AN4677
Application note

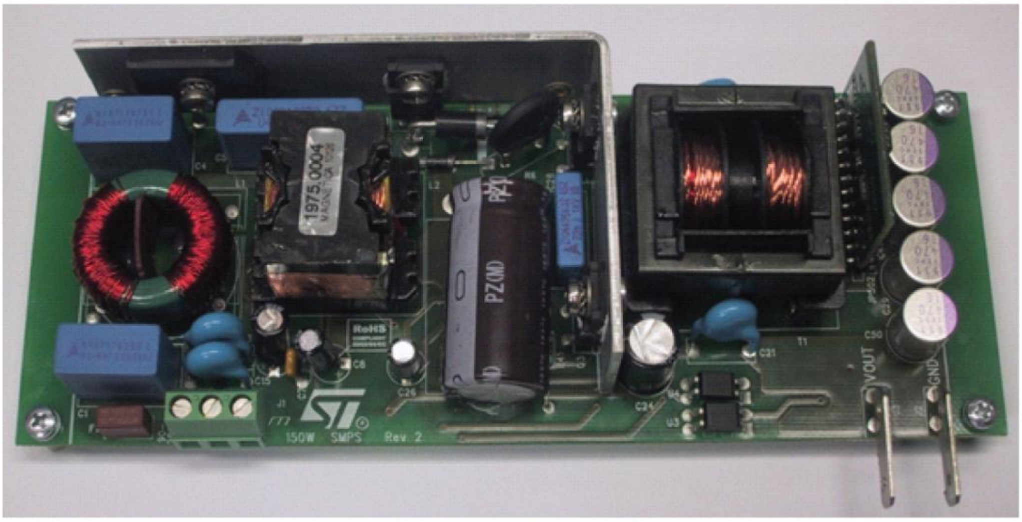
12 V - 150 W resonant converter with synchronous rectification based on L6563H, L6699 and SRK2001

Introduction

This application note describes the STEVAL-ISA170V1 demonstration board, featuring a 12 V - 150 W converter tailored to a typical specification for an all-in-one (AIO) computer power supply or a high power adapter.

The architecture is based on a two-stage approach: a front-end PFC pre-regulator based on the L6563H TM PFC controller and a downstream LLC resonant half-bridge converter using the L6699 resonant controller. The L6699 integrates some very innovative functions such as self-adjusting adaptive dead-time, anti-capacitive mode protection and a proprietary "safe-start" procedure preventing hard switching at startup. The innovative adaptive synchronous rectification controller SRK2001 allows efficiency maximization under all load conditions. Thanks to the chipset used, the main feature of this power supply is very high efficiency that is compliant with ENERGY STAR® eligibility criteria for adapters and computers. The power supply also offers good efficiency under light loads and complies with the EuP Lot 6 Tier 2 requirements. No-load input power consumption is also very low and within international regulation limits.

Figure 1: STEVAL-ISA170V1: 150 W SMPS demonstration board



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1 Main characteristics and circuit description

Table 1: SMPS main features

Parameter	Value
Input mains range	from 90 to 264 Vac - frequency 45 to 65 Hz
Output voltage	12 V at 12.5 A continuous operation
Mains harmonics	According to EN61000-3-2 Class-D or JEITA-MITI Class-D
No-load mains consumption	< 0.15 W at 230 Vac, according to European CoC ver. 5 Tier 2 requirements for external power supplies
Avg. efficiency	> 91% at 115 Vac, according to ENERGY STAR® 6.1 for external power supplies
Light load efficiency	According to EuP Lot 6 Tier 2 requirements
EMI	According to EN55022 Class-B
Safety	According to EN60950
Dimensions	65 x154 mm, 28 mm component maximum height
PCB	Double side, 70 µm, FR-4, Mixed PTH/SMT

The circuit is made up of two stages:

- a front-end PFC using the L6563H – an LLC resonant converter based on the L6699
- the SRK2001 controlling the SR MOSFETs on the secondary side.

The SR driver and the rectifier MOSFETs are mounted on a daughterboard.

The L6563H is a current mode PFC controller operating in transition mode and implements a high-voltage startup to power up the converter. The L6699 integrates all the functions necessary to properly control the resonant converter with a 50 % fixed duty cycle and operate with variable frequency.

The output rectification is managed by the SRK2001, an SR driver dedicated to LLC resonant topology.

The PFC stage functions as the pre-regulator and powers the resonant stage with a constant voltage of 400 V. The downstream converter only operates if the PFC is on and regulating.

In this way, the resonant stage can be optimized for a narrow input voltage range. The L6699 LINE pin (pin 7) is dedicated to this function. It is used to prevent the resonant converter from working with an input voltage that is too low, which can cause incorrect capacitive mode operation. The resonant startup does not proceed if the bulk voltage (PFC output) is below 380 V. The L6699 LINE pin internal comparator has a current hysteresis allowing the turn-on and turn-off voltage to be independently set. The turn-off threshold is set to 300 V so the resonant stage can continue operation in case of a mains sag and consequent PFC output dip. The transformer uses the integrated magnetic approach, incorporating the resonant series inductance. Therefore, no additional external coil is needed for the resonance. A center tap transformer configuration is used for the secondary winding.

On the secondary side, the SRK2001 core function is to switch each synchronous rectifier MOSFET on whenever the corresponding transformer half-winding starts conducting (i.e. when the MOSFET body diode starts conducting) and then switch it off when the flowing current approaches zero. For this purpose, the IC is provided with two pins (DVS1 and DVS2) to sense the drain voltage level of the MOSFET. The SRK2001 automatically detects light load operation and enters sleep mode, which decreases its consumption and disables MOSFET driving. This function saves a lot of power under light loads with respect to benchmark SR solutions. In order to decrease the output capacitors size, aluminum solid capacitors with very low ESR are used instead of standard electrolytic ones. Therefore, high frequency output voltage ripple is limited and an output LC filter is not required. This choice reduces output inductor power dissipation, which can be significant in high output current applications such as this.

1.1 Standby power saving

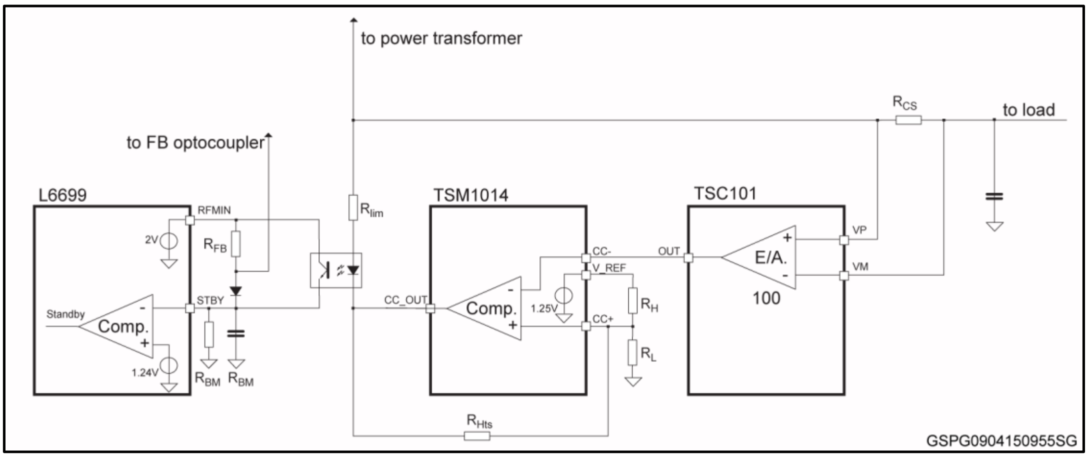
The board implements a burst mode function that allows power saving during light load operation. The L6699 STBY pin (pin 5) senses the optocoupler's collector voltage (U3), which is related to the feedback control. This signal is compared with an internal reference (1.24 V). If the voltage on the pin is lower than the reference, the IC enters an idle state and its quiescent current is reduced. When the voltage exceeds the reference by 30 mV, the controller restarts the switching. The burst mode operation load threshold can be set by changing the resistor connecting the optocoupler to pin RFMIN (R34). Basically, R34 sets the switching frequency at which the controller enters burst mode. Since the power at which the converter enters burst mode operation heavily influences converter efficiency at light load, it must be set correctly. However, even if this threshold is set correctly, the light load efficiency of mass production converters will vary considerably if the tolerance is too large.

The main factors affecting the burst mode threshold tolerance are the control circuitry tolerances and, more so, the tolerances of the resonant inductance and resonant capacitor. Slight changes in resonance frequency can affect the switching frequency and hence significantly alter the burst mode threshold. The normal production variations in these parameters, while acceptable for many applications, are no longer acceptable if very low power consumption in standby must be guaranteed.

As reducing the production tolerances of resonant components implies increased costs, a new cost-effective solution is necessary.

The key point of the proposed solution is to directly sense the output load to set the burst mode threshold. In this way, the resonant element parameters no longer affect this threshold. The implemented circuit block diagram is shown in *Figure 2: "Burst-mode circuit block diagram"*.

Figure 2: Burst-mode circuit block diagram



1. the output current is sensed by a resistor (RCS)
2. the voltage drop across this resistor is amplified by the TSC101, a dedicated high-side current sense amplifier

3. its output is compared with a set reference by the TSM1014:
   - if the output load is high, the signal fed into the CC- pin is above the reference voltage, CC_OUT stays down and the optocoupler transistor pulls up the L6699 STBY pin to the RFMIN voltage (2 V), setting continuous switching operation (no burst mode)
   - if the load decreases, the voltage on CC- falls below the set threshold, CC_OUT goes high opening the connection between RFMIN and STBY and allowing burst mode operation by the L6699

RCS is dimensioned according to two criteria:

1. the maximum power dissipation allowed based on the efficiency target
2. the need to feed a reasonable voltage signal into the TSM1014A inverting input; signals which are too small affect system accuracy

On this board, the maximum acceptable power dissipation is set to $P_{loss,MAX}$ = 500 mW.

The maximum value of R_{CS} is:

$$R_{CS,MAX} = \frac{P_{loss,MAX}}{I^2_{out,MAX}} = 3.2m\Omega$$

The burst mode threshold is set at 5 W, which corresponds to I_{BM} = 417 mA output current at 12 V. Choosing V_{CC+min} = 50 mV as the minimum reference of the TSM1014A provides a good signal to noise ratio.

The RCS minimum value is:

$$R_{CS,min} = \frac{V_{CC+,min}}{100 \cdot I_{BM}} = 1.2m\Omega$$

The actual value of the mounted resistor is 2 mΩ, which corresponds to P_{loss} = 312 mW power loss at full load. The actual resistor value at the burst mode threshold current provides a TSC101 output voltage of 83 mV. The reference voltage of TSM1014 VCC+ is set at this level.

The resistor divider setting the TSM1014 R_H and R_L thresholds should be in the order of kiloohms to minimize dissipation.

For R_L = 22 kΩ, the right R_H value is:

$$R_H = \frac{R_L\left(1.25V - V_{BM}\right)}{V_{BM}} = 309k\Omega$$

The value of the mounted resistor is 330 kΩ. R_{Hts} sets a small debouncing hysteresis and is in the order of megaohms. R_{lim} is in the order of tens of kiloohms and limits the current flowing through the optocoupler's diode.

Both L6699 and L6563H implement their own burst mode function but, in order to improve the overall power supply efficiency, at light load the L6699 drives the L6563H via the PFC_STOP pin and enables the PFC burst mode. As soon as the L6699 stops switching due to load drops, its PFC_STOP pin pulls down the L6563H PFC_OK pin, disabling PFC switching.

Thanks to this simple circuit, the PFC is forced into idle state when the resonant stage is not switching and rapidly wakes up when the downstream converter begins switching again.

1.2 Startup sequence

The PFC acts as the master and the resonant stage can only operate while the PFC output is delivering the rated output voltage. Therefore, the PFC starts before the LLC converter turns on. initially, the L6563H is supplied by the integrated high-voltage startup circuit. As soon as the PFC starts switching, a charge pump circuit connected to the PFC inductor supplies both PFC and resonant controllers and the HV internal current source is therefore disabled. Once both stages have been activated, the controllers are also supplied by the auxiliary winding of the resonant transformer, ensuring correct supply voltage even during standby operation. The disabling of the L6563H integrated HV startup circuit greatly reduces power consumption when the power supply operates at light load.

1.3 L6563H brownout protection

Brownout protection prevents the circuit from working with abnormal mains levels. It is easily achieved using the RUN pin (pin 12) of the L6563H. This pin is connected through a resistor divider to the VFF pin (pin 5), which provides the mains voltage peak value information. An internal comparator enables IC operation if the mains level is within the nominal limits.

Circuit operation is inhibited at startup if the input voltage is below 90 Vac (typ.).

1.4 L6563H fast voltage feed-forward

The voltage on the L6563H VFF pin (pin 5) is the peak value of the voltage on the MULT pin (pin 3). The RC network (R15+R26, C12) connected to VFF completes a peak-holding circuit. This signal is necessary to derive information from the RMS input voltage to compensate the loop gain that is mains voltage dependent.

Generally speaking, if the time constant is too small, the generated voltage is affected by a considerable amount of ripple at twice the mains frequency, therefore distorting the current reference (resulting in higher THD and lower PF). If the time constant is too large, there is a considerable delay in setting the right amount of feed-forward, resulting in excessive overshoot or undershoot of the pre-regulator's output voltage in response to large line voltage changes.

To overcome this issue, the L6563H implements the fast voltage feed-forward function. As soon as the voltage on the VFF pin decreases by a set threshold (40 mV typically), a mains dip is assumed and an internal switch rapidly discharges the VFF capacitor via a 10 kΩ resistor. Thanks to this feature, it is possible to set an RC circuit with a long time constant, assuring a low THD and maintaining a fast response to mains dip.

1.5 L6699 overload and short circuit protection

The current flowing into the primary winding is sensed by the lossless circuit R41, C27, R78, R79, and C25, and fed into the ISEN pin (pin 6). In case of overload, the voltage on the pin rises over an internal threshold (0.8 V) that triggers a protection sequence.

