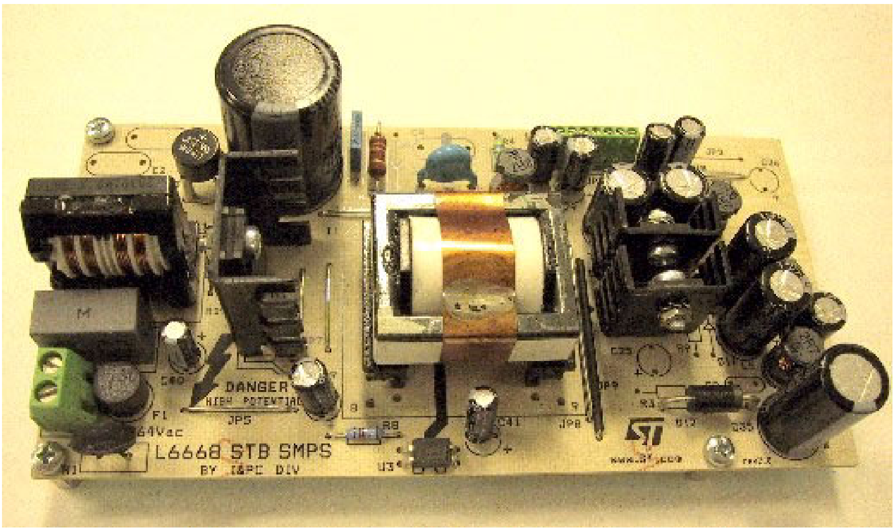
AN2242
APPLICATION NOTE

Reference design: high performance, L6668-based flyback converter for Set-Top boxes and PVRs

Introduction

This document describes a reference design of a 40W Switch Mode Power Supply dedicated to Set-Top box application. The board accepts wide range input voltage (90 to 265Vrms) and delivers 4 outputs. It is based on the new controller L6668, working in PWM fixed frequency current mode. High efficiency and low standby consumption are the main characteristics of this board. Such features, coupled with the minimal part count required and the global solution low cost approach, makes it an ideal solution for powering digital consumer equipment, meeting worldwide standby rules.

Figure 1. EVAL6668-STB Demo Board, Described In This Application Note



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1 Main Characteristics

The main characteristics of the SMPS are listed here below:

- **INPUT VOLTAGE:**

  - Vin: 90 - 264 Vrms

  - f: 45-66Hz

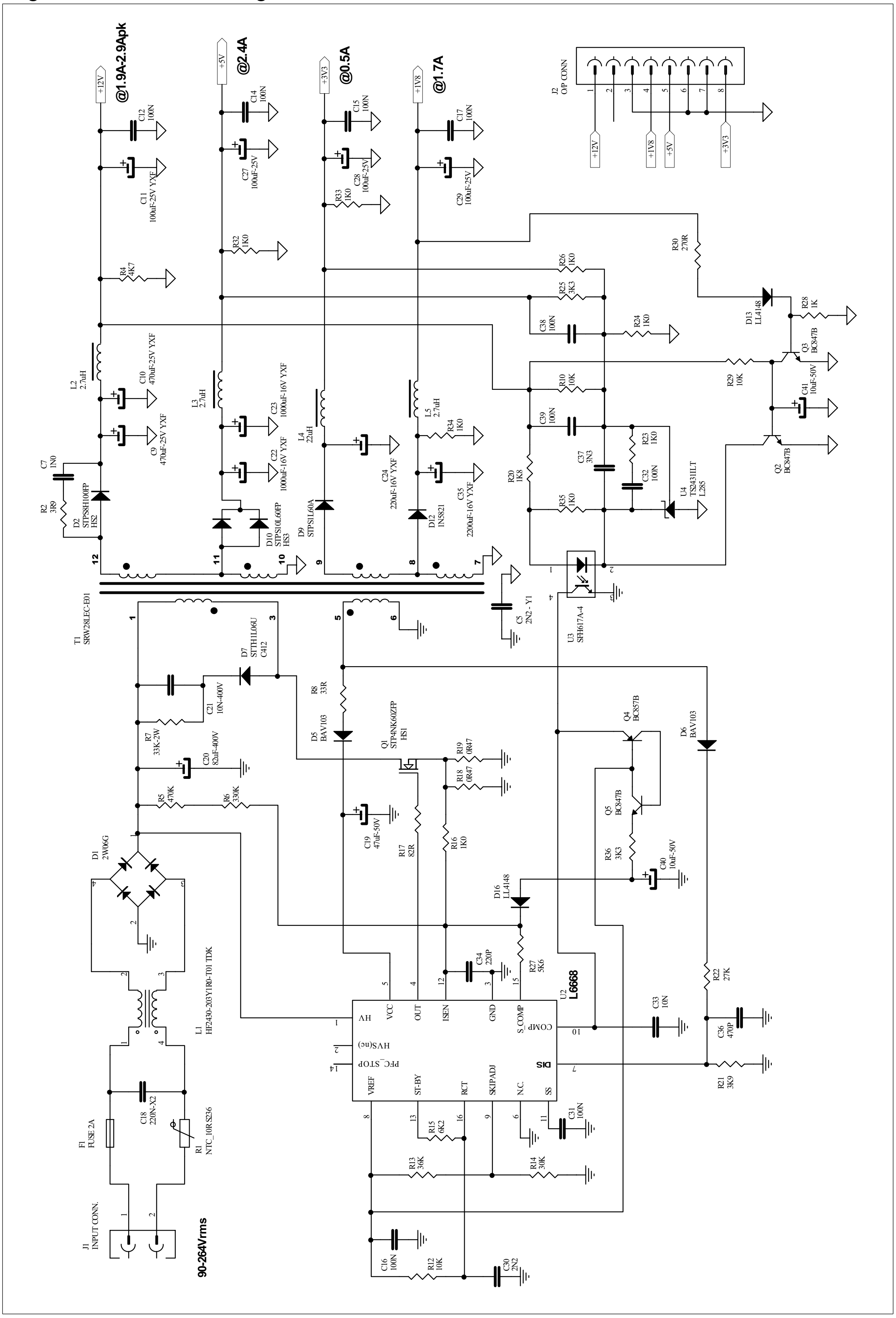
- **OUTPUT VOLTAGES:**

Table 1. Output Voltages

Vout	$Iout_{MAX}$	$Iout_{MIN}$	P_{MAX}	STABILITY	NOTES
1.8V	1.73A	0.20A	3.1W	±7%	Dedicated to digital circuitry and to 1.2V local post regulators
3.3V	0.5A	0.03A	1.65W	±5%	Dedicated to analog peripherals and 2.5V regulators
5V	2.4A	0.3A	12W	±10%	Dedicated to HDD and 5V circuitry
12V	1.9Avg 2.9Apk	0.05A	34.8W	±8%	Dedicated to HDD, SCART, LNBP21 for satellite STB. Average load is 1.9A, 2.9A is dedicated to HDD spin-up
P_{OUT}(W)=40W_{AVG} / 51W_{pk}					

- **STANDBY:** Below 1W with 5V at 50mA residual load
- **SHORT CIRCUIT PROTECTION:** On all outputs, with auto-restart at short removal
- **PCB TYPE & SIZE:** Single Side 70um (2-Oz), CEM-1, 150 x 75mm
- **SAFETY:** Acc. to EN60065, creepage and clearance minimum distance 6.4mm
- **EMI:** Acc. to with EN50022-Class B

Figure 2. Electrical Diagram

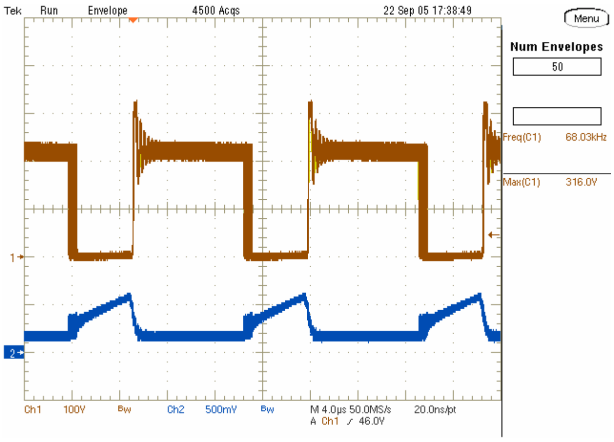


2 Circuit Description

The topology used in this schematic is a classical flyback, working in continuous and discontinuous conduction mode with fixed frequency, achieves the best tradeoff between peak/ rms current ratio and the output capacitors' size. The nominal switching frequency, 65kHz, has been chosen to get a compromise between the transformer size and the harmonics of the switching frequency, optimizing the input filter size and its cost. The input EMI filter is a classical Pi-filter, 1-cell for differential and common mode noise. A NTC limits the inrush current produced by the capacitor charging at plug-in. The MOSFET is a standard and cheap 600V-2Ω max, TO-220FP, needing a small heat sink. The transformer is a layer type, using a standard ferrite type EER28L. The transformer, designed according to the EN60065, is manufactured by TDK. The reflected voltage is 70V, providing enough room for the leakage inductance voltage spike with still margin for reliability of the MOSFET. The network D7, R7, C21 clamps the peak of the leakage inductance voltage spike. The controller is the new L6668, integrating all the functionalities needed to control an SMPS with high performance and minimum component count, offering the maximum flexibility. A new functionality embedded in the device is a high-voltage current source used at start-up that draws current from the DC bus and charges the capacitor C19. After the voltage on C19 has reached the L6668 turn-on threshold and the circuit starts to operate, the controller is powered by the transformer via the diode D5. After the start-up, the HV current source is deactivated, saving power during normal operation and allowing very good circuit efficiency during standby. The control system is Current Mode, so the current flowing in the primary is sensed by R18 and R19 and is then fed into pin #12 (Isen). R5 and R6 are also connected to pin #12 (Isen). Their purpose is to compensate the power capability change vs. the input voltage. The resistor R27 connected between pin #12 (Isen) and pin #15 (S_Comp) provides the correct slope compensation to the current signal, necessary for the correct loop stability. The circuit connected to pin #7 (DIS) provides over voltage protection in case of feedback network failures and open loop operation. An internal comparator senses this pin voltage and in case its threshold is exceeded the L6668 stops operating and reduces its consumption. To definitely latch this state an internal circuitry of the L6668 monitors the Vcc periodically reactivates the HV current source to supply the IC. After OVP detection and Disable intervention the controller operation can be resumed only after disconnecting 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 the pin #13 (ST-BY) and resistor R15, proportionally to the load consumption. The resistor dividers R13 and R14 connected to pin #9 (SKIPADJ) allow to set 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 5V reference available externally. The output rectifiers have been selected according to the calculated maximum reverse voltage, forward voltage drop and power dissipation. The rectifiers for 5V and 12V outputs are Schottky, low forward voltage drop type, hence they dissipate less power with respect to standard types. A small heat sink for both devices is required, as indicated on the BOM. The other two output rectifiers are Schottky too but with a smaller package. The snubber made up of R2 and C7 damps the oscillation produced by the diode D2 at MOSFET turn-on. The output voltage regulation is performed by secondary feedback on the 12V, 5V and 3.3V output, while for the 1.8V output the regulation is achieved by the transformer coupling. The feedback network uses a TS2431 driving an optocoupler, in this case a SFH617A-4, ensuring the required insulation between primary and secondary. The opto-transistor drives directly the COMP pin of the L6668. A small LC filter has been added on all outputs in order to filter the high frequency ripple without increasing the output capacitors and a 100nF capacitor has been placed on each output, very close to the output connector solder points, to limit the spike amplitude.

