# Design Example Report

| | |
|---|---|
| **Title** | ***2.37 W 2-Output Non-isolated Cooktop Controller Using LNK306PN*** |
| **Specification** | 100 VAC – 132 VAC Input; 5 V, 81 – 162 mA and 12 V, 56 – 130 mA Outputs<br>Non-isolated 0 - 105 °C Operating Ambient |
| **Application** | Appliance |
| **Author** | Applications Engineering Department |
| **Document Number** | DER-226 |
| **Date** | February 16, 2010 |
| **Revision** | 1.0 |


**Summary and Features**

- Two non-isolated outputs with coupled inductor for good cross regulation
- Wide operating temperature range of 0 – 105 °C for cooktop and other high ambient temperature applications
- Extremely low cost, low component count
- Low cost 8-pin DIP package IC and no external heatsink required
- No-load input power of <65 mW at 132 VAC
- Full load efficiency >75%

## Table of Contents



**Important Note:**
Although this board is designed to satisfy safety isolation requirements, the engineering prototype has not been agency approved. Therefore, all testing should be performed using an isolation transformer to provide the AC input to the prototype board.

# 1 Introduction

This document is an engineering report describing a cooktop controller design with North American input voltage range (100 -132 VAC), 5 V /12 V non-isolated dual-output 2.37 W rated power supply utilizing LNK306PN device from LinkSwitch-TN family of ICs.

The document contains the power supply specification, schematic, bill of materials, inductor documentation, printed circuit layout, and performance data.

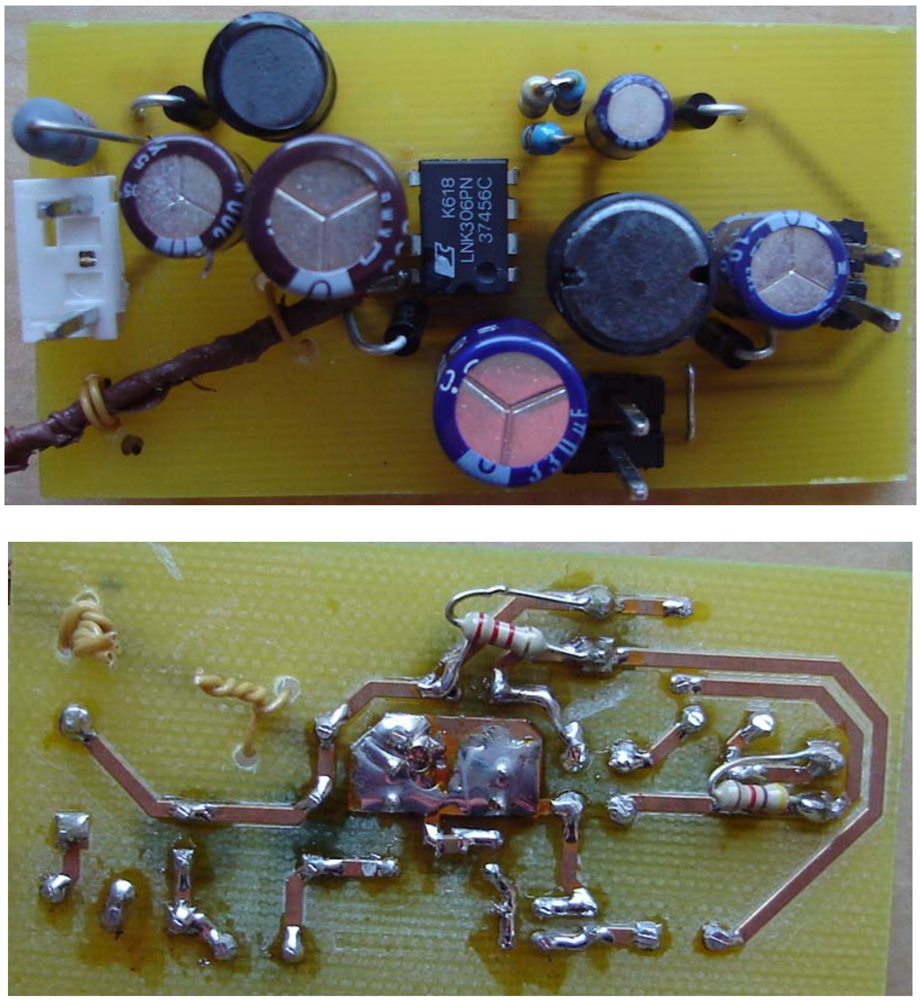


**Figure 1** – Photograph of Populated Circuit Board.



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## 2 Power Supply Specification

The table below represents the minimum acceptable performance of the design. Actual performance is listed in the results section.

| Description | Symbol | Min | Typ | Max | Units | Notes |
|---|---|---|---|---|---|---|
| Input Voltage | $V_{IN}$ | 100 | | 132 | VAC | |
| Frequency | $f_{LINE}$ | 47 | 50/60 | 64 | Hz | |
| **Output** | | | | | | |
| Output Voltage 1 | $V_{OUT1}$ | 4.5 | 5 | 5.5 | V | |
| Output Ripple Voltage 1 | $V_{RIPPLE1}$ | | | 100 | mV | 20 MHz bandwidth, 36 W Load |
| Output Current 1 | $I_{OUT1}$ | 81 | | 162 | mA | |
| Output Voltage 2 | $V_{OUT2}$ | 10.8 | 12 | 13.2 | V | |
| Output Ripple Voltage 2 | $V_{RIPPLE1}$ | | | 150 | mV | |
| Output Current 2 | $I_{OUT2}$ | 56 | | 130 | mA | |
| **Efficiency** | η | | 76 | | % | 25 °C |
| **Environmental** | | | | | | |
| Conducted EMI | | Meets CISPR22B / EN55022B | | | | |
| Operating Ambient Temperature | $T_{AMB}$ | 0 | | 105 | °C | |

