AN3290
Application Note

Reference design for double output SMPS for power line modem applications using ALTAIR04-900 primary controller

Introduction

This application note introduces a new "all-primary sensing" switching regulator ALTAIR04-900, used to build an innovative solution to supply a power line communication.

A demonstration board, implementing a wide-range double-output power supply, has been developed and the results of its bench evaluation are reported in this document.

The board uses the new ALTAIR04-900, a quasi-resonant (QR) current-mode controller IC specifically designed for QR ZVS (zero voltage switching at switch turn-on) flyback converters, which combines a high-performance low-voltage PWM controller chip and a typical 16 R_{DSon}, 900 V, avalanche-rugged power MOSFET in the same package.

The device is capable of providing constant output voltage regulation using primary-sensing constant voltage loop (CV loop). This eliminates the need for the optocoupler and the secondary voltage reference while still maintaining quite accurate regulation.

Also, using the primary constant current loop (CC loop), it is possible to set the maximum deliverable output current without any secondary components or current sensor.

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1 Test board design and evaluation

As a reference design, a 7.48 W nameplate output power SMPS has been specifically designed and developed according to the specifications for a complete power line communication based on ST7580 (by STMicroelectronics).

The power supply provides a 13 V output voltage to supply the power line modem (PLM) and the analog circuitry, and a post-regulated 3.3 V to supply digital circuitry and an optional external microcontroller.

Table 1 summarizes the electrical specifications of the power supply, *Table 2* provides the bill of material and *Table 3* lists the transformer specifications. The electrical schematic is shown in *Figure 2* and the PCB layout in *Figure 3* and *4*.

Table 1. ALTAIR04-900 power supply: electrical specification

Parameter	Note	Min.	Typ.	Max.	Unit
AC main input voltage		85		265	V_{AC}
Mains frequency (f_L)		50		60	Hz
Output voltage 1	Analog supply voltage	11.7	13	14.3	V
Output current 1	Rx mode	12			mA
	Tx mode	35		550	mA
Output voltage 2	Digital supply voltage		3.3		V
Output current 2	No external microcontroller connection		40	50	mA
	External microcontroller connection			100	mA
Total rated output power				7.48	W
Maximum output power	In TX mode	4.2			W

The input stage, consists of an NTC (NTC1) which limits the inrush current produced by the capacitor charging at plug-in and a varistor (RV1) that protects the power supply against temporary line overvoltage transients. The input EMI filter is a classic Pi-filter, 1-cell for common and differential mode noise. The clamping network (D2-D3) limits the peak of the leakage inductance voltage spike at turn-off, assuring reliable operation of the ALTAIR04-900.

The sense resistor R2 and the transformer primary-to-secondary turn ratio fix the maximum output current limitation, whereas the voltage divider made up of R6, R7, and R8 is used to set the output voltage setpoint, in order to ensure the desired output voltage regulation. The network connected on the COMP pin is used to compensate the loop, ensuring the right gain and phase margin to the system, whereas the voltage across the capacitor C10 is used to fix the voltage level for the CC loop; the value of this capacitor is not critical and e few nF are enough to ensure correct operation. The secondary side is provided by two output voltages; a nameplate 13 V output voltage is directly used to supply the analog circuitry of the PLM, whereas the lower voltage is achieved by a 3V3 LDO and is intended to supply the digital parts.

Figure 1. Electrical schematic

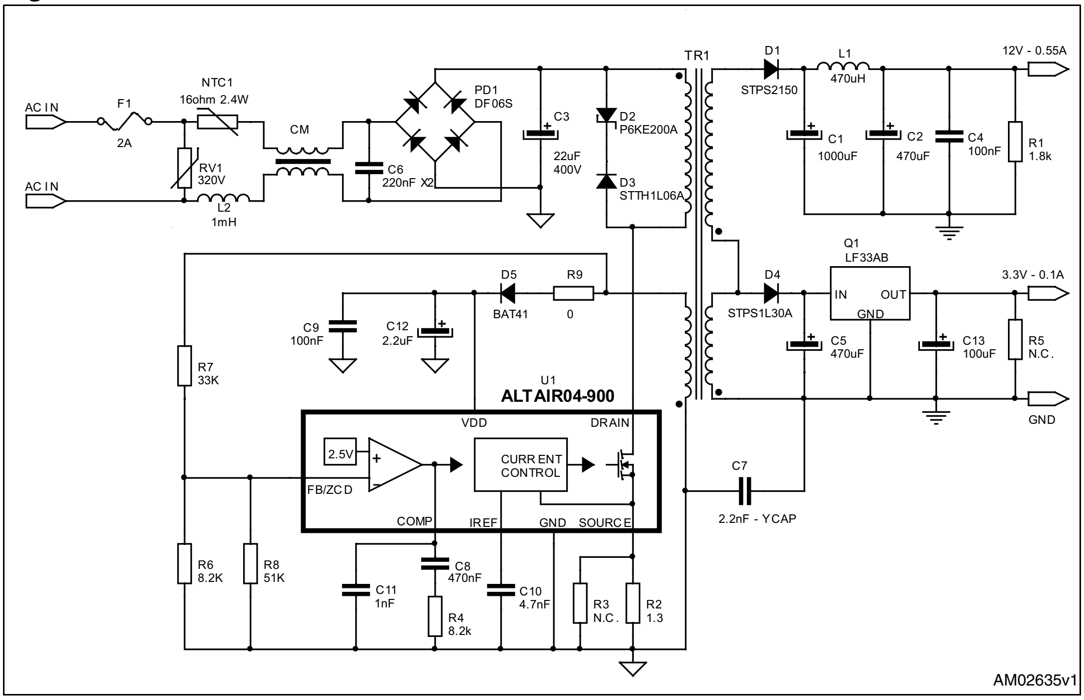


Figure 2. PCB: component side (not to scale)

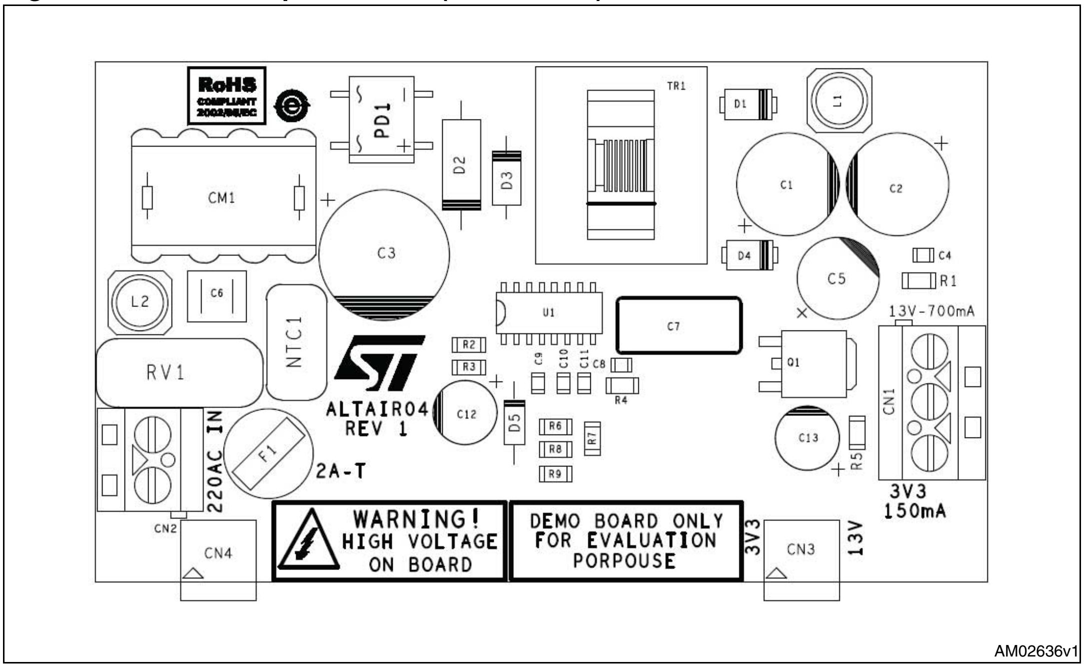


Figure 3. Demonstration board image: power supply board

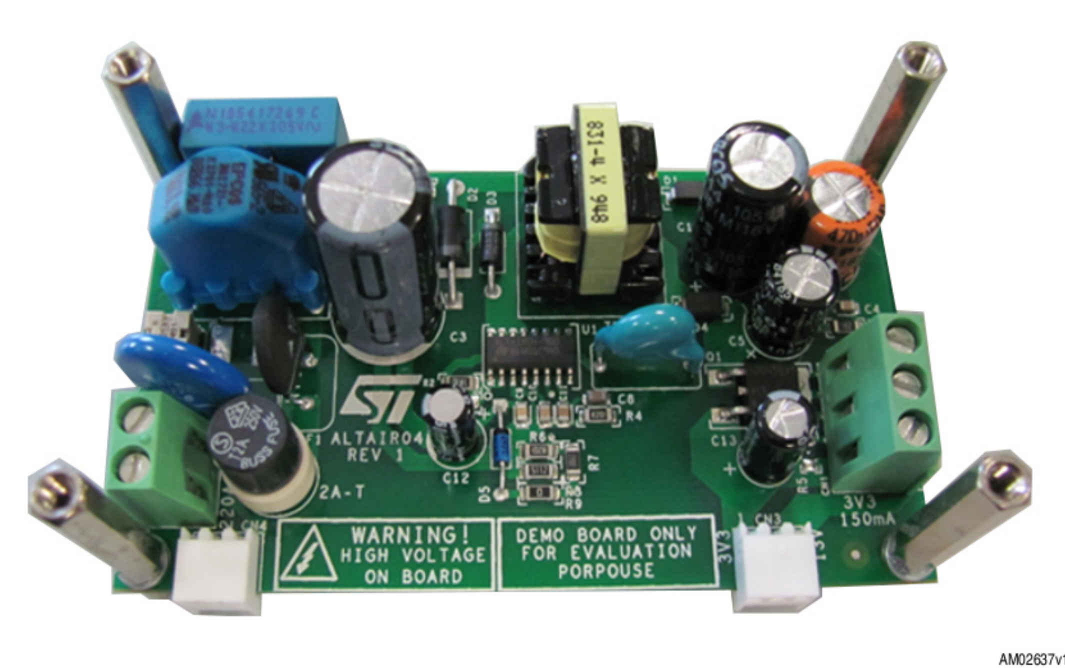


Figure 4. Demonstration board image: complete (power supply and PLM boards)

