12 V – 150 W power supply based on the STNRG011A digital combo and SRK2001 adaptive synchronous rectifier controller

Introduction

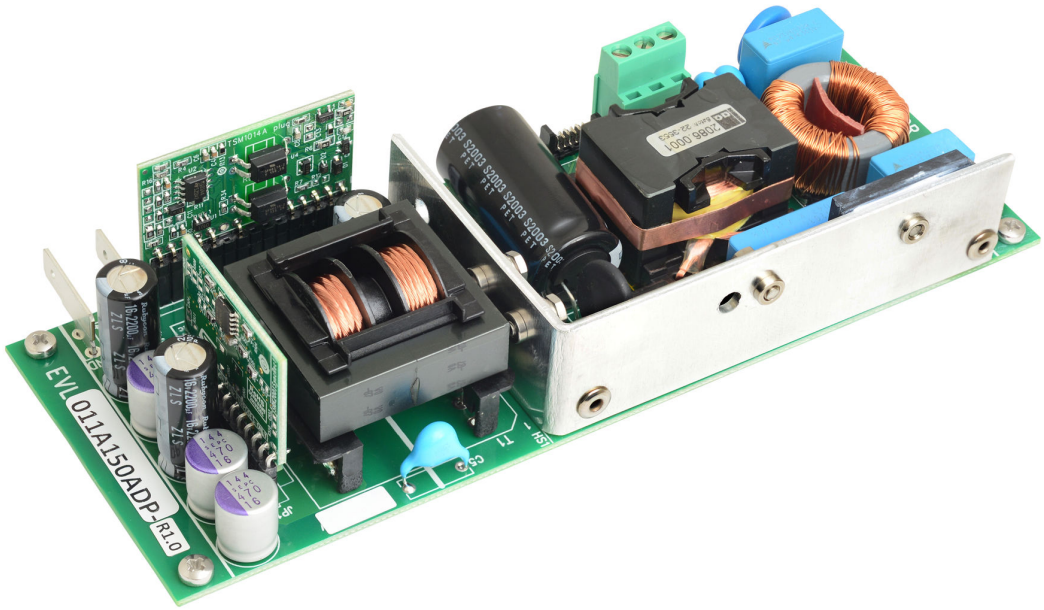
This application note describes the EVL011A150ADP, a 12 V, 150 W power supply demo board for 90 Vac to 264 Vac mains, which is representative of an AC-DC converter for an all in one (AiO) computer or a general purpose high power adapter.

The design is based on the STNRG011A IC, a digital combo that controls a two stage AC-DC SMPS. The front-end is a transition mode PFC pre-regulator and the second stage is an LLC HB resonant converter. The SRK2001 implements the synchronous rectification in order to obtain a higher efficiency.

No auxiliary supply is needed due to the very low consumption at no load.

A full set of auxiliary functions and protections is also provided; this allows to reduce the overall BOM while maintaining a rugged design.

Figure 1. EVL011A150ADP demo board



1 STNRG011A, the digital controller approach

The STNRG011A digital combo is a PFC+LLC digital controller that allows to design high efficiency SMPS with the minimum component count.

Even though the architecture of this demo board is somehow conventional and already seen with analog controllers, the full advantage of a digital implementation using the STNRG011A IC can be obtained without writing a single line of code. In fact, all the firmware and software are embedded in the controller, while the required flexibility can be achieved through a complete set of parameters, stored in its non-volatile memory (NVM), which allows to configure and fine-tune the application.

Moreover, if special, custom, functions are required, they can be coded and written in an external EEPROM.

At startup the controller reads this code and integrates it in the original SW.

The same memory is also used by the STNRG011A to store all the housekeeping data.

A two-wire serial bus is used for all the communications between STNRG011A, EEPROM, and an (optional) external device. A programmable asynchronous serial protocol is used for data exchange between the controller and the external unit, while I^2C allows to access the EEPROM.

A PC, with a dedicated hardware interface that guarantees the galvanic isolation, can be connected to the serial bus of the board, and a windows based application with a graphical user interface (GUI) is available for complete configuration and monitoring of the application.

Related documents

Additional information and details about parameter settings and the GUI and related hardware can be found in the following documents:

- UM3002 – STNRG011A NVM parameters description (see www.st.com)
- UM2945 – Getting started with the STEVAL-PCC020V2: USB to I^2C UART interface board for STNRG01x products (see www.st.com)

This evaluation board has been developed starting from the existing STEVAL-ISA170V1 demo board, based on full analog control. Its application note (AN4677 on www.st.com) can be used to obtain a comparison between a fully analog design and the digital one.

The NVM parameters stored in the STNRG011A are in Section Appendix A.

1.1 Target specifications

Table 1 summarizes the main specifications that were considered for the board design.

Table 1. Target specifications

Parameter	Value	Note
Input mains range	90 ÷ 264 Vac - frequency 45 ÷ 65 Hz	
Output power	0 W – 150 W continuous operation, 200 W peak	1
Nominal output voltage	12 V	
Output voltage regulation	+/- 5%	2
Ripple / Noise	< 120 mV_{p-p}	3
Full load efficiency	> 90% at 115/230 Vac	
Avg. efficiency (at 25, 50, 75, 100% of full load)	> 90% at 115/230 Vac	
Efficiency (at 250 mW)	> 60% at 115/230 Vac	
No load mains consumption	< 75 mW	
Hold-up time	> 10 ms	
Mains harmonics according to	EN-61000-3-2 Class-D and JEITA-MITI, Class-D	
EMI	According to EN55022 Class-B	
Safety	According to EN60950	

Parameter	Value	Note
Dimensions	175 x 65 x 35 mm	
PCB	Double side, 70 µm, CEM-1, mixed PTH/SMT	

1. Peak power loading for 100 ms minimum.
2. Steady-state and dynamic load (0.5 A/µs), no load to full load.
3. Measured over a bandwidth of 20 MHz with a 10 µF electrolytic capacitor in parallel with a 100 nF ceramic capacitor placed at the point of measurement.

1.2 Electrical diagrams

Figure 2. Motherboard electrical diagram

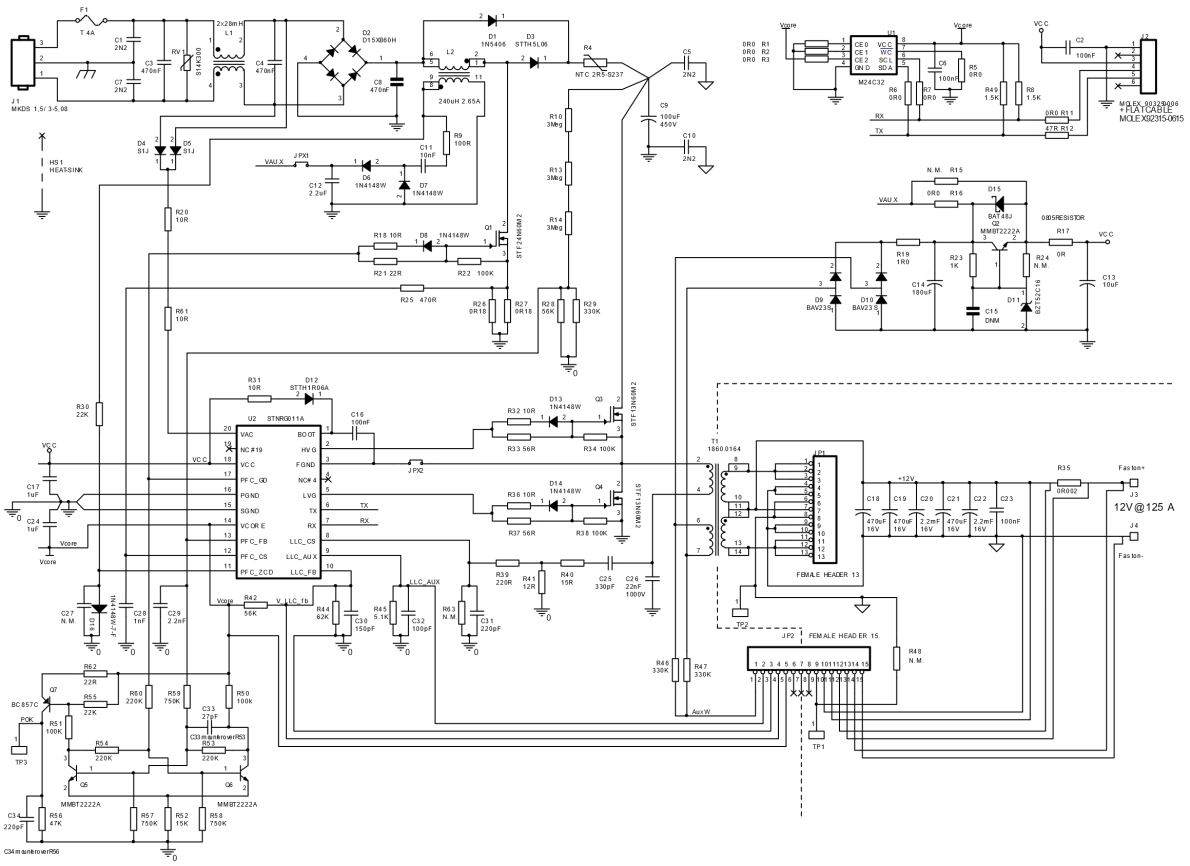


Figure 3. Synchronous rectification (SRK) board electrical diagram

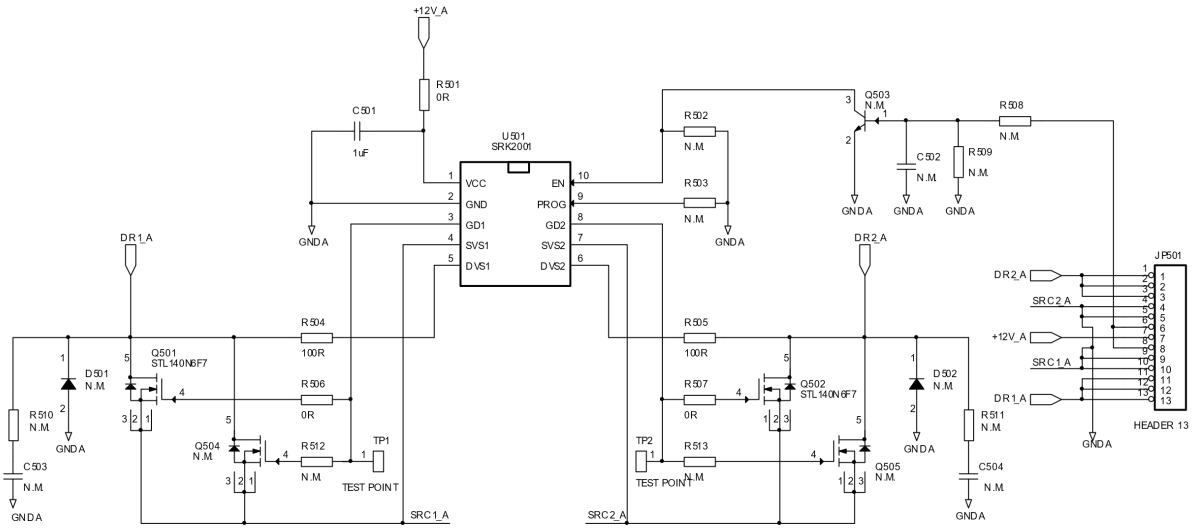


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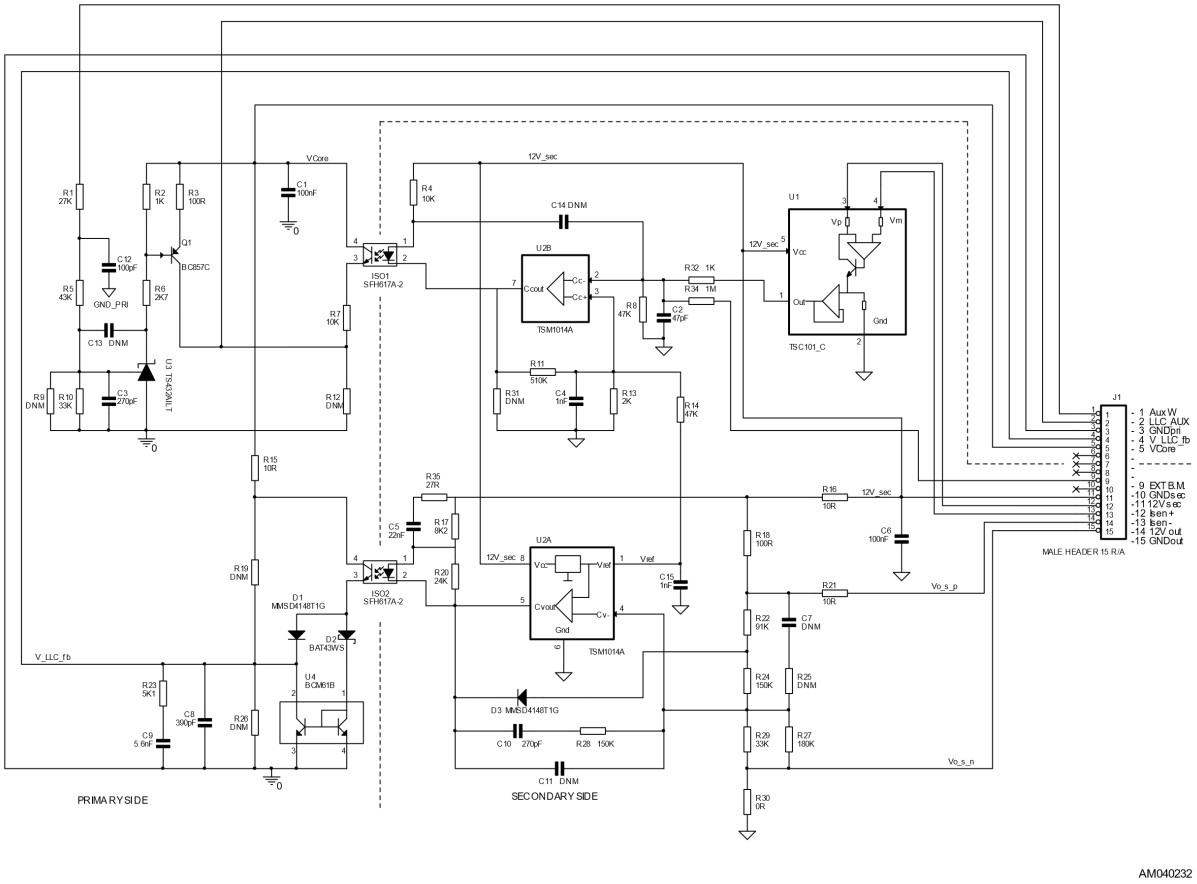
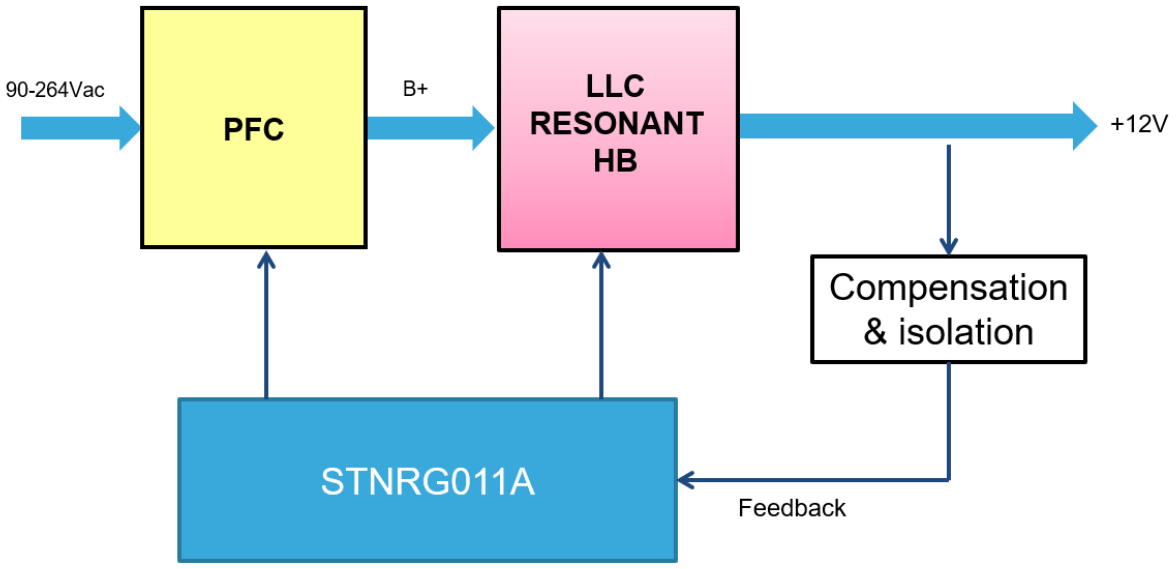
Figure 4. **Feedback (control) board electrical diagram**



1.3 Board architecture

The block diagram of the demo board is shown in Figure 5: the architecture is a standard Transition Mode PFC pre-regulator that generates the 400 V bulk voltage and an LLC half-bridge resonant downstream converter that generates the isolated 12 V output. The feedback signal comes from the secondary side with an optocoupler that guarantees galvanic isolation from primary to secondary side. All the compensation related network for the LLC converter is analog and located on the secondary side of the converter. The SRK2001 synchronous rectification is used on the secondary side to increase the overall efficiency of the board.

Figure 5. **Block diagram of the demo board**



The design of the demo board reflects the analog implementation described in AN4677 (see www.st.com). For this reason, only the major differences are analyzed.

1.3.1 PFC power boost

The PFC power section is a standard PFC TM design. The ST proprietary Ramp-enhanced Constant On Time (ReCOT) algorithm of the STNRG011A allows to reach high PF and low THD also with high input capacitance at the mains input. The digital PI filter and a complete set of protections, allow to design the PFC with very low component count.

1.3.2 LLC half-bridge DC-DC converter

The LLC half-bridge resonant converter is designed to have a resonance frequency of about 100 kHz. The ST proprietary Time Shift Control algorithm of the STNRG011A allows high input voltage ripple rejection, even with a single pole compensation. Anyway, due to the tight requirements imposed, the LLC control loop has a more complex configuration than usual. The IC's protections for the LLC stage, always ensure the correct mode of operation, also avoiding entering into the capacitive region, and the new burst mode functionality guarantees the minimum power consumption at low loads.

1.3.3 Synchronous rectification

The synchronous rectification is the standard SRK2001 demo board with a PowerFLAT 5x6 package STEVAL-ISA168V. The SR-MOSFETs have been changed with the new STripFET F7 Power MOSFET STL140N6F7, which guarantees higher performance and lower switching losses compared with the STL140N4LLF5 mounted on the standard demo board. Also, the disabled circuit has been removed, being the feature not used in this application.

1.3.4 LLC control loop

It is worth noting that the tight requirements imposed, lead to a more complex configuration than usual, while for relaxed specs, conventional solutions can be used.

Table 2 indicates each requirement of the consequent main constraint and its implication.

Table 2. Constraints / implications vs. requirements

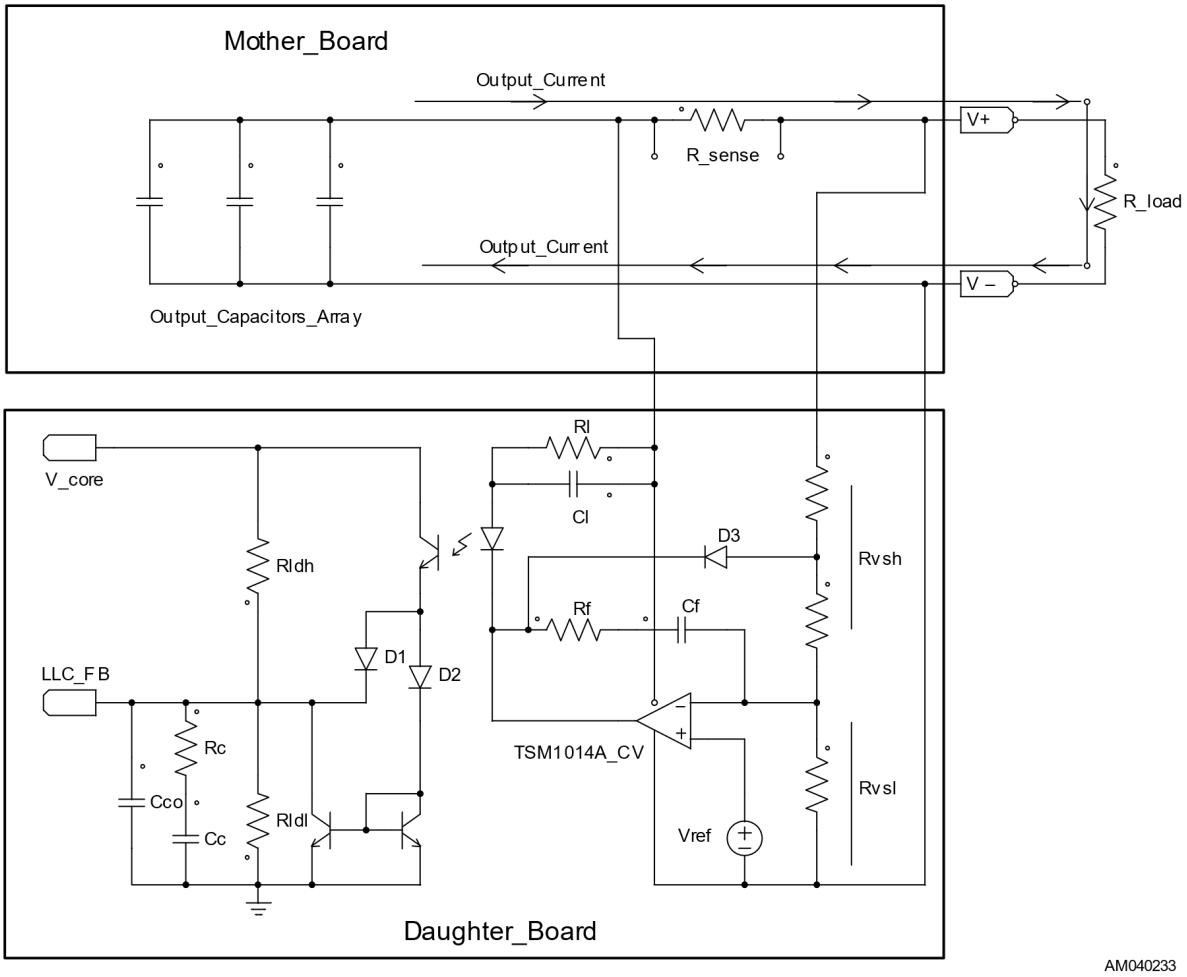
Constraints / implications	Requirements
DC accuracy	High DC loop gain, remote sense
Load transient response	Controlled large signal behavior, avoid saturation
Stability	Small signal transfer function with adequate phase margin
Output ripple	High bulk voltage rejection ratio: high gain at twice the line frequency
Power consumption at no load	Reduced currents, also for the optocoupler

An analog solution has been chosen to control the output voltage of the SMPS, in order to minimize the delay between an output voltage change and the correction of the time shift value that compensates it; assuring in this way a fast response to load transients and a good dynamic behavior.

The output voltage of the resonant converter is set by means of an analog feedback loop: a TSM1014A, at secondary side, provides a voltage reference and an error amplifier that compares the resistor divided output voltage to its internal reference. The optocoupler’s diode cathode is driven by the error amplifier output, while its anode is connected to the output capacitor's array through an R-C parallel network. On the primary side, the optocoupler’s phototransistor is configured as an emitter follower and drives the “diode section” of an integrated current mirror (BCM61B). Two diodes, D1 and D2, have been introduced to clamp the current mirror’s output in case of overdrive, also avoiding the saturation. The current mirror feeds a complex load and the central node of a voltage divider; this node is also connected to the LLC_FB pin of the STNRG011A IC, of which the 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.

Figure 6 shows the reference circuit diagram of the LLC control loop, used hereafter to describe its behavior.

Figure 6. Control loop reference circuit diagram



1.3.4.1 *Vout remote sense*

Due to the high load current (12.5 A and more during peak power) and being the TSM1014A controller mounted on a daughterboard, it has been chosen to connect the output voltage sense resistors (Rvsh, Rvsl) to the output faston connectors through dedicated PCB traces, as indicated in the circuit diagram in Figure 6.

In this way, the sense circuit is separated from the output current path and a more accurate measure of the voltage at the output terminals can be obtained.

1.3.4.2 *Secondary side error amplifier*

The CV section of the TSM1014A compares the output voltage divided by Rvsh and Rvsl, to its internal reference voltage and drives the cathode of an SFH617A photodiode, while its anode is connected to the output capacitors through Rl and Cl.

With this configuration the current through the photodiode is controlled by two paths:

- a “slow” one implemented by the TSM1014A and its compensation network.
- a “fast” one composed by the parallel Rl and Cl.

In static conditions the TSM1014A fixes the operating point and then the output voltage with good accuracy, while in case of fast load transients the photodiode current is modulated also by the output voltage variations through Rl and Cl, speeding up the response.

