UM0674
Application note

STEVAL-ISA054V1, 100 W SMPS based on the STW9N150 Power MOSFET and UC3844B for industrial applications

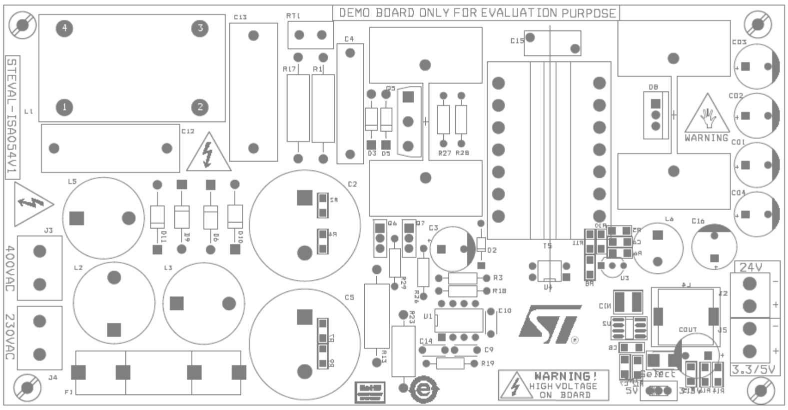
Introduction

This document introduces a solution for industrial power supplies. It takes advantage of the high voltage Power MOSFET, i.e. 1500 V breakdown voltage, to optimize the operation of the flyback converter based on the primary controller UC3844B.

The demonstration board has been designed and developed to address medium power applications. The board features two outputs, 24 V and 5 or 3.3 V (the latter sharing one output) and can deliver more than 100 W in total. The 5/3.3 V output is obtained by means of an integrated DC-DC converter based on L5970D, connected to the 24 V output, and adjustable by means of an external voltage divider.

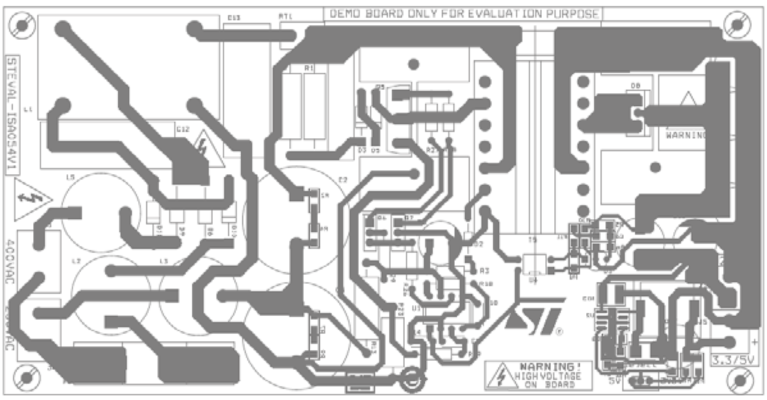
The board is orderable with the order code "STEVAL-ISA054V1".

Figure 1. STEVAL-ISA054V1 board layout: components



AM01981v1

Figure 2. STEVAL-ISA054V1 board layout: board layout and tracks



AM01982v1

Contents

List of tables

List of figures

1 Demonstration board description

The proposed board is based on a flyback converter and employs as primary switch the STW9N150, a 2.5 Ω, 8 A, 1500 V power MOSFET, which uses STMicroelectronics proprietary high voltage "mesh overlay" technology. Thanks to this technology, the switch features very low $R_{DS(on)}$ per area, low gate charge and high switching performances. The device is available in a TO-247 package.

The demonstration board has been designed according to the specifications listed in table below.

Table 1. Main specifications

Parameter	Value
Input voltage (CON1)	400 V_{acrms} ±20%
Input voltage (CON2)	180-265 V_{acrms}
Input frequency	50 Hz
Output 1	24 V at 4 A
Output 2	5 V at 1 A
	3.3 V at 1 A
Output power	100 W
Safety	EN60950
EMI	EN55014

The input section is provided with two connectors: CON1 for 400 Vac input voltage, and CON2 for 230 Vac input voltage. The output voltages are available on CON3 and CON4, with a shared ground between the two outputs, as shown in *Figure 3*.

The converter is controlled by the UC3844B, a primary controller for the flyback converter. The UC3844B controller provides the necessary features to implement off-line or DC-to-DC fixed-frequency current mode control schemes with a minimal number of external parts. The IC can control the power capability variations with the mains voltage by means of the feed-forward line voltage. The IC also includes a disable function, an on-chip filter on the current sense pin, an error amplifier with a precise reference voltage for primary regulation and an effective two-level overcurrent protection.

