AN3407
Application note

Resonant driver for LED SMPS demonstration board based on the L6585DE

Introduction

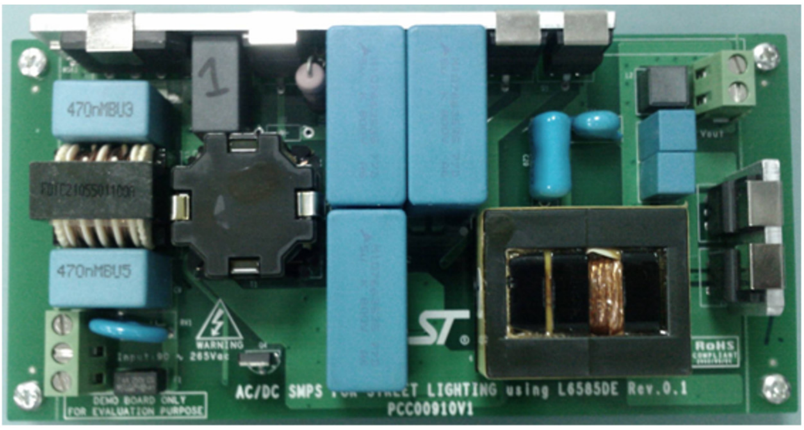
This application note describes the performance of a 100 W LED switched-mode power supply (SMPS). The L6585DE embeds a high-performance transition mode (TM) power factor correction (PFC) controller, half-bridge (HB) controller and all the relevant drivers necessary to build a combo IC. The L6585DE embeds a wide range of features to provide an energy-saving and cost-effective solution for the LED SMPS demonstration board (STEVAL-ILL038V1).

Previous dedicated ICs for LED SMPS applications allowed designers to achieve good driver efficiency. The PFC section has superior performance in terms of harmonic content mitigation. High power factor (PF) and total harmonic distortion (THD) reduction are obtained as required by international norms, especially concerning universal input voltage operations. The TM PFC operation and high-efficiency performance of the half-bridge topology provide very good overall circuit efficiency.

Film capacitors are one of the most popular types of discrete components. They generally offer excellent electrical properties and are advantageous in high current and high temperature conditions. For these reasons, film capacitors are used in LED SMPS applications. In order to guarantee maintenance-free operation required by these types of applications during the useful lifetime of the LED, electrolytic capacitors have been replaced by film capacitors in the STEVAL-ILL038V1 board.

Other features, such as half-bridge overcurrent with frequency increase and PFC overvoltage, allow designers to build a reliable, flexible solution with a reduced component count.

Figure 1. STEVAL-ILL038V1 demonstration board



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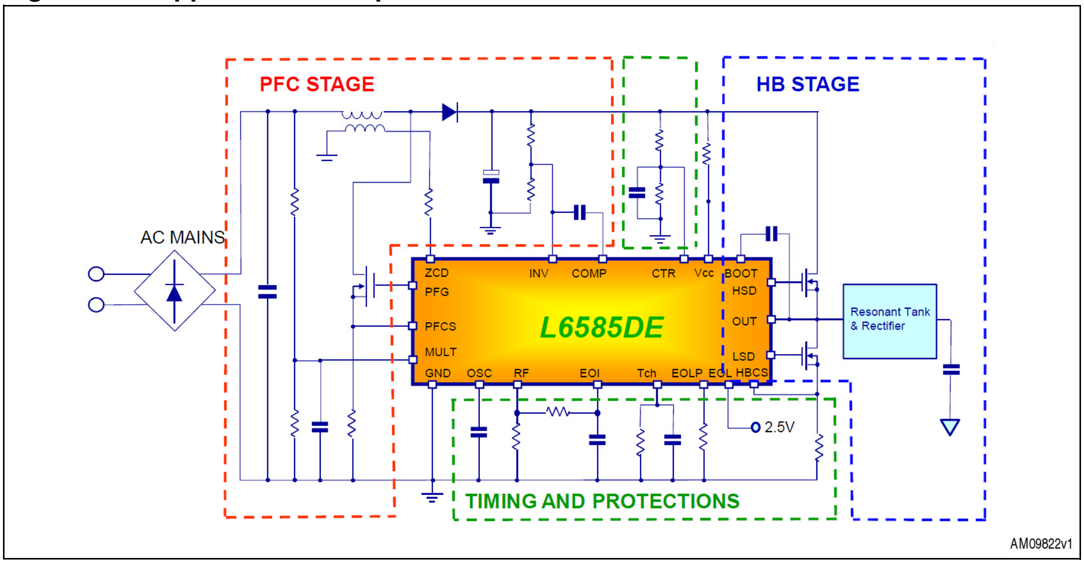
1 L6585DE combo IC

The L6585DE embeds both a PFC converter and a half-bridge resonant in a single SO20 package.

- Transition mode PFC converter with overvoltage and overcurrent protection
- Half-bridge controller with high-voltage driver (600 Vdc) and integrated bootstrap diode
- 3% precise, fully programmable oscillator
- Overcurrent protection
- Hard-switching detection

Figure 2. Application example



2 Main characteristics and circuit description

The main features of the SMPS are listed here below:

- Extended input mains range: 90 ~ 265 V_{AC} - frequency 50/60 Hz
- Output voltage: 48 V at 2.08 A
- Long-life, electrolytic capacitors are not used
- Mains harmonics: according to EN61000-3-2 Class-D
- Efficiency at full load: better than 90%
- Dimensions: 75 x 135 mm

2.1 VCC section

The L6585DE is supplied by applying voltage between the VCC pin and GND pin. An undervoltage lockout (UVLO) prevents the IC from operating with supply voltages too low to guarantee the correct behavior of the internal structures.

An internal voltage clamp limits the voltage to around 17 V and a delivery up to 20 mA. For this reason it cannot be used directly as a clamp for the charge pump (current peaks usually reach several hundreds of mA), but can be easily used during startup in order to charge the VCC capacitor or during save mode in order to keep the IC alive, for example, connecting VCC to input voltage through a resistor.

The L6585DE is supplied by the startup MOSFET Q4 and R40 charging the capacitor C25. A charge pump connected to the auxiliary winding of the HB inductor T2 supplies the controller via a small linear regulator represented by Q7. Once both stages have been activated, the controllers are supplied also by the auxiliary winding of the resonant transformer, assuring correct supply voltage during all load conditions. As the voltage on the VCC pin reaches the turn-on threshold, the chip is enabled, and the half-bridge and the PFC sections start at the same time.

2.2 Power factor corrector section

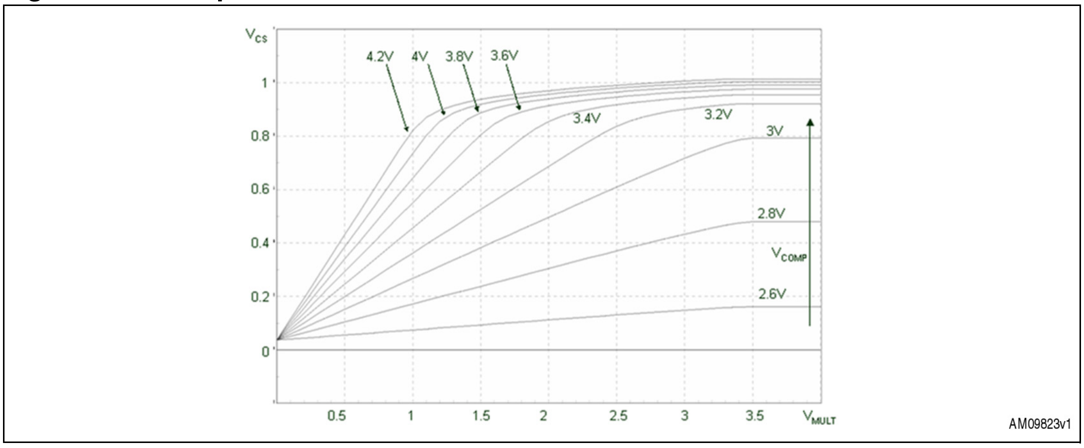
The PFC output voltage is controlled by means of a voltage-mode error amplifier and a precise internal voltage reference. The PFC section achieves current mode control operating in transition mode, offering a highly linear multiplier including a THD optimizer that allows for an extremely low THD, even over a large range of input voltages and loading conditions.