1.3.4.3 *Primary side optocoupler load*

The standard primary side optocoupler's transistor configuration is the common emitter with a resistor of several kilo ohms placed between its collector and the supply. The main drawback of this solution is that the high output capacitance of the phototransistor (approximately 3 nF to 8 nF) with the relatively high resistive load introduces a pole at low frequency in the response of the circuit, with consequent slow transient response.

To avoid this, the load resistor could be reduced, but this would increase the power consumption.

A better solution is instead implemented, connecting the phototransistor as emitter follower that drives a current mirror. In this way the phototransistor sees a low impedance, and the pole is pushed at higher frequencies, while maintaining the required resistive load.

Figure 7 shows the basic circuit diagram used for a simple simulation of the two configurations, while Figure 8 shows the resulting waveforms.

Figure 7. Optocoupler configurations

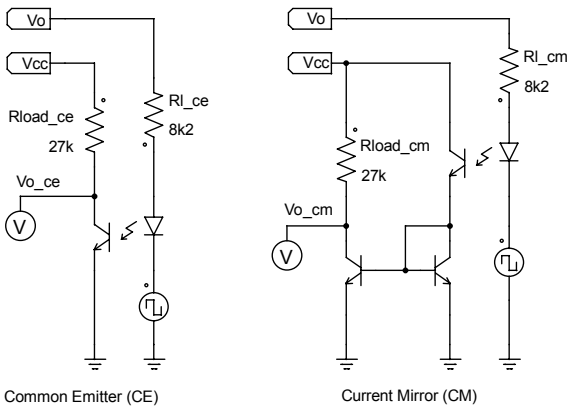
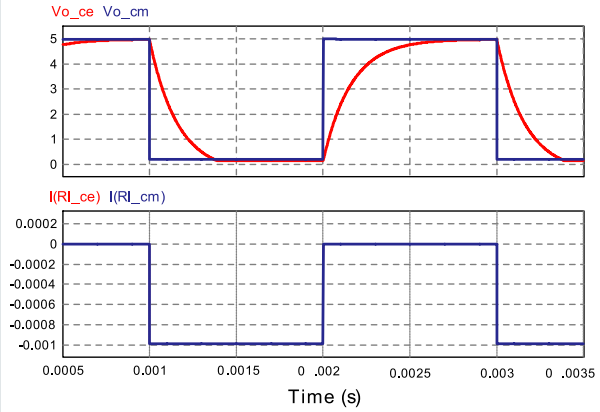


Figure 8. Transient responses



As can be seen, the current mirror configuration is much faster, and in the case of overdrive (due to heavy load transients), it avoids the phototransistor saturation and the consequent delay in response.

In order to analyze this point also in the frequency domain (small signal), a simple circuit that is representative of the actual configuration has been implemented with an SFH617A optocoupler:

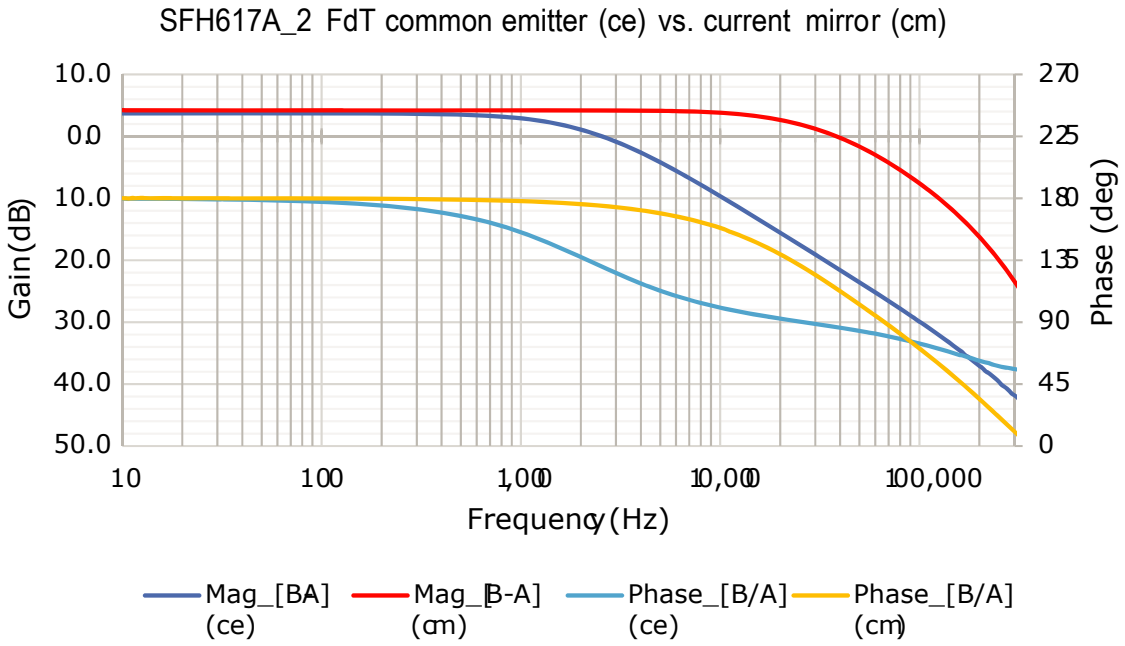
- The photodiode was polarized with a DC source with a series resistor, in order to fix the static current at 400 uA.
- The phototransistor was configured either as common emitter or with the current mirror circuit.

In both cases, the same resistive load has been used and it has been connected to a fixed voltage source to set up the bias voltage at 1.5 V.

A network analyzer has been connected to measure the transfer function (output voltage on the resistive load with respect to the photodiode current, in gain and phase) of the two configurations.

Figure 9 below compares the two structures: the current mirror configuration has a bandwidth about an order of magnitude wider than the common emitter.

Figure 9. **CE and CM optocouplers configurations frequency response**



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1.3.4.4 *Voltage clamps*

During heavy load transients, the nodes of the feedback path can be driven well out of the linear region and then the recovery time to the steady-state may be long. For this reason, a clamp mechanism has been introduced, both on the primary and on the secondary side.

On the primary side two diodes, D1 and D2, are placed between the emitter of the phototransistor and the collectors of the two transistors of the current mirror. In this way, in case of an overdrive, when an excess current flows in the optocoupler, D1 conducts and avoids the transistor saturation.

The second diode D2 has been introduced to raise the clamp level of the LLC_FB voltage to about 360 mV, thus accelerating the response when exiting burst mode.

Moreover, the current mirror load is composed of two resistors, one towards Vcore (equal to 56 kΩ) and the other towards ground (equal to 62 kΩ), such that when no current flows through the optocoupler, the LLC_FB voltage is limited to 2.627 V, about 100 mV over the A/D converter full scale of 2.5 V.

The clamp circuit on the secondary side has been introduced to avoid the TSM1014A saturation and to limit the maximum current in the photodiode. This has been done splitting the resistor between Vout and the inverting input of the error amplifier and placing a diode between these two resistors and the TSM1014A output. In steady-state condition the CV- input equals the CV+ (1.25 V of the reference voltage), and then the converter output voltage is at the nominal value of 12 V while the node between the two resistors is at 7.97 V. If the output voltage goes above the regulation point, the TSM1014A output is forced low, but it is clamped to 7.97 V – 0.7 V = 7.27 V because the diode starts conducting.

Taking into account a voltage drop on the phototransistor of 1.1 V, the maximum voltage excursion on the photodiode series resistor (equal to 8.2 kΩ) is 12 V – 7.27 V – 1.1 V = 3.63 V, that leads to a maximum current in the photodiode equal to 3.63 V / 8.2 kΩ = 443 µA. With this current the circuit must guarantee that the LLC_FB pin voltage goes towards zero (actually below the clamp voltage on the primary side), so the phototransistor has to sink the entire current that is equal to Vcore / 56 kΩ = 89 µA.

In other words, when in the photodiode flows the maximum current of 443 µA, in the phototransistor 89 µA must flow, and then the minimum CTR required for the optocoupler is 89 µA / 443 µA = 0.2 at a bias current of about 400 µA.

1.3.4.5 *Control loop stability*

A good starting point for the definition of the compensator is the evaluation of the transfer function of the power section (plant). In order to do this, the TSM1014A CV operational amplifier can be overcompensated increasing the Cf value to 0.1 µF to 1 µf and reducing RF to few hundreds ohms: in this way, the system would behave as having a single pole at low frequency. The plant transfer function can be measured with the network analyzer with this configuration, starting from low output current, and then increasing the output power while observing the output and feedback voltages, immediately stopping in case of signs of instability.

With this approach the result achieved was that the most critical condition from the stability point of view was at full load, when the plant first pole was at the highest frequency and the gain loop has the highest bandwidth, and for this reason the analysis and fine-tune was performed at this condition.

The final plots of the transfer functions of the power section, the compensation network, and the complete gain loop can be found in the performance verification section.

2 Functional verification

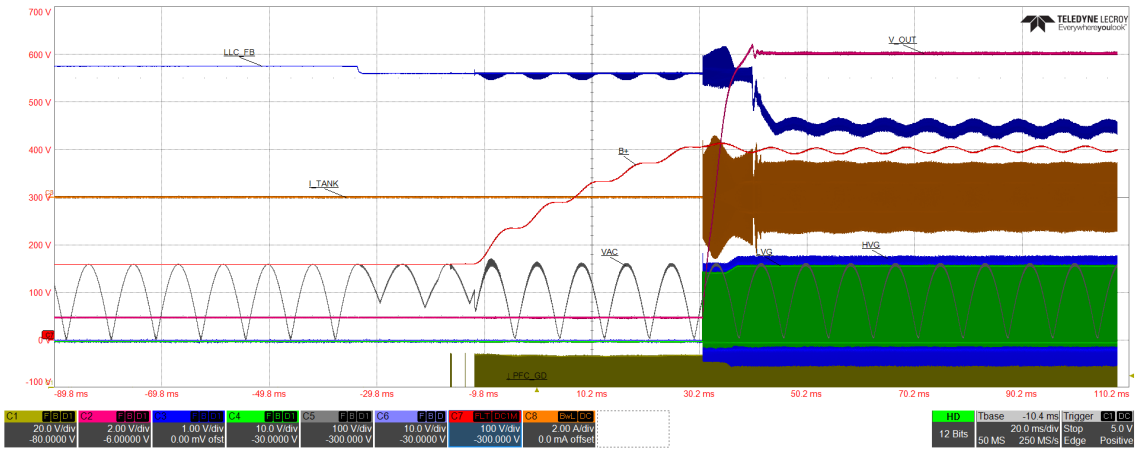
2.1 Startup

As soon as the mains is applied, the STNRG011A starts sinking current from the VAC pin, charging the VCC capacitor. The total VCC capacitor charging time is strictly related to the total capacitance connected to the VCC pin. When the VCC voltage reaches the 17 V threshold (Vcc_{On} threshold) the device turns on. It requires at least 1 complete mains cycle to perform the MCC synchronization. After that, the device turns on at the estimated peak of the mains voltage and at the falling edge of the internal MCC line comparator (that is, at about 135° of the sinusoidal voltage), in order to estimate the resonance period of the PFC boost section for TM and valley skipping operation. The PFC soft-start begins at the next mains estimated zero crossing, with a fixed power set by the “PFC pss” parameter.

The PFC soft-start ends when the PFC reaches the value set by NVM with the parameter “PFC Vout SS end (delta)”. The NVM of the device installed into the demo board is set in order to end the PFC soft-start when the bulk voltage reaches approximately 396 V. The LLC soft-start begins only at the next mains estimated zero crossing, until the output voltage reaches the regulation. The LLC soft-start ends when the LLC feedback reaches the steady-state condition.

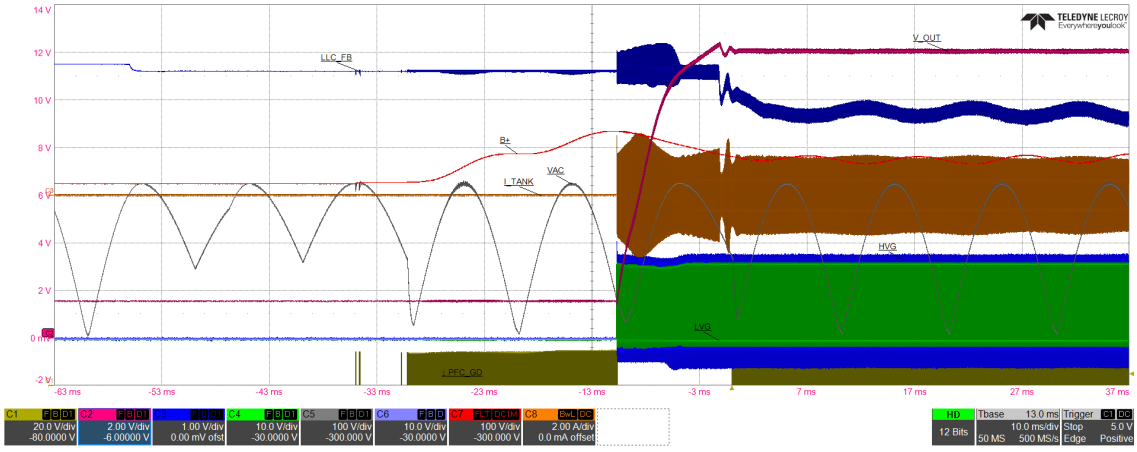
Figure 10 and Figure 11 show the full load startup from the PFC soft-start to the end of the LLC soft-start, when the mains voltage is 115 Vac / 60 Hz and 230 Vac / 50 Hz respectively. Figure 12 shows the PFC synchronization and startup, while Figure 13 shows the LLC startup with the safe start procedure that avoids hard switching during first turn-on.

Figure 10. Full load startup at 115 Vac / 60 Hz



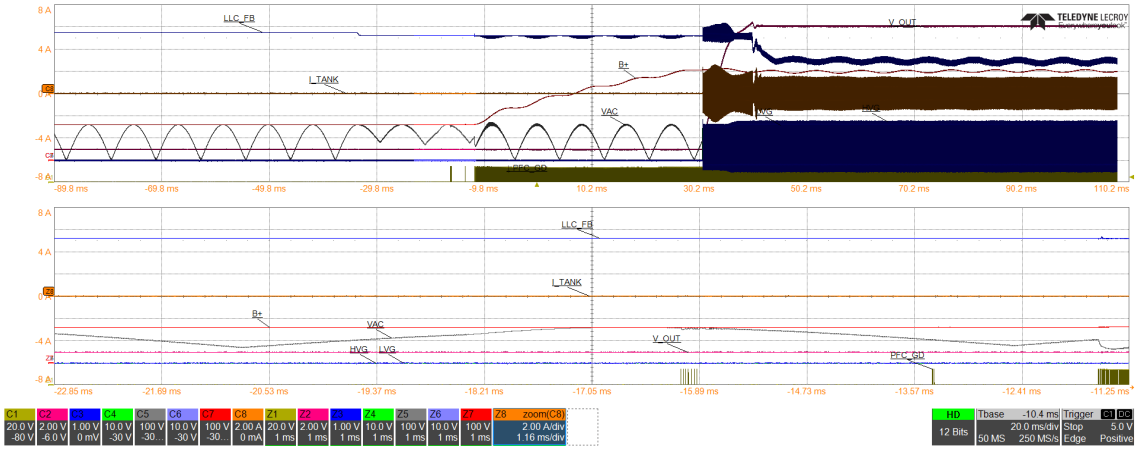
CH1 = PFC_GD; CH2 = VOUT; CH3 = LLC_FB; CH4 = LVG; CH5 = VAC; CH6 = HVG; CH7 = B+; CH8 = I_TANK

Figure 11. Full load startup at 230 Vac / 50 Hz



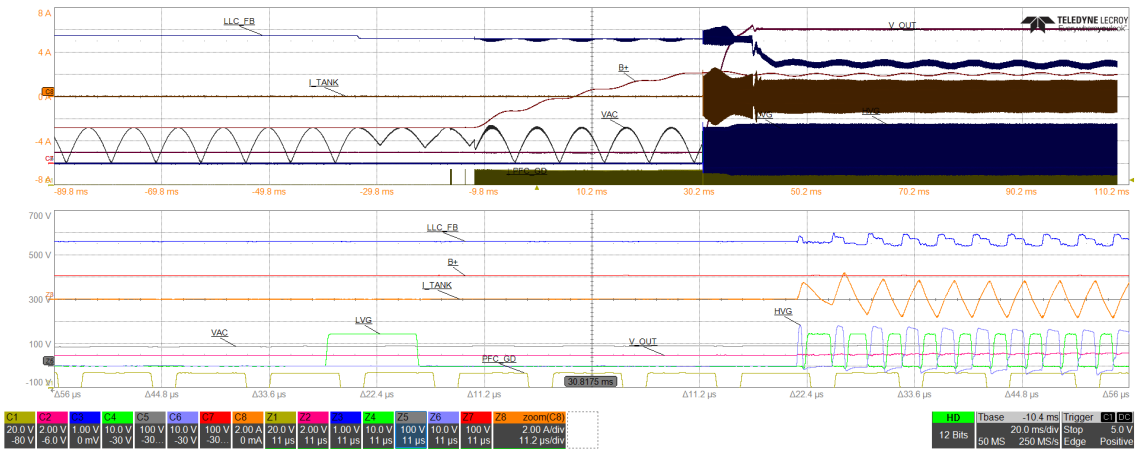
CH1 = PFC_GD; CH2 = VOUT; CH3 = LLC_FB; CH4 = LVG; CH5 = VAC; CH6 = HVG; CH7 = B+; CH8 = I_TANK

Figure 12. Full load startup at 115 Vac / 60 Hz, PFC turn-on



CH1 = PFC_GD; CH2 = VOUT; CH3 = LLC_FB; CH4 = LVG; CH5 = VAC; CH6 = HVG; CH7 = B+; CH8 = I_TANK

Figure 13. Full load startup at 115 Vac / 60 Hz, LLC turn-on



CH1 = PFC_GD; CH2 = VOUT; CH3 = LLC_FB; CH4 = LVG; CH5 = VAC; CH6 = HVG; CH7 = B+; CH8 = I_TANK

2.2 Early warning feature

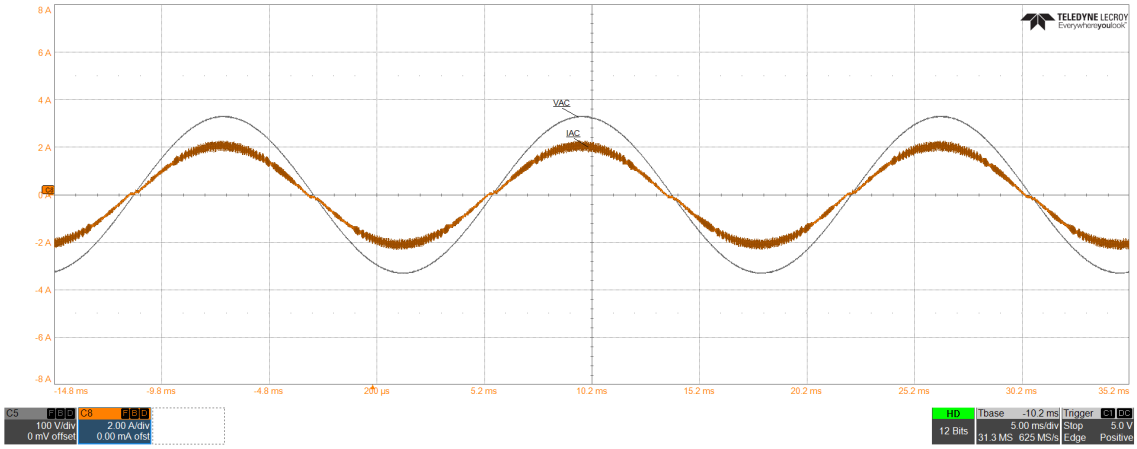
The STNRG011A has integrated the early warning feature to generate an early warning signal in case the system is shutting down. This feature is important in PC power applications where all the supplied devices must be informed that the power supply is shutting down. The early warning signal is generated on the PFC_FB pin, putting it up to 5 V and the information is latched with the Q5 and Q6 latch circuitry. The latch is reset as soon as the PFC gate drive restarts switching. Even though the demo board application is an adapter power supply, and the early warning feature is not necessary, it is anyway enabled in order to clarify how a practical application could be. For more information regarding the Power OK circuitry, please refer to the Section Appendix D.3.

2.3 PFC operation

2.3.1 ReCOT functionality

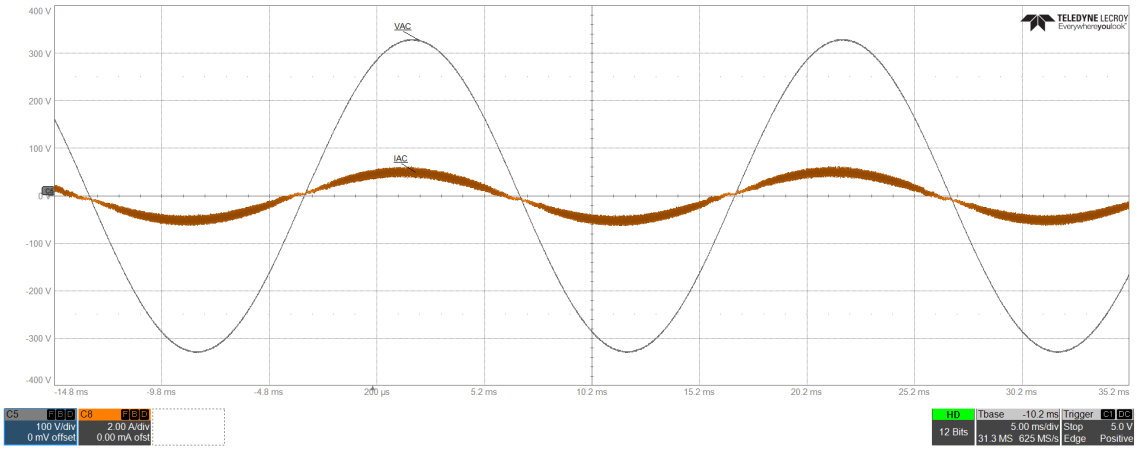
The STNRG011A controls the PFC MOSFET turn-on time with the proprietary Ramp Enhanced Constant On-Time algorithm. It allows to compensate the input EMI filter capacity, to increase the PF and consequently to reduce the THD, keeping it low not only at full load. Figure 14 and Figure 15 show the input voltage and current at 115 Vac / 60 Hz and 230 Vac / 50 Hz respectively.

Figure 14. Input voltage and current at 115 Vac / 60 Hz, full load



CH5 = VAC; CH8 = IAC

Figure 15. Input voltage and current at 230 Vac / 50 Hz, full load

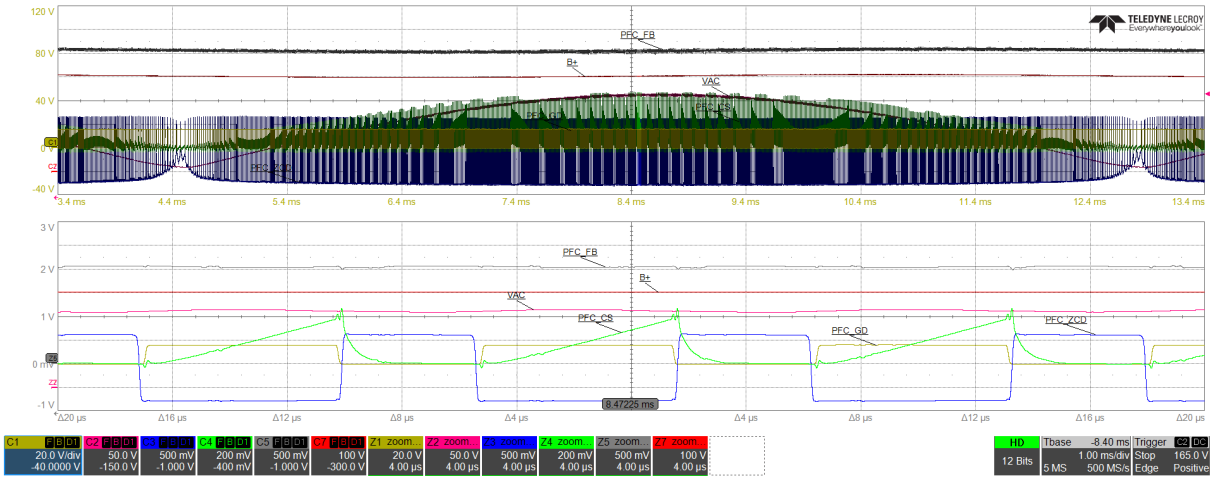


CH5 = VAC; CH8 = IAC

2.3.2 Operating modes: transition mode, valley skipping and DCM

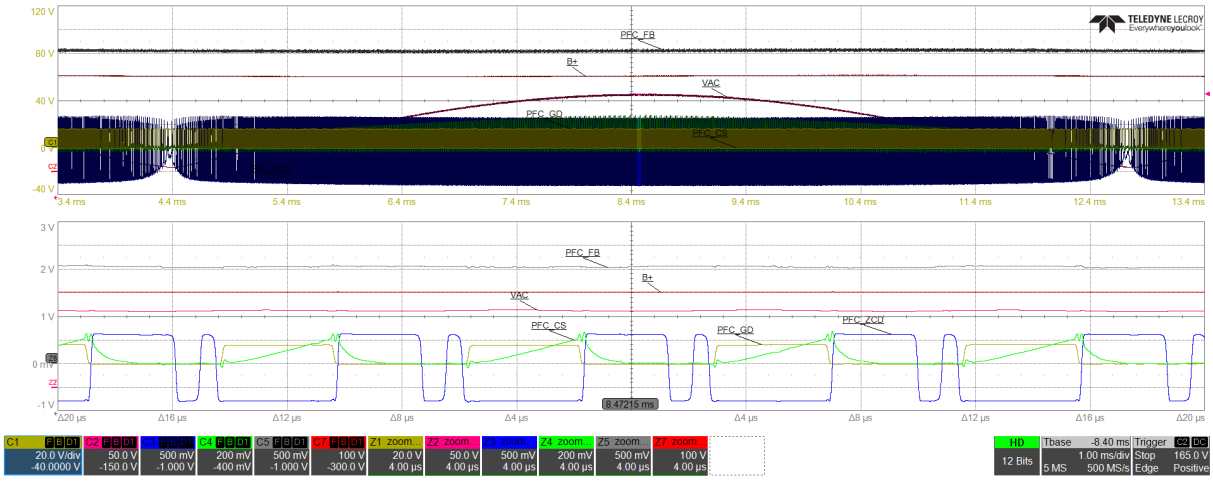
The PFC manager changes the operating mode dynamically, obtaining optimal performance in terms of both efficiency and THD, from transition mode to DCM, passing through one, two or three valley skippings. This is possible thanks to the NVM configurability that allows to fit the IC to the application. Figure 16 to Figure 20 show the different operating modes of the PFC.