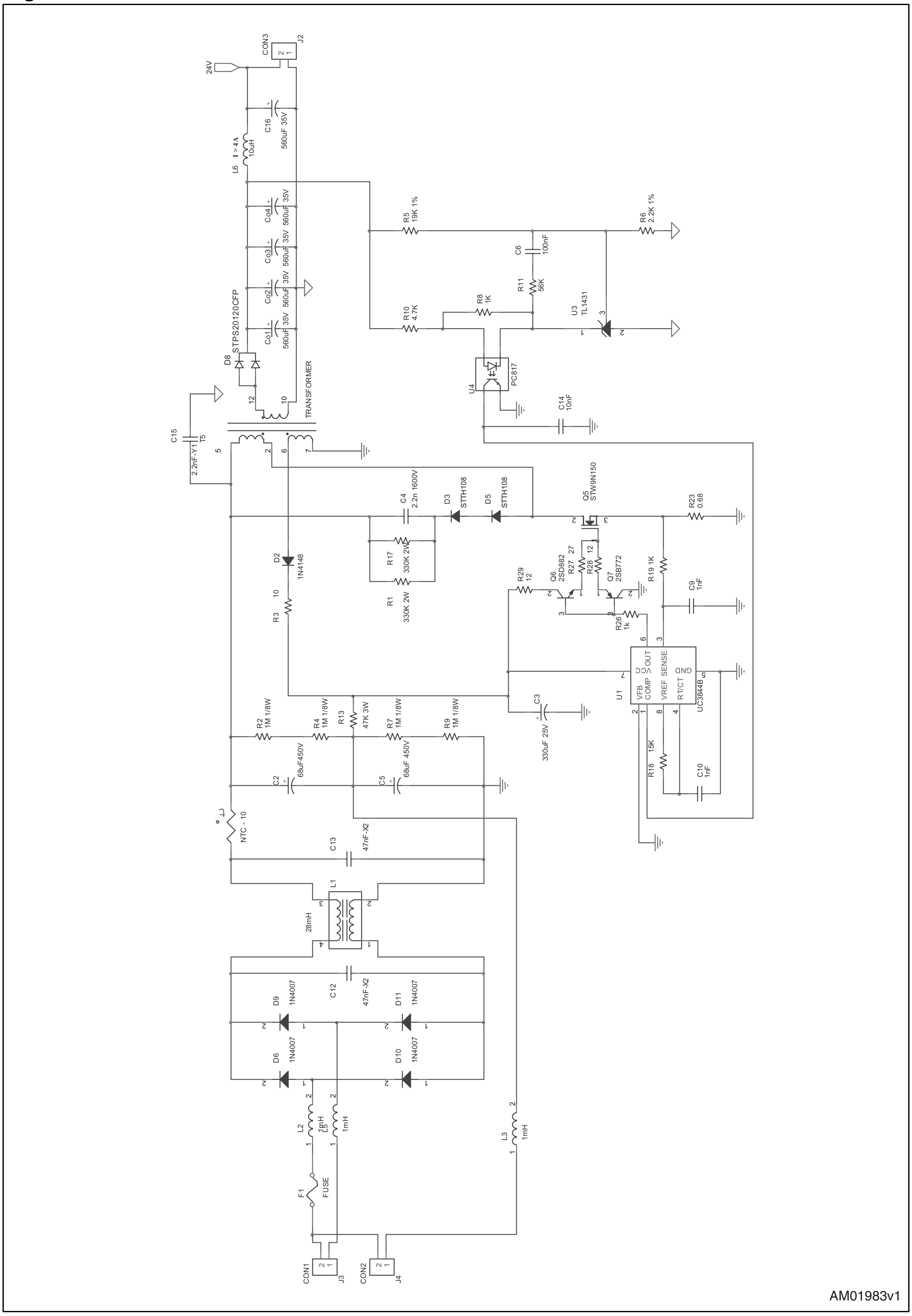
The reflected voltage of the transformer has been set to 400 V, providing enough margin for the leakage inductance voltage spike, and a small RCD clamper circuit is used to limit excess voltage on the drain of the MOSFET.

During normal operation, the IC is powered by the auxiliary winding of the transformer via the D2 diode. The primary current is measured using the external sensing resistor (R23) for current mode operation.

The output voltage regulation is performed by a secondary feedback on the 24 V output. The feedback network consists of a programmable voltage reference (TL1431C), which drives an optocoupler that ensures the required insulation between the primary and secondary sections is met. The optotransistor drives the feedback pin (COMP) which controls the operation of the IC.

The flyback transformer is manufactured by Magnetica, and guarantees that the safety insulation is in accordance with the EN60950 low-voltage directive. Transformer specifications are detailed in *Chapter 3*.

Figure 3. Circuit schematic



The 5 V output is obtained from the 24 V output by means of an integrated power IC, the L5970D. The L5970D is a step-down monolithic power switching regulator with a switch current limit of 1 A, able to deliver up to 1 A DC current to the load depending on the application conditions. The output voltage can be adjusted by a voltage divider supplying either 3.3 V or 5 V. More detailed information on DC-DC conversion is introduced in *Chapter 4*.

The whole power supply has been realized on a single-side 35 µm PCB, whose total surface amounts to 176 x 90 mm.

2 Specifics of the STW9N150 MOSFET

Using the well-consolidated high voltage MESH OVERLAY™ process, STMicroelectronics has designed an advanced family of power MOSFETs with outstanding performances. The strengthened layout coupled with the company's proprietary-edge termination structure gives the lowest $R_{DS(on)}$ per area, unrivalled gate charge and switching characteristics.

In particular, the proposed board employs as primary switch the STW9N150, a 1.8 Ω, 8 A, 1500 V power MOSFET. *Table 2*, *3*, *4*, and *5* show the characteristics of the MOSFET.

