

|                        |  |
|------------------------|--|
| <b>Title</b>           | <b><i>Engineering Prototype Report (EPR-000008)</i></b><br><br><i>1.2 W, Universal Input, Non-isolated, TNY254 (EP8)</i> |
| <b>Customer</b>        | Home Appliance Market  |
| <b>Author</b>          | S.L.   |
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**Abstract**

This document presents the specification, schematic & BOM, inductor calculation, test data and wave forms for a low cost, non-isolated, converter for a home appliance application (triac driving).

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## 1 Introduction

There are three specific requirements for this power supply:

1. To provide power for driving a trial requires that the output power be referenced to the input line (L), with no series impedance, therefore only  $\frac{1}{2}$  wave rectification is allowed and the switch must be in the return side of the primary switching circuit. EMI filtering, if necessary, has to be implemented at the system level.
2. The unit has to operate at 85 °C ambient.
3. The unit has to withstand 2 kV (configuration "1", page 4) and 6 kV (configuration "2", page 5) input surge voltage as defined by IEC 1000-4-5 (1.2/50  $\mu$ s). The surge protection added to satisfy these requirements reduces the converter efficiency. It would be more beneficial (lower cost, improved efficiency) if the surge protection were implemented at the system (appliance) level.

## 2 Power Supply Specification

The specification below is for the worst case (6 kV configuration "2")

| Description                | Symbol              | Min  | Typ | Max  | Units           | Comment                            |
|----------------------------|---------------------|------|-----|------|-----------------|------------------------------------|
| <b>Input</b>               |                     |      |     |      |                 |                                    |
| Input Voltage              | V <sub>AC</sub>     | 85   |     | 265  | V <sub>AC</sub> | 50/60 Hz                           |
| Input frequency            | f <sub>LINE</sub>   | 47   |     | 63   | Hz              |                                    |
| <b>Output</b>              |                     |      |     |      |                 |                                    |
| Output Voltage             | V <sub>OUT</sub>    | 10.8 | 12  | 13.2 | V               | 12 V +/-10%*                       |
| Output Ripple Voltage      | V <sub>RIPPLE</sub> |      | 80  | 120  | MV              | of V <sub>OUT</sub> @ full load    |
| Output Current             | I <sub>OUT</sub>    | 0    |     | 100  | MA              | ~200 mA short                      |
| Load Regulation            |                     |      |     |      |                 | 0-100% load                        |
| Line Regulation            |                     |      |     |      |                 | 85-265 V <sub>AC</sub> , full load |
| <b>Power Output</b>        |                     |      |     |      |                 |                                    |
| Continuous Output power    | P <sub>OUT</sub>    | 0    |     | 1.2  | W               | 0-85 °C internal ambient**         |
| Power supply efficiency    | $\eta$              | 50   |     |      | %               | @low line, full load               |
| <b>Environmental</b>       |                     |      |     |      |                 |                                    |
| <b>Temperature</b>         | T <sub>AMB</sub>    | 0    |     | 85   | C               | 6" x 6" x 4" enclosure             |
| <b>EMI – conducted</b>     |                     |      |     |      |                 | Designed to meet CISPR 22B (FCCB)  |
| <b>Safety</b>              |                     |      |     |      |                 |                                    |
| <b>Input Surge Voltage</b> | Config. "1"         | 2    |     |      | kV              | IEC1000-4-5                        |
| <b>Input Surge Voltage</b> | Config. "2"         | 6    |     |      | kV              | IEC1000-4-5                        |

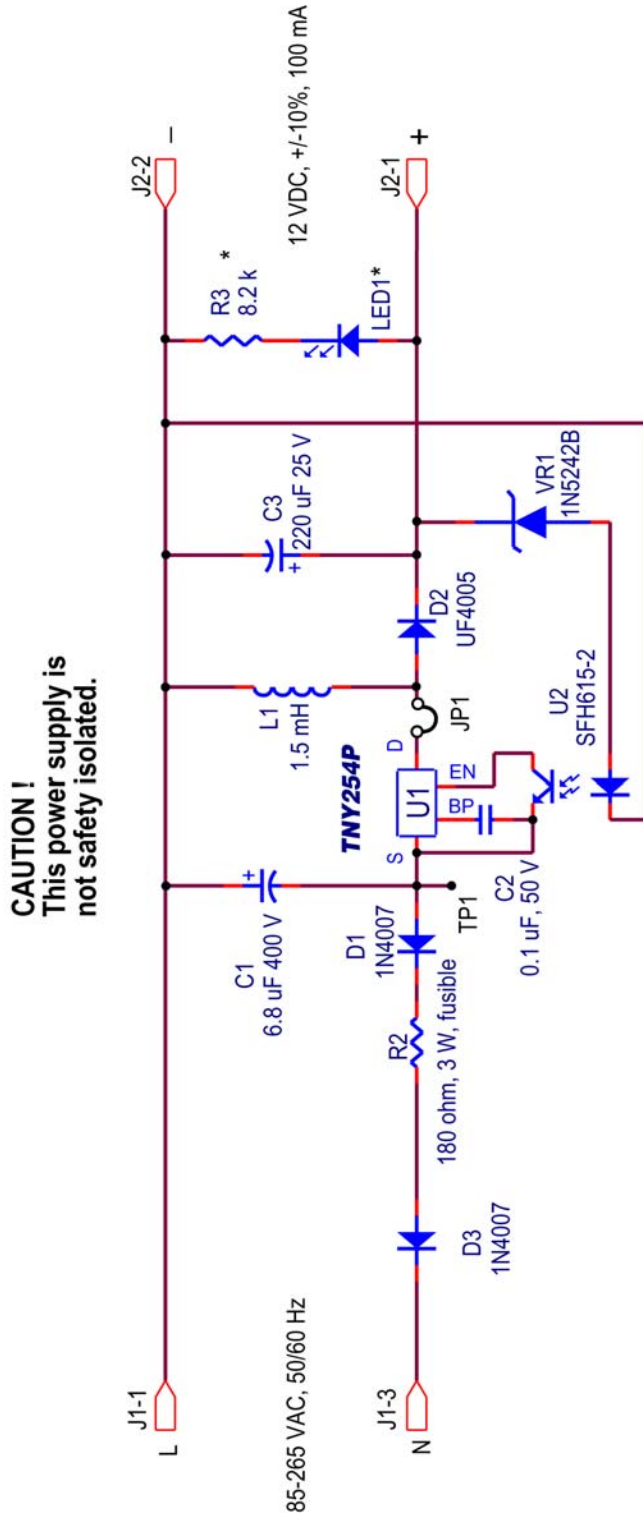
\* +/-5% with 2% Zener.

\*\*The unit was placed in a 6" x 6" x 4" enclosure inside the temperature chamber.



