Test Report: PMP31376

Universal AC Input to 9V–26.5V, 100W Battery Charger Reference Design

Description

This reference design is an offline isolated flyback. The AC-DC power stage is based on the UCC28750 fixed-frequency peak current mode controller, which features continuous conduction mode (CCM) and discontinuous conduction mode (DCM) modulation, as well as secondary-side regulation. Frequency foldback and burst mode improve light-load efficiency while frequency dithering reduces electromagnetic interference (EMI) signature. The controller provides several protection features, including over-under voltage lockout, V_{out} overvoltage, overpower, and short-circuit protections.

Resources

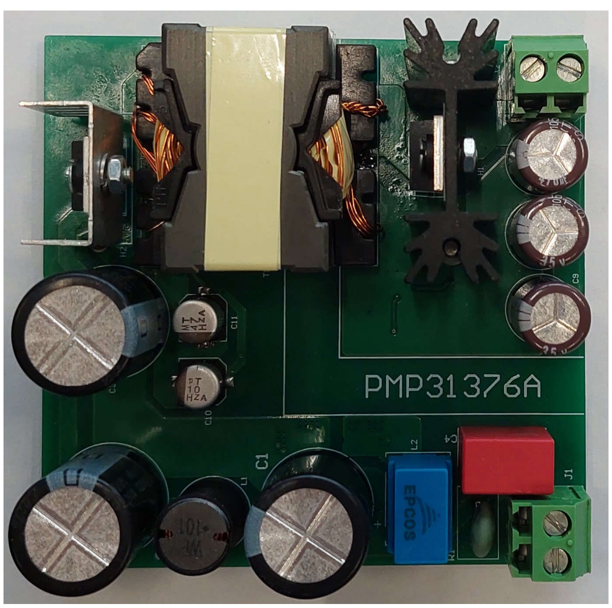
PMP31376	Design Folder
UCC28750	Product Folder
TL103W	Product Folder

Features

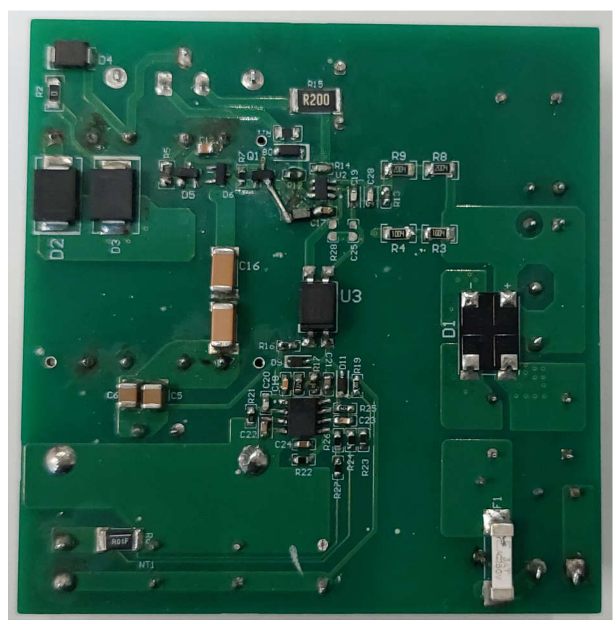
- Can charge two lead-acid batteries in series
- Provides independent constant voltage and constant current feedback
- No-load power consumption: 63.2mW at 115VAC, 9V output and 122mW at 230VAC

Applications

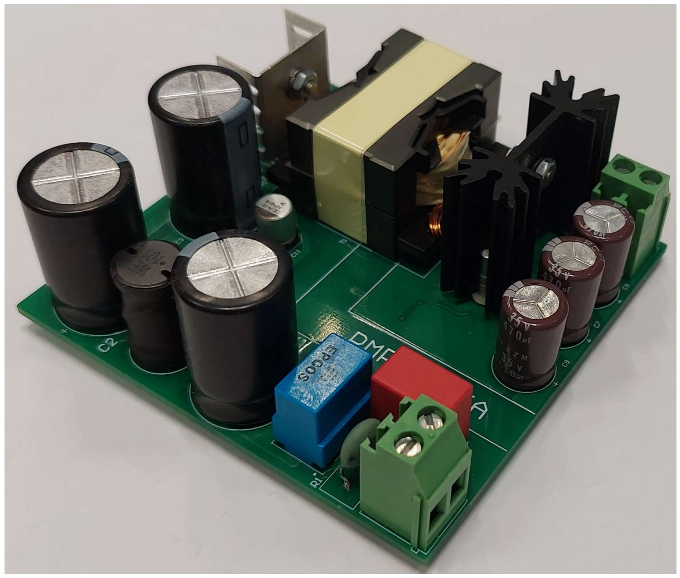
- Battery charger
- Battery pack: cordless power tool
- Other industrial battery pack (1S-9S)
- Mains powered tools



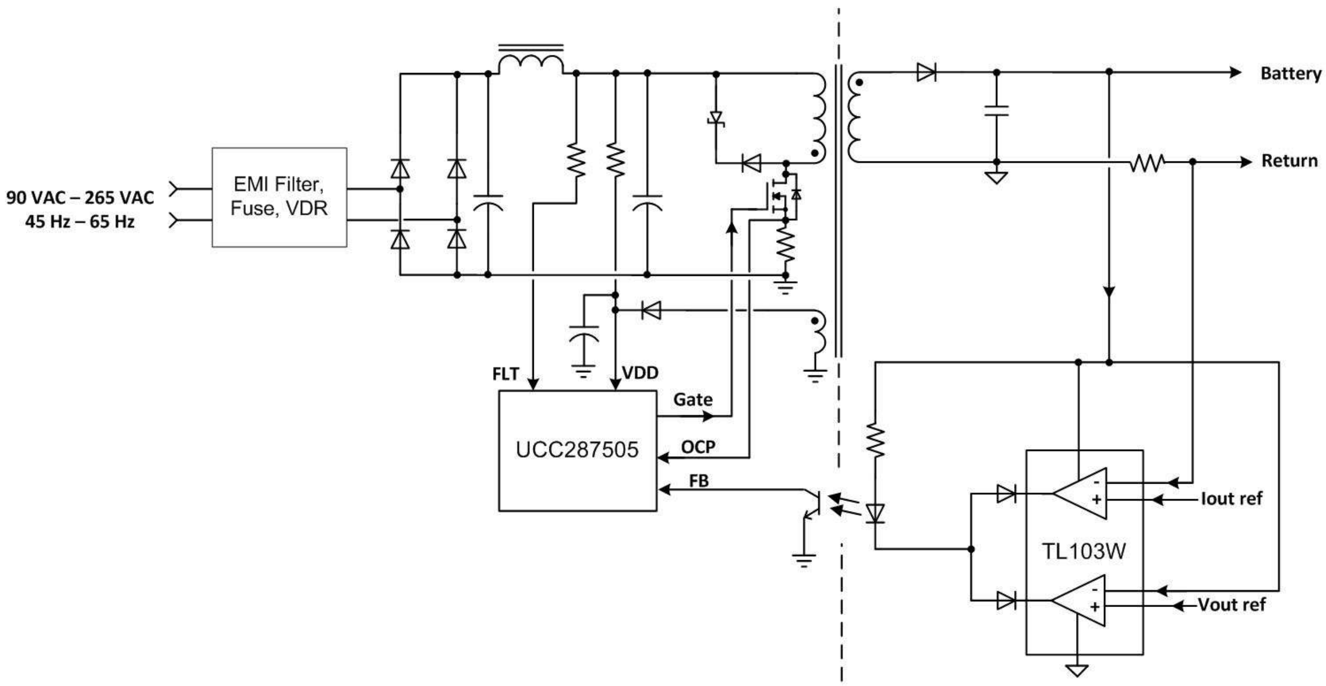
Top View



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	90 VAC to 264 VAC
Input voltage frequency	50Hz to 60Hz
Output voltage	9V to 26.5V
Maximum output current	4A

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
- True RMS multimeter: Metrahit pro
- Two elements of Yuasa NPH5-12 batteries

1.3 Considerations

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

1. Connect the AC source to J1-1 and J1-2
2. Connect the electronic load to J2-1 (positive) and J2-2 (negative), which allows testing the converter as standard power supply
3. Attach a current probe in series to the output to take load transient response behavior
4. In this report we are also connecting, later during the report, two lead-acid batteries in series, for example two Yuasa NPH5-12 (12V, 5Ah), instead of a standard constant current load.
5. Set V_{out} to 24V (by selecting R21 resistor), (nominal voltage is 26.5V by using the resistor described in schematic)
6. Set I_{out} to 4A by adjusting R26 to 324Ω (currently populated value, which defines CC set point
7. Turn on the AC source
8. During later CV/CC charging tests, please connect the series batteries to the converter, while AC source is on; this way high inrush current flowing from the battery into the output electrolytic capacitors C7, C8 and C9 can be avoided.
9. To avoid that the battery is charged or discharged too quickly and therefore the voltage is fluctuating, add the electronic load in parallel to the battery. When a certain battery voltage is reached, the electronic load is set to the charging current: this way, the net battery charging current is zero, keeping constant voltage.
10. Since the converter has current limit set to 4A, without a battery the converter works mainly as a constant voltage power supply, unless the output current is higher than the constant current (CC) set point.
11. As battery charger, the current limit must be set to a proper value, according to the charging current level suggested in the battery datasheet.
12. After turn off, discharge the capacitors C1, C2, and C3 by means of an external resistor (warning: HIGH VOLTAGE).

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.

WARNING

Board surface and heat sink is hot. Do not touch Contact can cause burns.

1.5 Dimensions

Board size: 79.4mm × 77.47mm × 24.5mm (W × L × H)

1.6 Test Setup

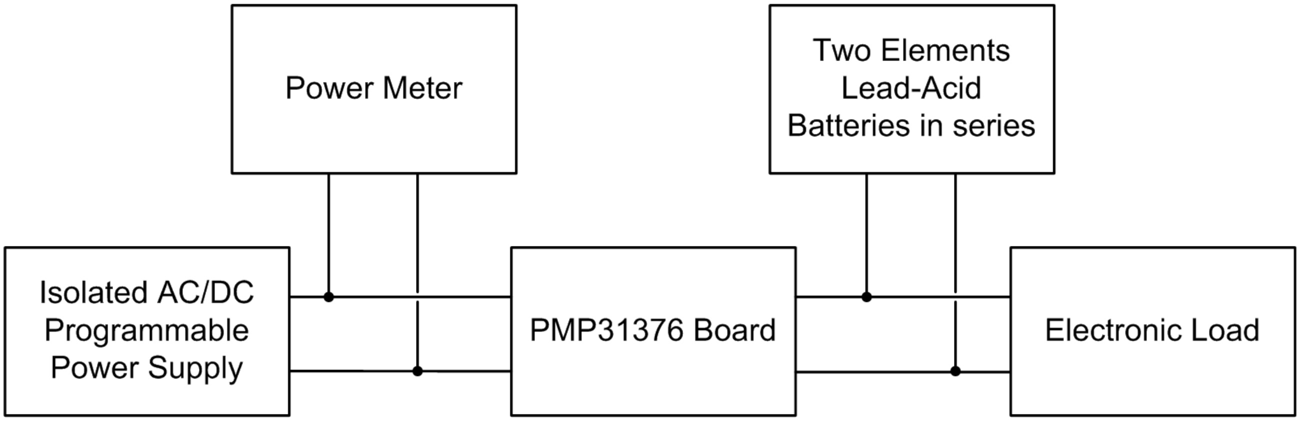


Figure 1-1. Test Setup

2 Testing and Results

2.1 Efficiency Graphs

Efficiency is shown in Figure 2-1 and Figure 2-2.

