# AN2600
# Application note

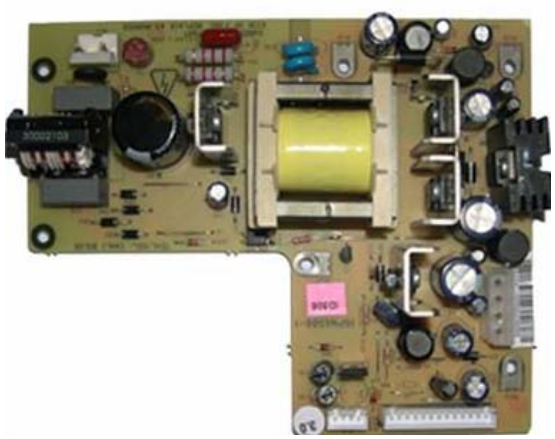
## SMPS for high-end PVR based on L6668

## Introduction

The set-top box (STB) market is growing very fast due to the high growth of both satellite and terrestrial/cable broadcasting. As expected, the market is always looking for solutions with high cost effectiveness and performance.

This document introduces a reference design of a 55 W switch-mode power supply dedicated to high-end set-top box applications, and in particular for PVRs (Personal Video Recorders). This kind of solution in addition to typical loads is able to supply HD and VFD front panels. The board accepts European input voltage range (from 185 to 265$V_{ac}$) and delivers eight outputs. It is based on the advanced current mode PWM controller L6668, working at fixed frequency. Despite high performance, standard parts are used, e.g. standard capacitors are connected on the outputs in place of low ESR components commonly used, contributing to an overall decrease of the total cost of the solution.

**Figure 1. STEVAL-ISA040V1**



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# 1 Main characteristics

The main characteristics of the SMPS are listed below:

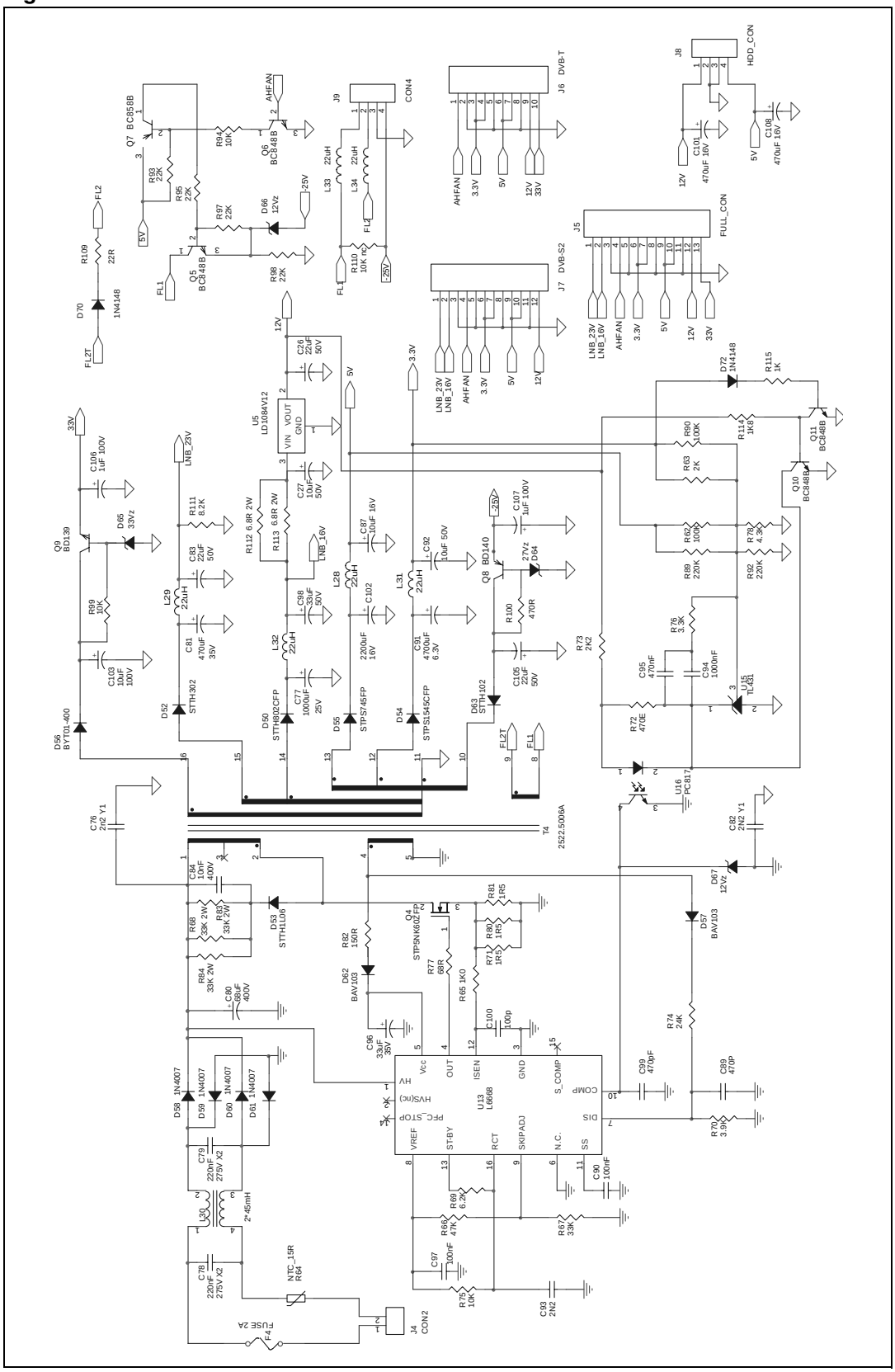
- Input voltage:
  - $V_{in}$ = 185 ÷ 265 $V_{rms}$
  - f=50 Hz

**Table 1. Output specifications**

| | Vout (V): | Iout (A) | Pout (W) | Tolerance | Notes |
|---|---|---|---|---|---|
| 1 | 3.3 | 3.5 | 11.55 | +/- 5% | Dedicated to 3.3 V circuitry, 2.6 V and 1.1 V local post regulators |
| 2 | 5 | 1.9 | 9.5 | +/- 5% | Dedicated to HDD, display, 5V circuitry and 2.6 V local post regulators |
| 3 | 12 | 0.8 | 9.6 | +/- 2% | Dedicated to HDD |
| 4 | 16 | 0.5 | 8 | +/- 10% | Dedicated to LNB for satellite DVB |
| 5 | 23 | 0.5 | 11.5 | +/- 10% | Dedicated to LNB for satellite DVB |
| 6 | -25 | 0.15 | 3.75 | +/- 10% | Dedicated to display |
| 7 | 3.3 AC | 0.08 | 0.25 | | Dedicated to the display filaments |
| 8 | 33 | 0.01 | 0.33 | +/- 10% | Dedicated to the tuner |
| | | $P_{OUT}$ (W) = | | 55 W | |

- EMI: in accordance with EN55022 Class B
- Safety: in accordance with IEC 60065 7$^{th}$ ed.

**Figure 2. Electrical schematic**



# 2 Circuit description

The topology used in this power supply is a standard flyback, working in continuous conduction mode with fixed frequency. The switching frequency (65 kHz) represents a good trade-off between the transformer size and the harmonics of the switching frequency, in order to optimize the input filter size and cost. The Power MOSFET is a 600 V-1.6 Ω in SuperMESH® technology, housed in a TO-220FP (insulated package). The reflected voltage is 70 V, providing enough room for the leakage inductance voltage spike with still margin for reliability. The network D53-R68- R83-R84-C84 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 startup internal circuit which draws current from the DC bus and charges the IC supply capacitor (C96). As soon as the voltage on this capacitor reaches the L6668 turn-on threshold, the controller starts to drive the MOSFET, and the IC is supplied only by the auxiliary winding of the transformer via the diode D62 (After startup, the HV current source is deactivated, saving power during normal operation).

The control system is Current Mode, so the current flowing in the primary is sensed by R71, R80 and R81 then filtered by R65 and C100 and fed into pin 12 (Isen). No slope compensation is needed as the duty cycle is kept well below 50%. The circuit connected to pin 7 (DIS) provides overvoltage 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. After Disable intervention the controller operation can be resumed only by disconnecting the mains plug. The switching frequency is programmed by the RC network connected to pin 16 (RCT) and in case of reduced load operation, the controller can decrease the operating frequency via pin 13 (ST-BY) and resistor R69 proportionally to the load consumption.

The output rectifiers have been chosen according to the maximum reverse voltage and power dissipation. The 3.3 V and 5 V outputs rectifiers are Schottky type, featuring lower losses compared to standard PN diodes. The diodes D50, D54 and D55 need a small heat sink, as indicated on the BOM. The other output rectifiers are fast recovery. The 12 V output is obtained from the 16 V output by a high-current low-drop voltage regulator.