### 3 Schematic

#### 3.1 Configuration “1” – 2 kV (1.2/50 μs) Surge Withstand



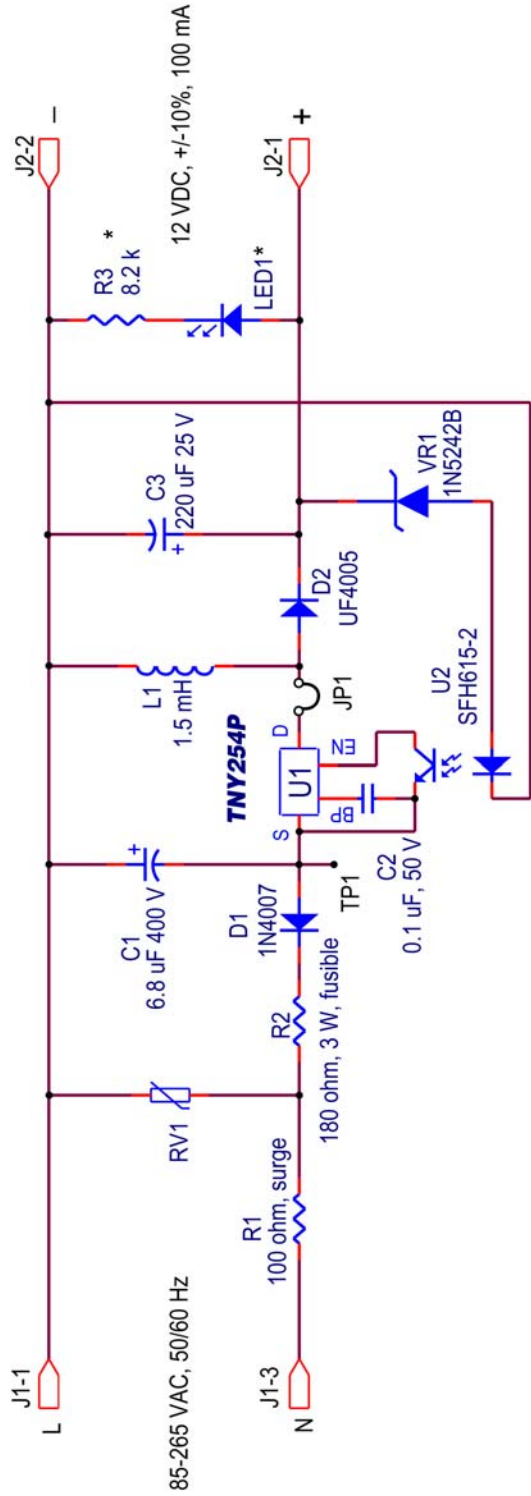
|                                    |                 |   |      |
|------------------------------------|-----------------|---|------|
| Title                              |                 | 12 V 1.2 W, fail-safe, non-isolated P.S.        |      |
| Size                               | Document Number | 2 kV (1.2/50 usec) surge protection (config.1). | Rev  |
| A                                  |                 |   | D    |
| Date: Wednesday, December 15, 1999 |                 | Sheet   | 1 of |

\* Optional



3.2 Configuration “2” – 6 kV (1.2/50 μs) Surge Withstand

**CAUTION !**  
This power supply is  
not safety isolated.



\* Optional

|                                  |   |  |      |
|----------------------------------|---|--|------|
| Title                            |   | 12 V 1.2 W, fail-safe, non-isolated P.S. |      |
| Size                             | A | Rev                                      | D    |
| Date: Tuesday, December 14, 1999 |   | Sheet                                    | 2 of |



## 4 Circuit Description

The circuit is a fail-safe, non-isolated fly-back topology. Fail-safe means that the output is not subjected to high voltage DC if the switch (U1) fails, since the diode D2 blocks the voltage.

During the ON time (U1 conducting), L1 is charged up to  $I_{LIMIT}$  of the TNY254 (0.25 A type.), from the energy stored in C1. During the OFF time (U1 blocking), the energy stored in L1 is transferred to C3 and the load via D2.

The device switching frequency is 44 kHz. The surge protection circuit has to prevent the *TinySwitch*  $V_{DSMAX}$  from exceeding 700 V. The surge protection for configuration "1" (2 kV) and configuration "2" (6 kV) is illustrated in the schematics (pages 4, 5).

Configuration "1" relies on the current/energy-limiting resistor R2 to keep the maximum charging voltage of C1 during a +2 kV surge below 700 V. For the -2 kV surge the diodes D1+D3 block the voltage.

Configuration "2" relies on the current/energy-limiting resistor R1 to limit the current in the MOV (RV1) to approximately 50 A peak, such that the RV1 clamping voltage is kept well under 1 kV (~700 V). During the +6 kV surge, R2 limits C1 charging current so that the maximum voltage does not exceed 700 V. During the -6 kV surge, D1 blocks the RV1 clamping voltage from reaching C1.

In both configurations, the fusible resistor R2 provides protection for component failure.



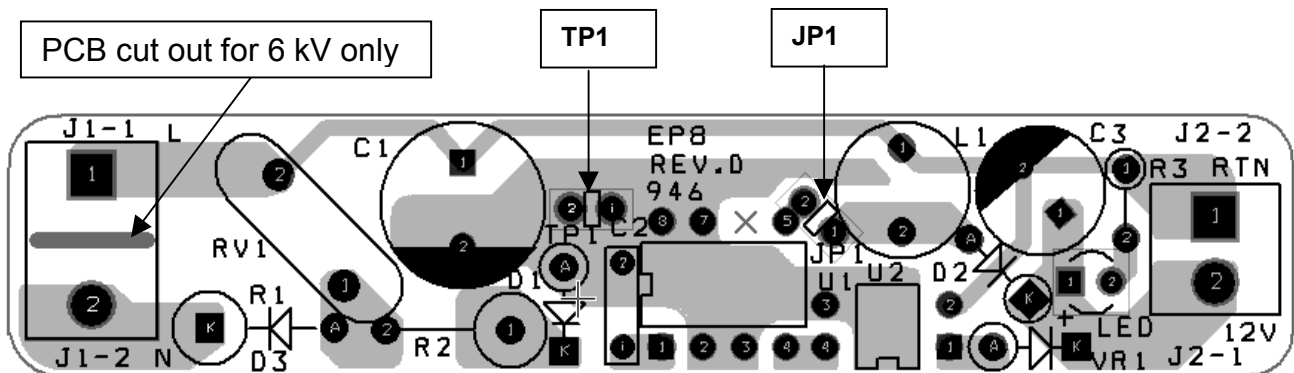
## 5 Layout

### CAUTION!

This is a non-isolated power supply with the low voltage return referenced to the input line (85-265 V<sub>AC</sub>). Do not touch the unit while it is powered. Power the board using a safety isolation transformer so the high voltage probe return is not referenced to the neutral of the input line.

For the drain-to-source voltage waveforms connect the high voltage probe tip to jumper JP1 and the probe ground to test point TP1.

For switching current waveforms replace jumper JP1 with a wire loop and use a Tektronix A6302 current probe and AM503 current probe amplifier (with TM501 power module) or equivalent.