Table 2. Absolute maximum ratings

Symbol	Parameter	Value	Unit
V_{DS}	Drain-source voltage (V_{GS} = 0)	1500	V
V_{GS}	Gate-source voltage	±30	V
I_D	Drain current (continuous) at T_C = 25 °C	8	A
I_D	Drain current (continuous) at T_C = 100 °C	5	A
I_{DM}(1)	Drain current (pulsed)	32	A
P_{TOT}	Total dissipation at T_C = 25°C	320	W
	Derating factor	2.56	W/°C
T_J T_{stg}	Operating junction temperature Storage temperature	-55 to 150	°C

1. Pulse width limited by safe operating area.

Table 3. Electrical characteristics: on /off states

Symbol	Parameter	Test conditions	Min.	Typ.	Max.	Unit
$V_{(BR)DSS}$	Drain source breakdown voltage	I_D = 1 mA, V_{GS} = 0	1500			V
I_{DSS}	Zero gate voltage drain current (V_{GS} = 0)	V_{DS} = max rating V_{DS} = max rating, T_C = 125° C			10 500	µA µA
I_{GSS}	Gate-body leakage current (V_{DS} = 0)	V_{GS} = ±30 V			±100	nA
$V_{GS(th)}$	Gate threshold voltage	V_{DS} = V_{GS}, I_D = 250 µA	3	4	5	V
$R_{DS(on)}$	Static drain source on resistance	V_{GS} = 10 V, I_D = 4 A		1.8	2.5	Ω

Table 4. Electrical characteristics: dynamic

Symbol	Parameter	Test conditions	Min.	Typ.	Max.	Unit
g_{fs}(1)	Forward transconductance	V_{DS} = 15 V, I_D = 4 A		7.5		S
Ciss Coss Crss	Input capacitance Output capacitance Reverse transfer capacitance	V_{DS} = 25 V, f = 1 MHz, V_{GS} = 0		3255 294 22.4		pF pF pF
C_{oss} eq.	Equivalent output capacitance	V_{GS} = 0, V_{DS} = 0 to 1200 V		118		pF
R_g	Gate input resistance	f = 1 MHz gate DC Blas = 0 Test signal level = 20 mV open drain		2.4		Ω
Q_g Q_{gs} Q_{gd}	Total gate charge Gate-source charge Gate-drain charge	V_{DD} = 1200 V, I_D = 8 A, V_{GS} = 10 V		89.3 15.8 50.4		nC nC nC

1. Pulsed: Pulse duration = 300 µs, duty cycle 1.5%

Table 5. Switching times

Symbol	Parameter	Test conditions	Min.	Typ.	Max.	Unit
$t_{d(on)}$ t_r $t_{d(off)}$ t_f	Turn-on delay time Rise time Turn-off delay time Fall time	V_{DD} = 750 V, I_D = 4 A R_G = 4.7 Ω, V_{GS} = 10 V		41 14.7 86 52		ns ns ns ns

3 Flyback transformer

Figure 4 and *Figure 5* show the electrical and mechanical specifications of the transformer. *Section 3.1* lists the technical specifications for the transformer.

Figure 4. Mechanical layout

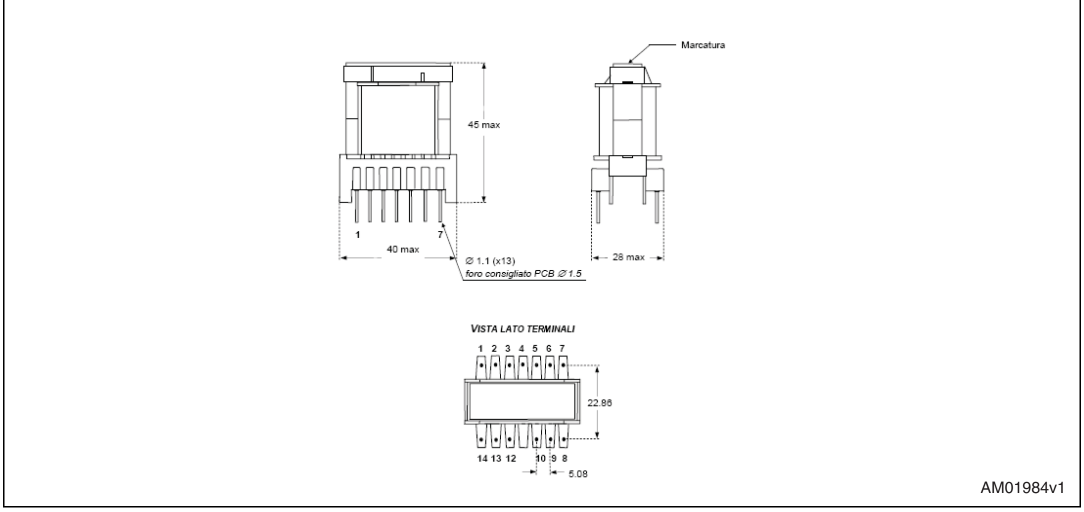
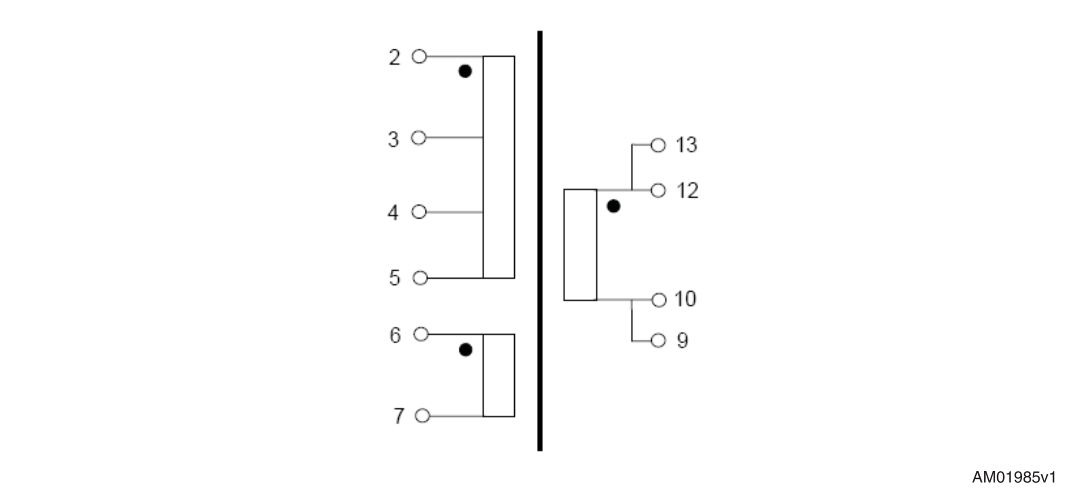


