the current value itself.

From this point of view, it is worth noting that in this solution Burst Mode has been implemented, to increase the efficiency, only at low output current and at low output voltages, as it comes at the expenses of a higher current ripple, and forces to find a compromise between the two requirements.

5 Startup

The startup of the EVL012LED board is based only on the STNRG012 internal sequence, as no auxiliary power supply is present: its “high_voltage_startup” module begins to sink current from the mains voltage, as soon as it is available, and charges the Vcc capacitors C8, C13, C5 and, through D6, the capacitors C45 and C46.

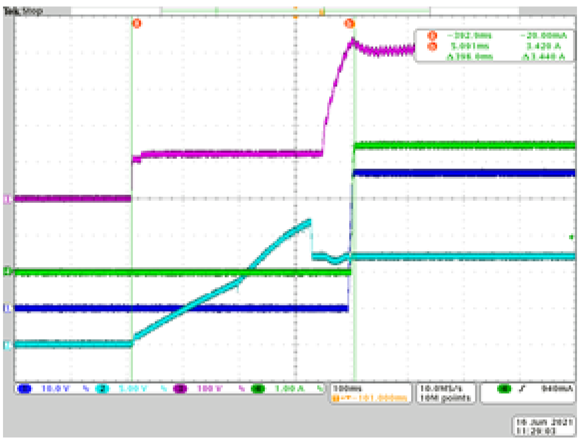
When the voltage on VCC pin reaches the turn-on threshold (Vcc_{ON}, 17 V typ.), the STNRG012 starts executing the BOOT and start-up phase. During the latter the device locks with the input line frequency to work in phase with Vac. After the device is synchronized, the PFC soft-start is activated with fixed power (set by “*PFC pss*” parameter #30) and charges the Bulk capacitor. When the B+ voltage reaches the value programmed by NVM parameter #41 “*PFC Vout SS end (delta)*” the resonant converter is enabled and its soft-start is activated at the next, estimated, mains zero crossing.

The waveforms relevant to the start-up phase, with dimming connector open and at different LED string voltages, have been captured from Figure 18 to Figure 29 (with 100% dimming) and from Figure 30 to Figure 41 (with 10% dimming). During all the measurements below, the start-up times have been recorded and put in. As can be seen in all conditions the time to light is shorter than 0.5s.

Table 3. Time to light with dimming 100%

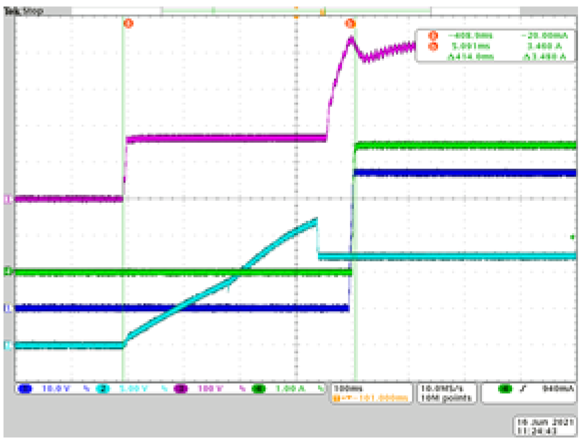
Vout	Vin [Vac V]	Frequency [HZ]	Start-up time (ms)
36V LED Lamp (Vout=37V)	90	60	398
	120	60	414
	230	50	410
	277	60	407
46V LED Lamp (Vout=49V)	90	60	402
	120	60	413
	230	50	417
	277	60	417
56V LED Lamp (Vout=56V)	90	60	418
	120	60	408
	230	50	421
	277	60	421

Figure 18. Startup at 90 Vac, V_{LED} = 37 V



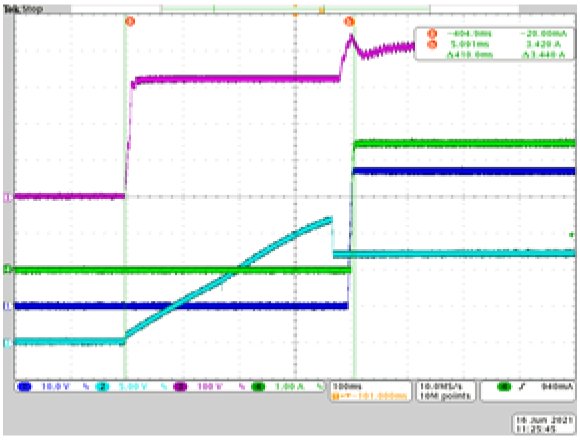
Ch1 = Vout Ch2 = Vcc Ch3 = Vbulk Ch4 = Iout

Figure 19. Startup at 120 Vac, V_{LED} = 37 V



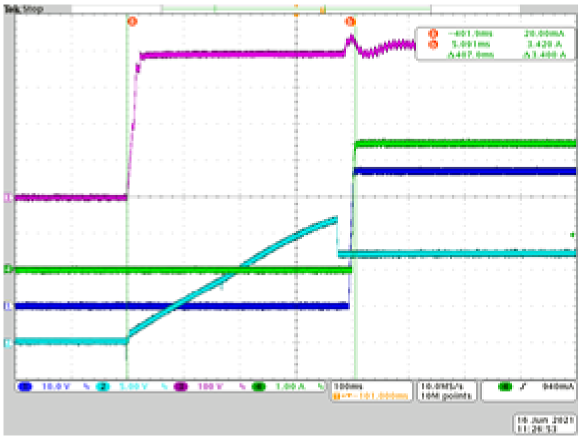
Ch1 = Vout Ch2 = Vcc Ch3 = Vbulk Ch4 = Iout

Figure 20. **Startup at 230 Vac, V_{LED} = 37 V**



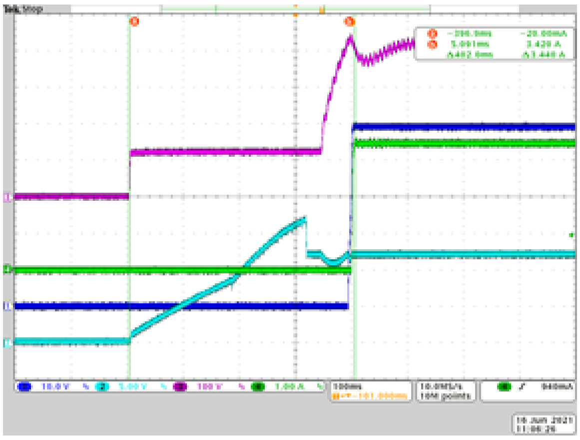
Ch1 = Vout Ch2 = Vcc Ch3 = Vbulk Ch4 = Iout

Figure 21. **Startup at 277 Vac, V_{LED} = 37 V**



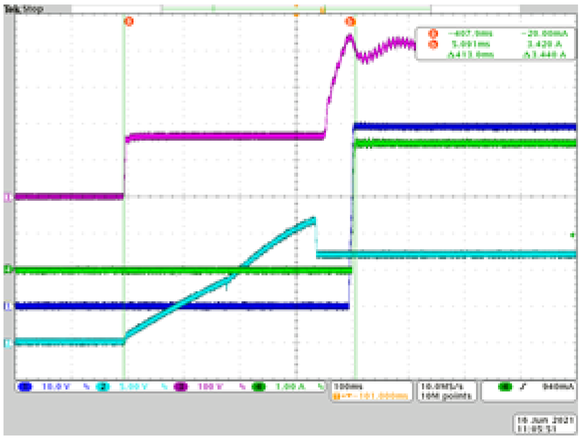
Ch1 = Vout Ch2 = Vcc Ch3 = Vbulk Ch4 = Iout

Figure 22. **Startup at 90 Vac, V_{LED} = 49 V**



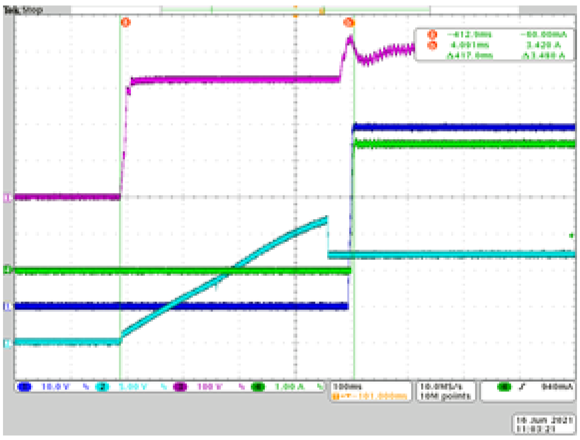
Ch1 = Vout Ch2 = Vcc Ch3 = Vbulk Ch4 = Iout

Figure 23. **Startup at 120 Vac, V_{LED} = 49 V**



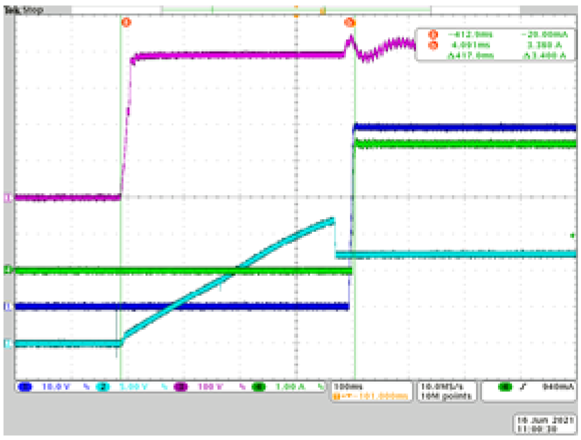
Ch1 = Vout Ch2 = Vcc Ch3 = Vbulk Ch4 = Iout

Figure 24. **Startup at 230 Vac, V_{LED} = 49 V**



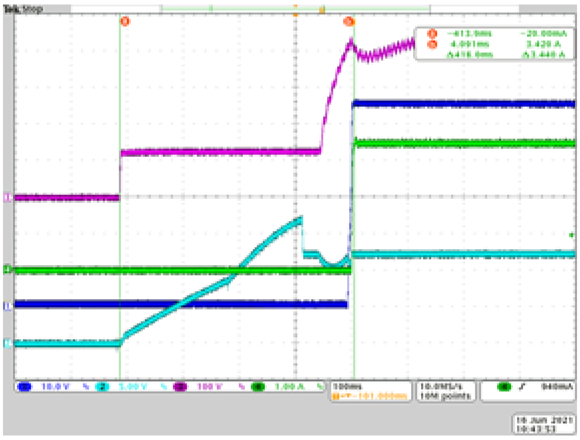
Ch1 = Vout Ch2 = Vcc Ch3 = Vbulk Ch4 = Iout

Figure 25. **Startup at 277 Vac, V_{LED} = 49 V**



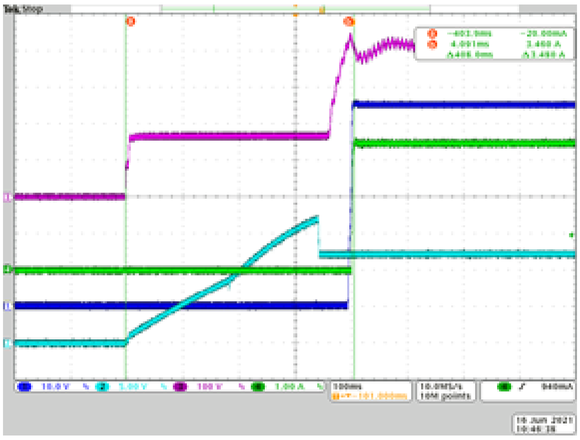
Ch1 = Vout Ch2 = Vcc Ch3 = Vbulk Ch4 = Iout

Figure 26. Startup at 90 Vac, V_{LED} = 56 V



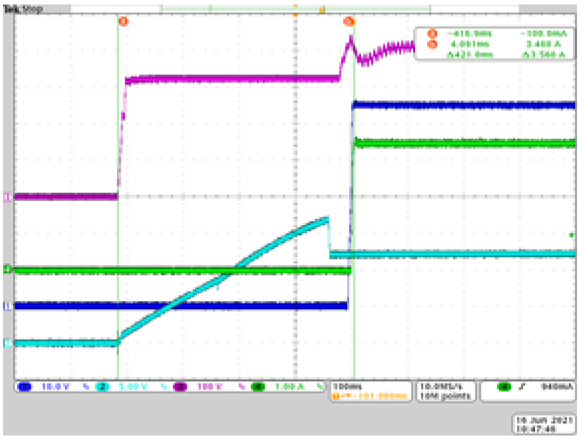
Ch1 = Vout Ch2 = Vcc Ch3 = Vbulk Ch4 = Iout

Figure 27. Startup at 120 Vac, V_{LED} = 56 V



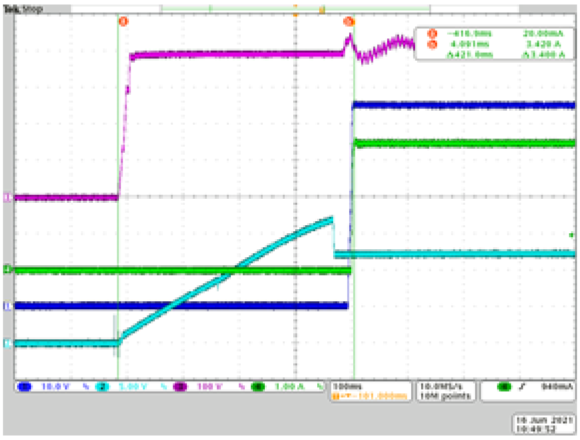
Ch1 = Vout Ch2 = Vcc Ch3 = Vbulk Ch4 = Iout

Figure 28. Startup at 230 Vac, V_{LED} = 56 V



Ch1 = Vout Ch2 = Vcc Ch3 = Vbulk Ch4 = Iout

Figure 29. Startup at 277 Vac, V_{LED} = 56 V

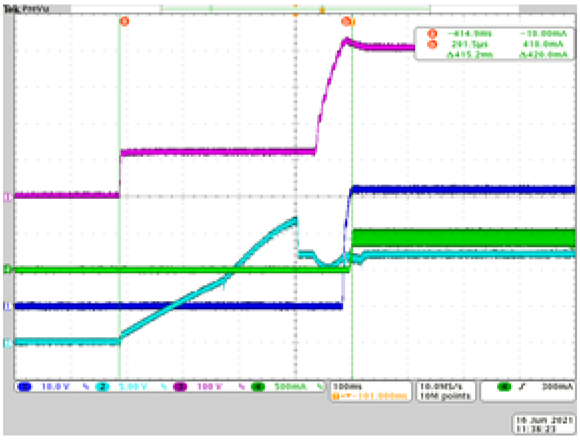


Ch1 = Vout Ch2 = Vcc Ch3 = Vbulk Ch4 = Iout

Table 4. Time to light with dimming 10%

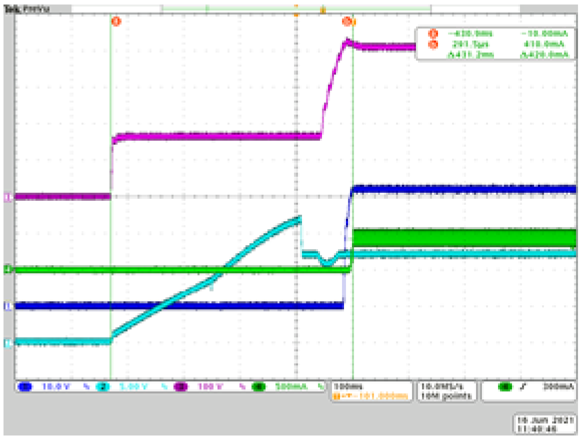
Vout	Vin [Vac V]	Frequency [HZ]	Startup time (ms)
36V LED Lamp (Vout=32V)	90	60	415
	120	60	431
	230	50	422
	277	60	421
46V LED Lamp (Vout=43V)	90	60	409
	120	60	430
	230	50	424
	277	60	429
56V LED Lamp (Vout=48V)	90	60	410
	120	60	418
	230	50	418
	277	60	422