The controller is the L6585DE (U1), working in transition mode and integrating all functions that are needed to perform the PFC. It delivers a stable 450 Vdc. It is a conventional boost converter connected to the output of the rectifier bridge. It includes the coil T1, the PFC transformer by YuJing, the diode D2 (STTH3L06U) and the PFC output capacitors C2, C3 and C4 by film type of 5 µF/800 V. The T1 provides also the information about the PFC coil core demagnetization to pin#11 (ZCD) of the L6585DE. The T1 auxiliary winding is connected to pin#11 (ZCD) of the L6585DE through the resistor R10. Its purpose is to provide the information that T1 has demagnetized which is needed by the internal logic for triggering a new switching cycle. The boost switch is represented by the power MOSFET Q2. The T1 secondary winding (pins#8-6) and related circuitry are dedicated to power the L6585DE during normal operation.

The divider R6, R9, R14 and R16 provides to the L6585DE multiplier the information of the instantaneous mains voltage that is used to modulate the peak current of the boost. In *Figure 3* the characteristic curves of the multiplier are given. The resistors R1, R3, R7 with R11 and C31 are dedicated to sense the output voltage and feed to the L6585DE the feedback information necessary to maintain the output voltage regulated. The components C7, R13 and C8 constitute the error amplifier compensation network necessary to keep the required loop stability.

The resistors R2, R4, R5 with R8 are dedicated to detecting two different overvoltage protections: dynamic overvoltage usually due to fast load transition, and static overvoltage due to an excessive input voltage. The PFC boost peak current is sensed by resistors R23 in series to the MOSFET source. The signal is fed into pin#12 (PFCS) of the L6585DE. The protection is not latched, once the PFCCS falls below 1.7 V, the PFC driver restarts.

Figure 3. Multiplier



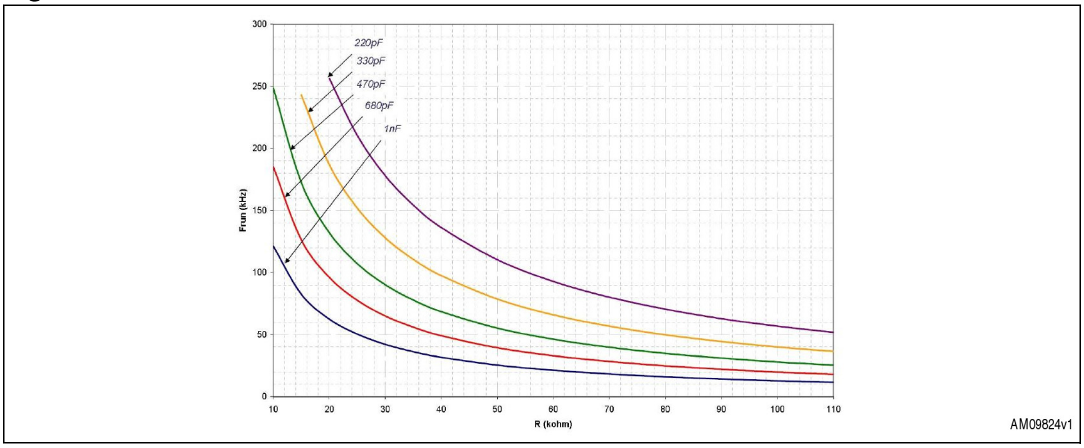
2.3 Resonant power section

The resonant converter half-bridge topology works in ZVS. The resonant transformer T2, manufactured by YuJing, uses the integrated magnetic approach. The leakage inductance is used for resonant operation of the circuit. The T2 doesn't need an external coil for the resonance. The T2 secondary winding configuration is the typical center tap, using a couple of type D5 and D7 power Schottky rectifiers. The output capacitors are film type C15 and C16 (4.7 µF/63 V). L2 and C17 filters have been added on the output, in order to filter the high-frequency ripple.

The half-bridge driver oscillation is regulated by a current-controlled oscillator. It needs a capacitor connected to pin#1 (OSC) of the L6585DE and uses the current flowing outside pin#2 (RF) of the L6585DE as reference. Pin#2 (RF) of the L6585DE has a 2 V precise voltage reference that lets the designer fix the run mode frequency simply by connecting a resistor R17 between pin#2 (RF) of the L6585DE and GND. Each curve is related to a value of the C13 capacitor and is depicted in *Figure 4*. Pin#3 (EOI) of the L6585DE is driven by the internal logic in order to set the frequency during the startup.

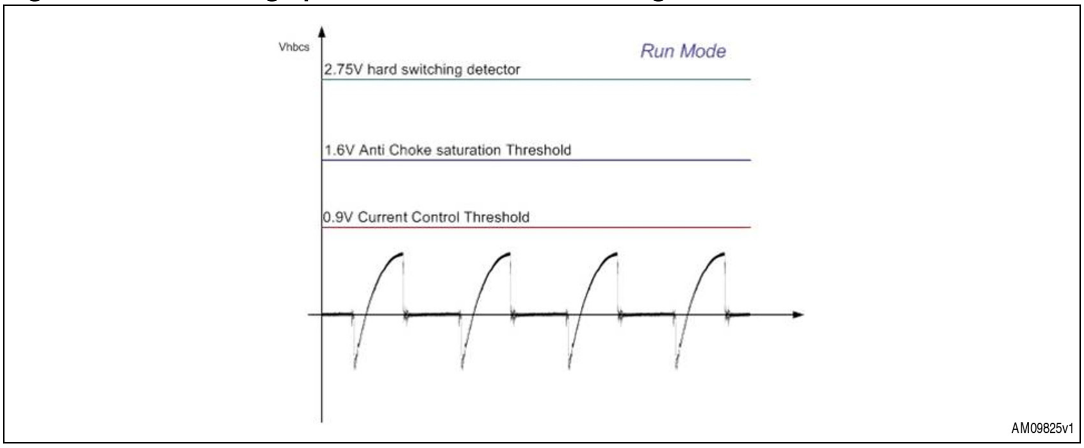
Pin#4 (Tch) of the L6585DE is connected to the parallel of a resistor R18 and C11 and is used to define the protection time. Pin#6 (EOL) of the L6585DE is the input of an internal window comparator that can be triggered by a voltage variation due to a rectifying effect. The reference of this comparator and the amplitude of the window can be set by connecting a suitable resistor to pin#5 (EOLP) of the L6585DE. The reference of this comparator can be set at a fixed voltage or at the same voltage as pin#7 (CTR) of the L6585DE.

Figure 4. Oscillator characteristics



Pin #14 (HBCS) of the L6585DE is equipped with a current sensing and a dedicated overcurrent management system. When the EOI voltage reaches 1.9 V, the IC enters run mode and the switching frequency is set only by R17 (RRUN). In *Figure 5* the protection thresholds are shown. They are sensed by the circuit C18, R26, D8, D9, R27, and C19 and are fed into the L6585DE pin#14 (HBCS).