An internal switch is turned on for 5 µs and discharges the soft-start capacitor C18. This quickly increases the oscillator frequency and thereby limits energy transfer. Under output short circuit conditions, this operation results in a peak primary current that periodically oscillates below the maximum value allowed by the sense resistor R78.

The converter operates under this condition for a time set by the capacitor (C45) on pin DELAY (pin 2). During this condition, C45 is charged by an internal 150 µA current generator and is slowly discharged by the external resistor (R24). If the voltage on the pin reaches 2 V, the soft start capacitor is completely discharged so that the switching frequency is pushed to its maximum value. When the voltage on the pin exceeds 3.5 V, the

IC stops switching and the internal generator is turned off so that the voltage on the pin will decay because of the external resistor. The IC is soft-restarted when the voltage drops below 0.3 V. In this way, under short-circuit conditions, the converter functions intermittently with very low average input power.

This procedure allows the converter to handle overload conditions within a set time to avoid IC shutdown in case of short overload or peak power transients.

In case of a dead short, however, a second comparator referenced to 1.5 V disables switching immediately and activates a restart procedure.

1.6 L6699 anti-capacitive protection

Normally, the resonant half-bridge converter operates with the resonant tank current lagging behind the square-wave voltage applied by the half-bridge leg. This is a necessary condition in order for soft-switching to occur. In reverse phase relationships, i.e. the resonant tank current leads the applied voltage (like in circuits with capacitive reactance), soft-switching would be lost. This condition is referred to as capacitive mode and must be avoided because of significant drawbacks associated with hard switching (refer to L6699 data sheet).

Resonant converters work in capacitive mode when their switching frequency falls below a critical value that depends on the loading conditions and the input-to-output voltage ratio. They are especially prone to run into capacitive mode when the input voltage is lower than the minimum specified and/or the output is overloaded or short circuited. Designing a converter so that it never works in capacitive-mode even under abnormal operating conditions is definitely possible, but this might pose unacceptable design constraints in some cases.

To avoid the severe drawbacks of capacitive-mode operation while enabling a design that ensures inductive-mode operation only in the specified operating range, neglecting abnormal operating conditions, the L6699 provides a capacitive-mode detection function.

The IC monitors the phase relationship between the tank current circuit sensed on the ISEN pin and the voltage applied to the tank circuit by the half-bridge, checking that the former lags behind the latter (inductive-mode operation). When the phase-shift approaches zero, which is indicative of imminent capacitive-mode operation, the monitoring circuit activates the overload procedure described above so that the resulting frequency rise prevents the converter from entering this dangerous condition. Also in this case, the DELAY pin is activated so that the OLP function, if used, is eventually tripped after time T_{SH}, causing intermittent operation and reducing thermal stress.

If the phase relationship reverses abruptly (which may occur in case of a dead short at the converter's output), the L6699 is stopped immediately, the soft-start capacitor C18 is totally discharged and a new soft-start cycle is initiated after 50 µs idle time. During this idle period, the PFC_STOP pin is pulled low to stop the PFC stage as well.

1.7 Output voltage feedback loop

The feedback loop is implemented via a typical circuit using the dedicated operational amplifier of TSM1014A modulating the current in the optocoupler's diode. The second comparator embedded in the TSM1014A, usually dedicated to constant current regulation, is used here for burst mode as previously described.

On the primary side, R80 and R34 connect RFMIN pin (pin 4) to the optocoupler's phototransistor closing the feedback loop. R31, which connects the same pin to ground, sets the minimum switching frequency. The RC series R44 and C18 sets the soft-start maximum frequency and duration.

1.8 Open loop protection

Both PFC and resonant circuit stages are equipped with their own over voltage protections.

The PFC controller L6563H monitors its output voltage via the resistor divider connected to a dedicated pin (PFC_OK, pin 7) protecting the circuit in case of loop failures or disconnection. If a fault condition is detected, the internal circuitry latches the L6563H operations and, via the PWM_LATCH pin (pin 8), also latches the L6699 through the DIS pin (pin 8). The converter is kept latched by the L6563H internal HV start up circuit that supplies the IC by charging the V_{CC} capacitor periodically. To resume converter operation, mains restart is necessary.

The output voltage is monitored by sensing the V_{CC} voltage. If V_{CC} voltage overrides the D12 breakdown voltage, Q9 pulls down the L6563H INV pin latching the converter.

1.9 SRK2001 configuration

The SRK2001 controller implements a special control scheme for secondary side synchronous rectification in LLC resonant converters which implements a transformer with center tap secondary winding for full wave rectification. It provides two high current gate drive outputs, each capable of driving one or more N-channel power MOSFETs.

Each gate driver is controlled separately and an interlock logic circuit prevents the two synchronous rectifier MOSFETs from conducting simultaneously. The control scheme in this IC ensures each synchronous rectifier is switched on when the corresponding half-winding starts conducting and switched off as its current approaches zero. The innovative turn-on logic with adaptive masking time and the adaptive turn-off logic allows maximizing the conduction time of the SR MOSFETs, eliminating the need for a parasitic inductance compensation circuit.

The low consumption mode of the device allows even the most stringent requirement for converter power consumption in light-load/no load conditions to be satisfied.

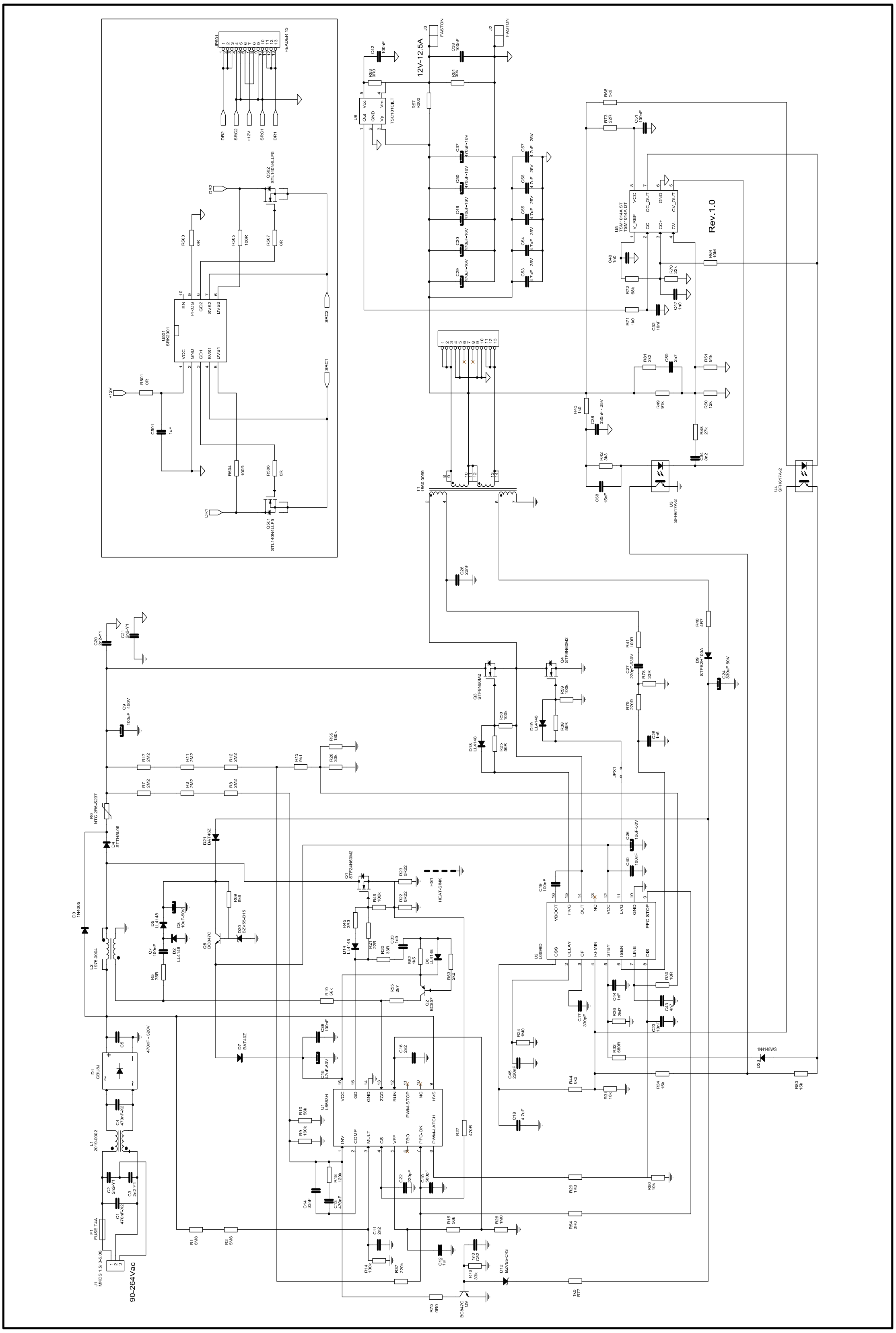
A unique feature of this IC is its sleep-mode function, with user programmable entering-exiting conduction duty-cycles (from look-up tables of the datasheet). It allows the detection of a low-power condition for the converter and puts the IC in low consumption sleep mode, where gate driving is stopped and quiescent consumption is reduced. In this way, the converter's efficiency improves at light load, where synchronous rectification is no longer beneficial. The IC automatically exits sleep mode and restarts switching when it detects an increased converter load. The sleep mode function may also be disabled by the user (see datasheet).

In this application, the IC has been configured to have a burst mode operation controlled by the primary side:

- R_{EN} = open --> SRK2001 automatic SR sleep mode disabled (SRK2001 BM follows HB)
- R_{PG} = 0R -->80% (SRK2001 restarts once SR duty is longer than 80% at HB restart)

This means that automatic sleep mode is disabled but the SR enters low-consumption mode when it detects that the HB converter has stopped. After the primary side switching restarts, the controller resumes operation when it detects that the conduction duty cycle has increased above 80%.

Figure 3: STEVAL-ISA170V1 electrical diagram



2 Efficiency measurement

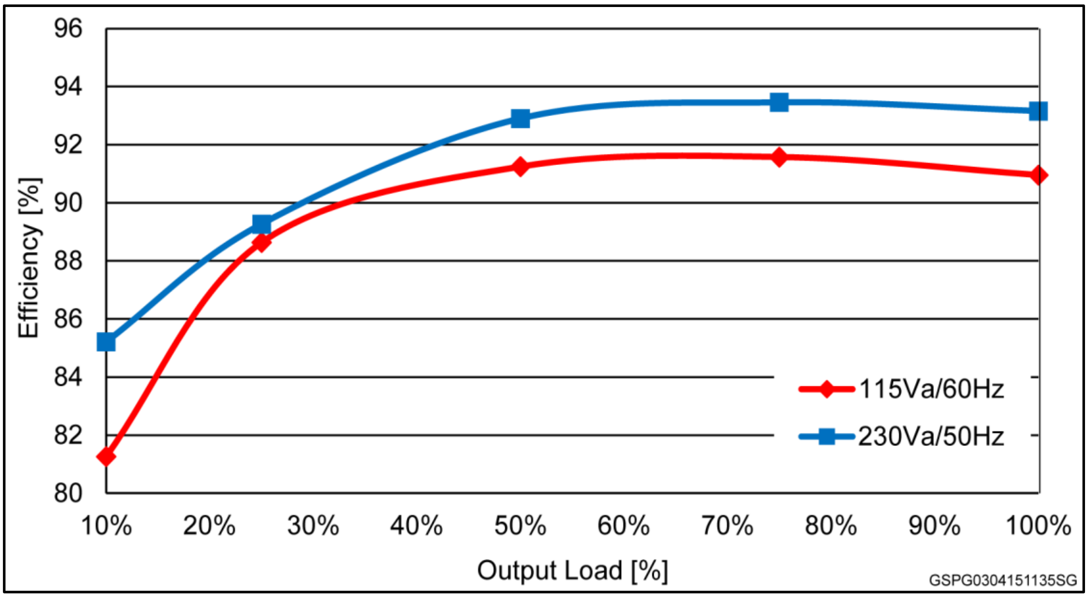
Table 1: "SMPS main features" shows the no load consumption and the overall efficiency measurements at the nominal mains voltages. At 115 Vac the full load efficiency is 90.96%, and at 230 Vac it is 93.16%, which are both high values for a double stage power supply and confirm the benefit of implementing the synchronous rectification. The results are also shown in *Figure 4: "Graph of efficiency measurements"* as a graph.

Also at no load, the board performance is superior for a 150 W power supply: no load consumption at nominal mains voltage is lower than 150 mW.

Table 2: Overall efficiency

Test	230 V - 50 Hz					115 V - 60 Hz				
	Vout [V]	Iout [A]	Pout [W]	Pin [W]	Eff. [%]	Vout [V]	Iout [A]	Pout [W]	Pin [W]	Eff. [%]
No load	11.93	0.00	0.00	0.145		11.93	0.00	0.00	0.140	
100 mW Load	11.93	0.0080	0.0960	0.2694	35.65%	11.93	0.0080	0.0960	0.2739	35.06%
250 mW Load	11.93	0.0212	0.2529	0.463	54.63%	11.93	0.0212	0.2529	0.486	52.04%
10% load eff.	11.93	1.25	14.91	17.5	85.21%	11.93	1.25	14.91	18.35	81.27%
25% load eff.	11.93	3.13	37.34	41.83	89.27%	11.93	3.13	37.34	42.13	88.63%
50% load eff.	11.92	6.26	74.61	80.32	92.90%	11.92	6.26	74.61	81.78	91.24%
75% load eff.	11.91	9.39	111.90	119.74	93.46%	11.91	9.39	111.90	122.2	91.58%
100% load eff.	11.91	12.52	149.11	160.06	93.16%	11.90	12.52	148.98	163.8	90.96%
Average eff.					92.20%					90.6%

Figure 4: Graph of efficiency measurements



3 Eco design requirement verification power supplies

In the following tables the comparison between the regulation requirements for Eco design and the STEVAL-ISA170V1 test results are reported: note that the design overcomes the requirements with margin.

