AN1934
Application note

VIPower™: the VIPer12A-E non-isolated flyback converter reference board

Introduction

This circuit can be used to produce multiple outputs, non-isolated positive or negative voltage. It is dedicated for an auxiliary power supply based on the VIPer12A-E monolithic device.

The aim of this reference board is to propose a solution of the power supply based on an offline discontinuous current mode flyback converter without isolation between input and output. The flyback topology allows the current capability of the monolithic device VIPer12A-E to be exploited when compared with the buck converter based on the power supply. To ensure low cost of the whole power supply, the isolation between input and output is not provided. This simplifies the transformer design and production. The VIPer12A-E incorporates the PWM controller with 60 kHz internal oscillator and altogether with the vertical power MOSFET switch in the SO-8 package. The presented power supply has four variants, which are included in this reference board thanks to different assembly options.

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1 Circuit description

1.1 Non-isolated flyback + 5 V/500 mA, +15 V/200 mA (variant 1)

Table 1. Operating conditions (variant 1)

Parameter	Value
Input voltage range	90-264 V_{AC}
Input voltage frequency range	50/60 Hz
Main output (regulated)	5 V / 500 mA
Second output	15 V/ 200 mA
Total maximum output power	5.5 W

1.1.1 Circuit operation (variant 1)

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 by a single rectification consisting of diodes D1 and D2. Two diodes in series are used for EMI reasons to sustain burst pulses of 2 kV. The capacitors C1, C2 and inductor L1 form an EMI filter.

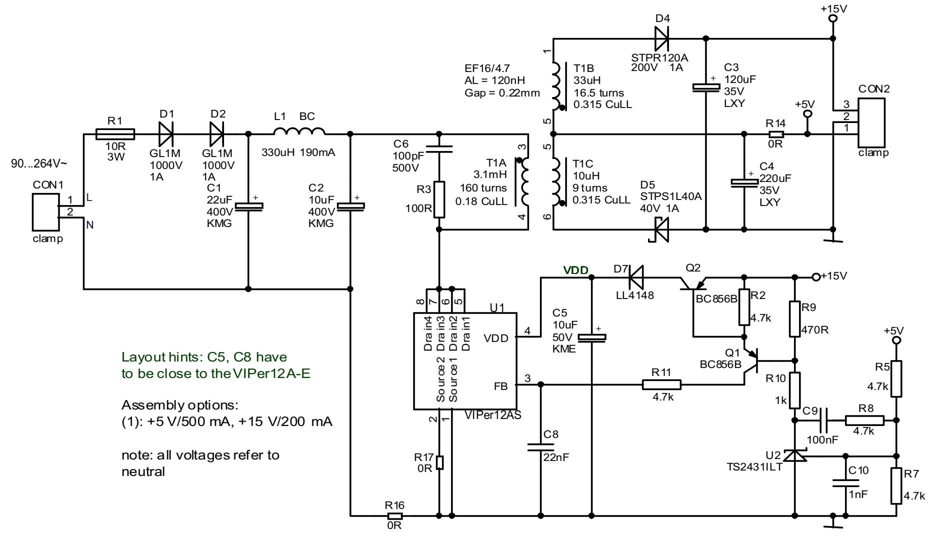
The DC voltage on C2 is applied to the primary winding of the transformer through the internal MOSFET switch of the VIPer12A-E during on-time of the switching period. The snubber circuit, consisting of resistor R3 and capacitor C6, reduces the voltage spike across the primary winding of the transformer due to the parasitic leakage inductance. It also slows down dv/dt of the primary winding voltage and improves EMI.

The power supply provides two outputs through rectifiers D4, D5 and smoothing capacitors C3 and C4. The VIPer12A-E is supplied by 15 V output voltage through transistor Q2 and diode D7.

The diode D7 ensures the proper startup of the converter by separating the 15 V output from the internal start-up current source of the VIPer12A-E, which charges the IC supply capacitor C5 with a specified start-up threshold voltage of about 16 V. 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 primary winding and primary current ramps up. As soon as the primary current reaches the VIPer12A-E internal set point defined by the 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 5 V output flows through diode D5 only. Because of the D5 location, the 15 V output is charged via both diode D4 and D5. Beside the slight decrease of the converter power efficiency, it significantly improves the cross-regulation of the outputs which is the main purpose of this arrangement.

The voltage feedback loop senses the 5 V output by resistor dividers R5, R7. The control IC U2 compares the resistor divider output voltage with the internal reference voltage of 2.5 V and changes the cathode voltage accordingly to keep 5 V output stable. If the 5 V output voltage rises above its nominal value, the U2 cathode voltage goes down and cathode current increases. The cathode current causes a voltage drop across R9 and opens transistor Q1 which injects the current from V_{cc} line to FB pin 3 of the VIPer12A-E. The FB pin current decreases 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 1 mA for U2 proper operation.

Figure 1. Non-isolated flyback converter schematic diagram (variant 1)



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

1.1.2 Bill of materials

The bill of material presented in *Table 2* 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 15 V output is required, resistor R6 connected from the 15 V output to U2 control input can be assembled.

Table 2. Bill of material for all variants of non-isolated flyback converter

Reference	Quantity	Variant	Description
CON1	1		Clamp, WECO, 2-pole, horizontal, 1.5 mm^2, 380 V, 15 A
CON2	1		Clamp, WECO, 3-pole, horizontal, 1.5 mm^2, 380 V, 15 A
C1	1		22 µF electrolytic capacitor, Nippon Chemi-Con, KMG 400 V, 20%
C2	1		10 µF electrolytic capacitor, Nippon Chemi-Con, KMG 400 V, 20%
C3	1		120 µF electrolytic capacitor, Nippon Chemi-Con, LXY 35 V 20%
C4	1	(1, 2, 4)	220 µF electrolytic capacitor, Nippon Chemi-Con, LXY 35 V 20%

Table 2. Bill of material for all variants of non-isolated flyback converter (continued)

Reference	Quantity	Variant	Description
C5	1		10 µF electrolytic capacitor, Nippon Chemi-Con, KME 50 V 20%
C6	1		100 pF ceramic capacitor, X7R, 500 V C1206 10%
C8	1		22 nF ceramic capacitor, X7R, 50 V C0805 10%
C9	1	(1, 4)	100 nF ceramic capacitor, X7R, 50 V C0805 10%
C10	1	(1, 4)	1 nF ceramic capacitor, X7R, 50 V C0805 10%
C11	1	(2) (3)	2.2 µF tantalum capacitor, size A, B45196E, 10 V 7.0R 20% 100 nF ceramic capacitor, X7R, 50 V C1206 10%
D1, D2	2		GL1M diode, Diotec, trr=1.5 µs 1000 V 1 A, MiniMELF
D4	1		STPR120A diode, fast recovery trr=25 ns 200 V 1 A SMA
D5	1	(1, 2, 4) (3)	STPS1L40A diode, Schottky, 40 V 1 A, SMA 0R resistor, metal film, R1206
D6	1	Optional	ST PKC-136 diode, peak clamp, VBR=160 V, 700 V, 1.5 W DO-15
D7	1		LL4148 diode 75 V 200 mA
D8	1	(2, 3)	ZMM13 Zener diode, 13 V 0.5 W 5%
L1	1		330 µH inductor, EPCOS, bobbin core, B78108-S1334-J, 190 mA 6.4R 10%
Q1, Q2	2	(1, 4)	BC856B bipolar transistor, PNP, 65 V 100 mA 330 mW
R1	1		10R resistor, Yageo, wirewound, fusible, TK120 CRF 254-4 3 W 5%
R2, R5, R7, R8	4	(1, 4)	4.7 K resistor, metal film, 100 V 0.125 W R0805 1%
R3	1		100 R resistor, metal film, 200 V 0.25 W R1206 1%
R4	1	(2, 3)	0R resistor, metal film, R1206
R6	1	Optional	24 K resistor, metal film, R0805, 100 V 0.125 W 1%
R9	1	(1, 4)	470 R resistor, metal film, R0805, 100 V 0.125 W 1%
R10	1	(1, 4)	1 K resistor, metal film, R0805, 100 V 0.125 W 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, order number 545 23 249 00 Ns=14/11 turn transformer, Vogt ferrite Fi324, EF16/4.7, order number 545 23 249 00
U1	1		VIPer12A-E, 730 V 0.4 A, 27R, f=60 kHz, SO-8
U2	1	(1, 4)	TS2431ILT shunt ref. IC, 2.5 V 1 mA to 100 mA 360 mW 2%

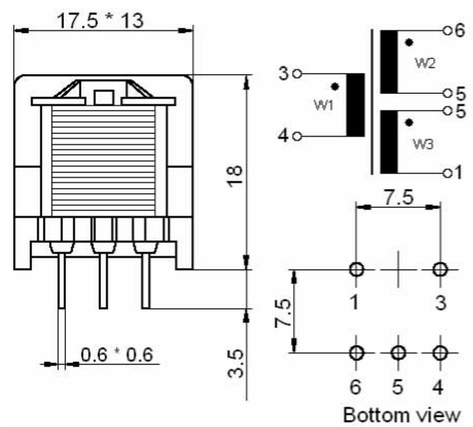
Table 2. Bill of material for all variants of non-isolated flyback converter (continued)

Reference	Quantity	Variant	Description
U3	1	(2) (3b)	L4931CD50 voltage regulator, low drop, with inhibit, 5 V, 250 mA 4% L78L05CD positive voltage reg., 5 V, 100 mA 10%
U4	1	(3a)	L78M05CDT positive voltage regulator, 5 V, 0.5 A 5%

1.1.3 Transformer design

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

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



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The basic parameters of the ferrite core selected from Vogt ferrite materials and shapes can be seen in *Table 3*. The gap size is optimized to ensure the appropriate current capability and inductance to fully exploit switching frequency and to switch peak current limit of the VIPer12A-E to achieve the maximum output power.

Table 3. Transformer core parameters

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

An overview of the most important parameters for each winding can be found in *Table 4*. This table is valid for all variants. The only difference is the number of turns for the secondary windings. The difference is indicated in the “number of turns” of the column.

