Test Report: PMP31179

400-W AC/DC Reference Design for Avionics

Description

This board is a compact, 30-V DC, 400-W reference design for avionics applications, working with mains frequency between 400 Hz and 800 Hz. A two-phase interleaved transition mode (TM) power factor correction (PFC) based on the UCC28064A is used to correct power factor and at the same time to minimizes harmonic content of input current. The DC/DC is implemented employing the HB-LLC stage, using UCC256404 device. The efficiency is further improved by using synchronous rectification on the secondary side.

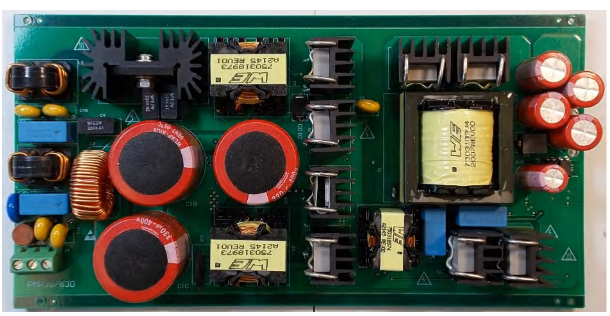
The reference design PMP31179 Rev_A was built on the PMP30763 Rev_D PCB.

Features

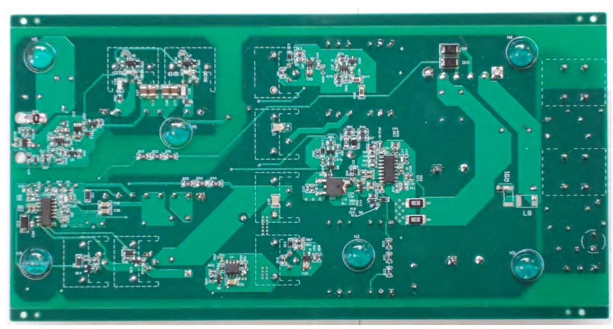
- Maximum 400-W output power at 96 VAC–134 VAC grid connection
- Two-stage converter achieving 92.8% plug-to-plug efficiency:
  - First stage: PFC interleaved Boost (97% efficiency) with UCC28064A, allows reduced EMI filter size and increases efficiency
  - Second stage: half-bridge resonant LLC converter (95% efficiency) isolates HV input, and supplies 30 V, 13.3 A
- No need of an auxiliary power supply, since the second stage provides the bias voltage for the PFC
- Specifically designed to comply with DO160-G harmonic limits in avionics applications for mains frequency in the 400 Hz–800 Hz range

Applications

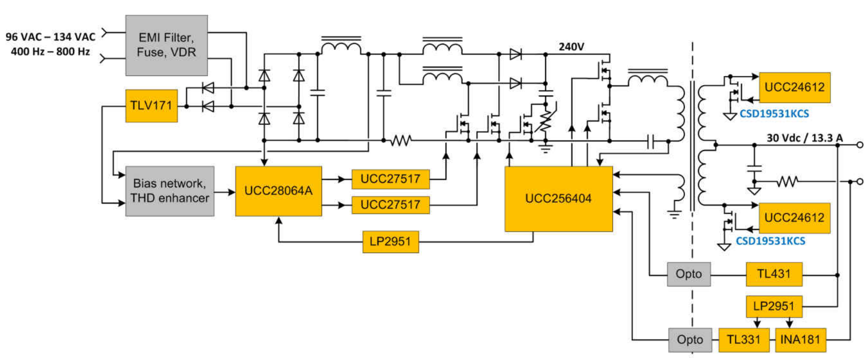
- Aircraft cockpit display
- Power conversion system (PCS)



Top of Board



Bottom of Board



Block Diagram

1 Test Prerequisites

1.1 Voltage and Current Requirements

Table 1-1. Voltage and Current Requirements

Parameter	Specifications
Input Voltage	96 VAC–134 VAC
Frequency	400 Hz–800 Hz
Output, Voltage	30 VDC
Output, Current	13.3 A

1.2 Required Equipment

- 0–150 VAC, 400 Hz–800 Hz (minimum current limit 7 A_{RMS}), AC constant voltage source (VS1)
- Electronic load, (constant current range 0–15 A)
- Oscilloscope (minimum 100-MHz bandwidth)
- Current probe (minimum 100-kHz bandwidth)
- Optional: infrared camera

1.3 Dimensions

The board dimensions are 218.44 mm x 102.26 mm, height 31.75 mm (transformer T1).

1.4 Test Setup

1. Connect the source VS1 to J3-1 and J3-2; earth connection to J3-3
2. Connect the load to terminals “30V” (plus) and “R_SENSE” (minus)
3. Attach a current probe in series to VS1 to measure the input current
4. Attach a current probe in series to L7 (by disconnecting one pin) to measure the resonant current
5. Turn on VS1 (accepted range: 96 VAC…134 VAC).
6. Increase the load on the output

> **WARNING**
> The following step involves working with high voltage. To minimize the risk of personal injury, never touch the board or its electrical circuits, as they could be at high voltages capable of causing an electrical shock hazard.

7. After turn off, discharge the capacitors C1A, C1B, and C1C (PFC capacitors) by means of an external resistor or active discharge circuit

2 Testing and Results

2.1 Efficiency Graphs

Figure 2-1 shows the plug-to-plug converter efficiency, versus output power.

The input voltage was set to 96 VAC, 115 VAC, and 134 VAC, while the mains frequency was 400 Hz.

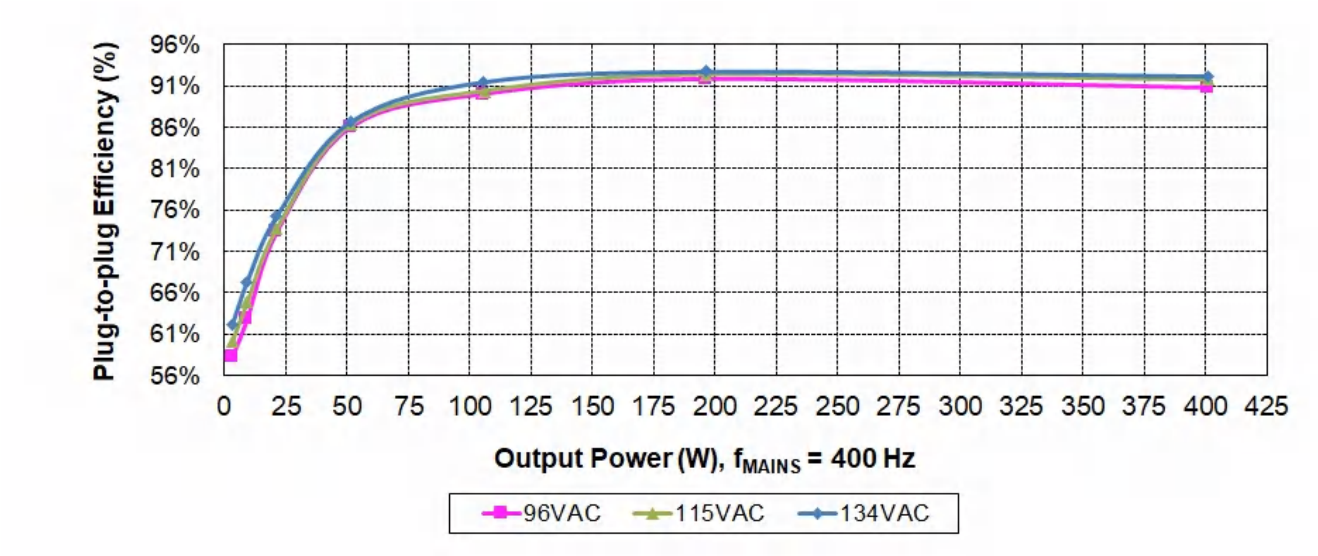


Figure 2-1. Efficiency Graph for Three Different VAC Input Voltages, Versus Output Power

2.2 Efficiency Data

Efficiency data is shown in the following tables.

