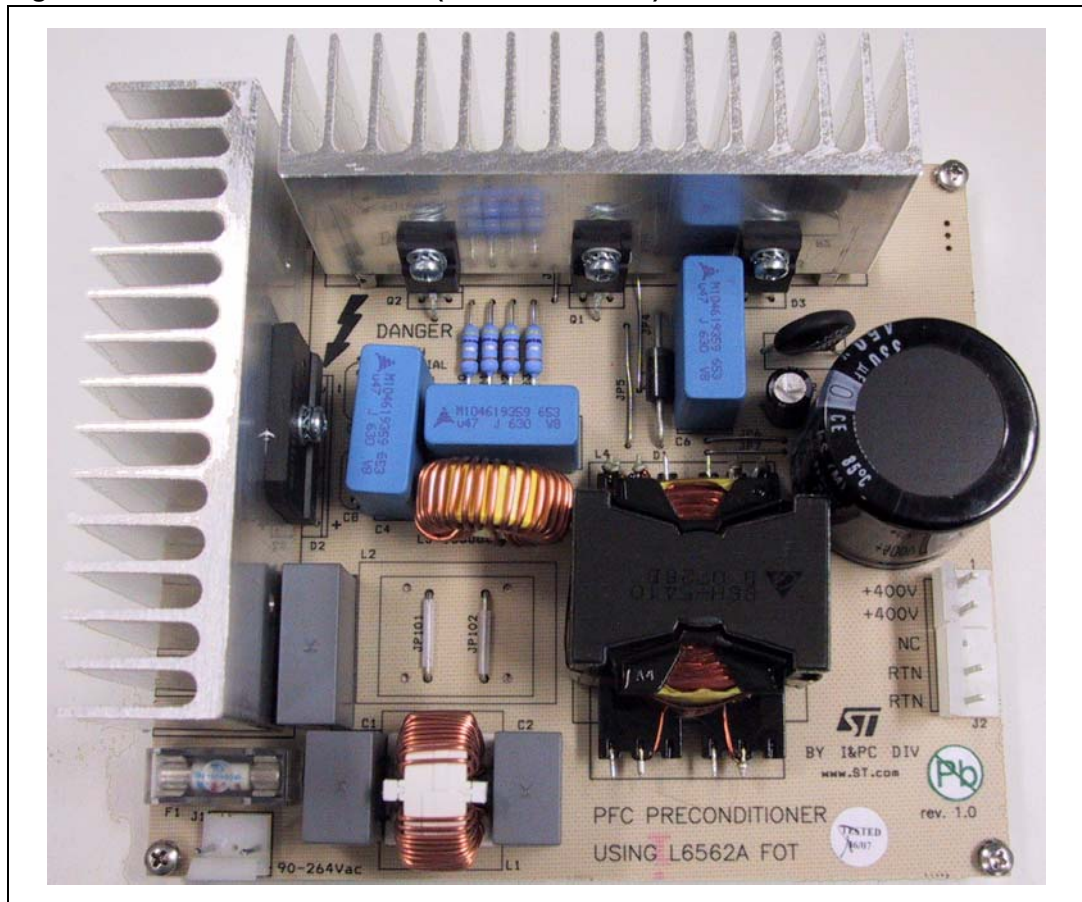


400 W FOT-controlled PFC pre-regulator with the L6562A

Introduction

This application note describes an demonstration board based on the transition-mode PFC controller L6562A and presents the results of its bench demonstration. The board implements a 400 W, wide-range mains input PFC pre-conditioner suitable for ATX PSU, flat screen displays, etc. In order to allow the use of a low-cost device like the L6562A at this power level, usually prohibitive for this device, the chip is operated with fixed-off-time control. This allows continuous conduction mode operation, normally achievable with more expensive control chips and more complex control architectures.

Figure 1. Demonstration board (EVL6562A-400W)



Contents

- 1 Main characteristics and circuit description 5**
- 2 Test results and significant waveforms 7**
 - 2.1 Harmonic content measurement 7
 - 2.2 Inductor current in FOT and L6562A THD optimizer 10
 - 2.3 Overvoltage protection and disable function 11
- 3 Layout hints 12**
- 4 Audible noise 13**
- 5 Thermal measures 14**
- 6 Conducted emission pre-compliance test 16**
- 7 Bill of material 17**
- 8 PFC coil specification 20**
 - 8.1 General description and characteristics 20
 - 8.2 Electrical characteristics 20
 - 8.3 Mechanical aspect and pin numbering 21
- 9 References 22**
- 10 Revision history 23**

List of tables

Table 1.	Measured temperature table at 115 Vac and 230 Vac - full load	15
Table 2.	Bill of material	17
Table 3.	Winding characteristics	20
Table 4.	Document revision history	23

List of figures

Figure 1.	Demonstration board (EVL6562A-400W)	1
Figure 2.	EVL6562A-400W demonstration board electrical schematic	6
Figure 3.	EVL6562A-400W compliance to EN61000-3-2 standard at full load	7
Figure 4.	EVL6562A-400W compliance to JEIDA-MITI standard at full load	7
Figure 5.	EVL6562A-400W compliance to EN61000-3-2 standard at 70 W load	7
Figure 6.	EVL6562A-400W compliance to JEIDA-MITI standard at 70 W load	7
Figure 7.	EVL6562A-400W input current waveform at 100 V - 50 Hz - 400 W load	8
Figure 8.	EVL6562A-400W input current waveform at 230 V - 50 Hz - 400 W load	8
Figure 9.	EVL6562A-400W input current waveform at 100 V - 50 Hz - 200 W load	8
Figure 10.	EVL6562A-400W input current waveform at 230 V - 50 Hz - 200 W load	8
Figure 11.	EVL6562A-400W input current waveform at 100 V - 50 Hz - 70 W load	8
Figure 12.	EVL6562A-400W input current waveform at 230 V - 50 Hz - 70 W load	8
Figure 13.	Power factor vs. Vin and load	9
Figure 14.	THD vs. Vin and load	9
Figure 15.	Efficiency vs. Vin and load	9
Figure 16.	Static Vout regulation vs. Vin and load	9
Figure 17.	EVL6562A-400W inductor current ripple envelope at 115 Vac - 60 Hz - full load	10
Figure 18.	EVL6562A-400W inductor current ripple (detail) at 115 Vac - 60 Hz - full load	10
Figure 19.	EVL6562A-400W inductor current ripple envelope at 230 Vac - 50 Hz - full load	11
Figure 20.	EVL6562A-400W Inductor current ripple (detail) at 230 Vac-50 Hz -full load	11
Figure 21.	EVL6562A-400W PCB layout (not scaled 1:1)	12
Figure 22.	Thermal map at 115 Vac - 60 Hz - full load	14
Figure 23.	Thermal map at 230 Vac - 50 Hz - full load	14
Figure 24.	115 Vac and full load - phase	16
Figure 25.	115 Vac and full load - neutral	16
Figure 26.	230 Vac and full load - phase	16
Figure 27.	230 Vac and full load - neutral	16
Figure 28.	Electrical diagram	20
Figure 29.	Pin side view	21

1 Main characteristics and circuit description

The main characteristics of the SMPS are listed here below:

- Line voltage range: 90 to 265 Vac
- Minimum line frequency (f_L): 47 Hz
- Regulated output voltage: 400 V
- Rated output power: 400 W
- Maximum $2f_L$ output voltage ripple: 10 V pk-pk
- Hold-up time: 22 ms (V_{DROF} after hold-up time: 300 V)
- Maximum switching frequency: 85 kHz ($V_{in} = 90$ Vac, $P_{out} = 400$ W)
- Minimum estimated efficiency: 90 % ($V_{in} = 90$ Vac, $P_{out} = 400$ W)
- Maximum ambient temperature: 50 °C
- EMI: In accordance with EN55022 class-B
- PCB type and size: Single side, 70 μ m, CEM-1, 148.5 x 132 mm
- Low profile design: 35 mm component maximum height

The demonstration board implements a power factor correction (PFC) pre-regulator delivering 400 W continuous power on a regulated 400 V rail from a wide-range mains voltage and provides for the reduction of the mains harmonics, which allows meeting the European norm EN61000-3-2 or the Japanese norm JEIDA-MITI. This rail is the input for the cascaded isolated DC-DC converter that provides the output rails required by the load.