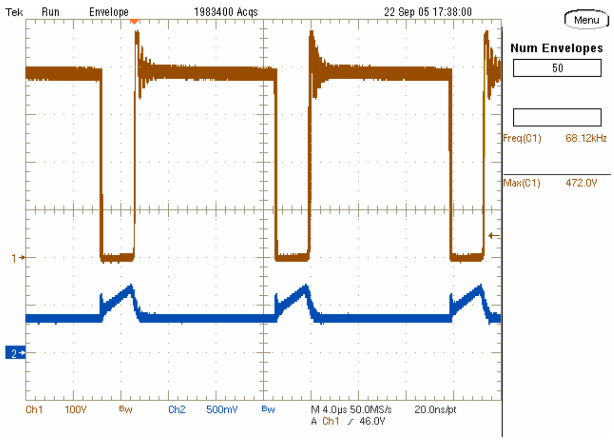
Here follow some waveforms during normal operation at full load:

Figure 3. Vin = 115 Vrms - 60Hz



CH1: DRAIN VOLTAGE
CH2: DRAIN CURRENT - V_{PIN12} (Isen)

Figure 4. Vin = 230 Vrms - 50Hz

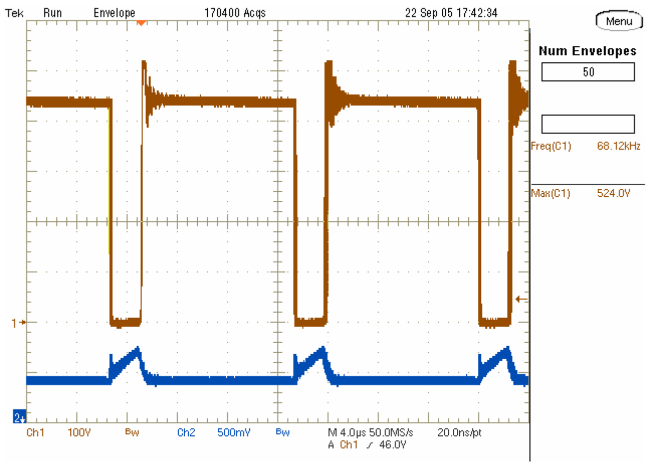


CH1: DRAIN VOLTAGE
CH2: DRAIN CURRENT - V_{PIN12} (Isen)

The pictures above show the drain voltage and current signal on pin #12 at the nominal input mains voltage during normal operation at full load. The Envelope acquisition of the scope provides for the possibility to observe the modulation of the two waveforms, due to the mains input voltage ripple at twice the line frequency.

Figure 5. The drain voltage waveforms and the measurement of the peak voltage at full load and maximum input mains voltage are shown. The maximum voltage peak in this condition is 524V, which ensures a reliable operation of the power MOSFET with a good margin against the maximum BVDSS. The operation during the hard-disk spin-up when the SMPS delivers the peak power to the loads, brings the drain voltage peak at 540Vpk.

Figure 5. Vin = 265 Vrms - 50Hz

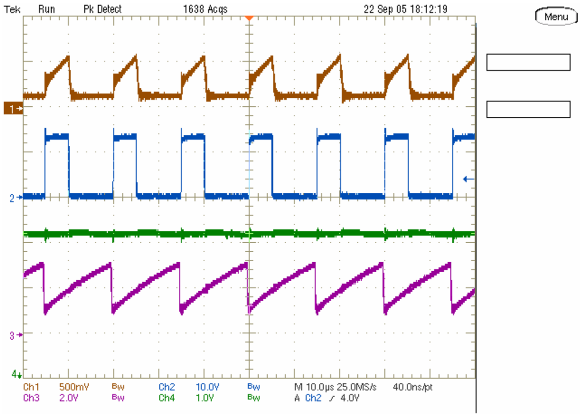


CH1: DRAIN VOLTAGE
CH2: DRAIN CURRENT - V_{PIN12} (Isen)

Figure 5. and *Figure 6.* depict the most salient controller IC signals. In all pictures it is possible to distinguish clean waveforms free of hard spikes or noise that could affect the controller

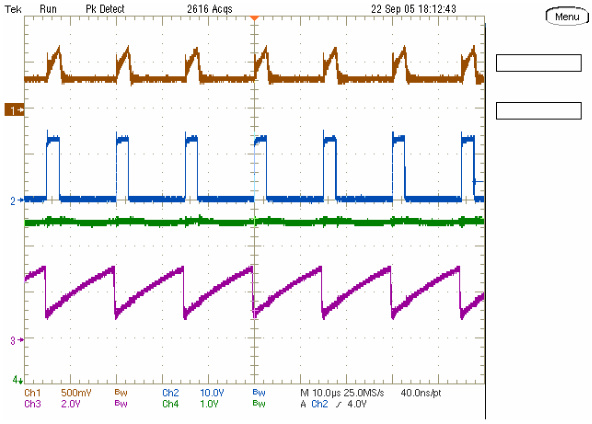
correct operation. More precisely, in *Figure 5.* and *Figure 6.* the waveforms during normal operation at max load and both nominal input mains voltage measured on current sense pin, gate drive, comp and oscillator pin have been captured. It is possible to notice that the circuit works in continuous over the entire input mains range.. Besides, the signal on pin #12 (Isen), has a different offset and similar peak for the effect of R5 and R6. Their purpose is in fact to compensate the over current set point variation with the input voltage, which instead has to be almost constantover the entire input voltage mains range. Of course, the oscillator waveform does not change in the two pictures.

Figure 6. Vin = 115 Vrms - 60Hz



CH1: V_{PIN12} - I_{SEN}
CH2: V_{PIN4} - OUT
CH3: V_{PIN16} - RCT
CH4: V_{PIN10} - COMP

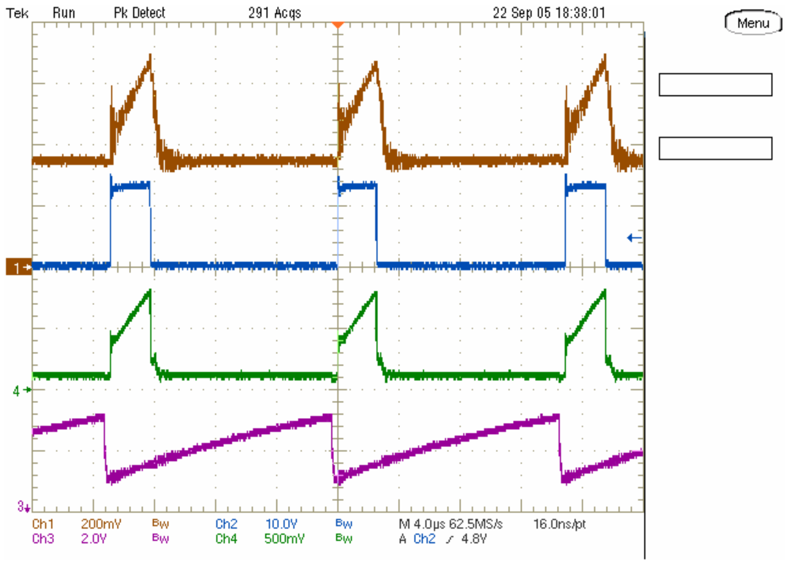
Figure 7. Vin = 220 Vrms - 50Hz



CH1: V_{PIN12} - I_{SEN}
CH2: V_{PIN4} - OUT
CH3: V_{PIN16} - RCT
CH4: V_{PIN10} - COMP

In *Figure 8.* channel 4 shows the slope compensation signal, coming from pin #15. This pin provides a voltage ramp during the MOSFET's ON-time, which is a repetition of the oscillator saw tooth and is dedicated to implementing additive slope compensation on current sense. This is needed to avoid the sub-harmonic oscillation that arises in all peak-current-mode-controlled converters working in continuous conduction mode with a duty cycle close to or exceeding 50%, as in this circuit. Besides, only a resistor is needed to implement slope compensation, and since the voltage ramp is delivered during the ON-time only, the correct operation of the control circuit is ensured even at light load. The slope compensation signal delivered only during ON-time in fact prevents perturbations on the current sense due to the injection of the residual part of the oscillator saw tooth that could affect the control circuit, as it happens using the oscillator total saw tooth for slope compensation.