Figure 16. Multi-mode PFC in TM



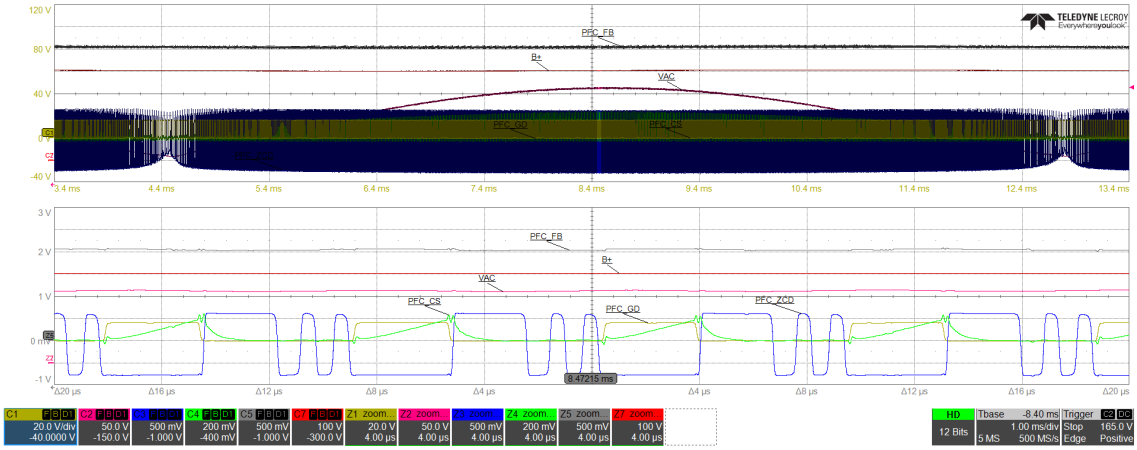
CH1 = PFC_GD; CH2 = VAC; CH3 = PFC_ZCD; CH4 = PFC_CS; CH5 = PFC_FB; CH7 = B+

Figure 17. Multi-mode PFC skipping 1 valley



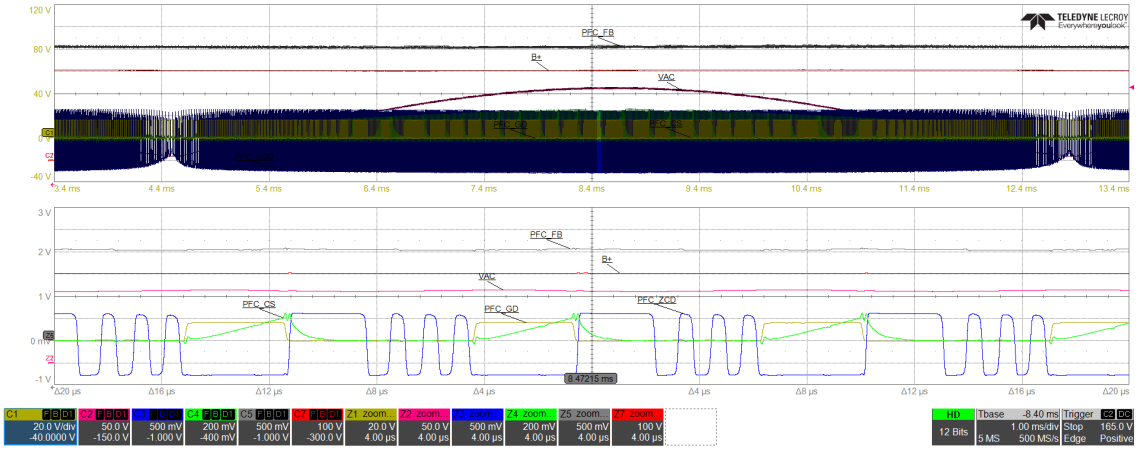
CH1 = PFC_GD; CH2 = VAC; CH3 = PFC_ZCD; CH4 = PFC_CS; CH5 = PFC_FB; CH7 = B+

Figure 18. Multi-mode PFC skipping 2 valleys



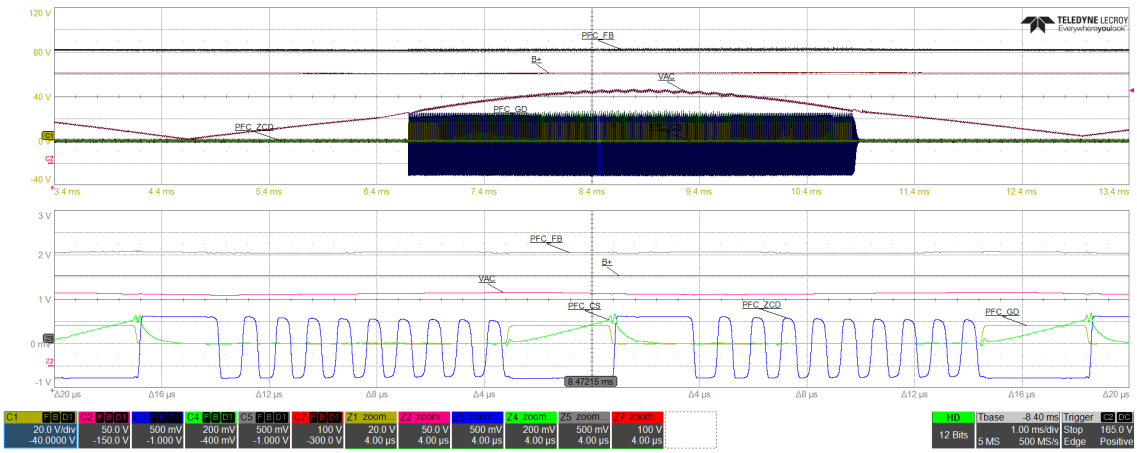
CH1 = PFC_GD; CH2 = VAC; CH3 = PFC_ZCD; CH4 = PFC_CS; CH5 = PFC_FB; CH7 = B+

Figure 19. Multi-mode PFC skipping 3 valleys



CH1 = PFC_GD; CH2 = VAC; CH3 = PFC_ZCD; CH4 = PFC_CS; CH5 = PFC_FB; CH7 = B+

Figure 20. Multi-mode PFC in DCM and deep skipping area



CH1 = PFC_GD; CH2 = VAC; CH3 = PFC_ZCD; CH4 = PFC_CS; CH5 = PFC_FB; CH7 = B+

2.3.3 Skipping area functionality (below 75 W)

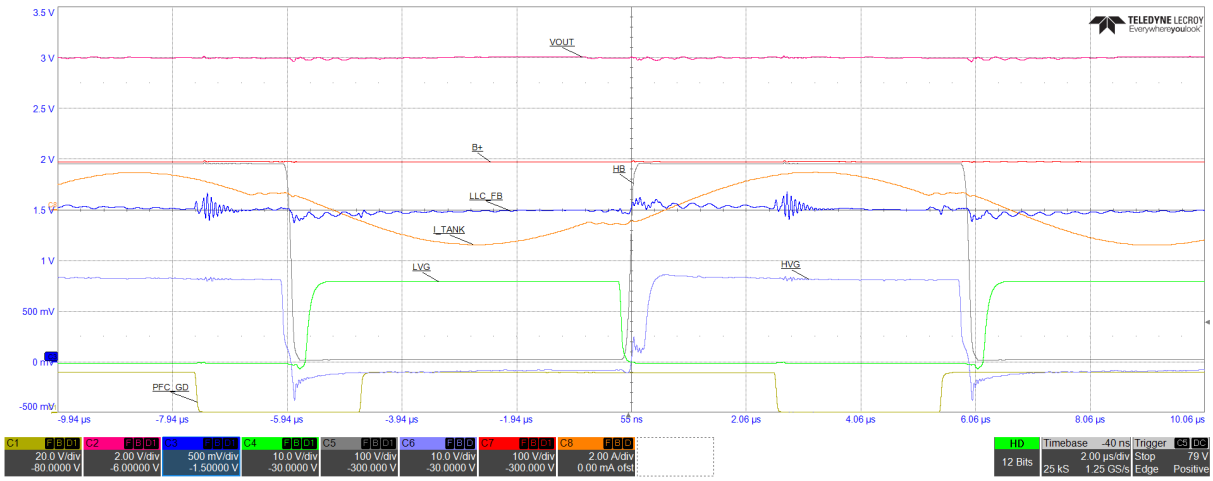
The skipping area feature allows to reduce the PFC dissipated power, turning on the PFC MOSFET only during the peak of the line voltage, either reducing the lost power having reduced the number of switching cycles and increasing the performance of the PFC where the transferred power is more efficient. The skipped area increases when the load decreases and the entering threshold has been set in order to be out of the skipping area feature when the input power is 75 W and above, in order to be compliant with the mains harmonic reduction standards at that power threshold. When the system is working in the skipping area power region, the operating mode and the MOSFET on-time are not fixed but modulated depending on the requested power, as can be seen previously in Figure 20.

2.4 LLC operation

2.4.1 Symmetric time shift control

The symmetric time shift control is the evolution of the time shift control that always guarantees 50% of 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 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 21 shows the resonant stage key waveforms at full load.

Figure 21. LLC resonant converter key waveforms



CH1 = PFC_GD; CH2 = VOUT; CH3 = LLC_FB; CH4 = LVG; CH5 = HB; CH6 = HVG; CH7 = B+; CH8 = I_TANK

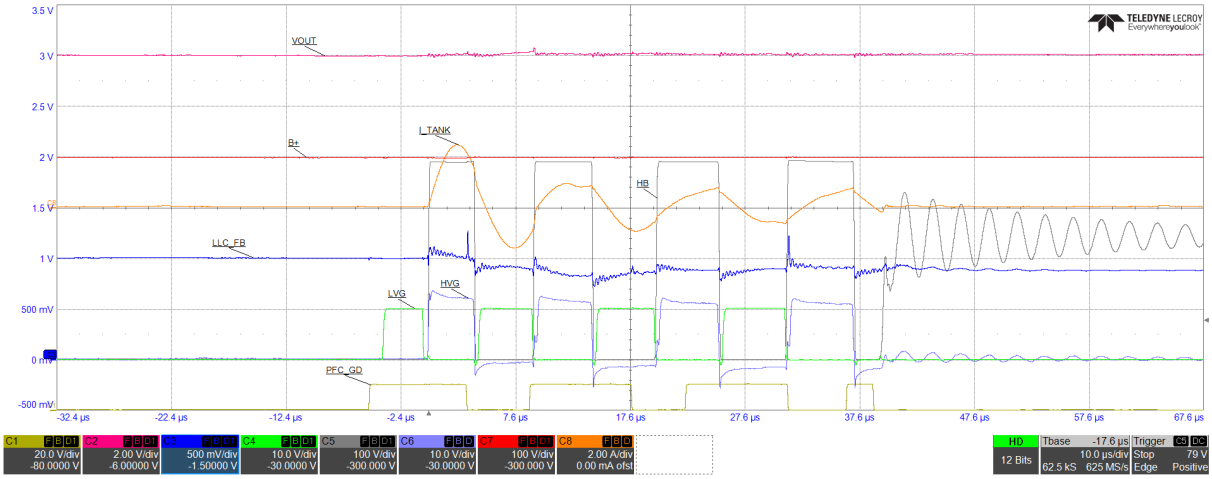
2.5 Burst mode

The STNRG011A has three kinds of burst mode: the LLC_FB controlled burst mode, the pure external burst mode and the hybrid external burst mode.

The EVL011A150ADP, and the NVM of the installed STNRG011A, is configured to use the LLC_FB controlled burst mode, but the demo board is ready for the pure external burst mode, changing two NVM parameters.

During burst mode, the PFC is always synchronized with the LLC and the PFC MOSFET on-time is modulated in order to reduce acoustic noise. Figure 22 shows a burst mode sequence at no load.

Figure 22. Burst sequence details at no load



CH1 = PFC_GD; CH2 = VOUT; CH3 = LLC_FB; CH4 = LVG; CH5 = HB; CH6 = HVG; CH7 = B+; CH8 = I_TANK

2.5.1 Feedback controlled

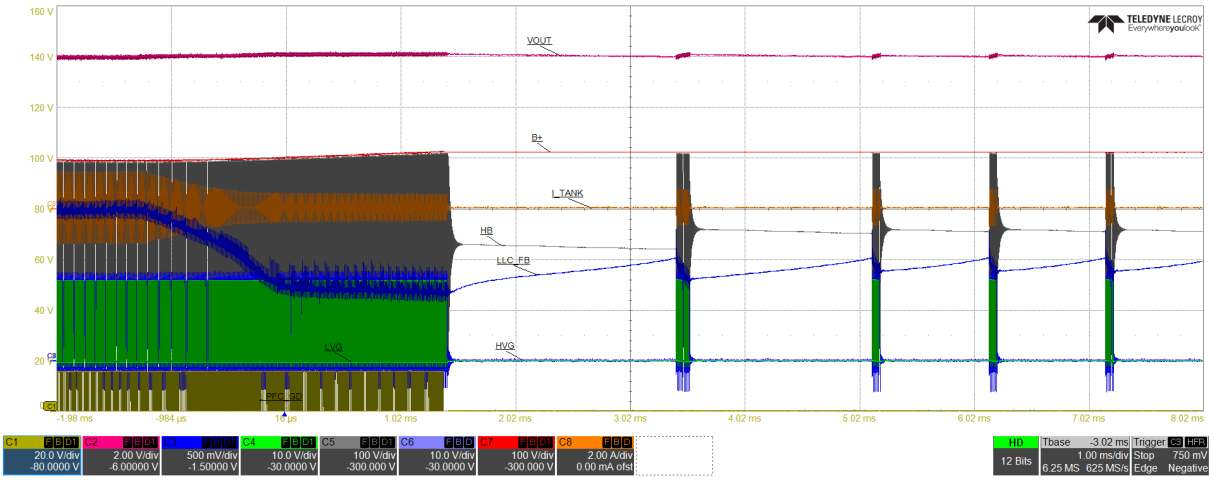
Figure 23 shows the behavior of the demo board when the LLC_FB voltage goes below the threshold set by the "LLC_FB burst entering threshold" parameter. After the digital filtering set by the "Burst entering digital filtering" parameter, the system enters burst mode.

Each burst sequence is performed when the LLC_FB value triggers the wake-up comparator, whose threshold is set by the "LLC_FB burst wake-up thr" parameter. The number of burst pulses is modulated depending on the load. Figure 22 shows a burst sequence at no load, where the number of burst pulses is the minimum and set by the "Min number of burst pulses" parameter. Figure 24 shows a burst sequence before exiting burst mode, where the number of burst pulses is the maximum and set by the "Max number of burst pulses (delta)" parameter.

If the load increases, as soon as the period of consecutive burst sequences is lower than "Minimum period to exit burst" parameter, the system exits burst. This is shown in Figure 25.

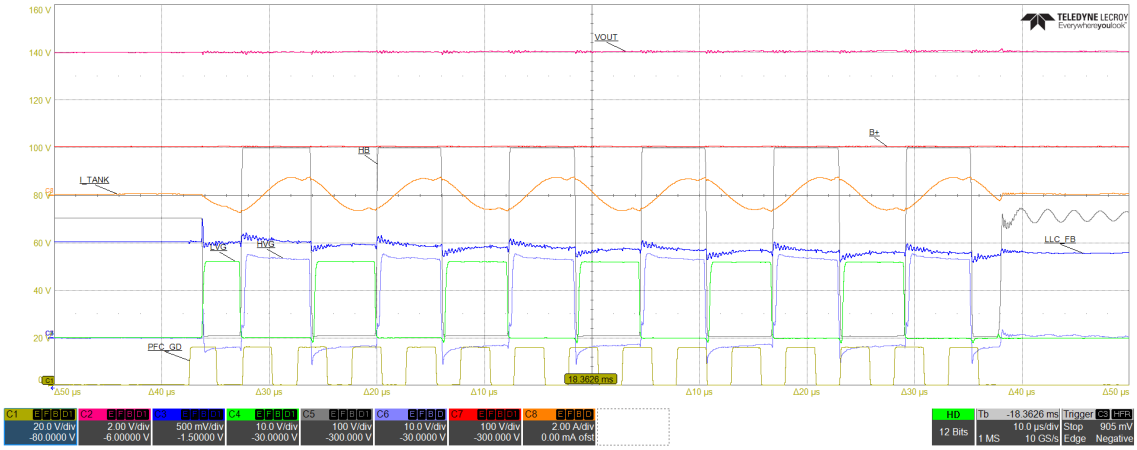
In order to respond on a heavy load transient, the system exits burst mode also in case the LLC_FB voltage after the burst sequence is sensed higher than the "LLC_FB burst wake-up thr" parameter minus the hysteresis set by the "LLC_FB burst wake-up hyst" parameter. This is shown in Figure 26.

Figure 23. Burst mode entering with a full load to 0.3 A transient



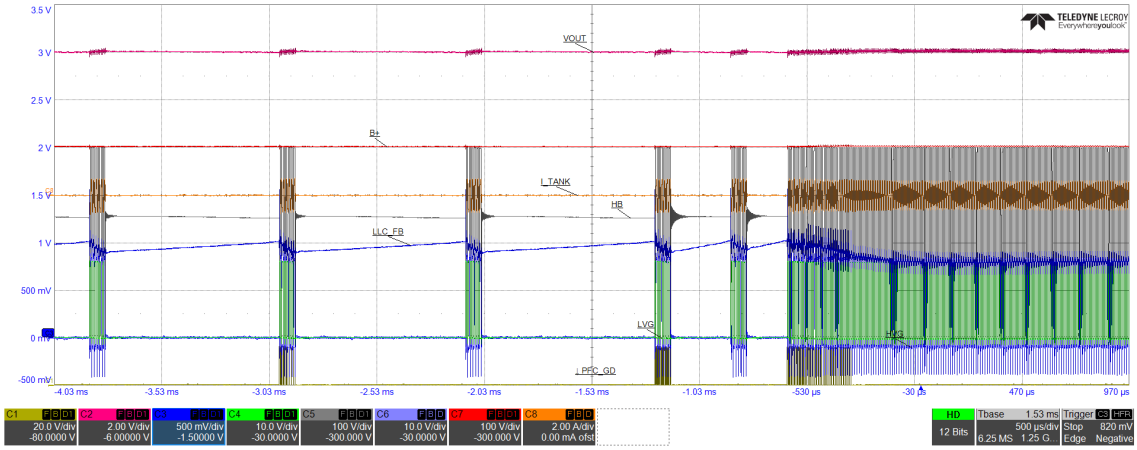
CH1 = PFC_GD; CH2 = VOUT; CH3 = LLC_FB; CH4 = LVG; CH5 = HB; CH6 = HVG; CH7 = B+; CH8 = I_TANK

Figure 24. Burst sequence detail with the maximum number of burst pulses set



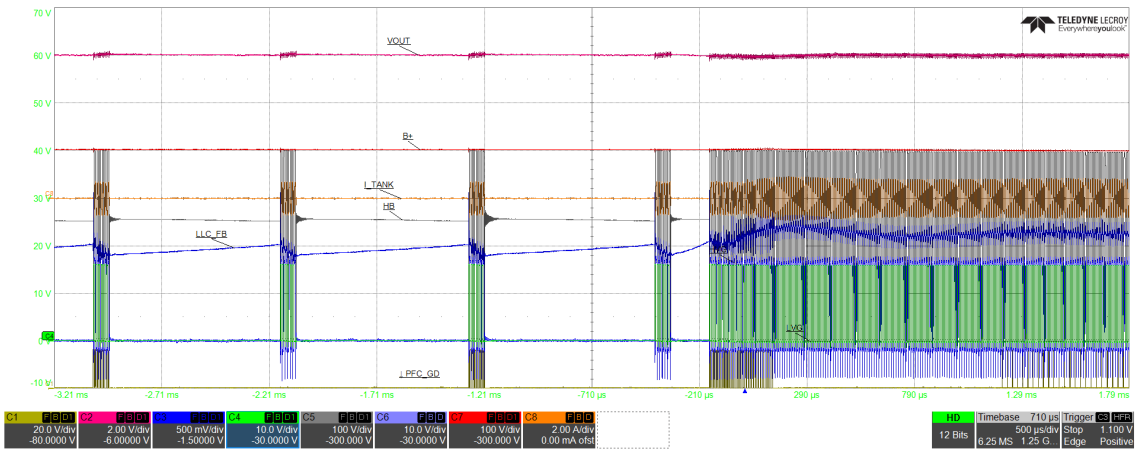
CH1 = PFC_GD; CH2 = VOUT; CH3 = LLC_FB; CH4 = LVG; CH5 = HB; CH6 = HVG; CH7 = B+; CH8 = I_TANK

Figure 25. Burst mode exiting with 0.3 A to 1 A load transient



CH1 = PFC_GD; CH2 = VOUT; CH3 = LLC_FB; CH4 = LVG; CH5 = HB; CH6 = HVG; CH7 = B+; CH8 = I_TANK

Figure 26. Burst mode exiting with 0.3 A to 5 A load transient



CH1 = PFC_GD; CH2 = VOUT; CH3 = LLC_FB; CH4 = LVG; CH5 = HB; CH6 = HVG; CH7 = B+; CH8 = I_TANK

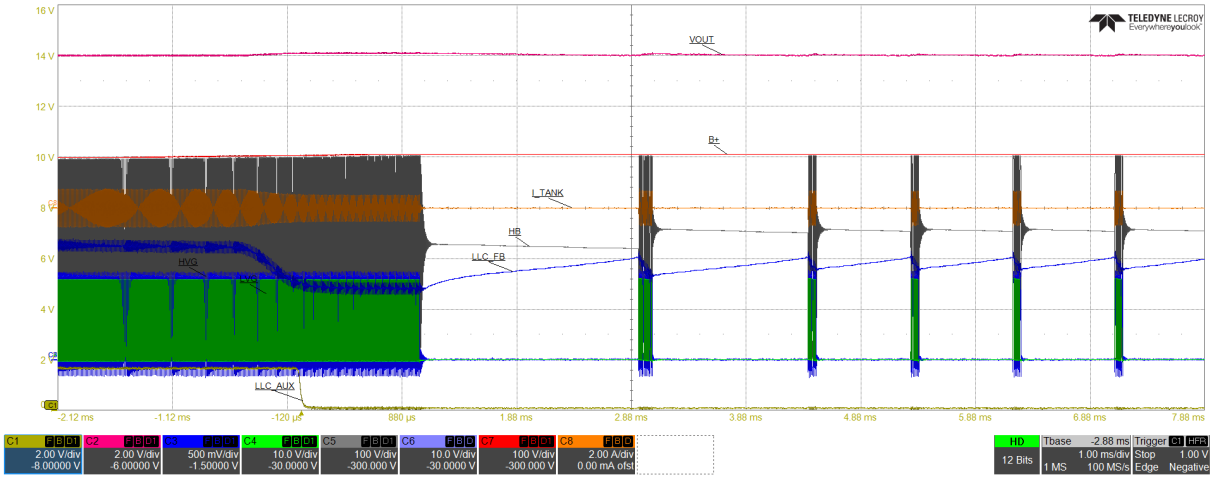
2.5.2 Load current controlled

In order to enable the load current controlled burst mode, it is necessary to change two NVM parameters. In particular, the “External burst mode” parameter must be set to “enabled” and the “LLC_FB burst entering threshold” parameter must be set to the minimum, otherwise the hybrid external burst mode is enabled, but it is not effective for this demo board.