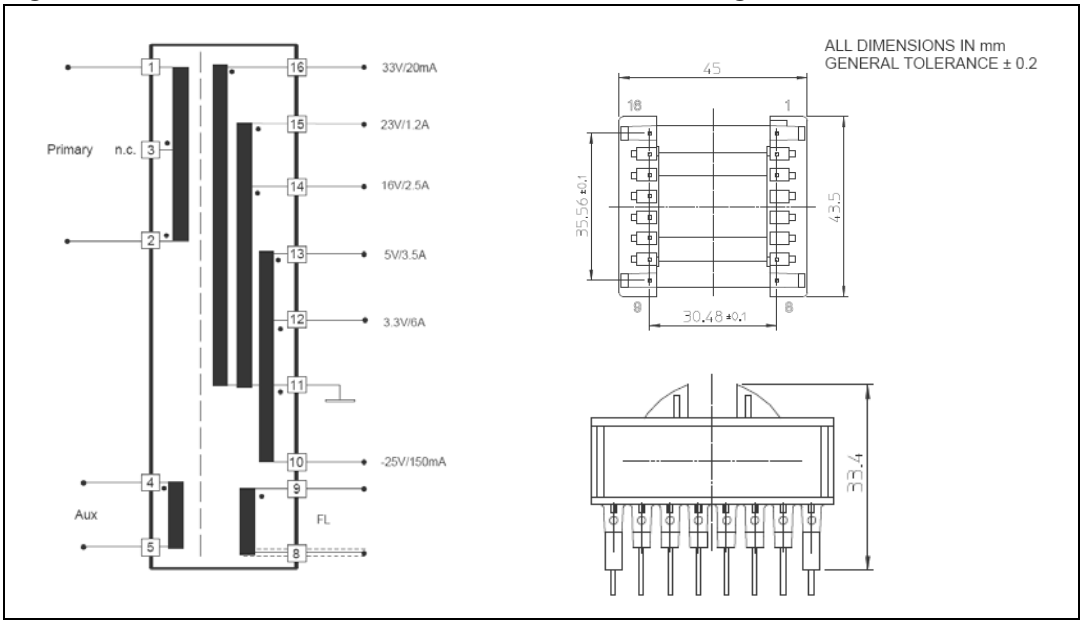
The output voltage control is performed by the secondary feedback on the 5 V and 3.3 V outputs, while for the other outputs the control is achieved by the transformer coupling. The feedback network uses a TL431 driving an opto-coupler, in this case a PC817, ensuring the required insulation between primary and secondary. The opto-transistor drives directly the COMP pin of the L6668. An LC filter has been added on all outputs in order to filter the high frequency ripple without increasing the output capacitors.

The input EMI filter consists of two X2 capacitors with a common mode choke in between. The NTC limits the inrush current charging the input capacitor at plug-in.

The transformer is layer type, manufactured by Pulse Eldor Corporation, in accordance with the safety standard IEC 60065 7$^{th}$ ed.

## 2.1 Transformer specification

**Figure 3. Transformer electrical and mechanical drawings**




- Primary inductance: 675 µH ±10% at 10 kHz - 1 V
- Leakage inductance: ≤20 µH at 100 kHz - 1 V
- Typical operating frequency: 65 kHz

### 2.1.1 Windings data

**Table 2. Windings parameters**

| Terminal no. | Windings | Number of turns | Wire |
|---|---|---|---|
| 2-3 | W1 primary/2 | 26 | 0.45 - G |
| 12-11 | W2 - 3.3 V | 3 | Cu-foil - W=10 mm T=0.1 mm |
| 13-12 | W3 - 5 V | 1 | Cu-foil - W=10 mm T=0.1 mm |
| 14-11 | W4 - 16 V | 12 | 2x0.45-G2 |
| 15-14 | W5 - 23 V | 4 | 0.45-G2 |
| 16-11 | W6 - 33 V | 26 | 0.25-G2 |
| 10-11 | W7 - 25 V | 20 | 0.25-G2 |
| 9-8 | W8 - FL | 3 | 0.25-G2 |
| 4-5 | W9 - Aux | 10 | 0.25-G2 |
| 3-1 | W10 - primary/2 | 26 | 0.45-G2 |

## 2.2 BOM

**Table 3. Bill of material**

| Qty | Reference | Value & part | Description |
|---|---|---|---|
| 3 | C26,C83,C105 | 22 µF 50 V | Electrolytic cap |
| 1 | C27 | 10 µF 50 V | Electrolytic cap |
| 2 | C76,C82 | 2.2 nF 4 Kv | Y1 cap |
| 1 | C77 | 1000 µF 25 V | Electrolytic cap |
| 2 | C78,C79 | 220 nF 75 V | X2 cap |
| 1 | C80 | 68 µF 400 V | Electrolytic cap |
| 1 | C81 | 470 µF 35 V | Electrolytic cap |
| 1 | C84 | 10 nF 400 V | Ceramic cap |
| 1 | C87 | 10 µF 16 V | Electrolytic cap |
| 2 | C89,C99 | 470 pF 0805 50 V | SMD ceramic cap |
| 1 | C90 | 100 nF 1206 50 V | SMD ceramic cap |
| 1 | C91 | 4700 µF 6.3 V | Electrolytic cap |
| 1 | C92 | 10 µF 50 V | Electrolytic cap |
| 1 | C93 | 2.2 nF 0805 50 V | SMD ceramic cap |
| 1 | C94 | 1000 nF 0805 50 V | SMD ceramic cap |
| 1 | C95 | 470 nF 1206 50 V | SMD ceramic cap |
| 1 | C96 | 33 µF 35 V | Electrolytic cap |
| 1 | C97 | 100 nF 0805 50 V | SMD ceramic cap |
| 1 | C98 | 33 µF 50 V | Electrolytic cap |
| 2 | C101, C108 | 470 µF 16 V | Electrolytic cap |
| 1 | C106, C107 | 1 µF 100V | Electrolytic cap |
| 1 | C100 | 100 pF 0805 25 V | SMD ceramic cap |
| 1 | C102 | 2200 µF 16 V | Electrolytic cap |
| 1 | C103 | 10 µF 100 V | Electrolytic cap |
| 1 | D50 | STTH802CFP | STMicroelectronics high-efficiency, ultrafast diode |
| 1 | D52 | STTH302 | STMicroelectronics high-efficiency, ultrafast diode |
| 1 | D53 | STTH1L06 | STMicroelectronics ultrafast, high-voltage rectifier |
| 1 | D54 | STPS1545CFP | STMicroelectronics power Schottky rectifier |
| 1 | D55 | STPS745FP | STMicroelectronics power Schottky rectifier |
| 1 | D56 | BYT01-400 | STMicroelectronics high-efficiency, ultrafast diode |
| 2 | D57,D62 | BAV103 | General-purpose rectifier |
| 4 | D58,D59,D60,D61 | 1N4007 | Rectifier |
| 1 | D63 | STTH102 | STMicroelectronics ultrafast diode |

**Table 3. Bill of material (continued)**

| Qty | Reference | Value & part | Description |
|---|---|---|---|
| 1 | D64 | 27Vz DO35 1 W | Zener diode |
| 1 | D65 | 33Vz D035 1 W | Zener diode |
| 2 | D66,D67 | 12Vz D034 | 0.5W Zener diode |
| 2 | D70,D72 | 1N4148 | General-purpose rectifier |
| 1 | F4 | FUSE 2 A | Radial fuse |
| 1 | J4 | CON2 7.62 mm pitch | Two-pin Input connector |
| 1 | J5 | Full_Con 2.54 mm pitch | 13-pin output connector |
| 1 | J8 | HDD_Con RS code:471-430 | Hard disk connector |
| 1 | J9 | CON4 2.54 mm pitch | 4-pin VFD connector |
| 4 | L28,L29,L31,L32 | 22 µH 5 A | Radial power inductor |
| 1 | L30 | 2*45 mH-HF2430-453 | TDK common-mode choke coils |
| 2 | L33,L34 | 22 µH 1 A | Radial inductor |
| 1 | Q4 | STP5NK60ZFP | STMicroelectronics N-Channel Power MOSFET |
| 4 | Q5,Q6,Q10,Q11 | BC848B | NPN general-purpose bipolar |
| 1 | Q7 | BC858B | PNP general-purpose bipolar |
| 1 | Q8 | BD140 | STMicroelectronics PNP Transistor |
| 1 | Q9 | BD139 | STMicroelectronics NPN Transistor |
| 3 | R62, | 100 kΩ 0805 | SMD resistor |
|  | R75,R94 | 10 kΩ 0805 | SMD resistor |
| 1 | R63 | 2 kΩ 0805 | SMD resistor |
| 1 | R64 | NTC_16 Ω 2.9 A | Inrush current suppressor |
| 1 | R65 | 1 kΩ 0805 | SMD resistor |
| 1 | R66 | 47 kΩ 0805 | SMD resistor |
| 1 | R67 | 33 kΩ 0805 | SMD resistor |
| 2 | R68,R83,R84 | 33 kΩ 2 W | Axial resistor |
| 1 | R69 | 6.2 kΩ 1206 | SMD resistor |
| 1 | R70 | 3.9 kΩ 0805 | SMD resistor |
| 3 | R71,R80,R81 | 1.5 Ω 1206 | SMD resistor |
| 1 | R72 | 470 Ω 0805 | SMD resistor |
| 1 | R73 | 2.2 kΩ 1206 | SMD resistor |
| 1 | R74 | 24 kΩ 1206 | SMD resistor |
| 1 | R76 | 3.3 kΩ 1206 | SMD resistor |
| 1 | R77 | 68 Ω 1206 | SMD resistor |
| 1 | R78 | 4.3 kΩ 0805 | SMD resistor |
| 1 | R79 not mounted | 1 MΩ ¼ W | Axial resistor |

**Table 3. Bill of material (continued)**

| Qty | Reference | Value & part | Description |
|---|---|---|---|
| 1 | R82 | 150 Ω 1206 | SMD resistor |
| 2 | R89,R92 | 220 kΩ 0805 | SMD resistor |
| 1 | R90 | 100 kΩ 0805 | SMD resistor |
| 4 | R93,R95,R97,R98 | 22 kΩ 0805 | SMD resistor |
| 1 | R99 | 10 kΩ 0805 | SMD resistor |
| 1 | R100 | 470 Ω ¼ W | Axial resistor |
| 1 | R109 | 22 Ω ¼ W | Axial resistor |
| 1 | R110 not mounted | 10 kΩ 0805 | SMD resistor |
| 1 | R111 | 8.2 kΩ ¼ W | Axial resistor |
| 2 | R112,R113 | 6.8 Ω 2 W | Axial resistor |
| 1 | R114 | 1.8 kΩ 0805 | SMD resistor |
| 1 | R115 | 1 kΩ 0805 | SMD resistor |
| 1 | T4 | 2522.5006C | Pulseeng SMT |
| 1 | U5 | LD1084V12 | STMicroelectronics 5 A low-drop, positive voltage regulator |
| 1 | U13 | L6668 | STMicroelectronics smart primary controller |
| 1 | U15 | TL431 | STMicroelectronics voltage reference |
| 1 | U16 | PC817 | OptoCoupler |

*Note: Q4 needs 15 °C/W heatsink;*
*D50, D54, D55 needs 20 °C/W heatsink;*
*U5 needs 12 °C/W heatsink;*

# 3 Test description

The set of tests performed on the board aim to evaluate the performance of the power supply for different load conditions, in terms of regulation, power consumption, efficiency and safe operating area of the Power MOSFET,

Moreover, in order to evaluate the behavior of the SMPS in terms of stability, the performance under dynamic load condition have been measured and several tests have been performed at startup with three different input voltage values and full load conditions.