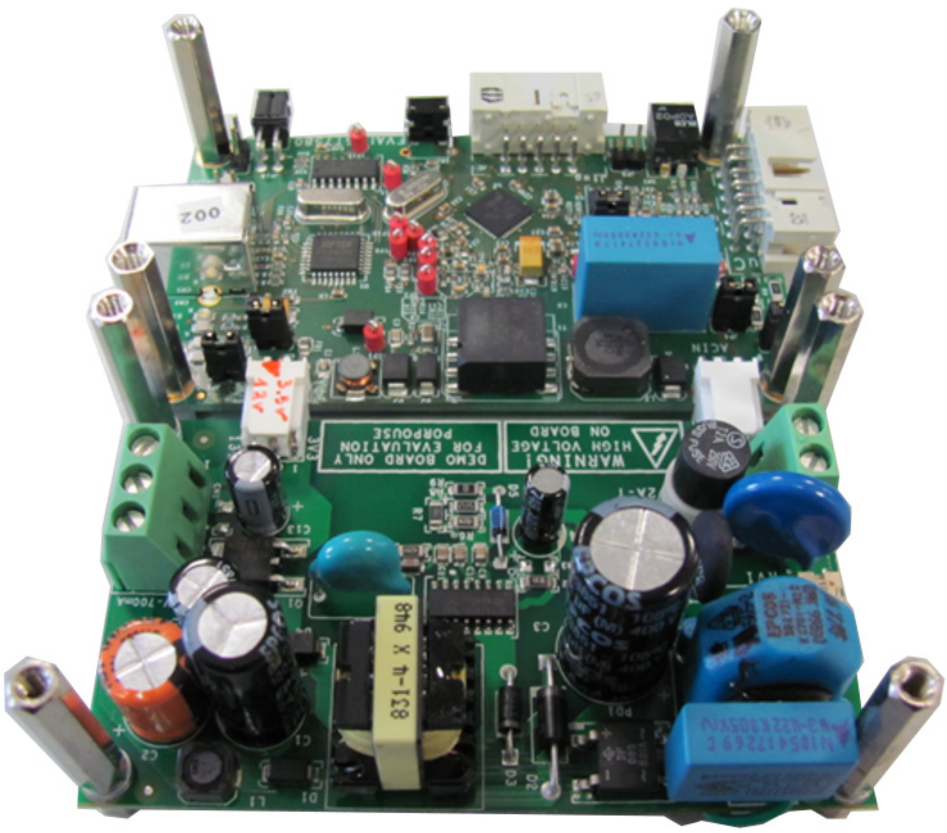


Table 2. ALTAIR04-900 power supply - bill of material

Reference	Part	Description	Note
R1		1.8 kΩ	
R2		1.3 Ω	1% tolerance
R3, R5		N.C.	
R4		8.2 kΩ	
R6		8.2 kΩ	1% tolerance
R7		27 kΩ	1% tolerance
R8		5.1 kΩ	1% tolerance
R9		0Ω	
C1	B41044A4108M	1000 µF - 16 V electrolytic	EPCOS
C2	B41858C4477M	470 µF - 16 V electrolytic	EPCOS
C3	B43851F9226M	22 µF - 400 V electrolytic	EPCOS
C4, C9		100 nF ceramic – 35 V	
C5	B41851A3477M	470 µF - 10 V electrolytic	EPCOS

Table 2. ALTAIR04-900 power supply - bill of material (continued)

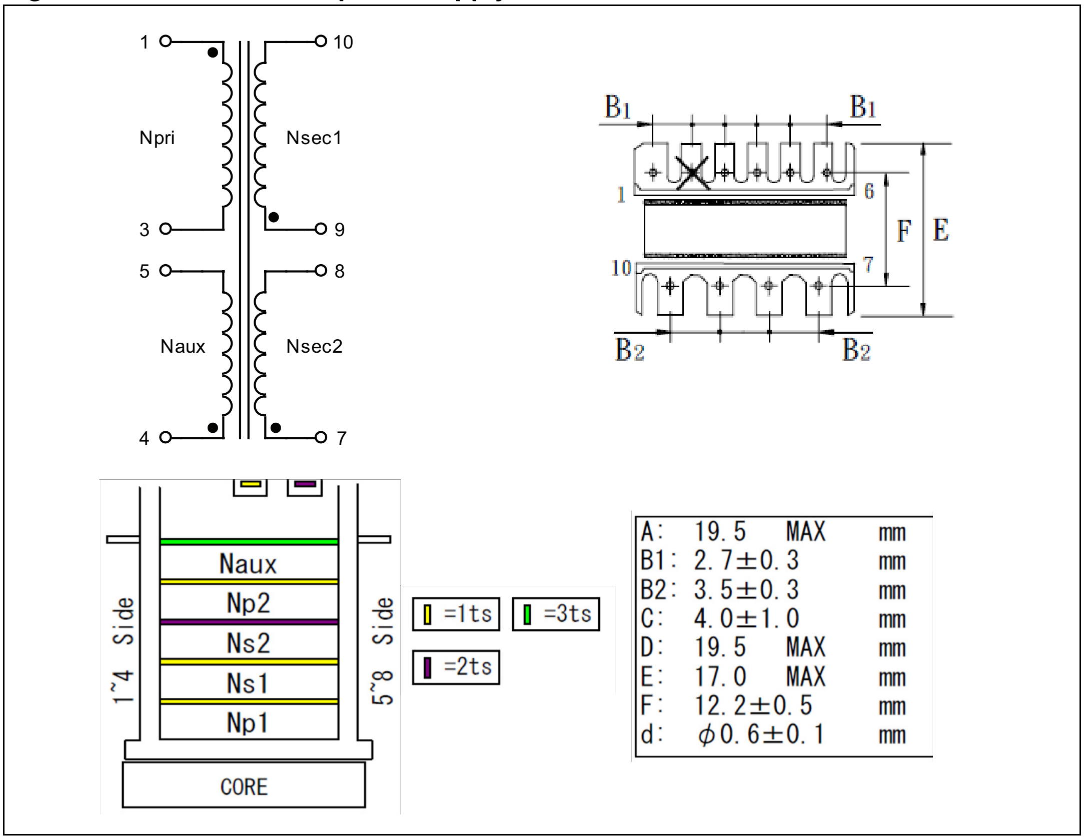
Reference	Part	Description	Note
C6	B32922C3224M	220 nF - X2	EPCOS
C7		2.2 nF - Y-CAP	
C8		470 nF ceramic - 25 V	
C10		4.7 nF ceramic - 25 V	
C11		1 nF ceramic - 25 V	
C12		3.3 µF - 35 V electrolytic	
C13	ZLH series	100 µF - 16 V electrolytic	Rubycon
D1	STPS2150A	Power Schottky diode	STMicroelectronics
D2	P6KE200A	Transil™	STMicroelectronics
D3	STTH1L06A	Ultra-fast high voltage diode	STMicroelectronics
D4	STPS1L30A	Power Schottky diode	STMicroelectronics
D5	BAT41	Small signal Schottky	STMicroelectronics
PD1	DF06S	Input bridge rectifier	
L1	B82462G4472M	4.7 µH power inductor	EPCOS
L2	B82422H1105K	1 mH SMT inductor	EPCOS
IC1	ALTAIR04-900	Primary switching regulator	STMicroelectronics
Q1	LF33AB	3.3 V LDO voltage regulator	STMicroelectronics
CM	B82721K2701	CM Choke	EPCOS
	744612101		Wurth
TF1	ECO2017SEO-X05V015	Flyback transformer	TDK
	760-871-431		Wurth
NTC1	B57236S0160M	NTC inrush current limiter	EPCOS
RV1	B72214S0321K	320 V Varistor	EPCOS
F1		2 A fuse	

Note: If not otherwise specified, all resistors are 5%, ¼ W.

Table 3. ALTAIR04-900 power supply: transformer characteristics

Core	E16
Primary inductance	2 mH
Leakage inductance	1.42% nom.
Primary winding	7.68 ± 5%
Np1	111 turns
Np2	55 turns
Ns1	13 turns
Ns2	6 turns
Naux	17 turns
Primary to auxiliary turn ratio	5.59 ± 5%
Primary saturation current	550 mA (@ 100 °C)
Insulation primary-secondary	AC 3 kV (1 s – 2 mA)

Figure 5. ALTAIR04-900 power supply: transformer characteristics



2 Output voltage characteristics

Figure 6 and *7* show the load and the line regulation of the output 1 when the other output is charged with 40 mA and 80 mA respectively.

All output voltages have been measured on the output connector of the board.

When the output 2 is heavy loaded and the output 1 is light loaded, V_{OUT1} increases due to the cross regulation. In any case, the voltages are within the tolerance given in the specifications.

Figure 6. Output voltage characteristics with 3V3 @ 40 mA

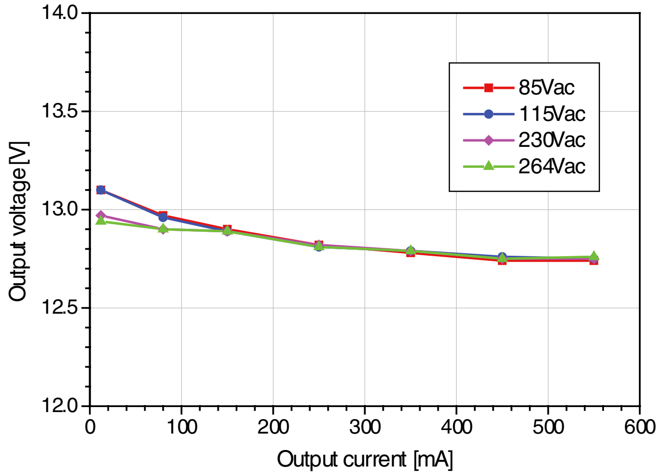
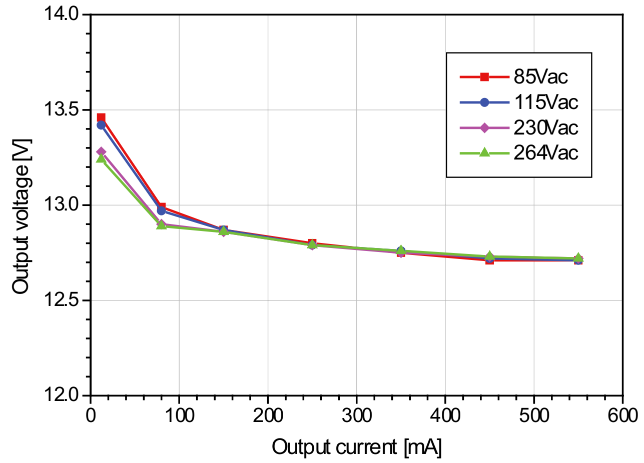


Figure 7. Output voltage characteristics with 3V3 @ 80 mA



3 Efficiency and no load measurements

In this section the converter efficiency has been measured at different output current levels on V_{OUT1} and V_{OUT2} fixed at 40 mA and 80 mA.

The figures below show the results.

