AN1934
APPLICATION NOTE

VIPower: VIPer12A NON ISOLATED FLYBACK CONVERTER REFERENCE BOARD

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ABSTRACT

Presented circuit can be used to produce multiple outputs, non isolated positive or negative voltage. It is dedicated for building an auxiliary power supply based on the VIPer12AS monolithic device.

1. INTRODUCTION

The aim of the presented reference boards is to propose a solution of the power supply based on an off-line discontinuous current mode flyback converter without isolation between input and output. The flyback topology allows to fully exploit current capability of the incorporated monolithic device VIPer12AS when compared with buck converter based power supply. To ensure low cost of the whole power supply the isolation between input and output is not provided. This greatly simplifies the transformer design and production. The VIPer12AS incorporates the PWM controller with 60 kHz internal oscillator and altogether with the vertical power MOSFET switch in a SO-8 package. The presented power supply has four variants. All these variants have been incorporated in presented reference board by different assembly options.

2. CIRCUIT DESCRIPTION

2.1 NON ISOLATED FLYBACK +5V/500MA, +15V/200MA (VARIANT 1)

2.1.1 Operating Conditions

Input Voltage range	90-264 VAC
Input Voltage Frequency range	50/60 Hz
Main Output (regulated)	5V / 500mA
Second Output	15V 200mA
Total Maximum Output Power	5.5W

2.1.2 Circuit Operation

The total schematic of the power supply (Variant 1) can be seen in figure 1. The output of the converter is not isolated from input. For this reason the reference ground is common for an input and output connection terminal. The input capacitor C1 is charged from the mains by single rectification consisting of diodes D1 and D2. Two diodes in series are used for EMI reasons to sustain burst pulses of 2kV. The capacitor C1 together with capacitor C2 and inductor L1 form an EMI filter.

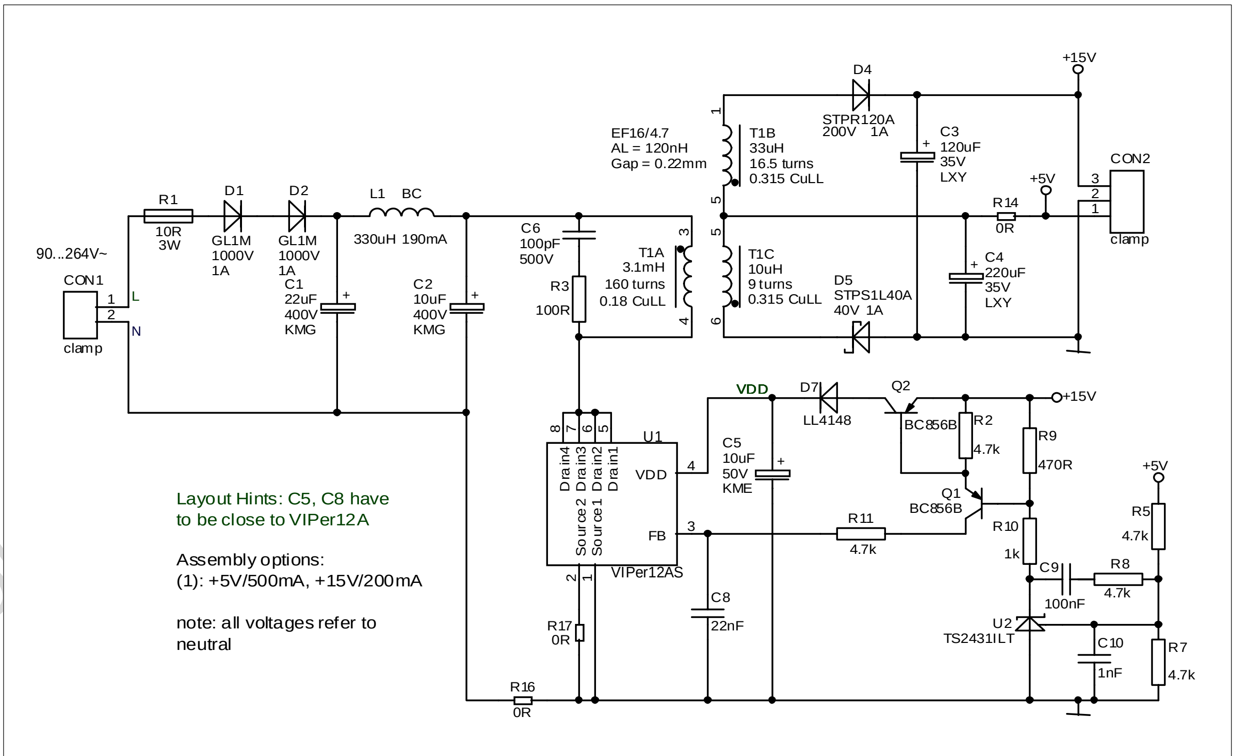
The DC voltage at C2 is then applied to the primary winding of the transformer through the internal MOSFET switch of VIPer12 during ON time of the switching period. The snubber circuit consisting of resistor R3 and capacitor C6 reduces the voltage spike across the primary winding of the transformer due to the parasitic leakage inductance. It also slows down dV/dt of the primary winding's voltage a little bit and thus improves EMI.

The power supply provides two outputs from two transformers‘ windings through rectifiers D4, D5 and smoothing capacitors C3 and C4. The VIPer12AS is supplied by 15V output voltage through transistor

Q2 and diode D7. The diode D7 ensures the proper start-up of the converter by separating the 15V output from the internal start-up current source of the VIPer12AS which will charge the IC supply capacitor C5 to a specified start-up threshold voltage of about 16V. As soon as C5 voltage reaches the start-up threshold the internal 60 kHz oscillator sets the internal flip-flop and turns on the internal high voltage power MOSFET through the output driver. The power MOSFET applies the bulk capacitor C1 and C2 high voltage to the transformer’s primary winding and primary current will ramp-up. As soon as the primary current ramp reaches the VIPer’s internal set-point defined by feedback loop, the internal power switch turns off. The output capacitor C3 or C4 is charged by energy stored in the transformer through rectifier diode D4 or D5. The current loop which charges the 5V output flows through diode D5 only. Because of the D5 location, the 15V output is charged via both diodes D4 and D5. Beside the slight decrease of the converter power efficiency, it significantly improves the cross-regulation of the outputs which was the main purpose of this arrangement.

The voltage feedback loop senses the 5V output by resistor divider R5, R7. The control IC U2 compares the resistor divider output voltage with internal reference voltage of 2.5V and changes the cathode voltage accordingly to keep 5V output stable. If the 5V output voltage rises above it’s nominal value, the cathode voltage of U2 goes down and cathode current will increase. The cathode current will cause a voltage drop across R9 and opens transistor Q1 which will inject the current from Vcc line to FB pin 3 of the VIPer12AS. The FB pin current will decrease the peak primary current to reduce the power delivered to the outputs. Resistor R10 limits the U2 cathode current. Resistor R9 has two roles: it works as pull up for Q1 and ensures bias current of at least 1mA for U2 proper operation.

Figure 1: Schematic diagram of non isolated flyback converter (variant 1)



Resistor R11 limits the feedback current to a safe value, which is lower than specified by the maximum rating table in the data sheet. Capacitor C8 improves noise immunity of the FB input against noise.

2.1.3 Bill of materials

The bill of material presented in Table 1 covers all power supply variants. The components which are specific for a particular variant can be recognized by column named "Variant". Peak clamp D6 connected across the primary winding is optional and it is not assembled on the board. In case a precise voltage regulation of the 15V output is required, resistor R6 connected from the 15V output to the control input of U2 can be assembled instead of R5.

Table 1: Bill of material for all variants of non isolated flyback converter

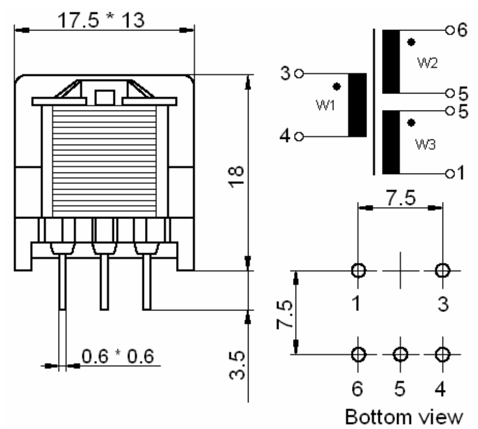
Ref.	Q.ty	Variant	Description
CON1	1		Clamp, WECO, 2 pole, horizontal, 1.5mm^2, 380V, 15A
CON2	1		Clamp, WECO, 3 pole, horizontal, 1.5mm^2, 380V, 15A
C1	1		22µF Electrolytic capacitor, Nippon Chemi-Con, KMG 400V, 20%
C2	1		10µF Electrolytic capacitor, Nippon Chemi-Con, KMG 400V, 20%
C3	1		120µF Electrolytic capacitor, Nippon Chemi-Con, LXY 35V 20%
C4	1	(1, 2, 4)	220µF Electrolytic capacitor, Nippon Chemi-Con, LXY 35V 20%
C5	1		10µF Electrolytic capacitor, Nippon Chemi-Con, KME 50V 20%
C6	1		100pF Ceramic capacitor, X7R, 500V C1206 10%
C8	1		22nF Ceramic capacitor, X7R, 50V C0805 10%
C9	1	(1, 4)	100nF Ceramic capacitor, X7R, 50V C0805 10%
C10	1	(1, 4)	1nF Ceramic capacitor, X7R, 50V C0805 10%
C11	1	(2) (3)	2.2µF Tantalum capacitor, Size A, B45196E, 10V 7.0R 20% 100nF Ceramic capacitor, X7R, 50V C1206 10%
D1, D2	2		GL1M Diode, Diotec, trr=1.5µs 1000V 1A, MiniMELF
D4	1		**STMicroelectronics STPR120A** Diode, fast recovery trr=25ns 200V 1A SMA
D5	1	(1, 2, 4) (3)	**STMicroelectronics STPS1L40A** Diode, Schottky, 40V 1A, SMA 0R Resistor, metal film, R1206
D6	1	optional	**STMicroelectronics PKC-136** Diode, Peak clamp, Vbr=160V, 700V, 1.5W DO-15
D7	1		LL4148 Diode 75V 200mA
D8	1	(2, 3)	ZMM13 Zener diode, 13V 0.5W 5%
L1	1		330µH Inductor, EPCOS, bobbin core, B78108-S1334-J, 190mA 6.4R 10%
Q1, Q2	2	(1, 4)	BC856B Bipolar transistor, PNP, 65V 100mA 330mW
R1	1		10R resistor, Yageo, wirewound, fusible, TK120 CRF 254-4 3W 5%
R2, R5, R7, R8	4	(1, 4)	4.7K resistor, metal film, 100V 0.125W R0805 1%
R3	1		100R resistor, metal film, 200V 0.25W R1206 1%
R4	1	(2, 3)	0R resistor, metal film, R1206
R6	1	optional	24K resistor, metal film, R0805, 100V 0.125W 1%
R9	1	(1, 4)	470R resistor, metal film, R0805, 100V 0.125W 1%
R10	1	(1, 4)	1K resistor, metal film, R0805, 100V 0.125W 1%
R17	1		0R resistor, metal film, R1206
T1	1	(1, 3, 4) (2)	Ns=16/9 turns transformer, Vogt, ferrite Fi324, EF16/4.7, ord. num. 545 23 249 00 Ns=14/11 turns transformer, Vogt, ferrite Fi324, EF16/4.7, ord. num. 545 23 249 00

U1	1		**STMicroelectronics VIPer12AS**, 730V 0.4A, 27R, f=60kHz, SO-8
U2	1	(1, 4)	**STMicroelectronics TS2431ILT** shunt ref. IC, 2.5V 1mA to 100mA 360mW 2%
U3	1	(2) (3b)	**STMicroelectronics L4931CD50** voltage reg., low drop, with inhibit, 5V, 250mA 4% **STMicroelectronics L78L05CD** positive voltage reg., 5V, 100mA 10%
U4	1	(3a)	**STMicroelectronics L78M05CDT** positive voltage reg., 5V, 0.5A 5%

2.1.4 Transformer Design

Since there is no requirement regarding isolation between primary and secondary side, the transformer construction is easier compared to the isolated version. There is only a single layer of Mylar tape between the primary winding and secondary windings. Its purpose is not to make transformer passing safety regulations but to ensure proper operation of the power supply. Also creepage distances between windings are not that critical. The physical appearance, dimensions and windings and pins arrangement can be seen in figure 2.