Table 2-1. V_{IN} = 96 VAC, F = 400 Hz

V_pfc (V)	P_{IN} (W)	PF (%)	iTHD (%)	V_{OUT} (V)	I_{OUT} (A)	P_{OUT} (W)	Efficiency (%)
238.7	0.58	0.0	0.00	29.93	0.000	0.00	0.00%
238.6	5.35	25.1	20.0	29.93	0.104	3.12	58.26%
238.6	14.52	49.2	36.5	29.93	0.305	9.12	62.83%
238.5	28.95	70.7	29.6	29.93	0.709	21.23	73.34%
238.4	59.87	88.2	19.33	29.93	1.720	51.49	86.01%
238.4	117.64	95.8	15.54	29.92	3.538	105.86	89.99%
238.3	214.08	98.8	7.740	29.92	6.566	196.47	91.77%
238.2	442.00	99.8	4.970	29.90	13.41	401.07	90.74%

Table 2-2. V_{IN} = 115 VAC, F = 400 Hz

V_pfc (V)	P_{IN} (W)	PF (%)	iTHD (%)	V_{OUT} (V)	I_{OUT} (A)	P_{OUT} (W)	Efficiency (%)
238.8	0.56	0.0	0.00	29.94	0.000	0.00	0.00%
238.7	5.19	18.7	15.0	29.94	0.104	3.12	60.09%
238.7	14.09	38.3	29.9	29.94	0.305	9.13	64.79%
238.6	28.82	59.7	35.7	29.94	0.710	21.25	73.72%
238.5	59.68	80.2	24.28	29.93	1.721	51.50	86.30%
238.4	117.23	92.4	17.83	29.93	3.539	105.91	90.34%
238.3	212.78	97.6	9.230	29.92	6.567	196.49	92.34%
238.3	437.50	99.5	5.207	29.91	13.42	401.28	91.72%

Table 2-3. V_{IN} = 134 VAC, F = 400 Hz

V_pfc (V)	P_{IN} (W)	PF (%)	iTHD (%)	V_{OUT} (V)	I_{OUT} (A)	P_{OUT}(W)	Efficiency (%)
238.7	0.54	0.0	0.00	29.93	0.000	0.00	0.00%
238.6	5.04	14.2	10.2	29.93	0.105	3.13	62.08%
238.5	13.59	30.7	21.4	29.93	0.305	9.14	67.26%
238.5	28.23	49.7	32.8	29.92	0.710	21.24	75.25%
238.4	59.38	72.3	29.54	29.92	1.721	51.49	86.72%
238.3	115.69	87.8	17.03	29.92	3.539	105.87	91.52%
238.2	211.73	95.4	12.69	29.91	6.568	196.44	92.78%
238.2	435.10	99.0	5.810	29.90	13.42	401.23	92.22%

2.3 Power Factor and iTHD Versus Load, VAC and Frequency

The power factor value was measured by varying the converter output power in the whole load range, for different VAC, repeated at 400-Hz and 800-Hz mains frequency.