Figure 5. Electrical schematic



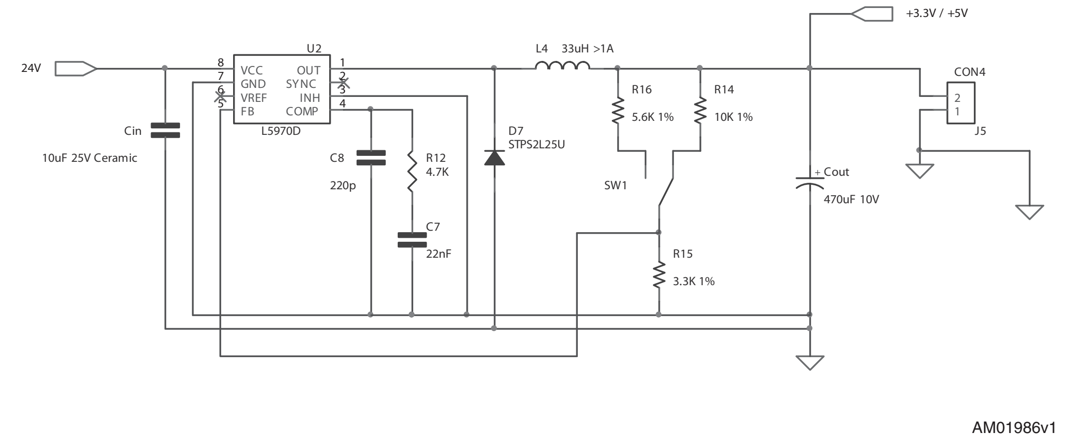
3.1 Transformer specifications

- Inductance: (at 1 kHz, 20 deg C)
  - Primary (pin 2-5): 2.25 mH +/-15 %
  - Auxiliary (pin 6-7): 3.3 µH +/-15 %
  - Secondary (pin 13,12-9,10): 9 µH +/-15 %
- Resistance: (at 20 deg C)
  - Primary (pin 2-5): 0.8 mΩ max
  - Auxiliary (pin 6-7): 45 mΩ max
  - Secondary (pin 12-9): 13 mΩ max
  - Secondary (pin 13-10): 15 mΩ max
- Transformer ratio: (at 10 kHz, 20 deg C)
  - Terminals 2-5 / 6-7: 28 +/-5 %
  - Terminals 2-5 / 13-9: 16 +/-5 %
  - Terminals 2-5 / 12-10: 16 +/-5 %
- Inductance losses: (pin 2-5, 6-7-9-10-12-13 at 10 kHz, Ta 20 deg. C): 1 % NOM
- Parasitic capacitance: (pin 2-5 at 650 kHz, Ta 20 deg. C): 26 pF NOM
- Saturation current: (pin 2-5 at 0.35T Bsat, Ta 20 deg. C): 1.5 Ap max
- Working current: (pin 2-5 at Pmax 103 W, F 70 kHz, Ta 20 deg. C): 1.2 Ap max
- Working frequency: (at Pmax 103 W, 70 kHz, Ta 20 deg. C): 70 kHz nom
- Temperature: (at Pmax 103 W): -10/+40 deg C
- Primary/Secondary isolation: (at 50 Hz, time 2",Ta 20 deg. C): 4000 V
- Dimensions max: 40 x 28 mm, h 45 mm
- Weight: ~ 68 g.

4 DC-DC converter

Figure 6 shows the schematic of the converter. The device uses an internal P-channel DMOS transistor, with a typical $R_{DS(on)}$ of 250 mΩ as switching element to avoid the use of a bootstrap capacitor, and guarantees high efficiency. An internal oscillator fixes the switching frequency at 250 kHz to minimize the size of the external components. The power IC features several protections, such as a pulse-by-pulse current limit with the internal frequency modulation aimed to an effective constant current short-circuit protection, feedback disconnection and thermal shutdown. Finally, it can be synchronized using a dedicated pin as well as inhibited for reduced stand-by power consumption and time sequence operations.

Figure 6. DC-DC converter



5 Primary and output waveforms

5.1 Primary side waveforms

All measurements have been performed at ambient temperature (about 25°C), with the input voltage in the range of 180 Vac_{rms} to 265 Vac_{rms}. The output voltage measurements during normal operation at no load and full load are listed in *Table 6*.