Figure 2: Transformer dimensions, windings and bottom view pin arrangement



The basic parameters of the ferrite core selected from Vogt's ferrite materials and shapes can be seen in table 2. The gap size was optimised to ensure appropriate current capability and inductance to fully exploit switching frequency and to switch peak current limit of the VIPer12AS to achieve maximum output power.

Table 2: Transformer's core parameters

Shape	EF16/4.7
Material	Vogt Fi 324
Gap size [mm]	0.24
Inductance Factor A_L [nH]	120

An overview of the most important parameters for each winding can be found in table 3. This table is valid for all variants. The only differentiation between the variants is the number of turns for the secondary windings. The difference is indicated in the "number of turns" column.

Table 3: Transformer's windings parameters

Order	Start Pin	End Pin	No. of turns	Wire diameter [mm]	Wire material	Inductance
1	3	4	160	0.18	CuLL	3.1mH
2	6	5	9 (1, 3, 4) 11 (2)	0.315	CuLL	10µH 15µH
3	5	1	16.5 (1, 3, 4) 14.5 (2)	0.315	CuLL	33µH 25µH

2.1.5 PCB Layout

The PCB is designed as a single sided board made of FR-4 material with 35µm copper plating with solder and silk screen mask. The assembled board contains both SMD and through hole components. The board includes all variants of the converter. The outline dimensions are 59x30mm. Assembly top side (trough-hole components) and solder bottom (SMD components) side can be seen in figure 3 and figure 4.

Figure 3: Assembly Top (not in scale)

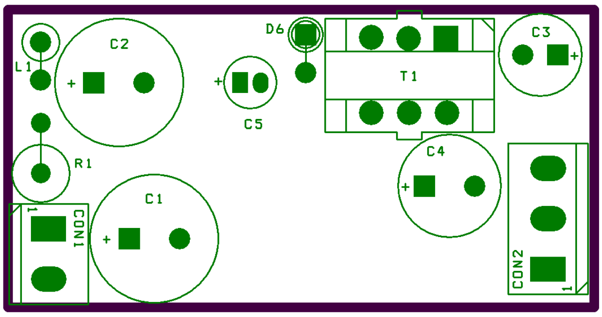
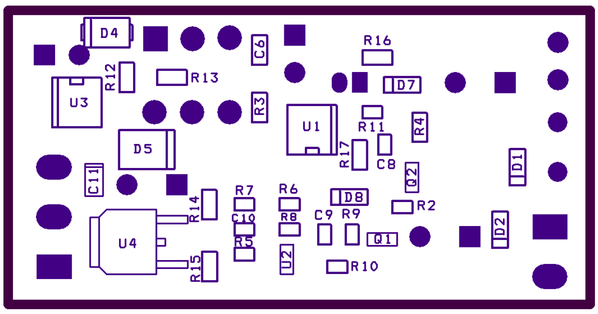
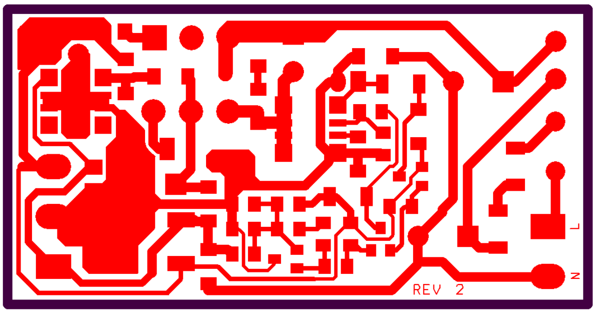


Figure 4: Assembly Solder Side (not in scale)



The PCB layout of the copper connections is depicted in figure 5. The holes for through-hole components are not seen in the picture.

Figure 5: PCB Layout (not in scale)



The physical appearance of the converter can be observed in figure 6.

Figure 6: Picture of the Converter

2.1.6 Evaluation and Measurements

The output regulation characteristics measured on 5V output can be seen in figure 7. It shows the voltage variation of the 5V output when different load is applied to 15V output. Figure 8 shows the same characteristic as figure 7 but measured at 375VDC input voltage.

Figure 7: Output Regulation Characteristics of 5V output at 125VDC Input Voltage (Parameter is load current on 15V output)

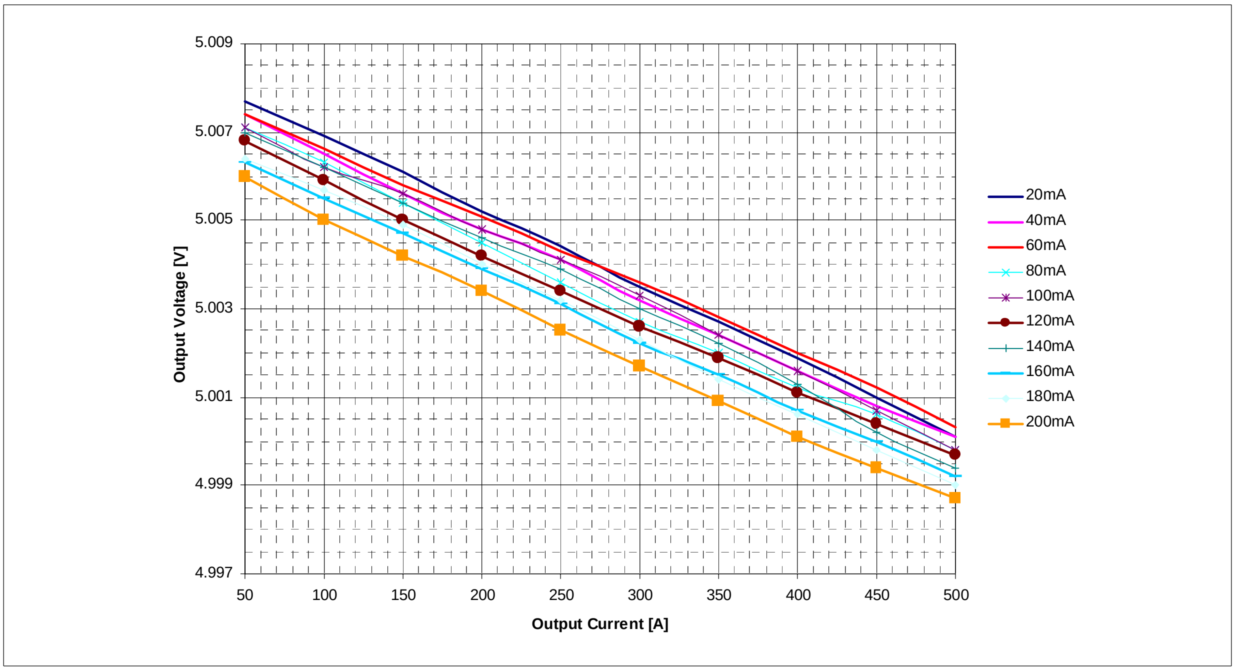
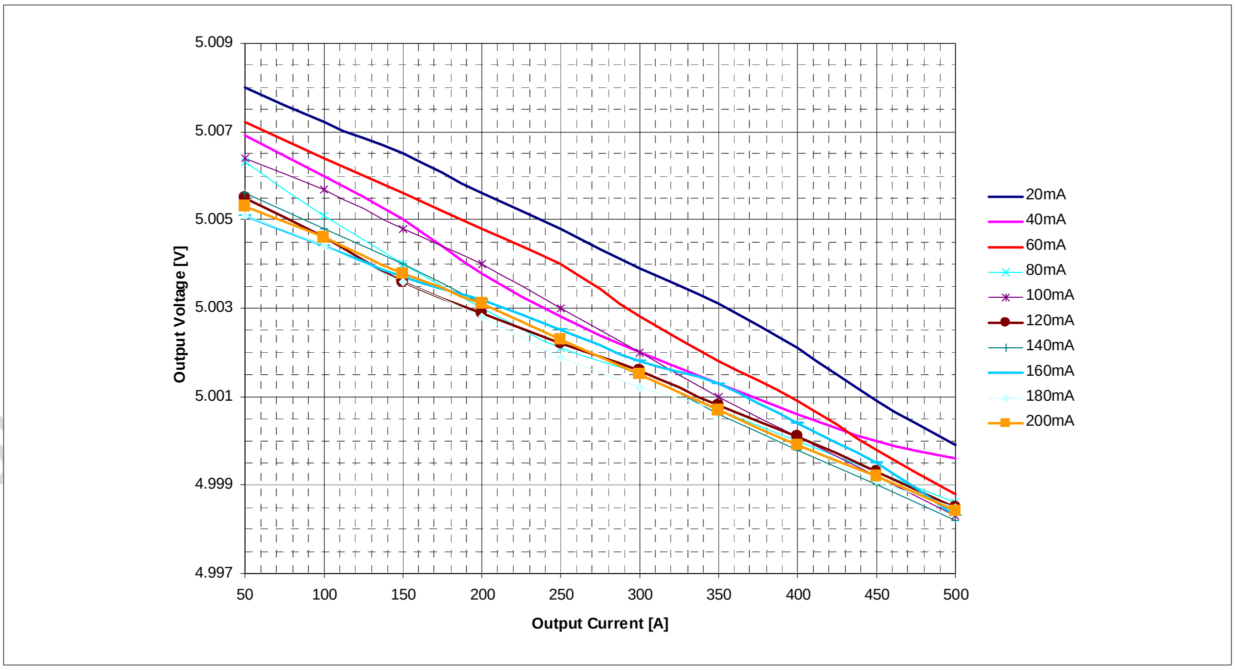


Figure 8: Output Regulation Characteristics of 5V output at 375VDC Input Voltage (Parameter is load current on 15V output)



Similarly figure 9 shows the output regulation characteristics measured on 15V output when different load current applied to 5V output. Figure 10 shows the same characteristic as figure 9 but measured at 375VDC input voltage.

Figure 9: Output Regulation Characteristics of 15V Output at 125VDC Input Voltage (Parameter is load current on 5V output)

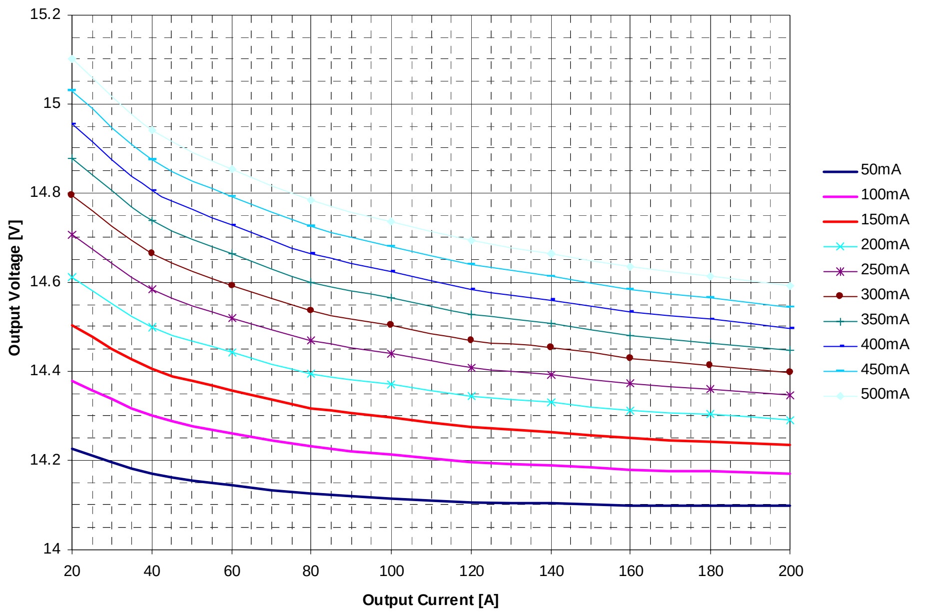
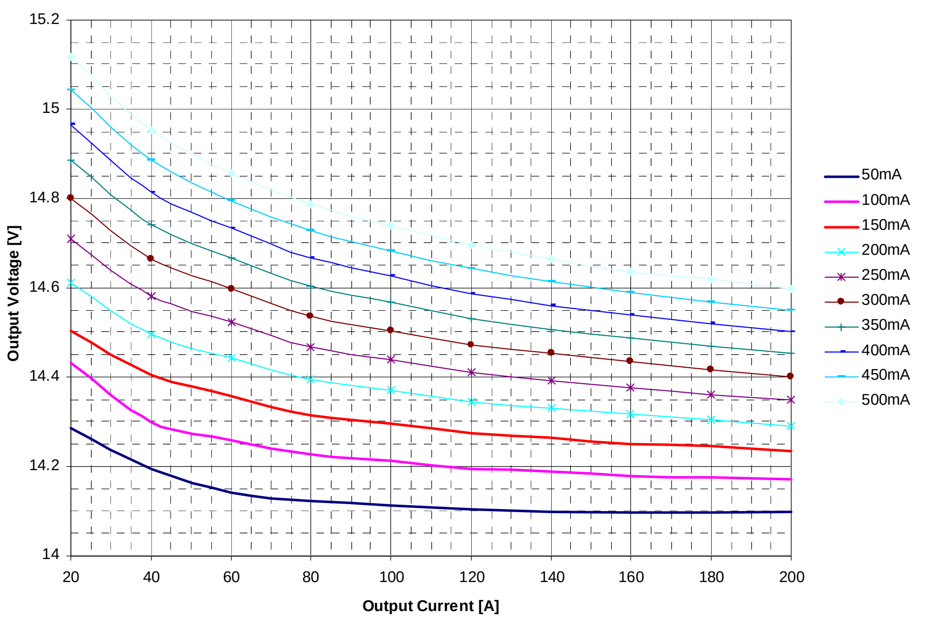


