Test Report: PMP31375

180VAC to 275VAC Input, 96W - 24W AC/DC Flyback With Self-Biasing GaN Reference Design

Description

This reference design is a power supply delivering 24V, 1A average and up to 96W for 4 seconds. This design supports all cases where high peak power like motor drive or transitory power loads need to be addressed. The integrated quasi-resonant controller, gallium nitride (GaN) switch, and self-biasing section deliver high efficiency while maintaining low stand-by loss and eliminate the need for auxiliary winding in the transformer. Simple transformer structure leads to lower leakage inductance and improves efficiency by reducing snubber loss. Additionally, removing the auxiliary winding and associated components, allows for the reduction of BOM cost and PCB space.

Resources

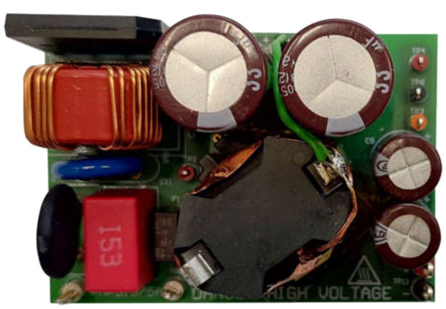
PMP31375	Design Folder
UCG28826	Product Folder
UCC24612	Product Folder
ATL431	Product Folder

Features

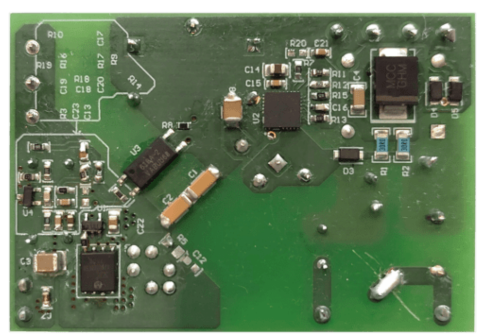
- Achieves 92.14% efficiency at 230VAC, 91.91% at 180VAC
- Suitable for high ambient temperature applications: only 25.8ºC delta-T between components and the ambient temperature, while delivering 96W for four seconds and 24W average power
- No load power consumption 46.2mW at 230VAC
- Meets DoE Level VI and CoC V5 Tier2 efficiency standards

Applications

- Coffee machine
- Power delivery

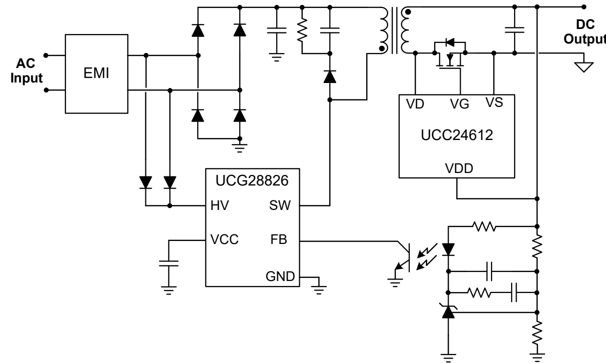


Top view



Bottom view

Angle view



Block Diagram

1 Test Prerequisites

1.1 Voltage and Current Requirements

Table 1-1. Voltage and Current Requirements

Parameter	Specifications
Input voltage range	180VAC to 275VAC
Input voltage frequency	47Hz to 53Hz
Output voltage	24V
Maximum output current	4A
Average output current	1A

1.2 Required Equipment

- AC source: California instruments 2001RP
- Digital power meter: Vitrek PA900
- Electronic load: HP 6063B
- Oscilloscope: LeCroy waverunner 64Xi-A
- Infrared thermal camera: Flir one edge pro
- True RMS multimeter: Metrahit pro

1.3 Considerations

All tests refer to ambient temperature of 25ºC, the board placed horizontal on the bench in still air condition.

1.4 Safety Considerations

Always follow TI's set-up and application instructions, including use of all interface components within the recommended electrical rated voltage and power limits. Always use electrical safety precautions to help verify your personal safety and those working around you. Contact TI's Product Information Center http://ti.com/customer support for further information.

WARNING

Failure to follow warnings and instructions can result in personal injury, property damage or death due to electrical shock and burn hazards.

The term TI HV EVM refers to an electronic device typically provided as an open framed, unenclosed printed circuit board assembly. It is *intended strictly for use in development laboratory environments, solely for qualified professional users having training, expertise and knowledge of electrical safety risks in development and application of high voltage electrical circuits*. Any other *use and/or application are strictly prohibited by Texas Instruments*. If you are not suitably qualified, then immediately stop from further use of the HV EVM.

1. Work Area Safety:
   a. Keep work area clean and orderly.
   b. Qualified observers must be present anytime circuits are energized.
   c. Effective barriers and signage must be present in the area where the TI HV EVM and the interface electronics are energized, indicating operation of accessible high voltages can be present, for the purpose of protecting inadvertent access.
   d. All interface circuits, power supplies, evaluation modules, instruments, meters, scopes, and other related apparatus used in a development environment exceeding 50Vrms/75VDC must be electrically located within a protected Emergency Power Off EPO protected power strip.
   e. Use stable and non-conductive work surface.
   f. Use adequately insulated clamps and wires to attach measurement probes and instruments. No freehand testing whenever possible.

1. Electrical Safety:
   a. As a precautionary measure, a good engineering practice is to assume that the entire EVM has fully accessible and active high voltages.
   b. De-energize the TI HV EVM and all the inputs, outputs and electrical loads before performing any electrical or other diagnostic measurements. Revalidate that TI HV EVM power has been safely deenergized.
   c. c. With the EVM confirmed de-energized, proceed with required electrical circuit configurations, wiring, measurement equipment hook-ups and other application needs, while still assuming the EVM circuit and measuring instruments are electrically live.
   d. d. Once EVM readiness is complete, energize the EVM as intended.

      WARNING

      While the EVM is energized, never touch the EVM or the electrical circuits, as the ciruits can be at high voltages capable of causing electrical shock hazard.
2. Personal Safety
   a. Wear personal protective equipment e.g. latex gloves or safety glasses with side shields or protect EVM in an adequate lucent plastic box with interlocks from accidental touch.

Limitation for safe use:

EVMs are not to be used as all or part of a production unit.

1.5 Dimensions

Board size: 45.72mm × 65.47mm × 25mm (W × L × H).

1.6 Test Setup

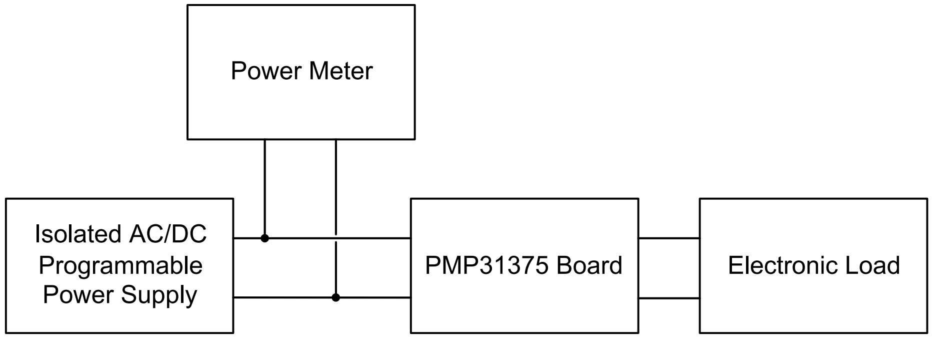


Figure 1-1. Test Setup

2 Testing and Results

2.1 Efficiency Graphs

Efficiency is shown in Figure 2-1.