Figure 8. Efficiency vs. output power with 3V3 @ 40 mA

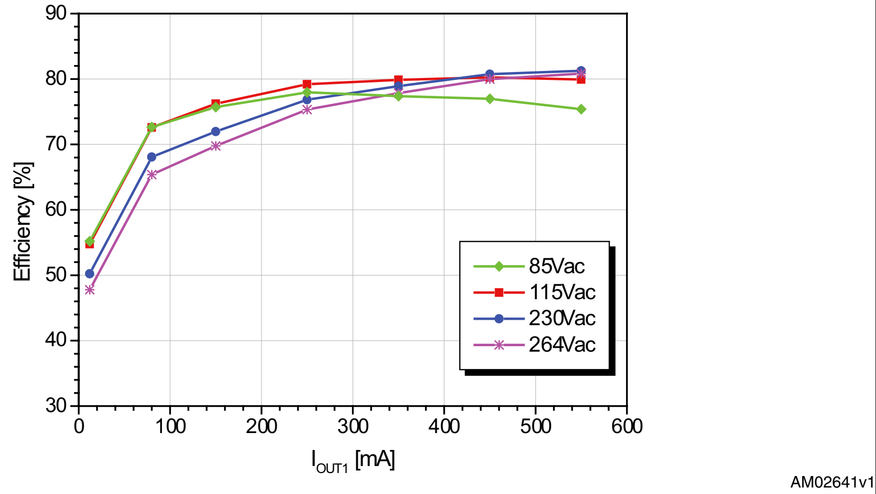
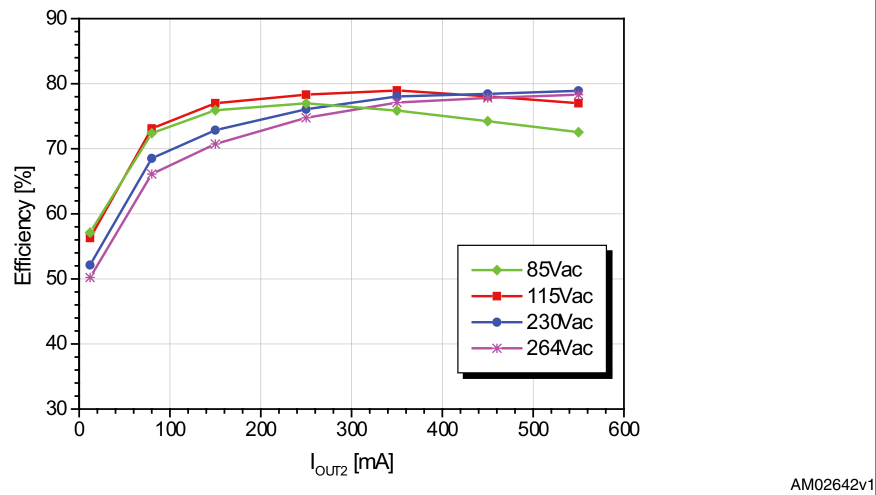


Figure 9. Efficiency vs. output power with 3V3 @ 80 mA



4 Typical board waveforms

Typical waveforms during TX mode and different input voltages are shown in this section. In this condition the load on output 1 changes from 35 to 550 mA with 1 Hz of repetition rate and 60% duty cycle. Output 2 is loaded at 100 mA.

Figures *Figure 10*, *11*, *12* and *13* show the drain voltage and drain current waveforms at different input voltage values.

Note that the maximum drain peak voltage at maximum input voltage is 576 V (*Figure 13*), ensuring a reliable operation of the MOSFET with good margin against its maximum BVDSS.

During PLM operations it is important that the output voltage remains regulated within specification limits, to ensure correct operations for the PLM power amplifier. In order to test such conditions, output 1 has been submitted to a dynamic step load according to the specifications of *Table 1* and output 2 has been loaded with different output currents, in order to simulate the widest possible operative conditions.

Results are shown in figures *13* to *21*; the output voltage is quite stable and clean with no abnormal oscillation during load changes and the steady-state values are within specification with very good margin.

