

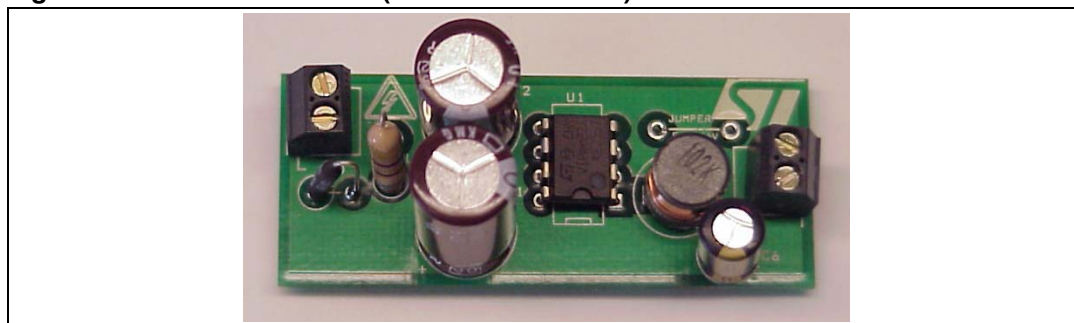
### Designing a low cost power supply using a VIPer12/22A-E in a buck configuration

#### Introduction

Many appliances today use non isolated power supply to furnish low output power required to run a micro, LED display, and a few relays or AC switches. This type of power supply has a single rectifier so as to reference the neutral to output ground in order to fire TRIACs or AC switches. This article describes the use of the VIPer12A-E and the VIPer22A-E which are pin for pin compatible and can supply power for many applications. This paper provides an off line, non isolated power supply evaluation board based on the VIPer12/22A-E. Four different examples will be covered. The VIPer12A-E will be used for 12 V at 200 mA and 16 V at 200 mA. The VIPer22A-E will be used for 12 V at 350 mA and 16 V at 350 mA. The same board can be used for any output voltage from 10 V to 35 V. For outputs less than 16 V, D6 and C4 are populated and W1 is omitted. For outputs greater than 16 V, D6 and C4 are omitted and W1 is populated. For more design detail, see AN1357 "VIPower: low cost power supplies using the VIPer12A-E in non isolated application." The objective of this application note is to familiarize the end user with this reference design and to quickly modify it for different voltage output. This design gives:

- Lowest possible component count
- Integrated thermal overload protection
- About 200 mW at no-load consumption
- Efficiency measured between 70% to 80% at full load
- Integrated Short circuit protection

**Figure 1. Evaluation board (STEVAL-ISA035V1)**



**Table 1. Operating conditions for the four samples**

| Board version (with changes)  |               | Output voltage and current |       |
|-------------------------------|---------------|----------------------------|-------|
| Input voltage range           |               | 85 Vac to 264 Vac          |       |
| Input voltage frequency range |               | 50/60 Hz                   |       |
| Output version 1              | VIPer22ADIP-E | 12 V at 350 mA             | 4.2 W |
| Output version 2              | VIPer12ADIP-E | 12 V at 200 mA             | 2.4 W |
| Output version 3              | VIPer22ADIP-E | 16 V at 350 mA             | 5.6 W |
| Output version 4              | VIPer12ADIP-E | 16 V at 200 mA             | 3.2 W |

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# 1 Circuit operation

## 1.1 Input line rectification and line conducted filter

The circuit operations for all four versions are basically the same. The difference is in the circuit for start up. Version 1 will be described here with reference to [Figure 3](#). The output of the converter is not isolated from the input. This makes neutral common to output ground thus giving a reference back to neutral. The buck is less expensive due to the fact that it does not use a transformer and an opto coupler. The AC line is applied through D1 which rectifies the line input every other half cycle.

C1, L0, C2 form an pie filter to reduce EMI noise. The value of the capacitor is chosen to maintain a reasonable valley, because the caps are charged every other half cycle. Two diodes can be used in place of D1 to sustain burst pulses of 2 kV. R10 serves two purpose, one is as inrush limiting and the other is to act as a fuse in case of a catastrophic failure. A wire wound resistor will handle the energy of the inrush. Flame proof resistor and a fuse can be used depending on system and safety requirements. C7 helps the EMI by balancing line and neutral noise without using an Xcap. This will pass EN55022 level "B". If the requirement is less, then this cap can be left out of the circuit.

## 1.2 Start circuit

The voltage across C2 is fed to the drain, pin 5 through 8. Inside the VIPer, the constant current source delivers 1mA to the  $V_{dd}$  pin 4. This current charges C3. When the voltage on the  $V_{dd}$  pin reaches 14.5 V nominal, the current source turns off and the VIPer starts pulsing. During this time, the energy is being supplied from the  $V_{dd}$  cap. The energy stored must be greater than the energy needed to supply the output current plus the energy to charge of the output capacitor, before the  $V_{dd}$  cap falls below 9 V. This can be seen on [Figure 8](#) and [Figure 9](#). The value of the capacitor is therefore chosen to accommodate the start up time. During a short circuit, the  $V_{dd}$  cap discharges below the minim value enabling the internal high voltage current generator to initiates a new start up sequence. The charging and discharging of the capacitor determine the time period the power supply to be on and off. This reduces the RMS heating affect on all components. The regulation circuit consists of Dz, C4 and D8. D8 peak charges C4 during the free wheeling time when D5 is conducting. During this time, the source or reference to the VIPer is one diode drop below ground, which compensates for the D8 drop. So basically the zener voltage is the same as the output voltage. C4 is connected across  $V_{fb}$  and source to filter the regulation voltage. Dz is a BZT52C12,  $\frac{1}{2}$  W zener with a specified test current of 5 mA. These zeners that are specified at a lower current will give better accuracy of the output voltage. If the output voltage is lower than 16 V the circuit can be configured as in [Figure 3](#) where  $V_{dd}$  is separated from  $V_{fb}$  pin. When the internal current source charges the  $V_{dd}$  cap, the  $V_{dd}$  can reach 16V at worse case condition. A 16 V zener with a 5% low tolerance can be 15.2 V plus the internal resistance to ground is 1230  $\Omega$  which is an additional 1.23 V for a total of 16.4 V. For 16 V output and higher, the  $V_{dd}$  pin and the  $V_{fb}$  pin can share a common diode and capacitor filter similar to [Figure 4](#).