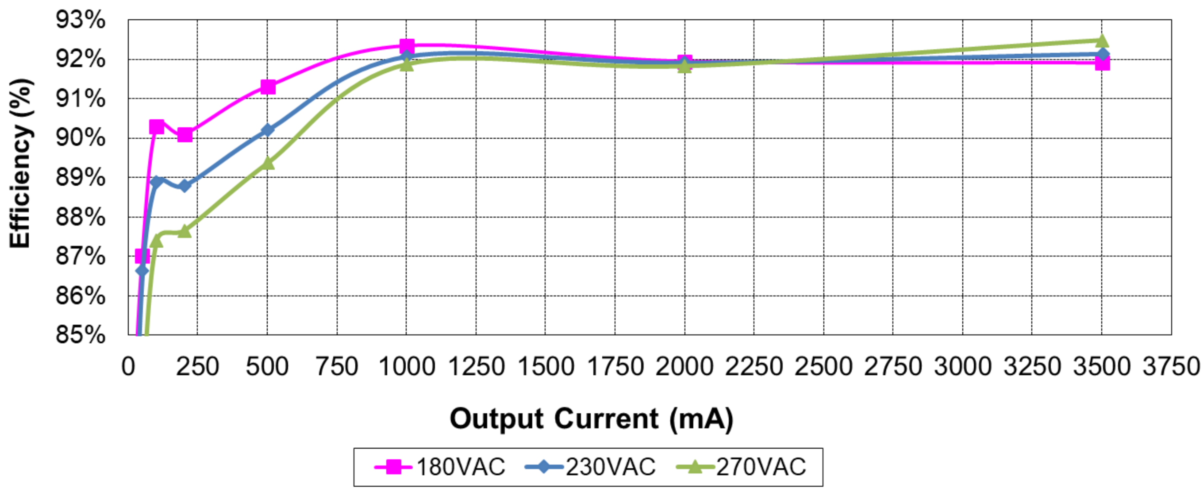


Figure 2-1. Efficiency Graph versus VAC and Load Current

2.2 Efficiency Data

Efficiency data are shown in Table 2-1.

Table 2-1. Efficiency Data at 230VAC

P_{IN} (W)	V_{OUT} (V)	I_{OUT} (mA)	P_{OUT} (W)	P_{LOSS} (W)	Efficiency (%)
0.0462	24.06	0	0	0.0462	0
0.2181	24.06	5.5	0.132	0.0858	60.67
0.3585	24.06	10.9	0.262	0.0962	73.15
0.6472	24.06	21.7	0.522	0.1251	80.67
1.419	24.06	51.1	1.229	0.1895	86.64
2.758	24.06	101.9	2.452	0.3063	88.89
5.438	24.06	200.7	4.829	0.6092	88.80
13.352	24.06	500.6	12.044	1.3076	90.21
26.140	24.05	1000.7	24.067	2.0732	92.07
52.29	24.03	2000	48.060	4.2300	91.91
91.26	23.99	3505	84.085	7.1751	92.14

Table 2-2. Efficiency Data at 180VAC

P_{IN} (W)	V_{OUT} (V)	I_{OUT} (mA)	P_{OUT} (W)	P_{LOSS} (W)	Efficiency (%)
0.0332	24.06	0	0	0.0332	0
0.2069	24.06	5.5	0.135	0.0722	65.12
0.3498	24.06	10.9	0.262	0.0875	74.97
0.6321	24.06	21.7	0.522	0.1100	82.60
1.413	24.06	51.1	1.229	0.1832	87.03
2.715	24.06	101.9	2.452	0.2633	90.30
5.359	24.06	200.7	4.829	0.5302	90.11
13.191	24.06	500.6	12.044	1.1466	91.31
26.063	24.05	1000.7	24.067	1.9962	92.34
52.27	24.03	2000	48.060	4.2100	91.95
91.41	23.99	3502	84.013	7.3970	91.91

Table 2-3. Efficiency Data at 270VAC

P_{IN} (W)	V_{OUT} (V)	I_{OUT} (mA)	P_{OUT} (W)	P_{LOSS} (W)	Efficiency (%)
0.076	24.06	0	0	0.076	0
0.247	24.06	5.6	0.135	0.1123	54.55
0.392	24.06	10.9	0.262	0.1297	66.90
0.681	24.06	21.7	0.522	0.1589	76.67
1.476	24.06	51.1	1.229	0.2465	83.30
2.805	24.06	101.9	2.452	0.3533	87.41
5.509	24.06	200.7	4.829	0.6802	87.65
13.477	24.06	500.6	12.044	1.4326	89.37
26.196	24.05	1000.7	24.067	2.1292	91.87
52.34	24.03	2000	48.060	4.2800	91.82
90.88	24.00	3502	84.048	6.8320	92.48

2.3 Thermal Images

Thermal image is shown in Figure 2-2.

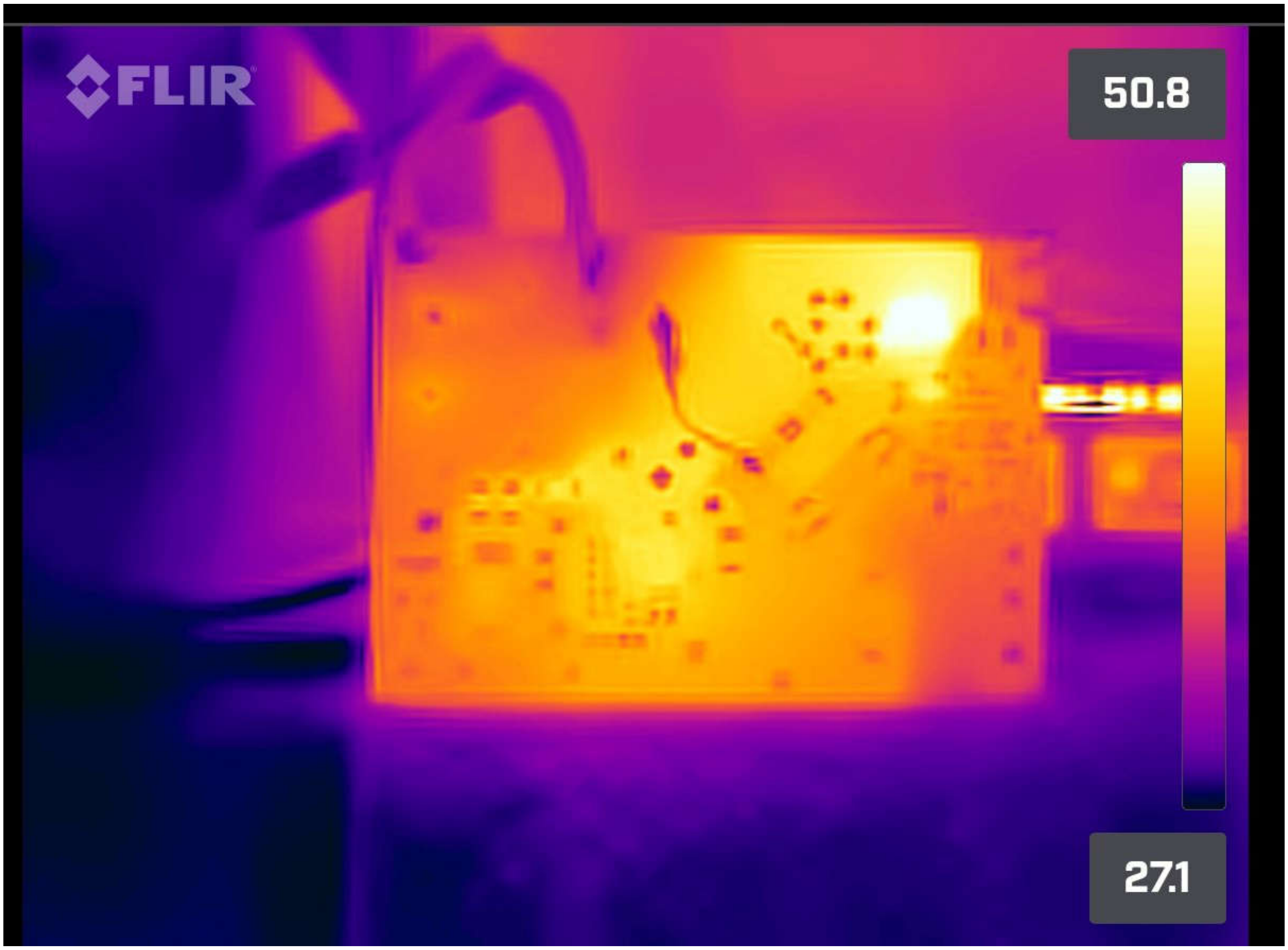


Figure 2-2. Thermal at 96W Peak (4 Seconds), 24W Average, PCB Bottom Side

2.4 Bode Plots

Bode plot is shown in Figure 2-3. Crossover frequency at 230VAC, 3A load is 1.861 kHz, phase margin 67.33 deg. and gain margin 11.75dB. The remaining two measurements are associated to 1A and 2A load.