Table 4. Transformer winding parameters

Order	Start pin	End pin	Number of turns	Wire diameter [mm]	Wire material	Inductance
1	3	4	160	0.18	CuLL	3.1 mH
2	6	5	9 (1, 3, 4) 11 (2)	0.315	CuLL	10 µH 15 µH
3	5	1	16.5 (1, 3, 4) 14.5 (2)	0.315	CuLL	33 µH 25 µH

1.1.4 PCB layout

The PCB is designed as a single-sided board made of FR-4 material with 35 µm 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 59x30 mm. 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)

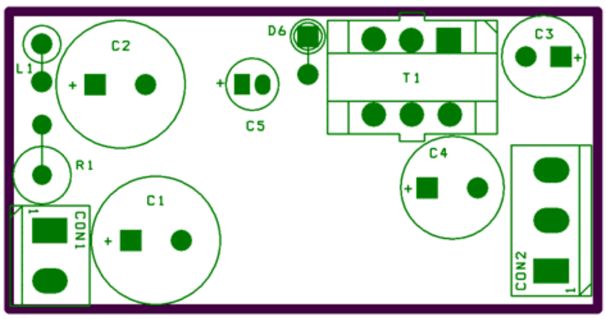
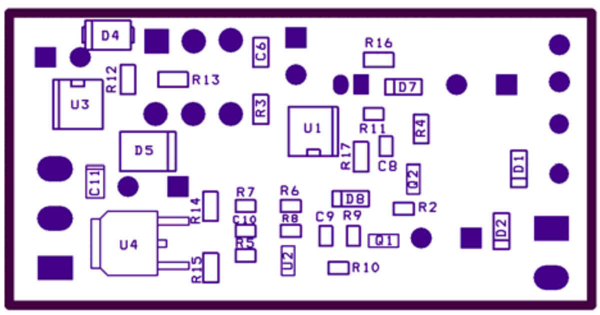
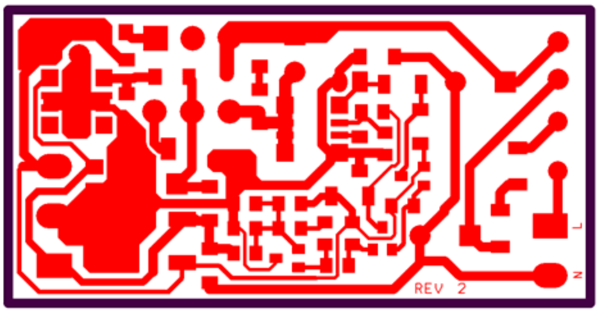


Figure 4. Assembly solder side (not in scale)



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

1.1.5 Evaluation and measurements

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

Figure 7. Output regulation characteristics of 5 V output at 125 VDC input voltage (load current parameter is on 15 V output)

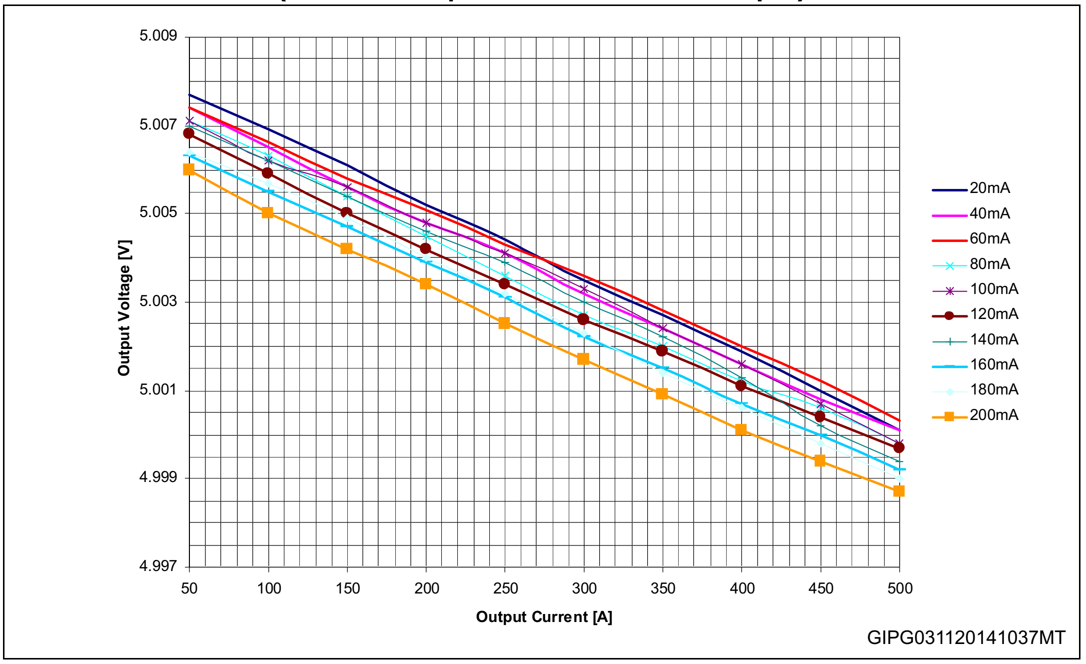
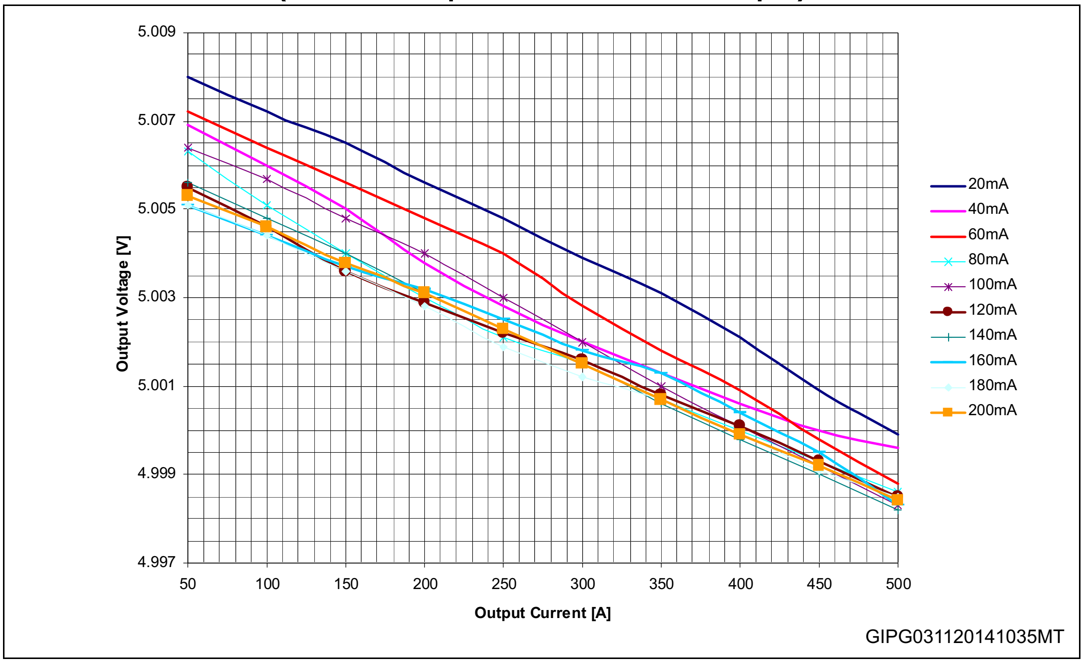


Figure 8. Output regulation characteristics of 5 V output at 375 VDC input voltage (load current parameter is on 15 V output)



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

Figure 9. Output regulation characteristics of 15 V, output at 125 VDC input voltage (load current parameter is on 5 V output)

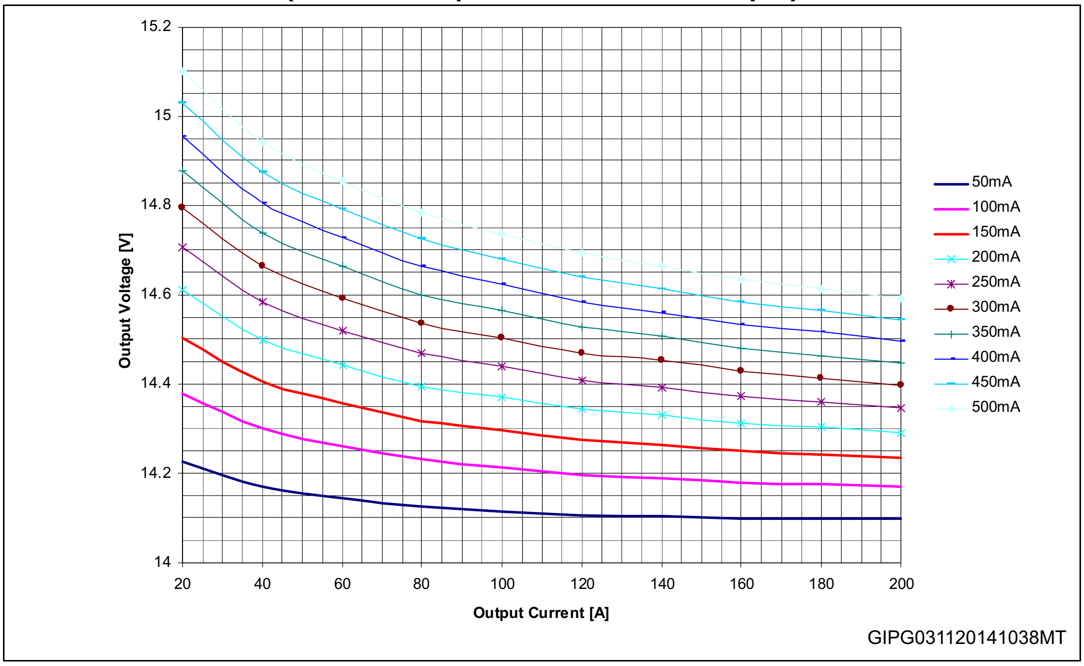
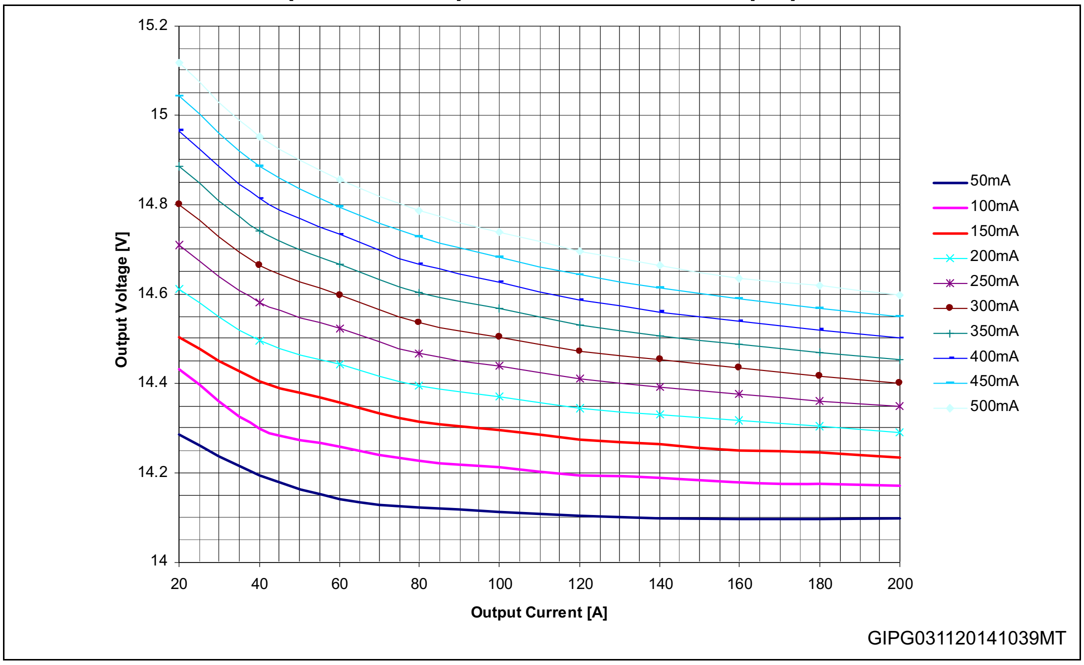