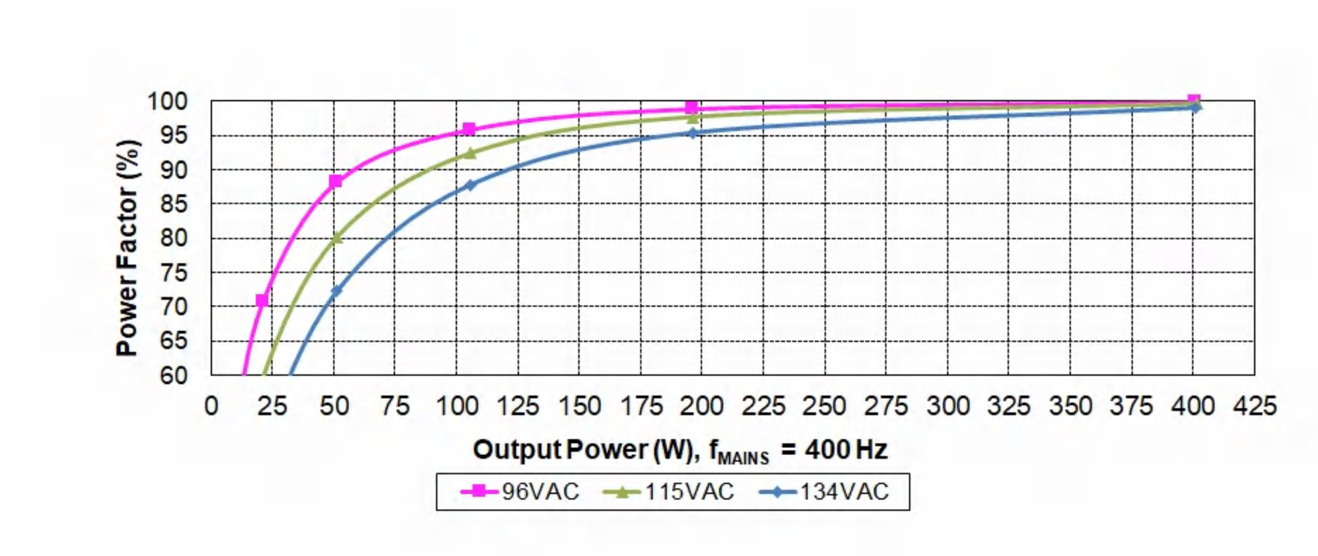


Figure 2-2. Power Factor Versus Output Power at 400 Hz

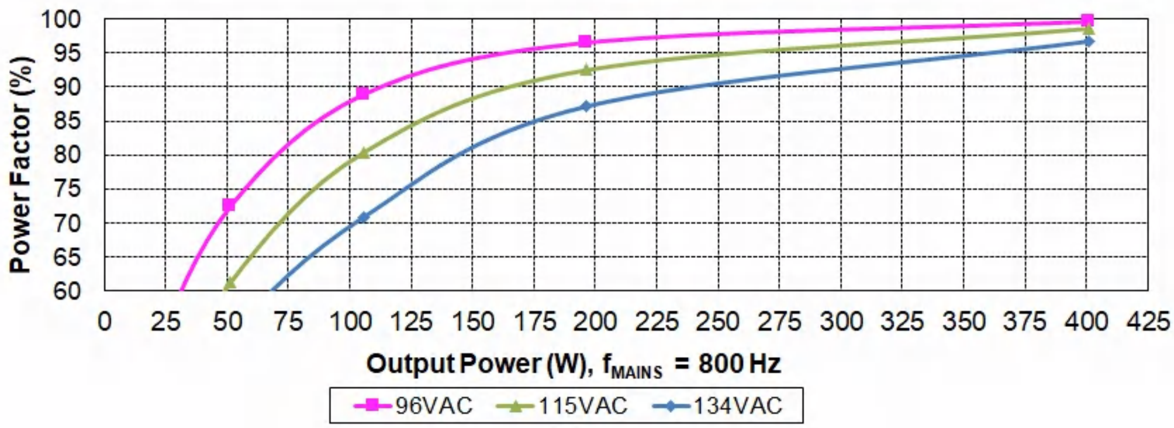


Figure 2-3. Power Factor Versus Output Power at 800 Hz

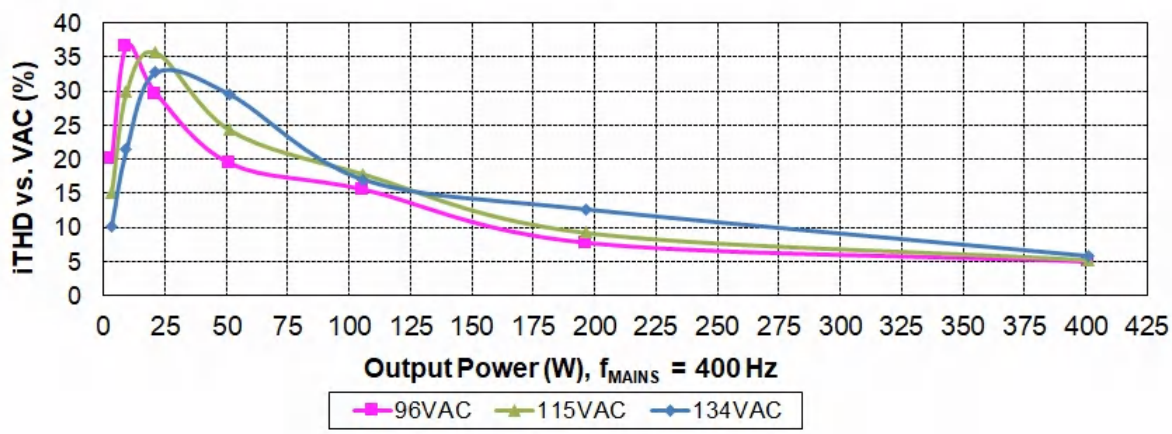


Figure 2-4. iTHD Versus Output Power at 400 Hz

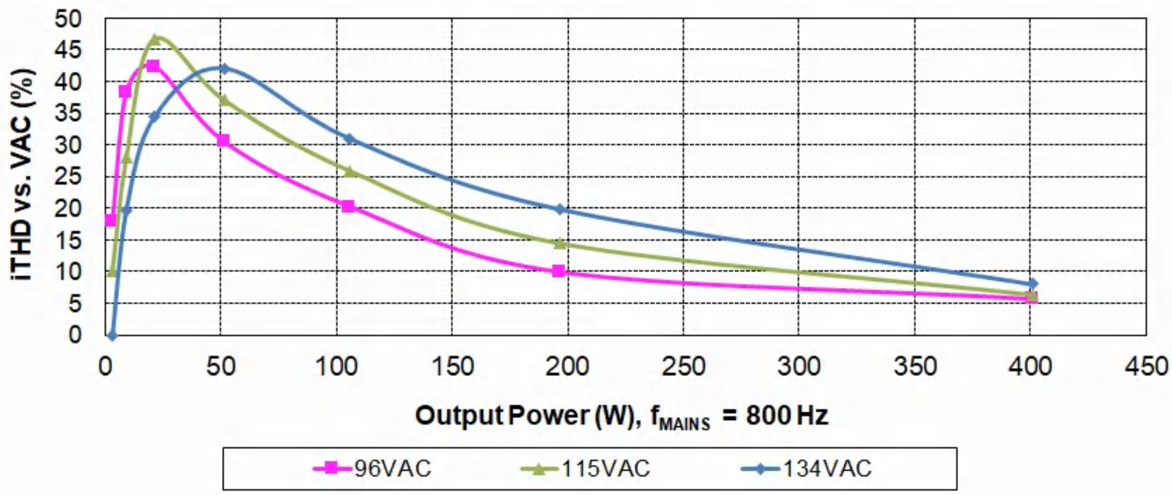


Figure 2-5. iTHD Versus Output Power at 800 Hz

2.3.1 Power Factor and iTHD Tables

The following tables show all values of power factor (PF) and input current harmonic distortion (iTHD) versus output power.

Table 2-4. V_{IN} = 115 VAC, F = 800 Hz

PF (%)	iTHD (%)	P_{OUT} (W)
0.00	0.00	0.00
10.8	10.2	3.12
24.0	28.1	9.13
40.4	46.7	21.25
61.2	37.07	51.50
80.4	25.90	105.91
92.5	14.52	196.49
98.6	6.38	401.28

Table 2-5. V_{IN} = 96 VAC, F = 800 Hz

PF (%)	iTHD (%)	P_{OUT} (W)
0.00	0.00	0.00
14.7	17.8	3.12
31.9	38.2	9.12
50.9	42.3	21.23
72.4	30.40	51.49
88.9	20.17	105.86
96.5	9.84	196.47
99.6	5.56	401.07

Table 2-6. V_{IN} = 134 VAC, F = 800 Hz

PF (%)	iTHD (%)	P_{OUT} (W)
0.00	0.00	0.00
8.0	0.0	3.13
18.9	19.7	9.14
33.1	34.4	21.24
53.1	42.06	51.49
70.8	30.97	105.87
87.1	19.88	196.44
96.7	8.05	401.23

2.4 Thermal Image

Figure 2-6 and Table 2-7 show the thermal picture of the converter supplied at 115 VAC and 400 Hz, taken after 30 minutes soak time, at 25°C ambient temperature.

The board runs at full load with a fan, placed on the side (DC/DC output).