Figure 30. **Startup at 90 Vac, V_{LED} = 32 V**



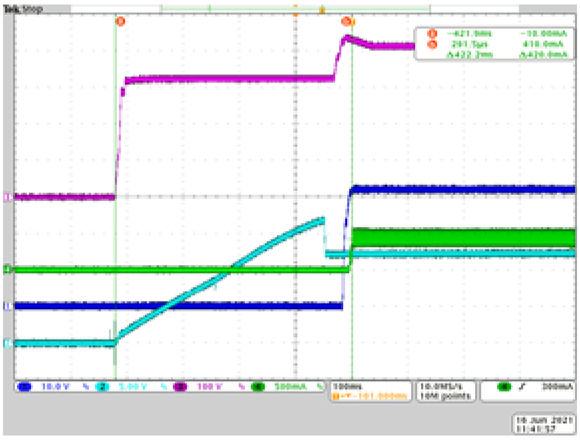
Ch1 = Vout Ch2 = Vcc Ch3 = Vbulk Ch4 = Iout

Figure 31. **Startup at 120 Vac, V_{LED} = 32 V**



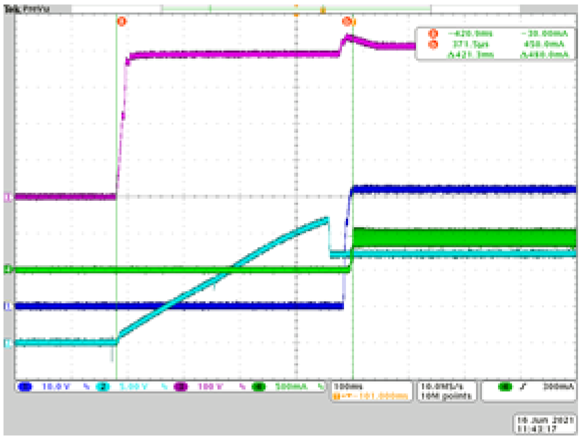
Ch1 = Vout Ch2 = Vcc Ch3 = Vbulk Ch4 = Iout

Figure 32. **Startup at 230 Vac, V_{LED} = 32 V**



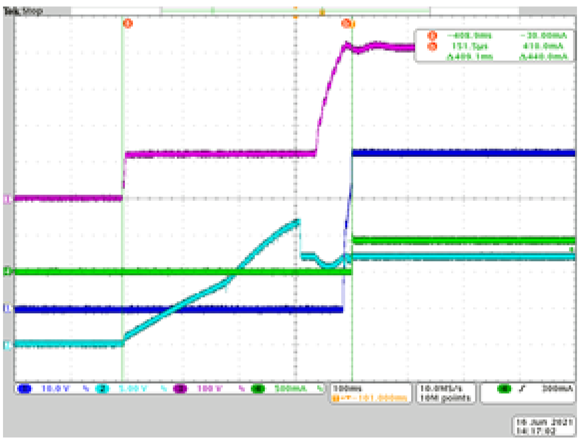
Ch1 = Vout Ch2 = Vcc Ch3 = Vbulk Ch4 = Iout

Figure 33. **Startup at 277 Vac, V_{LED} = 32 V**



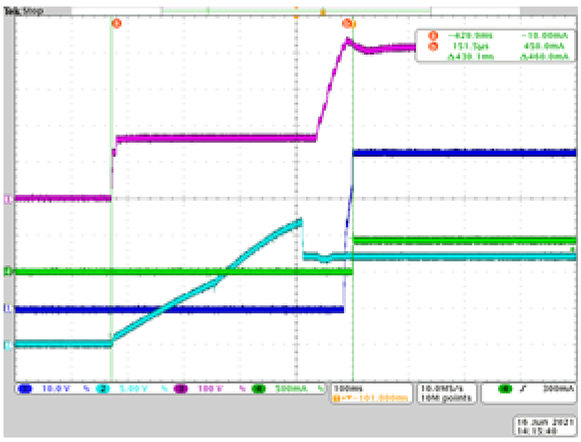
Ch1 = Vout Ch2 = Vcc Ch3 = Vbulk Ch4 = Iout

Figure 34. **Startup at 90 Vac, V_{LED} = 43 V**



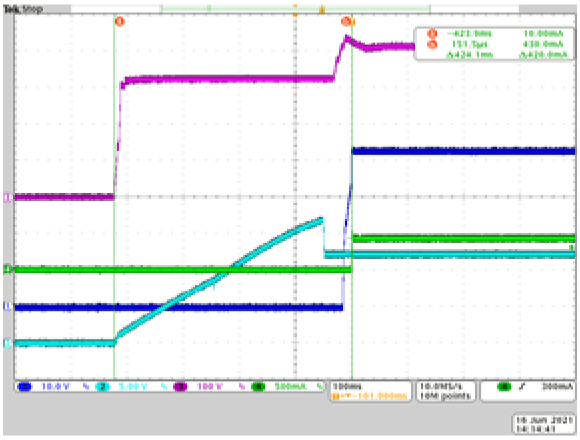
Ch1 = Vout Ch2 = Vcc Ch3 = Vbulk Ch4 = Iout

Figure 35. **Startup at 120 Vac, V_{LED} = 43 V**



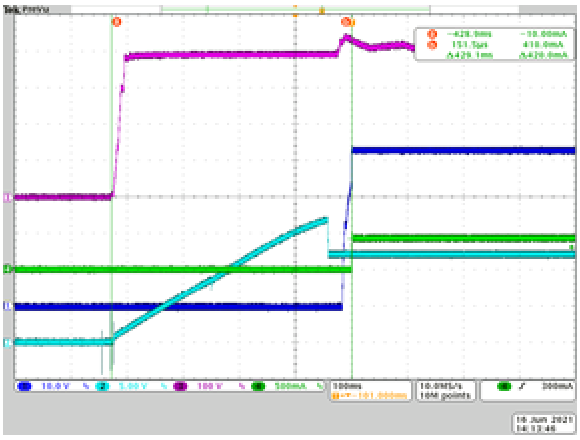
Ch1 = Vout Ch2 = Vcc Ch3 = Vbulk Ch4 = Iout

Figure 36. **Startup at 230 Vac, V_{LED} = 43 V**



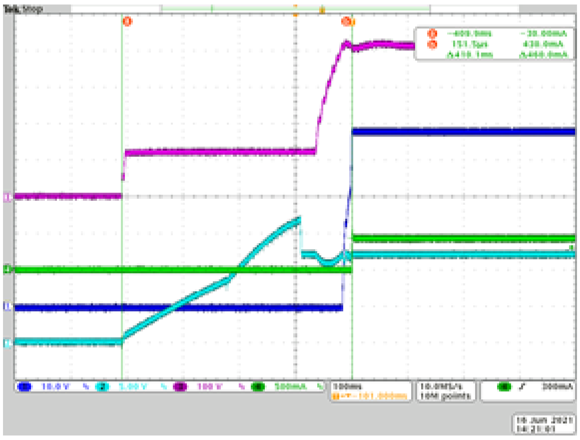
Ch1 = Vout Ch2 = Vcc Ch3 = Vbulk Ch4 = Iout

Figure 37. **Startup at 277 Vac, V_{LED} = 43 V**



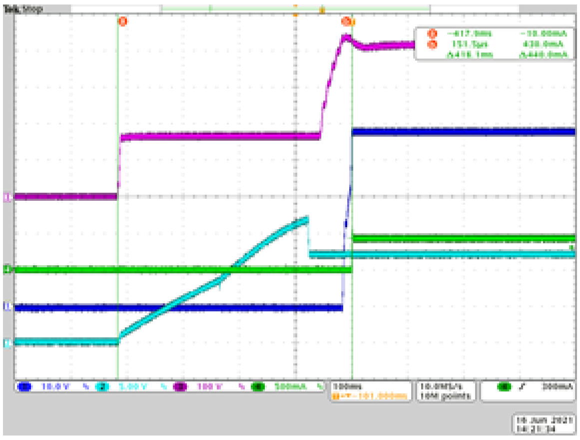
Ch1 = Vout Ch2 = Vcc Ch3 = Vbulk Ch4 = Iout

Figure 38. **Startup at 90 Vac, V_{LED} = 48 V**



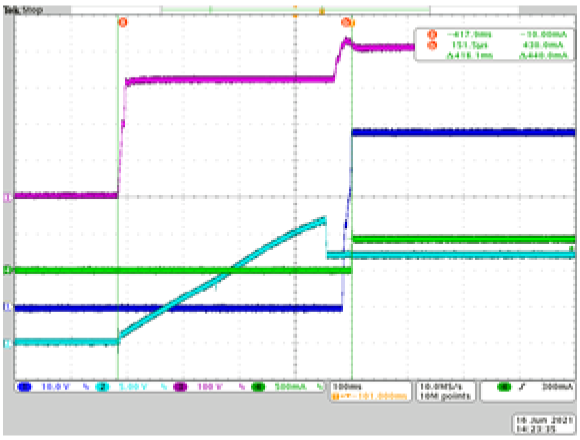
Ch1 = Vout Ch2 = Vcc Ch3 = Vbulk Ch4 = Iout

Figure 39. **Startup at 120 Vac, V_{LED} = 48 V**



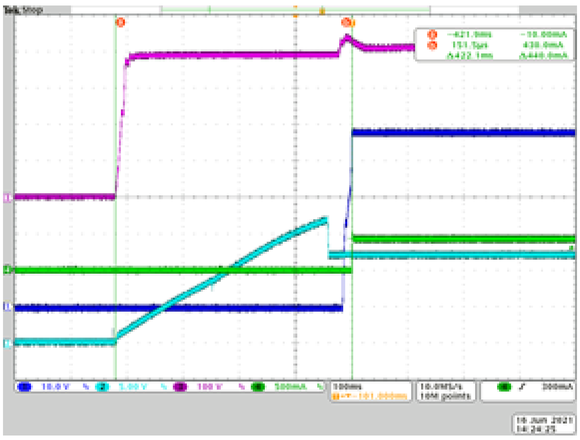
Ch1 = Vout Ch2 = Vcc Ch3 = Vbulk Ch4 = Iout

Figure 40. **Start-up at 230Vac, V_{LED} = 48V**



Ch1 = Vout Ch2 = Vcc Ch3 = Vbulk Ch4 = Iout

Figure 41. **Startup at 277 Vac, V_{LED} = 48 V**



Ch1 = Vout Ch2 = Vcc Ch3 = Vbulk Ch4 = Iout

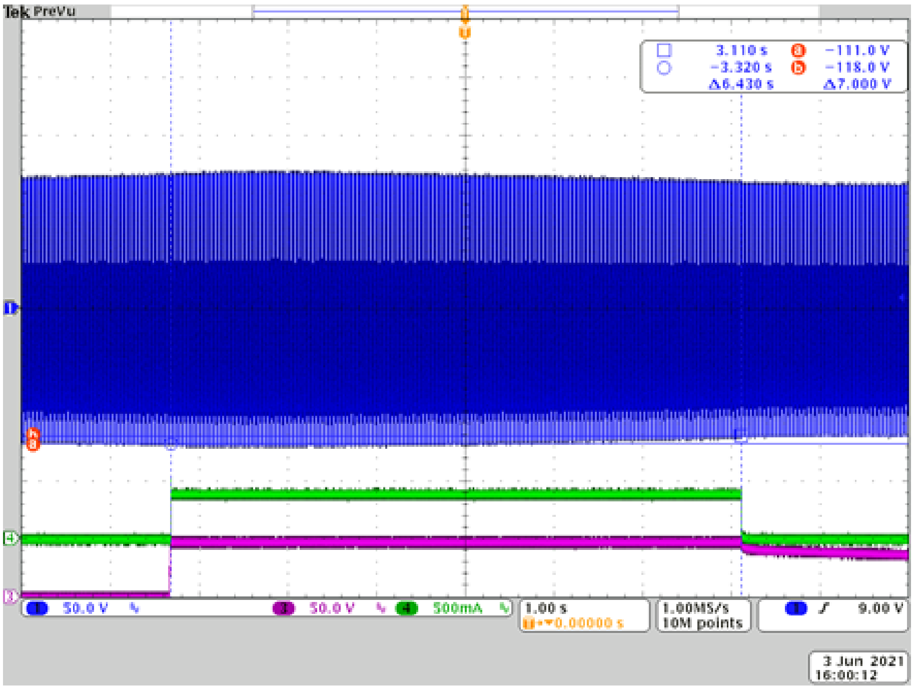
5.1 AC brown-out

The STNGR012 is equipped with brown-in and brown-out protections to avoid operating the driver at too low input voltage.

As the mains is plugged in, if the AC voltage is below the brown-in threshold, the HV start-up generator charges the capacitors on Vcc net until it reaches the turn-on threshold (VCC_{ON}), but both converter's operations are inhibited. They are enabled only once the AC mains is higher than the brown-in threshold.

An example of brown-in is reported hereafter: with AC mains voltage below threshold, we can see the Vcc hiccup, while the PFC and LLC converters are blocked. Then, slightly increasing the AC mains voltage, once it reaches the brown-in threshold, the SMPS operation is allowed and the start-up sequence is initiated.

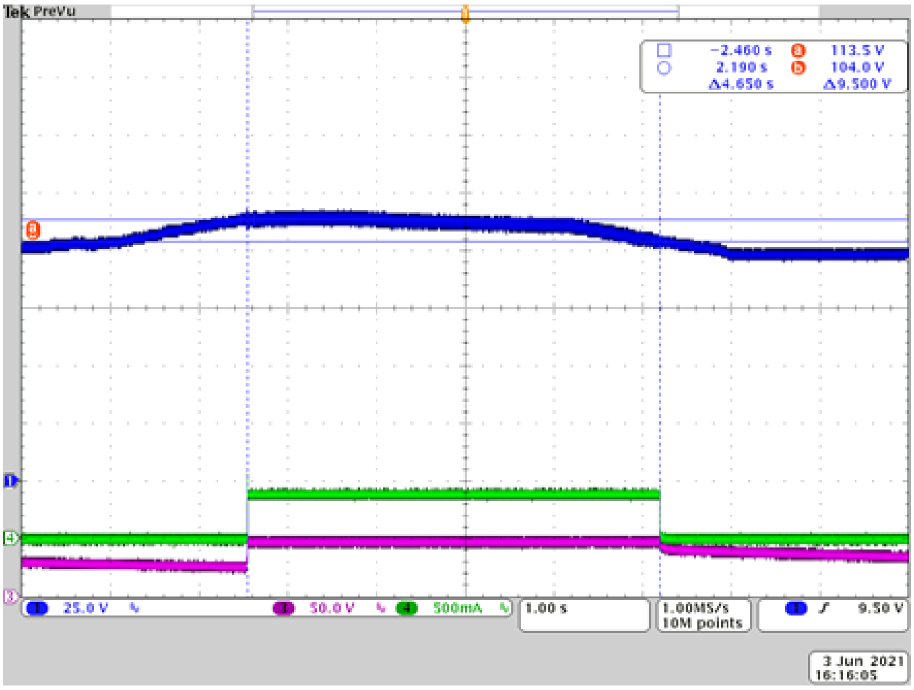
Figure 42. Brown-in and brown-out vac_pk= 118 V / 60 Hz V_{LED} = 50 V I_{LED} = 0.4 A



CH1: Input voltage	CH2: NA	CH3: Vout	CH4: Iout
Top screenshot:	100ms/div.	Bottom zoom:	20ms/div.

As mentioned before, the STNRG012 can operate also with DC input voltages, and hereafter is the snapshot of a startup at Vin = 114 V_dc.

Figure 43. **Brown-in and brown-out Vdc = 114 V V_{LED} = 56 V I_{LED} = 1.0 A**



CH1: Vin	CH2: NA	CH3: Vout	CH4: Iout
Top screenshot:	100ms/div.	Bottom Zoom:	20ms/div.

If, during normal operation, the AC mains voltage drops below the brown-out threshold, the PFC and LLC sections are turned off after a 45 ms debounce time, to avoid the unexpected intervention of this protection in case of missing cycles or short dips of the mains.