# 3 Schematic

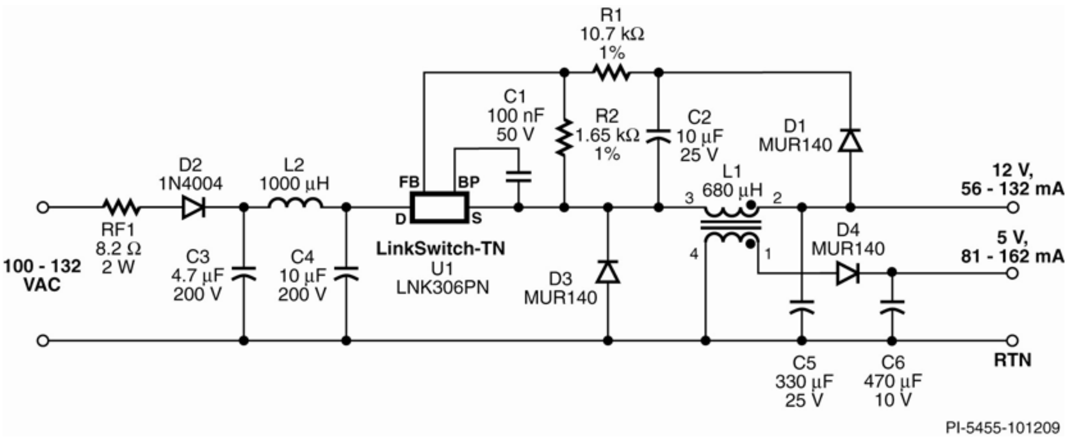


**Figure 2** – Schematic.



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# 4 Circuit Description

The power supply described was designed using cost effective buck converter topology. It has two outputs with 12 V rated at 132 mA and 5 V at 162 mA. The commonly known linear regulator design (5 V is linearly bucked down from 12 V output) could not be used due to high heat dissipation on the linear regulator. This would require the use of a larger TO-220 package linear regulator which is a more expensive and less efficient solution. The power supply proposes a coupled inductor design with the 5 V output in a flyback configuration. The 12 V output voltage is sensed and fed back to U1 via a direct resistor divider network.

## *4.1 Input Rectification and EMI Filtering*

Rectifier D2 half-wave rectifies AC input. Half wave was used due to application requirement that 12 V output RTN be referenced to input Neutral. Capacitor C3 and C4 filter the rectified DC and provide energy storage. Fusible resistor RF1 is a flameproof and wire wound resistor which provides inrush current limiting as well as circuit protection. In the event of a severe failure such as a short circuit, high current flowing through RF1 causes it to fail to open-circuit, thereby protecting subsequent circuitry. Capacitor C3, L2 and C4 together provide differential mode EMI filtering.

## *4.2 LNK306PN Operation*

LNK306PN belongs to the LinkSwitch-TN family of devices which operate at 66 kHz switching frequency. This is optimum for off-line applications as higher frequencies increase switching losses and result in unacceptably high switch di/dt values due to the lower value of inductance. The ±4 kHz frequency jittering helps reduce EMI.

The 100 nF BYPASS (BP) pin capacitor C1 is the internal supply voltage node for LNK306PN and is maintained at a typical voltage of 5.8 V. When LNK306PN is on, it runs off of the energy stored in C1. When LNK306PN is off, C1 is recharged via the voltage on the DRAIN pin.

At input AC start-up, C3 and C4 are charged up. When the bulk DC voltage reaches 50 V or above LNK306PN starts to switch. The LNK306PN has a maximum 700 V Drain-Source rating.

## *4.3 Output Rectification*

When the internal MOSFET of U1 is on, current ramps in the loop formed C4, U1, L1 and C5 while simultaneously delivering load current to the 12 V output. Diode D4 is reversed biased so C6 supports the 5 V output current.

When the MOSFET of U1 turns off, the polarity of L1 reverses and D3 is forward biased. Current flows in the loop formed by D3, L1 and C5. Simultaneously D4 is forwarded biased delivering current into C6 and the 5 V output. As the current ramps down, the energy stored in L1 during the MOSFET on time is delivered to the outputs.

The turns ratio between the two windings on the inductor matches the ratio between the two output voltages. The benefit of adding a second winding for the 5 V output is higher efficiency than a simple linear regulator for the 12 V output.

### *4.4 Feedback*

To regulate the 12 V output, the LinkSwitch-TN family of devices uses a simple and efficient On/Off control scheme. For each enabled switching cycle the MOSFET is turned on, the current ramps and the MOSFET is turned off once the current limit is reached.

Output regulation is maintained by adjusting the ratio of enabled and disabled (skipped) cycles.

A feedback signal is derived from the output (the voltage across C5) through a simple voltage divider formed by 1% tolerance metal film resistors R1 and R2. The input signal to this voltage divider is the voltage on capacitor C2, which closely tracks the output voltage and is charged whenever diode D1 is forwarded biased. Switching cycles are skipped whenever current in excess of 49 μA flows into the FEEDBACK (FB) pin.

Diode D1 is necessary to prevent the FB pin from delivering current to the output whenever the MOSFET is conducting, since the FB pin has a voltage of 1.65 V + $V_{SOURCE}$. The voltage divider does not need to take into account the forward voltage drop of D1 because, to a first order, the forward voltage of D1 and D3 are equal and cancel, and thus the feedback network tracks the output voltage.



