# AN4154
# Application note

## Power supply for energy meter and power line modem

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## Introduction

The power supply is based on the quasi resonant mode of operation using the ST primary side flyback switch ALTAIR04-900. The ALTAIR04-900 is a high-voltage all-primary sensing switcher intended for operating directly from the rectified mains with minimum external parts. It combines a high performance low voltage PWM controller chip and a 900 V avalanche-rugged power section in the same package.
The controller is a current-mode specifically designed for offline quasi-resonant flyback converters. The device is capable of providing constant output voltage using all primary sensing feedback. This eliminates the need for the optocoupler, the secondary voltage reference, and the current sensor, while still maintaining quite accurate regulation. It is also possible to set the maximum deliverable output current, therefore increasing end product safety and reliability during fault events. Quasi-resonant operation is guaranteed by means of a transformer demagnetization sensing input that turns on the power section. The same input serves also the output voltage monitor, to perform CV regulation, and the input voltage monitor, to achieve mains-independent maximum deliverable output current (line voltage feedforward).
The maximum switching frequency is top-limited below 166 kHz, so that at medium-light load a special function automatically lowers the operating frequency still maintaining the valley switching operation. At very light load, the device enters a controlled burst-mode operation that, along with the built-in high voltage startup circuit and the low operating current, helps minimize the standby power. Although an auxiliary winding is required in the transformer to correctly perform CV/CC regulation, the chip is able to power itself directly from the rectified mains. This is especially useful during CC regulation, where the flyback voltage generated by the winding drops below the UVLO threshold. However, if ultra-low no-load input consumption is required to comply with the most stringent energy-saving recommendations, then the device needs to be powered via the auxiliary winding.
In addition to these functions that optimize power handling under different operating conditions, the device offers protection features that considerably increase end product safety and reliability: auxiliary winding disconnection - or brownout - detection and shorted secondary rectifier - or transformer saturation - detection. All of these are in auto restart mode.

