AN1376
APPLICATION NOTE

25W QUASI-RESONANT FLYBACK CONVERTER FOR SET-TOP BOX APPLICATION USING THE L6565

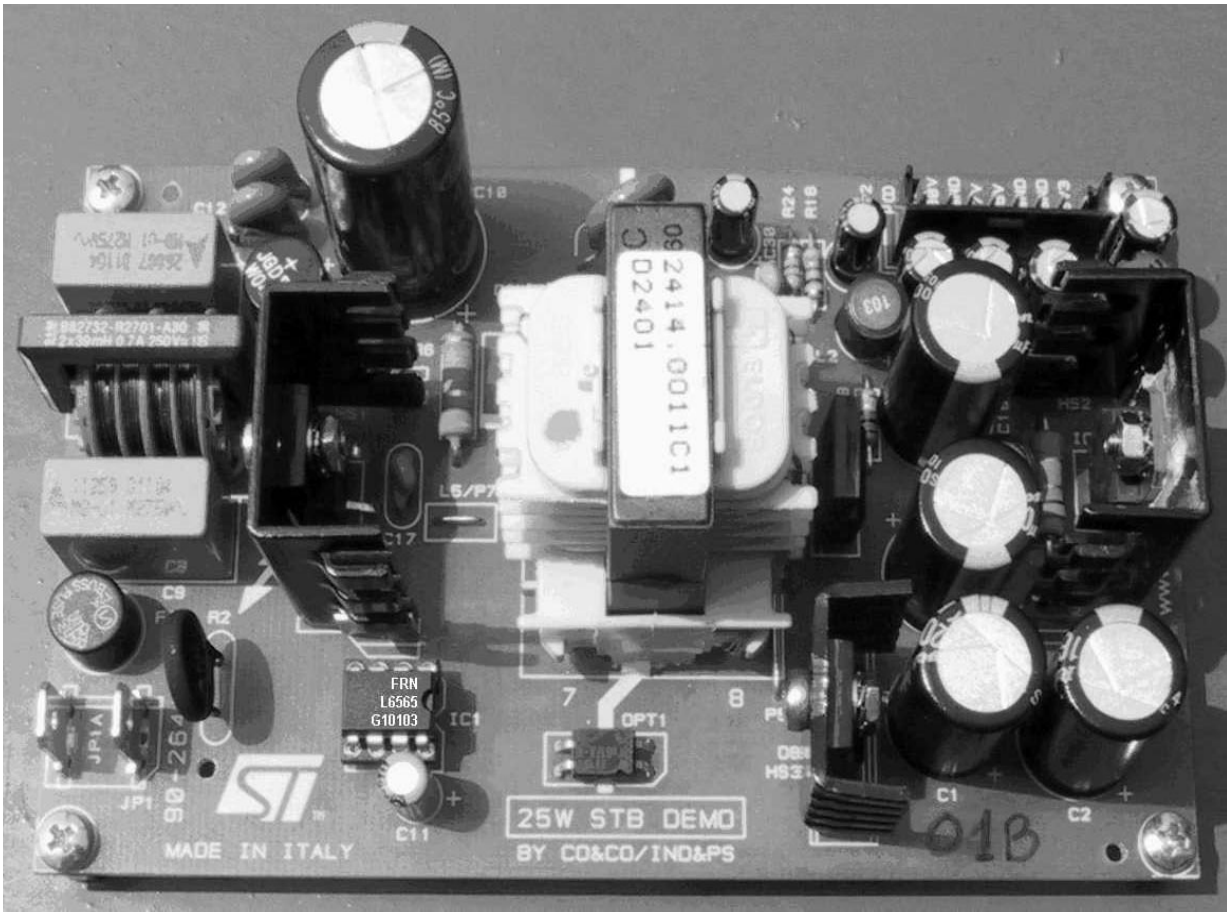
by Claudio Spini

This document describes a reference design of a 25W Switch Mode Power Supply dedicated to Set-Top Box application. The board accepts full range input voltage (90 to 265Vrms) and delivers 5 outputs. It is based on the new controller L6565, working in variable frequency mode.

1 INTRODUCTION

Set-Top Boxes are growing very fast and they are becoming very popular in all Countries either for satellite or cable decoding. Hence the market is asking for solutions having high cost effectiveness, providing for good performances, low noise, small volumes at low cost. The Quasi-resonant operation and the high flexibility of the L6565 make it a very suitable device, able to satisfy all the requirements with only few external components.

The board has been designed with mixed technology components, both PTH and SMT. For this reason some components are doubled, in accordance with their ratings.



2 MAIN CHARACTERISTICS

The main characteristics of the SMPS are listed here below:

- INPUT VOLTAGE:
  Vin: 90 - 264 Vrms
  f: 45-66 Hz
- OUTPUT VOLTAGES:

Vout (V):	**Iout (A):**	**Pout (W):**	**STABILITY**	**NOTES**
3.3	2.00	6.6	+/- 2%	
5	1.1	5.5	+/- 2%	(A)
12	0.7	8.4	+/- 5%	(B)
7	0.5	3.5	+/- 8%	(C)
30	0.015	0.45	+/- 2%	(D)
P_{OUT} (W) =		**24.45**		

NOTES:

(A) Dedicated to 5V digital circuitry and to 3.3v local post regulators

(B) Dedicated to SCART, LNBP21 for satellite STB. For other applications the current is 0.4A

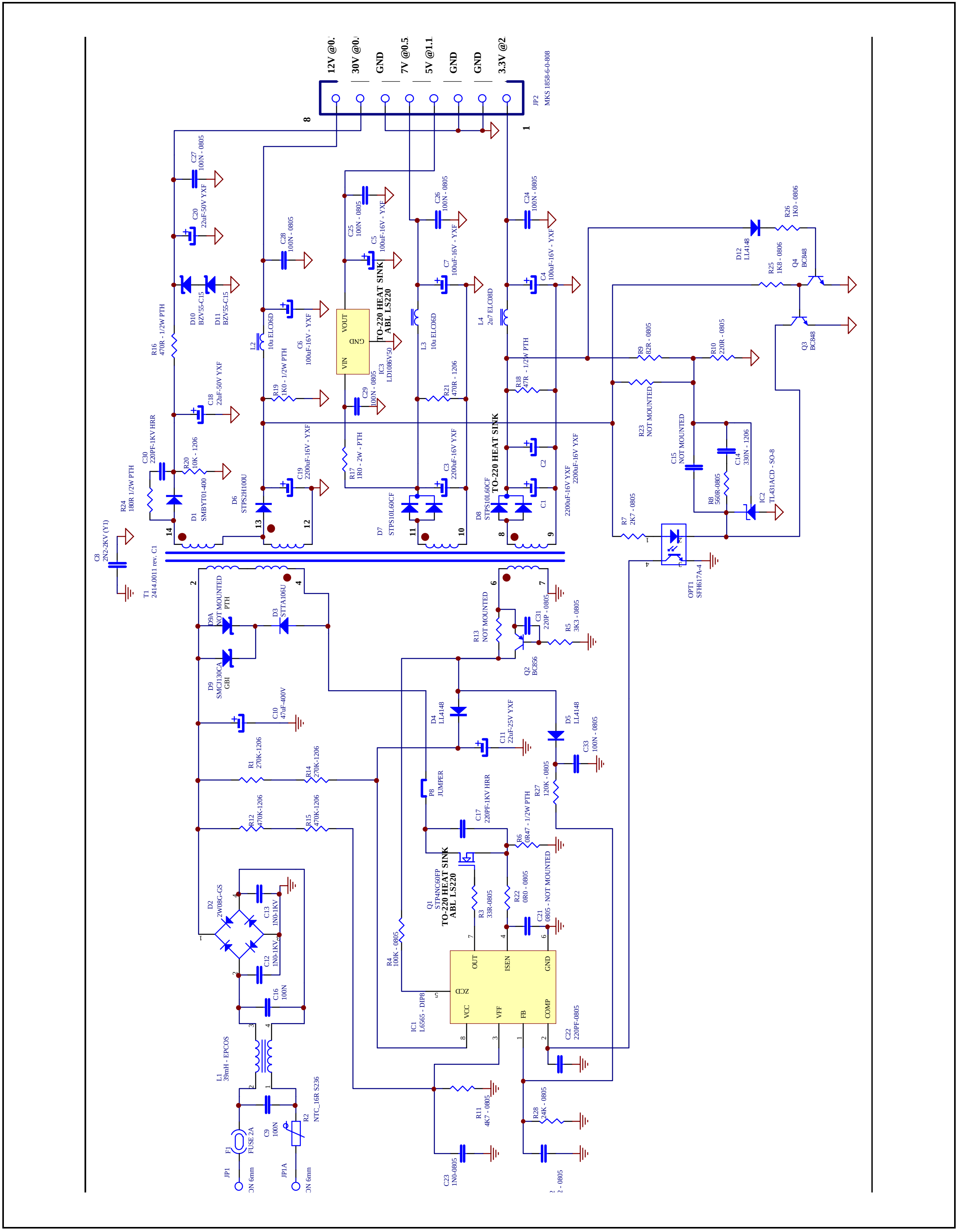
(C) Dedicated to 5V local post regulators

(D) Dedicated to tuner

- STAND-BY
  No stand-by mode is foreseen by equipment
- OVERCURRENT PROTECTION
  On all outputs, with auto-restart at short protection
- PCB TYPE & SIZE:
  Cu Single Side 35 um, FR-4, 122.5 x 75 mm
- SAFETY:
  In acc. with EN60950, creepage and clearance minimum distance 6.4mm
- EMI:
  In acc. with EN50022 Class B

3 ELECTRICAL DIAGRAM

Figure 1. Electrical Diagram



The switching frequency (minimum is ~30 kHz @V_{in} = 80 V_{DC}) has been chosen to get a compromise between the transformer size and the harmonics of the switching frequency, in order to optimise the input filter size and its cost. The MOSFET is a standard and cheap 600V-2.2Ω, TO-220FP. It needs a small heat sink. The transformer reflected voltage is 90V, providing enough room for the leakage inductance voltage spike with still margin for reliability. The network D9+D3 clamps the peak of the leakage inductance voltage spike. These two components are SMT, allowing cost saving of the manual labour with respect to a passive solution, needing manual insertion on the PCB. A 220pF HV capacitor has been added across the drain to optimise MOSFET losses by a small snubbing effect on the drain voltage rate of rise.

The controller L6565 is activated by a couple of dropping resistors (R1+R14, for voltage and power rating reasons) that draws current from the DC bus and charges the capacitor C11. This circuit dissipates only about 240mW @ 264 Vac, thanks to the extremely low start-up current. During the normal operation the controller is powered by the transformer via the diode D4. The network Q101, C102, R104 acts as a spike killer, improving the auxiliary voltage fluctuations and the performance in short circuit. R12+R15 and R11 compensate for the power capability change vs. the input voltage (Voltage Feed-forward). A 1nF ceramic capacitor bypasses any noise on pin #3 to ground (C23). The current flowing in the transformer primary is sensed by the resistor R6. The circuit connected to pin1 (FB) provides for the over voltage protection in case of feedback network failures and open loop operation.

The output rectifiers have been chosen in accordance with the maximum reverse voltage and power dissipation. The rectifiers for 3.3V and 7V outputs are Schottky, type STPS10L60CF. These diodes are low forward voltage drop, hence dissipating less power with respect to standard types. Both are the same to decrease the component diversity, as well as for the capacitors C1 to C3 and C19. The diode D8 needs a small heat sink, as indicated on the BOM. The other two output rectifiers are SMT, fast recovery. The snubber R102 and C101 damps the oscillation produced by the diode D1 at MOSFET turn-on.

The output voltage regulation is performed by secondary feedback on the 3.3V output, while for other voltages the regulation is achieved by the transformer coupling. The feedback network is the classical TL431 driving an optocoupler, in this case an SFH617A-4, insuring the required insulation between primary and secondary. The opto-transistor drives directly the COMP pin of the controller. The 5V output is linearly post-regulated from the 7V output to get a very stable voltage. A zener regulator assures the 30V stability at low cost. The 5V regulator needs to be dissipated.

A small LC filter has been added on the +12V, +7V, +3.3V in order to filter the high frequency ripple without increasing the output capacitors.