The board is equipped with enough heat sinking to allow full-load operation in still air. With an appropriate airflow and without any change in the circuit, the demonstration board can easily deliver up to 450 W.

The controller is the L6562A (U1), integrating all the functions needed to control the PFC stage.

The L6562A controller chip is designed for transition-mode (TM) operation, where the boost inductor works next to the boundary between continuous (CCM) and discontinuous conduction mode (DCM). However, with a slightly different usage, the chip can operate so that the boost inductor works in CCM, hence surpassing the limitations of TM operation in terms of power handling capability. The gate-drive capability of the L6562A is also adequate to drive the MOSFETs used at higher power levels. This approach, which couples the simplicity and cost-effectiveness of TM operation with the high-current capability of CCM operation, is the Fixed-OFF-time (FOT) control. The control modulates the ON-time of the power switch, while its OFF-time is kept constant. More precisely, it uses the line-modulated FOT (LM-FOT) where the OFF-time of the power switch is not rigorously constant but is modulated by the instantaneous mains voltage. Please refer to [2] for a detailed description of this technique.

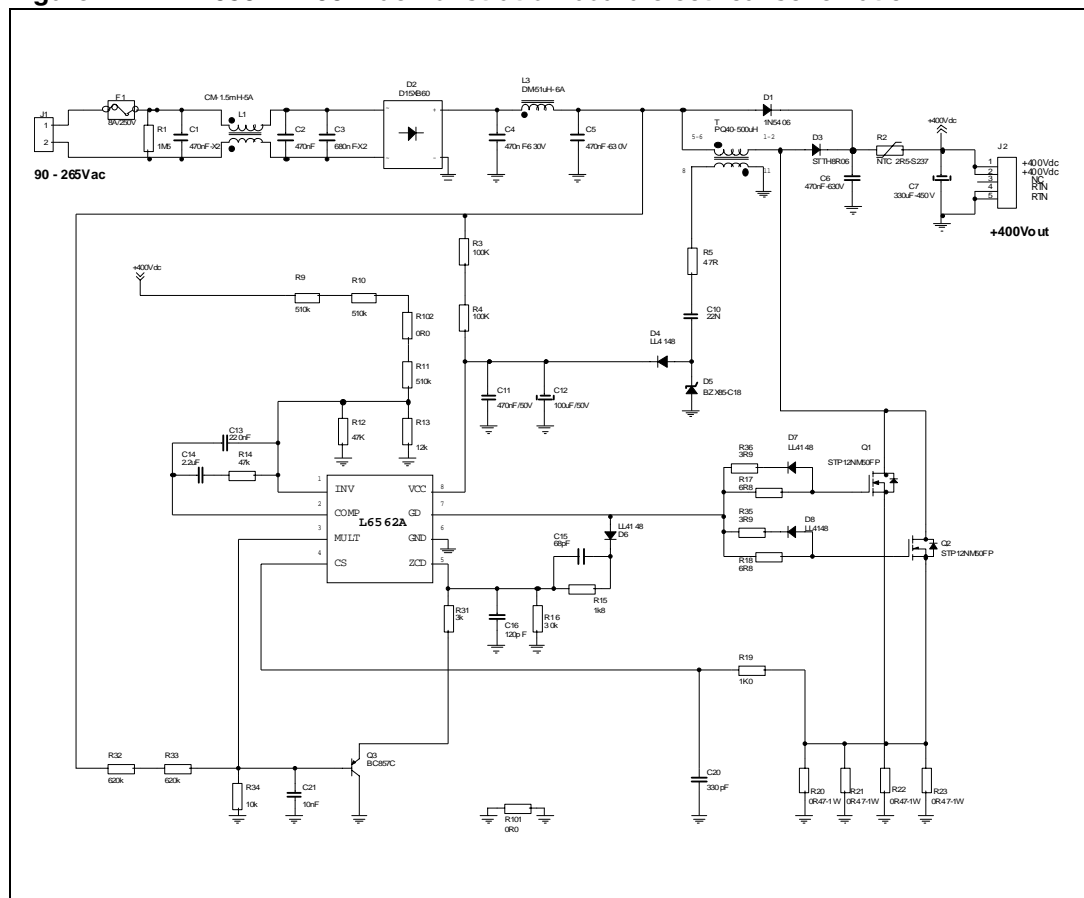
The power stage of the PFC is a conventional boost converter, connected to the output of the rectifier bridge D2. It includes the coil L4, the diode D3 and the capacitors C6 and C7. The boost switch is represented by the power mosfets Q1 and Q2. The NTC R2 limits the inrush current at switch-on. It has been connected on the DC rail, in series to the output electrolytic capacitor, in order to improve the efficiency during low-line operation. Additionally, the splitting in two of output capacitors (C6 and C7) allows managing the AC current mainly by the film capacitor C7 so that the electrolytic can be cheaper as it just has to bear the DC part only.

At startup the L6562A is powered by the Vcc capacitor (C12) that is charged via the resistors R3 and R4. Then the L4 secondary winding (pins 8-11) and the charge pump circuit (R5, C10, D5 and D4) generate the Vcc voltage powering the L6562A during normal operation.

The divider R32, R33 and R34 provides the L6562A multiplier with the information of the instantaneous voltage that is used to modulate the boost current. The divider R9, R10, R11, R12 & 13 is dedicated to sense the output. The Line-Modulated FOT is obtained by the timing generator components D6, C15, R15, C16, R16, R31, Q3.

The board is equipped with an input EMI filter designed for a 2-wire input mains plug. It is composed of two stages, a common mode pi-filter connected at the input (C1, L1, C2, C3) and a differential mode pi-filter after the input bridge (C4, L3, C5). It also offers the possibility to easily connect a downstream converter.

Figure 2. EVL6562A-400W demonstration board electrical schematic



2 Test results and significant waveforms

2.1 Harmonic content measurement

One of the main purposes of a PFC pre-conditioner is the correction of input current distortion, decreasing the harmonic contents below the limits of the actual regulations. Therefore, the board has been tested according to the European rule EN61000-3-2 class-D and Japanese rule JEIDA-MITI class-D, at full load and 70 W output power, at both the nominal input voltage mains.

As shown in the following figures of this page, the circuit is capable of reducing the harmonics well below the limits of both regulations from full load down to light load. 70 W of output power has been chosen because it approaches the lower power limit at which the harmonics have to be limited according to the mentioned rules.