**Figure 1. Board photo**

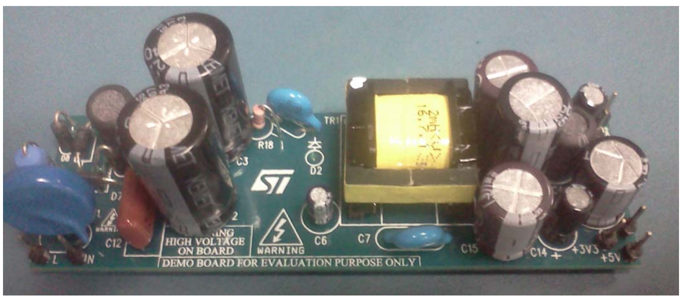

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**Figure 2. Block diagram**

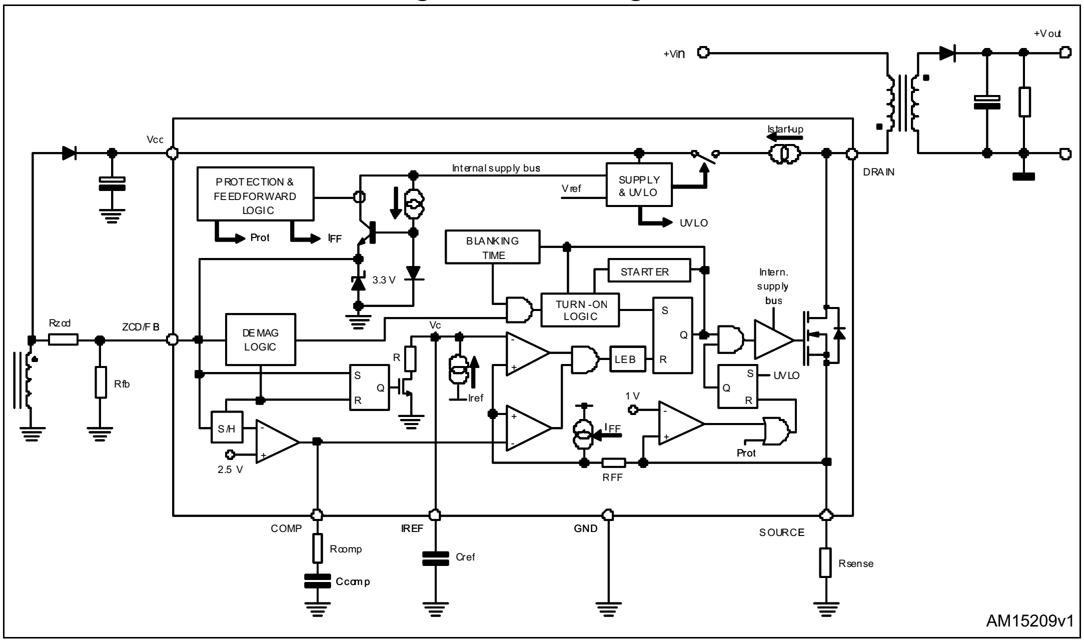



**Figure 3. ALTAIR04-900 pin connection (top view)**

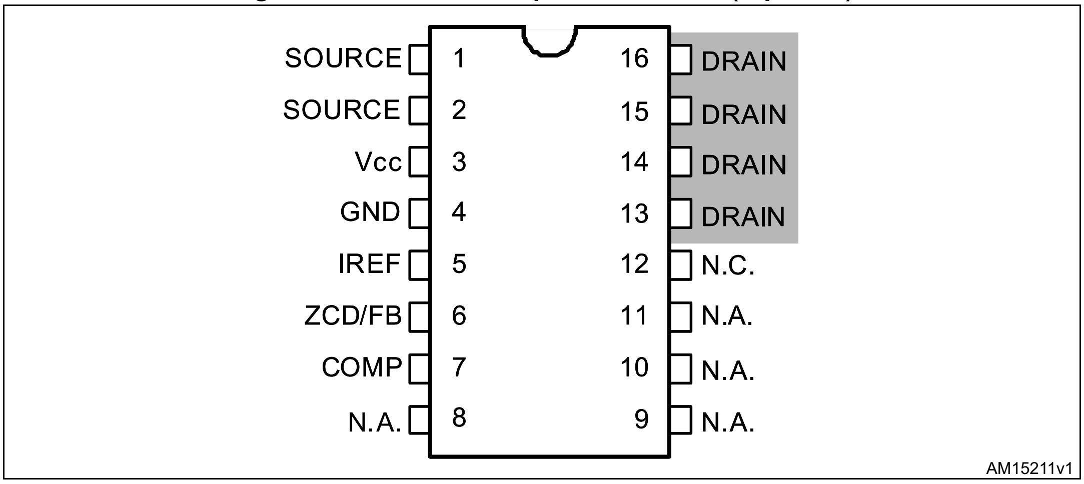
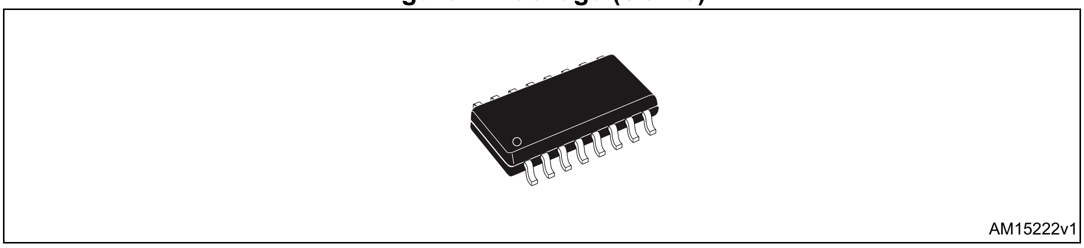



**Figure 4. Package (SO-16)**

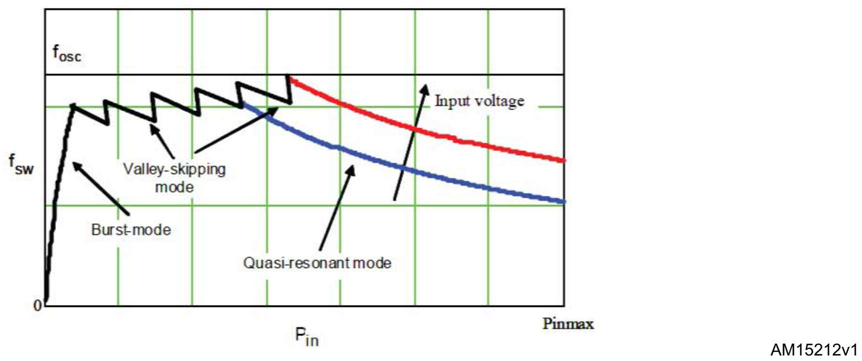


## 1.1 ALTAIR04-900 operation modes

The device is an all-primary sensing switching regulator, based on quasi-resonant flyback topology. Depending on the converter load condition, the device is able to work in different modes (see *Figure 5*):

1. QR mode at heavy load. Quasi-resonant operation lies in synchronizing MOSFET turn-on to the transformer's demagnetization by detecting the resulting negative-going edge of the voltage across any winding of the transformer. The system then works close to the boundary between discontinuous (DCM) and continuous conduction (CCM) of the transformer. As a result, the switching frequency is different for different line/load conditions (see the hyperbolic-like portion of the curves in *Figure 5*). Minimum turn-on losses, low EMI emission and safe behavior in short-circuit are the main benefits of this kind of operation.
2. Valley-skipping mode at medium/ light load. Depending on voltage on the COMP pin, the device defines the maximum operating frequency of the converter. As the load is reduced MOSFET turn-on no longer occurs on the first valley but on the second one, the third one and so on. In this way the switching frequency is no longer increased (piecewise linear portion in *Figure 5*).
3. Burst-mode with no or very light load. When the load is extremely light or disconnected, the converter enters a controlled on/off operation with constant peak current. Decreasing the load results in frequency reduction, which can go down even to a few hundred hertz, therefore minimizing all frequency-related losses and making it easier to comply with energy saving regulations or recommendations. The peak current being very low, no issue of audible noise arises.

**Figure 5. Multi-mode operation of ALTAIR04-900**



## 1.2 Main features

The main features of the controller and internal block diagram are shown below:

- Primary side constant voltage operations with no optocoupler
- Adjustable and mains-independent maximum output current for safe operation during overload/short-circuit conditions
- 900 V avalanche rugged internal power section
- Quasi-resonant valley switching operation
- Low standby consumption
- Overcurrent protection against transformer saturation and secondary diode short-circuit
- SO-16 package.