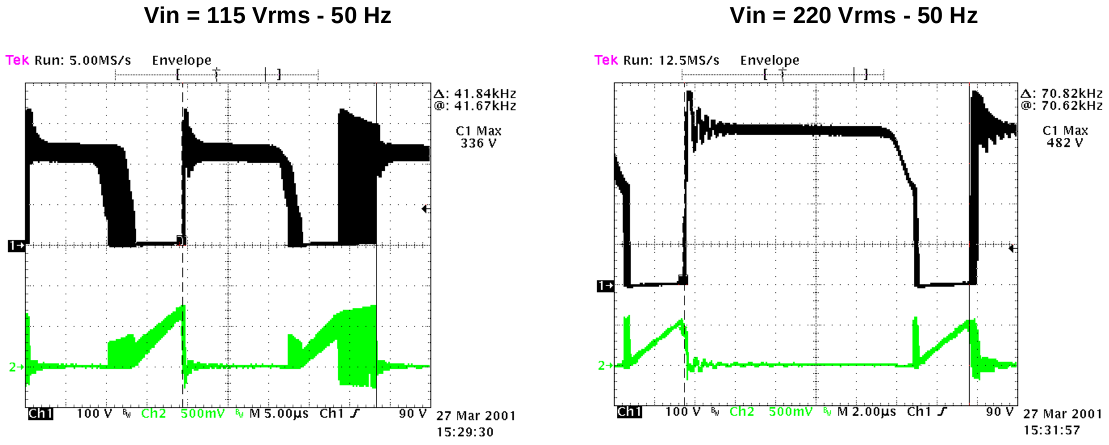
A 100nF capacitor has been connected on each output, very close to the output connector soldering points to limit the spike amplitude.

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 transformer is slot type, manufactured by Eldor Corporation, in accordance with the EN60950.

Here following some waveforms during the normal operation at full load:

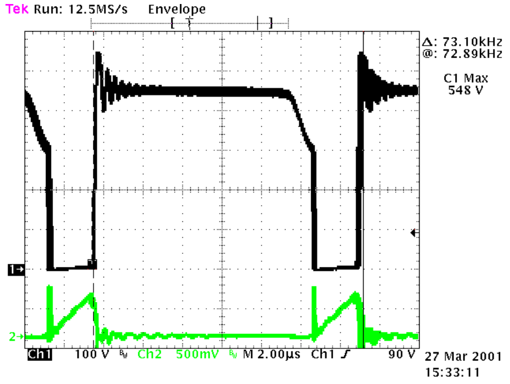
Figure 2. Vds & Id @ Full Load



CH1: DRAIN VOLTAGE;
CH2: RAIN CURRENT - $V_{R.SENSE}$ (R6)

The pictures above show the drain voltage and current at the nominal input mains voltage during normal operation at full load. The Envelope acquisition of the scope provides for the possibility to see the modulation of the two waveforms due to the input voltage ripple.

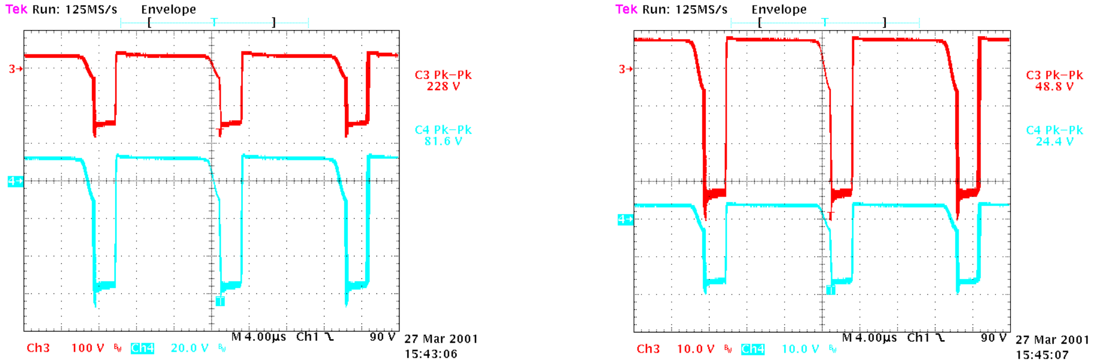
Figure 3. Vds & Id @ Full Load (Vin = 265 Vrms - 50 Hz)



This picture gives the measurement of the drain peak voltage at full load and maximum input mains voltage. The voltage peak, which is 548V, assures a reliable operation of the PowerMOS with a good margin against the maximum BV_{DSS}.

CH1: DRAIN VOLTAGE;
CH2: RAIN CURRENT - $V_{R.SENSE}$ (R6)

Figure 4. Vin = 265 Vrms - 50 Hz, @FULL LOAD: DIODE PIV



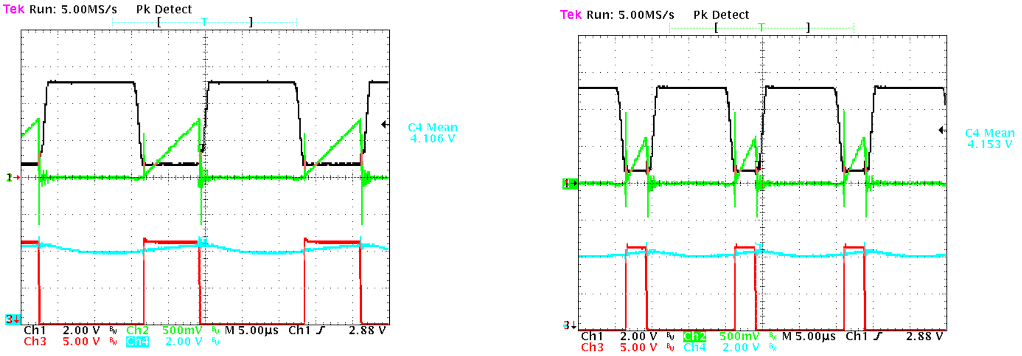
CH3: +35V DIODE: ANODE VOLTAGE;
CH4: +12V DIODE: ANODE VOLTAGE

CH3: +7V DIODE: ANODE VOLTAGE;
CH4: +3V3 DIODE: ANODE VOLTAGE

The maximum PIV of the diodes has been measured during the worst operating condition and it is indicated on the right of each picture. The margin, with respect to the maximum voltage sustained by the diodes, assures a safe operating condition for the devices.

Here following the most salient controller IC signals are depicted. In both the pictures is possible to distinguish clean waveforms free of hard spikes or noise that could affect the controller correct operation.

Figure 5. Vin = 115 Vrms - 50 Hz **Vin = 220 Vrms - 50 Hz**



CH1:	V_{PIN5} - ZCD
CH2:	V_{PIN4} - I_{SENSE}
CH3:	V_{PIN7} - OUT
CH4:	V_{PIN2} - COMP

4 CROSS REGULATION

In the following tables the output voltage cross regulation is measured with static and dynamic loads and the overall efficiency of the converter measured at different input voltages. All the output voltages have been measured **after** the load connector soldering point of the STB motherboard. The length of the connection cable is 100 mm.

- FULL LOAD

Vout [V} =	30.06	7.23	12.297	3.278	4.492
Iout [A] =	0.015	0.500	0.702	2.073	1.103
Pout [W] =	0.451	3.615	8.632	6.795	4.955

Vin [Vrms]=	**115**
Iin [Arms] =	0.51
Pin [W] =	36.0

V_{UNREG} = 37.2

$Pout_{TOT}$ [W] = 24.448

V_{C11} = 11.88

EFF. = 67.91%

f_S = 41÷51 kHz

ALL VOLTAGES ARE WITHIN TOLERANCE

Vout [V} =	30.5	7.197	12.19	3.279	4.94
Iout [A] =	0.015	0.5	0.702	2.073	1.103
Pout [W] =	0.458	3.599	8.557	6.797	5.449

Vin [Vrms]=	**220**
Iin [Arms] =	0.31
Pin [W] =	35.1

V_{UNREG} = 37.2

$Pout_{TOT}$ [W] = 24.860

V_{C11} = 12.04

EFF. = 70.82%

f_S = 66÷68 kHz

ALL VOLTAGES ARE WITHIN TOLERANCE

The efficiency of the converter is not very high but it is heavily affected by 5V the linear regulator delivering 1.1 A. Delivering 1.6A on the 7V output but removing the 5V regulator the efficiency measured is **75.6%** @220Vac and **76.9%** at 115Vac.

- Reduced Load - for Cable STB, without the LNB

Vout [V} =	31.4	7.18	12.11	3.359	4.965
Iout [A] =	0	0.25	0.3	1.008	0.55
Pout [W] =	0.000	1.795	3.633	3.386	2.731

Vin [Vrms]=	**115**
Iin [Arms] =	0.26
Pin [W] =	16.8

V_{UNREG} = 35.5

$Pout_{TOT}$ [W] = 11.545

V_{C11} = 11.39

EFF. = 68.72%

f_S = 83÷89 kHz

ALL VOLTAGES ARE WITHIN TOLERANCE

Vout [V} =	31.4	7.16	12.08	3.36	4.975
Iout [A] =	0	0.25	0.3	1.008	0.55
Pout [W] =	0.000	1.790	3.624	3.387	2.736

Vin [Vrms]=	220
Iin [Arms] =	0.17
Pin [W] =	17.6

V_{UNREG} = 35.4

$Pout_{TOT}$ [W] = 11.537

V_{C11} = 11.5

EFF. = 65.55%

f_S = 112 kHz

ALL VOLTAGES ARE WITHIN TOLERANCE

The above tables shown the output voltage measured applying the same loads that we could have in case of a different Set-top Box type is powered (e.g. a terrestrial or cable) without the LNB block of the satellite antenna. Like before all the output voltages are within the tolerances.

- Reduced Load - 9W

Vout [V} =	31.6	7.16	12.77	3.36	4.96
Iout [A] =	0	0.300	0.051	1.008	0.6
Pout [W] =	0.000	2.148	0.651	3.387	2.976

Vin [Vrms]=	**115**
Iin [Arms] =	0.22
Pin [W] =	14.2

V_{UNREG} = 36

$Pout_{TOT}$ [W] = 9.162

V_{C11} = 11.48

EFF. = 64.52%

f_S = 94÷101 kHz

ALL VOLTAGES ARE WITHIN TOLERANCE

Vout [V} =	31.5	7.16	12.76	3.36	4.96
Iout [A] =	0	0.300	0.051	1.008	0.602
Pout [W] =	0.000	2.148	0.651	3.387	2.986

Vin [Vrms]=	220
Iin [Arms] =	0.15
Pin [W] =	15.2

V_{UNREG} = 35.8

$Pout_{TOT}$ [W] = 9.172

V_{C11} = 11.7

EFF. = 60.34%

f_S = PFM/PWM

ALL VOLTAGES ARE WITHIN TOLERANCE

Even still reducing the load till 9W, Thanks to the good coupling of the transformer, all the output voltages are still in tolerance.

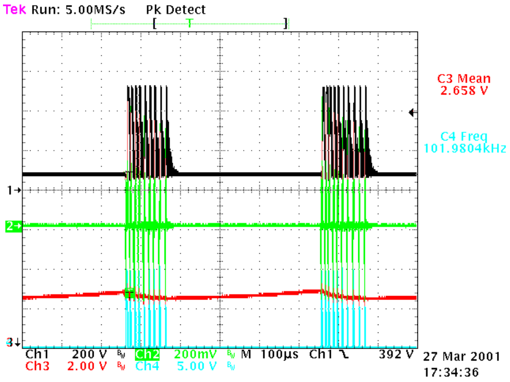
- At No-Load (Output connector unplug)

Vout [V] =	30.4	7.20	12.15	3.39	5.00
Vout [V] =	30.4	7.20	12.0	3.38	5.00

Vin [Vrms]=	**220**
Pin [W] =	1.6
Vin [Vrms]=	**115**
Pin [W] =	1.5

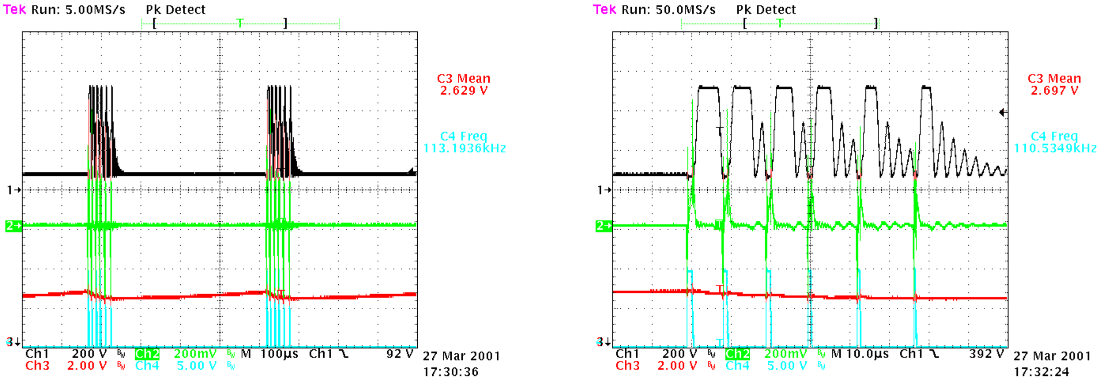
Figure 6.