Figure 10. Output regulation characteristics of 15 V, output at 375 VDC input voltage (load current parameter is on 5 V output)



One of the most observed parameters when the converter performance is judged is the power efficiency. *Figure 11* and *12* depict the dependency of the efficiency on load applied to the 5 V output (load current parameter is on 15 V output). Similarly *Figure 13* shows the dependency on the 15 V output current (load current parameter is on 5 V output). *Figure 13* and *14* show the same characteristics as *Figure 10*, *11* and *12*, but measured on input voltage of 375 VDC.

Figure 11. Efficiency variation with 5 V output current at 125 VDC input voltage (load current parameter is on 15 V output)

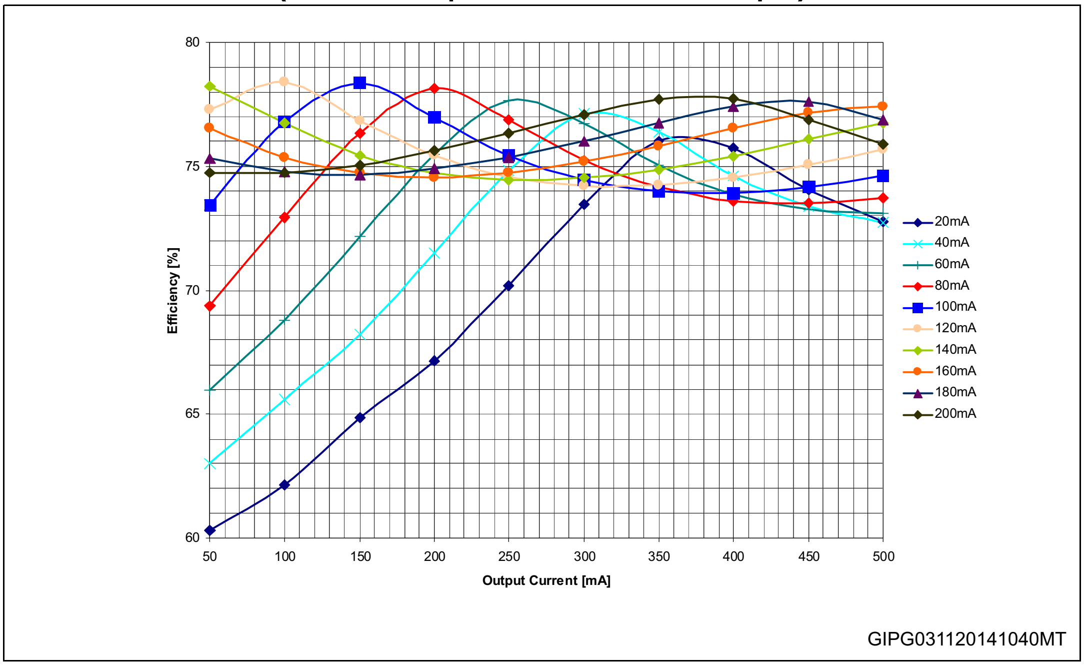


Figure 12. Efficiency variation with 15 V, output current at 125 VDC input voltage (load current parameter is on 5 V output)

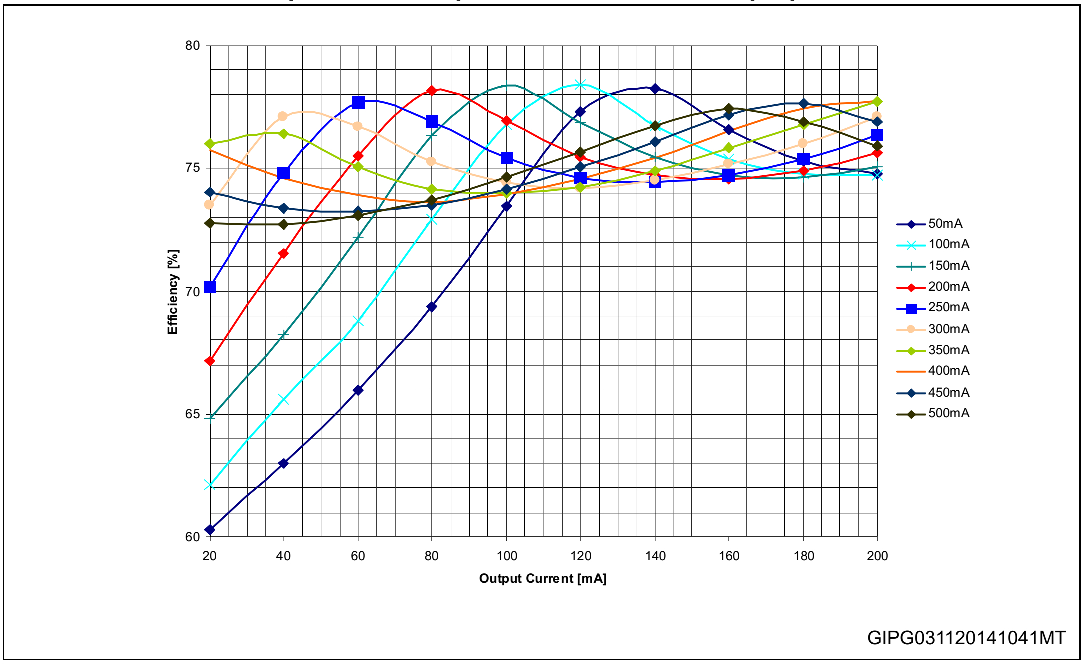


Figure 13. Efficiency variation with 5 V output current at 375 VDC input voltage (load current parameter is on 15 V output)

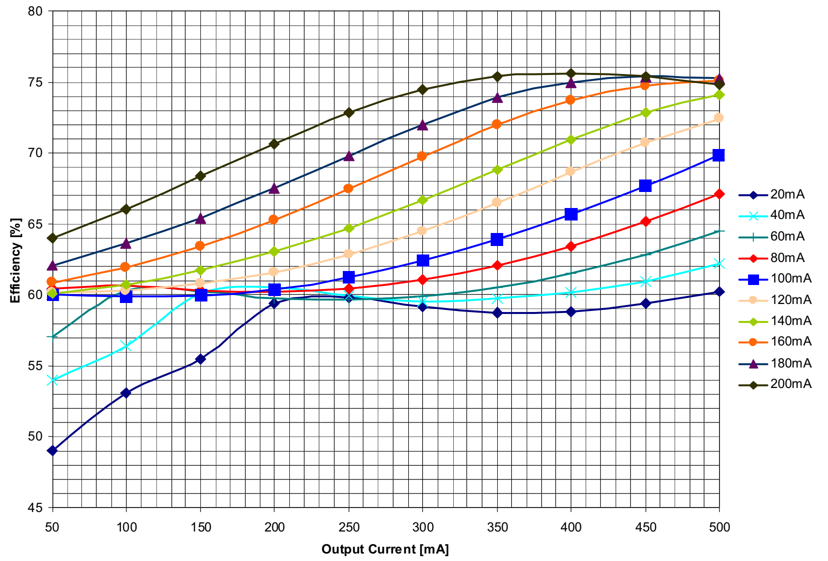


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Figure 14. Efficiency variation with 15 V output current at 375 VDC input voltage (load current parameter is on 5 V output)

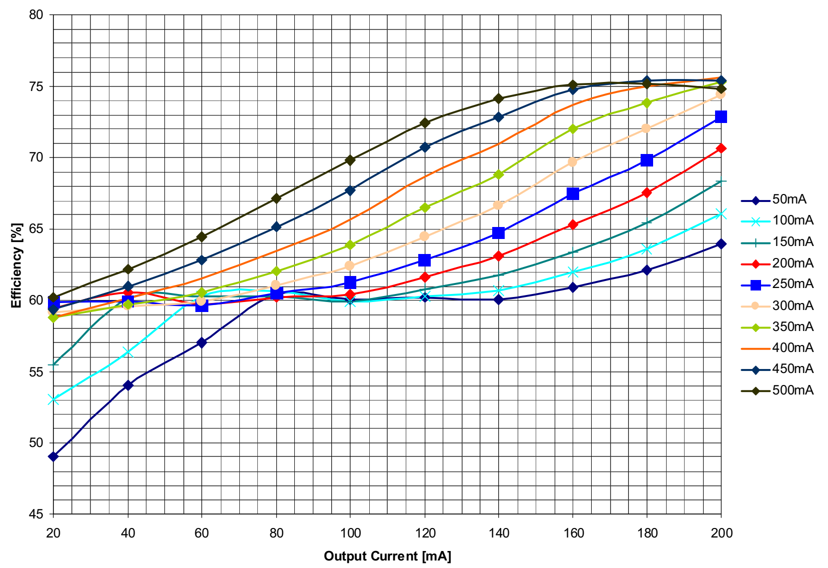

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Figure 15 to *Figure 24*, the most important voltage or current waveforms at different input and output conditions are shown. Channel 1 (pink) is the power MOSFET source terminal voltage of the VIPer12A-E. Channel 4 (blue) shows the drain current of the VIPer12A-E. 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 on the output shorted condition.