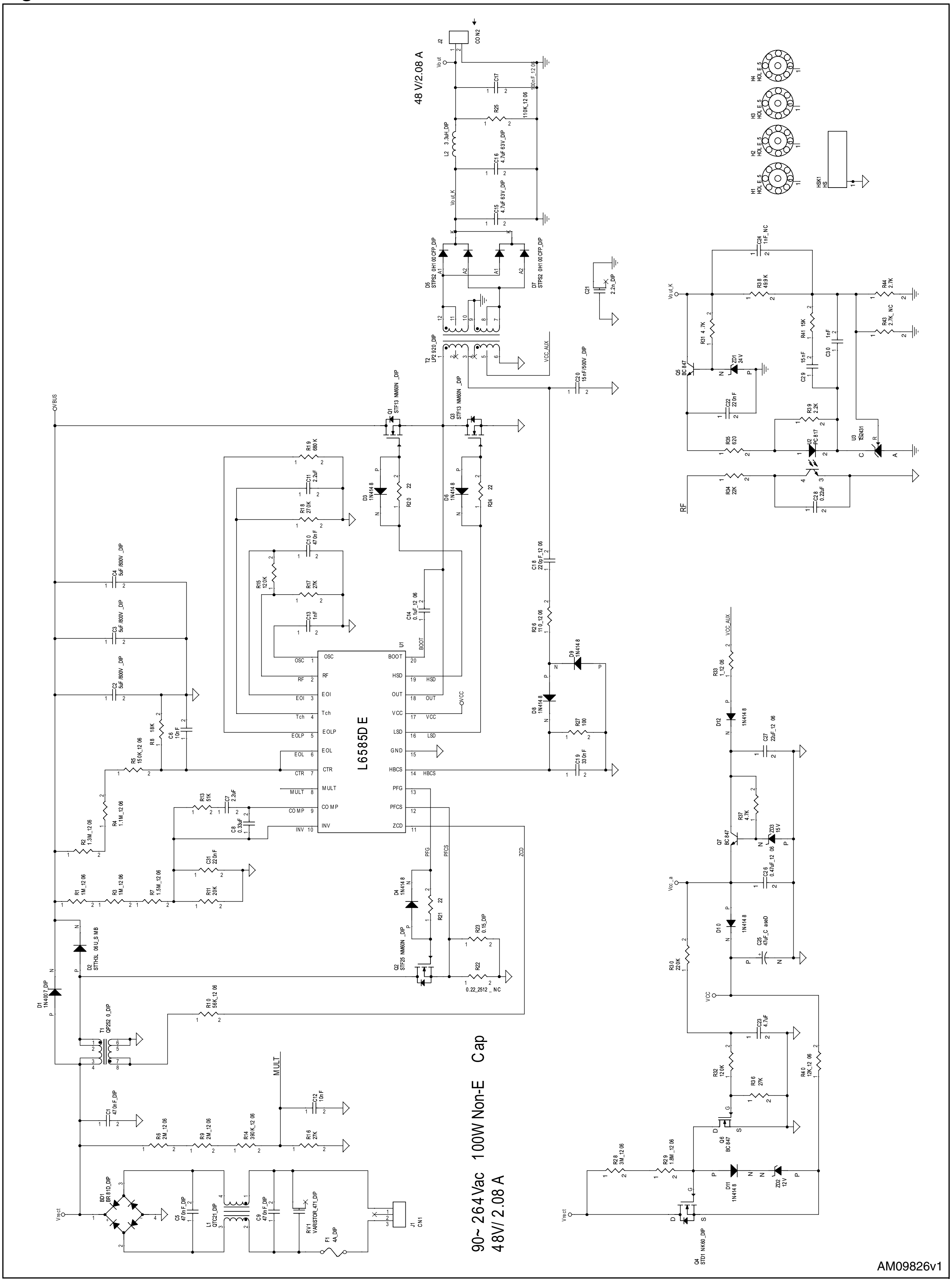
Figure 5. Half-bridge protection thresholds during run mode



2.4 Output voltage feedback loop

The output voltage is kept stable by means of a feedback loop implementing a typical circuit using U3 (TS2431) modulating the current in the optocoupler diode. On the primary side, R34 connecting pin#2 (RF) of the L6585DE to the optocoupler's phototransistor allows modulating the L6585DE oscillator frequency, thus keeping the output voltage regulated. R17 connects the same pin to ground and sets the minimum switching frequency.

Figure 6. Electrical schematic



3 Efficiency measurements

Table 1 shows the overall efficiency, measured at 115 V_{AC} - 60 Hz. *Table 2* shows the overall efficiency, measured at 230 V_{AC} - 50 Hz.

Table 1. Efficiency at 115 V_{AC}

Load	115 V_{AC} - 60 Hz					
	Vout (V)	Iout (A)	Pout (W)	Pin (W)	PF	Eff (%)
25%	48.67	0.525	25.55	29.30	0.982	87.21
50%	48.67	1.050	51.10	55.87	0.996	91.47
75%	48.67	1.560	75.93	82.01	0.995	92.58
100%	48.67	2.086	101.53	109.28	0.991	92.90
Average eff.						91.04

Table 2. Efficiency at 230 V_{AC}

Load	230 V_{AC} - 50Hz					
	Vout (V)	Iout (A)	Pout (W)	Pin (W)	PF	Eff (%)
25%	48.67	0.525	25.55	29.45	0.793	86.76
50%	48.67	1.048	51.01	55.59	0.924	91.76
75%	48.67	1.560	75.93	81.06	0.966	93.67
100%	48.67	2.083	101.38	107.46	0.980	94.34
Average eff.						91.63

The overall circuit efficiency is measured at different loads, powering the board at the two nominal input mains voltages. The measures have been done after 30 minutes at load. The high efficiency of the PFC working in transition mode and the very high efficiency of the resonant stage working in ZVS provides for an overall efficiency better than 90%.

Figure 7 shows the efficiency at 25%, 50%, 75% and 100% load at 115 V_{AC} and 230 V_{AC}. *Figure 8* shows the efficiency at full load over the entire AC input voltage mains range. *Figure 9* shows the power factor (PF) versus load variations.