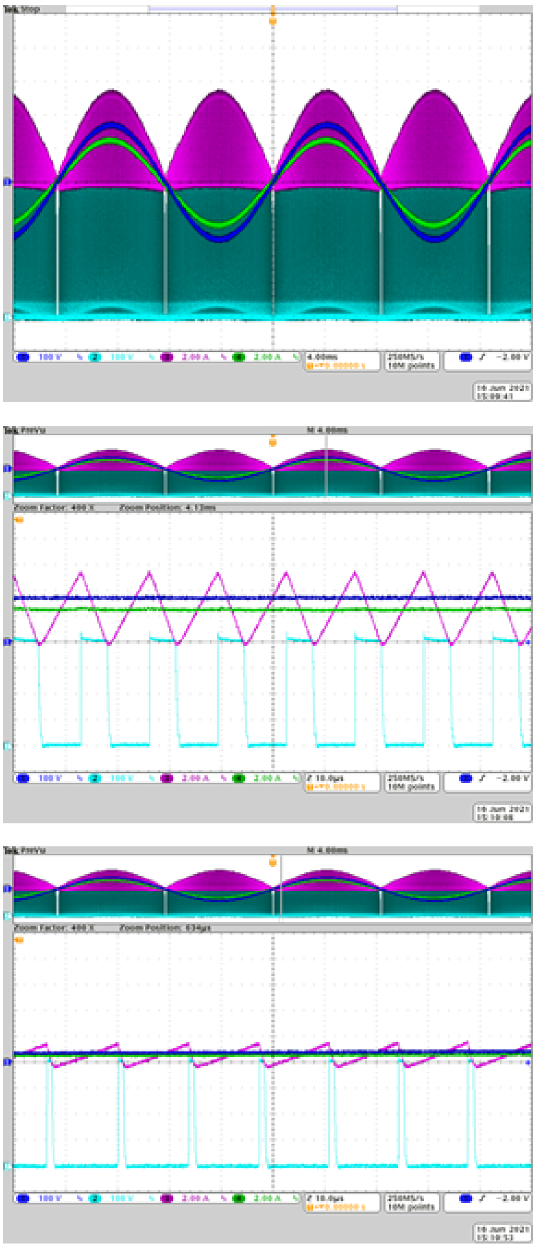
The VCC is maintained by the High Voltage Startup section of the STNRG012.

6 PFC main waveforms and protections

The STNRG012 controls the PFC MOSFET turn-on time with the proprietary ramp enhanced constant on-time algorithm (ReCOT). It compensates the input EMI filter capacity, to increase the PF and to reduce the THD, keeping it low not only at the full load. Figure 44 and Figure 45 show the input voltage and current at 120 Vac / 60 Hz and 230 Vac / 50 Hz respectively.

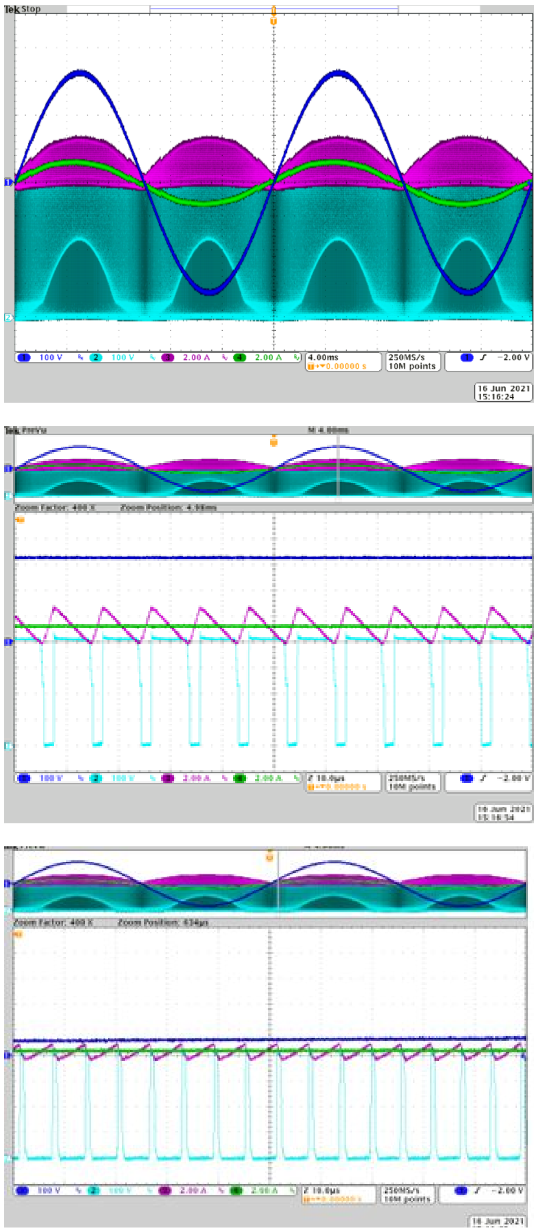
The PFC manager changes the operating mode dynamically, obtaining optimal performance in terms of both efficiency and THD, from the transition mode to DCM, passing through one, two or three valleys skipping. This is possible thanks to the NVM configurability that allows to match the IC to the application. Figure 46 to Figure 51 show the different operating modes of the PFC.

Figure 44. 120 Vac, full load



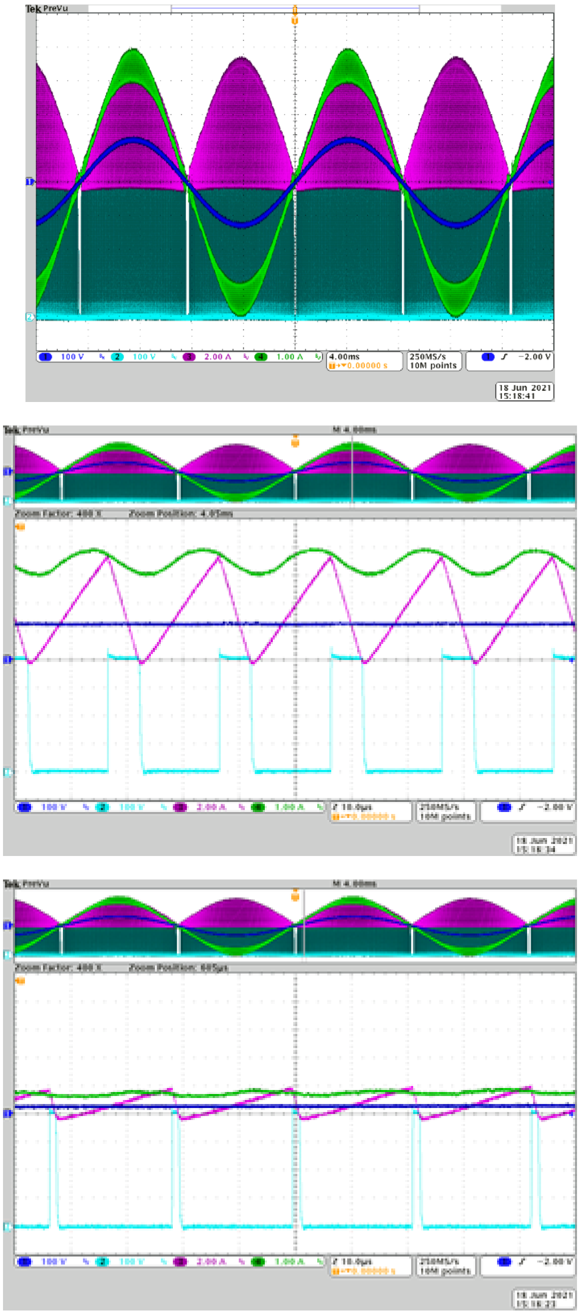
Ch1 = Vout Ch2 = Vcc Ch3 = Vbulk Ch4 = Iout

Figure 45. 230 Vac, full load



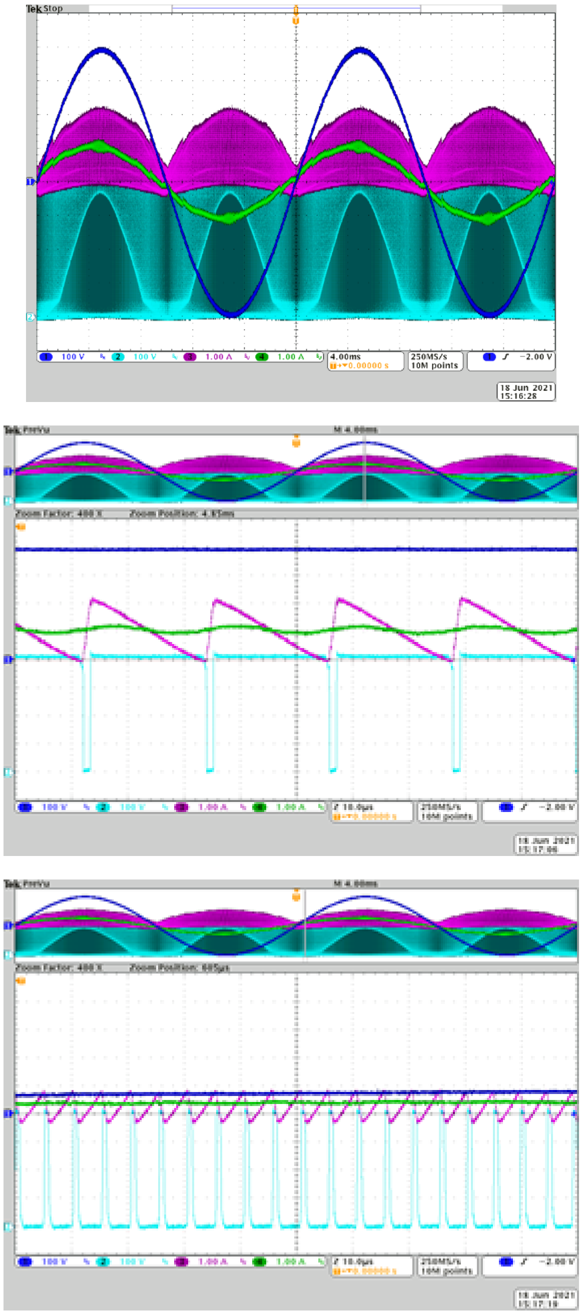
Ch1 = Vout Ch2 = Vcc Ch3 = Vbulk Ch4 = Iout

Figure 46. **90 Vac, full load**



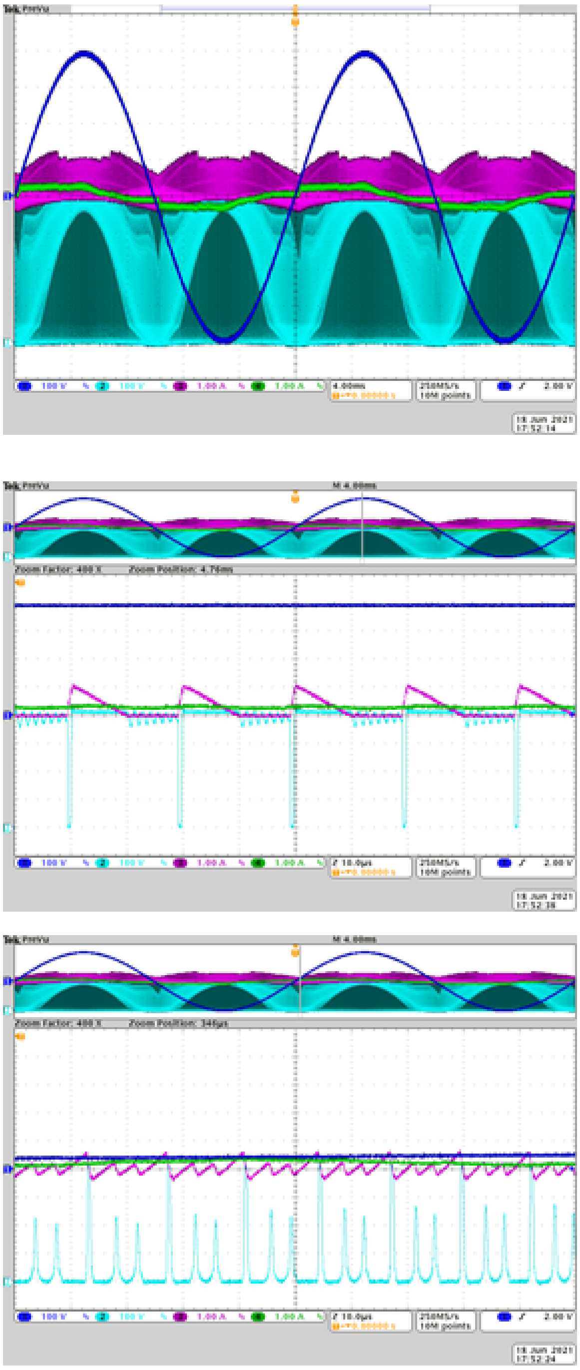
Ch1 = Vout Ch2 = Vcc Ch3 = Vbulk Ch4 = Iout

Figure 47. **277 Vac, full load**



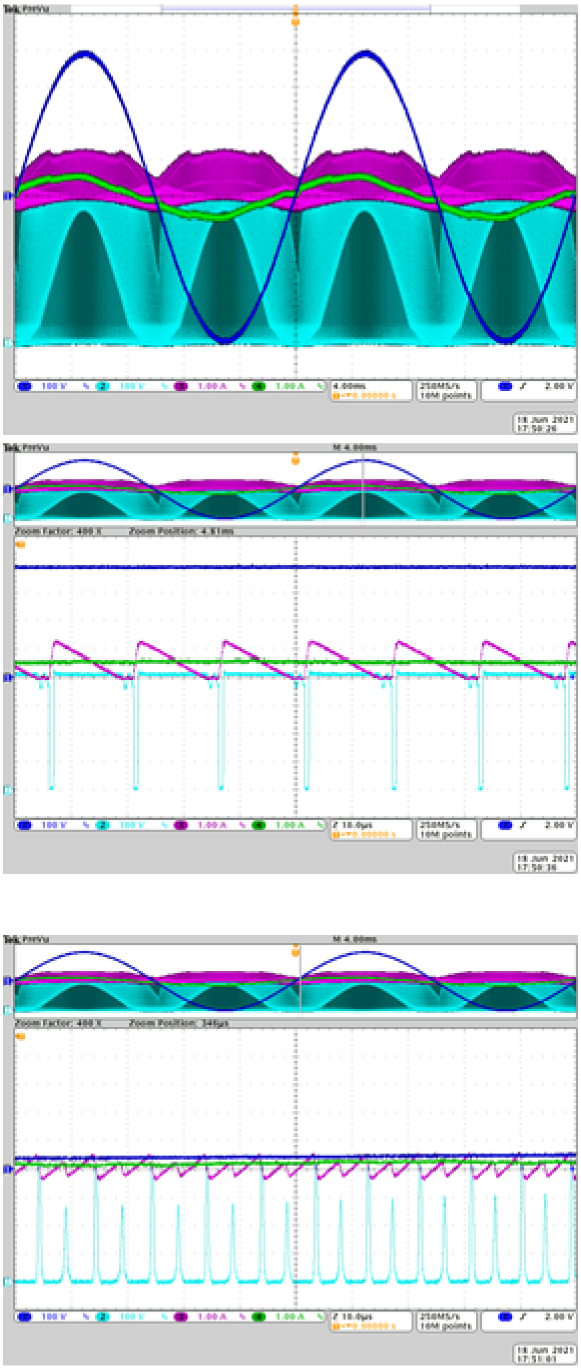
Ch1 = Vout Ch2 = Vcc Ch3 = Vbulk Ch4 = Io