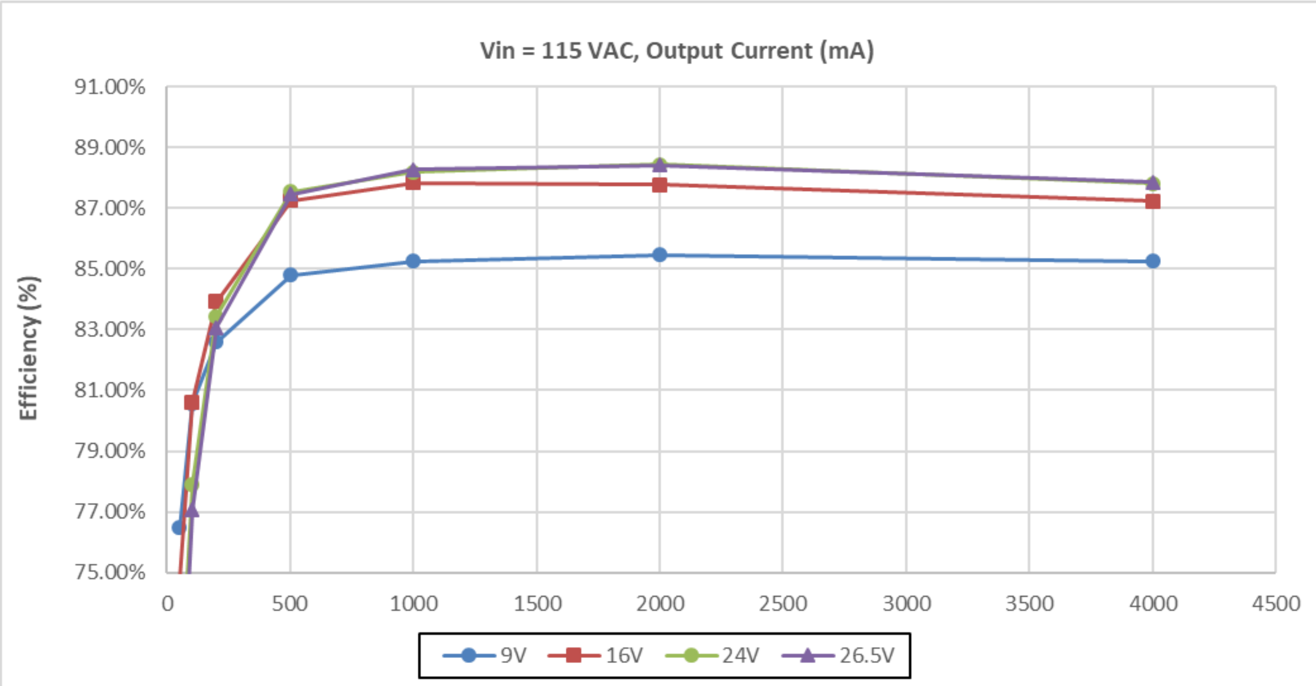


Figure 2-1. Efficiency Graph Versus Load Current and Voltage at 115VAC

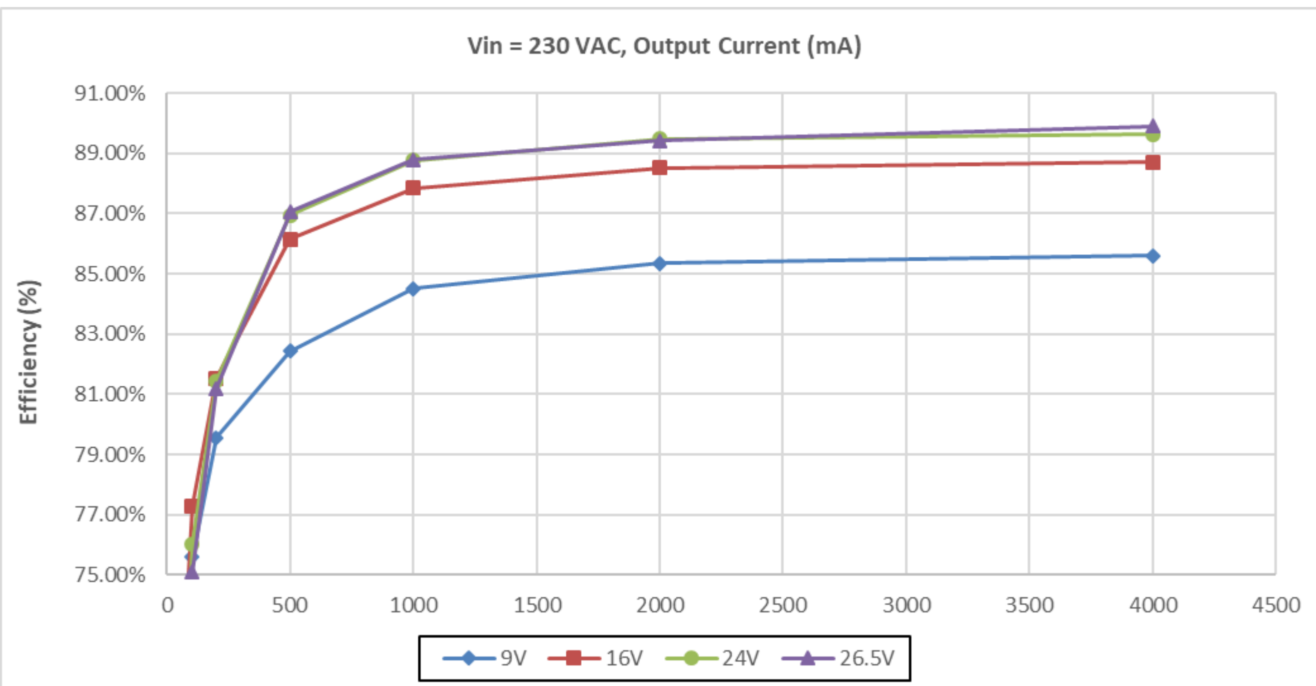


Figure 2-2. Efficiency Graph Versus Load Current and Voltage at 230VAC

2.2 Efficiency Data

Efficiency data are shown in Table 2-1 through Table 2-8.

Table 2-1. Efficiency Data at 115VAC, F = 60Hz, V_{out} = 9V

P_{IN} (W)	V_{OUT} (V)	I_{OUT} (mA)	P_{OUT} (W)	P_{LOSS} (W)	Efficiency (%)
0.0632	9	0	0	0.0632	0
0.1776	8.999	10.87	0.0978	0.0798	55.07
0.2912	8.998	21.63	0.1946	0.0966	66.83
0.6	8.997	51	0.4589	0.1411	76.48
1.136	8.996	101.7	0.9152	0.2208	80.56
2.1816	8.995	200.3	1.802	0.3796	82.60
5.327	8.99	502	4.5174	0.8096	84.80
10.566	8.984	1001	9.008	1.558	85.25
21.072	8.971	2001	18.007	3.065	85.45
42.23	8.948	4001	36.005	6.225	85.26

Table 2-2. Efficiency Data at 115VAC, F = 60Hz, V_{out} = 16V

P_{IN} (W)	V_{OUT} (V)	I_{OUT} (mA)	P_{OUT} (W)	P_{LOSS} (W)	Efficiency (%)
0.1567	16.05	0	0	0.1567	0
0.3587	16.05	10.94	0.1756	0.1831	48.95
0.5565	16.05	21.71	0.3484	0.2081	62.61
1.094	16.05	51	0.8186	0.2754	74.82
2.027	16.05	101.8	1.6339	0.3931	80.61
3.831	16.05	200.3	3.2148	0.6162	83.92
9.228	16.04	502	8.0521	1.1759	87.26
18.27	16.03	1001	16.046	2.224	87.83
36.52	16.02	2001	32.056	4.464	87.78
73.38	16	4001	64.016	9.364	87.24

Table 2-3. Efficiency Data at 115VAC, F = 60Hz, V_{out} = 24V

P_{IN} (W)	V_{OUT} (V)	I_{OUT} (mA)	P_{OUT} (W)	P_{LOSS} (W)	Efficiency (%)
0.339	24.03	0	0	0.339	0
0.6425	24.02	11.03	0.2649	0.3776	41.24
0.9389	24.02	21.77	0.5229	0.4160	55.69
1.7429	24.02	51.1	1.2274	0.5155	70.42
3.1385	24.02	101.8	2.4452	0.6933	77.91
5.768	24.02	200.4	4.8136	0.9544	83.45
13.77	24.01	502	12.053	1.717	87.53
27.24	24.00	1001	24.024	3.216	88.19
54.26	23.98	2001	47.984	6.276	88.43
109.13	23.95	4001	95.824	13.29	87.81

Table 2-4. Efficiency Data at 115VAC, F = 60Hz, V_{out} = 26.5V

P_{IN} (W)	V_{OUT} (V)	I_{OUT} (mA)	P_{OUT} (W)	P_{LOSS} (W)	Efficiency (%)
0.414	26.50	0	0	0.414	0
0.749	26.50	11.05	0.2928	0.4562	39.10
1.075	26.50	21.81	0.5780	0.497	53.76
1.965	26.50	51.1	1.3542	0.6108	68.91
3.504	26.50	101.9	2.7004	0.8036	77.06
6.394	26.49	200.5	5.3112	1.0828	83.07

Table 2-4. Efficiency Data at 115VAC, F = 60Hz, V_{out} = 26.5V (continued)

P_{IN} (W)	V_{OUT} (V)	I_{OUT} (mA)	P_{OUT} (W)	P_{LOSS} (W)	Efficiency (%)
15.20	26.48	502	13.293	1.907	87.45
30.03	26.48	1001	26.506	3.794	88.27
59.91	26.47	2001	52.966	6.994	88.41
120.4	26.44	4001	105.786	14.614	87.86

Table 2-5. Efficiency Data at 230VAC, F = 50Hz, V_{out} = 9V

P_{IN} (W)	V_{OUT} (V)	I_{OUT} (mA)	P_{OUT} (W)	P_{LOSS} (W)	Efficiency (%)
0.122	9.029	0	0	0.122	0
0.238	9.028	10.93	0.0987	0.1393	41.46
0.360	9.027	21.66	0.1955	0.1645	54.31
0.671	9.026	51.0	0.4603	0.2107	68.60
1.214	9.025	101.7	0.9178	0.2962	77.60
2.272	9.024	200.3	1.8075	0.4645	79.56
5.482	9.020	501	4.5190	0.963	82.43
10.675	9.013	1001	9.0220	1.653	84.52
21.10	9.000	2001	18.099	3.001	85.35
41.95	8.977	4000	35.908	6.042	85.60

Table 2-6. Efficiency Data at 230VAC, F = 50Hz, V_{out} = 16V

P_{IN} (W)	V_{OUT} (V)	I_{OUT} (mA)	P_{OUT} (W)	P_{LOSS} (W)	Efficiency (%)
0.217	16.05	0	0	0.217	0
0.427	16.05	10.99	0.1764	0.2506	41.31
0.6285	16.05	21.72	0.3486	0.2799	55.47
1.173	16.05	51.1	0.8202	0.3528	69.92
2.114	16.05	101.8	1.6339	0.5101	77.29
3.945	16.05	200.4	3.2164	0.7286	81.53
9.328	16.04	501	8.0360	1.2920	86.15
18.277	16.04	1001	16.056	2.221	87.85
36.217	16.02	2001	32.056	4.161	88.51
72.14	16.00	4000	64.000	8.140	88.72