Table 6. Output voltage

Vinrms	24 V output	5 V output	3.3 V output
180-265 Vacrms	No load → 24.09 V	No load → 4.928 V	No load → 3.293 V
	Full load → 24.079 V Max voltage spike → 510 mV	Full load → 4.932 V Max voltage spike → 490 mV	Full load → 3.295 V Max voltage spike → 320 mV

Figure 7. Drain voltage (blue) and current (green) at 230 Vac, full load

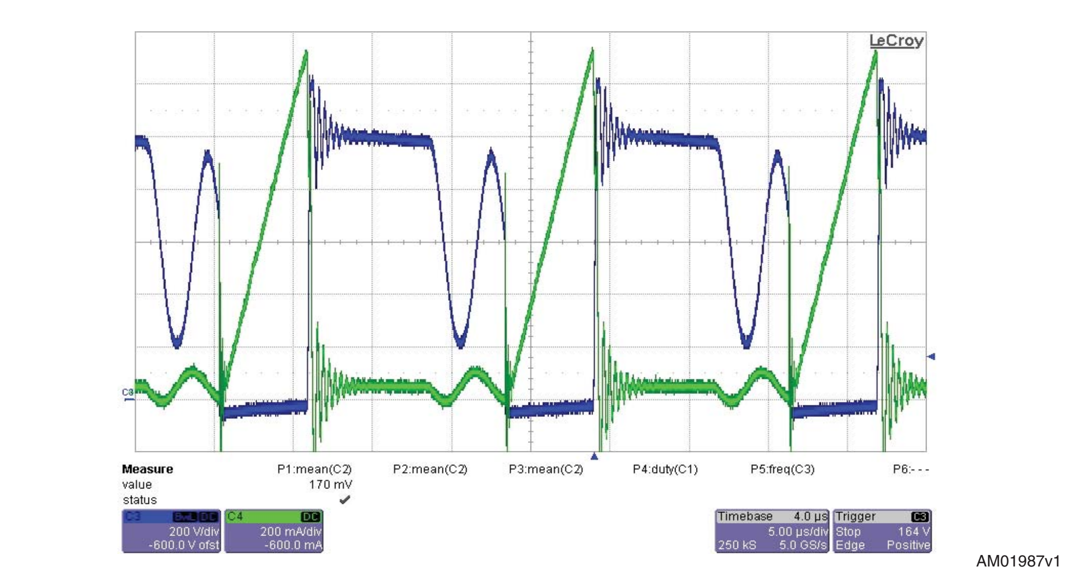
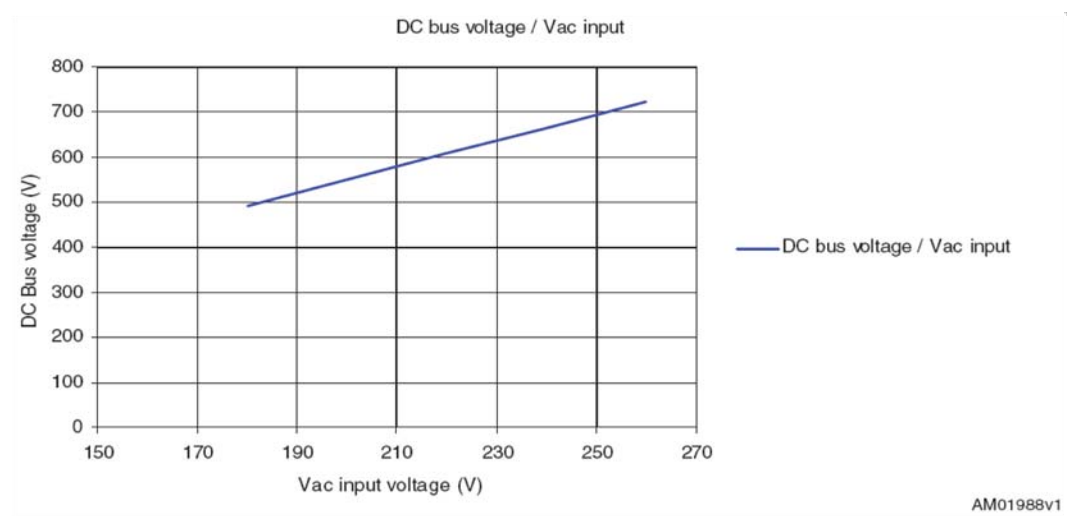


Figure 8 shows the DC bus voltage at input AC voltage variations. The load current is fixed on a 1/10 value of the maximum output current.

Figure 8. DC bus voltage at 180-265 Vac_{rms} input AC voltage range with 0.4 A fixed output current



5.2 Output side waveforms

Figure below shows the output voltage ripple for a 24 V output at full load. The output voltage ripple has been minimized by choosing output capacitors with a very low ESR and high ripple current. The spikes have a peak-to-peak amplitude smaller than 510 mV. An additional LC filter has been introduced after the first output capacitor bank in order to reduce the voltage ripple and large voltage spike.