### 1.3 Inductor selection

A starting point for the inductor operating in discontinuous mode can be derived from the following formula which gives a good approximation of the inductor.

#### Equation 1

$$L = 2 \cdot \frac{P_{out}}{(I_{d_{peak}})^2 \cdot f}$$

Where  $I_{d_{peak}}$  is the minimum peak drain current, 320 mA for the VIPer12A-E and 560 mA for the VIPer22A-E,  $f$  is the switching frequency at 60 kHz. The maximum peak current limits the power delivered in the buck topology. Therefore, the calculation above is for an inductor that operates in discontinuous mode. If the current swings down to zero, then the peak current is twice the output. This limits the output current to 280 mA for a VIPer22A-E. But if the inductor is a larger value, operating between continuous and discontinuous mode, we can reach 200 mA comfortably away from the current limit point. C6 has to be a low ESR capacitor to give the low ripple voltage

#### Equation 2

$$V_{ripple} = I_{ripple} \cdot C_{esr}$$

D5 needs to be a fast recovery diode but D6 and D8 can be standard diodes. DZ1 is used to clamp the voltage to 16 V. The nature of the buck topology is to peak charge at no load. A zener 3 to 4 V higher than the output voltage is recommended.

### 1.4 Design example

[Figure 3](#) is the schematic for the demo board. It is set up for 12 V with a maximum current of 350 mA. If less current is required, then the VIPer22A-E can be changed to a VIPer12A-E and C2 can be decreased from 10  $\mu$ F to 4.7  $\mu$ F. This will deliver up to 200 mA.

[Figure 4](#) shows the same board but for 16 V output or higher, D6 and C4 can be left out. The jumper will bridge the output voltage to the  $V_{dd}$  pin.

### 1.5 Design hints and trade off

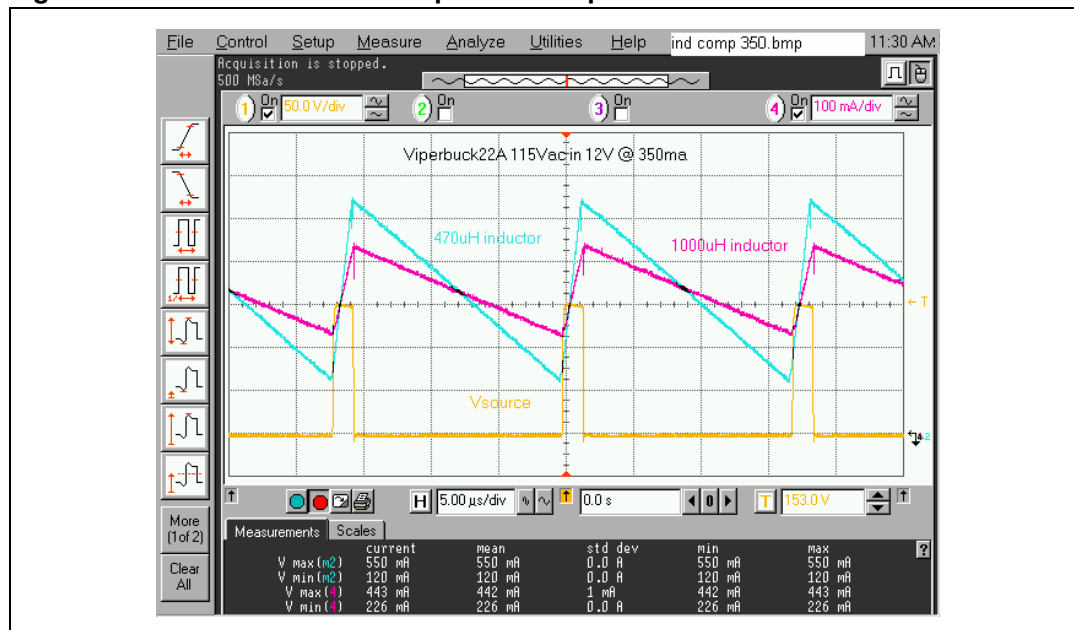
The value of  $L$  determines the boundary condition between continuous and discontinuous mode for a given output current. In order to operate in discontinuous mode, the inductor value has to be lower than

#### Equation 3

$$L = \frac{1}{2} \cdot R \cdot T \cdot (1 - D)$$

Where  $R$  is the load resistance,  $T$  is the switching period, and  $D$  is the duty cycle.

There are two points to consider. One is the more discontinuous the higher the peak current is. This point should be kept lower than the minimum pulse by pulse current limit of the VIPer22A-E which is 0.56 A. The other is if we use a large value to run continuous all of the time, we run into excess heat from switching losses of the MOSFET inside the VIPer. Of course, the inductor current rating must be higher than the output current to prevent the risk of saturating the core.

**Figure 2. Inductor current: 470  $\mu$ H VS 1000  $\mu$ H**

Blue trace is the current with 470  $\mu$ H inductor and the purple trace is the current with a 1000  $\mu$ H inductor.

On the above scope plot, the trace represents the current going through the inductor. Current charges up the inductor during the time the MOSFET is on. At this time, the source pin is the same as the rectified line input and the current is ramping up. At 350 mA output current, the peak of the current is 550 mA for a 470  $\mu$ H inductor, the blue trace. The worse case condition for the VIPer Idlim is 560 mA. So therefore we are close to the pulse by pulse current limit trip point. This is manifested by the output voltage dropping as the output current is being raised past the limit. 470  $\mu$ H inductor is the minimum value that can be used from the calculations for a 350 mA output. A good compromise is a 1000  $\mu$ H making the swing less, keeping the peak at 443 mA, away from the 560 mA current limit. Looking at the purple trace the turn on losses are increased and the turn off losses are decreased in the MOSFET inside the VIPer.

It is best to choose the inductor to give  $\frac{1}{2}$  the ripple current between discontinuous to continuous. This is the best compromise when working close to the maximum current. The trade off is a little more heat for the safety margin away from the current trip point.