Table 2-7. Efficiency Data at 230VAC, F = 50Hz, V_{out} = 24V

P_{IN} (W)	V_{OUT} (V)	I_{OUT} (mA)	P_{OUT} (W)	P_{LOSS} (W)	Efficiency (%)
0.402	24.09	0	0	0.402	0
0.717	24.09	11.06	0.2664	0.4506	37.16
1.010	24.09	21.8	0.5251	0.4849	52.00
1.895	24.09	53.8	1.2960	0.5990	68.39
3.228	24.09	101.9	2.4548	0.7732	76.05
5.925	24.08	200.4	4.8256	1.0994	81.45
13.875	24.08	501	12.064	1.811	86.95
27.14	24.07	1001	24.094	3.046	88.78
53.80	24.06	2001	48.144	5.656	89.49
107.28	24.04	4000	96.160	11.12	89.63

Table 2-8. Efficiency Data at 230VAC, F = 50Hz, V_{out} = 26.5V

P_{IN} (W)	V_{OUT} (V)	I_{OUT} (mA)	P_{OUT} (W)	P_{LOSS} (W)	Efficiency (%)
0.489	26.49	0	0	0.489	0
0.826	26.49	11.09	0.2938	0.5322	35.57
1.148	26.49	21.82	0.5780	0.5700	50.35

Table 2-8. Efficiency Data at 230VAC, F = 50Hz, V_{out} = 26.5V (continued)

P_{IN} (W)	V_{OUT} (V)	I_{OUT} (mA)	P_{OUT} (W)	P_{LOSS} (W)	Efficiency (%)
2.043	26.49	51.2	1.3563	0.6867	66.39
3.595	26.49	101.9	2.6993	0.8957	75.09
6.541	26.49	200.5	5.3112	1.2298	81.20
15.273	26.49	502	13.2980	1.197	87.07
29.85	26.48	1001	26.5065	3.343	88.80
59.24	26.47	2001	52.9665	6.273	89.41
117.65	26.44	4000	105.760	11.89	89.89

2.3 Thermal Images

Thermal image are shown in Figure 2-3 through Figure 2-6. The board is placed horizontal on the bench, and runs in still air condition.