Table 3: ENERGY STAR® requirements for computers ver. 6.1

ENERGY STAR® requirements for computers ver. 6.1	Test results		Limits	Status
	115 Vac - 60 Hz	230 Vac - 50 Hz		
Efficiency @ 20 % load	84.2%	86.63%	> 82%	Pass
Efficiency @ 50 % load	91.24%	92.90%	> 85%	
Efficiency at 100 % load	90.96%	93.16%	> 82%	
Power factor	0.9897	0.9521	> 0.9	

Table 4: EuP Lot 6 Tier 2 requirements for household and office equipment

EuP Lot 6 Tier2 requirements	Test results		Limits	Status
	115 Vac - 60 Hz	230 Vac - 50 Hz		
Avg. Efficiency measured at 25%, 50%, 75%, 100%	90.6%	92.20%	> 87%	Pass
Efficiency @ 250 mW load	52.04%	54.63%	> 50%	
Efficiency @ 100 mW load	35.06%	35.65%	> 33%	

Table 5: European CoC ver. 5 Tier 2 requirements for External Power Supplies

European CoC ver. 5 Tier-2 requirements for External Power Supplies	Test results		Limits	Status
	115 Vac - 60 Hz	230 Vac - 50 Hz		
Avg. Efficiency measured at 25%, 50%, 75%, 100%	90.6%	92.20%	> 89%	Pass
Efficiency @ 10% load	81.27%	85.21%	> 79%	
No Load Input Power [W]	0.140 W	0.145 W	< 0.15 W	

3.1 Light load operation efficiency

Computer power supplies must now meet higher efficiency limits even at light load because the latest regulations such as the EuP Ecodesign requirements for household and office equipment Lot 6 Tier 2 have lowered maximum power consumption thresholds during computer standby and off modes.

Measurement results are reported in *Table 5: "European CoC ver. 5 Tier 2 requirements for External Power Supplies"* and plotted in *Figure 5: "Light load efficiency diagram"*. As can be seen, efficiency is better than 50% even for very light loads like 250 mW. This high efficiency at light load renders the board comlpiant with the low power status ENERGY STAR® program for computers ver. 6.1.

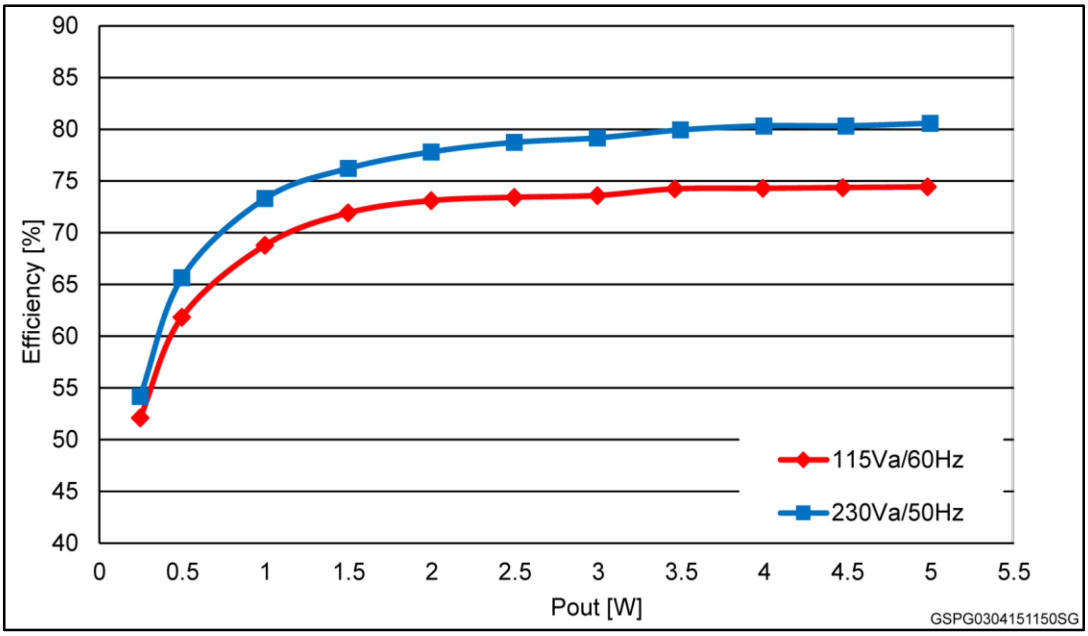
4 Measurement procedure

1. As the current flowing through the circuit under measurement is relatively small, the current measurement circuit is connected to the demonstration board side and the voltage measurement circuit is connected to the AC source side. In this way, the current absorbed by the voltage circuit is not considered in the measurement.
2. During efficiency measurements, remove any oscilloscope probe from the board.
3. For any measurement load, apply a warm-up time of 20 minutes for each different load.
4. Loads are applied increasing the output power from minimum to maximum.
5. Because of the input current shape during light load condition, the input power measurement may be critical or unreliable using a power meter in the usual way. To overcome this, all light measurements are performed by measuring the active energy consumption of the demonstration board under test and then calculating the power as the energy divided by the integration time. The integration time is set to 36 seconds, as a compromise between a reliable measurement and a reasonable measurement time. The energy is measured in mWh and the result in mW is then calculated by simply dividing the instrument reading (in mWh) by 100. We used the Yokogawa WT210 power meter to perform the measurements.

Table 6: Light load efficiency

Test	230 V - 50 Hz					115 V - 60 Hz				
	Vout [V]	Iout [mA]	Pout [W]	Pin [W]	Eff. [%]	Vout [V]	Iout [mA]	Pout [W]	Pin [W]	Eff. [%]
0.25 W	11.93	20.60	0.246	0.45	54.19%	11.93	20.60	0.250	0.47	52.12%
0.5 W	11.93	41.60	0.497	0.76	65.65%	11.93	41.60	0.499	0.80	61.85%
1.0 W	11.93	83.50	0.997	1.36	73.31%	11.93	83.60	0.999	1.45	68.81%
1.5 W	11.93	125.50	1.497	1.96	76.22%	11.93	125.50	1.499	2.08	71.92%
2.0 W	11.93	167.40	1.996	2.57	77.82%	11.93	167.50	1.999	2.73	73.11%
2.5 W	11.93	209.40	2.496	3.17	78.74%	11.93	209.50	2.500	3.40	73.43%
3.0W	11.93	251.50	2.995	3.78	79.17%	11.93	251.50	3.009	4.07	73.61%
3.5 W	11.93	293.60	3.496	4.37	79.95%	11.93	291.00	3.509	4.66	74.25%
4.0 W	11.93	336.00	3.996	4.97	80.34%	11.93	335.00	4.015	5.37	74.30%
4.5 W	11.93	378.10	4.49	5.59	80.34%	11.93	376.00	4.510	6.01	74.38%
5.0 W	11.93	420.00	4.996	6.20	80.58%	11.93	419.00	5.003	6.69	74.44%

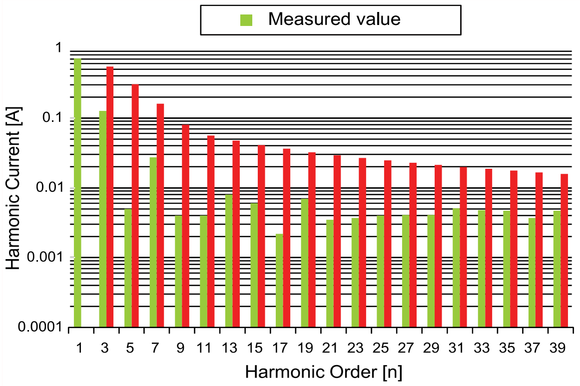
Figure 5: Light load efficiency diagram



5 Harmonic content measurement

The board has been tested according to the European Standard EN61000-3-2 Class-D and Japanese standard JEITA-MITI Class-D, at both the nominal input voltage mains. As reported in the following figures, the circuit is able to reduce the harmonics well below the limits of both regulations. The total harmonic distortion and power factor measurements are included below the charts. The values in all conditions clearly indicate the correct functionality of the PFC.

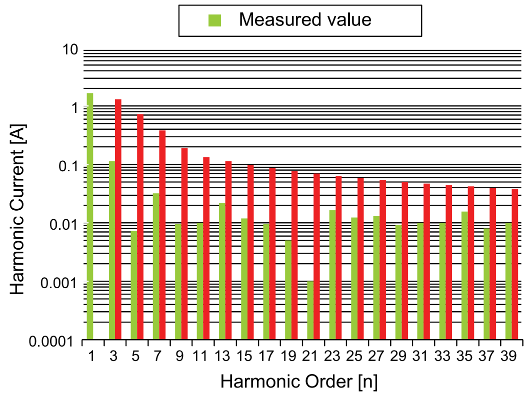
Figure 6: Compliance to EN61000-3-2 at 230 Vac - 50 Hz, full load



THD = 16.8% - PF = 0.9541

GSPG0304151525SG

Figure 7: Compliance to JEITA-MITI at 100 Vac - 50 Hz, full load

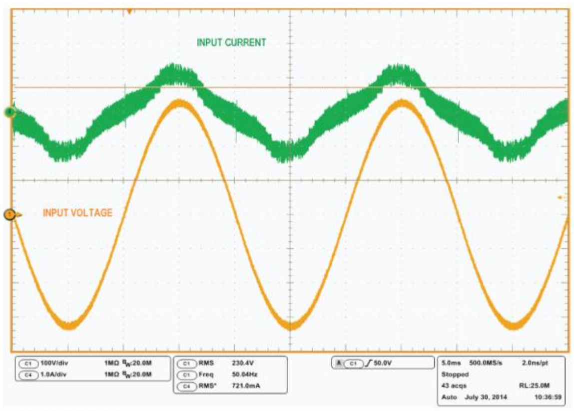


THD = 8% - PF = 0.9898

GSPG0304151535SG

In *Figure 8: "Mains voltage and current waveforms at 230 V - 50 Hz - full load - PF = 0.9521"* and *Figure 9: "Mains voltage and current waveforms at 100 V - 50 Hz - full load - PF = 0.9897"*, the input mains current is given for both European and Japanese nominal mains input voltages. For European mains, the waveforms show a slightly higher THD value because the PFC switching frequency is limited to around 125 kHz in order to increase the efficiency. However, all harmonics are within the limits specified by both regulations.

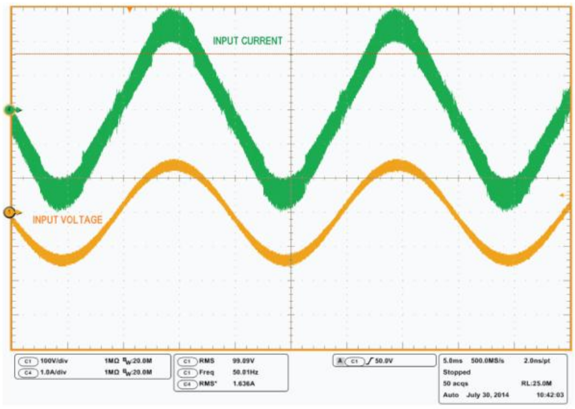
Figure 8: Mains voltage and current waveforms at 230 V - 50 Hz - full load - PF = 0.9521



CH1:Mains Voltage
CH4: Mains Current

GSPG0704150955SG

Figure 9: Mains voltage and current waveforms at 100 V - 50 Hz - full load - PF = 0.9897



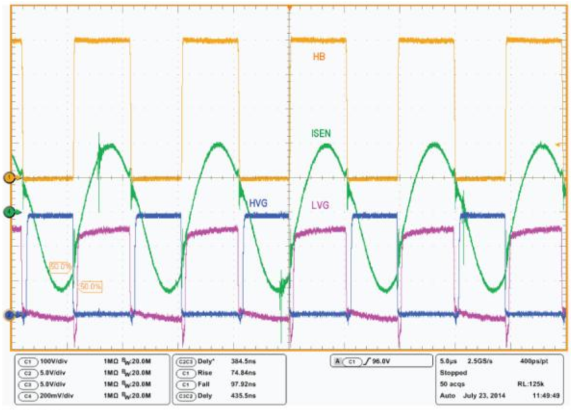
CH1:Mains Voltage
CH4: Mains Current

GSPG0704151005SG

6 Functional check

In *Figure 10: "Resonant stage waveforms at 115 Vac - 60 Hz - full load"*, some waveforms relevant to the resonant stage during steady-state operation are reported. The selected switching frequency is about 105 kHz to achieve a good trade-off between transformer loss and dimensions. The converter operates slightly above the resonance frequency. *Figure 11: "SRK2001 key signals at 115 Vac - 60 Hz - full load"* shows key signals from the SRK2001: each rectifier MOSFET is switched on and off according to its drain-source voltage which, during conduction, is the voltage of the current flowing through the MOSFET.

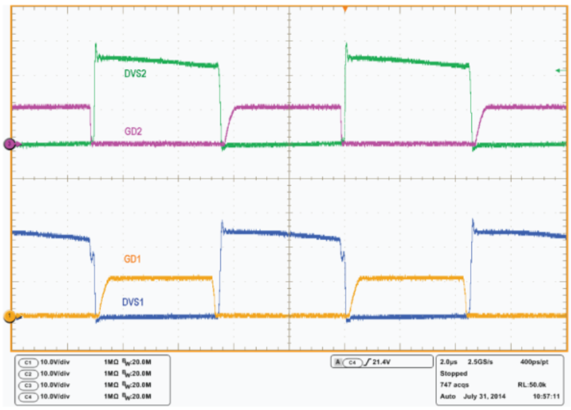
Figure 10: Resonant stage waveforms at 115 Vac - 60 Hz - full load



CH1: HB
CH2: HVG
CH3: LVG
CH4: ISEN

GSPG0704151010SG

Figure 11: SRK2001 key signals at 115 Vac - 60 Hz - full load

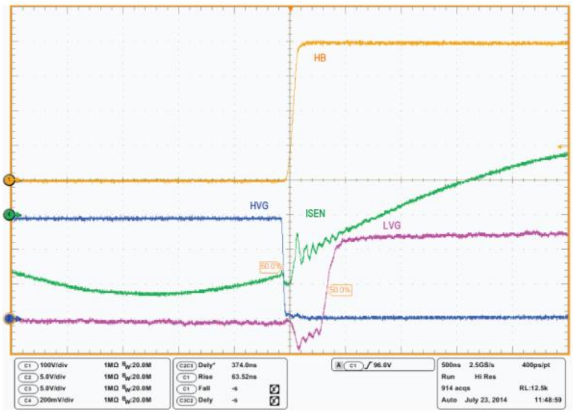


CH1: GD1
CH2: DVS1
CH3: GD2
CH4: DVS2

GSPG0704151015SG

Figure 12: "HB transition at full load - rising edge" and *Figure 13: "HB transition at full load - falling edge"* show the waveforms during full load operation; note the measurement of the edges and the relevant dead time.