Figure 15. V_{in}=127 VDC, no-load

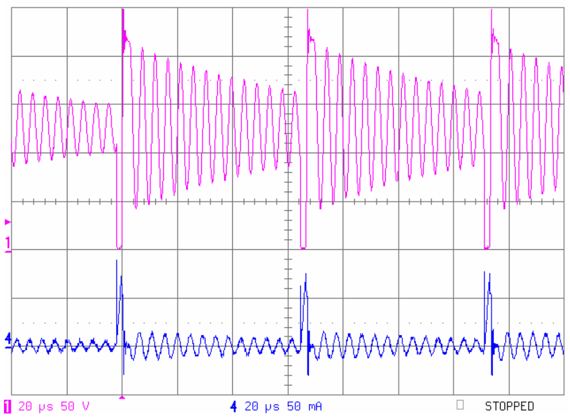


Figure 16. V_{in}=373 VDC, no-load

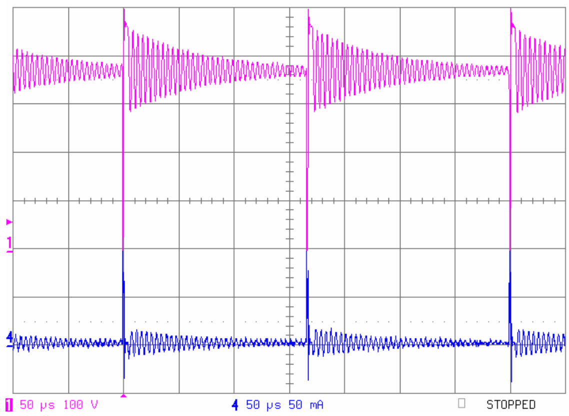


Figure 17. V_{in}=127 VDC, nominal load

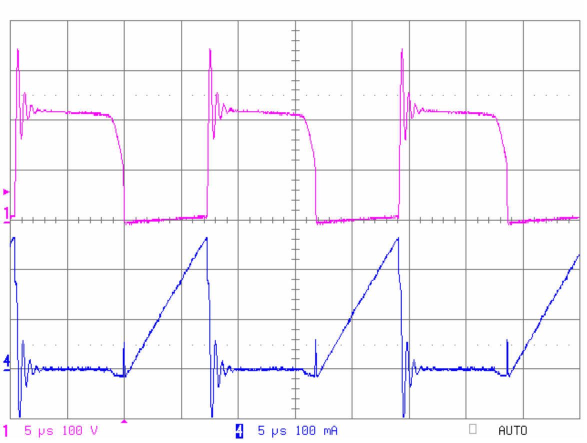


Figure 18. V_{in}=373 VDC, nominal load

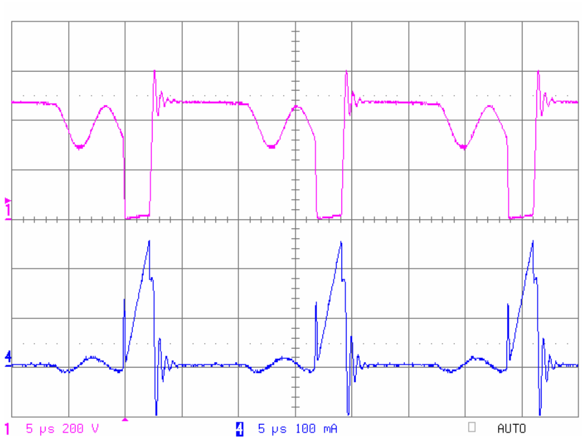


Figure 19. V_{in}=127 VDC, 50% load on both outputs

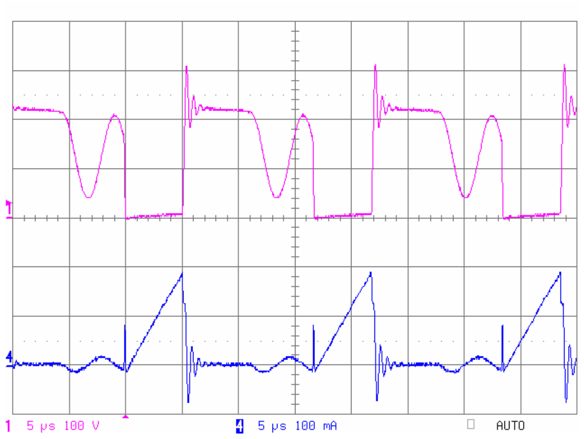


Figure 20. V_{in}=373 VDC, 50% load on both outputs

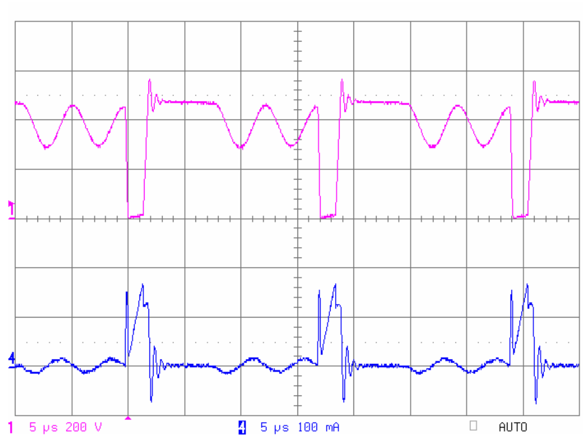


Figure 21. V_{in}=127 VDC, 5 V output shorted, 15 V output no-load

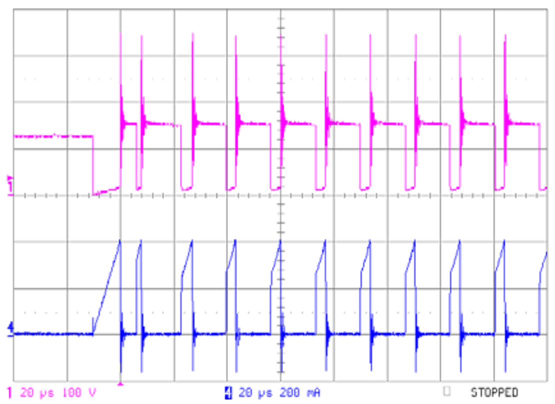


Figure 22. V_{in}=127 VDC, 15 V output shorted, 5 V output no-load

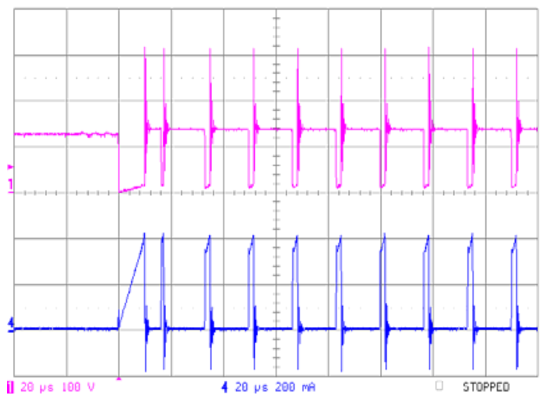


Figure 23. V_{in}=373 VDC, 5 V output shorted, 15 V output no-load

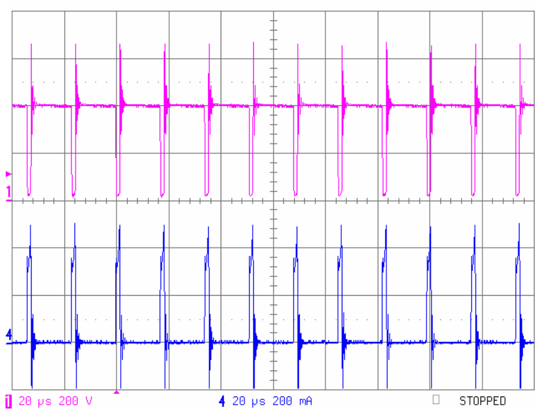
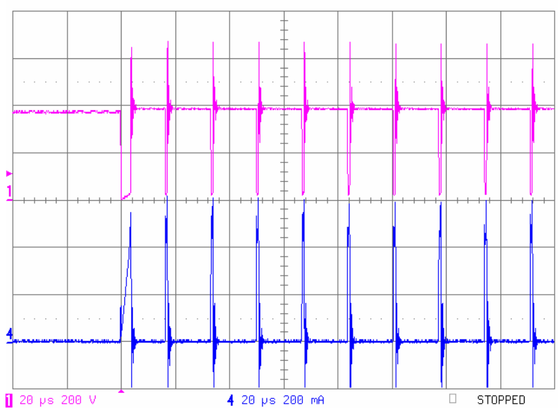


Figure 24. V_{in}=373 VDC, 15 V output shorted, 5 V output no-load



The feedback loop stability and reaction to the load change are indicated from *Figure 25* to *28*.

Figure 25. Load transient response, 50 mA to 0.5 A on 5 V output, 15 V output unloaded, V_{in}=127 VDC

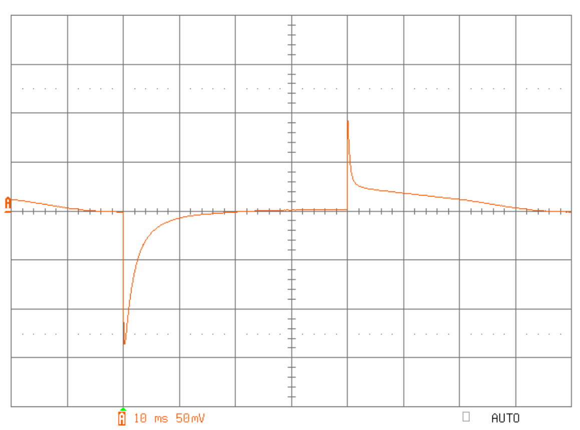


Figure 26. Load transient response, 50 mA to 0.5 A on 5 V output, 15 V output nominal load, V_{in}=127 VDC

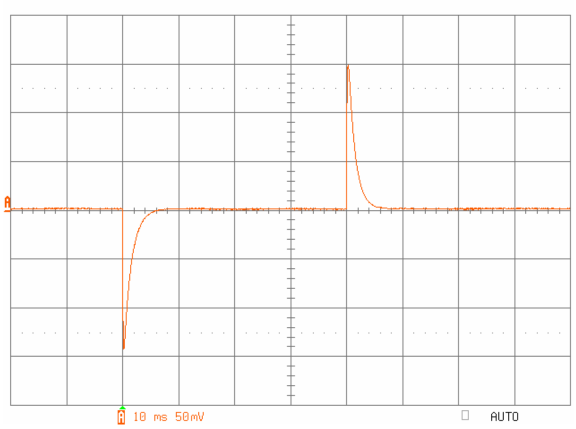


Figure 27. Load transient response, 50 mA to 0.5 A on 5 V output, 15 V output unloaded, V_{in}=373 VDC