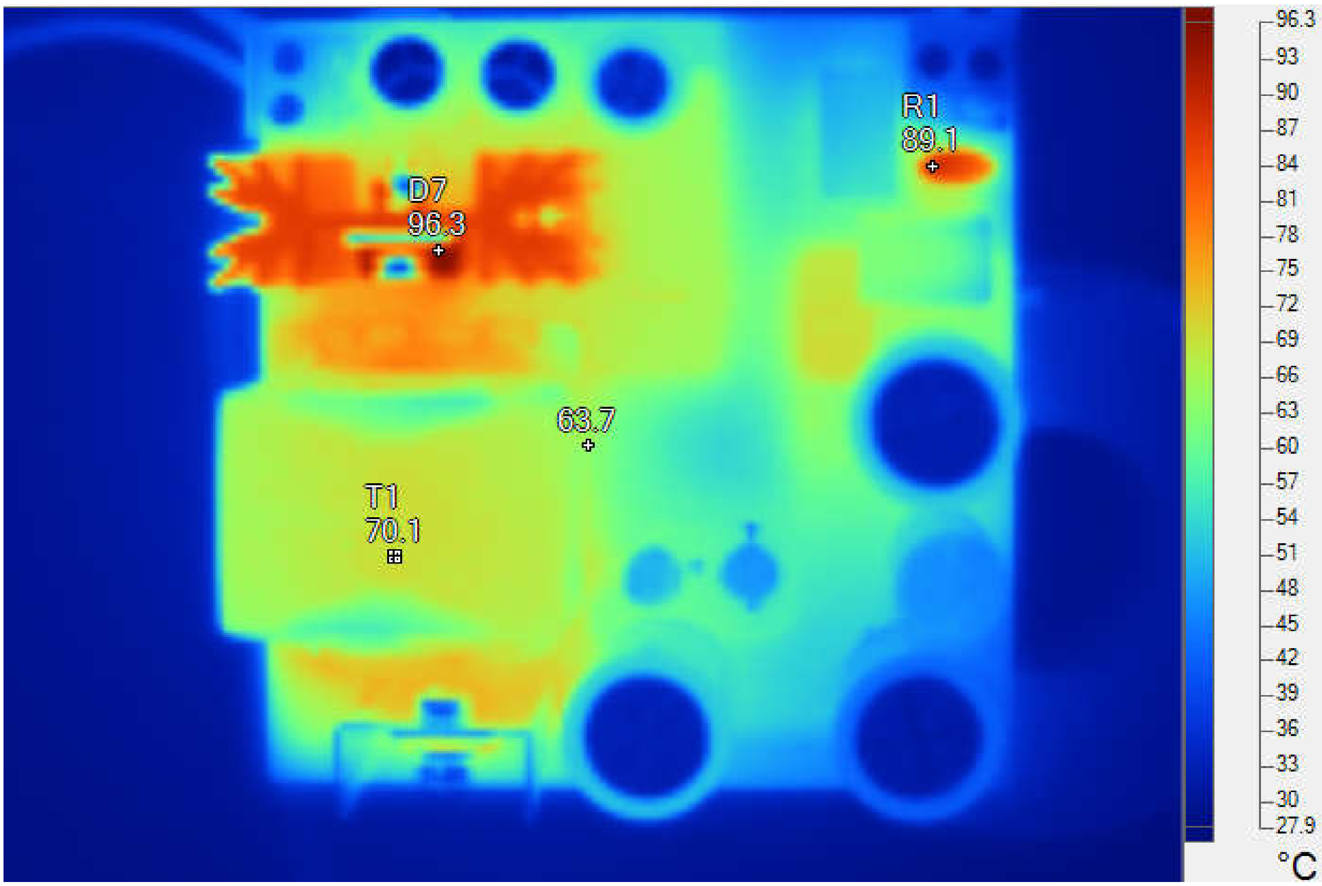


Figure 2-3. Thermal Image at 115VAC, 60Hz, 24V, and 4A, PCB Top Side

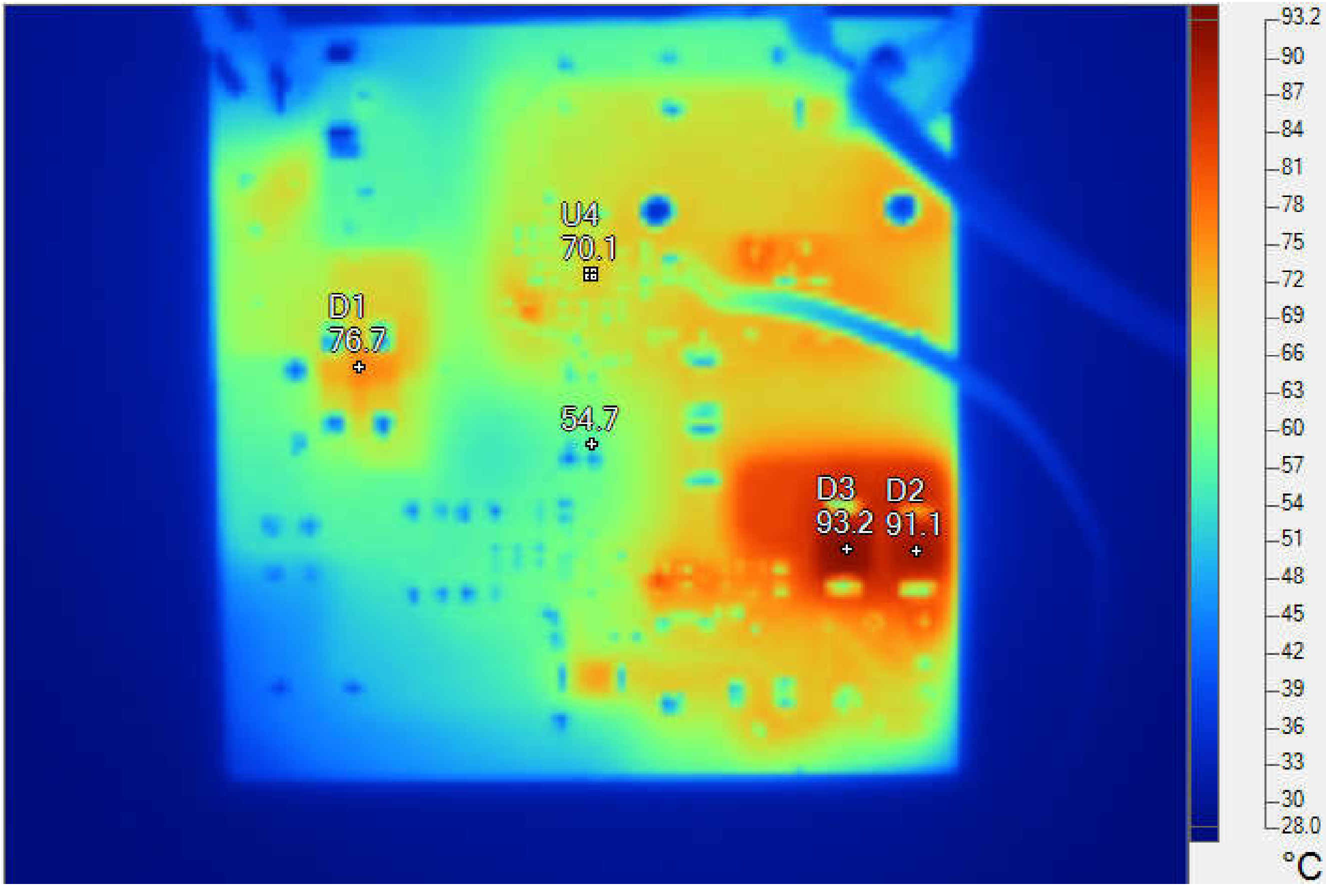


Figure 2-4. Thermal Image at 115VAC, 60Hz, 24V, and 4A, PCB Bottom Side

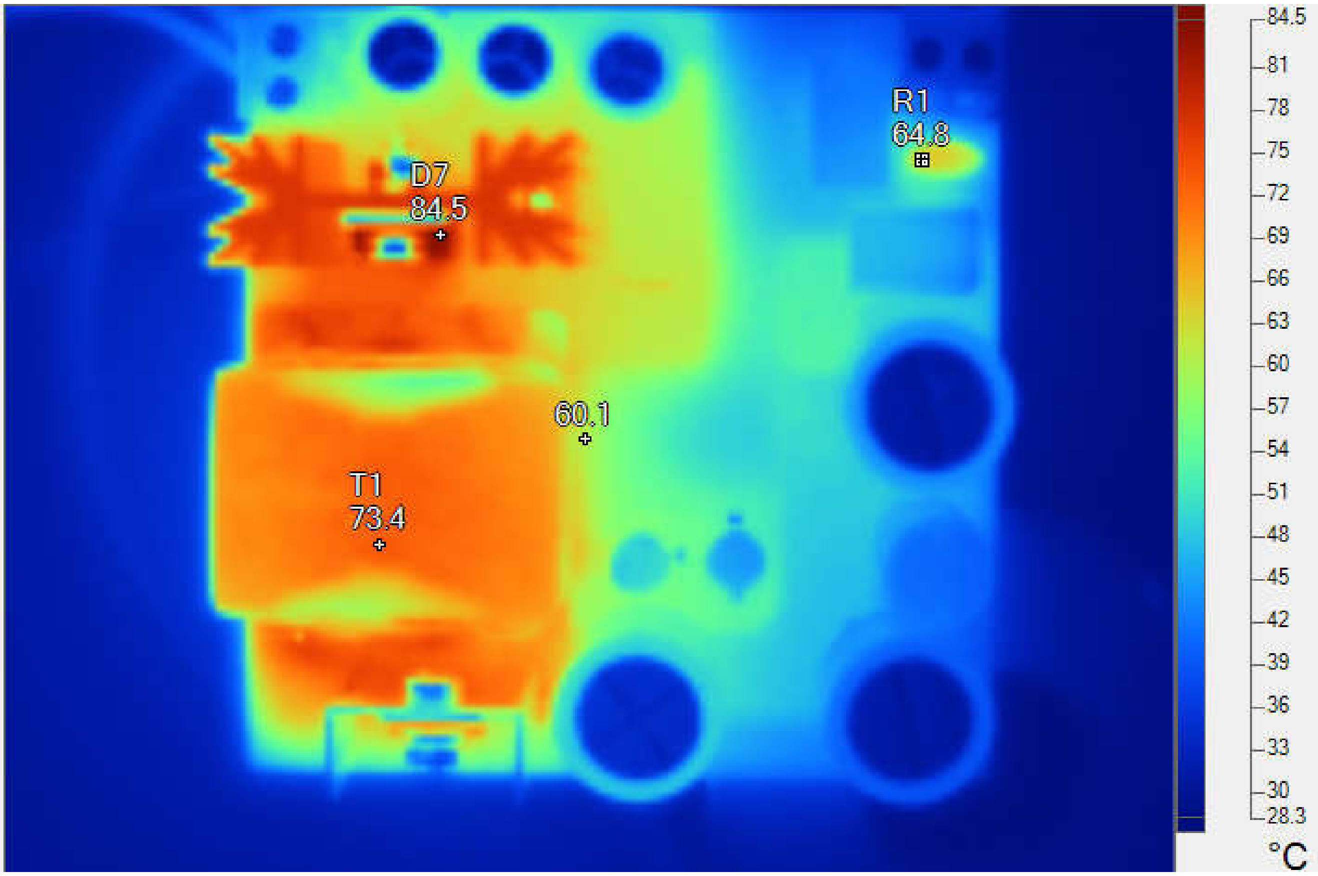


Figure 2-5. Thermal Image at 230VAC, 50Hz, 24V, and 4A, PCB Top Side

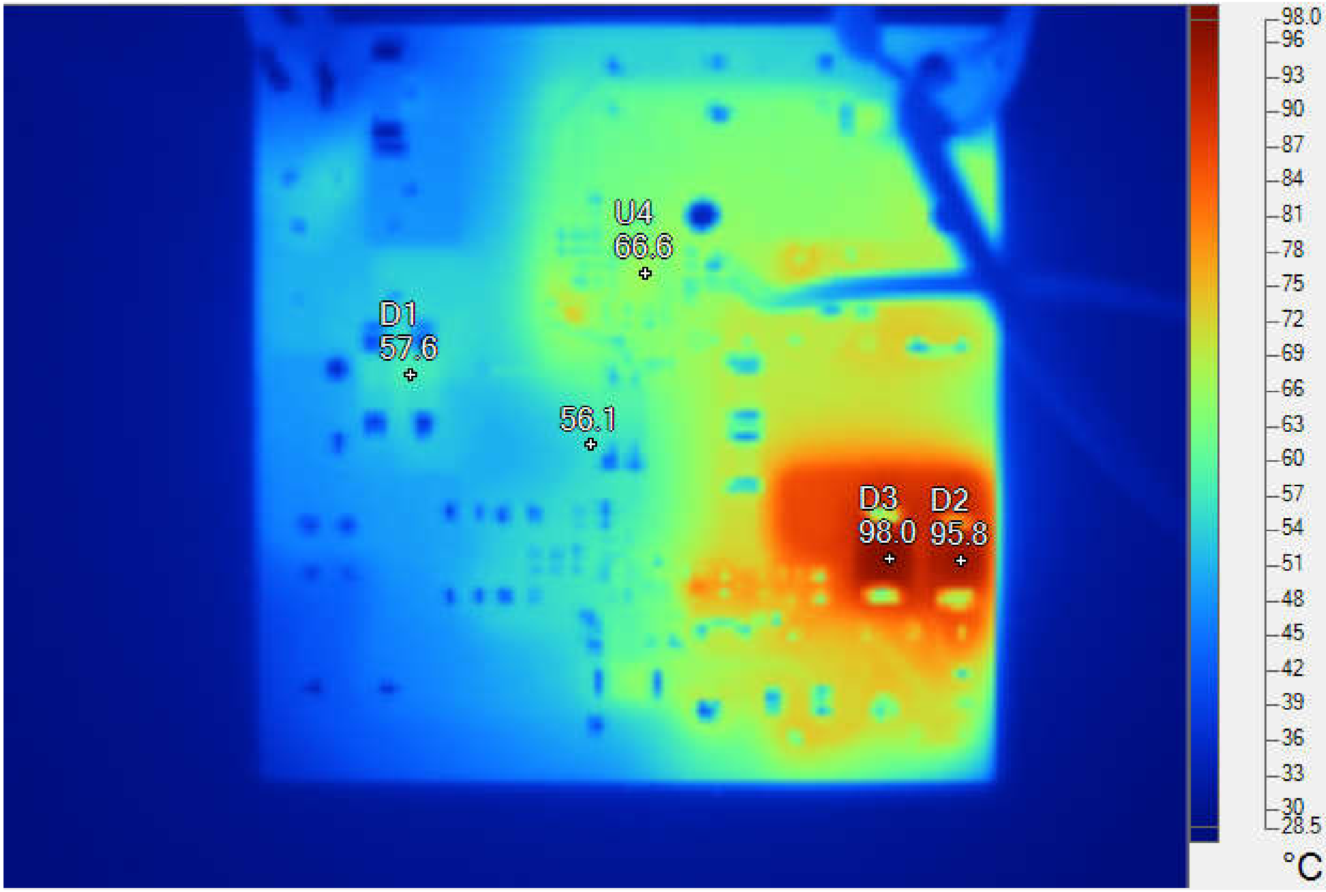


Figure 2-6. Thermal Image at 230VAC, 50Hz, 24V and 4A, PCB Bottom Side

2.4 Bode Plots

Bode plots are shown in Figure 2-7 through Figure 2-10. The table recaps all relevant parameters read on the plots. The electronic load is set to 4A in constant current mode.

Table 2-9. Bode Plot Main Parameters

Input DC Voltage (V)	Output Voltage (V)	Crossover Frequency (kHz)	Phase Margin (degrees)	Gain Margin (dB)
162	9	4.461	63.47	14.05
325	9	4.261	65.5	16.19
162	16	4.731	66.86	14.24
325	16	4.610	62.5	15.44
162	24	1.825	81.01	22.12
325	24	1.911	86.76	21.24
162	26.5	1.694	80.81	23.16
325	26.5	1.488	84.52	22.94