## 6 Bill of Materials

### 6.1 Configuration "1", 2 kV

| Item | Qty. | Ref.   | Description   | Manufacturer                  | Part Number       |
|------|------|--------|---|-------------------------------|-------------------|
| 1    | 1    | C1     | 6.8 $\mu$ F, 400 V, 105 C   | Rubycon                       | 400BXA6R8M10x16   |
| 2    | 1    | C2     | 0.1 $\mu$ F, 50 V, ceramic  | Panasonic                     | ECU-S1H104KBB     |
| 3    | 1    | C3     | 220 $\mu$ F 25 V (0.12 $\Omega$ )   | Panasonic                     |                   |
| 4    | 2    | D1, D3 | Glass Passivated Diode  | Vishay/Lite On                | 1N4007GP          |
| 5    | 1    | D2     | 600 V, 1 A, 75 ns   | General Instrument            | UF4005            |
| 6    | 1    | **J1   | Header, 3 pos., 0.156 spacing   | Molex                         | 26-48-1035        |
| 7    | 1    | J2     | Header, 2 pos., 0.156 spacing   | Molex                         | 26-48-1025        |
| 8    | 1    | *LED1  | low current   | Siemens/HP                    | LG3369/HLMP1790   |
| 9    | 1    | L1     | 1.5 mH, 0.4 A <sub>DC</sub> , 0.2 A <sub>AC</sub> , 600 V <sub>DC</sub> , | Chilisin                      |                   |
| 10   | 1    | R2     | 180 $\Omega$ , flame proof, fusible, 3 W;                                 | Vitrohm (Farnell Components.) | (08WX7849)        |
| 11   | 1    | *R3    | 8.2 k $\Omega$ , ¼ W  |                               |                   |
| 12   | 1    | U1     | Off-line Switcher   | Power Integrations            | TNY254P           |
| 13   | 1    | U2     | Optocoupler   | Siemens/NEC                   | SFH615-2/PS2501-1 |
| 14   | 1    | VR1    | Zener, 12 V $\pm$ 5%  | Diodes Incorporated           | 1N5242B           |

\*Optional

\*\*Remove middle pin

### 6.2 Configuration "2", 6 kV

(Add the following items to Configuration "1" and subtract D3)

| Item | Qty. | Ref. | Description                              | Manufacturer      | Part Number |
|------|------|------|--|-------------------|-------------|
| 15   | 1    | RV1  | Varistor, 275 V <sub>AC</sub> , 14 mm    | Harris/Littlefuse | V275LA20A   |
| 16   | 1    | R1   | 100 $\Omega$ , 15 J, 500 V <sub>AC</sub> | Ohmite            | OX 101      |





## 7 Inductor

### 7.1 Calculation

The inductor value can be determined using the TNY253-255 flyback transformer spreadsheet with the following considerations:

1) the frequency value ( $f_L$ ) is  $\frac{1}{2}$  the line frequency, 25 Hz for 50 Hz, 30 Hz for 60 Hz, to account for half wave rectification.

2) Z factor, the ratio between the secondary losses and the total losses, has to reflect the dominance of the primary losses, as the *TinySwitch* losses (high  $R_{dson}$ ) overshadow the output diode losses. Z factor does not reflect the extra power loss due to R1 and R2. The efficiency used in the spreadsheet is only the efficiency of the converter portion of the supply, it does not include the losses in the input resistor.

3) the output diode rating can be calculated from the formula ( $V_R \geq P_{IVS/0.8}$ ), where  $P_{IVS} = V_{MAX} + V_O - V_{DS}$ . The inductor can be looked at as a transformer with 1:1 turns ratio, therefore  $V_{OR} = V_O + V_D$ .

4) the output capacitor minimum value is dictated by the output RMS ripple current and the maximum value by the specified maximum output voltage ripple.

Select the next higher standard “L” value (for the rated “I”) from a qualified vendor (min. 400 V<sub>DC</sub> voltage rated inductor) like Chilisin, and the smallest DC resistance.



## 7.2 Spreadsheet

| ACDC_TNY_Rev1.8_072699<br>Copyright Power<br>Integrations, Inc. 1999 |          | INPUT      | OUTPUT | UNIT                    | ACDC_TNY_REV1_8_072699.xls: TinySwitch<br>Continuous/Discontinuous Flyback Transformer Design<br>Spreadsheet |
|--|----------|------------|--------|-------------------------|--|
| <b>ENTER APPLICATION VARIABLES</b>                                   |          |            |        |                         | Customer   |
| VACMIN   | 77       |            |        | V                       | Minimum AC Input Voltage   |
| VACMAX   | 265      |            |        | V                       | Maximum AC Input Voltage   |
| fL   | 25       |            |        | Hz                      | AC Mains Frequency   |
| VO   | 12       |            |        | V                       | Output Voltage   |
| PO   | 1.2      |            |        | W                       | Output Power   |
| n  | 0.65     |            |        |                         | Efficiency Estimate  |
| Z  | 0.1      |            |        |                         | Loss Allocation Factor   |
| tC   | 3        |            |        | mS                      | Bridge Rectifier Conduction Time Estimate  |
| CIN  | 6.8      |            |        | μF                      | Input Filter Capacitor   |
| <b>MODE OF OPERATION</b>   |          |            |        |                         |  |
| Continuous ('c') or<br>Discontinuous ('d')?                          | <b>C</b> |            |        |                         | Continuous Mode Operation or Discontinuous Mode<br>Operation?  |
|  | <b>n</b> | Continuous |        |                         |  |
| <b>ENTER TinySwitch Parameters</b>                                   |          | Universal  |        | 115/230 V <sub>AC</sub> |  |
| TinySwitch   | TNY254   | 4 W        | 5 W    |                         |  |
| ILIMITMIN  |          | 0.23       |        | A                       | Minimum Current Limit  |
| ILIMITMAX  |          | 0.28       |        | A                       | Maximum Current Limit  |
| fSmin  |          | 40000      |        | Hz                      | Minimum Frequency  |
| VDS  | 10       |            |        | V                       | Voltage Drop Between Drain to Source   |
| <b>ENTER Output Diode Parameters</b>                                 |          |            |        |                         |  |
| Output Diode   |          |            |        |                         |  |
| VR   | 500      |            |        | V                       | Diode Maximum Peak Repetitive Reverse Voltage  |
| ID   | 1        |            |        | A                       | Diode Average Forward Current  |
| VD   | 1        |            |        | V                       | Diode Forward Voltage Drop   |
| k  | 0.8      |            |        |                         | Diode Peak to RMS Current Factor (k=0.9 for Schottky, k=0.8<br>for PN Diode)                                 |
| <b>Design Parameters</b>   |          |            |        |                         |  |
| VMIN   |          |            | 51     | V                       | Minimum DC Input Voltage   |
| VMAX   |          |            | 375    | V                       | Maximum DC Input Voltage   |
| IP   |          |            | 0.21   | A                       | Peak Primary Current   |
| DMAX   |          |            | 0.252  |                         | Duty Cycle at Minimum DC Input Voltage   |
| KRP  |          |            | 0.62   |                         | Ripple to Peak Current Ratio (0.6<KRP<1.0)   |
| VOR  |          |            | 13.91  | V                       | Reflected Output Voltage   |
| VDRAIN   |          |            | 445.63 | V                       | Maximum Drain Voltage Estimate   |
| PIVS   |          |            | 362    | V                       | Output Rectifier Peak Inverse Voltage  |
| LP   |          |            | 1552   | μH                      | Minimum Primary Inductance   |
| <b>CURRENT WAVEFORM SHAPE PARAMETERS</b>                             |          |            |        |                         |  |
| Iavgmax  |          |            | 0.04   | A                       | Maximum Average Primary Current  |
| Iavgmin  |          |            | 0.00   | A                       | Minimum Average Primary Current  |
| IRMS   |          |            | 0.07   | A                       | Primary RMS Current  |
| IR   |          |            | 0.13   | A                       | Primary Ripple Current   |
| ISP  |          |            | 0.22   | A                       | Maximum Peak Secondary Current   |
| ISRMS  |          |            | 0.14   | A                       | Secondary RMS current  |
| IO   |          |            | 0.10   | A                       | Power Supply Output Current  |
| IRIPPLE  |          |            | 0.09   | A                       | Output Capacitor RMS Ripple Current  |
| IOS  |          |            | 0.24   | A                       | Estimated Short Circuit Current  |