Figure 9. 24 V output voltage spikes at full load

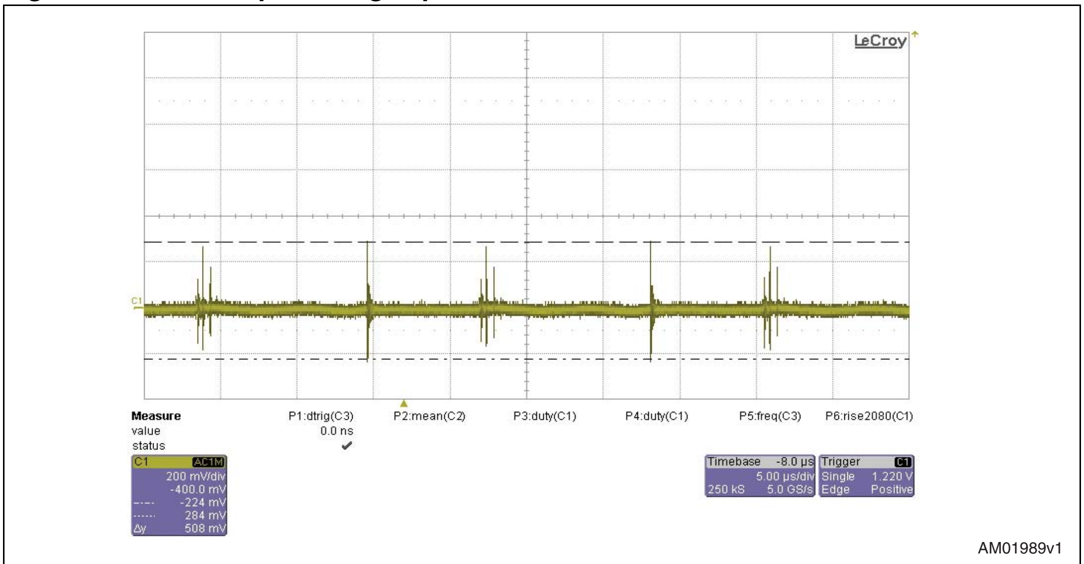
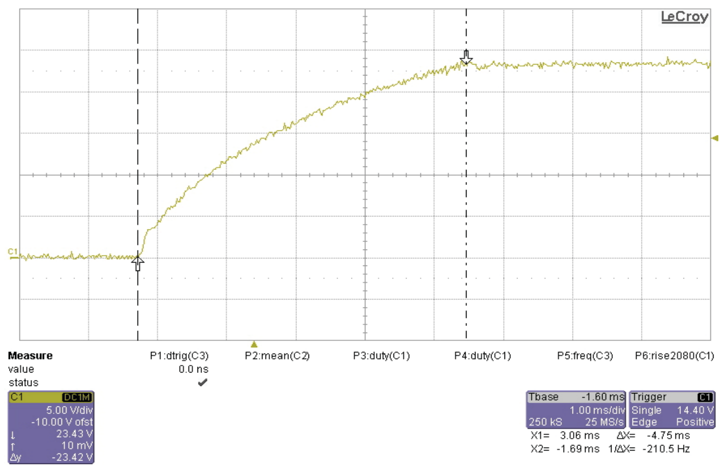


Figure 10 shows the 24 V output voltage time response at start-up.

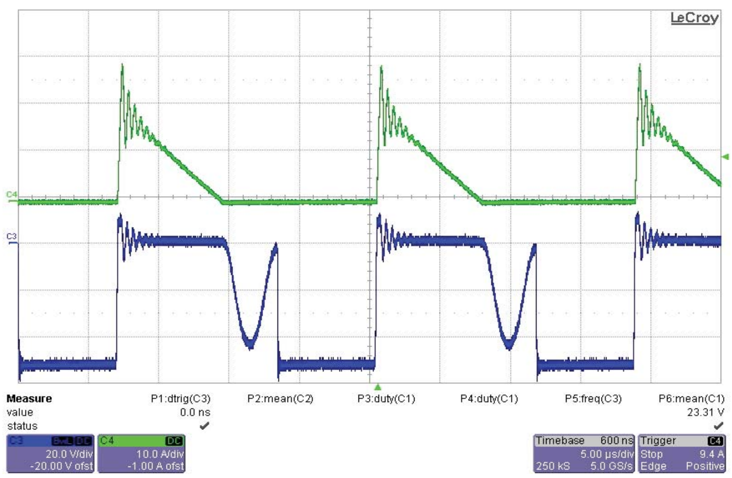
Figure 10. 24 V output voltage at start-up



AM01990v1

Figure 11 shows the output voltage and current for diode STPS20120CFP. The green waveform is the current flowing through the diode and the blue waveform is the voltage across the diode.

Figure 11. Output diode voltage (blue) and current (green) at 180 Vac input voltage, full load



AM01991v1

6 System time response at load variations

Some tests have been done varying the load current, switching between the maximum and minimum values and vice versa. *Figure 12* shows the output overshoot after current load switching from 4 A to 0.4 A, with a response time of 30 ms.

