Test Report: PMP31164

100W CCM PFC Boost Converter Reference Design for Avionics

Description

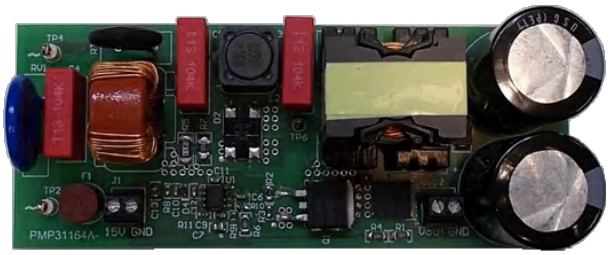
This board is a compact, 360V_{DC}, 100W reference design for avionics applications, working with mains voltage range 90V_{AC} to 130V_{AC} and frequency range 400Hz to 800Hz. A single-phase continuous conduction mode (CCM) power factor correction (PFC) based on the UCC28180 is used to correct power factor and at the same time to minimize harmonic content of input current.

Features

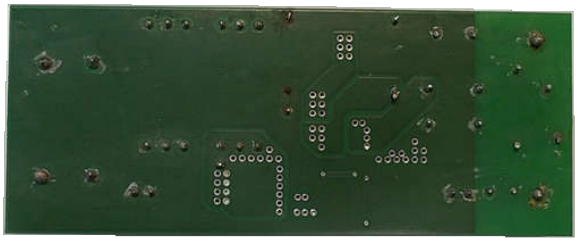
- Simple single-phase PFC Boost with UCC28180
- Designed for avionics applications
- Covers 400Hz to 800Hz range
- 118.75mm × 47.63mm PCB

Applications

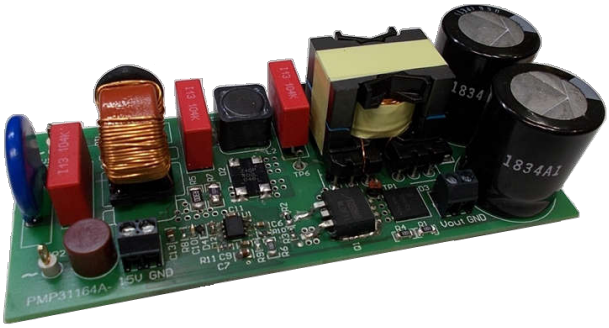
- Standalone avionics PFC



Top of Board



Bottom of Board



Angled View of Board

1 Test Prerequisites

1.1 Voltage and Current Requirements

Table 1-1. Voltage and Current Requirements

Parameter	Specifications
Input Voltage	$90V_{AC}$ to $130V_{AC}$
Frequency	400Hz to 800Hz
Output Voltage	$360V_{DC}$
Output Current	280mA

1.2 Required Equipment

- $0V_{AC}$ to $150V_{AC}$, 400Hz to 800Hz (minimum current limit $2A_{RMS}$) AC constant voltage source (VS1)
- Isolated electronic load with constant current range 0A to 1A, or power resistor (covering the range 1.2kΩ to 10kΩ)
- 12V isolated power supply (VS2)
- Oscilloscope (minimum 100MHz bandwidth)
- Current probe (minimum 100kHz bandwidth)
- Infrared camera

1.3 Testing Conditions

WARNING

High Voltage: Power supply is not isolated from AC input. Failure to follow warnings and instructions can result in personal injury, property damage, or death due to electrical shock and burn hazards.

1. Connect the source VS1 to TP2 and TP4
2. Connect the load to connector J2, with positive to pin 1
3. Connect the source VS2 to J1, with positive to pin 1
4. Attach a current probe in series to VS1 to measure the input current
5. Turn on VS1 (accepted range: $90V_{AC}$ to $130V_{AC}$) and VS2 without any sequence restriction
6. Increase the load current on the output
7. After turn off, discharge the capacitors C1 and C2 by means of an external resistor (see High Voltage Warning) or active discharge circuit.

1.4 Considerations

The reference design PMP31164 Rev_B was built on PMP31164 Rev_A PCB.

1.5 Dimensions

The board dimensions of the two-layer board are 118.75mm × 47.63mm, height 26mm (electrolytic capacitors C1 and C2). The copper weight is 1oz on each layer.