## 8.0 Performance Data

### 8.1 Efficiency

#### TEST EQUIPMENT

INPUT: AC POWER ANALYZER PM1000 (VOLTECH).

OUTPUT: ELECTRONIC LOAD PLZ 153 W (KIKUSUI).

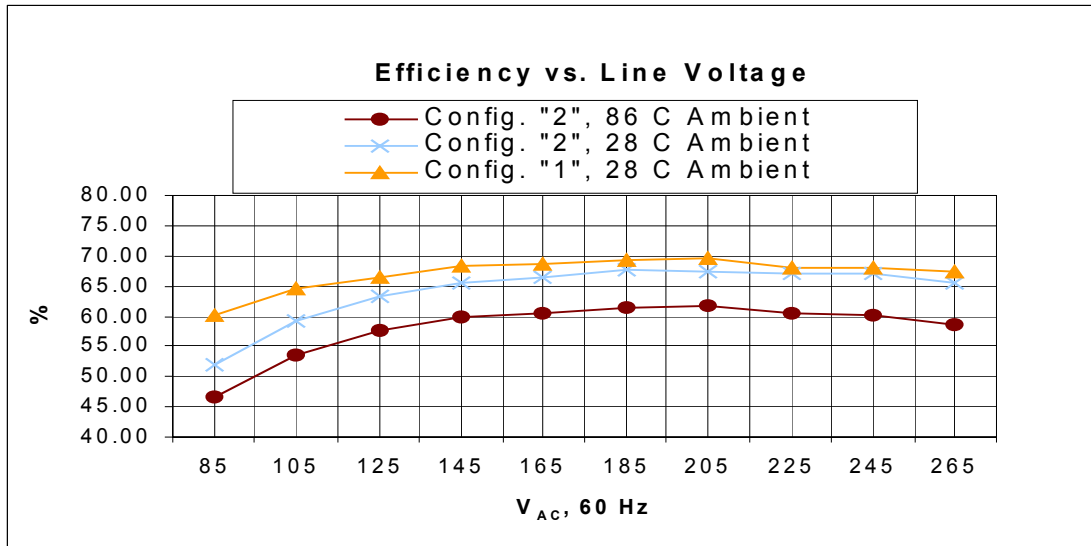


Figure 8.1.1 - Efficiency vs. Input Voltage.

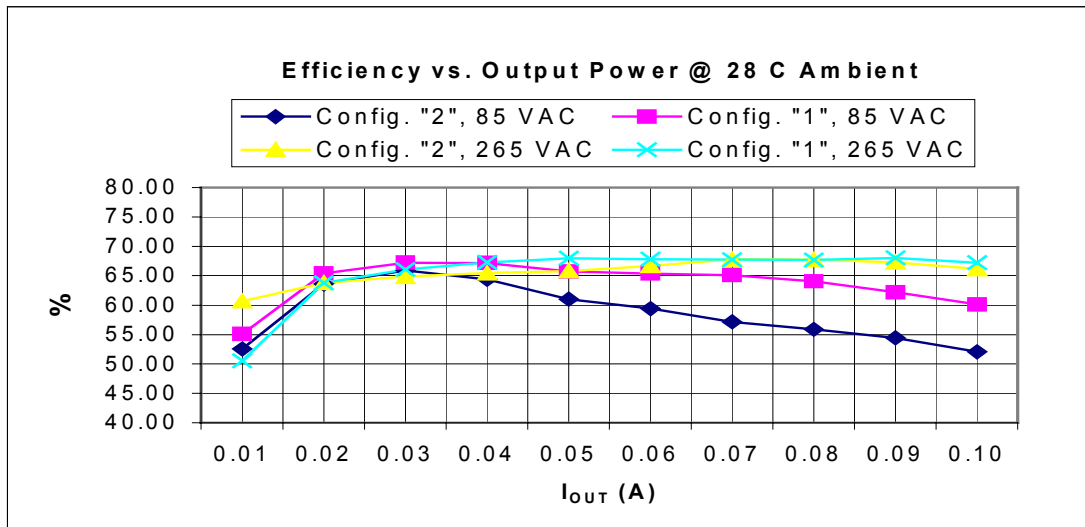


Figure 8.1.2 - Efficiency vs. Output Power.



## 8.2 Regulation

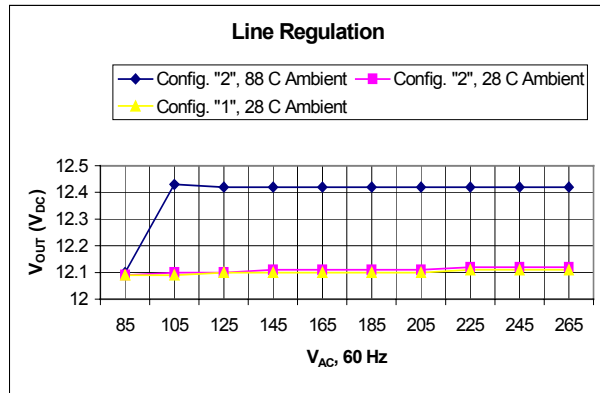


Figure 5.2.1 – Line Regulation at Full Load, 28 °C Ambient.

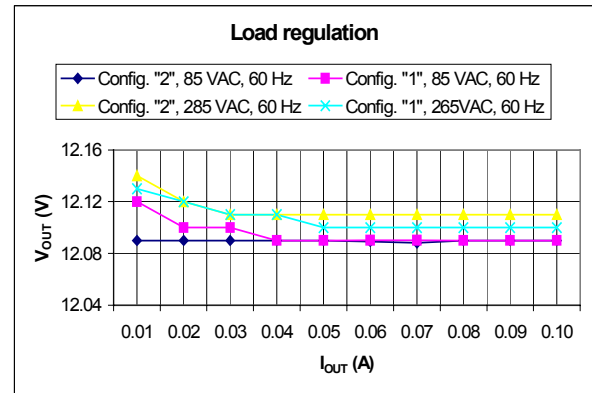


Figure 5.2.2 – Load Regulation, at 28 °C Ambient.