Finally the conducted emission measurements and the thermal performances of the main critical components have been evaluated.

## 3.1 Cross regulation and main waveforms

In *Table 4*, *5*, and *6* the output voltage cross regulation is given 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 by means of a digital multimeter. The length of the connection cable is 100 mm. Moreover the primary Power MOSFET STP5NK60Z main waveforms are shown.

- Full load - Satellite2 DVB

**Table 4. Output voltages measurement at $V_{in}$= 184 V and full load**

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| $V_{out}$ [V] | 3.42 | 5.1 | 11.94 | 16.8 | 22.94 | 32.28 | -26.9 | $V_{in}$ [$V_{rms}$] | 184 |
| $\Delta V_{out}$% | + 3.6 | + 2 | -0.5 | + 5 | - 0.26 | -2.2 | + 7.6 | | |
| $I_{out}$ [A] | 3.5 | 1.9 | 0.8 | 0.5 | 0.5 | 0.01 | 0.15 | $I_{in}$[$A_{rms}$] | 0.742 |
| $P_{out}$ [W] | 11.97 | 9.69 | 9.55 | 8.41 | 11.49 | 0.32 | 4.03 | $P_{in}$ [W] | 76.3 |
| $P_{outTOT}$ [W] | 55.46 | | | | | | | η(%) | 73 |
| $f_s$ [kHz] | 67.8 | | | | | | | | |

*Note: All voltages are within tolerance.*

**Table 5. Output voltages measurement at $V_{in}$= 230 V and full load**

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| $V_{out}$ [V] | 3.44 | 5.08 | 11.9 | 16.71 | 22.8 | 31.98 | -26.67 | $V_{in}$ [$V_{rms}$] | 230 |
| $\Delta V_{out}$% | 4.2 | +1.6 | -0.8 | +4.4 | -0.8 | -2.2 | +6.68 | | |
| $I_{out}$ [A] | 3.5 | 1.9 | 0.8 | 0.5 | 0.5 | 0.01 | 0.15 | $I_{in}$[$A_{rms}$] | 0.623 |
| $P_{out}$ [W] | 12.04 | 9.65 | 9.52 | 8.37 | 11.44 | 0.32 | 4 | $P_{in}$ [W] | 75.2 |
| $P_{outTOT}$ [W] | 55.34 | | | | | | | η(%) | 73.6 |
| $f_s$ [kHz] | 67.1 | | | | | | | | |

*Note: All voltages are within tolerance.*

**Table 6. Output voltages measurement at $V_{in}$= 276 V and full load**

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| $V_{out}$ [V] | 3.42 | 5.09 | 11.91 | 16.69 | 22.8 | 32.21 | -26.72 | $V_{in}$ [$V_{rms}$] | 276 |
| $\Delta V_{out}$% | 3.6 | +1.8 | -0.75 | +4.3 | -0.8 | -2.4 | +6.88 | | |
| $I_{out}$ [A] | 3.5 | 1.9 | 0.8 | 0.5 | 0.5 | 0.01 | 0.15 | $I_{in}$[$A_{rms}$] | 0.548 |
| $P_{out}$ [W] | 11.97 | 9.67 | 9.53 | 8.36 | 11.41 | 0.32 | 4 | $P_{in}$ [W] | 74.9 |
| $P_{outTOT}$ [W] | 52.5 | | | | | | | η(%) | 73.8 |
| $f_s$ [kHz] | 66.4 | | | | | | | | |

*Note: All voltages are within tolerance.*

**Figure 4. $V_{ds}$ and $I_d$ of STP5NK60Z in full load at $V_{in}$ = 184 $V_{rms}$ - 50 Hz**

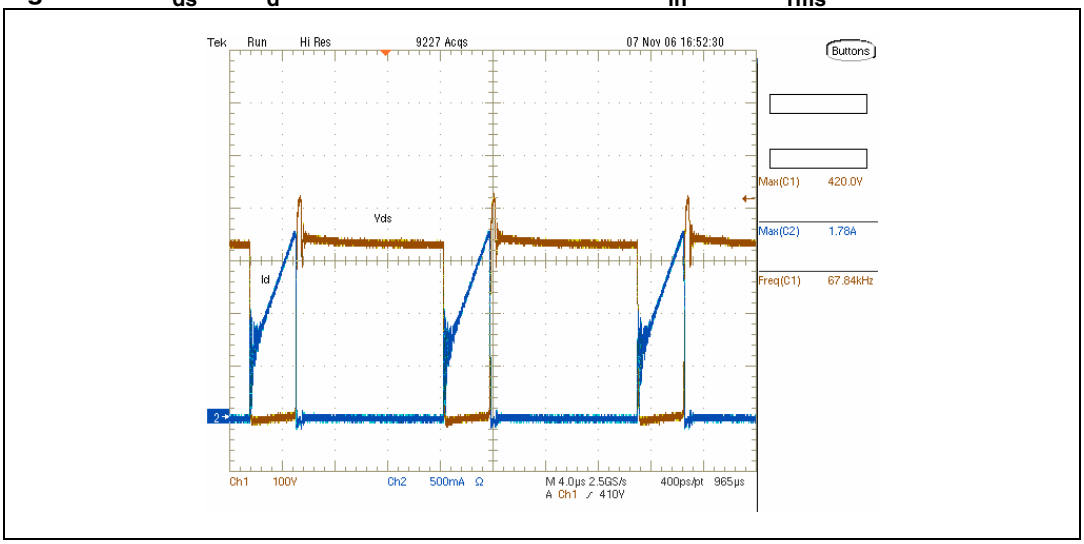



**Figure 5. $V_{ds}$ and $I_d$ of STP5NK60Z in full load at $V_{in}$ = 230 $V_{rms}$ - 50 Hz**

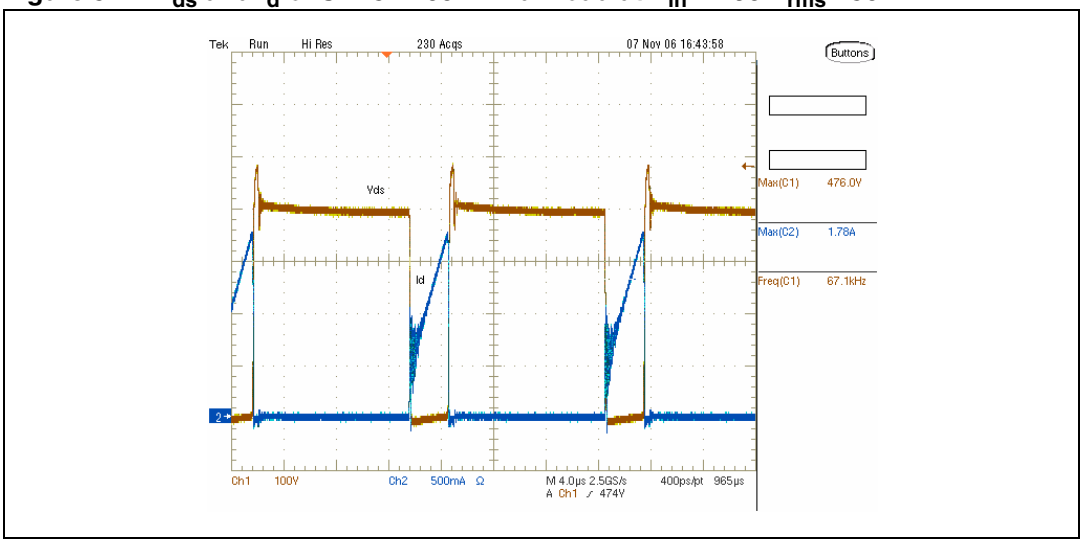
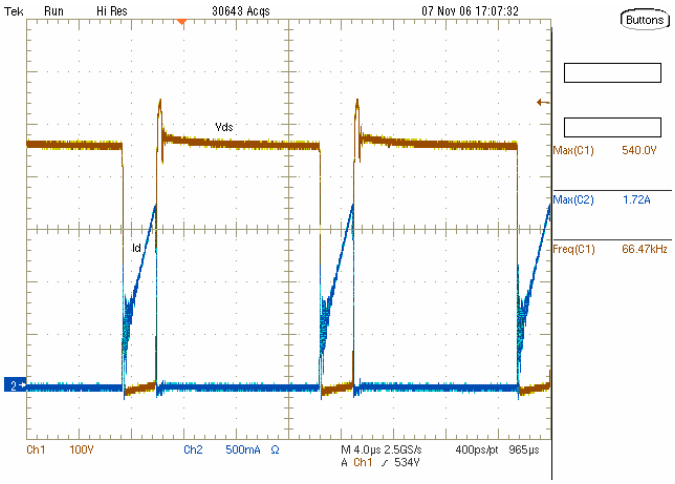


**Figure 6. $V_{ds}$ and $I_d$ of STP5NK60Z in full load at $V_{in}$ = 276 $V_{rms}$ - 50 Hz**




*Note: CH1: drain voltage (brown)*

*CH2: drain current (blue)*

- $V_{in}$ ($V_{ac}$): 184 - 230 - 276
- $V_{dsMax}$ (V): 420 - 476 - 540
- $I_{dpk}$ (A): 1.78 - 1.78 - 1.72

The measured values are the drain peak voltage and current at minimum, nominal and maximum input mains voltage, during normal operation at full load. The voltage peak, which is 540 V, assures a reliable operation of the STP5NK60ZFP with a good margin against the maximum $BV_{DSS}$.