Figure 10: Output Regulation Characteristics of 15V Output at 375VDC Input Voltage (Parameter is load current on 5V output)



One of the most observed parameters when judging the converter performance is power efficiency. Figure 11 depicts the dependency of the efficiency on load applied to the 5V output (parameter is load current on 15V output). Similarly figure 12 shows the dependency on the 15V output current (parameter is load current on 5V output). Figures 12 and 13 show the same characteristics as figures 10, 11a and 11b, but measured at input voltage of 375 VDC.

Figure 11a: Efficiency variation with 5V Output Current at 125VDC Input Voltage (Parameter is loaded current on 15V output)

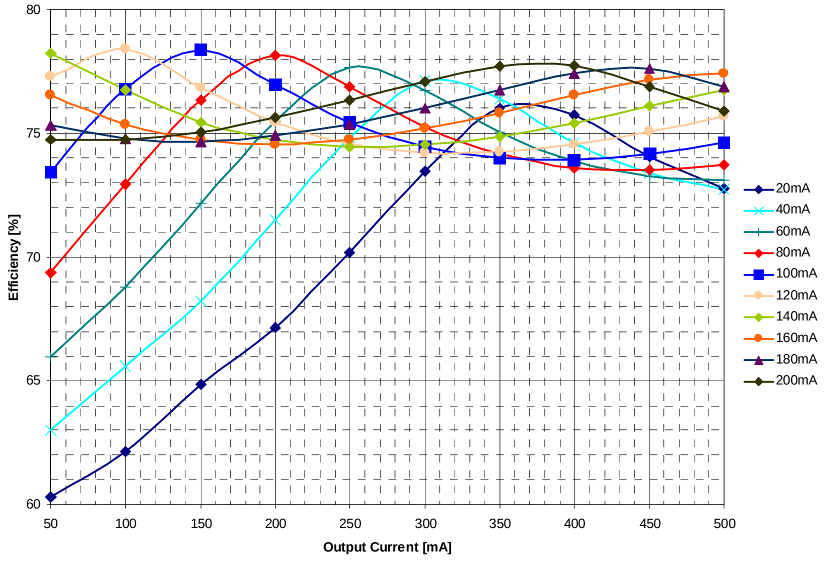


Figure 11b: Efficiency variation with 15V Output Current at 125VDC Input Voltage (Parameter is loaded current on 5V output)

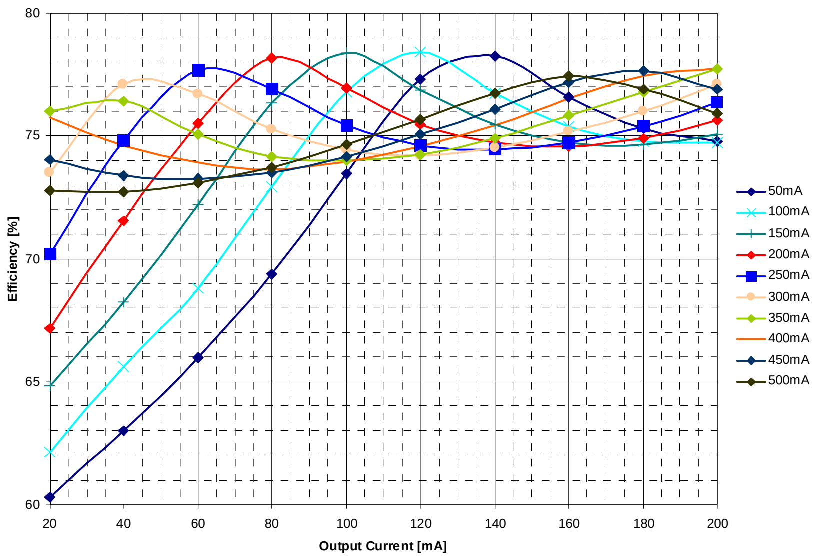


Figure 12: Efficiency variation with 5V Output Current at 375VDC Input Voltage (Parameter is loaded current on 15V output)

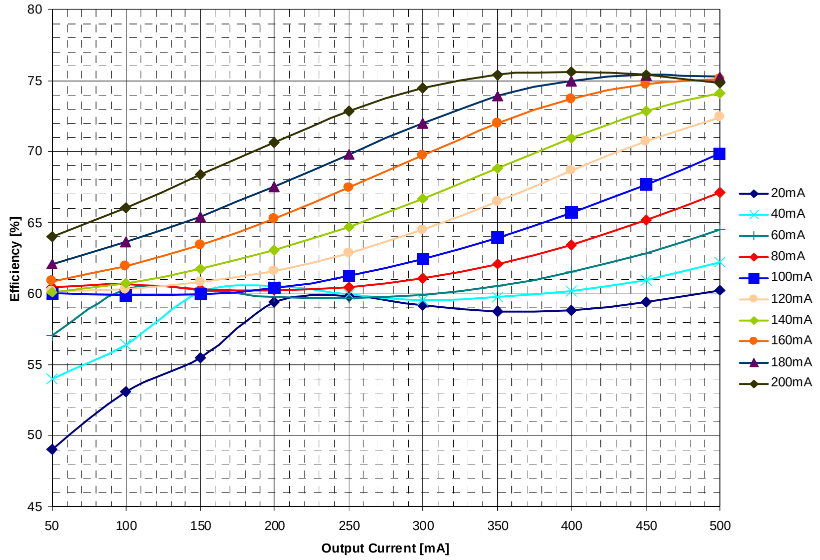


Figure 13: Efficiency variation with 15V Output Current at 375VDC Input Voltage (Parameter is loaded current on 5V output)

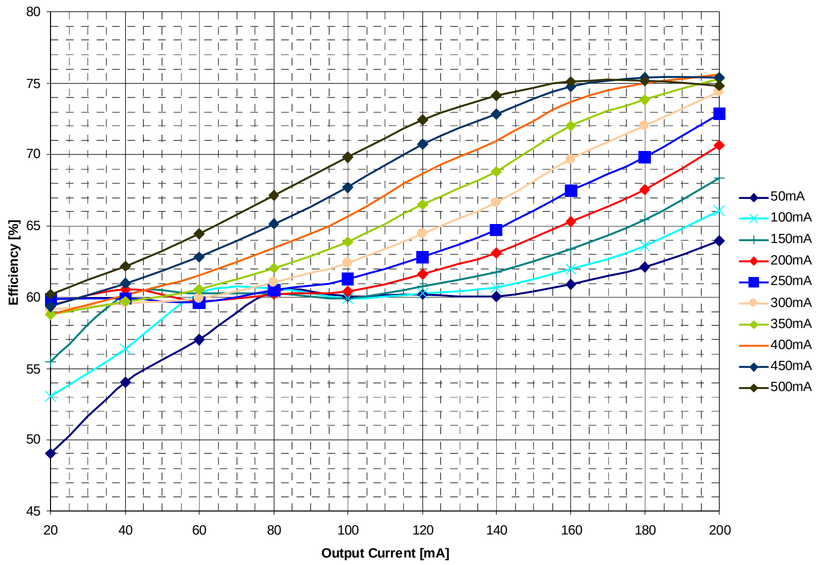


Figure 14 to figure 23 show the most important voltage or current waveforms at different input and output conditions. Channel 1 (pink) is the power MOSFET Source terminal voltage of the VIPer12. Channel 4 (blue) shows the drain current of the VIPer12. The purpose of those pictures is to demonstrate the skipping cycle function at light or no-load condition and cycle-by-cycle primary current limitation at output shorted condition