Figure 7. STEVAL-ILL038V1 demonstration board: efficiency vs. load

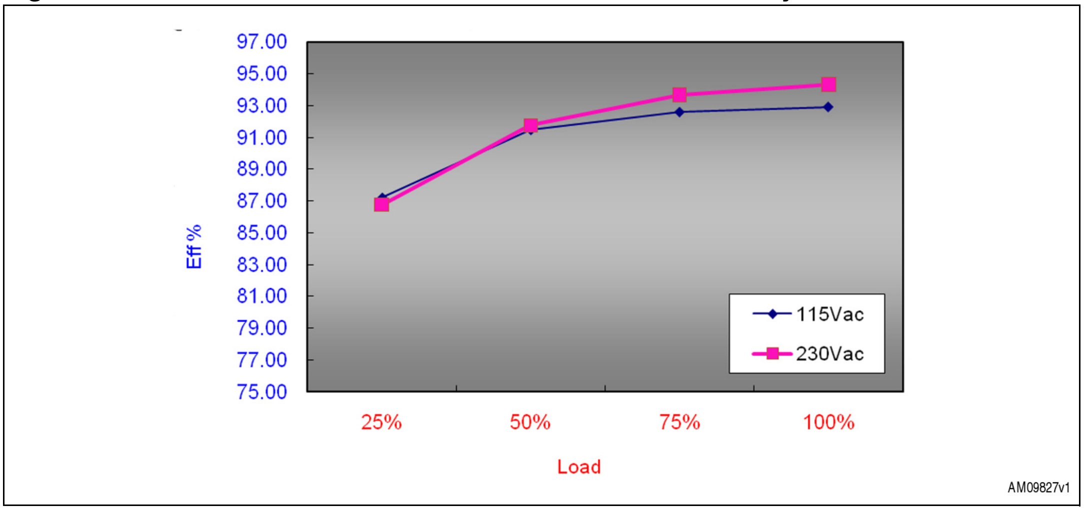


Figure 8. STEVAL-ILL038V1 demonstration board: full-load efficiency vs. V_{AC}

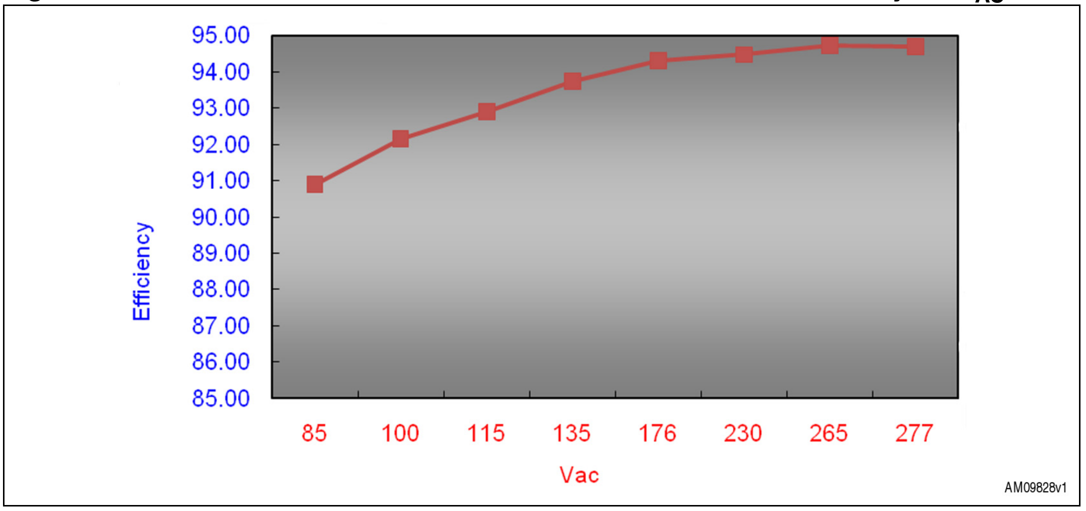
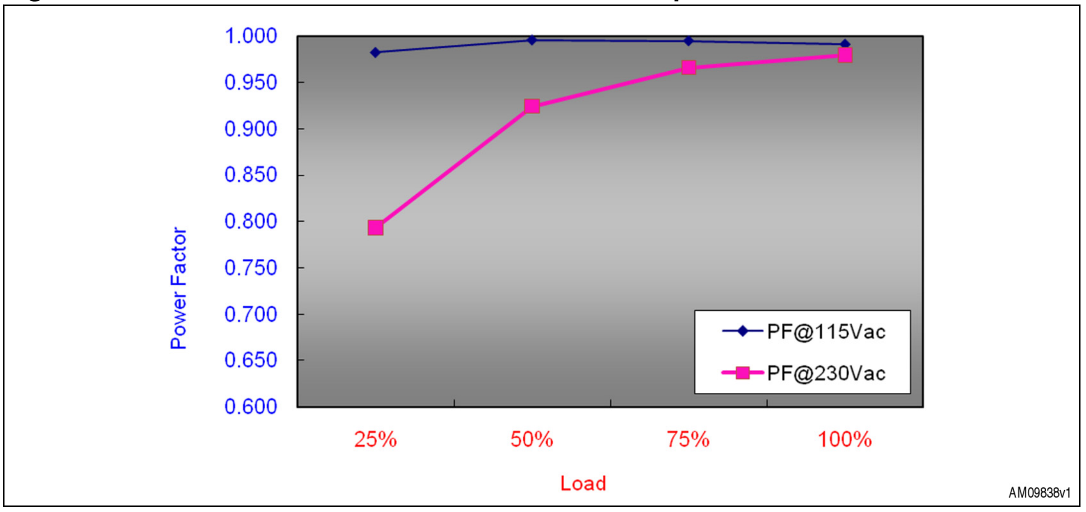


Figure 9. STEVAL-ILL038V1 demonstration board: power factor vs. load



4 Input current harmonics measurement

The internal THD optimizer increases the performance when the mains voltage reaches zero which reduces crossover distortion and avoids introducing offset. One of the main purposes of a PFC pre-conditioner is the correction of input current distortion, decreasing the harmonic contents below the limits of the relevant regulations. The board has been tested according to the European norm EN61000-3-2 Class-D, at full load and nominal input voltage mains. *Figure 10* and *11* show the measurement results.

Figure 10. EN61000-3-2 Class-D standard - 185 V_{AC}/50 Hz, THD=4.86%, PF=0.993 at full load

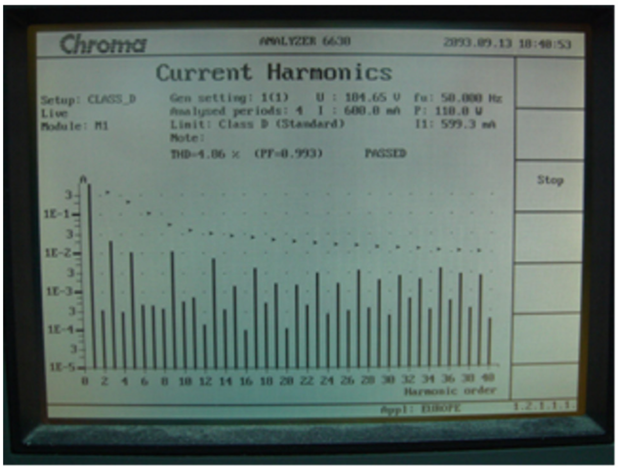


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Figure 11. EN61000-3-2 Class-D standard - 230 V_{AC}/50 Hz, THD=5.98%, PF=0.980 at full load

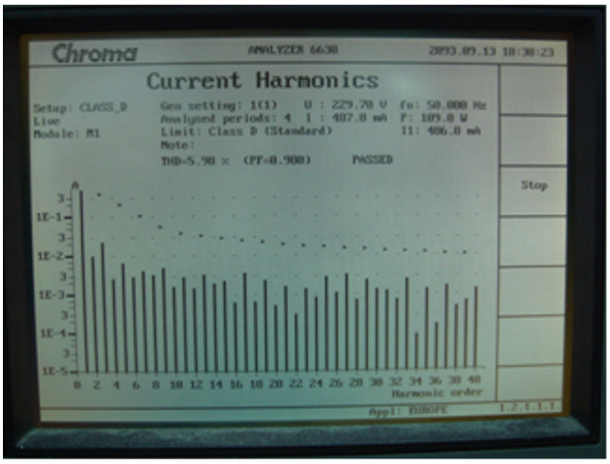

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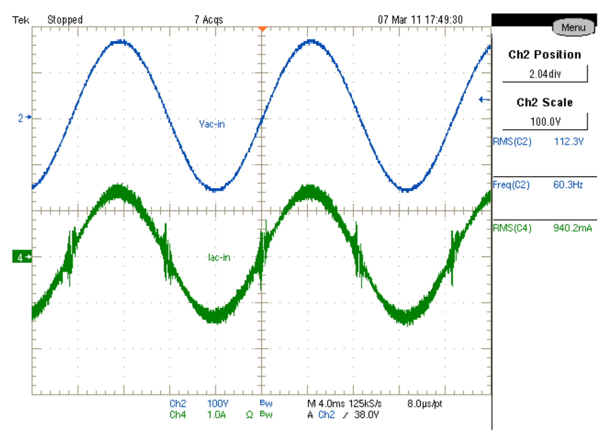
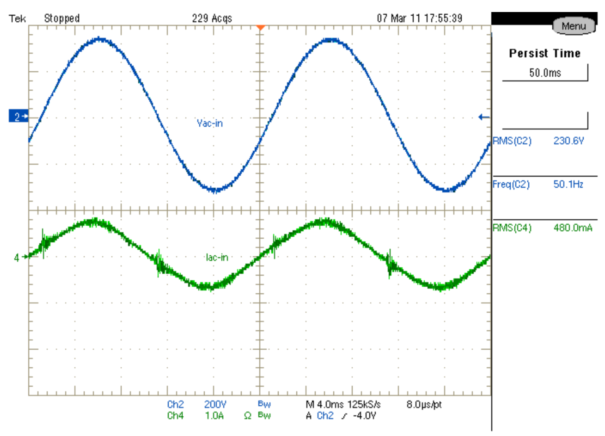
Figure 12 and *13* show the waveforms of the input current and voltage at 115 V_{AC} and 230 V_{AC} during full load.

Figure 12. Input current waveforms - full load at 115 V_{AC}



CH2: Vac-in CH4: Iac-in

Figure 13. Input current waveforms - full load at 230 V_{AC}



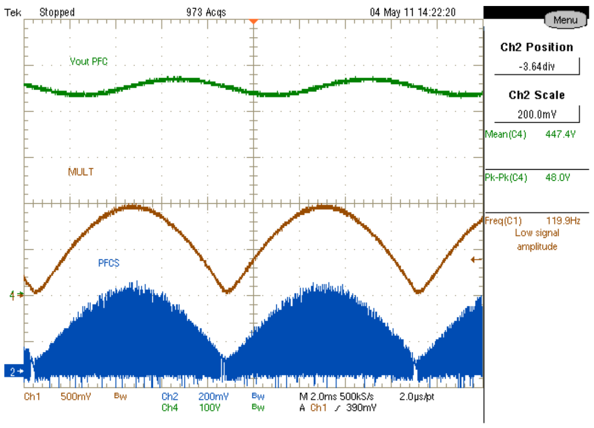
CH2: Vac-in CH3: Iac-in

5 Functional check

5.1 PFC circuit

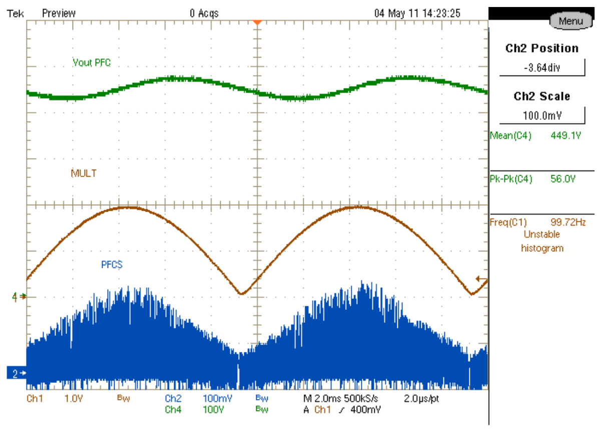
The waveforms measured in the PFC stage have been captured during full load operation at nominal 115 V_{AC} and 230 V_{AC} in *Figure 14* and *15*. It can be seen in both figures that the envelope of the waveform of pin#12 (PFCS) is in phase with that of pin#8 (MULT) and has same sinusoidal shape, demonstrating the proper functionality of the PFC stage. It is also possible to measure the peak-to-peak value of the voltage ripple superimposed on the PFC output voltage due to the low value of the PFC output capacitors. The details of the waveforms at switching frequency are measured in *Figure 16* and *17*.