- Reduced load - terrestrial DVB (without LNB)

**Table 7. Output voltages measurement at $V_{in}$= 184 V and reduced load**

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **$V_{out}$ [V]** | 3.38 | 5.11 | 11.92 | 17.19 | 24.26 | 32.2 | -26.83 | **$V_{in}$ [$V_{rms}$]** | 184 |
| **$\Delta V_{out}$%** | +2.42 | +2.2 | -0.6 | +7.4 | +5.4 | -2.4 | +7.32 | | |
| **$I_{out}$ [A]** | 3.5 | 1.9 | 0.8 | - | 0.003(1) | 0.01 | 0.15 | **$I_{in}$[$A_{rms}$]** | 0.531 |
| **$P_{out}$ [W]** | 11.83 | 9.7 | 9.54 | - | 0.072 | 0.32 | 4 | **$P_{in}$ [W]** | 52.6 |
| **$P_{outTOT}$ [W]** | 35.5 | | | | | | | **η(%)** | 67.5 |
| **$f_s$ [kHz]** | 63.5 | | | | | | | | |

1. With a 8.2 kΩ 1/4 W dummy load

*Note: All voltages are within tolerance.*

**Table 8. Output voltages measurement at $V_{in}$= 230 V and reduced load**

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| $V_{out}$ [V] | 3.39 | 5.09 | 11.92 | 17.15 | 24.21 | 32.2 | -26.7 | $V_{in}$ [$V_{rms}$] | 230 |
| $\Delta V_{out}$% | +2.72 | +1.8 | -0.6 | +7.18 | +5.26 | -2.4 | +6.8 | | |
| $I_{out}$ [A] | 3.5 | 1.9 | 0.8 | - | 0.003 (1) | 0.01 | 0.15 | $I_{in}$[$A_{rms}$] | 0.448 |
| $P_{out}$ [W] | 11.86 | 9.67 | 9.54 | - | 0.072 | 0.32 | 4 | $P_{in}$ [W] | 52.3 |
| $P_{outTOT}$ [W] | 35.47 | | | | | | | η(%) | 67.8 |
| $f_s$ [kHz] | 62.2 | | | | | | | | |

1. With a 8.2 kΩ 1/4 W dummy load

*Note: All voltages are within tolerance.*

**Table 9. Output voltages measurement at $V_{in}$= 276 V and reduced load**

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| $V_{out}$ [V] | 3.37 | 5.1 | 11.92 | 17.16 | 24.2 | 32.24 | -26.82 | $V_{in}$ [$V_{rms}$] | 276 |
| $\Delta V_{out}$% | +2.12 | +2 | -0.6 | +7.2 | +5.2 | -2.3 | +7.28 | | |
| $I_{out}$ [A] | 3.5 | 1.9 | 0.8 | - | 0.003 (1) | 0.01 | 0.15 | $I_{in}$[$A_{rms}$] | 0.396 |
| $P_{out}$ [W] | 11.79 | 9.69 | 9.54 | - | 0.072 | 0.32 | 4.1 | $P_{in}$ [W] | 52.3 |
| $P_{outTOT}$ [W] | 35.5 | | | | | | | η(%) | 67.9 |
| $f_s$ [kHz] | 61 | | | | | | | | |

1. With a 8.2 kΩ 1/4 W dummy load

*Note: All voltages are within tolerance*

*Table 7*, *8* and *9* show the output voltage measured applying the same loads that we could have if a different DVB type is powered (e.g. a terrestrial or cable) without the LNB. As under the load condition described before, all the output voltages are within the tolerances. To keep the 23 V LNB output within the tolerance, a negligible dummy load has to be connected on this output.

**Figure 7. $V_{ds}$ and $I_d$ of STP5NK60Z at reduced load $V_{in}$ = 184 $V_{rms}$ - 50 Hz**

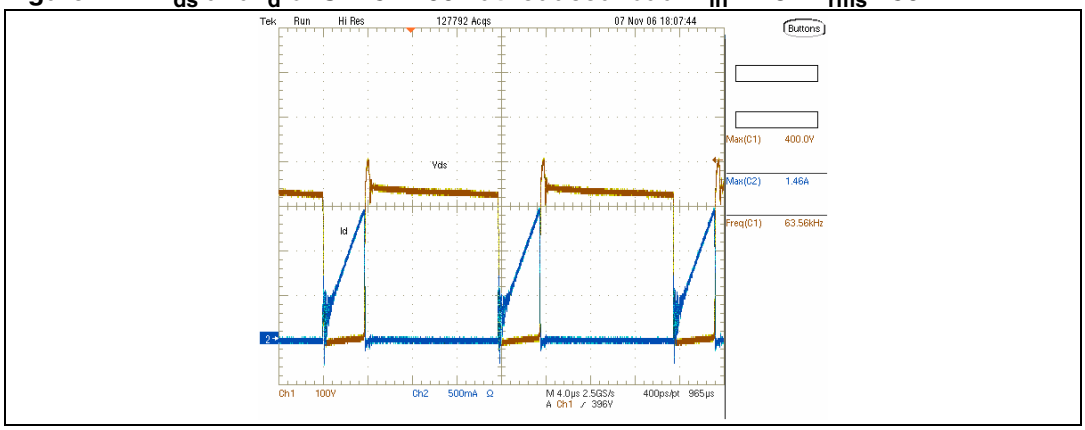


**Figure 8. $V_{ds}$ and $I_d$ of STP5NK60Z at reduced load $V_{in}$ = 230 $V_{rms}$ - 50 Hz**

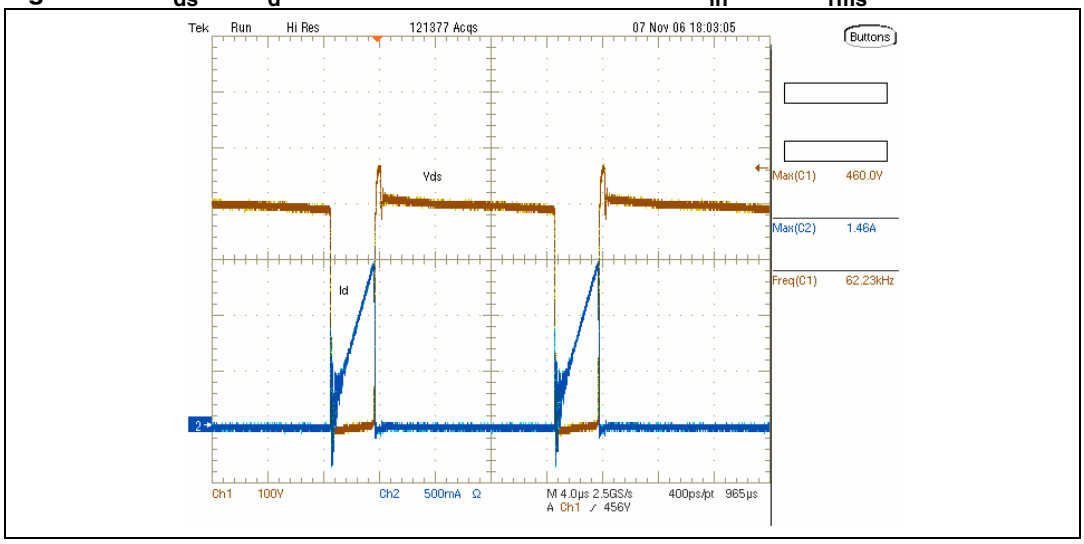
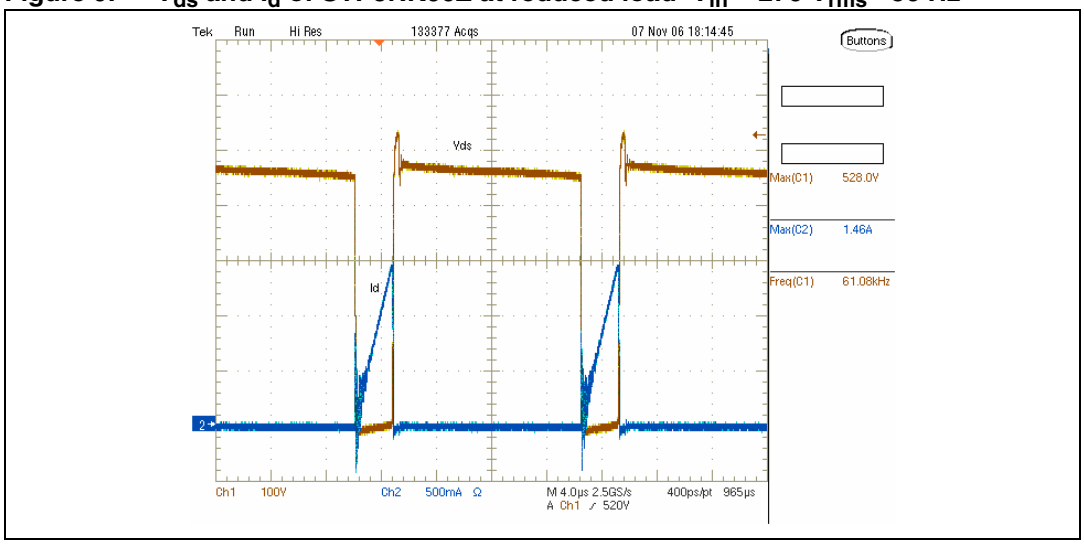



**Figure 9. $V_{ds}$ and $I_d$ of STP5NK60Z at reduced load $V_{in}$ = 276 $V_{rms}$ - 50 Hz**




*Note: CH1: drain voltage (brown)*

*CH2: drain current (blue)*

- $V_{in}$ ($V_{ac}$): 184 - 230 - 276
- $V_{dsMax}$ (V): 400 - 460 - 528
- $I_{dpk}$ (A): 1.46 - 1.46 - 1.46

The measured values are the drain peak voltage and current at minimum, nominal and maximum input mains voltage, during normal operation at full load. The voltage peak, which is 528 V, assures a reliable operation of the STP5NK60Z with a good margin against the maximum $BV_{DSS}$.