Figure 14: V_{in}=127VDC, no-load

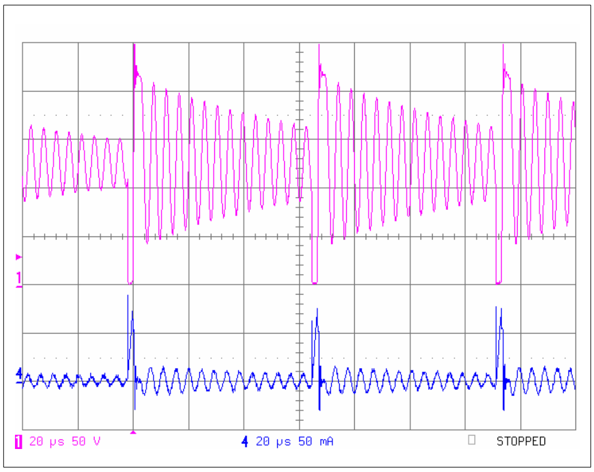


Figure 15: V_{in}=373VDC, no-load

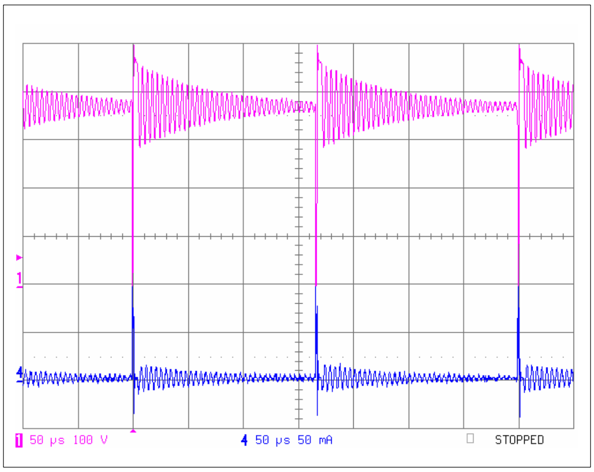


Figure 16: V_{in}=127VDC, nominal load

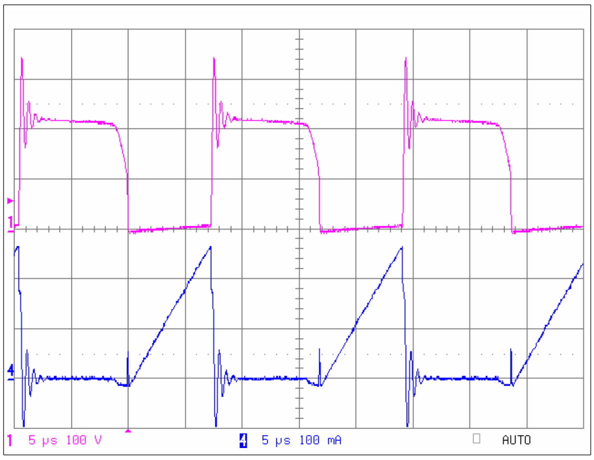


Figure 17: V_{in}= 373VDC, nominal load

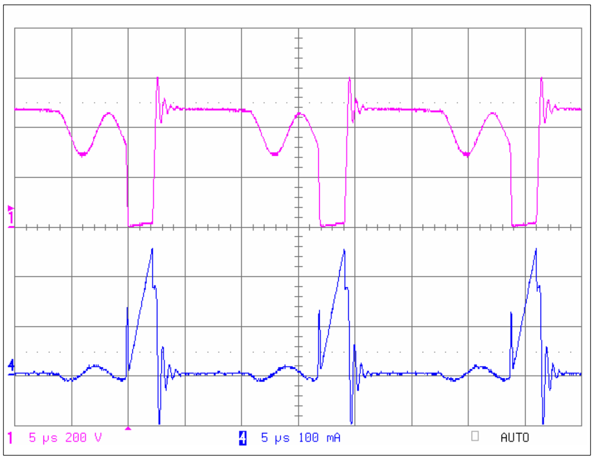


Figure 18: V_{in}=127VDC, 50% load on both outputs

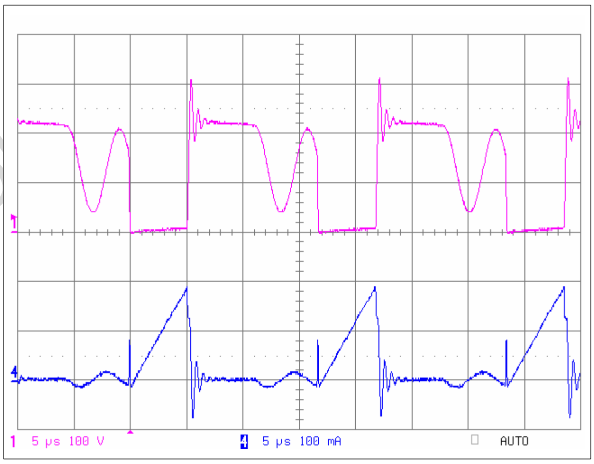


Figure 19: V_{in}=373VDC, 50% load on both outputs

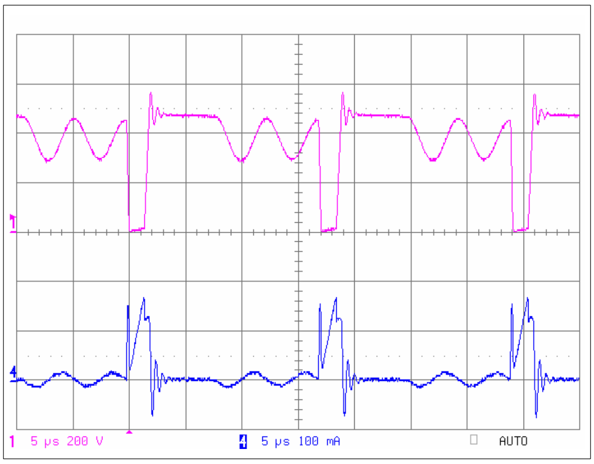


Figure 20: Vin=127VDC, 5V output shorted, 15V output no-load

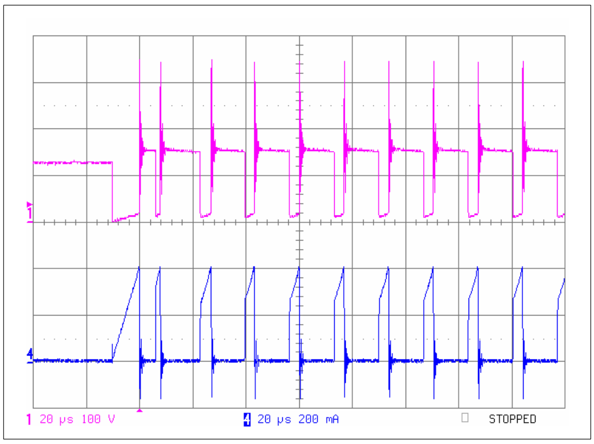


Figure 21: Vin=127VDC, 15V output shorted, 5V output no-load

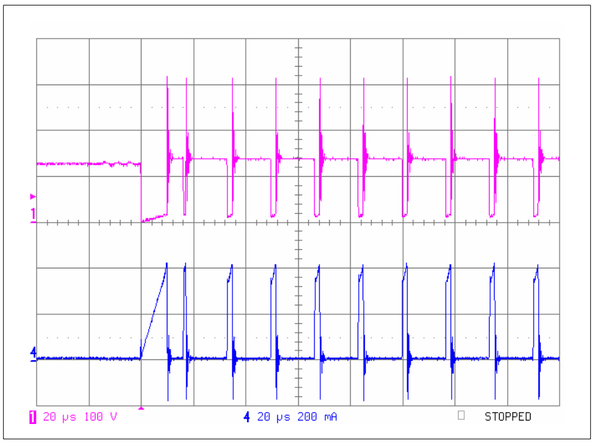


Figure 22: Vin=373VDC, 5V output shorted, 15V output no-load

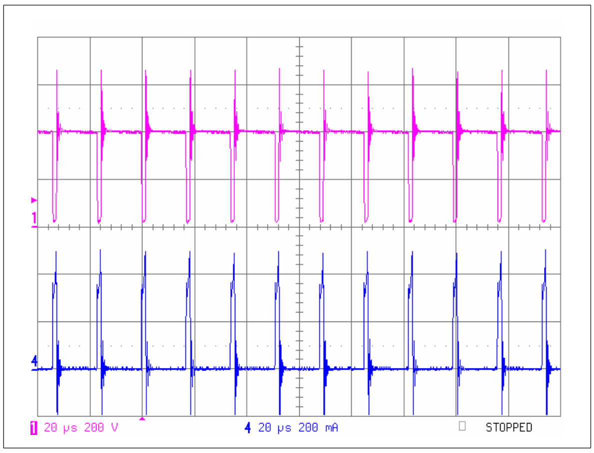
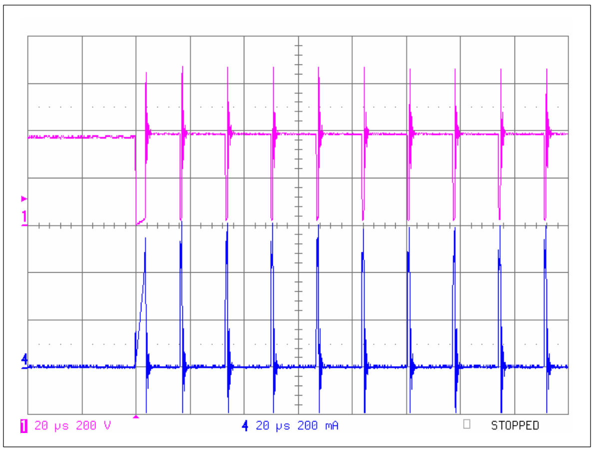


Figure 23: Vin=373VDC, 15V output shorted, 5V output no-load



The feedback loop stability and reaction to the load change are demonstrated from figures 24 to 27.

Figure 24: Load transient response, 50mA to 0.5A on 5V output, 15V output unloaded, Vin=127VDC

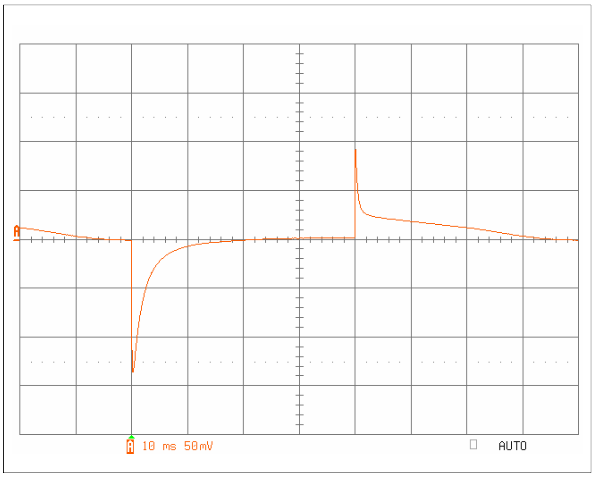


Figure 25: Load transient response, 50mA to 0.5A on 5V output, 15V output nominal load, Vin=127VDC

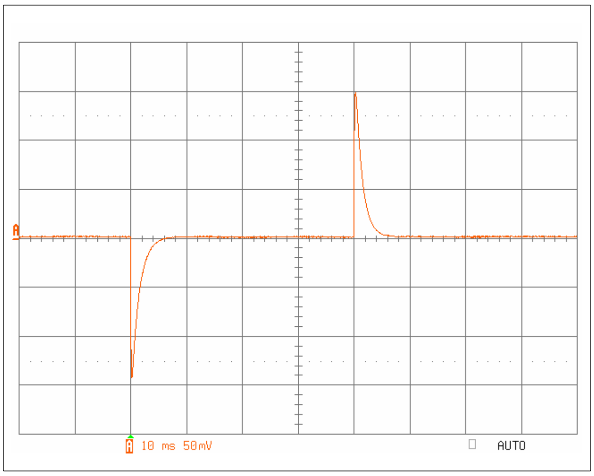


Figure 26: Load transient response, 50mA to 0.5A on 5V output, 15V output unloaded, Vin=373VDC

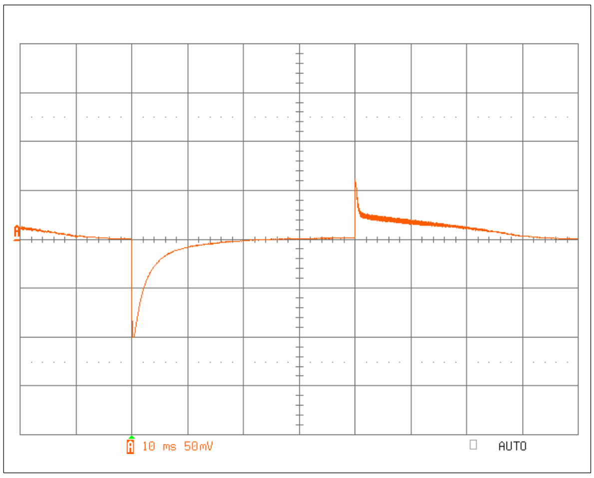
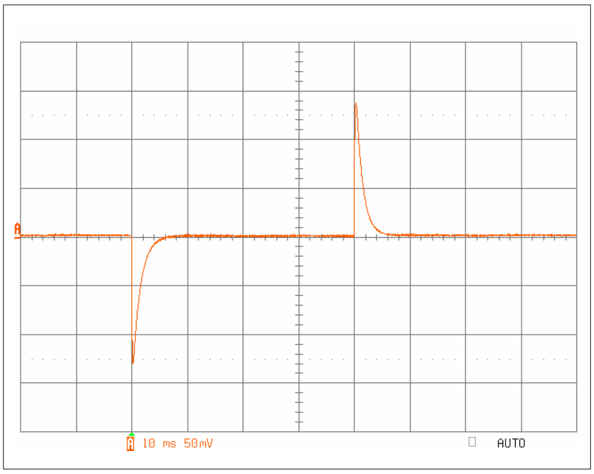


Figure 27: Load transient response, 50mA to 0.5A on 5V output, 15V output nominal load, Vin=373VDC



Furthermore, conducted emissions were measured in neutral and line wire using a peak or average detector. The measurements were performed at 230VAC input voltage and both outputs were fully loaded. The results can be seen from figures 28 to 31.