Figure 3. EVL6562A-400W compliance to EN61000-3-2 standard at full load

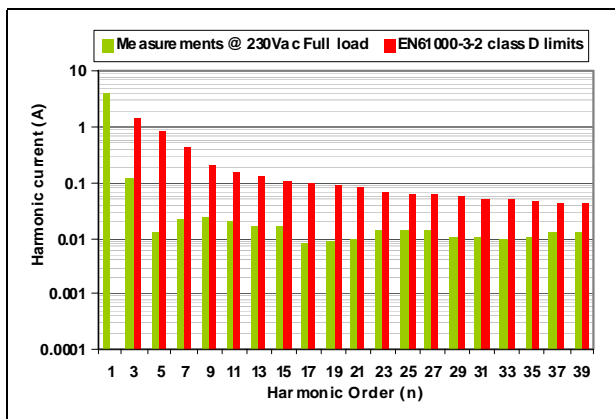


Figure 4. EVL6562A-400W compliance to JEIDA-MITI standard at full load

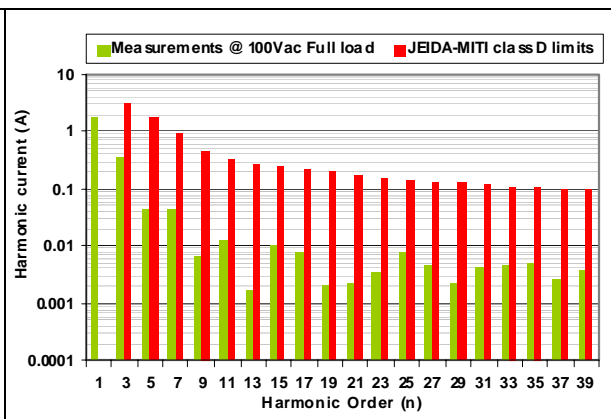


Figure 5. EVL6562A-400W compliance to EN61000-3-2 standard at 70 W load

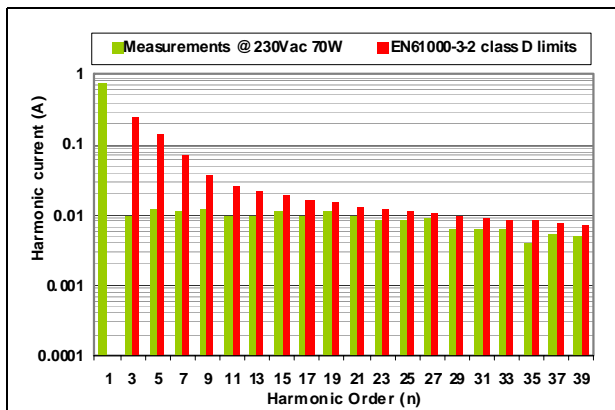
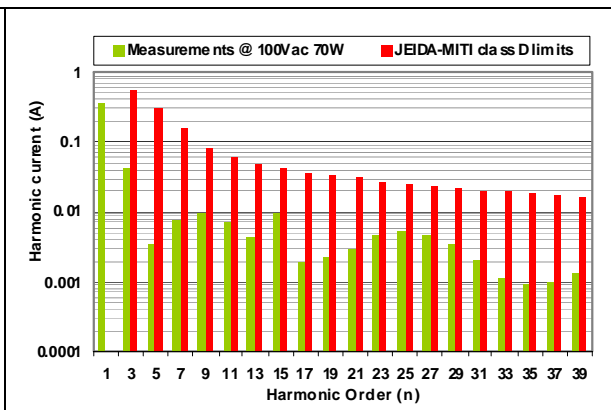


Figure 6. EVL6562A-400W compliance to JEIDA-MITI standard at 70 W load



For user reference, waveforms of the input current and voltage at the nominal input voltage mains and different load conditions are shown in the following figures.

Figure 7. EVL6562A-400W input current waveform at 100 V - 50 Hz - 400 W load

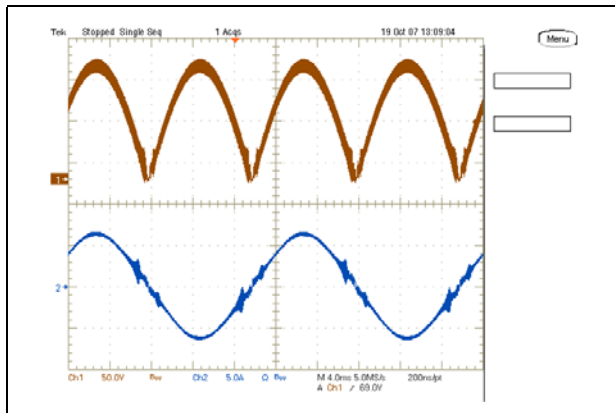


Figure 8. EVL6562A-400W input current waveform at 230 V - 50 Hz - 400 W load

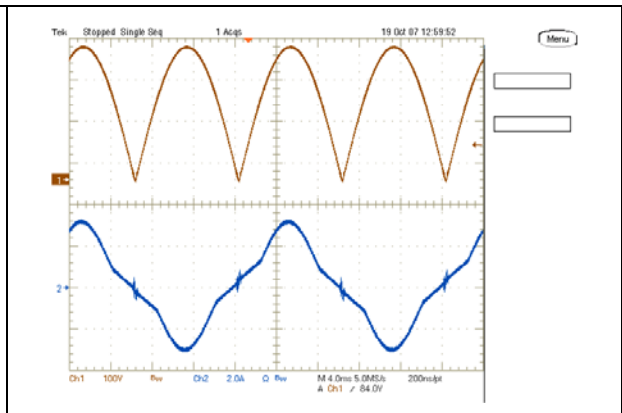


Figure 9. EVL6562A-400W input current waveform at 100 V - 50 Hz - 200 W load

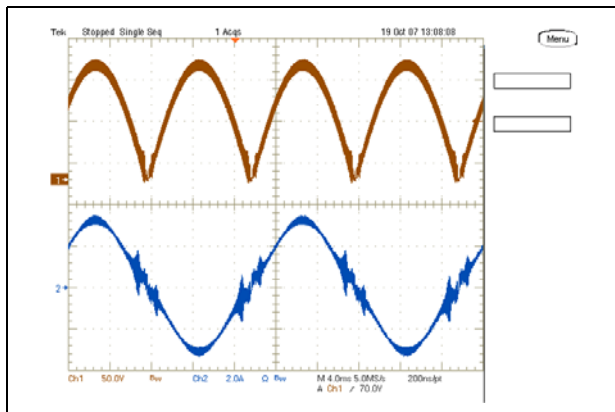


Figure 10. EVL6562A-400W input current waveform at 230 V - 50 Hz - 200 W load

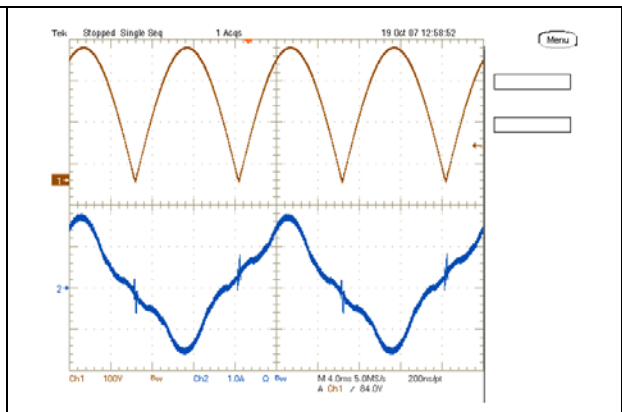


Figure 11. EVL6562A-400W input current waveform at 100 V - 50 Hz - 70 W load

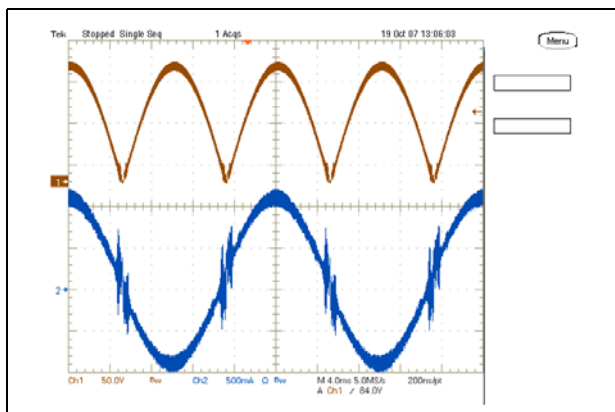
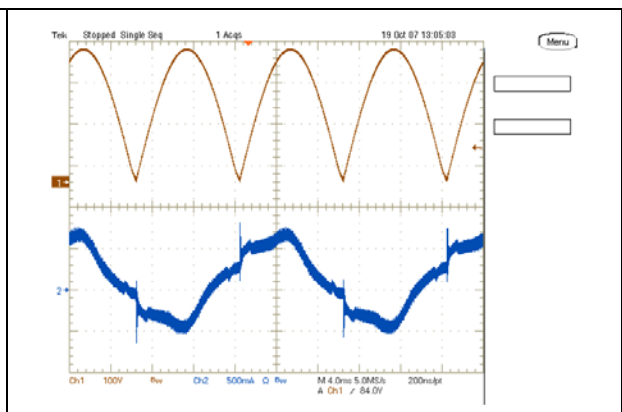


Figure 12. EVL6562A-400W input current waveform at 230 V - 50 Hz - 70 W load



The power factor (PF) and the total harmonic distortion (THD) have been measured too and the results are shown in [Figure 13](#) and [Figure 14](#). As visible, the PF at full load and half load remains close to unity throughout the input voltage mains range while, when the circuit is delivering 70 W, it decreases at high mains range. THD is low, remaining within 30 % at maximum input voltage.