- Reduced load - total power = 20 W

**Table 10. Output voltages measurement at $V_{in}$= 184 V and reduced load (20 W)**

| $V_{out}$ [V] | 3.5 | 5 | 12 | 16.56 | 23.01 | 32.15 | -26.2 | $V_{in}$ [$V_{rms}$] | 184 |
|---|---|---|---|---|---|---|---|---|---|
| $\Delta V_{out}$% | +6 | +0 | +0 | +3.5 | +0 | -2.5 | +4.8 | | |
| $I_{out}$ [A] | 1.75 | 1 | 0.4 | - | 0.003(1) | 0.01 | 0.15 | $I_{in}$[$A_{rms}$] | 0.301 |
| $P_{out}$ [W] | 6.125 | 5 | 4.8 | - | 0.07 | 0.32 | 3.93 | $P_{in}$ [W] | 28.3 |
| $P_{outTOT}$ [W] | 20.2 | | | | | | | η(%) | 71.4 |
| $f_s$ [kHz] | 53.8 | | | | | | | | |

1. With a 8.2 kΩ 1/4 W dummy load

**Table 11. Output voltages measurement at $V_{in}$= 230 V and reduced load (20 W)**

| $V_{out}$ [V] | 3.5 | 5 | 11.98 | 16.57 | 23.03 | 32.1 | -26.2 | $V_{in}$ [$V_{rms}$] | 230 |
|---|---|---|---|---|---|---|---|---|---|
| $\Delta V_{out}$% | +6 | +0 | -0.16 | +3.6 | +0.1 | -2.72 | +4.8 | | |
| $I_{out}$ [A] | 1.75 | 1 | 0.4 | - | 0.003(1) | 0.01 | 0.15 | $I_{in}$[$A_{rms}$] | 0.256 |
| $P_{out}$ [W] | 6.125 | 5 | 4.79 | - | 0.07 | 0.32 | 3.93 | $P_{in}$ [W] | 28.35 |
| $P_{outTOT}$ [W] | 20.2 | | | | | | | η(%) | 71.4 |
| $f_s$ [kHz] | 52 | | | | | | | | |

1. With a 8.2 kΩ 1/4 W dummy load

**Table 12. Output voltages measurement at $V_{in}$= 276 V and reduced load (20 W)**

| $V_{out}$ [V] | 3.5 | 5.04 | 11.98 | 16.59 | 23.04 | 32.17 | -26.2 | $V_{in}$ [$V_{rms}$] | 276 |
|---|---|---|---|---|---|---|---|---|---|
| $\Delta V_{out}$% | +6 | +0.8 | -0.16 | +3.7 | +0.1 | -2.5 | +4.8 | | |
| $I_{out}$ [A] | 1.75 | 1 | 0.4 | - | 0.003(1) | 0.01 | 0.15 | $I_{in}$[$A_{rms}$] | 0.225 |
| $P_{out}$ [W] | 6.125 | 5.04 | 4.79 | - | 0.07 | 0.32 | 3.93 | $P_{in}$ [W] | 28.3 |
| $P_{outTOT}$ [W] | 20.2 | | | | | | | η(%) | 71.4 |
| $f_s$ [kHz] | 50 | | | | | | | | |

1. With a 8.2 kΩ 1/4 W dummy load

Even still reducing the load down to 20 W, thanks to the coupling of the transformer, all the output voltages are well regulated. The tables above show that the switching frequency is decreased according to the power consumption.

**Figure 10. $V_{ds}$ and $I_d$ of STP5NK60Z at reduced load (20 W) $V_{in}$ = 184 $V_{rms}$ - 50 Hz**

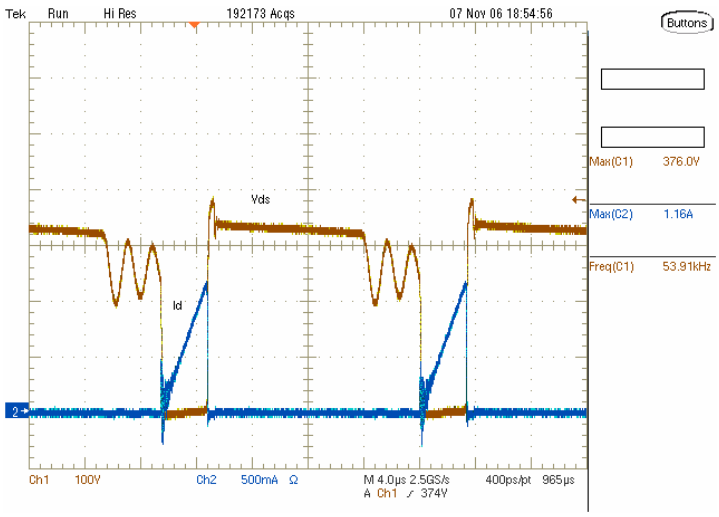



**Figure 11. $V_{ds}$ and $I_d$ of STP5NK60Z at reduced load (20 W) $V_{in}$ = 230 $V_{rms}$ - 50 Hz**

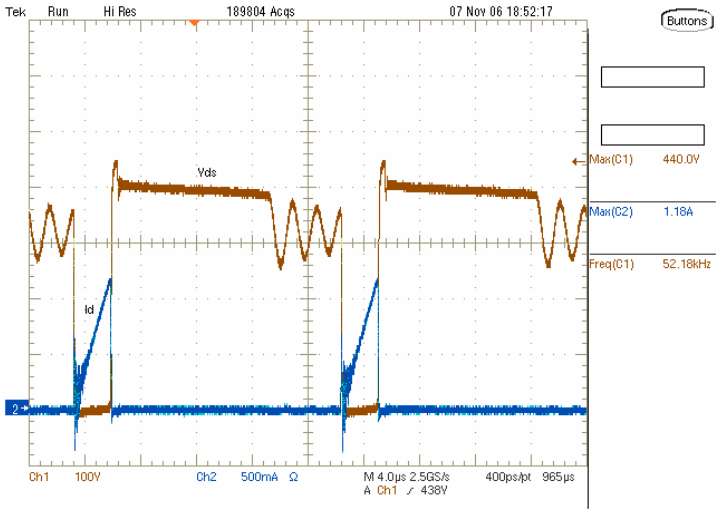
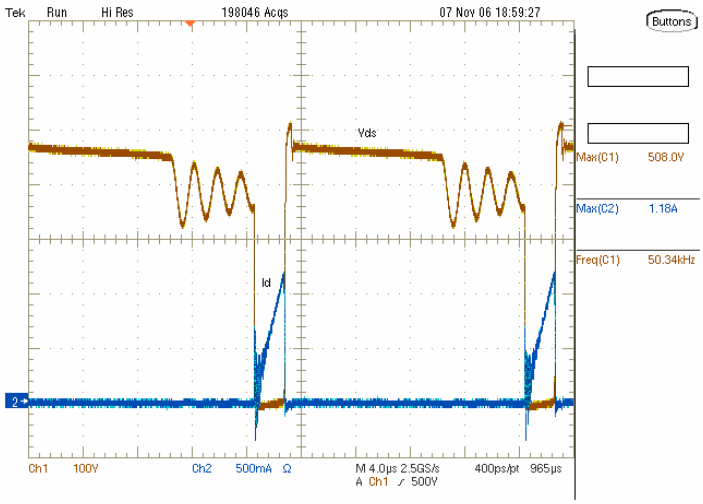


**Figure 12. $V_{ds}$ and $I_d$ of STP5NK60Z at reduced load (20 W) $V_{in}$ = 276 $V_{rms}$ - 50 Hz**




*Note: CH1: drain voltage (brown)*

*CH2: drain current (blue)*

- $V_{in}$ ($V_{ac}$): 184 - 230 - 276
- $V_{dsMax}$ (V): 376 - 440 - 508
- $I_{dpk}$ (A): 1.16 - 1.18 - 1.18

The measured values are the drain peak voltage and current at minimum, nominal and maximum input mains voltage, during normal operation at full load. The voltage peak, which is 508 V, assures a reliable operation of the STP5NK60Z with a good margin against the maximum $BV_{DSS}$.