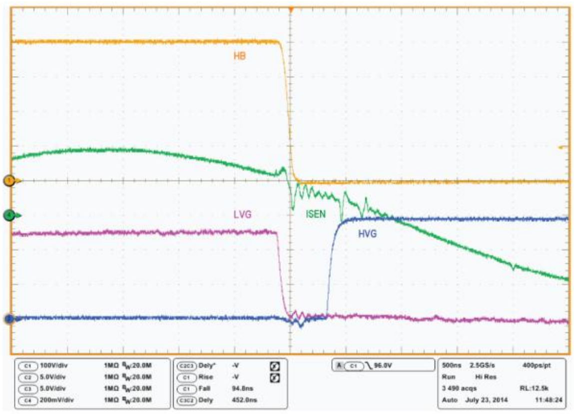
Figure 12: HB transition at full load - rising edge



CH1: HB
CH2: HVG
CH3: LVG
CH4: ISEN

GSPG0704151020SG

Figure 13: HB transition at full load - falling edge



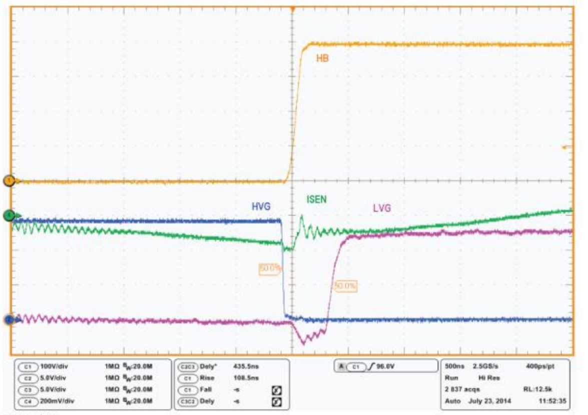
CH1: HB
CH2: HVG
CH3: LVG
CH4: ISEN

GSPG0704151025SG

A peculiarity of the L6699 is the self-adaptive dead time modulated by the internal logic according to the half bridge node transition time. This feature allows the maximization of the transformer magnetizing inductance, therefore obtaining good light load efficiency and also maintaining correct HB operation.

In *Figure 14: "HB transition at 0.25 A - rising edge"* and *Figure 15: "HB transition at 0.25 A - falling edge"*, the same images are captured during light load operation: note that because of the resonant tank parameters, the half bridge transitions have similar rise and fall times because the switched current is almost the same value in both load conditions. In this case, the L6699 does not appreciably change the dead time. In all conditions, both MOSFETs are turned on while resonant current is flowing through their body diodes and the drain-source voltage is zero, therefore achieving the ZVS operation of the MOSFETs at turn-on.

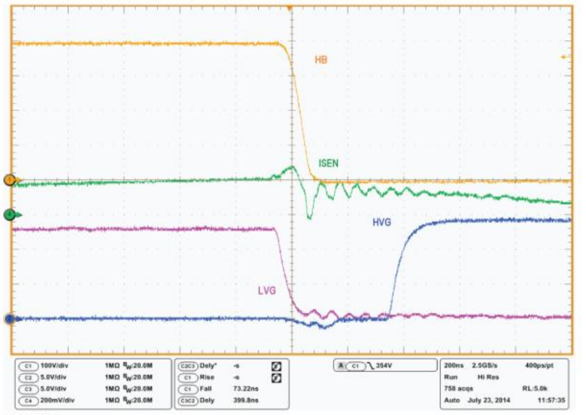
Figure 14: HB transition at 0.25 A - rising edge



CH1: HB
CH2: HVG
CH3: LVG
CH4: ISEN

GSPG0704151035SG

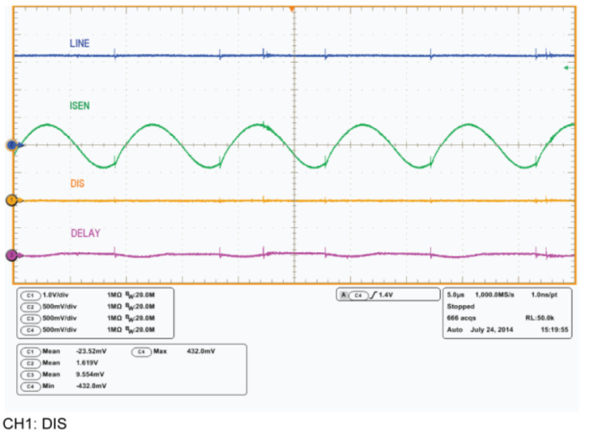
Figure 15: HB transition at 0.25 A - falling edge



CH1: HB
CH2: HVG
CH3: LVG
CH4: ISEN

GSPG0704151040SG

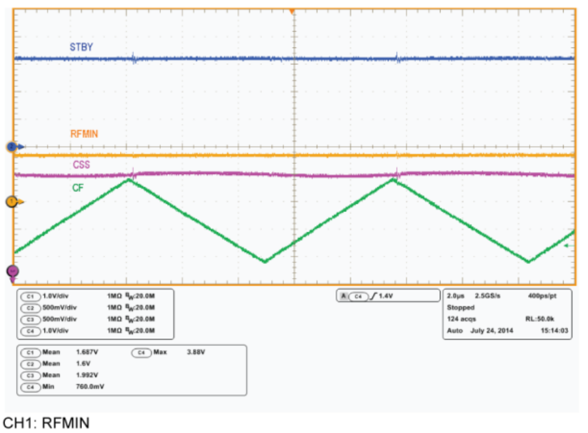
Figure 16: L6699 pin signals-1



CH1: DIS
CH2: LINE
CH3: DELAY
CH4: ISEN

GSPG0704151045SG

Figure 17: L6699 pin signals-2



CH1: RFMIN
CH2: STBY
CH3: CSS
CH4: CF

GSPG0704151050SG

In *Figure 16: "L6699 pin signals-1"*, some signals at L6699 pins are measured. It can be seen that the signal on the ISEN pin (pin 6) matches the instantaneous current flowing in the transformer primary side.

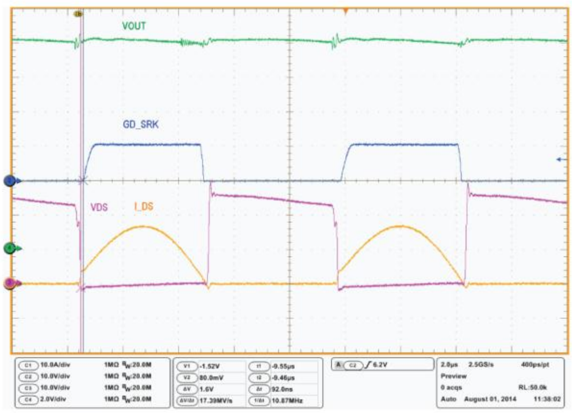
Contrary to former resonant controllers like the L6599A requiring a current signal integration, the L6699 integrates anti-capacitive mode protection; therefore it needs to sense the instantaneous value of the current in order to check the phase between the voltage and current.

The LINE pin (pin 7) is dimensioned to start up the L6699 once the PFC output voltage has reached the rated value for correct converter sequencing, with PFC starting first and LLC later in order to optimize the design of the LLC converter and prevent capacitive mode operation due to operation at insufficient input voltage.

The DELAY pin (pin 2) is zero during normal operation because it only becomes active in overcurrent protection mode. The DIS pin (pin 8) is used for open loop protection and its voltage is therefore also at ground level.

In *Figure 17: "L6699 pin signals-2"*, the pin voltages relevant to the control part of the L6699 are reported: the R_{Fmin} pin (pin 4) is a 2 V (typ.) reference voltage for the oscillator; the switching frequency is proportional to the current flowing out of the pin. The CSS pin (pin 1) voltage is the same as pin 4 because it is connected to the latter via a resistor (R44), determining the soft-start frequency. Capacitor (C18) is also connected between the CSS pin and ground to set the soft-start time. At the beginning of L6699 operation, the voltage on the CSS pin is at ground level because C18 is discharged, then the CSS pin (pin 1) voltage increases according to the time constant until the R_{Fmin} voltage level is reached. The STBY pin (pin 5) senses the optocoupler voltage; once the voltage decreases to 1.25 V, both gate drivers stop switching and the circuit works in burst mode. The CF pin (pin 3) is the controller oscillator; its ramp speed is proportional to the current flowing out of the R_{Fmin} pin (pin 4). The CF signal must be clean and undistorted to obtain a symmetrical half bridge current. Care must therefore be taken in the layout of the PCB.

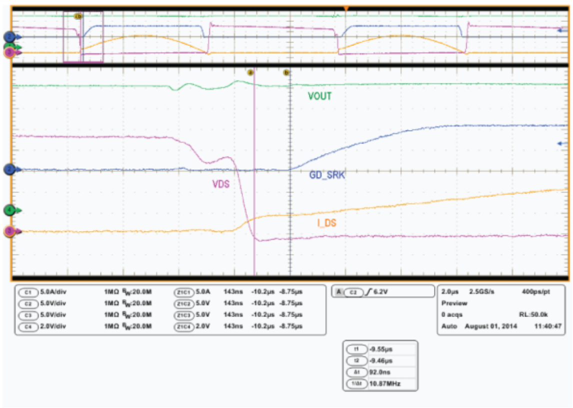
Figure 18: SRK2001 key signals at 115 Vac - 60 Hz - full load



CH1: I_DS
CH2: GD_SRK
CH3: VDS
CH4: ISEN

GSPG0704151055SG

Figure 19: SRK2001 key signals at 115 Vac - 60 Hz - full load-zoom of the turn-on-Tdelay=100ns



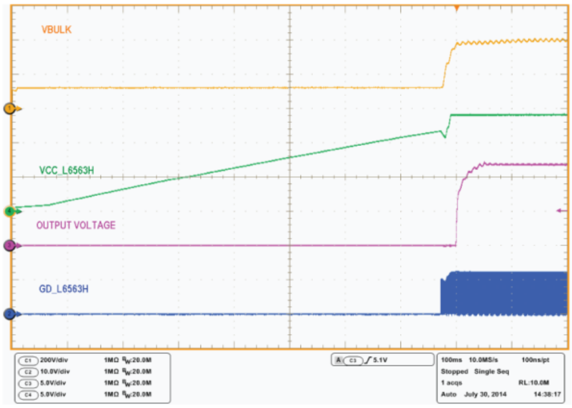
CH1: I_DS
CH2: GD_SRK
CH3: VDS
CH4: ISEN

GSPG0704151100SG

6.1 Startup

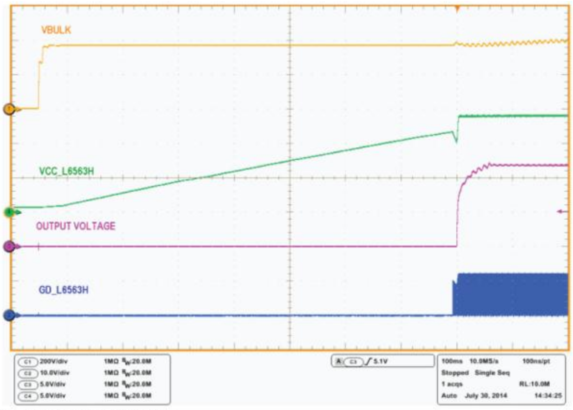
The waveforms relevant to the board startup at 90 Vac and full load are shown in *Figure 20: "Startup at 115 Vac - full load"*. Note that the output voltage reaches the nominal value approximately 800 ms after plug-in. The L6563H, HV PFC controller, has an embedded high-voltage startup charging the V_{CC} capacitor by a constant current, ensuring a constant wake-up time. This can be seen by comparing *Figure 20: "Startup at 115 Vac - full load"* with *Figure 21: "Startup at full load - detail"* relevant to a startup at 265 Vac and no load; the output voltage rises to the nominal level in the same time. In both conditions, the output voltage has no overshoot or dips.

Figure 20: Startup at 115 Vac - full load



CH1: C9 BULK VOLTAGE
CH2: GD L6563H
CH3: VOUT+12V
CH4: VCC L6563H
GSPG0704151105SG

Figure 21: Startup at full load - detail



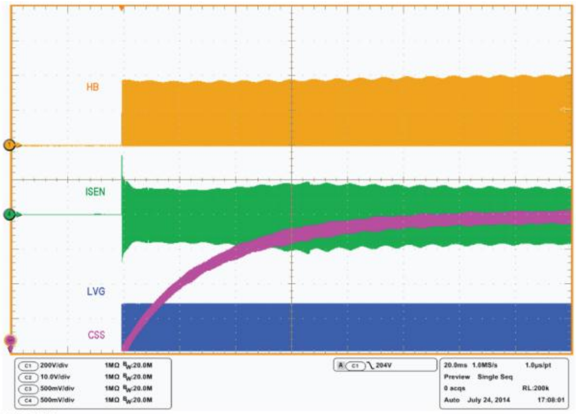
CH1: C9 BULK VOLTAGE
CH2: GD L6563H
CH3: VOUT+12V
CH4: VCC L6563H
GSPG0704151110SG

In *Figure 22: "Startup at 115 Vac"*, the salient waveforms in the resonant tank during LLC start-up are shown. In *Figure 23: "Startup at 115 Vac full load - detail"*, the waveform detail at the beginning of operation shows that the resonant circuit is working correctly at zero voltage switching operation from the initial cycles.