Figure 8. Vin = 230 Vrms - 50Hz



CH1: V_{PIN12} - I_{SEN}
CH2: V_{PIN4} - OUT
CH3: V_{PIN16} - RCT
CH4: V_{PIN15} - S_COMP

3 Cross Regulation and Standby

The following tables show the output voltage measurements and the overall efficiency of the converter measured at different input voltages. All the output voltages have been measured on the output connector.

Table 2. Output Voltage Measurement at Full Load

at 115Vac - 60Hz				at 230Vac - 50Hz			
Voltage [V]	**Current [A]**	**Deviation**		**Voltage [V]**	**Current [A]**	**Deviation**	
11.70	1.9	-2.50%	**OK**	11.6	1.9	-3.33%	**OK**
1.81	1.7	0.56	**OK**	1.82	1.7	1.11%	**OK**
4.82	2.4	-3.60%	**OK**	4.82	2.4	-3.60%	**OK**
3.28	0.5	-0.61%	**OK**	3.28	0.5	-0.61%	**OK**

Pout=38.52W
Vin= 115Vac
Iin= 0.75Arms
Pin= 49W
EFF.= 78.6%

Pout=38.34W
Vin= 230Vac
Iin= 0.44Arms
Pin= 47.6W
EFF.= 80.6%

Table 2. lists the output voltage measurements at both nominal mains range: all voltages are within the tolerance given in the specification. The efficiency measured is very good for this kind of SMPS, thanks to the absence of post regulators.

Table 3. shows the same measurement done during the HDD spin-up, which means higher current from the 12V output, while the other output currents are not changed.

Table 3. Output Voltage Measurement at HDD SPIN-UP

at 115Vac - 60Hz				at 230Vac - 50Hz			
Voltage [V]	**Current [A]**	**Deviation**		**Voltage [V]**	**Current [A]**	**Deviation**	
11.51	**2.9**	-4.08%	**OK**	11.46	**2.9**	-4.50%	**OK**
1.81	1.7	0.56%	**OK**	1.82	1.7	1.11%	**OK**
4.77	2.4	-4.60%	**OK**	4.80	2.4	-4.00%	**OK**
3.3	0.5	-0.00%	**OK**	3.29	0.5	-0.30%	**OK**

Pout=49.55W
Vin= 115Vac
Iin= 0.93Arms
Pin= 64.5W
EFF.= 76.8%

Pout=49.49W
Vin= 230Vac
Iin= 0.55Arms
Pin= 61.2W
EFF.= 80.9%

As clearly visible in this table, the output voltages are still within the given tolerance. The heavier load does not affect efficiency. Please note that that the total output power of *Table 3.* is the so-called "electrical power", not the "thermal power". Therefore, the circuit has been designed to deliver the "electrical power" for a short time only - typically the HDD spin-up has duration of 1 second - but it cannot be delivered significantly longer because, from the thermal point of view, the circuit can manage the full load only with the required reliability. The board has been designed to power a digital decoder equipped with a hard disk drive but it can be used even for powering a Set-Top box without the Hard disk drive. The measurements shown in *Table 4.* are relevant to a load condition typical of a satellite Set-Top box. The 12V and 5V loads have been reduced with respect to the previous measurements.

Table 4. Output Voltage Measurement at Reduced, W/O HDD

at 115Vac - 60Hz				at 230Vac - 50Hz			
Voltage [V]	**Current [A]**	**Deviation**		**Voltage [V]**	**Current [A]**	**Deviation**	
11.86	1.1	-1.17%	**OK**	11.76	1.1	-2.00%	**OK**
1.79	1.7	-0.56%	**OK**	1.81	1.7	0.56%	**OK**
4.85	1.8	-3.00%	**OK**	4.9	1.8	-2.00%	**OK**
3.27	0.5	-0.91%	**OK**	3.26	0.5	-1.21%	**OK**
Pout=	**26.45**	**W**		**Pout=**	**26.46**	**W**	

Pout=26.45W
Vin= 115Vac
Iin= 0.48Arms
Pin= 33.1W
EFF.= 79.9%

Pout=26.45W
Vin= 230Vac
Iin= 0.29Arms
Pin= 33.4W
EFF.= 79.2%

At minimum load the power supply is still capable of keeping the output voltages regulated within the specification, as indicated by the measurements in *Table 5.* Additionally, the auxiliary voltage has been measured too: note that the voltage powering the IC has a good margin with respect to the L6668 turn-off voltage.

Table 5. Output Voltage Measurement at Minimum Load

at 115Vac - 60Hz				at 230Vac - 50Hz			
Voltage [V]	**Current [A]**	**Deviation**		**Voltage [V]**	**Current [A]**	**Deviation**	
11.72	0.05	-2.33%	**OK**	11.65	0.05	-2.92%	**OK**
1.80	0.2	0.00%	**OK**	1.80	0.2	0.00%	**OK**
4.77	0.3	-4.600%	**OK**	4.78	0.3	-4.40%	**OK**
3.35	0.03	1.52%	**OK**	3.34	0.03	1.21%	**OK**

Pout=2.48W
Vin= 115Vac
Iin= 0.082Arms
Pin= 3.6W
Vaux=1.5V
EFF.= 68.8%

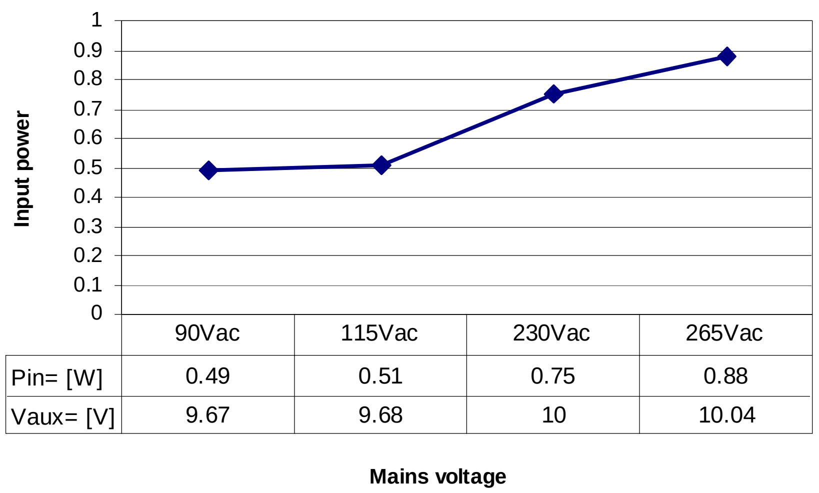
Pout=2.48W
Vin= 230Vac
Iin= 0.05Arms
Pin= 4.2W
Vaux=11.4V
EFF.= 59.0%

Table 6. Output Voltage Measurement at Standby Load

at 115Vac - 60Hz				at 230Vac			
Voltage [V]	**Current [A]**	**Deviation**		**Voltage [V]**	**Current [A]**	**Deviation**	
11.80	0	-1.67%	**OK**	11.70	0	-2.50%	**OK**
1.92	0	6.67%	**OK**	1.92	0	6.67%	**OK**
4.71	0.047	-5.80%	**OK**	4.73	0.047	-5.40%	**OK**
3.36	0	1.82%	**OK**	3.36	0	1.82%	**OK**
Pout=0.22W Vin= 115Vac Iin= 0.017Arms **Pin=0.51W** Vaux=9.68V **EFF.= 43.5%**				**Pout=0.22W** Vin= 230Vac Iin= 0.0217Arms **Pin=0.75W** Vaux=10V **EFF.= 29.8%**			

In *Table 6.* the output voltage measurements during standby operation are shown. Even in this load condition the circuit is able to regulate the output voltages within the required tolerance.

Figure 9. Input Power vs. Mains Voltage During Standby



It is clearly visible that, while delivering the required standby load, (5V at 50mA, 1.8V, 3.3V and 12V at 0mA) ***the input power consumption is below 800mW*** at both the nominal input voltage ranges and remains below 900mW at 265Vac. *Figure 10.* represents the input power variation as a function of the 5V current.

During the standby operation the circuit works in burst mode, thus the number of switching cycles decreases and, therefore it brings to an equivalent continuous switching frequency reduction. This minimizes all frequency-related losses and maximizes the efficiency with respect to other controllers without this feature. The L6668 enters automatically in burst mode when its internal circuitry detects a light load by monitoring the voltage on pin #10 (Comp). When it falls by 50mV below the threshold programmed via the divider connected at to pin #9 (SKIPADJ), the IC is disabled and its consumption is reduced to minimize the Vcc capacitor discharge. The soft-start capacitor is not discharged. The control voltage now will increase as a result of the feedback reaction to the energy delivery stop, the threshold will be exceeded and the IC will restart switching again. In this way the converter works in burst-mode with a constant peak current defined by the disable level applied at to pin #9. This functionality is well visible in *Figure 11.*, where the most significant waveforms are depicted during the standby operation. It is possible to check that the circuit stops switching as soon as the COMP pin voltage is equal to the SKIPADJ voltage and restarts to operate as soon as the threshold returns at the same level with the mentioned voltage histeresys. In the above table also the auxiliary voltage measurement is shown. At minimum load the value is still enough to ensure correct operation of the L6668 with margin. During standby operation the output voltages are only affected by a slight ripple at burst frequency, due to the operation of the internal control comparator. The ripple peak to peak measured in worst case at 265Vac on the 5V output was 68mV.