Figure 12. 24 V DC output at load switching from 4 A to 0.4 A

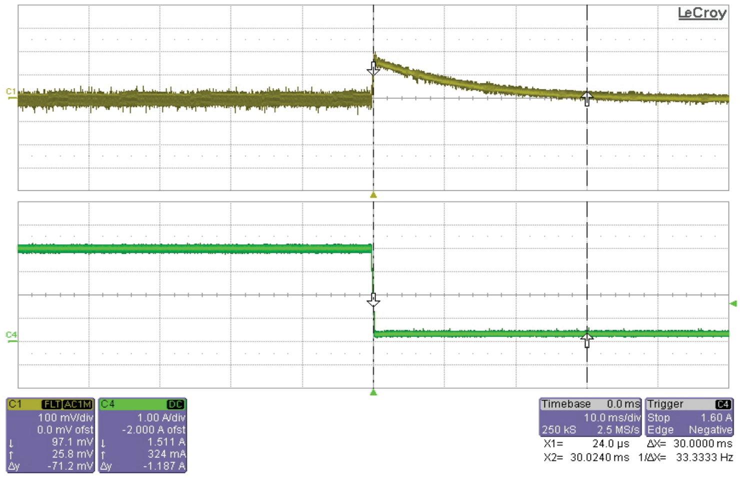
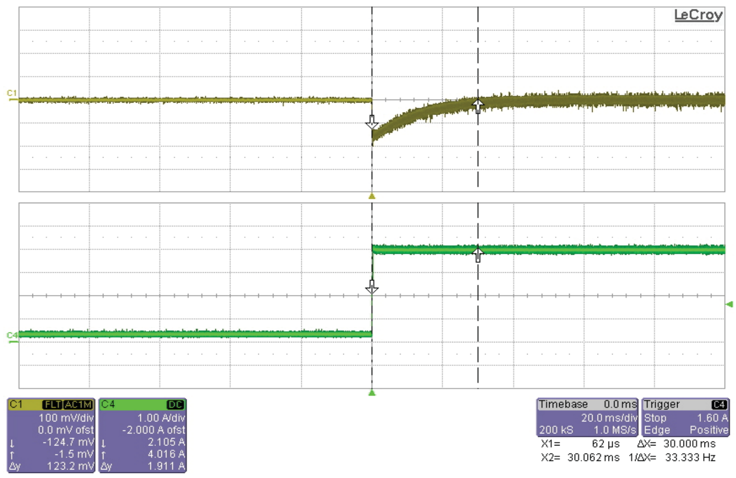


Figure 13 shows the output overshoot after current load switching from 0.4 A to 4 A, with a response time of 30 ms.

Figure 13. 24 V DC output at load switching from 0.4 A to 4 A



7 Efficiency

Figure 14 shows the ratio pout/pin as a function of the input AC voltage. The input voltage range is between 180 V and 265 Vrms. The output load current is fixed at 4 A for 24 Vdc out and 1 A for 5 Vdc out. The maximum efficiency is about 82% and is reached with an input voltage of 230 Vac_{rms}.

Figure 14. Efficiency at I_{out1} = 4 A for 24 Vdc output and I_{out2} = 1 A for 5 Vdc output

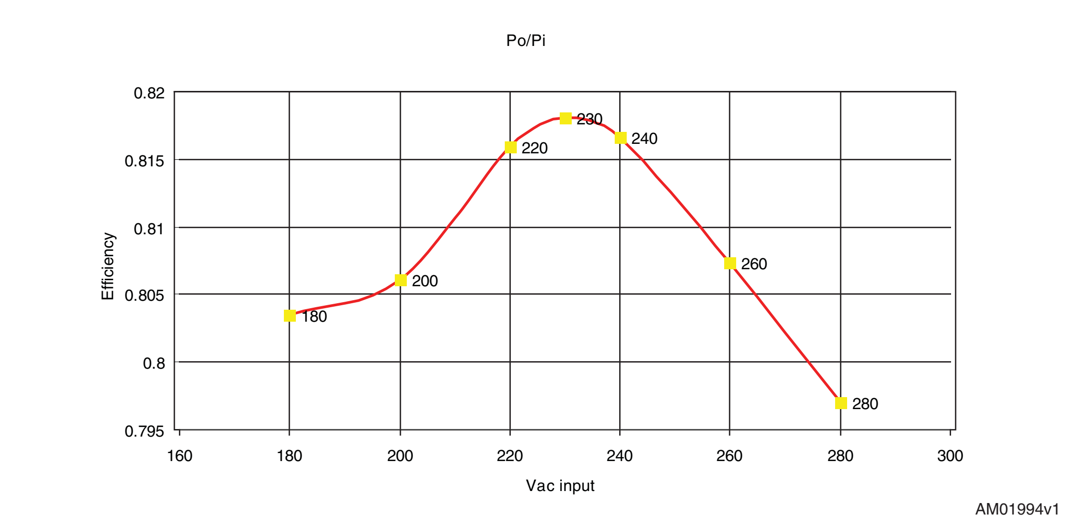
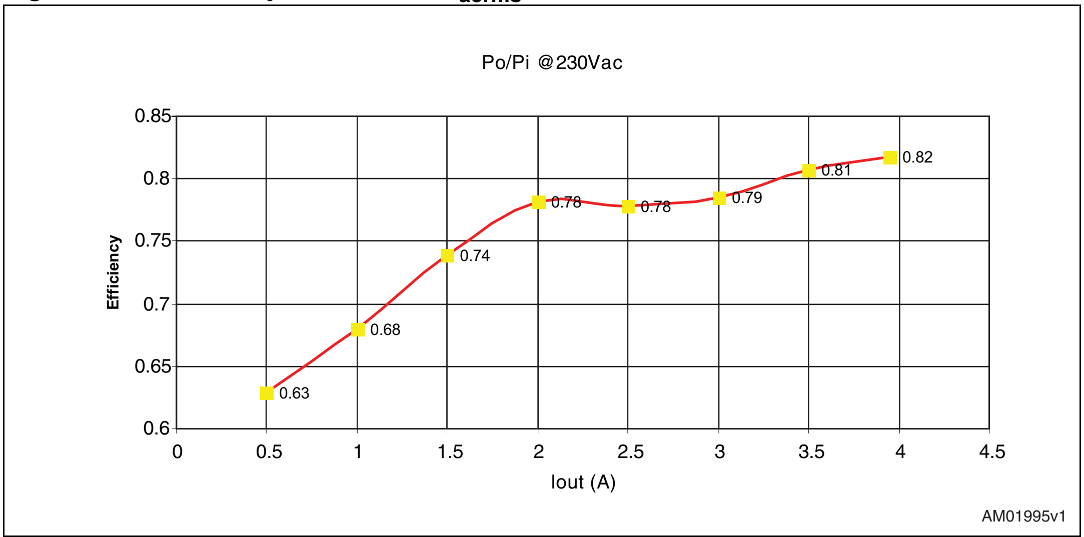


Figure 15 shows the ratio of pout/pin depending on the output current variation. The current range is between 0.5 A and 4 A for a 24 V output. The input AC voltage is fixed at 230 Vac_{rms}.