## 8.3 Temperature

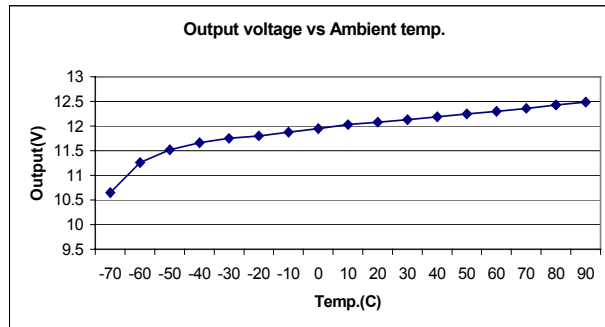


Figure 8.3.1 – Output Voltage at Full Load (0.1 A) Over -70° C to 90° C Ambient.

| Thermocouple location | Low T <sub>AMB</sub> (°C)<br>265 V <sub>AC</sub> , full load | High T <sub>AMB</sub> (°C)<br>85 V <sub>AC</sub> , full load |
|-----------------------|--|--|
| External Ambient      | 0  | 84   |
| Internal Enclosure    | 2.3  | 85.4   |
| TNYSwitch (U 1)       | 26   | 100  |
| R2                    | 39   | 102  |
| Output Diode (D2)     | 15   | 90   |
| Input Cap (C1)        | 17   | 91   |

Table 8.1 – Components Temperature at Low and High Ambient

Worst case input voltage was selected for the two temperature extremes, 265 V<sub>AC</sub> (minimum losses) for “Low T” and 85 V<sub>AC</sub> (maximum losses) for “High T”.

The temperature dependence of the output voltage can be reduced by using two, lower voltage Zener diodes in series.

The unit shut down at 96 °C inside internal enclosure.



8.4 Waveforms

8.4.1 Turn-on delay/hold-up time

8.4.1.1 2 kV config."1" 85 V<sub>AC</sub>

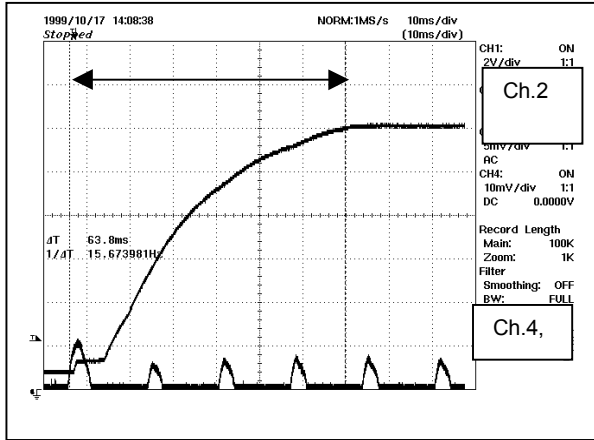


Figure 8.4.1.1 - Output Voltage Turn On Delay at Full Load.  
 CH2: V<sub>OUT</sub> (2 V/div),  
 CH4: I<sub>IN\_MAINS</sub> (0.1 A/div)

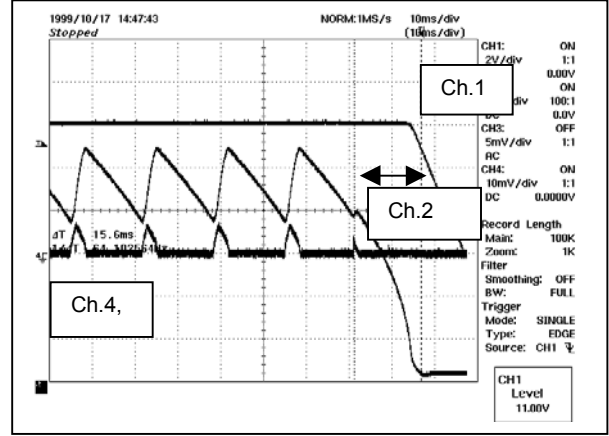


Figure 8.4.1.2 - Output Voltage Hold Up Time.  
 CH1: V<sub>OUT</sub> (2 V/div),  
 CH2: V<sub>OUT</sub> (2 V/div),  
 CH4: I<sub>IN\_MAINS</sub> (0.1 A/div)

8.4.1.2 6 kV config."1" 85 V<sub>AC</sub>

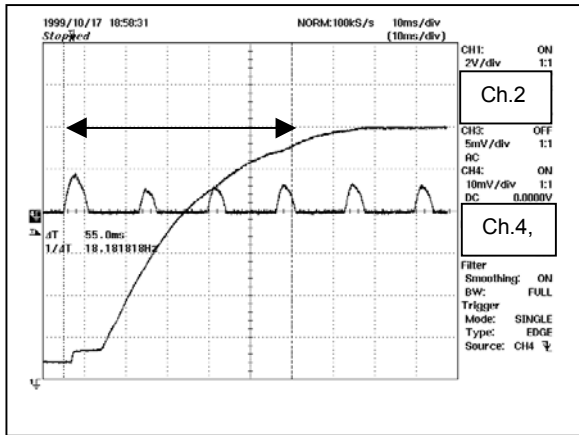


Figure 8.4.1.3 - Output Voltage Turn-on Delay at Full Load.  
 CH2: V<sub>OUT</sub> (2 V/div),  
 CH4: I<sub>IN\_MAINS</sub> (0.1 A/div)

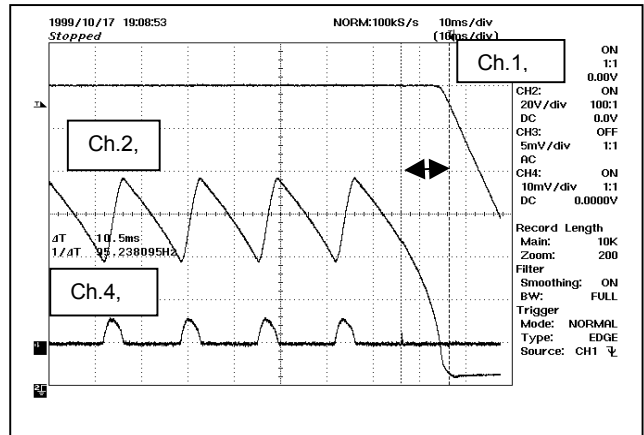
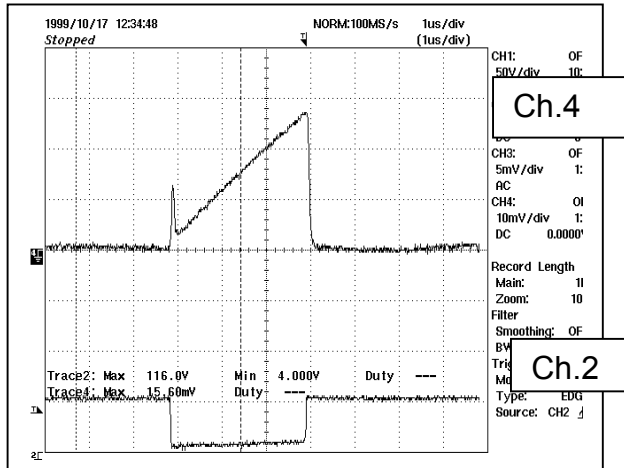