Figure 10. Pin at 230vac vs. Iout 5V

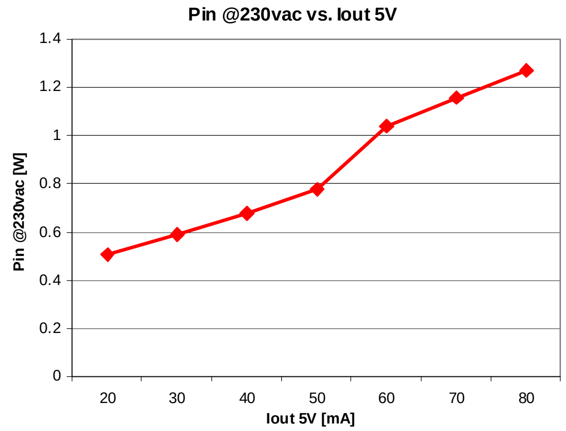
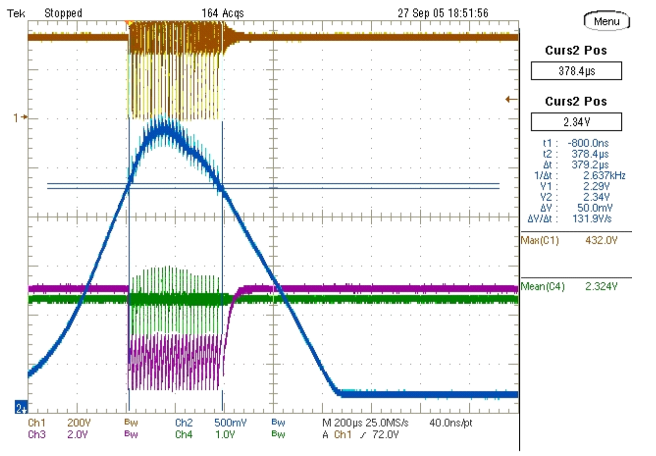


Figure 11. Vin = 230 Vrms - 50Hz



CH1: V_{DRAIN} **CH3: V_{PIN16} - RCT**

CH2: V_{PIN10} - COMP **CH4: V_{PIN9} - SKIP_ADJ**

4 Functional Checking

4.1 Start-up Behaviour at Full Load

Figure 12. Vin = 90 V_{AC} - 60Hz

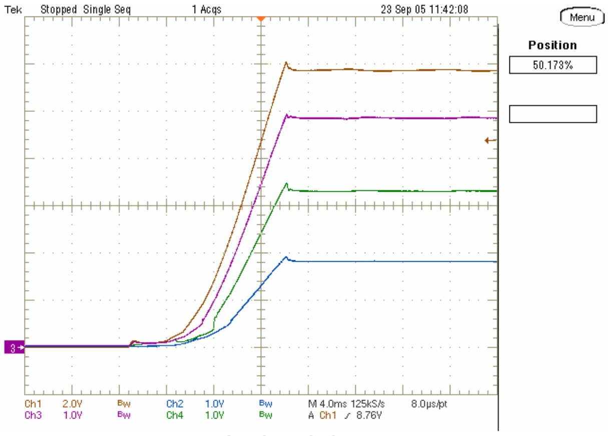
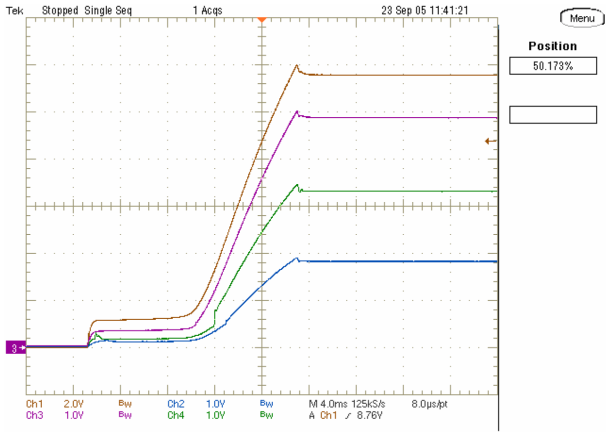


Figure 13. Vin = 265 V_{AC} - 50Hz



CH1: +12 Vout CH3: +3.3 Vout
CH2: +5 Vout CH4: +1.8 Vout

Figure 12. and *Figure 13.* capture the rising slopes at full load of output voltages at minimum and maximum input mains voltage. As shown in the pictures, the rising times are constant and there is no difference between the rise time of the output voltages. To avoid problems at start-up, this characteristic is quite important when the loads are a microprocessor and its peripherals, as in our case. Just a negligible overshoot is present at both mains voltages, without consequences for the supplied circuitry. The soft start time can be programmed via the soft-start capacitor connected to pin #11 of the L6668.

4.2 Wake-up Time

The wake-up time is the time needed for the power supply to deliver the nominal output voltages once it has been plugged-in or, if there is any, the mains switch has been closed. Generally, with wide mains power supplies using passive solutions for start-up like the largest part on the market, it is difficult to find a good compromise between the wake-up time at low mains, the dissipation at high mains and the circuit complexity. The following figures show the waveforms with the wake-up time measurements at both nominal input mains. The measured wake-up time at 115Vac and 230Vac is 750millisecond, which is a common value for this kind of power supplies. Thus, thanks to high voltage circuitry integrated in the L6668, the wake-up time is perfectly constant vs. the input voltage, which can be achieved without any external component or special circuitry. Moreover, as soon as the IC has started, the HV current source is switched off, saving power that would affect the efficiency and the standby performance of the SMPS otherwise.

Figure 14. at 115 V_{AC} - 60Hz

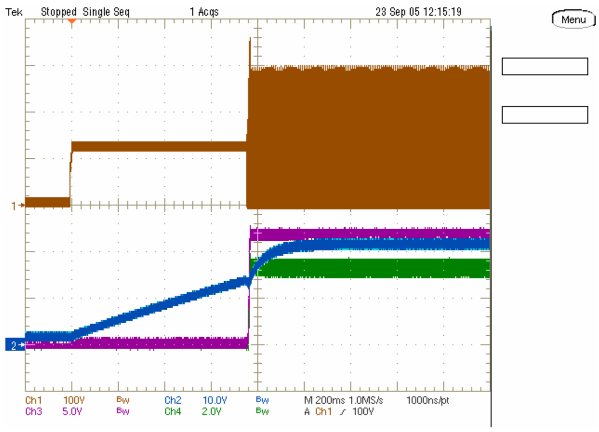
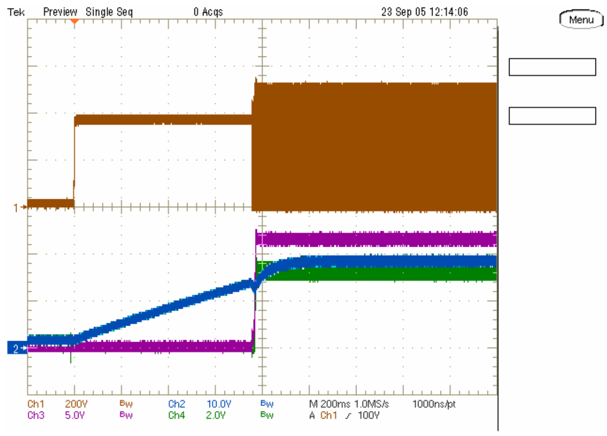


Figure 15. at 230 V_{AC} - 50Hz



CH1: V_{DD} **CH3: +12 Vout**
CH2: V_{C19} (Vaux) **CH4: +1.8 Vout**

To avoid spurious start-up attempts when power supply is plugged in with abnormal, lower voltage mains, the HV current source has a turn-on threshold so that it is not activated if the input voltage is lower than the Start voltage (typ. value is 80V).

As visible in *Figure 14.* and *Figure 15.* captured at the nominal mains voltages there is not any overshoot, undershoot, dip or abnormal behaviour during the power supply start-up phase. The power supply has been checked over the entire input voltage range with same positive results as in the above figures.

4.3 Power-down

Even at turn off the transition is clean, without any abnormal behaviour like restart or glitches on both the auxiliary and the output voltages. This is still provided by the HV start-up circuitry that controls the power down sequence: at converter power-down the system loses regulation, then Vcc drops and IC activity is stopped as it falls below the UVLO threshold (8.7V typ.). To prevent restart attempts of the converter and to ensure monotonic output voltage decay at power-down an internal logic re-enables the HV current source only if the Vcc voltage goes below the threshold Vcc_{rest} located at about 5V. Thus, the HV generator can restart but, if Vin is lower than Vin_{start}, the HV generator is disabled.

Figure 16. and *Figure 17.* also the hold-up time at both nominal mains voltages is measured 115 Vac the input Elcap stores enough energy to keep the regulation for 20mS at full load. After that the converter loses regulation and the output voltages drop. The measured time is enough to provide the required immunity of the Set-Top box against standard mains dip or short interruptions tests, required by the standard rules such as the IEC1000 and protecting the unit

against lost of channel tuning or video disturbances while the end user is watching TV or recording programs.

Figure 16. at 115 V_{AC} - 60Hz

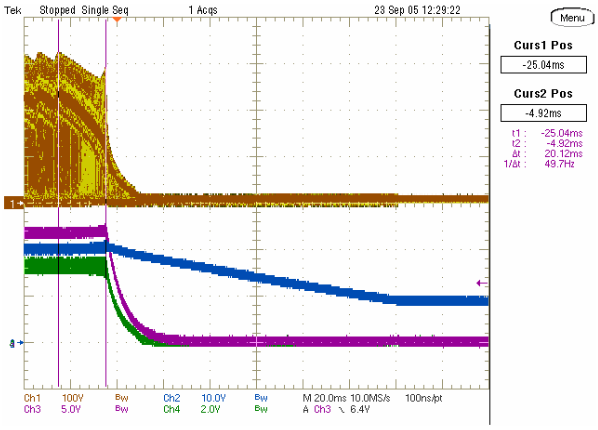
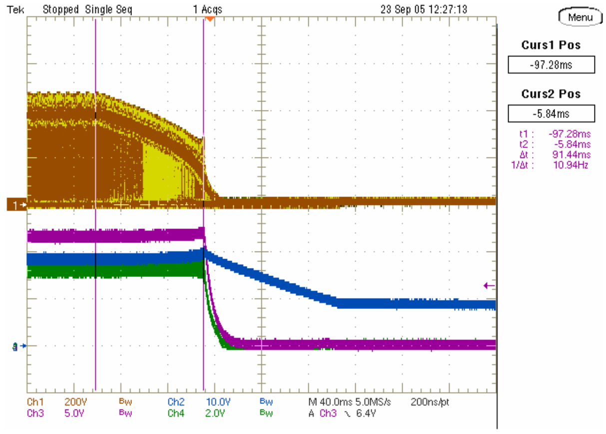


Figure 17. at 230 V_{AC} - 50Hz



CH1: V_{DD} **CH3: +12 Vout**
CH2: V_{C19} (Vaux) **CH4: +1.8 Vout**

4.4 Short-Circuit Tests

An important functionality of any power supply is the capability to survive in case of load short circuit and to avoid any consequent failure. Additionally, the power supply must be compliant with safety rules, which require that, in case of fault, no component will melt or burn-out. The SMPS protection is another issue of power supplies. Sometimes it is easy to find circuits with good protection capability against shorts of the load but which are not able to survive in case of a very hard short like that of an output electrolytic capacitor or of a rectifier or transformer saturation. Besides, in case of a shorted rectifier the equivalent circuit changes and the energy is delivered even during the on time, as in forward mode. In case of a short, the voltage at pin Isen exceeds the $V_{ISENdis}$ threshold (Hiccup-mode OCP level) and the controller stops the operation, so avoiding the destruction of the components at primary side. The controller remains in off-state until the voltage across the Vcc pin decreases below the UVLO threshold. It will then try to restart without success until the secondary short is removed. This provides a low frequency hic-cup working mode, preventing the power supply from being destroyed.