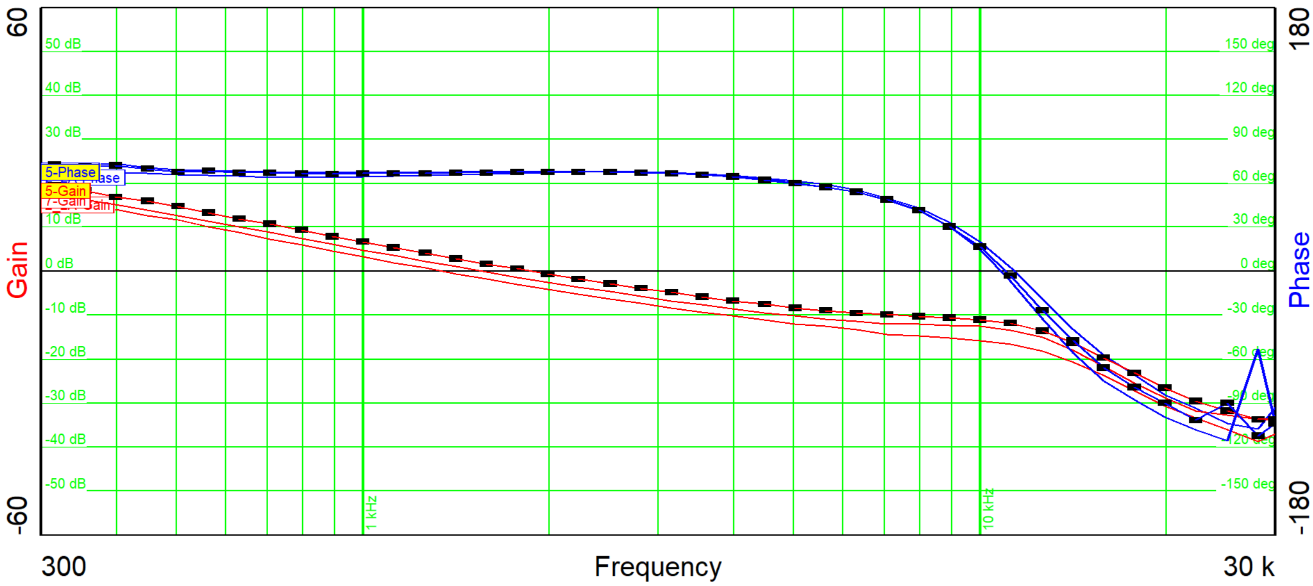


Figure 2-3. Bode Plot of the Converter. Dashed Line Refers to 230VAC and 3A Load

2.5 EMI

EMI measurements shown in Figure 2-4 and Figure 2-5.