VIPer temperature rise with two different inductors at 350 mA is:

**Table 2. VIPer temperature rise with different inductors**

| Inductor     | Maximum peak current | VIPer22ADIP-E temperature rise |
|--------------|----------------------|--------------------------------|
| 470 $\mu$ H  | 550 mA               | 34 $^{\circ}$ C                |
| 1000 $\mu$ H | 443 mA               | 40.5 $^{\circ}$ C              |

**Figure 3. Schematic for 12 V @ 350 mA**

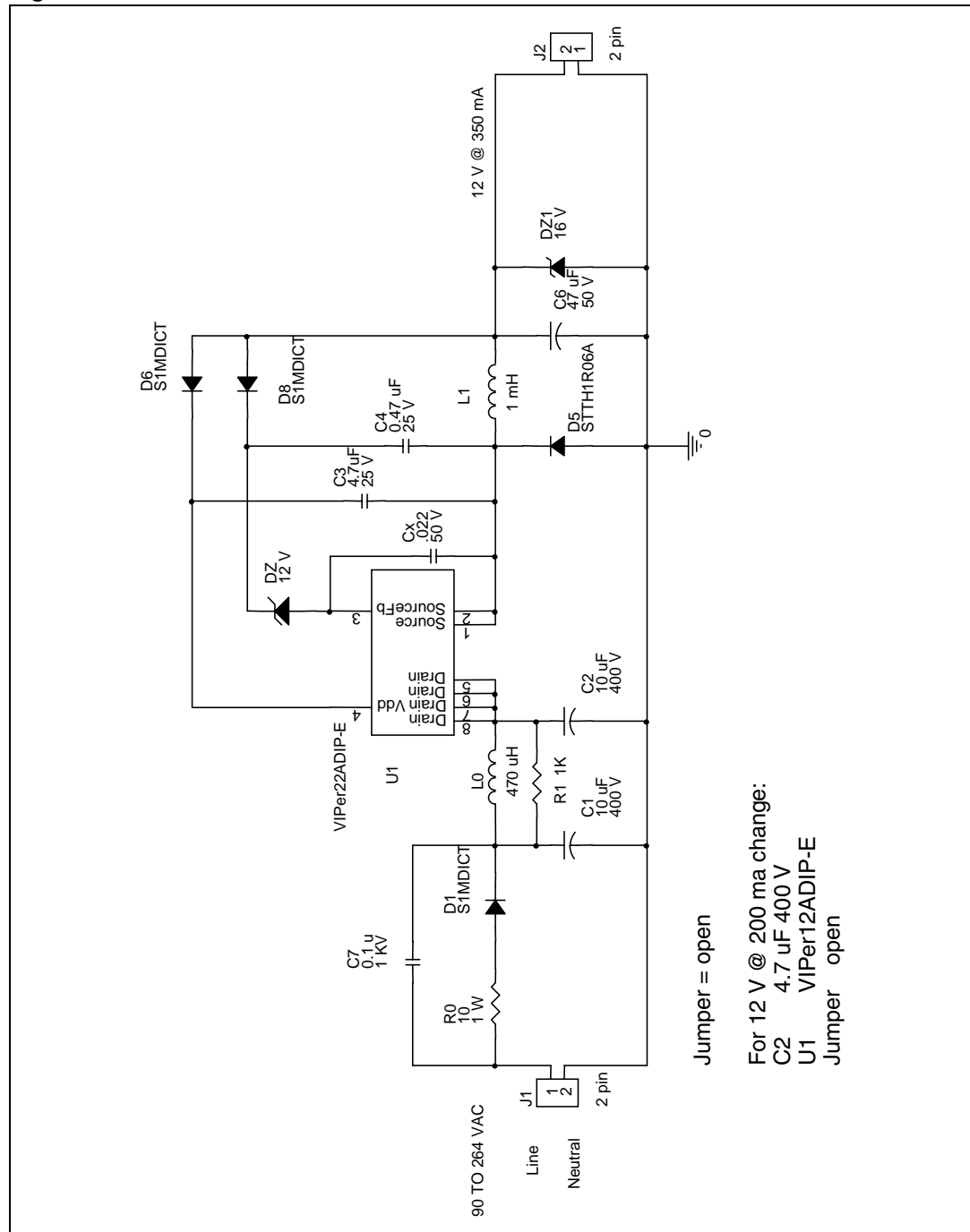
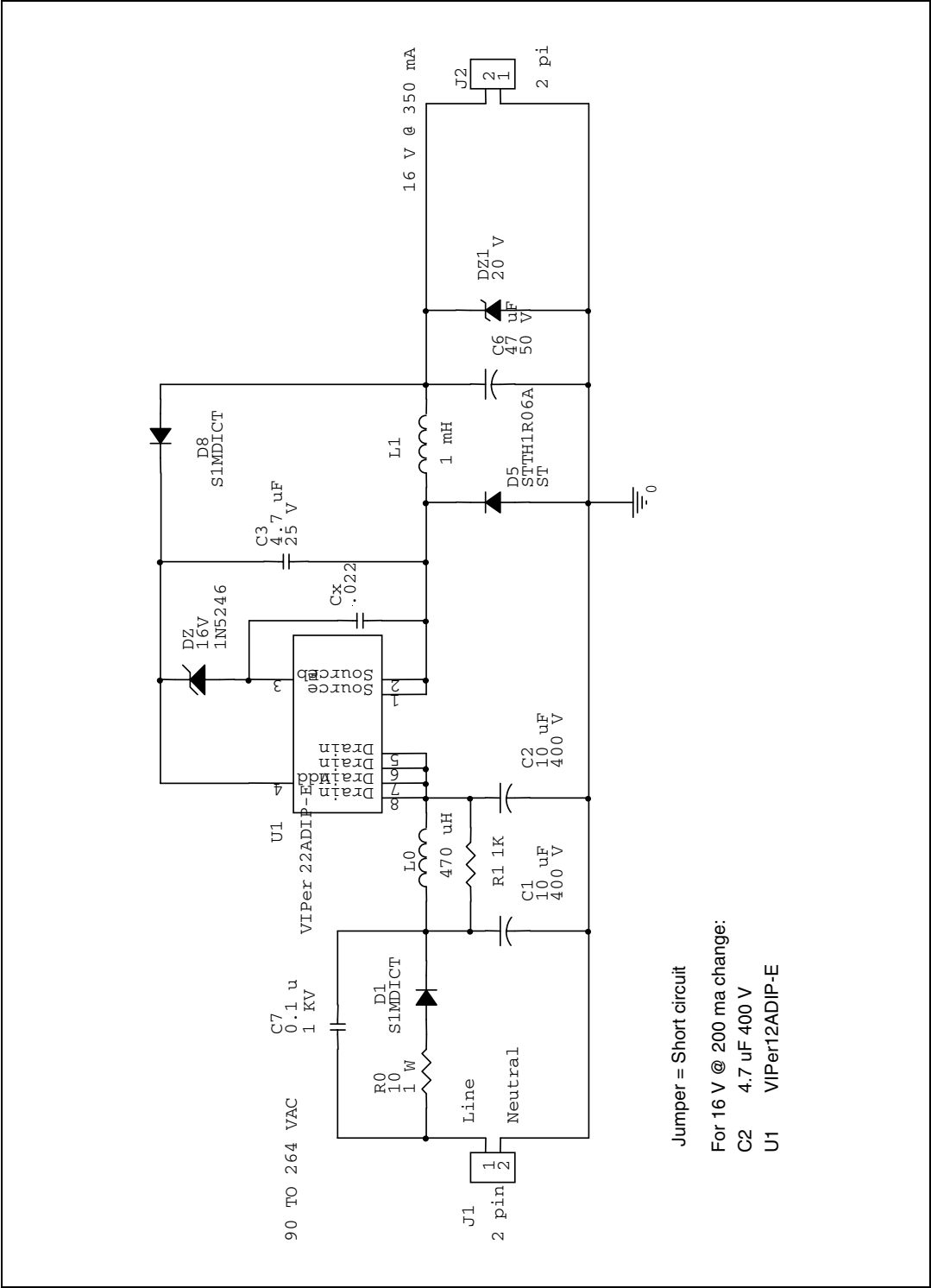