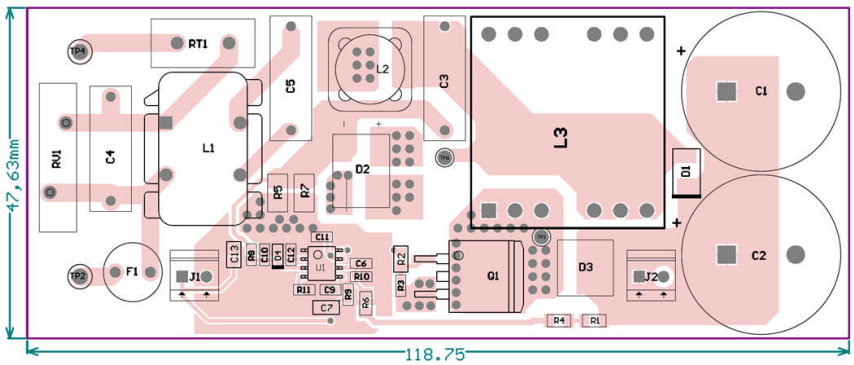


Figure 1-1. Board Outline

2 Testing and Results

2.1 Efficiency

The graphs in Figure 2-1 and Figure 2-2 show the converter efficiency versus output power, AC source voltage and frequency.

The input voltage was set to $90V_{AC}$, $115V_{AC}$, and $130V_{AC}$, while the mains frequency was respectively 400Hz and 800Hz.

2.1.1 400Hz Mains Frequency

2.1.1.1 Efficiency Graph

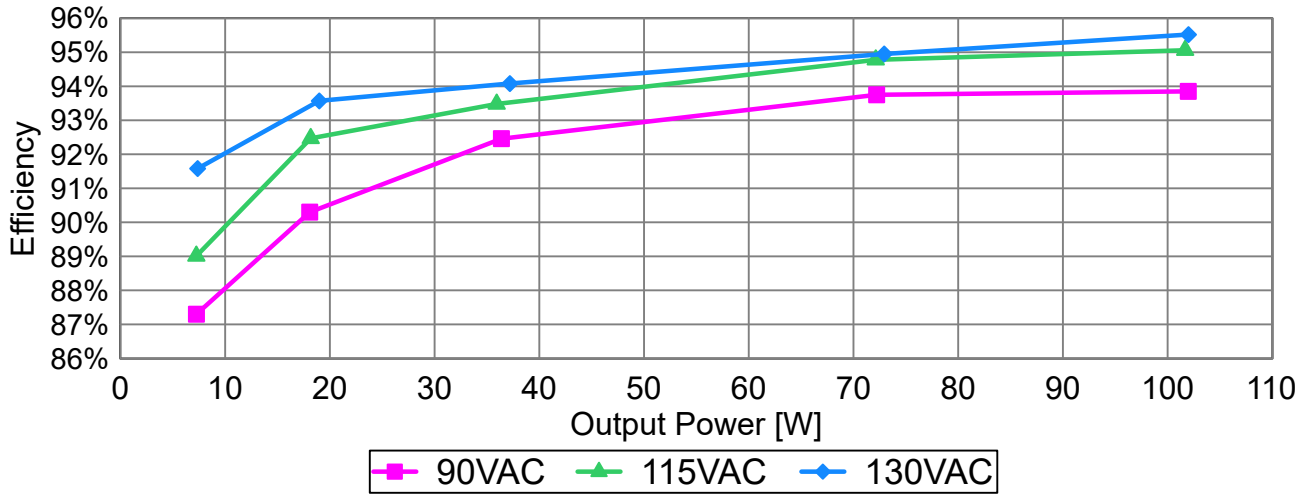


Figure 2-1. Efficiency Graph; 400Hz

2.1.1.2 Efficiency, Power Factor, and Input Current Harmonic Distortion (iTHD) Data

The efficiency graph report all data taken from following tables with the input voltage selected between $115V_{AC}$, $90V_{AC}$, and $130V_{AC}$, while the frequency was set to 400Hz.