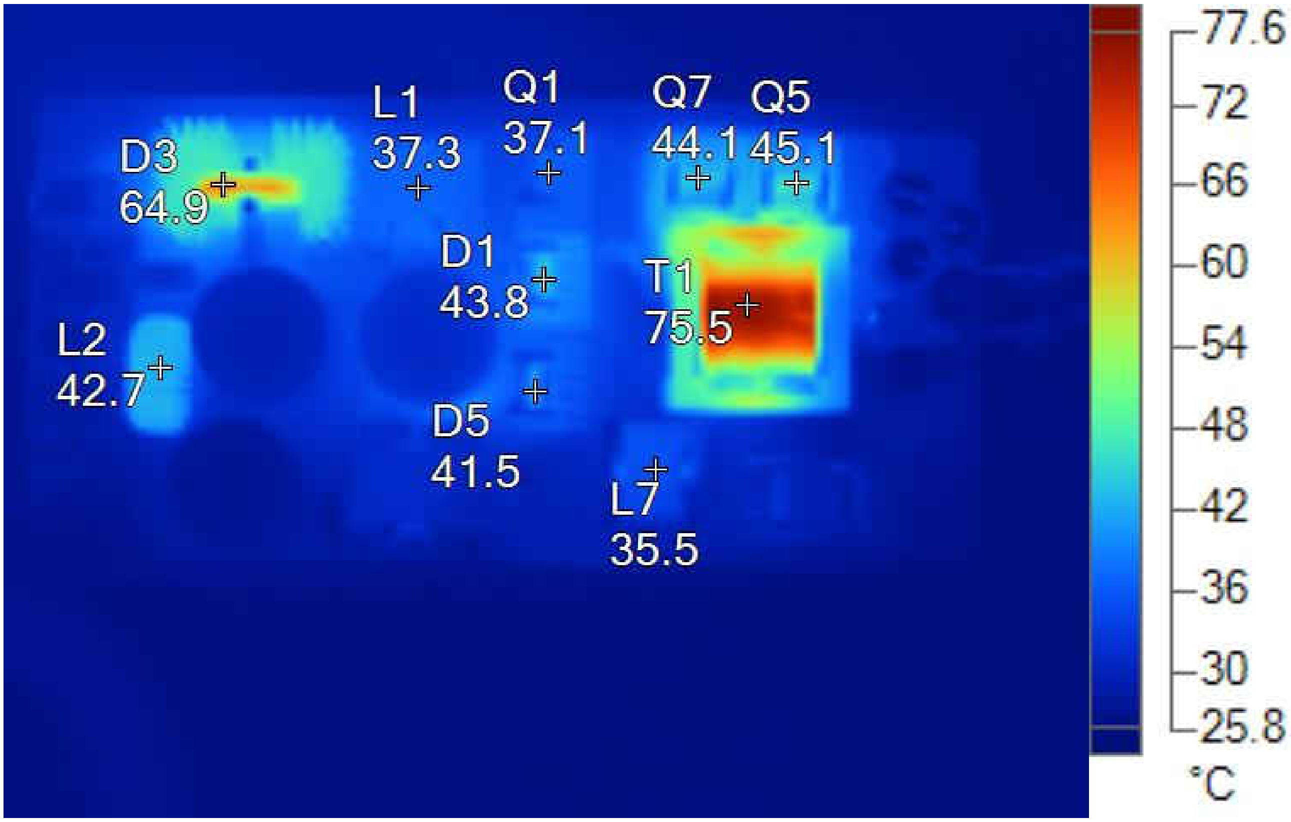


Figure 2-6. Thermal Image, 30 Minutes, Full Load

Table 2-7. Main Image Markers

Name	Temperature	Emissivity	Background
D3	64.9°C	0.96	25.5°C
L2	42.7°C	0.96	25.5°C
L1	37.3°C	0.96	25.5°C
Q1	37.1°C	0.96	25.5°C
D1	43.8°C	0.96	25.5°C
D5	41.5°C	0.96	25.5°C
L7	35.5°C	0.96	25.5°C
T1	75.5°C	0.96	25.5°C
Q5	45.1°C	0.96	25.5°C
Q7	44.1°C	0.96	25.5°C

2.5 Bode Plots

Figure 2-7 shows the bode plot of the converter, when supplied at 115 VAC, 400 Hz, while loaded at 5 A and 13 A. To measure the stability of the DC/DC stage, a 50-Ω resistor was inserted in series to the common connection of R17 and R48 to the net “30V”.

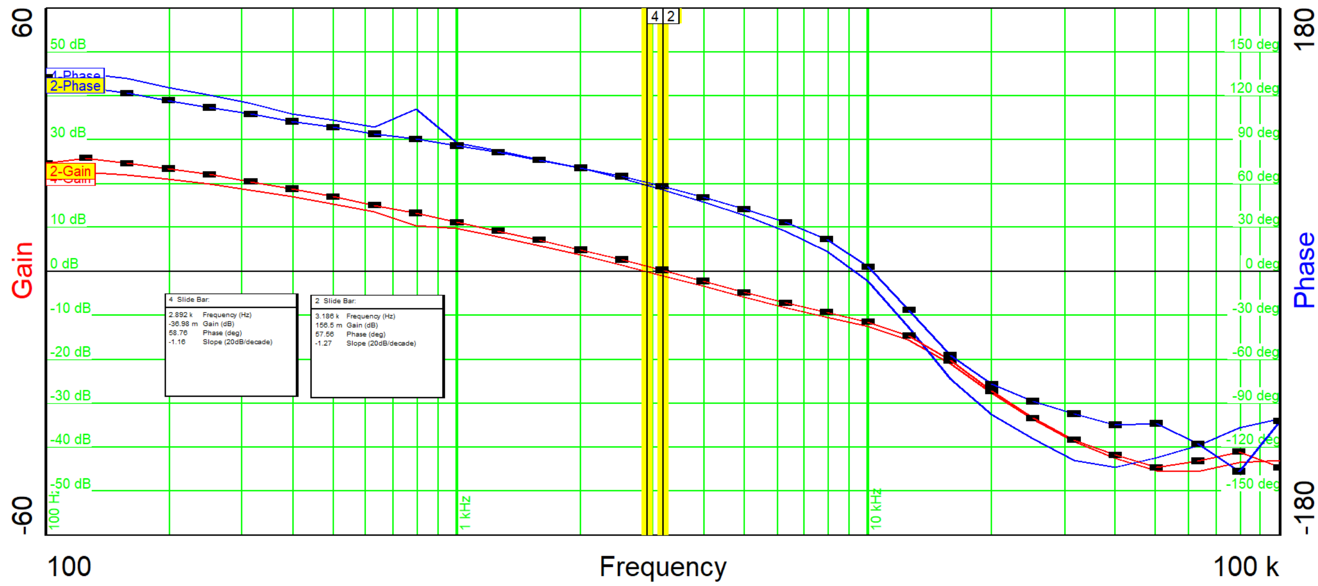


Figure 2-7. Bode Plot at 5 A and 13 A Load Current

Table 2-8. Crossover Frequency, Phase Margin and Gain Margin

Parameter	I_{OUT} = 5A	I_{OUT} = 13 A
Crossover frequency	3.186 kHz	2.892 kHz
Phase margin	57.56 degrees	58.76 degrees
Gain margin	11.67 dB	11.99 dB

2.6 Input AC Current Measurements: Compliance to DO160 Harmonic Limits

All harmonics were tested according to the DO-160-G limits.

In details, measure the first harmonic (fundamental) of the current at full load and nominal VAC (in this case 115 VAC). The AC source frequency was set to 400 Hz, 600 Hz, and 800 Hz.

For all even harmonics with order > 4, it should be considered an absolute limit of 10 mA, regardless on the order number (DO-160-G limits). Figure 2-8 through Figure 2-10 show each harmonic current (in mA) versus number of order.