Figure 28: Phase L, average detector

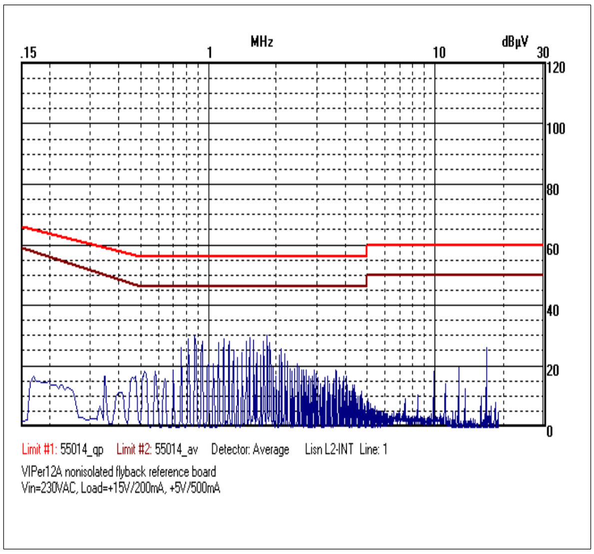


Figure 29: Phase L, peak detector

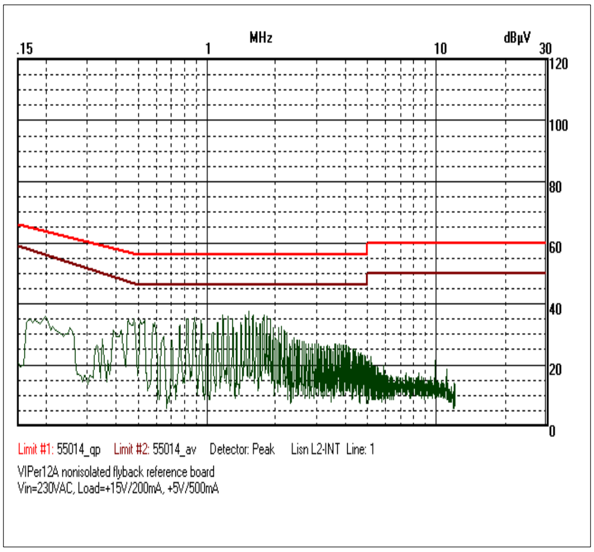


Figure 30: Phase N, average detector

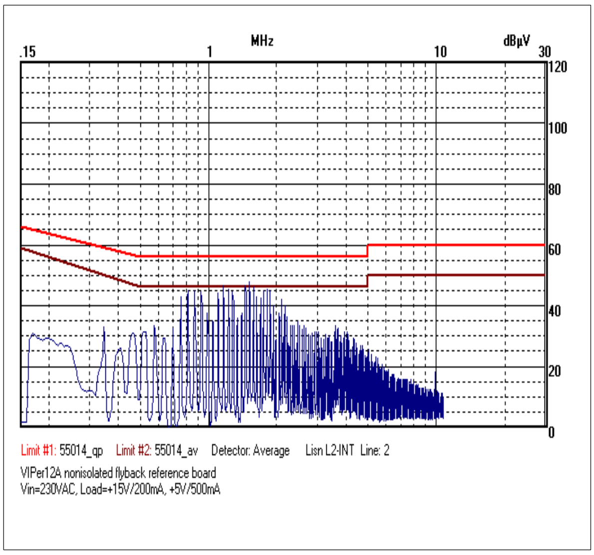
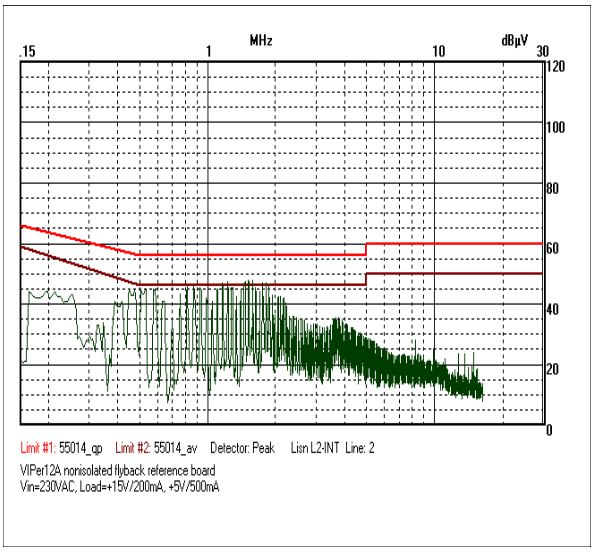


Figure 31: Phase N, peak detector



2.2 NON ISOLATED FLYBACK +5V/250mA, +15V/200mA (VARIANT 2)

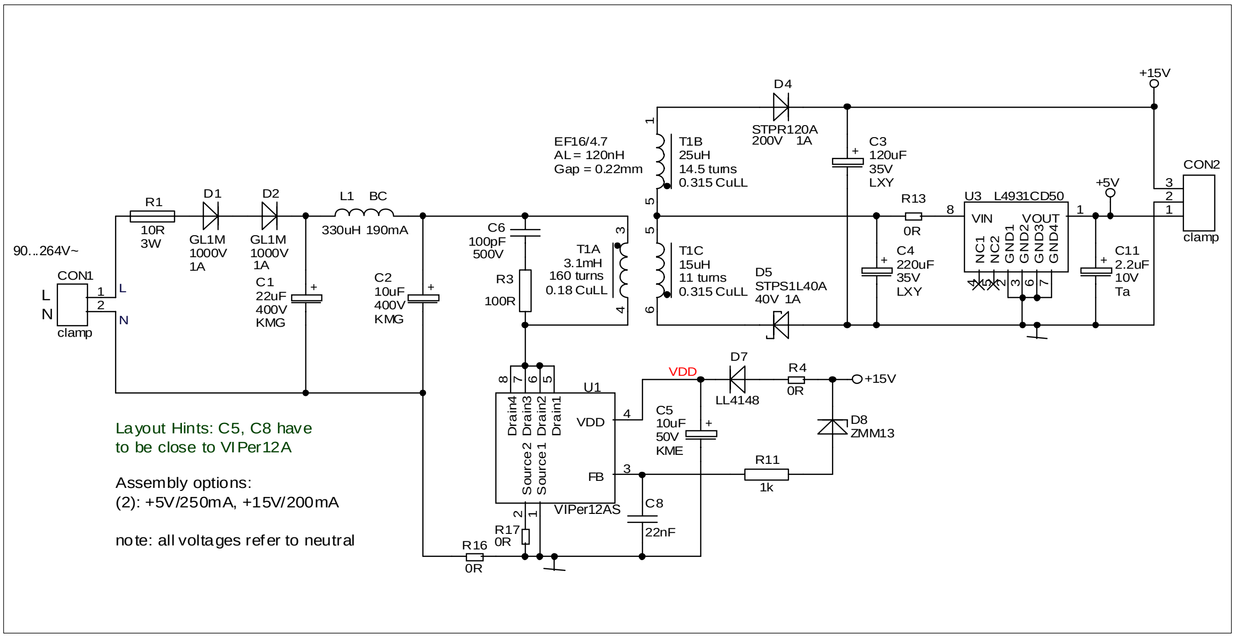
2.2.1 Operating Conditions

Input Voltage range	90-264 VAC
Input Voltage Frequency range	50/60 Hz
Main Output (regulated)	15V / 200mA
Second Output	5V / 250mA
Total Maximum Output Power	4.25W

2.2.2 Circuit Operation

The total schematic of the power supply can be seen in figure 32. Compared to variant 1, this variant has some differences. The major difference is the feedback loop. Instead of 5V output the 15V output is regulated by a simple circuit consisting of zener diode D8 a resistor R11. Since 5V output is not well stabilized by the feedback loop a linear regulator U3 is used. The linear regulator requires some input-to-output voltage difference to assure a minimum dropout voltage. For this reason the number of turns of secondary windings is slightly different compared to variant 1 (see table 3).

Figure 32: Schematic diagram of non isolated flyback converter (Variant 2)



2.3 NON ISOLATED FLYBACK +15V/200mA, +5V/60mA (VARIANT 3)

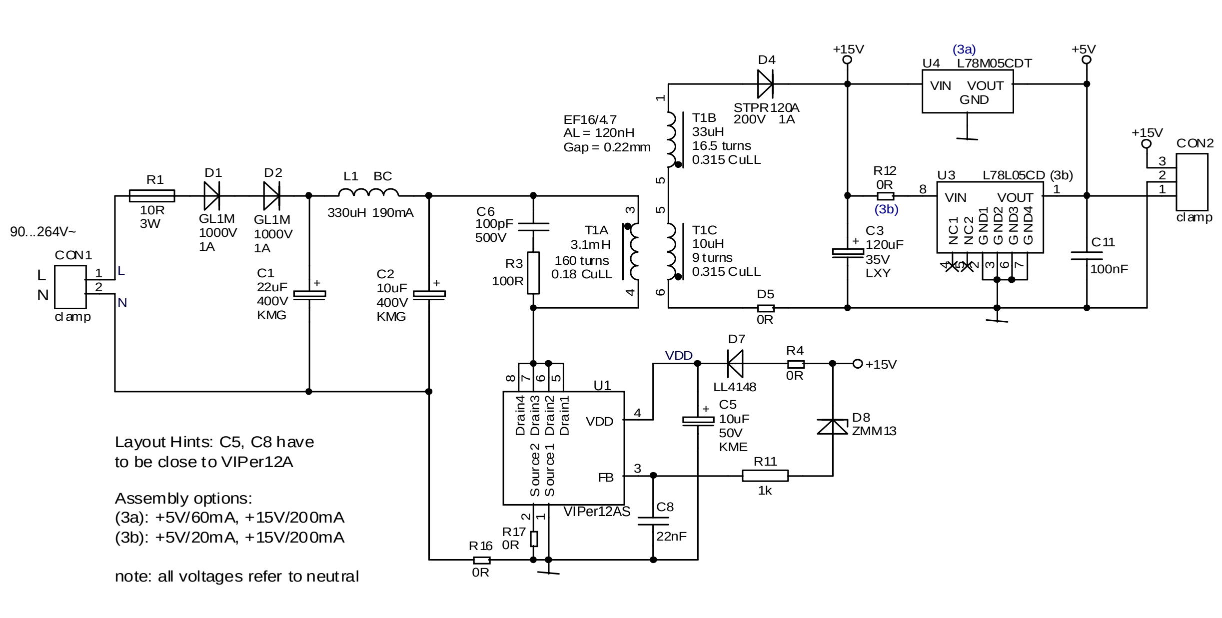
2.3.1 Operating Conditions

Input Voltage range	90-264 VAC
Input Voltage Frequency range	50/60 Hz
Main Output (regulated)	15V / 200mA
Second Output	5V / 20mA or 60mA
Total Maximum Output Power	4.25W

2.3.2 Circuit Operation

The schematic diagram is depicted in figure 33 and is very similar to the schematic of variant 2. It has only one output rectifier diode and one output electrolytic capacitor. The 5V linear regulator is directly supplied from 15V output. There are two sub-variants. Depending on the output current requirement for 5V output, U3 or U4 can be mounted.

Figure 33: Schematic Diagram of Non Isolated Flyback Converter (Variant 3)



2.3.3 Evaluation and Measurements

The output regulation characteristics measured on 5V output can be seen in figure 34. It shows the voltage variation of the 5V output when a different load is applied to 15V output. Figure 35 shows the same characteristic as figure 34 but measured at 375VDC input voltage.