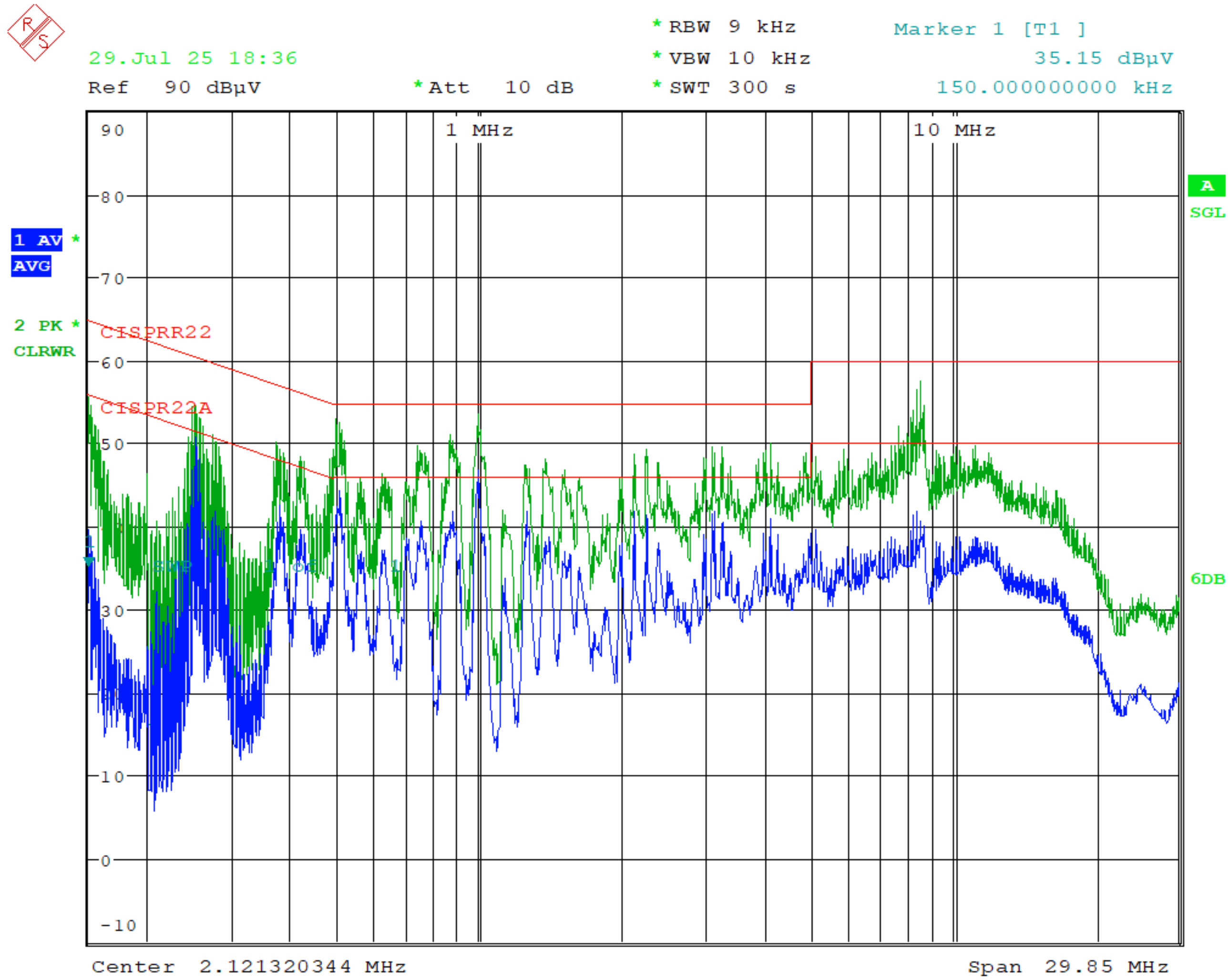


Figure 2-4. EMI Scan at 230VAC and 1A Load - Line Input

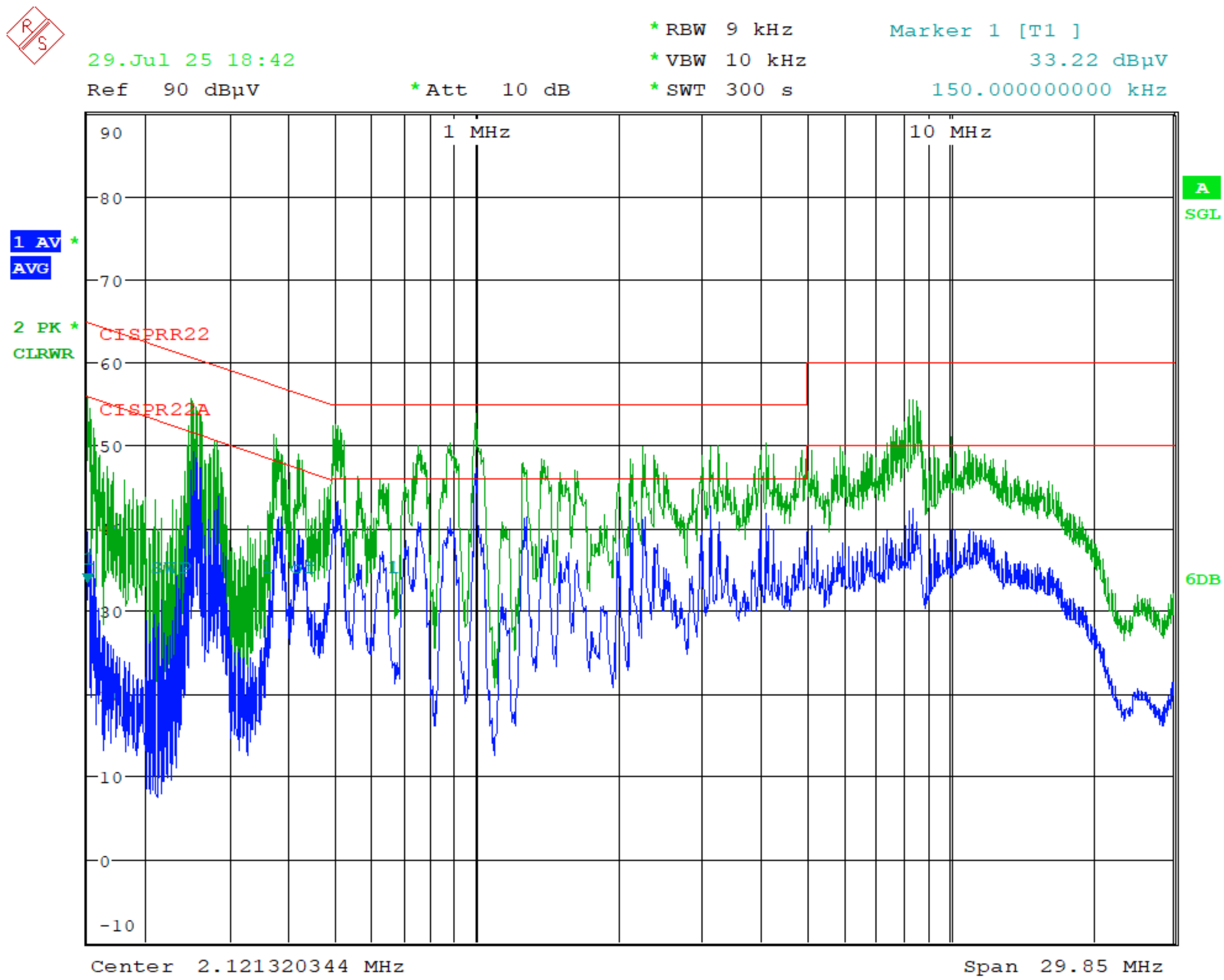


Figure 2-5. EMI Scan at 230VAC and 1A Load - Neutral Input

3 Waveforms

3.1 Switching

Switching behavior is shown in the following figures. C1: Vds of Q1, C4: SW pin of U2.

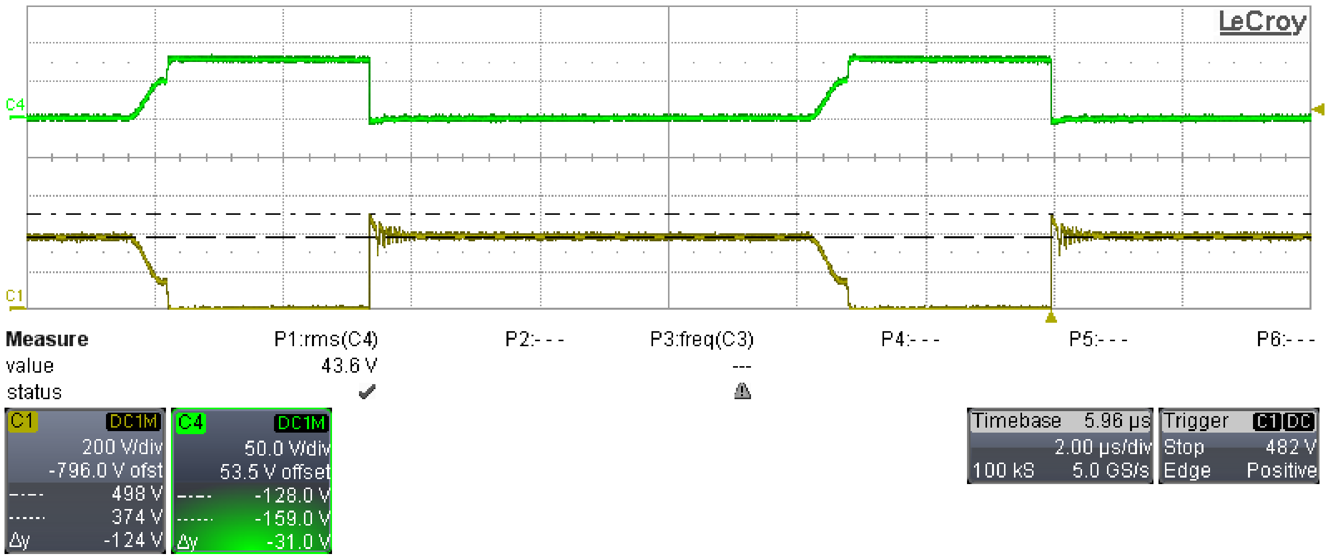