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# 5 PCB Layout

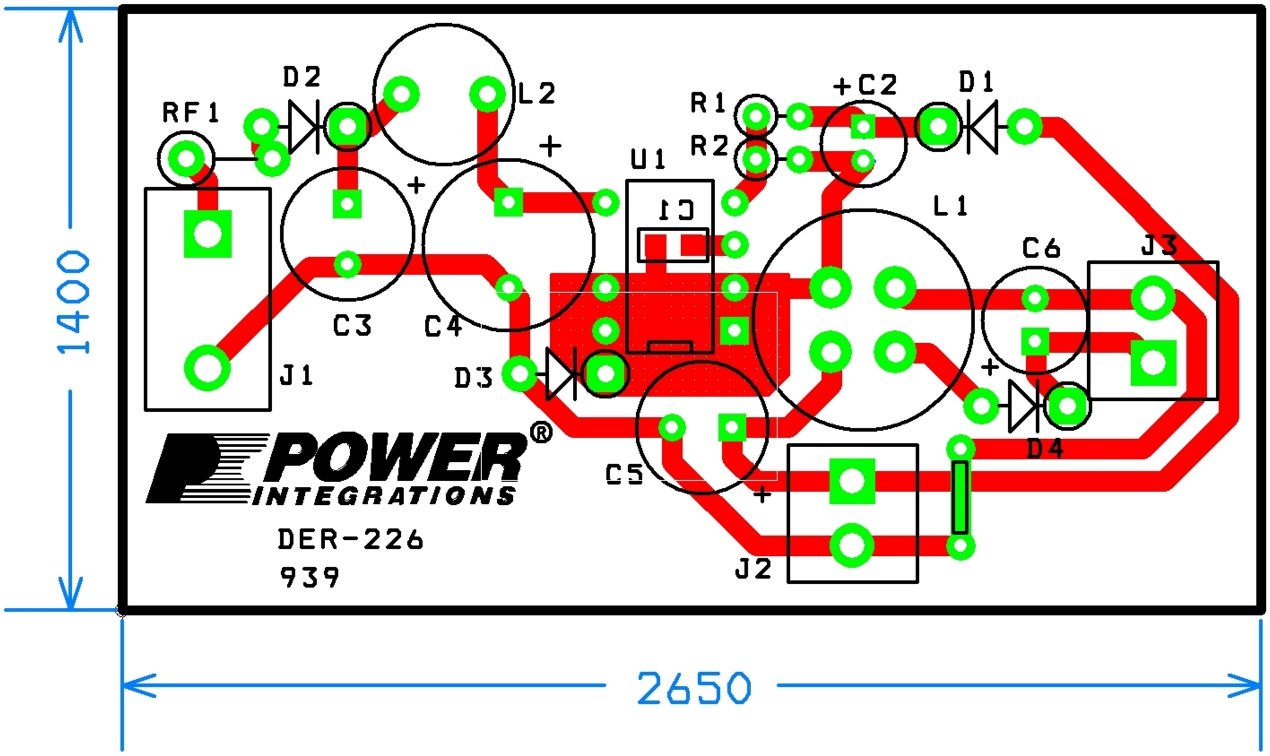


**Figure 3** – PCB Layout.

# 6 Bill of Materials

| Item | Qty | Ref Des | Description | Mfg Part Number | Mfg |
|---|---|---|---|---|---|
| 1 | 1 | C1 | Cap, 100 nF, 50 V, Ceramic | B37987F5104K000 | Epcos |
| 2 | 1 | C2 | Cap, 10 μF, 25 V, Elect | EKMG250ELL470ME11D | UCC |
| 3 | 1 | C3 | Cap, 4.7 μF, 200 V, Elect | EKMG201ELL4R7MHB5D | UCC |
| 4 | 1 | C4 | Cap, 10 μF, 200 V, Elect | EKMG201ELL100MJ16S | UCC |
| 5 | 1 | C5 | Cap, 330 μF, 25 V, Elect Low ESR | ELXZ250ELL331MJC5S | UCC |
| 6 | 1 | C6 | Cap, 470 μF, 10 V, Elect Low ESR | ELXZ100ELL471MH12D | UCC |
| 7 | 3 | D1 D3 D4 | Diode, 400 V, 1 A, Ultrafast | MUR140 | ON Semi |
| 8 | 1 | D2 | Diode, 400 V, 1 A, DO-41 | 1N4004 | Vishay |
| 9 | 1 | L1 | Inductor, 680 μH, 0.6 A, radial 4-Pin | RL-8064-3 | Renco |
| 10 | 1 | L2 | Inductor, 1 mH, 0.28 A, radial | SBC3-102-281 | Tokin |
| 11 | 1 | R1 | Res, 10.7 kΩ, 1%, 1/4 W, Metal Film | MFR-25FBF-10K7 | Yageo |
| 12 | 1 | R2 | Res, 1.65 kΩ, 1%, 1/4 W, Metal Film | MFR-25FBF-1K65 | Yageo |
| 13 | 1 | RF1 | Res, 8.2 Ω, 2 W, Fusible, Wire Wound | CRF253-4 5T 8R2 | Vitrohm |
| 14 | 1 | U1 | LinkSwitch-TN, DIP-8B | LNK306PN | Power Integrations |


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# 7 Coupled Inductor Specification

## 7.1 Electrical Diagram

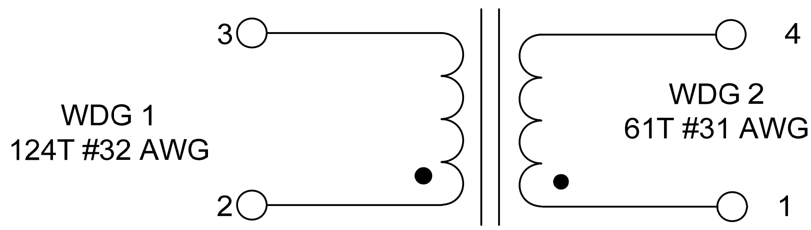


**Figure 4** – Coupled Inductor Electrical Diagram.

## 7.2 Electrical Specification

| | | |
|---|---|---|
| **Primary Inductance** | Pin 2 to pin 3, all other windings open, 66 khz, 0.4 VRMS | 680 μH, ±10% |
| **Resonant Frequency** | Pins 2 to pin 3, all other windings open | 850 MHz (Min.) |
| **Primary Leakage Inductance** | Pin 2 to pin 3, with pin 1 and 4 shorted, 0.4 VRMS | 21 μH (Max.) |

## 7.3 Materials

| Item | Description |
|---|---|
| **[1]** | Core: Renco RL-8064-3 drum core |
| **[2]** | Magnet wire: #32 AWG single poly nylon (SPN) insulated wire |
| **[3]** | Magnet wire: #31 AWG single poly nylon (SPN) insulated wire |
| **[4]** | Heatshrink tube |
| **[5]** | Varnish |