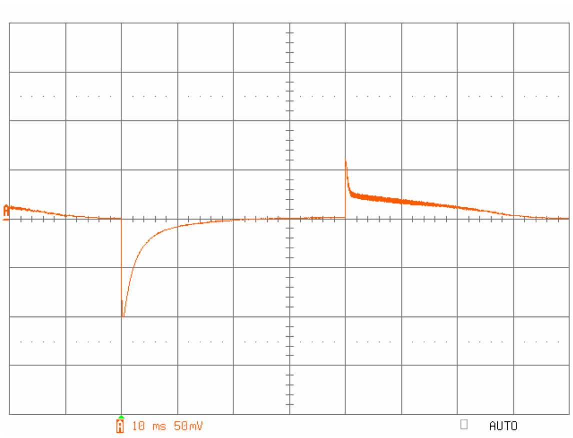
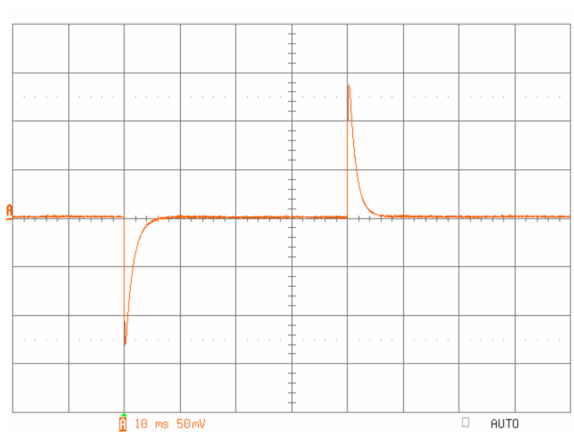


Figure 28. Load transient response, 50 mA to 0.5 A on 5 V output, 15 V output nominal load, V_{in}=373 VDC



Furthermore, conducted emissions have been measured in neutral and line wire using a peak or average detector. The measurements have been performed at 230 VAC input voltage and both outputs have been loaded. The results can be seen from *Figure 29* to *32*.

Figure 29. Phase L, average detector

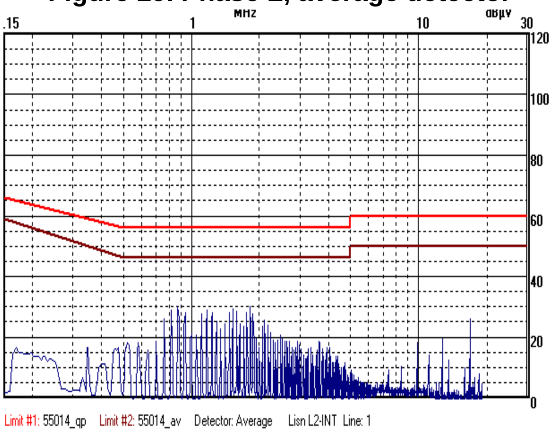


Figure 30. Phase L, peak detector

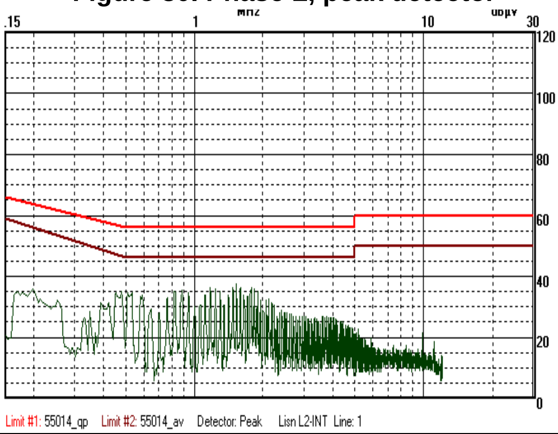


Figure 31. 5 V/500 mA phase N, average detector

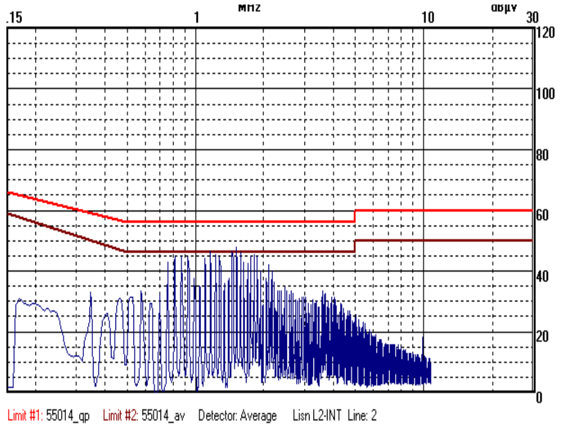
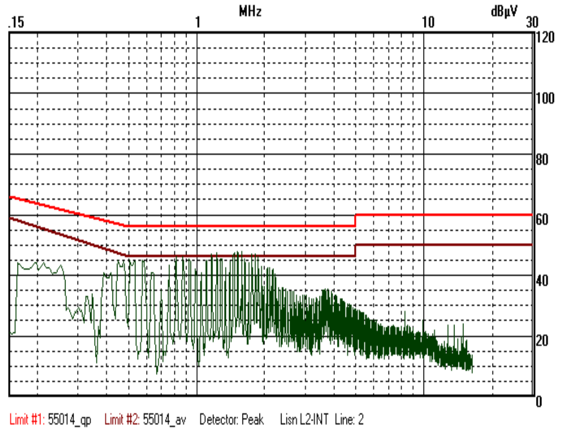


Figure 32. +15 V/200 mA phase N, peak detector



1.2 Non-isolated flyback + 5 V/250 mA, + 15 V/200 mA (variant 2)

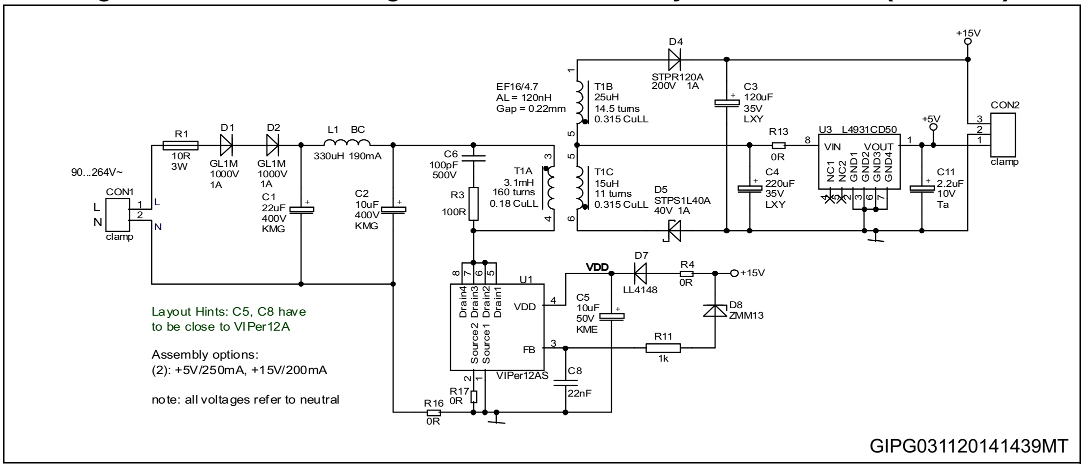
Table 5. Operating conditions (variant 2)

Parameter	Value
Input voltage range	90-264 VAC
Input voltage frequency range	50/60 Hz
Main output (regulated)	15V / 200 mA
Second output	5V / 250 mA
Total maximum output power	4.25 W

1.2.1 Circuit operation (variant 2)

The total schematic of the power supply can be seen in *Figure 32*. Compared to variant 1, this variant is different, specially the feedback loop. Instead of 5 V output, the 15 V output is regulated by a simple circuit consisting of a Zener diode D8 and a resistor R11. Since 5 V 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 the secondary windings is slightly different compared to variant 1.

Figure 33. Schematic diagram of non-isolated flyback converter (variant 2)



1.3 Non-isolated flyback +15 V/200 mA, +5 V/60 mA (variant 3)

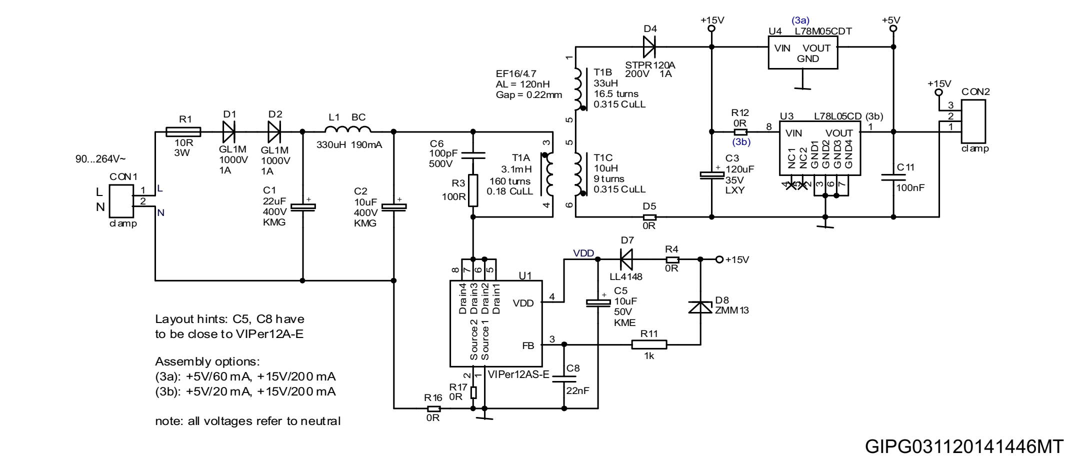
Table 6. Operating conditions (variant 3)

Parameter	Value
Input voltage range	90 to 264 VAC
Input voltage frequency range	50/60 Hz
Main output (regulated)	15V/200 mA
Second output	5 V/20 mA or 60 mA
Total maximum output power	4.25 W

1.3.1 Circuit operation (variant 3)

The schematic diagram is depicted in *Figure 34* and is very similar to the schematic of variant 2. It has only one output rectifier diode and one output electrolytic capacitor. The 5 V linear regulator is directly supplied from 15 V output. There are two sub-variants. Depending on the output current requirement for 5 V output, U3 or U4 can be mounted.

Figure 34. Schematic diagram of non-isolated flyback converter (variant 3)



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1.3.2 Evaluation and measurements

The output regulation characteristics measured on 5 V output can be seen in *Figure 35*. It shows the voltage variation of the 5 V output when a different load is applied to 15 V output. *Figure 36* shows the same characteristic as *Figure 35* but measured at 375 VDC input voltage.