In the L6699, a new "safe-start" procedure has been included to prevent loss of soft-switching during the initial switching cycles, which typically is not guaranteed by the usual soft-start procedure. At startup, the voltage across the resonant capacitor is often quite different to Vin/2 during normal steady-state operation, so it takes some time for its DC component to reach this steady-state value. During this transient, the transformer is not driven symmetrically and there is a significant V · s imbalance in two consecutive half-cycles. If this imbalance is large, there is a significant difference in the up and down slopes of the tank current and, in a typical controller working with fixed 50% duty cycle, as the duration of the two half-cycles is the same, the current may not reverse in a switching half-cycle. Therefore, for a few cycles, one MOSFET can be turned on while the body diode of the other is conducting.

To prevent this, the L6699 is provided with a proprietary circuit that modifies the normal operation of the oscillator during the initial switching cycles so that the initial V · s unbalance is almost eliminated. Its operation is such that current reversal in every switching half-cycle, and therefore soft-switching, is ensured. In *Figure 23: "Startup at 115 Vac full load - detail"*, the duty cycle of the half bridge is initially considerably less than 50% and the tank current has lower peak values and changes sign every half-cycle while the DC voltage across the resonant capacitor approaches a steady state. The device goes to normal operation after approximately 50 µs from the first switching cycle. This transition is almost seamless and only a small perturbation of the tank current is observed.

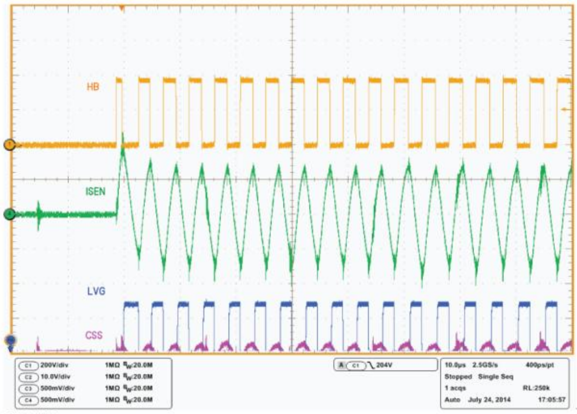
Figure 22: Startup at 115 Vac



CH1: HB
CH2: LVG
CH3: CSS
CH4: ISEN

GSPG0704151115SG

Figure 23: Startup at 115 Vac full load - detail



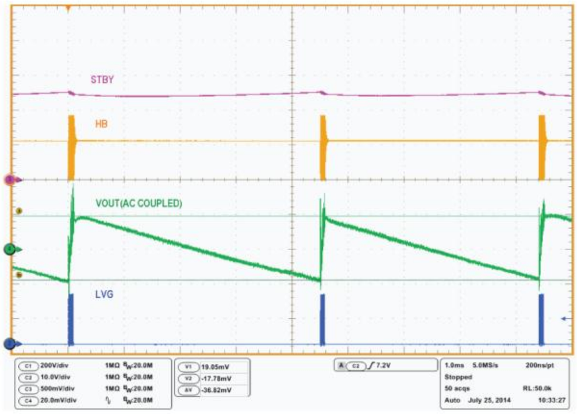
CH1: HB
CH2: LVG
CH3: CSS
CH4: ISEN

GSPG0704151120SG

6.2 Burst mode operation at light load

In *Figure 24: "Pout = 250 mW operation"*, some burst mode pulses are captured during 250 mW load operation. The burst pulses are very narrow and their period is quite long, therefore the resulting equivalent switching frequency is very low, ensuring high efficiency. The resulting output voltage ripple during burst mode operation is about 37 mV peak-to-peak. In *Figure 25: "Pout = 250 mW operation - detail"*, the detail of the burst is given: the first initial pulse is shorter than the following ones, thus avoiding the typical high current peak at half bridge operation restart, due to the recharging or the resonant capacitor. The maximum operating frequency of the half bridge set by the resistor R34 in series with the optocoupler is around 75 kHz.

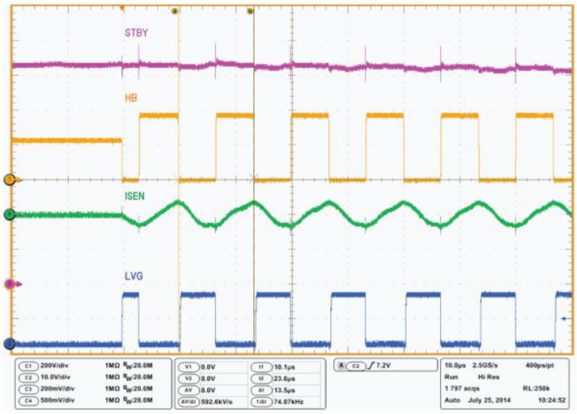
Figure 24: Pout = 250 mW operation



CH1: HB
CH2: LVG
CH3: STBY
CH4: VOUT (AC COUPLED)

GSPG0704151125SG

Figure 25: Pout = 250 mW operation - detail

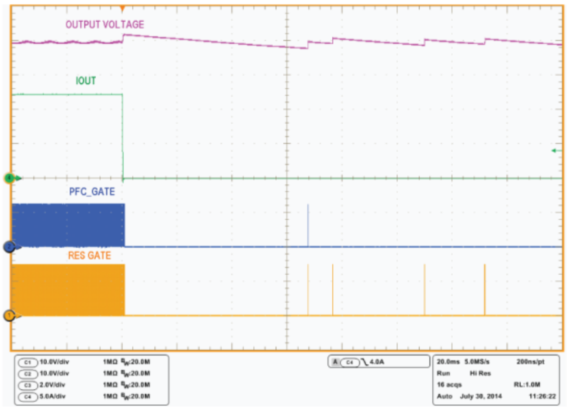


CH1: HB
CH2: LVG
CH3: STBY
CH4: VOUT (AC COUPLED)

GSPG0704151130SG

In *Figure 26: "Transition full load to no load at 115 Vac - 60 Hz"* and *Figure 27: "Transition no load to full load at 115 Vac - 60 Hz"*, the transitions from full load to no load and vice versa are shown. As seen in the images, both transitions are clean and there isn't any output voltage dip.

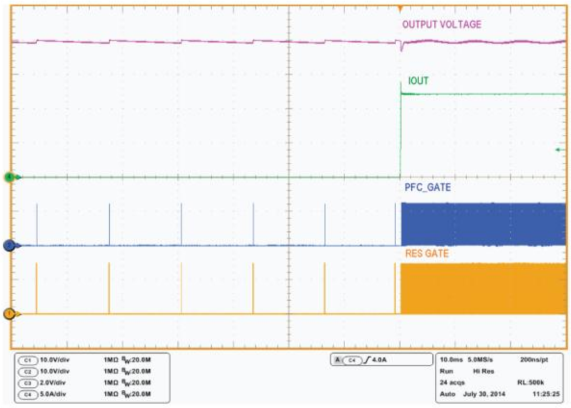
Figure 26: Transition full load to no load at 115 Vac - 60 Hz



CH1: LVG
CH2: PFC GD
CH3: Output voltage
CH4: Output current

GSPG0704151135SG

Figure 27: Transition no load to full load at 115 Vac - 60 Hz



CH1: LVG
CH2: PFC GD
CH3: Output voltage
CH4: Output current

GSPG0704151140SG

6.3 Overcurrent and short-circuit protection

The L6699 is equipped with a current sensing input (pin 6, ISEN) and a dedicated overcurrent management system. The current flowing in the resonant tank is detected and the signal is fed into the ISEN pin. It is internally connected to an initial comparator, referenced to 0.8 V, and to a second comparator referenced to 1.5 V. If the voltage externally applied to the pin exceeds 0.8 V, the first comparator is tripped causing an internal switch to be turned on and to discharge the soft-start capacitor CSS.

Under an output short-circuit condition, this operation results in a nearly constant peak primary current. With the L6699, the board designer can externally program the maximum time that the converter is allowed to run overloaded or under short-circuit conditions. Overloads or short-circuits lasting less than the set time do not cause any other action, therefore providing the system with immunity to short duration phenomena. If the overload condition persists, a protection procedure is activated that shuts down the L6699 and, in the case of continuous overload/short-circuit, results in continuous intermittent operation with a user-defined duty cycle. This function is realized with the DELAY pin (pin 2), by means of a capacitor C45 and the parallel resistor R24 connected to ground. When the voltage on the ISEN pin exceeds 0.8 V, the first OCP comparator, in addition to discharging CSS, turns on an internal 150 µA current generator that charges C45 via the DELAY pin. When the voltage on C45 is 3.5 V, the L6699 stops switching and the PFC_STOP pin is pulled low.

The internal generator is also turned off so that C45 is slowly discharged by R24. The IC restarts when the voltage on C45 drops to lower than 0.3 V.

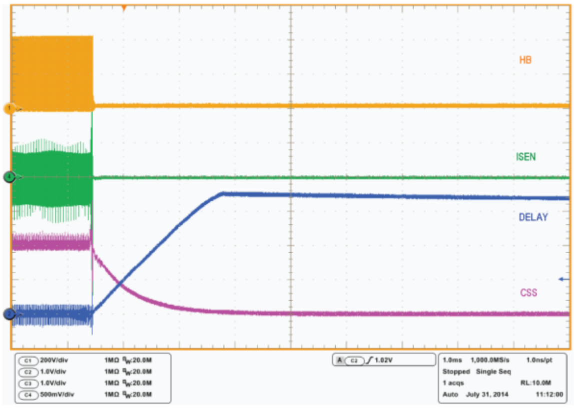
Additionally, if the voltage on the ISEN pin reaches 1.5 V for any reason (e.g. transformer saturation), the second comparator is triggered, the L6699 shuts down and C45 is charged to 3.5 V. Even in this case, the operation is resumed once the voltage on C45 drops below 0.3 V.

Figure 28: "Short-circuit at full load" shows a dead short-circuit event. In this case, the overcurrent protection is triggered by the second comparator referenced at 1.5 V which immediately stops switching of the L6699 and discharging of the soft-start capacitor. At the same time, the capacitor connected to the DELAY pin (pin 2) begins charging up to 3.5 V (typ.). When the voltage on the DELAY pin reaches 3.5 V, the L6699 stops charging the delay capacitor (C45) and L6699 operation resumes once the DELAY pin (pin 2) voltage

decays to 0.3 V (typ.) due to the parallel resistor (R24), via a soft-start cycle. If the short-circuit condition is removed, the converter recommences operation; if the short persists, the converter determines an intermittent operation (Hiccup mode) with a narrow converter operating duty cycle to prevent overheating the power components, as can be noted in *Figure 29: "Short-circuit at full load - detail"*.

In *Figure 30: "Short-circuit - hiccup mode"*, details of peak current with short-circuit occurring is shown. It is possible to see the correct ZVS operation of the half bridge MOSFETs.

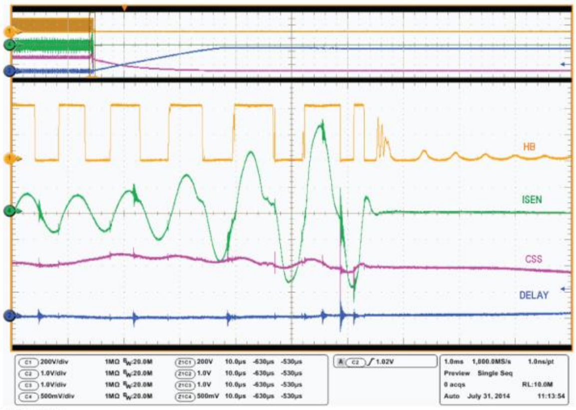
Figure 28: Short-circuit at full load



CH1: HB
CH2: DELAY
CH3: CSS
CH4: ISEN

GSPG0704151145SG

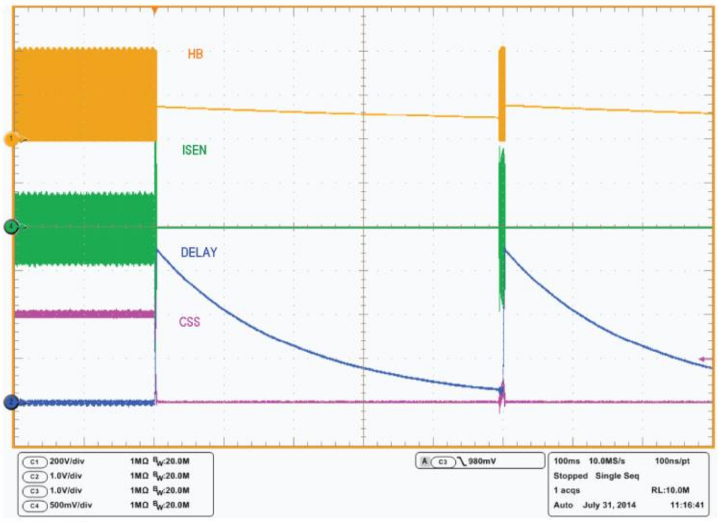
Figure 29: Short-circuit at full load - detail



CH1: HB
CH2: DELAY
CH3: CSS
CH4: ISEN

GSPG0704151150SG

Figure 30: Short-circuit - hiccup mode



CH1: HB
CH2: DELAY
CH3: CSS
CH4: ISEN

GSPG0704151155SG

6.4 Anti-capacitive mode protection

The STEVAL-ISA170V1 demonstration board has been designed so that the system does not work in capacitive mode during normal operation or failure conditions. As seen in

Figure 29: "Short-circuit at full load - detail", even under dead short conditions, the LLC operates correctly in the inductive region and the same correct operation occurs during load or input voltage transients. Normally, the resonant half bridge converter operates with the resonant tank current lagging behind the square-wave voltage applied by the half bridge leg, like a circuit having a reactance of an inductive nature. In this way, the applied voltage and the resonant current have the same sign at every transition of the half bridge, which is a necessary condition for soft-switching to occur (zero-voltage switching, ZVS at turn-on for both MOSFETs).