Figure 14. PFC stage waveforms at 115 V_{AC} - full load



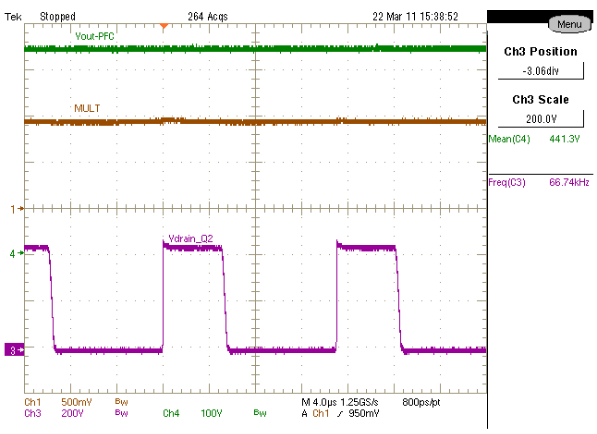
CH1: MULT CH2: PFCS CH4: Vout_PFC

Figure 15. PFC stage waveforms at 230 V_{AC} - full load



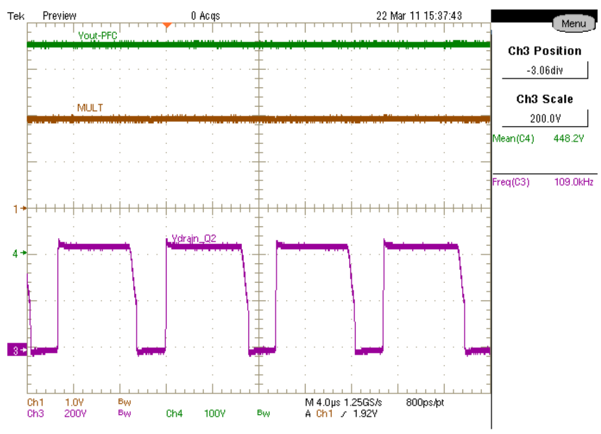
CH1: MULT CH2: PFCS CH4: Vout_PFC

Figure 16. PFC stage waveforms at 115 V_{AC} - full load - detail



CH1: MULT CH3: Vdrain_Q2 CH3: Vout_PFC

Figure 17. PFC stage waveforms at 230 V_{AC} - full load - detail



CH1: MULT CH3: Vdrain_Q2 CH4: Vout_PFC

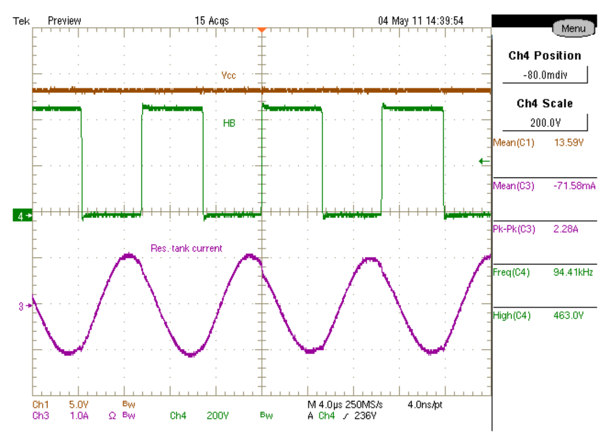
5.2 Half-bridge resonant LLC circuit

The waveforms are measured in the resonant stage ZVS operation in *Figure 18*. Both MOSFETs are turned on when resonant current is flowing through their body diodes and drain-source voltage is almost zero, thus achieving good efficiency. The switching frequency has been chosen around 94 kHz.

Figure 18 shows waveforms during steady-state operation of the circuit at full load. A slight asymmetry of operating modes by each half portion of the sine wave is visible: one half-cycle is working at resonant frequency while the other half is working above the resonant frequency. This is due to a small difference between each half's secondary leakage inductance of the transformer reflected to the primary side, providing two slightly different resonant frequencies. This phenomenon is typically due to a different coupling of the transformer's secondary windings and in this case it is not an issue.

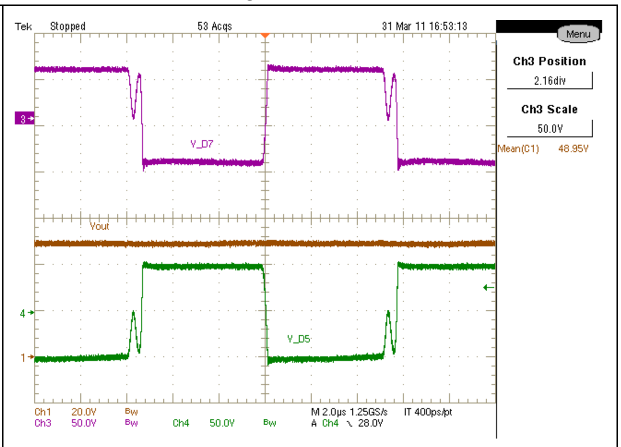
Figure 19 demonstrates that during one half-cycle the circuit is working below the resonant frequency, while during the following half-cycle it is working at resonance frequency. Waveforms relevant to the secondary side are shown: the rectifier's reverse voltage is measured by Ch3 and Ch4 on the right of the picture. It is a bit higher than the theoretical value that would be 2 (VOUT+VF), hence about 100 V.

Figure 18. Primary side LLC waveforms at 115 V_{AC} - full load



CH1: VCC CH3: Res. Tank current CH4: HB

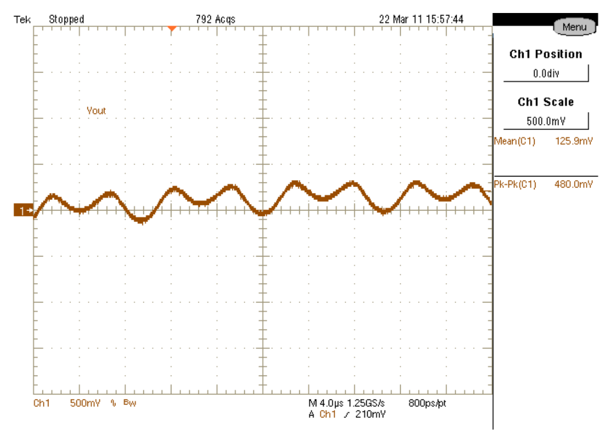
Figure 19. Secondary side LLC waveforms at 230 V_{AC} - full load



CH1: Vout CH3: V_D7 CH4: V_D5

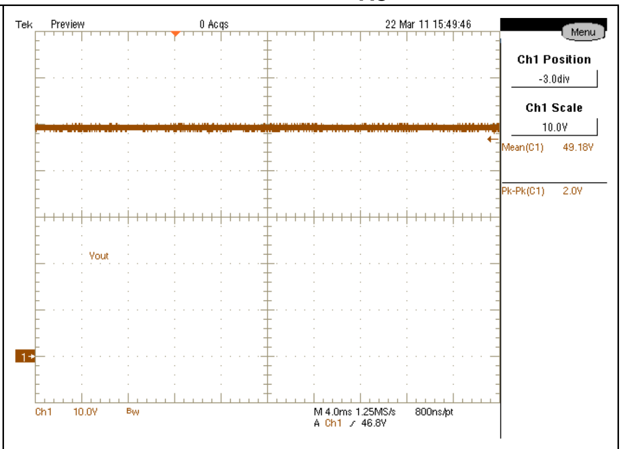
The ripple and noise on the output voltage is shown on CH1. *Figure 20* shows the waveform during the high-frequency ripple of the circuit at full load. The peak-to-peak value is high but it doesn't affect the application, in fact the converters regulating the current flowing in each LED strip can reject the ripple. *Figure 21* shows the waveform during the low-frequency ripple of the circuit at full load.