Figure 48. 277 Vac, 25% full load



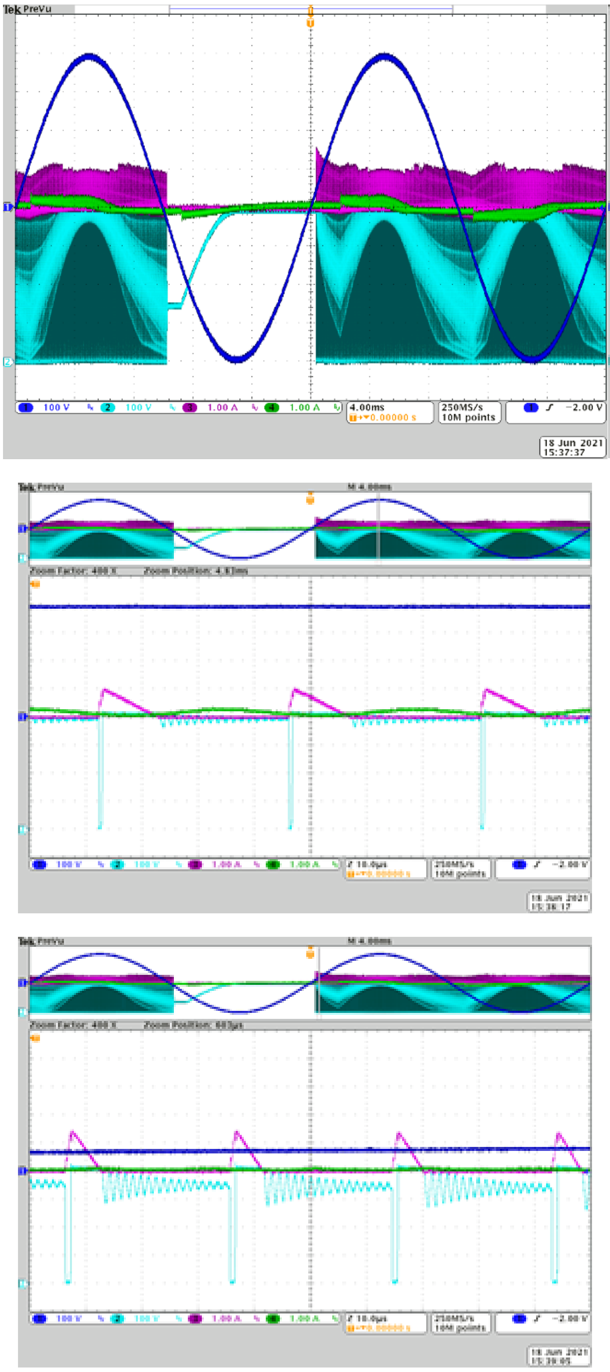
Ch1 = Vout Ch2 = Vcc Ch3 = Vbulk Ch4 = Iout

Figure 49. 277 Vac, half load



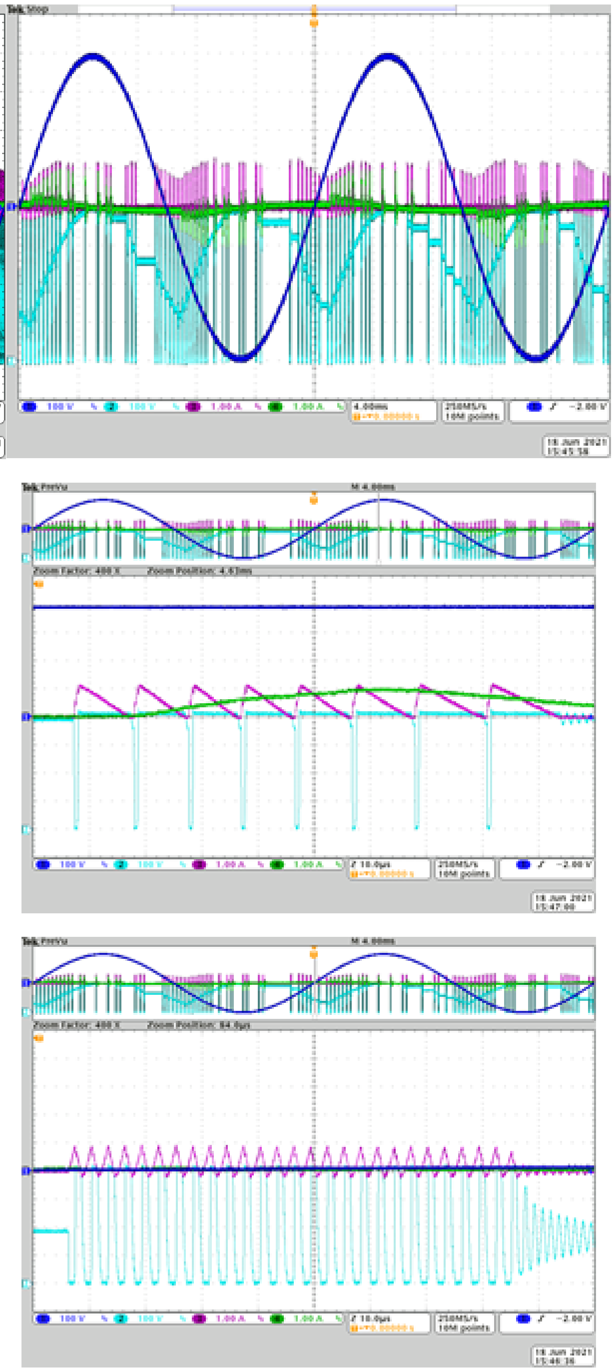
Ch1 = Vout Ch2 = Vcc Ch3 = Vbulk Ch4 = Iout

Figure 50. 277 Vac, 10% load Vled = 48V



Ch1 = Vout Ch2 = Vcc Ch3 = Vbulk Ch4 = Iout

Figure 51. 277 Vac, 10% load Vled = 32V

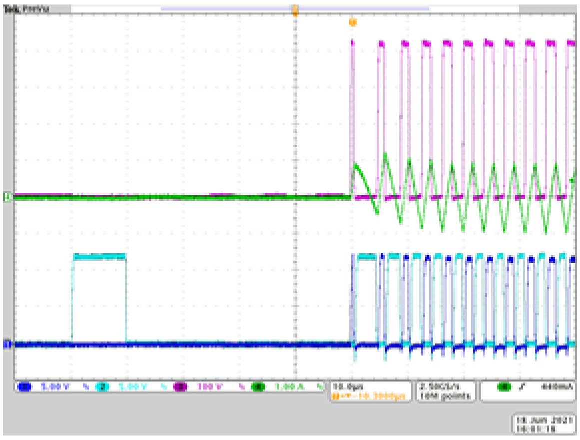


Ch1 = Vout Ch2 = Vcc Ch3 = Vbulk Ch4 = Iout

7 LLC main waveforms and protections

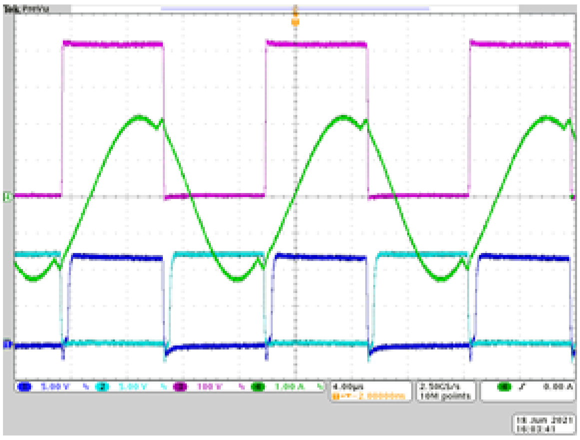
The “Symmetric Time Shift Control” is the evolution of the time shift control that always guarantees 50% of the duty cycle for the half-bridge resonant converter. The algorithm changes the time between the zero current detection and the MOSFET turn-off of the low-side MOSFET and the cycle-by-cycle copies the total on-time to the high-side MOSFET. The time shift applied is directly converted from the LLC_FB pin, while the deadtime between half-bridge gate drivers is set by the “LLC deadtime” NVM parameter. Figure 53 shows the resonant stage key waveforms at the full load.

Figure 52. Startup at 230 Vac



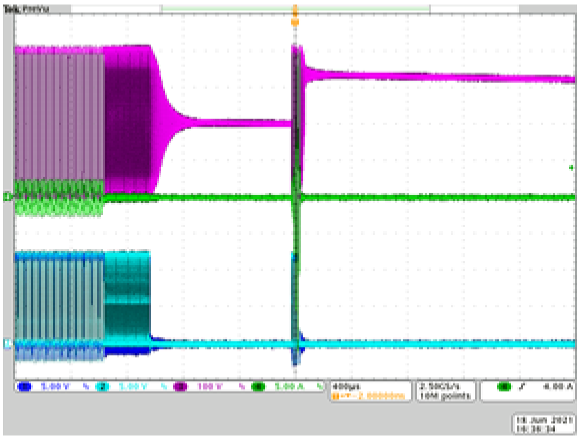
Ch1 = LLC_LVG | Ch2 = LLC_HVG | Ch3 = LLC low-side MOSFET Vds | Ch4 = LLC resonant tank current

Figure 53. Full load



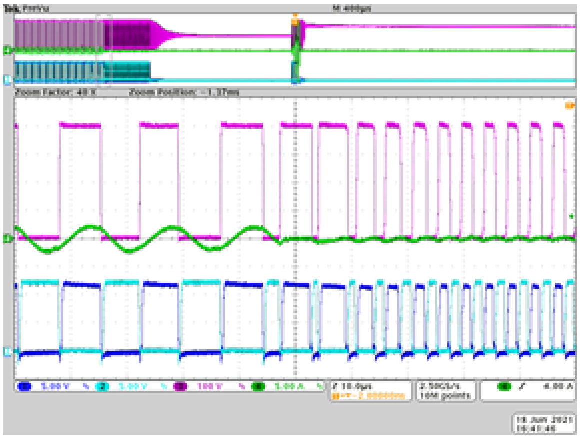
Ch1 = LLC_LVG | Ch2 = LLC_HVG | Ch3 = LLC low-side MOSFET Vds | Ch4 = LLC resonant tank current

Figure 54. Short output circuits



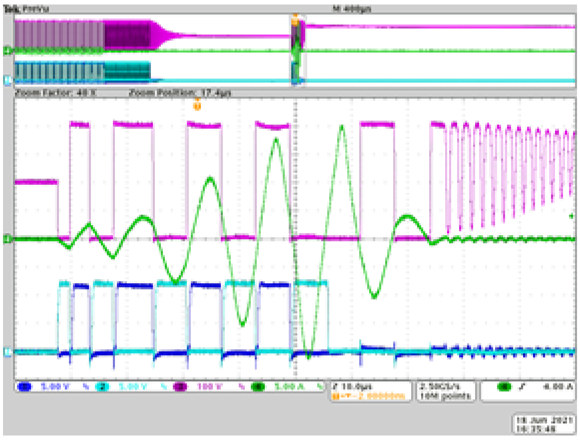
Ch1 = LLC_LVG | Ch2 = LLC_HVG | Ch3 = LLC low-side MOSFET Vds | Ch4 = LLC resonant tank current

Figure 55. Short output circuits (current feedback loop response)



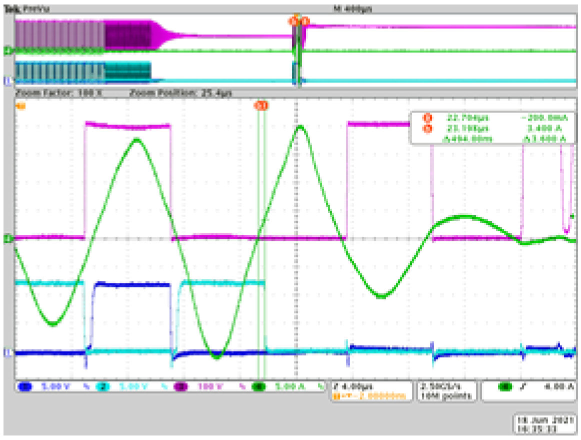
Ch1 = LLC_LVG | Ch2 = LLC_HVG | Ch3 = LLC low-side MOSFET Vds | Ch4 = LLC resonant tank current

Figure 56. Short output circuits



Ch1 = LLC_LVG
Ch2 = LLC_HVG
Ch3 = LLC low-side MOSFET Vds
Ch4 = LLC resonant tank current

Figure 57. Short output circuits (Hard ACP)



Ch1 = LLC_LVG
Ch2 = LLC_HVG
Ch3 = LLC low-side MOSFET Vds
Ch4 = LLC resonant tank current

8 Mains dips and short interruptions

During the design validation, the board has been submitted to several tests for compliance against the EN61000-4-11, with maximum output load at Vout = 56 V and Iout = 3.56 A, obtained with the dimming voltage at 10 V, and a Chroma LED_LOAD setup at 52.44 V / 3.56 A / 1 ohm.

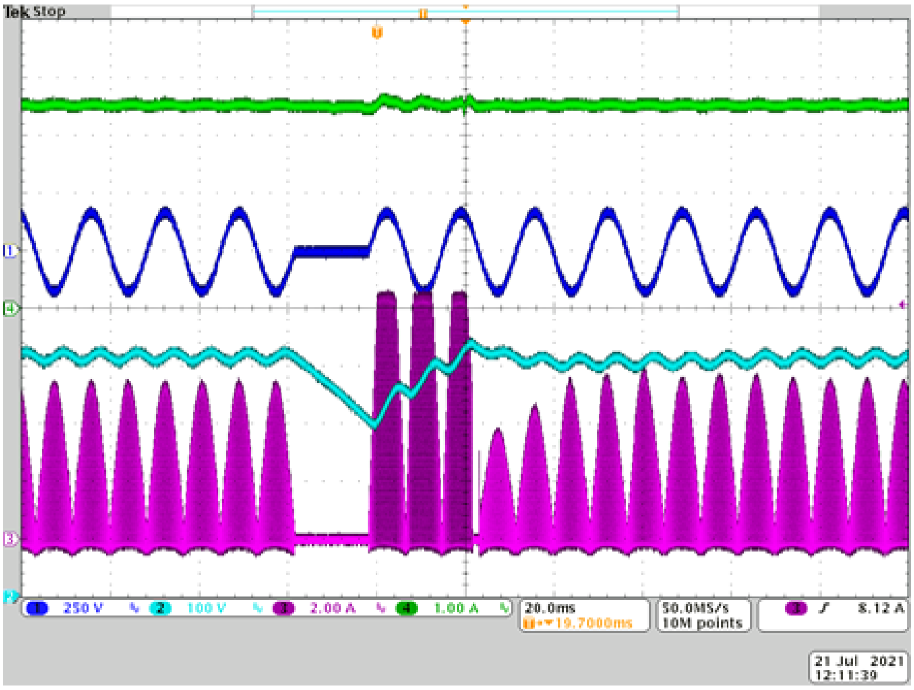
Table 5. Mains dip and short interruption tests

Percentage	Cycle type	Description	Figure reference nbr.
Mains dip to 0%	single cycle	16.6ms at 120Vac / 60Hz	Figure 58
Mains dip to 0%	single cycle	20ms at 230Vac / 50H	Figure 59
Mains dip to 0%	half cycle	10ms at 230Vac / 50Hz	Figure 60
Mains dip to 0%	single cycle	16.6ms at 277Vac / 60Hz	Figure 61
Mains dip to 0%	5 cycles	83.3ms at 120Vac / 60Hz	Figure 62
Mains dip to 0%	50 cycles	830ms at 120Vac / 60Hz	Figure 63
Mains sag	72 cycles	120Vac to 50Vac / 60Hz 1.2s	Figure 64
Add sag	30 cycles	115Vac to 46Vac / 60Hz 500.1ms	Figure 65
Add sag	10 cycles	230Vac to 92Vac / 50Hz 200ms	Figure 66
Add Mains		90Vac -> 277Vac / 60Hz	Figure 67
Add transitions		277Vac -> 90Vac / 60Hz	Figure 68

And no anomalous condition has been noticed or missed / false restart evidenced.

