AN4878
Application note

STEVAL-ISA175V1 three-output isolated flyback converter for smart meter and power line communication systems based on VIPER26HD

Introduction

The STEVAL-ISA175V1 evaluation board implements a three output isolated flyback specifically designed to supply the STCOMET smart meter and power line communication system.

The board is developed using the VIPER26HD offline high-voltage converter by STMicroelectronics. The device features an 800 V avalanche-rugged power section, PWM operation at 115 kHz with frequency jittering for lower EMI, current limiting with adjustable set point, on-board soft-start, safe auto-restart after a fault condition and low standby power.

The power supply provides 15 V @ 550 mA_{rms} (700 mA peak) to the power line modem (PLM) and the analog circuitry, a post-regulated 5 V @ 100 mA and a 3.3 V @ 200 mA supply through a dedicated DC-DC converter connected on the 15 V rail for digital circuitry and other low voltage parts.

Although the power supply is designed to operate over a wide, 90-264 V_{AC} input voltage range, it can also withstand a maximum AC main up to 440 V_{AC}. The board can even operate with incorrect phase-to-phase connection in a three-phase network, though thermal performance would be worse.

The board can be used in a stand-alone configuration or with the dedicated STCOMET development kit and the PCB layout is specifically designed to fit inside a real meter.

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The STEVAL-ISA175V1 features:

- Triple output voltage: 15 V @ 0.55 A_{rms} (0.7 A peak), 3.3 V @ 200 mA and 5 V @ 100 mA
- Extended AC mains input voltage range: 90 to 264 V_{AC}
- Meets STCOMET smart meter and power line communication system specs
- EMC with EN55022, EN61000, EN61000-4-4, EN61000-4-5, EN61000-4-6
- RoHS compliant

Table 1: STEVAL-ISA175V1 board electrical specifications

Parameter	Min.	Typ.	Max.
Operative AC main input voltage	90 V_{AC}		264 V_{AC}
Overvoltage AC main			440 V_{AC}
Mains frequency	50 Hz		60 Hz
Output voltage 1 - V_{OUT1}	14 V	15 V	16 V
Output current 1 - I_{OUT1}	10 mA		550 mA (rms)
			700 mA (peak)
Output voltage 2 - V_{OUT2}	4.75 V	5 V	5.25 V
Output current 2 - I_{OUT2}	10 mA	60 mA	100 mA
Output voltage 3 - V_{OUT3}	3.1 V	3.3 V	3.5 V
Output current 3 - I_{OUT3}		100 mA	200 mA
Maximum peak power			11.66 W
Maximum rms power			9.4 W
Efficiency at full load	72.48 %		
Ambient operating temperature	-40 °C		85 °C