Figure 3-1. Switching Waveforms at 180VAC and 4A Load

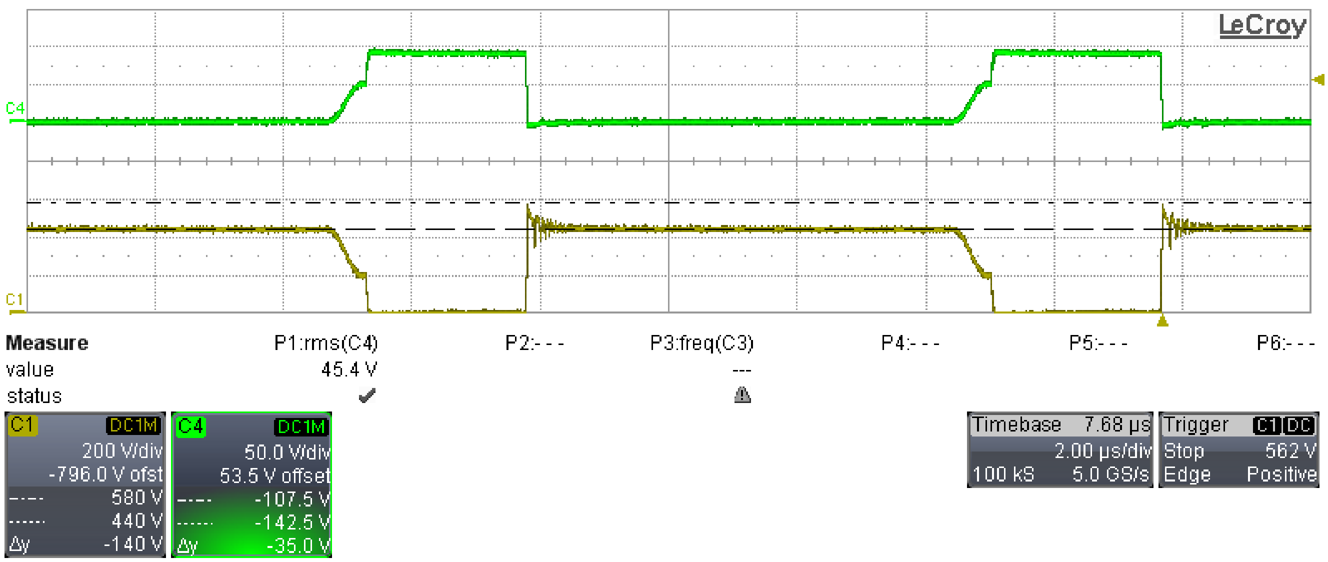


Figure 3-2. Switching Waveforms at 230VAC and 4A Load

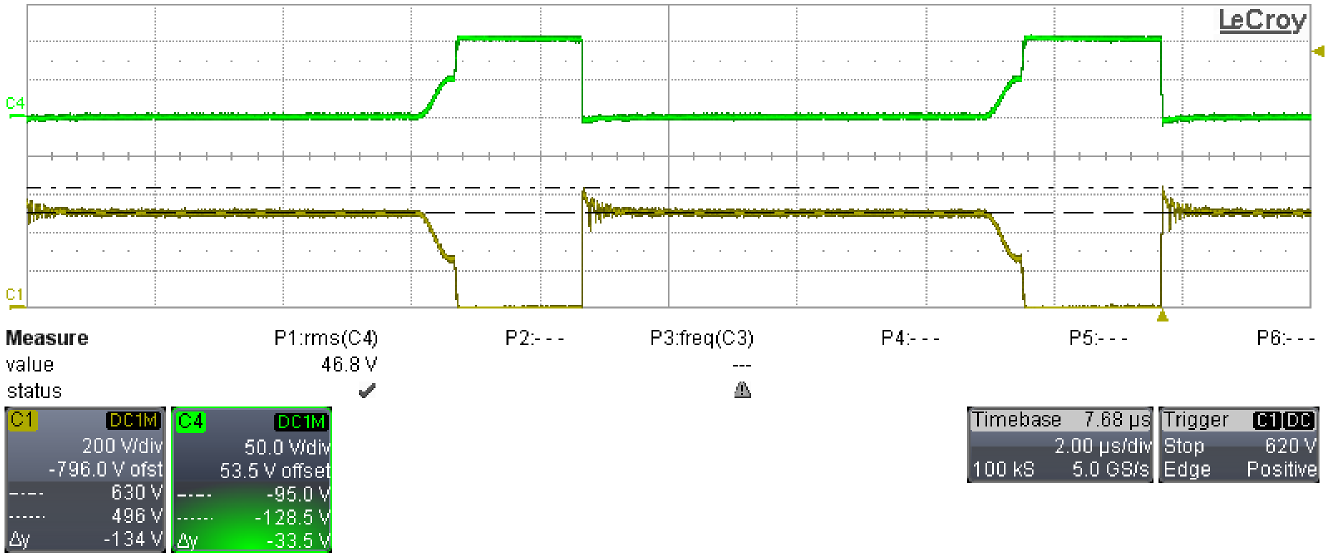


Figure 3-3. Switching Waveforms at 275VAC and 4A Load

3.2 Output Voltage Ripple

Output voltage ripple is shown in Figure 3-4 through Figure 3-8. C4: Output voltage, AC coupled, 20MHz bandwidth limit.