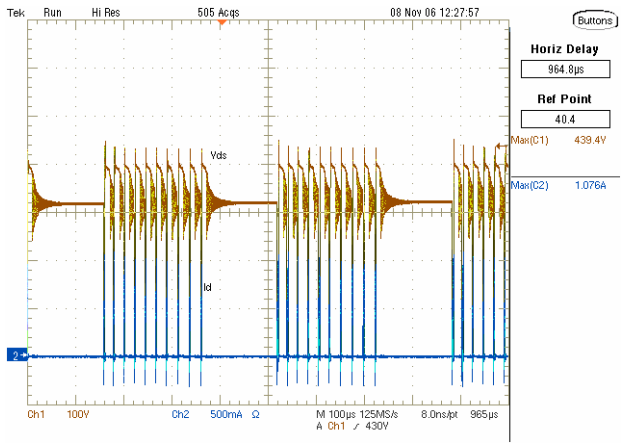
- Light load

**Table 13. Output voltages measurement at $V_{in}$= 230 V and light load**

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **$V_{out}$ [V]** | 3.58 | 5.25 | 12 | 16.52 | 22.65 | 32 | -25.74 | **$V_{in}$ [$V_{rms}$]** | 230 |
| **$I_{out}$ [A]** | 0.8 | 0.08 | 0.08 | - | 0.003(1) | 0.01 | 0.15 | **$I_{in}$[$A_{rms}$]** | 0.114 |
| **$P_{out}$ [W]** | 2.86 | 0.42 | 0.96 | - | 0.07 | 0.32 | 3.93 | **$P_{in}$ [W]** | 11.3 |
| **$P_{outTOT}$ [W]** | 8.56 | | | | | | | **η(%)** | 75.7 |
| **$f_s$ [kHz]** | Burst mode | | | | | | | | |

1. with a 8.2 kΩ 1/4 W dummy load

**Figure 13. $V_{ds}$ and $I_d$ of STP5NK60Z at light load at 230 V**




Also in this load condition the circuit is still able to maintain all voltages under control, Hence a perfect functionality of the circuit is achieved also in this abnormal condition. During light load operation the circuit works in burst mode and, thanks to the controller functionality, the switching frequency inside the burst pulses is kept low. This allows low power consumption of the power supply under light load.

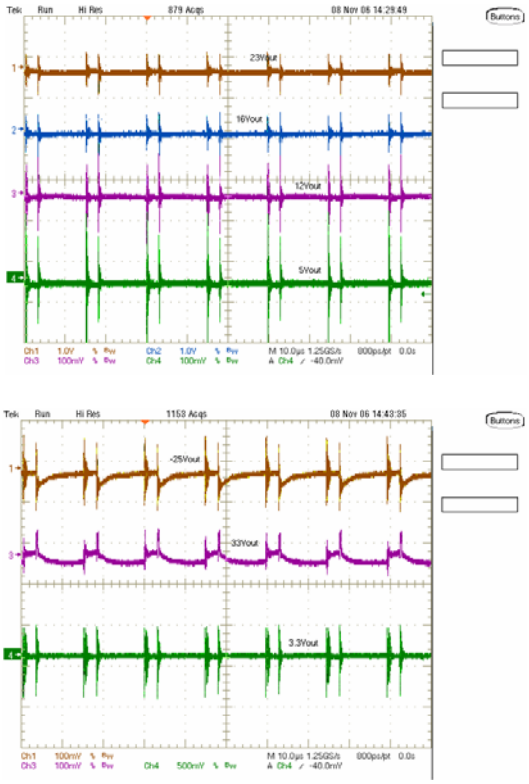
## 3.2 High frequency ripple of output voltages at full load

The output voltage ripple at switching frequency has been measured, as listed in *Table 14*. In *Figure 14* the waveforms of the voltage ripple are shown.

**Table 14. Measurement of high frequency ripple of output voltages at $V_{in}$= 230 V and full load**

| $V_{out}$ [V] | 3.3 | 5 | 12 | 16 | 23 | 33 | -25 |
|---|---|---|---|---|---|---|---|
| $\Delta V_{outHF}$ [mV] | 11 | 6 | 4.8 | 46 | 36 | 29 | 43 |

**Figure 14. High frequency ripple of output voltages at full load at 230 V**



CH1: +23 $V_{out}$ (brown)
CH2: +16 $V_{out}$ (blue)
CH3: +12 $V_{out}$ (purple)
CH4: +5 $V_{out}$ (green)



CH1: -25 $V_{out}$ (brown)
CH3: +33 $V_{out}$ (purple)
CH4: +3.3 $V_{out}$ (green)

## 3.3 Measurement of RMS current of output capacitors

*Table 15* shows the RMS current values flowing into the output capacitors at 230$V_{ac}$, full load. All the RMS currents are within the rating of the capacitor type indicated. This avoids any component overstress that could affect the reliability and the expected lifetime of the SMPS.

**Table 15. Measurement of RMS current of output capacitors at $V_{in}$= 230 V and full load**

| $I_{CapC77}$ (16$V_{out}$) | $I_{CapC91}$ (3.3$V_{out}$) | $I_{CapC81}$ (23$V_{out}$) | $I_{CapC102}$ (5$V_{out}$) |
|---|---|---|---|
| 0.850 | 1.9 | 0.550 | 1 |

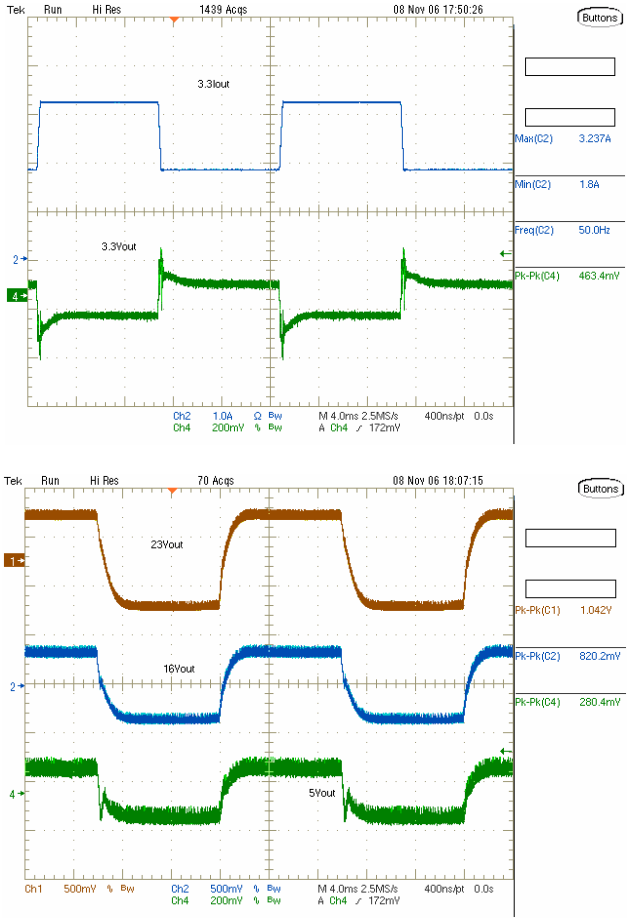
## 3.4 Dynamic load test

The dynamic load tests have been performed by varying the load on 3.3 V and 5 V outputs, keeping the other outputs at full load. Varying the load on 3.3 V output, the following results have been obtained:

**Table 16. Dynamic load test on 3.3 $V_{out}$**

| Outputs | Load condition |
|---|---|
| +5 V, +12 V, +16 V, +23 V, +33 V, -25 V | Full load |
| +3.3 V | Load 50% ÷ 90% |

**Figure 15. Outputs behavior under dynamic load on 3.3 V output at $V_{in}$ =230 V**




CH2: +3V3 $I_{out}$ (blue)
CH4: +3V3 $V_{out}$ (green)

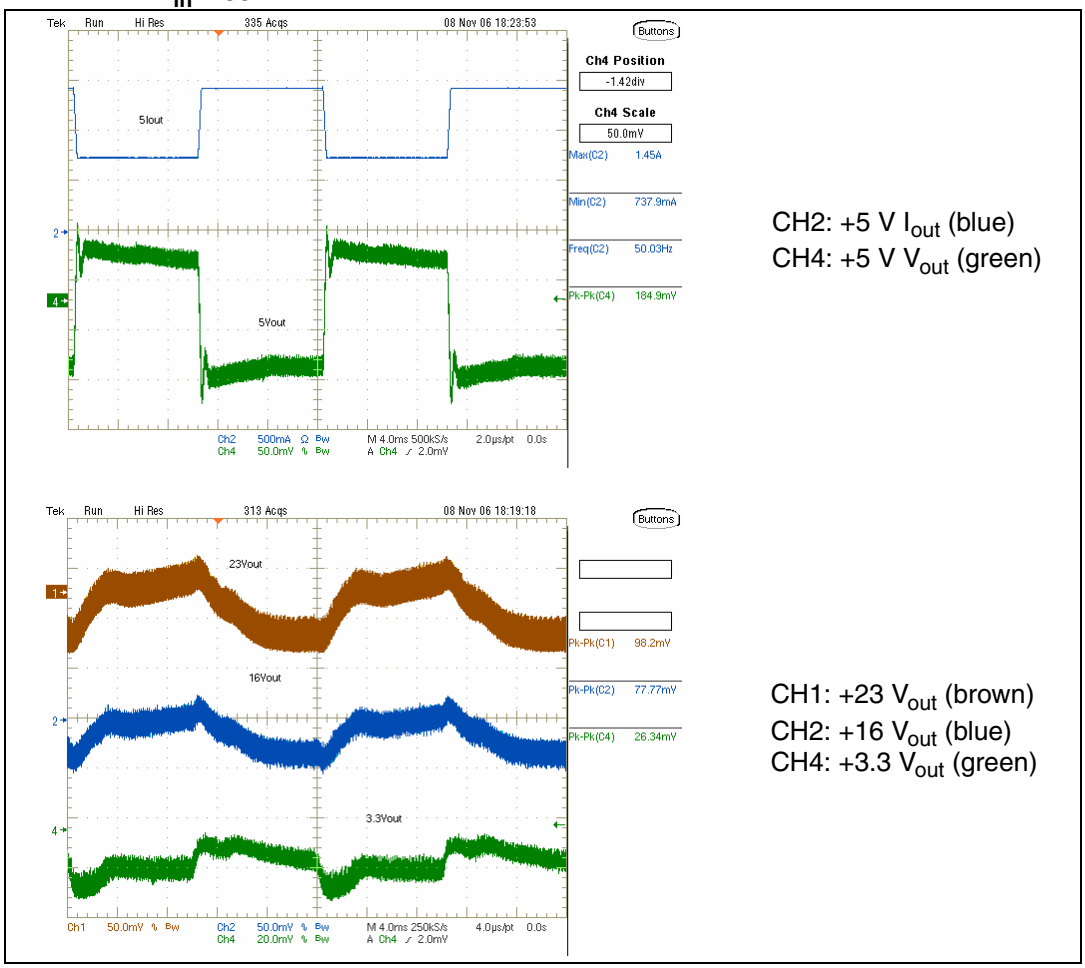
CH1: +23 $V_{out}$ (brown)
CH2: +16 $V_{out}$ (blue)
CH4: +5 $V_{out}$ (green)

Varying the load on 5 V output, the following results have been obtained:

**Table 17. Dynamic load test on 5 $V_{out}$**

| Outputs | Load condition |
|---|---|
| +3.3 V, +12 V, +16 V, +23 V, +33 V, -25 V | Full load |
| +5 V | Load 50% ÷ 90% |

**Figure 16. Behavior of outputs with dynamic load applied to 5 V output at $V_{in}$=230 V**




The worst case condition happens when the 3.3 V output load is increased from 50% to 90% of full load value.