Figure 1: Main PSU schematic

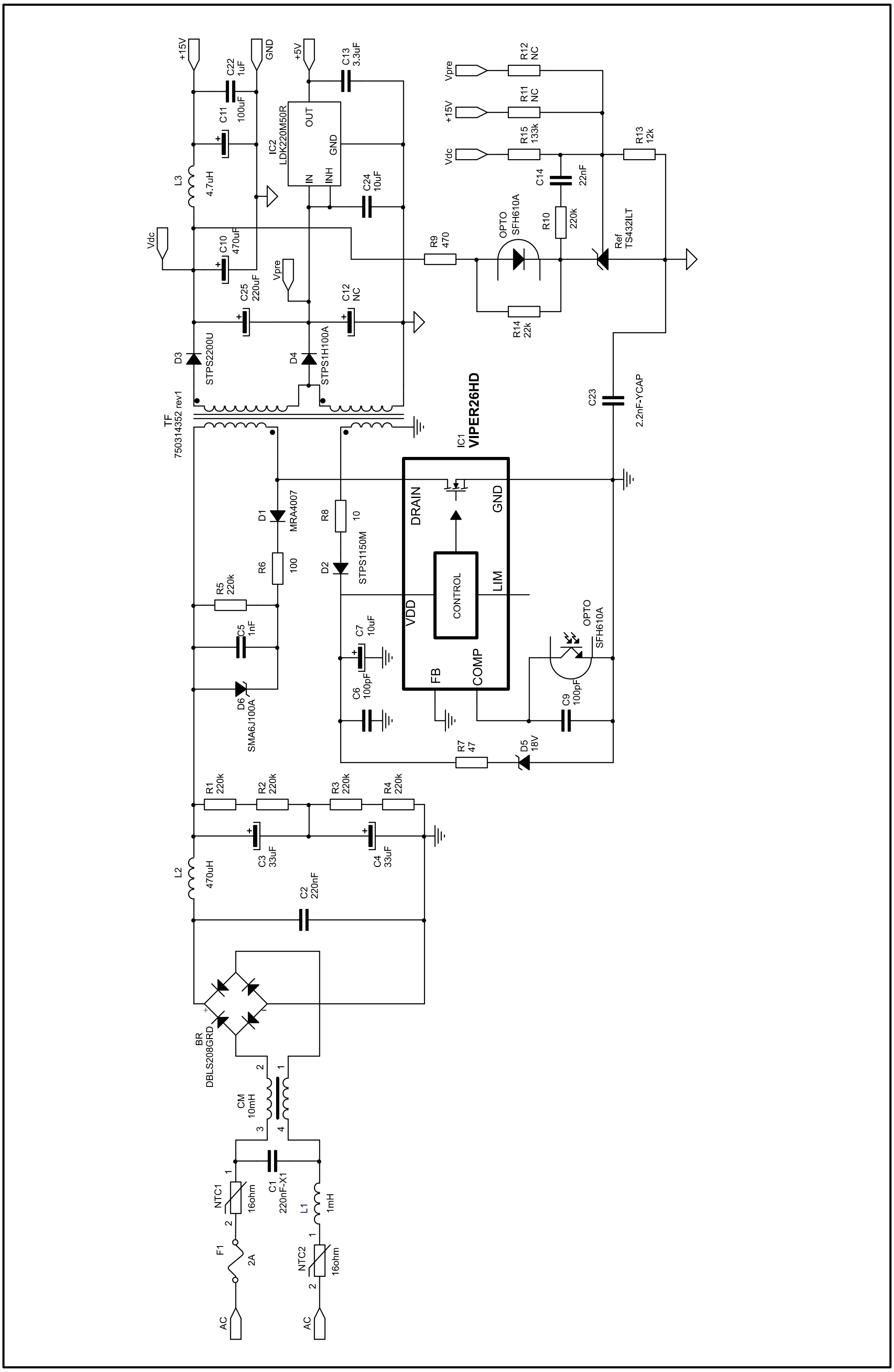


Figure 2: Dedicated DC/DC for 3V3 rail schematic

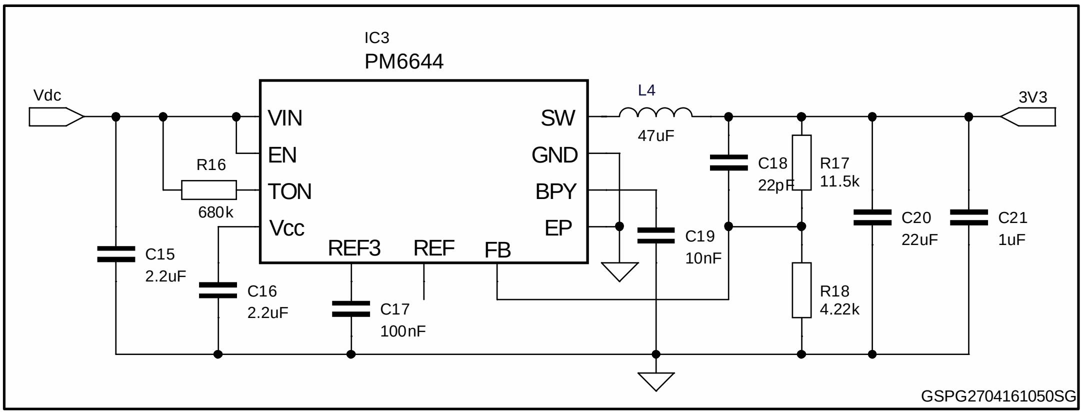


Figure 3: STEVAL-ISA175V1 board (92 x 42mm)

Figure 4: STEVAL-ISA175V1 board bottom

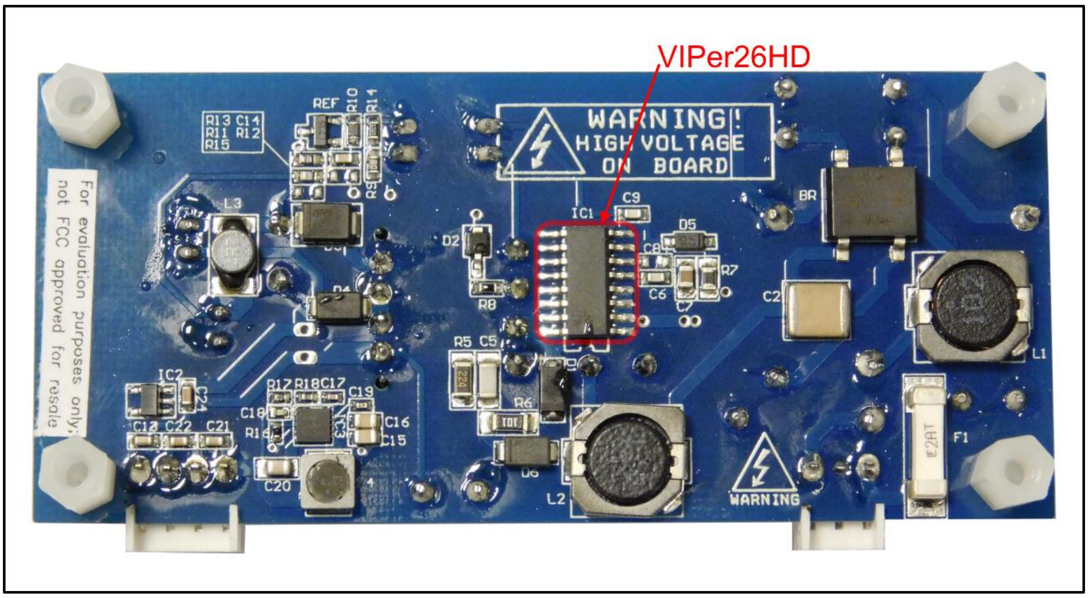


Table 2: Bill of materials

Reference	Part	Manufacturer	Description
C1	PHE844RD6220KR06L2	Kemet	X1 film capacitor 220nF-440VAC
C2	GRM55DR72J224KW01L	Murata	MLCC capacitor 220nF-630V
C3	UCY2V330MHD1TO	Nichicon	Elcap 33µF-350V
C4	UCY2V330MHD1TO	Nichicon	Elcap 33µF-350V
C5	C3216C0G2J102JT	TDK	MLCC capacitor 1nF-630V
C6	GRM1885C1H101JA01D	Murata	MLCC capacitor 100pF-50V
C7	C2012X5R1E106K125AB	TDK	MLCC capacitor 10µF-25V
C9	GRM1885C1H101JA01D	Murata	MLCC capacitor 100pF-50V
C10	25ZLH470MEFC10X12.5	Rubycon	Elcap 470µF-25V
C11	25YXF100MEFC6.3X11	Rubycon	Elcap 100µF-2V
C12	Not connected		
C13	GRM188R61A335KE15D	Murata	MLCC capacitor 3.3µF-10V
C14	GRM188R71H223KA01D	Murata	MLCC capacitor 22nF-50V
C15	C1608X5R1V225K080AC	TDK	MLCC capacitor 2.2µF-35V
C16	C1608X5R1V225K080AC	TDK	MLCC capacitor 2.2µF-35V
C17	C1005X5R1H104K050BB	TDK	MLCC capacitor 100nF-50V
C18	VJ0402A220JNAAJ	Vishay	MLCC capacitor 22pF-50V
C19	GRM155R71H103KA88D	Murata	MLCC capacitor 10nF-50V
C20	GRM21BR60J226ME39L	Murata	MLCC capacitor 22µF-6.3V
C21	GRM188C81E105KAADD	Murata	MLCC capacitor 1µF-25V
C22	GRM188C81E105KAADD	Murata	MLCC capacitor 1µF-25V
C23	DE2E3KY222MA2BM01	Murata	Ceramic Y-cap 2.2nF 250Vac
C24	GRM188R61E106MA73J	Murata	MLCC capacitor 10µF-25V
C25	25PK220MEFC6.3X11	Rubycon	Elcap 220µF-25V
D1	MRA4007T3G	ON Semiconductor	1A-1000V Power rectifier diode
D2	STPS1150M	STMicroelectronics	Power schottky 150V-1A
D3	STPS2200U	STMicroelectronics	Power schottky 200V-2A
D4	STPS1H100A	STMicroelectronics	Power schottky 100V-1A
D5	MMSZ5248B-V-GS08	Vishay	Zener diode 18V-0.5W
D6	SMA6J100A-TR	STMicroelectronics	100V Transil
L1	7447713102	Wurth Elektronik	1mH Shielded Power inductor
L2	7447713471	Wurth Elektronik	470µH Shielded Power inductor
L3	74455047	Wurth Elektronik	4.7µH Power inductor
L4	744043470	Wurth Elektronik	47µH Shielded Power inductor
CM	744821110	Wurth Elektronik	10mH Common Mode choke