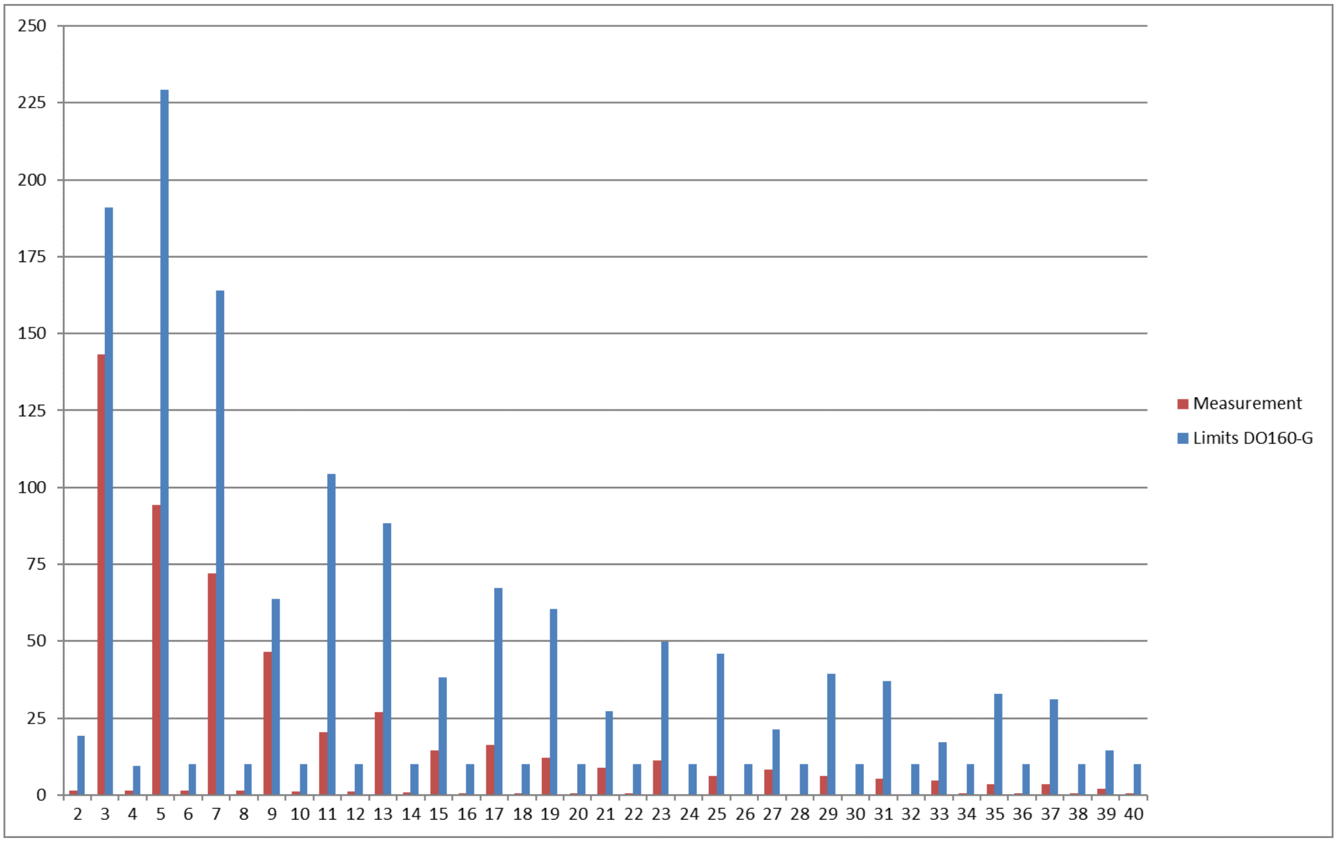


Figure 2-8. F = 400 Hz

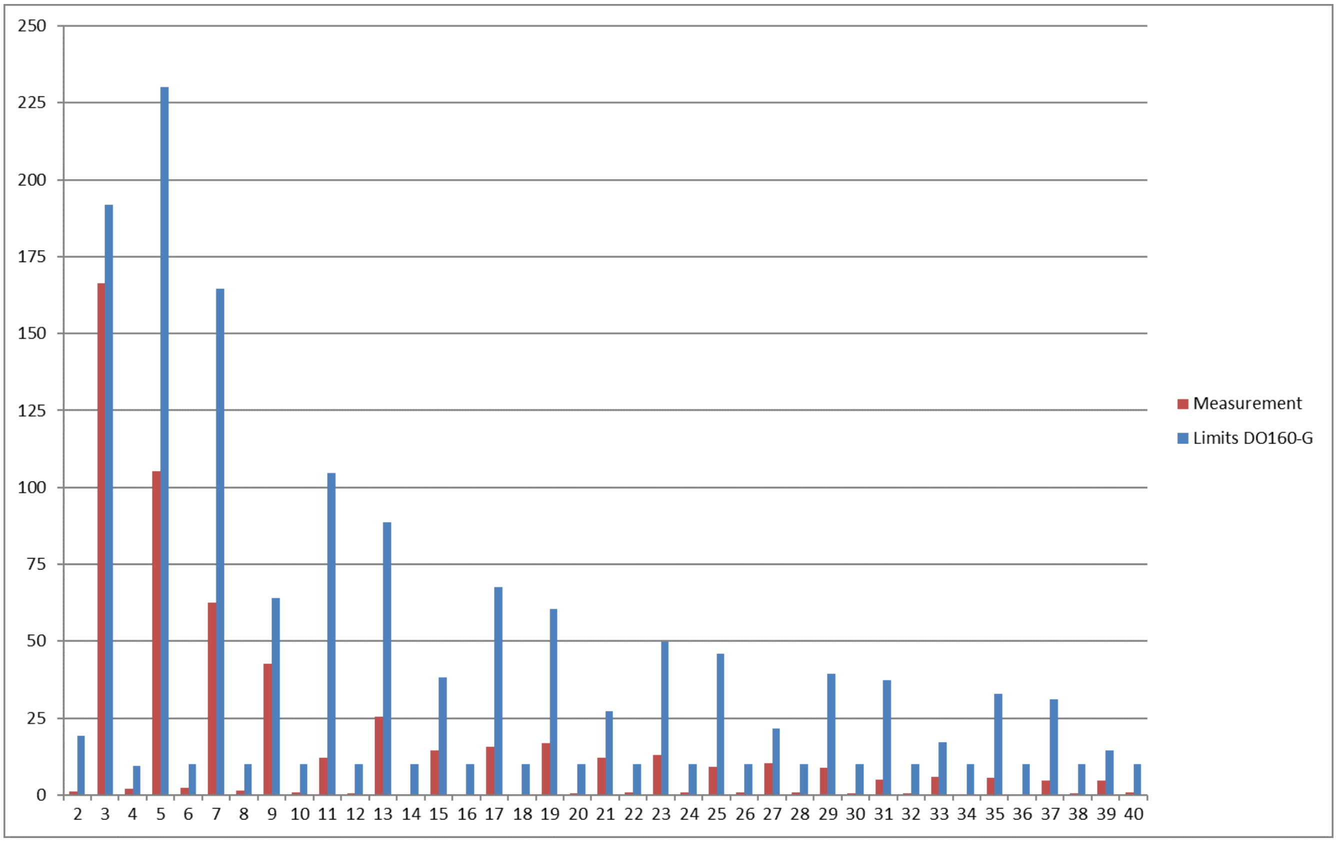


Figure 2-9. F = 600 Hz

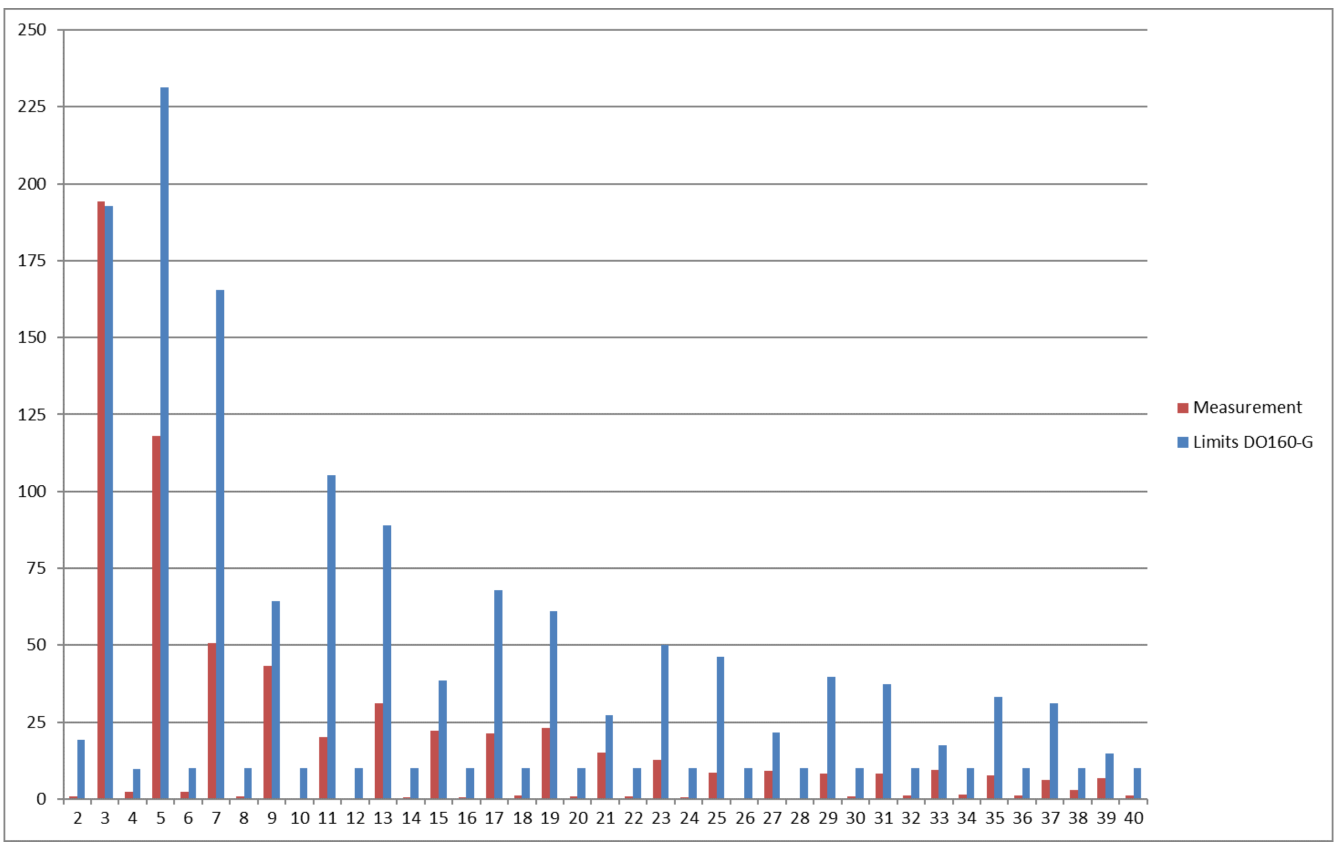


Figure 2-10. F = 800 Hz

3 Waveforms

3.1 Switching

Switching waveforms on FETs of the PFC stage, as well primary-side FETs and sync FETs of the LLC stage, were taken by supplying the converter at 96 VAC and 115 VAC, F = 400 Hz, and full load.