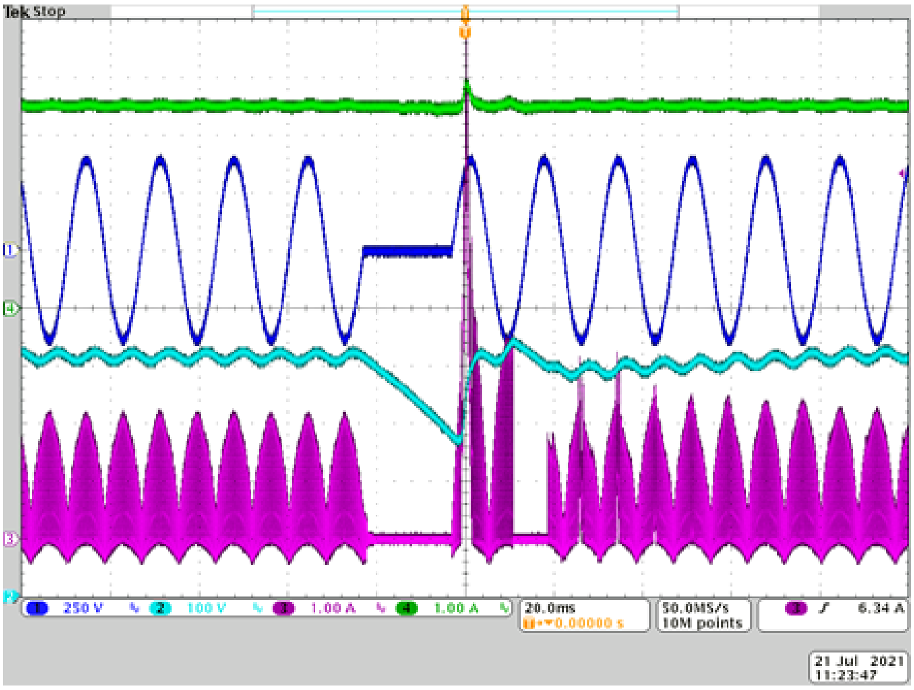
In case of short dips, the output current is maintained, while for longer mains interruption the LEDs string is correctly switched off, and then restarted as the mains reappears. Hereafter some significant iamges taken during the tests.