Reference	Part	Manufacturer	Description
R1	ERJ-P08J224V	Panasonic	220kΩ±1% - 0.33W - 200V
R2	ERJ-P08J224V	Panasonic	220kΩ±1% - 0.33W - 200V
R3	ERJ-P08J224V	Panasonic	220kΩ±1% - 0.33W - 200V
R4	ERJ-P08J224V	Panasonic	220kΩ±1% - 0.33W - 200V
R5	ERJ-P08J224V	Panasonic	220kΩ±1% - 0.33W - 200V
R6	ERJP08J101V	Panasonic	100Ω±5% - 0.33W
R7	ERJP06F47R0V	Panasonic	47Ω±1% - 0.5W
R8	ERJP03F10R0V	Panasonic	10Ω±1% - 0.2W
R9	ERJ3GEYJ102V	Panasonic	1kΩ±1% - 0.1W
R10	ERJP03F1803V	Panasonic	180kΩ±1% - 0.2W
R11	CRCW0603133KFKEA	Vishay	133kΩ±1% - 0.1W
R12	Not connected		
R13	ERJ3GEYJ123V	Panasonic	12kΩ±5% - 0.1W
R14	ERJP03F1202V	Panasonic	12kΩ±1% - 0.2W
R15	Not connected		
R16	CRG0402F680K	TE Connectivity	680kΩ±1% - 1/16W
R17	CPF0402B11K5E1	TE Connectivity	11.5kΩ±0.1% - 0.1W
R18	RN73C1E4K22BTG	TE Connectivity	4.22kΩ±0.1% - 0.1W
TF	750314352 rev1	Wurth Elektronik	Flyback transformer
IC1	VIPer26HD	STMicroelectronics	High Voltage Converter
IC2	LDK220M50R	STMicroelectronics	5V LDO
IC3	PM6644	STMicroelectronics	Step down regulator
REF	TS432ILT	STMicroelectronics	Reference
OPTO	SFH610A-2	Vishay	Optocoupler
NTC1	B57236S160M	Epcos	16Ω inrush current limiter
NTC2	B57236S160M	Epcos	16Ω inrush current limiter
F1	0461002.ER	Littlefuse	2A fuse
OUT	0022152046	Molex	4-way female connector
IN	0022162030	Molex	3-way female connector

Table 3: Transformer characteristics

Manufacturer	Wurth Elektonik
Part number	750314352 rev .6A
Core	E16
Primary inductance	900 µH ±10%
Saturation current	820 mA (20% roll-off from initial)
Leakage inductance	45 µH max.
Primary-to-auxiliary turns ratio	5.63 ±1%
Primary-to-sec1 turns ratio	8.92 ±1%
Primary-to-sec2 turns ratio	11.88 ±1%

Figure 5: Transformer electrical schematic

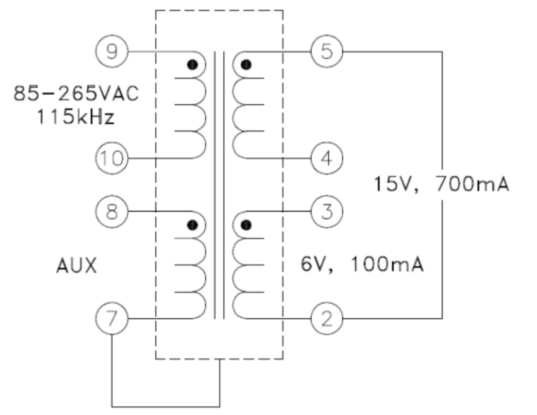


Figure 6: Transformer bottom view

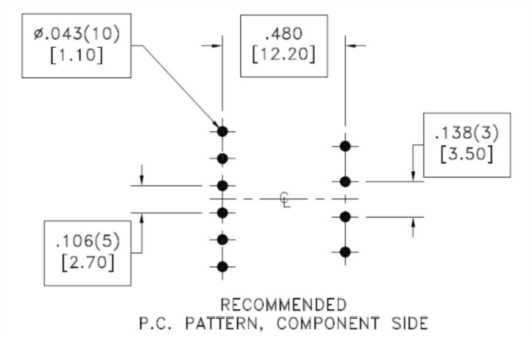
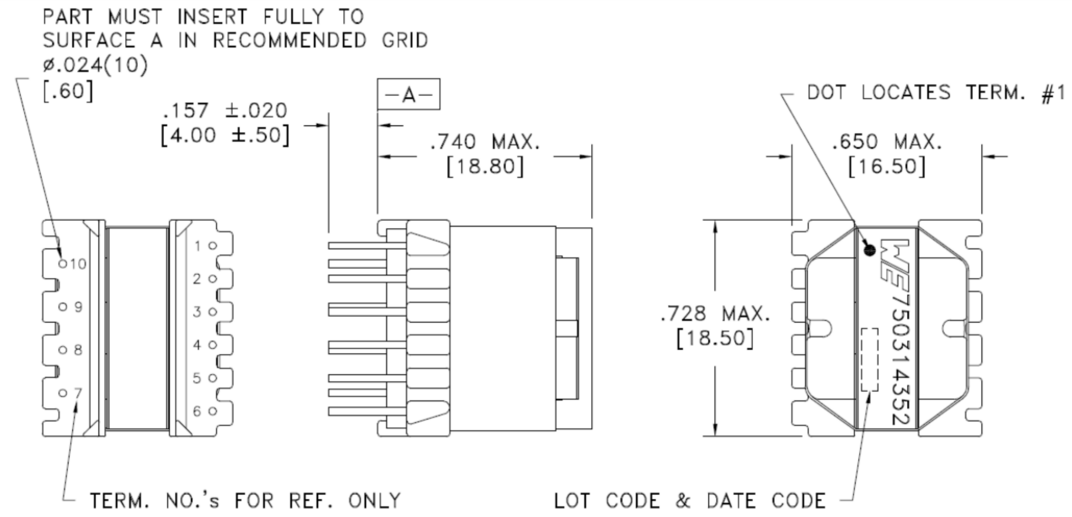


Figure 7: Transformer package schematic



2 Circuit description

2.1 Input stage and filtering

The input stage is appropriately designed to sustain operation up to 440 V_{AC}.

Fuse F1 prevents catastrophic failure and two input NTCs limit the inrush current of the capacitors at plug-in and protect the bridge rectifier (BR); the total required resistance of the NTC is halved to ensure safe operation of the NTC components without exceeding the allowed voltage rate across it.

The total bulk capacitance is achieved by two capacitors in series for a total voltage rate above the maximum operative rectified input voltage (approx. 620 V_{DC}); resistors R1 to R4 ensure equal voltage sharing between the capacitors.

Special emphasis has been placed on filtering the conducted noise of the converter to render power line communication less sensitive to the switching power supply. Both differential and common mode filtering is implemented.

2.2 Snubber network

The R5-C5-D1 clamping network limits the leakage inductance voltage spike by dissipating the related energy at MOSFET turn-off for reliable power supply operation.

Resistor R2 helps further reduce the ringing of the transformer, damping the resonance oscillations at turn-off between leakage inductance and equivalent drain capacitance.

A Transil (D6) is also used to limit the drain voltage in case of voltage exceeding the limits.