Figure 20. High-frequency ripple on output voltage at 115 V_{AC} - 60 Hz - full load



CH1: Vout

Figure 21. Low-frequency ripple on output voltage at 115 V_{AC} - 60 Hz - full load

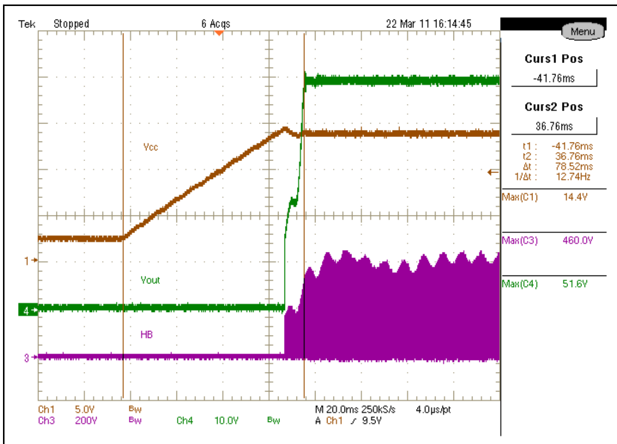


CH1: Vout

5.3 Converter startup

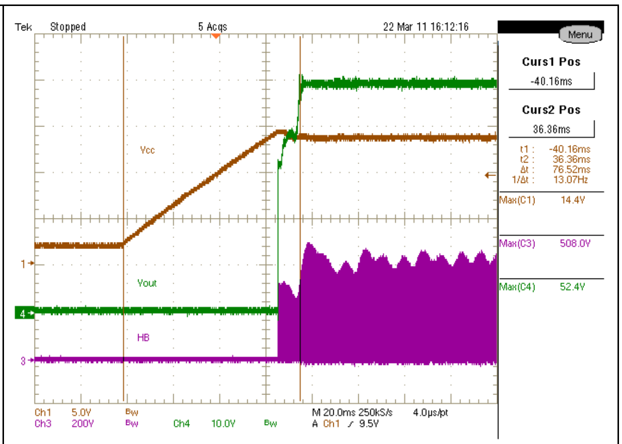
The converter startup is captured in *Figure 22* and *23*. The converter begins operation around 80 ms at 115 V_{AC} and 230 V_{AC}. This is the time needed to charge the VCC to turn-on voltage. The L6585DE starts switching and the PFC and HB output voltage starts increasing.

Figure 22. Wake-up at 115 V_{AC} - 60 Hz - full load



CH1: VCC CH3: VOUT CH4: HB

Figure 23. Wake-up at 230 V_{AC} - 60 Hz - full load



CH1: VCC CH3: VOUT CH4: HB

6 Bill of material

Table 3. STEVAL-ILL038V1 demonstration board: bill of material

Reference	Part / value	Tolerance %	Voltage	Manufacturer
BD1	GBU8J_DIP			VISHAY
C1,C5,C9	470nF_DIP		305 V_{AC}	EPCOS
C2,C3,C4	5uF/800 V_DIP		800 V	EPCOS
C6,C12	10 nF	X7R	50 V	
C7,C11	2.2 µF	X7R	50 V	
C8	0.33 µF	X7R	50 V	
C10	470 nF	X7R	50 V	
C13,C30	1 nF	X7R	50 V	
C14	0.1 µF_1206	X7R	50 V	
C15,C16	4.7 µF 63 V_DIP		63 V	EPCOS
C17	100 nF_1206	X7R	100 V	
C18	220 pF_1206	X7R	1000 V	AVX
C19	330 nF	X7R	50 V	
C20	15 nF_DIP		1000 V	EPCOS
C21	2.2 nF_DIP			Murata
C22,C31	220 nF	X7R	50 V	
C23	4.7 µF	X7R	25 V	
C25	47 µF_CaseD		20 V	SANYO
C26	0.47 µF_1206	X7R	50 V	
C27	2.2 µF_1206	X7R	50 V	
C28	0.22 µF	X7R	50 V	
C29	15 nF	X7R	50 V	
D1	1N4007_DIP			VISHAY
D2	STTH3L06U_SMB			STMicroelectronics
D3,D4,D6,D8,D9, D10,D11,D12	1N4148			CHENMKO
D5,D7	STPS10150CG			STMicroelectronics
F1	4 A_DIP			Littlefuse
J1	CN1			PHOENIX CONTACT
J2	CON2			PHOENIX CONTACT
L1	QTC21_DIP			YU JING
L2	3.3 µH_DIP			MAGI

Table 3. STEVAL-ILL038V1 demonstration board: bill of material (continued)

Reference	Part / value	Tolerance %	Voltage	Manufacturer
Q1,Q3	STF8NM60N_DIP		600 V	STMicroelectronics
Q2	STF21NM60N_DIP		600 V	STMicroelectronics
Q4	STQ1HNK60R_DIP			STMicroelectronics
Q5,Q6,Q7	BC847			CHENMKO
RV1	VARISTOR		300 V_{AC}	EPCOS
R1,R3	1 MΩ_1206	1%		
R2	1.3 MΩ_1206	1%		
R4	1.1 MΩ_1206	1%		
R5	150 kΩ_1206	1%		
R6,R9	2 MΩ_1206	1%		
R7	1.5 MΩ_1206	1%		
R8	18 kΩ	1%		
R10	56 kΩ_1206	1%		
R11	19.6 kΩ	1%		
R13	51 kΩ	1%		
R14	390 kΩ_1206	1%		
R15,R32	120 kΩ	1%		
R16,R17,R36	27 kΩ	1%		
R18	270 kΩ	1%		
R19	680 kΩ	1%		
R20,R21,R24	22 Ω	5%		
R23	0.15_DIP	1%		
R25	110 kΩ_1206	1%		
R26	110_1206	1%		
R27	100 Ω	1%		
R28	3 MΩ_1206	1%		
R29	1.8 MΩ_1206	1%		
R30	220 kΩ	1%		
R31,R37	4.7 kΩ	5%		
R33	1_1206	5%		
R34	22 kΩ	1%		
R35	620 Ω	1%		
R38	49.9 kΩ	1%		
R39	2.2 kΩ	1%		
R40	12 kΩ_1206	1%		

Table 3. STEVAL-ILL038V1 demonstration board: bill of material (continued)

Reference	Part / value	Tolerance %	Voltage	Manufacturer
R41	15 kΩ	1%		
R44	2.7 kΩ	1%		
T1	QP2520_DIP			YU JING
T2	LP2920_DIP			YU JING
U1	L6585DE			STMicroelectronics
U2	SFH617A			VISHAY
U3	TS2431			STMicroelectronics
ZD1	24 V			CHENMKO
ZD2	12 V			CHENMKO
ZD3	15 V			CHENMKO