When the secondary side burst mode comparator senses the output current below its threshold, the LLC_AUX pin is put below 0.8 V and, after the digital filtering set by the “Burst entering digital filtering” parameter, the system enters burst mode, as shown in Figure 27. The burst mode function is still managed by the LLC_FB voltage and a burst sequence is started when it triggers the wake-up comparator, whose threshold is set by the “LLC_FB burst wake-up thr” parameter.

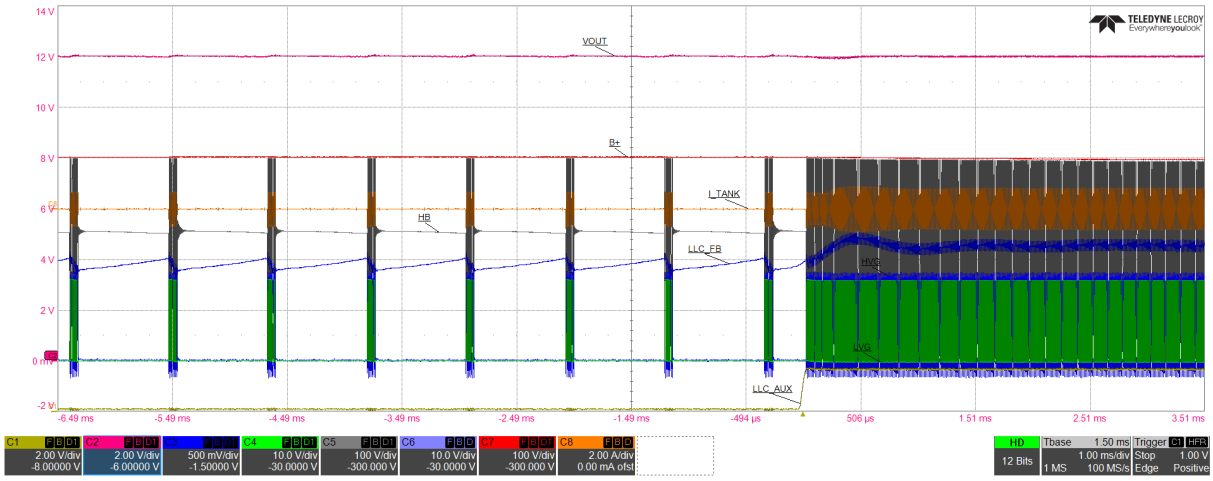
The system exits burst mode when the secondary side current level exceeds the comparator threshold and the LLC_AUX pin is put above 0.9 V. This is shown in Figure 28.

Figure 27. External burst mode entering



CH1 = LLC_AUX; CH2 = VOUT; CH3 = LLC_FB; CH4 = LVG; CH5 = HB; CH6 = HVG; CH7 = B+; CH8 = I_TANK

Figure 28. External burst mode exiting

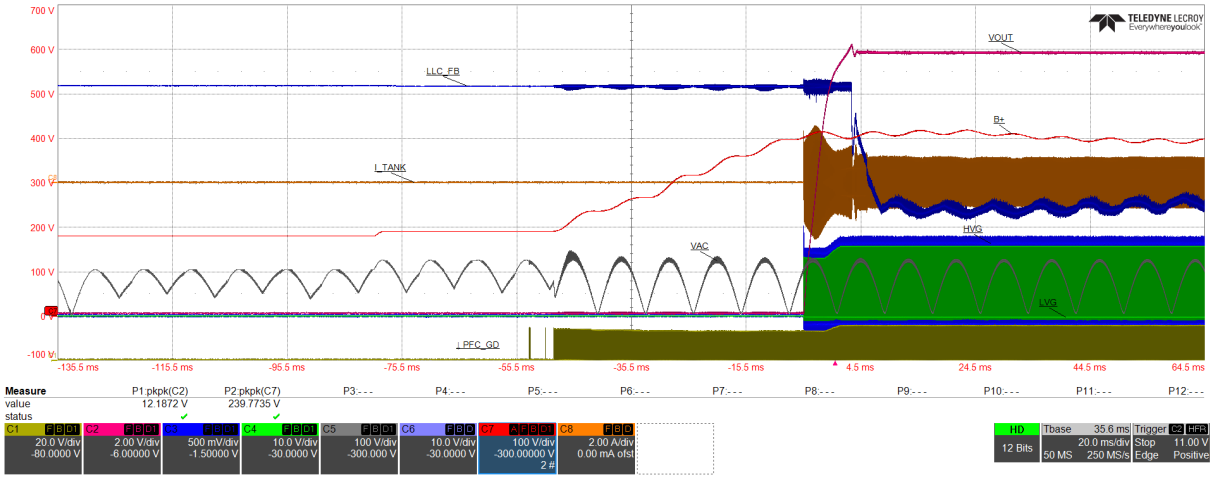


CH1 = LLC_AUX; CH2 = VOUT; CH3 = LLC_FB; CH4 = LVG; CH5 = HB; CH6 = HVG; CH7 = B+; CH8 = I_TANK

2.6 Brown-in / brown-out

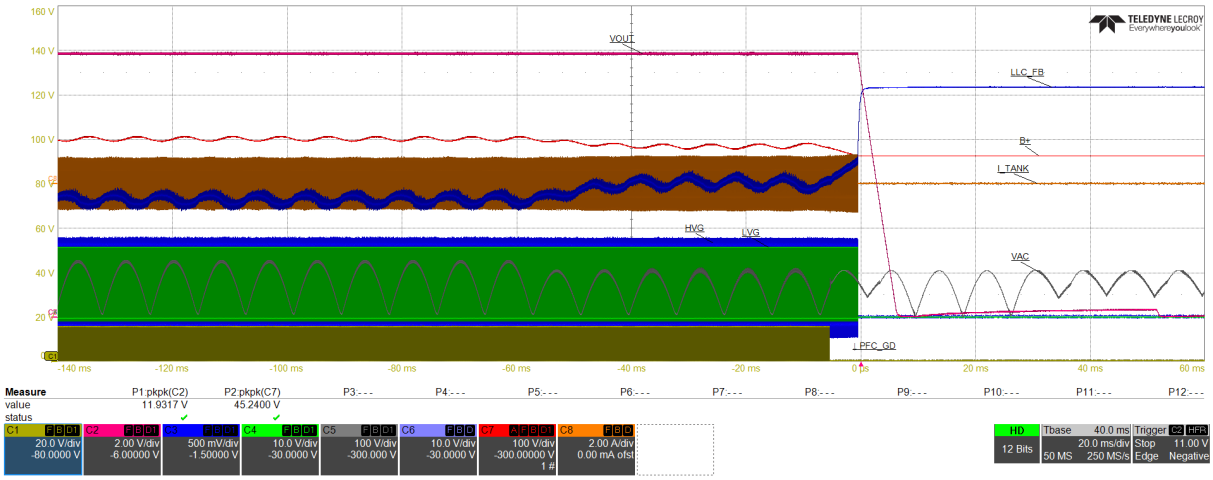
The STNRG011A has integrated the mains brown-in / brown-out function. Figure 29 and Figure 30 show both functions when mains voltage changes from 70 Vac to 85 Vac and vice versa.

Figure 29. **Brown-in during line transient from 70 Vac to 85 Vac**



CH1 = PFC_GD; CH2 = VOUT; CH3 = LLC_FB; CH4 = LVG; CH5 = VAC; CH6 = HVG; CH7 = B+; CH8 = I_TANK

Figure 30. **Brown-out during line transient from 85 Vac to 70 Vac**

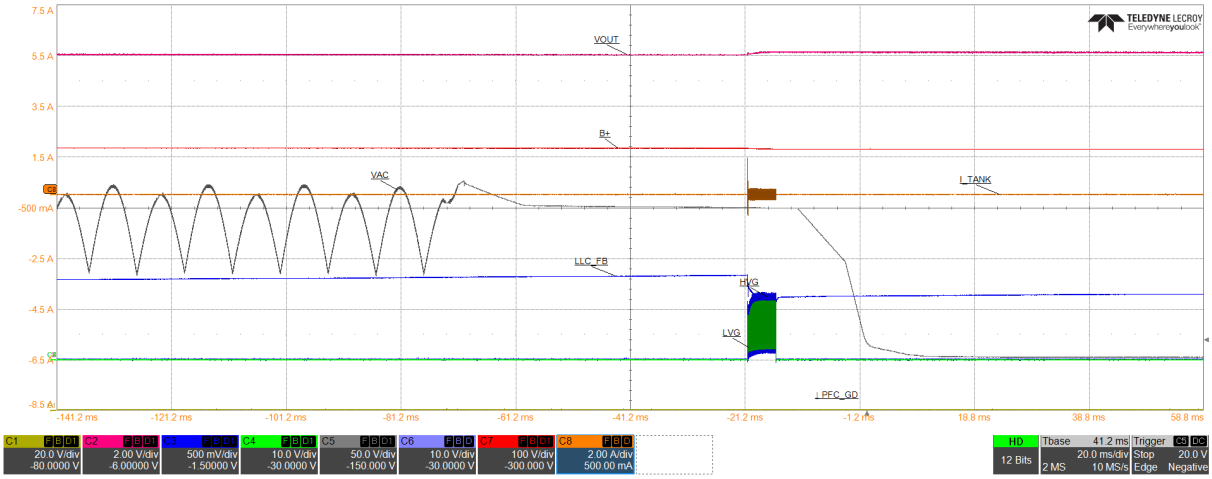


CH1 = PFC_GD; CH2 = VOUT; CH3 = LLC_FB; CH4 = LVG; CH5 = VAC; CH6 = HVG; CH7 = B+; CH8 = I_TANK

2.7 X-Cap discharge

The integrated X-Cap discharge function compliant with IEC 62368-1 is activated anytime there is no activity sensed on the line, for about 50 ms. Figure 31 shows the activation of the XCD function at no load, simulating the cable unplugging on the mains connector. As soon as the STNRG011A detects the inactivity, it restarts LLC switching for 5 ms in order to generate the early warning signal and to keep the output regulated. This feature could be disabled in case the application is not designed to keep the output voltage regulated also at no load, changing the “EW signal in burst mode” NVM parameter from “normal” to “quick”. This applies for any early warning managed fault in burst mode.

Figure 31. **X-Cap discharge function activation and normal early warning pulse at no load**

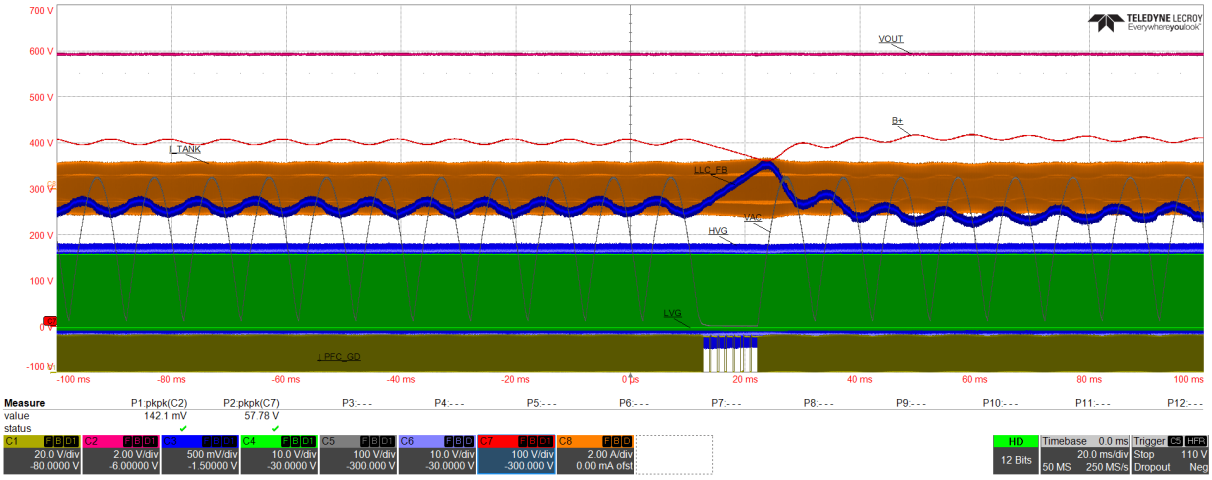


CH1 = PFC_GD; CH2 = VOUT; CH3 = LLC_FB; CH4 = LVG; CH5 = VAC; CH6 = HVG; CH7 = B+; CH8 = I_TANK

2.8 Mains dip

The system was designed to keep the output voltage regulated if a half-cycle mains dip occurs. Figure 32 shows the behavior of the demo board at 230 Vac / 50 Hz: the output voltage stays within the regulation bandwidth during the mains dip.

Figure 32. **Waveforms during 10 ms mains dip**

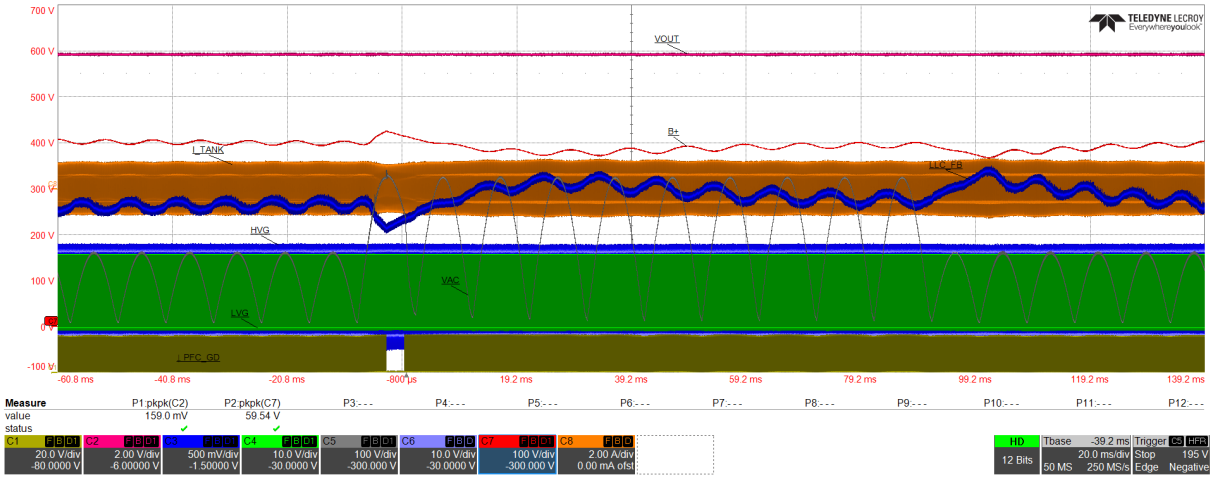


CH1 = PFC_GD; CH2 = VOUT; CH3 = LLC_FB; CH4 = LVG; CH5 = VAC; CH6 = HVG; CH7 = B+; CH8 = I_TANK

2.9 Line transient

In case a line voltage transient is detected, the STNRG011A immediately adapts the PFC MOSFET turn-on time. Figure 33 shows a line voltage transient from 115 Vac to 230 Vac and vice versa.

Figure 33. **Line transient from 115 Vac to 230 Vac and vice versa**



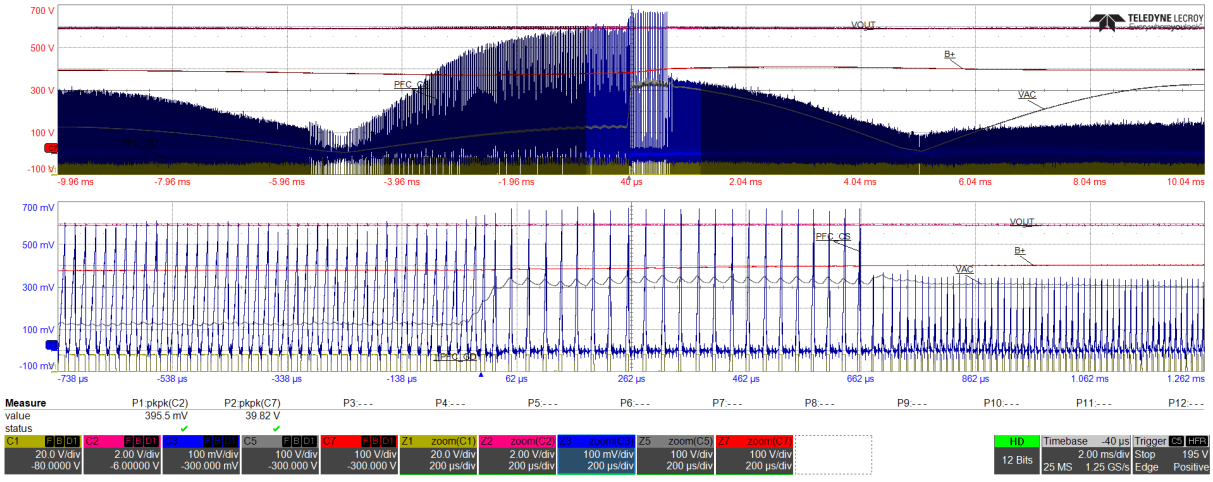
CH1 = PFC_GD; CH2 = VOUT; CH3 = LLC_FB; CH4 = LVG; CH5 = VAC; CH6 = HVG; CH7 = B+; CH8 = I_TANK

2.10 Faults managing

2.10.1 PFC OCP1

The PFC OCP1 sets the limit for the maximum allowed peak current into the PFC MOSFET. The protection works cycle-by-cycle. If the PFC OC1 comparator threshold is hit, the PFC state machine turns off the PFC gate drive for this cycle and the entire system continues to run. Figure 34 shows the behavior of the PFC during full load line transient from 90 Vac to 265 Vac at the peak of the line.

Figure 34. **PFC_CS hit PFC OC1 comparator**



CH1 = PFC_GD; CH2 = VOUT; CH3 = PFC_CS; CH5 = VAC; CH7 = B+

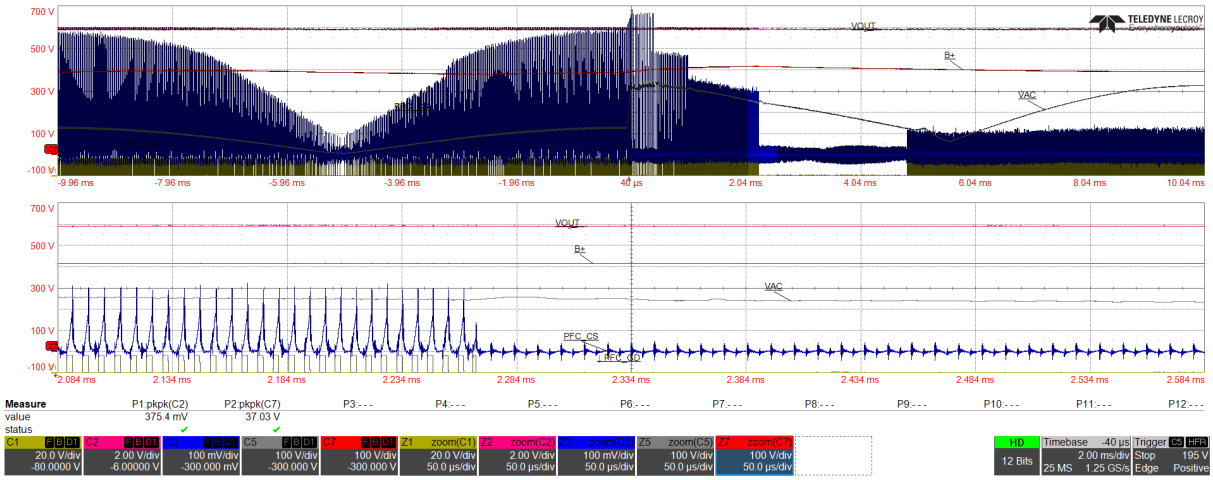
2.10.2 PFC OCP2

The PFC OCP2 fault is generated when the PFC OC2 comparator is triggered. The protection turns off the PFC MOSFET until the next mains half cycle for a maximum number of times defined by the “Max number of PFC OC2” parameter, beyond which the system shuts down. The counter is decreased every new line half cycle when the PFC OC2 comparator does not trigger any overcurrent for at least one line half cycle. The protection is usually triggered if the PFC coil saturates, and the current is no longer controlled.

2.10.3 PFC SW OVP

The PFC SW OVP fault turns off the PFC MOSFET until the next mains half cycle if the bulk voltage exceeds the value defined by the “PFC SW OVP threshold (delta)” parameter. The fault never shuts down the system. Figure 35 shows the behavior of the converter when the PFC SW OVP is triggered during a line transient.

Figure 35. PFC_FB hit the software overvoltage protection



CH1 = PFC_GD; CH2 = VOUT; CH3 = PFC_CS; CH5 = VAC; CH7 = B+

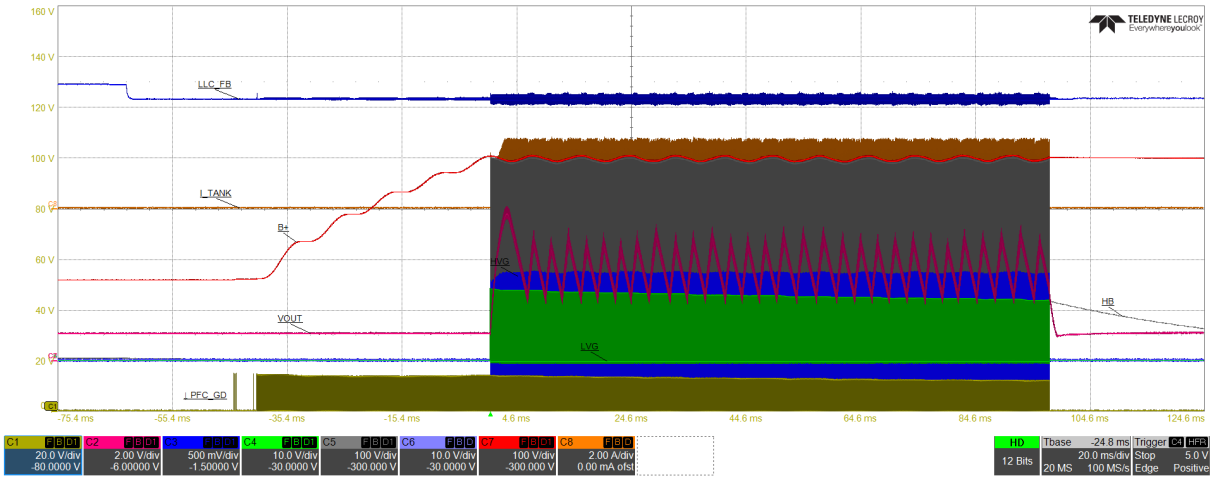
2.10.4 PFC HW OVP

The PFC HW OVP fault immediately shuts down the system as soon as the HW OVP threshold is reached. The PFC SW OVP is usually able to avoid that the PFC HW OVP comparator shuts down the system.

2.10.5 LLC SS timeout

The LLC SS timeout fault is declared if the LLC is stuck in the soft-start state for at least 100 ms. This usually happens when the system starts with the output short circuited and cannot reach the regulation, as shown in Figure 36.

Figure 36. LLC SS timeout protection

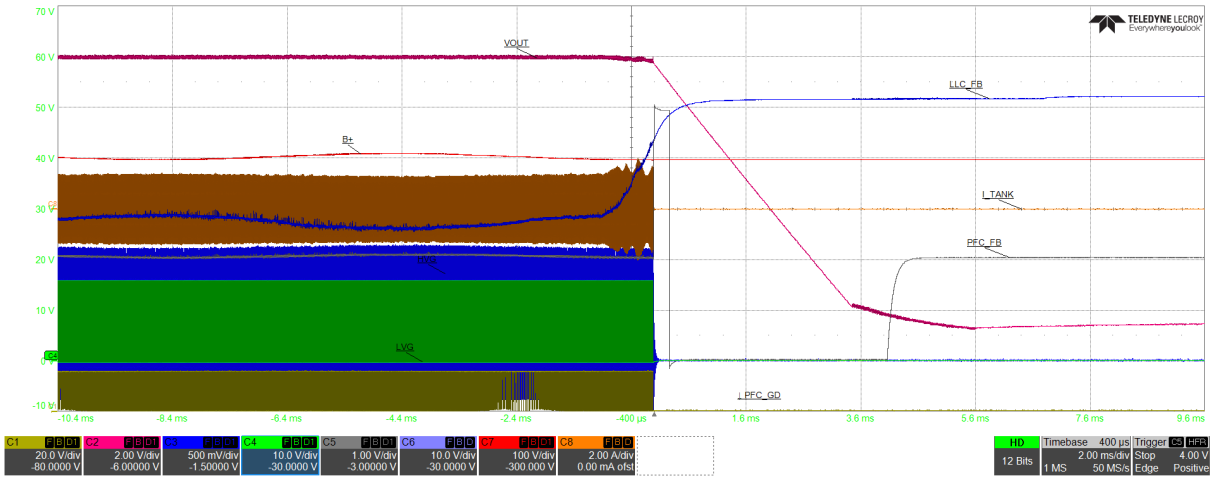


CH1 = PFC_GD; CH2 = VOUT; CH3 = LLC_FB; CH4 = LVG; CH5 = HB; CH6 = HVG; CH7 = B+; CH8 = I_TANK

2.10.6 LLC OLP frequency-based management

The LLC OLP frequency-based management allows the system to source an output current higher than the nominal one, for a maximum number of occurrences defined by the “Maximum OLP occurrences” parameter. Figure 37 shows the behavior of the converter in case of a load transition from 12.5 A to 16 A.