Figure 34: Output Regulation Characteristics of 5V output at 125VDC Input Voltage (Parameter is loaded current on 15V output)

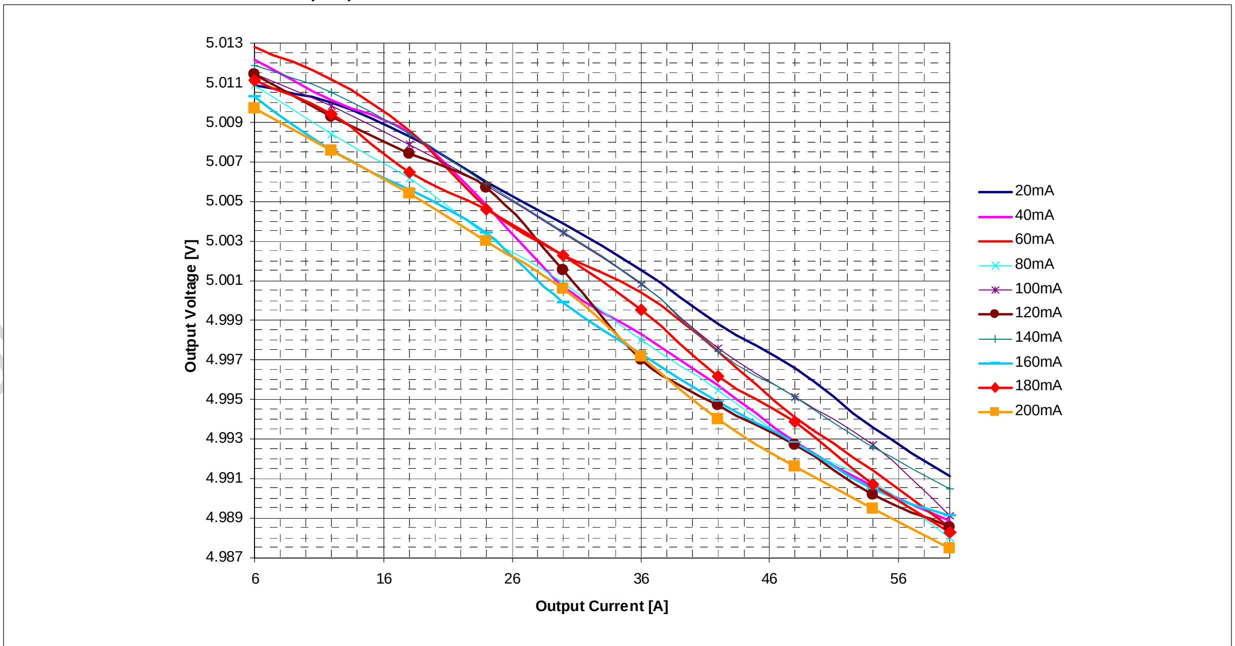
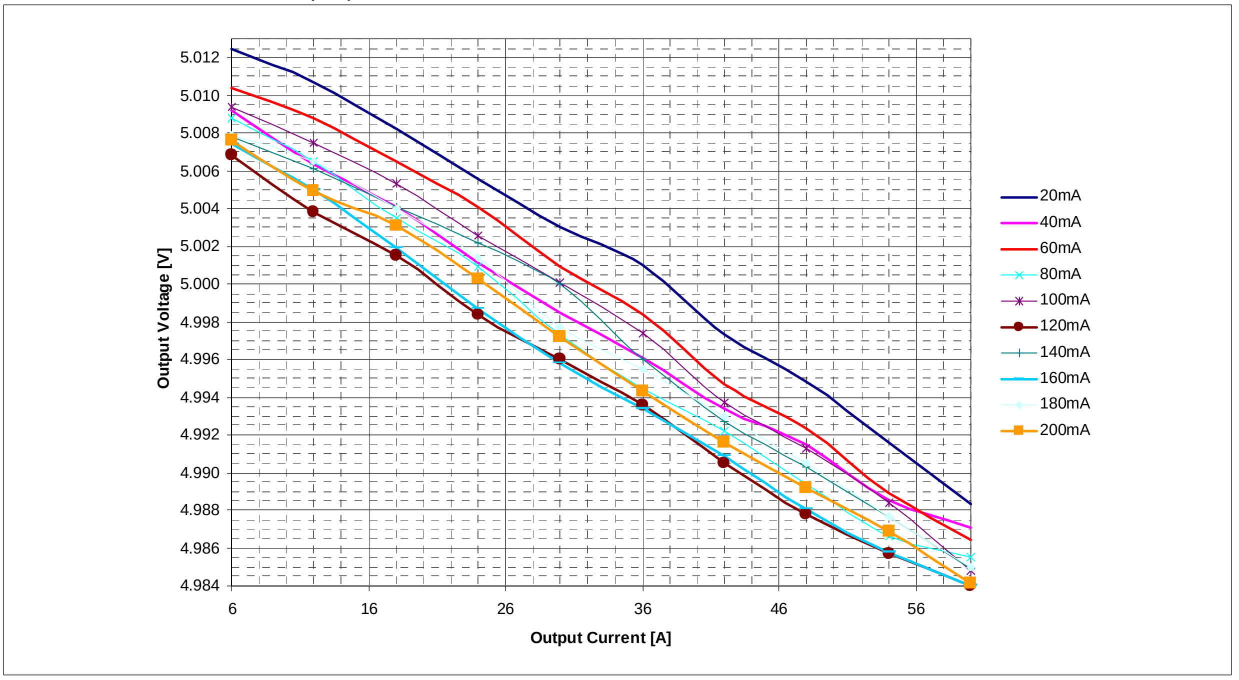


Figure 35: Output Regulation Characteristics of 5V output at 375VDC Input Voltage (Parameter is loaded current on 15V output)



Similarly, figure 36 shows the output regulation characteristics measured on 15V output when different load current applied to 5V output. Figure 37 shows the same characteristic as figure 36 but measured at 375VDC input voltage.

Figure 36: Output Regulation Characteristics of 15V Output at 125VDC Input Voltage (Parameter is loaded current on 5V output)

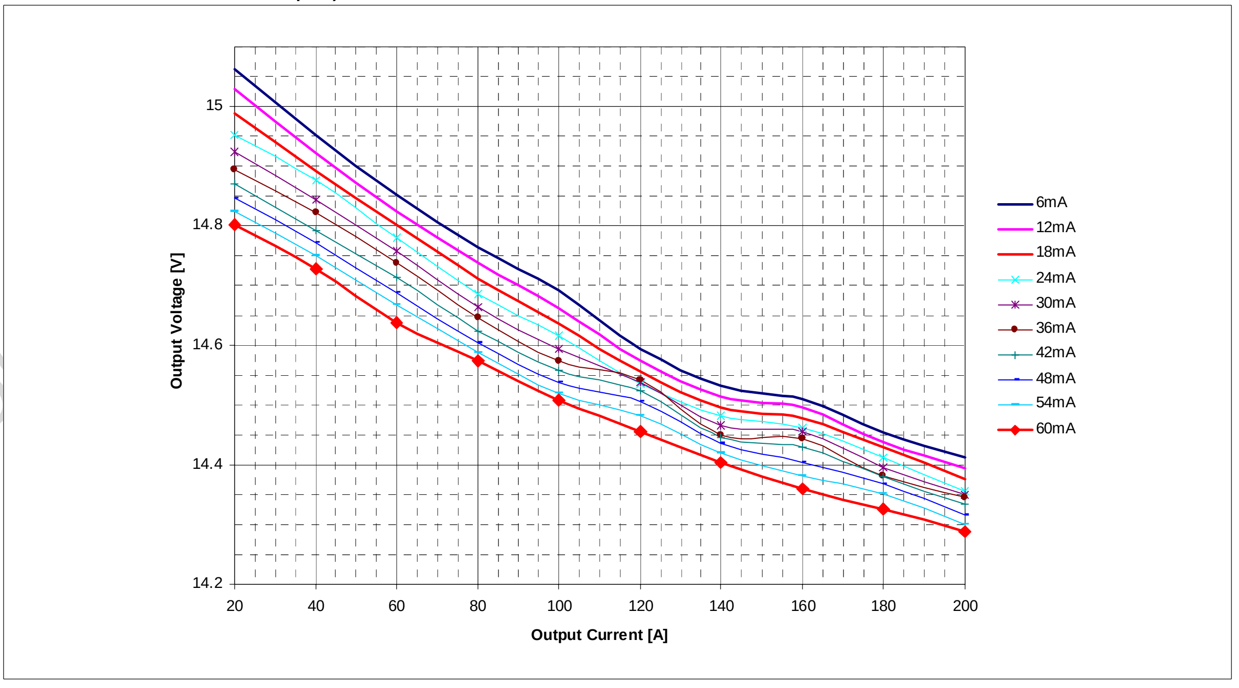


Figure 37: Output Regulation Characteristics of 15V Output at 375VDC Input Voltage (Parameter is loaded current on 5V output)

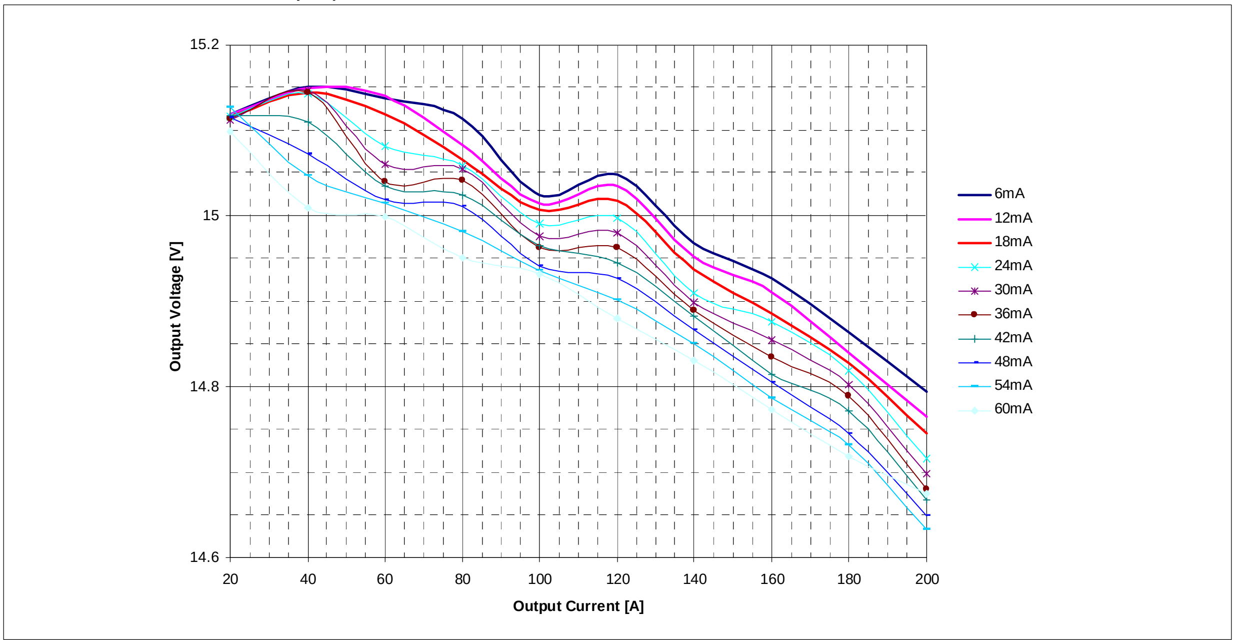


Figure 38 depicts the dependency of the efficiency on load applied to the 5V output (parameter is load current on 15V output). Similarly, figure 39 shows the dependency on the 15V output current (parameter is load current on 5V output). Figures 40 and 41 show the same characteristics as figures 38 and 39 but measured at input voltage of 375 VDC.

Figure 38: Efficiency variation with 5V Output Current at 125VDC Input Voltage (Parameter is loaded current on 15V output)

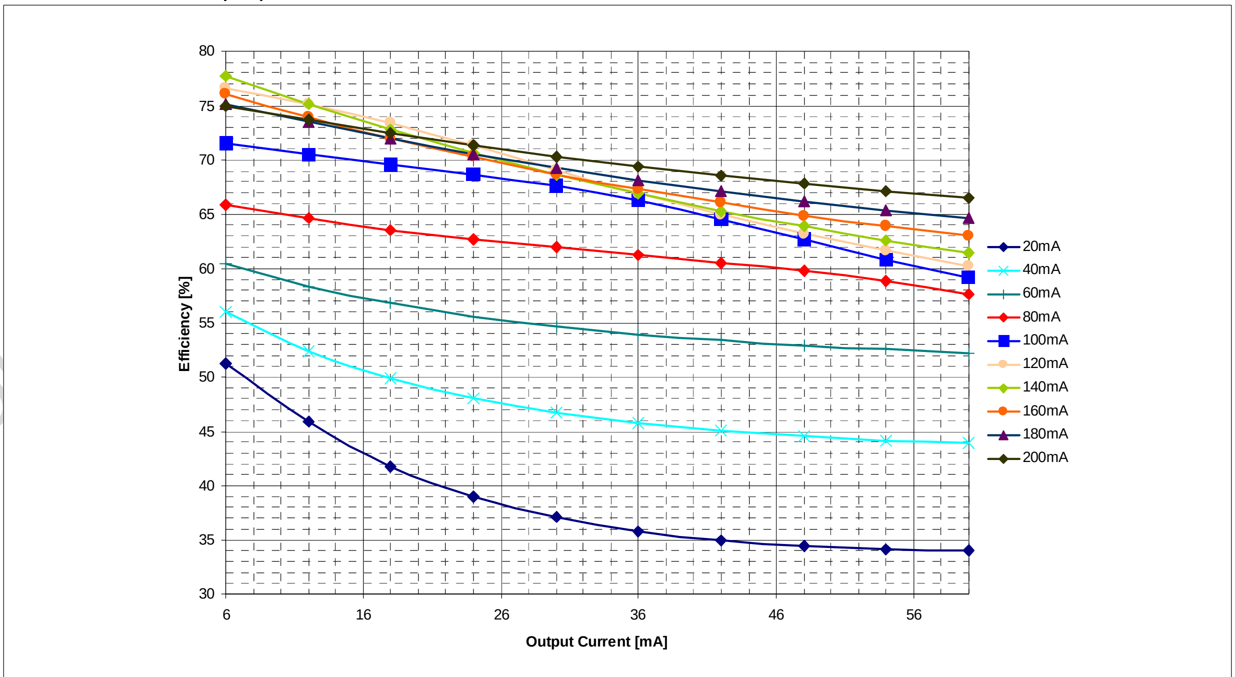


Figure 39: Efficiency variation with 15V Output Current at 125VDC Input Voltage (Parameter is loaded current on 5V output)