## 3.5 Startup behavior

*Figure 17*, *18*, *19* show the rise slopes at full load of the output voltage at nominal, minimum and maximum input voltage. As shown in the graphs, the rise times are almost constant.

**Figure 17. Startup behavior of the system at $V_{in}$ = 184 $V_{rms}$ - 50 Hz**

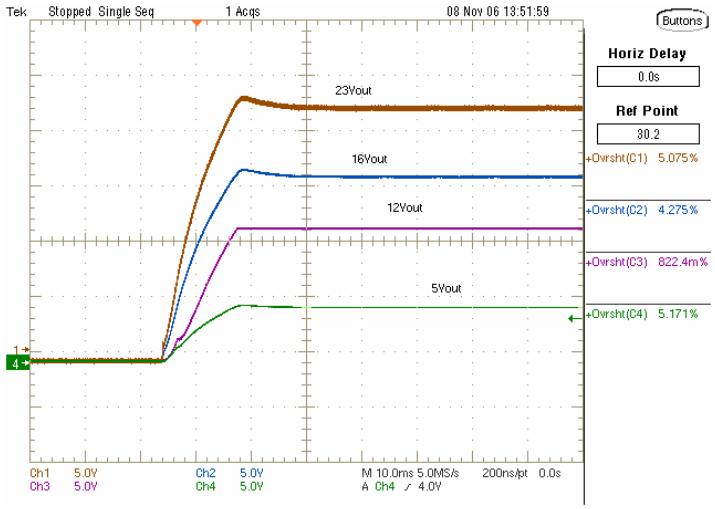



**Figure 18. Startup behavior of the system at $V_{in}$ = 230 $V_{rms}$ - 50 Hz**

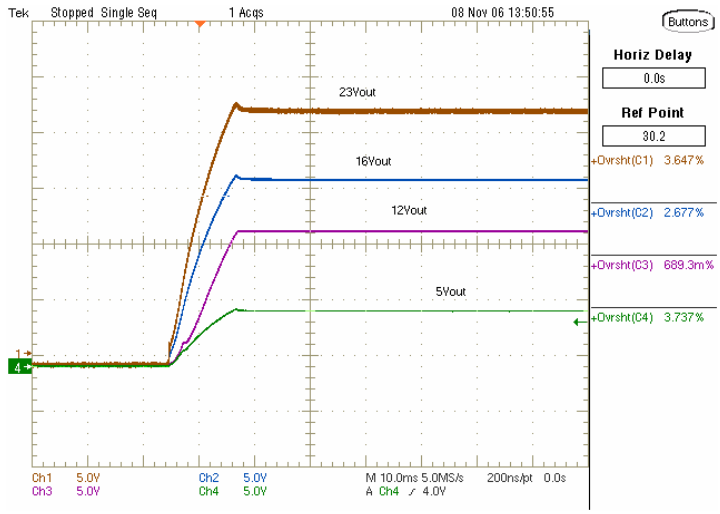
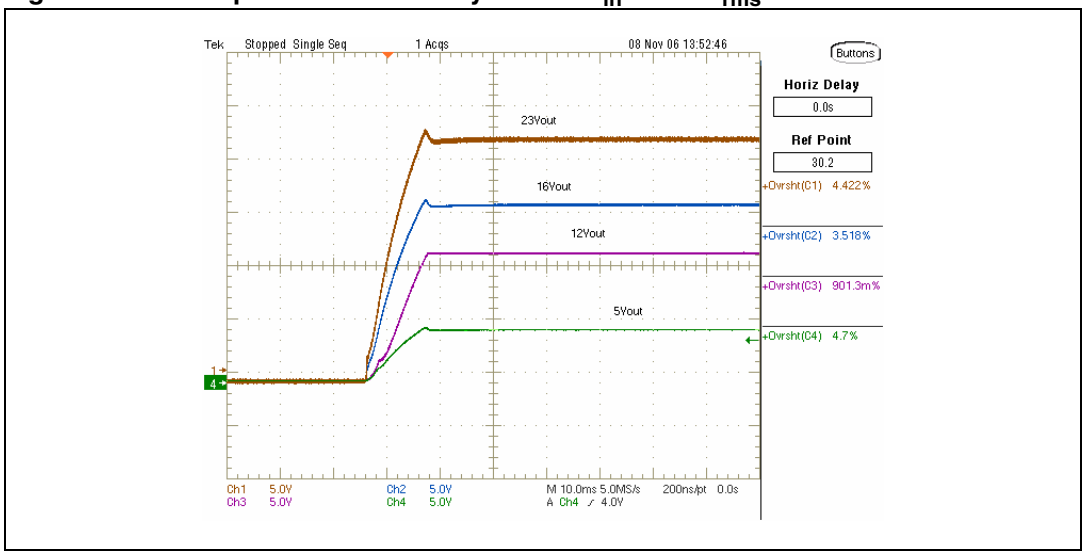


**Figure 19. Startup behavior of the system at $V_{in}$ = 276 $V_{rms}$ - 50 Hz**




*Note:* *CH1: +23 $V_{out}$ (brown)*

*CH2: +16 $V_{out}$ (blue)*

*CH3: +12 $V_{out}$ (purple)*

*CH4: +5 $V_{out}$ (green)*

**Table 18. Overshoot**

| $V_{in}(V_{ac})$ | 23 $V_{out}$ (%) | 16 $V_{out}$ (%) | 12 $V_{out}$ (%) | 5 $V_{out}$ (%) |
|---|---|---|---|---|
| 184 | 5 | 4.2 | 0.8 | 5.1 |
| 230 | 3.6 | 2.6 | 0.6 | 3.7 |
| 276 | 4.2 | 3.5 | 0.9 | 4.7 |

*Table 18* lists the overshoot for the most significant outputs at startup, giving the performances of the power supply in terms of stability. All voltages are well controlled.

## 3.6 Wakeup time

*Figure 20*, *21*, *22* show the waveforms at startup with the wakeup time measurement at the minimum, nominal at maximum input mains. Obviously, due to the circuitry characteristics, the wakeup time is constant and independent from the input voltage. The measured value is about 0.9 s, according to the IC startup high voltage current generator.