Figure 58. Mains dips 16.6 ms @120 Vac / 60 Hz



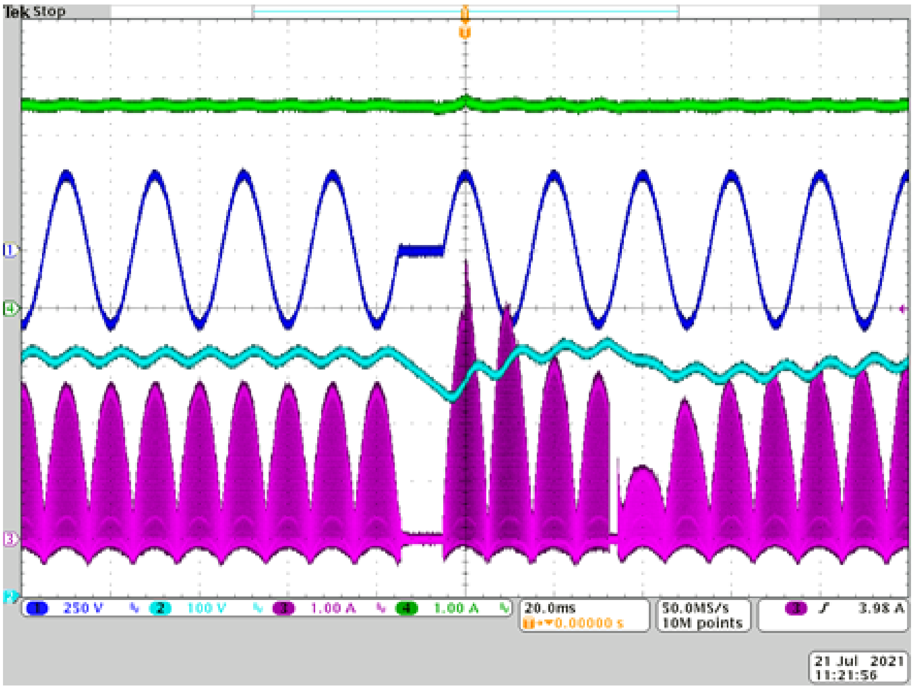
CH1: Vac CH2: Vcc CH3: Iout CH4: I_Tank

Figure 59. **Mains dips 20.0 ms @230 Vac / 50 Hz**



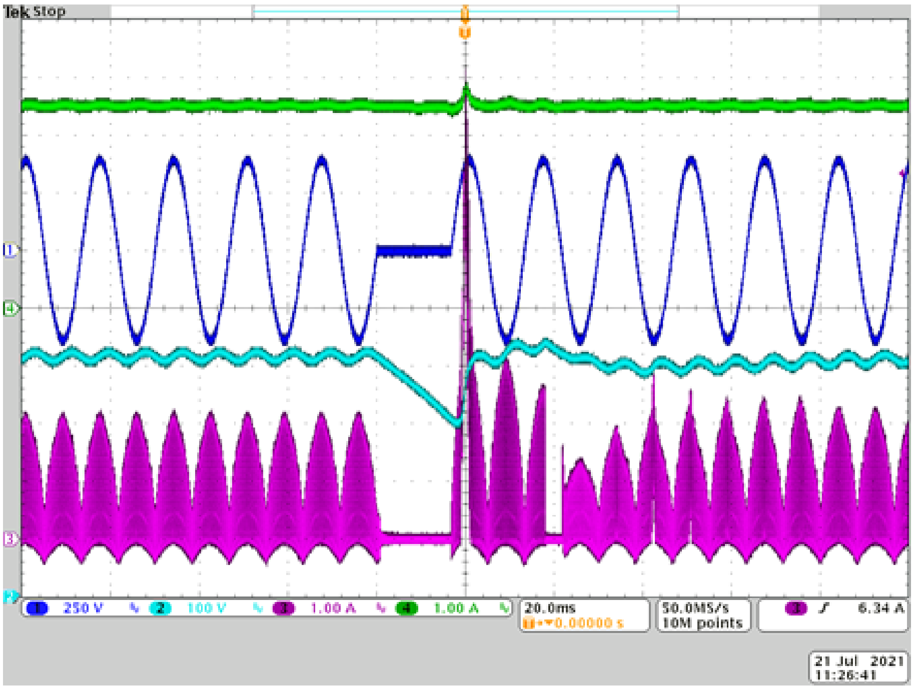
CH1: Vac CH2: Vcc CH3: Iout CH4: I_Tank

Figure 60. **Mains dips 10.0 ms @230 Vac / 50 Hz**



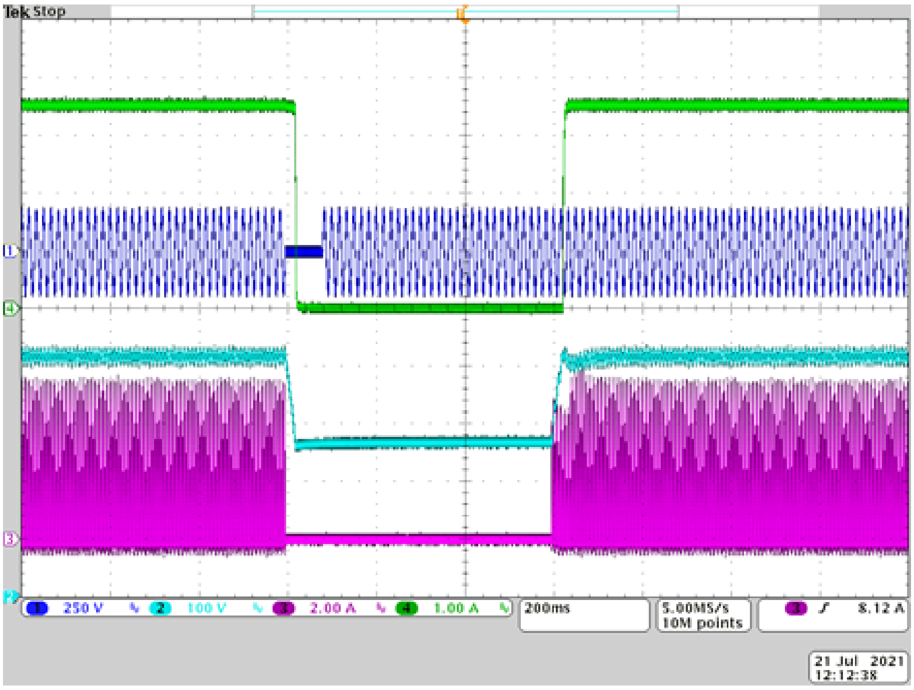
CH1: Vac CH2: Vcc CH3: Iout CH4: I_Tank

Figure 61. Mains dips 16.6 ms @277 Vac / 60 Hz



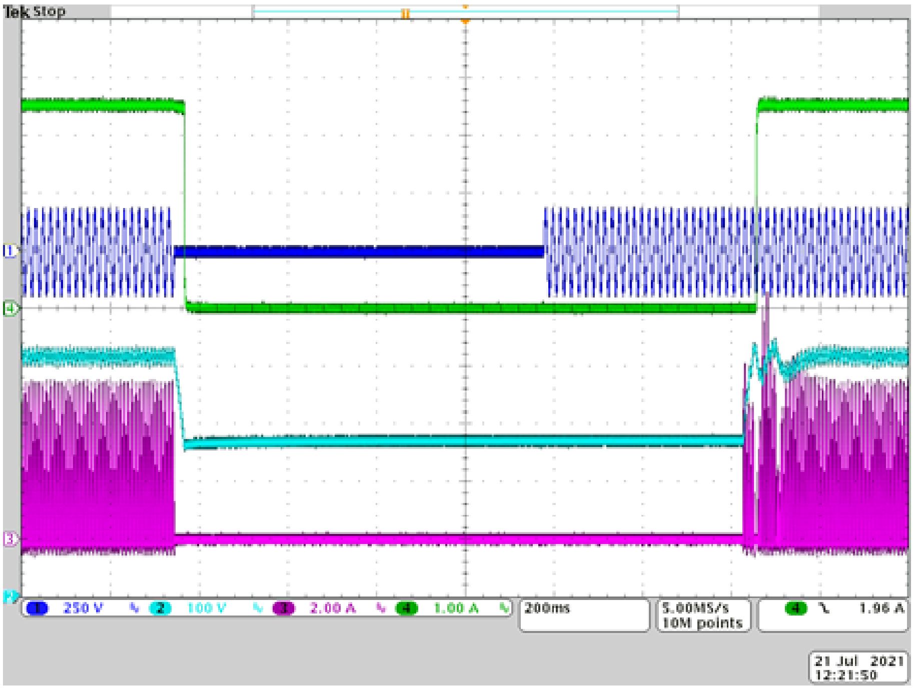
CH1: Vac CH2: Vcc CH3: Iout CH4: I_Tank

Figure 62. Mains dips 83.3 ms @120 Vac / 60 Hz



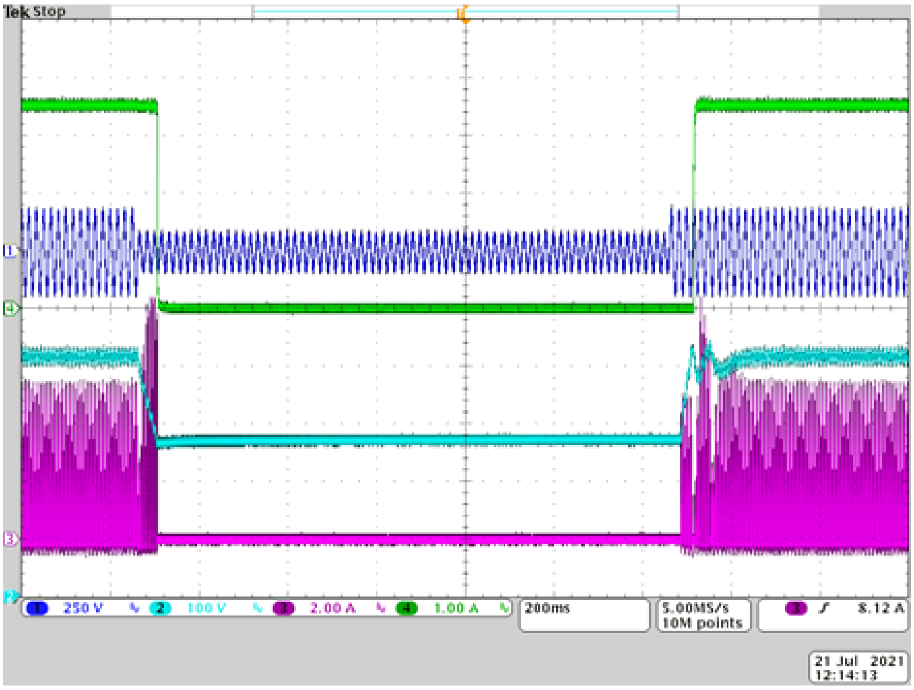
CH1: Vac CH2: Vcc CH3: Iout CH4: I_Tank

Figure 63. **Mains dips 830 ms @120 Vac / 60 Hz**



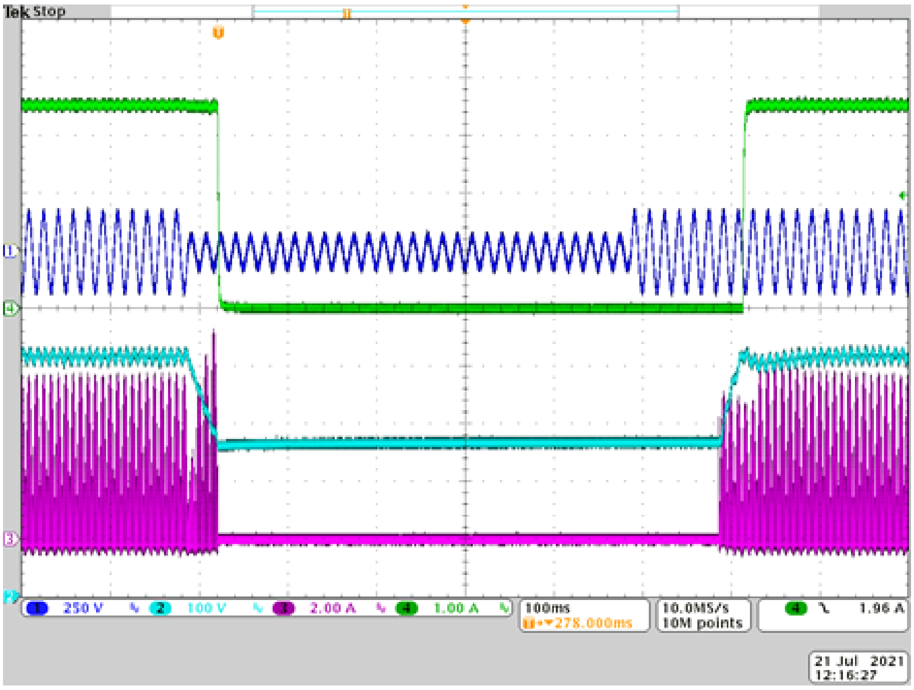
CH1: Vac CH2: Vcc CH3: Iout CH4: I_Tank

Figure 64. **Mains sag 120 to 50 Vac/ 60 Hz - 1.2 s**



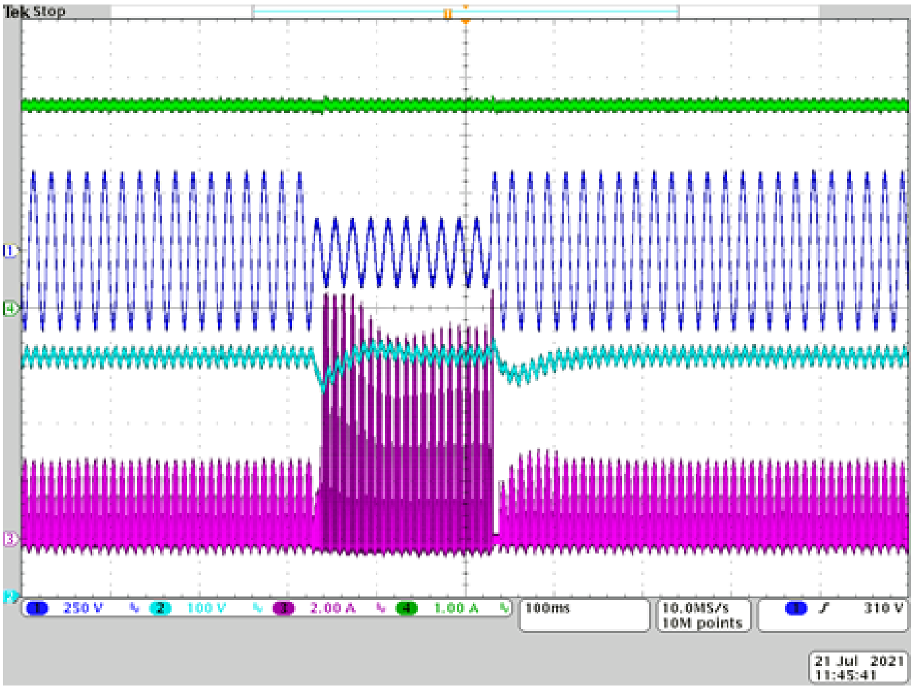
CH1: Vac CH2: Vcc CH3: Iout CH4: I_Tank

Figure 65. Mains sag 115 Vac to 46 Vac / 60 Hz 500.1 ms



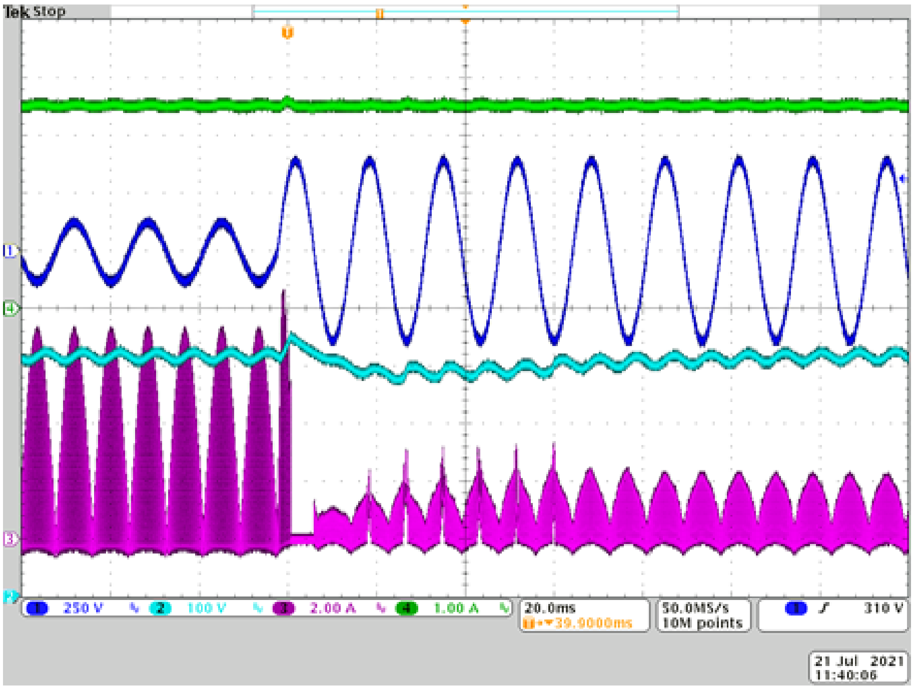
CH1: Vac CH2: Vcc CH3: Iout CH4: I_Tank

Figure 66. Mains sag 230 Vac to 92 Vac / 50 Hz 200 ms



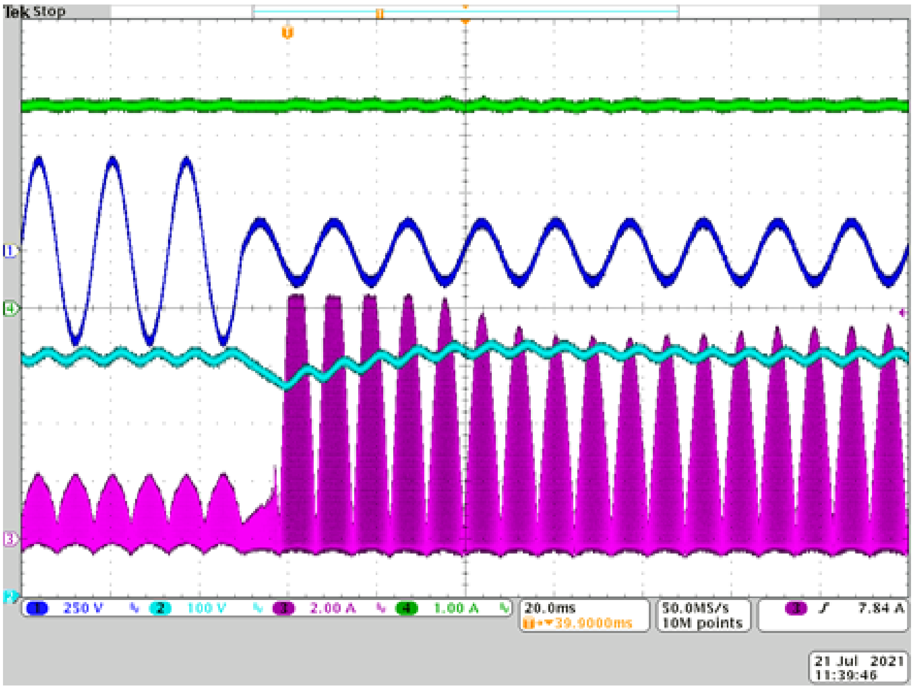
CH1: Vac CH2: Vcc CH3: Iout CH4: I_Tank

Figure 67. **Mains sag 90 Vac -> 277 Vac / 60 Hz**



CH1: Vac CH2: Vcc CH3: Iout CH4: I_Tank

Figure 68. **Mains sag 277 Vac -> 90 Vac / 60 Hz**



CH1: Vac CH2: Vcc CH3: Iout CH4: I_Tank

9 Thermal maps

Some images of the board have been taken with an IR Camera, to see if any component could be exposed to excessive temperature rise and become critical from a reliability point of view.

Figure 69 shows the board thermal maps at full load with the main voltage set at 115 Vac / 60 Hz. Figure 70 is the same representation of the board, at full load and 230 Vac input, but the temperature scale has been expanded (20 … 90 degC) to put in evidence the temperature of the main components while Figure 71 is the same image in the visible spectrum, to better locate all the parts. The ambient temperature during the measurements was at 25 °C to be confirmed.

Figure 69. Thermal map (20 … 135 degC) at 115 Vac – 60 Hz - full load

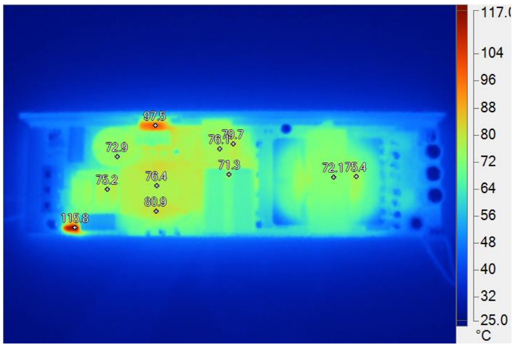


Figure 70. Thermal map (20 … 90 degC) at 230 Vac – 50 Hz - full load detailed view

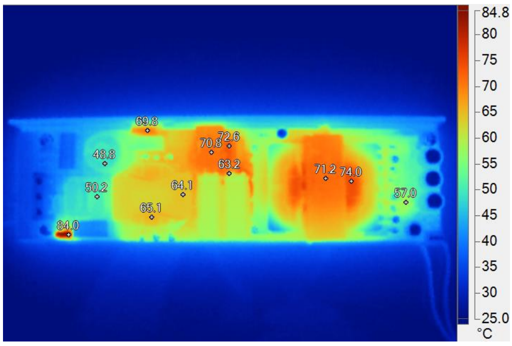
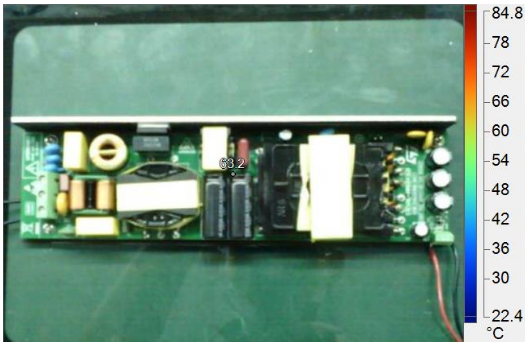


Figure 71. Same board image in visible spectrum (as reference).



10 Conducted emission pre-compliance test.

The following figures are the measurements of the conducted emission in quasi_peak and average mode detection, at full load and nominal mains voltage, line (L) and neutral (N). The limits shown in the diagrams are the EN55015 for lighting equipments.

Figure 72. CE at 120 Vac and full load (L)

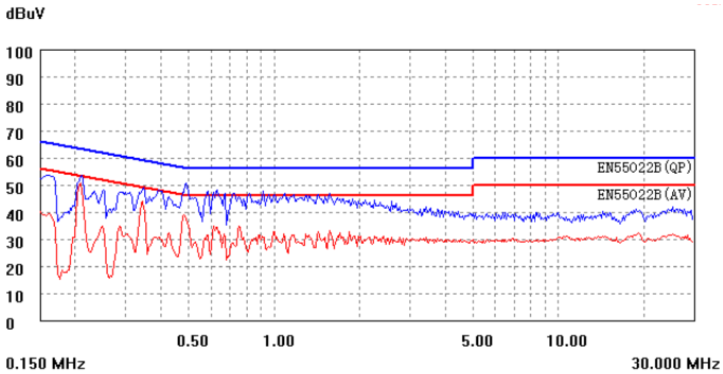


Figure 73. CE at 115 Vac and full load (N)

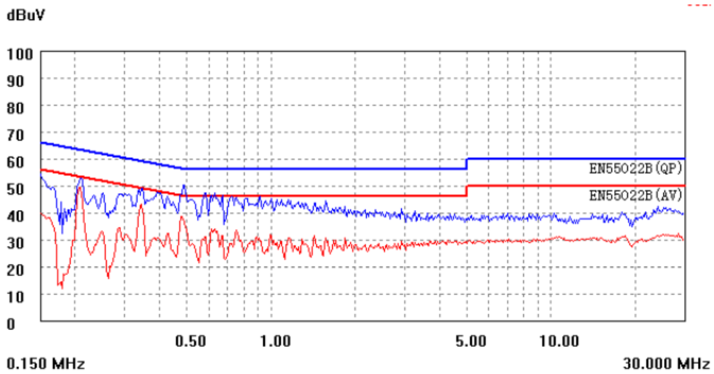


Figure 74. CE at 230 Vac and full load (L)

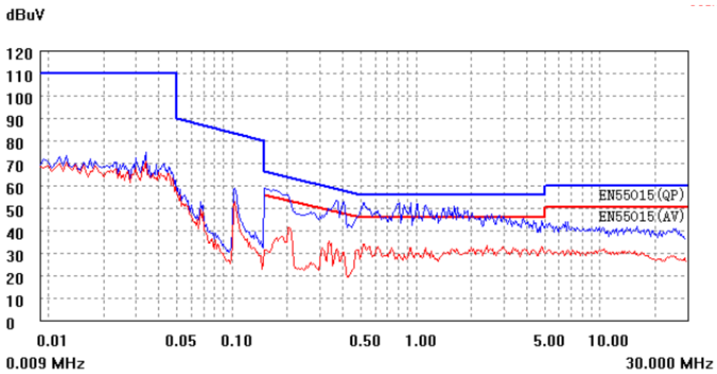
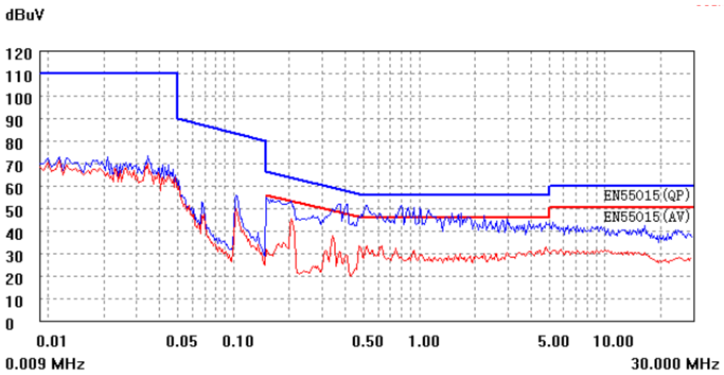


Figure 75. CE at 230 Vac and full load (N)



11 Bill of material

Table 6. **EVL012LED board: bill of material**

Part nbr/Part value	Designator	Description	Supplier	Package
1uF/450V	C1	Film capacitor	Panasonic	C-BOX-7*18
2.2nF/25V 0603	C2	Ceramic capacitor		C0603
100nF/25V 0603	C3, C14, C25, C31, C36, C39, C42	Ceramic capacitor		C0603
6.8nF/50V 0805	C4	Ceramic capacitor		C0805
4.7uF/25V 0805	C5	Ceramic capacitor		C0805
220pF/25V 0603	C6, C19	Ceramic capacitor		C0603
1uF/25V 0603	C7, C8, C26	Ceramic capacitor		C0603
1uF/50V 0805	C9	Ceramic capacitor		C0805
NM	C10			
1nF/50V 0603	C11	Ceramic capacitor		C0603
100nF/25V 0805	C12, C41	Ceramic capacitor		C0805
4.7uF/25V 0603	C13	Ceramic capacitor		C0603
100pF/1KV 1206	C15	Ceramic capacitor	Yageo	C1206
47uF/450V	C17, C18	Aluminum electrolytic capacitor	Rubycon	2 pins radial (5 mm pitch)
330pF/1KV 1206	C20	Ceramic capacitor	Yageo	C1206
47pF/1KV 1206	C21, C22	Ceramic capacitor	Yageo	C1206
22nF/800V	C23	Film capacitor	Panasonic	2 pins radial (11.5 mm patch)
1nF/25V 0603	C16, C24, C34, C48	Ceramic capacitor		C0603
33uF/35V	C27	Aluminum electrolytic capacitor	Panasonic	2 pins radial (3.5 mm pitch)
NM	C28, C29			
220pF/200V 1206	C30, C33	Ceramic capacitor		C1206
10nF/25V 0603	C32	Ceramic capacitor		C0603
2.2uF/16V 0603	C35	Ceramic capacitor		C0603
47nF/25V 0603	C37	Ceramic capacitor		C0603
100uF/80V	C38, C40, C44	Aluminum electrolytic capacitor	Panasonic	2 pins radial (5mm pitch)
1nF/16V 0603	C43	Ceramic capacitor		C0603
100uF/35V	C45	Aluminum electrolytic capacitor	Panasonic	2 pins radial (2.5 mm pitch)
1uF/50V 0805	C46	Ceramic capacitor		C0805
220nF/16V 0603	C47	Ceramic capacitor		C0603
NM	C49			
LCL-008-B-ZY	CM1	CM choke	Zhengyi	
X2-0.33uF 275VAC	CX1, CX2	X2 capacitor	Champion	2 pins radial (15 mm pitch)

Part nbr/Part value	Designator	Description	Supplier	Package
Y1 P=10mm 220pF ±10%	CY1, CY2	Y1 capacitor	Dersonic	2 pins radial (10 mm pitch)
Y1 P=10mm 2.2nF ±10%	CY3, CY6	Y1 capacitor	Dersonic	2 pins radial (10 mm pitch)
10nF/1KV	CY4, CY5	Y3 capacitor	Fenghua	2 pins radial (7.5 mm pitch)
S1J-13-F SMA	D1, D2	Diode	Diodes	SMA
1N4148 SOD-123	D3, D4, D5, D6, D11, D15, D16, D20, D23, D25	Fast diode		SOD-123
STTH1R06A SMA	D7	Fast diode	STMicroelectronics	SMA
S8KC SMC	D9	Diode	Diodes	SMC
STTH5L06B DPAK	D12	Fast diode	STMicroelectronics	DPAK
BAV23S SOT-23	D13, D14, D17, D21	Fast diode	Nexperia	SOT-23
BAT54ZFILM SOD-123	D18, D19	Schottky diode	STMicroelectronics	SOD-123
STPS1L30A SMA	D24	Schottky diode	STMicroelectronics	SMA
GBP808N	DB1	Rectifier bridge	LITEON	4 pins (3.8 mm pitch)
2 pins (p=2.54mm)	DIM1	Connector	Harwin Inc.	4 pins radial (2.54 mm pitch)
80401879-Yamaxi	DM1	DM choke	Yamaxi	
Fuse 6.3A 300V	F1	Fuse	Littelfuse	2 pins radial (5.08 mm pitch)
BPH403025W4-470T	FB1	Ferrite bead	TAI-TECH	SMD,4x3.1x2.5mm
NM	FB3			
M24C32-RMN6TP	IC1	EEPROM	STMicroelectronics	SO-8
STNRG012 SO20	IC2	PFC & LLC comb		SO20
TL431ACL3T	IC3, IC6	IC	STMicroelectronics	SOT-23
TSM1014IDT	IC4	IC	STMicroelectronics	SO-8
SRK2001	IC5	SR controller	STMicroelectronics	SSOP10
TSC213ICT	IC7	Amplifier	STMicroelectronics	SC70-6
TSX632IDT	IC8A, IC8B	Amplifier	STMicroelectronics	MiniSO-8
BK-42-1A (PQ38 220uH)	L1	PDC inductor	Zhengyi	
BK-20-0A(PQ2014 90uH)	L2	LLC inductor	Zhengyi	
TVR10561KSY	MOV1	Varistor (voltage-sensitive resistor)	Thinking	2 pin radial
LTV1018	OP1, OP2	Optocoupler	Liten	LTV-10XX-G series
PZ127V-11-04-0720	PC1	Connector	Harwin Inc.	4 pins radial (1.27 mm pitch)
			Samtec Inc.	4 pins radial (1.27 mm pitch)
GMKDS 1.5/3-7.62-1717732	Pin1	Connector	Phoenix	3 pins radial (7.62 mm pitch)
	PO-1	Connector	Phoenix	3 pins radial (2.54 mm pitch)
NM	Q1	NPN BJT		
BCX54-16 SOT89	Q2	NPN BJT	Nexperia	SOT89