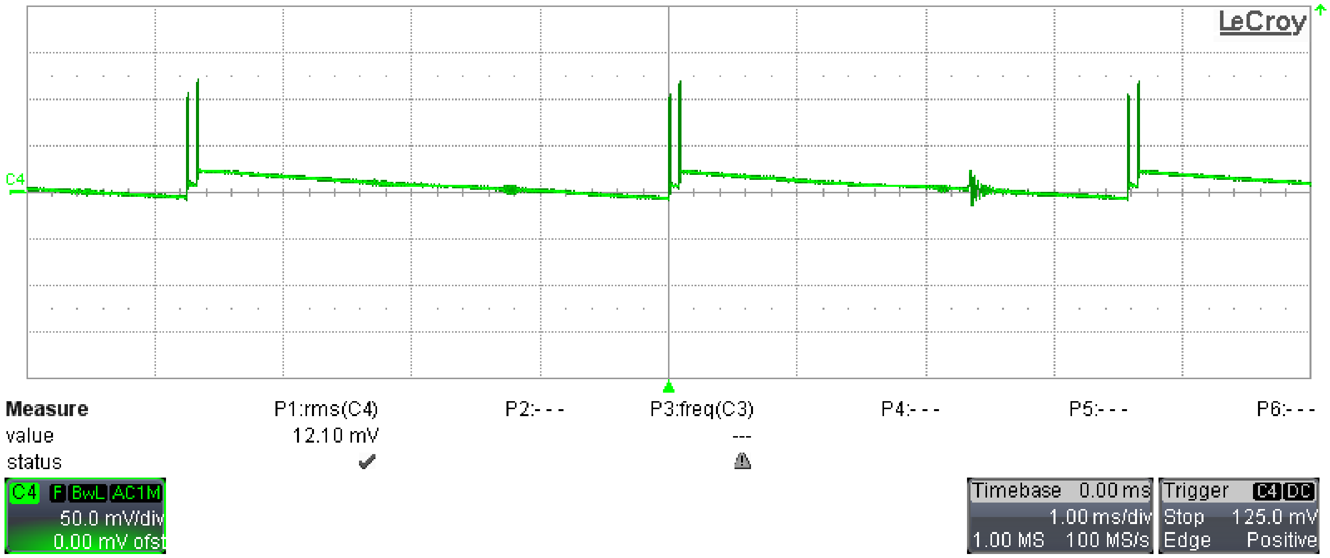


Figure 3-4. Output Voltage Ripple at Zero Load and 230VAC

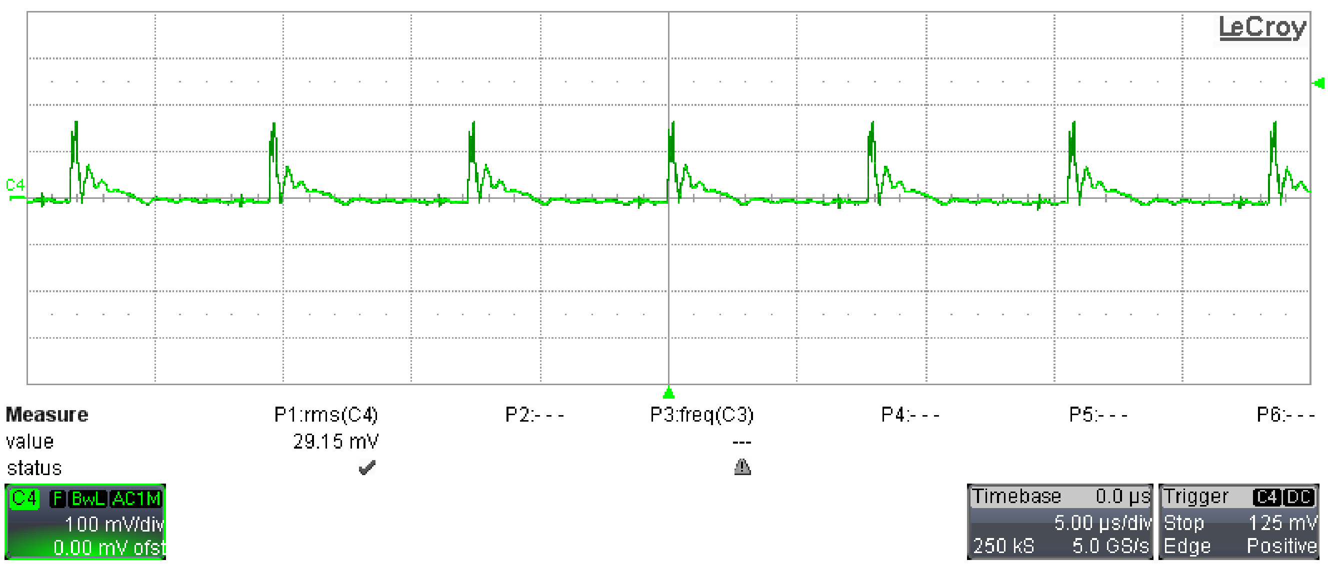


Figure 3-5. Output Voltage Ripple at 1A Load and 230VAC

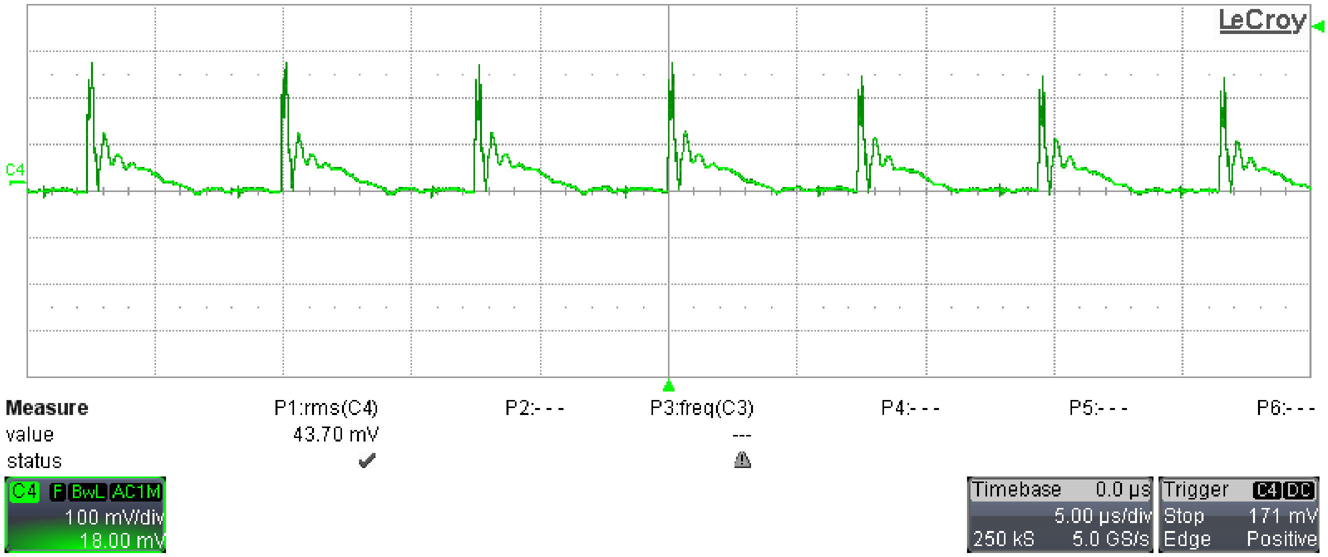


Figure 3-6. Output Voltage Ripple at 2A Load and 230VAC

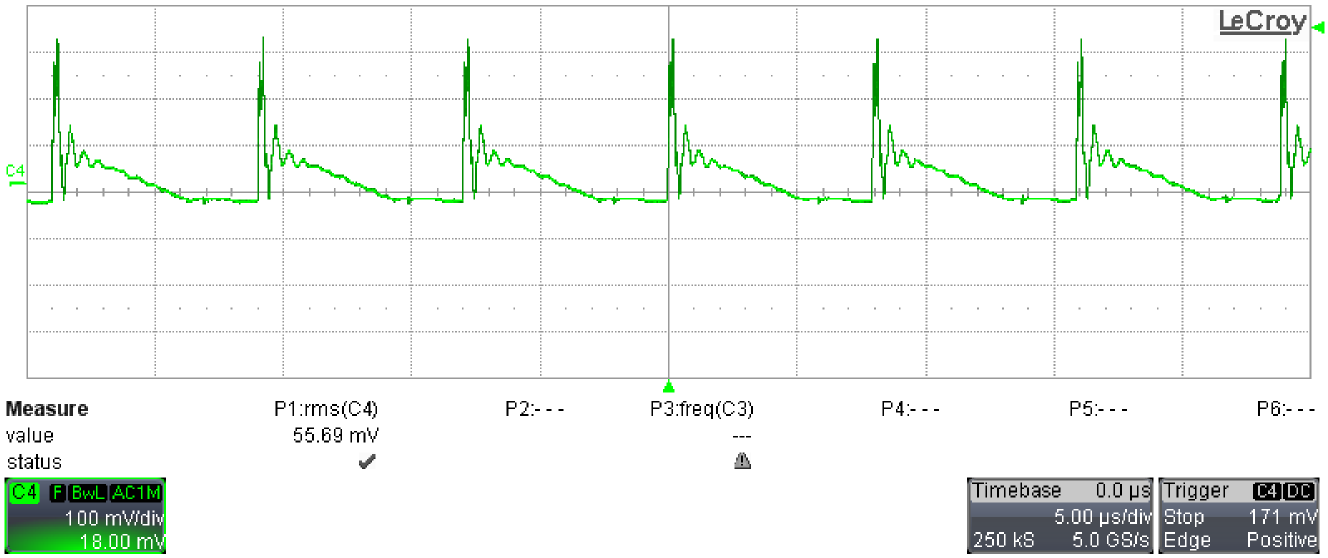


Figure 3-7. Output Voltage Ripple at 3A Load and 230VAC

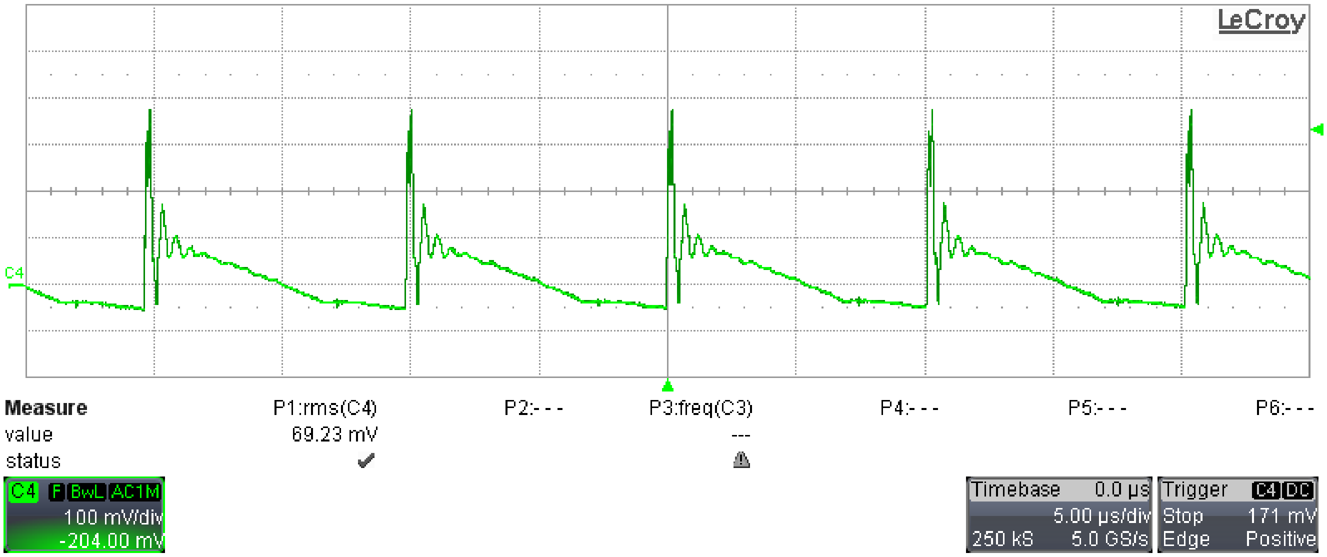


Figure 3-8. Output Voltage Ripple at 4A Load and 230VAC

3.3 Load Transients

Load transient response is shown in Figure 3-9. C4: output voltage, AC coupled, C3: output current, DC coupled, 20MHz bandwidth limit for both waveforms.

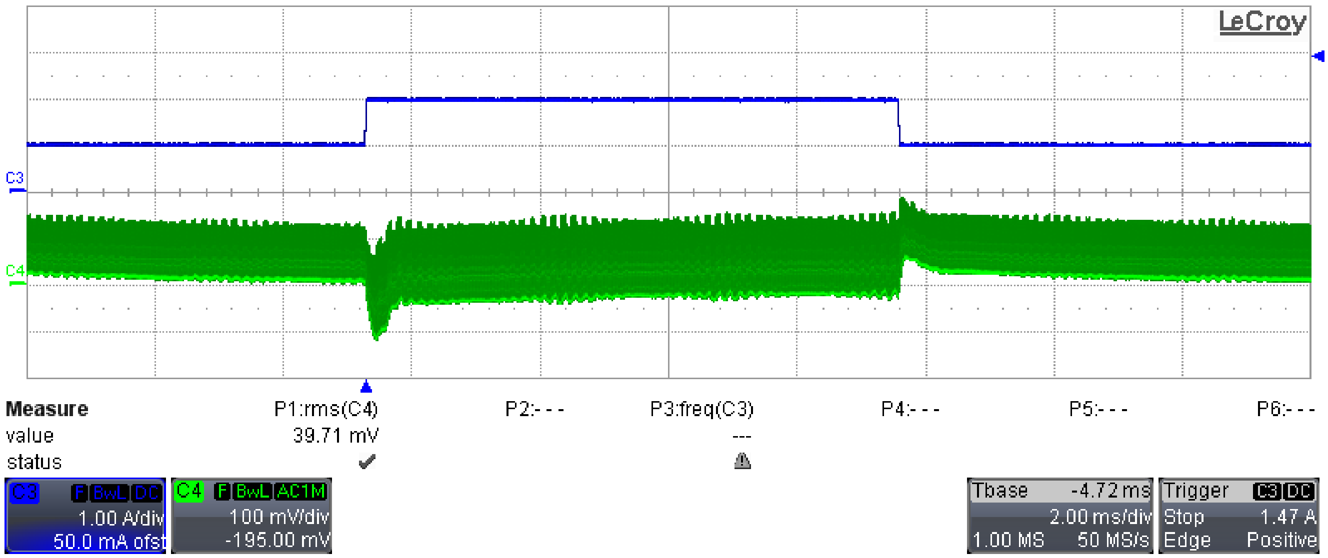


Figure 3-9. Load Transient at 230VAC, Output Current Switched between 1A and 2A

3.4 Start-up Sequence

Start-up behavior is shown in Figure 3-10 and Figure 3-11. C4: output voltage, C1: input AC voltage