# 2 Electrical specifications

**Table 1. Input/output specifications**

| Parameters | Limits |
|---|---|
| Min. operating voltage, Vacmin | 90 Vac |
| Max. operating voltage, Vacmax | 265 Vac, 440 Vmax. |
| Mains frequency, $f_L$ | 50 Hz+/-3 Hz |
| Input / output isolation | Yes, galvanic isolation, >2.7 kV |
| Nominal output voltage, Vout | – 5 V/70 mA nominal, 1 A max.<br>– 3.3 V/30 mA nominal, 150 mA max.<br>– 12 V/2 mA nominal, 100 mA max.<br>– 5 V_ISO/ 2 mA nominal, 80 mA max. |
| Total output power, Pout | 1 W nominal, 7.5 W (during transmission mode) |
| Typical efficiency at 230 Vac | >75% |
| Output voltage peak-to-peak ripple | <100 mV |
| Protection | – Should be able to withstand 440 V for 3 hrs<br>– Short-circuit protection |
| Topology | Q-resonant flyback converter, primary side regulation |
| Reflected voltage of transformer (VR) | 100 V |
| Max. ambient temperature | 45 °C |
| Enclosure type | Open |

# 3 Transformer specifications

**Table 2. Flyback transformer specifications**

| Parameter | Specification |
|---|---|
| Max. output power | 7 W |
| Input voltage range | 90 - 265 Vac |
| Primary inductance | 2 mH at 50 kHz |
| Primary side leakage inductance | < 3% at 50 kHz |
| Peak primary current | 0.4 A |
| Saturation current | 1 A |
| Minimum switching frequency | 50 kHz |
| Core size | E20/10/6 |
| Ferrite material | N87, EPCOS or equivalent |
| Bobbin | 10-pin horizontal |
| Isolation Pri to Sec | >2 kV |
| Isolation Vsec7V_iso to VSec5V | >4 kV |

# 4 Winding details

Table 3. Transformer winding data

| Winding name | Start | Stop | No. of turns | Wire gauge | Order of windings |
|---|---|---|---|---|---|
| 1/2_Npri | 3 | 2 | 60 | 0.2 mm | Bottom |
| Naux | 4 | 5 | 24 | 0.1 mm | Above bottom 1/2 Npri |
| Nsec5V | 7 | 6 | 10 | 0.35 mm | Above Naux |
| Nsec12V | 8 | 7 | 10 | 0.2 mm | Above Nsec5 V |
| Nsec7V_iso | 10 | 9 | 10 | 0.2 mm | Above Nsec12 V |
| 1/2_Npri | 2 | 1 | 60 | 0.2 mm | Top |

# 5 Test results at maximum load

**Table 4. Prototype test results**

| Vin (V) | Specified Vo (V) | Measured Vo (V) | Measured Io (A) | Po (W) |
|---|---|---|---|---|
| 90 | 5V_Iso | 4.98 | 0.107 | 0.53 |
| | 12 V | 12.29 | 0.15 | 1.84 |
| | 4.2 V | 4.205 | 0.892 | 3.75 |
| | 3.3 V | 3.3 | 0.109 | 0.36 |
| | **Total output power** | | | **6.49** |
| 150 | 5V_Iso | 4.98 | 0.106 | |
| | 12 V | 12.11 | 0.15 | |
| | 4.2 V | 4.227 | 0.896 | |
| | 3.3 V | 3.29 | 0.108 | |
| | **Total output power** | | | **6.49** |
| 230 | 5V_Iso | 4.98 | 0.106 | |
| | 12 V | 12.02 | 0.15 | |
| | 4.2 V | 4.236 | 0.9 | |
| | 3.3 V | 3.3 | 0.108 | |
| | **Total output power** | | | **6.50** |
| 265 | 5V_Iso | 5 | 0.108 | |
| | 12 V | 12.01 | 0.15 | |
| | 4.2 V | 4.235 | 0.9 | |
| | 3.3 V | 3.3 | 0.108 | |
| | **Total output power** | | | **6.51** |
| 300 | 5V_Iso | 4.99 | 0.1 | |
| | 12 V | 12 | 0.15 | |
| | 4.2 V | 4.23 | 0.9 | |
| | 3.3 V | 3.3 | 0.11 | |
| | **Total output power** | | | **6.47** |
| 450 | 5V_Iso | 4.8 | 0.11 | |
| | 12 V | 10.8 | 0.15 | |
| | 4.2 V | 3.76 | 0.786 | |
| | 3.3 V | 3.3 | 0.1 | |
| | **Total output power** | | | **5.43** |

Table 4. Prototype test results (continued)

| Vin (V) | Specified Vo (V) | Measured Vo (V) | Measured Io (A) | Po (W) |
|---|---|---|---|---|
| 480 | 5V_Iso | 4.83 | 0.1 | |
| | 12 V | 11.18 | 0.15 | |
| | 4.2 V | 3.92 | 0.825 | |
| | 3.3 V | 3.3 | 0.11 | |
| | **Total output power** | | | **5.76** |

# 6 Operating waveforms

The converter is operated at different mains conditions (refer to *Figure 6* and *Figure 12*), starting from 90 to 450 Vac and the drain switching waveform and drain current waveforms are captured at each line voltage at typical load conditions. Referring to *Figure 11*, the peak-to-peak voltage across the MOSFET is 775 V. It clearly indicates that there is a good safe margin (= 125 V) in operating the device even at worst line voltage 450 Vac and therefore it confirms the reliable operation of the converter at high line operating conditions.

**Figure 6. Drain-source voltage and current at 90 Vac and typical load on all outputs**

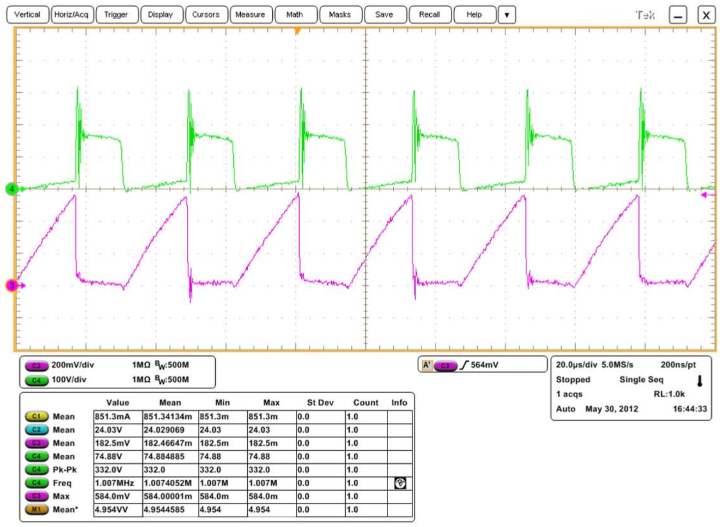



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**Figure 7. Drain-source voltage and current at 150 Vac and typical load on all outputs**