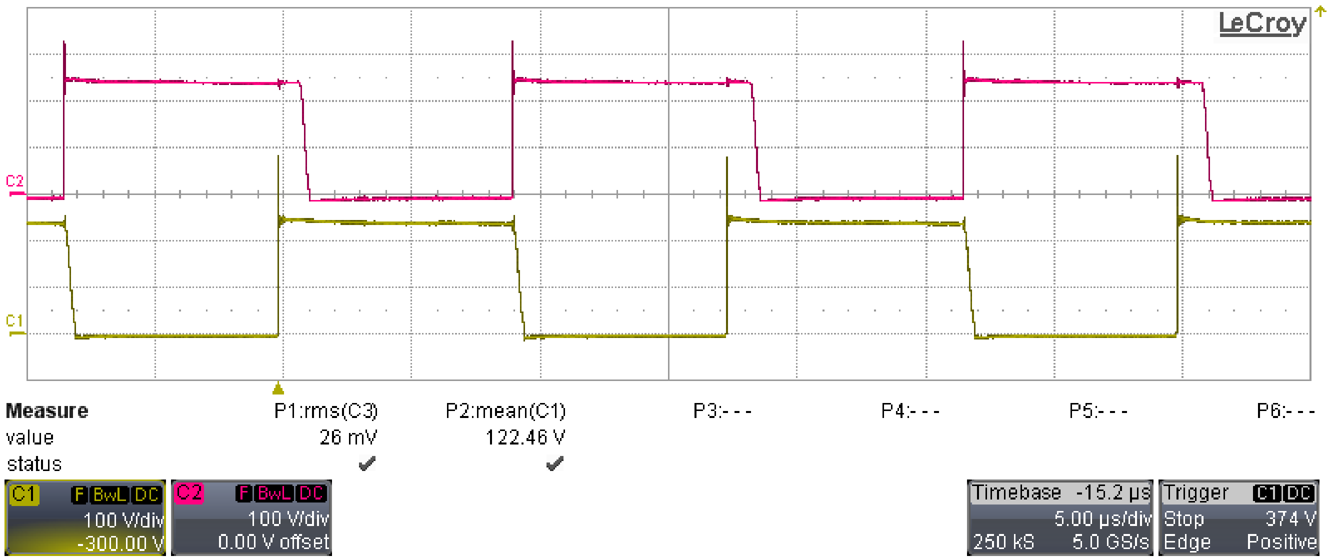


Figure 3-1. Drain-Source Voltages on Q1 and Q12 (C1: Q12-Vds, C2: Q1-Vds) at 96 VAC

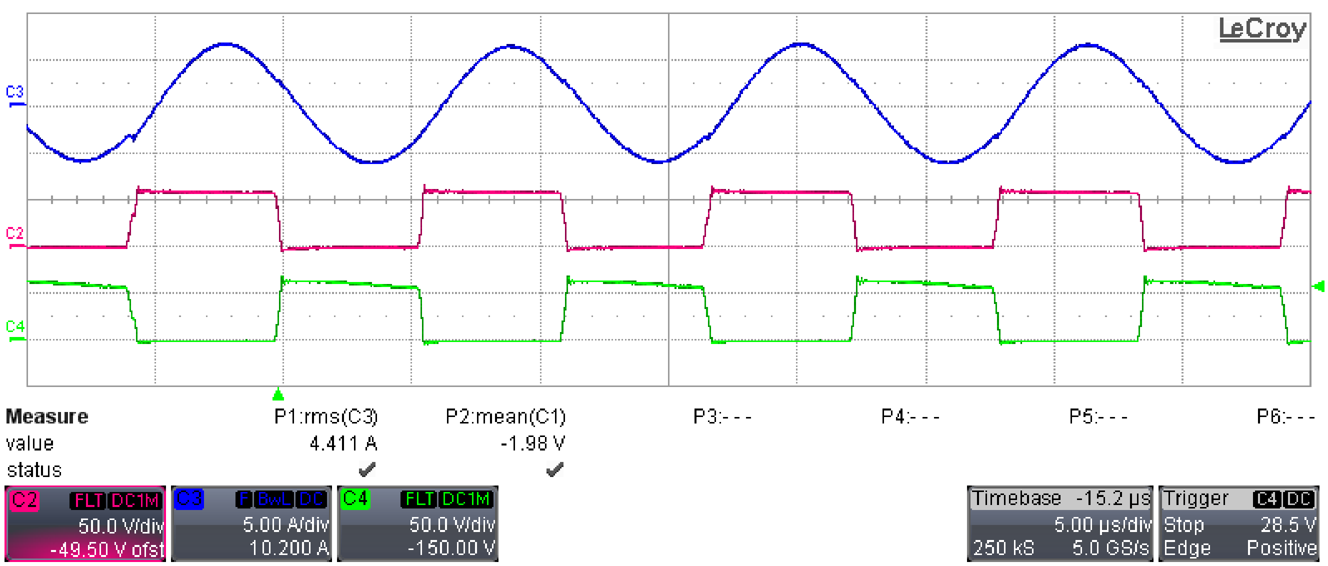


Figure 3-2. Drain-Source Voltages and Resonant Current at 115 VAC (C4: Q7-Vds, C3: I(L7), C2: Q5-Vds

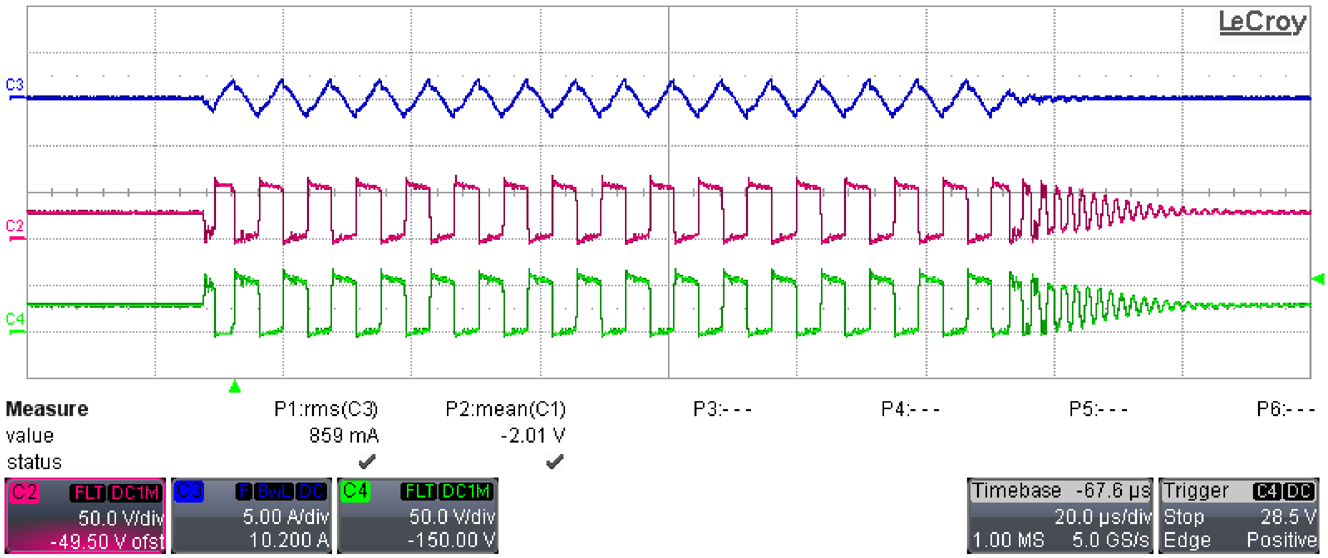


Figure 3-3. Burst Mode Waveforms (C4: Q7-Vds, C3: I(L7), C2: Q5-Vds) at 115 VAC and 200-mA Load

