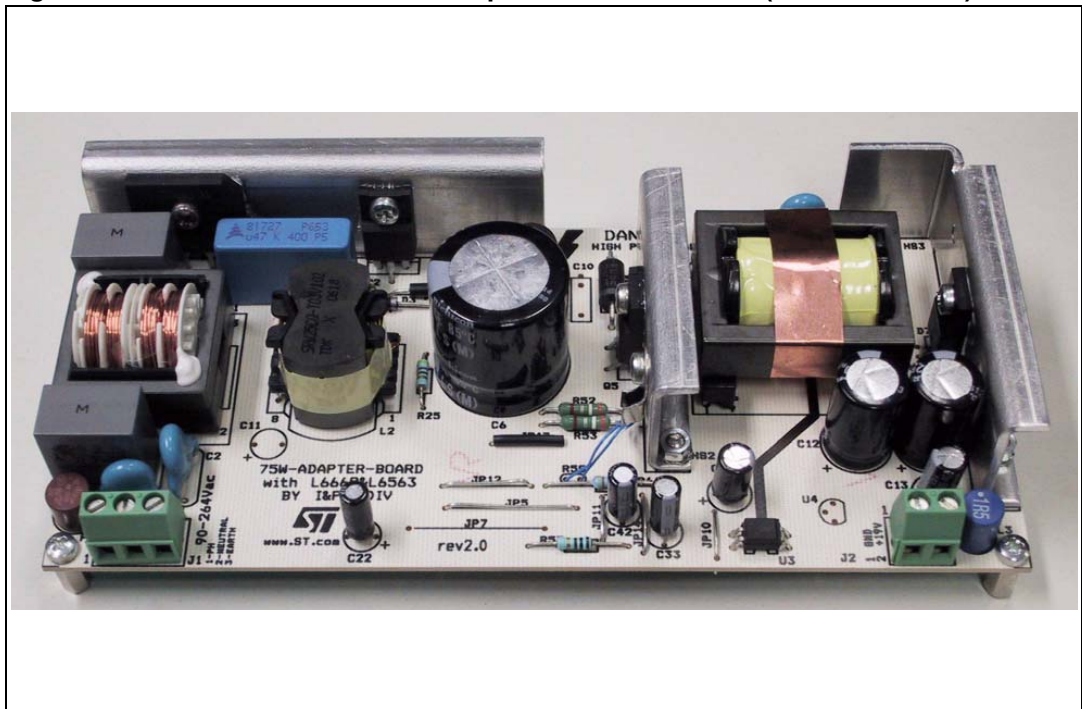


## 19 V - 75 W laptop adapter with tracking boost PFC pre-regulator, using the L6563 and L6668

### Introduction

This application note describes the characteristics and features of a 75 W wide range input mains and power-factor-corrected ac-dc adapter evaluation board. Its electrical specification is tailored to a typical high-end portable computer power adapter. The distinctive attributes of this design are the very low standby input consumption ( $< 0.3 \text{ W}$  at 265 V), the excellent global efficiency ( $> 85\%$ ) for a two stage architecture and the low cost.

**Figure 1.** L6668 and L6563-75W adapter evaluation board (EVAL6668-75W)



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# 1 Main characteristics and circuit description

The main characteristics of the SMPS are listed here below:

- Universal input mains range: 90 - 264 Vac, 45 –65 Hz
- Output voltages: 19 V @ 4 A continuous operation
- Mains harmonics: in accordance with EN61000-3-2 class-D
- Standby mains consumption: less than 0.3 W @ 265 Vac
- Overall efficiency: greater than 85%
- EMI: in accordance with EN55022-class B
- Safety: in accordance with EN60950
- PCB single layer: single side, 70  $\mu$ m, CEM-1, 78 x 174 mm, mixed PTH/SMT

The circuit is made up of two stages: a front-end PFC using the L6563 and a flyback converter based on the L6668. The electrical schematic is shown in [Figure 2](#).

The flyback stage works as the master stage and therefore is dedicated to controlling circuit operation, including standby and protection functions. Additionally, it switches the PFC stage on and off by means of a dedicated pin on the control IC, thus helping to achieve good efficiency even at light load. The input EMI filter is a classic Pi-filter, 1-cell for differential and common mode noise. An NTC in series with the PFC output capacitor limits the inrush current produced by the charging of the capacitor at plug-in.

The purpose of the PFC stage is to reduce the harmonic content of the input current to be within the limits imposed by European norm EN61000-3-2. Additionally, it provides a regulated dc bus used by the downstream converter.

The PFC controller is the L6563 (U1), working in transition mode. It integrates all functions needed to control the PFC as well as an interface to the master converter. Its power stage topology is a conventional boost converter, connected to the output of the rectifier bridge. It includes the coil L2, the diode D3, the capacitor C6 and the power switch Q2, a power MOSFET.

The secondary winding of L2 (pins 8-3) provides the L6563 with information about the core demagnetization of the PFC coil, needed by the controller for TM (transition mode) operation. The divider R7, R12 and R18 provides the L6563 with the instantaneous input voltage information that is used to modulate the boost current, and to derive additional information such as the average value of the ac line, which is used by the  $V_{FF}$  (voltage feed-forward) function. The divider R2, R6, R8, R9 is dedicated to sensing the output voltage and feeds the information to the error amplifier, while the divider R3, R5, R11, R19, directly connected to the output voltage, is dedicated to protecting the circuit in case of voltage loop failure. To maximize overall efficiency, the PFC makes use of the so-called "tracking boost option" (TBO). With this function implemented the dc output voltage of the PFC changes proportionally with the mains voltage. The L6563 achieves this functionality by adding a resistor (R30) connected to the dedicated TBO pin (#6).

The PFC is switched on and off by a switch (Q1) on the  $V_{CC}$  pin of the L6563, which is activated by the PFC-STOP pin of the L6668. The PFC-STOP pin is intended to stop the PFC controller at light load by cutting its supply. This happens when the COMP pin on the L6668 controller goes below 2.2V.

The downstream converter, acting as the master stage, is managed by the L6668 IC (U2), a current mode controller. The 65 kHz nominal switching frequency has been chosen to

achieve a compromise between the transformer size and the harmonics of the switching frequency, thereby optimizing the input filter size and the total solution cost. The power MOSFET is a standard, inexpensive 800 V component housed in a TO-220FP package, requiring a small heat sink. The transformer is the layer type, using the standard ferrite core EER35. The transformer is manufactured by TDK and designed in accordance with EN60950. The reflected voltage is ~130 V, providing sufficient room for the leakage inductance voltage spike while maintaining a margin for the reliability of the power MOSFET. The rectifier D8 and the Transil D4 clamp the peak of the leakage inductance voltage spike at turn-off of the power MOSFET.

The controller L6668 offers maximum flexibility by integrating all the functionality needed for high performance SMPS control with a minimum component count. A new feature embedded in the device is a high voltage current source used at start-up which draws current directly from the dc bus and charges capacitor C33. After the voltage on C33 has reached the L6668 turn-on threshold and the circuit starts to operate, the controller is powered by the transformer via the auxiliary winding and diode D11. After start-up, the HV current source is deactivated, saving power during normal operation and allowing very good circuit efficiency during standby.

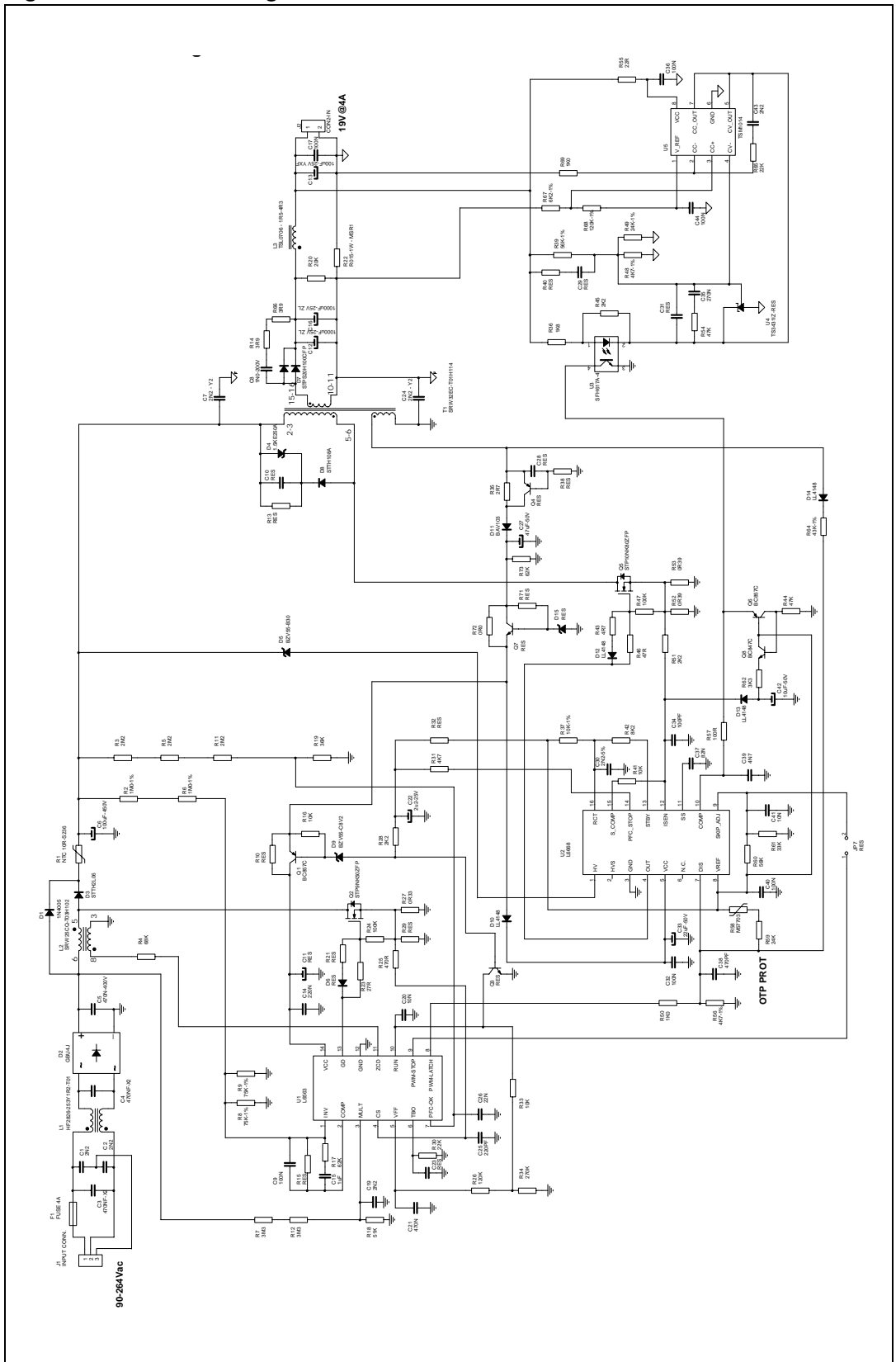
The L6668 utilizes a Current Mode control system, so the current flowing through the primary winding is sensed by R52 and R53 and is then fed into pin #12 (ISEN). Resistor R41 connected between pin #12 (ISEN) and pin #15 (S\_COMP) provides the correct slope compensation to the current signal, necessary for correct loop stability in CCM mode at duty cycles greater than 50%. The circuit connected to pin #7 (DIS) provides over-voltage protection in case of feedback network failure, while the thermistor R58 provides for a thermal protection of the power MOSFET (Q5). This pin is also connected to the PWM\_LATCH pin of the L6563 which is dedicated to stopping activity of the flyback converter in case of PFC loop failure that could be damaging to the circuit. To definitively latch this state, the internal circuitry of the L6668 monitors the  $V_{CC}$  and periodically reactivates the HV current source to supply the IC. After OVP detection and L6668 Disable intervention, circuit operation can be resumed only after disconnection of the mains plug. The switching frequency is programmed by the RC connected to pin #16 (RCT) and in case of reduced load operation the controller can decrease the operating frequency via pin #13 (STBY) and resistor R42, proportionate with the load consumption. The resistor divider R60 and R61 connected to pin #9 (SKIPADJ) allows setting of the initial L6668 threshold to Burst Mode functionality when the power supply is lightly loaded. Additional functions embedded in the L6668 are the programmable soft-start and a 5 V reference, available externally.

Circuit regulation is achieved by modulating the voltage on the COMP pin (#10), by means of the optocoupler U3. Also connected to the COMP pin is the Q6, Q8, R44, R62, C42 and D13 network, which is dedicated to driving ISEN over its hiccup mode threshold in case of overload or short condition. In this case the device will be shut down and its consumption will decrease almost to pre-start-up level. The device will resume operation as soon as the  $V_{CC}$  voltage has dropped below the  $V_{CC}$  restart level. Thus a reliable hiccup mode is invoked until the short is removed. A short on-time and long off-time of the hiccup mode are obtained allowing the average current flowing in the secondary side components to be kept at a safe level, avoiding consequent catastrophic failures due to their overheating.