Figure 24. PCB: topside and through-hole components

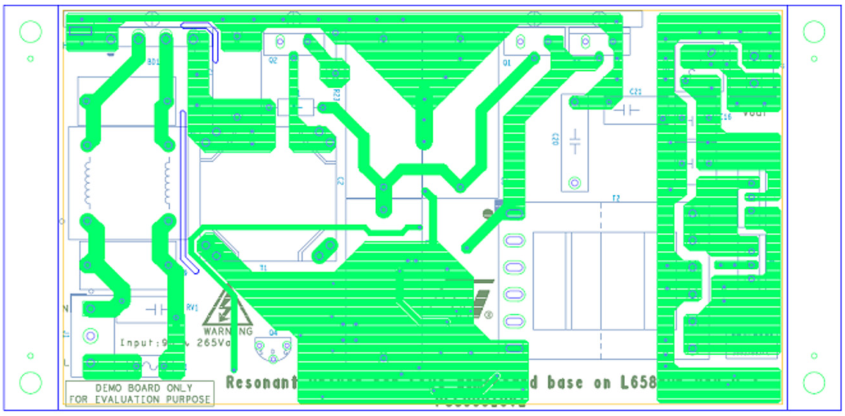


Figure 25. PCB: bottomside and SMD components

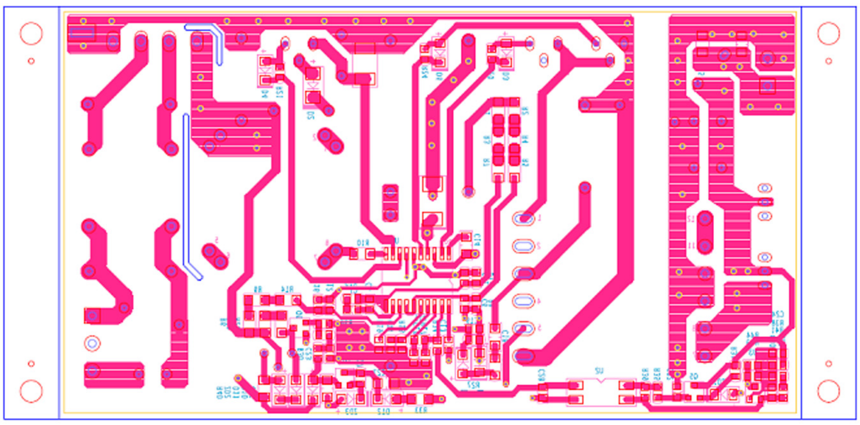


Figure 26. PCB: topside placement

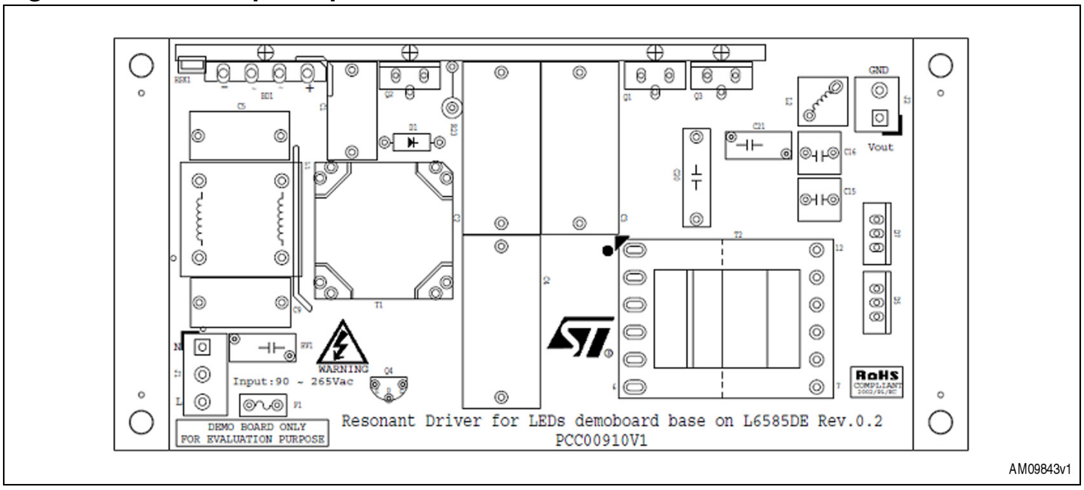
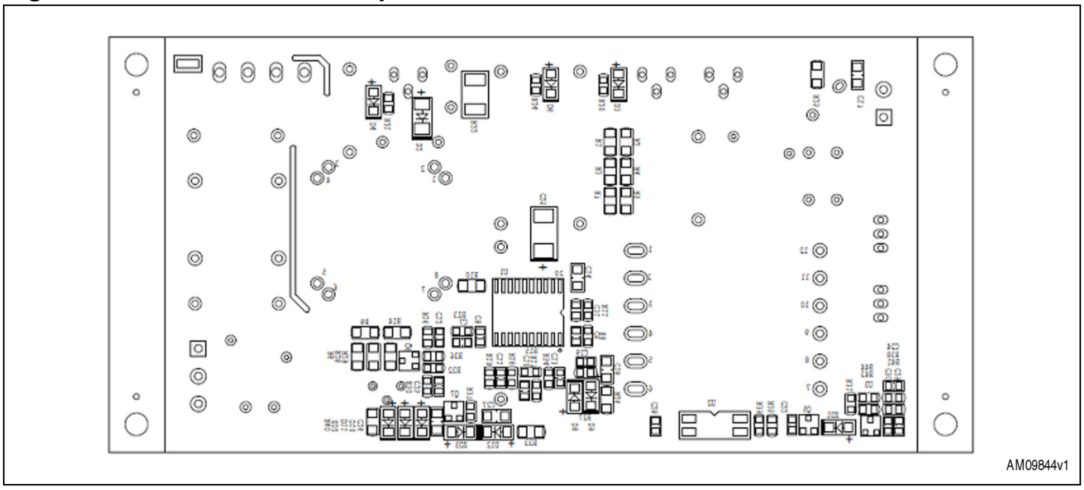


Figure 27. PCB: bottomside placement



7 EMI choke

Figure 28. EMI: OTC21V-4S vertical type EMI choke

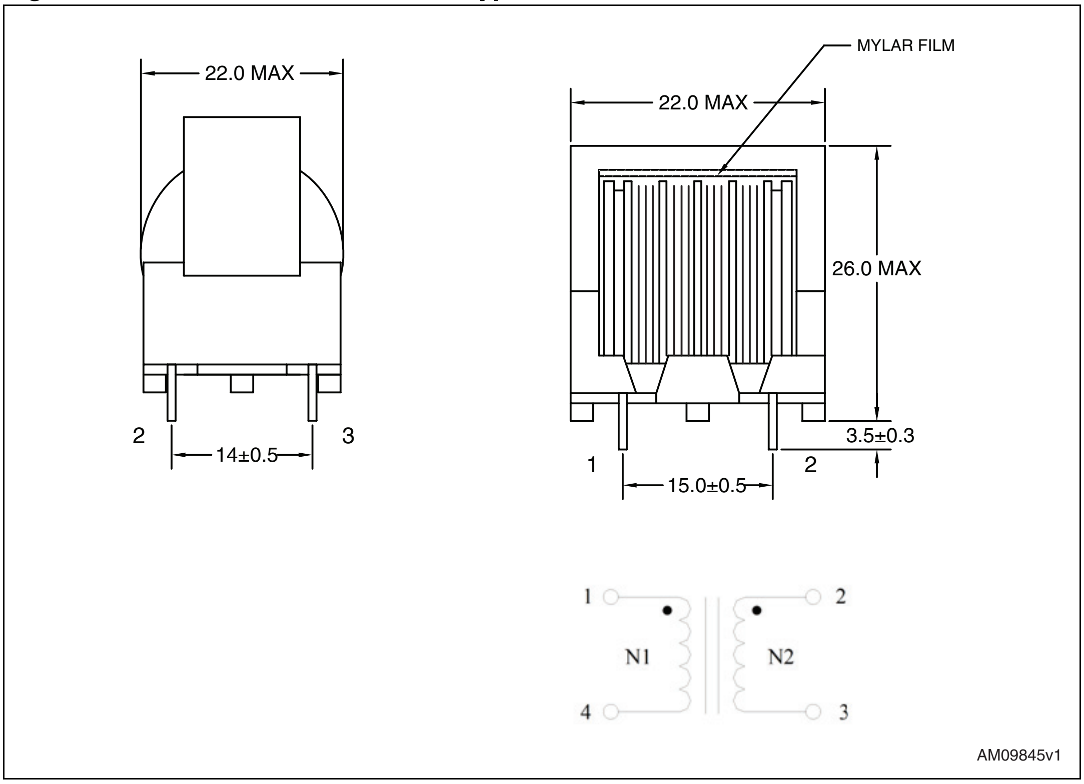


Table 4. Transformer specifications

Core spec-OTC21							
Ae	26.1 mm^2		Le	55.2 mm			
Wiring spec. for resonant transformer							
No.	Start	Finish	Wire	Winding	Turns	Inductance	DCR (mΩ)
L1	1	4	0.55 Φ*		48	11.0 µH min	200 max.
L2	2	3	0.55 Φ*		48	96 µH min	200 max.