2.3 HV converter

The core of the power supply is the VIPER26HD offline high-voltage converter with 800 V avalanche-rugged power section featuring maximum $R_{DS(on)} \leq 7\ \Omega$, and a current-mode 115 kHz fixed frequency PWM controller. The device includes several other features which considerably reduce BOM cost and improve system reliability.

Regulation is achieved by adjusting the voltage on the COMP pin, which transfers output voltage information via the optocoupler. The capacitors and the pin are used for proper loop compensation.

During normal operation, the V_{DD} pin is powered by the auxiliary winding of the transformer. The output of the auxiliary winding is rectified by diode D2 and capacitor C7. Resistor R8 filters auxiliary spikes at turn-off and limits voltage fluctuation on the pin. Capacitor C6 filters any narrow voltage spikes entering the V_{DD} pin. The R7 and D5 clamp network is connected across the V_{DD} pin to avoid transient voltages exceeding the pin absolute maximum rating.

The LIM pin, which is used to adjust the cycle-by-cycle current limitation, is left floating because maximum current limitation is required.

2.4 Output stage

The secondary of the transformer is designed for a two-output option: the secondary windings are wound using a stack arrangement, in order to improve the cross regulation of the non- regulated output.

The first secondary signal is rectified by diode D3 and filtered by output capacitor C10, which is designed to ensure sufficient AC ripple capability to avoid overheating. The L3-

C11 post filter further reduces residual output ripple, while capacitor C22 further reduces output switching noise.

The other secondary signal is rectified by diode D4 and capacitor C24; as this output is not directly connected to the feedback loop, an LDO is used to provide a stable and precise +5V output.

Capacitor C25 is added between the cathodes of the diodes to further limit cross regulation between the regulated and unregulated outputs.

The output voltage is sensed by the voltage divider R15 and R13 and compared with the internal 1.24 V reference of the shunt voltage reference TS432; its output is converted, via the optocoupler, into a current signal control for the primary PWM IC.

The 3.3 V output is achieved with a step-down regulator based on the STMicroelectronics PM6644, which allows the construction of a low cost synchronous buck converter based on COT (constant on-time) architecture.

3 Performance data

3.1 Output voltage characteristics

The following tables provide board line and load regulation data, measured at the PCB output connectors for both 115 V_{AC} and 230 V_{AC}.

Table 4: Load regulation at 115 V_{AC}

I_{OUT1} [mA]	I_{OUT2} [mA]	I_{OUT3} [mA]	V_{OUT1} [V]	V_{OUT2} [V]	V_{OUT3} [V]
10	10	100	15.23	5.00	3.33
10	60	100	15.20	4.99	3.33
10	100	100	15.19	4.98	3.33
700	10	100	15.11	4.99	3.32
700	60	100	15.10	4.98	3.32
700	100	100	15.10	4.98	3.32
10	10	200	15.22	4.99	3.31
10	60	200	15.21	4.98	3.30
10	100	200	15.20	4.98	3.30
700	10	200	15.12	4.98	3.30
700	60	200	15.10	4.98	3.29
700	100	200	15.10	4.98	3.29

Table 5: Load regulation at 230 V_{AC}

I_{OUT1} [mA]	I_{OUT2} [mA]	I_{OUT3} [mA]	V_{OUT1} [V]	V_{OUT2} [V]	V_{OUT3} [V]
10	10	100	15.19	5.00	3.33
10	60	100	15.18	4.99	3.33
10	100	100	15.17	4.98	3.33
700	10	100	15.00	4.99	3.32
700	60	100	15.00	4.98	3.32
700	100	100	15.00	4.98	3.32
10	10	200	15.20	4.99	3.30
10	60	200	15.20	4.98	3.30
10	100	200	15.18	4.98	3.30
700	10	200	15.05	4.98	3.30
700	60	200	15.00	4.98	3.29
700	100	200	15.00	4.98	3.29

3.2 Efficiency and light load measurements

Converter efficiency and light load consumption are measured for 115 V_{AC} and 230 V_{AC} nominal input voltages. *Table 6: "Efficiency at typical and maximum load"* shows the converter efficiency measured under typical and maximum load conditions, while *Table 7: "Load consumption at minimum load (P_{OUT} = 0.16 W)"* shows input consumption when the power supply is loaded with the minimum loads shown in *Table 1: "STEVAL-ISA175V1 board electrical specifications"*.

Table 6: Efficiency at typical and maximum load

Output condition	Efficiency	
	115 V_{AC}	230 V_{AC}
15V at 550mA / 5V at 60mA / 3.3V at 100mA	75.94 %	78.21 %
15V at 700mA / 5V at 100mA / 3.3V at 200mA	72.65 %	76.48 %

Table 7: Load consumption at minimum load (P_{OUT} = 0.16 W)

Input voltage	Input power
115 V_{AC}	310 mW
230 V_{AC}	430 mW

4 Typical waveforms

Typical waveforms for TX mode and various input voltages are shown below, with the load on output 1 changing from 10 to 700 mA at 1 Hz repetition rate and 70% duty cycle. Output 2 and 3 are loaded at typical values (60 mA and 100 mA respectively). During PLM operation, the output voltage must remain regulated within specification limits to ensure correct PLM power amplifier operation.

Figure 8: "V_{OUT1} and I_{OUT1} under normal operation in TX mode at 115 V_{AC}" and *Figure 9: "V_{OUT1} and I_{OUT1} under normal operation in TX mode at 230 V_{AC}"* show a stable and clean output voltage with no abnormal oscillation during load changes and steady-state values well within specification.