Vin = 115 Vrms - 50 Hz



Unplugging the output connector the circuit is still able to maintain all the voltages perfectly under control and within the tolerance. Hence a perfect functionality of the circuit is achieved also in this abnormal condition. During the no load operation the circuit works in burst mode and, thanks to the controller functionality, the switching frequency inside the Burst pulses is kept at low. This provides for a low power consumption of the power supply, making it suitable to support stand-by operation with low consumption from the mains. It has to be kept into account that this circuit **has not been optimized** for the Stand-by operation, hence it could be improved.

Vin = 220 Vrms - 50 Hz



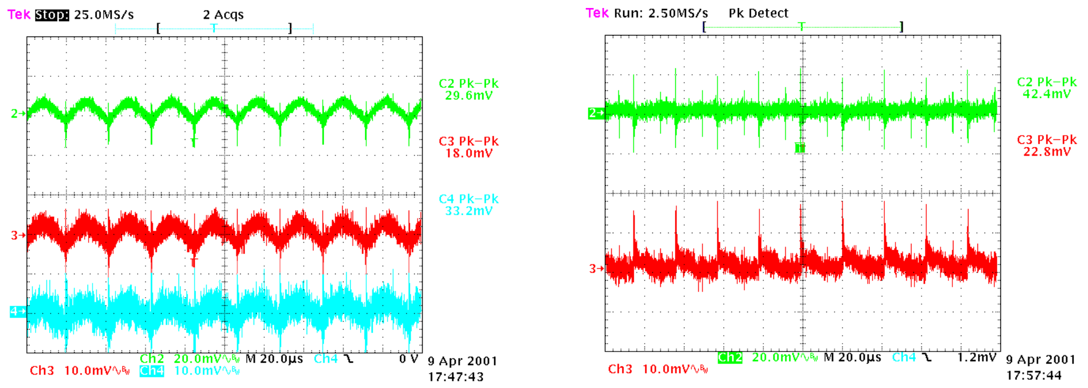
CH1:	V_{PIN5} - ZCD
CH2:	V_{PIN4} - I_{SENSE}
CH3:	V_{PIN7} - OUT
CH4:	V_{PIN2} - COMP

5 OUTPUT VOLTAGE RIPPLE @FULL LOAD

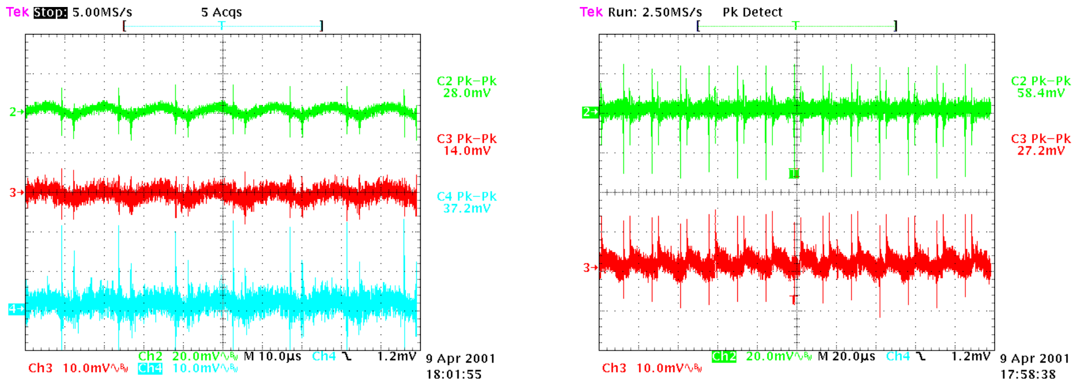
In the following picture all the output voltage ripple at switching and mains frequency are measured. As per the previous measures, the probes have been connected on test points after the output flat cable. As shown in the pictures, the ripple and the spikes are very low.

Figure 7.

@115 V_{AC} - 50Hz



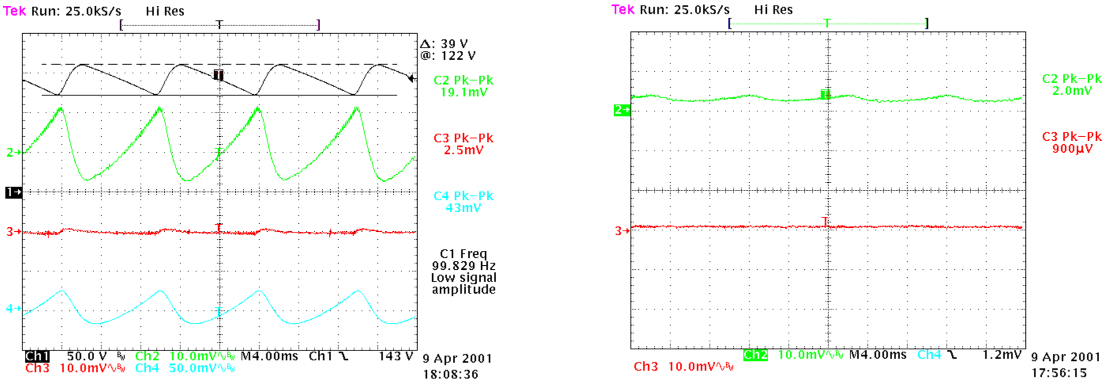
@220 V_{AC} - 50Hz



CH2:	+7 Vout	CH2:	+30 Vout
CH3:	+3.3 Vout	CH3:	+5 Vout
CH4:	+12 Vout		

Figure 8.

@115 V_{AC} - 50Hz - LINE FREQUENCY RIPPLE



CH1:	V_{C10}	CH2:	+30 Vout
CH2:	+7 Vout	CH3:	+5 Vout
CH3:	+3.3 Vout		
CH4:	+12 Vout		

The low frequency residual ripple compared with the ripple across C10 (input Elcap) shows an excellent rejection of the circuit (>80 dB).

6 MEASUREMENT OF THE RMS CAPACITOR CURRENTS

The tables show the rms currents flowing in the output capacitors at 115Vac and 220Vac, full load. All the rms currents are within the rating of the capacitor type indicated (Rubycon, YXF series). This avoids the component overstress that should affect the reliability and/or the expected lifetime of the SMPS

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@ **115Vac:** I_{CAP} C1 = 1.02 A_{RMS}	@ **115Vac:** I_{CAP} C3 = 1.78 A_{RMS}
@ **115Vac:** I_{CAP} C19 = 1.15 A_{RMS}	@ **115Vac:** I_{CAP} C18 = 140 mA_{RMS}

@ **220Vac:** I_{CAP} C1 = 0.7 A_{RMS}	@ **220Vac:** I_{CAP} C1 = 1.4 A_{RMS}
@ **220Vac:** I_{CAP} C19 = 0.92 A_{RMS}	@ **220Vac:** I_{CAP} C18 = 130 mA_{RMS}

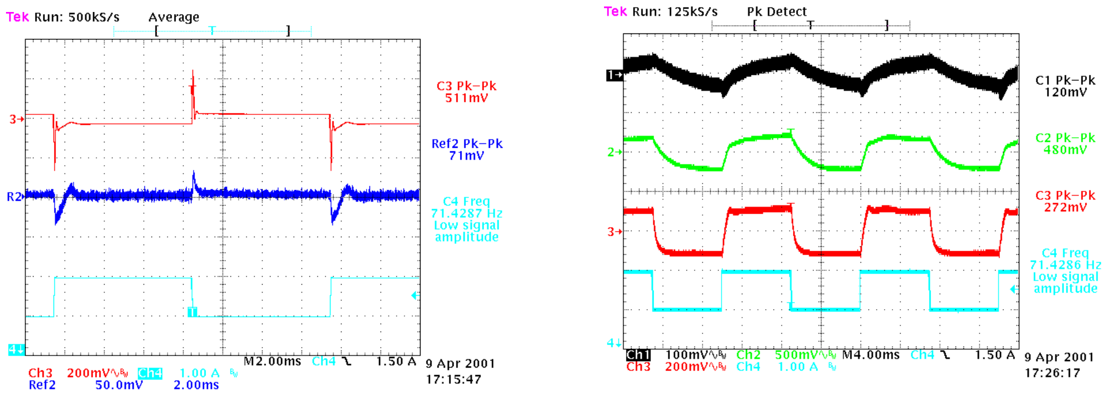
7 DYNAMIC LOAD TESTS

Regulated Output

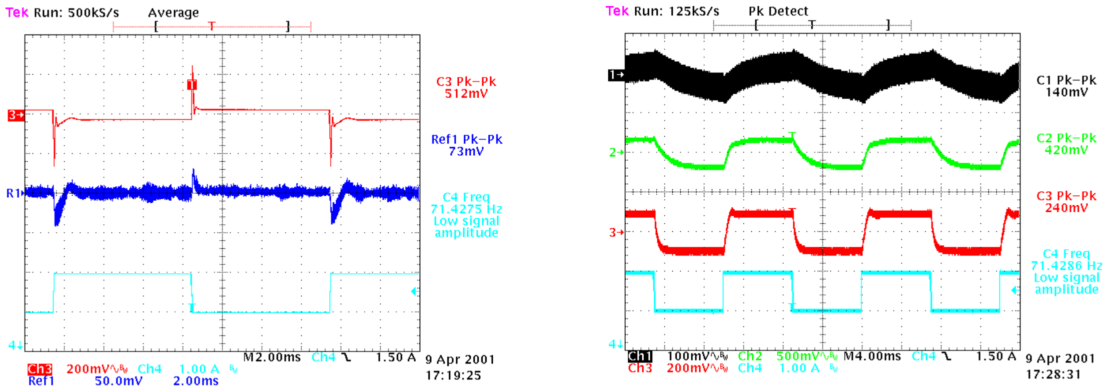
Load condition:	+5V, +7V, +12V, +30V:	FULL LOAD
	+3,3V:	LOAD 50 %÷100%, 70Hz

Figure 9.

@115 V_{AC} - 50Hz



@220 V_{AC} - 50Hz



CH3:	+3V3 Vout at test points	CH1:	+30 Vout
CH4:	+3V3 Iout	CH2:	+12 Vout
R1:	+3V3 Vout before L4	CH3:	+7 Vout
		CH4:	+3V3 Iout

The pictures show the output voltage regulation against a dynamic load variation of the feed backed voltage, at the nominal input voltage values. As shown in the left pictures the response after the connector is not very good from the peak point of view, even if the response is quite fast. Making the same measure before the filter inductor (L4), at the feed back divider connection points, the response is much better (≈2.2 %). This means that the filter inductor heavily affect the response. To avoid any expensive solution to improve it the better way is to measure the voltage regulation during the normal operation, powering the real load circuitry. This, because there are some local capacitors or filters helping a lot the regulation. Moreover, normally the dynamic load changes are less than the testing value indicated.

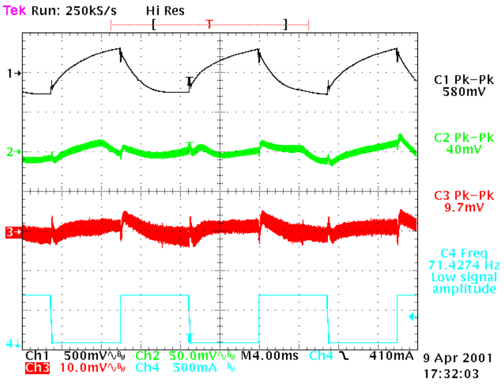
The regulation for all the other output voltage is good, remaining well within tolerances.

- Unregulated Outputs

The following tests show the response of the output voltages varying the load for each unregulated output. The load conditions are specified at the right of each picture. The regulation has been tested at both the nominal mains voltages.

Figure 10.

@115 V_{AC} - 50Hz

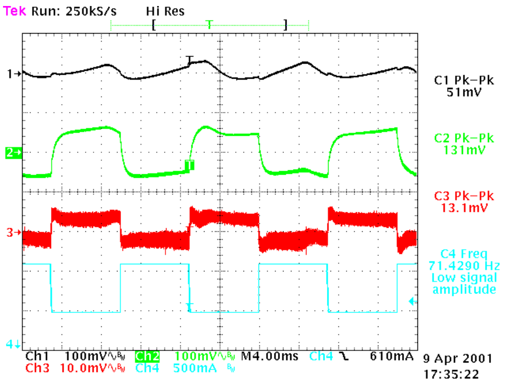


CH1:	+12 Vout
CH2:	+7 Vout
CH3:	+3V3 Vout
CH4:	+12V Iout

+3,3V +5V, +7V, +30V: FULL LOAD

+12V: DYNAMIC LOAD 0.1 to 0.7A, 70Hz

@ 220Vac the waveforms have the same amplitude.