Output regulation is done by means of two loops, a voltage and a current loop working alternately. A dedicated control IC, the TSM1014, has been used. It integrates two operational amplifiers and a precise voltage reference. The output signal of the error amplifiers drives optocoupler SFH617A-4 to transfer the information to the primary side and achieve the required insulation of the secondary side. The output rectifier D7 is a dual common-cathode Schottky diode. The output rectifier has been selected according to the

calculated maximum reverse voltage, forward voltage drop and power dissipation. The snubber, made up of R14, R66 and C8, damps the oscillation produced by the diode D7. A small LC filter has been added on the output in order to filter the high frequency ripple.

Figure 2. Electrical diagram



## 2 Test results

### 2.1 Efficiency measurements at full load, tracking boost option (TBO)

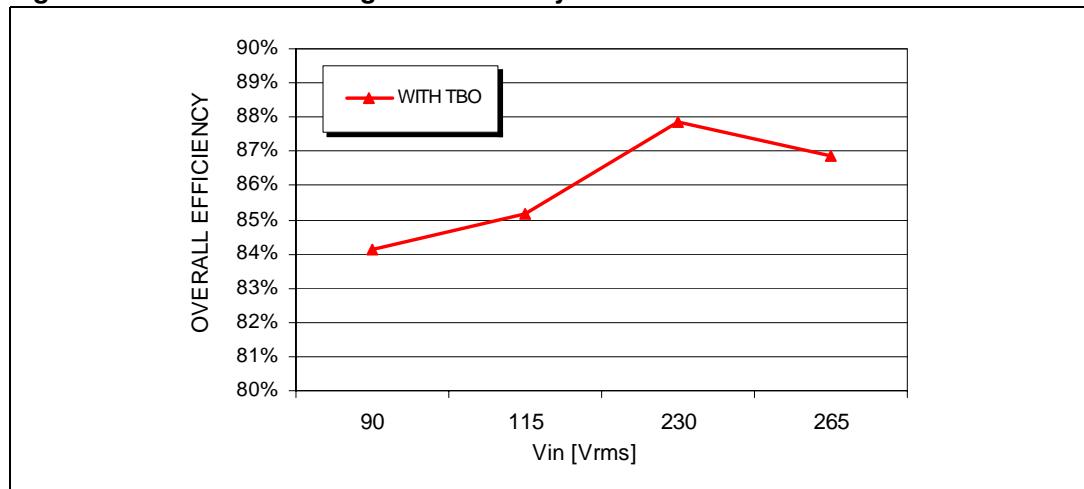
The following table and diagrams show the single converter and overall efficiency measured at different input voltages. These measurements are performed with nominal load (4 A).

**Table 1. Efficiency measurements at full load using the TBO function**

Vin <sub>ac</sub>	Efficiency		
	PFC	dc-dc	Global
90 [V]	93.63%	89.83%	84.11%
115 [V]	95.62%	89.07%	85.17% <sup>(1)</sup>
230 [V]	97.84%	89.81%	87.87% <sup>(1)</sup>
265 [V]	97.53%	89.06%	86.86%

1. Compliant to CEC, EU-COC, regulation. In [Table 1](#) and [Figure 3](#) the single converter efficiency measurement is shown. Thanks to the very good efficiency of any single block the overall efficiency is very high too, especially if we compare this data with similar converters using a double stage and a flyback topology as downstream converter.

**Figure 3. EVAL6668-75W global efficiency measurements at full load**



**Table 2. ENERGY STAR compliance**

Vin <sub>ac</sub>	ENERGY STAR efficiency				
	1 A	2 A	3 A	4 A	Average
115 [V]	85.26%	86.32%	86.28%	85.17%	85.75%
230 [V]	83.4%	85.2%	86.74%	87.87%	85.8%

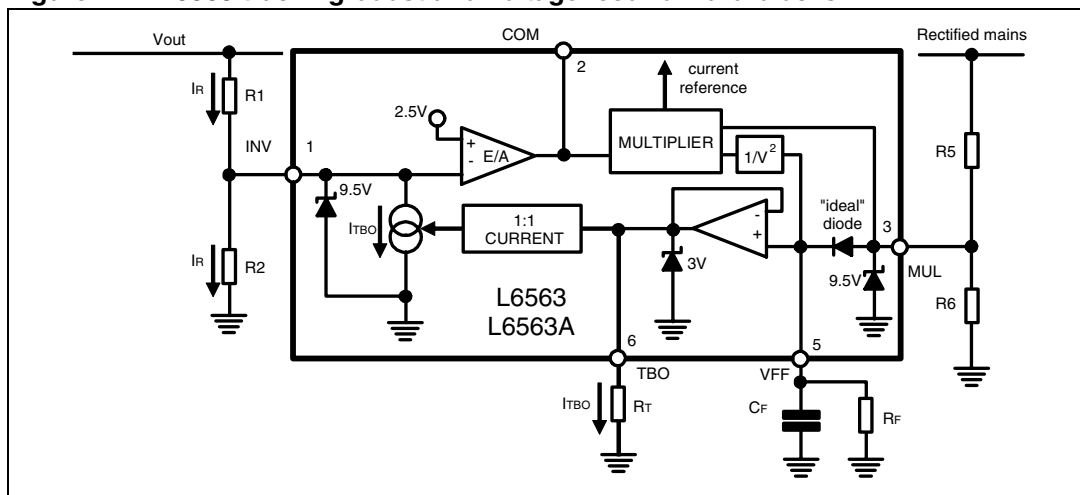
In [Table 2](#) the ENERGY STAR efficiency measurements are shown. The average of the two mains voltage inputs in four different load conditions is compliant with the target requirement (better than 84%).



To achieve optimal efficiency the PFC stage implements the tracking boost function. It consists of a PFC output voltage that follows the input voltage. Typically, in traditional PFC stages, the dc output voltage is regulated at a fixed value (typically 400 volts) but in some applications, such as this one using a flyback as the downstream converter, it could be advantageous to regulate the PFC output voltage with the tracking boost or "follower boost" approach. In this way the circuit with the TBO function provides improved efficiency and, thanks to the lower differential voltage across the boost inductor, the value of L2 can be reduced as compared to the same circuit without the TBO function. In the present case a 400  $\mu\text{H}$  inductor has been used, while with a fixed output voltage PFC working at a similar operating frequency, a 700  $\mu\text{H}$  inductor is required.

To achieve the TBO function on the L6563, a dedicated input of the multiplier is available on TBO pin #6. This function can be implemented by simply connecting a resistor ( $R_T$ ) between the TBO pin and ground.

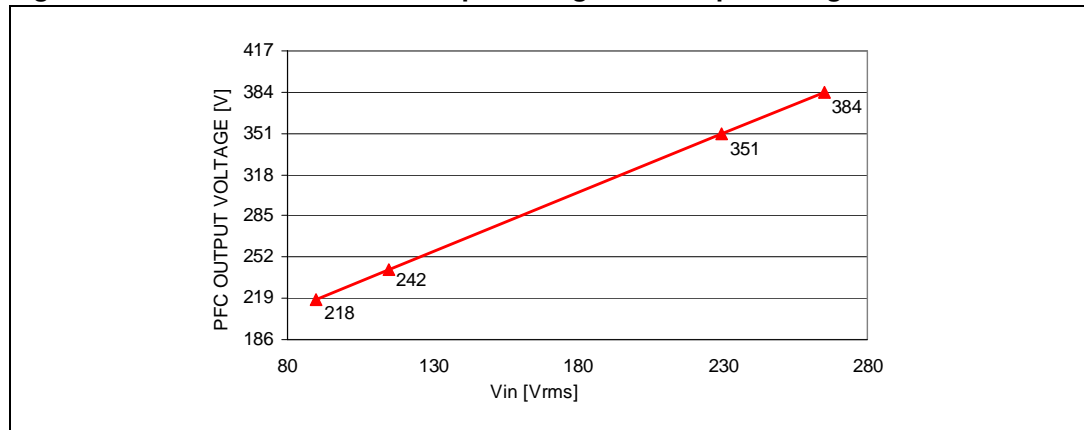
**Figure 4. L6563 tracking boost and voltage feed-forward blocks**



The TBO pin presents a dc level equal to the peak of the MULT pin voltage and is then representative of the mains RMS voltage. The resistor defines the current, equal to  $V(\text{TBO})/R_T$ , which is internally mirrored 1:1 and sunk from the INV pin (pin 1) input of the error amplifier. In this way, when the mains voltage increases, the voltage at the TBO pin will increase as well, and so will the current flowing through the resistor connected between TBO and GND. A larger current will then be sunk by the INV pin and the output voltage of the PFC pre-regulator will be forced higher. Obviously, the output voltage will move in the opposite direction if the input voltage decreases.

To avoid an unwanted rise in output voltage should the mains voltage exceed the maximum specified value, the voltage at the TBO pin is clamped at 3 V. By properly selecting the multiplier bias it is possible to set the maximum input voltage above which input-to-output tracking ends and the output voltage becomes constant. If this function is not used, the pin should be left open; the device will regulate at a fixed output voltage.

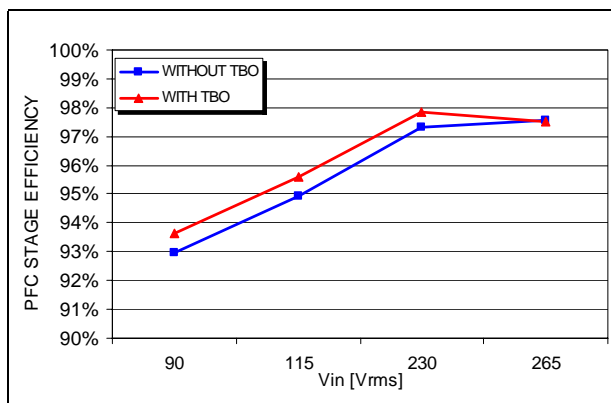
**Figure 5. EVAL6668-75W PFC output voltage vs. ac input voltage**



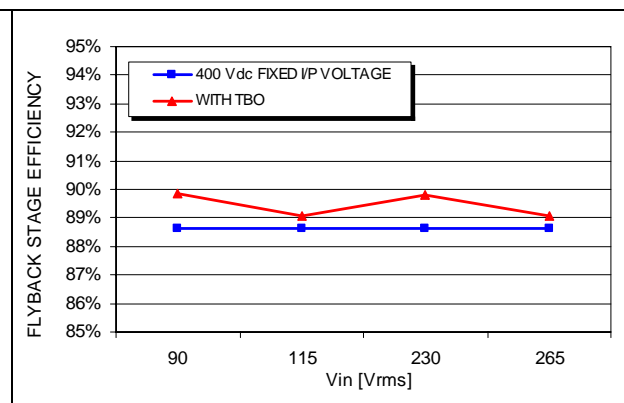
In [Figure 5](#) we can see that the PFC output voltage variation vs. the ac input voltage (i.e. the input voltage for the flyback stage) is dependent on the input mains voltage, but its range is narrower than a wide range input. Thus the design of the flyback converter is not completely optimized as with a standard PFC delivering a stable 400 V output, but its design is much simpler than that of a wide range flyback. Additionally, the PFC converter using the TBO, with its lower differential voltage across the inductor and lower current ripple, will have lower RMS current and therefore better efficiency at low mains, where normally the efficiency of typical PFCs is lower. The result is a global efficiency of the circuit that will be higher than that of a fixed output voltage one circuit, especially at lower mains. Most of the power dissipation will not be concentrated on the PFC only but will be shared with the flyback. Therefore, there will not be thermal hotspots and the reliability of the circuit will be improved.

This is confirmed in the diagram in [Figure 6](#), where the efficiency of the PFC has been measured both with the active TBO function and without it. As shown, at low input mains the circuit has an efficiency improvement better than 2 percent. As the input mains voltage increases the switching losses become more significant and the fixed output voltage PFC appears more efficient.