Figure 35. Output regulation characteristics of 5 V output at 125 VDC input voltage for variant 3 (load current parameter is on 15 V output)

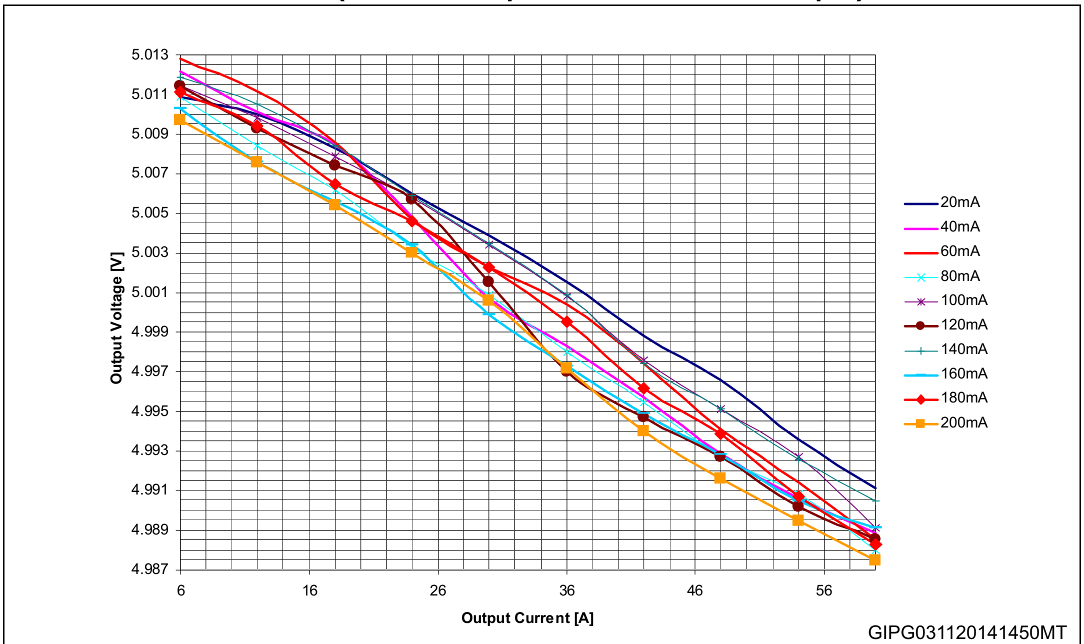

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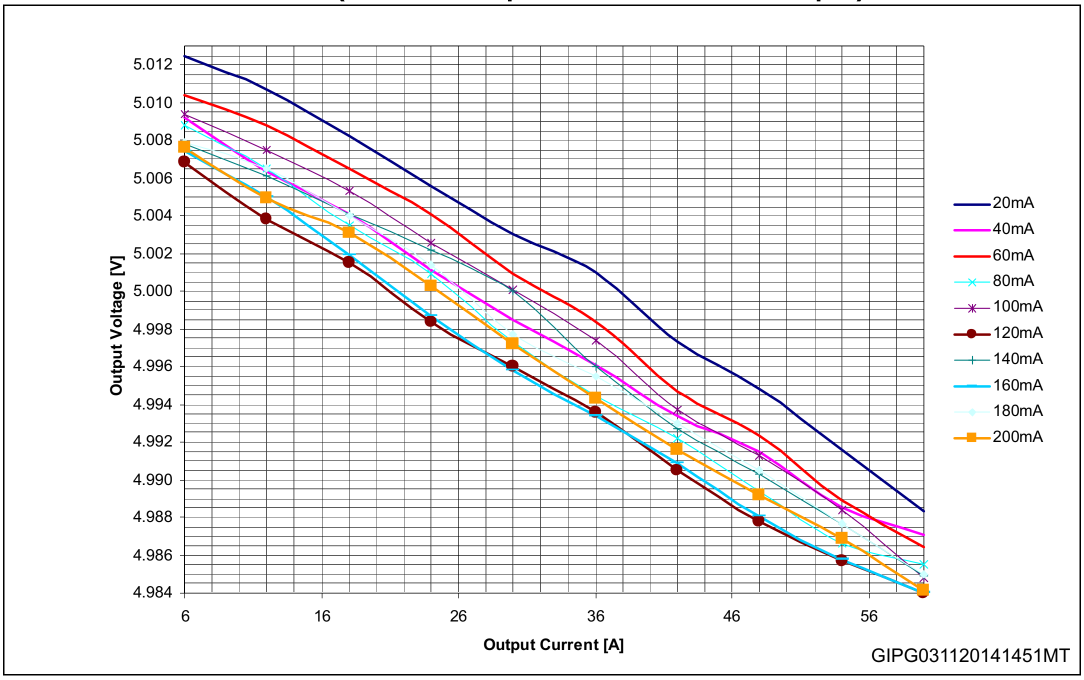
Figure 36. Output regulation characteristics of 5 V output at 375 VDC input voltage for variant 3 (load current parameter is on 15 V output)



Similarly, *Figure 37* shows the output regulation characteristics measured on 15 V output when a different load current is applied to 5 V output. *Figure 38* shows the same characteristic as *Figure 37* but measured at 375 VDC input voltage.

Figure 37. Output regulation characteristics of 15 V output at 125 VDC input voltage for variant 3 (load current parameter is on 5 V output)

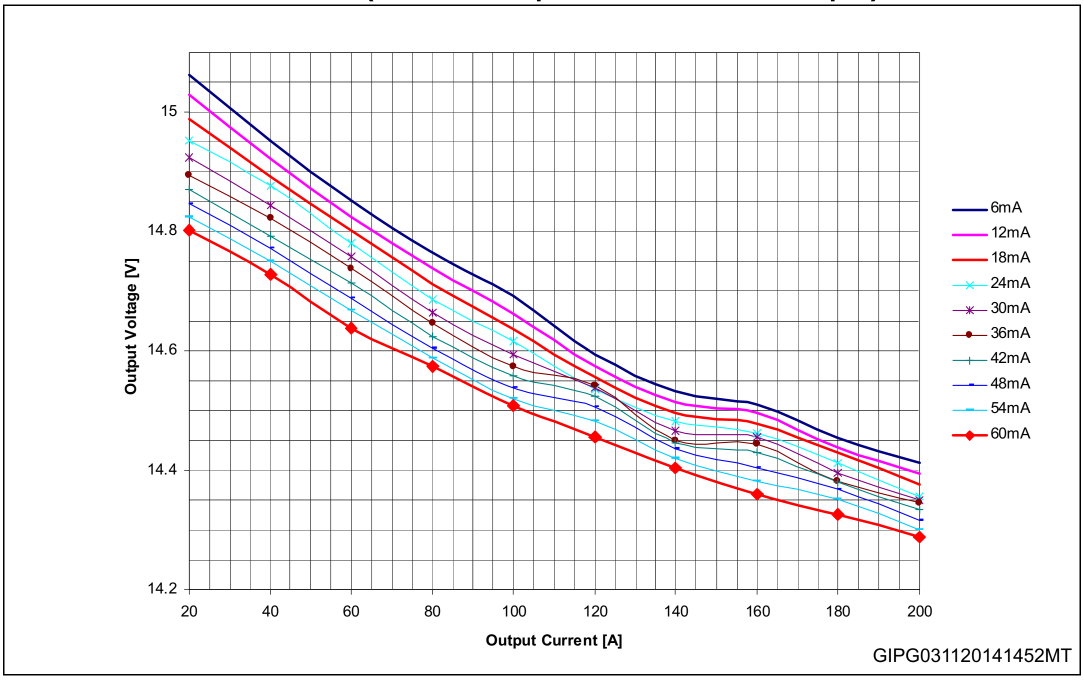


Figure 38. Output regulation characteristics of 15 V output at 375 VDC input voltage for variant 3 (load current parameter is on 5 V output)

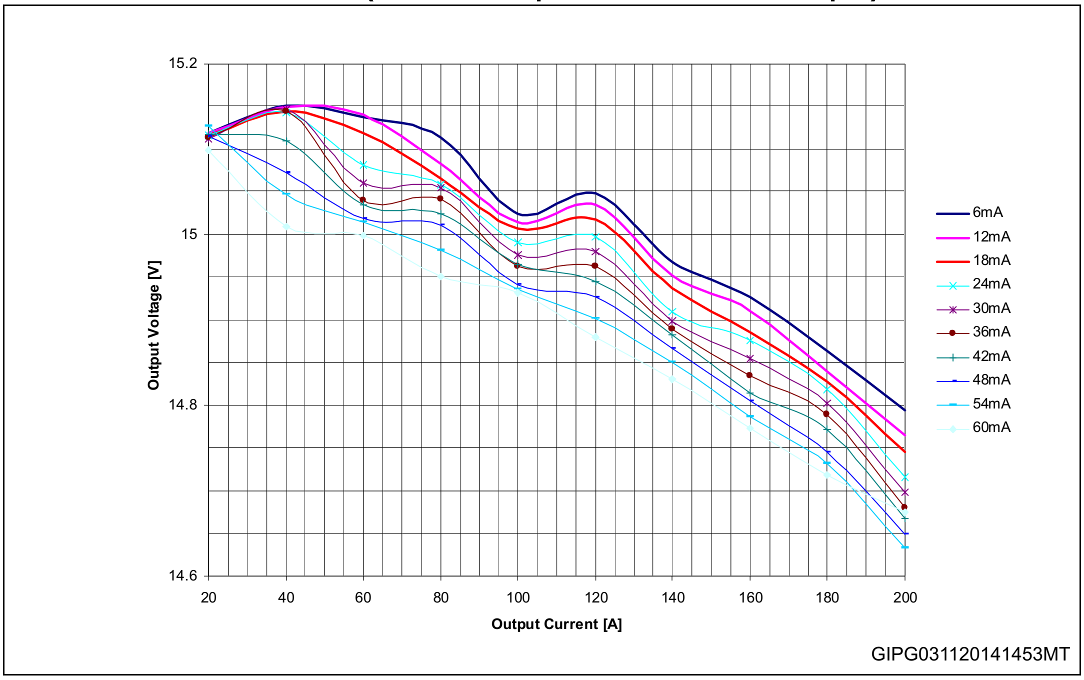


Figure 39 depicts the dependency of the efficiency on load applied to the 5 V output (load current parameter is on 15 V output). Similarly, *Figure 40* shows the dependency on the 15 V output current (load current parameter is on 5 V output). *Figure 41* and *42* show the same characteristics as *Figure 39* and *40* but measured at input voltage of 375 VDC.