CH1:	+12 Vout
CH2:	+7 Vout
CH3:	+3V3 Vout
CH4:	+5V Iout

+3,3V +5V, +7V, +30V: FULL LOAD

+5V: DYNAMIC LOAD 0.5 to 1.1A, 70Hz

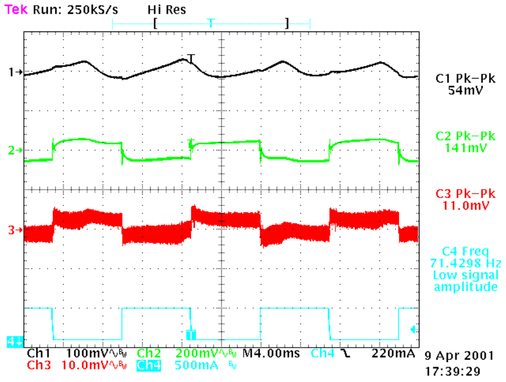
5V modulation: 20 mVpp

@ 220Vac the waveforms have the same amplitude.

ALL THE VOLTAGES ARE WITHIN TOLERANCES, AT BOTH INPUT MAINS VOLTAGES

Figure 11.

@115 V_{AC} - 50Hz



+3,3V +5V, +7V, +30V: FULL LOAD

+7V: DYNAMIC LOAD 0.1 to 0.5A, 70Hz

5V modulation: 20 mVpp

@ 220Vac the waveforms have the same amplitude.

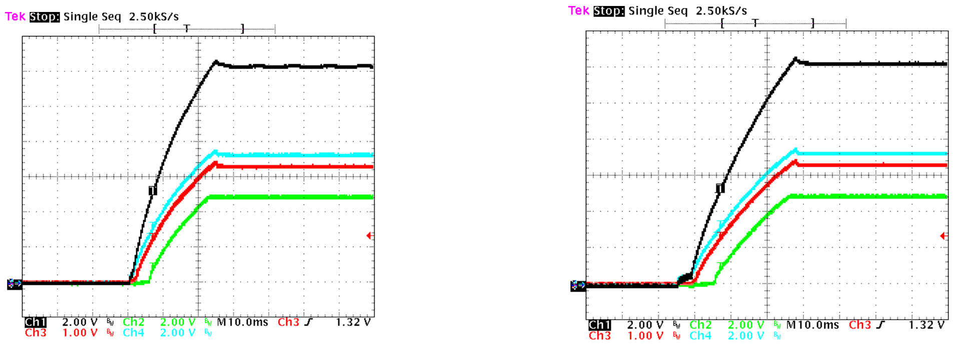
ALL THE VOLTAGES ARE WITHIN TOLERANCES, AT BOTH INPUT MAINS VOLTAGES

CH1:	+12 Vout	CH3:	+3V3 Vout
CH2:	+7 Vout	CH4:	+7V Iout

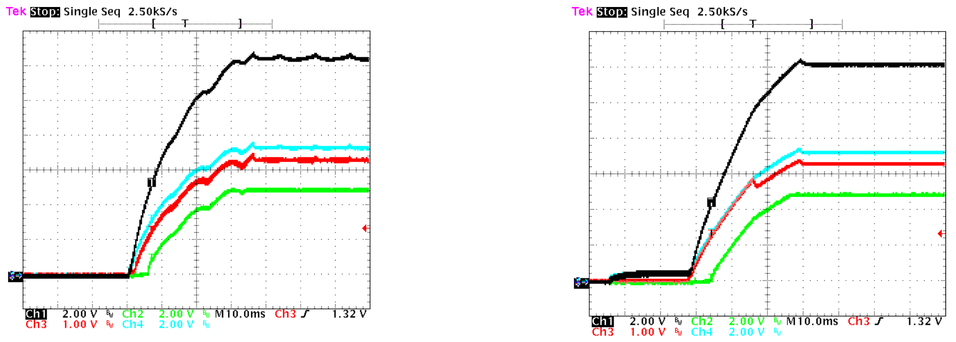
8 START-UP BEHAVIOUR @FULL LOAD

Figure 12.

@115 VAC - 50Hz **@220 VAC - 50Hz**



@85 VAC - 50Hz **@265 VAC - 50Hz**



CH1:	+12 Vout	CH3:	+3.3 Vout
CH2:	+5 Vout	CH4:	+7V Iout

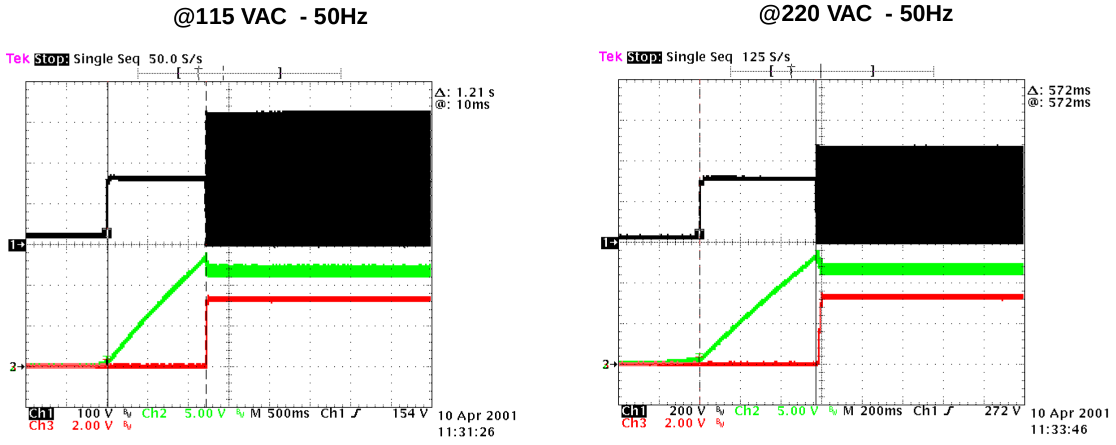
In the previous 4 pictures there are the rising slopes at full load of the more significant output voltages at nominal, minimum and maximum input mains voltage. As shown in the pictures, the rising times are constant and there is only a slight difference for the 5V rise time, with respect to the other outputs. This characteristic is quite important when the loads are a µP and its peripherals as in our case, to avoid problem at start-up. At minimum voltage a super imposed ripple at line frequency is present, due to the high ripple at the input that is not completely rejected by the loop before reaching the steady state operation. This because while the input voltage is rising, the ripple valley voltage is less than the minimum operating voltage of the circuit, therefore the ripple it is properly rejected only when it reaches that value.

9 WAKE-UP TIME

In the following pictures there are the waveforms with the wake-up time measures at the nominal input mains. Obviously, due to the circuitry characteristics, the wake-up time is not constant but it is dependent on the input voltage. The measured time at 115 and 220 Vac are 1.2 and 0.6 second, which are rather common values for this kind of Power Supplies.

The worst condition, of course, is at 85 Vac when the start-up time becomes around 1.7 seconds, which is quite a long time even if still acceptable. This because there is anyway the start-up time of the STB which is longer. Additionally, the 85Vac input mains is a steady state voltage but it is not a very common value.

Figure 13.

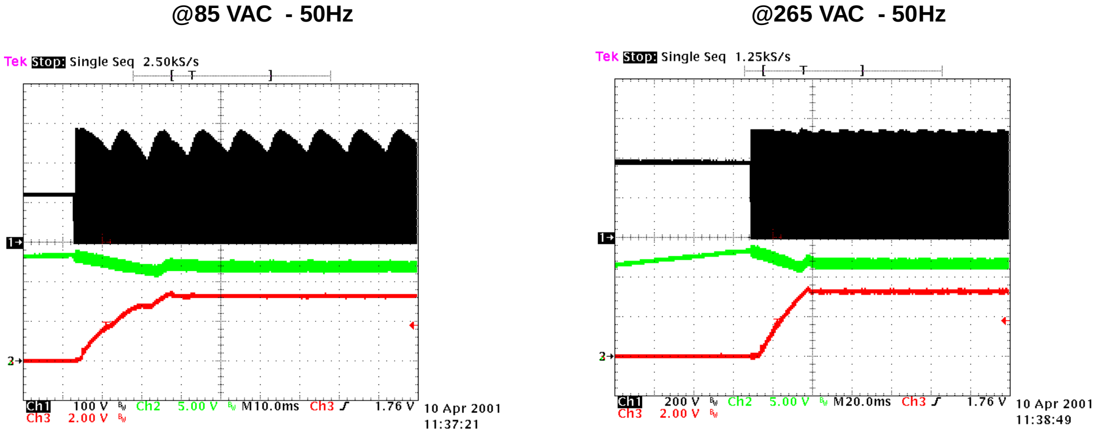


@115 VAC - 50Hz

@220 VAC - 50Hz

In Figure 14 there are the waveforms at minimum and maximum voltage with a magnification of the time base: on the picture is clearly indicated that no any overshoot, undershoot, dip or lost of control happens during the power supply start-up phase. Obviously also the nominal voltages are been detected without showing any abnormal behaviour.

Figure 14.



@85 VAC - 50Hz

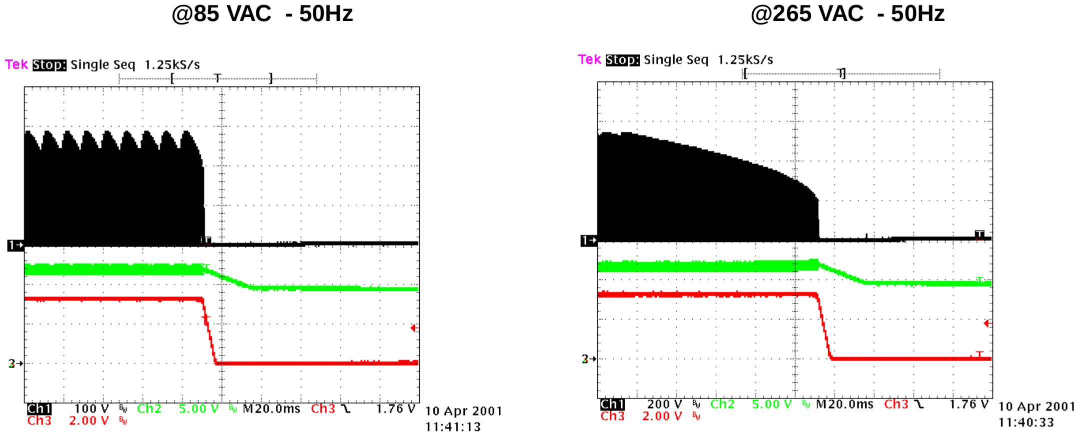
@265 VAC - 50Hz

CH1:	V_{DD}	CH1:	V_{DD}
CH2:	V_{C11} (Vaux)	CH2:	V_{C11} (Vaux)
CH3:	+3V3 Vout	CH3:	+3V3 Vout

10 TURN-OFF

Even at turn off the transition is clean, without any abnormal behaviour like restart or glitches both on the primary or secondary side.

Figure 15.



@85 VAC - 50Hz

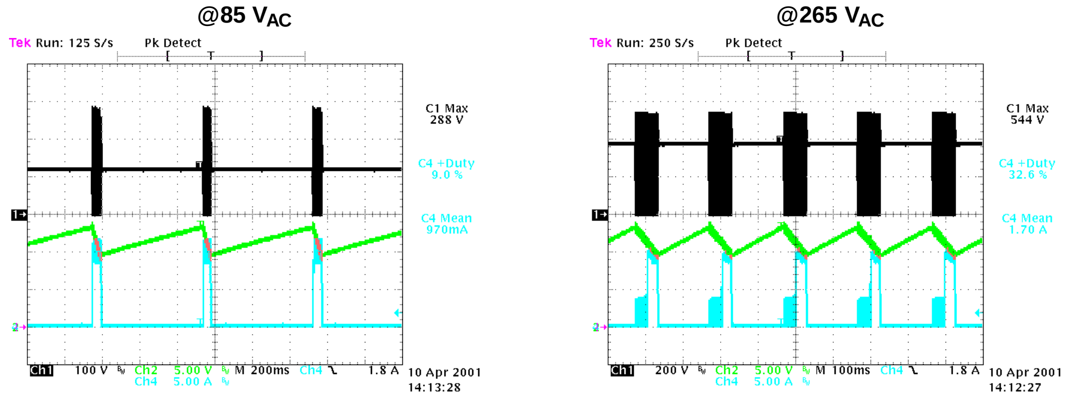
@265 VAC - 50Hz

CH1:	V_{DD}	CH1:	V_{DD}
CH2:	V_{C11} (Vaux)	CH2:	V_{C11} (Vaux)
CH3:	+3V3 Vout	CH3:	+3V3 Vout

11 SHORT-CIRCUIT TESTS @ FULL LOAD

The short circuit tests have been done in two phases, both making the test shorting by a power switch the output electrolytic capacitor or making the short by the active load option. This gives an idea about the circuit behaviour with a hard short (at very low impedance) or with a "soft" short that could happen on the STB main board, having slightly higher impedance. All the tests have been done at maximum and minimum input voltage. For all conditions the drain voltage is always below the BVDSS, while the mean value of the output current has a value close to the nominal one, then preventing component melting for excessive dissipation. The auto-restart is correct at short removal in all conditions.