The board has been tested over the entire input voltage mains range. Two critical circuit parameters, the Vds and the output current have been checked during short circuit tests. In all conditions the measured drain voltage is always below the BV_{DSS}, while the mean value of the output current has a value lower or close to the nominal one, therefore preventing the component damage. As indicated by the waveforms in *Figure 18.* and *Figure 19.*, once an output is shorted, the circuit begins to work in hic-cup mode, keeping the mean value of the current at levels sustainable by the component rating. Because the working time and the dead time are imposed by the charging and discharging time of the auxiliary capacitor C19, thanks to the L6668 current source and related circuitry, the on-off periods are independent from the input mains voltage, contrary to controller using a passive start-up circuitry where the on time duration increases significantly with the mains voltage. The auto-restart at short removal is correct in all conditions.

Figure 18. 12V OUTPUT SHORT at 90 V_{AC}

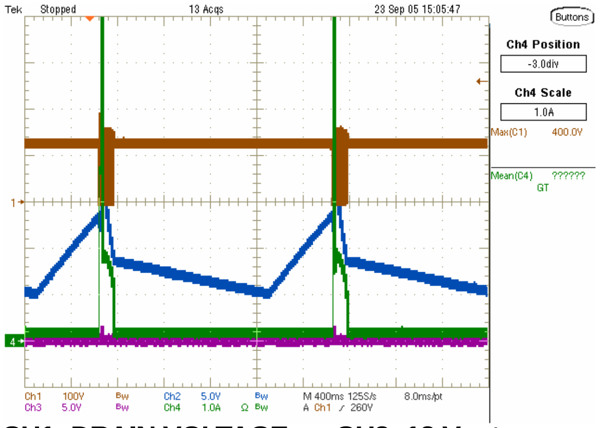
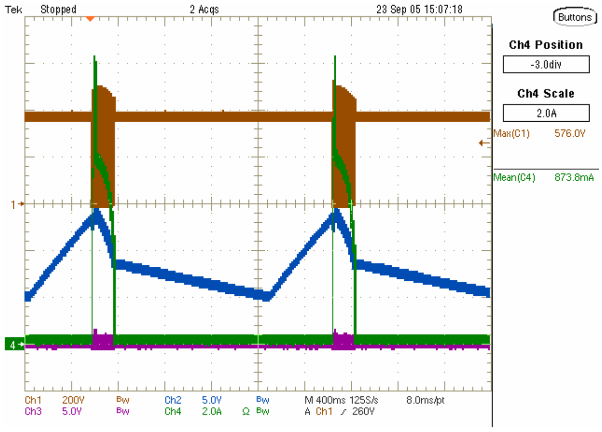


Figure 19. 3.3V OUTPUT SHORT at 265 V_{AC}



CH1: DRAIN VOLTAGE
CH2: V_{PIN12}(Vcc)
CH3: 12 Vout
CH4: $I_{SHORT\ CIRCUIT}$

Figure 20. 3.3V OUTPUT SHORT at 265 V_{AC}

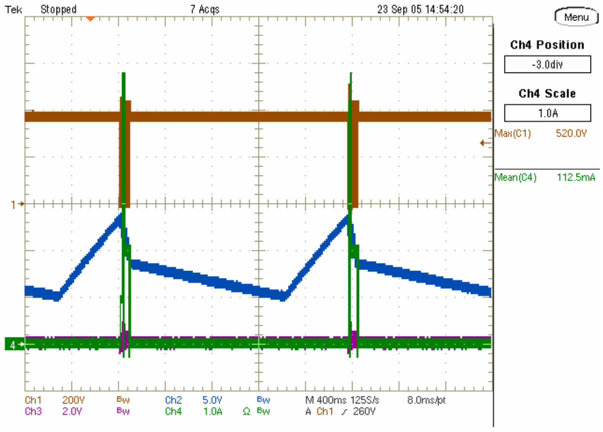
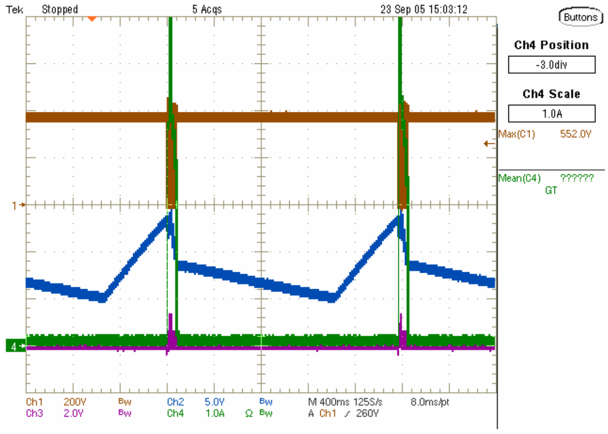


Figure 21. 5V OUTPUT SHORT at 265 V_{AC}



CH1: DRAIN VOLTAGE
CH2: V_{PIN12}(Vcc)
CH3: 3.3 Vout
CH4: $I_{SHORT\ CIRCUIT}$

CH1: DRAIN VOLTAGE
CH2: V_{PIN12}(Vcc)
CH3: 5 Vout
CH4: $I_{SHORT\ CIRCUIT}$

Figure 20. and *Figure 21.* show the short circuit waveforms shorting the 3.3V and the 5V output. Like the 12V output voltage the controller keeps under control the circuit preventing in all conditions the power supply from catastrophic failures. Even the 1.8V output is well protected against shorts, in fact figures *Figure 22.* and *Figure 23.* are relevant to a short at minimum and maximum mains voltage. Because the coupling between the 1.8V and the auxiliary windings is poor, to help the circuit enter in burst mode the circuitry based on Q2 and

Q3 has been added. This circuit senses the output voltage and drive the circuit to work in hic-cup mode if the 1.8V output voltage disappears

Figure 22. 1.8V OUTPUT SHORT at 90 V_{AC}

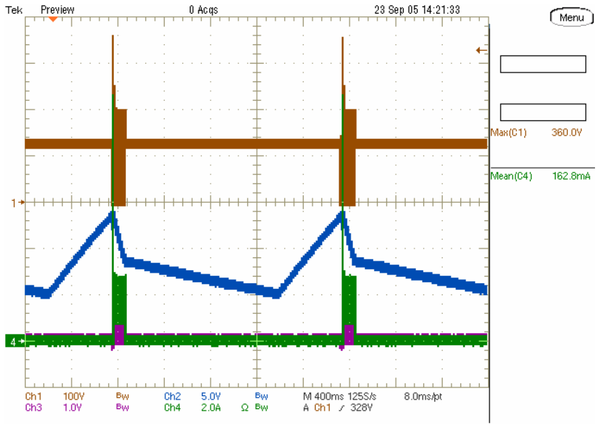
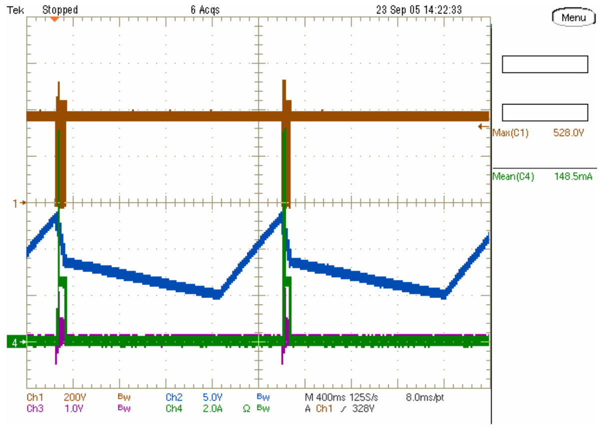


Figure 23. 1.8V OUTPUT SHORT at 265 V_{AC}

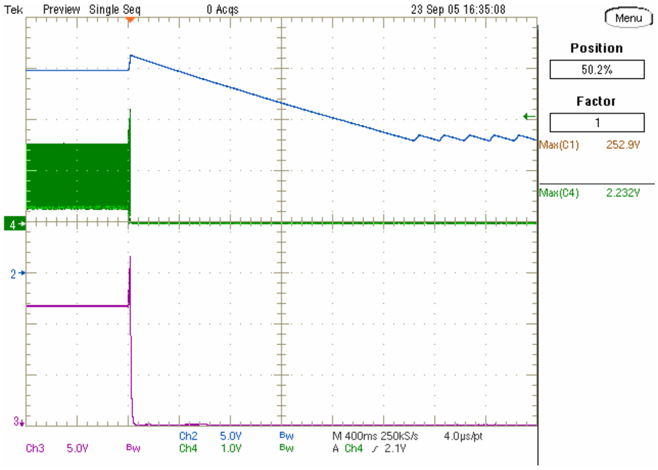


CH1: DRAIN VOLTAGE **CH3: 1.8 Vout**
CH2: V_{PIN12}(Vcc) **CH4: $I_{SHORT CIRCUIT}$**

4.5 Over Voltage Protection

A protection that all power supplies must have is that against the failure of the feedback circuitry. If this occurs, the SMPS output voltages can get high values, depending on the load on each output and the transformer coupling between the windings. Consequently, the rectifiers and the output capacitors are overstressed and they can be destroyed. To avoid this SMPS failure, a dedicated low-cost circuit has been added that senses the auxiliary voltage, thus providing a protection threshold not as dependent on the mains voltage or the load. This signal is connected to the L6668, pin 7 (DIS), dedicated to a latched protection of the circuit, as needed to properly protect the power supply from OVP or OTP. The IC pin #7 is the non-inverting input of a comparator having the inverting input internally referenced to 2.2V (typ.). As the voltage on the pin exceeds the threshold, the L6668 stops the operation and its consumption is reduced to a low value. The status is latched until the Vcc goes below the UVLO threshold. To remain in the latch status, the L6668 internal HV generator is activated periodically so that the Vcc oscillates between the start-up threshold Vcc_{ON} and Vcc_{ON} - 0.5V. The SMPS can restart after the disconnection of the converter from the mains and the Vcc pin decreases below the UVLO threshold. *Figure 24.* depicts the circuit behaviour described above. During a feedback loop failure, the board OVP circuitry voltage intervention threshold allows the 12V output to rise up to 16.8V at 115Vac, and doesn't change significantly with the input voltage or the load.