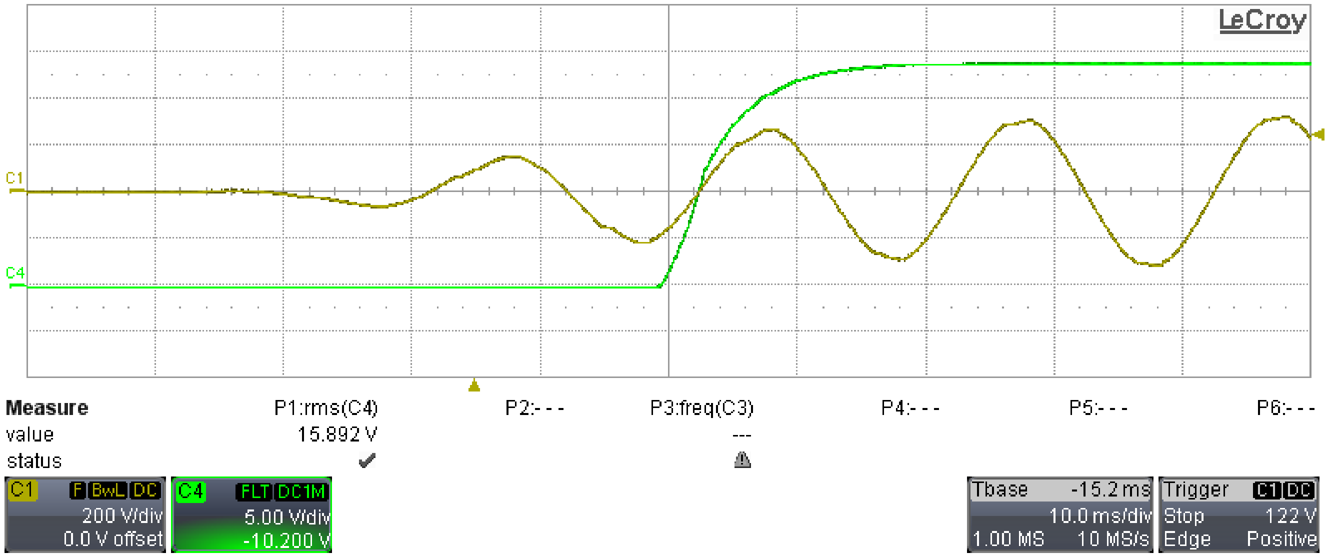


Figure 3-10. Start-up at 230VAC and Zero Load

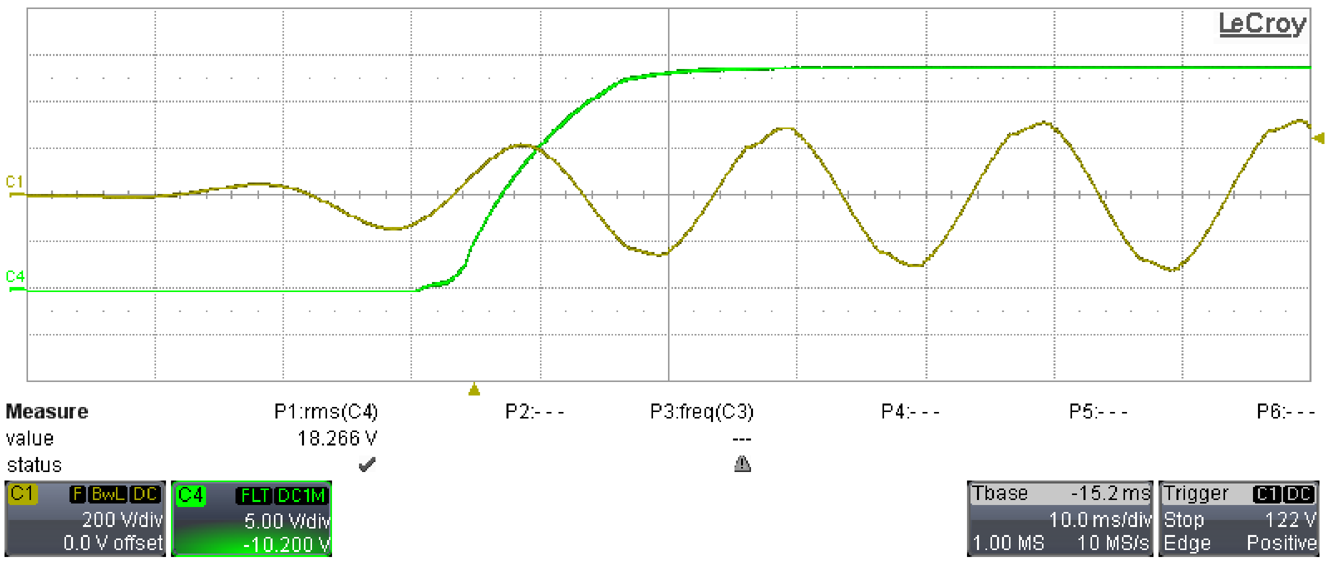


Figure 3-11. Start-up at 230VAC and 4A Load

3.5 Shut-down Sequence

AC input source turns off, while the converter runs. C4: output voltage, C1: input AC voltage

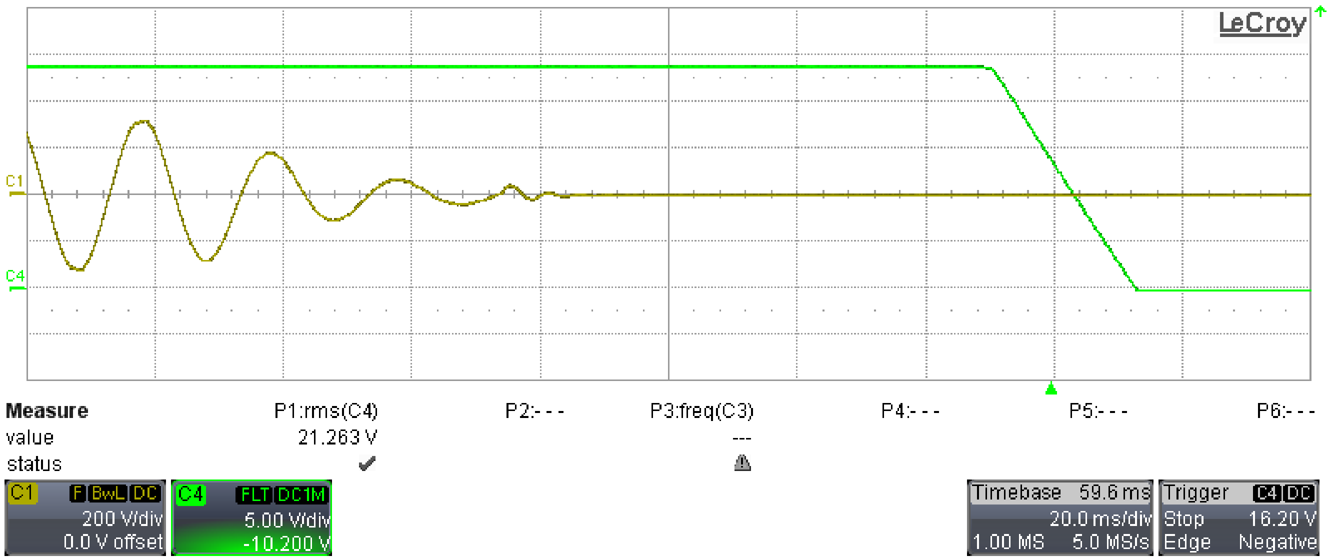


Figure 3-12. AC Source Turned OFF, at 230VAC and 1A Load

4 Static Regulation

The static regulation performance is shown in Figure 4-1.

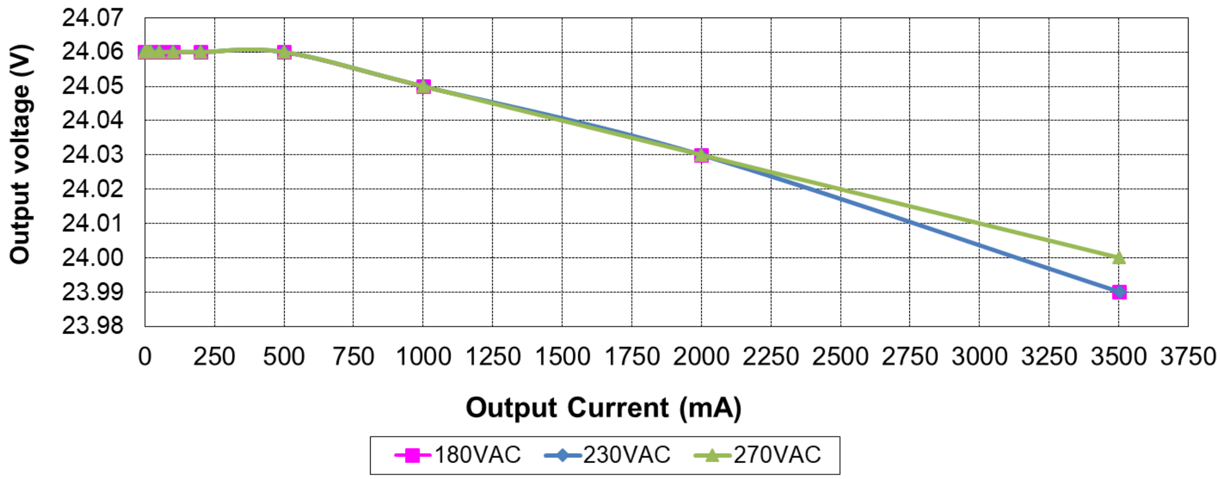


Figure 4-1. Output Voltage Static Regulation Versus Load and VAC

5 Transformer Details

The Flyback transformer for this reference design is developed by using RM10 platform.