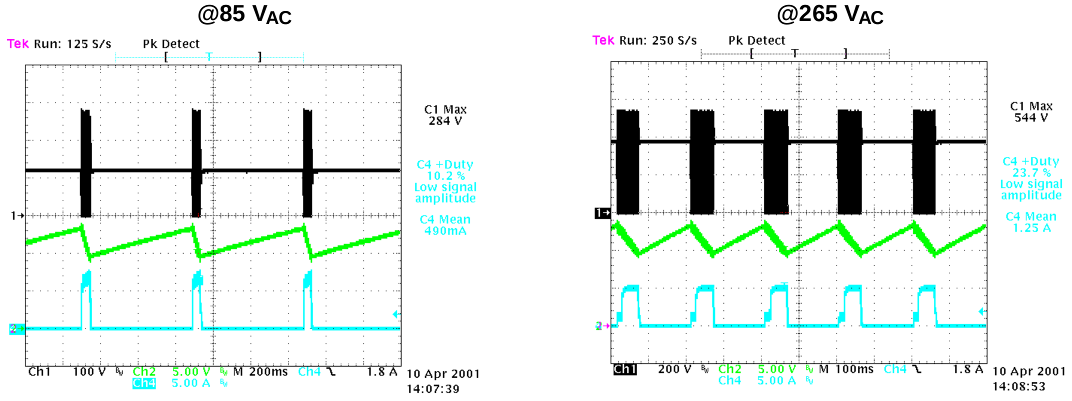
Figure 16. 7V OUTPUT: SHORT C3



CH1:	DRAIN VOLTAGE	CH1:	DRAIN VOLTAGE
CH2:	V_{C11} (Vaux)	CH2:	V_{C11} (Vaux)
CH4:	$I_{SHORT\ CIRCUIT}$	CH4:	$I_{SHORT\ CIRCUIT}$

As clearly indicated by the waveforms, the circuit start to work in hic-cup mode, so maintaing the mean value of the current at levels supported by the component rating. Because the working time and the dead time are imposed by the charging and discharging time of the auxiliary capacitor C11, it is proportional to the input mains voltage.

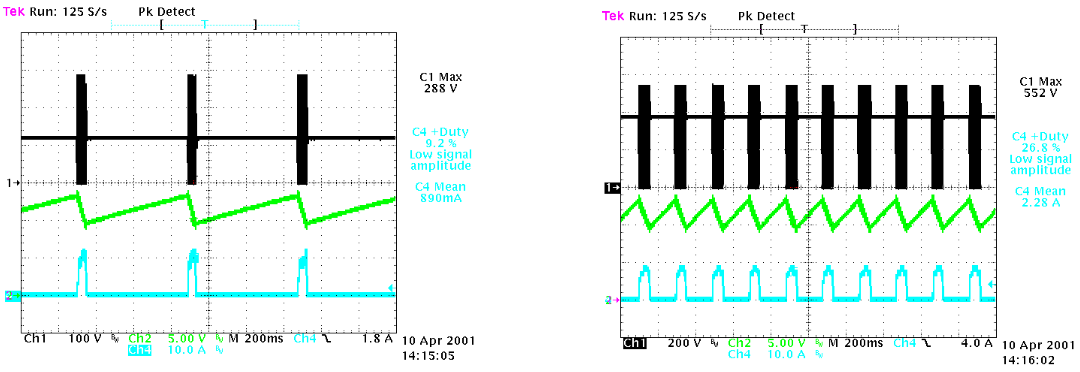
Figure 17. 7V OUTPUT: SHORT BY ACTIVE LOAD



CH1:	DRAIN VOLTAGE	CH1:	DRAIN VOLTAGE
CH2:	V_{C11} (Vaux)	CH2:	V_{C11} (Vaux)
CH4:	$I_{SHORT\ CIRCUIT}$	CH4:	$I_{SHORT\ CIRCUIT}$

As expected the circuit protects itself as well. The secondary peak current is obviously lower, due to the higher circuit impedance.

Figure 18. 3V3 OUTPUT: SHORT C1

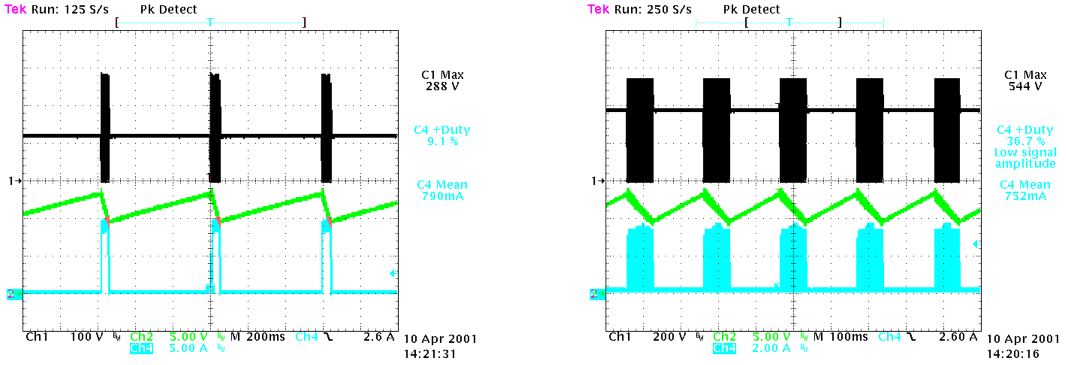

@85 V_{AC}

@265 V_{AC}

CH1:	DRAIN VOLTAGE	CH1:	DRAIN VOLTAGE
CH2:	V_{C11} (Vaux)	CH2:	V_{C11} (Vaux)
CH4:	$I_{SHORT\ CIRCUIT}$	CH4:	$I_{SHORT\ CIRCUIT}$

Like the previous output voltage the controller keeps under control the circuit preventing in all conditions the circuit from catastrophic failures. This happens even shorting the output by the active load.

Figure 19. 12V OUTPUT: SHORT C19

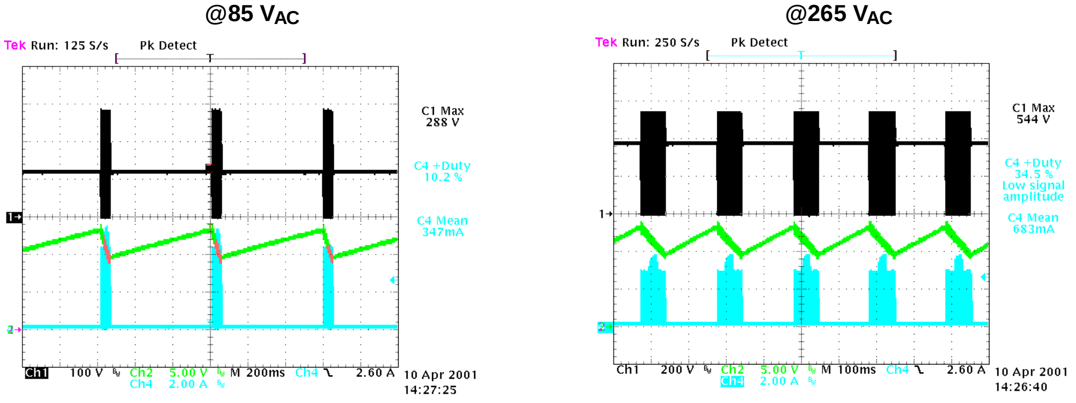

@85 V_{AC}

@265 V_{AC}

CH1:	DRAIN VOLTAGE	CH1:	DRAIN VOLTAGE
CH2:	V_{C11} (Vaux)	CH2:	V_{C11} (Vaux)
CH4:	$I_{SHORT\ CIRCUIT}$	CH4:	$I_{SHORT\ CIRCUIT}$

Even the 12V output is well protected against shorts, either by a power switch or by the active load

Figure 20. 35V OUTPUT: SHORT C18

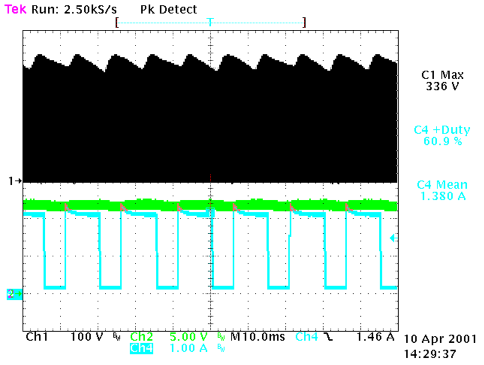

@85 V_{AC} @265 V_{AC}

CH1:	DRAIN VOLTAGE	CH1:	DRAIN VOLTAGE
CH2:	V_{C11} (Vaux)	CH2:	V_{C11} (Vaux)
CH4:	$I_{SHORT\ CIRCUIT}$	CH4:	$I_{SHORT\ CIRCUIT}$

The above pictures are relevant to a hard short by switch of the output capacitor C11. The short by active load has not been tested because the load is not connected on this point, but after the zener limiting resistors.

The short circuit on the +30V has not been tested because the power rating of the limiting resistors in series to the zener diode is not enough to insure a reliable protection against long-term short circuits. A solution could be to PUT a PTC resistor or similar component, or changethe present resistor with a fusible resistor.

Figure 21. 5V OUTPUT: SHORT BY ACTIVE LOAD


@115 V_{AC}

A short circuit made on the flat cable soldering points with a power switch provides for the current limiting intervention of the regulator at 2A **(LD1086V50)** Then, due to the internal over temperature protection the regulator starts to switch on and off itself, always keeping the output current under control. Hence, with this transformer and this regulator, an overcurrent on the 5V is not able to provide for the hic-cup working mode the previous tests but anyway all the most important circuit parameters are below any dangerous overstress point.

CH1:	DRAIN VOLTAGE
CH2:	V_{C11} (Vaux)
CH4:	$I_{SHORT\ CIRCUIT}$

12 SHORT CIRCUIT PROTECTION @ LOW LOAD

After the full load tests some checks on the short circuit protection with reduced loads have been done.

@Half Load

35V	12V	7V	5V	3.3V
15mA	0.25 A	0.35A	0.55A	1A
Pout_{TOT} = 12.6W				

At Vin = 115Vac: shorting each output by the active load the over current protection works correctly, providing for the hic-cup working mode, except for the 5V which is protected by the current limiting of the linear regulator.

At Vin = 220Vac: the circuit behaves like at 115V.

@Reduced Load - 1

35V	12V	7V	5V	3.3V
15mA	0.5 A	0A	0A	1A
Pout_{TOT} = 9.5W				

At Vin = 115Vac: shorting the 3.3V, 7V, 12V and 35V it provides for the hic-cup working mode of the circuit.

At Vin = 220Vac: the behaviour is the same.

@Reduced Load - 2

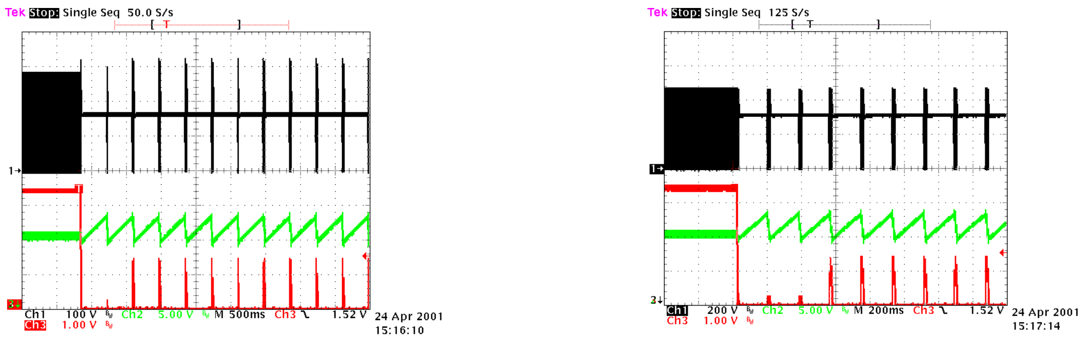
35V	12V	7V	5V	3.3V
15mA	0.4 A	0A	0A	0A

Both at 115V and 220V the circuit is still protected against short circuits on all the outputs

13 AT NO LOAD

Even in this abnormal condition, with the output connector unplugged, a short on the outputs provides for the same results of the previous tests, both at 115Vac or at 220 Vac.