Figure 4. Schematic for 16 V @ 350 mA

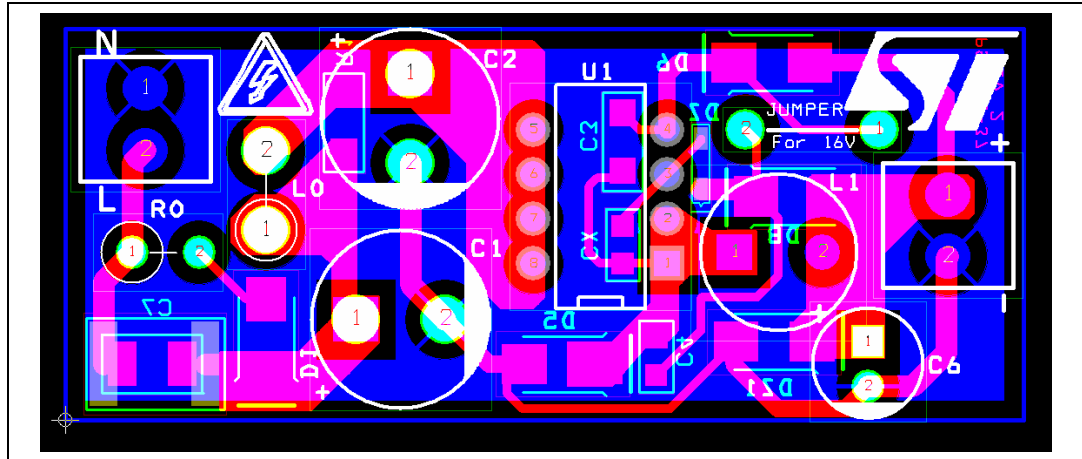




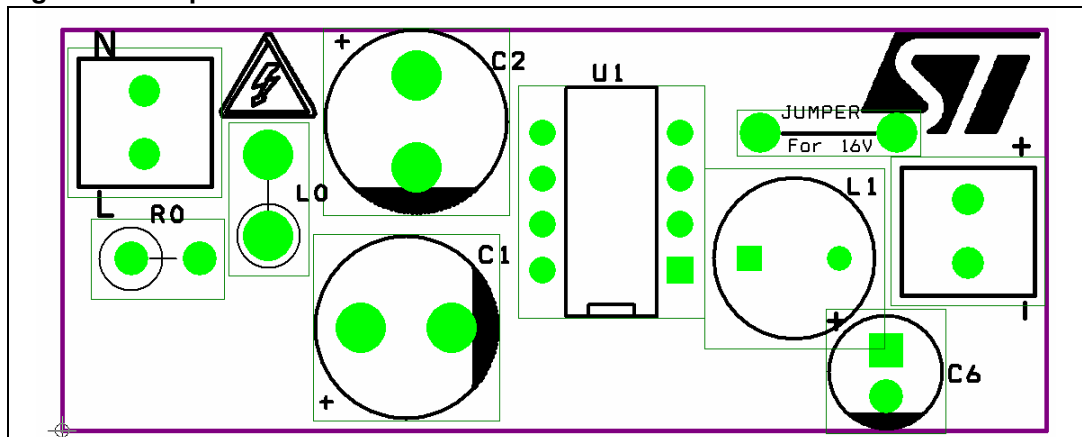
## 1.6 Board layout

A composite view of the board shows a double sided board with surface mounts components on the bottom. The top is a ground plane which helps with EMI. The actual measurements of the PC board are 55 mm by 23 mm.