3.2 Output Voltage Ripple

The 30 V (V_{OUT}) and PFC (V_{PFC}) output voltage ripples were measured by supplying the converter at 115 VAC, 400 Hz at full load; the bandwidth limit of the scope has been set to 20 MHz.

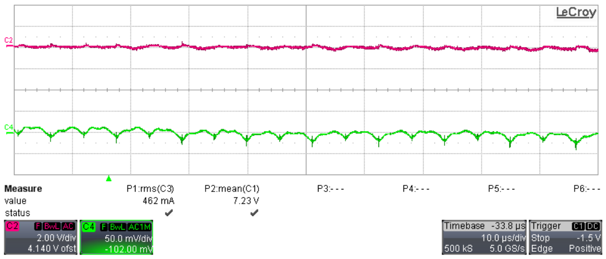


Figure 3-4. PFC and V_{OUT} Voltage Ripple (C2: V_{PFC}, C4: V_{OUT})

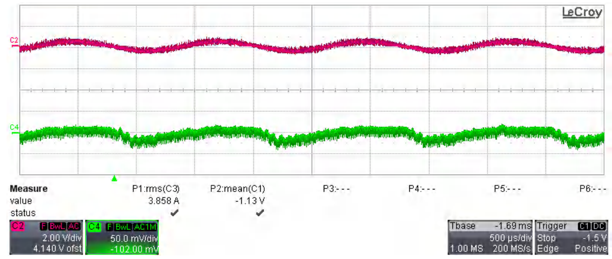


Figure 3-5. PFC and V_{OUT} Voltage Ripple at Time-base = 500 µs/div

3.3 AC Waveforms (Input Voltage and Current, PFC Output Voltage)

All screenshots in Figure 3-6 through Figure 3-11 show the input voltage V_{IN} (AC) and current I_{IN} (AC) of the PFC stage, as well as the PFC voltage at 96 VAC, 115 VAC, and 134 VAC, with mains frequency = 400 Hz and 800 Hz in full load condition (C2: V_{PFC}, C1: V_{IN}, C3: I_{IN}).

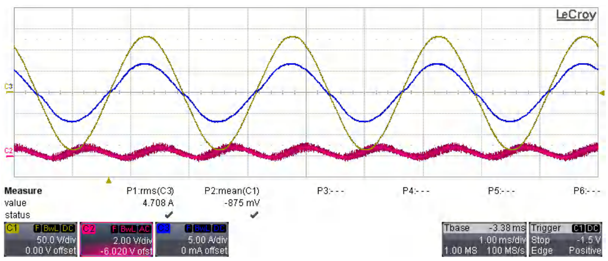


Figure 3-6. V_{IN} = 96 VAC, F = 400 Hz

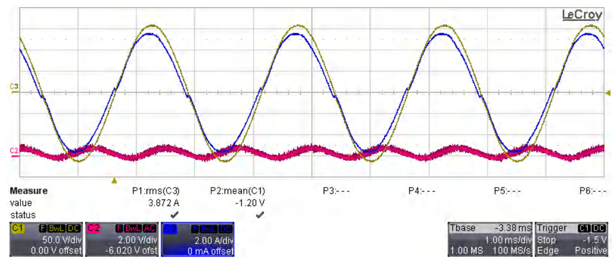


Figure 3-7. V_{IN} = 115 VAC, F = 400 Hz

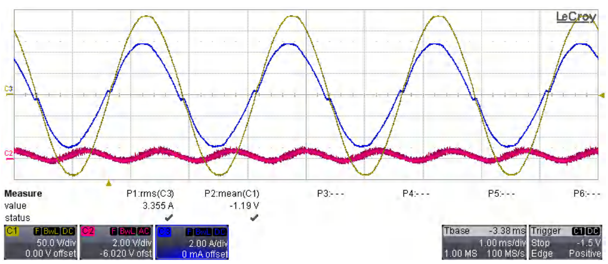


Figure 3-8. V_{IN} = 134 VAC, F = 400 Hz

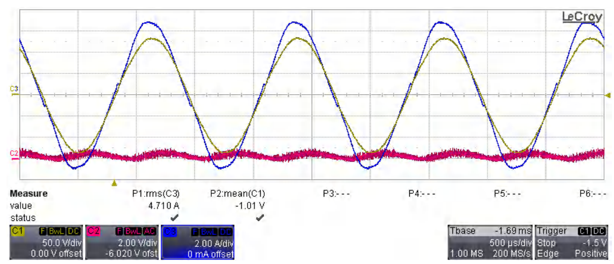


Figure 3-9. V_{IN} = 96 VAC, F = 800 Hz

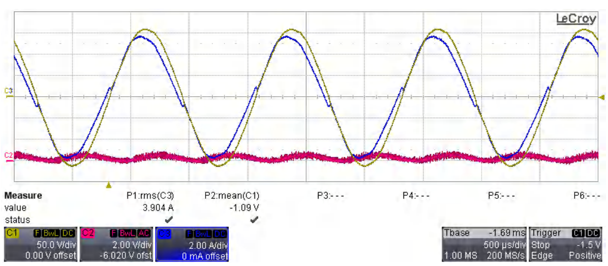


Figure 3-10. V_{IN} = 115 VAC, F = 800 Hz

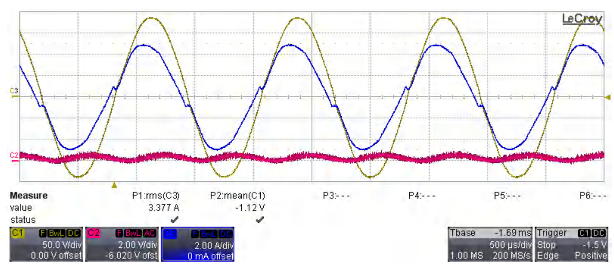


Figure 3-11. V_{IN} = 134 VAC, F = 800 Hz

3.4 Load Transients

V_{OUT} and V_{PFC} output voltages, during load transients, were measured by supplying the converter at 96 VAC and 115 VAC, with F_{MAINS} = 400 Hz. The load was switched between 5 A and 13 A. For all waveforms in Figure 3-12 and Figure 3-13, the bandwidth limit of the oscilloscope was set to 20 MHz.