Part nbr/Part value	Designator	Description	Supplier	Package
STO33N60M6	Q3	N-Channel power MOSFET	STMicroelectronics	TOLL
STL22N60M6	Q4, Q5	N-Channel power MOSFET	STMicroelectronics	PowerFLAT™ 5x6 HV
ZVN3320F SOT-23	Q6, Q10	N-Channel power MOSFET	Diodes	SOT-23
BSC190N15NS3G	Q7, Q9	N-Channel power MOSFET	Infineon	PowerFLAT™ 5x6
BSS169	Q8	N-Channel power MOSFET	Infineon	SOT-23
BC807 SOT-23	Q11	PNP BJT	Nexperia	SOT-23
22K 0603 ±1%	R1	Resistor		R0603
20R 1206 ±1%	R2	Resistor		R1206
150R 1206 ±1%	R3, R7	Resistor		R1206
1R 1206 ±1%	R17, R52	Resistor		R1206
0R 1206 ±1%	R5	Resistor		R1206
470R 0603 ±1%	R6	Resistor		R0603
10R 0805 ±1%	R8, R12, R24, R25	Resistor		R0805
4.7K 0603 ±1%	R9	Resistor		R0603
1R 0603 ±1%	R10	Resistor		R0603
82R 0805 ±1%	R11	Resistor		R0805
1.5K 0603 ±1%	R13, R15	Resistor		R0603
100K 0603 ±1%	R14, R36, R37, R76	Resistor		R0603
6.8K 0603 ±1%	R16, R21	Resistor		R0603
47R 0603 ±1%	R18	Resistor		R0603
1K 0603 ±1%	R20, R23, R41, R42, R47, R59, R74	Resistor		R0603
2R2 0603 ±1%	R22	Resistor		R0603
220R 0603 ±1%	R26	Resistor		R0603
56R 0805 ±1%	R27, R28	Resistor		R0805
68K 0603 ±1%	R29	Resistor		R0603
3M 1206 ±1%	R30, R31, R32	Resistor		R1206
10R 0603 ±1%	R33, R66, R70, R71	Resistor		R0603
15R 0603 ±1%	R34	Resistor		R0603
120K 0603 ±1%	R35	Resistor		R0603
20K 0603 ±1%	R38, R69, R77	Resistor		R0603
10K 0603 ±1%	R39, R62, R83	Resistor		R0603
5K1 0603 ±1%	R40, R54	Resistor		R0603
4.3K 0603 ±1%	R43	Resistor		R0603
102K 0603 ±1%	R44	Resistor		R0603
2.2R 0805 ±1%	R45, R61	Resistor		R0805
100R 0603 ±1%	R46, R56, R73	Resistor		R0603
150K 0603 ±1%	R48, R65	Resistor		R0603
22R 1206 ±1%	R49, R51	Resistor		R1206

Part nbr/Part value	Designator	Description	Supplier	Package
2K 0603 ±1%	R50	Resistor		R0603
180K 0603 ±1%	R53	Resistor		R0603
200K 0805 ±1%	R55	Resistor		R0805
13K 0603 ±1%	R57	Resistor		R0603
47K 0603 ±1%	R58	Resistor		R0603
270K 0603 ±1%	R60	Resistor		R0603
22R 0603 ±1%	R63	Resistor		R0603
27K 0603 ±1%	R64	Resistor		R0603
60mR 2512 ±1%	R67	Resistor		R2512
NM	R4,R68	Resistor		R0603
3m 2512 ±1%	R72	Resistor		R2512
82R 0603 ±1%	R75	Resistor		R0603
120R 0603 ±1%	R78	Resistor		R0603
39K 0603 ±1%	R79	Resistor		R0603
1M 1206 ±1%	R80, R81, R82	Resistor		R1206
0R 0603 ±1%	R101, R102	Resistor		R0603
NTC SCK10035MSY	RT1	NTC resistor	Thinking	2 pins radial (5 mm pitch)
T-EE50B	T1	Transformer	Zhengyi	
Zener 13V ±2% SOD-123	ZD1	Zener	Nexperia	SOD-123
Zener 47V ±2% SOD-123	ZD2	Zener	Nexperia	SOD-123
Zener 11V ±2% SOD-123	ZD3	Zener	Nexperia	SOD-123
		Aluminum shell		
210x80x0.25mm		MYLAR		
60x45x0.25mm		Thermally conductive insulator		
30x20x0.25mm	DB1	Thermally conductive insulator		
15x15x2mm	DB1, Q4, Q5	Thermally conductive gap pad		
15x15x0.8mm	Q3, D12	Thermally conductive gap pad		

12 PFC coil specification – L1

1. **General description and characteristics**
   – Application type: industrial, lighting
   – Manufacturer: HAINING ZHENGYI ELECTRONICS 2020-9-14 CO.LTD
   – Model: BK-42-1A

Table 7. PFC coil BK-42-1A: bill of material

Item	Part_no.	Temp.	Manufacturer	UL no.
CORE	PQ3812 NH9	-	LFG	
BOBBIN	PQ3812 PM-9630	150°C	CHANGCHUN PLASTIC CO LTD	E59481
WIRE	2 UEW	155°C	HENG YA DIAN GONG ZHEJIANG HONG BO WUXI JUFENG	E245514 E221719 E206882
TRIPLE INSULATION	ALTIW-B	130°C	WUHU OULY ELECTRONICS CO LTD	E466302
TAPE	Mylar (25um) UL510	130°C	SU ZHOU JING YI YA HUA CHANG SHU LIANG YI	E188295 E165111 E246820
VARNISH	1038	130°C	JIA XING RONG TAI	E227128

2. Electrical diagram and winding characteristics

Table 8. **Electrical characteristics**

Parameter	Terminal	Specification	Note
Inductance	L 6 - 1	220uH +/- 7%	HP4980 100K Hz, 1V, 25°C
DC resistance	R 6 - 1	220mΩ max.	YY2511
Dielectric Stength	P – S P, S - C	AC 50Hz 1.0KV / 5mA AC 50Hz 1.0KV / 5mA	CJ2671 60s
Insulation Resistance	P – S P, S - C	R > = 100M ohm	AR907 DC 500V

Note: Measured at tamb = 25 °C, humidity = 45% - 80%, normal pressure

Figure 76. **PFC coil electrical diagram**

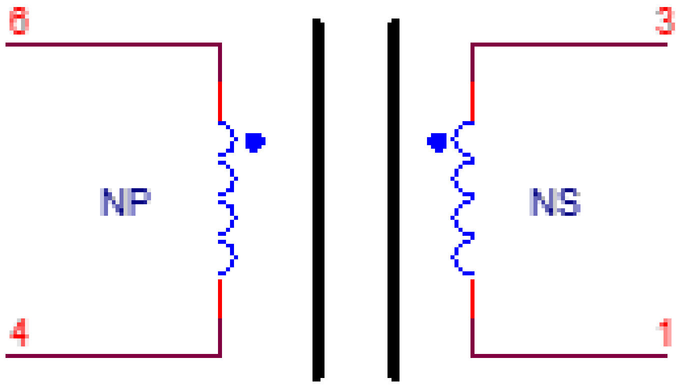


Table 9. **PFC coil winding data**

Pins	Windings	Number of turns	Wire type
6 - 4	Primary	40	2UEW 50x ϕ 0.10 mm
3 - 1	Aux	4	TIW-B ϕ 0.20 mm

3. **Mechanical drawing and pin numbering**
   - 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.
   - Three layers of adhesive tape to secure outside.

Figure 77. PFC coil mechanical aspect

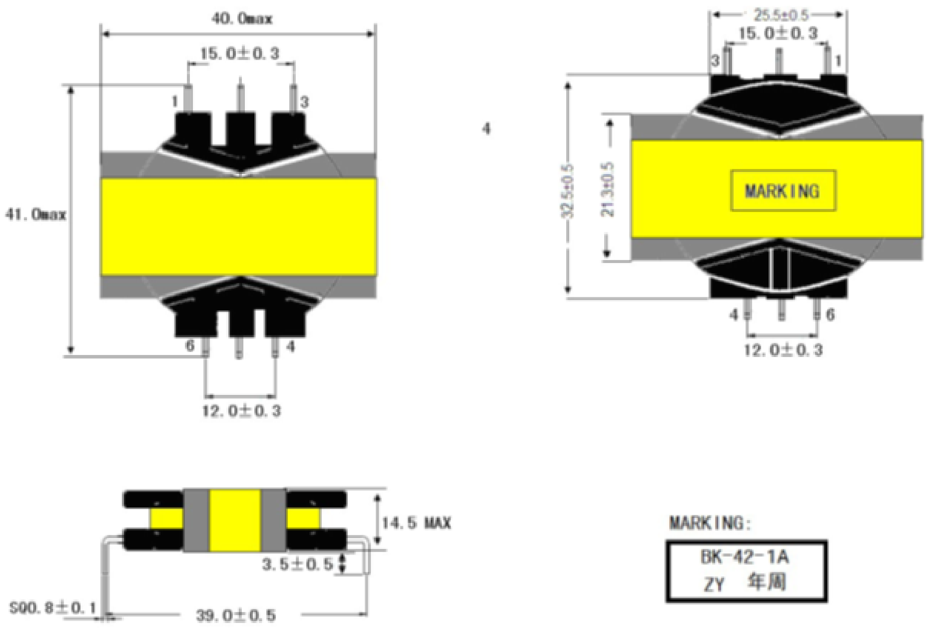
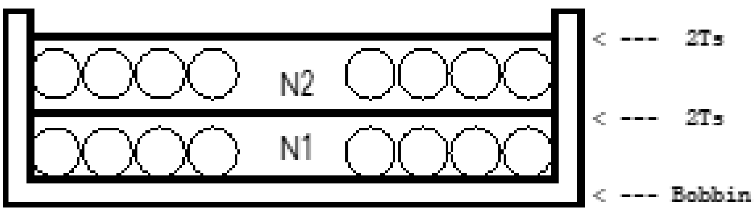


Figure 78. PFC coil construction scheme



13 Transformer specification – T1

1. **General description and characteristics**
   - Application type: industrial, lighting
   - Manufacturer: HAINING ZHENGYI ELECTRONICS 2020-9-14 CO., LTD
   - Model: BCK-150-L050B

Table 10. Transformer T1: bill of material

Item	Part no.	Temp.	Manufacturer	UL no.
CORE	EE50 PC95	-	TAIZHOUMAOXIANG	
BOBBIN	EE5013A+B PM-9630	150°C	CHANGCHUN PLASTICS CO LTD	E59481
WIRE	2UEW 50x f 0.10 mm 100x f 0.10 mm	155°C	HENG YA DIAN GONG ZHEJIANG HONG BO WUXI JUFENG	E245514 E221719 E206882
TAPE	Mylar (25um) UL510	130°C	SU ZHOU JING YI YA HUA CHANG SHU LIANG YI	E188295 E165111 E246820
Varnish	1038	130°C	JIA XING RONG TAI	E227128

2. Electrical diagram and winding characteristics

Table 11. Electrical characteristics

Parameter	Terminal	Specification	Note
Inductance	L1-2	0.5mH±7%	HP4980 100KHZ 0.3V 25℃
Leakage Inductance	LK1-2	110uH±10%	HP4980 100KHZ 0.3V 25℃
DC resistance	R1-2	175mΩ max.	YY2511
Dielectric Stength	P-S P,S-C	AC50HZ 3.75KV/5mA AC50HZ 1.75KV/5mA	CJ2671 60s 5mA
Insulation Resistance	P-S P,S-C	R≥100MΩ	AR907 DC 500V

Note: Measured at tamb = 25 °C, humidity = 45% - 80%, normal pressure

Figure 79. Transformer T1 electrical diagram

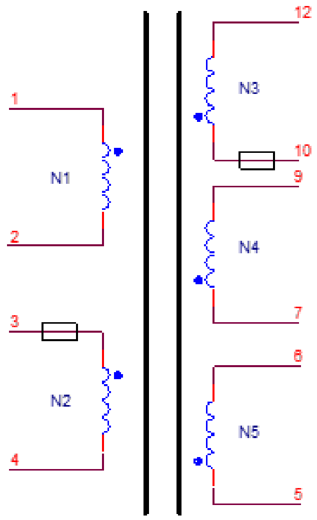


Table 12. Transformer T1 winding data

Pins	Winding	Number of turns	Wire type
1 - 2	N1: PRIMARY	44	2UEW 50X f 0.10 mm
3 - 4	N2: AUX_P	3	f 0.20 mm
7 - 9	N3: SEC. A	8	100X f 0.10 mm
10 - 12	N4: SEC. B	8	100X f 0.10 mm
5 - 6	N5: AUX_S	4	f0.20 mm

Note: SEC. A (7 – 9) / SEC. B (10 – 12): Parallel winding

3. **Mechanical aspect and pin numbering**

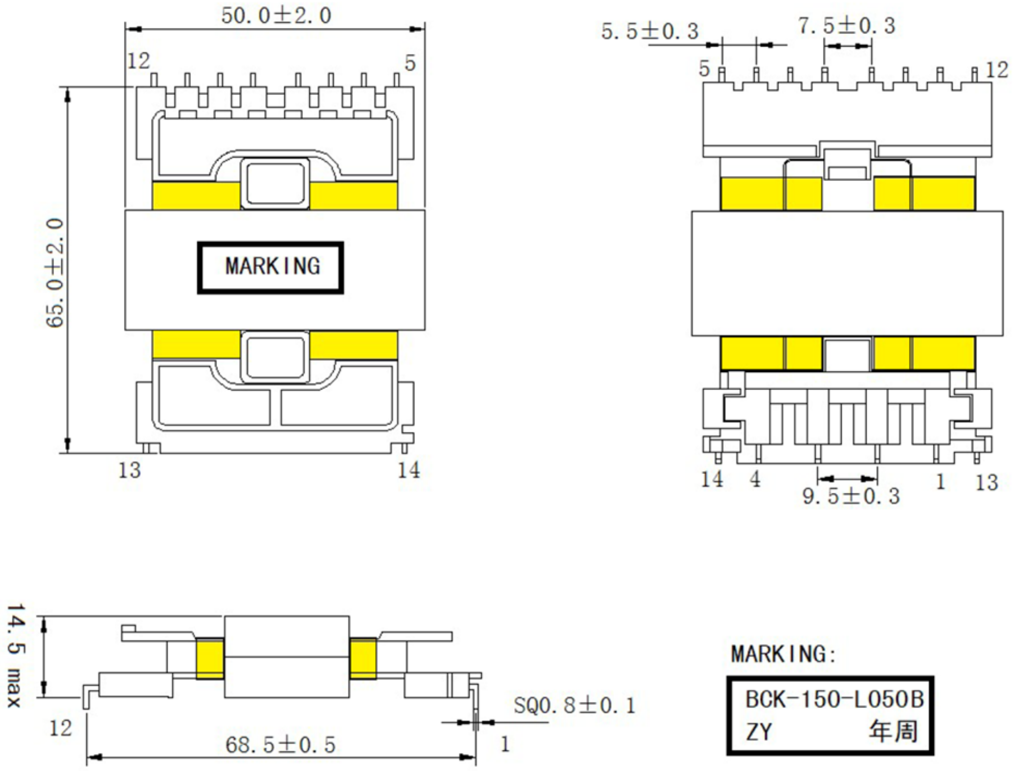
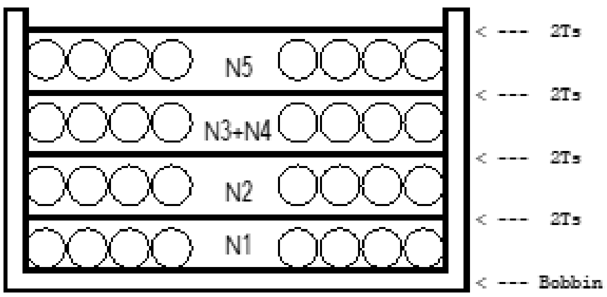