Figure 13. Power factor vs. Vin and load

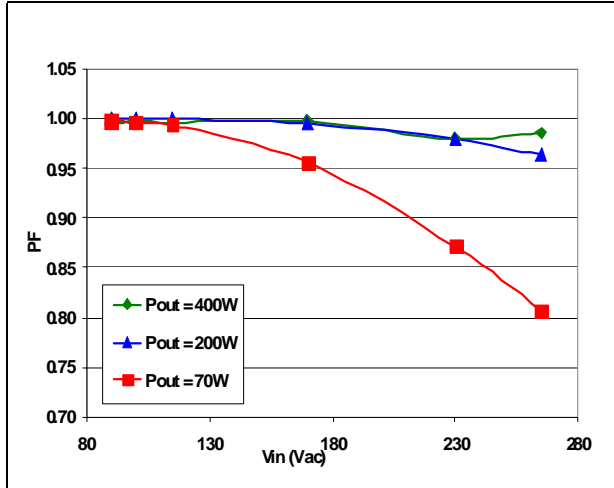
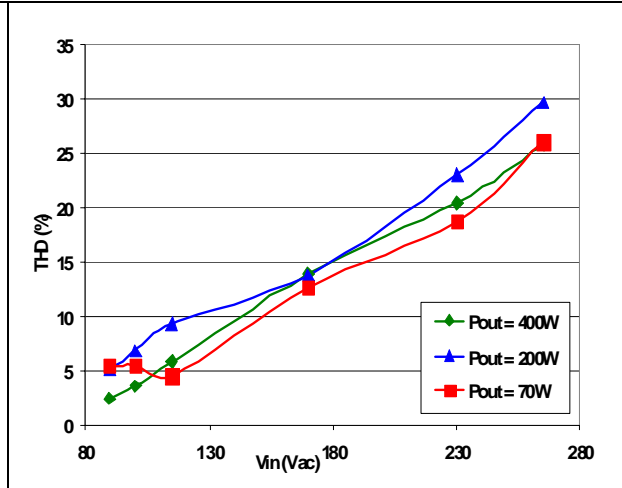


Figure 14. THD vs. Vin and load



The efficiency is very good at all load and line conditions. At full load it is always significantly higher than 90%, making this design suitable for high efficiency power supply.

The measured output voltage variation at different line and load conditions is shown in [Figure 16](#). As visible, the voltage is perfectly stable over the input voltage range. Just at 265 Vac and light load, there are negligible deviations of 1 V due to the intervention of the burst mode (for the "static OVP") function.

Figure 15. Efficiency vs. Vin and load

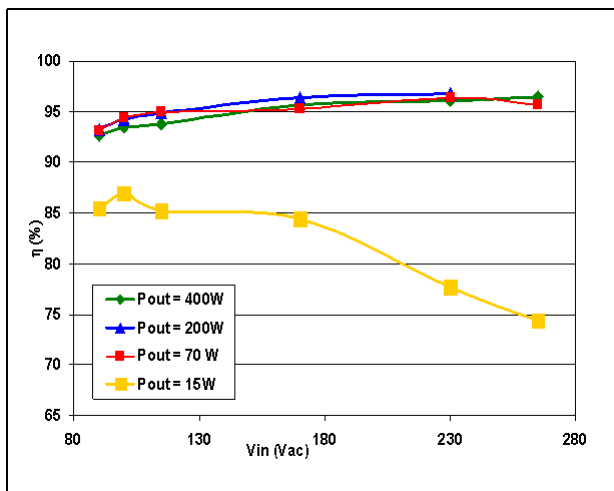
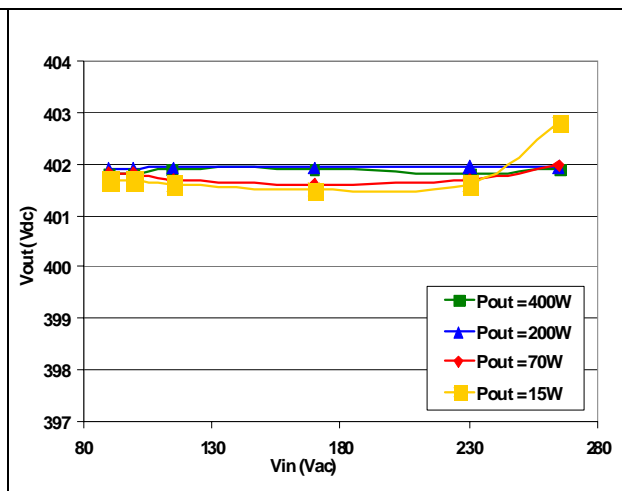


Figure 16. Static Vout regulation vs. Vin and load



2.2 Inductor current in FOT and L6562A THD optimizer

The following figures show the waveforms relevant to the inductor current at different voltage mains. As visible in [Figure 17](#) and [Figure 19](#), the inductor current waveform over a line half-period is very similar to that of a CCM PFC. In [Figure 18](#) and [Figure 20](#) the magnification of the waveforms at the peak of the sine wave shows the different ripple current and off-times, which is modulated by the input mains voltage. We can also note the transition angle from DCM to CCM that occurs closer to the zero-crossing of the current sine wave at low mains and moves toward the top if the circuit is working at high mains.

Figure 17. EVL6562A-400W inductor current ripple envelope at 115 Vac - 60 Hz - full load

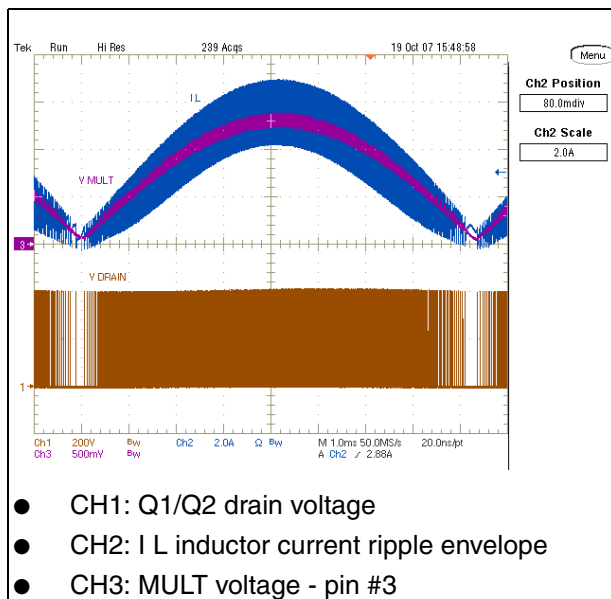
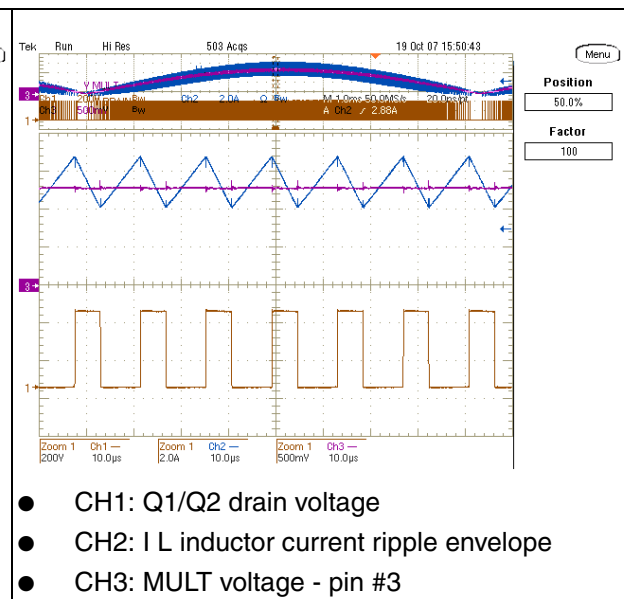


Figure 18. EVL6562A-400W inductor current ripple (detail) at 115 Vac - 60 Hz - full load



On both the drain voltage traces shown in [Figure 17](#) and [Figure 19](#), close to the zero-crossing points of the sine wave, it is possible to note the action of the THD optimizer embedded in the L6562A. It is a circuit that minimizes the conduction dead-angle occurring to the AC input current near the zero-crossings of the line voltage (crossover distortion). In this way, the THD (Total Harmonic Distortion) of the current is considerably reduced. A major cause of this distortion is the inability of the system to transfer energy effectively when the instantaneous line voltage is very low. This effect is magnified by the high-frequency filter capacitor placed after the bridge rectifier, which retains some residual voltage that causes the diodes of the bridge rectifier to be reverse-biased and the input current flow to temporarily stop. To overcome this issue the device forces the PFC pre-regulator to process more energy near the line voltage zero-crossings as compared to that commanded by the control loop.