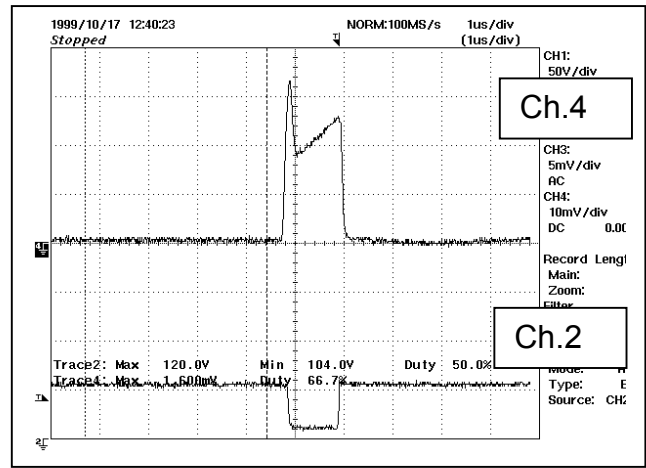
Figure 8.4.1.4 - Output Voltage Hold-up Time at Full Load. CH1: V<sub>OUT</sub> (2 V/div),  
 CH2: V<sub>OUT</sub> (2 V/div),  
 CH4: I<sub>IN\_MAINS</sub> (0.1 A/div)



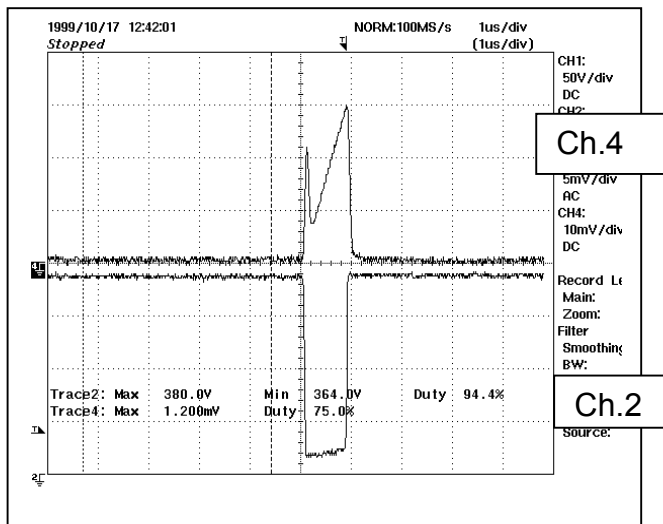
8.4.2 Switch Current and Drain-to-Source Voltage



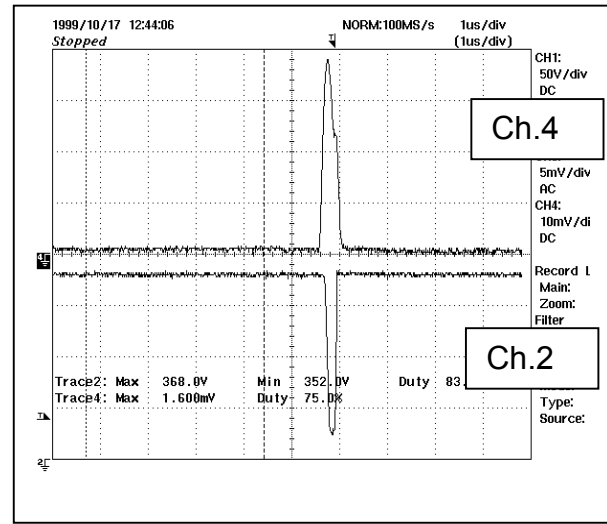
**Figure 8.4.2.1** - Full Load at 85 V<sub>AC</sub>.  
CH4: I<sub>DRAIN</sub>, (100 mA/div),  
CH2: V<sub>DS</sub> (100 V/Div)



**Figure 8.4.2.2** - Short Circuit at 85 V<sub>AC</sub>.  
CH4: I<sub>DRAIN</sub>, (100 mA/div),  
CH2: V<sub>DS</sub> (100 V/Div)



**Figure 8.4.2.3** - Full Load at 265 V<sub>AC</sub>.  
CH4: I<sub>DRAIN</sub>, (100 mA/div),  
CH2: V<sub>DS</sub> (100 V/Div)



**Figure 8.4.2.4** - Short Circuit at 265 V<sub>AC</sub>.  
CH4: I<sub>DRAIN</sub>, (100 mA/div),  
CH2: V<sub>DS</sub> (100 V/Div)

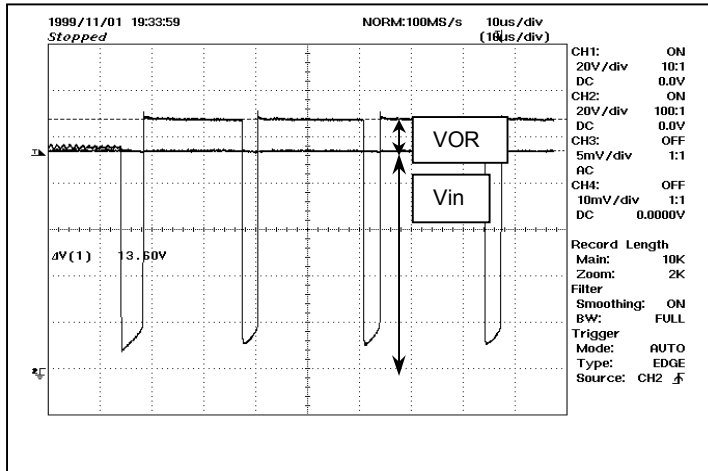


Figure 8.4.2.5 - Drain-Source Voltage ( $V_{DS}$ ). CH2 (20 V/div).  $V_{OR} = V_O + V_D = 13.6V$

### 8.4.3 Output Voltage Ripple

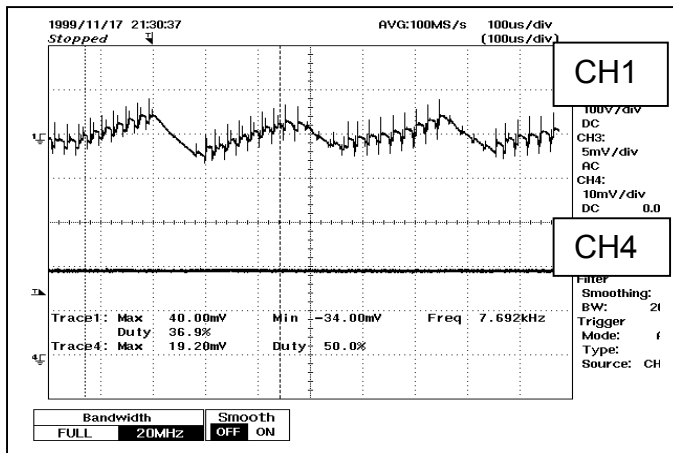


Figure 8.4.3.1 - Switching Ripple at Full Load.  
CH1:  $V_{OUT}$  (50 mV/div),  
CH4:  $I_{OUT}$  (50 mA/div)