Figure 10. Normal operations in TX mode at 85 V_{AC}

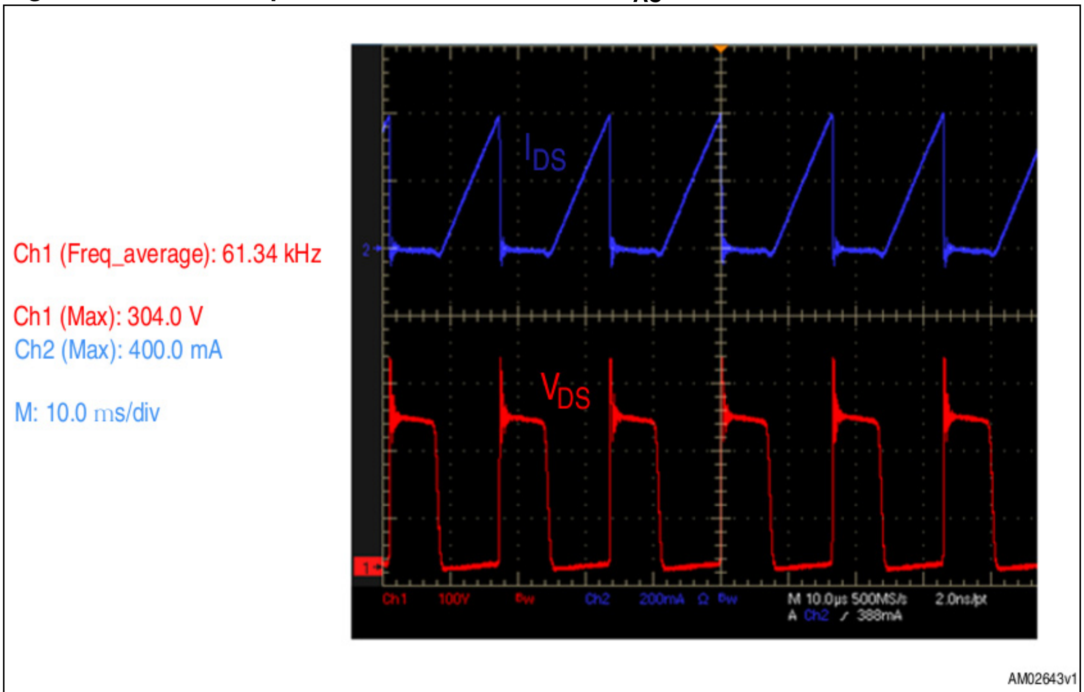


Figure 11. Normal operations in TX mode at 115 V_{AC}

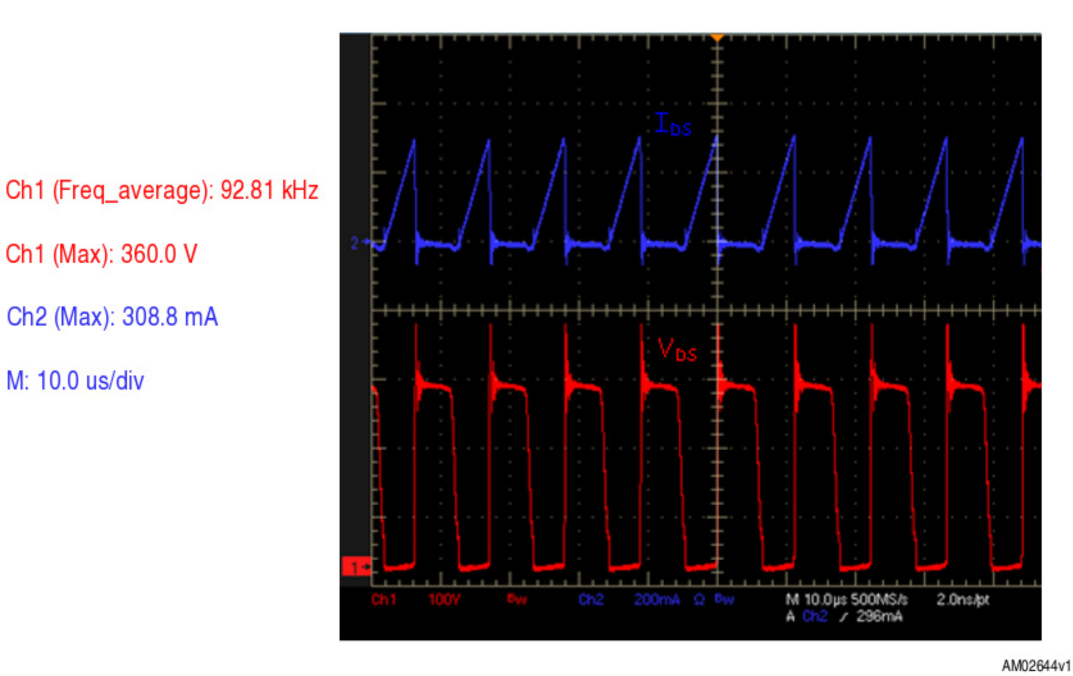


Figure 12. Normal operations in TX mode at 230 V_{AC}

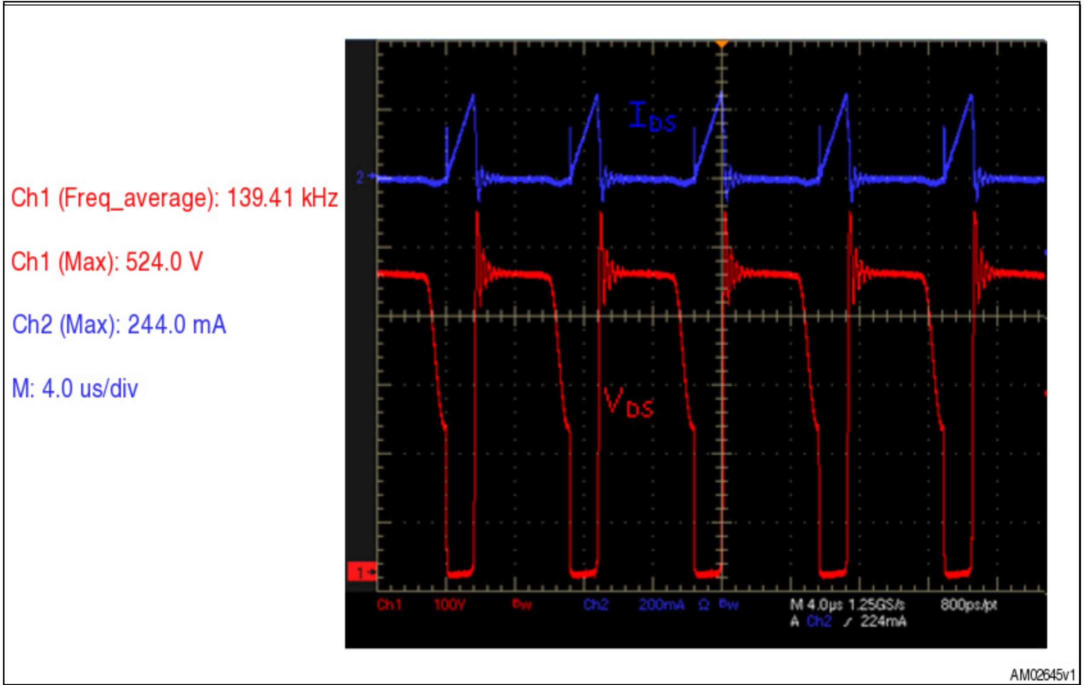


Figure 13. Normal operations in TX mode at 264 V_{AC}

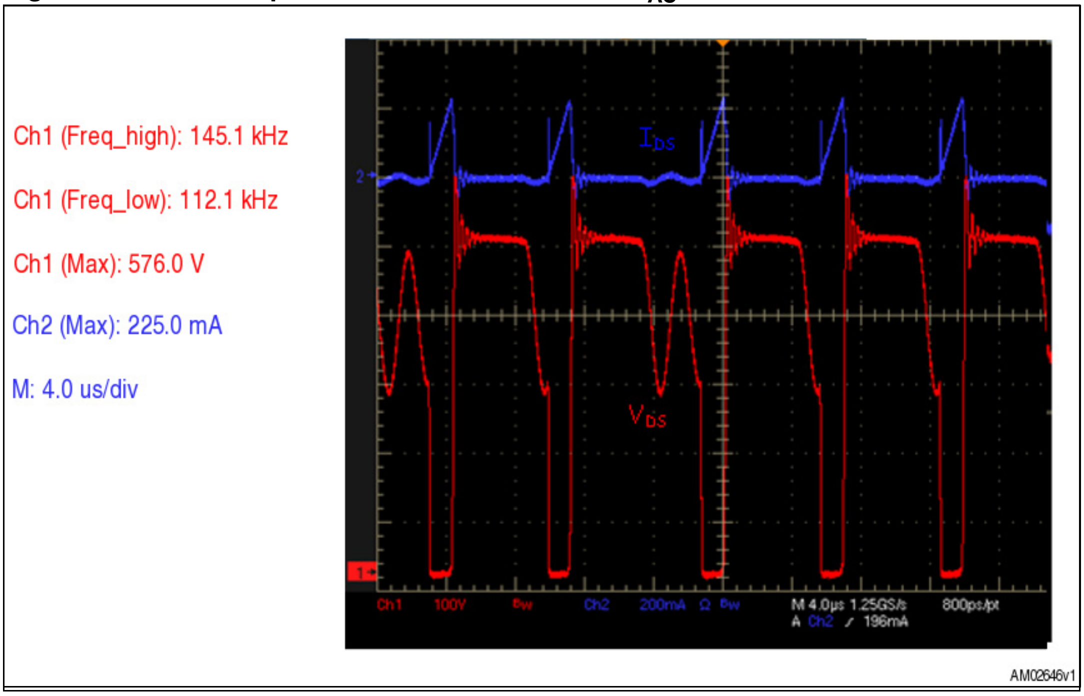


Figure 14. Normal operation in TX mode at 85 V_{AC} and I_{OUT2}=40 mA

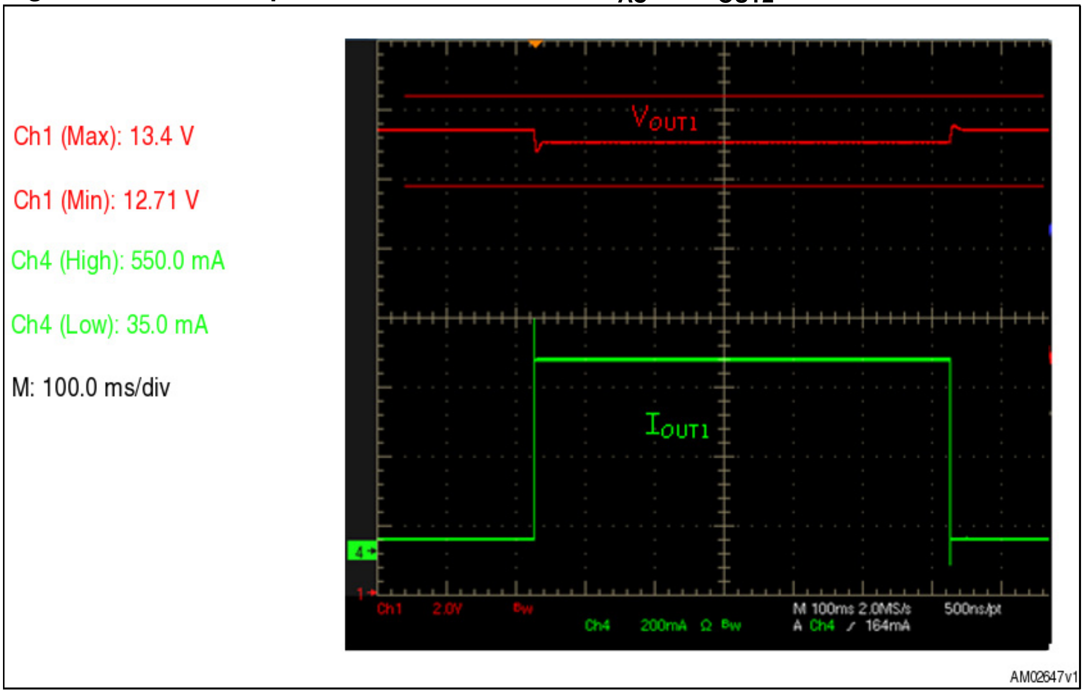


Figure 15. Normal operation in TX mode at 85 V_{AC} and I_{OUT2}=80 mA

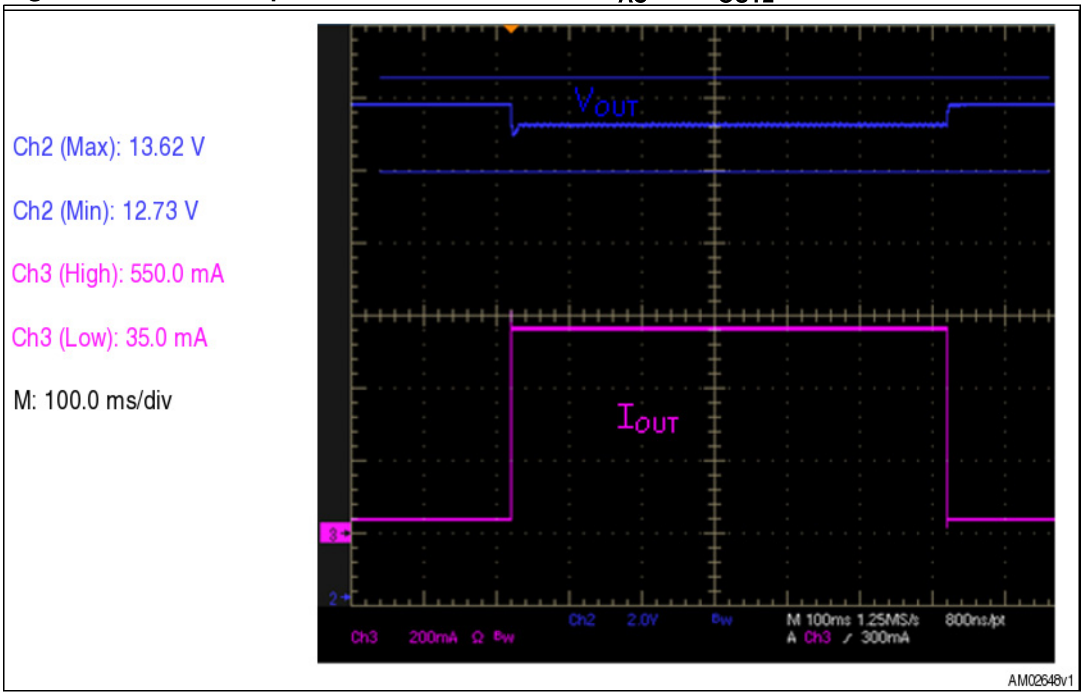


Figure 16. Normal operation in TX mode at 115 V_{AC} and I_{OUT2}=40 mA

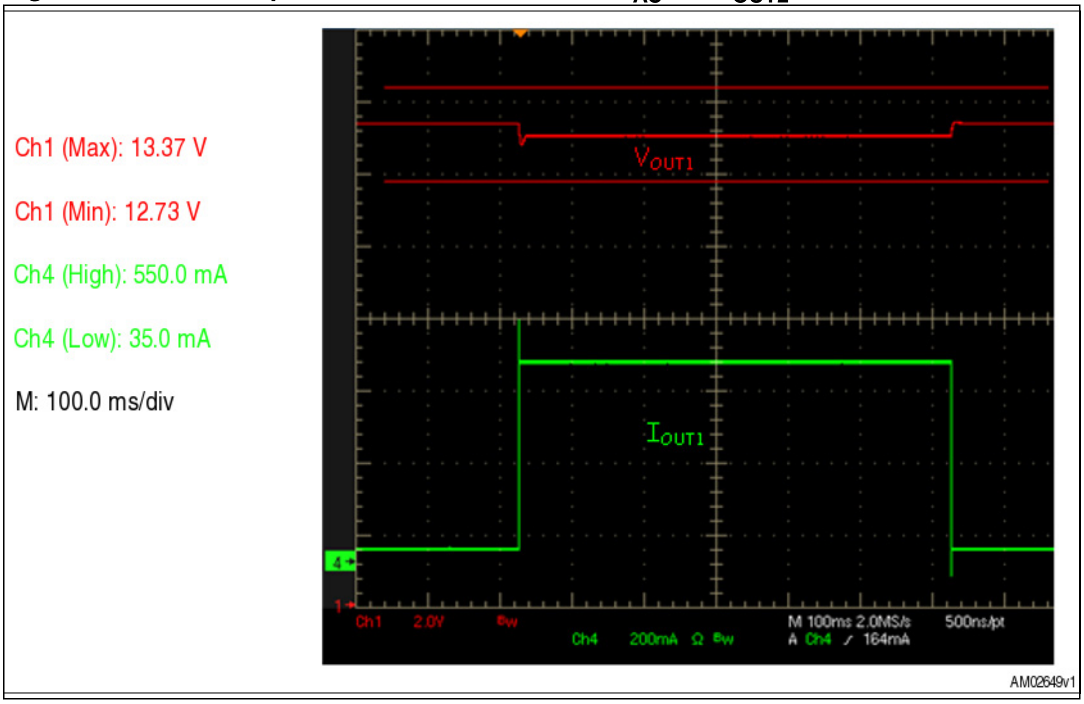


Figure 17. Normal operation in TX mode at 115 V_{AC} and I_{OUT2}=80 mA

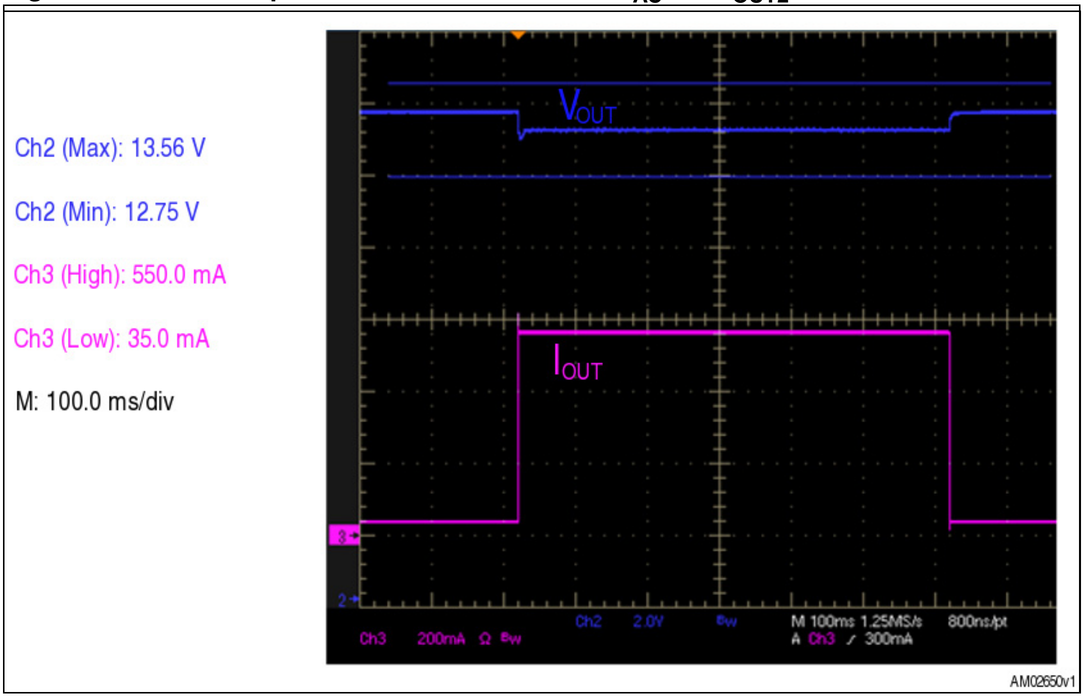


Figure 18. Normal operation in TX mode at 230 V_{AC} and I_{OUT2}=40 mA

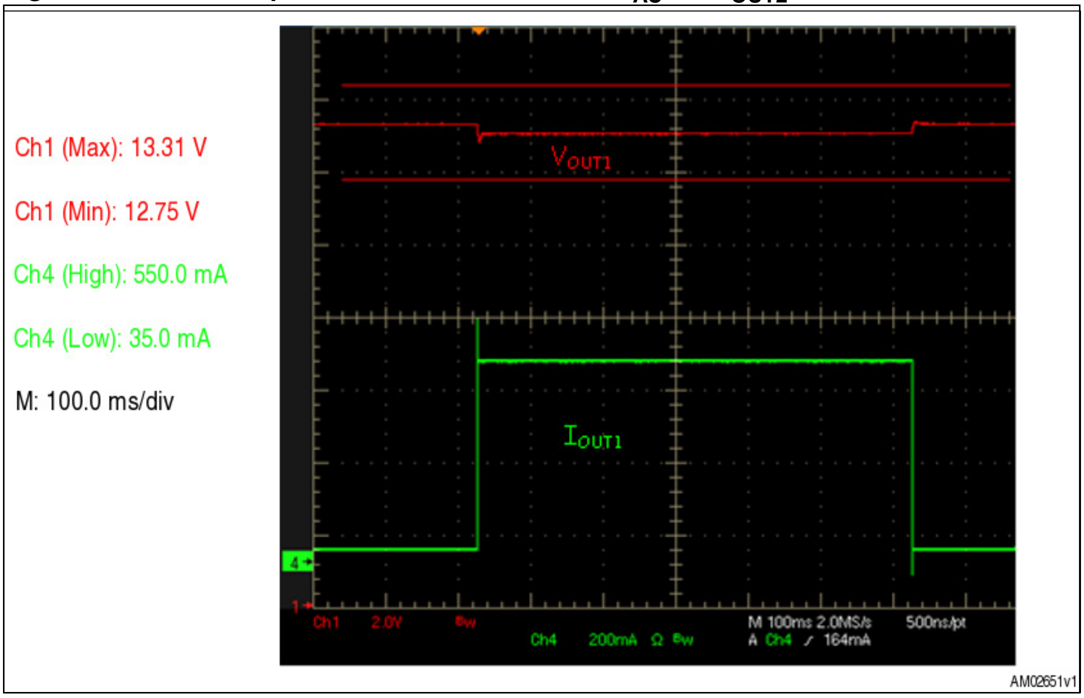


Figure 19. Normal operation in TX mode at 230 V_{AC} and I_{OUT2}=80 mA

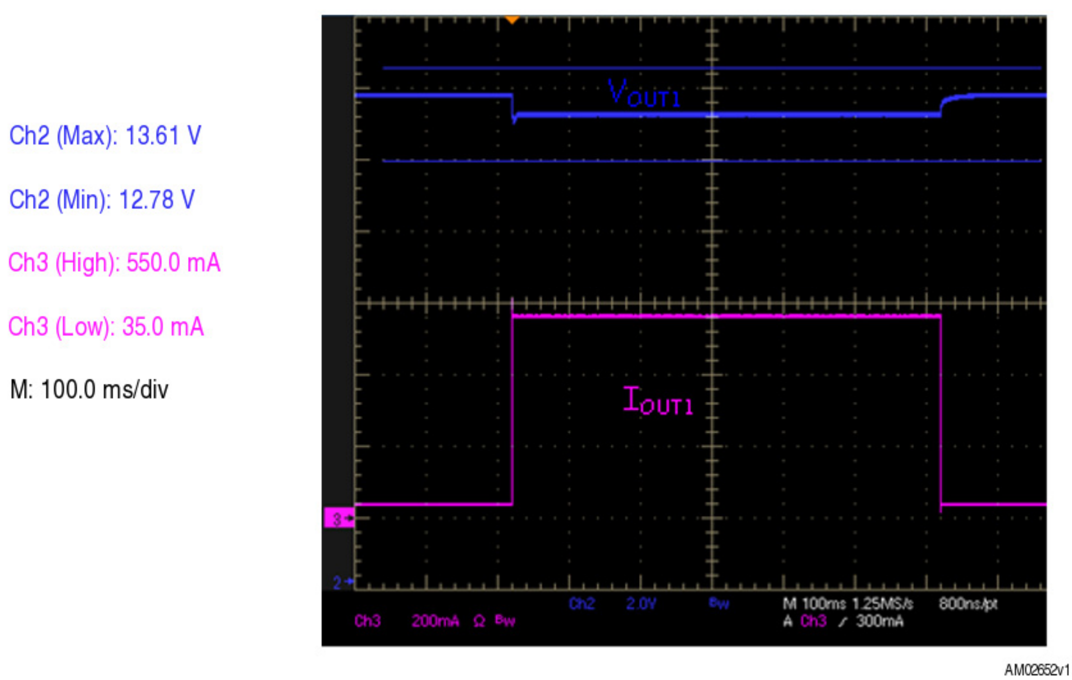


Figure 20. Normal operation in TX mode at 264 V_{AC} and I_{OUT2}=40 mA

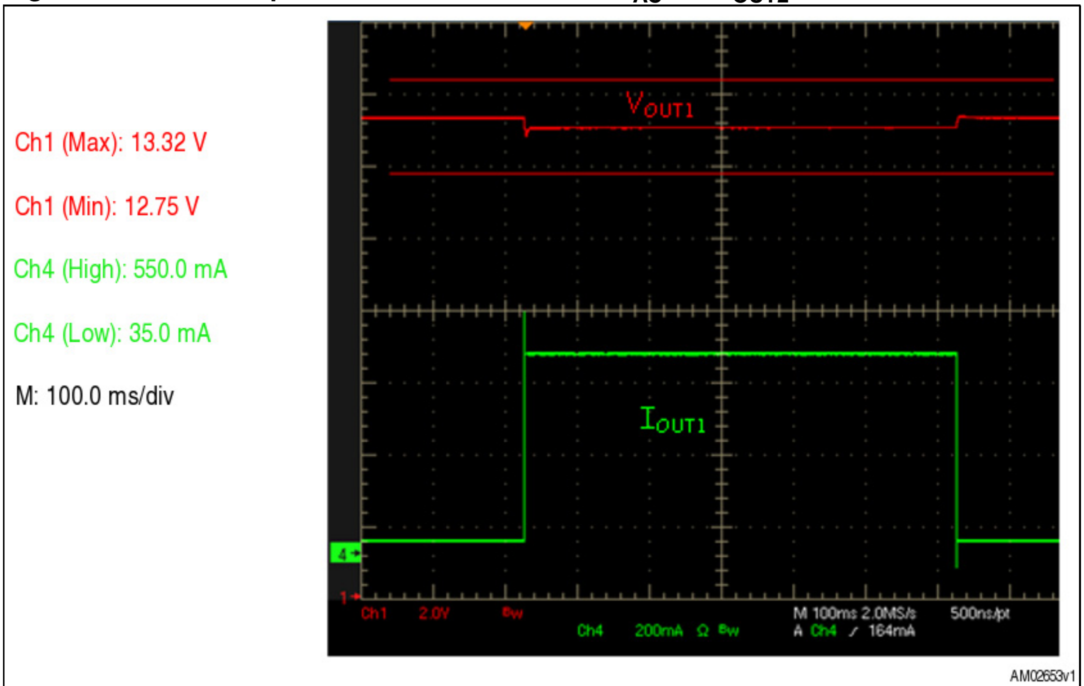
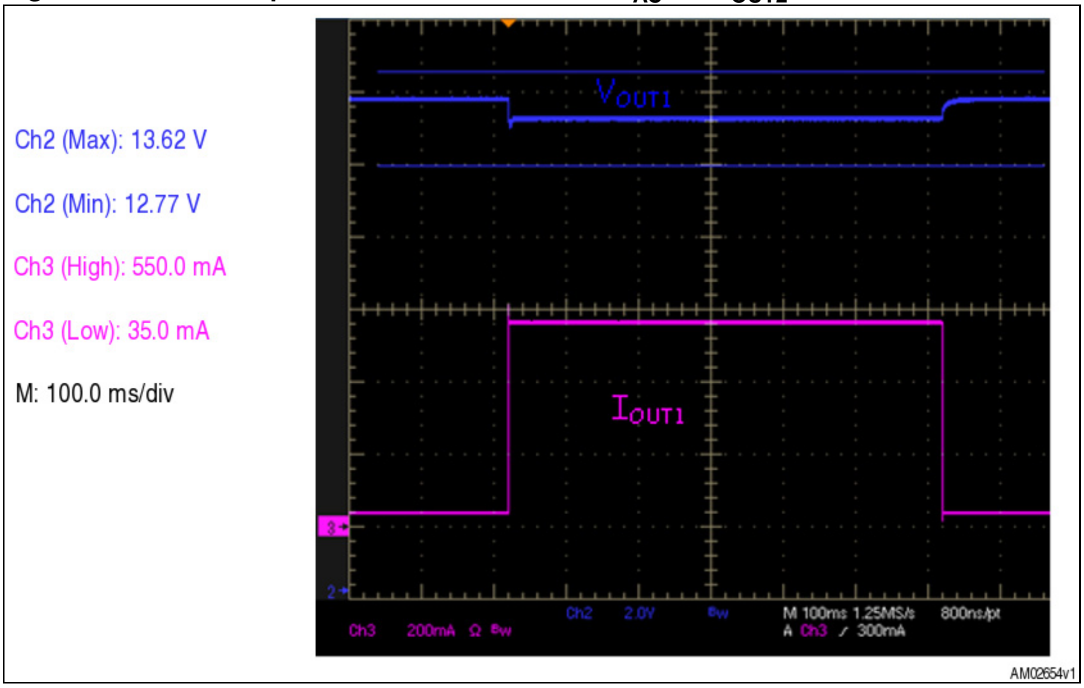


Figure 21. Normal operation in TX mode at 264 V_{AC} and I_{OUT2}=80 mA



5 Protection features

The ALTAIR04-900 has several protection features that considerably increase end-product safety and reliability: auxiliary winding disconnection (or brownout) detection, shorted secondary rectifier detection, and transformer saturation protection.

Moreover, using the primary CC loop it is possible to set the maximum deliverable output current without any secondary extra component, therefore providing a best-in-class protection against overload and short-circuit.

In the following paragraphs all protections are tested and the results are presented.

5.1 Overload and short-circuit protection

The CC mode circuitry is able to regulate the maximum deliverable output current also when the output is shorted with good precision.

This means that during short-circuit protection, the output voltage is close to zero, while the output current is fixed to a constant value close to the maximum operative output current, resulting in an extremely safe mode of operation, with no overcurrent stress on the secondary components.

At the same time, the overload also coincides with the maximum operative output current.

Figures *22* and *23* show the drain voltage and the output current waveforms at different input voltage values and output 1 shorted.