# 8 Transformer Design Spreadsheet

| ACDC_LinkSwitch-TN_041607; Rev.2.6; Copyright Power Integrations 2007 | INPUT | INFO | OUTPUT | UNIT | LinkSwitch-TN_Rev_2-6.xls: LinkSwitch-TN Design Spreadsheet |
|---|---|---|---|---|---|
| **INPUT VARIABLES** | | | | | |
| VACMIN | 100 | | | Volts | Minimum AC Input Voltage |
| VACMAX | 132 | | | Volts | Maximum AC Input Voltage |
| FL | 50 | | | Hertz | Line Frequency |
| VO | 12.00 | | | Volts | Output Voltage |
| IO | 0.200 | | | Amps | Output Current |
| EFFICIENCY (User Estimate) | 0.70 | | | | Overall Efficiency Estimate (Adjust to match Calculated, or enter Measured Efficiency) |
| EFFICIENCY (Calculated Estimate) | | | 0.84 | | Calculated % Efficiency Estimate |
| CIN | 13.20 | | 13.20 | uF | Input Filter Capacitor |
| Input Stage Resistance | | | 0.00 | ohms | Input Stage Resistance, Fuse & Filtering |
| Ambient Temperature | 105 | | 105 | deg C | Operating Ambient Temperature (deg Celsius) |
| Switching Topology | | | Buck | | Type of Switching topology |
| Input Rectification Type | H | | ***H*** | | Choose H for Half Wave Rectifier and F for Full Wave Rectification |
| **DC INPUT VARIABLES** | | | | | |
| VMIN | | | 105.7 | Volts | Minimum DC Bus Voltage |
| VMAX | | | 186.7 | Volts | Maximum DC Bus Voltage |
| **LinkSwitch-TN** | | | | | |
| LinkSwitch-TN | **LNK306** | | LNK306 | | Selected LinkSwitch-TN. Ordering info - Suffix P/G indicates DIP 8 package; suffix D indicates SO8 package; second suffix N indicates lead free RoHS compliance |
| ILIMIT | | | 0.482 | Amps | Typical Current Limit |
| ILIMIT_MIN | | | 0.450 | Amps | Minimum Current Limit |
| ILIMIT_MAX | | | 0.515 | Amps | Maximum Current Limit |
| FSMIN | | | 62000 | Hertz | Minimum Switching Frequency |
| VDS | | | 6.2 | Volts | Maximum On-State Drain To Source Voltage drop |
| PLOSS_LNK | | | 0.21 | Watts | Estimated LinkSwitch-TN losses |
| **DIODE** | | | | | |
| VD | | | 0.70 | Volts | Freewheeling Diode Forward Voltage Drop |
| VRR | | | 400 | Volts | Recommended PIV rating of Freewheeling Diode |
| IF | | | 1 | Amps | Recommended Diode Continuous Current Rating |
| TRR | | | 35 | ns | Recommended Reverse Recovery Time |
| Diode Recommendation | | | **BYV26C** | | Suggested Freewheeling Diode |
| **OUTPUT INDUCTOR** | | | | | |
| L_TYP | | | 479.4 | uH | Required value of Inductance to deliver Output Power (Includes device and inductor tolerances) Choose next higher standard available value |
| **L** | | | **680** | **uH** | **Output Inductor, Recommended Standard Value** |
| L_R | | | 2.0 | Ohms | DC Resistance of Inductor |
| **OPERATING MODE** | | | **MDCM** | | **Mostly Discontinuous Conduction Mode (at VMIN)** |
| KL_TOL | | | 1.15 | | Inductor tolerance Factor. Accounts for basic (10% - 20%) Manufacturing Tolerances 1.1 < KL_TOL < 1.2 See AN-37 for detailed explanation |
| K_LOSS | | | 0.800 | | Loss factor. Accounts for "off-state" power loss to be supplied by inductor Calculated efficiency < K_LOSS < 1. See AN-37 for detailed explanation |
| ILRMS | | | 0.24 | Amps | Estimated RMS inductor current (at VMAX) |
| **OUTPUT CAPACITOR** | | | | | |
| DELTA_V | | | 0.12 | Volts | Target Output Voltage Ripple |
| MAX_ESR | | | 267 | m-Ohms | Maximum Capacitor ESR (milli-ohms) |
| I RIPPLE | | | 0.45 | Amps | Output Capacitor Ripple current |
| **FEEDBACK COMPONENTS** | | | | | |
| RBIAS | | | 2.00 | k-Ohms | Bias Resistor. Use closest standard 1% value |


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| | | | | | |
|---|---|---|---|---|---|
| RFB | | | 11.86 | k-Ohms | Feedback Resistor. Use closest standard 1% value |
| CFB | | | 10 | uF | Feedback Capacitor |
| C_SOFT_START | | | 1 - 10 | uF | If the output Voltage is greater than 12 V, or total output and system capacitance is greater than 100 uF, a soft start capacitor between 1uF and 10 uF is recommended. See AN-37 for details |

# 9 Performance Data

All measurements performed with power supply in open air at room temperature unless specified.

## 9.1 Line / Load / Cross Regulation

| $V_{IN}$ (VAC) | 12 V $I_O$ (A) | 12 V $V_O$ (V) | 5 V $I_O$ (A) | 5 V $V_O$ (V) |
|---|---|---|---|---|
| 100 | 0.06 | 12.63 | 0.08 | 5.16 |
| 100 | 0.06 | 12.62 | 0.16 | 4.79 |
| 100 | 0.13 | 12.57 | 0.08 | 5.37 |
| 100 | 0.13 | 12.55 | 0.16 | 5.12 |
| 132 | 0.06 | 12.63 | 0.08 | 5.23 |
| 132 | 0.06 | 12.61 | 0.16 | 4.89 |
| 132 | 0.13 | 12.57 | 0.08 | 5.42 |
| 132 | 0.13 | 12.56 | 0.16 | 5.19 |

## 9.2 Efficiency

| $V_{IN}$ (VAC) | $P_{IN}$ (W) | 12 V $I_O$ (A) | 12 V $V_O$ (V) | 5 V $I_O$ (A) | 5 V $V_O$ (V) | Efficiency (%) |
|---|---|---|---|---|---|---|
| 100 | 3.24 | 0.13 | 12.55 | 0.16 | 5.12 | 76.0 |
| 115 | 3.24 | 0.13 | 12.55 | 0.16 | 5.13 | 76.0 |
| 132 | 3.26 | 0.13 | 12.56 | 0.16 | 5.19 | 75.9 |

## 9.3 Standby power

| $V_{IN}$ (VAC) | 12 V $I_O$ (A) | 5 V $I_O$ (A) | Standby Power (mW) |
|---|---|---|---|
| 100 | 0.003 | 0.001 | 55 |
| 132 | 0.003 | 0.001 | 63 |

Note: Standby power is for information only for this application. The application has minimum of about 50% rated load on each output. To measure standby power 3 mA on 12 V and 1 mA on 5 V were added in order for outputs to stay within output capacitor voltage ratings.


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## 9.4 Steady-state Thermal Evaluation

| $V_{IN}$ = 100 VAC, Full Load | | T (°C) 105 °C Ambient (Calculated) |
|---|---|---|
| Component | T (°C) 25 °C Ambient | |
| D2 | 28.3 | 108.3 |
| C3 | 27.3 | 107.3 |
| C4 | 29.3 | 109.3 |
| U1 (LNK306PN) | 43.7 | 123.7 |
| L1 | 35.0 | 115.0 |
| D3 | 37.5 | 117.5 |
| C5 | 30.8 | 110.8 |
| D4 | 40.9 | 120.9 |
| C6 | 33.3 | 113.3 |

Note: The LNK306PN was measured to be 119.2 °C during thermal chamber testing at 105 °C.

