

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".

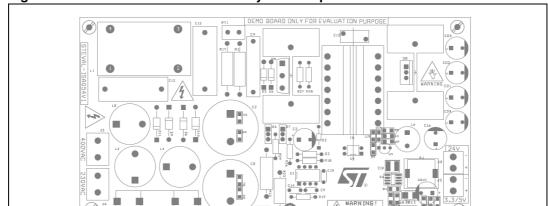
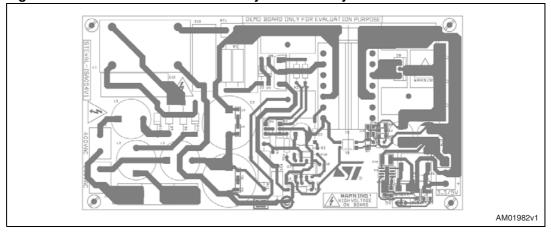


Figure 1. STEVAL-ISA054V1 board layout: components





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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.

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

Table 1. Main specifications

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*.



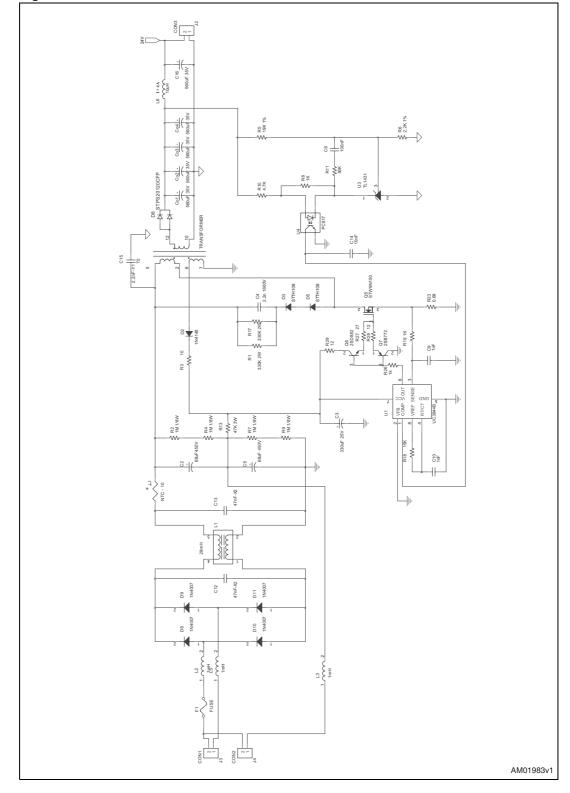


Figure 3. Circuit schematic

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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 μ m PCB, whose total surface amounts to 176 x 90 mm.

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2 Specifics of the STW9N150 MOSFET

Using the well-consolidated high voltage MESH OVERLAYTM 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 | Α |
| I _D | Drain current (continuous) at T _C = 100 °C | 5 | Α |
| I _{DM} ⁽¹⁾ | Drain current (pulsed) | 32 | Α |
| 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. | Тур. | Max. | Unit |
|----------------------|-------------------------------------------------------|---------------------------------------------------------------------|------|------|-----------|--------------------------|
| V _{(BR)DSS} | Drain source breakdown voltage | I _D = 1 mA, V _{GS} = 0 | 1500 | | | ٧ |
| I _{DSS} | Zero gate voltage drain current (V _{GS} = 0) | V_{DS} = max rating V_{DS} = max rating, T_{C} = 125° C | | | 10 500 | μ Α μ Α |
| I _{GSS} | Gate-body leakage current (V _{DS} = 0) | V _{GS} = ±30 V | | | ±100 | nA |
| V _{GS(th)} | Gate threshold voltage | $V_{DS} = V_{GS}, I_{D} = 250 \mu A$ | 3 | 4 | 5 | ٧ |
| R _{DS(on)} | Static drain source on resistance | V _{GS} = 10 V, I _D = 4 A | | 1.8 | 2.5 | Ω |

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Table 4. Electrical characteristics: dynamic

| Symbol | Parameter | Test conditions | Min. | Тур. | Max. | Unit |
|------------------------------------------------------|-------------------------------------------------------------------|---------------------------------------------------------------------------|------|----------------------|------|----------------|
| 9 _{fs} ⁽¹⁾ | Forward transconductance | $V_{DS} = 15 \text{ V}, I_D = 4 \text{ A}$ | | 7.5 | | S |
| Ciss Coss Crss | Input capacitance Output capacitance Reverse transfer capacitance | $V_{DS} = 25 \text{ V, f} = 1 \text{ MHz,}$ $V_{GS} = 0$ | | 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 μ s, duty cycle 1.5%