Figure 15. Efficiency at Vin = 230 V_{acrms}



8 Bill of material

Table 7. STEVAL-ISA054V1: bill of materials

Reference	Part / value	Tecnology information
Cin	10 µF, 25 V ceramic	Monolithic ceramic capacitors
Cout	470 µF, 10 V-ZL series	Aluminium electrolityc capacitors
Co1,Co2,Co3,Co4,C16	560 µF, 35 V-ZL series	Aluminium electrolityc capacitors
C2	68 µF, 450 V-MXC series	Aluminium electrolityc capacitors
C3	330 µF, 25 V	Electrolytic capacitors
C4	2.2 nF, 1600 V R73 KP series	FILM-FOIL polypropylene capacitors
C5	68 µF, 450 V-MXC series	Aluminium electrolityc capacitors
C6	100 nF	SMD mult.ceramic capacitors
C7	22 nF	SMD mult.ceramic capacitors.
C8	220 pF, 5%	SMD mult.ceramic capacitors
C9	1 nF, K	Ceramic capacitors
C10	1 nF, K	COG ceramic capacitors
C12,C13	47 nF, X2 660 Vac	Multi-layer metallized capacitors
C14	10 nF	Ceramic capacitors
C15	2.2 nF, Y1	Y1 capacitor
D2	1N4148	Ultrafast 100 mA-75 V diode
D3,D5	STTH108	Turboswitch diode STMicroelectronics
D6,D9,D10,D11	1N4007	RECTIFIER 1 A-1000 V
D7	STPS2L25U	Schottky diode 2 A-25 V STMicroelectronics
D8	STPS20120CFP	Schottky diode 20 A-120 V STMicroelectronics
F1	FUSE, 2 A 6.3 x 32	Fuse
J2	CON3, 24 V	Power connector
J3	CON1, 400 Vac	Power connector
J4	CON2, 230 Vac	Power connector
J5	CON4, 3.3/5 V	Power connector
L1	28 mH, 2 A	EMI filter
L2,L3,L5	1 mH, 2 A	Line inductor
L4	33 µH, 2 A	Inductor
L6	10 µH, 4 A	Filter inductor
Q5	STW9N150	HV power MOSFET 1500 V STMicroelectronics

Table 7. STEVAL-ISA054V1: bill of materials

Reference	Part / value	Tecnology information
Q6	2SD882	NPN medium power transistor STMicroelectronics
Q7	2SB772	PNP medium power transistor STMicroelectronics
RT1	NTC - 10	NTC thermistor
R1, R17	330 kΩ, 2 W	Resistor
R2,R4,R7,R9	1 MΩ, 1/4 W	SMD resistor
R3	10	Resistor
R5	91 kΩ, 1%	SMD resistor
R6	2.2 kΩ, 1%	SMD resistor
R8	1 kΩ	SMD resistor
R19	1 kΩ	Resistor
R10	4.7 kΩ	SMD resistor
R12	4.7 kΩ	SMD resistor
R11	56 kΩ	SMD resistor
R13	47 kΩ, 3 W	Metal oxide film resistor
R14	10 kΩ, 1%	SMD resistor
R15	3.3 kΩ, 1%	SMD resistor
R16	5.6 kΩ, 1%	SMD resistor
R18	15 k, 1%	Resistor
R20	24 kΩ, 1%	SMD resistor
R23	0.68	Metal oxide sensing resistor
R26	1 kΩ	Resistor
R27	27	Resistor
R28	12	Resistor
R29	12	Resistor
SW1	SW1	Jumper
T5	Transformer	Transformer
U1	UC3844B	Current mode Flyback controller - STMicroelectronics
U2	L5970D	Integrated DC-DC converter - STMicroelectronics
U3	TL1431C	Shunt regulator - STMIcroelectronics
U4	PC817	Optocoupler
	HEAT SINK, 4.7 K/W	Heat sink

9 Conclusion

This document introduces a complete solution for an auxiliary power supply in a typical industrial application. The board has been fully characterized, showing good performance in all test conditions, confirming the suitability of the proposed solution for industrial applications. The STW9N150 described in this document belongs to ST's 1500 V power MOSFET series (see *Table 8*) that has been specifically created to satisfy the growing demand in the industrial market for very high voltage power MOSFETs.

Table 8. 1500 V power MOSFET product range

P/N	BVdss [V]	$R_{DS(on)}$ at 10 V [Ω]	ID[A]	Package
STW9N150	1500	2.5	8.0	TO-247
STFW4N150		7	4.0	TO-3PF
STW4N150			4.0	TO-247
STP4N150			4.0	TO-220
STFW3N150		9	2.5	TO-3PF
STW3N150			2.5	TO-247
STP3N150			2.5	TO-220

10 Revision history

Table 9. Document revision history

Date	Revision	Changes
24-Sep-2009	1	Initial release.