Figure 22. 3.3V OUTPUT: SHORT @NO LOAD



@115 V_{AC}

@220 V_{AC}

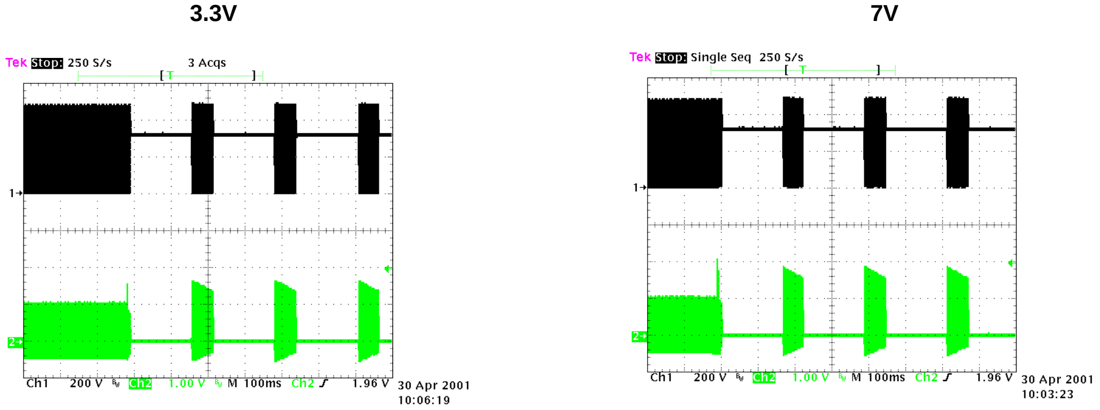
CH1:	DRAIN VOLTAGE	CH1:	DRAIN VOLTAGE
CH2:	V_{C11} (Vaux)	CH2:	V_{C11} (Vaux)
CH3:	3.3V OUTPUT	CH4:	3.3V OUTPUT

14 SHORT CIRCUIT OF THE OUTPUT RECTIFIERS

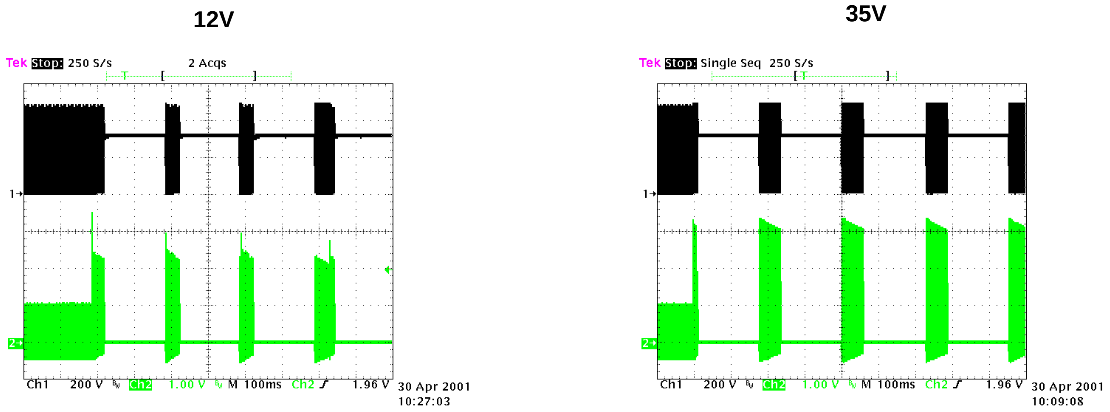
A frequent problem in a power supply is relevant to the protection of the SMPS itself: thus sometimes it is easy to find circuits with a good protection capability against shorts of the load but which are not able to survive in case of a very hard short like an output electrolytic capacitor or a diode. Besides, in case of a rectifier shorted the equivalent circuit changes and the energy is delivered even during the on time, like in forward mode.

To insure reliable operation of the design, even this fault condition has been simulated for each rectifier. Thanks to the controller functionality, the SMPS can withstand this failure, working in burst mode as visible in the pictures,

Figure 23. RECTIFIERS SHORT: @FULL LOAD - 220 VAC



CH1:	DRAIN VOLTAGE	CH1:	DRAIN VOLTAGE
CH2:	V_{PIN4} - I_{SENSE}	CH2:	V_{PIN4} - I_{SENSE}



CH1:	DRAIN VOLTAGE	CH1:	DRAIN VOLTAGE
CH2:	V_{PIN4} - I_{SENSE}	CH2:	V_{PIN4} - I_{SENSE}

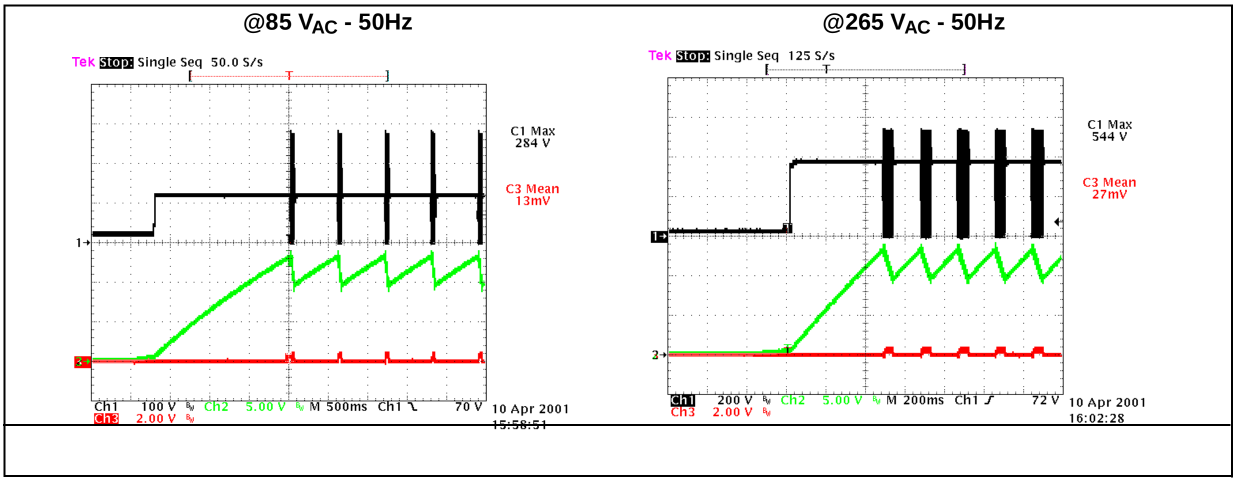
In case of an output diode short, the current sensing voltage exceeds a second protection level, then the controller stops the operation, so avoiding the destruction of the components at primary side. The controller remains in off-state until the voltage across the Vcc pin decreases below the UVLO threshold. Then it try to restart and it will switch off again until the secondary short is removed. This provides for the hic-cup working mode, preventing the circuit destruction. The operating frequency inside the burst is the internal timer one (~2.5 Khz).

15 SWITCH ON AND TURN OFF IN SHORT CIRCUIT CONDITION

- FULL LOAD
- SHORT ON 3V3 BY ACTIVE LOAD

The following pictures describe the SMPS behaviour during the start-up phase with an output voltage shorted. As clearly visible the circuit starts correctly then it works in hic-cup mode protecting itself. The start-up phase is clean in all conditions, without showing any dangerous transition for the SMPS circuitry.

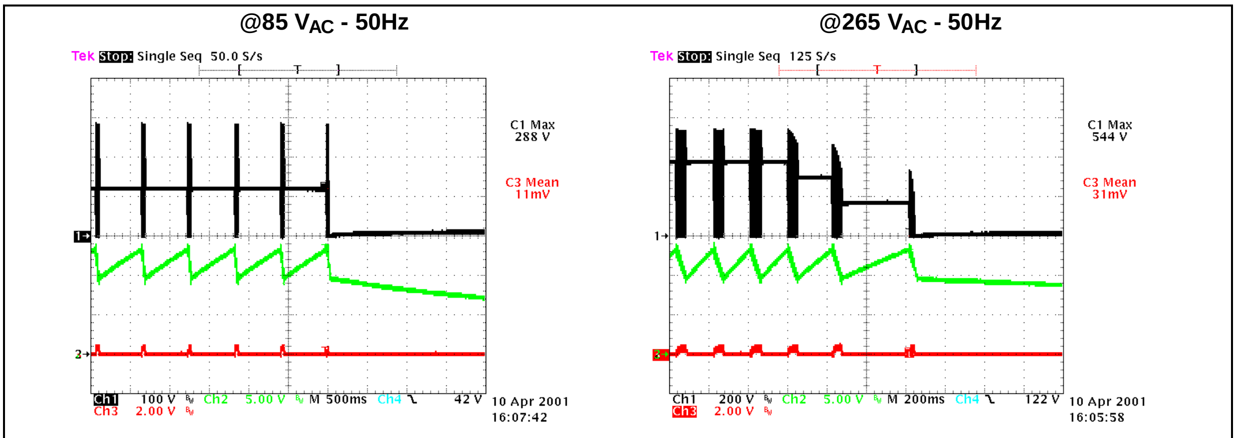
Figure 24. START



@85 V_{AC} - 50Hz

@265 V_{AC} - 50Hz

Figure 25. TURN-OFF



@85 V_{AC} - 50Hz

@265 V_{AC} - 50Hz

CH1:	V_{DD}	CH1:	V_{DD}
CH2:	V_{C11} (Vaux)	CH2:	V_{C11} (Vaux)
CH3:	+3V3 Vout	CH3:	+3V3 Vout

Even at turn off in short circuit the SMPS functionalities are good, protecting properly the circuit. No any abnormal transition or level has been observed during the tests.

16 OVER VOLTAGE PROTECTION

A dangerous fault that could happen in case is the failure of the feedback circuitry. If this occurs, the SMPS output voltages can get high values, depending on the load by each output and the transformer coupling between the windings. Consequently, the rectifiers and the output capacitors are overstressed and can be destroyed. To avoid the SMPS failure a suitable protection circuit has been added. Then the circuit has been tested opening the loop, giving the following results:

3.3V OUTPUT: @ full load	
@115V – 50Hz	@220V – 50Hz
V_{3V3}: 4.02 V	V_{3V3}: 4.08 V

3.3V OUTPUT: @ No load	
@115V – 50Hz	@220V – 50Hz
V_{3V3}: 4.64 V	V_{3V3}: 4.67 V

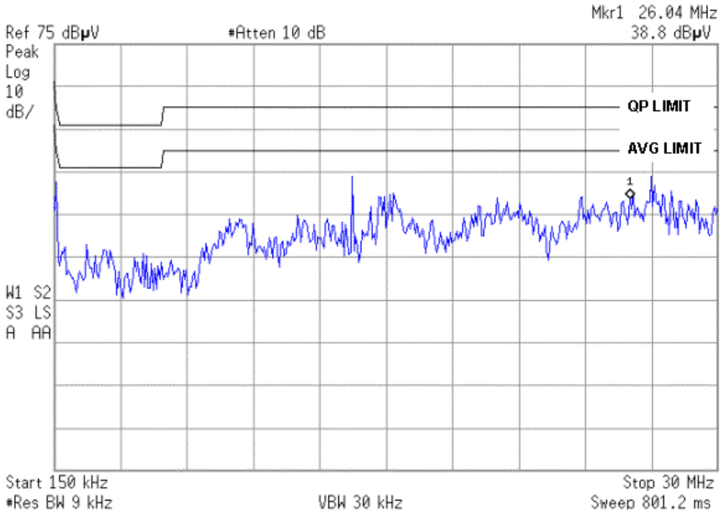
17 CONDUCTED NOISE MEASUREMENTS (PRE-COMPLIANCE TEST)

The following pictures are the peak and quasi-peak conducted noise measurements at full load and nominal mains voltages. The limits shown on the diagrams are the EN55022 CLASS B ones, which is the most widely rule for domestic equipments like a STB. As visible on the diagrams there is a good margin of the measures with respect to the limits, either in peak or quasi-peak mode.

The detail of the filtering components used is on the right of each diagram.

Figure 26.