## *9.5 Output Voltage Start-up Profile*

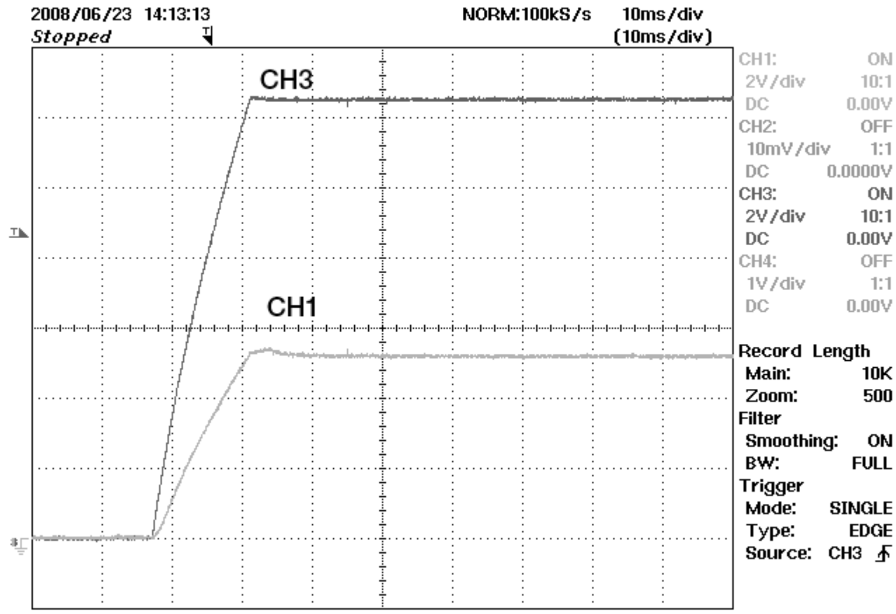


**Figure 5** – CH3 = 12 V CH1 = 5 V at 100 VAC, 12 V $I_O$ = 56 mA, 5 V $I_O$ = 81 mA.

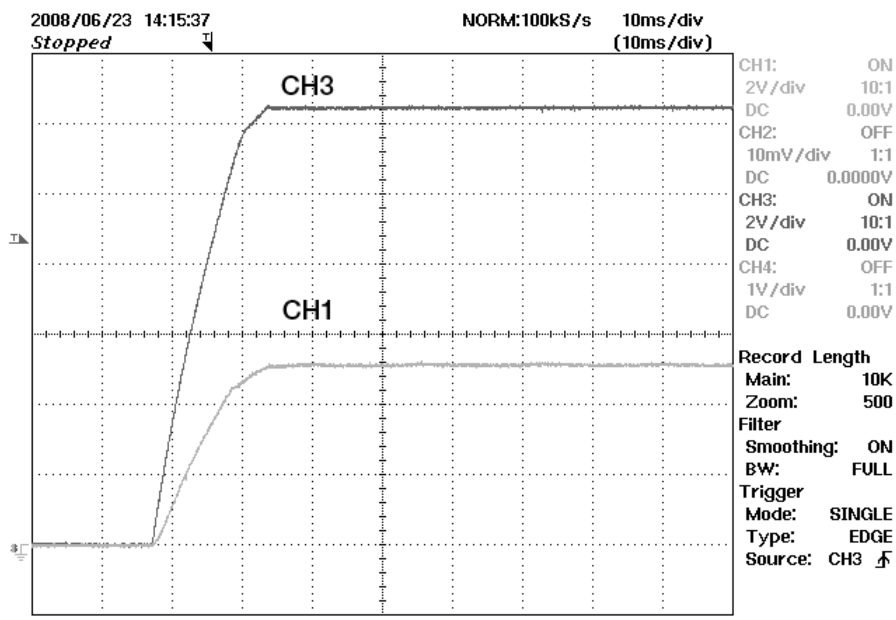


**Figure 6** – CH3 = 12 V CH1 = 5 V at 100 VAC, 12 V $I_O$ = 130 mA, 5 V $I_O$ = 162 mA.

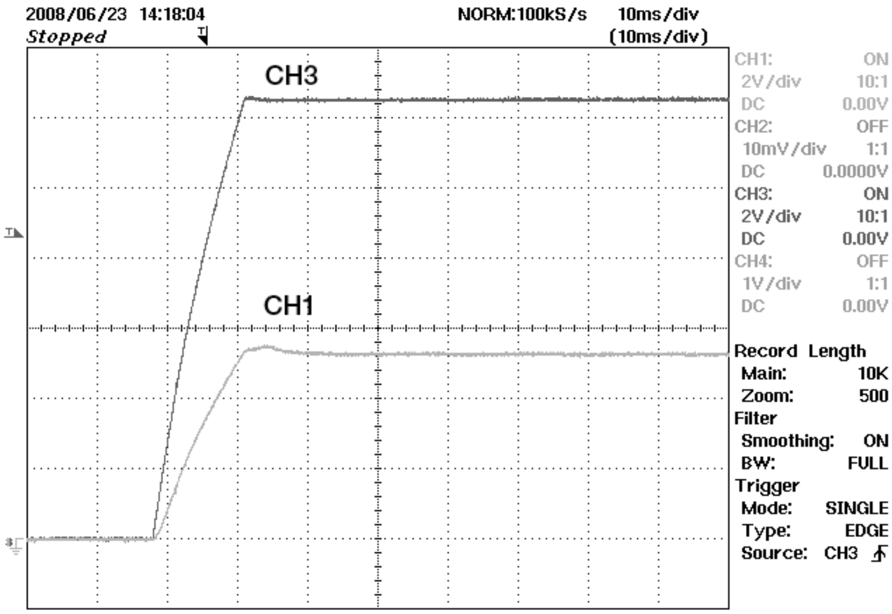


**Figure 7** – CH3 = 12 V CH1 = 5 V at 132 VAC, 12 V $I_O$ = 56 mA, 5 V $I_O$ = 81 mA.

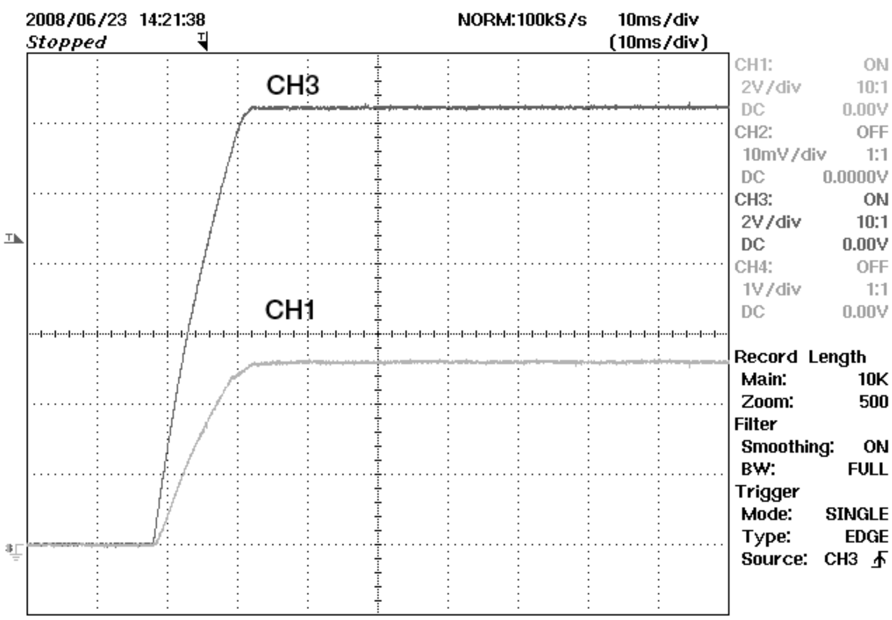


**Figure 8** – CH3 = 12 V CH1 = 5 V at 132 VAC, 12 V $I_O$ = 130 mA, 5 V $I_O$ = 162 mA.

### 9.6 Output Ripple Measurements

For DC output ripple measurements, a modified oscilloscope test probe must be utilized in order to reduce spurious signals due to pickup. Details of the probe modification are provided in following figures