Table 5. Switching times

| Symbol | Parameter | Test conditions | Min. | Тур. | Max. | Unit |
|---------------------|---------------------|-----------------------------------------------|------|------|------|------|
| t _{d(on)} | Turn-on delay time | | | 41 | | ns |
| t _r | Rise time | V _{DD} = 750 V, I _D = 4 A | | 14.7 | | ns |
| t _{d(off)} | Turn-off delay time | $R_G = 4.7 \Omega$, $V_{GS} = 10 V$ | | 86 | | ns |
| t _f | Fall time | | | 52 | | 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

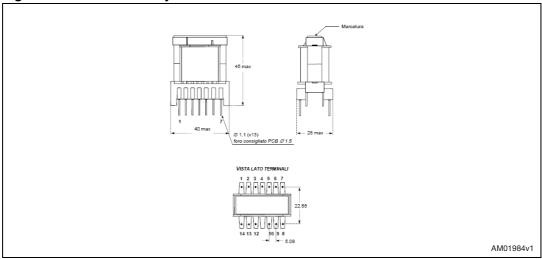
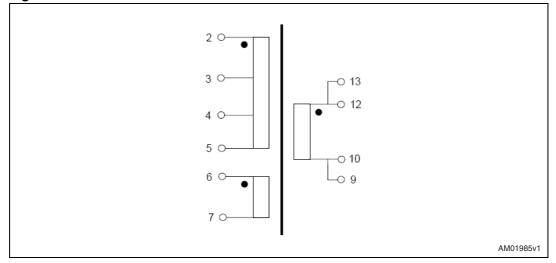


Figure 5. Electrical schematic



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Flyback transformer UM0674

3.1 Transformer specifications

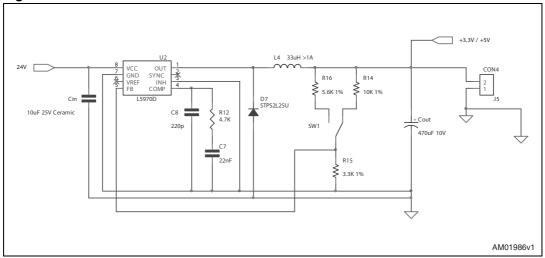
- Inductance: (at 1 kHz, 20 deg C)
 - Primary (pin 2-5): 2.25 mH +/-15 %
 - Auxiliary (pin 6-7): 3.3 μH +/-15 %
 - Secondary (pin 13,12-9,10): 9 μ H +/-15 %
- Resistance: (at 20 deg C)
 - Primary (pin 2-5): $0.8 \text{ m}\Omega$ max
 - Auxiliary (pin 6-7): 45 m Ω max
 - Secondary (pin 12-9): 13 m Ω max
 - Secondary (pin 13-10): 15 m Ω 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.

UM0674 DC-DC converter

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 |
|----------------|----------------------------------------------------------------------------|---------------------------------------------------------------------------|---------------------------------------------------------------------------|
| | No load \rightarrow 24.09 V | No load \rightarrow 4.928 V | No load \rightarrow 3.293 V |
| 180-265 Vacrms | Full load \rightarrow 24.079 V Max voltage spike \rightarrow 510 mV | Full load \rightarrow 4.932 V Max voltage spike \rightarrow 490 mV | Full load \rightarrow 3.295 V Max voltage spike \rightarrow 320 mV |

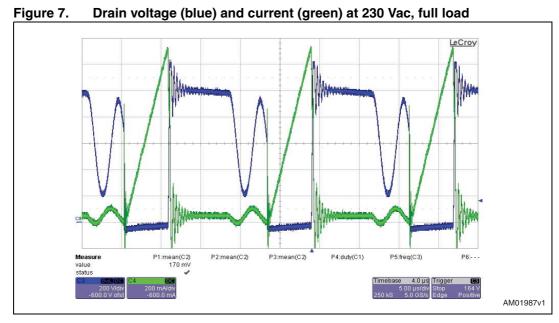


Figure 8 shows the DC bus voltage at input AC voltage variations. The load current is fixed on a 1/10 value of the maximum output current.

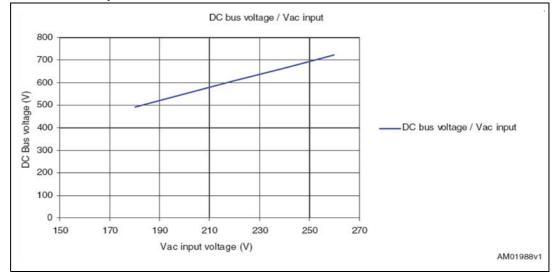


Figure 8. DC bus voltage at 180-265 Vac_{rms} input AC voltage range with 0.4 A fixed output current

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.