This results in both minimizing the time interval where energy transfer is lacking and fully discharging the high-frequency filter capacitor after the bridge. Essentially, the circuit artificially increases the ON-time of the power switch with a positive offset added to the output of the multiplier in the proximity of the line voltage zero-crossings.

This offset is reduced as the instantaneous line voltage increases, so that it becomes negligible as the line voltage moves toward the top of the sinusoid.

To maximally benefit from the THD optimizer circuit, the high-frequency filter capacitors after the bridge rectifier should be minimized, compatibly with EMI filtering needs. A large capacitance, in fact, introduces a conduction dead-angle of the AC input current in itself thus reducing the effectiveness of the optimizer circuit.

Figure 19. EVL6562A-400W inductor current ripple envelope at 230 Vac - 50 Hz - full load

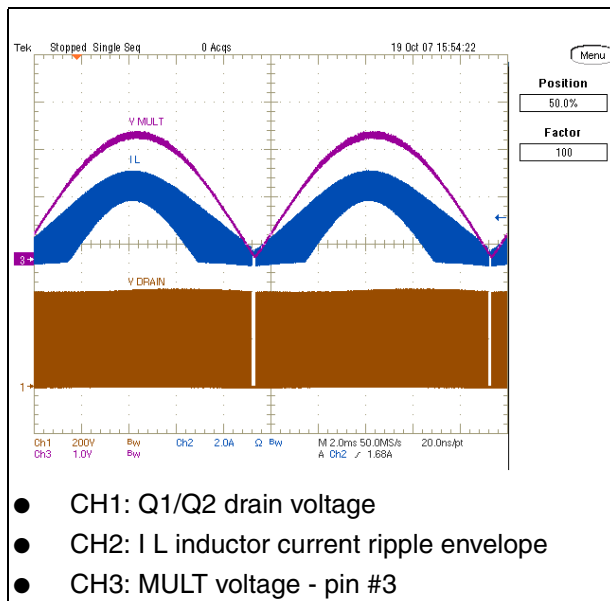
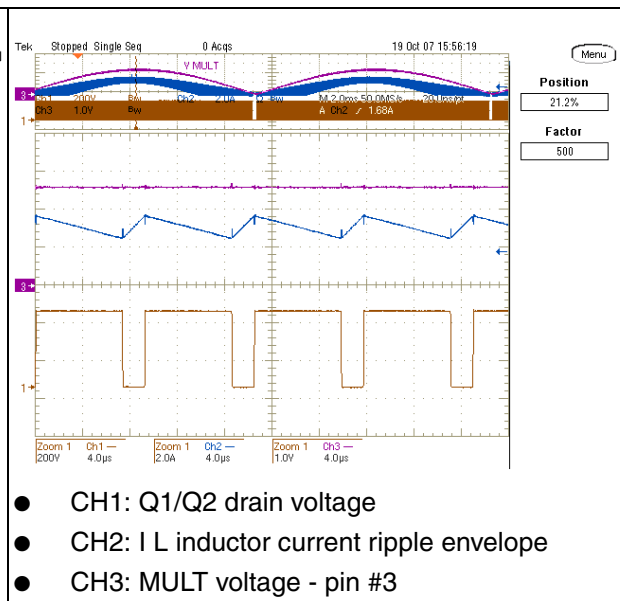


Figure 20. EVL6562A-400W Inductor current ripple (detail) at 230 Vac-50 Hz - full load



2.3 Overvoltage protection and disable function

The L6562A is equipped by an OVP, monitoring the current flowing through the compensation network and entering in the error amplifier (pin COMP, #2). When this current reaches about $24 \mu\text{A}$ the output voltage of the multiplier is forced to decrease, thus reducing the energy drawn from the mains. If the current exceeds $27 \mu\text{A}$, the OVP is triggered (dynamic OVP), and the external power transistor is switched off until the current falls approximately below $7 \mu\text{A}$. However, if the overvoltage persists (e.g. in case the load is completely disconnected), the error amplifier eventually saturates low hence triggering an internal comparator (static OVP) that keeps the external power switch turned off until the output voltage comes back close to the regulated value.

The OVP function described above is able to handle abnormal overload conditions, i.e. those resulting from an abrupt load/line change or occurring at startup.

The INV pin doubles its function as a non-latched IC disable. A voltage below 0.2 V shuts down the IC and reduces its consumption to a lower value. To restart the IC, the voltage on the pin must exceed 0.45 V . The main usage of this function is a remote ON/OFF control input that can be driven by a PWM controller for power management purposes. However it also offers a certain degree of additional safety since it causes the IC to shut down in case the lower resistor of the output divider is shorted to ground or if the upper resistor is missing or fails to open.

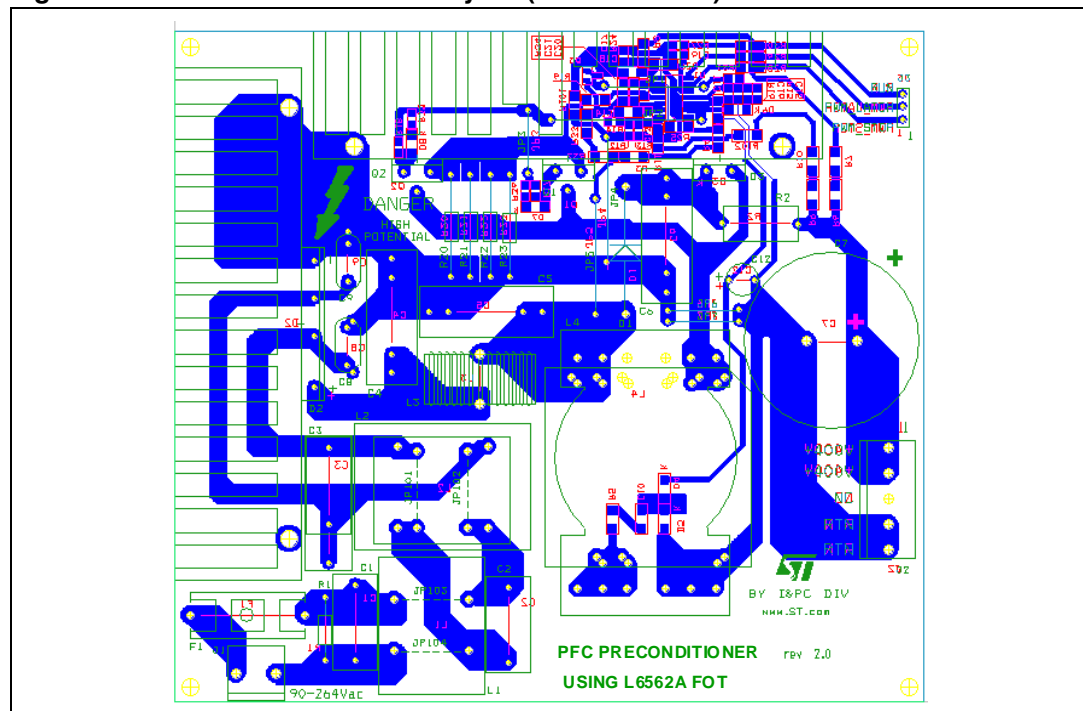
3 Layout hints

The layout of any converter is a very important phase in the design process that sometimes does not have enough attention from the engineers. Even if the layout phase sometimes looks time-consuming, a good layout does save time during the functional debugging and the qualification phases. Additionally, a power supply circuit with a correct layout needs smaller EMI filters or less filter stages which allows consistent cost savings.