Figure 8: V_{OUT1} and I_{OUT1} under normal operation in TX mode at 115 V_{AC}

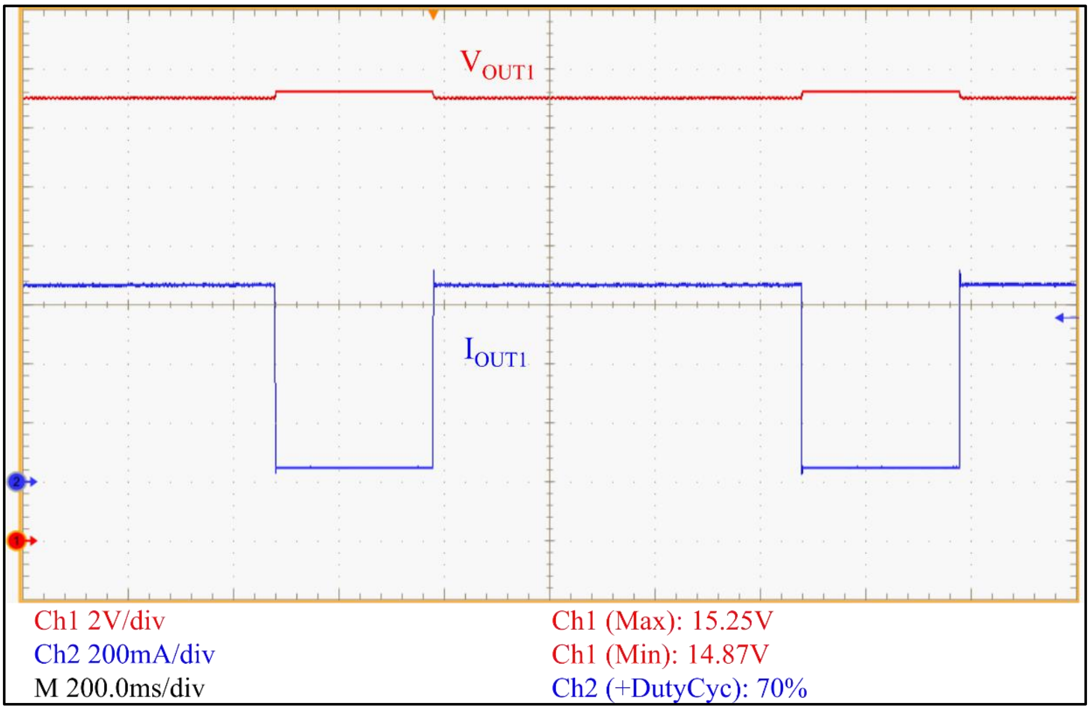


Figure 9: V_{OUT1} and I_{OUT1} under normal operation in TX mode at 230 V_{AC}

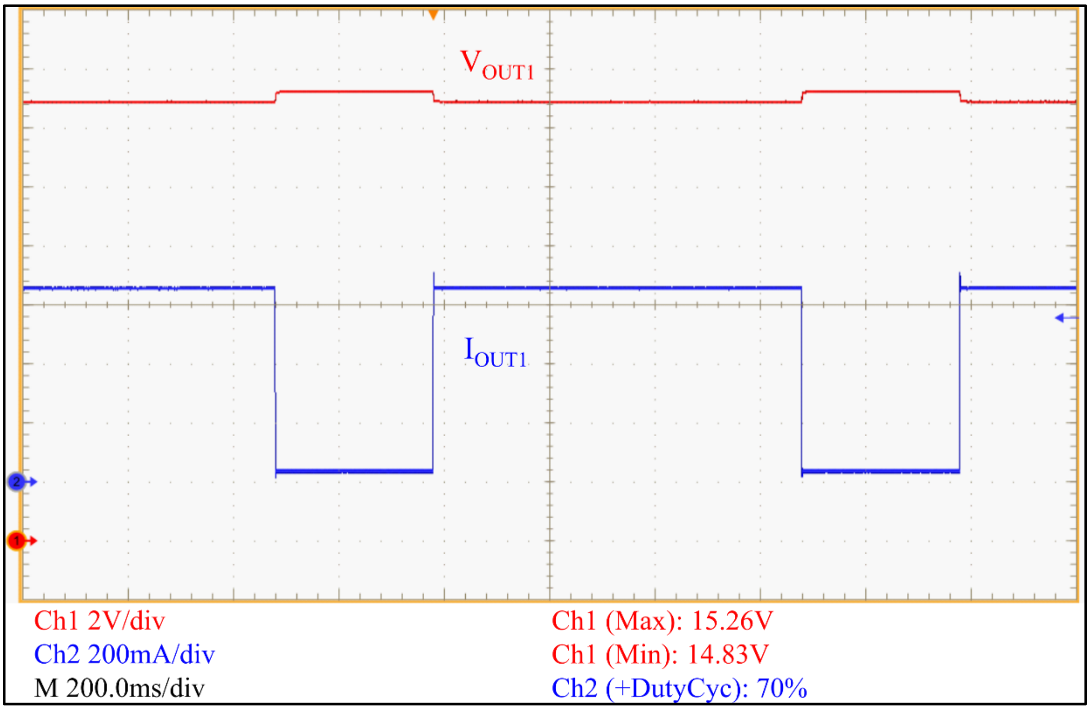


Figure 10: "V_{DS} and I_{DS} waveforms under normal operation in TX mode at 115 V_{AC}" to *Figure 12: "V_{OUT1}, V_{DS} and I_{DS} waveforms under normal operation at 440 V_{AC}"* show the drain voltage and drain current waveforms for the two nominal input voltages and 440 V_{AC}.

Figure 10: V_{DS} and I_{DS} waveforms under normal operation in TX mode at 115 V_{AC}

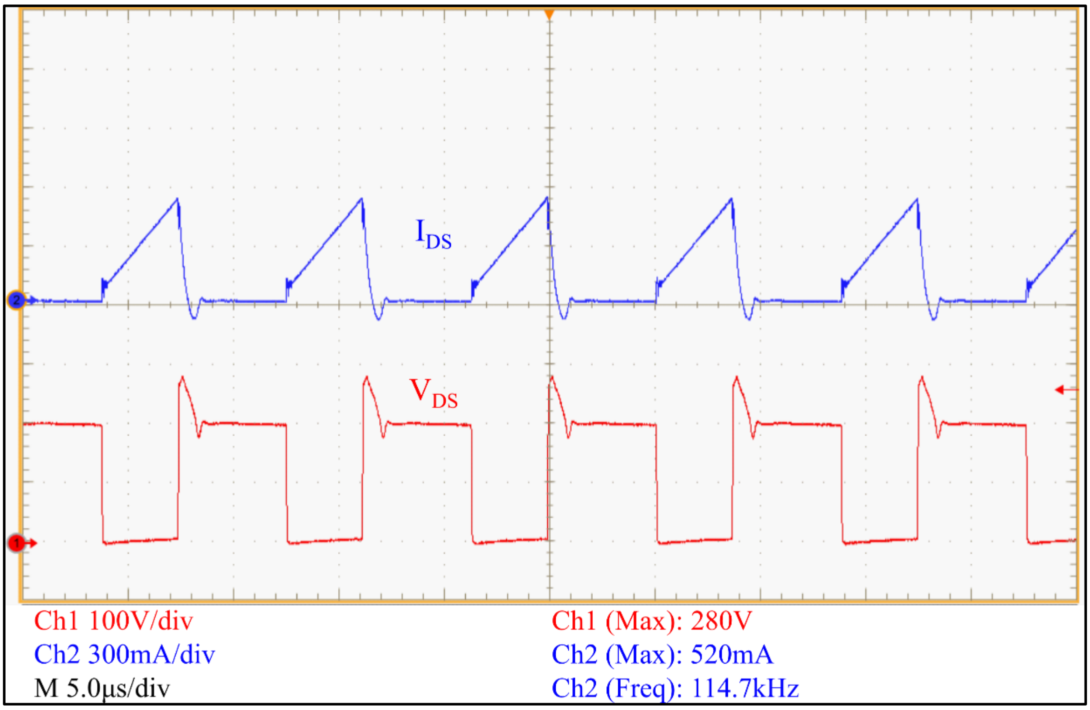


Figure 11: V_{DS} and I_{DS} waveforms under normal operation in TX mode at 230 V_{AC}