The 5125BA probe adapter is affixed with two capacitors tied in parallel across the probe tip. The capacitors include one (1) 0.1 μF/50 V ceramic type and one (1) 1.0 μF/50 V aluminum electrolytic. *The aluminum electrolytic type capacitor is polarized, so proper polarity across DC outputs must be maintained (see below).*

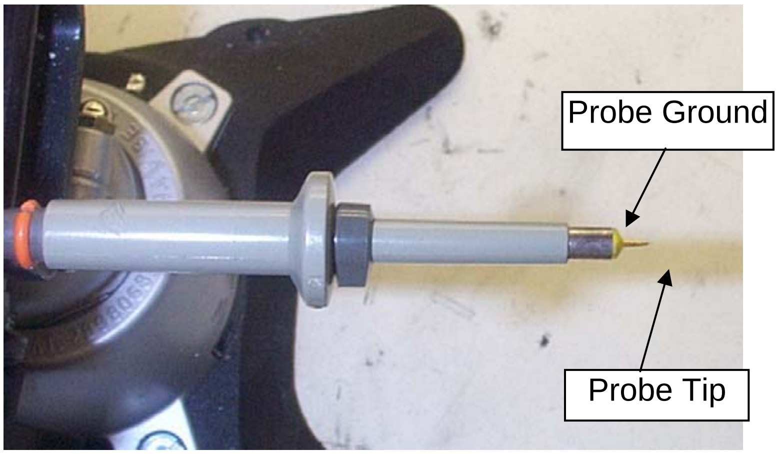


**Figure 9** – Oscilloscope Probe Prepared for Ripple Measurement.
(End cap and ground lead removed)

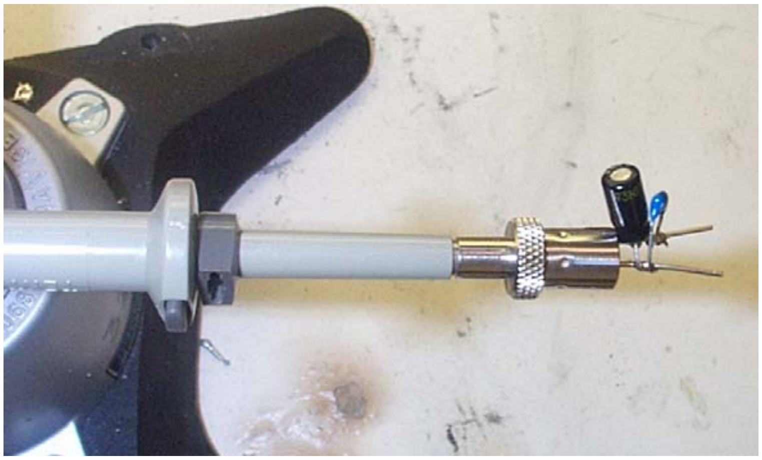

**Figure 10** – Oscilloscope Probe with Probe Master 5125BA BNC Adapter.
(Probe modified with wires for probe ground, and two parallel decoupling capacitors added).


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### 9.6.1 Measurement Results