Figure 37. LLC overload protection, frequency-based management.

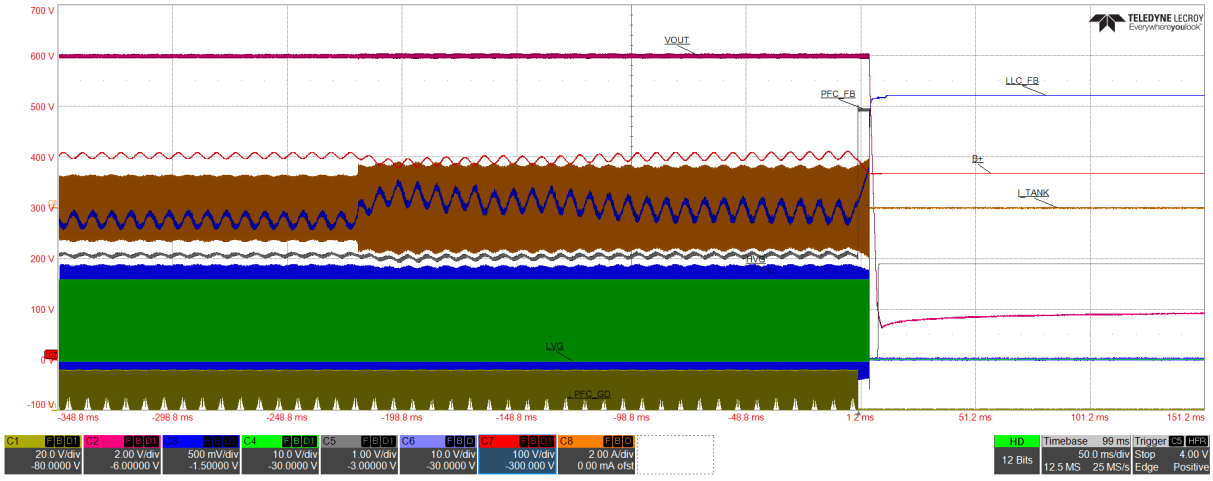


CH1 = PFC_GD; CH2 = VOUT; CH3 = LLC_FB; CH4 = LVG; CH5 = PFC_FB; CH6 = HVG; CH7 = B+; CH8 = I_TANK

2.10.7 LLC OLP time-based management

The LLC OLP time-based management allows the system to source an output current higher than the nominal one, for a maximum allowed time defined by the “LLC OLP timeout” parameter. Figure 38 shows the behavior of the converter in case of a load transition from 12.5 A to 16 A.

Figure 38. LLC overload protection, time-based management

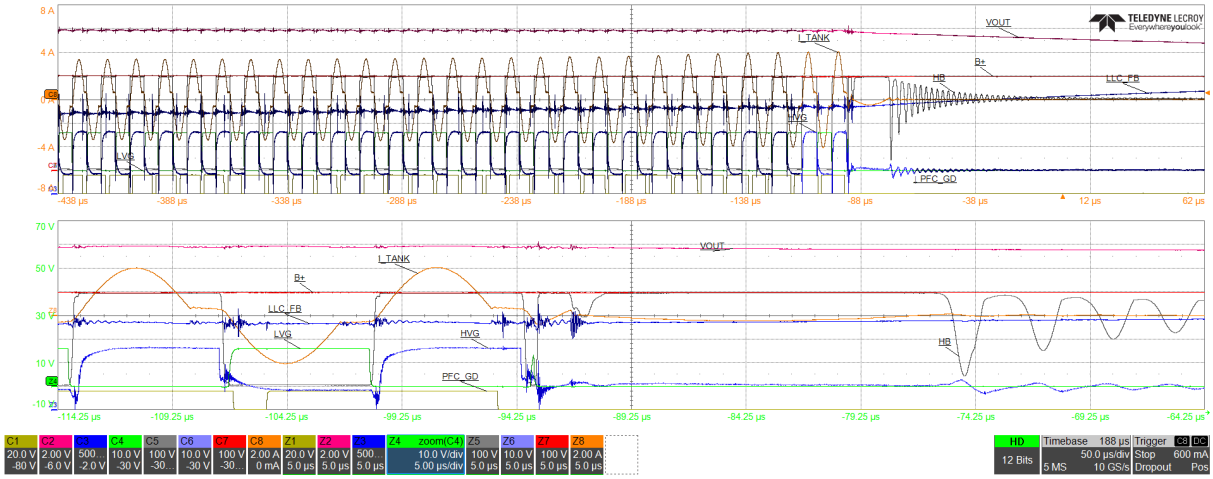


CH1 = PFC_GD; CH2 = VOUT; CH3 = LLC_FB; CH4 = LVG; CH5 = PFC_FB; CH6 = HVG; CH7 = B+; CH8 = I_TANK

2.10.8 LLC OCP2

The LLC OCP2 fault is generated when the LLC OC2 comparator is triggered for a maximum number of times defined by the “Max number of LLC OC2” parameter. This could happen in case of a sudden output short-circuit, as shown in Figure 39. The soft ACP functionality avoids also reaching capacitive region.

Figure 39. **LLC_CS hit the LLC OC2 comparator during output short at full load**



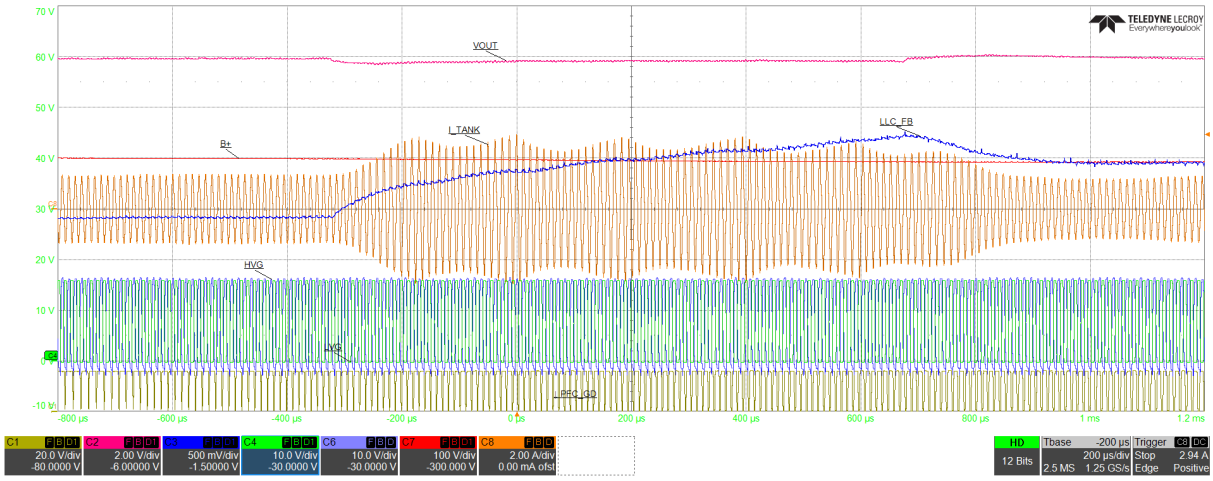
CH1 = PFC_GD; CH2 = VOUT; CH3 = LLC_FB; CH4 = LVG; CH5 = HB; CH6 = HVG; CH7 = B+; CH8 = I_TANK

2.10.9 LLC ACP

The LLC ACP feature avoids that the resonant converter works in the capacitive region, losing the soft switching capability. The soft ACP feature intervenes in case the resonant tank is approaching the capacitive region, as shown in Figure 40 in case of a heavy load transient from 12.5 A to 22 A for 1 ms. The feature immediately decreases the time shift value, in order to move aside the capacitive region.

The hard ACP feature intervenes in case the system reaches the capacitive mode, where the resonant tank current changes its sign during deadtime or during the half-bridge MOSFET turn-on instant. Usually, the soft ACP feature avoids entering the capacitive region and loosing ZVS operation, triggering the hard ACP.

Figure 40. **LLC soft ACP intervention during heavy load transient**

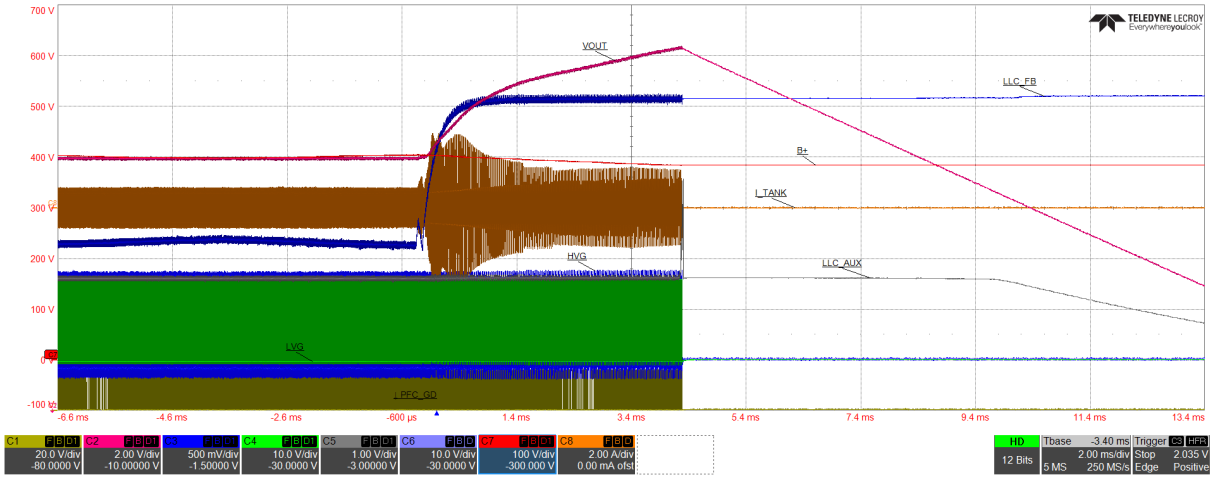


CH1 = PFC_GD; CH2 = VOUT; CH3 = LLC_FB; CH4 = LVG; CH6 = HVG; CH7 = B+; CH8 = I_TANK

2.10.10 LLC OVP

The LLC OVP function is active on the LLC_AUX pin: if the voltage on the auxiliary winding of the LLC resonant transformer is sensed higher than the OVP threshold, the LLC_AUX pin is brought up to Vcore voltage and the LLC OVP fault is declared, as shown in Figure 41.

Figure 41. **LLC OVP simulation, shorting the diode section of the optocoupler**



CH1 = PFC_GD; CH2 = VOUT; CH3 = LLC_FB; CH4 = LVG; CH5 = LLC_AUX; CH6 = HVG; CH7 = B+; CH8 = I_TANK

3 Performance verification

The test setup was done with a Chroma AC source and a Chroma DC Electronic Load connected to the board. The tests input voltage was set to 115 Vac / 60 Hz and to 230 Vac / 50 Hz, while the output current was set to the nominal point of measurement.

3.1 Efficiency

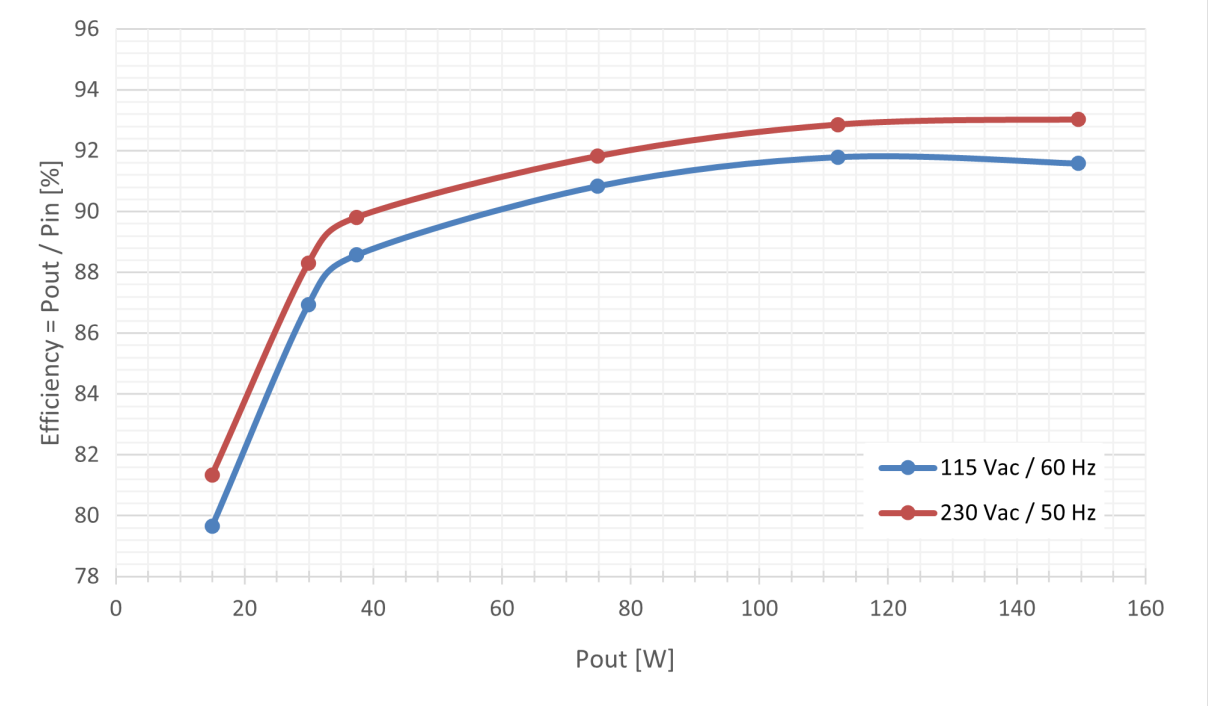
3.1.1 Overall

Table 3 and Figure 42 show the overall efficiency of the EVL011A150ADP demo board, measured at the nominal mains voltages, after a warm-up time of about ½ h at full load after which each measurement point has been kept for about ¼ h, starting from heavy loads down to light loads. Active load has been set in CC mode with output voltage sensing. The output voltage and current have been read on the active load display, while the output power has been computed as Vout * Iout. The input power has been measured through a power meter with voltage probe at the AC inlet of the converter.

Table 3. Overall efficiency

Output Load	115 Vac / 60 Hz					230 Vac / 50 Hz				
	Vout [V]	Iout [A]	Pout [W]	Pin [W]	η [%]	Vout [V]	Iout [A]	Pout [W]	Pin [W]	η [%]
10%	11.997	1.246	14.95	18.77	**79.65**	11.992	1.246	14.94	18.37	**81.34**
20%	11.985	2.496	29.91	34.41	**86.94**	11.985	2.496	29.91	33.88	**88.30**
25%	11.982	3.121	37.40	42.22	**88.57**	11.983	3.121	37.40	41.64	**89.81**
50%	11.976	6.246	74.80	82.35	**90.83**	11.978	6.246	74.81	81.48	**91.82**
75%	11.970	9.371	112.17	122.21	**91.79**	11.973	9.371	112.20	120.82	**92.86**
100%	11.967	12.495	149.53	163.27	**91.58**	11.966	12.495	149.52	160.71	**93.03**
	Average (100, 75, 50, 25 %) =				**90.69**	Average (100, 75, 50, 25 %) =				**91.88**

Figure 42. Overall efficiency vs. output load



3.1.2 Light Load

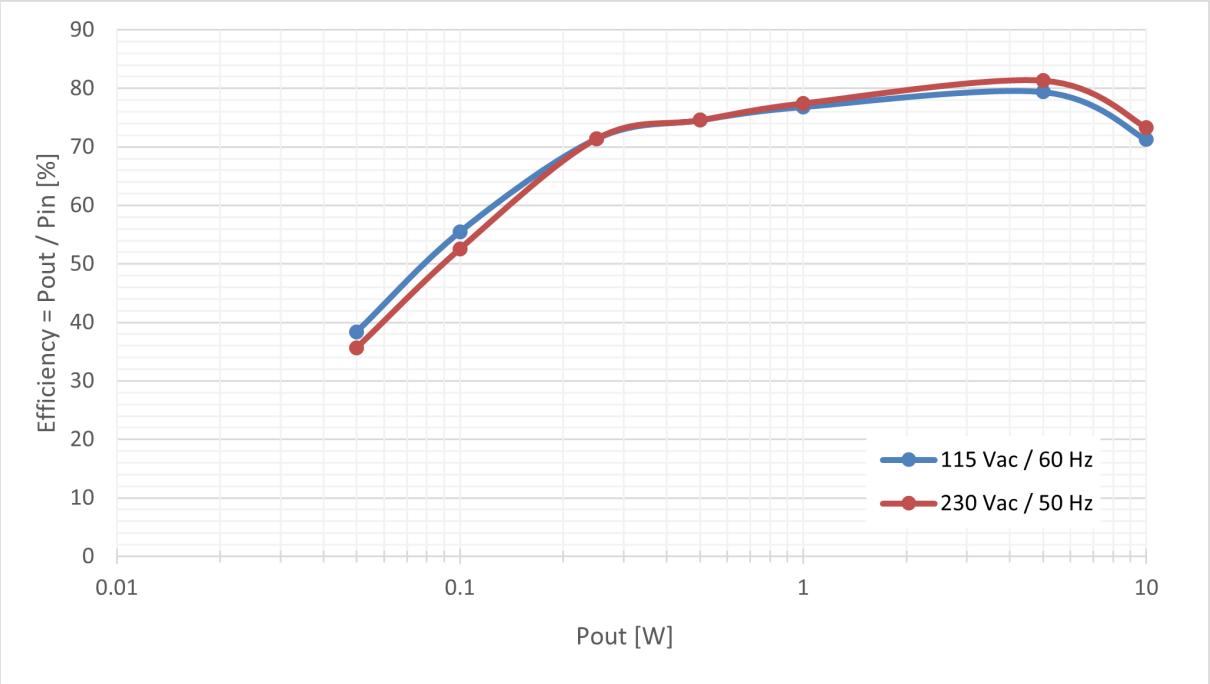
The light load measurement procedure is described hereafter, while results are shown in Table 4 and Figure 43.

1. The board under test is supplied by the AC source and it is loaded by the active load set in CC mode with output voltage sensing. Input power and voltage are measured by a power meter while the output current and voltage are read through multimeters. Output power has been computed as Vout * Iout. At light loads, the current drawn by the board under test from the AC source is irregular and its measurement is typically unstable. To overcome this issue, the active energy consumption is measured by integration in mWh, and the corresponding input power is computed as energy divided by time. For the very light loads, that is, from open load to 500 mW, integration time has been 6 minutes, while for loads between 1 W and 10 W, the integration time has been 36 s.
2. Each measurement point is kept for about 5 minutes, hence the values are taken. Loads have been applied increasing the output power from minimum to maximum. For the no load input power measurements, the only connection to the board was the input AC source.

Table 4. Light load efficiency

Output	115 Vac / 60 Hz					230 Vac / 50 Hz				
Load	Vout [V]	Iout [mA]	Pout [W]	Pin [W]	η [%]	Vout [V]	Iout [mA]	Pout [W]	Pin [W]	η [%]
0 mW	11.992	-	-	0.051	-	11.993	-	-	0.063	-
50 mW	11.995	4.16	0.05	0.13	38.38	11.997	4.16	0.05	0.14	35.65
100 mW	11.995	8.33	0.10	0.18	55.51	11.996	8.33	0.10	0.19	52.59
250 mW	11.999	20.83	0.25	0.35	71.41	12.001	20.83	0.25	0.35	71.42
500 mW	11.995	41.66	0.50	0.67	74.58	11.995	41.66	0.50	0.67	74.58
1 W	11.989	83.33	1.00	1.30	76.85	11.991	83.33	1.00	1.29	77.46
5 W	11.987	416.66	4.99	6.29	79.40	11.989	416.66	5.00	6.14	81.36
10 W	11.993	833.33	9.99	14.03	71.23	11.994	833.33	9.99	13.63	73.33

Figure 43. Light load efficiency vs. output load



3.2 Eco design requirement

The most important eco design requirements are summarized in Table 5, Table 6 and Table 7.

Table 5. ENERGY STAR® requirements for computers ver. 6.1

ENERGY STAR® for computers ver. 6.1	Test results		Limits	Status
	115Vac / 60Hz	230Vac / 50Hz		
Efficiency at 20% load	86.72%	88.07%	> 82%	PASS
Efficiency at 50% load	91.03%	92.12%	> 85%	
Efficiency at 100% load	91.54%	93.12%	> 82%	
Power factor at 100% load	0.995	0.982	> 0.9	

Table 6. EuP Lot 6 Tier 2 requirements for household and office equipment

EuP Lot 6 Tier 2	Test results		Limits	Status
	115Vac / 60Hz	230Vac / 50Hz		
Avg. Efficiency measured at 25, 50, 75, 100%	90.66%	91.94%	> 87%	PASS
Efficiency at 250mW load	66.45%	66.45%	> 50%	
Efficiency at 100mW load	57.03%	54.18%	> 33%	

Table 7. European CoC ver. 5 Tier 2 requirements for external power supplies

European CoC ver. 5 Tier-2 for Ext. Pow. Sup.	Test results		Limits	Status
	115Vac / 60Hz	230Vac / 50Hz		
Avg. Efficiency measured at 25, 50, 75, 100%	90.66%	91.94%	> 89%	PASS
Efficiency at 10% load	79.77%	81.06%	> 79%	
No Load Input Power [W]	0.051 W	0.063 W	< 0.15 W	

3.3 PFC

3.3.1 Harmonics contents measurements

The board has been tested according to the European standard EN-61000-3-2 Class-D and Japanese standard JEITA-MITI Class-D, at 230 Vac and 100 Vac / 50 Hz, both at full load and at 75 W of input power. As reported from Figure 44 to Figure 47, the circuit is able to reduce the harmonics well below the limits of both regulations. The total harmonic distortion and power factor measurements are included in the charts below. The values clearly indicate the correct functionality of the PFC in all conditions.