Figure 80. Transformer T1 overall drawing

Note:
1. *One layer of tape along the direction of the magnetic core when the frame is assembled.*
2. *Three-layer tape for fixing.*
3. *The label faces pins 13 and 14.*
4. *The product is vacuum impregnated.*

Figure 81. *Transformer T1 construction scheme*



14 Inductor specification – L2

1. **General description and characteristics**
   - Application type: industrial, lighting
   - Manufacturer: HAINING ZHENGYI ELECTRONICS 2020-9-14 CO., LTD
   - Model: BK-20-0A

Table 13. Inductor L2: bill of material

Item	Part no.	Temp.	Manufacturer	UL no.
CORE	PQ2014 NH9	-	LFG	
BOBBIN	PQ2014 PM-9630	150°C	CHANGCHUN PLASTICS CO LTD	E59481
WIRE	2UEW 30x Φ 0.10mm	155°C	HENG YA DIAN GONG ZHEJIANG HONG BO WUXI JUFENG	E245514 E221719 E206882
INSULATION TAPE	Mylar (25um) UL510	130°C	SU ZHOU JING YI YA HUA CHANG SHU LIANG YI	E188295 E165111 E246820
VARNISH	1038	130°C	JIA XING RONG TAI	E227128

2. Electrical diagram and winding characteristics

Table 14. **Electrical characteristics**

Parameter	Terminal	Specification	Note
Inductance	L1-4	90uH±7%	HP4980 100KHZ 1V 25℃
DC resistance	R1-4	mΩ max.	YY2511
Dielectric Stength	P-S P,S-C	AC50HZ 1.0KV/5mA AC50HZ 1.0KV/5mA	CJ2671 60s 5mA
Insulation Resistance	P-S P,S-C	R≥100MΩ	AR907 DC 500V

Note: Measured at Tamb = 25 °C, humidity = 45% - 80%, normal pressure

Figure 82. **Inductor L2 electrical diagram**

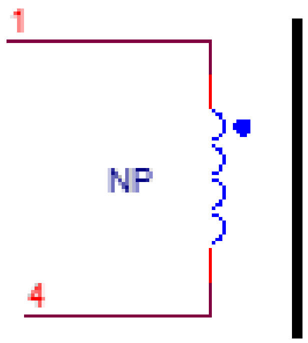
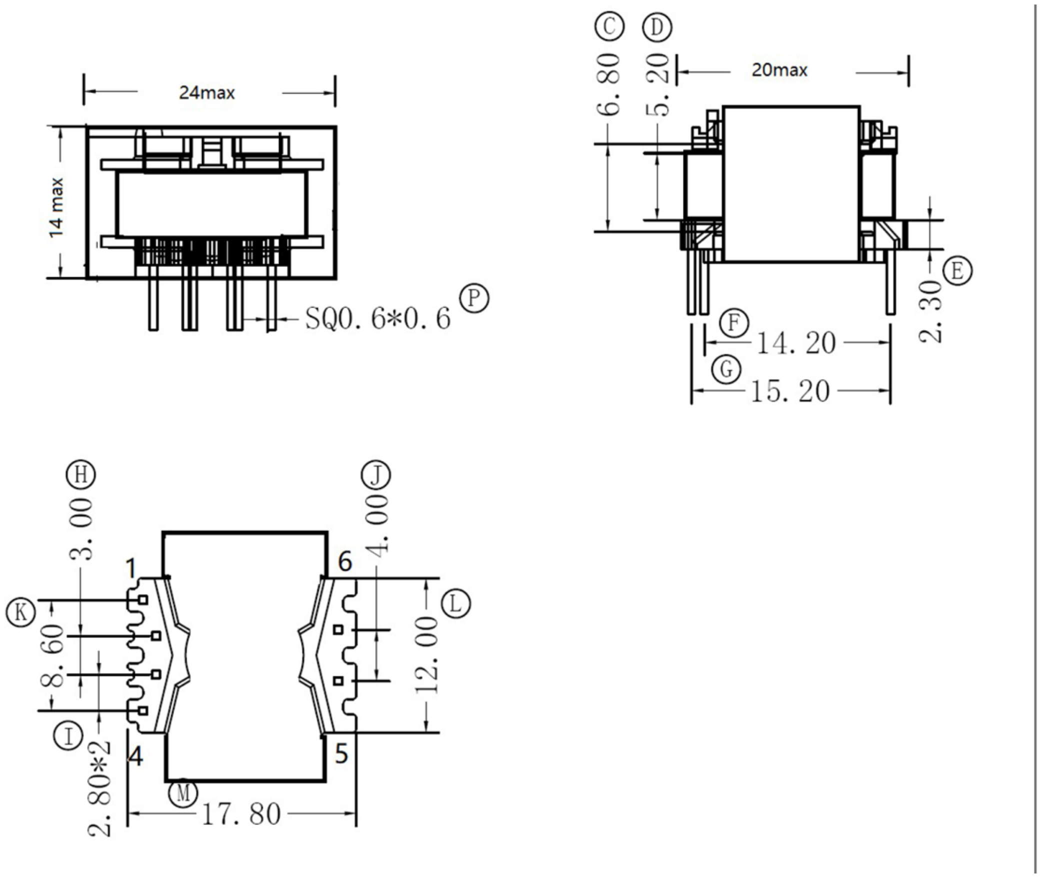


Table 15. **Inductor L2 winding data**

Pins	Winding	Number of turns	Wire type
1 – 4	PRIMARY	24	2UEW 30x f 0.10 mm

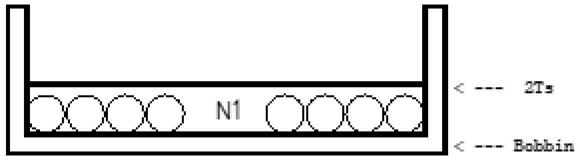
3. **Mechanical aspect and pin numbering**

Figure 83. Inductor L2 overall drawing



Note: 1. Three-layer tape for fixing.
2. The label faces pins 1 and 4.
3. The product is vacuum impregnated.

Figure 84. Inductor L2 construction scheme



15 Common mode inductor specification – CM1

1. **General description and characteristics**
   – Application type: industrial, lighting
   – Manufacturer: HAINING ZHENGYI ELECTRONICS CO., LTD
   – Model: LCL-008-B

Table 16. Common mode inductor CM1: bill of material

Item	Part_no.	Temp.	Manufacturer	UL no.
CORE	SQ1918 R10K	-	Jiu Xin / Shen Yong	
BOBBIN	SQ1918 T375HF	150°C	CHANGCHUN PLASTICS CO LTD	E59481
WIRE	2UEW 1.5x Φ 0.20mm	180°C	WELL ASCENT ELECTRONIC (GANZHOU) CO LTD YANTAI TOMO PRECISION WIRE CO LTD	E318511 E477046
VARNISH	T-4260GK	155°C	SUZHOU TAIHU ELECTRIC ADVANCED MATERIAL CO LTD	E228349

2. Electrical diagram and winding characteristics

Table 17. Electrical characteristics

Parameter	Terminal	Specification	Note
Inductance	L1-2 = L4-3	8mH min.	HP4980 100KHZ 0.3V 25℃
Inductance Balance	L1-2 - L4-3	0.3mΩ max.	
DC resistance	R1-2 = R4-34	120mΩ max.	YY2511
Dielectric Stength	Coil - Coil	AC50HZ 1.0KV/5mA AC50HZ 1.0KV/5mA	CJ2671 5s
Insulation Resistance	Coil - Coil	R≥100MΩ	AR907 DC 500V

Figure 85. Common mode inductor CM1 electrical diagram

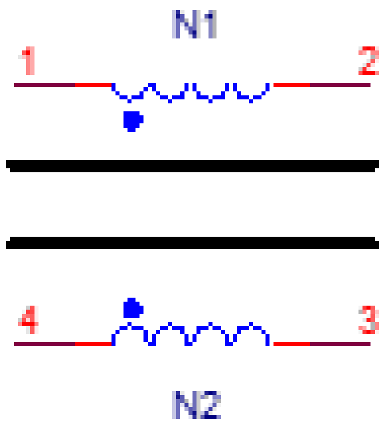
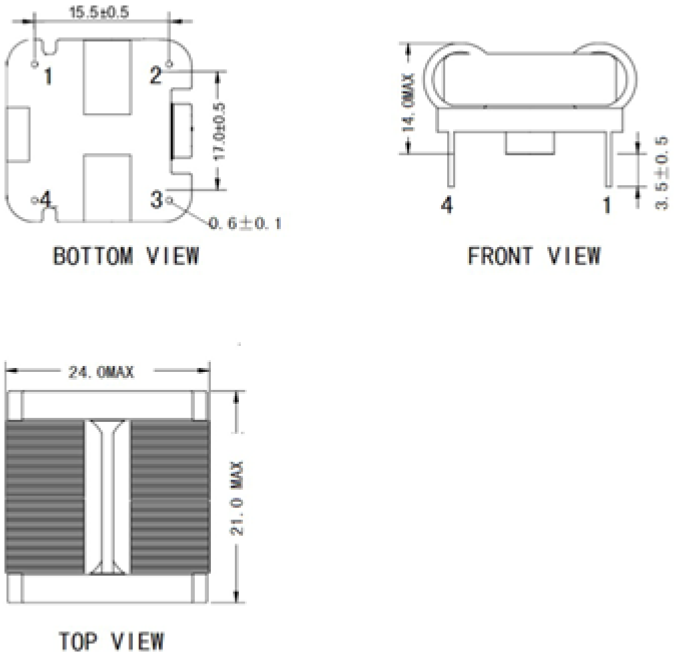


Table 18. Common mode inductor CM1 winding data

Pins	Winding	Number of turns	Wire type
1 – 2	-	50	2UEW 1.5x f 0.20 mm
4 – 3	-	50	2UEW 1.5x f 0.20 mm

3. Mechanical aspect and pin numbering

Figure 86. Common mode inductor CM1 overall drawing



16 NVM parameters configuration

Table 19. NVM parameters configuration

Nbr	Name	Value
0	Shutdown feature	0 - Shutdown disabled
1	Non latched faults timer	0 - 546ms
2	ATE mode	0 = Enabled
3	Patch upload from EEPROM	0 = Disabled
4	System monitoring	0 = Enabled
5	VAC reading improvement	1 = Enabled
6	LLC OVP detection	1 = Enabled
7	Surge detection	0 = Disabled
8	PFC OC2 detection	1 = Enabled
9	Max. number of PFC OC2	0 = 1 (immediate)
10	LLC OC2 detection	0 = Disabled
11	Max. number of LLC OC2	3 = 8
12	PFC HW OVP detection	1 = PFC OVP Comparator Enabled
13	Disconnection faults detection	1 = Enabled
14	PFC OC2 behavior	0 = Not Latched
15	PFC UVP behavior	1 = Immediate
16	PFC UVP Auto Restart Timer	0 = Non latched faults timer
17	LLC SS timeout behavior	0 = Not Latched
18	LLC ACP behavior	0 = Not Latched
19	LLC OC2 behavior	0 = Not Latched
20	LLC OLP behavior	0 = Not Latched
21	LLC OVP behavior	1 = Latched
22	PFC Ki	12
23	PFC Kp	32
24	PFC boost exiting burst	0 = PFC Boost Exiting Burst Disabled
25	PFC Mosfet LEB	8 = 133.3ns
26	PFC THD improver base	3 = 6 mV
27	PFC THD Optimizer	1 = THD Optimizer enabled
28	PFC THD improver gain	7 (ibase increased of 6 on 6 slices)
29	PFC maximum power	15872
30	PFC pss	5120
31	PFC pcc	3218
32	PFC Min. Pin Vskip	1856
33	PFC Max. Pin Vskip (delta)	2048
34	PFC Delta Pin Vskip	160
35	PFC maximum DCM power	2816
36	PFC Min. Tsw Vskip	256 = 234kHz
37	PFC Max. Tsw Vskip	1984 = 29kHz

Nbr	Name	Value
38	Skipping Area setting	6 = Skipping Area Disabled
39	PFC High Voltage Range	1 = +11% Vbulk (400V * 1.100 = 444V)
40	PFC Vout target	56 = 388.83V
41	PFC Vout SS end (delta)	24 = 11.36V
42	PFC UVP threshold (delta)	224 = 136.3V
43	PFC SW OVP threshold (delta)	2 = 20.35V
44	LLC low frequency range	1 = LLC very Low frequency management Disabled
45	LLC HVG first Ton	24 = 400ns
46	LLC LVG first TS	24 = 400ns (566.7ns)
47	LLC deadtime	28 = 466.7ns
48	LLC soft-start speed	1 = 8.3ns (16.6ns)
49	Minimum time shift	0 = 125ns (250ns)
50	Maximum time shift	480 = 7.96us (15.92us)
51	LLC OLP threshold	31 = 500mV
52	LLC OLP timeout	1 = 200ms
53	ACP sensitivity	0 = Low (= No delay)
54	Hard ACP detection	1 = ACP HARD enabled
55	Soft ACP feature	0 = ACP Soft management Enabled
56	Soft ACP entering threshold	6 = 100ns (200ns)
57	Soft ACP TS decrement	24 = 400 ns (800 ns)
58	Maximum soft ACP occurrences	1 = 66
59	External burst mode	0 = External Burst Disabled
60	BM enter for minimum TS	0 = Disabled
61	Burst Entering digital filtering	0 = 270 us
62	LLC_FB burst entering thr	110 = 268.6mV - 350ns (700ns)
63	LLC_FB burst wake-up thr	0 = 0.75V - 2us (4us)
64	LLC_FB burst wake-up hyst	0 = 5mV
65	Min. TS in burst mode	8 = 2.07us (5.27us)
66	Min. number of burst pulses	10
67	Max. number of burst pulses (delta)	0
68	Min. time between burst seq	0 = 5.93ms
69	Max. time between burst seq (delta)	0 = 2.83ms
70	Minimum period to exit burst	0 = 66.7us
71	No-Burst window width	0 = 90 usec
72	Surge comp digital filtering	30 = 500ns
73	PFC CS comp digital filtering	3 = 50ns
74	PFC OC2 comp digital filtering	0 = NO FILTERING
75	PFC OC1 comp digital filtering (delta)	2 = +33.3ns
76	PFC ZCD comp digital filtering	4 = 66.7ns
77	PFC ZCD comp falling thr	0 = 0mV
78	PFC ZCD comp rising thr	1 = 110mV (N/A for TH_F[3] = 200mV)

Nbr	Name	Value
79	PFC HW OVP comp digital filtering	255 = 4.25us
80	LLC OLP comp digital filtering	3 = 50ns
81	LLC OC2 comp digital filtering	8 = 133.3ns
82	LLC ZCD comp digital filtering	3 = 50ns
83	LLC ZCD comp hysteresis	0 = 5mV
84	LLC OVP comp digital filtering	31 = 516.7ns

Revision history

Table 20. **Document revision history**

Date	Version	Changes
09-Mar-2022	1	Initial release.

Contents

List of tables

List of figures