Therefore, should the phase relationship reverse, i.e. the resonant tank current leads the applied voltage (such as in circuits having a capacitive reactance), soft-switching would be lost. This is called capacitive mode operation and must be avoided because of its significant drawbacks:

1. Both MOSFETs feature hard-switching at turn-on, like in conventional PWM-controlled converters (see *Figure 14: "HB transition at 0.25 A - rising edge"*). The associated capacitive losses may be considerably higher than the total power normally dissipated under "soft-switching" conditions and this may easily lead to their overheating as heat sinking is not usually sized to handle this abnormal condition.
2. The body diode of the MOSFET that has just switched off conducts current during the deadtime and its voltage is abruptly reversed by the other turned on MOSFET (see *Figure 14: "HB transition at 0.25 A - rising edge"*). Therefore, the conducting body diode (which does not generally have great reverse recovery characteristics) maintains its low impedance until it recovers, giving rise to a condition equivalent to a shoot-through of the half bridge leg. This is a potentially destructive condition (see point 3) and causes additional power dissipation due to the current and voltage of the conducting body diode being simultaneously high during part of its recovery.
3. There is an extremely high reverse dv/dt (many tens of V/ns) experienced by the conducting body diode at the end of its recovery with the other MOSFET turned on. This dv/dt may exceed the rating of the MOSFET and lead to an immediate failure because of the second breakdown of the parasitic BJT intrinsic in its structure. If a MOSFET is hot, the turn-on threshold of its parasitic BJT is lower and the dv/dt-induced failure is far more likely.
4. When either MOSFET is turned on, the other one can be parasitically turned on too, if the current injected through its Cgd and flowing through the gate driver's pull-down is large enough to raise the gate voltage close to the turn-on threshold. This represents a lethal shoot-through condition for the half bridge leg.
5. The recovery of the body diodes generates large and energetic negative voltage spikes because of the unavoidable parasitic inductance of the PCB subject to its di/dt. These are coupled to the OUT pin and may damage the L6699.
6. There is a large common-mode EMI generation that adversely affects EMC.

Resonant converters work in capacitive mode when their switching frequency falls below a critical value that depends on the loading conditions and the input-to-output voltage ratio. They are especially prone to run in capacitive mode when the input voltage is lower than the minimum specified and/or the output is overloaded or short-circuited. Designing a converter so that it never works in capacitive mode, even under abnormal operating conditions, is certainly possible but this may pose unacceptable design constraints in some cases.

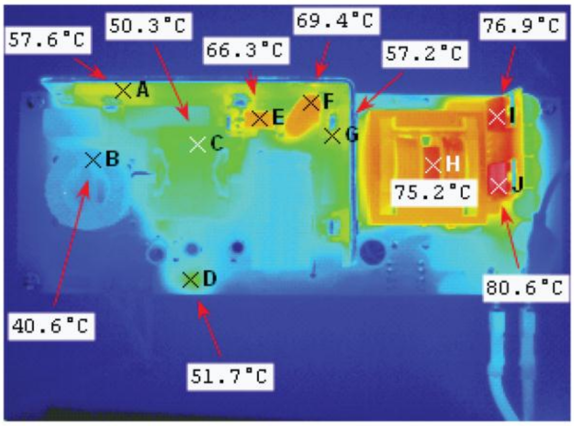
The L6699 provides a capacitive mode detection function to prevent the severe drawbacks of capacitive mode operation while enabling a design that ensures inductive mode operation only in the specified operating range in spite of abnormal operating conditions.

The L6699 monitors the phase relationship between the tank current circuit sensed on the ISEN pin and the voltage applied to the tank circuit by the half bridge, to ensure that the former lags behind the latter (inductive mode operation). If the phase-shift approaches zero (signalling imminent capacitive mode operation), the monitoring circuit activates the anti-capacitive mode protection procedure so that the resulting frequency rise prevents the converter from entering this dangerous condition. Also in this case, the DELAY pin is activated so that the OLP function (if used) is eventually tripped, causing intermittent operation and reducing thermal stress. If the phase relationship reverses abruptly (which may occur in the case of a dead short at the converter output), the L6699 is stopped immediately, the soft-start capacitor CSS is totally discharged and a new soft-start cycle is initiated after 50 µs idle time. During this idle period the PFC_STOP pin is pulled low to stop the PFC stage as well.

7 Thermal map

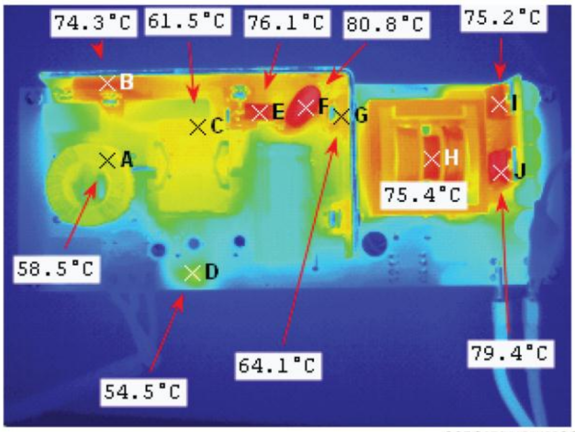
Thermal mapping with an IR camera was performed to verify the design reliability. The figure below shows the thermal measurements of the component side of the board at nominal input voltages. Key components or components showing higher temperatures are highlighted. The ambient temperature during measurement is 26 °C.

Figure 31: Thermal map at 115 Vac - 60 Hz - Full load



GSPG0704151350SG

Figure 32: Thermal map at 230 Vac - 50 Hz - Full load



GSPG0704151400SG

Table 7: Thermal maps reference points

Point	Reference	Description	Temp. @ 115 Vac / 60 Hz	Temp. @ 230 Vac / 50 Hz
A	D1	Bridge rectifier	57.6 ºC	58.5 ºC
B	L1	EMI filtering inductor	40.6 ºC	74.3 ºC
C	L2	PFC inductor	50.3 ºC	61.5 ºC
D	Q8	ICs supply regulator	51.7 ºC	54.5 ºC
E	D4	PFC output diode	66.3 ºC	76.1 ºC
F	R6	Inrush limiting NTC resistor	69.4 ºC	80.8 ºC
G	Q4	Resonant Low side MOSFET	57.2 ºC	64.1 ºC
H	T1	Resonant power transformer	75.2 ºC	75.4 ºC
I	Q501	SR MOSFET	76.9 ºC	75.2 ºC
J	Q502	SR MOSFET	76.9 ºC	79.4 ºC

8 Conducted emission pre-compliance test

The following figures represent the average measurement of the conducted emission at full load and nominal mains voltages. The EN55022 Class-B limit relevant to average measurements is indicated in red on the diagrams. In all test conditions the measurements are significantly below the limits.

Figure 33: CE average measurement at 115 Vac - 60 Hz and full load

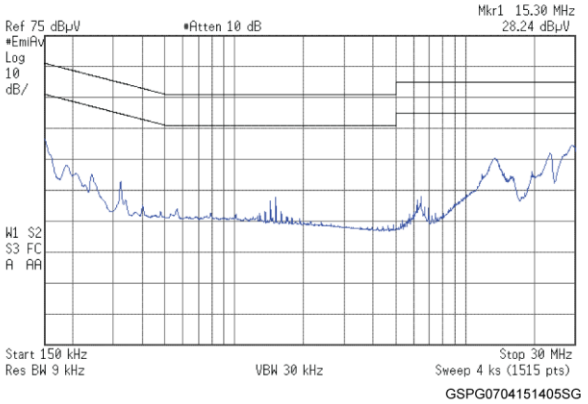
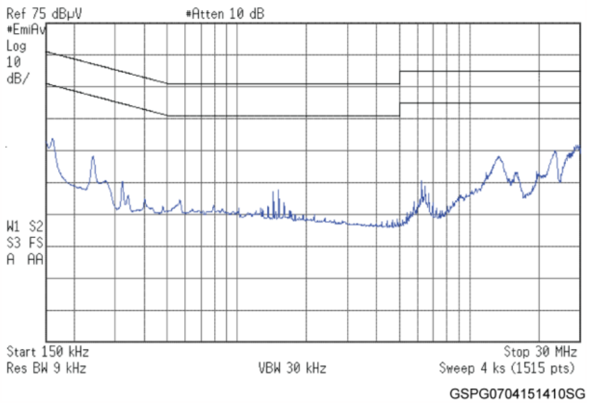


Figure 34: CE average measurement at 230 Vac - 50 Hz and full load



9 Bill of material

Table 8: STEVAL-ISA170V1 evaluation board: mother board bill of material

Des.	Part number	Description	Case	Supplier
C1	470nF-X2	X2 - FILM CAP - B32922C3474K	9.0 × 18.0 p15mm	EPCOS
C2	2n2-Y1	Y1 SAFETY CAP. CD12-E2GA222MYGSA	p10mm	EPCOS
C3	2n2-Y1	Y1 SAFETY CAP. CD12-E2GA222MYGSA	p10mm	EPCOS
C4	470nF-X2	X2 - FILM CAP - B32922C3474K	9.0 × 18.0 p15mm	EPCOS
C5	470nF - 520V	520V - FILM CAP - B32673Z5474K	7.0 x 26.5 p22.5mm	EPCOS
C7	100nF	100V CERCAP - General Purpose	PTH	AVX
C8	10uF-50V	ALUMINIUM ELCAP - YXF Series - 105°C	DIA 5.0 x 11 p2mm	RUBYCON
C9	100uF - 450V	ALUMINIUM ELCAP - UPZ Series - 105°C	DIA 18 x 32 mm	NICHICON
C10	560pF	50V CERCAP - General Purpose	SMD 0805	AVX
C11	2n2	50V CERCAP - General Purpose	SMD 0805	AVX
C12	1uF	25V CERCAP - General Purpose	SMD 0805	AVX
C13	470nF	25V CERCAP - General Purpose	SMD 1206	AVX
C14	33nF	50V CERCAP - General Purpose	SMD 0805	AVX
C15	47uF-50V	ALUMINIUM ELCAP - YXF series - 105°C	DIA 6.3 x 11 p2.5mm	RUBYCON
C16	2n2	50V CERCAP - General Purpose	SMD 1206	AVX
C17	330pF	50V - 5% - C0G - CERCAP	SMD 0805	AVX
C18	4.7uF	25V CERCAP - General Purpose	SMD 1206	AVX
C19	100nF	50V CERCAP - General Purpose	SMD 1206	AVX
C20	2n2-Y1	Y1 SAFETY CAP. CD12-E2GA222MYGSA	p10mm	EPCOS
C21	2n2-Y1	Y1 SAFETY CAP. CD12-E2GA222MYGSA	p10mm	EPCOS
C22	220pF	50V CERCAP - General Purpose	SMD 0805	AVX
C23	10nF	50V CERCAP - General Purpose	SMD 0805	AVX
C24	330uF-50V	ALUMINIUM ELCAP - YXF series - 105°C	DIA10 x 20 p5mm	RUBYCON
C25	1n5	50V CERCAP - General Purpose	SMD 0805	AVX
C26	10uF-50V	ALUMINIUM ELCAP - YXF series - 105°C	DIA 5.0 x 11 p2 mm	RUBYCON
C27	220pF-630V	630V CERCAP - GRM31A7U2J221JW31	SMD 1206	MURATA
C28	22nF	1KV - FILM CAP - B32652A223K	5.0 x 18.0 p15mm	EPCOS
C29	470uF-16V	16V ALUMINIUM CAP 16SEPC470M	DIA 10 X 13 p5mm	SANYO
C30	470uF-16V	16V ALUMINIUM CAP 16SEPC470M	DIA 10 x 13 p5mm	SANYO
C32	10nF	50V CERCAP - General Purpose	SMD 0805	AVX

Des.	Part number	Description	Case	Supplier
C33	1n5	50V CERCAP - General Purpose	SMD 0805	AVX
C34	8n2	50V CERCAP - General Purpose	SMD 0805	AVX
C36	330nF	50V CERCAP - General Purpose	SMD 1206	AVX
C37	470uF-16V	16V ALUMINIUM CAP 16SEPC470M	DIA 10 x 13 p5mm	SANYO
C38	100nF	50V CERCAP - General Purpose	SMD 0805	AVX
C39	100nF	50V CERCAP - General Purpose	SMD 0805	AVX
C40	100nF	50V CERCAP - General Purpose	SMD 1206	AVX
C42	100nF	50V CERCAP - General Purpose	SMD 0805	AVX
C43	4n7	50V CERCAP - General Purpose	SMD 0805	AVX
C44	1nF	50V CERCAP - General Purpose	SMD 0805	AVX
C45	220nF	25V CERCAP - General Purpose	SMD 0805	AVX
C47	1n0	50V CERCAP - General Purpose	SMD 0805	AVX
C48	1n0	50V CERCAP - General Purpose	SMD 0805	AVX
C49	470uF-16V	16V ALUMINIUM CAP 16SEPC470M	DIA 10 x 13 p5mm	SANYO
C50	470uF-16V	16V ALUMINIUM CAP 16SEPC470M	DIA 10 x 13 p5mm	SANYO
C51	100nF	50V CERCAP - GENERAL PURPOSE	SMD 0805	AVX
C52	1n0	25V CERCAP - GENERAL PURPOSE	SMD 0805	AVX
C53	4.7uF - 25V	25V CERCAP X7R - General Purpose	SMD 1206	MURATA
C54	4.7uF - 25V	25V CERCAP X7R - General Purpose	SMD 1206	MURATA
C55	4.7uF - 25V	25V CERCAP X7R - General Purpose	SMD 1206	MURATA
C56	4.7uF - 25V	25V CERCAP X7R - General Purpose	SMD 1206	MURATA
C57	4.7uF - 25V	25V CERCAP X7R - General Purpose	SMD 1206	MURATA
C58	15nF	50V CERCAP - General Purpose	SMD 0805	AVX
C59	2n7	50V CERCAP - General Purpose	SMD 1206	AVX
D1	GBU8J	SINGLE PHASE BRIDGE RECTIFIER	STYLE GBU	VISHAY
D2	LL4148	HIGH SPEED SIGNAL DIODE	MINIMELF SOD-80	VISHAY
D3	1N4005	GENERAL PURPOSE RECTIFIER	DO-41 DO - 41	VISHAY
D4	STTH5L06	ULTRAFAST HIGH VOLTAGE RECTIFIER	DO-201	STMicroelectronics
D5	LL4148	HIGH SPEED SIGNAL DIODE	MINIMELF SOD-80	VISHAY
D6	LL4148	HIGH SPEED SIGNAL DIODE	MINIMELF SOD-80	VISHAY
D7	BAT46Z	POWER SCHOTTKY DIODE	SOD-123	STMicroelectronics
D9	STPS2H100A	POWER SCHOTTKY DIODE	SMB	STMicroelectronics
D12	BZV55-C43	ZENER DIODE	MINIMELF SOD-80	VISHAY
D14	LL4148	HIGH SPEED SIGNAL DIODE	MINIMELF SOD-80	VISHAY
D18	LL4148	HIGH SPEED SIGNAL DIODE	MINIMELF SOD-80	VISHAY