The L6562A does not need any special attention to the layout, just the general layout rules for any power converter have to be carefully applied. Basic rules are listed below, using the EVL6562A-400W schematic as a reference. They can be used for other PFC circuits having any power level, working either in FOT or TM control.

1. Keep power and signal RTNs separated. Connect the return pins of component-carrying high currents such as C4, C5 (input filter), sense resistors, and C6, C7 (output capacitors) as close as possible. This point is the RTN star point. A downstream converter must be connected to this return point.
2. Minimize the length of the traces relevant to L3, boost inductor L4, boost rectifier D4 and output capacitor C6 and C7.
3. Keep signal components as close as possible to each L6562A relevant pin. Specifically, keep the tracks relevant to pin #1 (INV) net as short as possible. Components and traces relevant to the error amplifier have to be placed far from traces and connections carrying signals with high dv/dt like the MOSFET drains (Q1 and Q2).
4. Connect heat sinks to power GND.
5. Add an external shield to the boost inductor and connect it to power GND.
6. Connect a ceramic capacitor (100 ÷ 470 uF) to pin #8 (Vcc) and to pin #6 (GND) and close to the L6562A. Connect pin #6 (GND) to the RTN star point (see 1).

Figure 21. EVL6562A-400W PCB layout (not 1:1 scaled)



4 Audible noise

Differential mode currents in a circuit with high-frequency and low-frequency components (like in a PFC) may produce audible noise due to intermodulation between operating frequency and mains line frequency.

The phenomenon is produced because of mechanical vibration of reactive components like capacitors and inductors. Current flowing in the winding can cause the vibration of wires or ferrite which produces buzzing noise. Therefore to avoid this noise, boost and filter inductors have to be wound with correct wire tension, and the component has to be varnished or dipped. Frequently, X-capacitors and filter capacitors after the bridge generate acoustic noise because of the AC current that causes the electrodes to vibrate which produces buzzing noise. Thus, in order to minimize the AC current, inserting a differential mode (pi-filter between the bridge and the boost inductor) helps to reduce the acoustic noise and additionally the EMI filter benefits. This type of filter decreases significantly the ripple current that otherwise has to be filtered by the EMI filter. The capacitors to select are polypropylene, preferably dipped type, because boxed ones are generally more at risk to generate acoustic noise.

The grounding of the boost inductor may help, because we decrease the emissions from the most efficient "antenna" of our circuit. In fact, in case of improper layout, some picofarads of layout parasitic capacitance, together with the very high dV/dt of the MOSFET drain voltage, may inject noise somewhere in the circuit.

5 Thermal measures

In order to check the design reliability, a thermal mapping by means of an IR camera was done. *Figure 22* and *23* show thermal measures on the board component side at nominal input voltages and full load. Some pointers visible on the pictures placed across key components show the relevant temperature. *Table 1* provides the correlation between measured points and components for both thermal maps. The ambient temperature during both measurements was 27 °C. According to these measurement results, all components of the board are working within their temperature limits.

Figure 22. Thermal map at 115 Vac - 60 Hz - full load

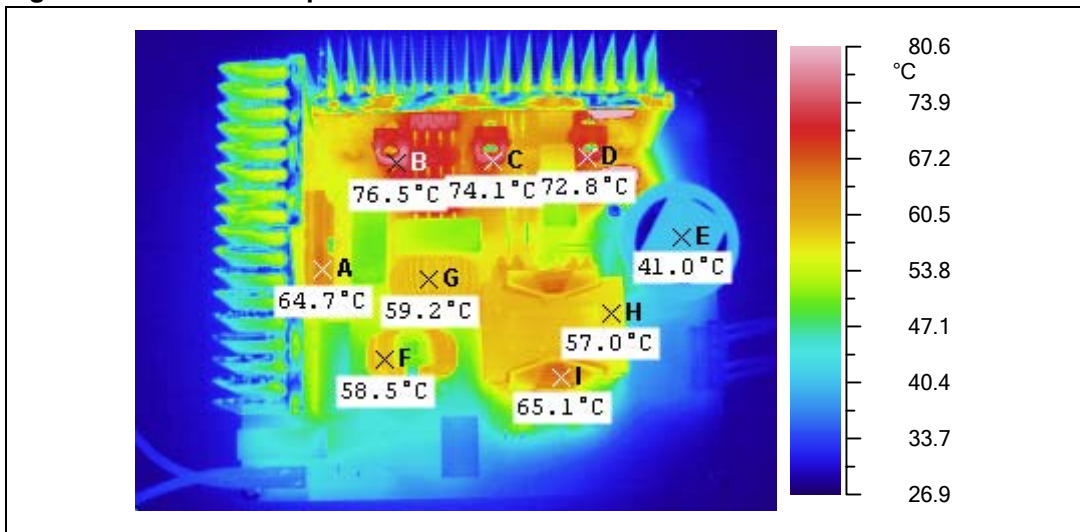


Figure 23. Thermal map at 230 Vac - 50 Hz - full load

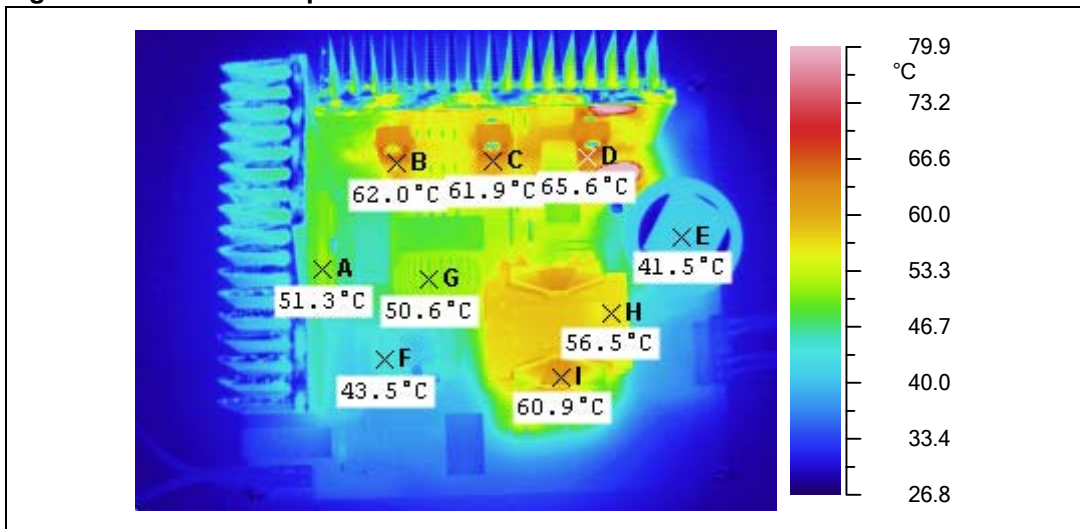


Table 1. Measured temperature table at 115 Vac and 230 Vac - full load

Point	Component	Temperature at 115 Vac	Temperature at 230 Vac
A	D2	64.7 °C	51.3 °C
B	Q2	76.5 °C	62.0 °C
C	Q1	74.1 °C	61.9 °C
D	D3	72.8 °C	65.6 °C
E	C7	41.0 °C	41.5 °C
F	L1	58.5 °C	43.5 °C
G	L3	59.2 °C	50.6 °C
H	L4 – CORE	57.0 °C	56.5 °C
I	L4 - WINDING	65.1 °C	60.9 °C

6 Conducted emission pre-compliance test

The following figures show the peak measurement of the conducted noise at full load and nominal mains voltages. The limits shown in the diagrams are EN55022 class-B which is the most popular rule for domestic equipment using a two-wire mains connection. As visible in the diagrams, in all test conditions there is a good margin of the measures with respect to the limits.