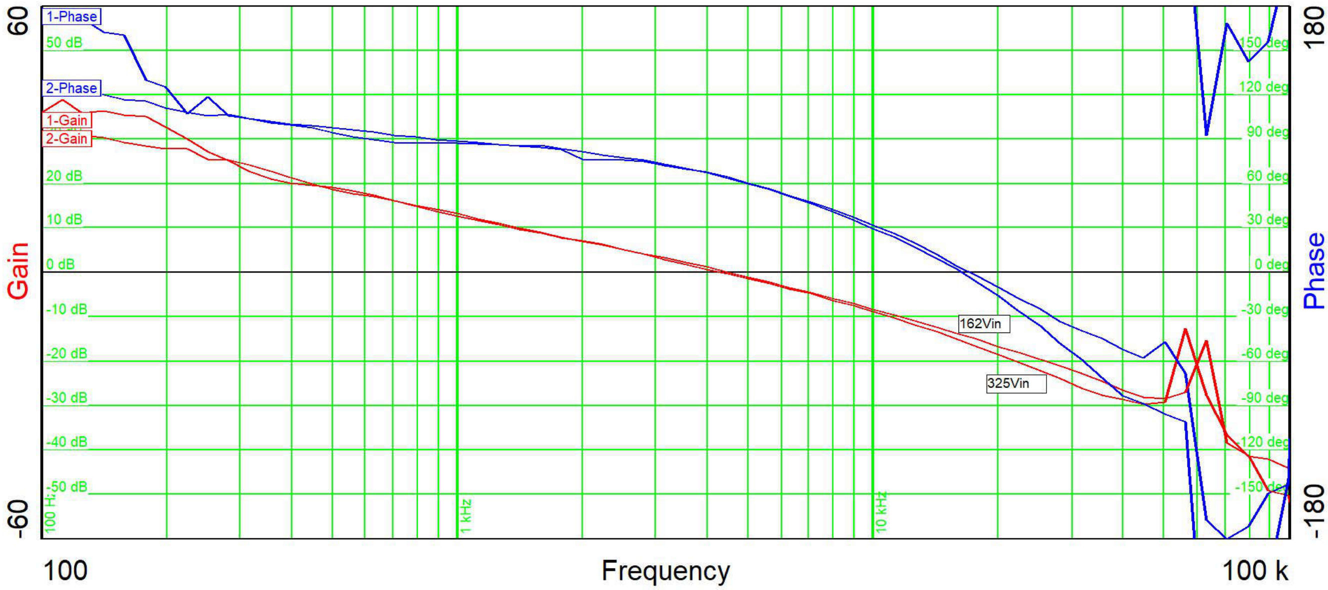


Figure 2-7. Bode Plot of the Converter with the Output Voltage Set to 9V

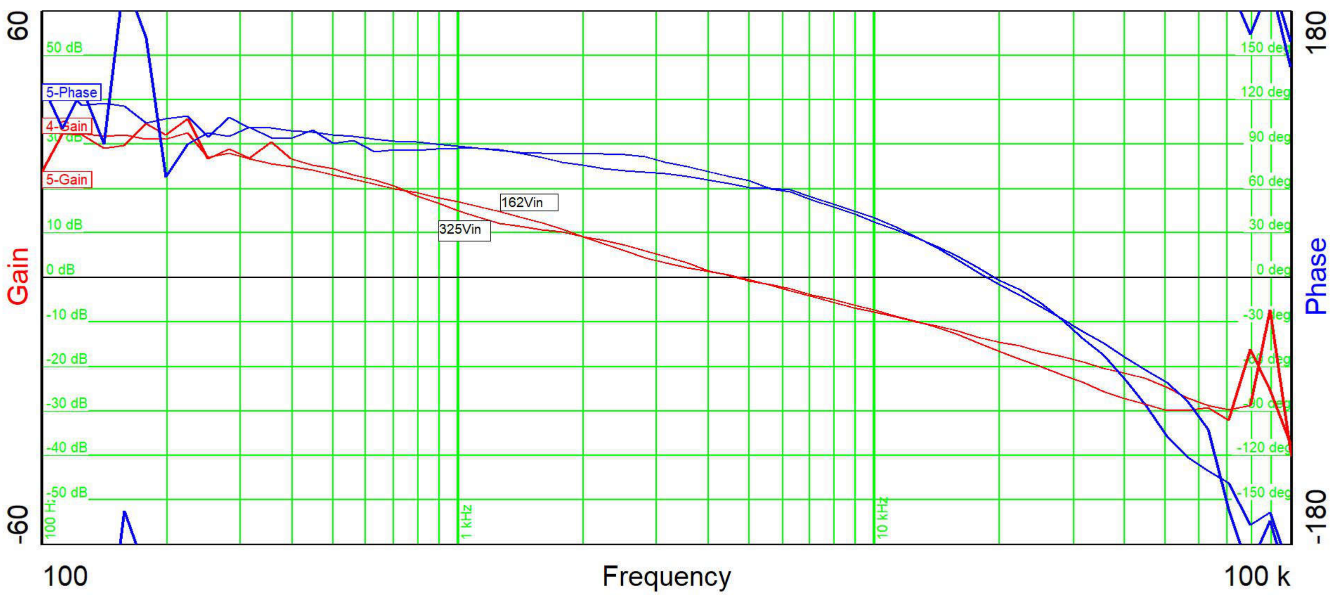


Figure 2-8. Bode Plot of the Converter with the Output Voltage Set to 16V

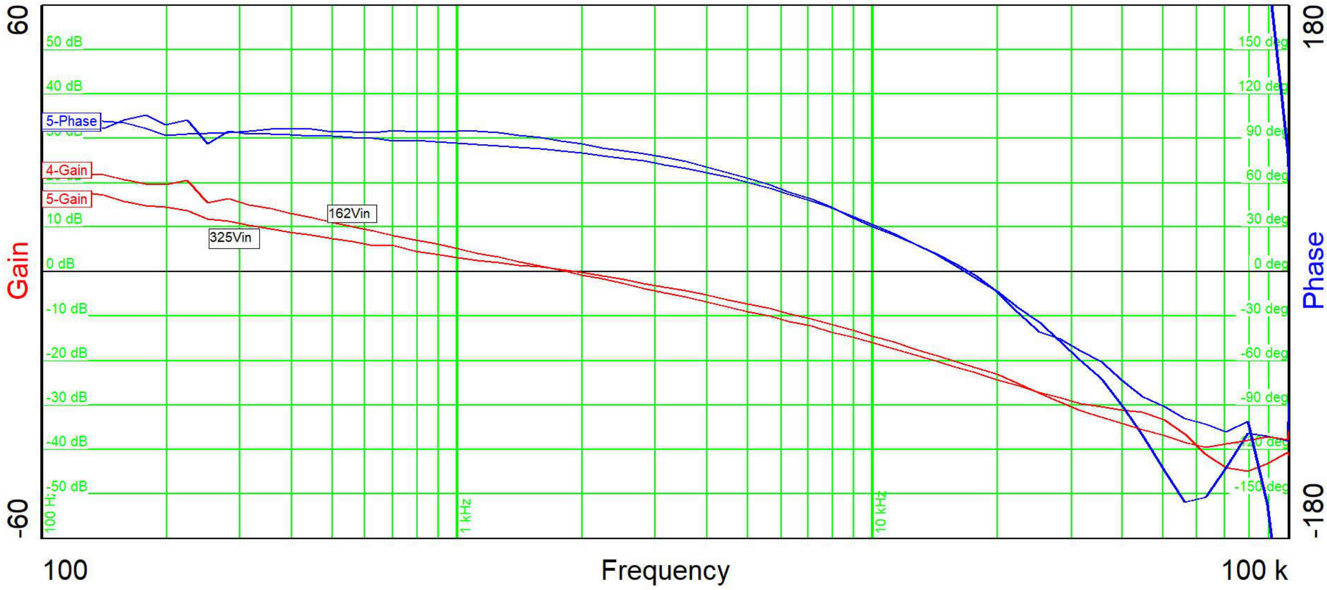


Figure 2-9. Bode Plot of the Converter with the Output Voltage Set to 24V

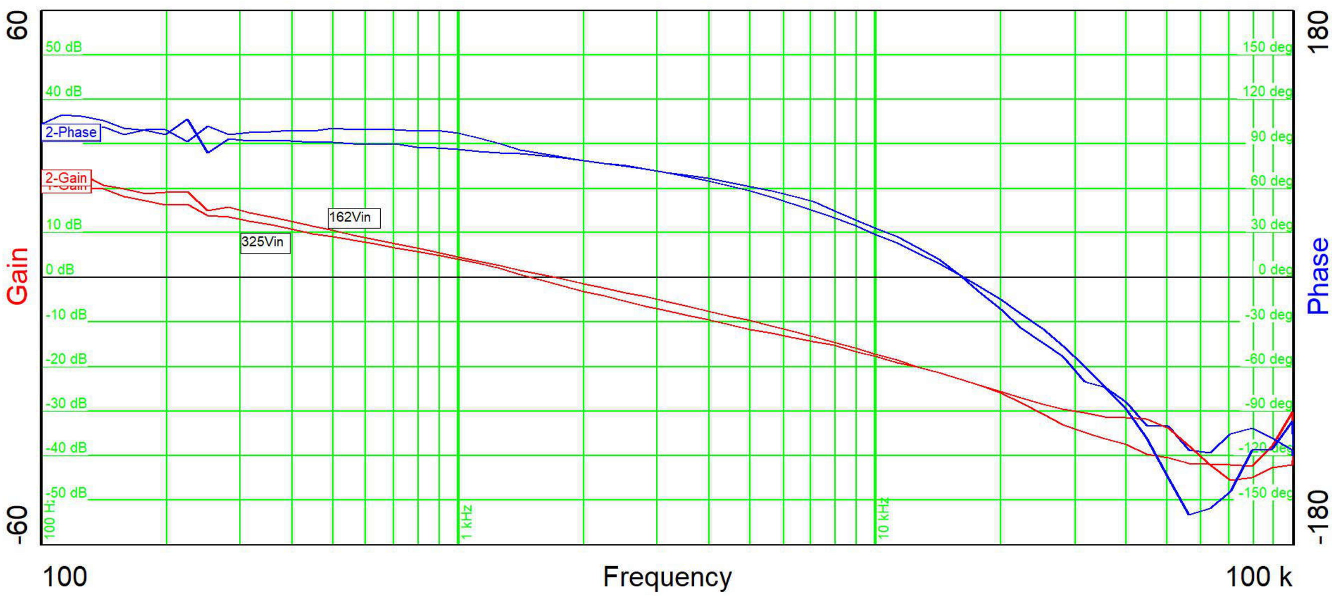


Figure 2-10. Bode Plot of the Converter with the Output Voltage Set to 26.5V

3 Waveforms

3.1 Switching

Switching behavior is shown in Figure 3-1 and Figure 3-3.

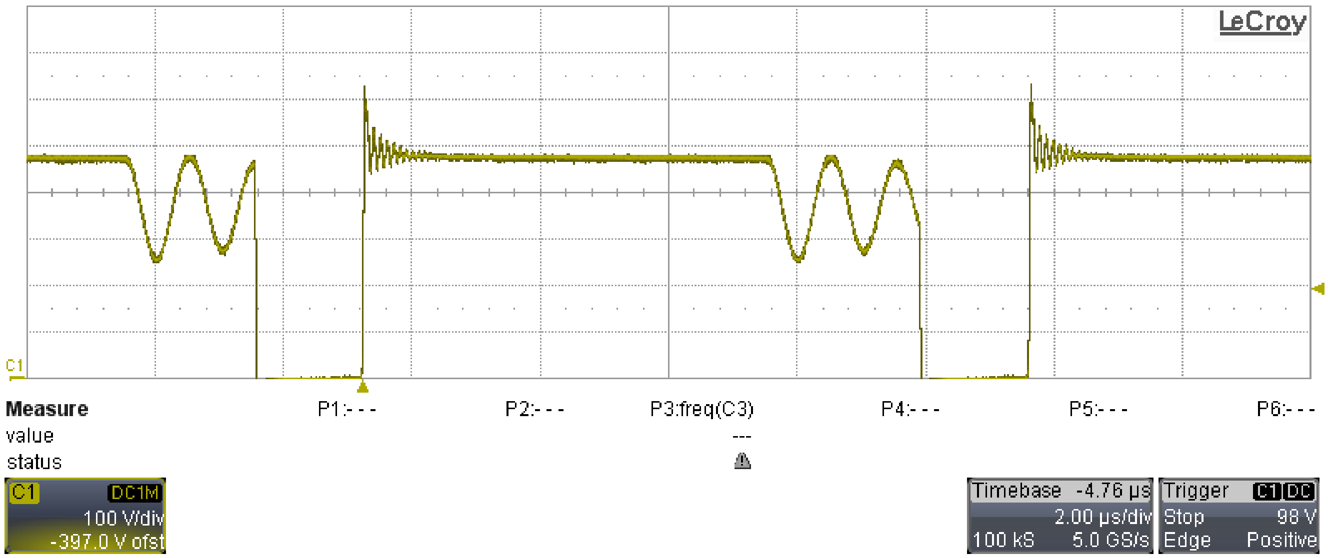


Figure 3-1. Drain-Source Waveform of Q3 at 375VDC, 24V Output and 4A Load

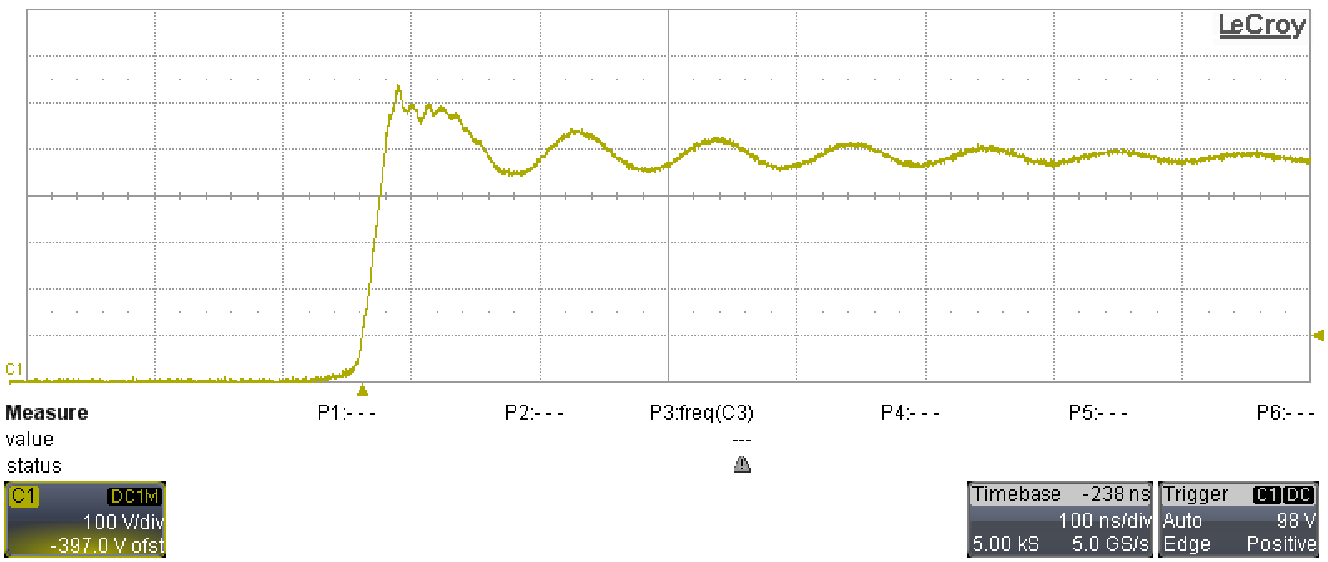


Figure 3-2. Drain-Source Waveform (Vds) of Q3 at 375VDC, 24V Output and 4A Load (100 nsec/division)

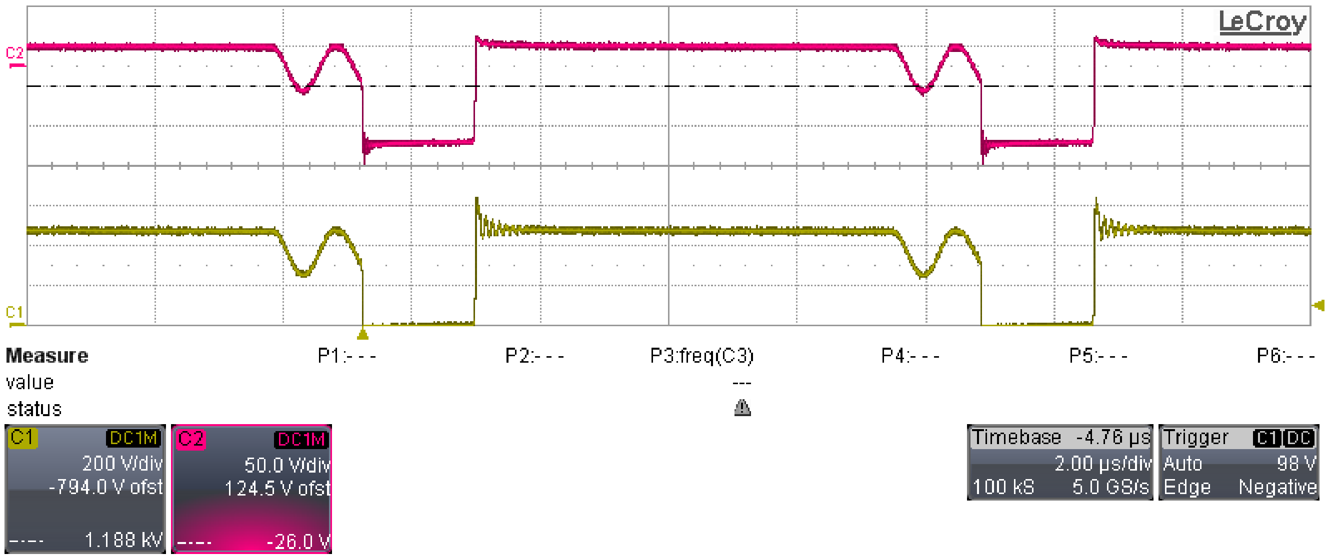


Figure 3-3. Vds of Q3 and D7 Anode-Ground Waveforms at 375VDC, 24V Output and 4A Load

3.2 Output Voltage Ripple

Output voltage ripple is shown in Figure 3-4.