Vin = 115 Vrms 50 Hz – FULL LOAD	***Limits: EN55022 CLASS B***



PEAK MEASURE

BOARD **#2**

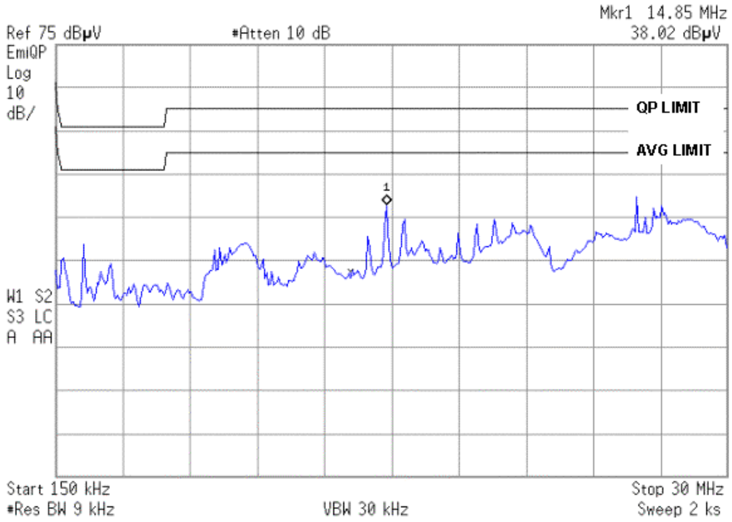
C9 = 100nF EPCOS

L = 39 mH EPCOS

C16 = 100nF EPCOS

TRAFO 2412.0011 **REV. C1**

Pout = 25W



QUASI-PEAK MEASURE

BOARD **#2**

C9 = 100nF EPCOS

L = 39 mH EPCOS

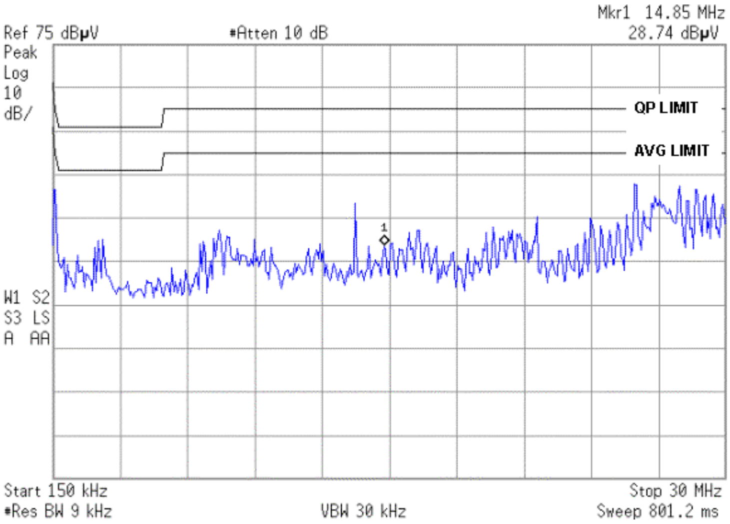
C16 = 100nF EPCOS

TRAFO 2412.0011 **REV. C1**

Pout = 25W

Figure 27.

Vin = 220 Vrms 50 Hz – FULL LOAD	***Limits: EN55022 CLASS B***



PEAK MEASURE

BOARD **#2**

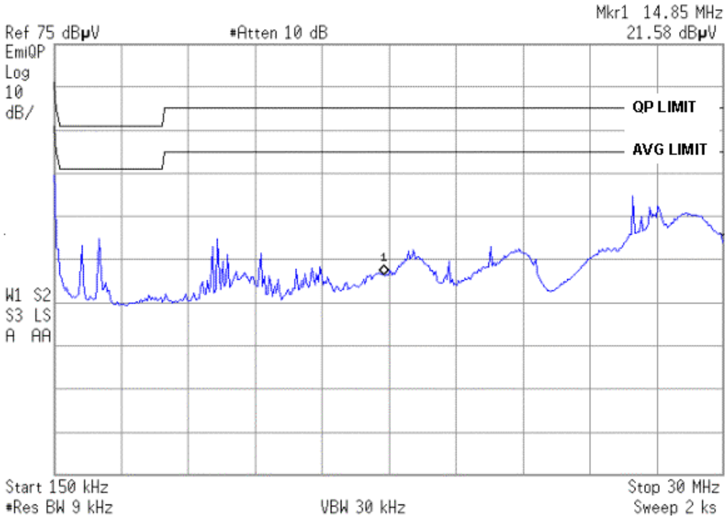
C9 = 100nF EPCOS

L = 39 mH EPCOS

C16 = 100nF EPCOS

TRAFO 2412.0011 **REV. C1**

Pout = 25W



QUASI-PEAK MEASURE

BOARD **#2**

C9 = 100nF EPCOS

L = 39 mH EPCOS

C16 = 100nF EPCOS

TRAFO 2412.0011 **REV. C1**

Pout = 25W

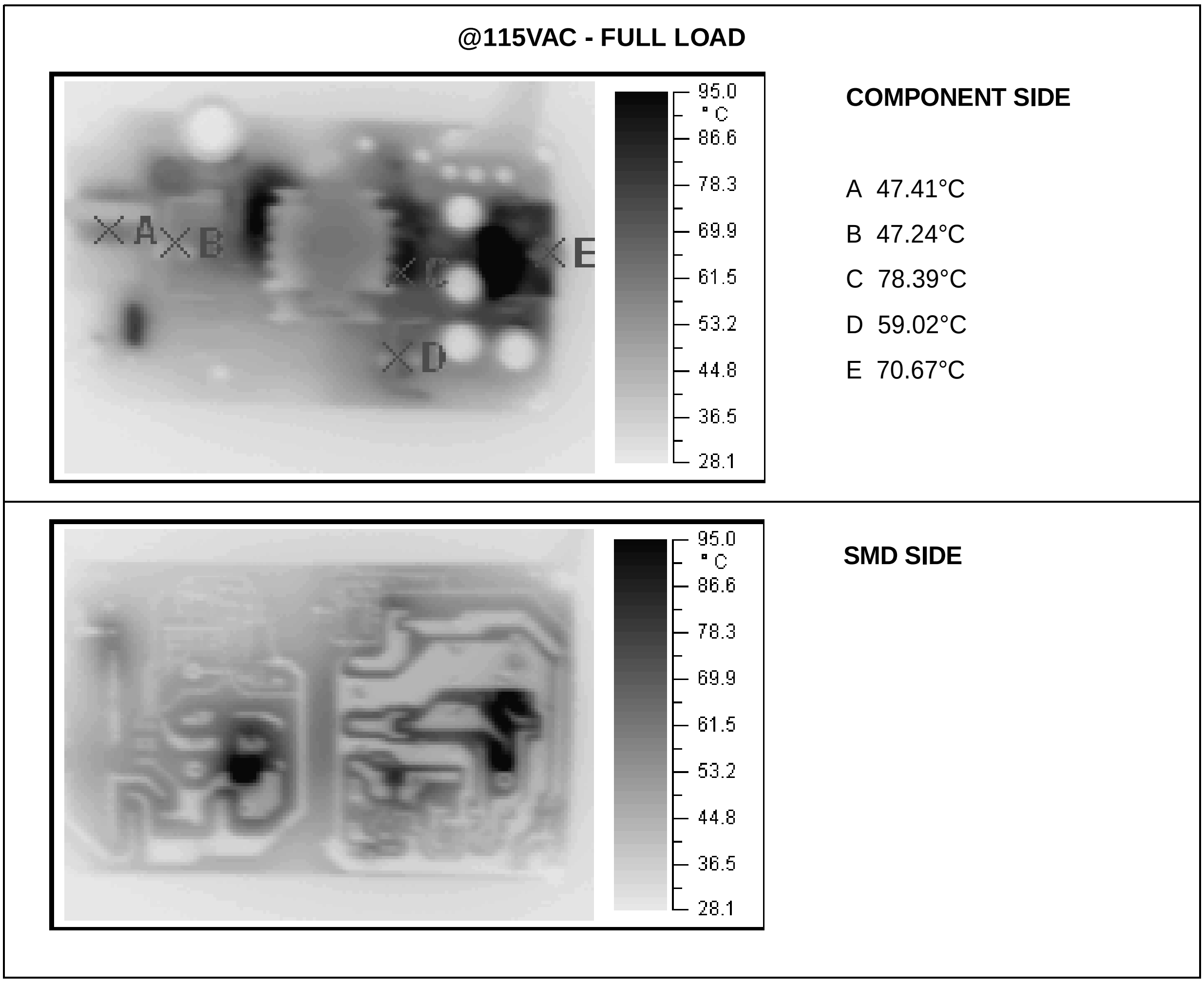
18 THERMAL MEASURES

In order to check the reliability of the design a thermal mapping by means of an IR Camera was done. Here below the thermal measures on the board, at both nominal input voltages at ambient temperature (24 °C) are shown. The pointers A¸E have been placed across some key components, affecting the reliability of the circuit. The points correspond to the following components:

component side	
A	Input coil - L1
B	PowerMOS – Q1
C	+7V diode – D7
D	+3.3V diode – D8
E	+5V regulator – IC3

As shown on the maps, all the other points of the board are within the temperature limits assuring a reliable performance of the devices.

Figure 28.

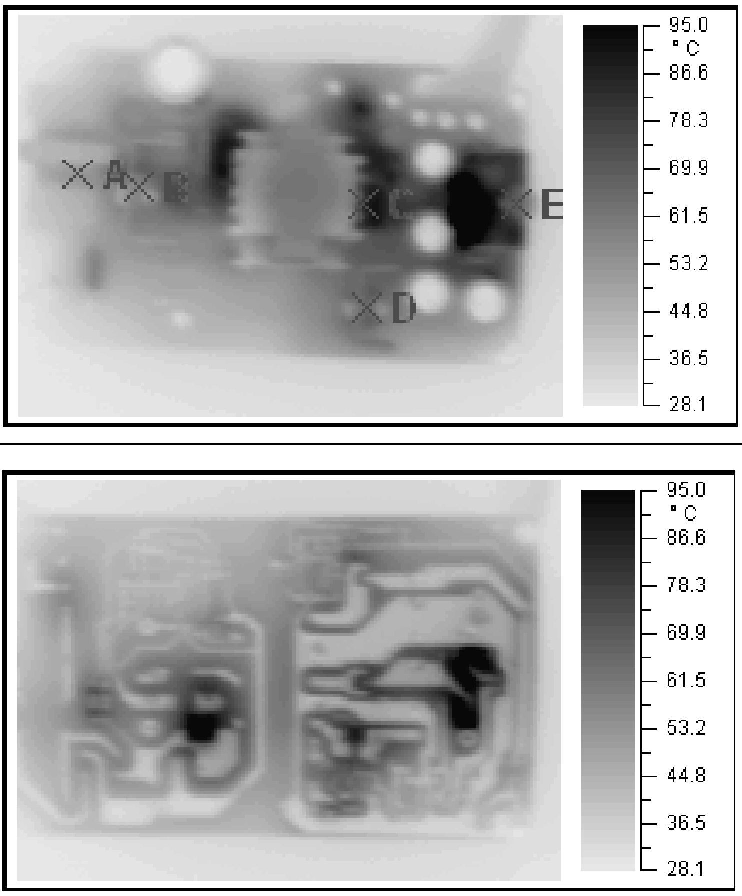


The highest temperatures are for the NTC thermistor, the filter inductor, the input bridge, the clamp diode (D9), the 5V regulator and the output diodes D7 and D6. The temperature rise of the transformer is around 40 °C.

Regarding the thermistor, the bridge and the output diodes the temperature rise is compatible with reliable operation of the circuit.

Figure 29.

@220VAC - FULL LOAD



COMPONENT SIDE

A 39.31°C

B 54.21°C

C 80.15°C

D 60.05°C

E 72.00°C

SMD SIDE

At 220Vac the input circuitry is thermally less stressed and generally the component temperature rise is lower.

19 CONCLUSIONS

A SMPS for Set-Top Box has been completely designed, assembled and tested, giving positive results from all the different aspects (Component Stress, Functionalities, Protections, EMI, thermal behaviour). The design meets also the low-cost requirement, a key driver in the Consumer Electronic market.