5.1 Material List

- RM10 core set N87 – B65813J0000R087
- Coil former B65814N1012D001
- 0.2mm, 0.3mm and 0.5mm enameled copper wire (ECW)
- Mylar tape 0.05mm

5.2 Winding Details

Table 5-1. Winding Table

Winding	Start Pin	Finish Pin	Direction	Turns	Wire Size / Type
Np/2	3	1	CW	15	0.5mm, ECW, single wire
Nb/2	Floating A	Floating C	CW	3	0.2mm, ECW, 3 strands
Nb/2	Floating C	Floating B	CW	3	0.2mm, ECW, 3 strands
Ns1	9	4	CW	6	0.3mm, ECW, 9 strands
Ns2	8	5	CW	6	0.3mm, ECW, 9 strands
Ns3	7	6	CW	6	0.3mm, ECW, 9 strands
Shield	Floating C	Open	CW	1	single-turn copper foil (8mm width, 0.05mm thick)
Np/2	1	11	CW	15	0.5mm, ECW, single wire

5.3 Schematic

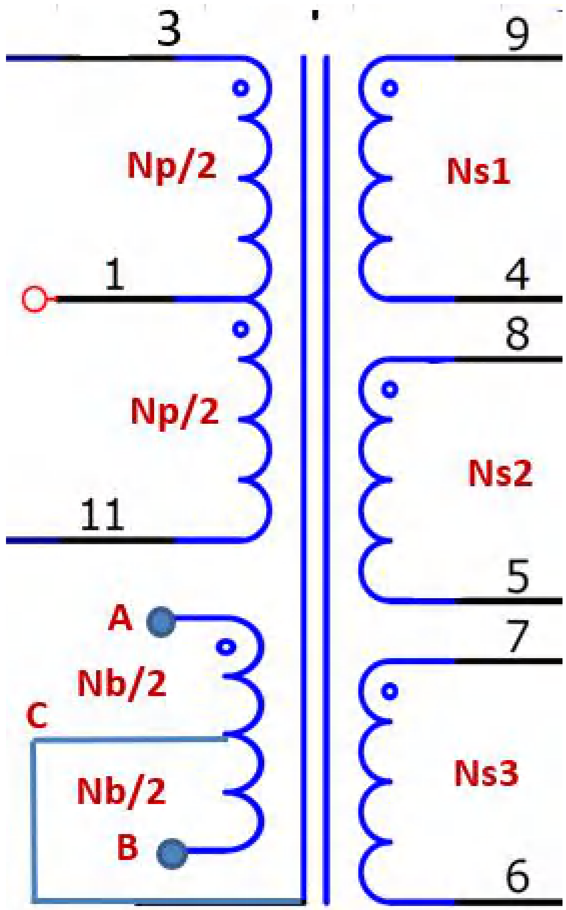


Figure 5-1. Winding Schematic

5.4 Winding Instructions

- First half primary Np/2 winding: space evenly over the bobbin. Cover with one layer of tape
- Wind first half of balancing section Nb/2, spread over half width of the bobbin, start on floating pin A and return to floating pin C
- Wind second half of balancing section Nb/2, by starting from pin C and finishing covering the bobbin width; return to floating pin B. Cover with two layers of tape
- Wind Ns1, Ns2 and Ns3 (6 turns, 9 strands split over three pair of pins) starting on pins 9, 8 and 7 and ending respectively on pins 4, 5 and 6. Apply spacers according to safety requirements or use triple insulated wires (TIW). Cover with two layers of tape in case of ECW wire, with one layer only in case of TIW.
- Shield: wind a single-turn copper foil (8mm width, 0.05mm thick) and connect it to terminal C. Cover with one layer of tape
- Finish by winding the second half primary Np/2; space evenly over the bobbin. Cover with one layer of tape
- Add copper foil shield around the assembled core connected to floating pin C, cover with tape.

5.5 Details about Core and Air Gap and Bobbin

- Target primary inductance: 330uH
- Core type: N87 core
- Air gap: 0.15mm on center leg
- Equivalent A_L value: 366nH / t^2
- Remove pins 2, 10 and 12
- Use clamps p/n B65814B2203X000 to assemble the cores

5.6 Bobbin Mechanical Details

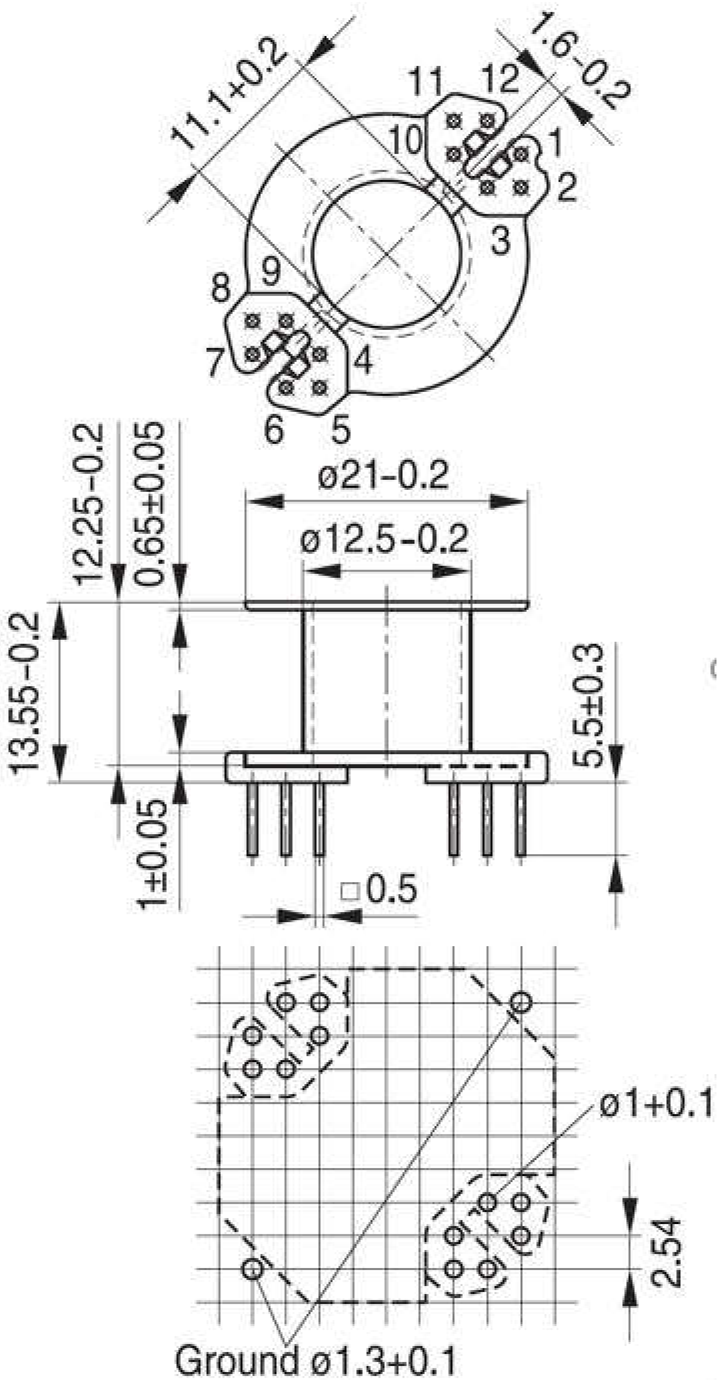


Figure 5-2. Mechanical Details of the Bobbin

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