2.1.1.2.1 $115V_{AC}$ Input Voltage

Efficiency Values for $115V_{AC}$ Input Voltage and 400Hz

P_{IN} (W)	V_{OUT} (V)	I_{OUT} (mA)	iTHD (%)	Power Factor	P_{OUT} (W)	Efficiency (%)
0.241	359.1	0.0	0.00	0.0000	0.00	0.00%
8.147	359.0	20.2	20.5	0.6594	7.25	89.01%
19.65	359.1	50.6	7.64	0.8782	18.17	92.47%
38.43	359.3	100.0	5.35	0.9583	35.93	93.48%
76.09	359.5	200.6	3.83	0.9878	72.12	94.78%
106.95	359.9	282.5	3.57	0.9939	101.67	95.06%

2.1.1.2.2 90V_{AC} Input Voltage

Efficiency Values for 90V_{AC} Input Voltage and 400Hz

P_{IN} (W)	V_{OUT} (V)	I_{OUT} (mA)	iTHD (%)	Power Factor	P_{OUT} (W)	Efficiency (%)
0.285	359.3	0.0	0.00	0.0000	0.00	0.00%
8.314	359.3	20.2	19.2	0.8217	7.26	87.30%
20.02	359.4	50.3	8.77	0.9468	18.08	90.30%
39.35	359.5	101.2	4.71	0.9841	36.38	92.46%
77.03	359.8	200.7	4.09	0.9957	72.21	93.75%
108.66	360.2	283.1	4.38	0.9979	101.97	93.85%

2.1.1.2.3 130V_{AC} Input Voltage

Efficiency Values for 130V_{AC} Input Voltage and 400Hz

P_{IN} (W)	V_{OUT} (V)	I_{OUT} (mA)	iTHD (%)	Power Factor	P_{OUT} (W)	Efficiency (%)
0.219	360.1	0.0	0.00	0.0000	0.00	0.00%
8.056	359.9	20.5	20.8	0.5621	7.38	91.58%
20.30	359.7	52.8	13.18	0.8472	18.99	93.57%
39.53	359.7	103.4	5.59	0.9396	37.19	94.08%
76.81	359.8	202.7	3.92	0.9814	72.93	94.95%
106.77	360.0	283.3	3.50	0.9898	101.99	95.52%

2.1.2 800Hz Mains Frequency

2.1.2.1 Efficiency Graph

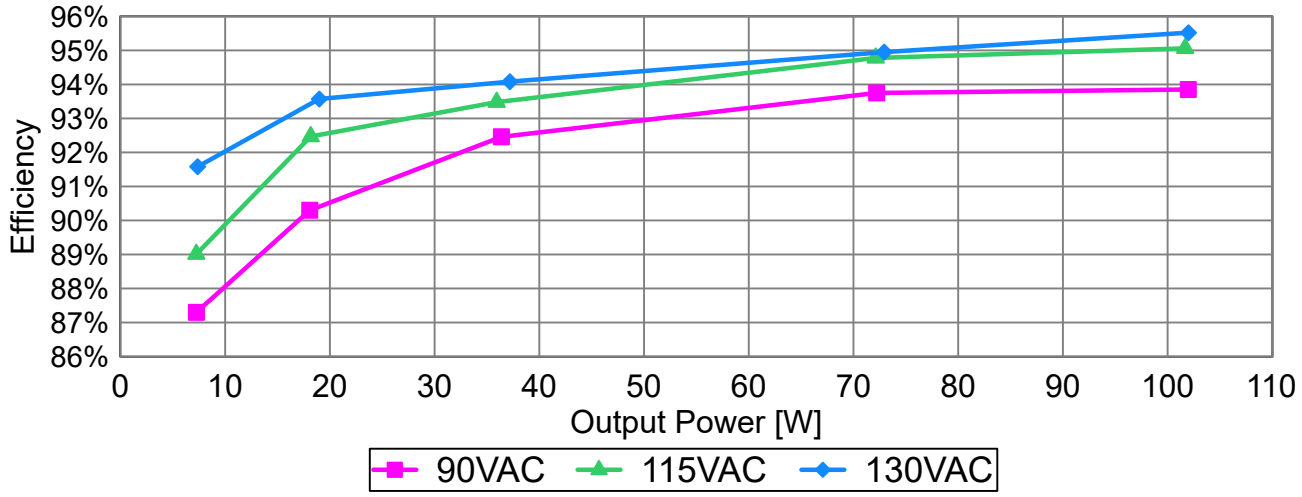


Figure 2-2. Efficiency Graph; 800Hz

2.1.2.2 Efficiency, Power Factor, and Input Current Harmonic Distortion Data

The efficiency graph report all data taken from the following tables with the input voltage selected between $115V_{AC}$, $90V_{AC}$, and $130V_{AC}$, while the frequency was set to 800Hz.