Figure 24. 115 Vac and full load - phase

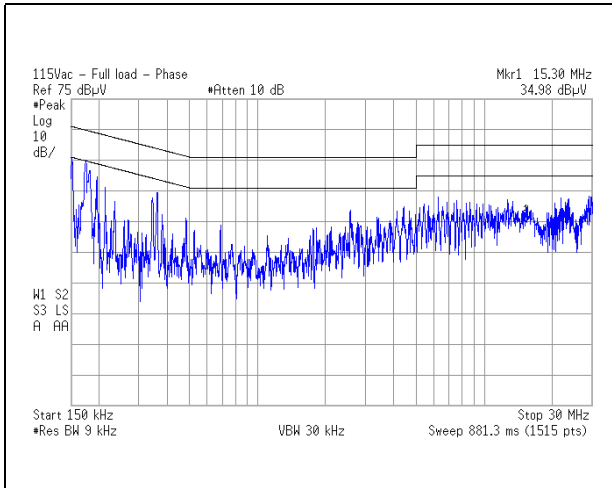


Figure 25. 115 Vac and full load - neutral

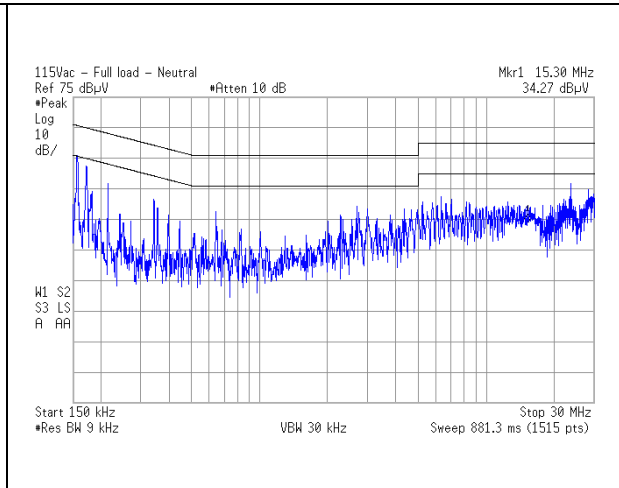


Figure 26. 230 Vac and full load - phase

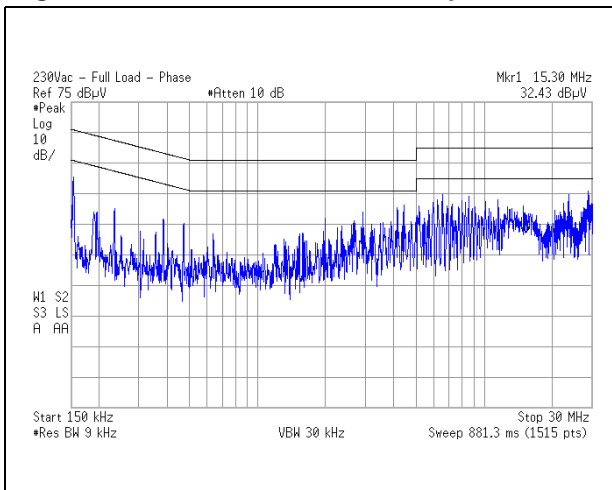
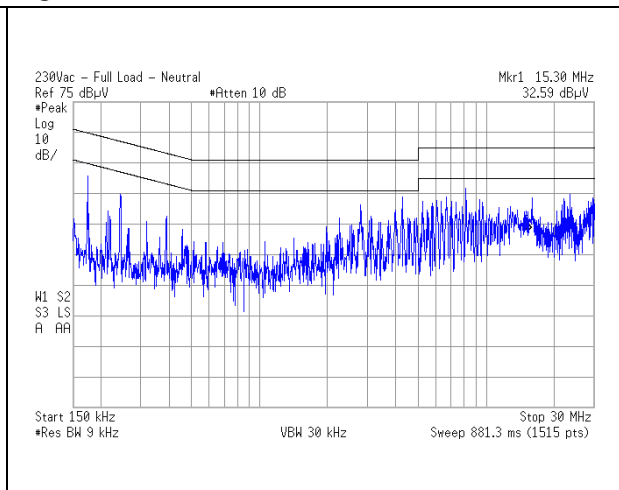


Figure 27. 230 Vac and full load - neutral



7 Bill of material

Table 2. Bill of material

Ref. Des.	Part type-part value	Case/Package	Description	Supplier
C1	470 nF - X2	DWG	X2 film capacitor R46-I 3470--M1-	ARCOTRONICS
C10	22 nF	1206	100 V SMD cericap - general purpose	AVX
C11	470 nF	1206	50 V SMD cericap - general purpose	AVX
C12	100 uF	DIA8X11 (MM)	Aluminium elcap - YXF SERIES - 105 °C	Rubycon
C13	220 nF	0805	50 V SMD cericap - general purpose	AVX
C14	2.2 uF	1206	50 V SMD cericap - general purpose	AVX
C15	100 pF	0805	50 V SMD cericap - general purpose	AVX
C16	120 pF	0805	50 V SMD cericap - general purpose	AVX
C2	470 n F - X2	DWG	X2 film capacitor R46-I 3470--M1-	Arcotronics
C20	330 pF	0805	50 V SMD cericap - general purpose	AVX
C21	10 nF	1206	50 V SMD cericap - general purpose	AVX
C3	680 nF - X2	DWG	X2 film capacitor R46-I 3680--M1-	Arcotronics
C4	470 nF / 630 V	DWG	Film capacitor MKP - B32653A6474J	EPCOS
C5	470 nF / 630 V	DWG	Film capacitor MKP - B32653A6474J	EPCOS
C6	470 nF / 630 V	DWG	Film capacitor MKP- B32653A6474J	EPCOS
C7	330 uF / 450 V	DIA 35x35 (MM)	Aluminium elcap - LLS series - 85 °C	Nichicon
C8	RES	DWG	Not used	-
C9	RES	DWG		
D1	1N5406	DO-201	Standard recovery rectifier	Vishay
D2	D15XB60	DWG	Rectifier bridge	Shindengen
D3	STTH8R06	TO-220FP	Ultrafast high voltage rectifier	STMicroelectronics
D4	LL4148	MINIMELF	Fast switching diode	Vishay
D5	BZX85-C18	MINIMELF	Zener diode	
D6	LL4148	MINIMELF	Fast switching diode	
D7	LL4148	MINIMELF	Fast switching diode	
D8	LL4148	MINIMELF	Fast switching diode	
F1	8A/250V	5x20 MM	8 A mains input fuse	Wickmann
J1			3-pins conn. (central rem.) P 3.96 KK series	Molex
J2			5-pins conn. (central rem.) P 3.96 KK series	
JP101	JUMPER		Wire jumper	

Table 2. Bill of material (continued)

Ref. Des.	Part type-part value	Case/Package	Description	Supplier
JP102	JUMPER		Wire jumper	
L1	CM-1.5 mH-5 A	DWG	CM choke - LFR2205B	Delta electronics
L2	RES	DWG	Not used	-
L3	DM-51 uH-6 A	DWG	Filter inductor - LSR2306-1	Delta electronics
L4	PQ40-500 uH	DWG	PFC inductor - 86H-5410B	
Q1	STP12NM50FP	TO-220FP	N-channel power MOSFET	STMicroelectronics
Q2	STP12NM50FP	TO-220FP	N-channel power MOSFET	
Q3	BC857C	SOT-23	Small signal BJT - PNP	Vishay
R1	1 M5	AXIAL	HV resistor	BC components
R10	510 k	1206	SMD STD film res - 1% - 250 ppm / °C	
R11	510 k	1206	SMD STD film res - 1% - 250 ppm / °C	
R12	47 k	0805	SMD STD film res - 1% - 250 ppm / °C	
R13	12 k	0805	SMD STD film res - 1% - 250 ppm / °C	
R14	47 k	0805	SMD STD film res - 5% - 250 ppm / °C	
R15	1 k8	0805	SMD STD film res - 1% - 100 ppm / °C	
R16	30 k	0805	SMD STD film res - 1% - 100 ppm / °C	
R17	6R8	0805	SMD STD film res - 5% - 250 ppm / °C	
R18	6R8	0805	SMD STD film res - 5% - 250 ppm / °C	
R19	1 K0	1206	SMD STD film res - 5% - 250 ppm / °C	
R2	NTC 2R5	DWG	NTC resistor 2R5 S237	
R20	0R47-1 W	AXIAL	Axial res - 5% - 250 ppm / °C	BC components
R21	0R47-1 W	AXIAL	Axial res - 5% - 250 ppm / °C	
R22	0R47-1 W	AXIAL	Axial res - 5% - 250 ppm / °C	
R23	0R47-1 W	AXIAL	Axial res- 5% - 250 ppm / °C	
R25	RES	1206	Not used	-