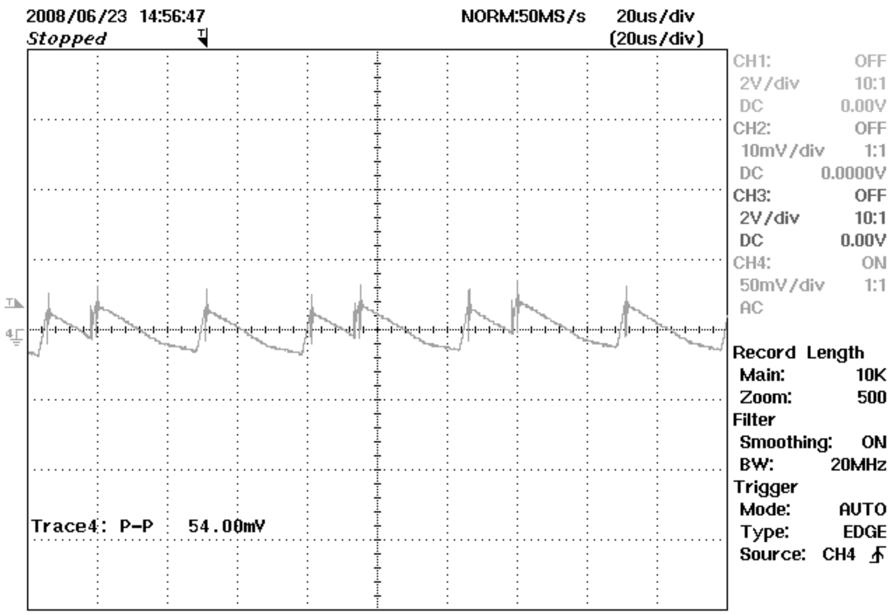


**Figure 11** – 12 V Ripple at 100 VAC, Full Load.

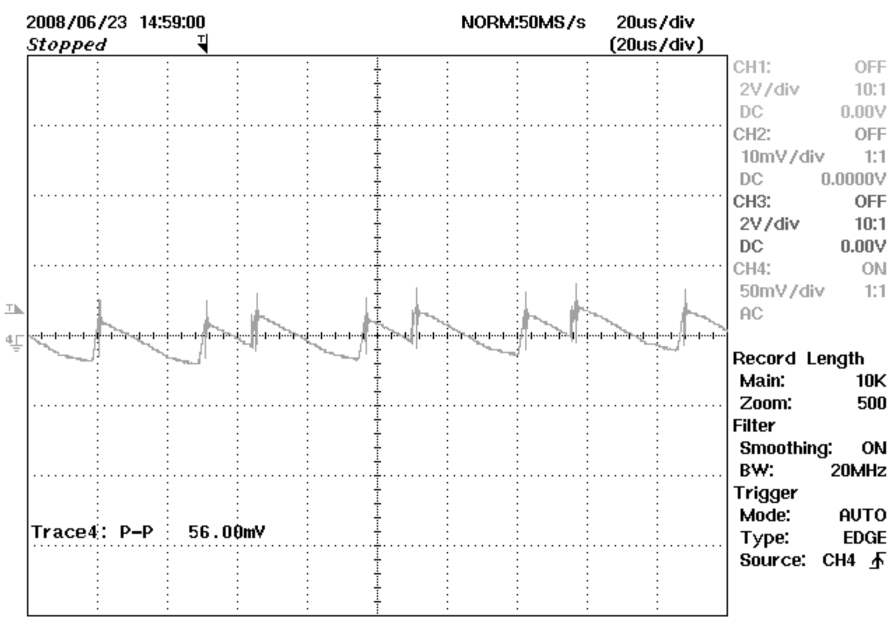


**Figure 12** – 12 V Ripple at 132 VAC, Full Load.

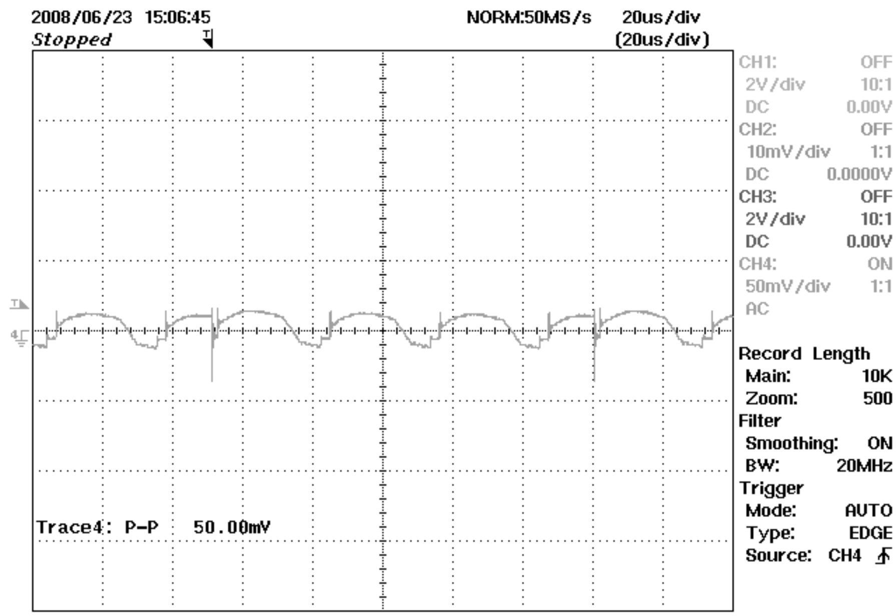


**Figure 13** – 5 V Ripple at 100 VAC, Full Load.

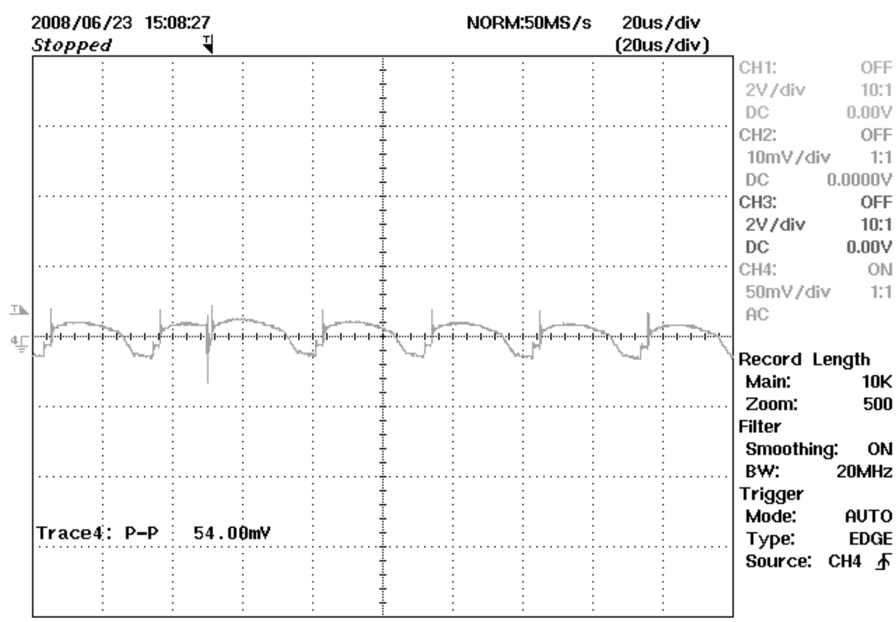


**Figure 14** – 5 V Ripple at 132 VAC, Full Load.


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## 9.7 Peak Drain Voltage

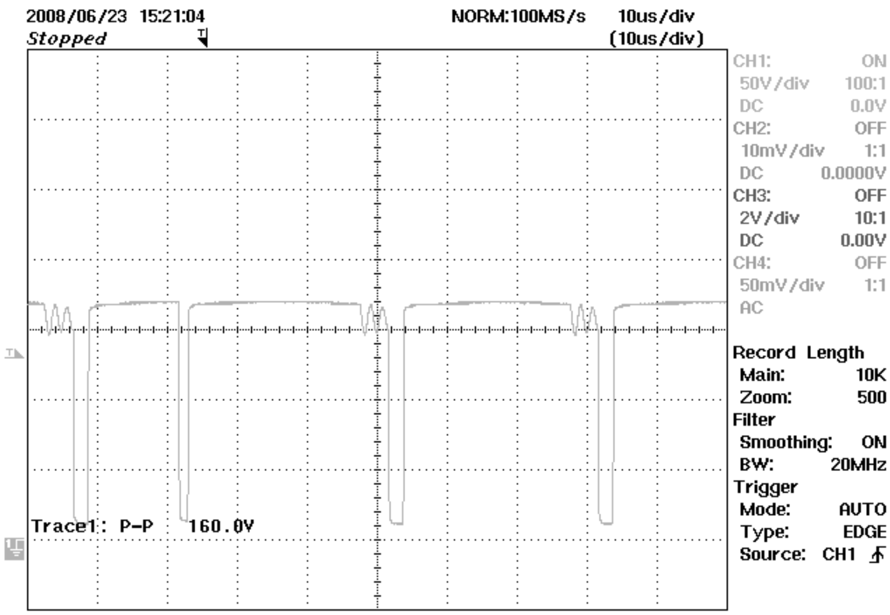


**Figure 15** – LNK306PN VDS Waveform at 132 VAC Full Load.

## 10 Conducted EMI

The upper and lower limits shown are quasi peak and the average limits as per EN55022 class B. The EMI tests were conducted without connecting the output return of the power supply connected to earth ground through the LISN earth connection. A resistive load was connected to DC output terminals. Measurements shown are peak measurements vs. QP and AVG limits.