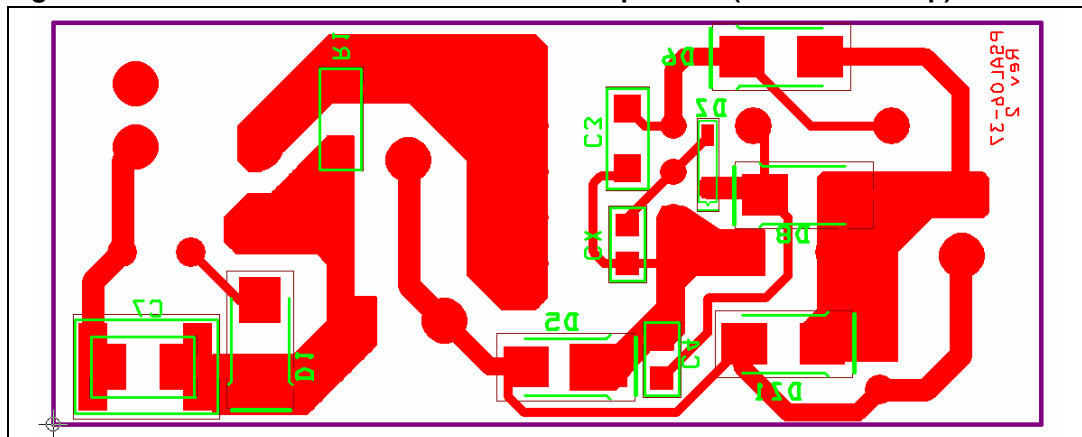
**Figure 5. Composite**



**Figure 6. Top side**



**Figure 7. Bottom side and surface mount components (viewed from top)**



**Table 3. Parts list for VIPer22A-E Buck 12 V at 350 mA**

| Item | Qty | Ref.     | Part          | V/W    | Description          | CAT#                                       |
|------|-----|----------|---------------|--------|----------------------|--|
| 1    | 1   | Cx       | 0.022         | 50 V   | X7R +/-10%           | GP SM Ceramic                              |
| 2    | 2   | C1,C2    | 10 $\mu$ F    | 400 V  | 105 C                | UCC<br>EKM401ELL100MJ20S                   |
| 3    | 1   | C3       | 4.7 $\mu$ F   | 25 V   | X7R +/-10%           | TDK C3216X7R1E475K                         |
| 4    | 1   | C4       | 0.47 $\mu$ F  | 25 V   | X7R +/-10%           | TDK C2012X7R1E474K                         |
| 5    | 1   | C6       | 47 $\mu$ F    | 50 V   | 105 C Low ESR        | Low ESR                                    |
| 6    | 1   | C7       | 0.1 $\mu$     | 1 kV   | X7R +/-15%           | Murata<br>GRM55DR73A104KW011               |
| 7    | 1   | DZ       | 12 V          | zener  |                      | BZT5212FDICT                               |
| 8    | 1   | DZ1      | 16 V          | zener  |                      | BZT5216FDICT                               |
| 9    | 3   | D1,D6,D8 | S1MDICT       |        | SM GP Diode 1 kV 1 A | S1MD                                       |
| 10   | 1   | D5       | STTH1R06A     |        | 600 V 1 A Ultrafast  | STMicroelectronics                         |
| 11   | 2   | J1, J2   | 2 pin         |        |                      | Mouser 651-1751099                         |
| 12   | 1   | L0       | 470 $\mu$ H   | 140 mA |                      | JW Miller 5300-33                          |
| 13   | 1   | L1       | 1 mH          | 400 mA |                      | Compostar Q3277 or<br>JW Miller RL895-102K |
| 14   | 1   | R0       | 10 $\Omega$   | 1 W    | wire wound           | ALSR1J-10                                  |
| 15   | 1   | R1       | 1 k $\Omega$  |        | 5%                   | SM 1206 CERAMIC                            |
| 16   | 1   | U1       | VIPer22ADIP-E |        |                      | STMicroelectronics                         |

**Table 4. Parts list for VIPer22A-E Buck 16 V at 350 mA**

| For 16 V or higher operation. |   |        |              |      |                        |                    |
|-------------------------------|---|--------|--------------|------|------------------------|--------------------|
| Omit                          | 1 | D8     | S1MDICT      |      | SM GP Diode<br>1 kV 1A | S1MD               |
| Omit                          | 1 | C4     | 0.47 $\mu$ F | 25 V | X7R +/-10%             | TDK C2012X7R1E474K |
| Add                           | 1 | Jumper | Wire jumper  |      | 24 AWG                 |                    |

The above board can be modified to any voltage output from 10 V to 15 V by changing DZ.

To modify the board to 16 V or higher D6 and C4 can be omitted and the jumper wire can be installed. For 16 V operation or higher  $V_{dd}$  and  $V_f$  can share the same source without having the current leak through the zener and  $V_f$  pin path. The output voltage can be changed by changing DZ from 16 V zener to a higher value matching the output voltage. If less current is required, the board can be changed with a VIPer12A-E dip which is pin for pin compatible with the VIPer22ADIP-E.

Also one the input capacitors, C2, can be reduced to 4.7  $\mu$ F. Data and waveforms from demo board:

The  $V_{dd}$  cap has to be sized according to the output load and the size of the output capacitor.

The VIPer internal 1 mA current source charges up the  $V_{dd}$  capacitor. When the voltage on the  $V_{dd}$  pin reaches the  $V_{dd}$  start up threshold (Worse case is 13 V) the VIPer starts pulsing, raising the output voltage to the point of bootstrapping. The  $V_{dd}$  capacitor needs to supply the energy to supply the necessary output current and to charge up the output capacitor, before the  $V_{dd}$  voltage falls below the  $V_{dd}$  under voltage shutdown threshold (worse case is 9 V). The following two pictures show a  $V_{dd}$  cap that is not large enough to start up the demo board under a resistive load of 350 mA.