Table 2. Bill of material (continued)

Ref. Des.	Part type-part value	Case/Package	Description	Supplier
R3	100 K	1206	SMD STD film res - 5% - 250 ppm / °C	BC components
R31	3 k	0805	SMD STD film res - 1% - 100 ppm / °C	
R32	620 k	1206	SMD STD film res - 5% - 250 ppm / °C	
R33	620 k	1206	SMD STD film res - 5% - 250 ppm / °C	
R34	10 k	1206	SMD STD film res - 5% - 250 ppm / °C	
R35	3R9	0805	SMD STD film res - 5% - 250 ppm / °C	
R36	3R9	0805	SMD STD film res - 5% - 250 ppm / °C	
R4	100 K	1206	SMD STD film res - 5% - 250 ppm / °C	
R5	47 R	1206	SMD STD film res - 5% - 250 ppm / °C	
R9	510 k	1206	SMD STD film res - 1% - 250 ppm / °C	
R101	0R0	1206	SMD STD film res - 5% - 250 ppm / °C	
R102	0R0	1206	SMD STD film res - 5% - 250 ppm / °C	
U1	L6562AD	SO-8	Transition-mode PFC controller	

8 PFC coil specification

8.1 General description and characteristics

- Application type: consumer, home appliance
- Inductor type: open
- Coil former: vertical type, 6+6 pins
- Max. temp. rise: 45 °C
- Max. operating ambient temperature: 60 °C

8.2 Electrical characteristics

- Converter topology: boost PFC pre-regulator, FOT control
- Core type: PQ40-30 material grade PC44 or equivalent
- Max. operating frequency: 100 kHz
- Primary inductance: 500 μH 10 % at 1 kHz - 0.25 V ^(a)
- Primary RMS current: 4.75 A

Figure 28. Electrical diagram

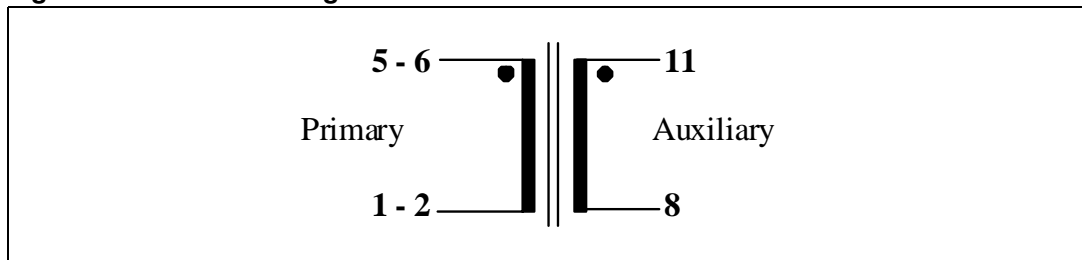


Table 3. Winding characteristics

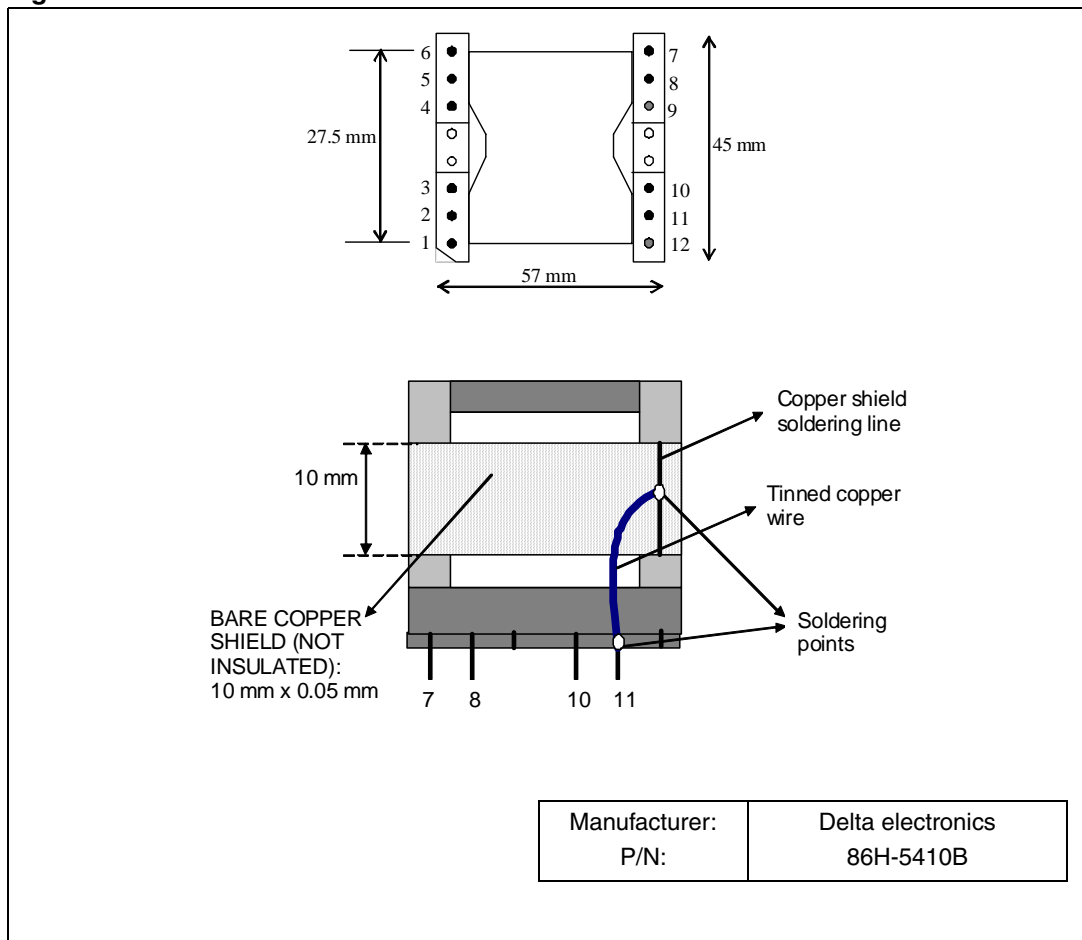
Start pins	End pins	Number of turns	Wire type	Wire diameter	Notes
11	8	5 (spaced)	Single – G2	0.28Ø	Bottom
5 - 6	1 - 2	65	Multistrand – G2	Litz 0.2Ø x 30	Top

a. Measured between pins 1-2 and 5-6

8.3 Mechanical aspect and pin numbering

- Maximum height from PCB: 31 mm
- Ferrite: Two symmetrical half cores, PQ40-30
- Material grade: PC44 or equivalent
- Central leg air gap: ~1 mm
- Coil former type: vertical, 6+6 pins
- Pin distance: 5 mm
- Row distance: 45.5 mm
- Cut pins: 9 - 12
- External copper shield: not insulated (for EMI reasons), connected to pin 11 (GND)

Figure 29. Pin side view



9 References

1. "L6562A transition-mode PFC controller" datasheet
2. "Design of fixed-off-time-controlled PFC pre-regulators with the L6562", AN1792
3. "EVAL6562-375W demonstration board L6562-based 375W FOT-controlled PFC pre-regulator" AN1895
4. "L6561, enhanced transition-mode power factor corrector", AN966
5. "400 W FOT-controlled PFC pre-regulator with the L6563", AN2485

10 Revision history

Table 4. Document revision history

Date	Revision	Changes
30-Jul-2008	1	Initial release

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