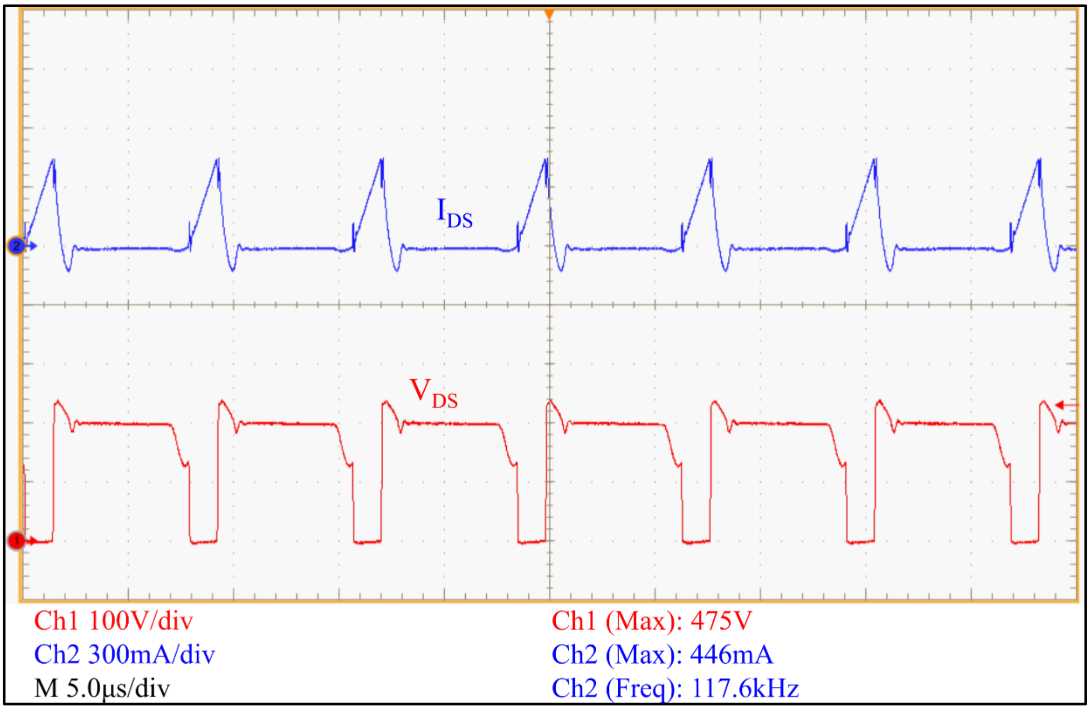
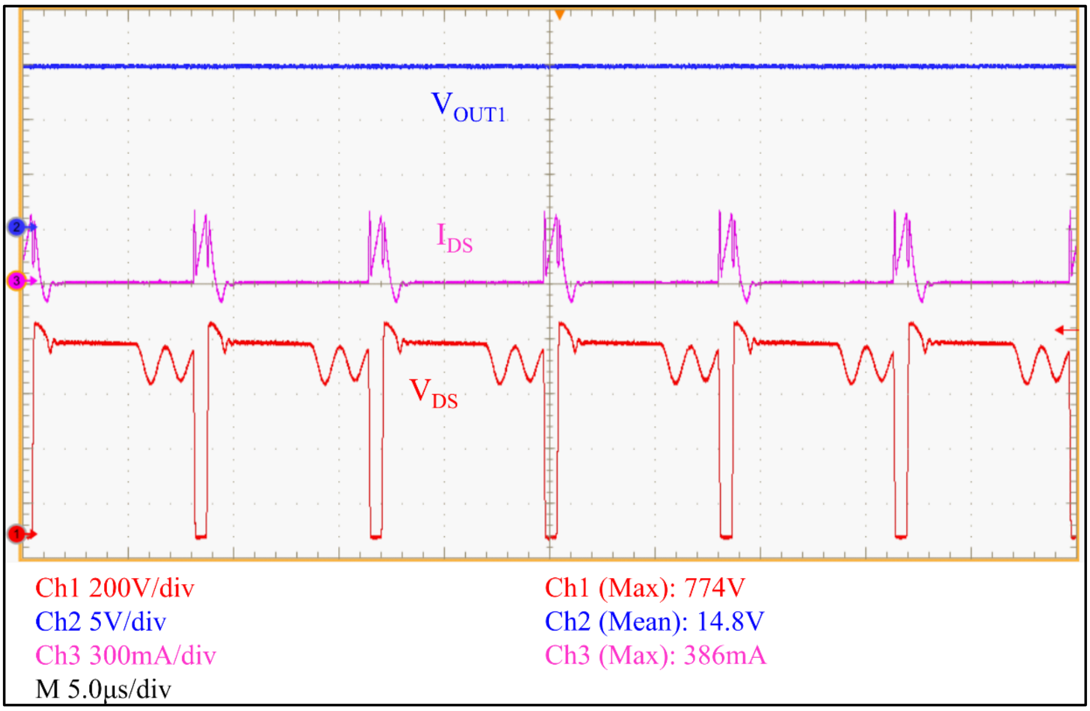


Figure 12: V_{OUT1}, V_{DS} and I_{DS} waveforms under normal operation at 440 V_{AC}



The output voltage ripple at the 15 V output for nominal input voltage and full load must be very low to ensure good sensitivity during the PLM operation. The results in *Figure 13: "Ripple at 115 V_{AC}"* and *Figure 14: "Ripple at 230 V_{AC}"* show the extremely low measured value around 0.1% of the nominal output voltage.