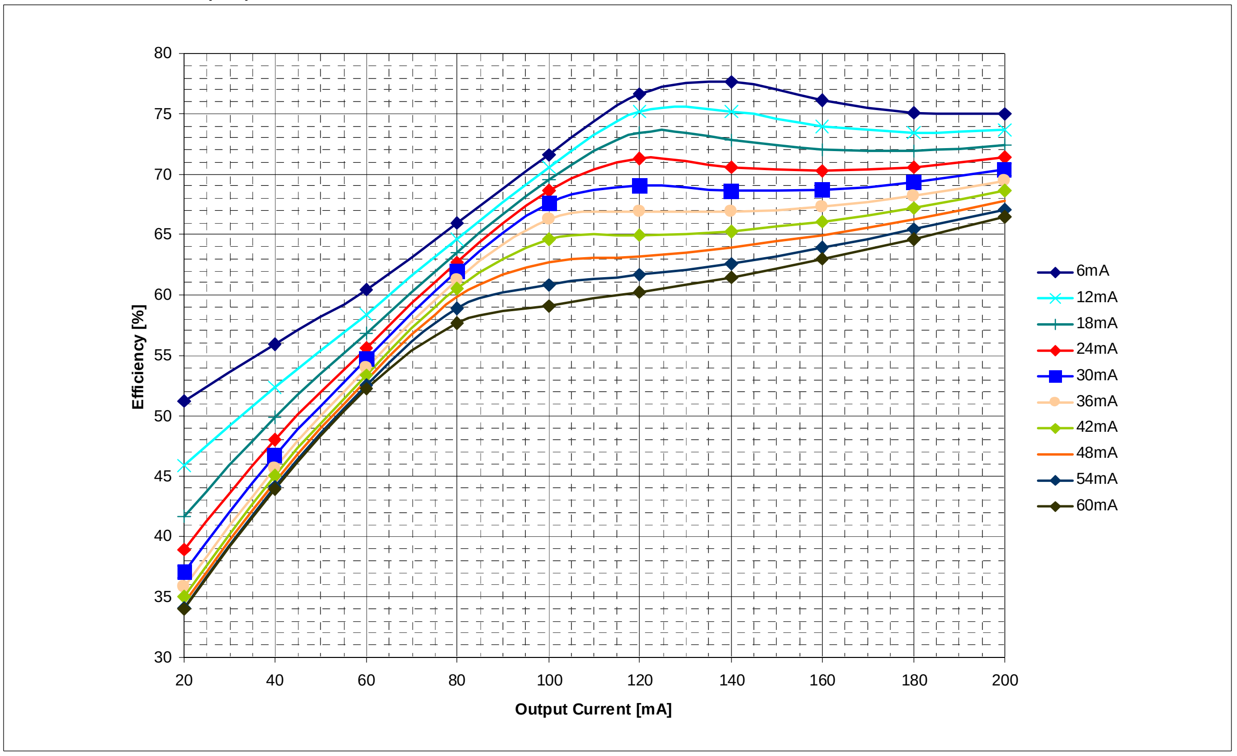


Figure 40: Efficiency variation with 5V Output Current at 375VDC Input Voltage (Parameter is loaded current on 15V output)

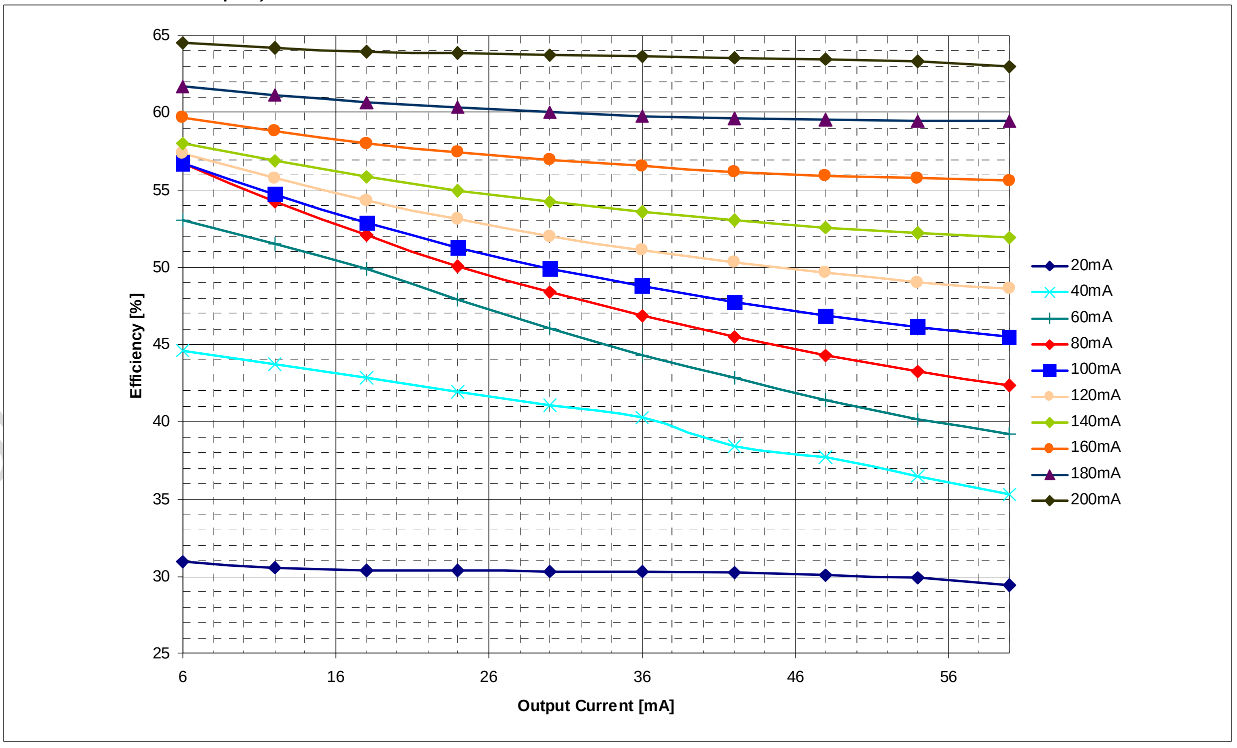
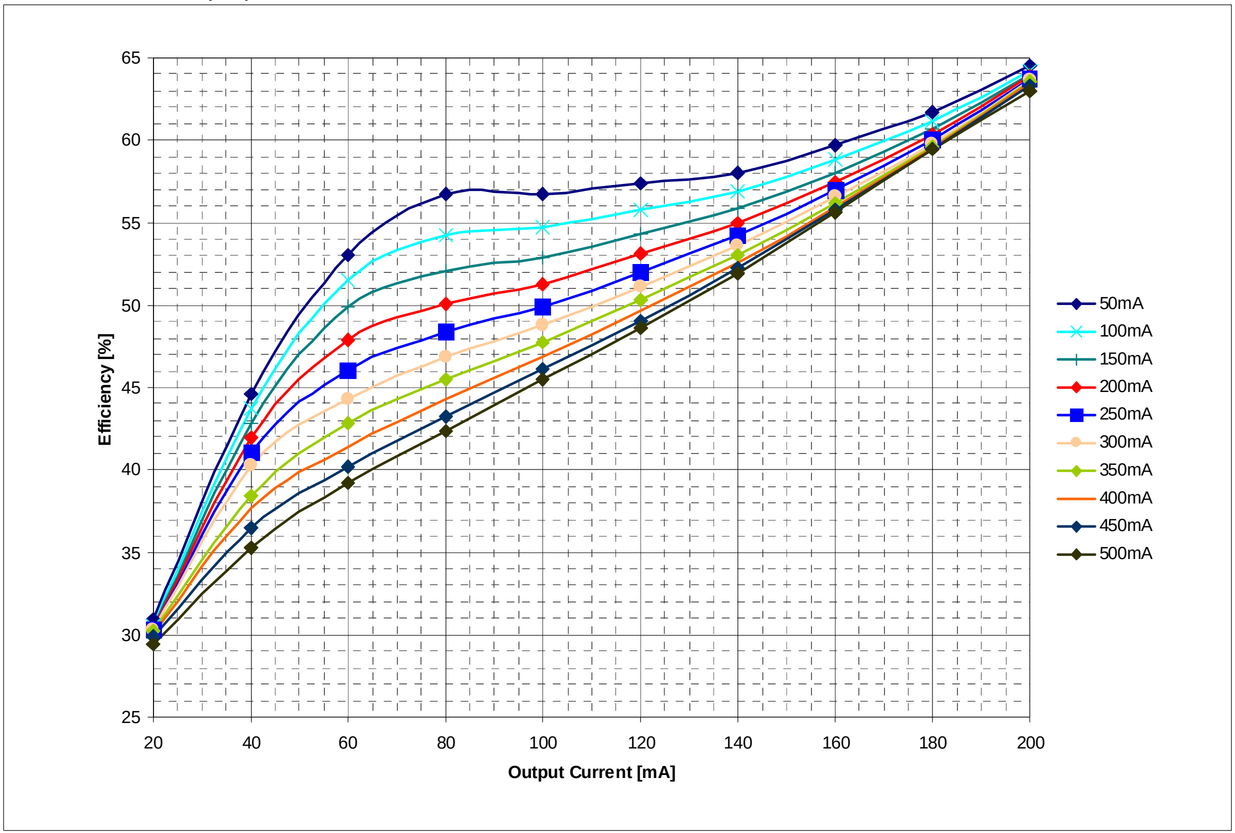


Figure 41: Efficiency variation with 15V Output Current at 375VDC Input Voltage (Parameter is loaded current on 5V output)



The feedback loop stability and response to load transients are demonstrated from figures 42 to 45.

Figure 42: Load transient response, 20mA to 0.2A on 15V output, 5V output unloaded, Vin= 127VDC

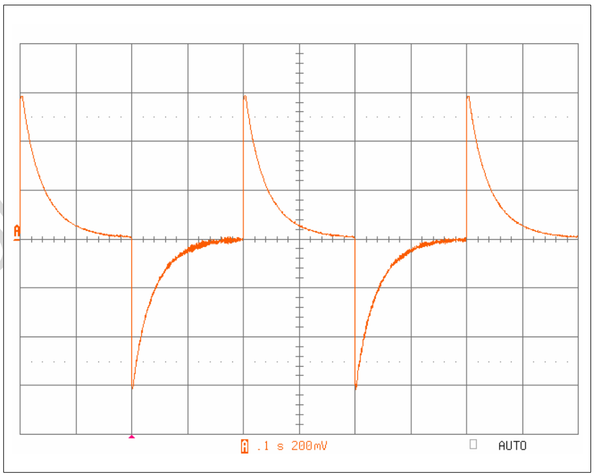


Figure 43: Load transient response, 20mA to 0.2A on 15V output, 5V output loaded by 60mA, Vin= 127VDC

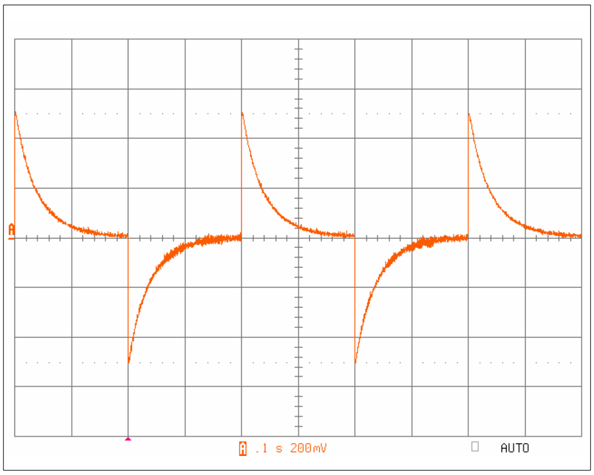


Figure 44: Load transient response, 20mA to 0.2A on 15V output, 5V output unloaded, Vin= 373VDC