C3: Output voltage, AC coupled, 20MHz bandwidth limit

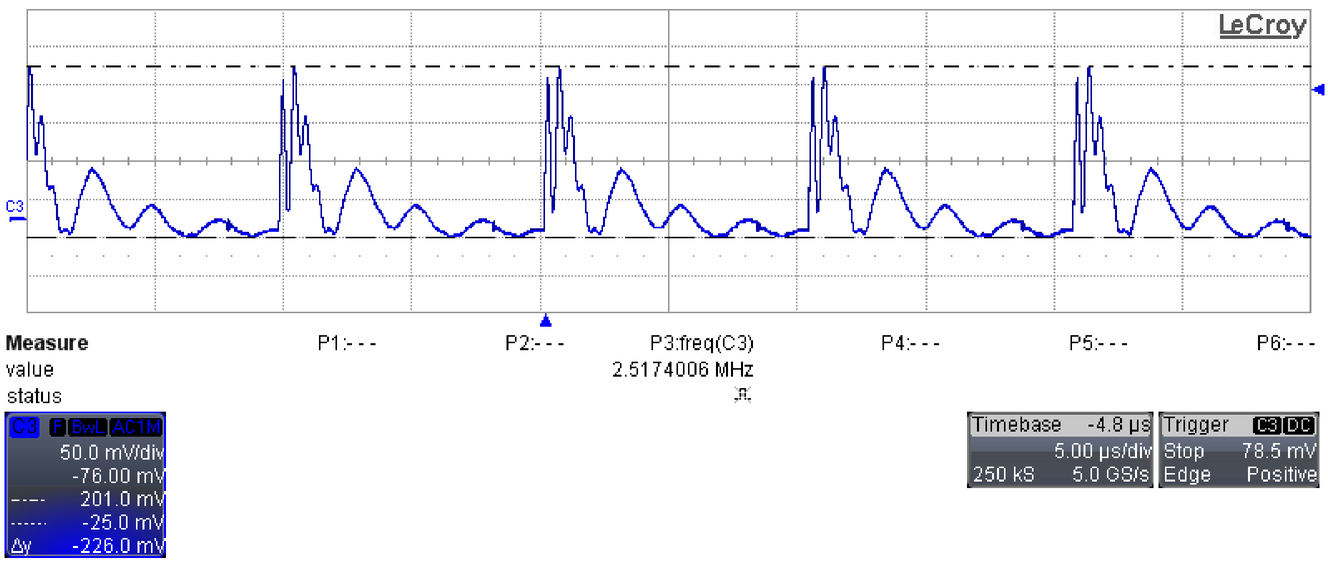


Figure 3-4. Output Voltage Ripple at 325VDC, 24V Output and 4A Load

3.3 Load Transients

Load transient response is shown in Figure 3-5.

C3: output voltage, AC coupled, C4: output current, DC coupled, 20MHz bandwidth limit for both waveforms

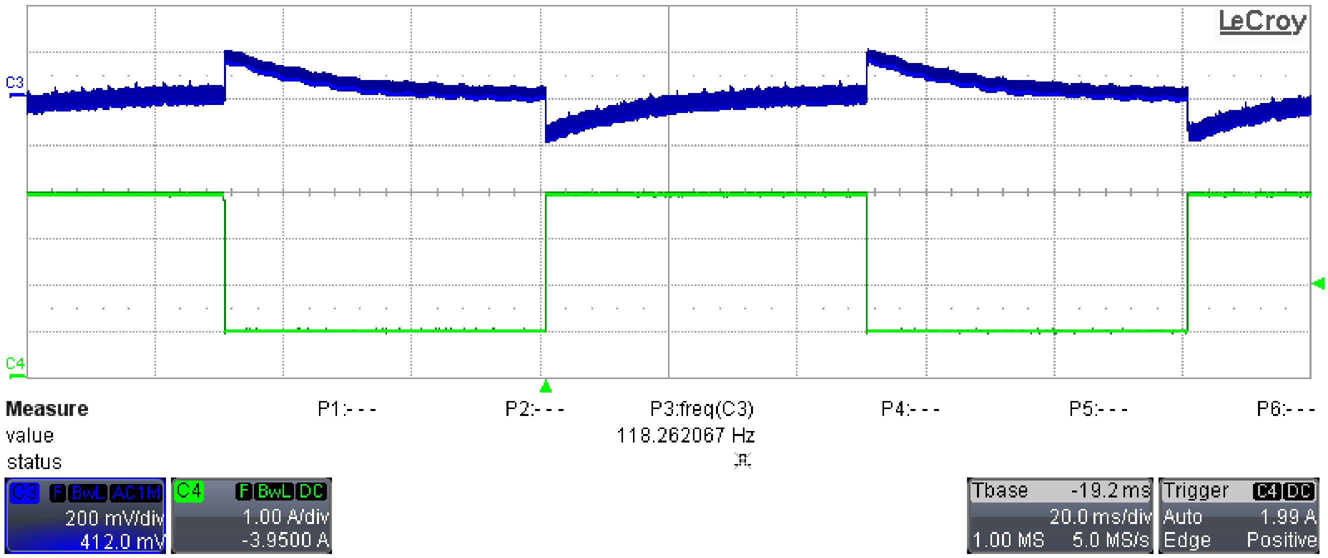


Figure 3-5. Load Transient at 325VDC, Output Current Switched Between 1A and 4A

3.4 Start-Up Sequence

Start-up behavior is shown in Figure 3-6 through Figure 3-8.