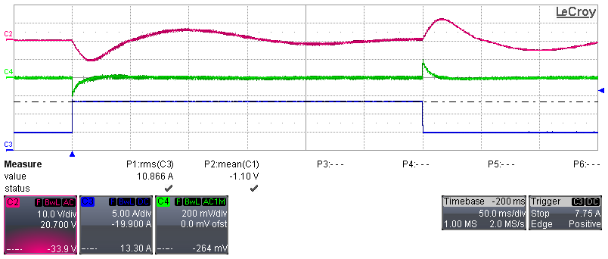


Figure 3-12. V_{IN} = 96 VAC (C2: V_{PFC}, C3: I_{OUT}, C4: V_{OUT})

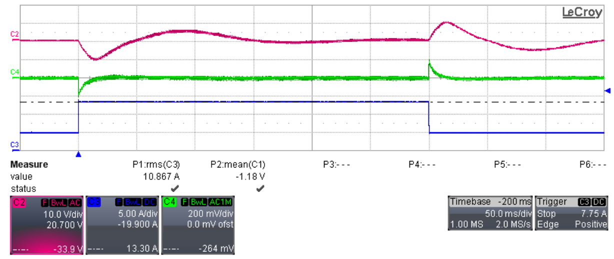


Figure 3-13. V_{IN} = 115 VAC (C2: V_{PFC}, C3: I_{OUT}, C4: V_{OUT})

3.5 Inrush Current

During this test, the AC source was turned on and input current and voltage, as well as the PFC voltage, were measured (with 20-MHz BWL). Figure 3-14 and Figure 3-15 show the inrush current limitation during start-up at V_{IN} = 115 VAC, F = 400 Hz, no load.

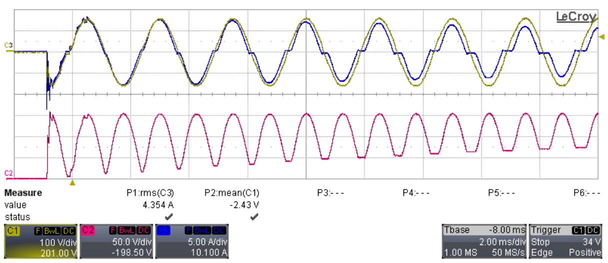


Figure 3-14. Time Division: 2 ms/div, (C2: V_{PFC}, C1: V_{IN}, C3: I_{IN})

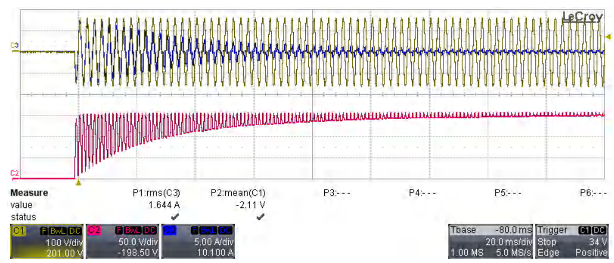


Figure 3-15. Time Division: 20 ms/div, (C2: V_{PFC}, C1: V_{IN}, C3: I_{IN})

3.6 Start-Up Sequence

After the V_{CC} capacitor C60 is charged, the converter starts up, supplying the LLC and PFC stage. Here V_{IN} was 115 VAC and the frequency was 400 Hz. The screenshots in Figure 3-16 through Figure 3-18 were taken, in no-load condition, 8-A and 13-A load.

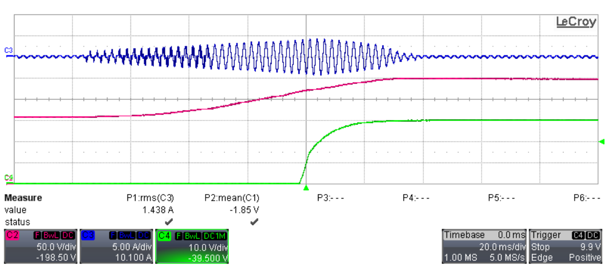


Figure 3-16. No Load (C2: V_{PFC}, C4: V_{OUT}, C3: I_{IN})

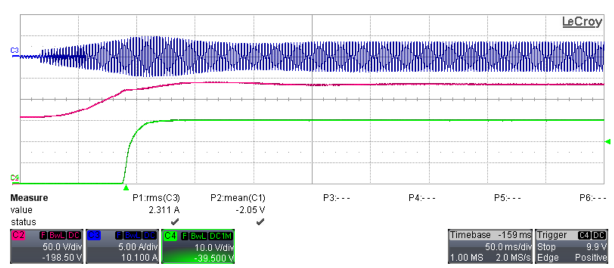


Figure 3-17. 8-A Load (C2: V_{PFC}, C4: V_{OUT}, C3: I_{IN})

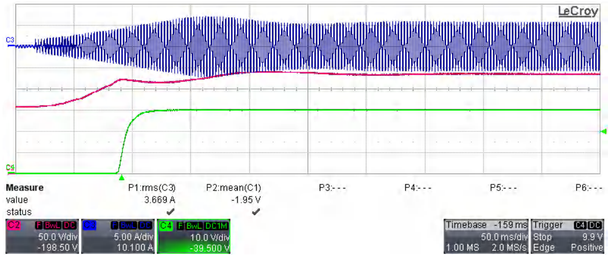


Figure 3-18. 13-A Load (C2: V_{PFC}, C4: V_{OUT}, C3: I_{IN})

3.7 Shutdown

The output voltage of 30 V_{OUT} and PFC stage have been measured by switching off the AC voltage source while the load was set to 5 A, V_{IN} to 115 VAC and the frequency to 400 Hz. Figure 3-19 shows the behavior of V_{PFC}, V_{IN}, V_{OUT}, and I_{IN}.

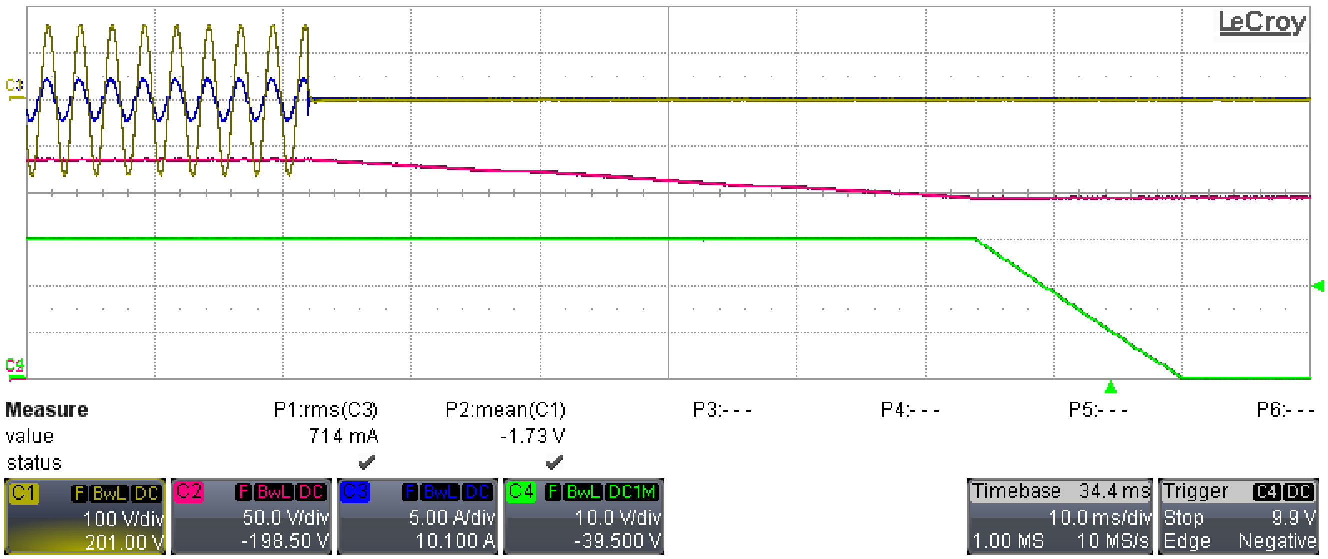


Figure 3-19. Behavior of V_{PFC} and V_{OUT} During Shutdown (C1: V_{IN}, C2: V_{PFC}, C3: I_{IN}, C4: V_{OUT})

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