Figure 13: Ripple at 115 V_{AC}

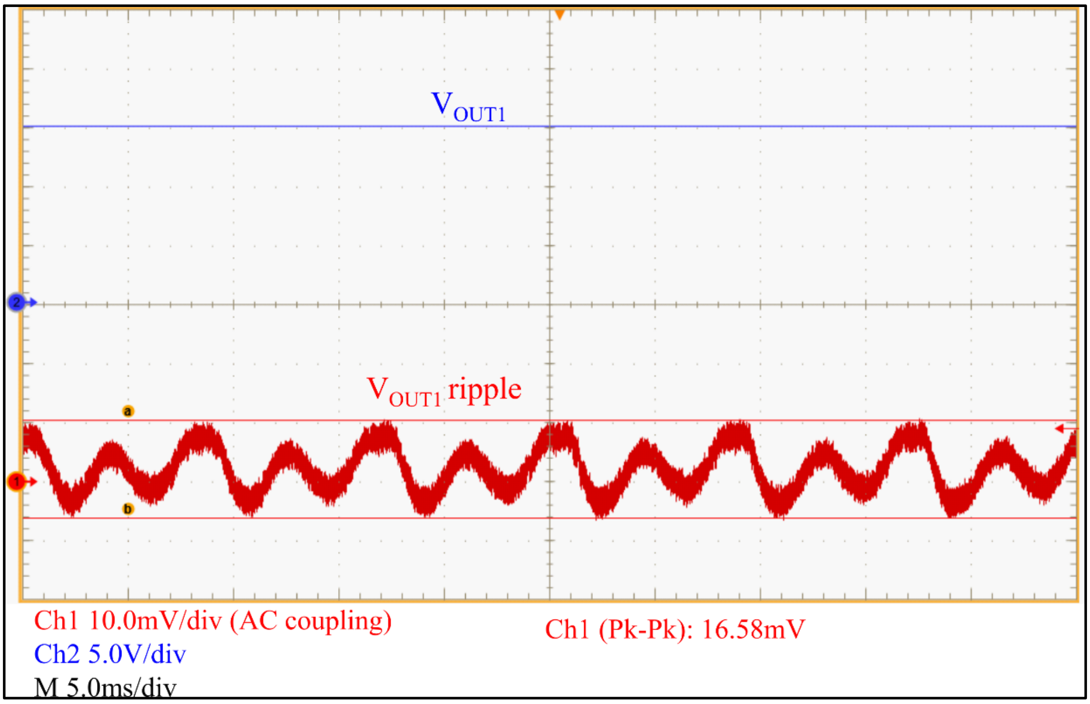
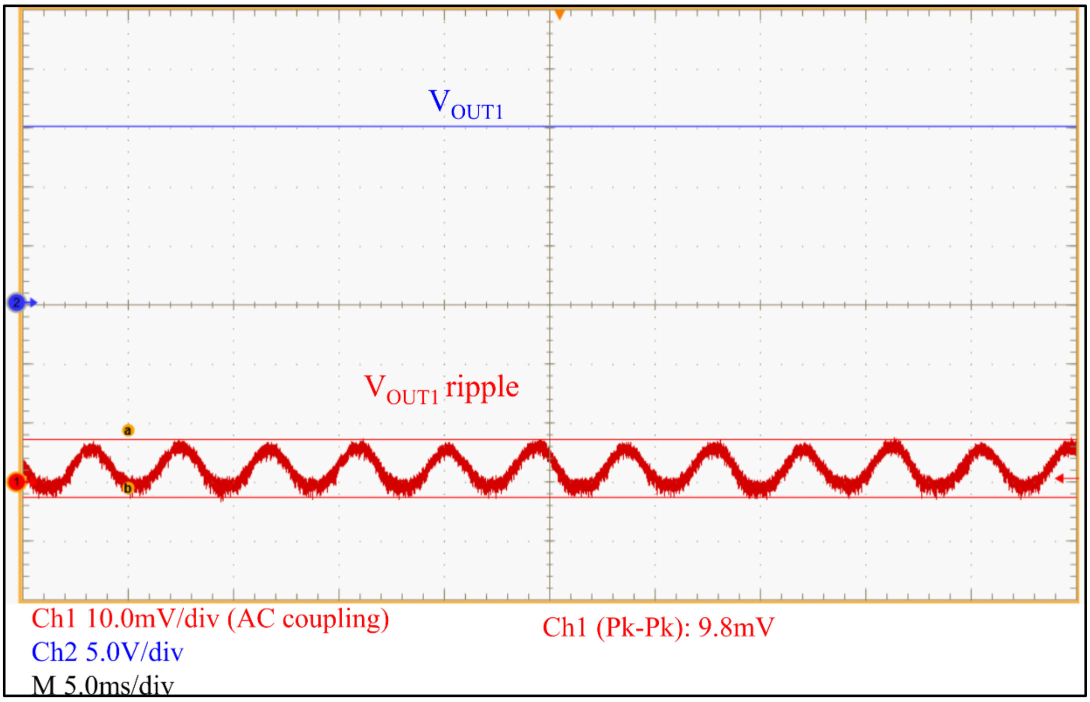


Figure 14: Ripple at 230 V_{AC}



5 EMC pre-compliance tests

EMC pre-compliance tests are required by European standard EN50065 for smart metering PLC applications on low voltage networks (which have the highest EMC test levels) and by IEC61000-4 for Electromagnetic compatibility.

All necessary testing was performed, with positive outcomes, as shown below.

Table 8: Required testing for EMC pre-compliance to EN50065 and IEC61000-4

Type	Basic standard	Test	Result
Conducted disturbance measurements	EN 55022	Conducted emissions (150 kHz - 30 MHz)	Pass
Radiated disturbance measurements	EN 55022	Radiated emissions (30 MHz - 1 GHz	Pass
Radiated immunity	EN 61000-4-3	RF radiated fields immunity test (80 - 1000 MHz, 10 V/m)	Pass
	EN 61000-4-8	Magnetic 50 Hz field immunity test (100 A/m, 300 A/m)	Pass
Contact/radiated immunity	EN 61000-4-2	Electrostatic discharges immunity test (8 kV contact and air mode)	Pass
Conducted immunity	EN 61000-4-4	Fast transients immunity test (2 kV, 5 kHz)	Pass
	EN 61000-4-5	Surge immunity test (4 kV, common mode and differential mode)	Pass
	EN 61000-4-11	Power voltage dips and interruption (30% - 10 ms; 60% - 100 ms; 100% - 5 s)	Pass

5.1 Conducted noise measurements

The pre-compliance tests for conducted noise emissions as per European normative EN55022 (Class B) were performed using quasi-peak and average detectors of the conducted art nominal mains voltage, and compared with corresponding limits.

Figure 15: "Line conducted disturbance" and *Figure 16: "Neutral conducted disturbance"* show very good margin between measurements and respective limits under all test conditions.