2.1.2.2.1 $115V_{AC}$ Input Voltage

Efficiency Values for $115V_{AC}$ Input Voltage and 800Hz

P_{IN} (W)	V_{OUT} (V)	I_{OUT} (mA)	iTHD (%)	Power Factor	P_{OUT} (W)	Efficiency (%)
0.279	358.8	0.0	0.00	0.0000	0.00	0.00%
8.237	359.0	20.2	22.5	0.4108	7.25	88.04%
19.71	359.1	50.4	14.54	0.7088	18.10	91.82%
38.80	359.2	100.5	8.36	0.8700	36.10	93.04%
76.50	359.5	201.4	5.19	0.9577	72.40	94.64%
106.20	359.8	280.3	4.39	0.9786	100.85	94.96%

2.1.2.2.2 $90V_{AC}$ Input Voltage

Efficiency Values for $90V_{AC}$ Input Voltage and 800Hz

P_{IN} (W)	V_{OUT} (V)	I_{OUT} (mA)	iTHD (%)	Power Factor	P_{OUT} (W)	Efficiency (%)
0.254	359.8	0.0	0.00	0.0000	0.00	0.00%
8.373	359.6	20.3	21.7	0.6032	7.30	87.18%
20.08	359.5	50.3	9.23	0.8334	18.08	90.08%
40.37	359.6	103.8	6.04	0.9467	37.33	92.47%
77.04	359.8	200.6	4.95	0.9858	72.18	93.69%
108.10	360.1	281.5	4.97	0.9946	101.37	93.77%

2.1.2.2.3 $130V_{AC}$ Input Voltage

Efficiency Values for $130V_{AC}$ Input Voltage and 800Hz

P_{IN} (W)	V_{OUT} (V)	I_{OUT} (mA)	iTHD (%)	Power Factor	P_{OUT} (W)	Efficiency (%)
0.235	360.1	0.0	0.00	0.0000	0.00	0.00%
8.462	359.9	20.4	23.1	0.3441	7.34	86.76%
19.63	359.7	50.7	18.69	0.6349	18.24	92.93%
39.32	359.7	102.5	10.27	0.8204	36.87	93.76%
76.04	359.8	201.0	6.03	0.9336	72.32	95.11%
107.00	360.0	283.7	4.78	0.9646	102.13	95.45%

2.2 Thermal Images

The picture and table below show the thermal picture of the converter supplied at 115V_{AC} and 400Hz, taken after 30minutes soak time, at 25°C ambient temperature. The board runs at full load in still air condition, placed horizontal on the bench.