**Figure 6. PFC efficiency with and without TBO function at full load**



**Figure 7. Flyback converter efficiency with and without TBO function at full load**

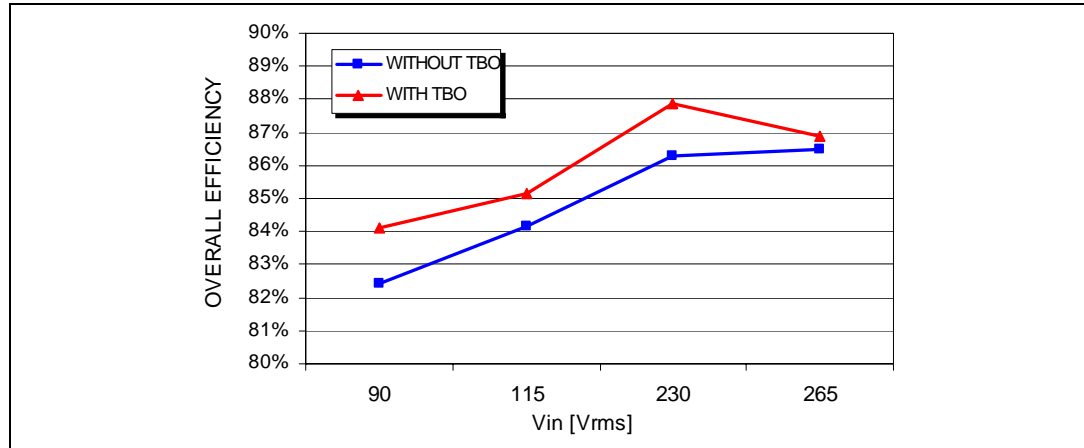


Using the TBO function even the flyback converter efficiency is very good, as shown in [Figure 7](#) where it is compared with the efficiency of the same converter powered by a fixed

400 V input voltage. It can be observed that an improvement is achieved at 90 Vac and 230 Vac mains.

As a final measurement, the comparison between the global efficiency with and without TBO is shown in *Figure 8*, confirming the previous measurements.

**Figure 8. Comparison between the global efficiency with and without TBO**

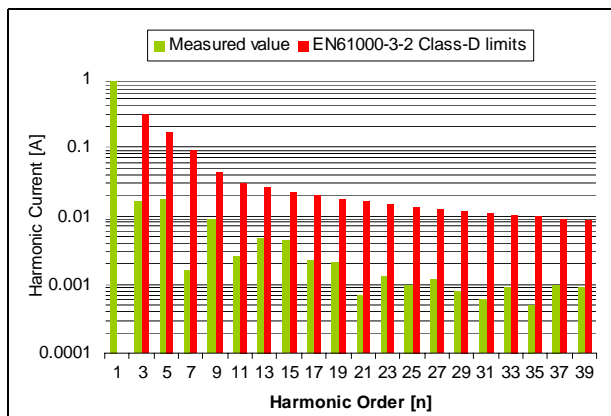


## 2.2 Harmonic content measurement

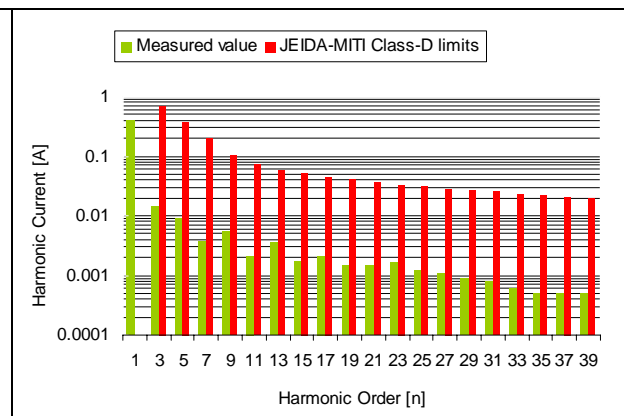
One of the main purposes of a PFC pre-conditioner is to correct the input current distortion, decreasing the harmonic contents below the limits of the relevant regulations. Therefore, the board has been tested according to the European rule EN61000-3-2 Class-D and Japanese rule JEIDA-MITI Class-D, at full load and 50% of output rated load, at both nominal input mains voltages.

As demonstrated in the illustrations below, the circuit is capable of reducing the harmonics well below the limits of both regulations from full load down to light load. Because the maximum input power of the board is close to the limit of 75 W, to demonstrate the correct behavior of the circuit it has been tested also a 37 W (half load). Of course, no current regulation requires meeting any limit at these power levels.

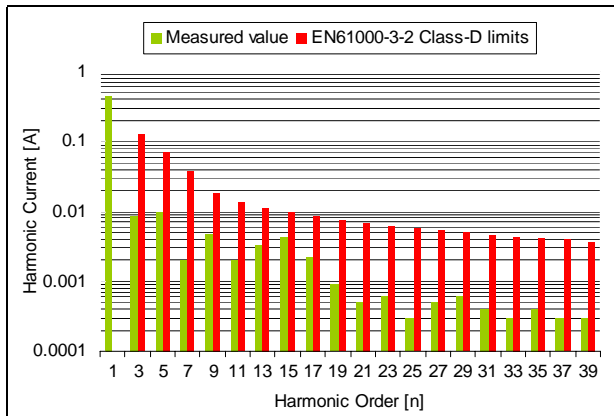
**Figure 9. EVAL6668-75W compliance to EN61000-3-2 standard @230 V, 50 Hz - full load**



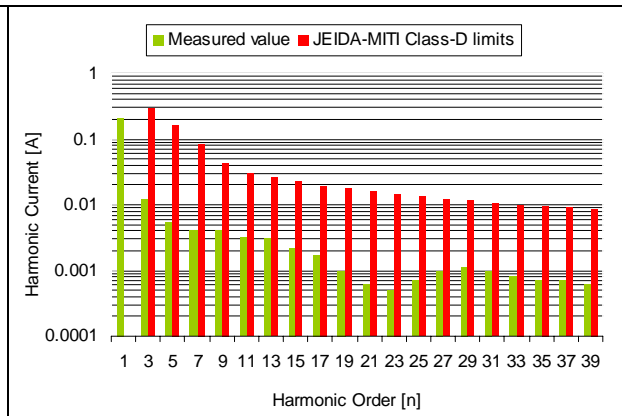
**Figure 10. EVAL6668-75W compliance to JEIDA-MITI standard @100 V, 60 Hz - full load**



**Figure 11. EVAL6668-75W compliance to EN61000-3-2 standard @230 V, 50 Hz - half load**



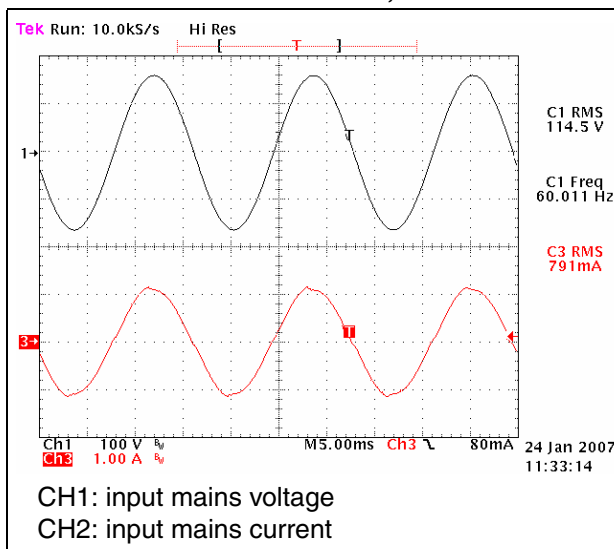
**Figure 12. EVAL6668-75W compliance to JEIDA- MITI standard @100 V, 60 Hz - half load**



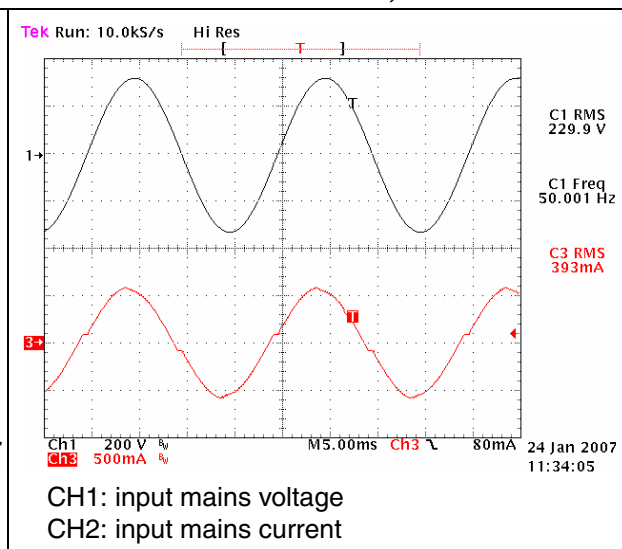
On the bottom side of each diagram the total harmonic distortion and power factor have been measured as well. The values in all conditions give a clear idea of the correct functioning of the PFC even if the tracking boost option has been implemented.

For user reference, input current and voltage waveforms at the nominal input mains voltages and full load are shown below.

**Figure 13. EVAL6668-75W input current waveform @100 V, 60 Hz - full load**



**Figure 14. EVAL6668-75W input current waveform @230 V, 50 Hz - full load**



### 3 Functional check

#### 3.1 Normal operation

Figure 15 and Figure 16 display some waveforms of the flyback stage during steady-state operation of the circuit at full load and nominal input voltage ranges. Under full load conditions the L6668 switching frequency has been set to 65 kHz in order to achieve good efficiency and to limit the switching noise.

It's possible to note that the CH3 relevant to the output voltage of the PFC circuit shows the tracking boost function setting at a different PFC output voltage (247 / 348 volts), which is dependent on the mains input voltage as mentioned on the previous page.

Figure 15. EVAL6668-75W flyback stage waveforms @115 V, 60 Hz-full load

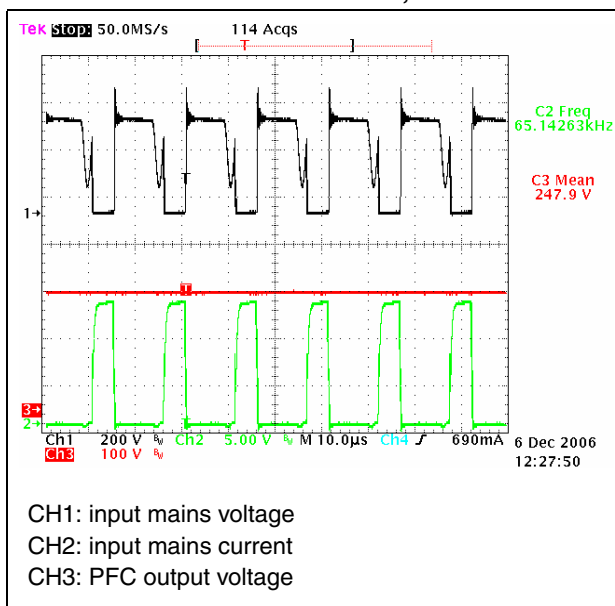
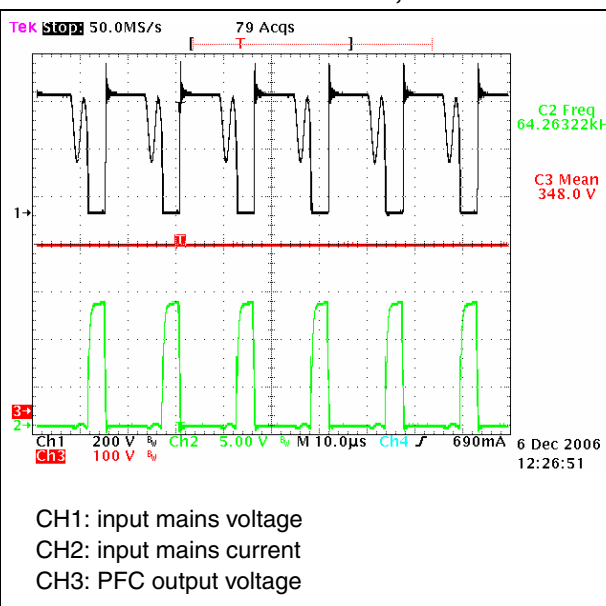


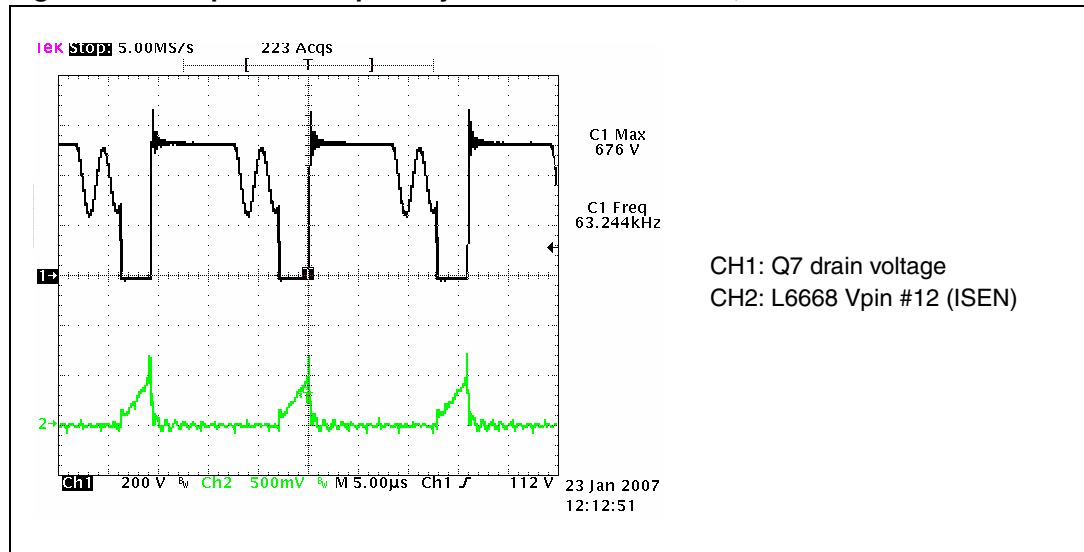
Figure 16. EVAL6668-75W flyback stage waveforms @230 V, 50 Hz-full load



In Figure 17 the drain voltage waveforms and the measurement of the peak voltage at full load and maximum mains input voltage are shown.