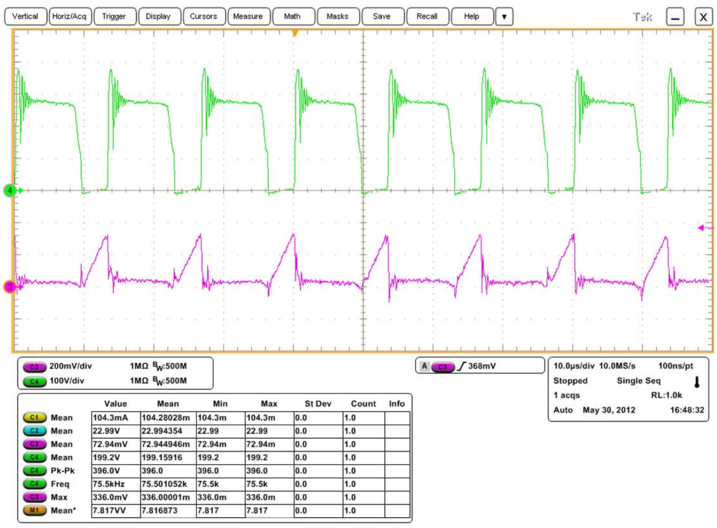


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**Figure 8. Drain-source voltage and current at 230 Vac and typical load on all outputs**