Figure 44. Compliance to EN-61000-3-2 at 230 Vac / 50 Hz – full load

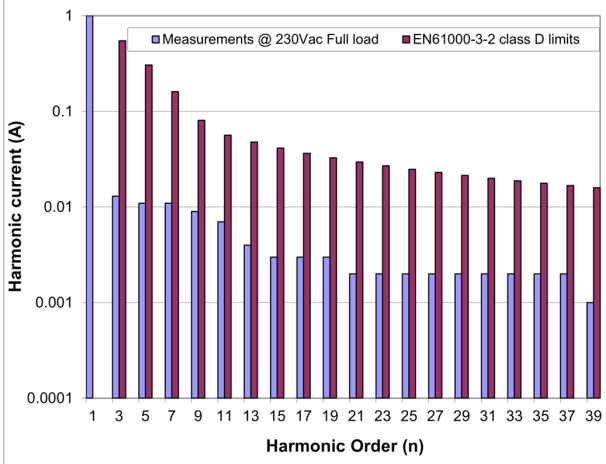


Figure 45. Compliance to JEITA-MITI at 100 Vac / 50 Hz – full load

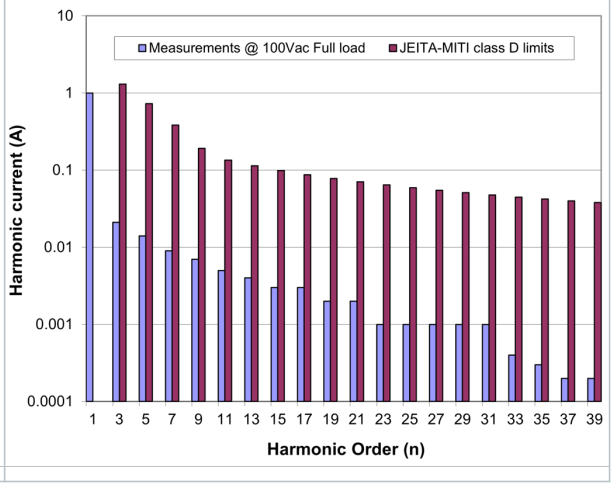


Figure 46. Compliance to EN-61000-3-2 at 230 Vac / 50 Hz – input power 75 W

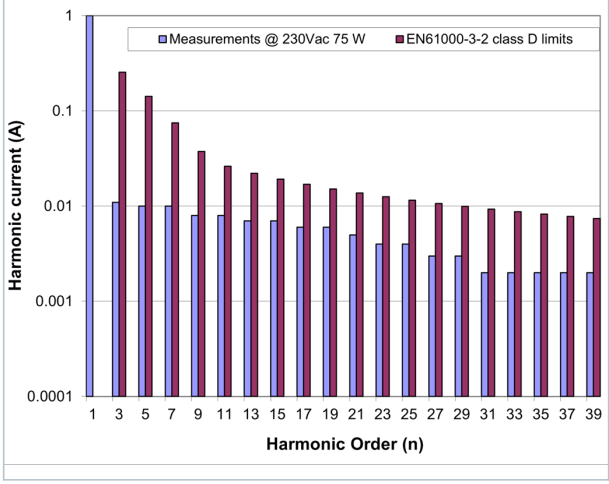
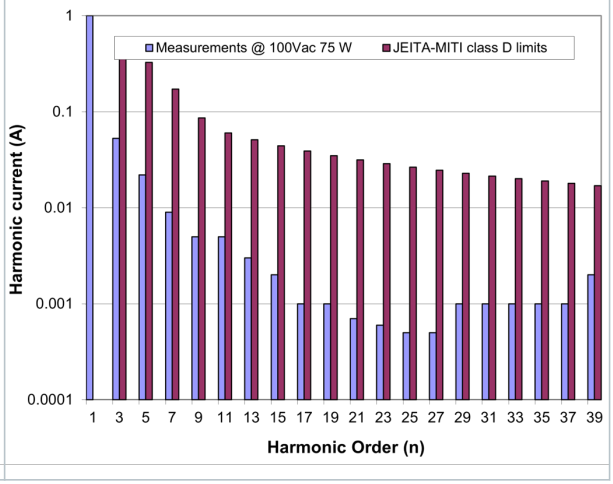


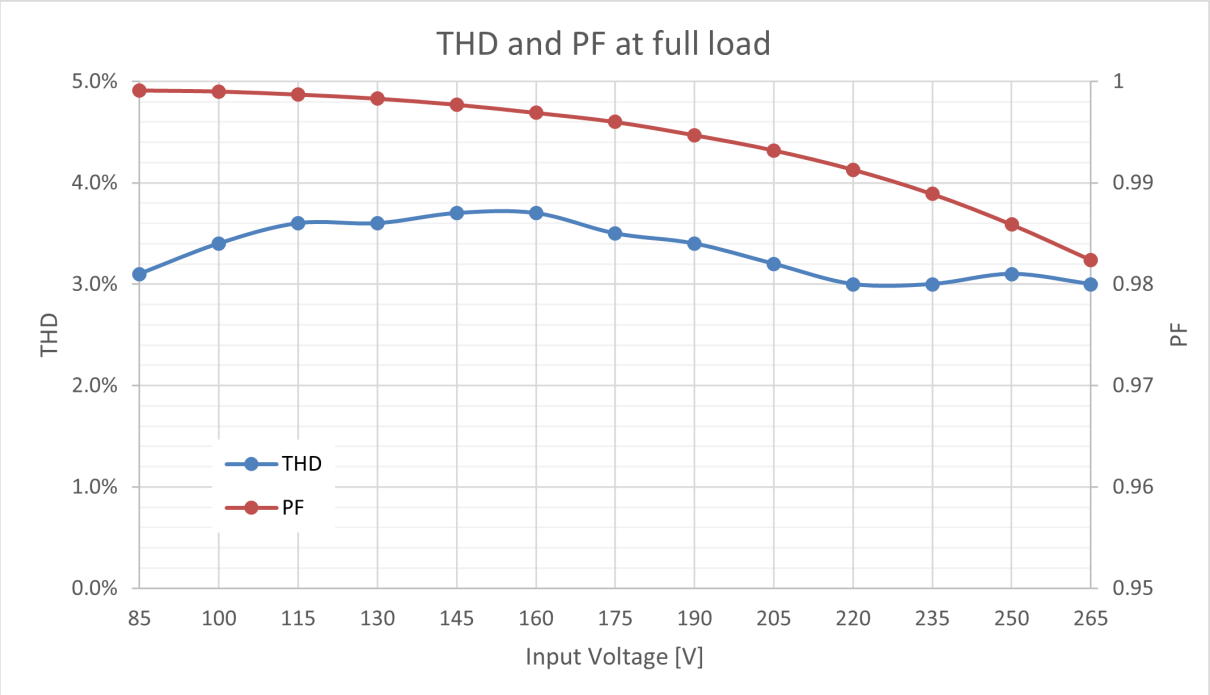
Figure 47. Compliance to JEITA-MITI at 100 Vac / 50 Hz – input power 75 W



3.3.2 Total Harmonic Distortion and Power Factor

The THD and the PF have been measured at full load varying the input voltage from 85 Vac to 265 Vac. The line frequency has been set to 50 Hz. Figure 48 shows the performance of the converter.

Figure 48. **THD and PF at full load, varying input voltage**



The THD and the PF have been measured also varying the output power from half to full load, with a fixed input voltage. These are shown in Figure 49 and Figure 50 respectively.

Figure 49. **THD vs. output power**

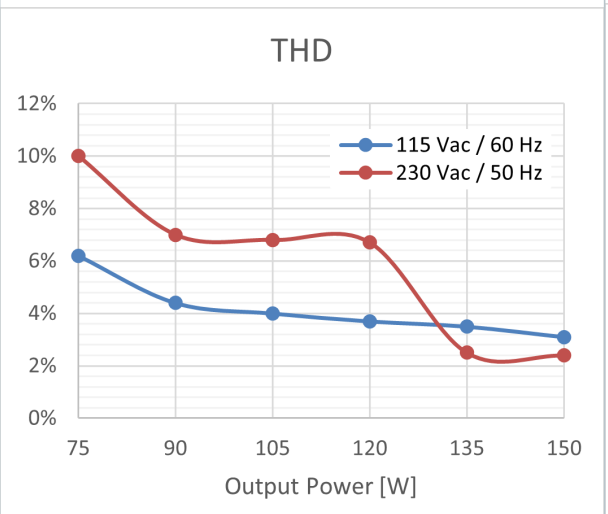
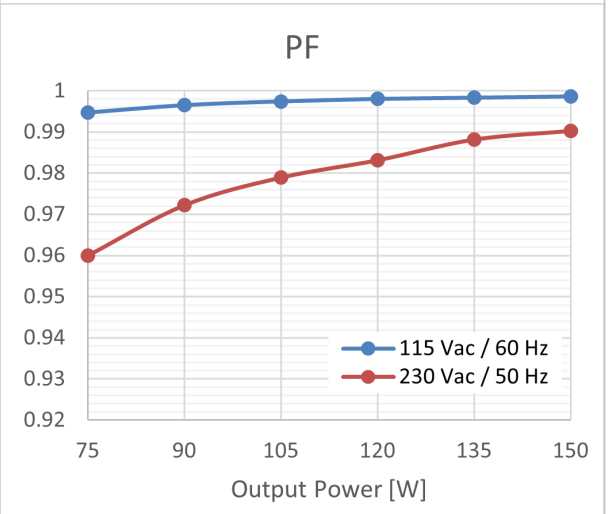


Figure 50. **PF vs. output power**



3.4 LLC

3.4.1 Output voltage regulation

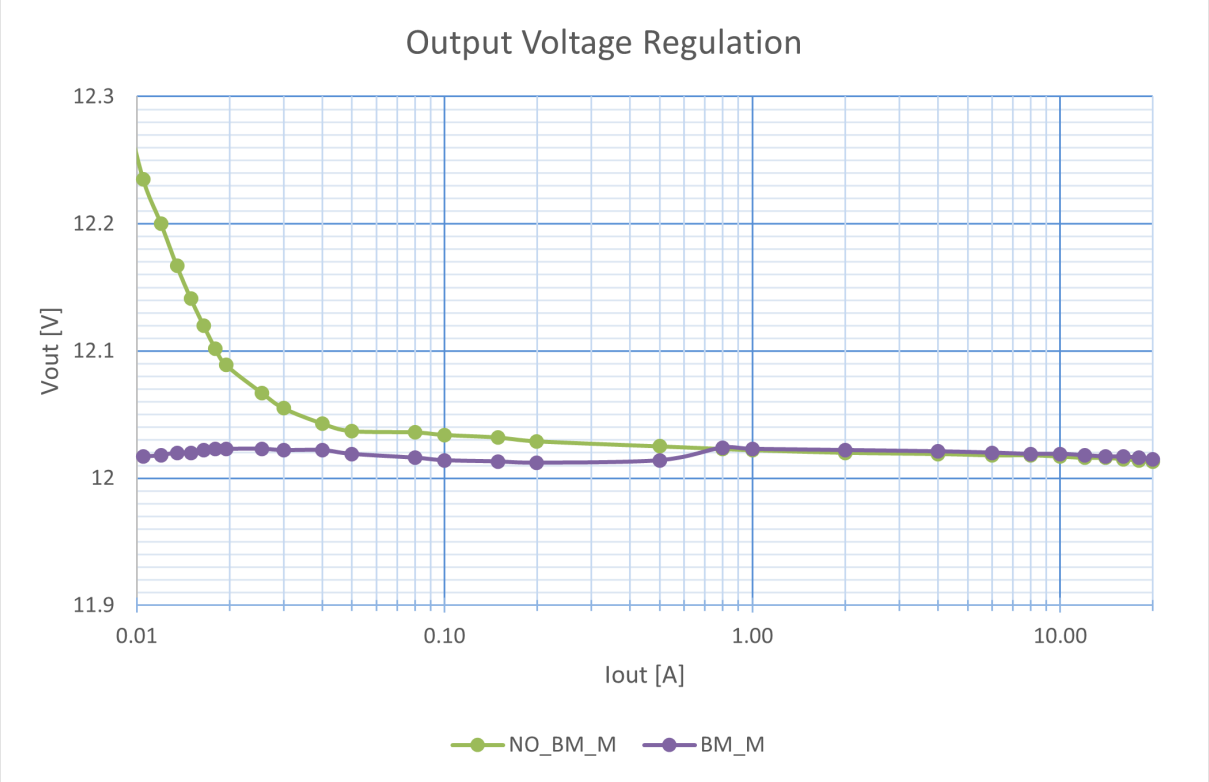
Figure 51 shows the output voltage as a function of the output current in case the burst mode is enabled (standard configuration) or in case it is disabled up to no load.

When burst mode is disabled, at very low output current (less than 30 mA), the output voltage is slightly above the set point (12 V nominal), and it increases up to 13.6 V when the load is disconnected.

On the other hand, when the burst mode is enabled, the regulation is maintained down to no load.

This behavior is due to the fact that the LLC resonant tank is not designed to work at no load, and thus, even with the minimum time shift, there is still enough energy-transfer to drive the output voltage above 12 V. Enabling the burst mode, instead, forces the system to stop and wait before restarting, until the output voltage goes below the regulation point. In this way the output voltage is always in range and the efficiency is increased. The only drawback is a higher output ripple. This strictly depends on two NVM parameters “LLC_FB burst entering thr” and “Minimum period to exit burst”, that allow to set the output-current thresholds to enter / exit the burst mode, and thus also the output voltage ripple.

Figure 51. Output voltage vs. output current



3.4.2 Transient response

The transient response is shown in the following figures. Test results are not affected by the input voltage and then, in the figures below, the AC input voltage information is not present. Also, the output current variation (dI/dt slope) is always in the order of 2.5 A/us as indicated on the Chroma menu.

Figure 52 and Figure 53 represent the most demanding situation of a load variation with 20 ms period (10 ms / 10 ms), and no load to full load swing.

Figure 54 and Figure 55 show the same load variation, but with longer periods, 200 ms and 800 ms.

Figure 56 is representative of a standby condition, where the load transition is between 0 A and 2.2 A.

Figure 57 shows a transition 0.2 A – 8.2 A with 20 ms period (10 ms / 10 ms).

Figure 58 and Figure 59 are representative of the active mode (0.2 A – 12.5 A).

Figure 52. Iout = 0.0 A -- 12.5 A, 10 ms / 10 ms

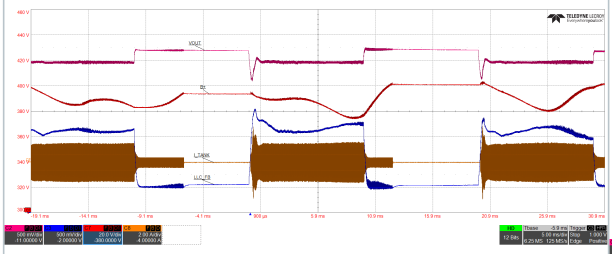


Figure 53. Iout = 0.0 A -- 12.5 A, 10 ms / 10 ms (zoom)

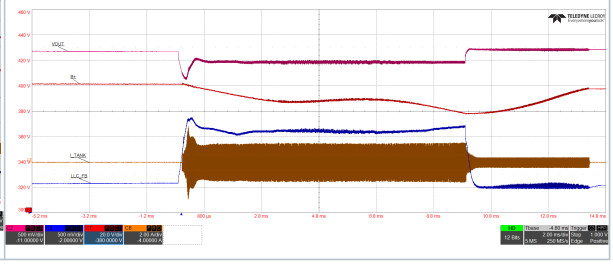


Figure 54. Iout = 0.0 A -- 12.5 A, 100 ms / 100 ms

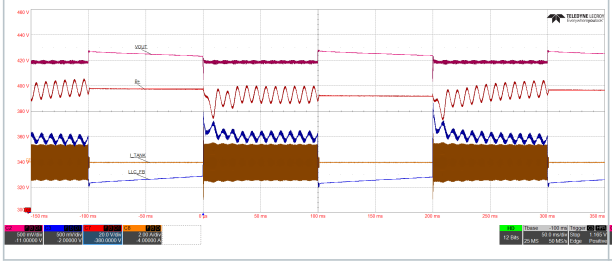


Figure 55. Iout = 0.0 A -- 12.5 A, 400 ms / 400 ms

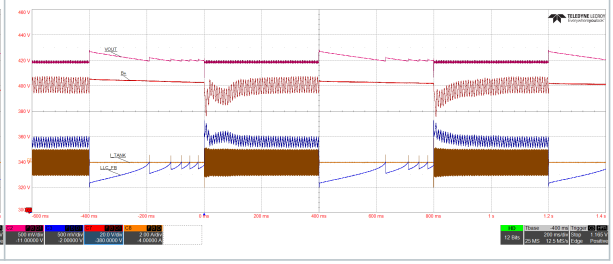


Figure 56. Iout = 0.0 A -- 2.2 A, 10 ms / 10 ms

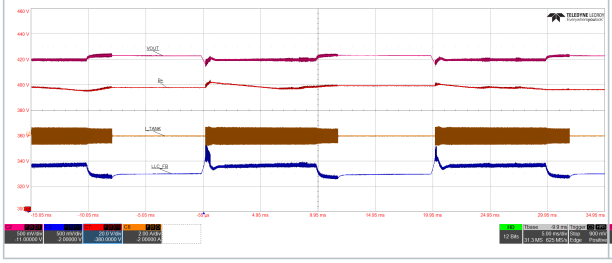


Figure 57. Iout = 0.2 A – 8.2 A, 10 ms / 10 ms

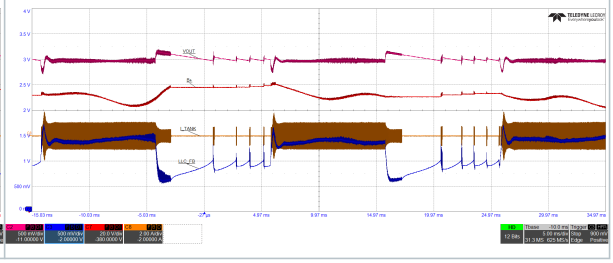


Figure 58. Iout = 0.2 A -- 12.5 A, 10 ms / 10 ms

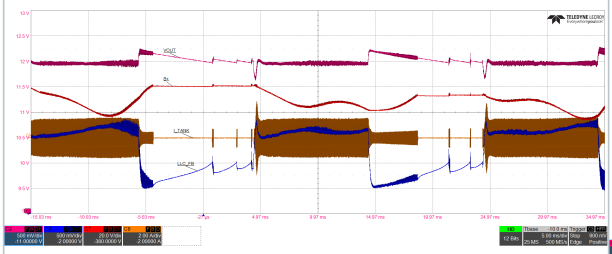
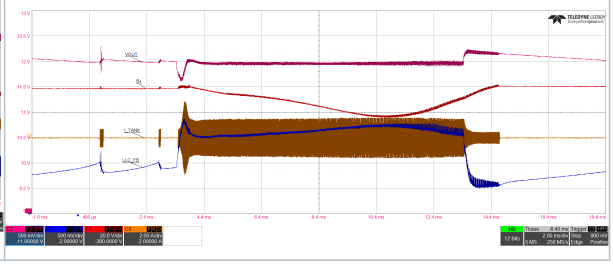


Figure 59. Iout = 0.2 A -- 12.5 A, 10 ms / 10 ms (zoom)



3.4.3 Transfer functions

A network analyzer has been used to evaluate the stability of the SMPS and its design margins.

To simplify the measurement, the resistor R18 (100 Ω) on the daughter control board has been shorted, and the injected signal was applied between this point and the output connector.

The plant transfer function was measured with a probe connected to the LLC_FB pin (J1 pin 4) and the other to the output connector J3. It is shown in Figure 60.

The controller transfer function was measured with a probe connected to R18 (shorted) and the other at the LLC_FB pin. It is shown in Figure 61.

The overall gain loop (Gloop) transfer function was measured with the probes connected at the injection points. The result is shown in Figure 62.

As can be seen, the phase margin is more than 60 degrees, and the loop gain at 100 Hz is about 36 dB, assuring a good stability as well as enough loop gain to reject the bulk voltage ripple.

Figure 60. Plant transfer function at Iout = 12.5 A

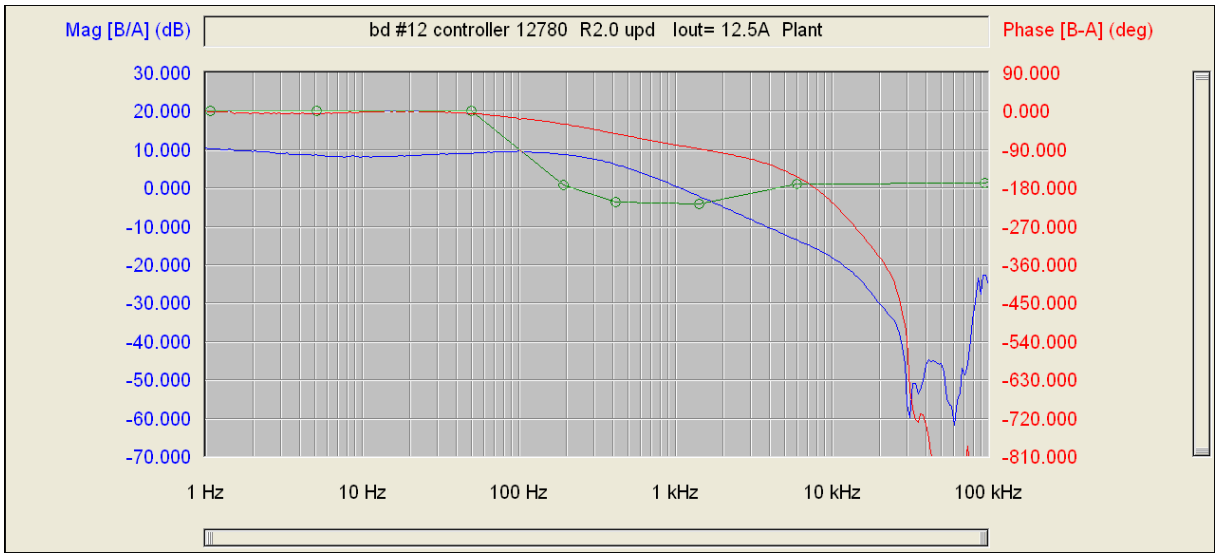


Figure 61. Controller transfer function at Iout = 12.5 A

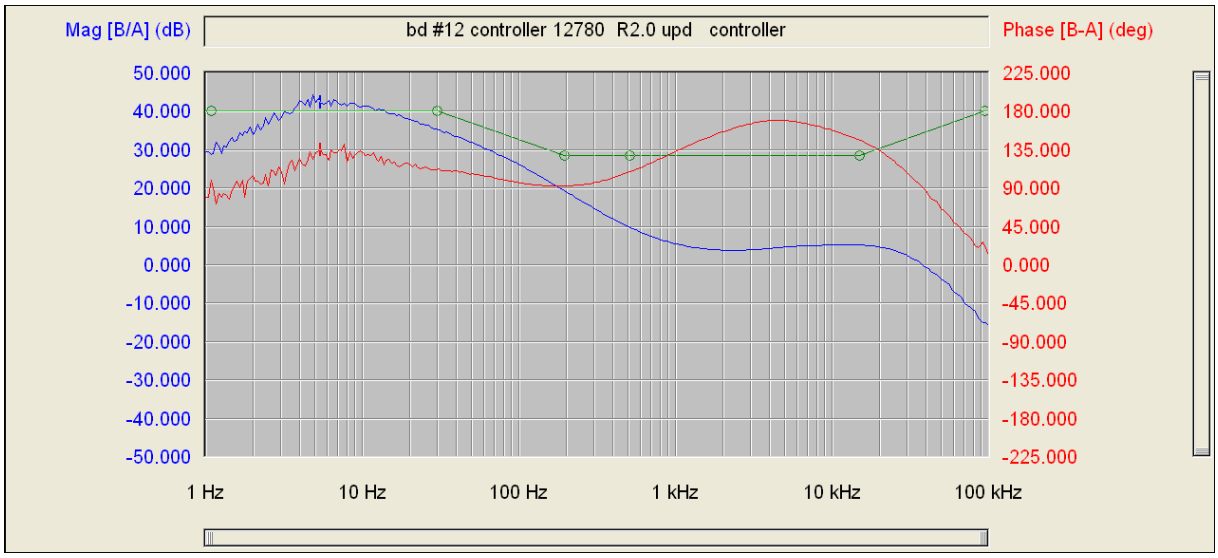
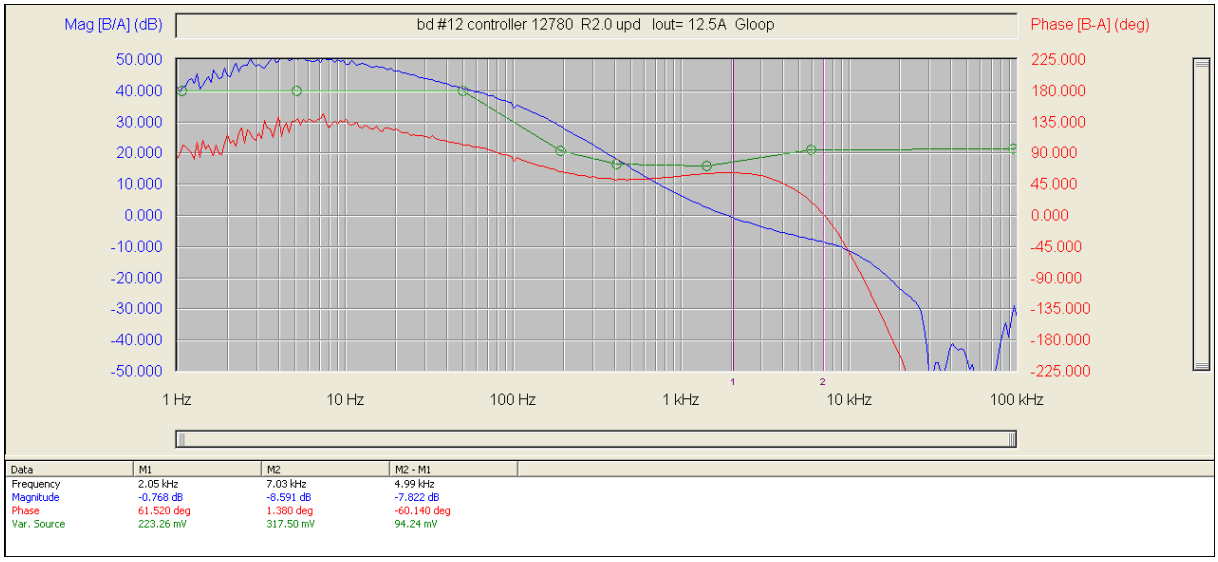


Figure 62. **Gloop transfer function at Iout = 12.5 A**



3.4.4 Output voltage ripple and noise

In order to measure the output ripple and noise, an oscilloscope has been used with the vertical channel set-up with a DC offset of about 12 V and a bandwidth of 20 MHz. A 10X probe was connected directly to the output connector of the board, with two capacitors of 10 µF and 0.1 µF in parallel, placed just at the probe tip.

The line voltage was set to 115 Vac / 60 Hz, then the tests were repeated at 230 Vac / 50 Hz. As no relevant differences appeared during the tests, only the first measurements are reported hereafter.