The maximum voltage peak in this condition is 676 V, which ensures reliable operation of the power MOSFET with a good margin against the maximum  $BV_{DSS}$ .

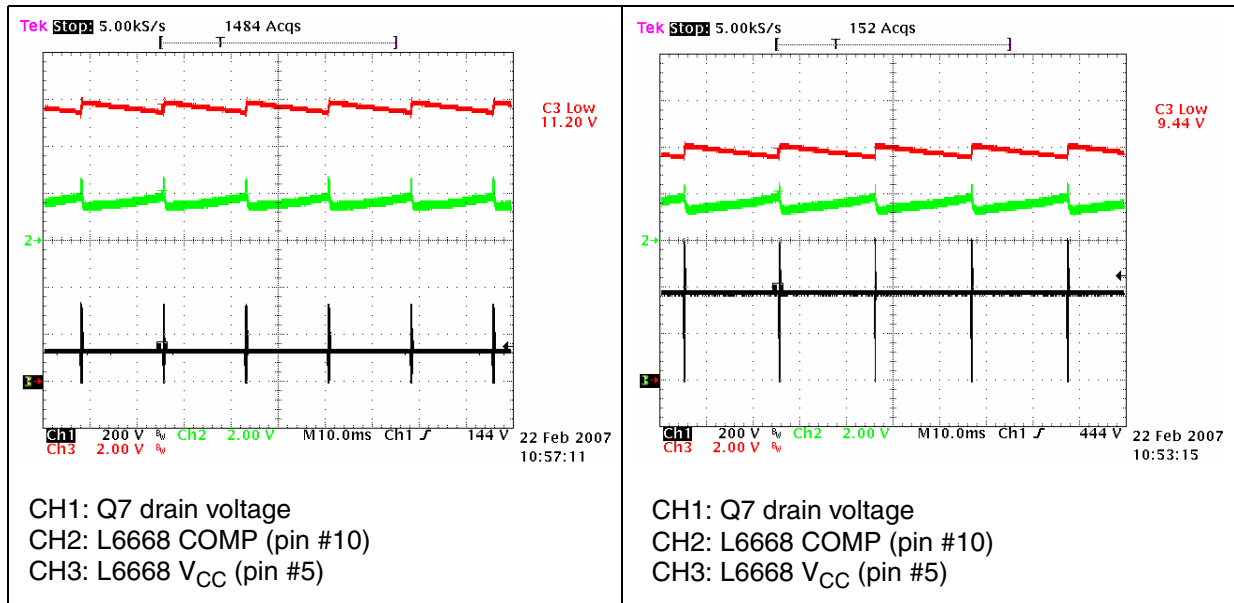
Figure 17. Adapter circuit primary side waveforms 265 V, 50 Hz



### 3.2 Standby and no-load operation

Figure 18. EVAL6668-75 W no-load operation waveforms @90 V, 60 Hz

Figure 19. EVAL6668-75 W no-load operation waveforms @265 V, 50 Hz



In [Figure 18](#) and [Figure 19](#), some no-load waveforms of the circuit are shown. As illustrated, the L6668 works in burst mode to achieve optimal efficiency. The burst mode threshold can be adjusted by setting the divider connected to the SKIPADJ pin (#9). When the voltage at the COMP pin falls 50 mV below the voltage on the SKIPADJ pin, the IC is shut down and consumption is reduced. The chip is re-enabled as the voltage on the COMP pin exceeds the voltage on the threshold set by pin 9 with its hysteresis. Additionally, in order to achieve the best efficiency during light load operation the PFC stage is turned off. In fact, the L6668 pin #14 (PFC\_STOP) is dedicated to enabling or disabling PFC operation according to the

output load level. This pin is intended to drive the base of a PNP transistor in systems including a PFC pre-regulator, to stop the PFC controller at light load by cutting its supply. Pin #14 (PFC\_STOP), while normally low, opens if the voltage on the COMP pin is lower than 2.2 V, and returns low when the voltage on the COMP pin exceeds 2.7 V. Whenever the IC is shut down, either latched (DIS > 2.2 V, ISEN > 1.5 V) or not latched (UVLO, SKIPADJ < 0.8), the pin is open as well. In [Figure 19](#), the V<sub>CC</sub> value is also given, showing that the IC is powered with a good margin with respect to the L6668 turn-off threshold (9.4 V), avoiding any spurious turn-off possibilities that could affect the output voltage stability.

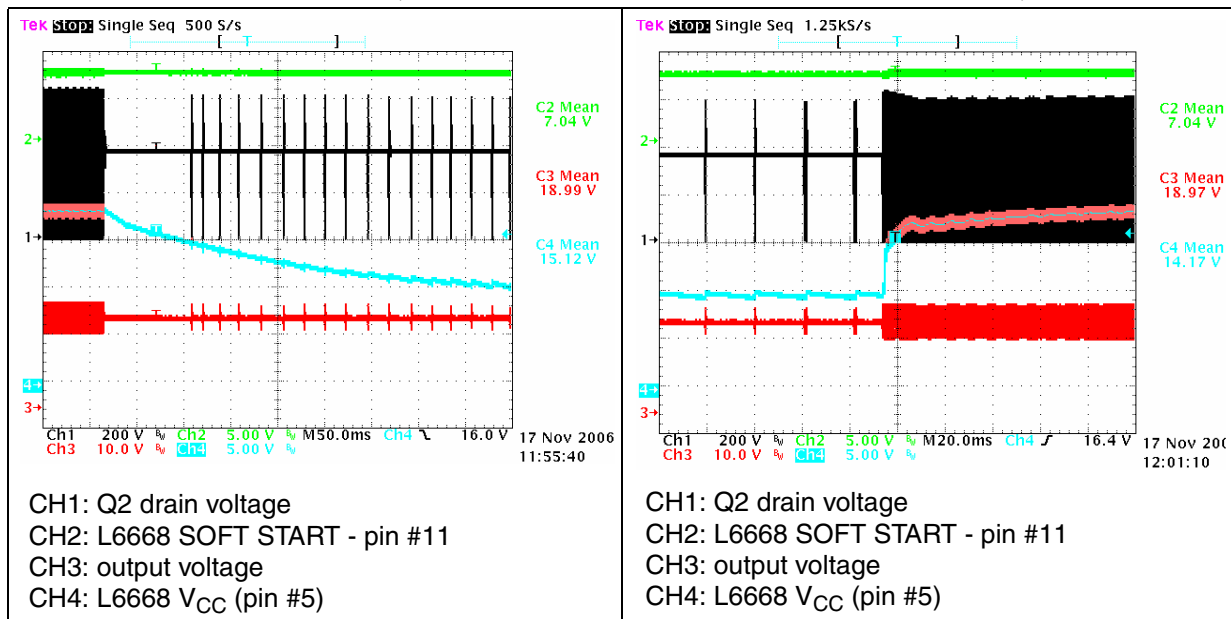
In [Table 3](#), the power consumption from the mains during no-load operation is shown. As can be observed, thanks to the L6668 standby functionality the input power constantly remains well below 300 mW. Therefore, all mandatory or voluntary regulations currently applicable or that will become effective in the near future can be respected using this chipset.

**Table 3. Input power at no-load vs. mains voltage**

Vin [Vrms]	Input power [W]
90	0.126
115	0.146 <sup>(1)</sup>
230	0.268 <sup>(1)</sup>
265	0.282

1. Compliant to CEC, EU-COC, Energy Star

**Figure 20. EVAL6668-75 W transition full load-to-no load at 265 V, 50 Hz**      **Figure 21. EVAL6668-75 W transition no load-to-full load at 265 V, 50 Hz**



In [Figure 20](#) and [Figure 21](#), the transitions from full load to no-load and vice-versa at maximum input voltage have been checked. The maximum input voltage has been chosen for the above illustrations because it is the most critical input voltage for transition. In fact, at no-load, the burst pulses have a lower repetition frequency and the V<sub>CC</sub> could drop, causing restart cycles of the controller. Additionally, there is a wider range variation for the input

voltage to the flyback converter as a result of the PFC turning on or off. As the figures show, both transitions are clean and there is no output voltage,  $V_{CC}$  dip or restarting attempt that could affect proper power supply operation.

The input power consumption of the board has also been checked at light load conditions, simulating an adapter powering a laptop PC during power-saving operation. The results are shown in [Table 4](#), [5](#) and [6](#) below, where the low load efficiency with standard inputs of 115 V and 230 V is calculated.

**Table 4. Light load efficiency (0.5 W)**

$V_{in_{ac}}$ [Vrms]	Pout [W]	Pin [W]	Efficiency
115	0.52	0.75 <sup>(1)</sup>	68.67%
230	0.52	0.88 <sup>(1)</sup>	58.52%

1. Compliant to US Executive order 13221 "1W \_Standby"

**Table 5. Light load efficiency (1.2 W)**

$V_{in_{ac}}$ [Vrms]	Pout [W]	Pin [W]	Efficiency
115	1.2	1.55	77.86%
230	1.2	1.71	70.35%

**Table 6. Light load efficiency (2.4 W)**

$V_{in_{ac}}$ [Vrms]	Pout [W]	Pin [W]	Efficiency
115	2.41	2.93	82.14%
230	2.4	3.14	76.56%

As visible in [Table 4](#), [5](#) and [6](#), the input power consumption is always very low and the efficiency remains significantly high even at output power levels where the power supply efficiency normally drops. This is achieved thanks to the burst mode adjustable threshold of the L6668 SKIPADJ pin and the PFC management by the PFC\_STOP pin, as previously described.

### 3.3 Over current and short circuit protection

An important function of any power supply is its ability to survive instances of output overload or short circuit, avoiding any consequent failure. Additionally, the power supply must be compliant with safety rules which require that the components will not melt or burn-out in fault conditions. It's common to find circuits with good protection capability against load shorts but which do not survive dead shorts such as those of an output electrolytic capacitor or a secondary rectifier, or in cases of transformer saturation. Moreover, in cases of a shorted rectifier the equivalent circuit changes and the energy are delivered even during the ON time, as in forward mode. In this evaluation board the over-current is managed by U5, a CC/CV controller. Inside the IC there is a reference and two Or-end operational amplifiers, one dedicated to act as the error amplifier of the voltage loop and the other dedicated to act as the error amplifier of the current loop. If the output current exceeds the programmed value, the current loop error amplifier takes over and, via the optocoupler,



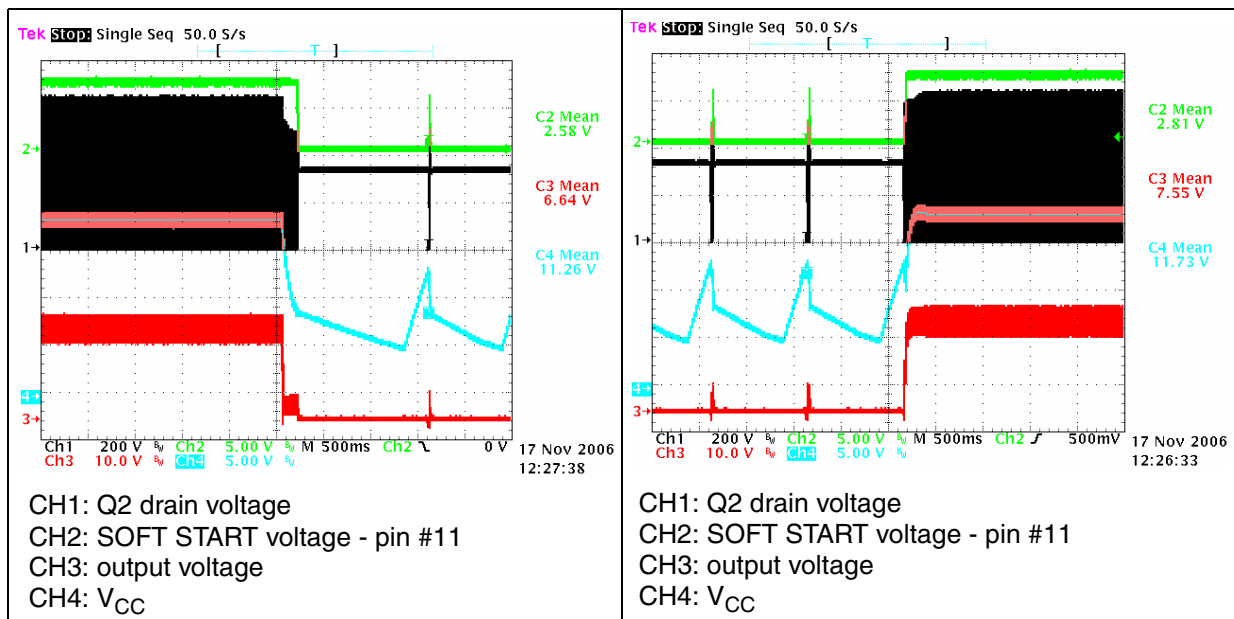
controls the voltage at the COMP pin of the L6668, thus regulating the output current. In case of a dead short, the current cannot be limited effectively by U5 because it will be unpowered. Therefore, additional, efficient protection circuitry on the primary side will be needed. In this board the voltage at the ISEN pin of the L6668 is sensed and if it exceeds the  $V_{ISENdis}$  threshold the controller is forced to work in hiccup mode. In this way the controller stops operation and will remain in the OFF state until the voltage across the  $V_{CC}$  pin decreases to a level below the UVLO threshold. It will then attempt to restart, but without success if the secondary short has not been removed. This provides a low frequency hiccup working mode, limiting the current flowing on the secondary side and thus preventing the power supply from overheating and failing.