C3: output voltage, C4: output current

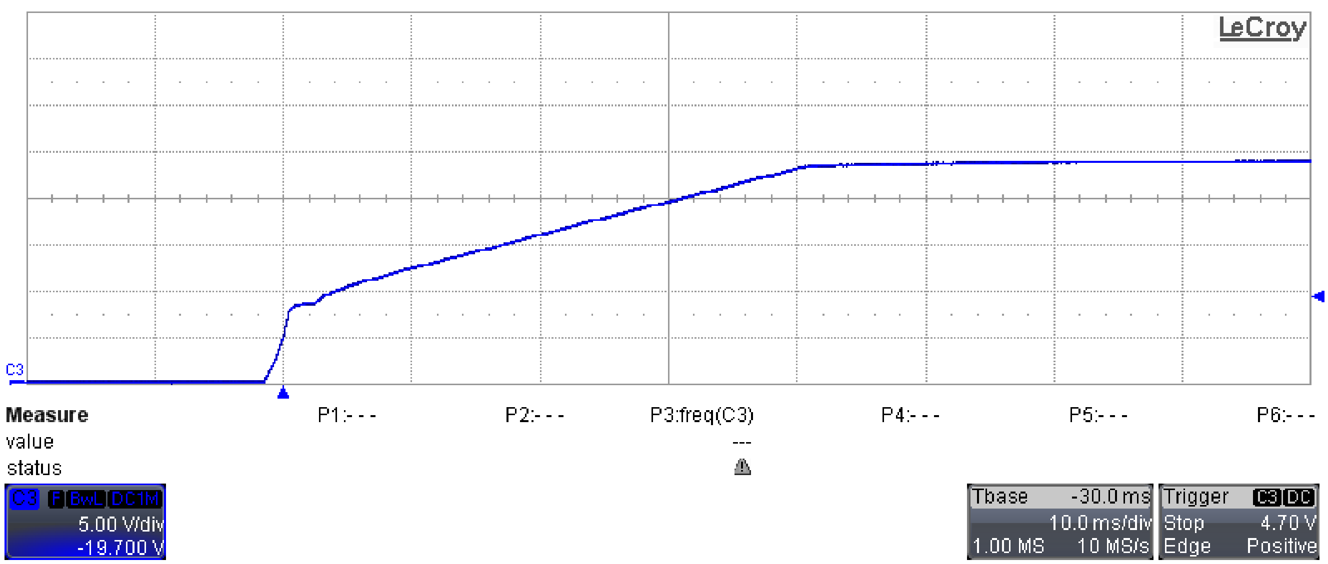


Figure 3-6. Start-Up at 325VDC and Zero Load

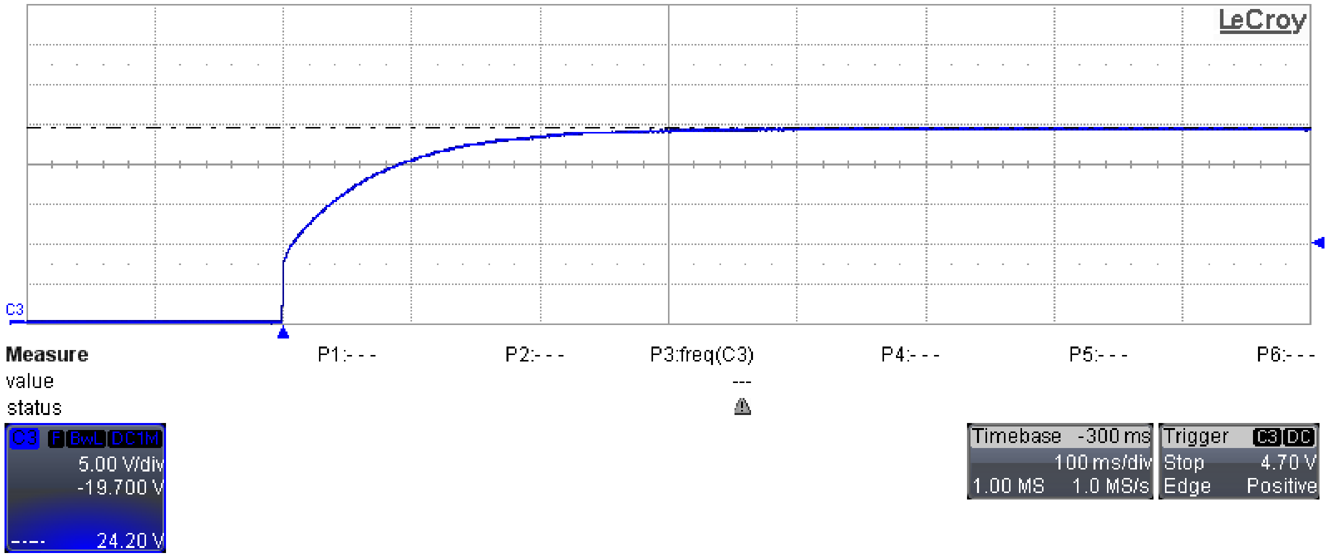


Figure 3-7. Start-Up at 325VDC, When the Output is Connected to 6Ω Resistor

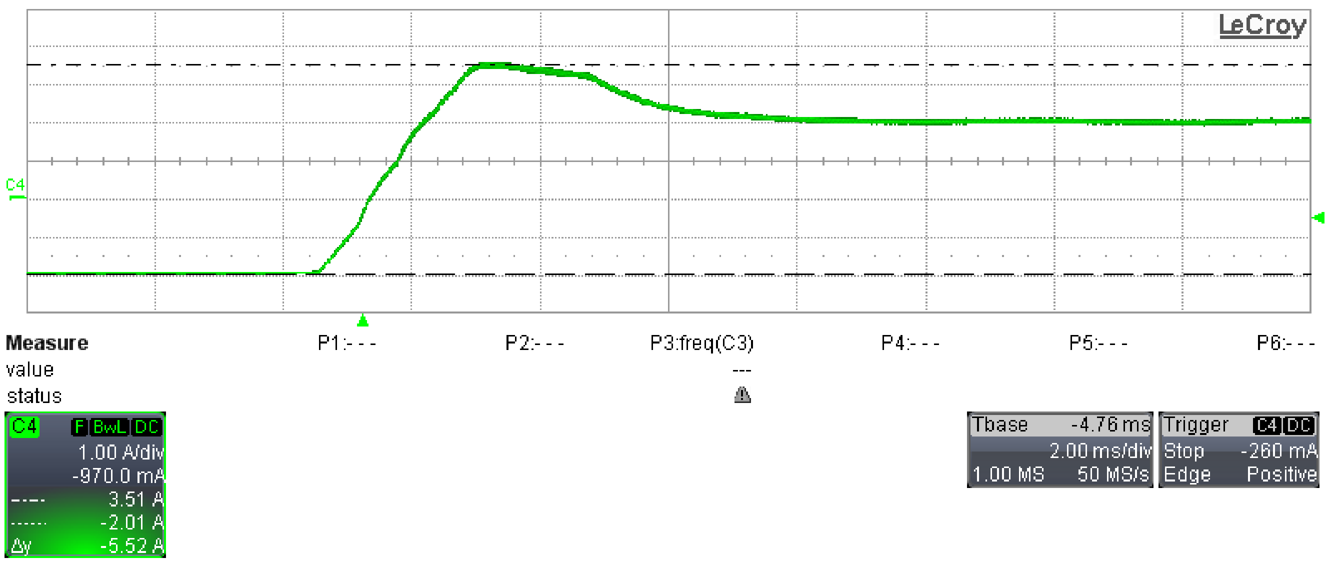


Figure 3-8. Start-up at 325VDC, with Output Connected to the Battery, and the Charging Current set to 2A

3.5 Shut-down Sequence

The DC input source turns off, while the converter runs.

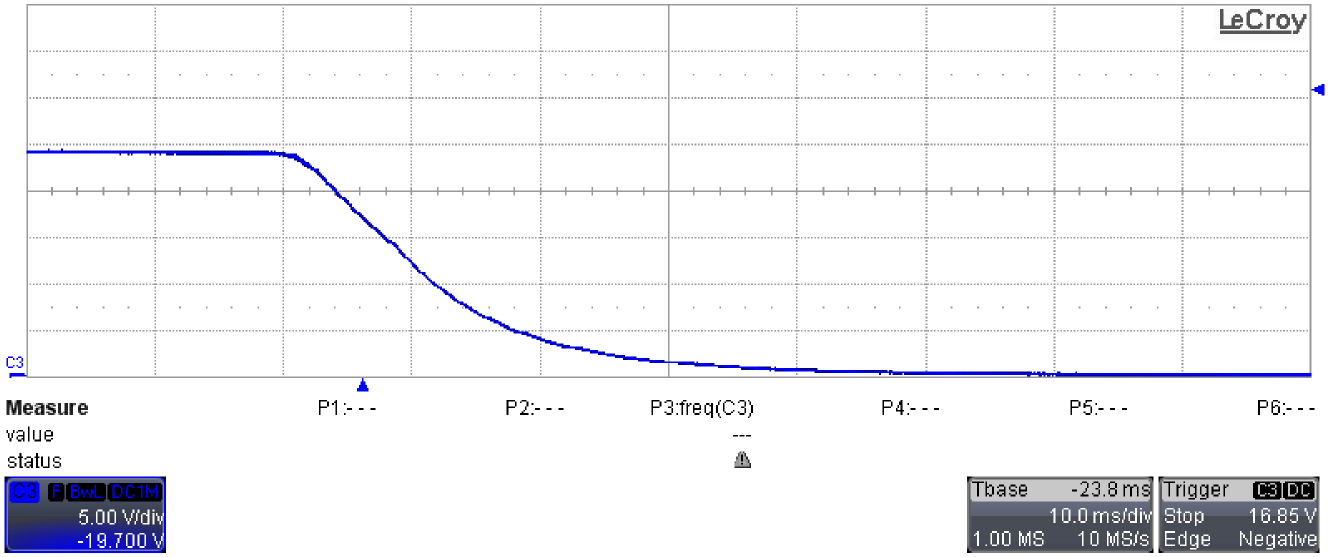


Figure 3-9. DC Source Turned OFF, at 325VDC; the Output is Connected to 6Ω Resistor

4 Static Regulation

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

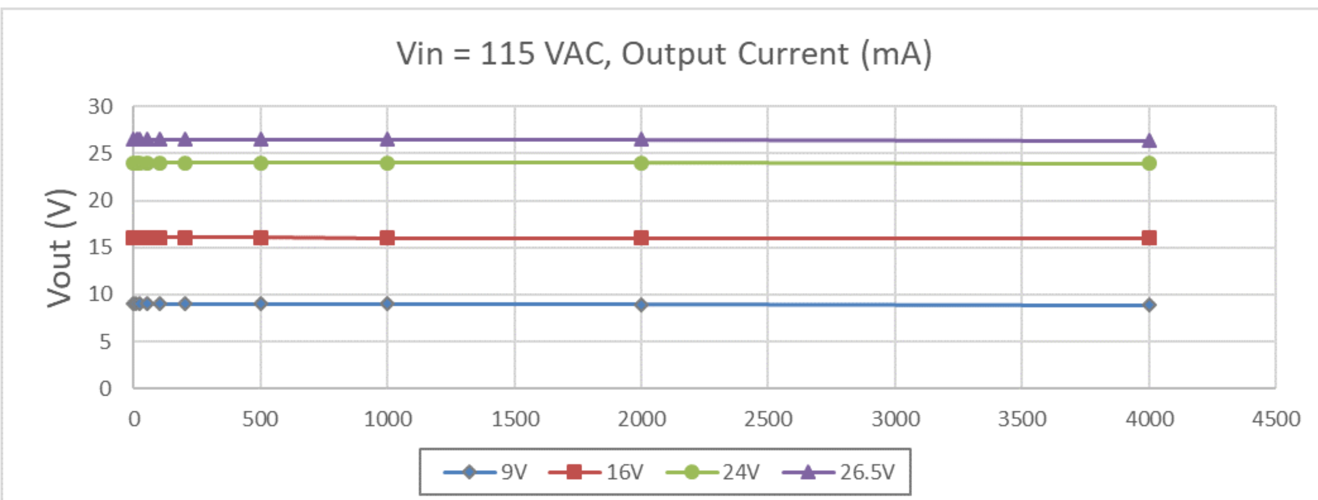


Figure 4-1. Output Voltage Static Regulation at 115VAC versus Load and Variable V_{out}

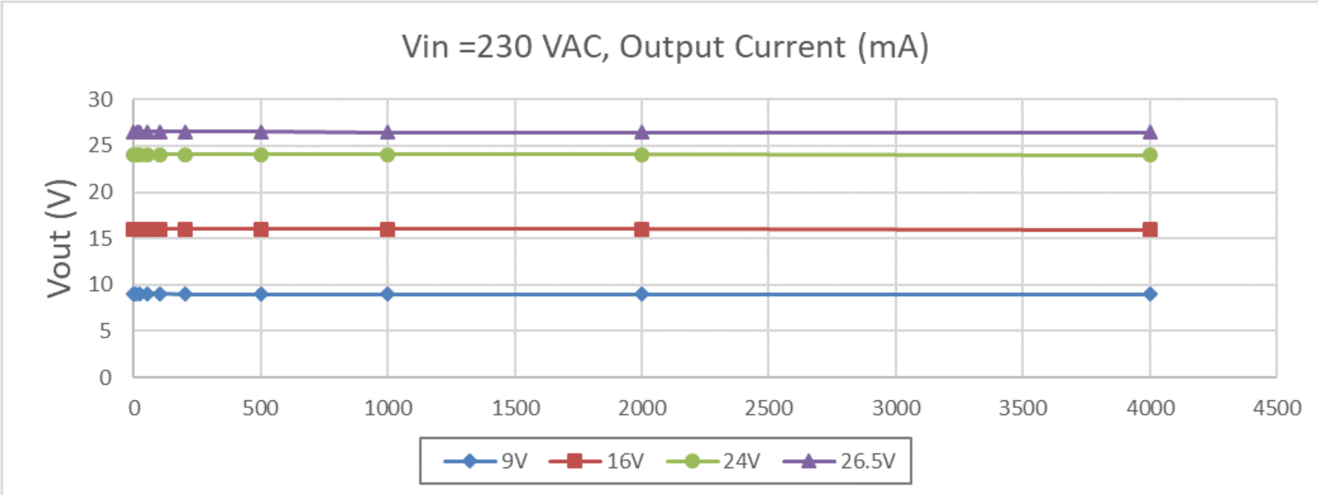


Figure 4-2. Output Voltage Static Regulation at 230VAC versus Load and Variable V_{out}

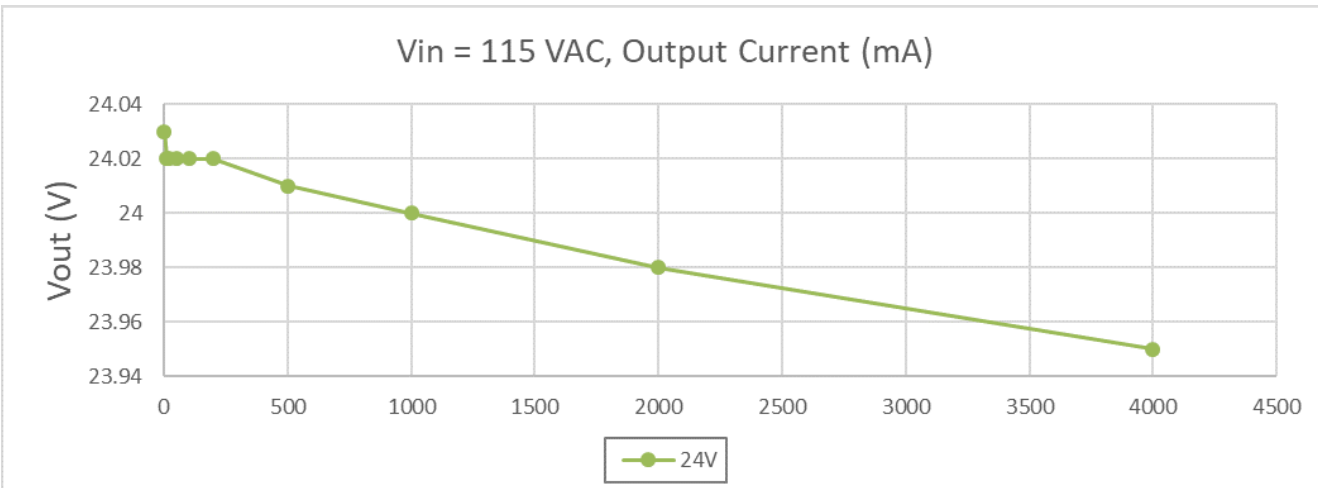


Figure 4-3. Output Voltage Static Regulation at 115VAC versus Load and Fixed V_{out}