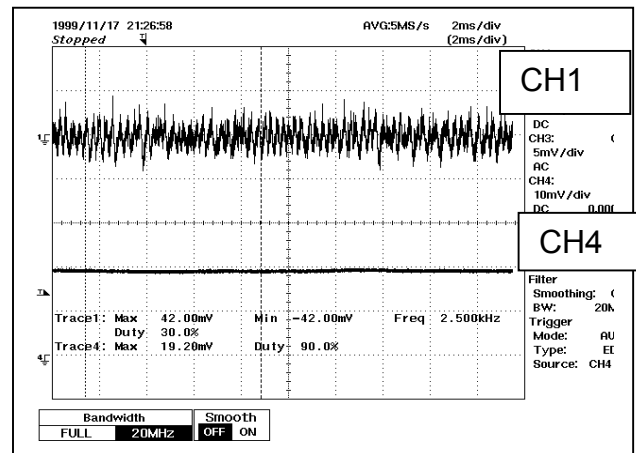
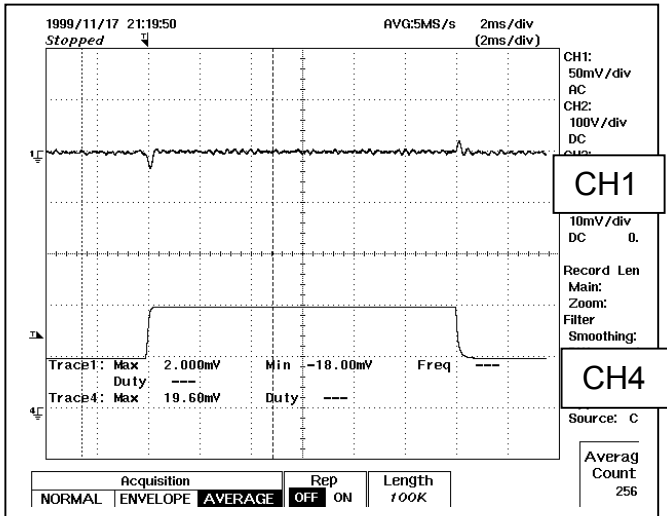


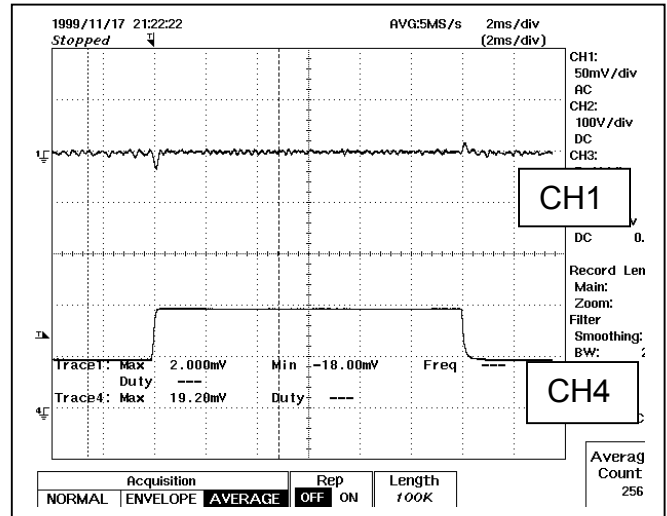
Figure 8.4.3.2 - Switching Frequency Ripple at Full Load.  
CH1:  $V_{OUT}$  (50 mV/div),  
CH4:  $I_{OUT}$  (50 mA/div)



### 8.5 Transient Response



**Figure 8.5.1** - Output Voltage Transient Response at 115 V<sub>AC</sub> 50-100% Load Change.  
 CH1: V<sub>OUT</sub> (50 mV/div),  
 CH2: I<sub>OUT</sub> (50 mA/div)



**Figure 8.5.2** - Output Voltage Transient Response at 230 V<sub>AC</sub> 50-100% Load Change.  
 CH1: V<sub>OUT</sub> (50 mV/div),  
 CH2: I<sub>OUT</sub> (50 mA/div)





## 8.6 Surge Voltage Immunity (2 kV and 6 kV, 1.2/50 $\mu$ s per IEC1000-4-5)

Two series of surge tests were performed:

Configuration “1” (2 kV), Fig. 8.6.1 and configuration “2” (6 kV), Fig. 8.6.2 passed 20 surges each at 45 seconds apart; 10 surges with positive (Fig. 8.6.3) and 10 with negative polarity (Fig. 8.6.4), all at high input line and full load. The 45 seconds delay between surges allows the energy rated components (R1, R2 and RV1) to cool down.

High input line is the worst case condition as the input capacitor (C1) reaches highest voltage therefore minimizing margin for *TinySwitch* breakdown voltage.

R2 limits the charging current during a +voltage surge such that C1 peak voltage does not exceed the TNY254 breakdown voltage.

R1 limits the maximum surge current to approximately 50 A, the value at which the clamping voltage of the varistor is characterized (<700 V). The 6 kV, 1.2/50  $\mu$ s pulse at 700 V clipping level is approximately 100  $\mu$ s (see Fig. 8.7.2). From the graph in Fig. 8.6.5, it can be inferred that the unit will survive 10 k surges of -6 kV (more of +6 kV as C1 can divert  $\sim$ 0.3 J).

Reducing the value of R1 would reduce the total number of 6 kV pulses the unit can survive.

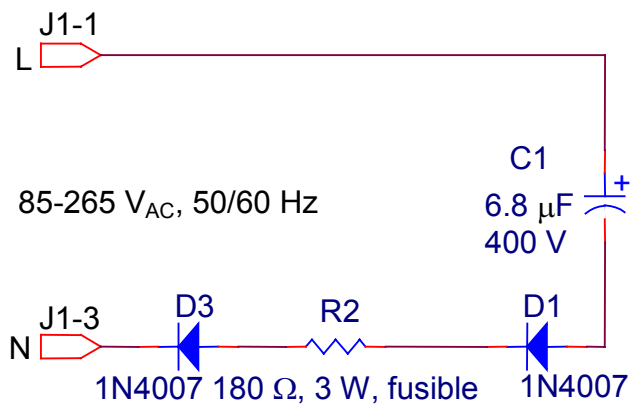


Figure 8.6.1 - Configuration “1”, 2 kV.