*Figure 22* shows the circuit behavior during short circuit. Observe that the L6668 stops switching, the  $V_{CC}$  voltage drops until it reaches the UVLO threshold. Then the IC decreases its consumption, thus increasing the duration of the OFF time, and avoiding high dissipation on the secondary side under short conditions. The soft start capacitor will also be discharged. At this point, the HV start-up pin recharges the  $V_{CC}$  capacitor and, as soon the turn-on threshold is reached, the circuit attempts to restart but it will cease operation within a few milliseconds, repeating the sequence just described. The restart attempt will be repeated indefinitely until the short is removed.

*Figure 23*, instead, shows the sequence of operation in short circuit when the short is removed. As the figure illustrates, a new start-up sequence takes place and the circuit resumes normal operation after a soft-start cycle.

**Figure 22. EVAL6668-75 W short circuit at full load & 230 Vac-50 Hz**

**Figure 23. EVAL6668-75 W short circuit removal at full load & 230 Vac-50 Hz**

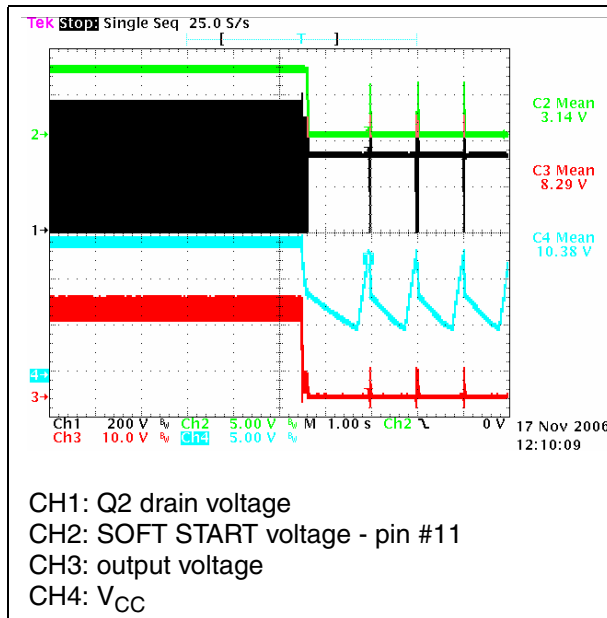


Thanks to the TSM1014 and the HV current source of the L6668, the fault protection sequences described in *Figure 22* and *Figure 23* do not change significantly for any other input voltage, above all not in the input voltage range of the board.

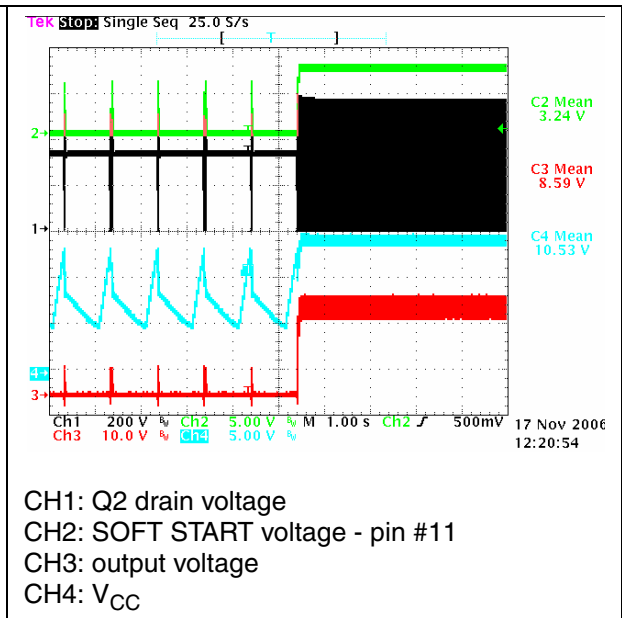
The protection described previously works correctly even in cases where the output short is applied during standby or no load operations. The L6668 protects the circuit via the sequences that has been described for the full load operation, and the circuit resumes

correct operation when the short is removed. In [Figure 24](#) and [Figure 25](#) both sequences are captured during 230 Vac operation but they do not change significantly over the input mains range.

**Figure 24. EVAL6668-75 W short circuit at no-load & 230 Vac-50 Hz**



**Figure 25. EVAL6668-75 W short circuit removal at no-load & 230 Vac-50 Hz**



### 3.4 Overvoltage and open loop protection

The EVAL6668-75W board implements two different open loop protections: one for the PFC and another for the flyback stage.

The PFC controller L6563 is equipped with an OVP, monitoring the current flowing through the compensation network and entering the error amplifier (pin COMP, #2). When this current reaches about 18  $\mu$ A the output voltage of the multiplier is forced to decrease, thus reducing the energy drawn from the mains. If the current exceeds 20  $\mu$ A, the OVP is triggered (dynamic OVP), and the external power transistor is switched off until the current falls below approximately 5  $\mu$ A. However, if the overvoltage persists (e.g. if the load is completely disconnected), the error amplifier will eventually saturate low, triggering an internal comparator (static OVP) which will keep the external power switch turned off until the output voltage returns to a point near the regulated value.

The OVP function described above is capable of handling "normal" overvoltage conditions, i.e. those resulting from an abrupt load/line change or occurring at start-up. It cannot handle the overvoltage generated, for instance, when the upper resistor of the output divider fails open. The voltage loop can no longer read the information on the output voltage and will force the PFC pre-regulator to work at maximum ON time, causing the output voltage to rise uncontrollably.

A pin on the L6563 (PFC\_OK, #7) has been provided for additional monitoring of the output voltage with a separate resistor divider (R3, R5, R11 high, R19 low, see [Figure 1](#) and [2](#)). This divider is selected so that the voltage at the pin reaches 2.5 V if the output voltage

exceeds a preset value, usually larger than the maximum  $V_o$  that can be expected, including also overshoots due to worst-case load/line transients.

In this case,  $V_o = 400\text{ V}$ ,  $V_{ox} = 460\text{ V}$ . Select:  $R3 + R5 + R11 = 6.6\text{ M}\Omega$  Three resistors in series have been chosen according to their voltage rating.

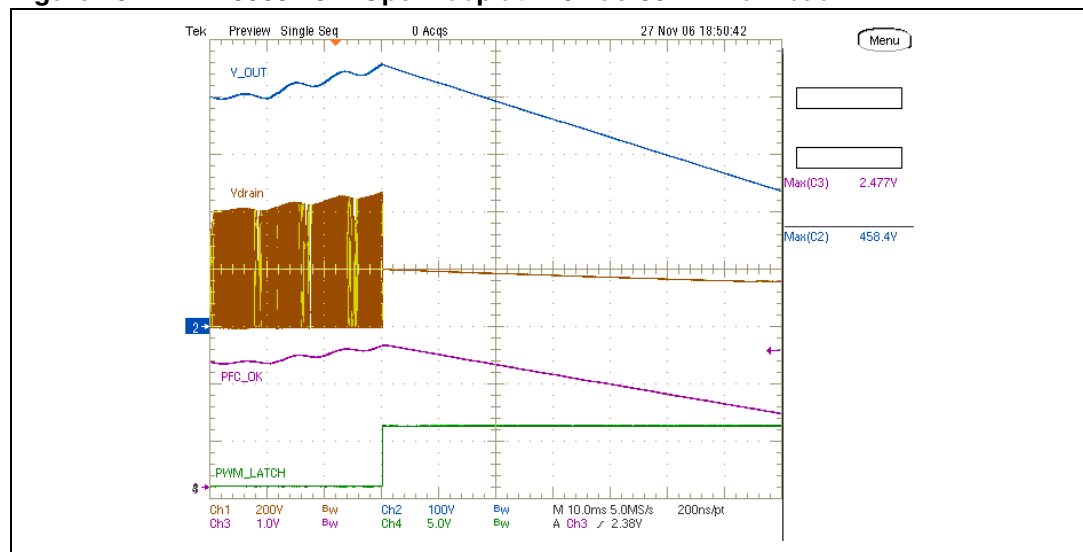
Thus:  $R19 = 6.6\text{ M}\Omega \cdot 2.5 / (460-2.5) = 36\text{ k}\Omega$

When this function is triggered, the gate drive activity is immediately stopped, the device is shut down, its quiescent consumption is reduced below  $250\text{ }\mu\text{A}$  and the condition is latched as long as the supply voltage of the IC is above the UVLO threshold. At the same time the pin PWM\_LATCH (pin #8) is asserted high. The PWM\_LATCH is an open source output capable of delivering  $3.7\text{ V}$  minimum with a  $0.5\text{ mA}$  load, intended for tripping a latched shutdown function of the PWM controller IC in the cascaded dc-dc converter, so that the entire unit is latched off. To restart the system it is necessary to recycle the input power, so that the  $V_{CC}$  voltages of both the L6563 and the PWM controller go below their respective UVLO thresholds.

The PFC\_OK pin doubles its function as a not-latched IC disable: a voltage below  $0.2\text{ V}$  will shut down the IC, reducing its consumption below  $1\text{ mA}$ . In this case both PWM\_STOP and PWM\_LATCH keep their high impedance status. To restart the IC simply let the voltage at the pin go above  $0.26\text{ V}$ .

Note that this function offers complete protection against not only feedback loop failures or erroneous settings, but also against a failure of the protection itself. If a resistor in the PFC\_OK divider fails short or open, or the PFC\_OK (#7) pin is floating, it will result in the shutting down of the L6563 and stopping of controller operation of the flyback stage.

**Figure 26. EVAL6668-75W Open loop at 115 Vac-60 Hz - full load**



An open loop event is captured in [Figure 26](#). Note the protection intervention stopping the operation of the L6563 and the activation of the PWM\_LATCH pin that is connected to the L6668 pin #7 (DIS). This function of the L6668 is a latched device shutdown. Internally the pin connects a comparator which shuts the IC down and brings its consumption to a value just higher than before start-up, when the voltage on the pin exceeds  $2.2\text{ V}$ . The information is latched and it is necessary to recycle the input power to restart the IC. The latch is removed as the voltage on the  $V_{CC}$  pin goes below the UVLO threshold.

The flyback stage is also protected against open loop conditions that lead to loss of control of the output voltage. A divider connected to the auxiliary winding of the transformer is also connected to the L6668 pin #7 (DIS) and, in case of excessively high output voltage resulting from loop failure, provides for the triggering of the internal comparator connected to that pin. In this case operation of the L6563 will cease because the L6668 will stop the PFC stage operation via the PFC\_STOP pin. The V<sub>CC</sub> powering both the ICs will be maintained by the HV start-up generator of the L6668. To restart the operation, it will be necessary to unplug and re-plug the mains, to unlatch the L6668.

## 4 EVAL6668-75W: thermal map

### 4.1 Thermal protection

The EVAL6668-75W is also equipped with thermal protection of the flyback's power MOSFET (Q5). Its temperature is sensed using the NTC thermistor R58 connected to the L6668 pin #7 (DIS). If the temperature of the heat sink rises above the maximum allowed level (80 - 85 °C), the threshold of the internal comparator will be exceeded and the L6668 latched as in the case of open loop. To restart the operation of the circuit, it will be necessary to unplug and re-plug the mains.