Figure 22. Short-circuit mode: 13 V shorted at 115 V_{AC}

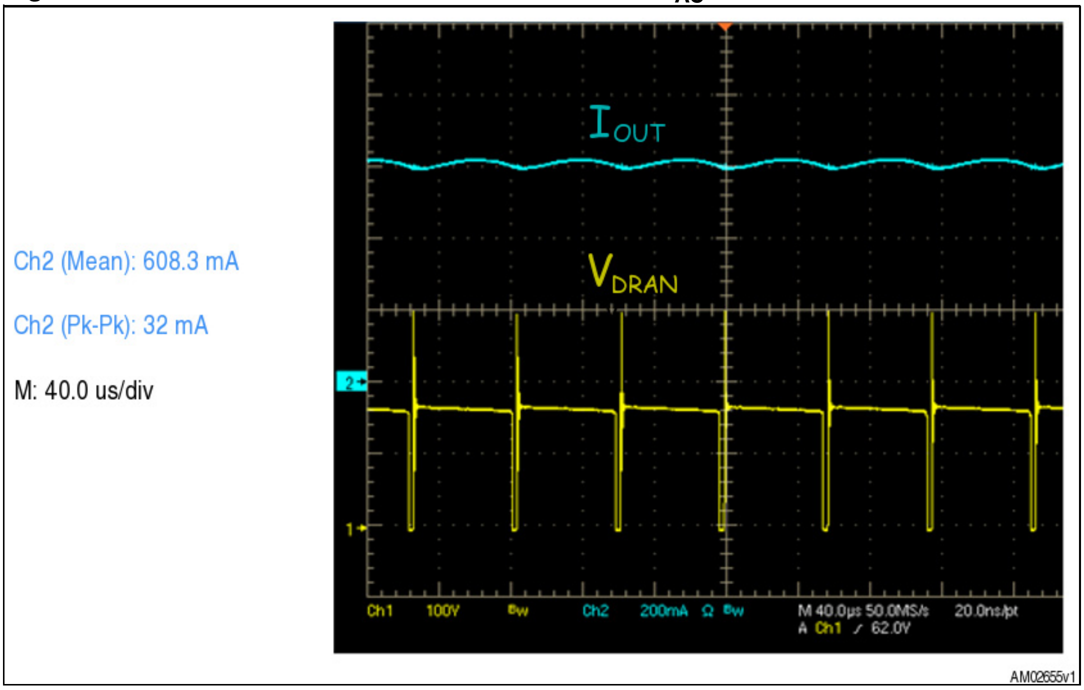
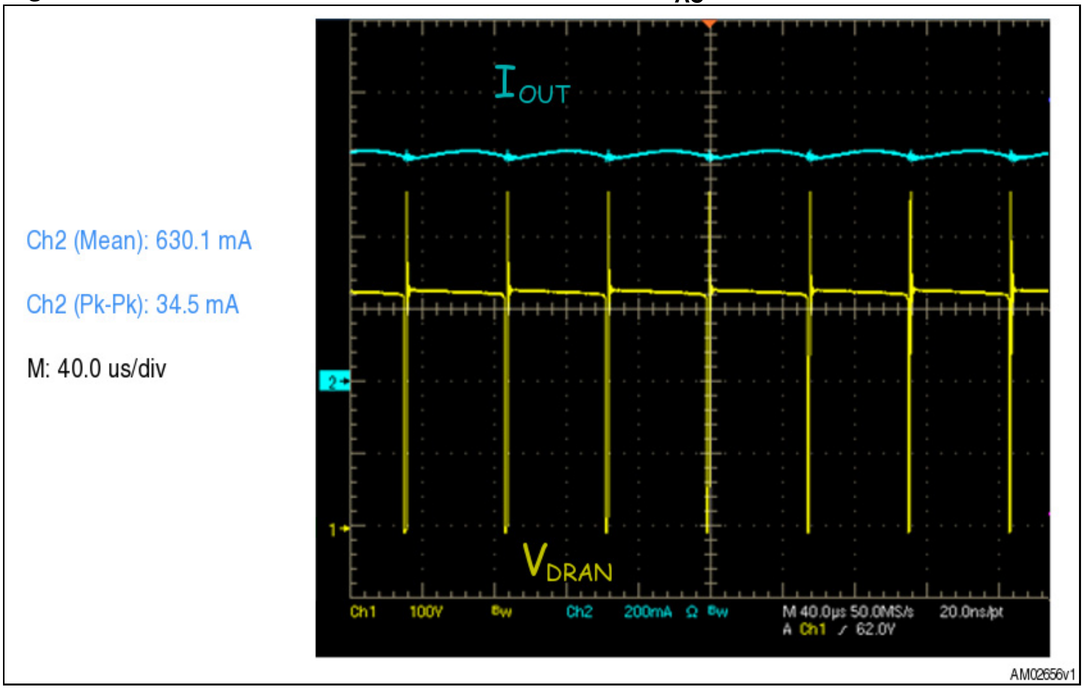


Figure 23. Short-circuit mode: 13 V shorted at 230 V_{AC}



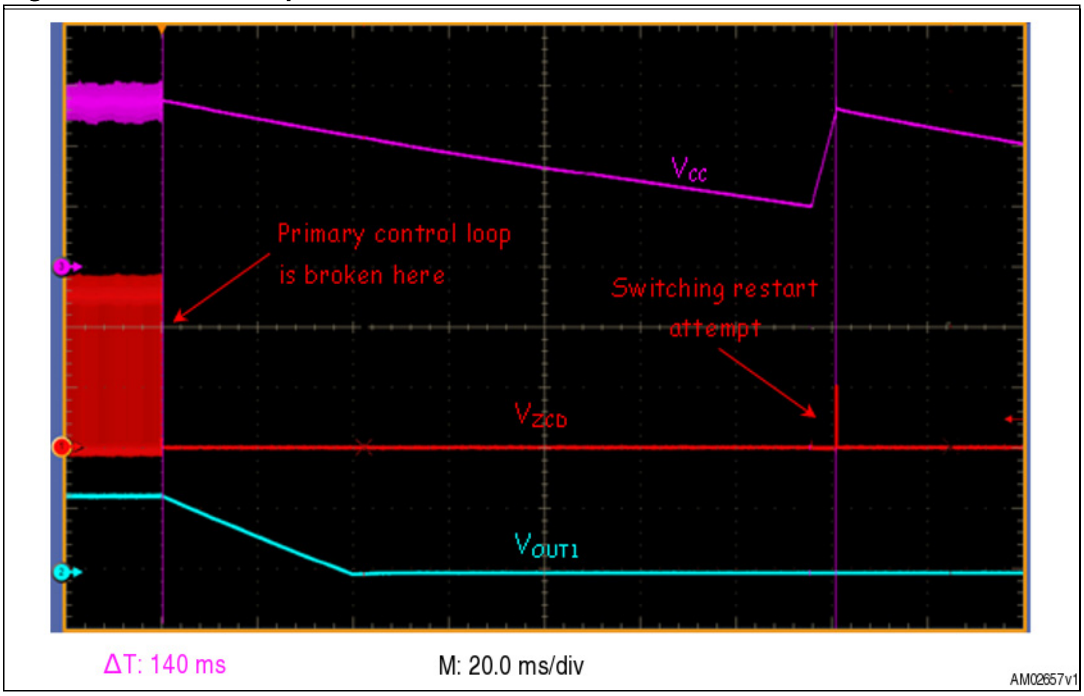
5.2 Auxiliary winding disconnection (brownout)

At any switching cycle, the current sourced from the ZCD pin during turn-on is sensed and compared with an internal reference, IZCDON (50 µA).

When the auxiliary winding is accidentally disconnected, no more current is sourced from the pin and the IC enters brownout, therefore, immediately stopping switching. After restart, once V_{CC} reaches the V_{CCon} threshold, the device restarts again and, if the fault is still present, the protection is maintained active.

This feature has been tested and the results are shown in *Figure 24*.

Figure 24. Brownout protection activation



5.3 Secondary winding short-circuit and transformer saturation protection

The ALTAIR04-900 is equipped with a hiccup mode overcurrent protection level.

If the voltage on the SOURCE pin exceeds the V_{CSdis} level (1 V typ.), it means the primary drain current exceeds the value $1/R_{SENSE}$ (where R_{SENSE} is set according to the total output power requirement), the device enters a warning state. If, at the next switching cycle, the hiccup mode level is exceeded again, the device assumes that a secondary winding short-circuit or a hard saturation of the transformer has occurred, so the device stops operating and the MOSFET is no longer allowed to switch on.

In order to enable the MOSFET to switch on again, the V_{CC} voltage must be recycled. That is, V_{CC} must go down to $V_{CCrestart}$, then rise up to V_{CCon} and the MOSFET switching can restart.

Of course, if the cause of the hiccup mode overcurrent protection activation is not removed, the device again enters auto-restart mode.

Thanks to the extremely low fault quiescent current value, the restart repetition rate is extremely low, resulting in very safe and reliable protection.

This protection was tested on the demonstration board. The secondary winding of the transformer was shorted in different operating conditions. Figures 25 to 28 show the behavior of the system during fault.

Figure 25. Hiccup mode OCP: protection tripping at V_{IN}=115 V_{AC} and full load

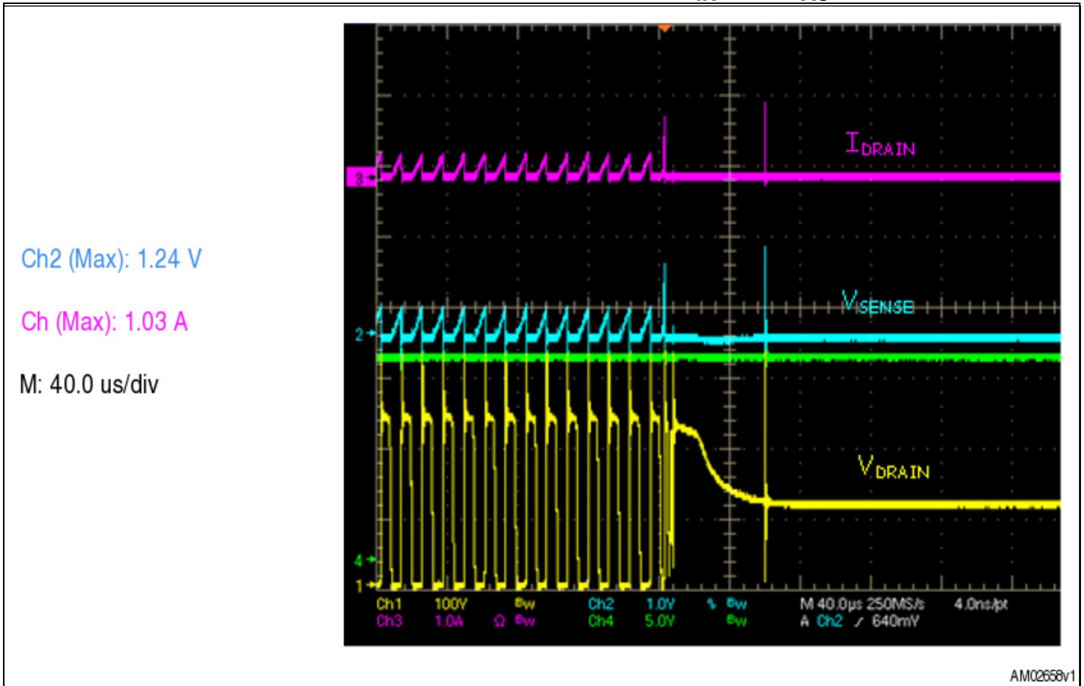


Figure 26. Hiccup mode OCP: protection tripping at V_{IN}=230 V_{AC} and full load