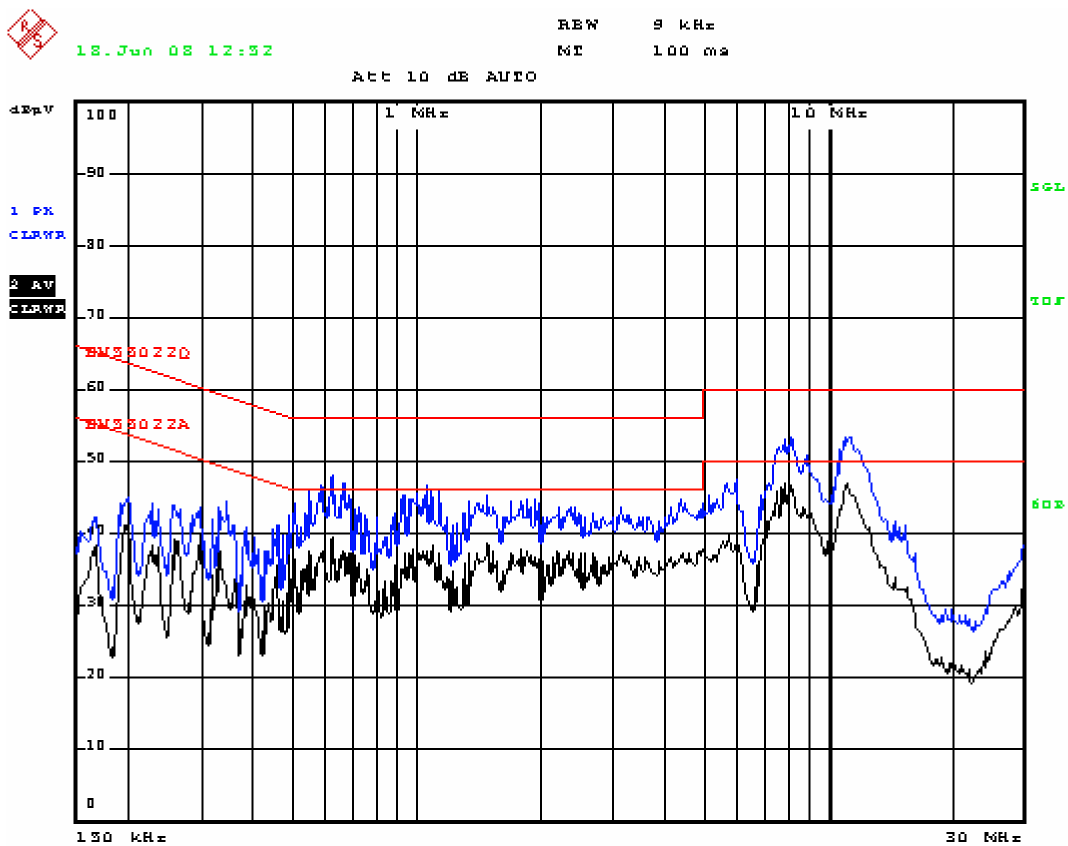


**Figure 16** – Peak and Average Scans, L, 115 VAC, Full Load.


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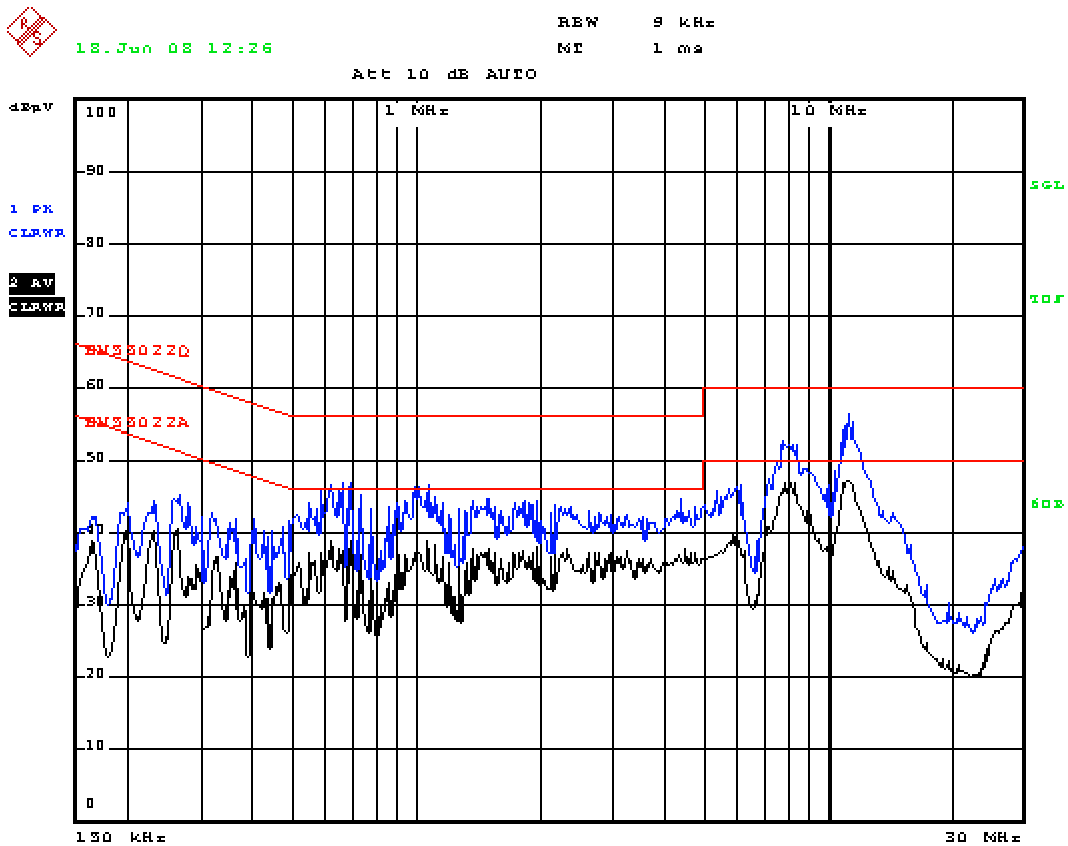


**Figure 17** – Peak Scan, N, 115 VAC, Full Load.

# 11 Revision History

| Date | Author | Revision | Description & changes | Reviewed |
|---|---|---|---|---|
| 16-Feb-10 | HY, EC | 1.0 | Initial Release | Apps and Mktg |
| | | | | |


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