### 4.2 Thermal map

In order to check the reliability of the design, thermal mapping has been performed using an infrared camera. In [Figure 27](#) and [28](#), the thermal measurements on the key components at nominal input voltage are shown. The correlation between the measurement points and components for both thermal maps is indicated in [Table 7](#) below. The ambient temperature during both measurements was 27 °C. All other components on the board work within the temperature limits, ensuring reliable long-term operation of the power supply.

**Figure 27. Thermal map at 115 Vac-60 Hz - full load**

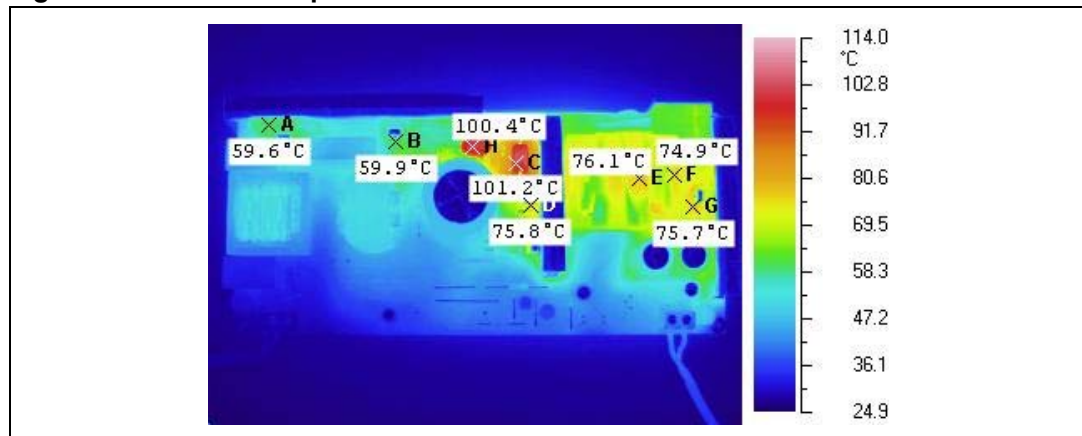


Figure 28. Thermal map at 230 Vac-50 Hz - full load

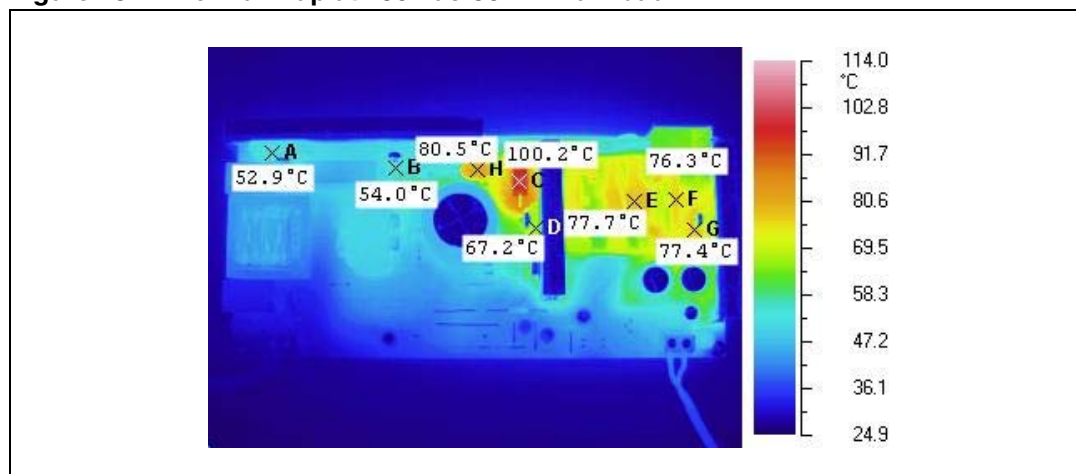


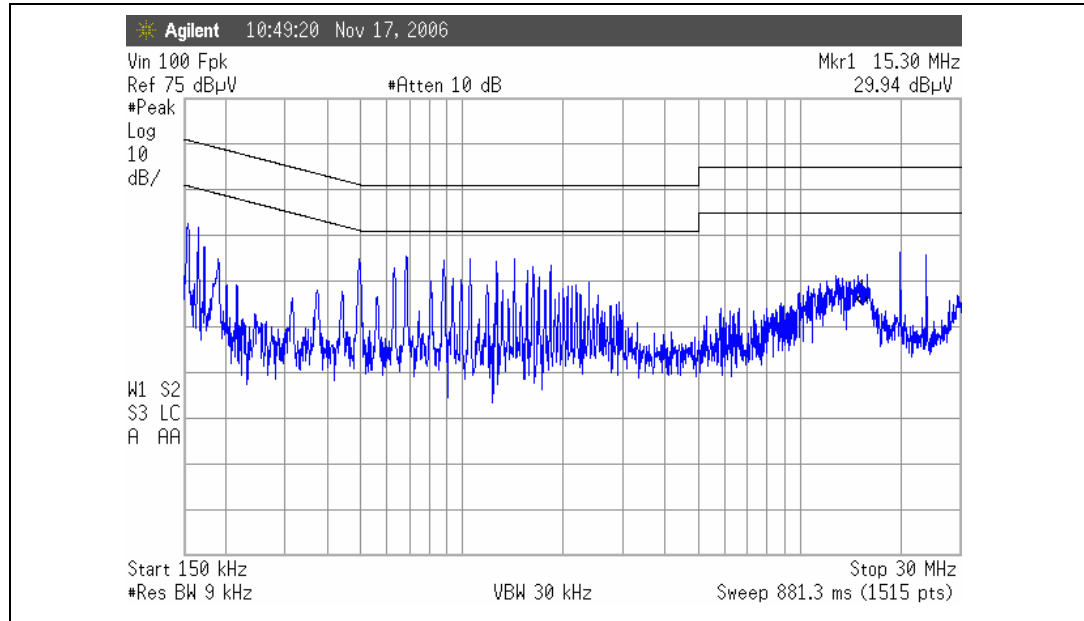
Table 7. Measured temperature table @115 Vac and 230 Vac - full load

Point	Component	Temperature @115 Vac	Temperature @230 Vac
A	D2	59.6 °C	52.9 °C
B	Q2	59.9 °C	54.0 °C
C	D4	101 °C	100 °C
D	Q5	75.8 °C	67.2 °C
E	T1 - WINDING	76.1 °C	77.7 °C
F	T1 - CORE	74.9 °C	76.3 °C
G	D7	77.4 °C	75.7 °C
H	R1 (NTC)	100 °C	80.5 °C

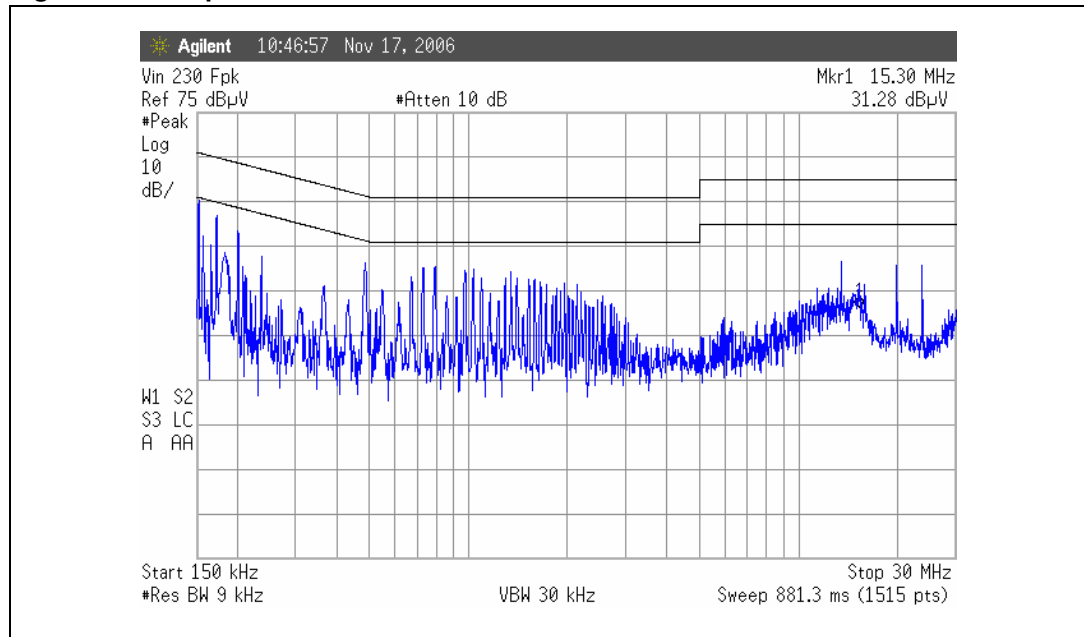
## 5 Conducted emission pre-compliance test

The following figures are the peak measurements of the conducted noise emissions at full load and nominal mains voltages. The limits shown on the diagrams are those of EN55022 Class-B, which are most popular requirements for domestic equipment and imposes less stringent limits compared to the Class-A, which is dedicated to IT technology equipment. As visible in the diagrams, in all test conditions there is a good margin for the measurements with respect to the limits.

**Figure 29. CE peak measure at 100 Vac and full load**



**Figure 30. CE peak measure at 230 Vac and full load**



## 6 Bill of material

**Table 8. EVAL6668-75W evaluation board: bill of material**

Des.	Part type/part value	Description	Supplier
C1	2N2	Y1 safety cap.	Murata
C10	Res.	Not used	
C11	Res.	Not used	
C12	1000 µF-25V ZL	Aluminium ELCAP - ZL series - 105 °C	Rubycon
C13	100 µF-25V YXF	Aluminium ELCAP - YXF series - 105 °C	Rubycon
C14	220NF	50 V CERCAP - general purpose	AVX
C15	1 µF	25 V CERCAP - general purpose	AVX
C16	1000 µF-25V ZL	Aluminium ELCAP - ZL series - 105 °C	Rubycon
C17	100N	50 V CERCAP - general purpose	AVX
C19	2N2	50 V CERCAP - general purpose	AVX
C2	2N2	Y1 safety cap.	Murata
C20	10N	50 V CERCAP - general purpose	AVX
C21	470N	25 V CERCAP - general purpose	AVX
C22	2µ2-25 V	Aluminium ELCAP - YXF series - 105 °C	Rubycon
C23	Res.	Not used	
C24	2N2 - Y1 - DE1E3KX222M	Y1 safety cap.	Murata
C25	220PF	50 V CERCAP - general purpose	AVX
C26	22N	50 V CERCAP - general purpose	AVX
C27	47 µF-50 V	Aluminium ELCAP - YXF Series - 105 °C	Rubycon
C28	Res.	Not used	
C29	Res.	Not used	
C3	470N-X2	X2 film CAPACITOR - R46-I 3470--M1-	Arcotronics
C30	2N2-5%	50 V - 5% - C0G - CERCAP	AVX
C31	Res.	Not used	
C32	100N	50 V CERCAP - general purpose	AVX
C33	22 µF-50 V	Aluminium ELCAP - YXF series - 105 °C	Rubycon
C34	100PF	50 V CERCAP - general purpose	AVX
C35	270N	25 V CERCAP - general purpose	AVX
C36	100N	50 V CERCAP - general purpose	AVX
C37	82N	50 V CERCAP - general purpose	AVX
C38	470PF	50 V CERCAP - general purpose	AVX

**Table 8. EVAL6668-75W evaluation board: bill of material (continued)**

Des.	Part type/part value	Description	Supplier
C39	4N7	50 V CERCAP - general purpose	AVX
C4	470N-X2	X2 film capacitor - R46-I 3470--M1-	Arcotronics
C40	100N	50 V CERCAP - general purpose	AVX
C41	10N	50 V CERCAP - general purpose	AVX
C42	10 µF-63 V	Aluminium ELCAP - SR series - 85 °C	Rubycon
C43	2N2	50 V CERCAP - general purpose	AVX
C44	100N	50 V CERCAP - general purpose	AVX
C5	470N-400 V	B32653A4474J - polyprop. film cap	EPCOS
C6	100 µF-450 V	Aluminium ELCAP - LLS Series - 85 °C	NICHICON
C7	2N2 - Y1 - DE1E3KX222M	Y1 safety cap.	Murata
C8	1N0-200 V	200 V CERCAP - general purpose	AVX
C9	100N	50 V CERCAP - general purpose	AVX
D1	1N4005	General purpose rectifier	Vishay
D10	LL4148	Fast switching diode	Vishay
D11	BAV103	Fast switching diode	Vishay
D12	LL4148	Fast switching diode	Vishay
D13	LL4148	Fast switching diode	Vishay
D14	LL4148	Fast switching diode	Vishay
D15	Res.	Not used	
D2	GBU4J	Single phase bridge rectifier	Vishay
D3	STTH2L06	Ultrafast high voltage rectifier	STMicroelectronics
D4	1.5KE250A	TRANSIL	STMicroelectronics
D5	BZV55-B30	ZENER diode	Vishay
D6	Res.	Not used	
D7	STPS20H100CFP	High voltage power Schottky rectifier	STMicroelectronics
D8	STTH108A	High voltage ultrafast rectifier	STMicroelectronics
D9	BZV55-C8V2	ZENER diode	Vishay
F1	FUSE 4 A	Fuse T4A - time delay	Wichmann
J1	MKDS 1,5/ 3-5,08	PCB term. block, screw conn., pitch 5MM - 3 W.	Phoenix Contact
J2	MKDS 1,5/ 2-5,08	PCB term. block, screw conn., pitch 5mm - 2 W.	Phoenix Contact
JP5	Jumper	Tinned copper wire jumper	
JP7	Res.	Tinned copper wire jumper - not used	
JP10	Jumper	Tinned copper wire jumper	
JP11	Jumper	Tinned copper wire jumper	