Des.	Part number	Description	Case	Supplier
D19	LL4148	HIGH SPEED SIGNAL DIODE	MINIMELF SOD-80	VISHAY
D20	BZV55-B15	ZENER DIODE	MINIMELF SOD-80	VISHAY
D21	BAT46Z	HIGH SPEED SIGNAL DIODE	SOD-123	VISHAY
D23	1N4148WS	HIGH SPEED SIGNAL DIODE	SOD-323	VISHAY
F1	FUSE T4A	FUSE 4A - TIME LAG - 3921400	8.5x4 p.5.08mm	LITTLEFUSE
HS1	HEAT-SINK	HEAT SINK FOR D1, Q1, Q3, Q4	DWG	
J1	MKDS 1,5 / 3 - 5,08	PCB term. block, screw conn., pitch 5 mm - 3 W	DWG	PHOENIX CONTACT
J2	FASTON	FASTON - CONNECTOR	DWG	
J3	FASTON	FASTON - CONNECTOR	DWG	
JPX1	Jumper			
L1	2019.0002	INPUT EMI FILTER	DWG	MAGNETICA
L2	1975.0004	PFC INDUCTOR - 0.31mH - PQ26/25	DWG	MAGNETICA
Q1	STF24N60M2	N-CHANNEL POWER MOSFET	TO-220FP	STMicroelectronics
Q2	BC857	PNP SMALL SIGNAL BJT	SOT-23	VISHAY
Q3	STF9N60M2	N-CHANNEL POWER MOSFET	TO-220FP	STMicroelectronics
Q4	STF9N60M2	N-CHANNEL POWER MOSFET	TO-220FP	STMicroelectronics
Q8	BC847C	NPN SMALL SIGNAL BJT	SOT-23	VISHAY
Q9	BC847C	NPN SMALL SIGNAL BJT	SOT-23	VISHAY
R1	6M8	SMD STD Film res - 1/4W - 5% - 250ppm/°C	SMD 1206	VISHAY
R2	5M6	SMD STD Film res - 1/4W - 5% - 250ppm/°C	SMD 1206	VISHAY
R3	2M2	SMD STD Film res - 1/4W - 1% - 100ppm/°C	SMD 1206	VISHAY
R5	75R	SMD STD Film res - 1/4W - 5% - 250ppm/°C	SMD 1206	VISHAY
R6	NTC 2R5-S237	NTC Resistor P/N B57237S0259M000	DWG	EPCOS
R7	2M2	SMD STD Film res - 1/4W - 1% - 100ppm/°C	SMD 1206	VISHAY
R8	2M2	SMD STD Film res - 1/4W - 1% - 100ppm/°C	SMD 1206	VISHAY
R9	160k	SMD STD Film res - 1/8W - 1% - 100ppm/°C	SMD 0805	VISHAY
R10	56k	SMD STD Film res - 1/8W - 1% - 100ppm/°C	SMD 0805	VISHAY
R11	2M2	SMD STD Film res - 1/4W - 1% - 100ppm/°C	SMD 1206	VISHAY
R12	2M2	SMD STD Film res - 1/4W - 1% - 100ppm/°C	SMD 1206	VISHAY
R13	9k1	SMD STD Film res - 1/4W - 1% - 100ppm/°C	SMD 1206	VISHAY

Des.	Part number	Description	Case	Supplier
R14	100k	SMD STD Film res - 1/8W - 5% - 250ppm/°C	SMD 0805	VISHAY
R15	56k	SMD STD Film res - 1/4W - 1% - 100ppm/°C	SMD 1206	VISHAY
R17	2M2	SMD STD Film res - 1/4W - 1% - 100ppm/°C	SMD 1206	VISHAY
R18	120k	SMD STD Film res - 1/8W - 5% - 250ppm/°C	SMD 0805	VISHAY
R19	56k	SMD STD Film res - 1/8W - 5% - 250ppm/°C	SMD 0805	VISHAY
R20	33R	SMD STD Film res - 1/8W - 5% - 250ppm/°C	SMD 0805	VISHAY
R21	22R	SMD STD Film res - 1/8W - 5% - 250ppm/°C	SMD 0805	VISHAY
R22	0R22	RSMF1TB - Metal Film res - 1W - 2% - 250ppm/°C	PTH	AKANEOHM
R23	0R22	RSMF1TB - Metal Film res - 1W - 2% - 250ppm/°C	PTH	AKANEOHM
R24	1M0	SMD STD Film res - 1/8W - 5% - 250ppm/°C	SMD 0805	VISHAY
R25	56R	SMD STD Film res - 1/8W - 5% - 250ppm/°C	SMD 0805	VISHAY
R26	1M0	SMD STD Film res - 1/8W - 1% - 100ppm/°C	SMD 0805	VISHAY
R27	470R	SMD STD Film res - 1/4W - 5% - 250ppm/°C	SMD 1206	VISHAY
R28	33k	SMD STD Film res - 1/8W - 1% - 100ppm/°C	SMD 0805	VISHAY
R29	1K0	SMD STD Film res - 1/4W - 5% - 250ppm/°C	SMD 1206	VISHAY
R30	10R	SMD STD Film res - 1/8W - 5% - 250ppm/°C	SMD 0805	VISHAY
R31	18k	SMD STD Film res - 1/8W - 1% - 100ppm/°C	SMD 0805	VISHAY
R32	560R	SMD STD Film res - 1/8W - 5% - 250ppm/°C	SMD 0805	VISHAY
R34	15k	SMD STD Film res - 1/8W - 1% - 100ppm/°C	SMD 0805	VISHAY
R35	180k	SMD STD Film res - 1/8W - 1% - 100ppm/°C	SMD 0805	VISHAY
R36	2M7	SMD STD Film res - 1/8W - 5% - 250ppm/°C	SMD 0805	VISHAY
R37	220k	SMD STD Film res - 1/4W - 5% - 250ppm/°C	SMD 1206	VISHAY
R38	56R	SMD STD Film res - 1/8W - 5% - 250ppm/°C	SMD 0805	VISHAY

Des.	Part number	Description	Case	Supplier
R40	4R7	SMD STD Film res - 1/4W - 5% - 250ppm/°C	SMD 1206	VISHAY
R41	100R	SFR25 AXIAL STAND. Film res - 0.4W - 5% - 250ppm/°C	PTH	VISHAY
R42	3k3	SMD STD Film res - 1/8W - 5% - 250ppm/°C	SMD 0805	VISHAY
R43	1k0	SMD STD Film res - 1/8W - 5% - 250ppm/°C	SMD 0805	VISHAY
R44	6k2	SMD STD Film res - 1/4W - 5% - 250ppm/°C	SMD 1206	VISHAY
R45	3R3	SMD STD Film res - 1/8W - 5% - 250ppm/°C	SMD 0805	VISHAY
R46	100k	SMD STD Film res - 1/8W - 5% - 250ppm/°C	SMD 0805	VISHAY
R48	27k	SMD STD Film res - 1/8W - 5% - 250ppm/°C	SMD 0805	VISHAY
R49	91k	SMD STD Film res - 1/8W - 1% - 100ppm/°C	SMD 1206	VISHAY
R50	12k	SMD STD Film res - 1/8W - 1% - 100ppm/°C	SMD 0805	VISHAY
R51	91k	SMD STD Film res - 1/8W - 1% - 100ppm/°C	SMD 0805	VISHAY
R52	1k5	SMD STD Film res - 1/8W - 1% - 100ppm/°C	SMD 0805	VISHAY
R53	2k2	SMD STD Film res - 1/8W - 1% - 100ppm/°C	SMD 0805	VISHAY
R54	0R0	SMD STD Film res - 1/8W - 5% - 250ppm/°C	SMD 0805	VISHAY
R55	2k7	SMD STD Film res - 1/8W - 1% - 100ppm/°C	SMD 0805	VISHAY
R57	R002	SMD - ERJM1WTF2M0U	2512	PANASONIC
R58	100k	SMD STD FILM RES - 1/8W - 5% - 250ppm/°C	SMD 0805	VISHAY
R59	100k	SMD STD Film res - 1/8W - 5% - 250ppm/°C	SMD 0805	VISHAY
R60	10k	SMD STD Film res - 1/8W - 5% - 250ppm/°C	SMD 0805	VISHAY
R61	30k	SMD STD Film res - 1/8W - 5% - 250ppm/°C	SMD 0805	VISHAY
R63	0R0	SMD STD Film res - 1/8W - 1% - 100ppm/°C	SMD 0805	VISHAY
R64	10M	SMD STD Film res - 1/8W - 5% - 250ppm/°C	SMD 0805	VISHAY
R68	5k6	SMD STD Film res - 1/8W - 5% - 250ppm/°C	SMD 0805	VISHAY
R69	5k6	SMD STD Film res - 1/8W - 5% - 250ppm/°C	SMD 0805	VISHAY

Des.	Part number	Description	Case	Supplier
R70	22k	SMD STD Film res - 1/8W - 1% - 100ppm/°C	SMD 0805	VISHAY
R71	1k0	SMD STD Film res - 1/8W - 5% - 250ppm/°C	SMD 1206	VISHAY
R72	68k	SMD STD Film res - 1/8W - 1% - 100ppm/°C	SMD 0805	VISHAY
R73	22R	SMD STD Film res - 1/8W - 5% - 250ppm/°C	SMD 0805	VISHAY
R75	0R0	SMD STD Film res - 1/8W - 5% - 250ppm/°C	SMD 0805	VISHAY
R76	33k	SMD STD Film res - 1/4W - 5% - 250ppm/°C	SMD 0805	VISHAY
R77	1k0	SMD STD Film res - 1/8W - 5% - 250ppm/°C	SMD 0805	VISHAY
R78	33R	SMD STD Film res - 1/4W - 5% - 250ppm/°C	SMD 1206	VISHAY
R79	270R	SMD STD Film res - 1/4W - 5% - 250ppm/°C	SMD 1206	VISHAY
R80	15k	SMD STD Film res - 1/4W - 1% - 100ppm/°C	SMD 0805	VISHAY
R81	2k2	SMD STD Film res - 1/8W - 1% - 100ppm/°C	SMD 0805	VISHAY
T1	1860.0069	RESONANT Power transformer	DWG - ETD34	MAGNETICA
U1	L6563H	HVS TM PFC controller	SO-16	STMicroelectronics
U2	L6699D	IMPROVED HV Resonant controller	SO-16	STMicroelectronics
U3	SFH617A-2	OPTOCOUPLER	DIP-4 - 10.16MM	INFINEON
U4	SFH617A-2	OPTOCOUPLER	DIP-4 - 10.16MM	INFINEON
U5	TSM1014AIST	LOW consumption CV/CC controller	MINI S0-8	STMicroelectronics
	Suggested Replacement: TSM1014AIDT		S0-8	
U6	TSC101CILT	HIGH SIDE current sense amplifier	SOT23-5	STMicroelectronics

Table 9: EVLSRK2001-SPF2 daughter board bill of material

Des.	Part number	Description	Case	Supplier
Q501	STL140N4LLF5	N-Channel Power MOSFET	POWER FLAT	STMicroelectronics
Q502	STL140N4LLF5	N-Channel Power MOSFET	POWER FLAT	STMicroelectronics
R501	0R	SMD STD Film res - 1/8W - 1% - 200ppm/°C	SMD 0805	BC COMPONENTS
R503	0R	SMD STD Film res - 1/8W - 5% - 200ppm/°C	SMD 0805	BC COMPONENTS
R504	100R	SMD STD Film res - 1/8W - 5% - 200ppm/°C	SMD 0805	BC COMPONENTS
R505	100R	SMD STD Film res - 1/8W - 5% - 200ppm/°C	SMD 0805	BC COMPONENTS

Des.	Part number	Description	Case	Supplier
R506	0R	SMD STD Film res - 1/8W - 5% - 200ppm/°C	SMD 0805	BC COMPONENTS
R507	0R	SMD STD Film res - 1/8W - 5% - 200ppm/°C	SMD 0805	BC COMPONENTS
U501	SRK2001	SRK2001 SR Controller	SSOP10	STMicroelectronics
JP501	HEADER 13	13 pin connector, 2.54mm-male-90degree		MOLEX

10 PFC coil specification

General description and characteristics

- Application Type: Consumer, Home appliance
- Transformer type: Open
- Coil Former: Vertical type, 6 + 6 pins
- Max. Temp. Rise: 45 ºC
- Max. Operating Ambient Temperature: 60 ºC
- Mains insulation: n.a.
- Unit Finishing: Varnished

General description and characteristics

- Converter Topology: Boost, Transition Mode
- Core Type: PQ26/25-PC44 or equivalent
- Min. Operating Frequency: 40 kHz
- Typical Operating Frequency: 120 kHz
- Primary Inductance: 310 µH ± 10% at 1 kHz-0.25 V
- Peak current: 5.6 Apk