Figure 8. Bad start

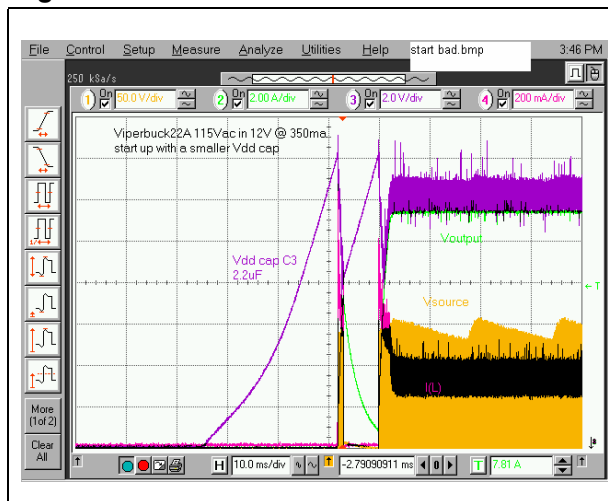
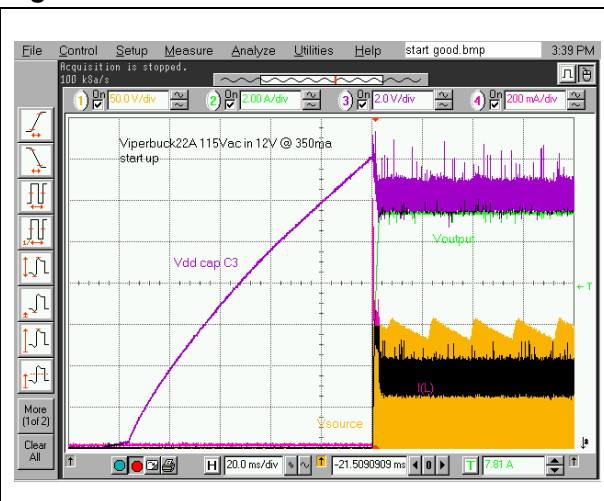


Figure 9. Good start



On the above picture, the purple trace is the  $V_{dd}$  voltage rising to ~14 V. The energy with the 2.2  $\mu$ F capacitor does not store enough energy. As seen the output voltage (green trace) does not reach high enough to bootstrap, It succeeds the second time after there is a partial charge on the output cap. [Figure 9](#) is using a 4.7  $\mu$ F  $V_{dd}$  cap. With adequate energy the power supply start the first time.

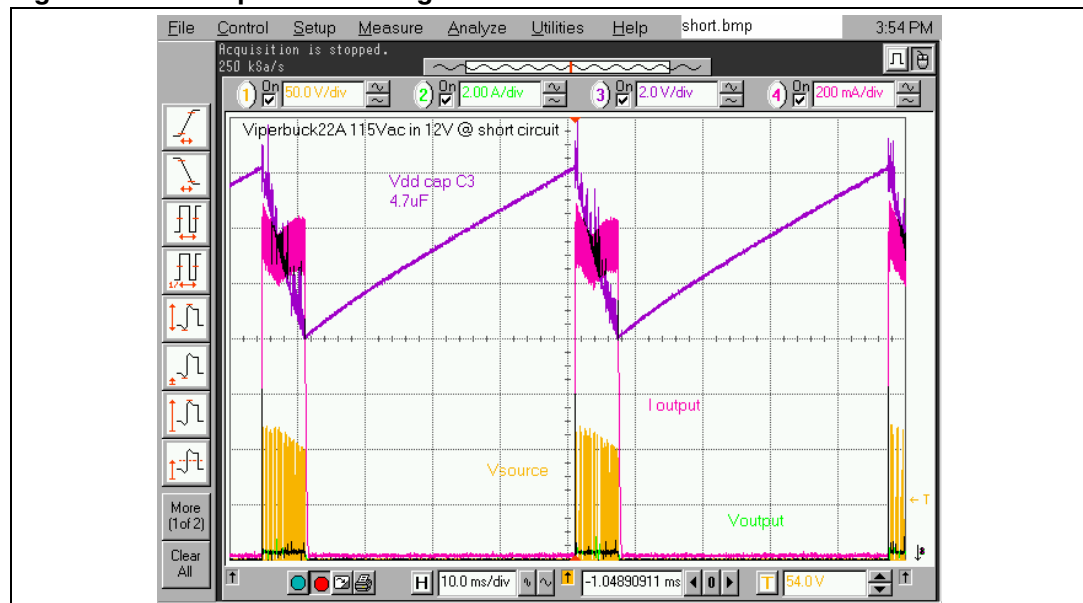
## 1.7 Burst mode in no load or very light load

At very light load, the on time becomes so small that some pulses are skipped in order to stay in regulation and meet energy requirement such as Blue Angel or Energy Star. This mode is called burst mode. It skips as many cycles as needed to maintain regulation. In the case below at no load about 9 cycles are skipped to maintain an output.

**Figure 10. Burst mode**

## 1.8 Short circuit

The VIPer has pulse by pulse current limit. When the current ramps up to the current limit, the pulse is terminated. This is manifested by reducing the output voltage as the current is increased. The voltage decreases until it falls below the under voltage shutdown threshold of 9 V, (pin4). During a short circuit the VIPer will turn on and off. When the  $V_{dd}$  reaches the starting voltage, the current is limited by the pulse by pulse current limit. The voltage falls to the under voltage shutdown point and the cycle repeats it self at a 16% duty cycle. This reduces the RMS current going through the circuit as seen on [Figure 11](#).

**Figure 11. ToVl operation during a short**

## 1.9 Performance

Regulation for the VIPer22A-E and VIPer12A-E can be seen below. Keep in mind that the buck topology will peak charge at zero load. DZ1 will clamp the voltage to 3 - 4 V above the output. Load regulation is taken from 0.03 A to 0.35 A.