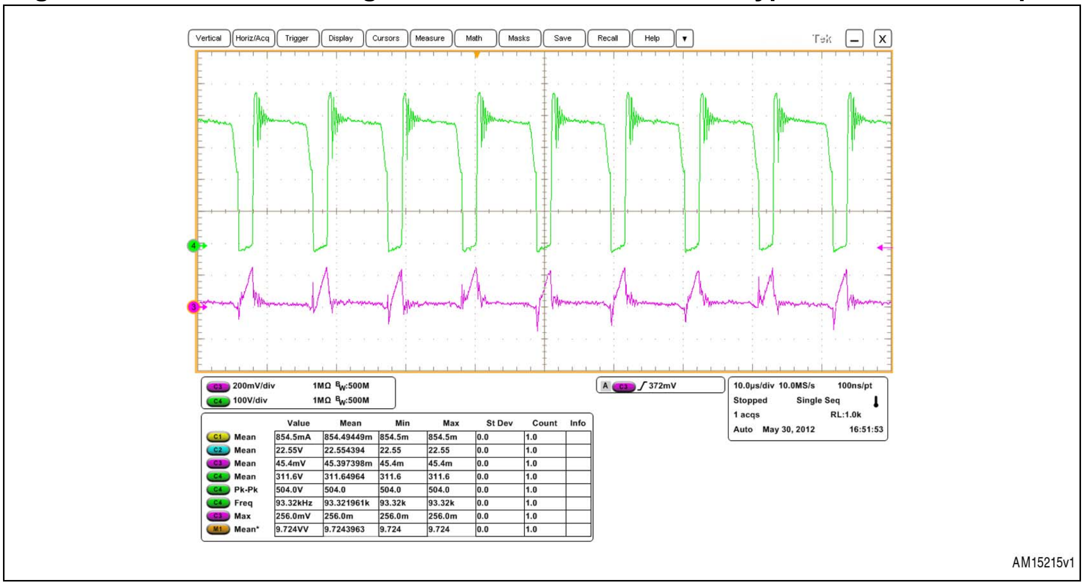



**Figure 9. Drain-source voltage and current at 265 Vac and typical load on all outputs**

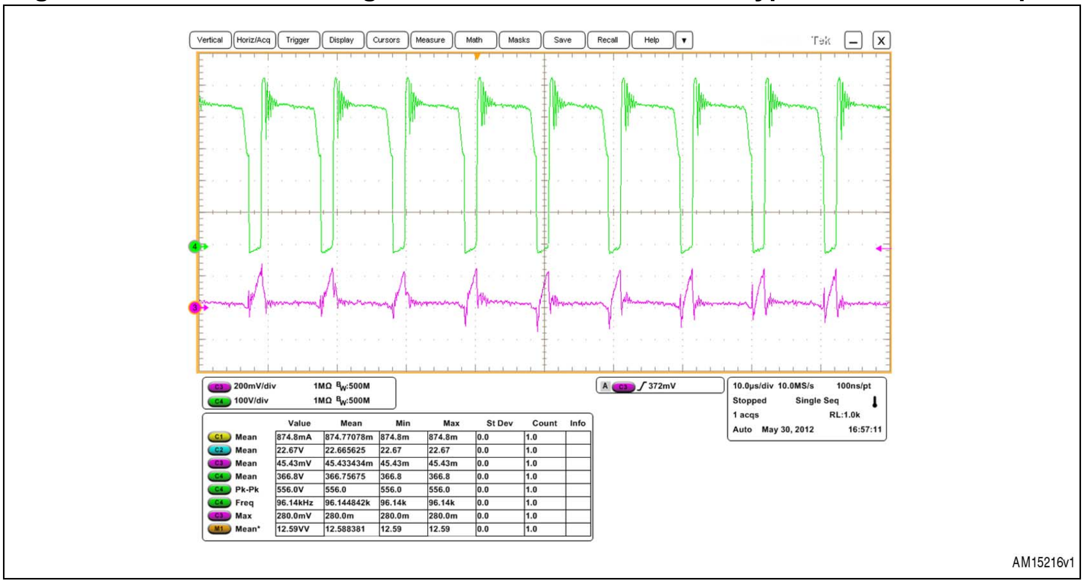


**Figure 10. Drain-source voltage and current at 300 Vac and typical load on all outputs**

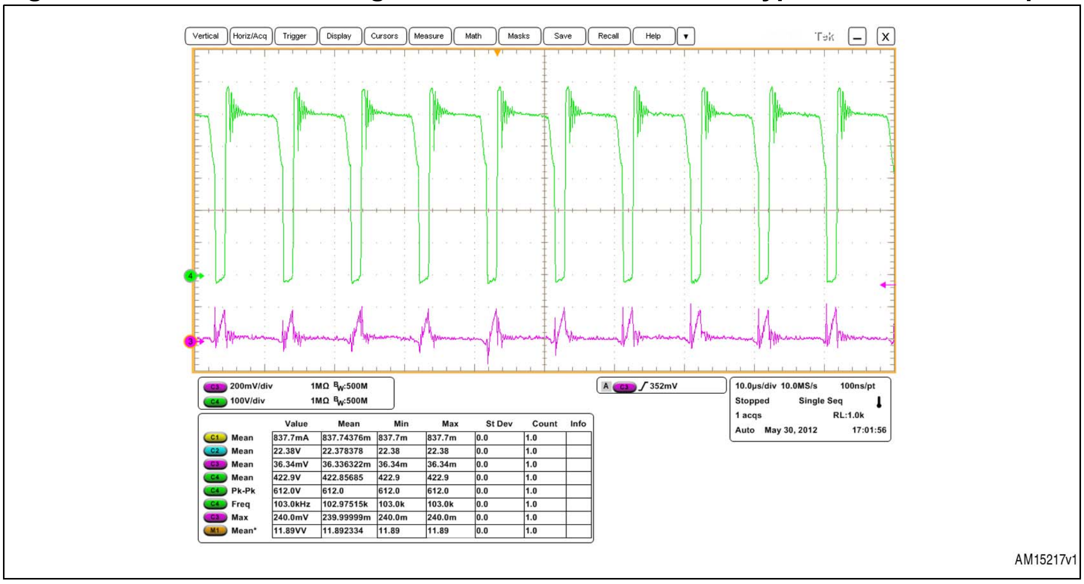