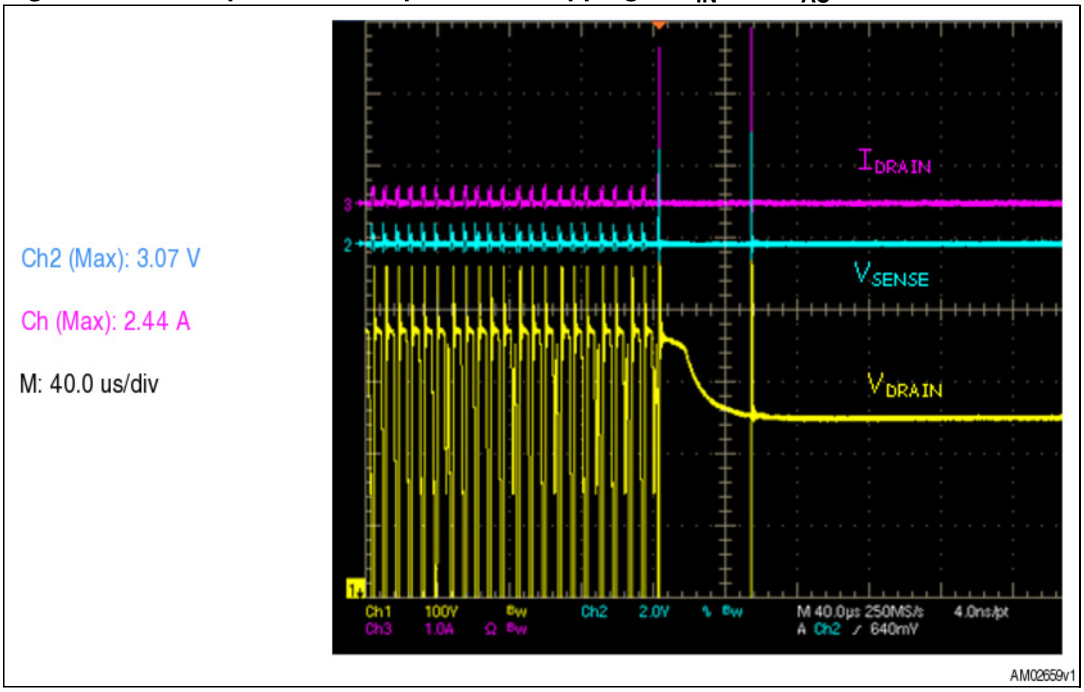


Figure 27. Hiccup mode OCP: operating condition at V_{IN}=115 V_{AC}

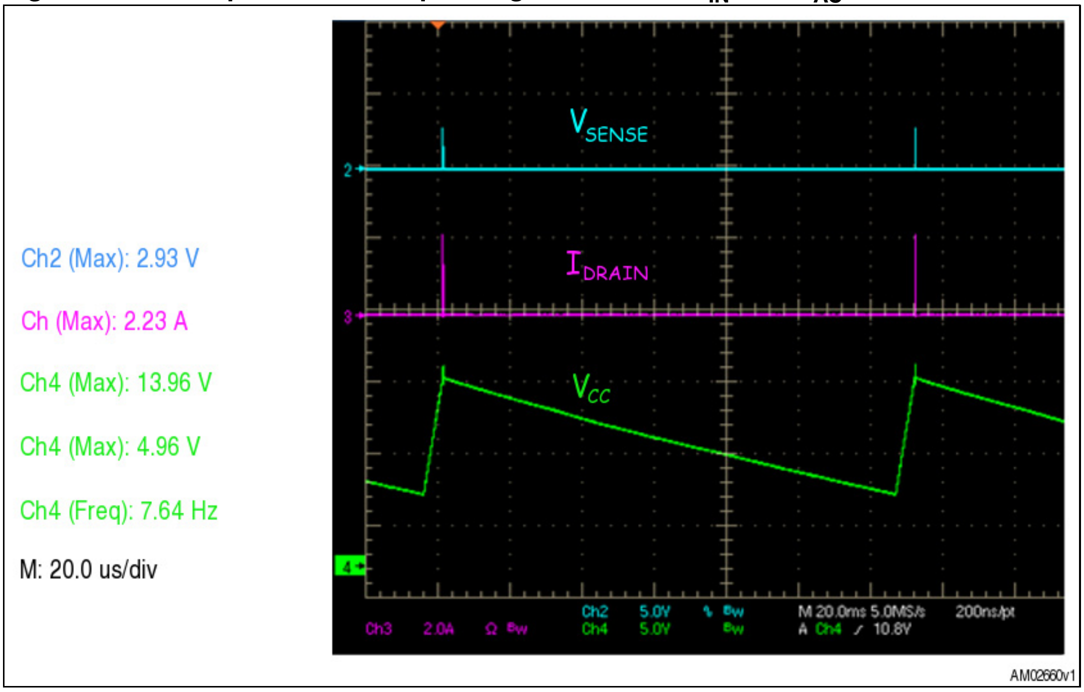
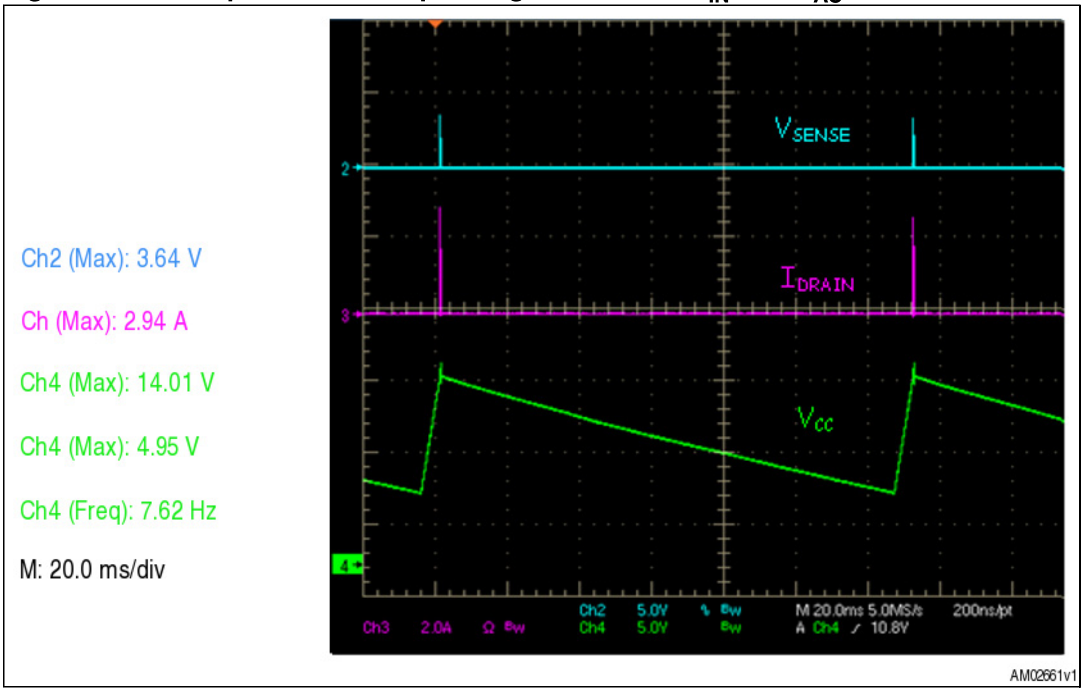


Figure 28. Hiccup mode OCP: operating condition at V_{IN}=230 V_{AC}



6 Conducted noise measurements

One of the main benefits of the quasi-resonant mode of operation concerns conducted EMI emissions. In mains operated applications, due to the ripple appearing across the input bulk capacitor, the switching frequency is modulated at twice the mains frequency with a depth depending on the ripple amplitude. This causes the spectrum to be spread over frequency bands, rather than being concentrated on single frequency values. Especially when measuring conducted emissions with the average detection method, the level reduction can be several dBµV.

A pre-compliance test for EN55022 (Class B) European normative was also performed and the average measurements of the conducted noise emissions at full load and nominal mains voltages (both line and neutral) are shown in figures 29 to 32. As seen in the diagrams, in all test conditions there is a good margin for the measurements with respect to the limits.