*Note: The following measurements were taken on the appropriate version of the boards. Discrepancy of measurements can be present, which is to be expected due to the 5% tolerance of the zener and equipment used for the measurements. The measurements shown are at room temperature. If higher operating temperatures are used, current loads will have to be adjusted accordingly.*

**Table 5. VIPer22ADIP-E, 12 V at 350 mA**

| VIPerbuck22 12 V / 350 mA           |                 |       |      |            |
|-------------------------------------|-----------------|-------|------|------------|
| Vin                                 | 12 V load       | 12 V  | W in | Efficiency |
| 90 Vac                              | 0               | 15.81 | 0.12 |            |
| 90 Vac                              | 0.03            | 12.58 | 0.45 |            |
| 90 Vac                              | 0.35            | 11.7  | 5.64 | 72.6%      |
| 264 Vac                             | 0.35            | 12.21 | 6.12 | 69.8%      |
| MIN                                 |                 | 11.7  |      |            |
| MAX                                 |                 | 12.58 |      |            |
| DELTA                               |                 | 0.88  |      |            |
| Line Reg.                           |                 | 6.0%  |      |            |
| +/- % load reg (.03 to max)         | 3.8%            |       |      |            |
| Ripple                              | mv pp @ 120 Vac |       | 52   |            |
| Blue Angel @ no load @ 115 Vac in W |                 |       | 0.12 |            |
| Short circuit                       |                 | ok    |      |            |

**Table 6. VIPer22ADIP-E, 12 V at 200 mA**

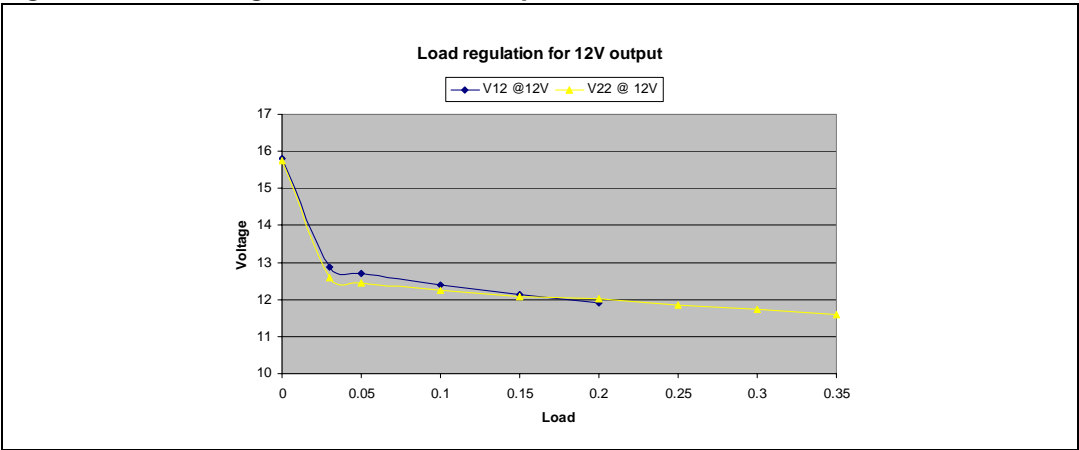
| VIPerbuck12 12 V / 200 mA #1 |           |       |       |            |
|------------------------------|-----------|-------|-------|------------|
| Vin                          | 12 V load | 12 V  | W in  | Efficiency |
| 90 Vac                       | 0         | 15.6  | 0.15  |            |
| 90 Vac                       | 0.03      | 12.7  | 0.495 |            |
| 90 Vac                       | 0.2       | 11.85 | 3.06  | 77.5%      |
| 264 Vac                      | 0.2       | 12.1  | 3.25  | 74.5%      |
| MIN                          |           | 11.85 |       |            |
| MAX                          |           | 12.7  |       |            |
| DELTA                        |           | 0.85  |       |            |
| Line Reg.                    |           | 2.9%  |       |            |
| +/- % load reg (.03 to max)  | 3.6%      |       |       |            |

Table 6. VIPer22ADIP-E, 12 V at 200 mA (continued)

| VIPerbuck12 12 V / 200 mA #1        |                 |      |      |            |
|-------------------------------------|-----------------|------|------|------------|
| Vin                                 | 12 V load       | 12 V | W in | Efficiency |
| Ripple                              | mv pp @ 120 Vac |      | 50   |            |
| Blue Angel @ no load @ 115 Vac in W |                 |      | 0.15 |            |
| Short circuit                       |                 | ok   |      |            |

A graphical representation of the 12 V output at 200 mA and VIPer22A-E at 350 mA of the above is shown:

Figure 12. Load regulations for 12 V output



Line regulation shown at three different current levels: 100 mA, 200 mA, and 350 mA.

Figure 13. Line regulation

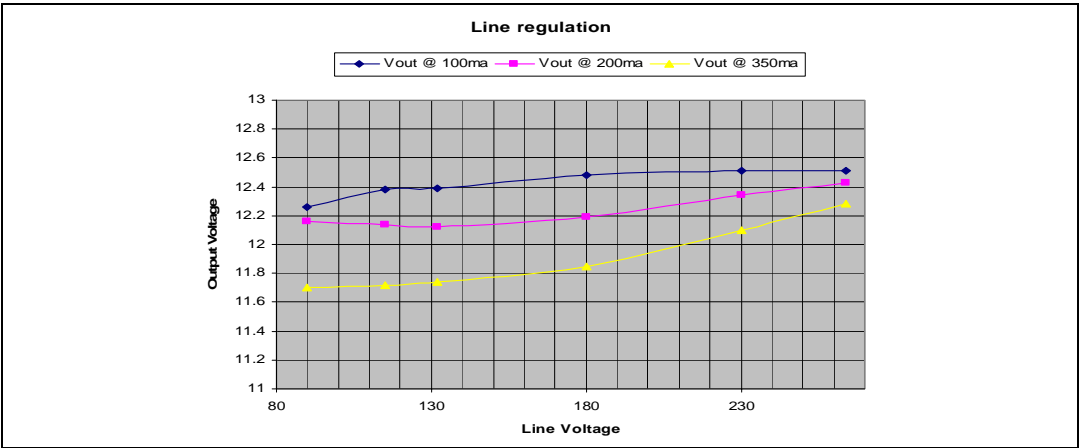
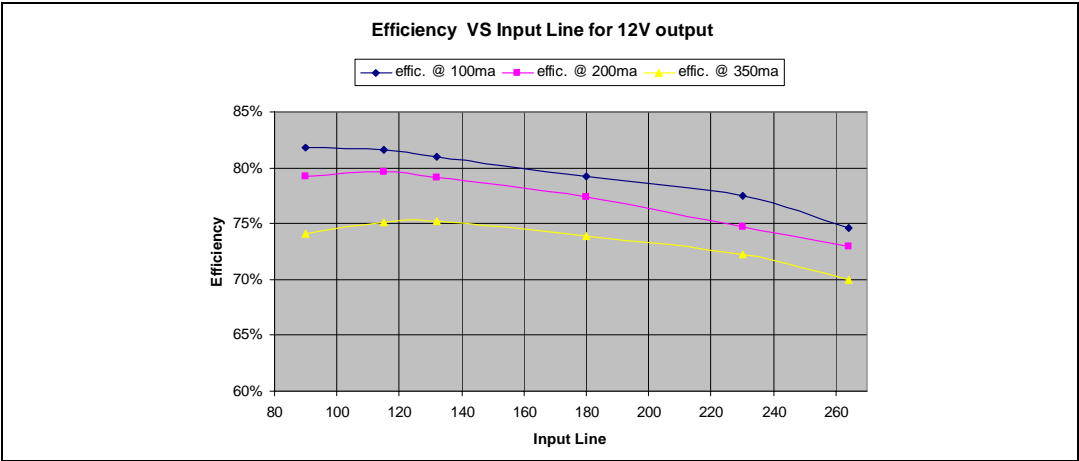