Figure 24. OVP at 115 V_{AC} - 60Hz



CH1: V_{PIN7} (OVP)
CH2: V_{C19}(Vaux)
CH3: +12 Vout

5 Conducted Noise Measurements (Pre-Compliance Test)

The following pictures are the conducted noise measurements at full load and 230Vac mains voltage, made on phase and neutral line with Peak detection. The limits shown in the diagrams are the EN55022 CLASS B ones, which is the most common rule for video domestic equipments, such as Set-Top boxes. As clearly visible in the diagrams there is a good margin of the measures with respect to the limits.

Figure 25. Conducted Noise Measurements - Phase A

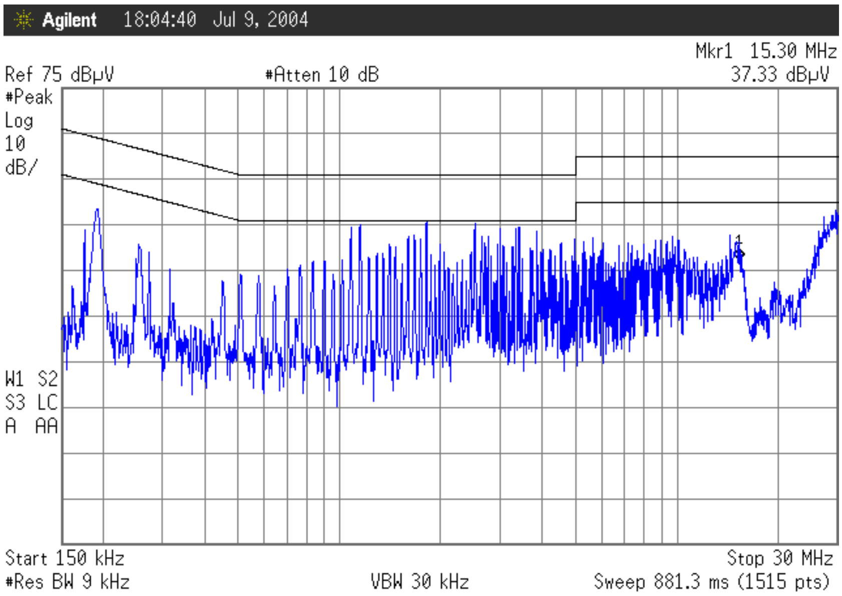
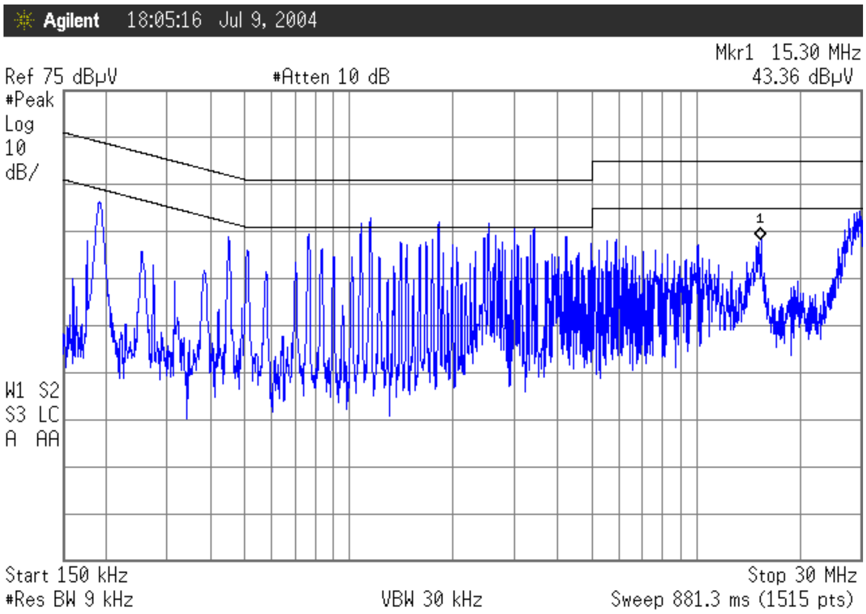


Figure 26. Concucted Noise Measurements - Phase B



6 Thermal Measures

In order to check the design reliability, a thermal mapping by means of an IR Camera was done. Here below the thermal measures of the component board side at nominal input voltage are shown. Some pointers visible on the pictures have been placed across key components or components showing high temperature. The correlation between measurement points and components is indicated on the right of both figures.

T_{AMB} = 28 degC for all measures

Figure 27. 115Vac-Max Load

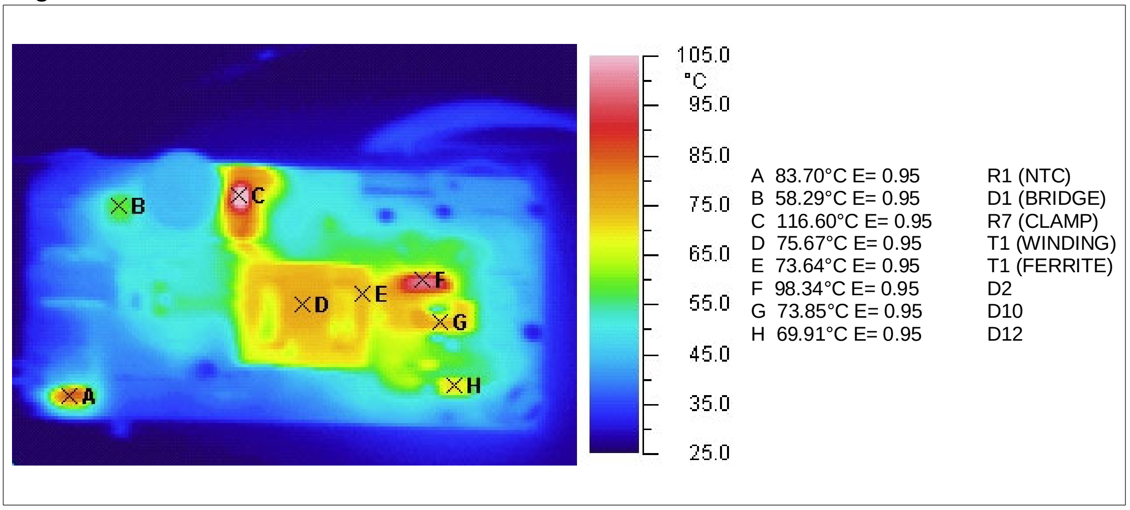
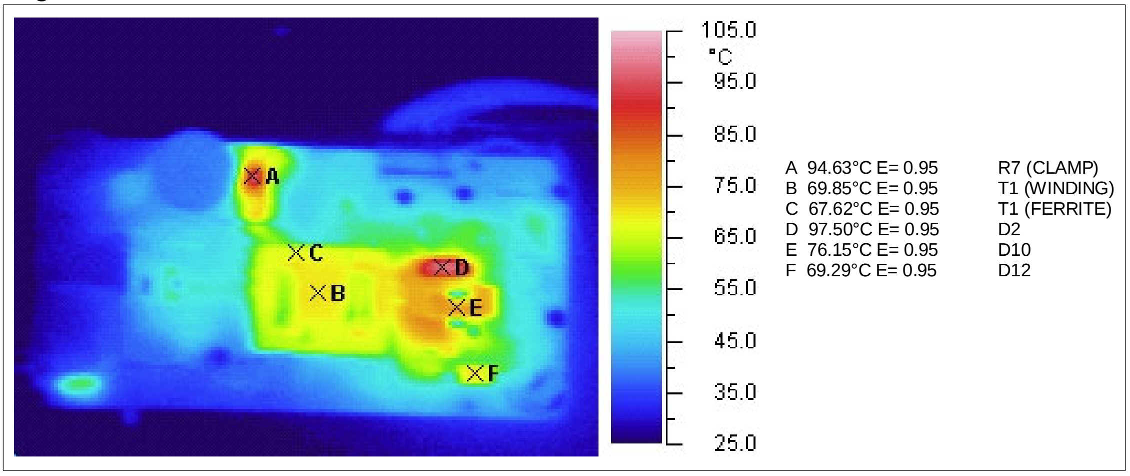


Figure 28. 230Vac-Max Load



The thermistor, bridge and output diodes temperature rise are compatible with the reliable operation of the components. Resistor R7 may need a bigger package to decrease its thermal resistance. All other components of the board are working within the temperature limits assuring a reliable long term operation of the power supply.