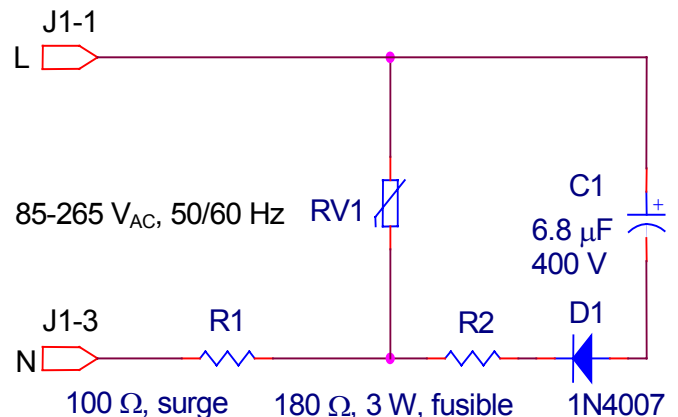


Figure 8.6.2 - Configuration “2”, 6 kV.

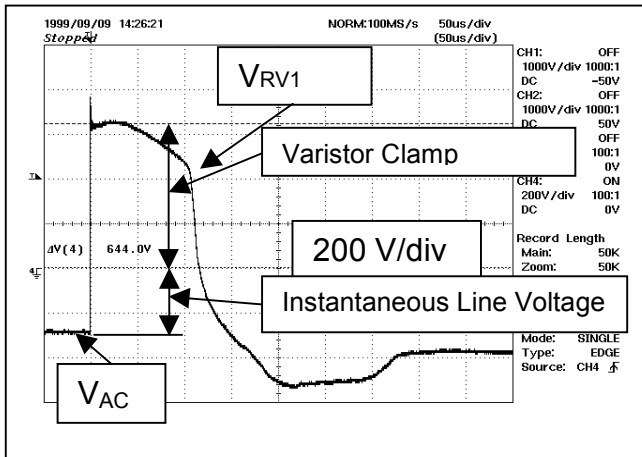


Figure 8.6.3 - RV1 Voltage During +6 kV, 1.2/50  $\mu$ s Surge.

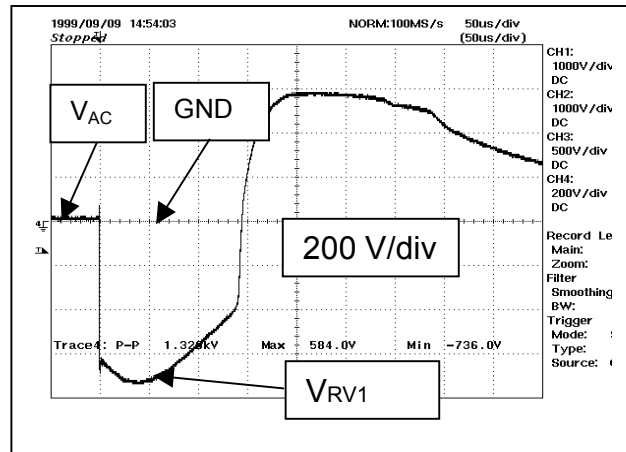


Figure 8.6.4 - RV1 Voltage During -6 kV, 1.2/50  $\mu$ s Surge.

The pre-trigger voltage is the instantaneous line voltage.  
 The RV1 voltage is post-trigger and is referenced to the ground.

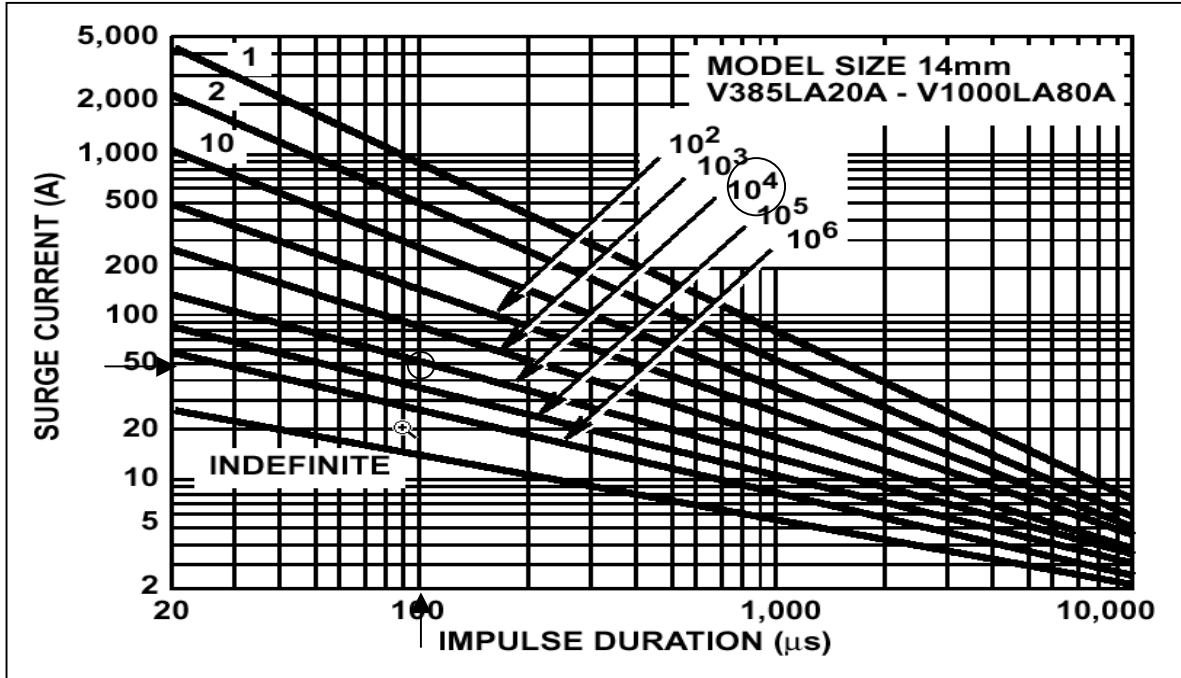


Figure 8.6.5 - Varistor Life (Number of Surges) as a Function of the Rectangular Pulse Amplitude and its Duration.



## Revision History

| <b>Date</b> | <b>Author</b> | <b>Rev</b> | <b>Description</b>               |
|-------------|---------------|------------|----------------------------------|
| 5-Aug-1999  | S. L.         | 1          | First Draft                      |
| 30-Aug-1999 | S. L.         | 2          | Second Draft                     |
| 7-Sep-1999  | S. L.         | 3          | Third Draft                      |
| 16-Oct-1999 | S. L.         | 4          | Fourth Draft                     |
| 18-Nov-1999 | S. L.         | 5          | Fifth Draft                      |
| 24-Nov-1999 | S. L.         | 6          | Sixth Draft                      |
| 23-Feb-2000 | S. L.         | 7          | Seventh Draft                    |
| 23-Mar-2000 | S. L.         | 8          | Release                          |
| 9-Oct-2000  | S. L.         | 9          | Pg.6, D1+D2 to D1+D3             |
| 23-Apr-2001 | S. L.         | 10         | Pg.8, 6.2 Config. Items 4 and 10 |



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