Figure 15: Line conducted disturbance

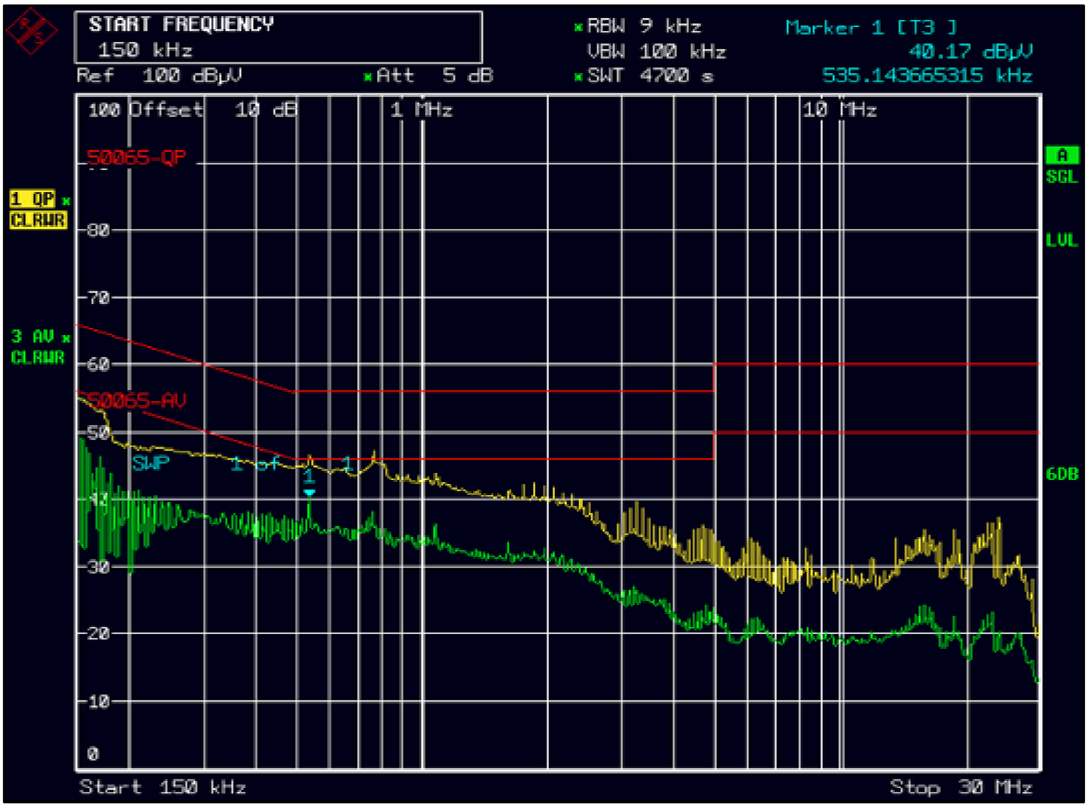
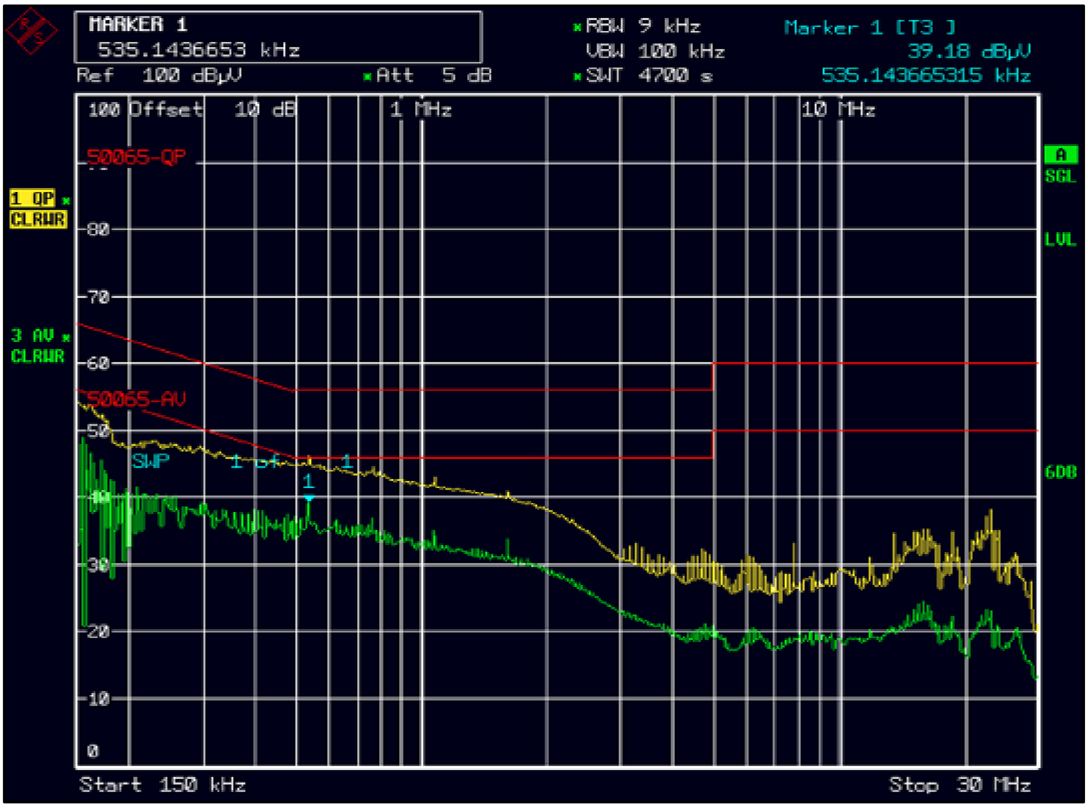


Figure 16: Neutral conducted disturbance



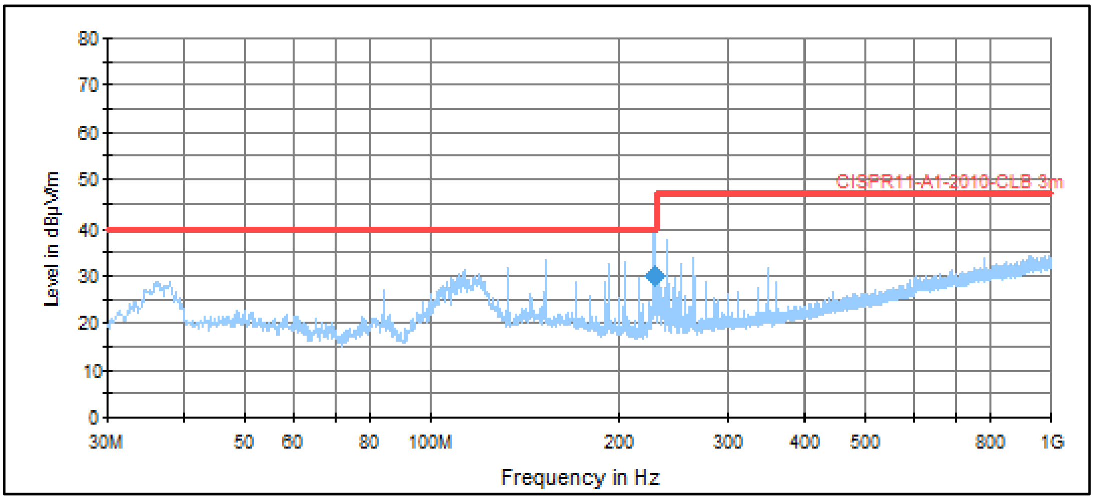
5.2 Radiated disturbance field strength (EN50065-1 section 7.3)

Information regarding the analysis of radiated disturbances generated by the board is provided below.

Table 9: Analyzer setup with quasi-peak detector

Parameter	Data	
Measurement Results	Max. level: 48 dBµV/Line; 48 dBµV/Neutral	
Limit	30 to 230 MHz:	40 dBµV/m
	230 MHz to 1 GHz	47 dBµV/m
	As the measurement distance is reduced to 3 meters, limits are increased by a factor of 10 dB with respect to EN50065-1 limits	
Result	PASS	

Figure 17: Radiated disturbance field strength



6 Conclusion

We have presented a three-output isolated flyback converter reference design for smart meter and power line communication systems, using the VIPER26HD.

The input filter setup, compliance with European standards for smart metering PLC applications and for Electromagnetic compatibility, and overall board performance render it suitable for any power line communication system.

7 Revision history

Table 10: Document revision history

Date	Version	Changes
14-Jun-2016	1	Initial release.