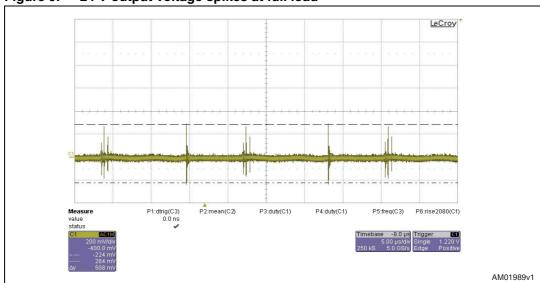


Figure 9. 24 V output voltage spikes at full load

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

Figure 10. 24 V output voltage at start-up

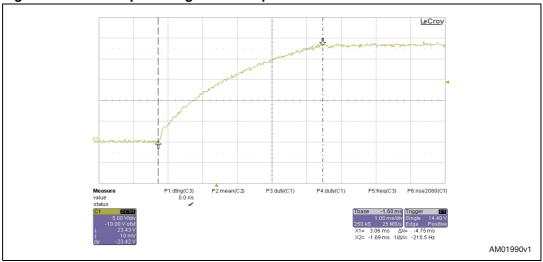
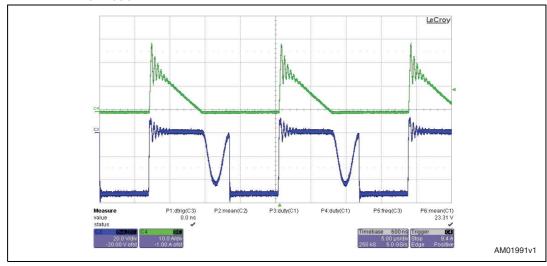


Figure 11 shows the output voltage and current for diode STPS20120CFP. The green waveform is the current flowing through the diode and the blue waveform is the voltage across the diode.

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



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.

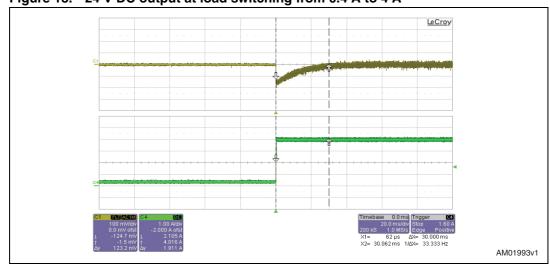


Figure 13. 24 V DC output at load switching from 0.4 A to 4 A

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Efficiency UM0674

Efficiency 7

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}.

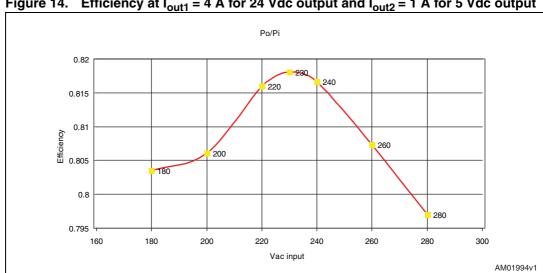
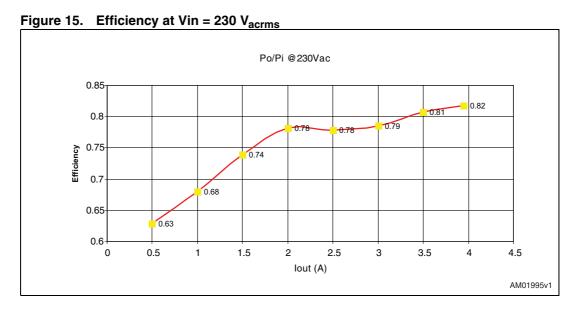


Figure 14. Efficiency at I_{out1} = 4 A for 24 Vdc output and I_{out2} = 1 A for 5 Vdc output

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}.



UM0674 Bill of material

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 capaci | |
| 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 RECT | | RECTIFIER 1 A-1000 V |
| | | Schottky diode 2 A-25 V STMicroelectronics |
| D8 | 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 In | | Inductor |
| L6 | 10 μH, 4 A | Filter inductor |
| Q5 | STW9N150 | HV power MOSFET 1500 V STMicroelectronics |

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Bill of material UM0674

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 | R16 5.6 k Ω , 1% SMD resistor | | |
| R18 | R18 15 k, 1% Resistor | | |
| R20 | 24 kΩ, 1% | 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 | |
| | | Current mode Flyback controller - STMicroelectronics | |
| U2 | U2 L5970D Integrated DC-DC converter - STMicroelectronics | | |
| U3 | TL1431C | Shunt regulator - STMIcroelectronics | |
| U4 | PC817 | Optocoupler | |
| | HEAT SINK, 4.7 K/W | Heat sink | |

UM0674 Conclusion

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 |

Revision history UM0674

10 Revision history

Table 9. Document revision history

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

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