7 Part List

Table 7. Part List

Des	Part Type/ Part Value	Description	Supplier
C10	470uF-25V YXF	ALUMINIUM ELCAP - YXF SERIES - 105°C	RUBYCON
C11	100uF-25V YXF	ALUMINIUM ELCAP - YXF SERIES - 105°C	RUBYCON
C12	100N - 50V	CERCAP - GENERAL PURPOSE	AVX
C14	100N - 50V	CERCAP - GENERAL PURPOSE	AVX
C15	100N - 50V	CERCAP - GENERAL PURPOSE	AVX
C16	100N - 50V	CERCAP - GENERAL PURPOSE	AVX
C17	100N - 50V	CERCAP - GENERAL PURPOSE	AVX
C18	220N-X2	X2 FILM CAPACITOR - R46-KI 3220 00 L2M	ARCOTRONICS
C19	47uF-50V YXF	ALUMINIUM ELCAP - YXF SERIES - 105°C	RUBYCON
C20	82uF-400V	SMH400VN82xx22A - ALUMINIUM ELCAP - SMH SERIES - 85°C	NIPPON CHEMICON
C21	10N-400V	R66MD2100AA6-K - METALLIZED POLYESTER FILM CAP.	ARCOTRONICS
C22	1000uF-16V YXF	ALUMINIUM ELCAP - YXF SERIES - 105°C	RUBYCON
C23	1000uF-16V YXF	ALUMINIUM ELCAP - YXF SERIES - 105°C	RUBYCON
C24	220uF-16V YXF	ALUMINIUM ELCAP - YXF SERIES - 105°C	RUBYCON
C27	100uF-25V YXF	ALUMINIUM ELCAP - YXF SERIES - 105°C	RUBYCON
C28	100uF-25V YXF	ALUMINIUM ELCAP - YXF SERIES - 105°C	RUBYCON
C29	100uF-25V YXF	ALUMINIUM ELCAP - YXF SERIES - 105°C	RUBYCON
C30	2N2 - 50V	CERCAP - GENERAL PURPOSE	AVX
C31	100N - 50V	CERCAP - GENERAL PURPOSE	AVX
C32	100N - 50V	CERCAP - GENERAL PURPOSE	AVX
C33	10N - 50V	CERCAP - GENERAL PURPOSE	AVX
C34	220P - 50V	CERCAP - GENERAL PURPOSE	AVX
C35	2200uF-16V YXF	ALUMINIUM ELCAP - YXF SERIES - 105°C	RUBYCON
C36	470P - 50V	CERCAP - GENERAL PURPOSE	AVX
C37	3N3 - 50V	CERCAP - GENERAL PURPOSE	AVX
C38	100N - 50V	CERCAP - GENERAL PURPOSE	AVX
C39	100N - 50V	CERCAP - GENERAL PURPOSE	AVX
C40	10uF-50V YXF	ALUMINIUM ELCAP - YXF SERIES - 105°C	RUBYCON

Table 7. Part List

Des	Part Type/ Part Value	Description	Supplier
C41	10uF-50V YXF	ALUMINIUM ELCAP - YXF SERIES - 105°C	RUBYCON
C5	DE1E3KX222M	2N2 - Y1 SAFETY CAP.	MURATA
C7	1N0 - 200V	200V CERCAP - GENERAL PURPOSE	KEMET
C9	470uF-25V YXF	ALUMINIUM ELCAP - YXF SERIES - 105°C	RUBYCON
D1	2W06G	SINGLE PHASE BRIDGE RECTIFIER	VISHAY
D10	STPS10L60FP	POWER SCHOTTKY RECTIFIER	**STMicroelectronics**
D12	1N5821	LOW DROP POWER SCHOTTKY RECTIFIER	**STMicroelectronics**
D13	LL4148	FAST SWITCHING DIODE	VISHAY
D16	LL4148	FAST SWITCHING DIODE	VISHAY
D2	STPS8H100FP	HIGH VOLTAGE POWER SCHOTTKY RECTIFIER	**STMicroelectronics**
D5	BAV103	FAST SWITCHING DIODE	VISHAY
D6	BAV103	FAST SWITCHING DIODE	VISHAY
D7	STTH1L06U	ULTRAFAST HIGH VOLTAGE RECTIFIER	**STMicroelectronics**
D9	STPS1L60A	LOW DROP POWER SCHOTTKY RECTIFIER	**STMicroelectronics**
F1	FUSE T2A	FUSE 2 AMP. TIME DELAY	WICKMANN
J1	MKDS 1,5/ 2-5,08	PCB TERM. BLOCK, SCREW CONN., PITCH 5MM - 2 WAYS	PHOENIX CONTACT
J2	MPT 0,5/ 8-2,54	PCB TERM. BLOCK, SCREW CONN., PITCH 5MM - 8 WAYS	PHOENIX CONTACT
L1	HF2430-203Y1R0-T01	COMMON MODE CHOKE COIL	TDK
L2	2u7-ELC08D	POWER INDUCTOR	PANASONIC
L3	2u7-ELC08D	POWER INDUCTOR	PANASONIC
L4	22uH-RCH654	POWER INDUCTOR	SUMIDA
L5	2u7-ELC08D	POWER INDUCTOR	PANASONIC
Q1	STP4NK60ZFP	N-CHANNEL POWER MOSFET	**STMicroelectronics**
Q2	BC847B	SMALL SIGNAL NPN TRANSISTORS	**STMicroelectronics**
Q3	BC847B	SMALL SIGNAL NPN TRANSISTORS	**STMicroelectronics**
Q4	BC847B	SMALL SIGNAL NPN TRANSISTORS	**STMicroelectronics**
Q5	BC847B	SMALL SIGNAL NPN TRANSISTORS	**STMicroelectronics**
R1	NTC_10R S236	NTC RESISTOR P/N B57236S0100M000	EPCOS
R10	10K	SMD STANDARD FILM RES - 1/8W - 1% - 100ppm/°C	BC COMPONENTS
R12	10K	SMD STANDARD FILM RES - 1/8W - 1% - 100ppm/°C	BC COMPONENTS
R13	36K	SMD STANDARD FILM RES - 1/8W - 5% - 250ppm/°C	BC COMPONENTS
R14	30K	SMD STANDARD FILM RES - 1/4W - 5% - 250ppm/°C	BC COMPONENTS

Table 7. Part List

Des	Part Type/ Part Value	Description	Supplier
R15	6K2	SMD STANDARD FILM RES - 1/4W - 5% - 250ppm/°C	BC COMPONENTS
R16	1K0	SMD STANDARD FILM RES - 1/8W - 5% - 250ppm/°C	BC COMPONENTS
R17	82R	SMD STANDARD FILM RES - 1/8W - 5% - 250ppm/°C	BC COMPONENTS
R18	0R47	SFR25 AXIAL STANDARD FILM RES - 0.4W - 5% - 250ppm/°C	BC COMPONENTS
R19	0R47	SFR25 AXIAL STANDARD FILM RES - 0.4W - 5% - 250ppm/°C	BC COMPONENTS
R2	3R9	PR01 AXIAL STANDARD FILM RES - 1W - 5% - 250ppm/°C	BC COMPONENTS
R20	1K8	SMD STANDARD FILM RES - 1/4W - 1% - 100ppm/°C	BC COMPONENTS
R21	3K9	SMD STANDARD FILM RES - 1/8W - 5% - 250ppm/°C	BC COMPONENTS
R22	27K	SMD STANDARD FILM RES - 1/8W - 5% - 250ppm/°C	BC COMPONENTS
R23	1K0	SMD STANDARD FILM RES - 1/8W - 5% - 250ppm/°C	BC COMPONENTS
R24	1K0	SMD STANDARD FILM RES - 1/4W - 1% - 100ppm/°C	BC COMPONENTS
R25	3K3	SMD STANDARD FILM RES - 1/8W - 1% - 100ppm/°C	BC COMPONENTS
R26	1K0	SMD STANDARD FILM RES - 1/8W - 1% - 100ppm/°C	BC COMPONENTS
R27	5K6	SMD STANDARD FILM RES - 1/8W - 5% - 250ppm/°C	BC COMPONENTS
R28	1K0	SMD STANDARD FILM RES - 1/8W - 5% - 250ppm/°C	BC COMPONENTS
R29	10K	SMD STANDARD FILM RES - 1/8W - 5% - 250ppm/°C	BC COMPONENTS
R30	270R	SMD STANDARD FILM RES - 1/8W - 5% - 250ppm/°C	BC COMPONENTS
R32	1K0	SMD STANDARD FILM RES - 1/4W - 5% - 250ppm/°C	BC COMPONENTS
R33	1K0	SMD STANDARD FILM RES - 1/4W - 5% - 250ppm/°C	BC COMPONENTS
R34	1K0	SMD STANDARD FILM RES - 1/4W - 5% - 250ppm/°C	BC COMPONENTS
R35	1K0	SMD STANDARD FILM RES - 1/8W - 5% - 250ppm/°C	BC COMPONENTS
R36	3K3	SMD STANDARD FILM RES - 1/8W - 5% - 250ppm/°C	BC COMPONENTS
R4	4K7	SFR25 AXIAL STANDARD FILM RES - 0.4W - 5% - 250ppm/°C	BC COMPONENTS
R5	470K	SMD STANDARD FILM RES - 1/4W - 5% - 250ppm/°C	BC COMPONENTS
R6	330K	SMD STANDARD FILM RES - 1/4W - 5% - 250ppm/°C	BC COMPONENTS
R7	33K-2W	PR02 AXIAL STANDARD FILM RES - 2W - 5% - 250ppm/°C	BC COMPONENTS
R8	33R	PR02 AXIAL STANDARD FILM RES - 2W - 5% - 250ppm/°C	BC COMPONENTS
T1	SRW28LEC-E01 H117	POWER TRANSFORMER	TDK
U2	L6668	PRIMARY CONTROLLER	**STMicroelectronics**

Table 7. Part List

Des	Part Type/ Part Value	Description	Supplier
U3	SFH617A-4	OPTOCOUPLER	INFINEON
U4	TS2431ILT	PROGRAMMABLE SHUNT VOLTAGE REFERENCE	**STMicroelectronics**
HS1	LS220	Q1 HEAT SINK	ABL ALUMINIUM COMP.
HS2	507302	D2 HEAT SINK	AAVID THERMALLOY
HS3	507302	D10 HEAT SINK	AAVID THERMALLOY