20 REFERENCES

[1] "L6561-based Fly-back Converters" (AN1060)

[2] "L6565 Quasi-Resonant Controller " (AN1326)

[3] "How to handle Short Circuit Conditions with ST's Advanced PWM Controllers" (AN1215)

21 ANNEX 1

PART LIST

	Designator	Part Type	Description	Supplier
1	C1	2200uF-16V YXF	ELCAP	RUBYCON
2	C10	47uF-400V	ELCAP	SAMHWA
3	C11	22uF-25V YXF	ELCAP	RUBYCON
4	C12	1N0-1KV 30LVD10	CERCAP HV	CERA-MITE
5	C13	1N0-1KV 30LVD10	CERCAP HV	CERA-MITE
6	C14	330N - 1206	CHIP CAPACITOR	AVX
7	C15	0805 - NOT MOUNTED	CHIP CAPACITOR	AVX
8	C16	100N-275Vac - B81133	X CAP	EPCOS
9	C17	220PF-1KV HRR	CERCAP HV	MURATA
10	C18	22uF-50V YXF	ELCAP	RUBYCON
11	C19	2200uF-16V - YXF	ELCAP	RUBYCON
12	C2	2200uF-16V YXF	ELCAP	RUBYCON
13	C20	22uF-50V YXF	ELCAP	RUBYCON
14	C21	0805 - NOT MOUNTED	CHIP CAPACITOR	AVX
15	C22	220PF-0805	CHIP CAPACITOR	AVX
16	C23	1N0-0805	CHIP CAPACITOR	AVX
17	C24	100N-0805	CHIP CAPACITOR	AVX
18	C25	100N-0805	CHIP CAPACITOR	AVX
19	C26	100N-0805	CHIP CAPACITOR	AVX
20	C27	100N-0805	CHIP CAPACITOR	AVX
21	C28	100N-0805	CHIP CAPACITOR	AVX
22	C29	100N-0805	CHIP CAPACITOR	AVX
23	C3	2200uF-16V YXF	ELCAP	RUBYCON
24	C30	220PF-1KV HRR	CERCAP HV	MURATA
25	C31	220P - 0806	CHIP CAPACITOR	AVX
26	C32	2N2-0805	CHIP CAPACITOR	AVX
27	C33	100N-0805	CHIP CAPACITOR	AVX
28	C4	100uF-16V - YXF	ELCAP	RUBYCON
29	C5	100uF-16V - YXF	ELCAP	RUBYCON
30	C6	100uF-16V - YXF	ELCAP	RUBYCON
31	C7	100uF-16V - YXF	ELCAP	RUBYCON
32	C8	2N2-4KV (Y1) 44LD22	CERCAP-SAFETY	CERA-MITE
33	C9	100N-275Vac - B81133	X CAP	EPCOS
34	D1	SMBYT01-400	RECTIFIER	STMICROELECTRONICS
35	D10	BZV55-C15	ZENER DIODE	PHILIPS SEMICOND.

	Designator	Part Type	Description	Supplier
36	D11	BZV55-C15	ZENER DIODE	PHILIPS SEMICOND.
37	D12	LL4148	GEN. PURPOSE DIODE	PHILIPS SEMICOND.
38	D2	2W08G-GS	BRIDGE RECTIFIER	GEN. SEMICOND.
39	D3	STTA106U	RECTIFIER	STMICROELECTRONICS
40	D4	LL4148	GEN. PURPOSE DIODE	PHILIPS SEMICOND.
41	D5	LL4148	GEN. PURPOSE DIODE	PHILIPS SEMICOND.
42	D6	STPS2H100U	RECTIFIER	STMICROELECTRONICS
43	D7	STPS10L60CF	RECTIFIER	STMICROELECTRONICS
44	D8	STPS10L60CF	RECTIFIER	STMICROELECTRONICS
45	D9	SMCJ130CA (GBI) - SMC	TRANSIL	STMICROELECTRONICS
46	D9A	1,5KE150A - NOT MOUNTED	TRANSIL	STMICROELECTRONICS
47	F1	FUSE 2A		WICKMANN
48	HS1	ABL LS220	HEAT SINK FOR Q1	ABL
49	HS2	ABL LS220	HEAT SINK FOR IC3	ABL
50	HS3	6073	HEAT SINK FOR D8	THERMALLOY
51	IC1	L6565 - DIP8	INTEGRATED CIRCUIT	STMICROELECTRONICS
52	IC2	TL431ACD	INTEGRATED CIRCUIT	STMICROELECTRONICS
53	IC3	LD1086V50	LIN. REGULATOR	STMICROELECTRONICS
54	JP1	FASTON 6mm	CONNECTOR	
55	JP1A	FASTON 6mm	CONNECTOR	
56	JP2	MKS1858-6-0-808	CONNECTOR - 8 POLES	STOCKO
57	L1	B82732-R2701-B30	2*39 mH - FILTER COIL	EPCOS
58	L2	10u ELC06D	INDUCTOR	PANASONIC
59	L3	10u ELC06D	INDUCTOR	PANASONIC
60	L4	2u7 ELC06D	INDUCTOR	PANASONIC
61	OPT1	SFH617A-4	OPTOCOUPLER	INFINEON
62	P1	0R0-1206	CHIP RESISTOR	BEYSCHLAG
63	P2	0R0-1206	CHIP RESISTOR	BEYSCHLAG
64	P3	0R0-1206	CHIP RESISTOR	BEYSCHLAG
65	P4	0R0-1206	CHIP RESISTOR	BEYSCHLAG
66	P5		JUMPER, WIRE	
67	P6	0R0-1206	CHIP RESISTOR	BEYSCHLAG
68	P7	0R0-1206	CHIP RESISTOR	BEYSCHLAG
69	L5	NOT MOUNTED - SHORTED	JUMPER, WIRE	
70	PCB		35u, SINGLE SIDE, FR4	
71	Q1	STP4NC60FP	POWER MOSFET	STMICROELECTRONICS
72	Q2	BC856	SMALL SIGNAL BJT	ZETEX

	Designator	Part Type	Description	Supplier
73	Q3	BC848	SMALL SIGNAL BJT	ZETEX
74	Q4	BC848	SMALL SIGNAL BJT	ZETEX
75	R1	270K-1206	CHIP RESISTOR	BEYSCHLAG
76	R10	220R - 0805	CHIP RESISTOR	BEYSCHLAG
77	R11	4K7 - 0805	CHIP RESISTOR	BEYSCHLAG
78	R12	470K-1206	CHIP RESISTOR	BEYSCHLAG
79	R13	0805 - NOT MOUNTED	CHIP RESISTOR	BEYSCHLAG
80	R14	270K-1206	CHIP RESISTOR	BEYSCHLAG
81	R15	470K-1206	CHIP RESISTOR	BEYSCHLAG
82	R16	470R - 1/2W PTH	FUSE RESISTOR PTH	NEOHM
83	R17	1R0 - 2W PTH	POWER RESISTOR	NEOHM
84	R18	47R - 1/2W PTH	SFR RESISTOR PTH	BEYSCHLAG
85	R19	1K0 - 1/2W PTH	SFR RESISTOR PTH	BEYSCHLAG
86	R2	NTC_16R S236	NTC THERMISTOR	EPCOS
87	R20	10K - 1206	CHIP RESISTOR	BEYSCHLAG
88	R21	470R - 1206	CHIP RESISTOR	BEYSCHLAG
89	R22	0R0-0805	CHIP RESISTOR	BEYSCHLAG
90	R23	0805 - NOT MOUNTED	CHIP RESISTOR	BEYSCHLAG
91	R24	180R 1/2W PTH	SFR RESISTOR PTH	BEYSCHLAG
92	R25	1K8 - 0805	CHIP RESISTOR	BEYSCHLAG
93	R26	1K0 - 0805	CHIP RESISTOR	BEYSCHLAG
94	R27	120K - 0805	CHIP RESISTOR	BEYSCHLAG
95	R28	24K - 0805	CHIP RESISTOR	BEYSCHLAG
96	R3	33R-0805	CHIP RESISTOR	BEYSCHLAG
97	R4	100K - 0805	CHIP RESISTOR	BEYSCHLAG
98	R5	3K3 - 0805	CHIP RESISTOR	BEYSCHLAG
99	R6	0R47 - 1/2W PTH	SFR RESISTOR PTH	BEYSCHLAG
100	R7	2K7 - 0805	CHIP RESISTOR	BEYSCHLAG
101	R8	560R-0805	CHIP RESISTOR	BEYSCHLAG
102	R9	82R - 0805	CHIP RESISTOR	BEYSCHLAG
103	T1	2414.0011 **rev. C1**	TRANSFORMER	ELDOR CORPORATION

22 ANNEX 2

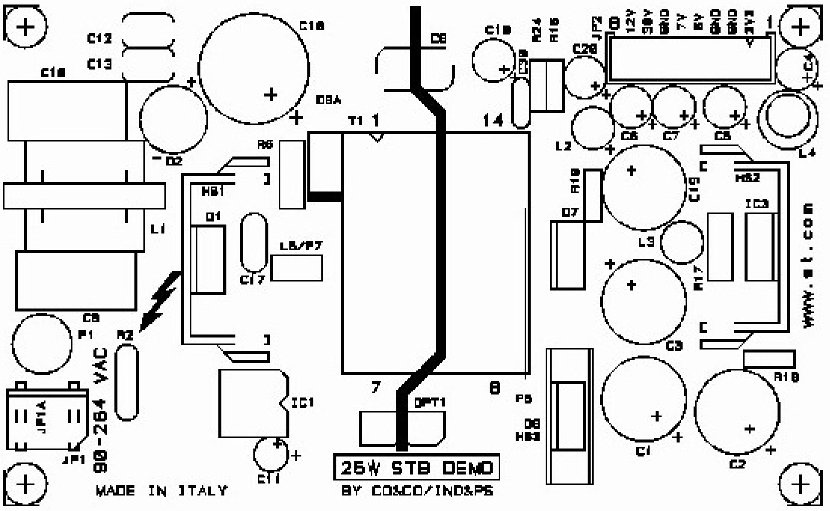


Figure 30. SILK SCREEN -TOP SIDE

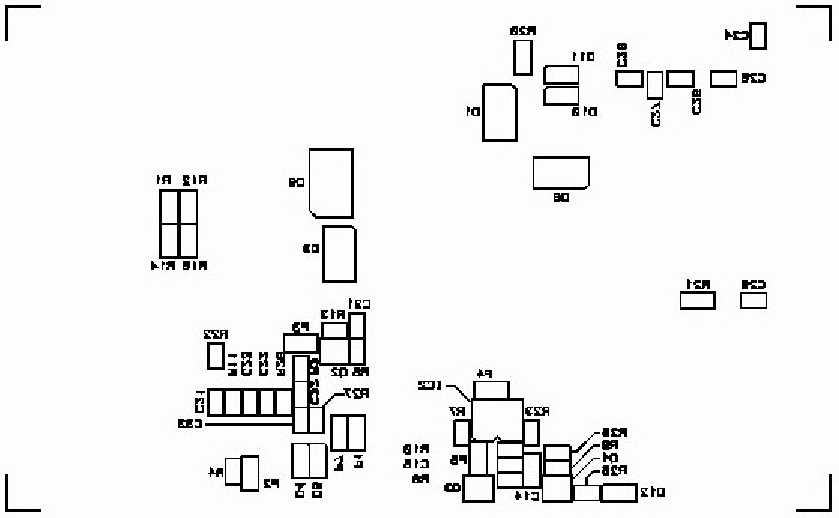
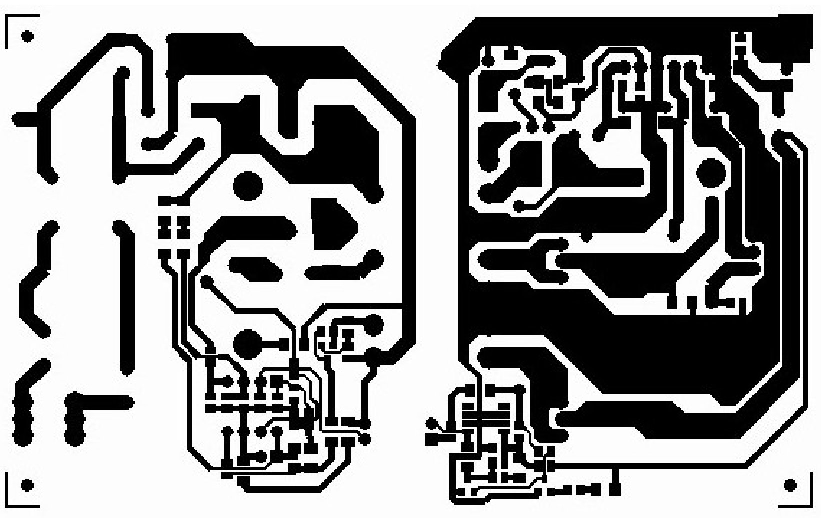


Figure 31. SILK SCREEN -BOTTOM SIDE

Figure 32. COPPER TRACKS



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