Note: *Class B insulation system: SBI4.2*

Hi-pot test: 1.5 kV, N1 to N2, 1.5 kV, N1 to core, 1.5 kV, N2 to core

8 PFC coil specifications

Figure 29. PFC: QP2520V-vertical type for PFC choke

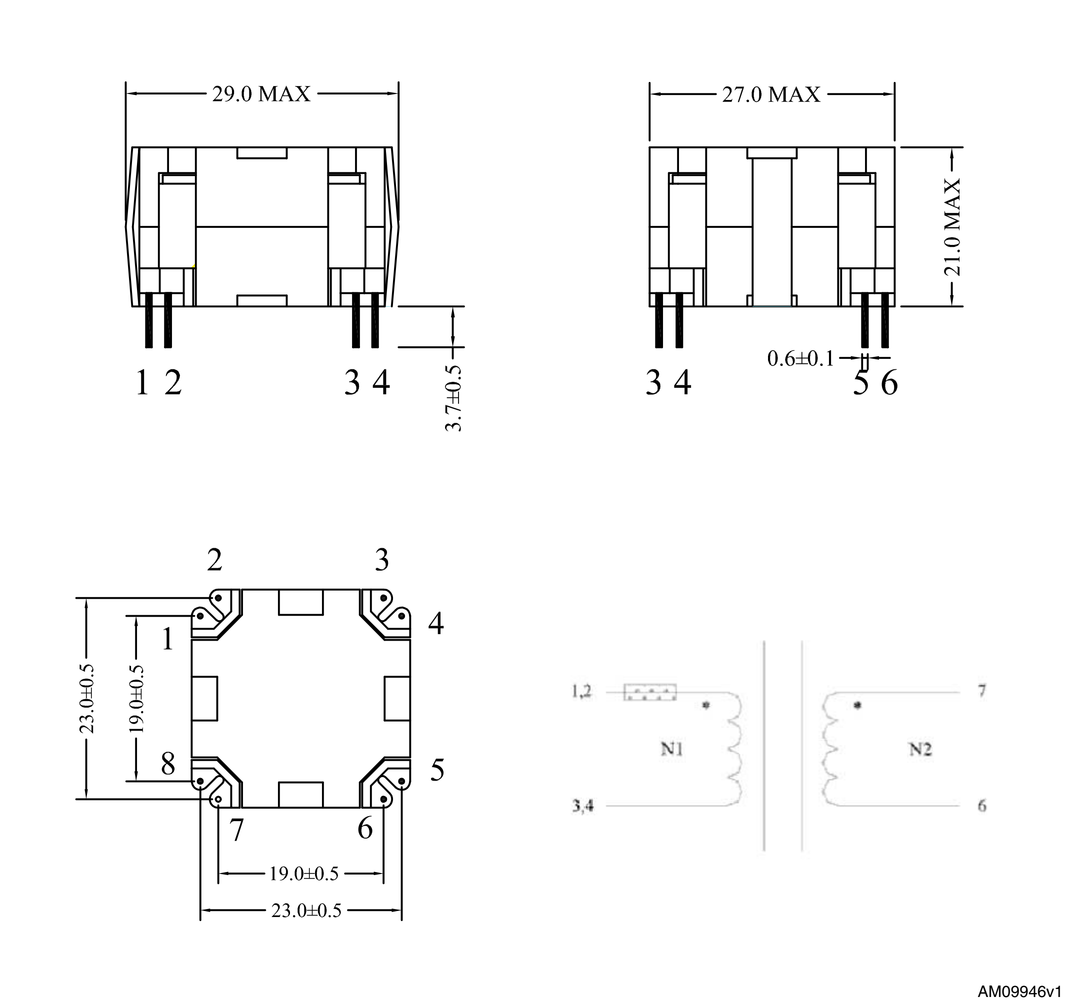


Table 5. Transformer specifications

Core spec-QP2520							
Ae	118.0 mm^2		Le	46 mm			
Wiring spec. for resonant transformer							
No.	Start	Finish	Wire	Winding	Turns	Inductance	DCR (mΩ)
L1	1.2	3.4	0.1Φ 35c* 1p(Litz)	Primary	62±0.5	580 µH ±10%	280 max.
L2	7	6	0.3 Φ* 1c	AUX	6±0.5		

Note: Class B insulation system: SBI4.2

with standing voltage: 1.0 kV/3 sec/AC/5 mA, primary to secondary, 0.5 kV/1 sec/AC/3 mA, primary to core, 0.5 kV/1 sec/AC/3 mA, secondary to core

9 Transformer specifications

Figure 30. Transformer: LP2920H - horizontal type for LLC transformer

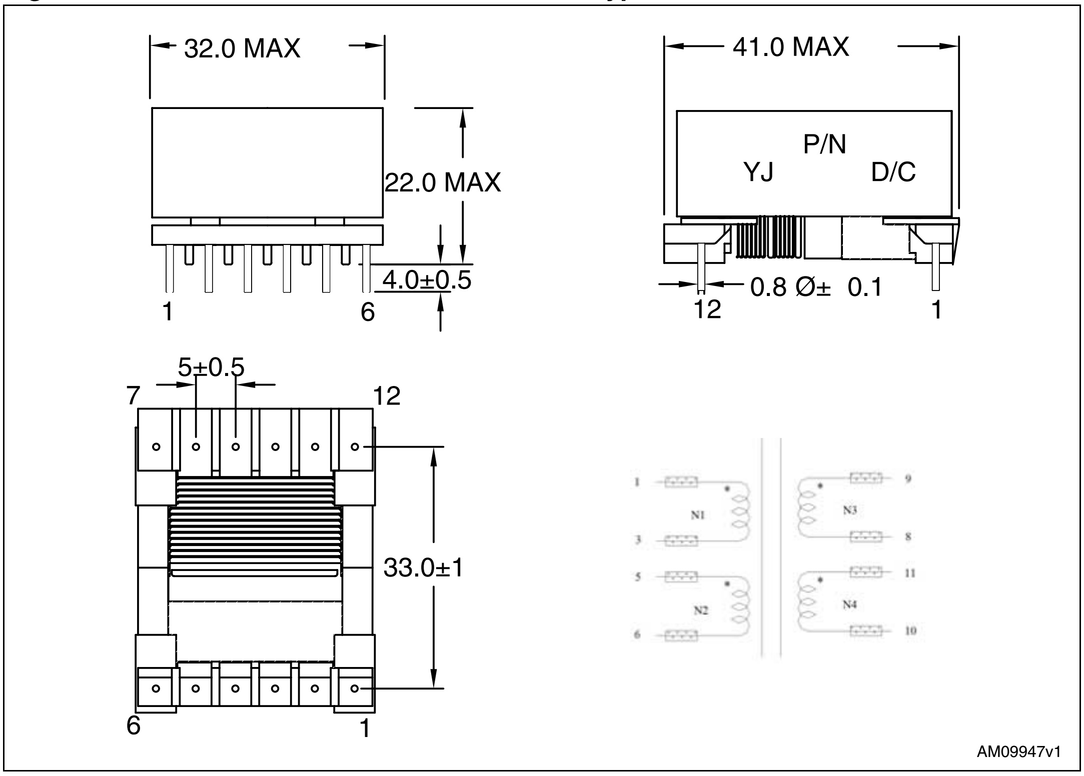


Table 6. Transformer specifications

Core spec-LP2920							
Ae	112.0 mm^2		Le	79.6 mm			
Wiring spec. for resonant transformer							
No.	Start	Finish	Wire	Winding	Turns	Inductance	DCR (mΩ)
L1	1	3	0.1Φ 30c* 1p(Litz)	Primary	47±0.5	770 µH ±10%	
L2	5	6	0.28 Φ* 1c (TEX-E)	AUX	3±0.5		
L3	9	8	0.1 Φ* 60C* 1p (Litz)	Second	9±0.5		
L4	11	10	0.1 Φ* 60c* 1p (Litz)	Second	9±0.5		
Lk	1	3	0.1 Φ* 30c* 1p (Litz)	Primary	47±0.5	170 µH ±10%	Sec.short

Note: *Class B insulation system: SBI4.2*

with standing voltage: 3.0 kV/1 sec/AC/5 mA, primary to secondary, 2.5 kV/1 sec/AC/3 mA, primary to core, 1.0 kV/1 sec/AC/3 mA, secondary to core

10 References

1. L6585DE datasheet, STMicroelectronics
2. L6562A datasheet, STMicroelectronics
3. L6599 datasheet, STMicroelectronics
4. Application notes: AN2870, AN3106, STMicroelectronics

11 Revision history

Table 7. Document revision history

Date	Revision	Changes
30-Aug-2011	1	Initial release.