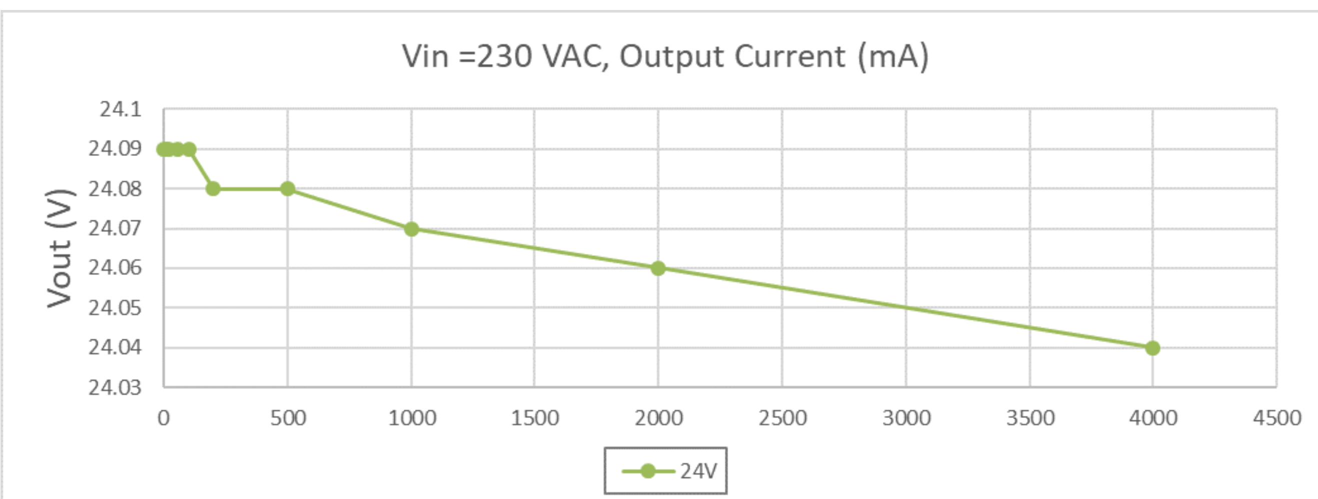


Figure 4-4. Output Voltage Static Regulation at 230VAC versus Load and Fixed V_{out}

5 Transformer Details

The Flyback transformer for this reference design is using PQ32/20 platform.

5.1 Material List

- PQ32/20 core set N87 – B65879A0000R087
- Coil former B65880E0012D001
- 0.2mm, 0.3mm and 0.4mm 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
Np1	3	2	CW	12	0.3mm, ECW, 4 wires in parallel
Na	4	5	CW	9	0.2mm, ECW, single wire
Ns1	11	9	CW	6	0.4mm, ECW, 5 wires in parallel
Ns2	10	8	CW	6	0.4mm, ECW, 5 wires in parallel
Np2	2	1	CW	12	0.3mm, ECW, 4 wires in parallel

5.3 Schematic

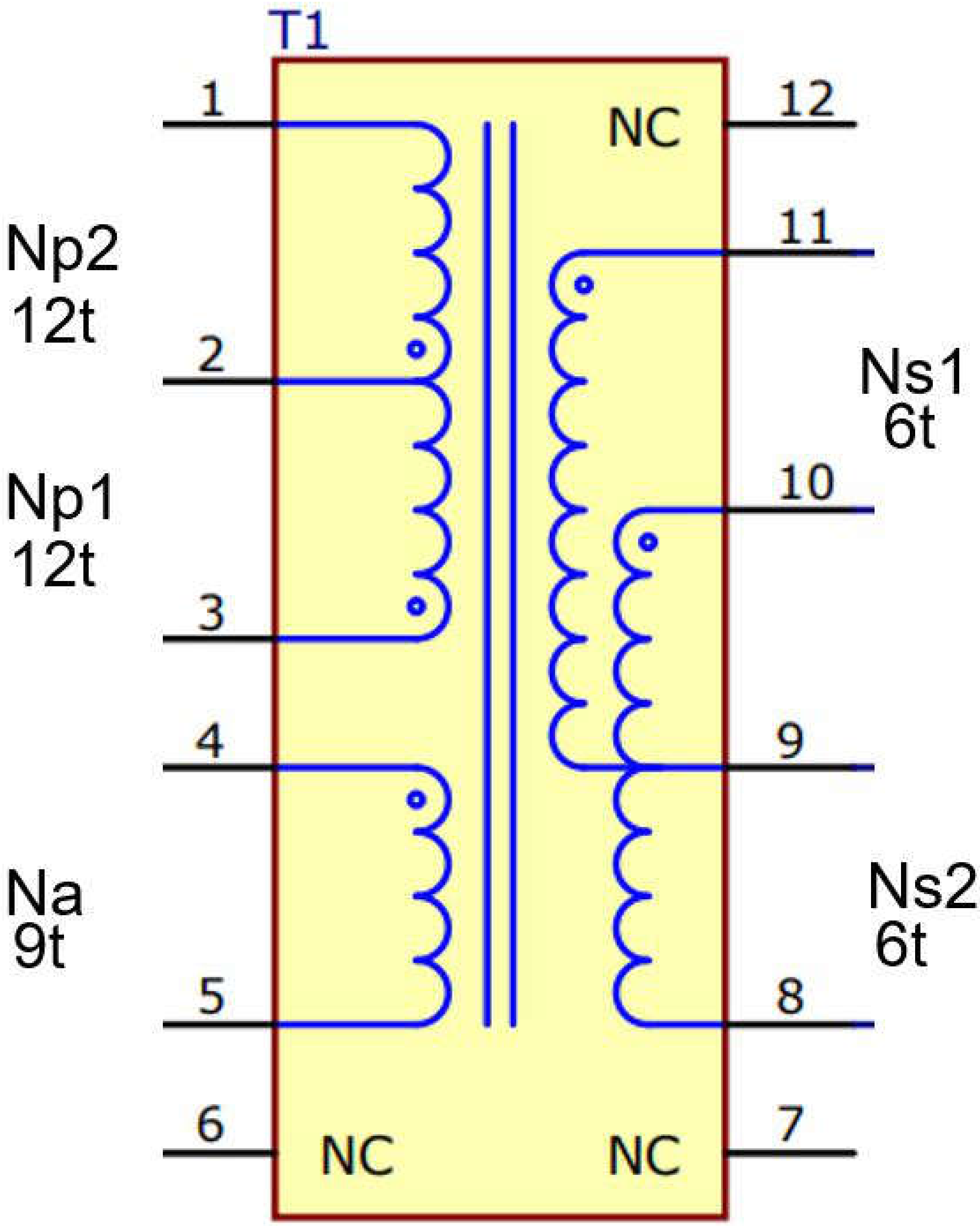


Figure 5-1. Winding Schematic

5.4 Winding Instructions

- First half primary Np1 winding: start on pin 3 and end on pin 2. Spread evenly over the bobbin. Cover with one layer of tape.
- Wind Ns1 with 6 turns, 5 strands in parallel starting on pin 11 and ending on pin 9. Apply spacers according to safety requirements or use triple insulated wires (TIW).
- Wind Ns2 with 6 turns, 5 strands in parallel starting on pin 10 and ending on pin 8. 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.
- Second half primary Np2 winding: start on pin 2 and end on pin 1. Spread evenly over the bobbin. Cover with one layer of tape.

5.5 Details about Core, Air Gap and Bobbin

- Target primary inductance: 200µH
- Core type: N87 core
- Air gap: 0.83mm on center leg
- Equivalent A_L value: 347nH / t^2

5.6 Bobbin Mechanical Details

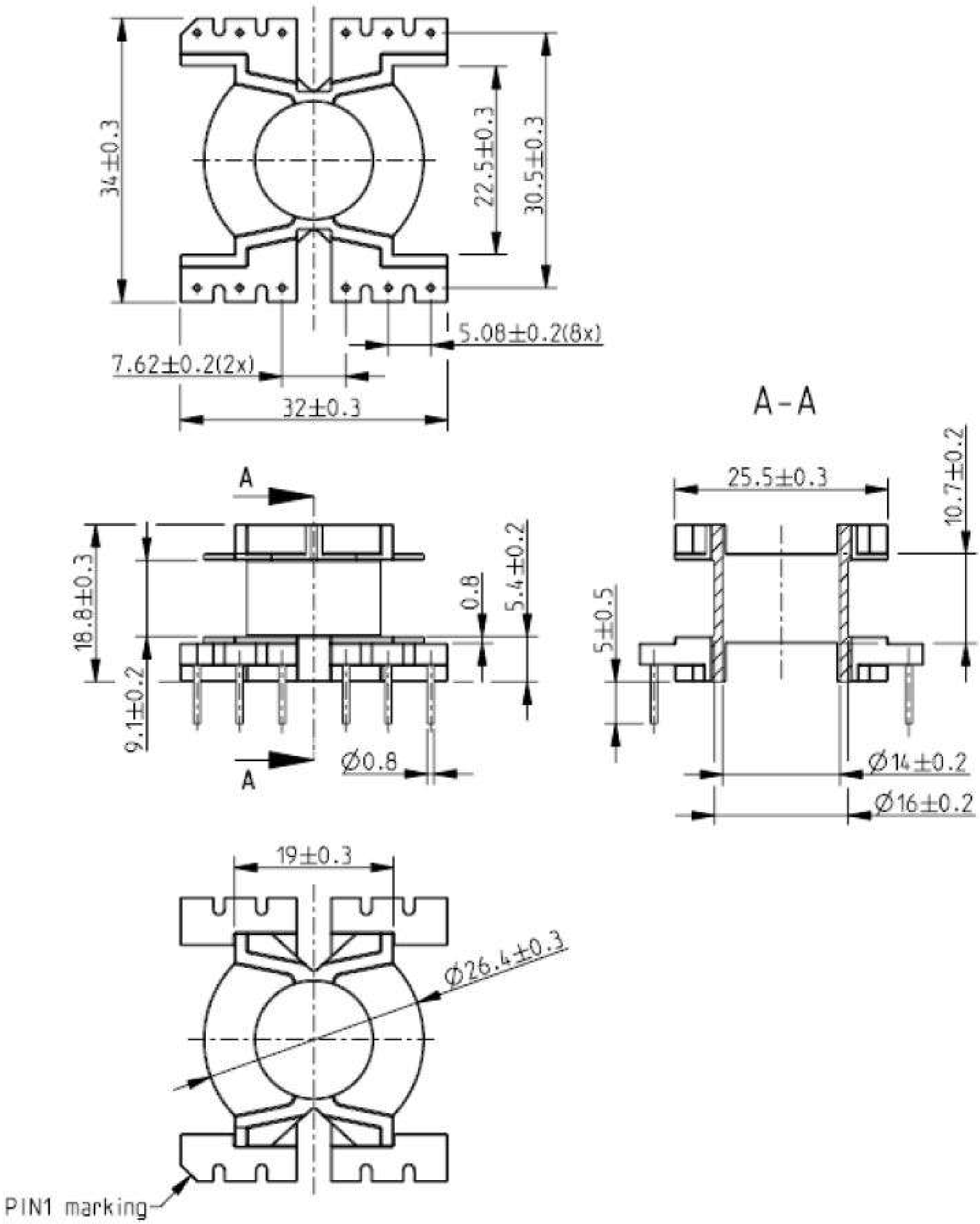


Figure 5-2. Mechanical Details of the Bobbin

Trademarks

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