Figure 14. Efficiency



Efficiency is about 75% at 120 Vac. Efficiency is better at higher output voltages.

1.10 EMI conducted

EMI was checked for all four versions for maximum peak reading of both sides of the line.

Figure 15. VIPer12-E, 12 V @ 350 mA output

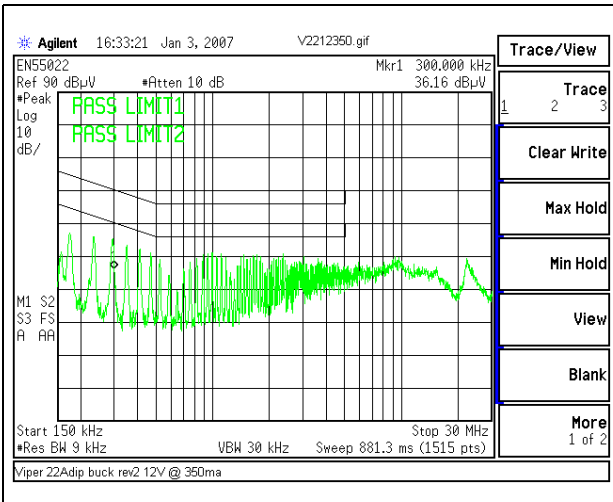


Figure 16. VIPer12-E, 12 V @ 200 mA output

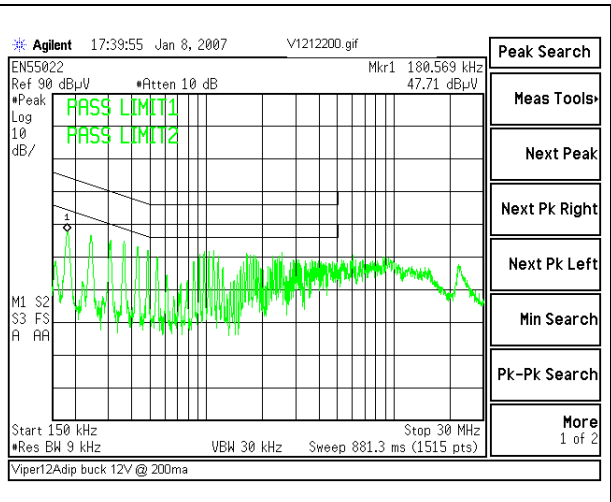


Figure 17. VIPer12-E, 16 V @ 350 mA output

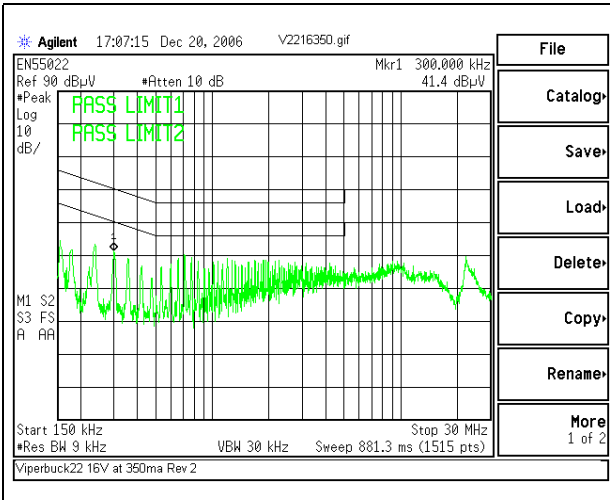
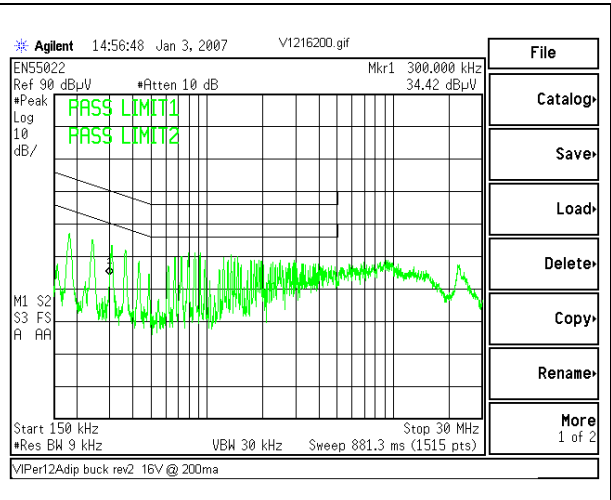


Figure 18. VIPer12-E, 16 V @ 200 mA output



## 2 Conclusion

Using the VIPer in the buck mode has its benefits for appliances and other industrial equipment which require a reference to neutral. For currents up to 350 mA and voltages greater than 10 V, it is beneficial to use this inexpensive power supply. The cost saving compared to a transformer, opto-coupler, and low parts count, makes this solution very attractive.

## 3 Revision history

Table 7. Document revision history

| Date        | Revision | Changes  |
|-------------|----------|--|
| 06-Jul-2007 | 1        | First issue  |
| 13-Sep-2007 | 2        | – Note added in <a href="#">Section 1.9: Performance</a><br>– Minor text changes |
| 21-Sep-2007 | 3        | Modified <a href="#">Figure 1</a>  |



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