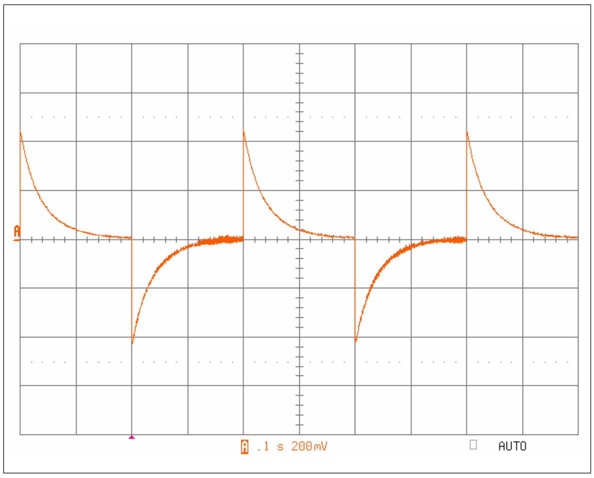
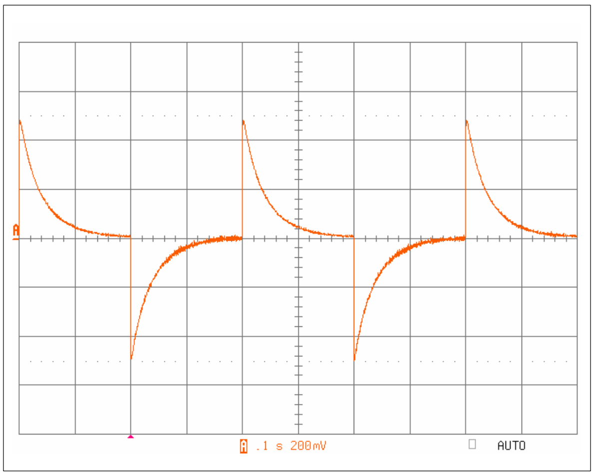


Figure 45: Load transient response, 20mA to 0.2A on 15V output, 5V output loaded by 60mA, Vin= 373VDC



Conducted emissions were measured in neutral and line wire using a peak or average detector. The measurements were performed at 230VAC input voltage and both outputs were fully loaded. The results can be seen from figures 46 to 48.

Figure 46: Phase L, peak detector

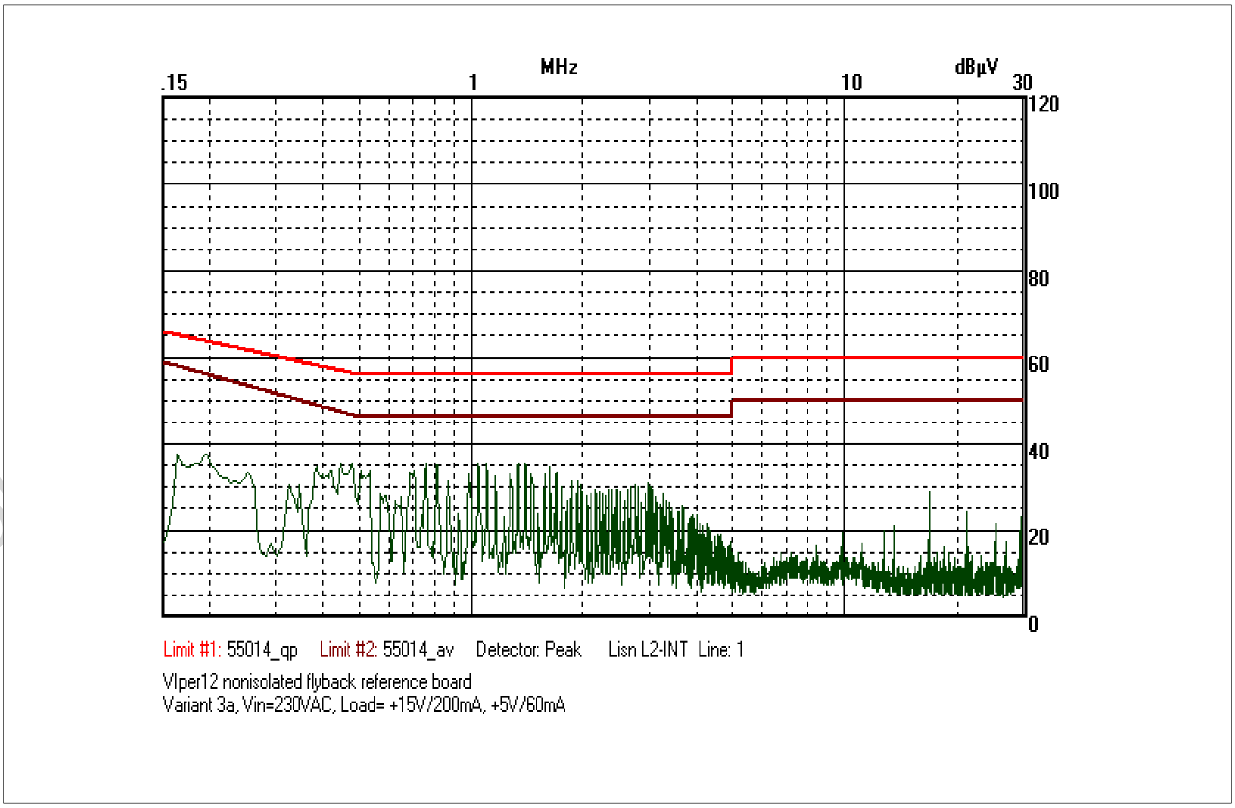


Figure 47: Phase N, average detector

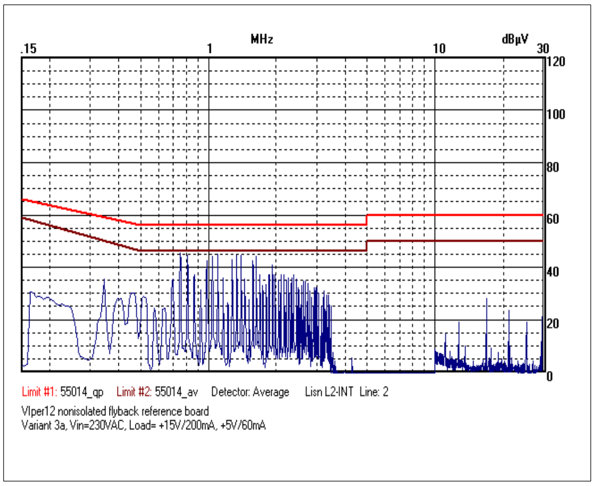
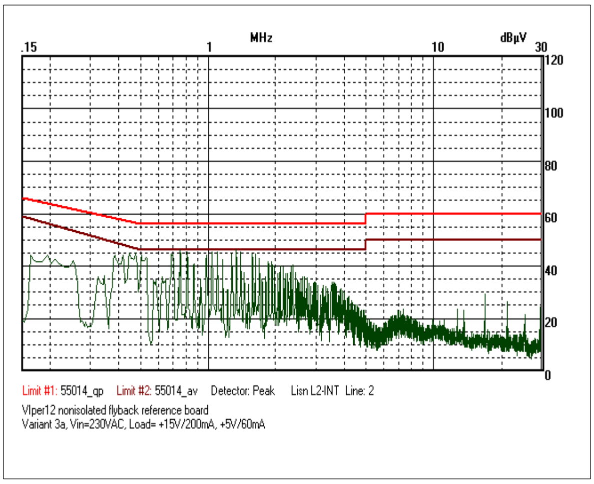


Figure 48: Phase N, peak detector



2.4 NON ISOLATED FLYBACK -5V/500mA, +10V/200mA (VARIANT 4)

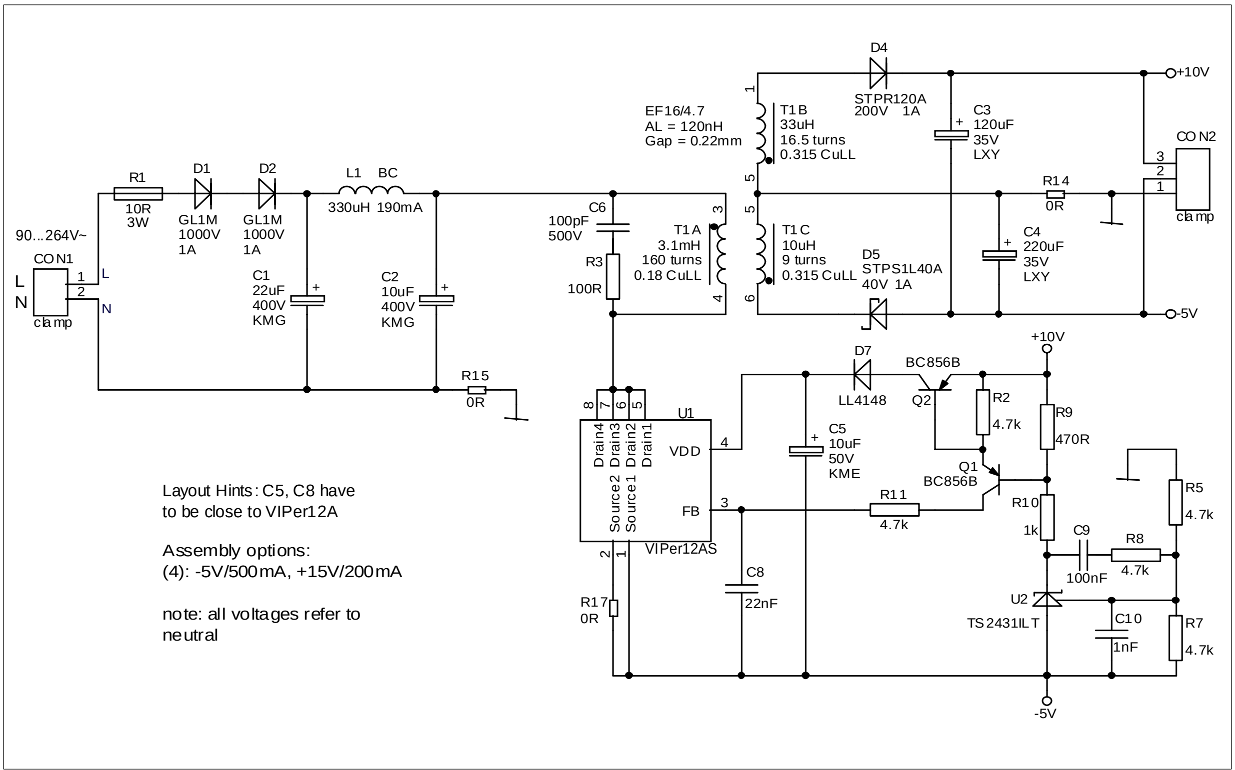
2.4.1 Operating Conditions

Input Voltage range	90-264 VAC
Input Voltage Frequency range	50/60 Hz
Main Output (regulated)	-5V / 500mA
Second Output	10V / 200mA
Total Maximum Output Power	5.5W

2.4.2 Circuit Operation

Variant 1 can be switched to variant 4 by removing short R16 and placement of R15. This reconfiguration will make previous +5V output terminal from variant 1 as a common ground. Previous output ground from variant 1 is disconnected from input ground and is referenced as -5V terminal. The total schematic of the power supply can be seen in figure 49.

Figure 49: Schematic Diagram of Non Isolated Flyback Converter (Variant 4)



3. CONCLUSION

Several variants of the reference board based on a non isolated flyback converter built with monolithic switcher VIPer12AS were presented. It was demonstrated, how the reference board can be easily switched between variants or options. Depicted output regulation, waveforms, overall converter efficiency characteristics and transient responses measured at different working conditions show good performance of the reference boards. Also, thanks to the presented PCB layout and EMI input filter, boards are EMI compliant with regards to the emissions as it was validated by presented EMI measurements. All boards also passed EMI surge and burst tests for power supply immunity against incoming noise from mains.