The table below summarizes the result of the measures of the output voltage corresponding to a load current of 12.5 A, 1.0 A, 0.4 A (out of burst mode), 0.4 A (in burst mode), 25 mA, and no-load.

The corresponding figures from Figure 63 to Figure 68 are also annexed. As can be seen, the ripple and noise values are well below the 120 mV peak-to-peak of the requirement.

Moreover, two averaged acquisitions have been taken to evaluate only the output ripple at 2*(F-line), while measuring the corresponding bulk voltage variations. These are shown in Figure 69 and Figure 70. In this way, the CMRR of the resonant converter at 2*(F-line) at a rated output current can be evaluated.

$$CMRR|_{Iout} = 20{*}Log\left(\frac{\Delta Vout}{\Delta Vbulk}\right)\Big|_{Iout}$$

$$CMRR|_{12.5\,A} = 20{*}Log\left(\frac{10.926 \cdot 10^{-3}}{11.840}\right)\Big|_{12.5\,A} = -60.70\,dB$$

$$CMRR|_{1\,A} = 20{*}Log\left(\frac{1.424 \cdot 10^{-3}}{2.528}\right)\Big|_{1\,A} = -64.99\,dB$$

Table 8. **Vout Ripple and Noise**

Iout	Vout (peak-to-peak)
12.5 A	60.62 mV
1.0 A	25.65 mV
0.4 A (not in BM)	22.37 mV
0.4 A (in BM)	68.59 mV
0.025 A	67.04 mV
0.0 A	33.01 mV

Figure 63. Vout at Iout = 12.5 A

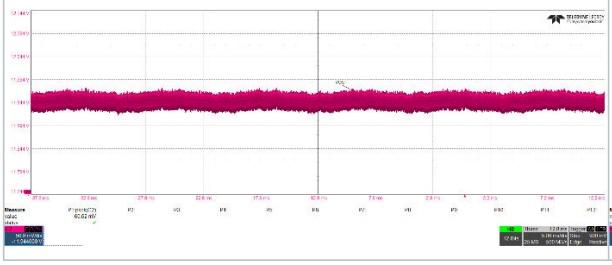


Figure 64. Vout at Iout = 1.0 A

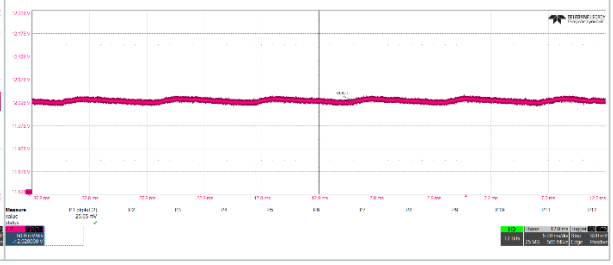


Figure 65. Vout at Iout = 0.4 A, not in burst mode

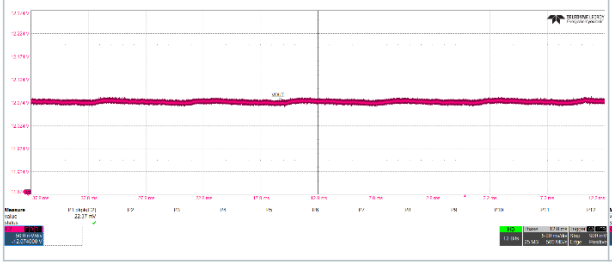


Figure 66. Vout at Iout = 0.4 A, in burst mode

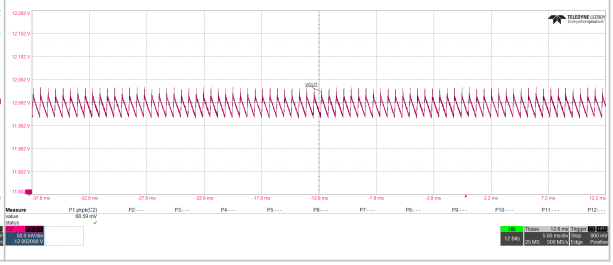


Figure 67. Vout at Iout = 0.025 A

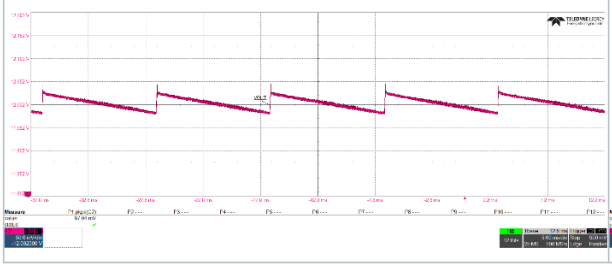


Figure 68. Vout at Iout = 0.0 A, no load

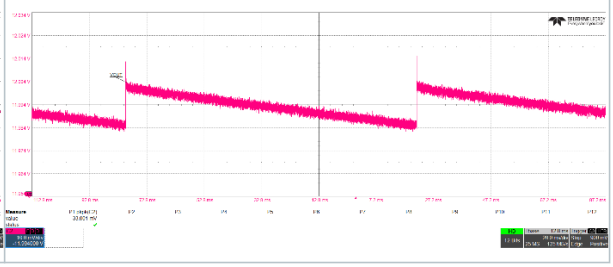


Figure 69. Vout at Iout = 12.5 A (averaged)

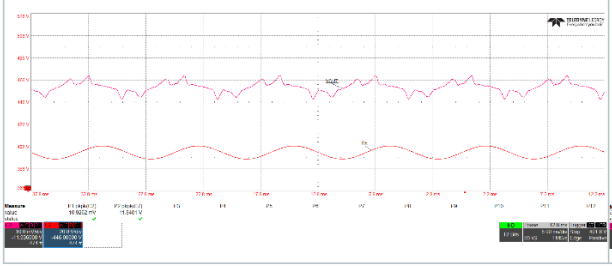
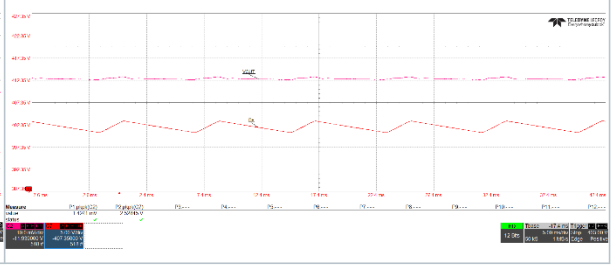


Figure 70. Vout at Iout = 1.0 A (averaged)



4 Thermal map

Thermal mapping with an IR image sensor was performed to verify the design reliability. Figure 71 and Figure 72 below show the thermal measurements of the component side of the board at nominal input voltages. Key components or components showing higher temperatures are highlighted. The ambient temperature during measurement is 26 °C. Table 9 summarizes all the values.

Figure 71. Thermal map at 115 Vac / 60 Hz – full load

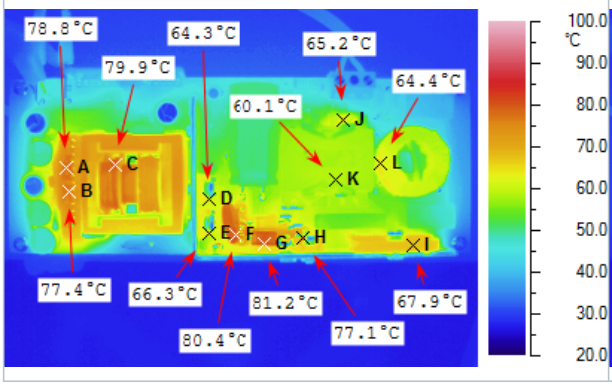


Figure 72. Thermal map at 230 Vac / 50 Hz – full load

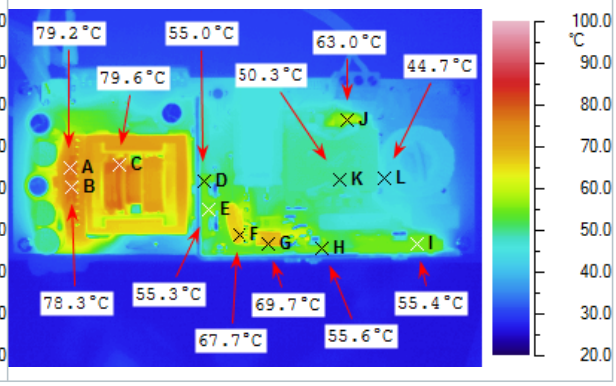


Table 9. Thermal maps reference points

Point	Reference	Description	Temp at 115 Vac / 60 Hz	Temp at 230 Vac / 50 Hz
A	Q502	SR MOSFET	78.8 °C	79.2 °C
B	Q501	SR MOSFET	77.4 °C	78.3 °C
C	T1	Resonant power transformer	79.9 °C	79.6 °C
D	Q4	Resonant low-side MOSFET	64.3 °C	55 °C
E	Q3	Resonant high-side MOSFET	66.3 °C	55.3 °C
F	R4	Inrush limiting NTC resistor	80.4 °C	67.7 °C
G	D3	PFC output diode	81.2 °C	69.7 °C
H	Q1	PFC MOSFET	77.1 °C	55.6 °C
I	D2	Bridge rectifier	67.9 °C	55.4 °C
J	R9	Charge pump limiting resistor	65.2 °C	63 °C
K	L2	PFC inductor	60.1 °C	50.3 °C
L	L1	EMI filtering inductor	64.4 °C	44.7 °C

5 Conducted emission pre-compliance test

Figure 73 and Figure 74 are the average measurements of the conducted emission noise at full load and nominal mains voltages. The limits shown in the diagrams are EN55022 Class-B, which is the most popular standard for domestic equipment and has more severe limits compared to Class-A, dedicated to IT technology equipment. The EN55022 Class-B limit relevant to average measurements is indicated in red on the diagrams. In all test conditions the measurements are significantly below the limits.

Figure 73. CE average measurement at 115 V - 60 Hz and full load - phase wire

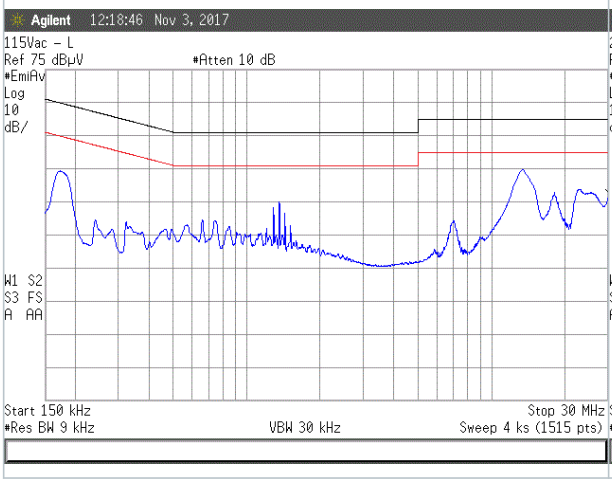
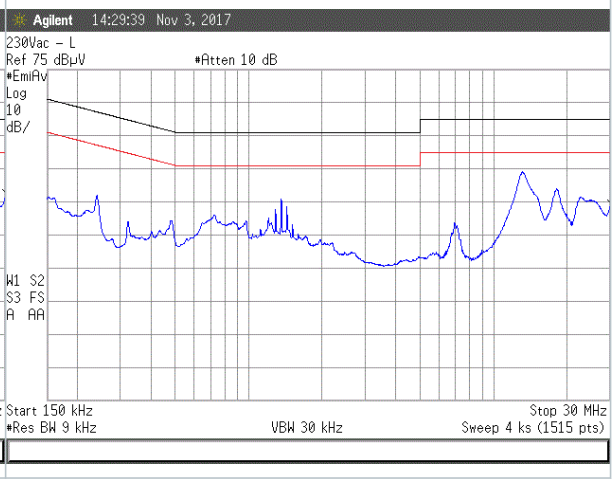


Figure 74. CE average measurement at 230 V - 50 Hz and full load - phase wire



Appendix A NVM parameters configuration

Table 10. **NVM parameters**

Item	Name	Raw	Value
0	Shutdown feature	0x00	0 = Disabled
1	Patch upload from EEPROM	0x01	1 = Enabled
2	ATE mode	0x00	0 = Enabled
3	System monitoring	0x00	0 = Enabled
4	VAC reading improvement	0x01	1 = Enabled
5	Early warning feature	0x00	0 = Enabled
6	EW signal in burst mode	0x01	1 = Quick
7	Non latched faults timer	0x03	3 = 4.37s
8	Surge detection	0x01	1 = Enabled
9	PFC OC2 detection	0x01	1 = Enabled
10	Max. number of PFC OC2	0x02	2 = 4
11	PFC HW OVP detection	0x01	1 = Enabled
12	LLC OC2 detection	0x01	1 = Enabled
13	Max. number of LLC OC2	0x02	2 = 4
14	LLC OVP detection	0x01	1 = Enabled
15	Disconnection faults detection	0x01	1 = Enabled
16	PFC OC2 behavior	0x01	1 = Latched
17	PFC HW OVP behavior	0x01	1 = Latched
18	PFC UVP behavior	0x01	1 = Adaptive
19	LLC SS timeout behavior	0x01	1 = Latched
20	LLC ACP behavior	0x00	0 = Not Latched
21	LLC OC2 behavior	0x01	1 = Latched
22	LLC OLP behavior	0x00	0 = Not Latched
23	LLC OVP behavior	0x01	1 = Latched
24	PFC Ki	0x02	8
25	PFC Kp	0x04	32
26	PFC MOSFET LEB	0x04	16 = 267ns
27	PFC THD improver base	0x05	5 = 10mV
28	PFC THD improver gain	0x00	0 = gain disabled
29	PFC maximum power	0x09	9216
30	PFC pss	0x03	2560
31	PFC pcc	0x03	10238
32	PFC min. pin Vskip	0x0E	2176
33	PFC max. pin Vskip (delta)	0x0A	2560
34	PFC delta pin Vskip	0x0C	352
35	PFC maximum DCM power	0x0C	3072
36	PFC min. Tsw Vskip	0x0C	448 = 134kHz
37	PFC max. Tsw Vskip	0x03	688 = 87kHz

Item	Name	Raw	Value
38	Skipping area threshold	0x0A	1536
39	PFC Vout target	0x05	80 = 2.063V - 400V
40	PFC Vout SS end (delta)	0x00	8 = 19.5mV - 3.8V
41	PFC UVP threshold (delta)	0x01	32 = 0.234V - 45V
42	PFC SW OVP threshold (delta)	0x02	2 = 105mV - 20V
43	Soft ACP feature	0x00	0 = Enabled
44	LLC HVG first Ton	0x04	24 = 400ns
45	LLC LVG first TS	0x07	30 = 400ns
46	LLC deadtime	0x02	24 = 400ns
47	LLC soft-start speed	0x01	2 = 16.7n
48	Minimum time shift	0x0F	60 = 625ns
49	Maximum time shift	0x0F	480 = 7.96us
50	LLC OLP threshold	0x09	19 = 309.55mV
51	LLC OLP timeout	0x01	1 = 200ms
52	Maximum OLP occurrences	0x00	0 = 8
53	LLC OLP management	0x00	0 = OLP time based management
54	ACP sensitivity	0x01	1 = High (= 150ns delay)
55	Hard ACP detection	0x01	1 = Enabled
56	Soft ACP entering threshold	0x02	14 = 233ns
57	Soft ACP TS decrement	0x05	5 = 400ns
58	Maximum soft ACP occurrences	0x00	0 = 33
59	External burst mode	0x00	0 = Disabled
60	BM enter for minimum TS	0x01	1 = Enabled
61	Burst entering digital filtering	0x03	18 = 990 us
62	LLC_FB burst entering thr	0x2E	294 = 717.8mV - 1883ns
63	LLC_FB burst wake-up thr	0x01	1 = 1.0V - 2.85us
64	LLC_FB burst wake-up hyst	0x01	1 = 10mV
65	Min. TS in burst mode	0x13	19 = 3.53us
66	Min. number of burst pulses	0x02	4
67	Max. number of burst pulses (delta)	0x02	2
68	Min. time between burst seq	0x01	128 = 10.2ms
69	Max. time between burst seq (delta)	0x01	64 = 4.97ms
70	Minimum period to exit burst	0x09	9 = 367us
71	No-burst window width	0x01	1 = 7.5ms
72	Surge comp digital filtering	0x01	30 = 500ns
73	PFC CS comp digital filtering	0x03	3 = 50ns
74	PFC OC2 comp digital filtering	0x03	24 = 400ns
75	PFC OC1 comp digital filtering (delta)	0x00	2 = +33.3ns
76	PFC ZCD comp digital filtering	0x00	2 = 33.3ns
77	PFC ZCD comp falling thr	0x00	0 = 0mV
78	PFC ZCD comp rising thr	0x01	1 = 110mV (N/A with TH_F[3] = 200mV)

Item	Name	Raw	Value
79	PFC HW OVP comp digital filtering	0x00	255 = 4.25us
80	LLC OLP comp digital filtering	0x01	1 = 16.7ns
81	LLC OC2 comp digital filtering	0x03	14 = 233.3nsec
82	LLC ZCD comp digital filtering	0x03	15 = 250ns
83	LLC OVP comp digital filtering	0x00	255 = 4.25us

Appendix B Bill of materials

Table 11. **EVL011A150ADP motherboard bill of materials**

Reference	Part number / part value	Description	Supplier	Case
C1, C5, C7, C10	2N2	Ceramic Y1 capacitor - 250Vac	Murata	p10mm
C2, C6, C23	100nF	SMD ceramic capacitor X7R	AVX	0805
C3, C4	470nF	Polypropylene X2 capacitor - 275Vac	EPCOS	9.0 × 18.0 p15mm
C8	470nF	Polypropylene Film Cap. - 630Vdc	EPCOS	Plastic radial
C9	100uF	Electrolytic capacitor TXW - 450V	Rubycon	DIA 18 x 32 mm
C11	10nF	SMD ceramic capacitor X7R - 100V	AVX	1206
C12	2.2uF	SMD ceramic capacitor X7R	AVX	1206
C13	10uF	Electrolytic capacitor YXF	Rubycon	DIA 5.0 x 11 mm p2mm
C14	180uF	Electrolytic capacitor ZLH - 63V	Rubycon	DIA10 x 20 mm p5mm
C15	N.M.	SMD ceramic capacitor		1206
C16	100nF	SMD ceramic capacitor X7R	AVX	1206
C17	1uF	SMD ceramic capacitor X7R	AVX	1206
C18, C19, C21	470uF	Aluminum polymer capacitor	Panasonic	DIA 10 x 13 mm p5mm
C20, C22	2.2mF	Elect Cap.	RUBYCON	Radial
C24	1uF	SMD ceramic capacitor X7R	AVX	0805
C25	330pF	Ceramic capacitor - 1kV	MURATA	1206
C26	22nF	Film capacitor - 1kV	EPCOS / TDK	CKR05
C27	N.M.	SMD ceramic capacitor X7R	AVX	0805
C28	1nF	SMD ceramic capacitor X7R	AVX	0805
C29	2.2nF	SMD ceramic capacitor X7R	AVX	0805
C30	150pF	SMD ceramic capacitor X7R	AVX	0805
C31	220pF	SMD ceramic capacitor X7R	AVX	0805
C32	100pF	SMD ceramic capacitor X7R	AVX	0805
C33 on R53	27pF	SMD ceramic capacitor X7R	AVX	0805
C34 on R56	220pF	SMD ceramic capacitor X7R	AVX	0805
D1	1N5406	General purpose rectifier	Vishay	DO-201
D2	D15XB60H	Bridge rectifier	Shindengen	5S
D3	STTH5L06	Ultrafast diode	STMicroelectronics	DO-201
D4, D5	S1J	Diode	Vishay	DO214AC-SMA
D6, D7, D8, D13, D14	1N4148W	SMD diode	Vishay	SOD123
D9, D10	BAV23S	Switching rectifier	Diodes Inc.	SOT23
D11	BZT52C16	SMD Zener diode	Diodes Inc.	SOD123
D12	STTH1R06A	Ultrafast rectifier	STMicroelectronics	DO214AC-SMA
D15	BAT48J	SMD Schottky diode SOD-323	STMicroelectronics	SOD323

Reference	Part number / part value	Description	Supplier	Case
D16	1N4148W-7-F	Fast switching rectifier	Diodes Inc.	SOD123
F1	T 4A	PCB fuse 4A time lag	Littelfuse	TE5
HS1	HEAT-SINK	HEAT SINK FOR D2, Q1, Q3, Q4		DWG
JPX1, JPX2	SHORTED	WIRE JUMPER		DWG
JP1	STRIP1X36PF	FEMALE HEADER 13 pin		p2.54mm
JP2	STRIP1X36PF	FEMALE HEADER 15 pin – pin 6,7,8 removed		p2.54mm
J1	MKDS 1,5/ 3-5,08	AC socket	Phoenix Contact	3P - p5mm
J2	MOLEX 90325-0006	Molex PicoFlex connector 6P 1,27mm pitch	MOLEX	1.27mm pitch
J3	FASTBFH/A1/6,3	Faston .250 TAB PCB	KEYSTONE	DWG
J4	FASTBFH/A1/6,3	Faston .250 TAB PCB	KEYSTONE	DWG
L1	2x28mH	Input EMI filter	Magnetica	DWG
L2	240uH 2.65A	PFC INDUCTOR - add Kapton to isolate inductor from PCB	Magnetica	DWG
Q1	STF24N60M2	Power MOSFET	STMicroelectronics	TO220-FP
Q2, Q5, Q6	MMBT2222A	SMD NPN transistor		SOT23
Q3, Q4	STF13N60M2	Power MOSFET	STMicroelectronics	TO220-FP
Q7	BC857C	Trans. PNP General Purpose	NXP	SOT23
RV1	S14K300	Metal oxide varistor	EPCOS	DIA.15x5 mm p7.5mm
R1, R2, R3, R5, R6, R7, R11, R16	0R0	SMD resistor	Vishay	0805
R4	NTC 2R5-S237	NTC resistor S237	EPCOS	DWG
R8, R49	1.5K	SMD resistor	Vishay	0805
R9	100R	SMD resistor 1/2W	Vishay	1206
R10, R13, R14	3M	SMD resistor	Vishay	1206
R12	47R	SMD resistor	Vishay	0805
R15, R24	N.M.	SMD resistor	Vishay	0805
R17	0R	SMD resistor	TTI	0805
R18, R32, R36	10R	SMD resistor	Vishay	0805
R19	1R0	SMD resistor	Vishay	1206
R20, R31, R61	10R	SMD resistor	Vishay	1206
R21, R62	22R	SMD resistor	Vishay	0805
R22, R34, R38, R50, R51	100K	SMD resistor	Multi-Comp	0805
R23	1K	SMD resistor	Vishay	0805
R25	470R	SMD resistor	Vishay	0805
R26, R27	0R18	SMD resistor	YAGEO (PHYCOMP)	2512
R28, R42	56K	SMD resistor	Multi-Comp	0805
R29	330K	SMD resistor	Multi-Comp	0805
R30, R55	22K	SMD resistor	Vishay	0805
R33, R37	56R	SMD resistor	Vishay	0805

Reference	Part number / part value	Description	Supplier	Case
R35	0R002	SMD resistor	YAGEO	2512
R39	220R	SMD resistor	Vishay	1206
R40	15R	SMD resistor	Vishay	0805
R41	12R	SMD resistor	Multi-Comp	0805
R44	62K	SMD resistor	Multi-Comp	0805
R45	5K1	SMD resistor	Multi-Comp	0805
R46, R47	330K	SMD resistor		1206
R48	N.M.	SMD resistor	Vishay	0805
R52	15K	SMD resistor	Multi-Comp	0805
R53, R54, R60	220K	SMD resistor	Multicomp	0805
R56	47K	SMD resistor	Multi-Comp	0805
R57, R58, R59	750K	SMD resistor	Multi-Comp	0805
TP1, TP2, TP3	TEST POINT	Testpoint		
T1	1860.0164	LLC transformer	Magnetica	ETD34
U1	M24C32	32-Kbit I²C 1MHz EEPROM	STMicroelectronics	SO-8
U2	STNRG011A	Digital combo controller	STMicroelectronics	SO-20

Table 12. EVL011A150ADP daughter (control) board bill of materials

Reference	Part number / part value	Description	Supplier	Case
C1, C6	100nF	SMD ceramic capacitor X7R	SCI	0603
C2	47pF	SMD ceramic capacitor C0G/NP0	SCI	0603
C3, C10	270pF	SMD ceramic capacitor X7R	SCI	0603
C4, C15	1nF	SMD ceramic capacitor X7R	SCI	0603
C5	22nF	SMD ceramic capacitor X7R	SCI	0603
C7, C11, C13	N.M.	SMD ceramic capacitor		0805
C8	390pF	SMD ceramic capacitor C0G/NP0	SCI	0603
C9	5.6nF	SMD ceramic capacitor C0G/NP0	SCI	0805
C12	100pF	SMD ceramic capacitor C0G/NP0	SCI	0603
C14	N.M.	SMD ceramic capacitor	SCI	0603
D1, D3	MMSD4148T1G	Switching rectifier	SCI	SOD123
D2	BAT43WS	Schottky rectifier	SCI	SOD323
ISO1, ISO2	SFH617A-2	Optocoupler	Vishay	DIP4
J1	MALE HEADER 15 R/A	Strip Male 15 Pin, 90° - pin 6,7,8,9,10 removed	SCI	p2.54mm
Q1	BC857C	Trans. PNP General Purpose	SCI	SOT23
R1	27K	SMD resistor	SCI	0805
R2	1K	SMD resistor	SCI	0805
R3, R18	100R	SMD resistor	SCI	0603
R4, R7	10K	SMD resistor	SCI	0603
R5	43K	SMD resistor		0603
R6	2K7	SMD resistor	SCI	0805