**Figure 11. Drain-source voltage and $V_{CC}$ at 450 Vac and typical load on all outputs**

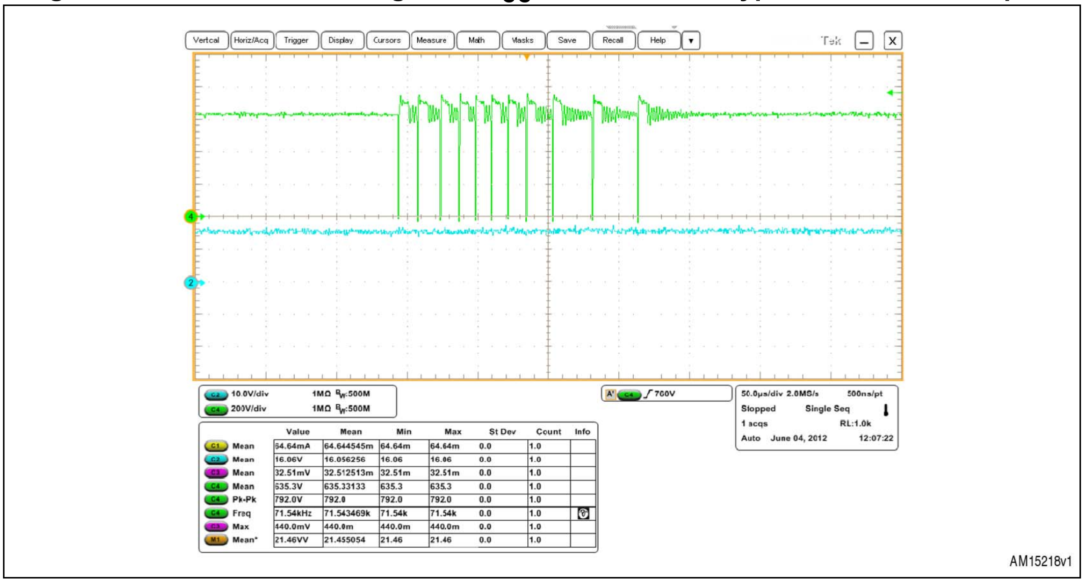
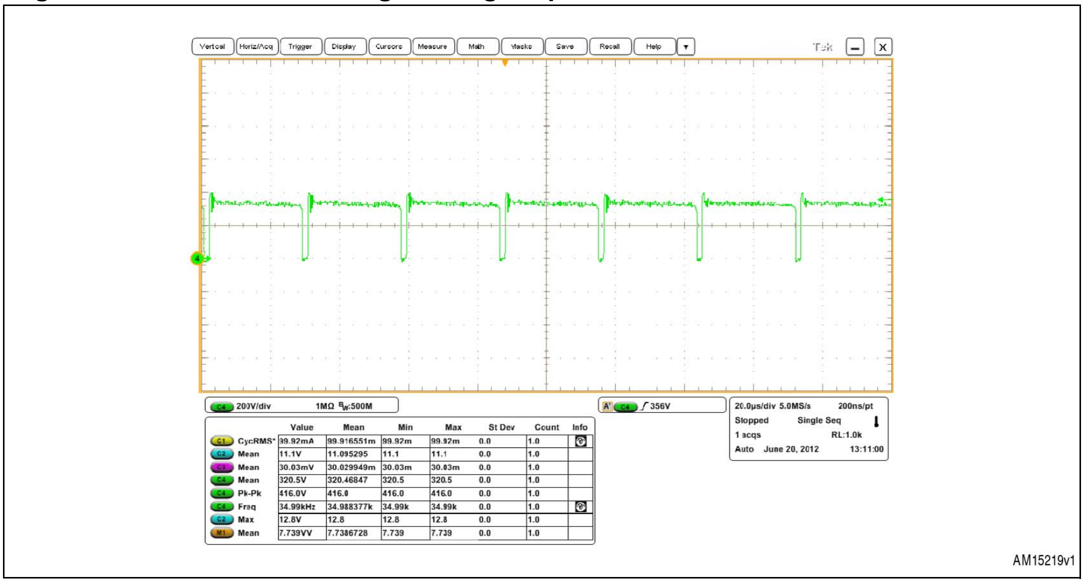
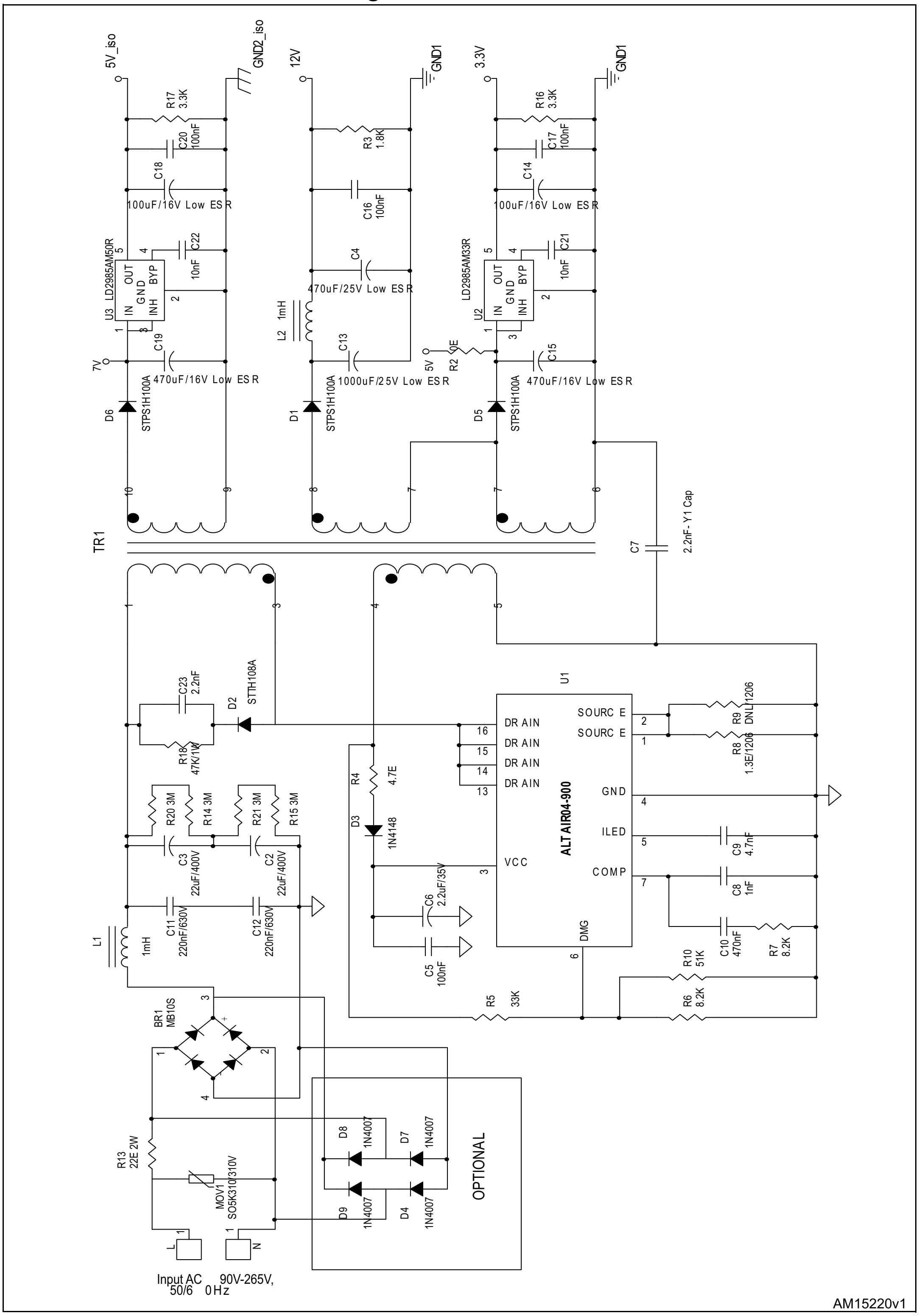


Figure 12. Drain-source voltage during output short-circuit at 230 Vac and max. load