Figure 39. Efficiency variation with 5 V output current at 125 VDC input voltage for variant 3 (load current parameter is on 15 V output)

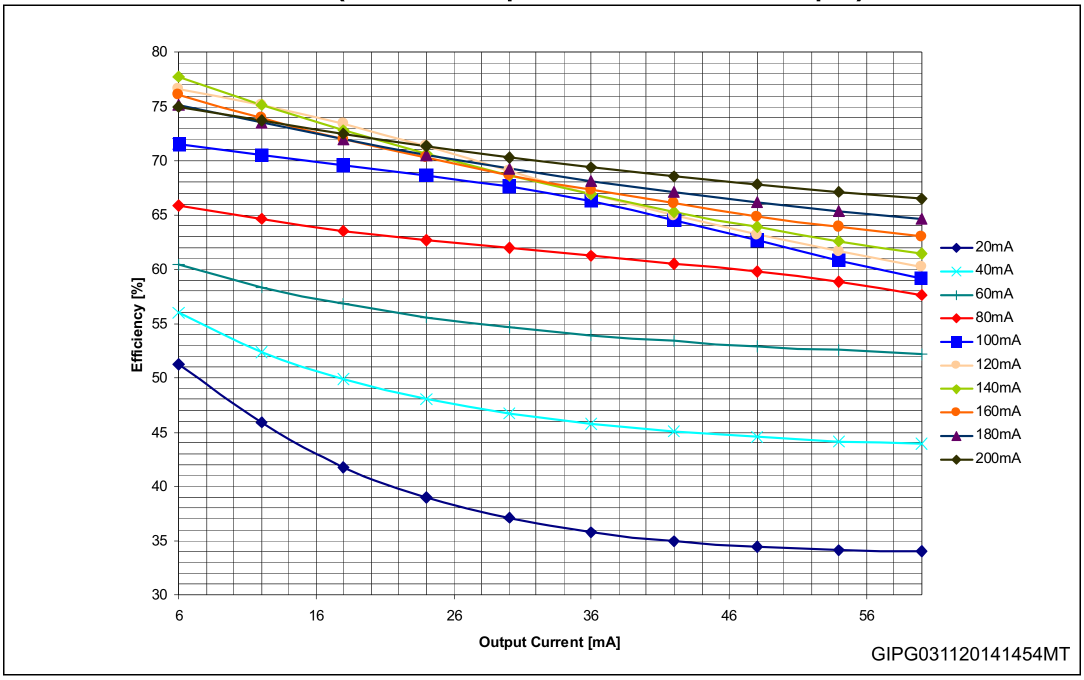


Figure 40. Efficiency variation with 15 V output current at 125 VDC input voltage for variant 3 (load current parameter is on 5 V output)

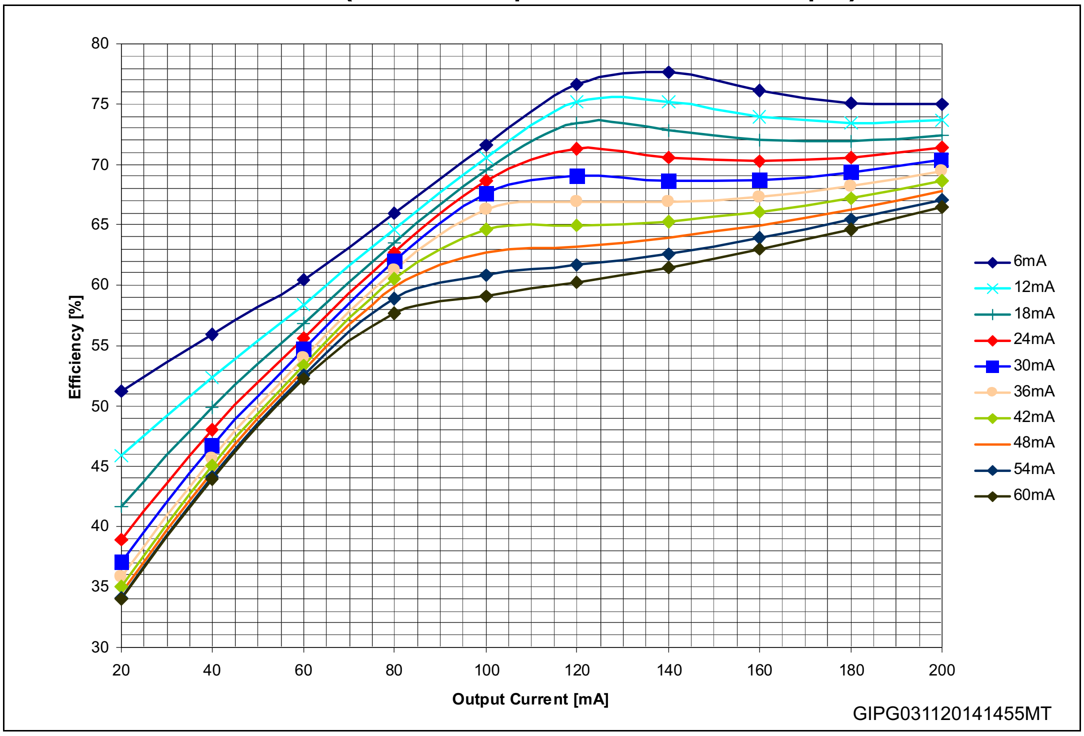


Figure 41. Efficiency variation with 5 V output current at 375 VDC input voltage for variant 3 (load current parameter is on 15 V output)

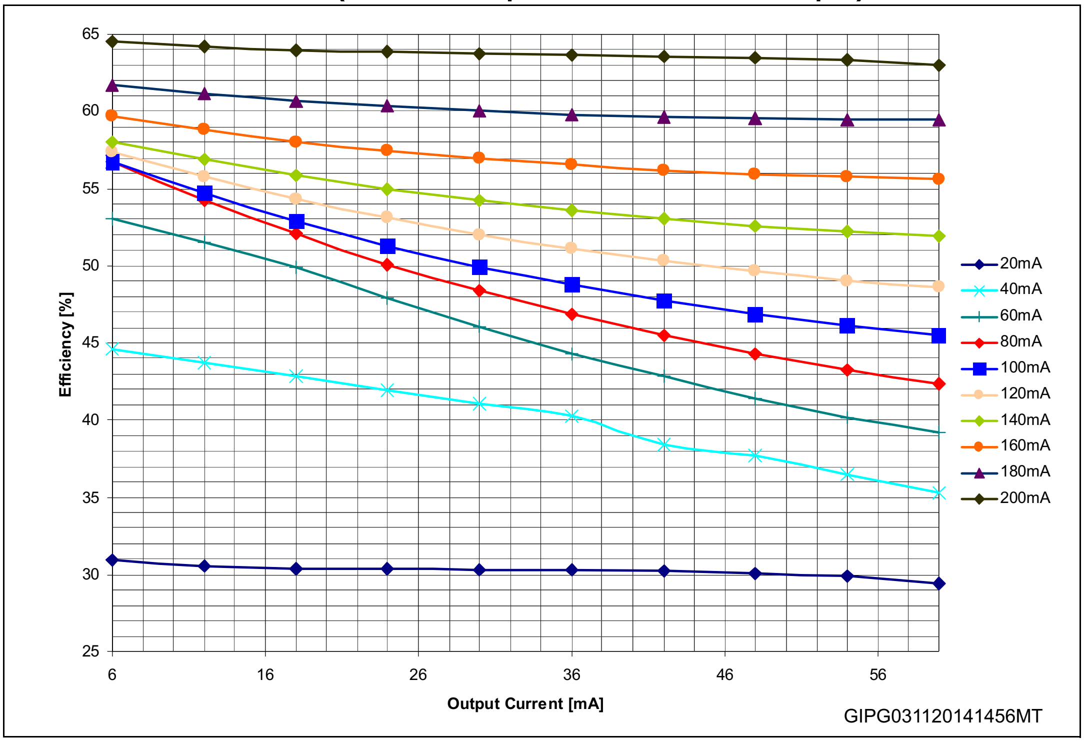
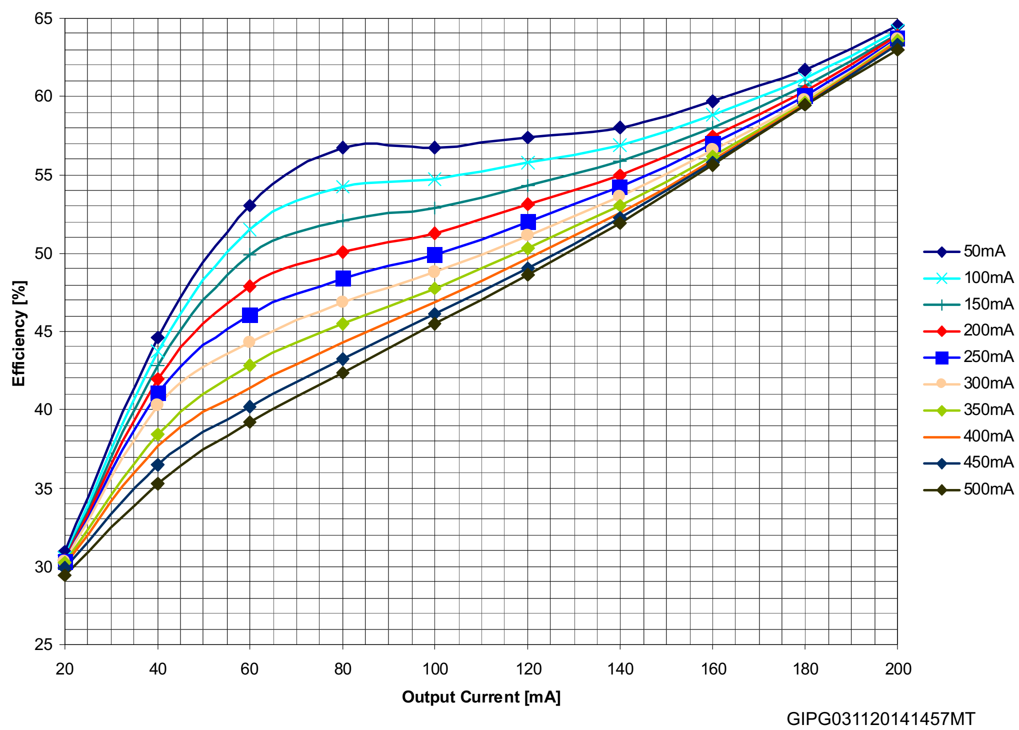


Figure 42. Efficiency variation with 15 V output current at 375 VDC input voltage for variant 3 (load current parameter is on 5 V output)



The feedback loop stability and response to load transients are demonstrated from *Figure 43* to *46*.