8 PCB Layout

Figure 29. Silk Screen -Top Side

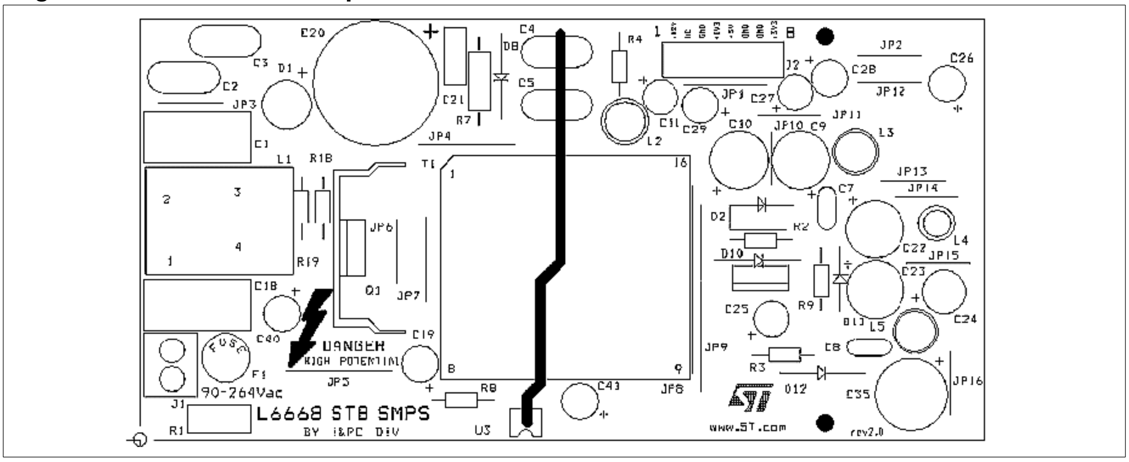


Figure 30. Silk Screen -Bottom Side

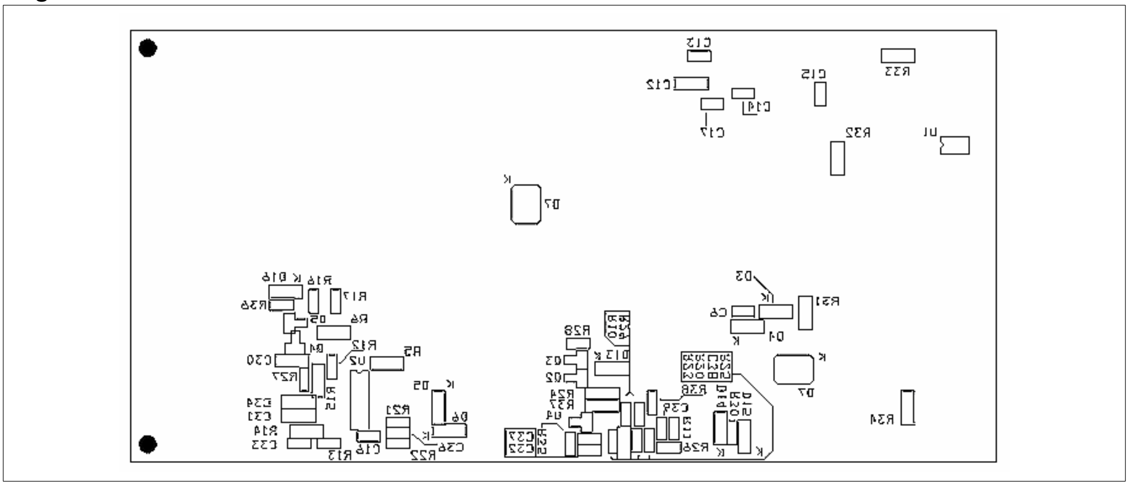
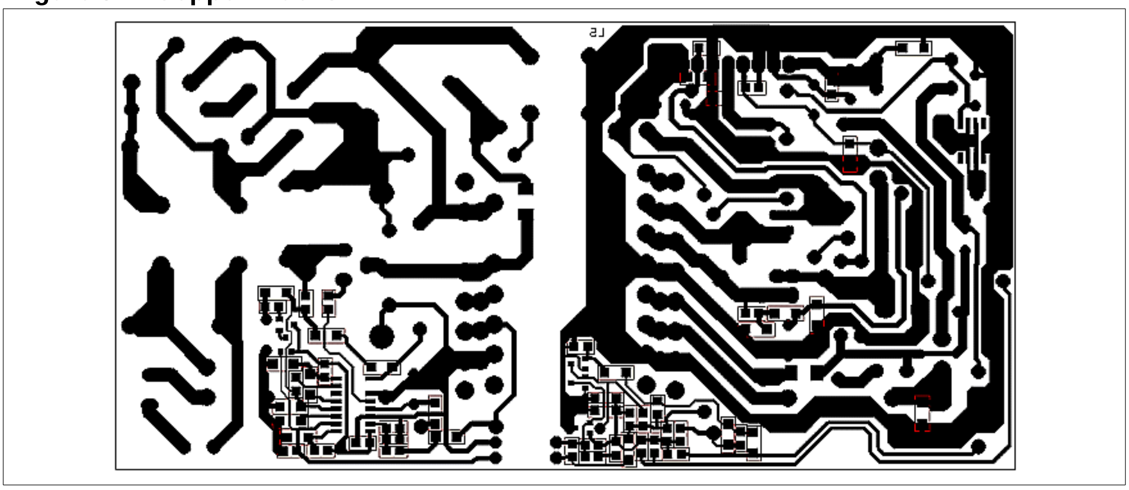


Figure 31. Copper Tracks



9 Transformer Specification

- APPLICATION TYPE: Consumer, Home Appliance
- TRANSFORMER TYPE: Open
- WINDING TYPE: Layer
- COIL FORMER: Horizontal type, 6+6 pins
- MAX. TEMP. RISE: 45°C
- MAX. OPERATING AMBIENT TEMP.: 60°C
- MAINS INSULATION: ACC. WITH EN60065

9.1 Electrical Characteristics

- CONVERTER TOPOLOGY: Flyback, CCM/DCM Mode
- CORE TYPE: EER28L - PC40 or equivalent
- TYPICAL OPERATING FREQ.: 65kHz
- PRIMARY INDUCTANCE: 910 µH ±10% at 1kHz - 0.25V (1)
- LEAKAGE INDUCTANCE: 15 µH MAX at 100kHz - 0.25V (2)
- MAX. PEAK PRIMARY CURRENT: 1.65 Apk
- RMS PRIMARY CURRENT: 0.65 A_{RMS}

Note: 1 Measured between pins 1-3

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

Figure 32. "Transformer Electrical Diagram

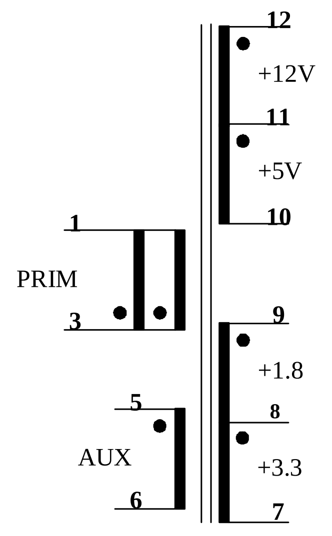
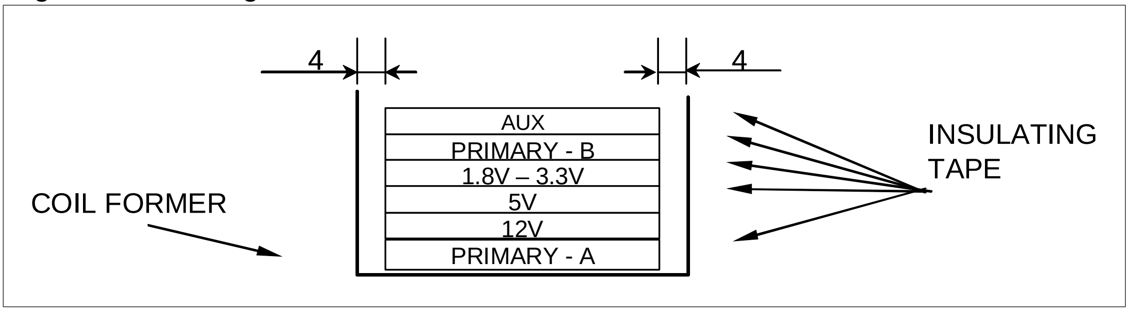


Table 8. Winding Characteristics

PINS	WINDING	O/P RMS CURRENT	NUMBER OF TURNS	WIRE TYPE
3-1	PRIMARY - A	0.32 A_{RMS}	95	G2 - 2X Φ 0.23mm
12-11	12V	2.3 A_{RMS}	9	G2 - 3X Φ 0.45mm
11-10	5V	3 A_{RMS}	7 SPACED	G2 - 3X Φ 0.45mm
9-8	3.3V	0.6 A_{RMS}	2	G2 - 3X Φ 0.45mm
8-7	1.8V	2.1 A_{RMS}	3	G2 - 3X Φ 0.45mm
3-1	PRIMARY	0.32 A_{RMS}	95	G2 - 2X Φ 0.23mm
5-6	AUX	0.05 A_{RMS}	17 SPACED	G2 - Φ 0.23mm

Figure 33. Winding Position



Note: Primaries A & B are in parallel

9.2 Mechanical Aspect

- MAXIMUM HEIGHT FROM PCB: 30mm
- COIL FORMER TYPE:HORIZONTAL, 6+6 PINS (PINS #2 and #4 ARE REMOVED)
- PIN DISTANCE: 5mm
- ROW DISTANCE: 30 mm
- PINS #3 and #4 ARE REMOVED
- EXTERNAL COPPER SHIELD: 12mm WIDTH

9.3 Manufacturer

TDK Electronics Europe - Germany

Transformer P/N: SRW28LEC-E01H117

10 Revision History

Date	Revision	Changes
05-Dec-2005	1.0	First edition