# 7 Schematic

**Figure 13. Schematic**



# 8 Bill of material

**Table 5. BOM**

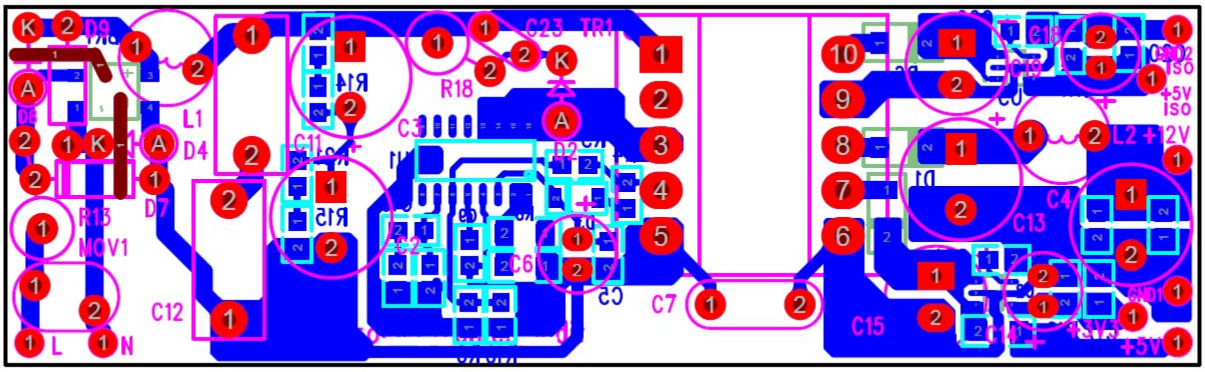
| Part reference | Part no. | Part description | Package | Make |
|---|---|---|---|---|
| BR1 | MB10S | 1000 V, bridge rectifier | SOIC4 | |
| C2,C3 | 22 µF/400 V | 22 µF, 400 V, 105 °C / Rubycon-MXR series or equivalent | TH | Rubycon |
| C4 | 470 µF/25 V low ESR | 470 F,25 V, 105 °C / Rubycon-ZL series or equivalent | TH | Rubycon |
| C5 | 100 nF | 100 nF plastic film or ceramic | 0805 | |
| C6 | 2.2 µF/35 V | 2.2 nF, 35 V, 105 °C / Sanyo-CG series or equivalent | TH | Sanyo |
| C7 | 2.2 nF - Y1 cap | 2.2 nF Y1 class | TH | |
| C8 | 1 nF | 1 nF, 1% plastic film or ceramic | 0803 | |
| C9 | 4.7 nF | 4.7 nF, 1% plastic film or ceramic | 0804 | |
| C10 | 470 nF | 470 nF, 1% plastic film or ceramic | 0805 | |
| C11,C12 | 220 nF/630 V | 220 nF, 630 V, Box capacitor | TH | |
| C13 | 1000 µF/25 V low ESR | 1000 nF, 25 V, 105 °C / Rubycon-ZL series or equivalent | TH | Rubycon |
| C14,C18 | 100 µF/16 V low ESR | 100 F, 16 V, 105 °C / Rubycon-ZL series or equivalent | TH | Rubycon |
| C15,C19 | 470 µF/16 V low ESR | 470 F, 16 V, 105 °C / Rubycon-ZL series or equivalent | TH | Rubycon |
| C16,C17,C20 | 100 nF | 470 nF, 1% plastic film or ceramic | 0805 | |
| C21,C22 | 10 nF | 470 nF, 1% plastic film or ceramic | 0806 | |
| C23 | 2.2 nF | 2.2 nF, 630 V, plastic film or ceramic | TH | |
| D1,D5,D6 | STPS1H100A | Schottky | SMB | STMicroelectronics |
| D2 | STTH108A | 1 A / 800 V, ultra fast | SMB | STMicroelectronics |
| D3 | 1N4148 | 0.3 A / 75 V, glass case | SOD-123 | |
| D4,D7,D8,D9 | 1N4007 | 1 A / 1000 V | TH | |
| L1,L2 | 1 mH | 1 mH, drum inductor | TH | |
| MOV1 | SO5K310/310V | Varistor, 460 Vac, 7 mm dia. | TH | EPCOS or equivalent |
| R2 | 0 E | 0 E | 0805 | |
| R3 | 1.8 kΩ | 1.8 kΩ | 0805 | |
| R4 | 4.7 E | 4.7 E | 0805 | |
| R5 | 33 kΩ | 33 kΩ | 0805 | |
| R6,R7 | 8.2 kΩ | 8.2 kΩ | 0805 | |
| R8 | 1.3 E/1206 | 1.3 E/1206 | 1206 | |

Table 5. BOM (continued)

| Part reference | Part no. | Part description | Package | Make |
|---|---|---|---|---|
| R9 | DNL/1206 | DNL/1206 | 1206 | |
| R10 | 51 kΩ | 51 kΩ | 0805 | |
| R13 | 22 E 2 W | 22 E 2 W | TH | |
| R14,R15,R20, R21 | 3 MΩ | 3 MΩ | 0805 | |
| R16,R17 | 3.3 kΩ | 3.3 kΩ | 0806 | |
| R18 | 47 kΩ/1 W | 47 kΩ/1 W | TH | |
| TR1 | TR1 | E20/10/6, N67 core | Transformer E20/10/6 | |
| U1 | ALTAIR04-900 | ALTAIR04-900 QR PWM controller | SOIC16_N | STMicroelectronics |
| U2 | LD2985BM33R | 3.3 V, very low drop and low noise voltage regulator | DPAK | STMicroelectronics |
| U3 | LD2985BM50R | 5.0 V, very low drop and low noise voltage regulator | DPAK | STMicroelectronics |

# 9 Layout

**Figure 14. PCB layout (top and bottom views)**




# 10 Modification suggestion in circuit

1. 12 V output : The 12 V is being used for powering two latching relays, used for the phase and neutral circuit for the purpose of disconnection.

   These are controlled latching relays, each coil is approx. the 3 W load at operating voltage of 12 V, so we get the 6 W switching load on 12 V for some duration less than 100 ms and relays get energized on the first pulse. Considering the repetition rate of pulses in a worst case scenario, the 12 V winding output stage is modified to provide the enough charge pump to supply relays without loading the transformer.