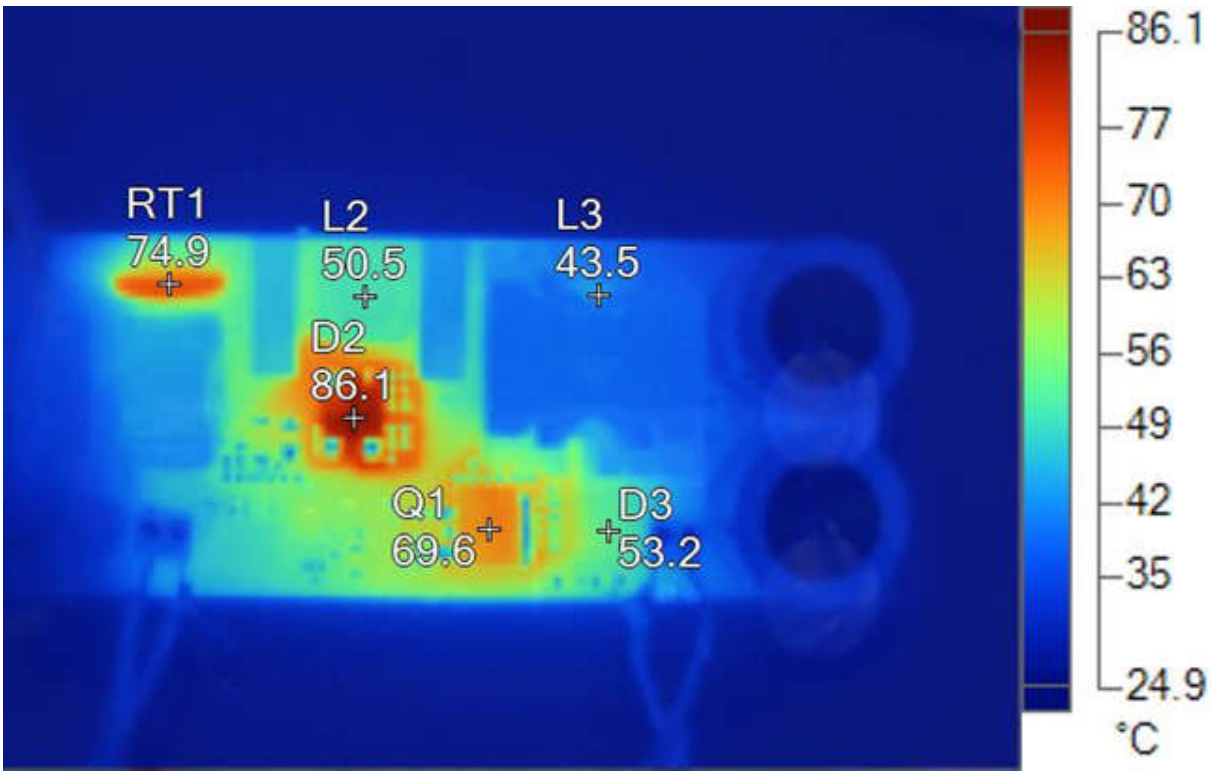


Figure 2-3. Thermal Image

Table 2-1. Main Image Markers

Name	Temperature	Emissivity	Background
RT1	74.9°C	0.96	25.5°C
D2	86.1°C	0.96	25.5°C
Q1	69.6°C	0.96	25.5°C
L3	43.5°C	0.96	25.5°C
L2	50.5°C	0.96	25.5°C
D3	53.2°C	0.96	25.5°C

2.3 Power Factor

The power factor value was measured by varying output power of the converter in the whole range, for different V_{AC}, repeated at 400Hz and 800Hz mains frequency.