**Figure 20. Wakeup behavior of the system at $V_{in}$ = 184 $V_{rms}$ - 50 Hz**

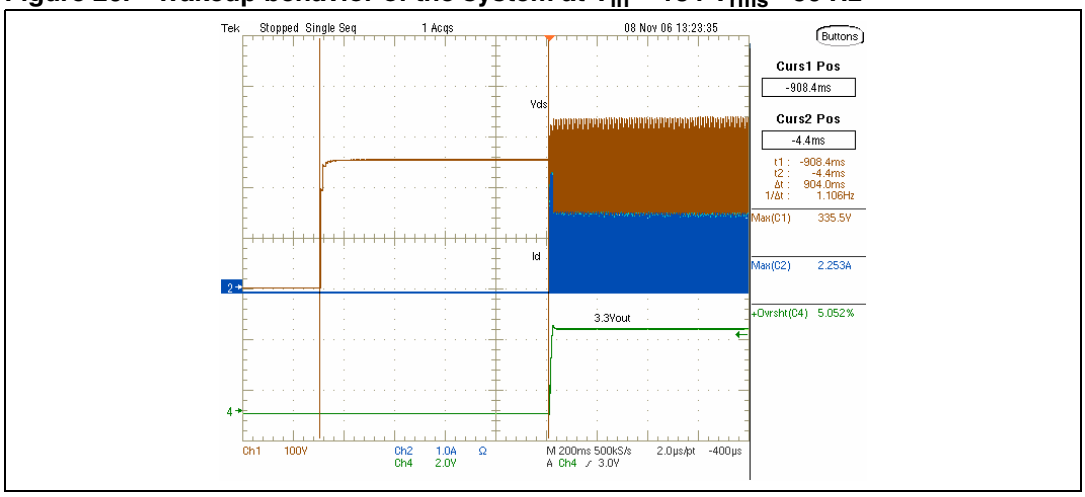



**Figure 21. Wakeup behavior of the system at $V_{in}$ = 230 $V_{rms}$ - 50 Hz**

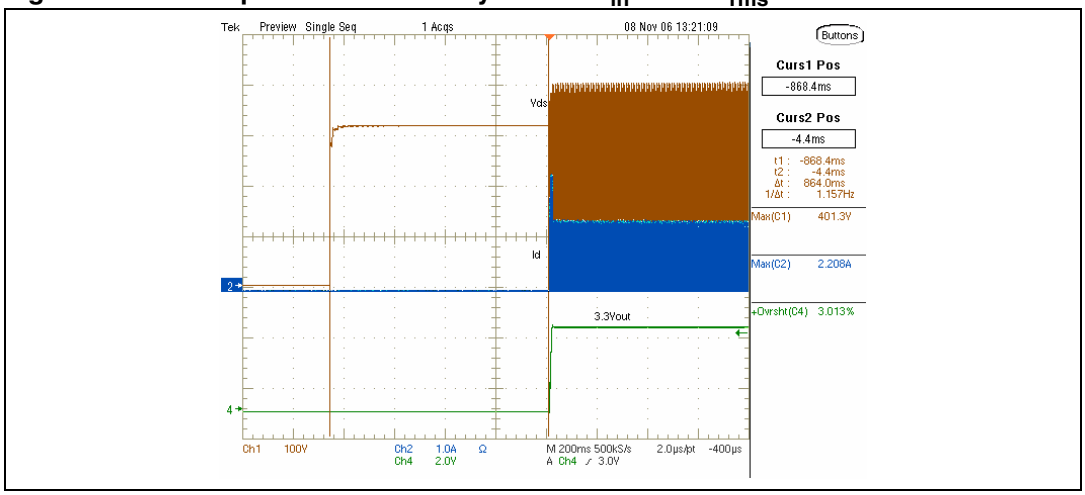
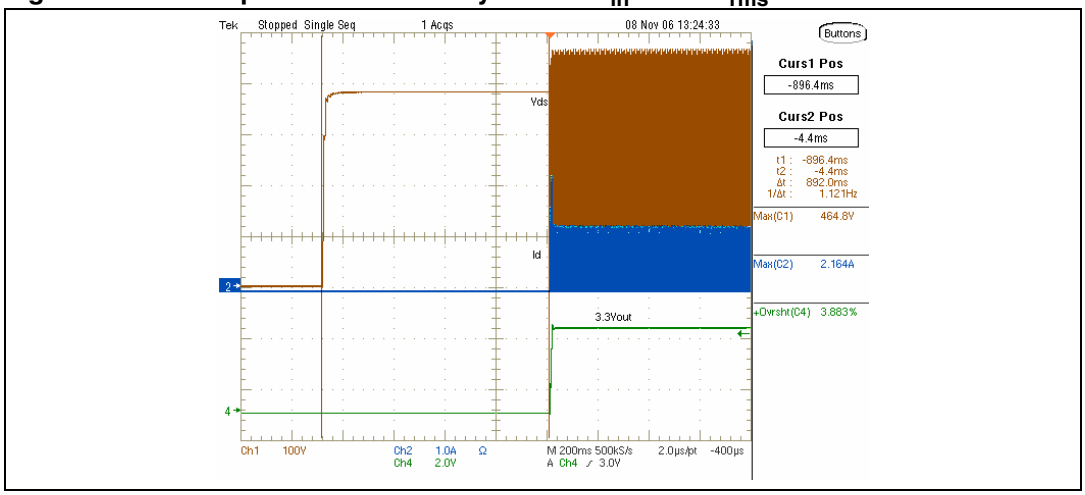


**Figure 22. Wakeup behavior of the system at $V_{in}$ = 276 $V_{rms}$ - 50 Hz**




*Note:* *CH1: drain voltage (brown)*

*CH2: drain current (blue)*

*CH4: +3.3 $V_{out}$*

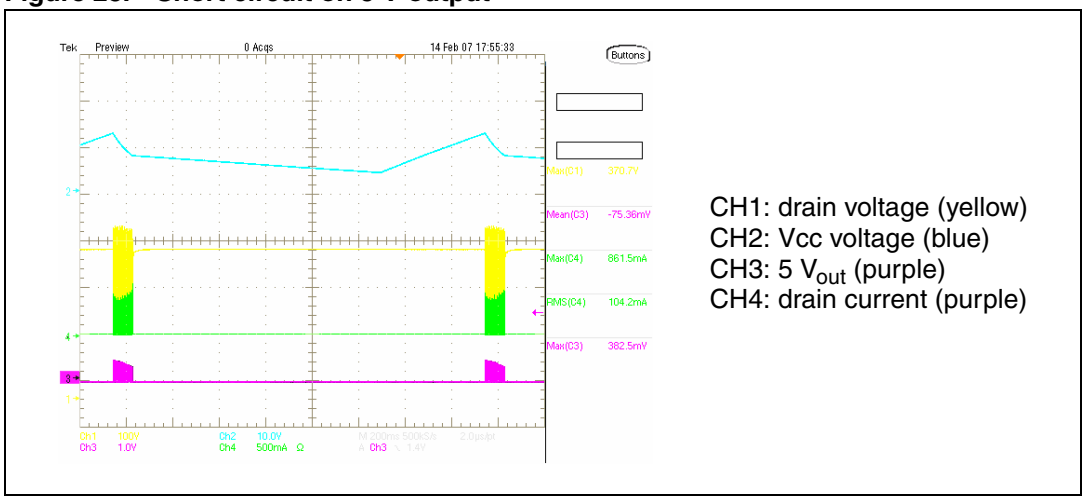
- $V_{in}$ ($V_{ac}$): 184 - 230 - 276
- $V_{dsmax}$ (V): 335 - 401 - 465
- $I_{dpk}$: 2.25 - 2.2 - 2.16

## 3.7 Short circuit test

The short circuit tests have been performed on the two regulated voltages. The short circuit has been provided by means of the electronic load, which is able to emulate the "soft" short circuit that could happen on the STB main board. The tests have been done at nominal input voltage with all outputs at full load.

The protection against short circuit on the +12 V is given by the protection of the voltage regulator.

**Figure 23. Short circuit on 5 V output**



As the coupling between the 3.3 V and the auxiliary windings is poor, to help the SMPS to enter hiccup mode in case of 3.3 V output shorted, the circuitry based on Q10 and Q11 has been added.

## 3.8 Conducted emission (EMI) measurements

Conducted emissions measurements at full load and nominal mains voltage have been performed, using a 50 Ω LISN and a spectrum analyzer with peak detector as shown in *Figure 24* and *25*. The emissions are below the limits given by the EN55022 standard for CLASS B equipment. As the margin between the limits and emission is acceptable, the power supply is ready for the final compliance test.

**Figure 24. Conducted emissions of the system at full load and $V_{in}$=230 V - phase conducted emission**

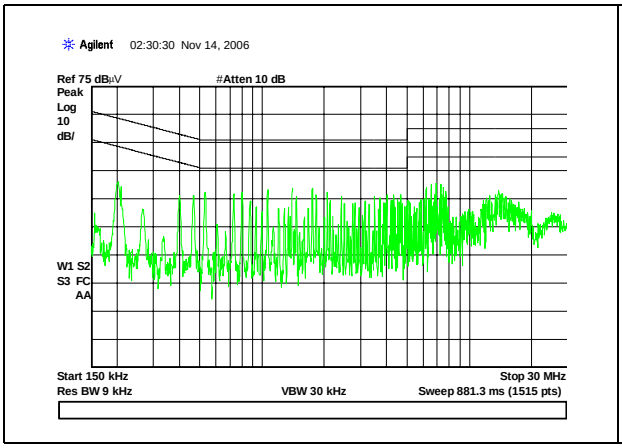
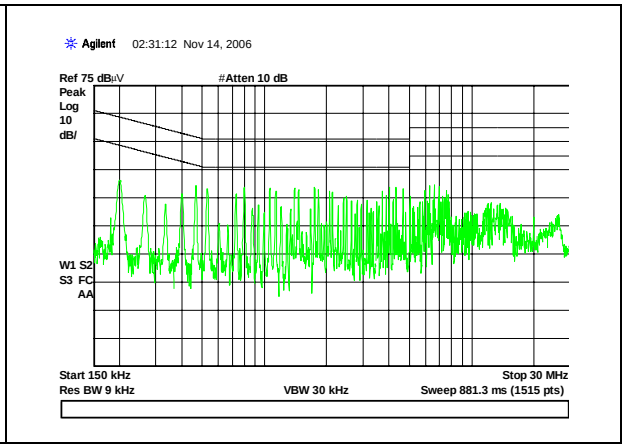



**Figure 25. Conducted emissions of the system at full load and $V_{in}$=230 V - neutral conducted emission**




## 3.9 Thermal measurements

In order to check the reliability of the design, thermal measurements using a thermocouple have been performed. *Table 19* and *Table 20* list the thermal measurements at nominal input voltage at ambient temperature (25 °C) for the most critical components under full load.

**Table 19. Thermal behavior of the components at primary side**

| | STP5NK60ZFP case (°C) | STP5NK60ZFP heatsink (°C) | Trafo core (°C) | Trafo windings (°C) | Snubber resistor (°C) |
|---|---|---|---|---|---|
| After 30 min | 66 | 57 | 43 | 50 | 60 |
| After 1 hour | 72 | 63 | 49 | 50 | 65 |

Table 20. Thermal behavior of the components at secondary side

| | D55 case (°C) | D54 case (°C) | U5 case (°C) | U5 heatsink (°C) | C102 (°C) |
|---|---|---|---|---|---|
| After 30 min | 58 | 69 | 79 | 64 | 61 |
| After 1 hour | 63 | 71 | 81 | 68 | 65 |

# 4 Conclusions

A 55 W SMPS for terrestrial and satellite DVB based on 7100 chipset has been designed and fully validated, resulting in an efficient, reliable, and cost-effective system.

The power supply is based on the L6668 controller with integrated high voltage startup circuit, which provides high efficiency also in standby and light load conditions, thanks to its dedicated functions related to "STBY" and "SKIPADJ" pins.

# 5 Revision history

Table 21. Document revision history

| Date | Revision | Changes |
|---|---|---|
| 17-Jan-2008 | 1 | Initial release |