   The capacitance at 12 V output is increased to 4700 µF. Also instead of the L2, we used the 470E resistor so that during each cycle of switching there is no inrush load on the transformer. The below circuit is tested at actual load condition which can be used to operate the relays with the enough charge pump.

   Following changes are suggested:

   a) L3 is changed with 470E/0.5 W through the hole of the resistor

   b) C13 is reduced to 470 µF

   c) C4 is increased to 4700 µF

   d) R3 is removed

2. Ripple reduction on 5 V output: To reduce the ripple on 5 V output, a small LC filter is inserted. Following changes are suggested:

   a) L2 = 22 µF DC filter is inserted

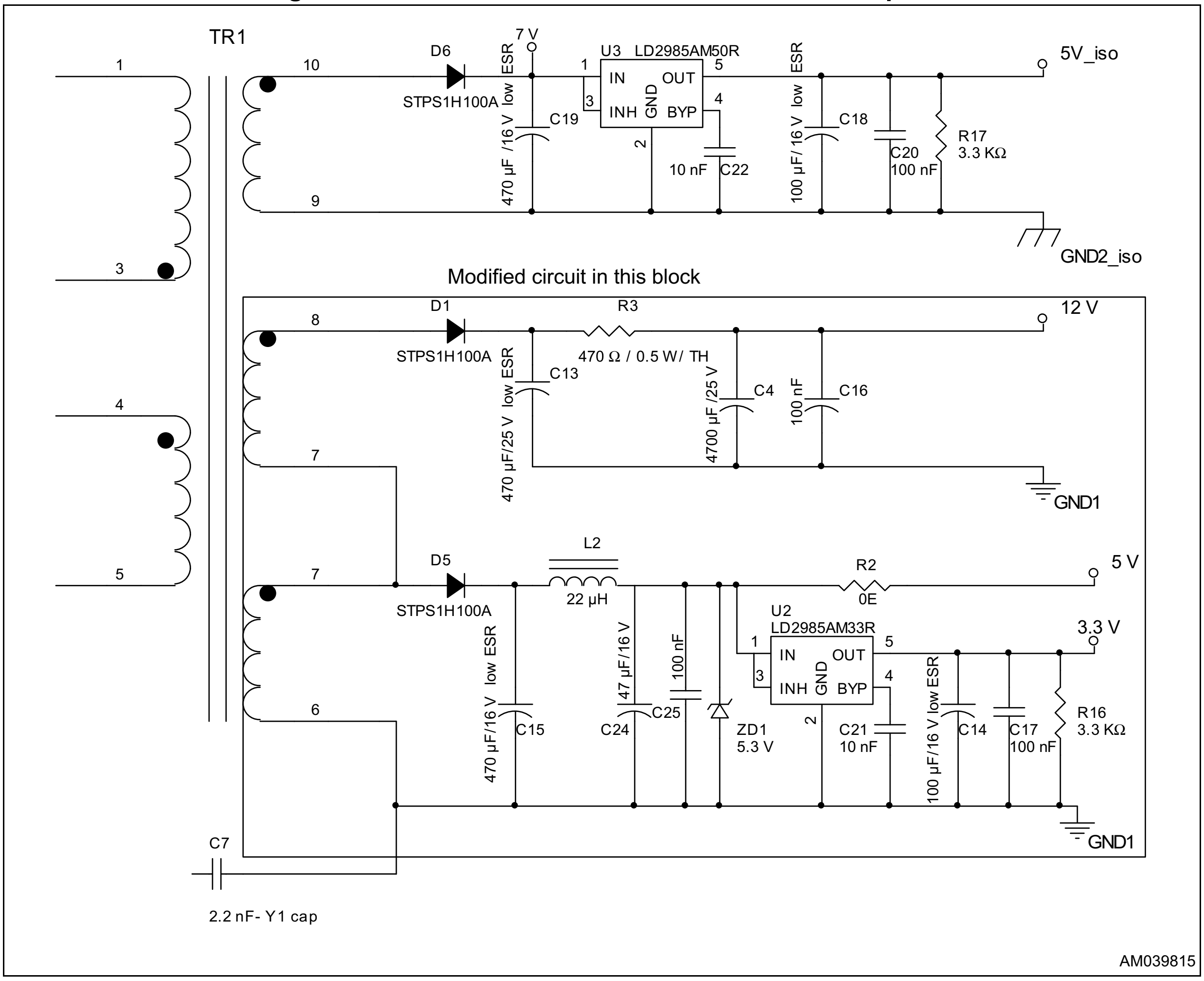
   b) C24 = 47 µF is inserted

   c) C25 = 100 nF/0805 is inserted

   d) ZD1 = 5.3 V is also inserted

The modifications in 12 V and 5 V outputs are as shown in *Figure 15*:

**Figure 15. Modified schematic for 12 V and 5 V outputs**



# 11 Reference

1. ALTAIR04-900 datasheet.

# 12 Revision history

**Table 6. Document revision history**

| Date | Revision | Changes |
|---|---|---|
| 22-Oct-2012 | 1 | Initial release. |
| 05-Nov-2012 | 2 | Added author's name on the coverpage. |
| 30-Nov-2015 | 3 | Modified author's name on the coverpage.<br>Added *Figure 1: Board photo on page 1*.<br>Moved *Section 1.2: Main features on page 6* from page 1.<br>Moved *Section 2: Electrical specifications on page 7* from page 4.<br>Updated *Figure 14: PCB layout (top and bottom views) on page 19* (replaced by new figure).<br>Added *Section 10: Modification suggestion in circuit on page 19*.<br>Minor modifications throughout document. |