Table 8. EVAL6668-75W evaluation board: bill of material (continued)

Des.	Part type/part value	Description	Supplier
JP12	Jumper	Tinned copper wire jumper	
JP13	Jumper	Tinned copper wire jumper	
JP14	Jumper	Tinned copper wire jumper	
L1	HF2826-253Y1R2-T01	25 MH-1.2 A input EMI filter	TDK
L2	SRW25CQ-T03H112	400 $\mu$ H PFC inductor	TDK
L3	TSL0706 - 1R5-4R3	1 $\mu$ 5 - radial inductor	TDK
Q1	BC857C	PNP small signal BJT	ZETEX
Q2	STP9NK50ZFP	N-channel power MOSFET	STMicroelectronics
Q3	Res.	Not used	
Q4	Res.	Not used	
Q5	STP10NK80ZFP	N-channel power MOSFET	STMicroelectronics
Q6	BC857C	PNP small signal BJT	ZETEX
Q7	Res.	not used	
Q8	BC847C	NPN small signal BJT	ZETEX
R1	NTC 10R-S236	NTC resistor 10R - P/N B57236S0100M000	EPCOS
R10	Res.	Not used	
R11	2M2 - 1%	SMD std film res. - 1/4 W - 1% - 100 ppm/ $^{\circ}$ C	BC Components
R12	3M3	SMD std film res. - 1/4 W - 1% - 100 ppm/ $^{\circ}$ C	BC Components
R13	Res.	Not used	
R14	3R9	SMD std film res. - 1/4 W - 5% - 250 ppm/ $^{\circ}$ C	BC Components
R15	Res.	Not used	
R16	10 k $\Omega$	SMD std film res. - 1/8 W - 1% - 100 ppm/ $^{\circ}$ C	BC Components
R17	62 k $\Omega$	SMD std film res. - 1/8 W - 5% - 250 ppm/ $^{\circ}$ C	BC Components
R18	51 k $\Omega$	SMD std film res. - 1/4 W - 5% - 250 ppm/ $^{\circ}$ C	BC Components
R19	36 k $\Omega$	SMD std film res. - 1/8 W - 1% - 100 ppm/ $^{\circ}$ C	BC Components
R101	0R0	SMD std film res. - 1/4 W - 5% - 250 ppm/ $^{\circ}$ C	BC Components
R102	0R0	SMD std film res. - 1/4 W - 5% - 250 ppm/ $^{\circ}$ C	BC Components
R103	0R0	SMD std film res. - 1/4 W - 5% - 250 ppm/ $^{\circ}$ C	BC Components
R104	0R0	SMD std film res. - 1/4 W - 5% - 250 ppm/ $^{\circ}$ C	BC Components
R105	0R0	SMD std film res. - 1/4 W - 5% - 250 ppm/ $^{\circ}$ C	BC Components
R2	1M0-1%	SMD std film res. - 1/4 W - 1% - 100 ppm/ $^{\circ}$ C	BC Components
R20	20 k $\Omega$	SMD std film res. - 1/4 W - 5% - 250 ppm/ $^{\circ}$ C	BC Components
R21	Res.	Not used	
R22	R015 - 1 W	SMD film res. 1 W - 2512 MSR1	MEGGIT
R23	27R	SMD std film res. - 1/4 W - 5% - 250 ppm/ $^{\circ}$ C	BC Components

**Table 8. EVAL6668-75W evaluation board: bill of material (continued)**

Des.	Part type/part value	Description	Supplier
R24	100 kΩ	SMD std film res. - 1/8 W - 5% - 250 ppm/°C	BC Components
R25	470R	SFR25 axial stand. film res. - 0.4 W - 5% - 250 ppm/°C	BC Components
R26	120 kΩ	SMD std film res. - 1/4 W - 5% - 250 ppm/°C	BC Components
R27	0R33	SFR25 axial stand. film res. - 0.4 W - 5% - 250 ppm/°C	BC Components
R28	2k2	SMD std film res. - 1/8 W - 5% - 250 ppm/°C	BC Components
R29	Res.	Not used	
R3	2M2 - 1%	SMD std film res. - 1/4 W - 1% - 100 ppm/°C	BC Components
R30	22 kΩ	SMD std film res. - 1/8 W - 5% - 250 ppm/°C	BC Components
R31	4k7	SMD std film res. - 1/4 W - 5% - 250 ppm/°C	BC Components
R32	Res.	Not used	
R33	10 kΩ	SMD std film res. - 1/4 W - 5% - 250 ppm/°C	BC Components
R34	270 kΩ	SMD std film res. - 1/8 W - 5% - 250 ppm/°C	BC Components
R35	2R7	SMD std film res. - 1/8 W - 5% - 250 ppm/°C	BC Components
R36	1k8	SMD std film res. - 1/8 W - 5% - 250 ppm/°C	BC Components
R37	10 kΩ - 1%	SMD std film res. - 1/8 W - 1% - 100 ppm/°C	BC Components
R38	Res.	Not used	
R39	56 kΩ - 1%	SMD std film res. - 1/4 W - 1% - 100 ppm/°C	BC Components
R4	68 kΩ	SMD std film res. - 1/4 W - 5% - 250 ppm/°C	BC Components
R40	Res.	Not used	
R41	10 kΩ	SMD std film res. - 1/8 W - 5% - 250 ppm/°C	BC Components
R42	8k2	SMD std film res. - 1/8 W - 5% - 250 ppm/°C	BC Components
R43	4R7	SMD std film res. - 1/8 W - 5% - 250 ppm/°C	BC Components
R44	47 kΩ	SMD std film res. - 1/8 W - 5% - 250 ppm/°C	BC Components
R45	2k2	SMD std film res. - 1/8 W - 5% - 250 ppm/°C	BC Components
R46	47R	SMD std film res. - 1/8 W - 5% - 250 ppm/°C	BC Components
R47	100 kΩ	SMD std film res. - 1/8 W - 5% - 250 ppm/°C	BC Components
R48	4k7 - 1%	SMD std film res. - 1/8 W - 1% - 100 ppm/°C	BC Components
R49	24 kΩ - 1%	SMD std film res. - 1/8 W - 1% - 100 ppm/°C	BC Components
R5	2M2 - 1%	SMD std film res. - 1/4 W - 5% - 250 ppm/°C	BC Components
R50	1k0	SMD std film res. - 1/8 W - 5% - 250 ppm/°C	BC Components
R51	2k2	SMD std film res. - 1/8 W - 5% - 250 ppm/°C	BC Components
R52	0R39	SFR25 AXIAL std film res. - 0.4 W - 5% - 250 ppm/°C	BC Components
R53	0R39	SFR25 axial stand. film res. - 0.4 W - 5% - 250 ppm/°C	BC Components
R54	47 kΩ	SMD std film res. - 1/8 W - 5% - 250 ppm/°C	BC Components
R55	22R	SMD std film res. - 1/8 W - 5% - 250 ppm/°C	BC Components

Table 8. EVAL6668-75W evaluation board: bill of material (continued)

Des.	Part type/part value	Description	Supplier
R56	4k7 - 1%	SMD std film res. - 1/8 W - 1% - 100 ppm/°C	BC Components
R57	100R	SFR25 axial stand. film res. - 0.4 W - 5% - 250 ppm/°C	BC Components
R58	M57703 - 10 kΩ	10 k thermistor - B57703M0103G040	EPCOS
R59	24 kΩ	SMD std film res. - 1/8 W - 5% - 250 ppm/°C	BC Components
R6	1M0 - 1%	SMD std film res. - 1/4 W - 1% - 100 ppm/°C	BC Components
R60	56 kΩ	SMD std film res. - 1/4 W - 5% - 250 ppm/°C	BC Components
R61	33 kΩ	SMD std film res. - 1/8 W - 5% - 250 ppm/°C	BC Components
R62	3k3	SMD std film res. - 1/8 W - 5% - 250 ppm/°C	BC Components
R63	0R0	SMD std film res. - 1/4 W - 5% - 250 ppm/°C	BC Components
R64	43 kΩ - 1%	SFR25 axial stand. film res. - 0.4 W - 1% - 100 ppm/°C	BC Components
R65	22 kΩ	SMD std film res. - 1/8 W - 5% - 250 ppm/°C	BC Components
R66	3R9	SMD std film res. - 1/4 W - 5% - 250 ppm/°C	BC Components
R67	6k2 - 1%	SMD std film res. - 1/4 W - 1% - 100 ppm/°C	BC Components
R68	120 kΩ - 1%	SMD std film res. - 1/8 W - 1% - 100 ppm/°C	BC Components
R69	1k0	SMD std film res. - 1/8 W - 5% - 250 ppm/°C	BC Components
R7	3M3	SMD std film res. - 1/4 W - 1% - 100 ppm/°C	BC Components
R71	Res.	Not used	
R72	0R0	SMD std film res. - 1/8 W - 5% - 250 ppm/°C	BC Components
R73	62 kΩ	SMD std film res. - 1/8 W - 5% - 250 ppm/°C	BC Components
R8	75 kΩ - 1%	SMD std film res. - 1/8 W - 1% - 100 ppm/°C	BC Components
R9	75 kΩ - 1%	SMD std film res. - 1/8 W - 1% - 100 ppm/°C	BC Components
T1	SRW32EC-T01H114	Power transformer	TDK
U1	L6563	Transition mode PFC controller	STMicroelectronics
U2	L6668	Smart primary controller	STMicroelectronics
U3	SFH617A-4	Optocoupler	Infineon
U4	res.	Not used	
U5	TSM1014	Low consumption CC/CV controller	STMicroelectronics
HS1		Heat sink for D2&Q2	
HS2		Heat sink for Q5	
HS3		Heat sink for D7	

## 7 PFC coil specification

### 7.1 General description and characteristics

- Application type: consumer, home appliance
- Inductor type: open
- Coil former: vertical type, 5+3 pins
- Max. temp. rise: 45 °C
- Max. operating ambient temp.: 60 °C
- Mains insulation: N.A.
- Unit finishing: varnished

### 7.2 Electrical characteristics

- Converter topology: boost, transition mode
- Core type: CQ25 - PC47
- Minimum operating frequency: 20 kHz
- Typical operating frequency: 400  $\mu\text{H} \pm 10\%$  @ 1 kHz - 0.25 V (see [Note: 1](#))
- Peak primary current: 3.5  $A_{pk}$
- RMS primary current: 1.2  $A_{rms}$

Note: 1 Measured between pins #5 and #6

### 7.3 Electrical schematic and winding characteristics

Figure 31. Electrical diagram

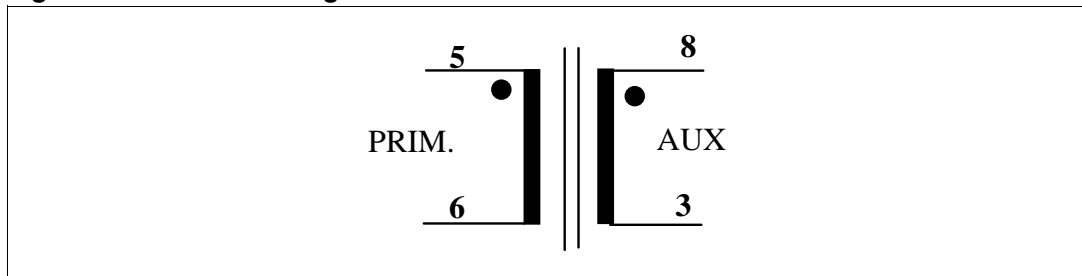


Table 9. Winding characteristics

PINS	Winding	RMS current	Number of turns	Wire type
8 - 3	AUX <sup>(1)</sup>	0.05 $A_{RMS}$	5 spaced	$\varnothing$ 0.28 mm
5 - 6	Primary <sup>(2)</sup>	1.2 $A_{RMS}$	50	Multi stranded #10 x $\varnothing$ 0.20 mm