Figure 35: PFC coil electrical diagram

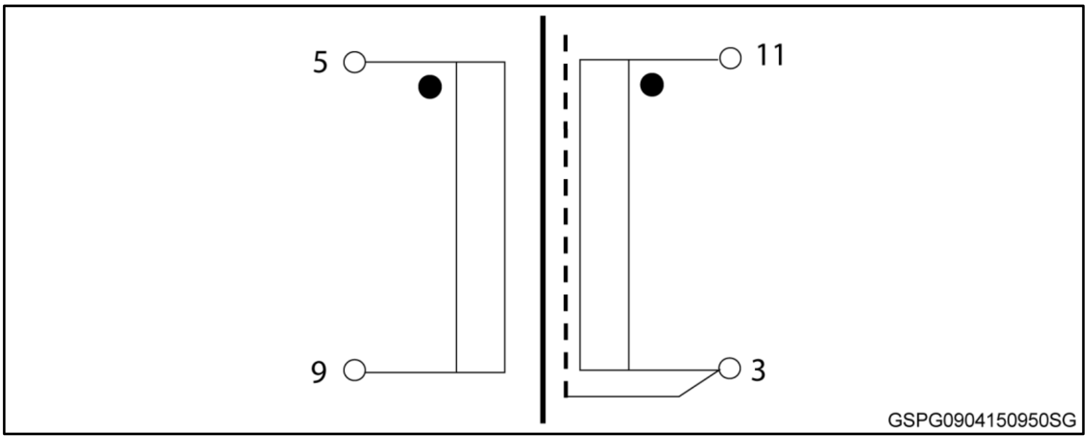


Table 10: PFC coil winding data

Pins	Windings	RMS Current	Number of turns	Wire type
11 - 3	AUX	0.05 A_{RMS}	5	f 0.28 mm – G2
5 - 9	PRIMARY [(1)]	2.3 A_{RMS}	50	50xf 0.1 mm – G1

Notes:

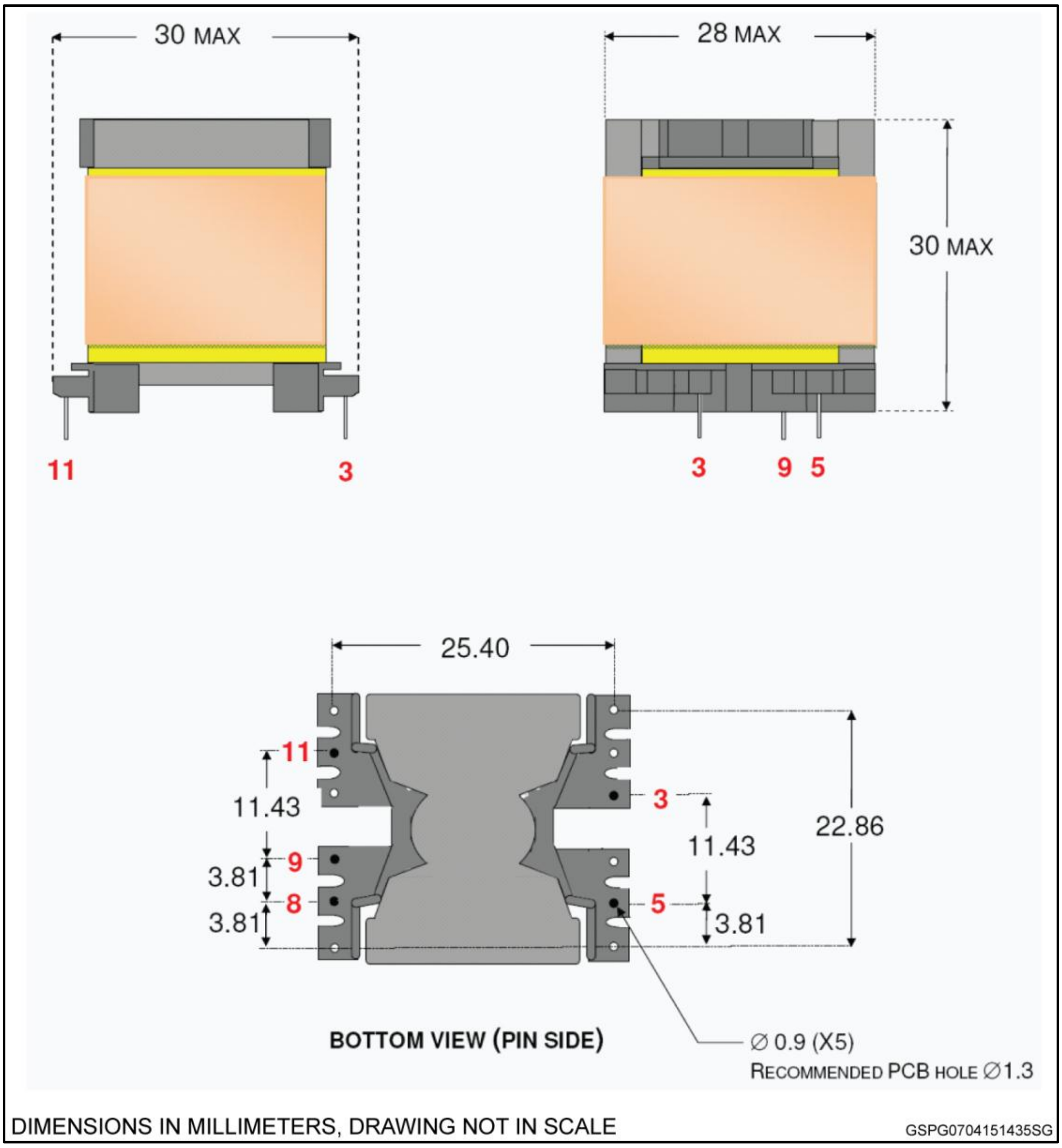
[(1)]Measured between pins #5 and #9

Mechanical aspect and pin numbering

- Maximum Height from PCB: 30 mm
- Coil Former Type: Vertical, 6 + 6 Pins (Pins 1, 2, 4, 6, 7, 10, 12 are removed)
- Pin distance: 3.81 mm
- Row distance: 25.4 mm

- External Copper Shield: Not insulated, wound around the ferrite core and including the coil former. Height is 8mm. Connected to pin #3 by a soldered solid wire.

Figure 36: PFC coil mechanical aspect



Manufacturer

- MAGNETICA - Italy
- Inductor P/N: 1975.0

11 Transformer specification

General description and characteristics

- Application Type: Consumer, Home appliance
- Transformer type: Open
- Coil Former: Horizontal type, 7 + 7 pins, two slots
- Max. Temp. Rise: 45 ºC
- Max. Operating Ambient Temperature: 60 ºC
- Mains insulation: Acc. With EN60065

Electrical characteristics

- Converter Topology: Half Bridge, resonant
- Core Type: ETD34-PC44 or equivalent
- Min. Operating Frequency: 60 kHz
- Typical Operating Frequency: 100 kHz
- Primary Inductance: 1000 µH ±10% at 1 kHz - 0.25 V
- Leakage inductance: 100 µH ±10% at 100 kHz - 0.25 V

Electrical diagram and winding characteristics

Figure 37: Transformer electrical diagram

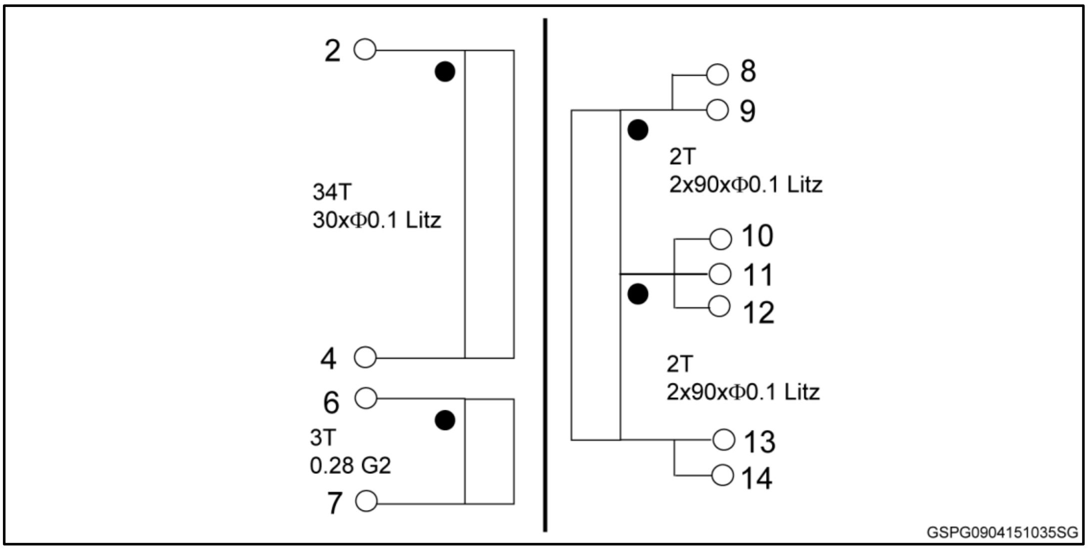


Table 11: Transformer winding data

Pins	Windings	RMS Current	Number of turns	Wire type
2 - 4	PRIMARY (1)	1 ARMS	34	30 x f 0.1 mm - G1
8 - 11	SEC-1A (2)	8.5 ARMS	2	90 x f 0.1 mm - G1
9 -10	SEC-1B 8 (2)	8.5 ARMS	2	90 x f 0.1 mm - G1
10 - 13	SEC-2A (2)	8.5 ARMS	2	90 x f 0.1 mm - G1
12 - 14	SEC-2B (2)	8.5 ARMS	2	90 x f 0.1 mm - G1
6 - 7	AUX (3)	0.05 ARMS	3	f 0.28 mm - G2

Notes:

(1) Measured between pins 2-4

(2) Secondary windings A and B are in parallel

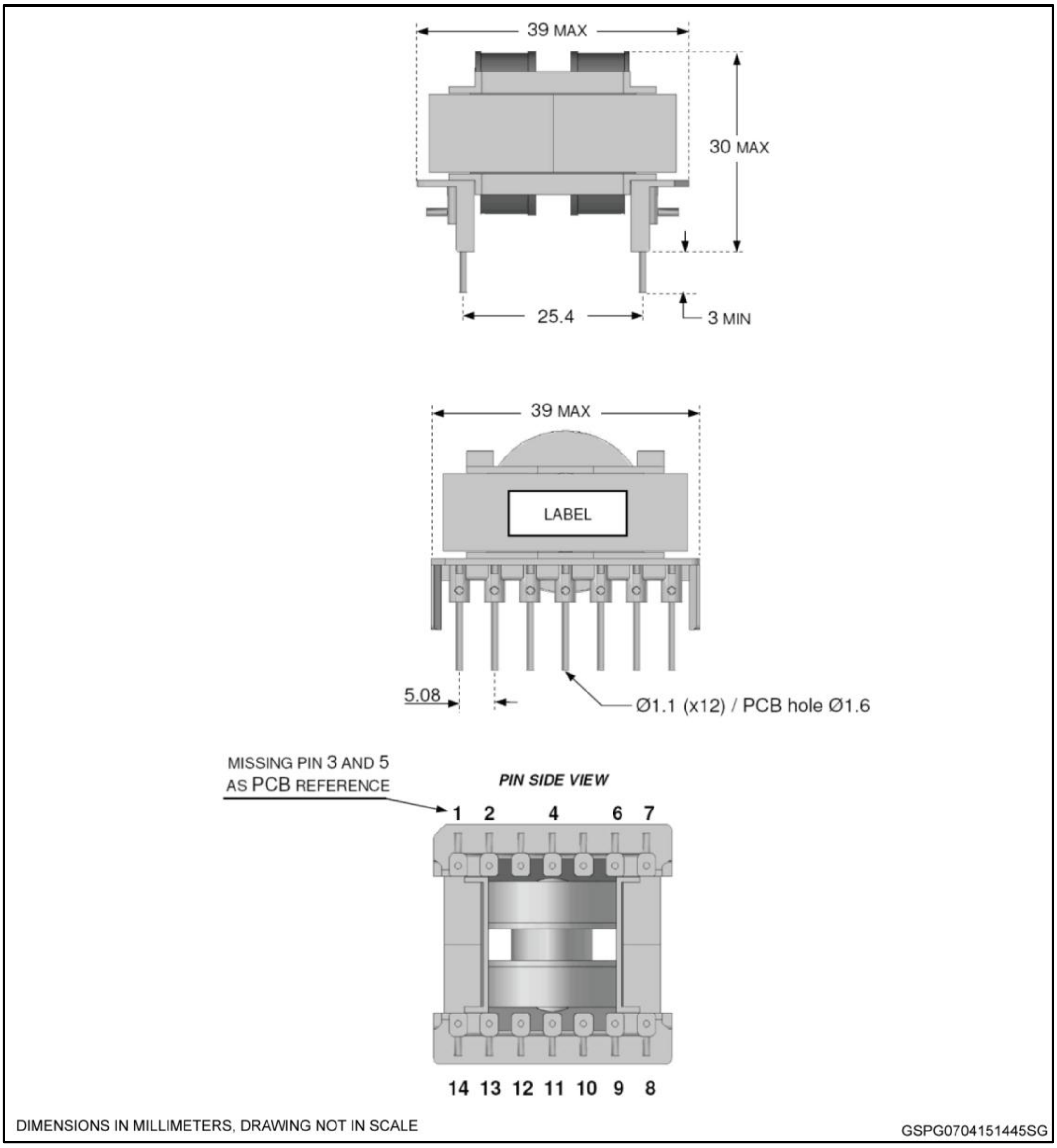
(3) Aux winding is wound on top of primary winding

Measured between pins 2-4 with only half secondary winding shorted at time.

Mechanical aspect and pin numbering

- Maximum Height from PCB: 30 mm
- Coil Former Type: Vertical, 6 + 6 Pins (Pins 1, 2, 4, 6, 7, 10, 12 are removed)
- Pin distance: 3.81 mm
- Row distance: 25.4 mm
- External Copper Shield: Not insulated, wound around the ferrite core and including the coil former. Height is 8mm. Connected to pin #3 by a soldered solid wire.

Figure 38: Transformer overall drawing



Manufacturer

- MAGNETICA - Italy
- Transformer P/N: 1860.0069

12 Revision history

Table 12: Document revision history

Date	Revision	Changes
25-May-2015	1	Initial release.