Figure 29. CE average measurement at 115 V_{AC} and full load: line

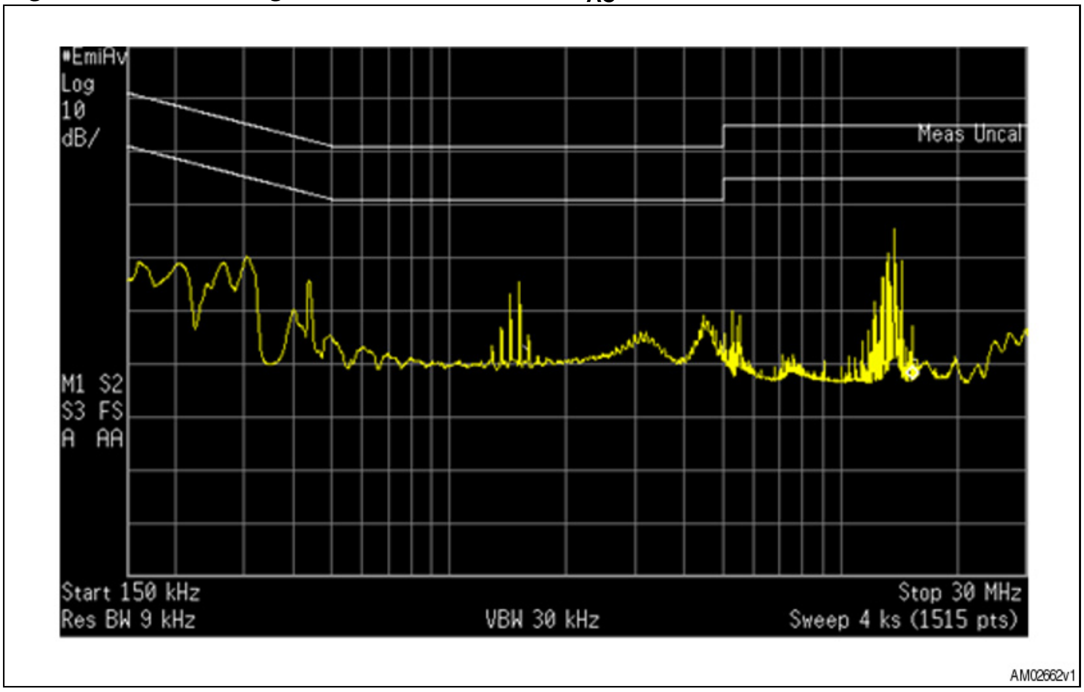


Figure 30. CE average measurement at 115 V_{AC} and full load: neutral

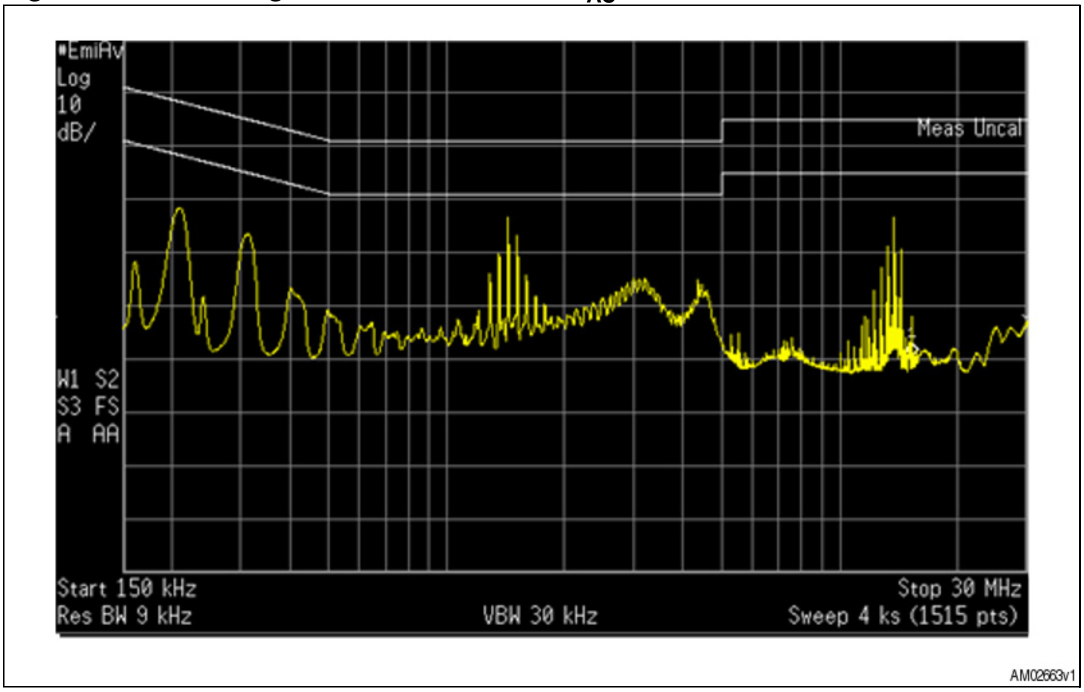


Figure 31. CE average measurement at 230 V_{AC} and full load: line

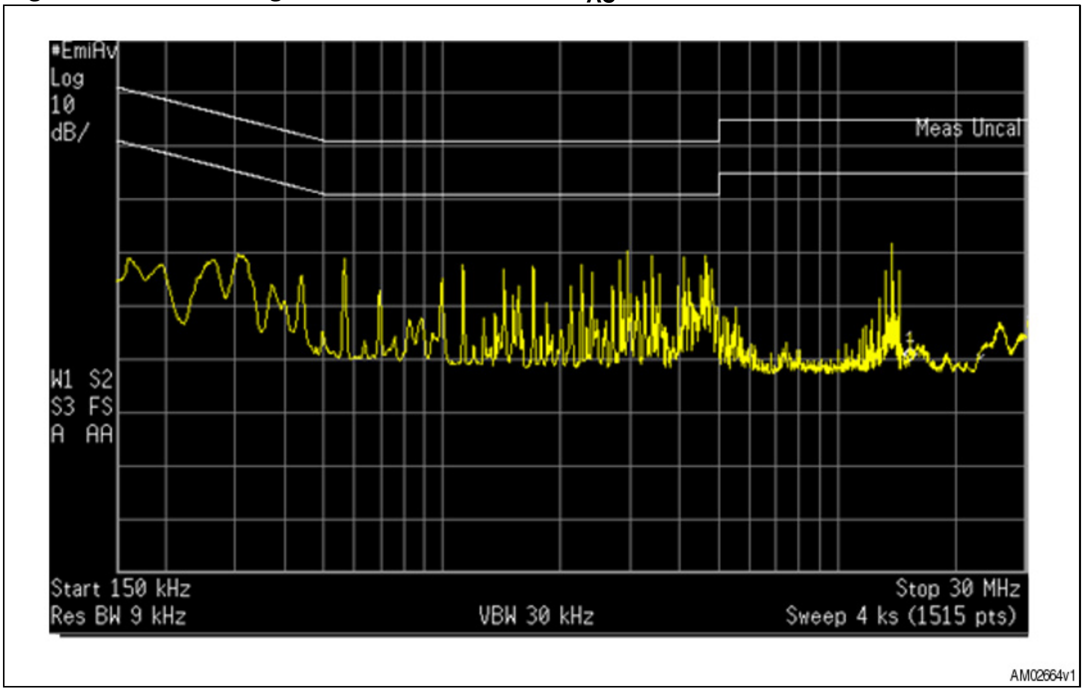
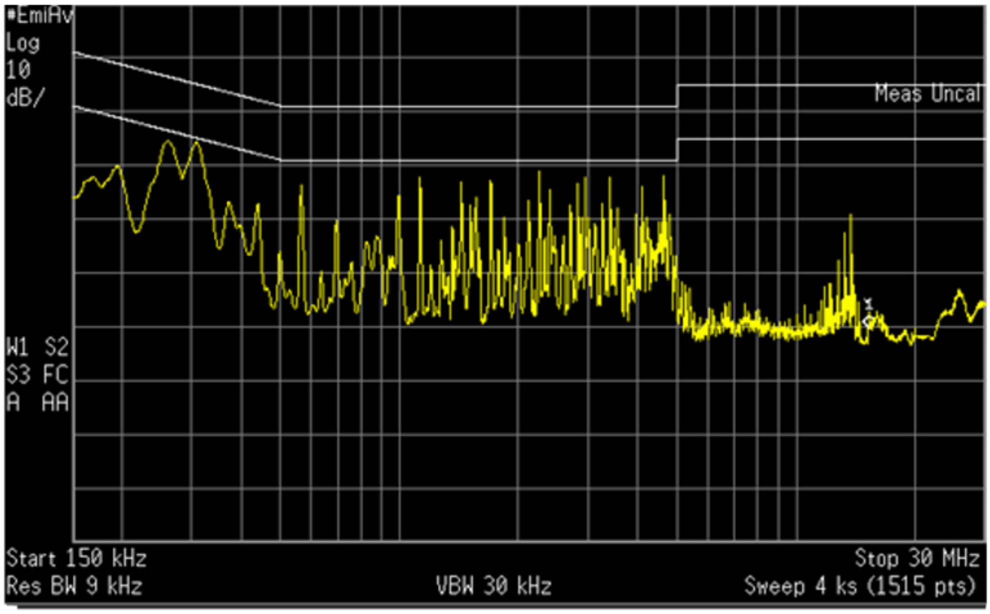


Figure 32. CE average measurement at 230 V_{AC} and full load: neutral



7 Modifications for ultra wide-range operations

Although the board has been developed in wide-range up to 264 V_{AC}, it can be easily modified in order to sustain ultra wide-range operation, up to 440 V_{AC}, with minimum parts modification, thanks to the 900 V rated power section B_{VDss} of the ALTAIR04-900.

In *Figure 33* the modified schematic is shown; the modifications mainly involve the input stage, which must be designed in order to meet the 440 V_{AC} operations. Also the diodes D3, D4, and D5 must be replaced in order to sustain the higher peak reverse voltage. No modifications are needed for the transformer and the IC.

The modified components are listed in the bill of material in *Table 4*; for other parts not specified in this table, the bill of material in *Table 2* is still valid.

Figure 33. Electrical schematic for 440 V_{AC} input voltage option

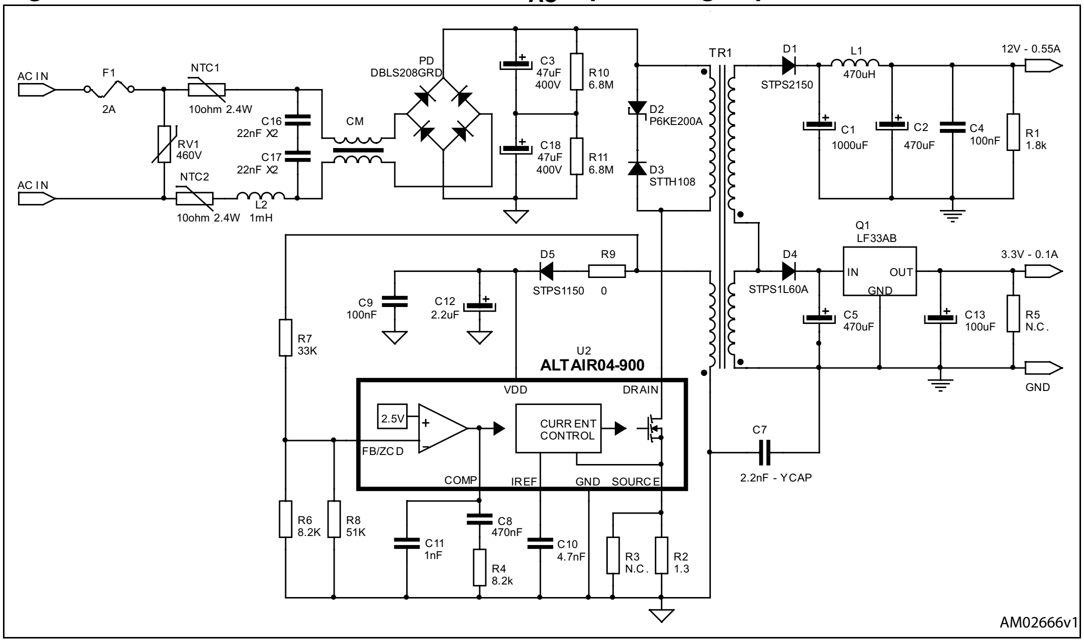


Table 4. ALTAIR04-900 power supply: bill of material for 440 V_{AC} input voltage option

Reference	Part	Description	Note
R10, R11		6.8 MΩ	
C3, C18		47 µF 350 V electrolytic	
C16, C17		22 nF - X2	
D3	STTH108	Ultra-fast high voltage diode	STMicroelectronics
D4	STPS1L60A	Power Schottky diode	STMicroelectronics
D5	STPS1150	Power Schottky diode	STMicroelectronics
PD	DBLS208G RD	Input bridge rectifier	Taiwan Semiconductor
NTC1, NTC2	B57236S0100M	10 Ω NTC inrush current limiter	EPCOS
RV1	B72214S0461K	460 V Varistor	EPCOS

Note: If not otherwise specified, all resistors are 5%, ¼ W.

8 Conclusions

A double-output flyback converter using the new ALTAIR04-900, specifically designed for power line modem systems based on ST7580 (by STMicroelectronics), has been introduced and the results are presented.

The demonstration board shows good performances in terms of load and line regulation and the overall efficiency is very good also at light load conditions.

The pre-compliant tests on conducted noise show that the QR mode of operation of the IC helps to meet the standards, therefore it is possible to reduce the size and the cost of the EMI filter compared to a fixed frequency IC.

The all-primary sensing control loop circuitry makes this device very competitive in terms of performance and price thanks of the absence of the optocoupler and any specific secondary circuitry for CV regulation and overload protection, including a secondary voltage reference and sense resistor.

Moreover, the 900 V avalanche-rugged power section, and the several protections that this device has onboard, makes this IC the device of choice for energy metering, 3-phase auxiliary power supplies and for all applications where the ultra wide-range is required.

9 Demonstration tools and documentation

The ALTAIR04-900 demonstration board order code is: EVLALTAIR900-M1.

In order to get a complete PLM system, the power supply can be connected with the EVALKITST7580-1.

Further information about these products are available in the ALTAIR04-900 datasheet at www.st.com.

10 Revision history

Table 5. Document revision history

Date	Revision	Changes
26-Apr-2011	1	Initial release