Reference	Part number / part value	Description	Supplier	Case
R8, R14	47K	SMD resistor	SCI	0603
R9, R19, R25, R26	N.M.	SMD resistor		0805
R10	33K	SMD resistor	SCI	0805
R11	510K	SMD resistor	SCI	0805
R12	N.M.	SMD resistor		0603
R13	2K	SMD resistor	SCI	0603
R15, R16, R21	10R	SMD resistor	SCI	0603
R17	8K2	SMD resistor	SCI	0603
R20	24K	SMD resistor	SCI	0805
R22	91K	SMD resistor	SCI	0603
R23	5K1	SMD resistor	SCI	0603
R24, R28	150K	SMD resistor	SCI	0603
R27	180K	SMD resistor	SCI	0805
R29	33K	SMD resistor	SCI	0603
R30	0R	SMD resistor	SCI	0603
R31	N.M.	SMD resistor		0603
R32	1K	SMD resistor	SCI	0603
R34	1M	SMD resistor	SCI	0603
R35	27R	SMD resistor	SCI	0603
U1	TSC101_C	High-side current sense amplifier	STMicroelectronics	SOT23-5
U2	TSM1014A	Voltage and current controller	STMicroelectronics	SO-8
U3	TS432AILT	Vol. Reg.	STMicroelectronics	SOT23
U4	BCM61B	Bipolar rectifier	SCI	SOT143-B

Table 13. EVL011A150ADP synchronous rectifier (SRK) board bill of materials

Reference	Part number / part value	Description	Supplier	Case
C501	1uF	SMD ceramic capacitor X7R	SCI	0805
C502	N.M.	SMD ceramic capacitor X7R		0805
C503, C504	N.M.	SMD ceramic capacitor X7R		0805
D501, D502	N.M.	SMD TRANSIL		0805
JP501	STRIP36PMDD90	Strip Male 13 Pin, 90°	SCI	p2.54mm
Q501, Q502	STL140N6F7	Power MOSFET	STMicroelectronics	PoweFLAT 5x6
Q503	N.M.	SMD NPN transistor		SOT-23
Q504, Q505	N.M.	Power MOSFET		PoweFLAT 5x6
R501, R506, R507	0R	SMD resistor	SCI	0805
R504, R505	100R	SMD resistor	SCI	0805
R508, R509	N.M.	SMD resistor		0805
R502	N.M.	SMD resistor		0805
R503	N.M.	SMD resistor		0805
R510, R511, R512, R513	N.M.	SMD resistor		0805
U501	SRK2001	SR controller	STMicroelectronics	SSOP10

Appendix C Magnetics specifications

C.1 PFC coil specifications

General description and characteristics

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

Electrical characteristics

- Converter topology: Boost, Transition mode
- Core type: PQ32/20-PC44 or equivalent
- Min. operating frequency: 30 kHz
- Typical operating frequency: 120 kHz
- Primary inductance: 240 µH ±15% at 1 kHz - 0.25 V (measured between pins 1,2 and 5,6)

Electrical diagram and winding characteristics

Figure 75. PFC coil electrical diagram

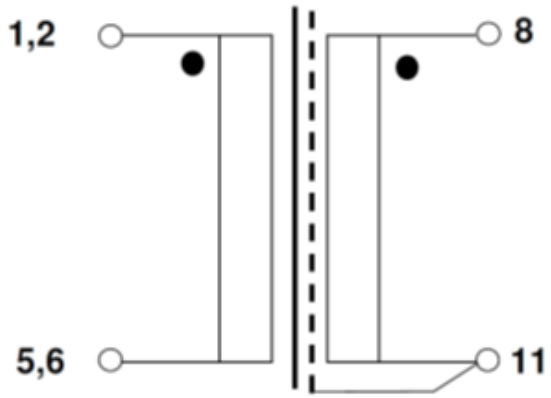


Table 14. PFC coil winding data

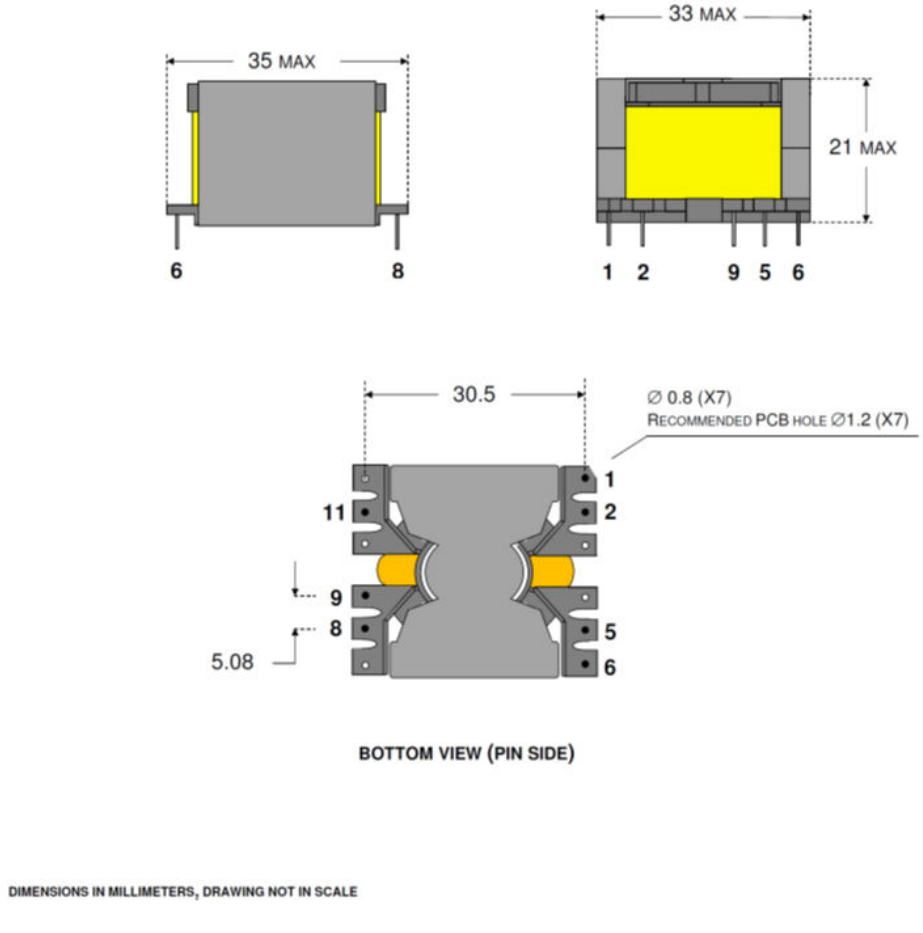
Pins	Windings	RMS current	Number of turns	Wire type
8 - 11	AUX	0.05 Arms	3 spaced	f 0.3 mm – G2
1,2 – 5,6	PRIMARY	2.65 Arms	28	2x40xf 0.1 mm – G2

Mechanical aspect and pin numbering

- Maximum height from PCB: 22 mm
- Coil former type: Vertical, 6+6 Pins (Pins #3, 4, 7, 12 are removed)

- Pin distance: 5.08 mm
- Row distance: 30.5 mm
- External copper shield: Not insulated, wound around the ferrite core and including the coil former. Height is 8 mm. Connected to pin #11 by a soldered solid wire.

Figure 76. PFC coil mechanical aspect



Manufacturer

- AQ Magnetica - Italy
- Inductor P/N: 2086.0001

C.2 Resonant power transformer specification

General description and characteristics

- Application type: consumer, home appliance
- Transformer type: open
- Coil former: horizontal type, 7+7 pins, two slots
- Max. temp. rise: 45 ºC
- Max. operating ambient temperature: 60 ºC
- Mains insulation: acc. to EN60065.

Electrical characteristics

- Converter topology: half-bridge, resonant
- Core type: ETD34-PC44 or equivalent
- Min. operating frequency: 60 kHz
- Typical operating frequency: 100 kHz
- Primary inductance: 910 µH ±10% at 1 kHz - 0.25 V
- (Measured between pins 2-4)
- Leakage inductance: 110 µH ±10% at 100 kHz - 0.25 V
- (Measured between pins 2-4 with only half secondary winding shorted at a time)

Electrical diagram and winding characteristics

Figure 77. Transformer electrical diagram

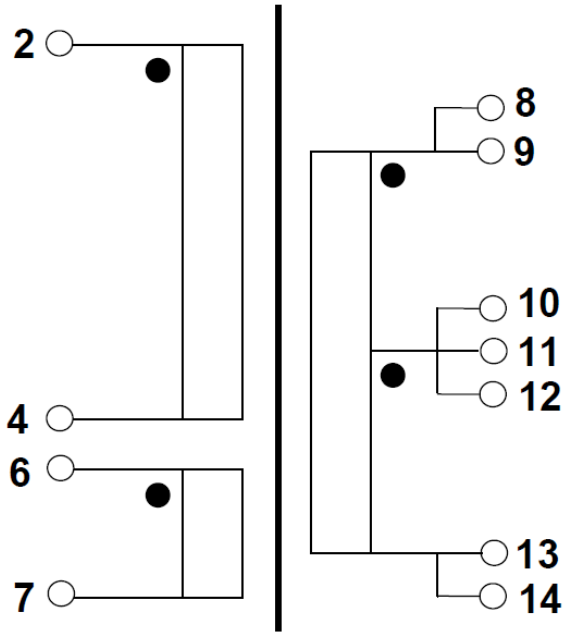


Table 15. Transformer winding data

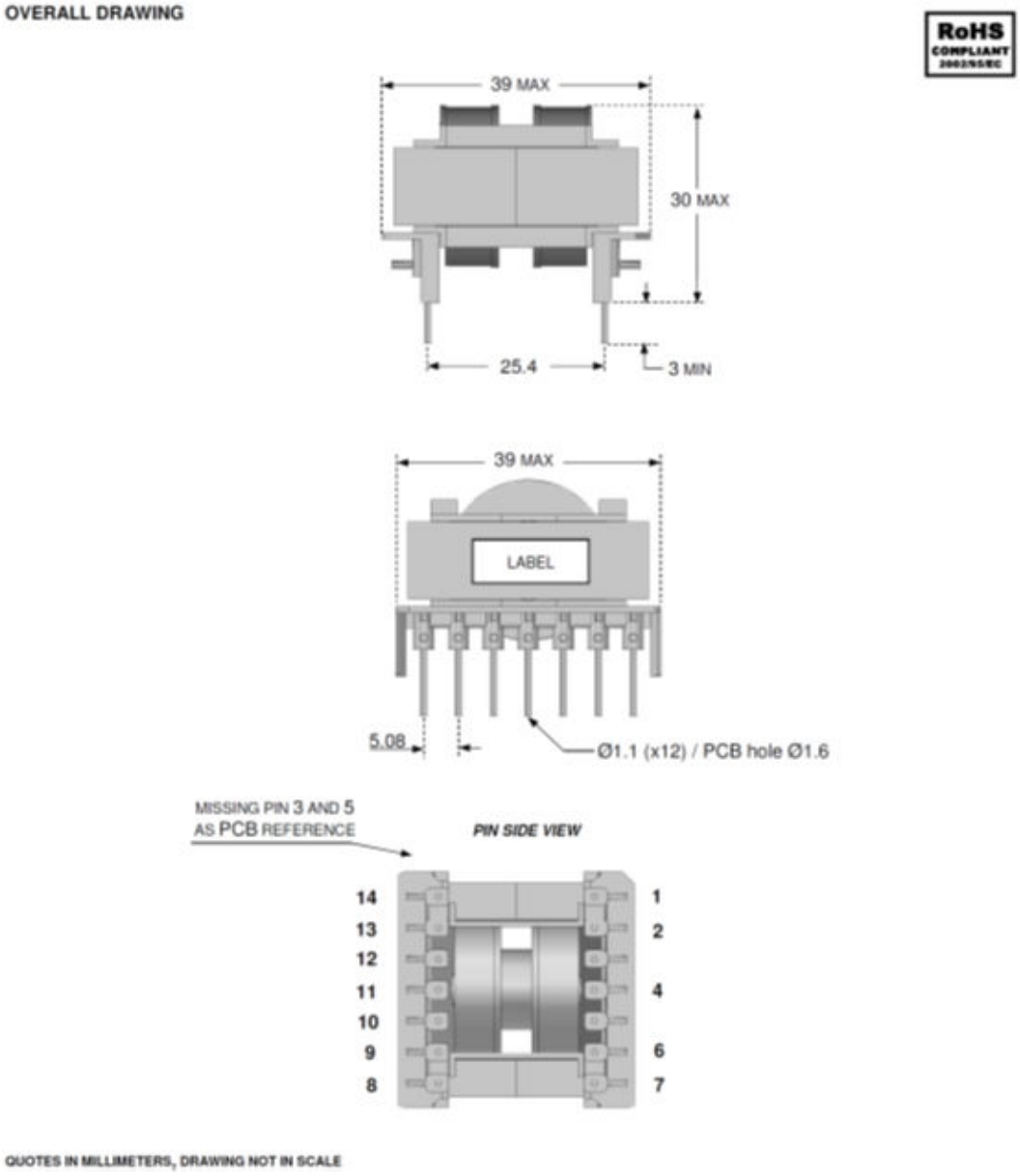
Pins	Windings	RMS current	Number of turns	Wire type
2 – 4	Primary	1 A_{RMS}	36	30 x F 0.1 mm – G1
8 – 11	SEC-1A(1)	8.5 A_{RMS}	2	90 x F 0.1 mm – G1
9 – 10	SEC-1B(1)	8.5 A_{RMS}	2	90 x F 0.1 mm – G1
10 – 13	SEC-2A(1)	8.5 A_{RMS}	2	90 x F 0.1 mm – G1
12 – 14	SEC-2B(1)	8.5 A_{RMS}	2	90 x F 0.1 mm – G1
6 – 7	AUX(2)	0.05 A_{RMS}	3	F 0.28 mm – G2

1. *Secondary windings A and B are in parallel.*
2. *Aux winding is wound on top of secondary windings.*

Mechanical aspect and pin numbering

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

Figure 78. Transformer overall drawing



Manufacturer

- AQ Magnetica - Italy
- Transformer P/N: 1860.0164

Appendix D Biasing circuitry and hardware connections

D.1 VAC pin connection

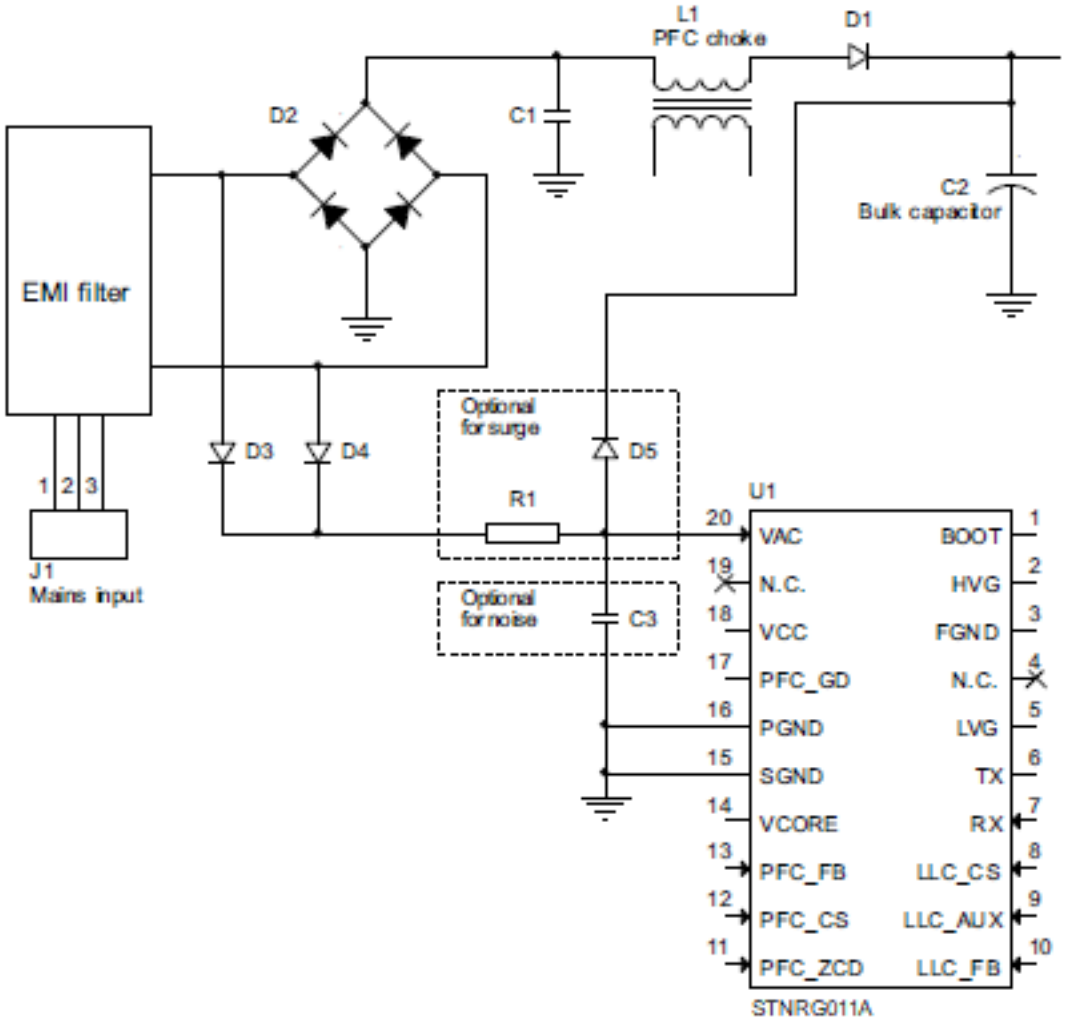
The VAC pin is used to perform several different functions related to the mains voltage.

The pin requires sensing the AC voltage and this can be done by using two diodes connected before the bridge diode like D3 and D4 in Figure 79. Please note that the device is sensing a low frequency signal (100 Hz ÷ 120 Hz) therefore a cheap standard diode should be used (like 1N4007 or similar).

Using an ultrafast rectifier does not add any benefit; depending on the board, it could even have the drawback of injecting noise on the VAC pin.

R1 and D5 can be used to protect the device in case of surge: D5 as a voltage clamp, while R1 limits the current through diodes.

Figure 79. VAC pin connection

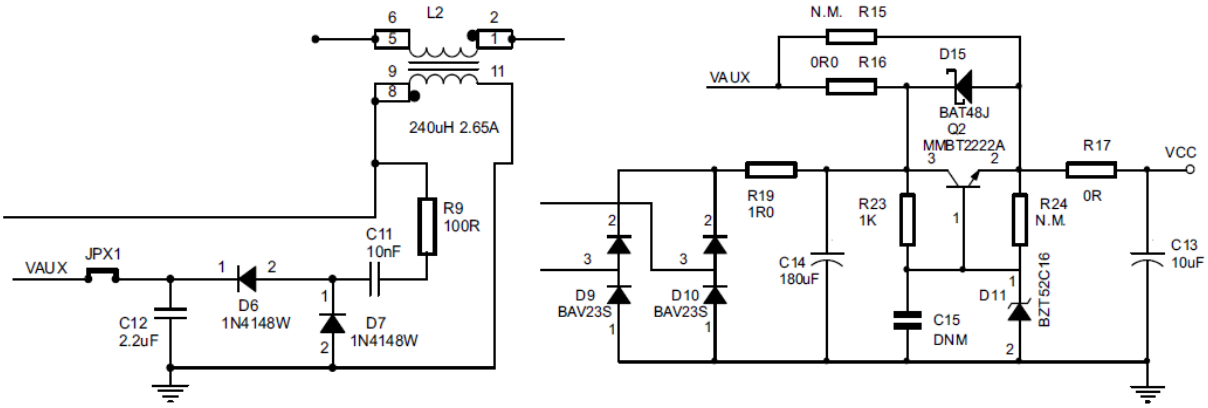


D.2 IC supply circuitry

Figure 80 shows the IC supply circuity, obtained from the original EVL011A150ADP circuit diagram. When the mains voltage is applied, the IC sinks the current from the VAC pin, charging the capacitor connected to the VCC pin. During this phase, both capacitors C13 and C14 are charged by the VCC pin, because the diode D15 conducts as soon as the voltage on C13 is higher than C14 plus the voltage of the diode forward drop. The diode also avoids the breakdown of the BTJ regulator Q2. A low voltage N-channel MOSFET can be used instead of the coupled BJT-diode.

As soon as the IC starts driving the PFC MOSFET, the charge pump R9-C11-D6-D7 connected to the auxiliary winding of the PFC inductor, recharges C14. The linear regulator Q2-R23-D11 ensures that the maximum VCC voltage during running is kept below 16 V. C14 is also recharged by the auxiliary winding of the LLC transformer through the full bridge rectification made with D9 and D10, in order to keep the VCC high also when the system works at low loads and the PFC charge pump is not able to sustain it.

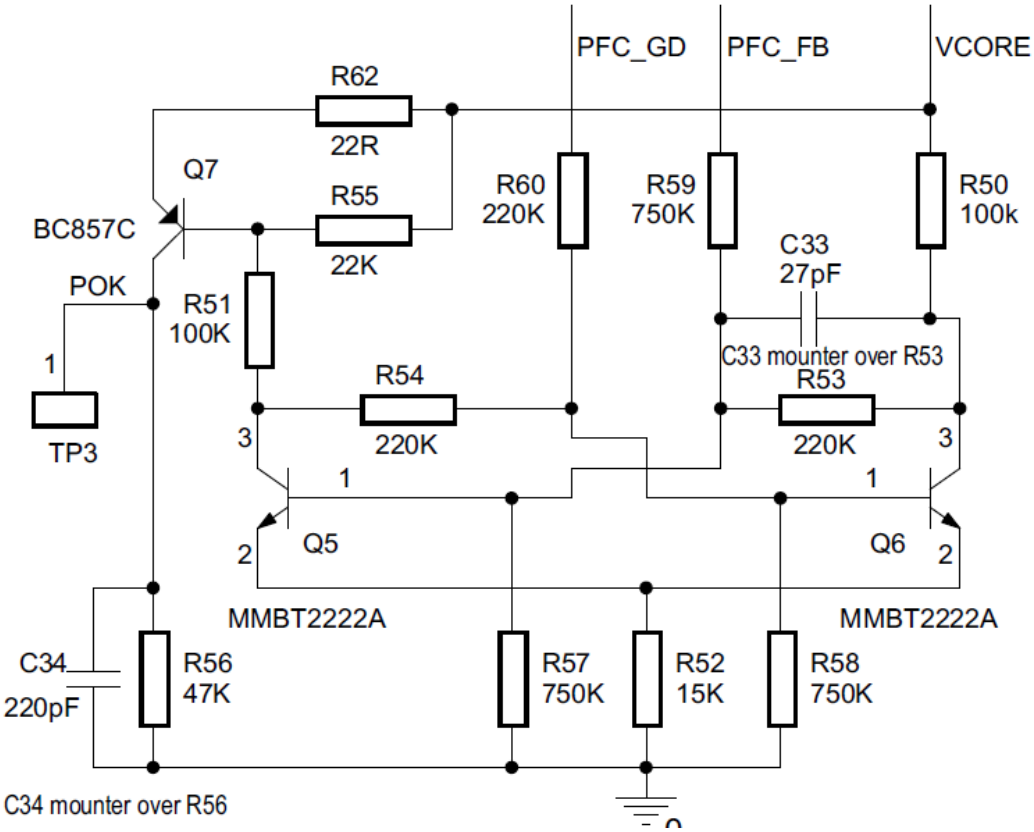
Figure 80. IC supply circuitry



D.3 Power OK (POK) signal generation circuitry

The Power OK signal is generated by the circuitry composed by the transistors latch Q5-Q6 and the common emitter transistor Q7, as shown in Figure 81. The latch is set (that is, the Q5 is turned on) during early warning signal generation when the PFC_FB pin voltage is put higher than 4 V, while it is reset when the PFC_GD is turned on. When the latch is set, also the transistor Q7 is on and the POK signal is put high (negative logic).

Figure 81. POK circuitry



Revision history

Table 16. **Document revision history**

Date	Version	Changes
18-Aug-2022	1	Initial release.
16-Sep-2024	2	Updated figures descriptions in Section 1.2.

Contents

List of tables

List of figures