Figure 43. Load transient response, 20 mA to 0.2 A on 15 V output, 5 V output unloaded, V_{in}=127 VDC

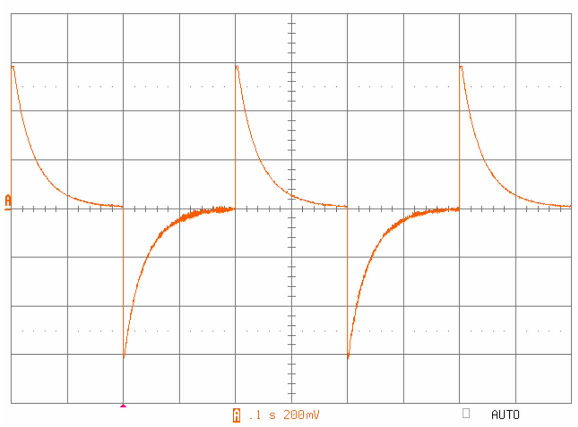


Figure 44. Load transient response, 20 mA to 0.2 A on 15 V output, 5 V output loaded by 60 mA, V_{in}=127 VDC

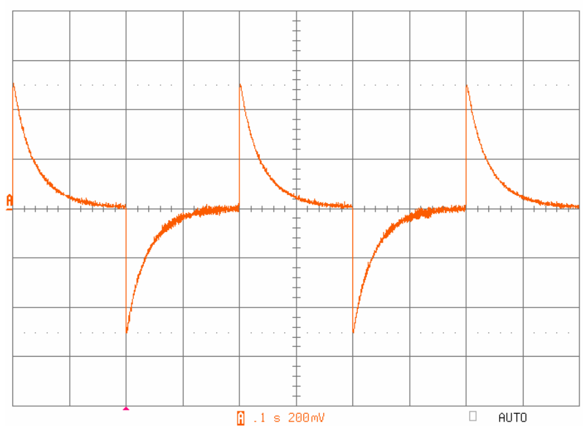


Figure 45. Load transient response, 20 mA to 0.2 A on 15 V output, 5 V output unloaded, V_{in}= 373 VDC

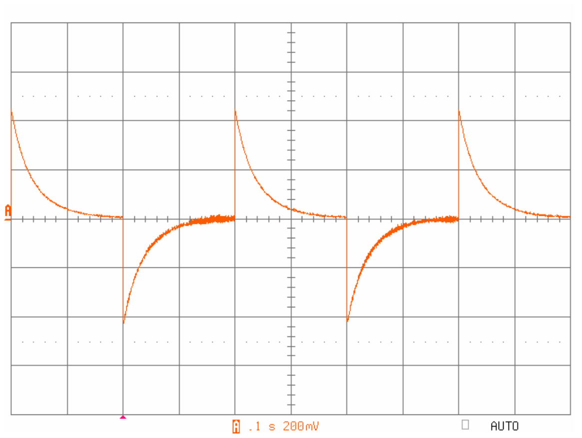
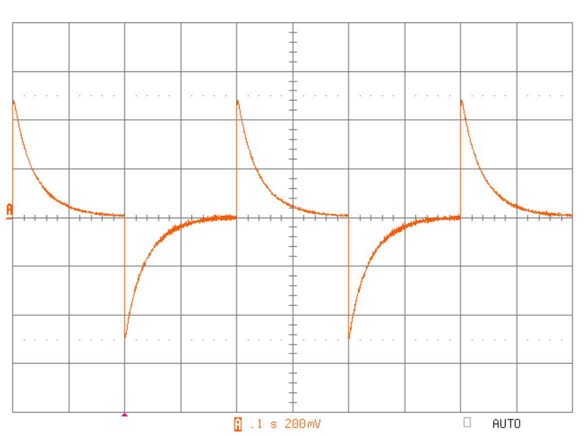


Figure 46. Load transient response, 20 mA to 0.2 A on 15 V output, 5 V output loaded by 60 mA, V_{in}= 373 VDC



Conducted emissions have been measured in neutral and line wire using a peak or average detector. The measurements have been performed at 230 VAC input voltage and both outputs have been loaded. The results can be seen from *Figure 47* to *49*.

Figure 47. Phase L, peak detector (variant 3)

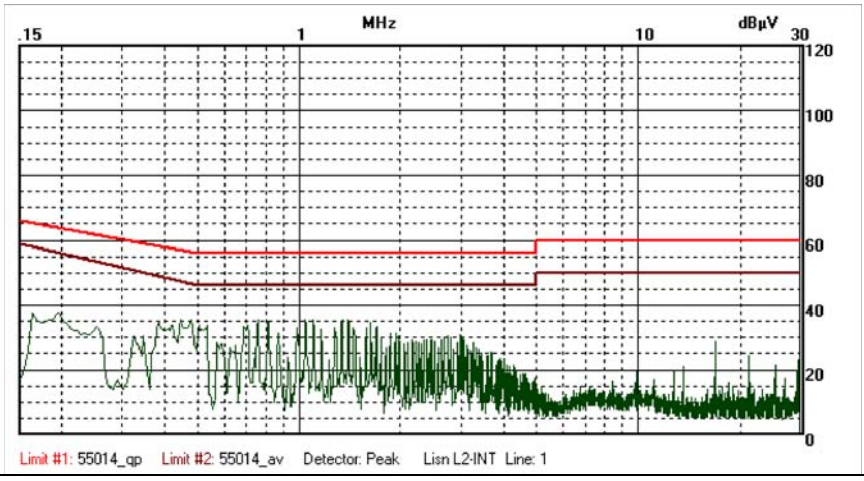


Figure 48. 15 V/200 mA phase N, average detector

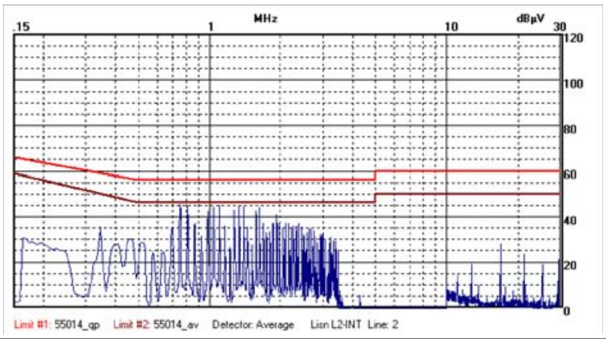
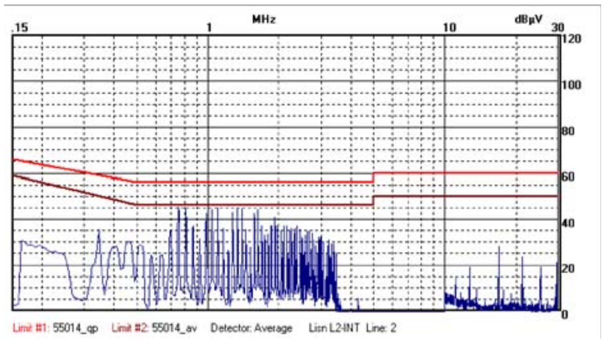


Figure 49. +5 V/60 mA phase N, peak detector



1.4 Non-isolated flyback -5 V/500 mA, +10 V/200 mA (variant 4)

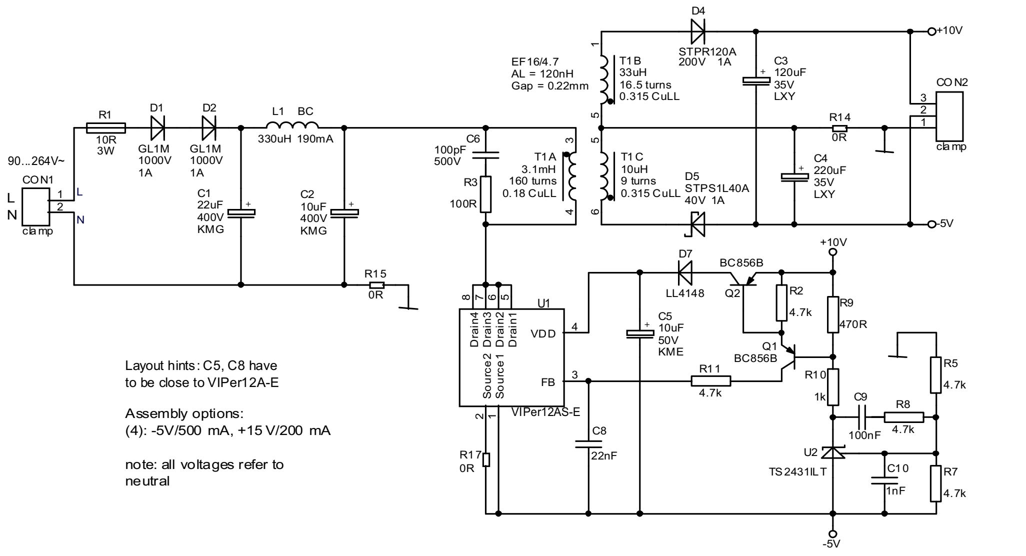
Table 7. Operating conditions (variant 4)

Parameter	Value
Input voltage range	90-264 VAC
Input voltage frequency range	50/60 Hz
Main output (regulated)	-5V / 500 mA
Second output	10V / 200 mA
Total maximum output power	5.5 W

1.4.1 Circuit operation (variant 4)

Variant 1 can be switched to variant 4 by removing short R16 and placement of R15. This reconfiguration makes previous +5 V output terminal from variant 1 as a common ground. Previous output ground from variant 1 is disconnected from input ground and is referenced as -5 V terminal. The total schematic of the power supply can be seen in *Figure 50*.

Figure 50. Schematic diagram of non-isolated flyback converter (variant 4)



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2 Conclusion

Several variants of the reference board based on a non-isolated flyback converter built with the monolithic switcher VIPer12A-E have been presented. How the reference board can be easily switched between variants or options has been shown. Depicted output regulation, waveforms, overall converter efficiency characteristics and transient responses measured at different working conditions show the good performance of the reference boards. Besides, thanks to the presented PCB layout and EMI input filter, boards are EMI compliant with regards to the emissions as validated by the presented EMI measurements. All boards have also passed EMI surge and burst tests for power supply immunity against incoming noise from mains.

3 Revision history

Table 8. Document revision history

Date	Revision	Changes
11-Nov-2014	2	Updated the title in cover page. Content reworked to improve readability, no technical changes.