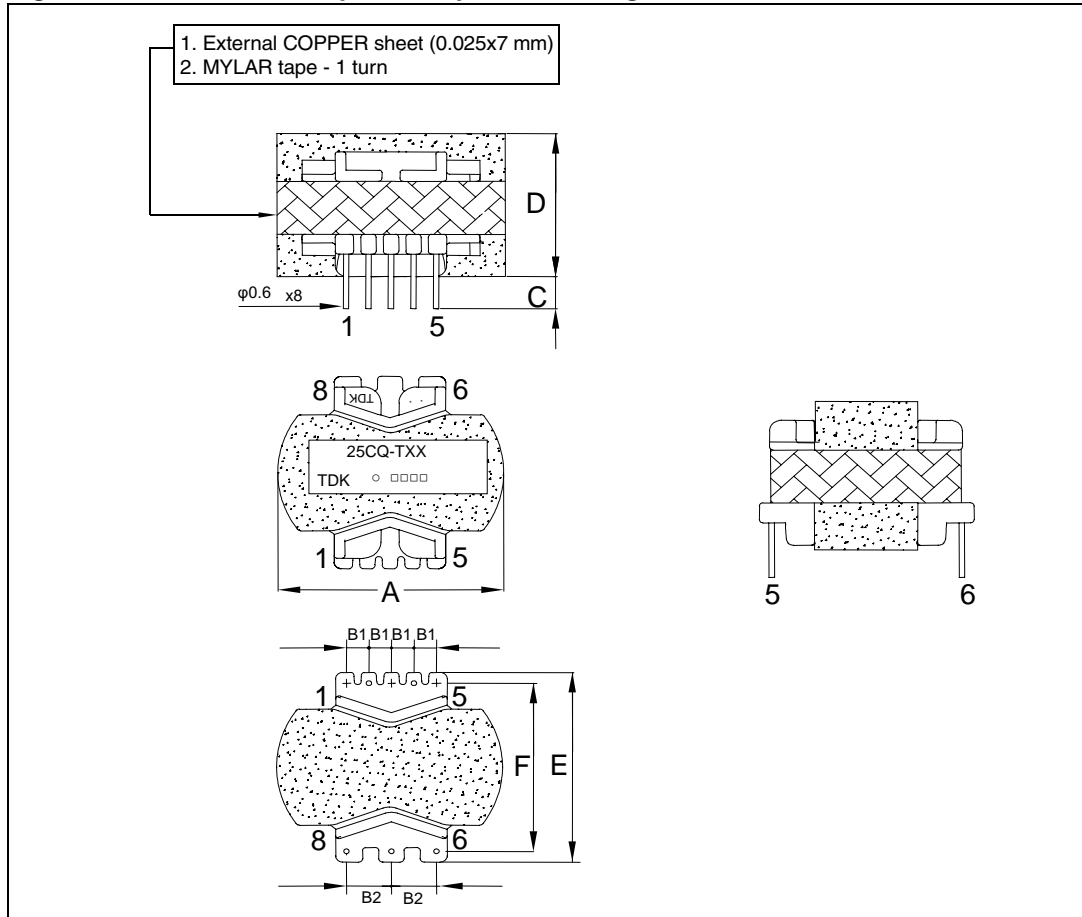
1. Aux winding is wound on coil former before primary winding. To be insulate with a layer of polyester tape.

2. Primary winding external insulation: 2 layers of polyester tape

### 7.4 Mechanical aspect and pin numbering

- Maximum height from PCB: 20 mm
- COIL former type: vertical, 5+3 pins
- PINS #1, 2, 4, 7 have been removed
- External copper shield: Not insulated, wound around the ferrite core and including the coil former. Height is 7 mm. Connected to pin #3 by a solid wire.

**Figure 32. Mechanical aspect and pin numbering of PFC coil**



- A: 27.0 max mm
- B1: 3.0 ± 0.3 mm
- B2: 5.0 ± 0.3 mm
- C: 3.3 ± 0.3 mm
- D: 19.0 max mm
- E: 21.0 ± 0.5 mm
- F: 23.7 ± 0.5 mm

## 8 Transformer specification

### 8.1 General description and characteristics

- Application type: consumer, home appliance
- Transformer type: open
- Winding type: layer
- Coil former: horizontal type, 9+9 pins
- Max. temp. rise: 45 °C
- Max. operating ambient temp.: 60 °C
- Mains insulation: acc. with EN60950
- Unit finishing: varnishing

### 8.2 Electrical characteristics

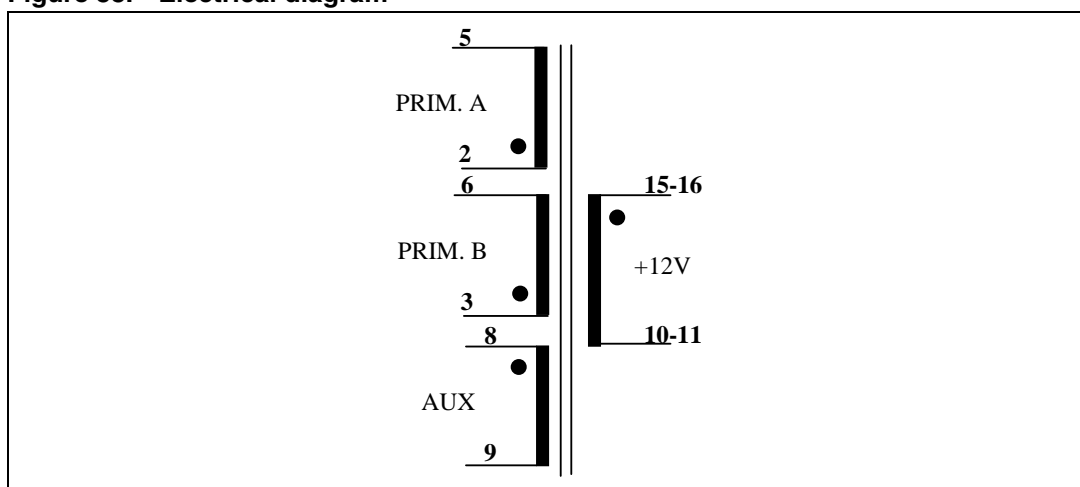
- Converter topology: flyback, CCM/DCM mode
- Core type: EER34 - PC47
- Min. operating frequency: -
- Typical operating freq: 60 kHz
- Primary inductance: 550  $\mu$ H 10% @ 1 kHz - 0.25 V (see [Note 1](#))
- Leakage inductance: 17  $\mu$ H max @ 100 kHz - 0.25 V (see [Note 1](#) - [Note 2](#))
- Max. peak primary current: 2.65 A<sub>pk</sub>
- RMS primary current: 0.78 A<sub>rms</sub>

Note: 1 Measured between pins 1-3

2 Measured between pins 1-3 with all secondary windings shorted

### 8.3 Electrical diagram and winding characteristics

Figure 33. Electrical diagram

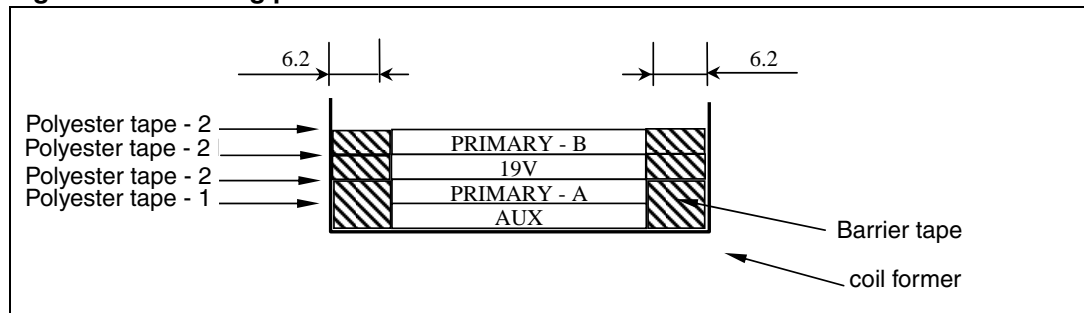


**Table 10. Winding characteristics**

Pin	Winding	O/P RMS current	Number of turns	Number of layers	Wire type
5 - 6	Aux	0.05 A <sub>RMS</sub>	7 spaced	1	G2 – $\phi$ 0.23 mm
3 - 1	Primary - A	0.39 A <sub>RMS</sub>	60	2	G2 – 2 x $\phi$ 0.23 mm
8 - 10	19 V	5.2 A <sub>RMS</sub>	8	1	Multistrand G2 - 4 x $\phi$ 0.64 mm
4 - 2	Primary - B	0.39 A <sub>RMS</sub>	60	2	G2- 2 x $\phi$ 0.23 mm

Note: All terminal wires must be insulated by tube

**Figure 34. Winding position on coil former**

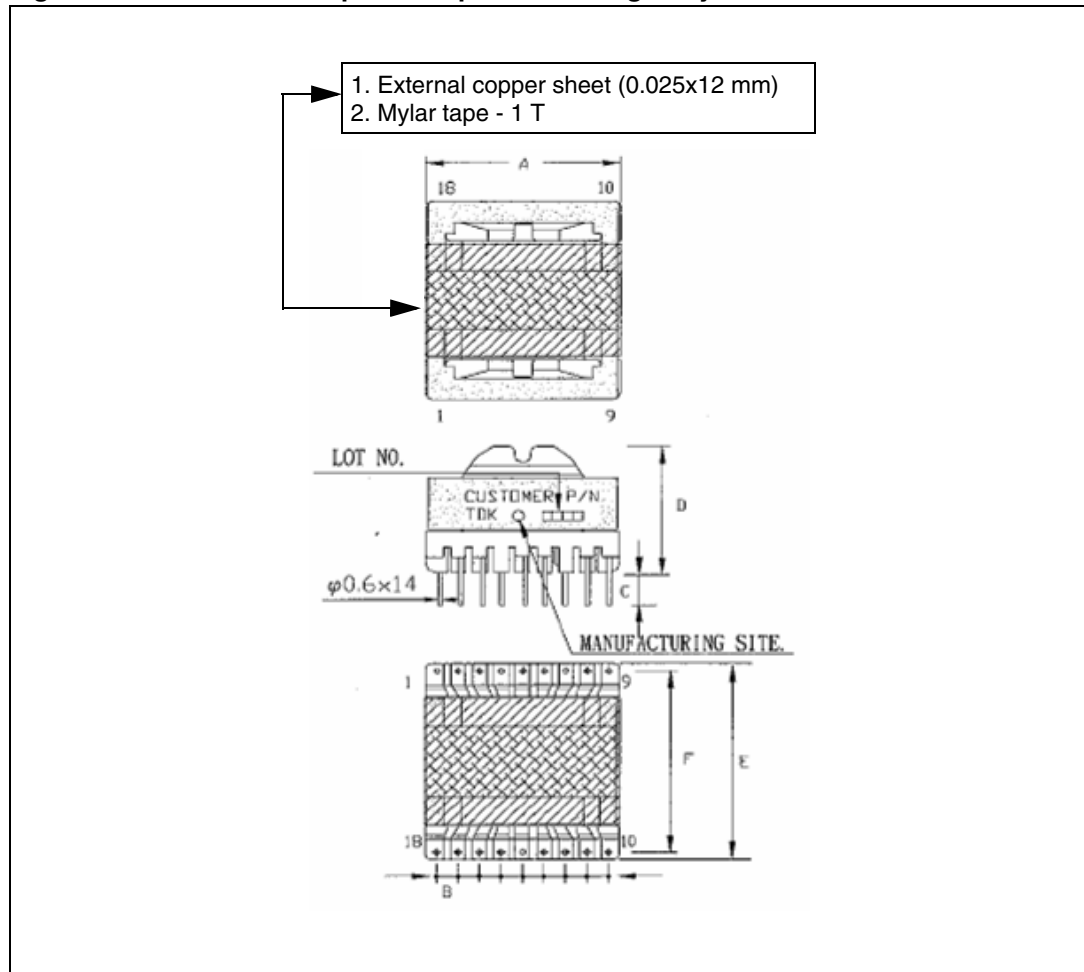


Note: Primaries A & B are in parallel

## 8.4 Mechanical aspect and pin numbering

- Maximum height from PCB: 30 mm
- Coil former type: horizontal, 9+9 pins (pin 2 removed)
- pin distance: 4 mm
- Row distance: 35 mm
- External copper shield: not insulated, wound around the ferrite core and including the coil former. Height is 12 mm.

Figure 35. Mechanical aspect and pin numbering of flyback transformer



- A: 38.0 max mm
- B: 4.0 ± 0.3 mm
- C: 3.5 ± 0.5 mm
- D: 26.5 max mm
- E: 40.0 max mm
- F: 35.0 ± 0.5 mm

## 9 Revision history

Table 11. Document revision history

Date	Revision	Changes
24-Oct-2007	1	Initial release



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