2.3.1 400Hz Mains Frequency

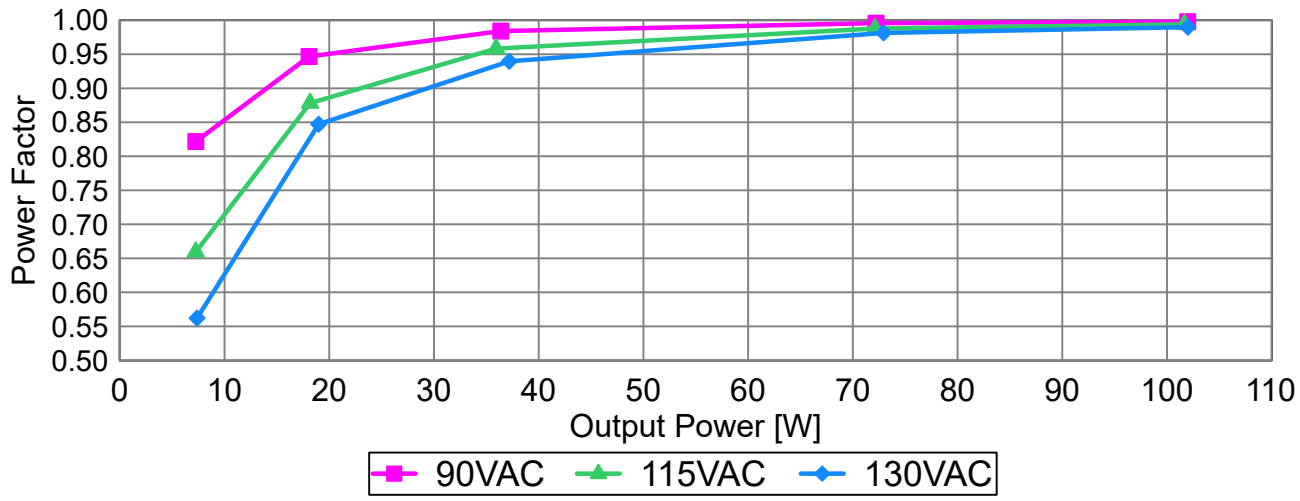


Figure 2-4. Power Factor; 400Hz

2.3.2 800Hz Mains Frequency

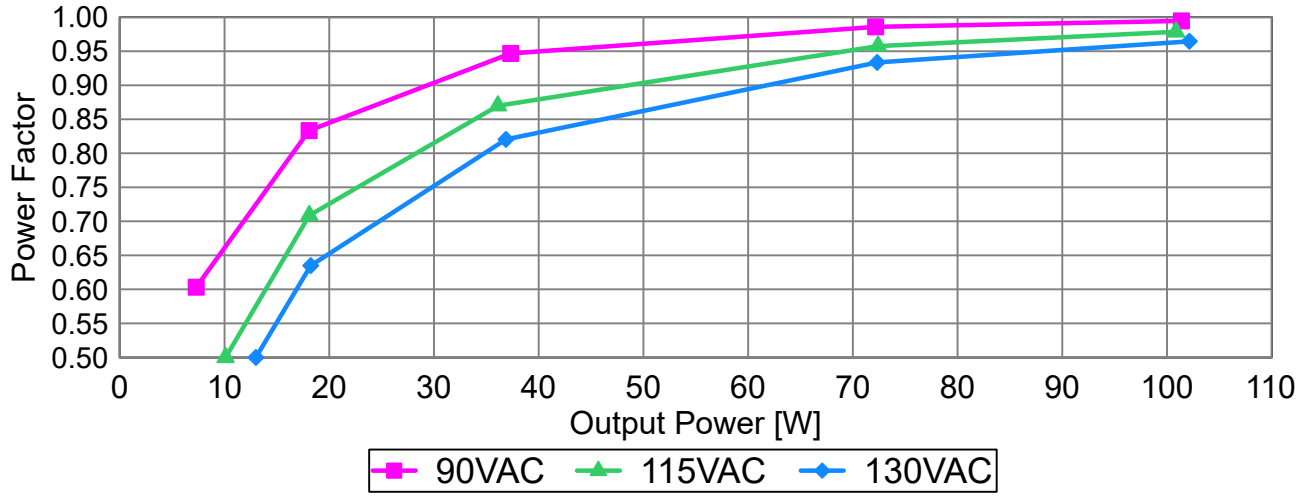


Figure 2-5. Power Factor; 800Hz

2.4 Total Harmonic Distortion (iTHD)

2.4.1 400Hz Mains Frequency

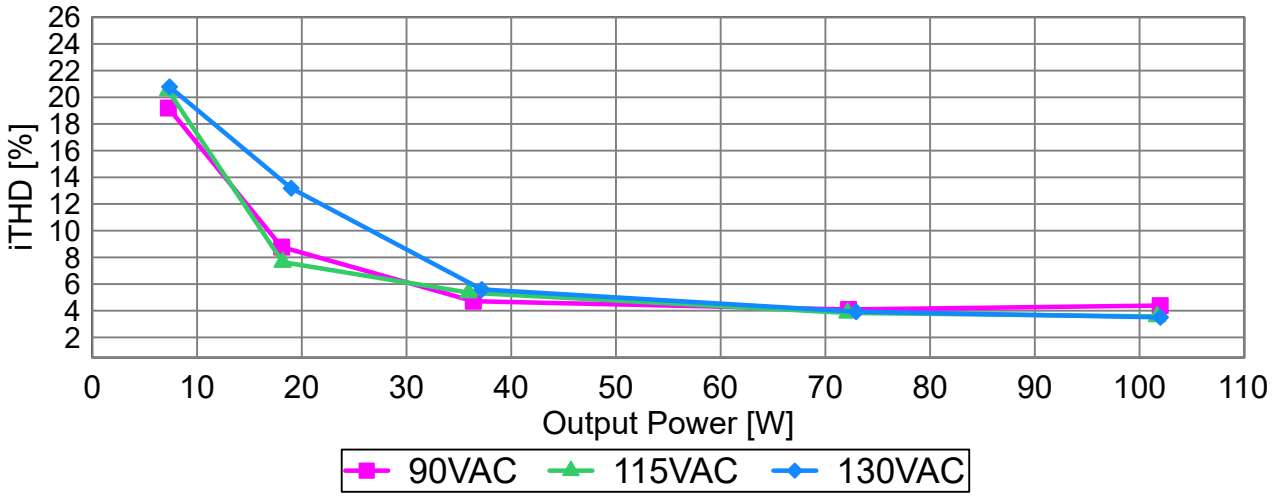


Figure 2-6. Total Harmonic Distortion (iTHD) at 400Hz

2.4.2 800Hz Mains Frequency

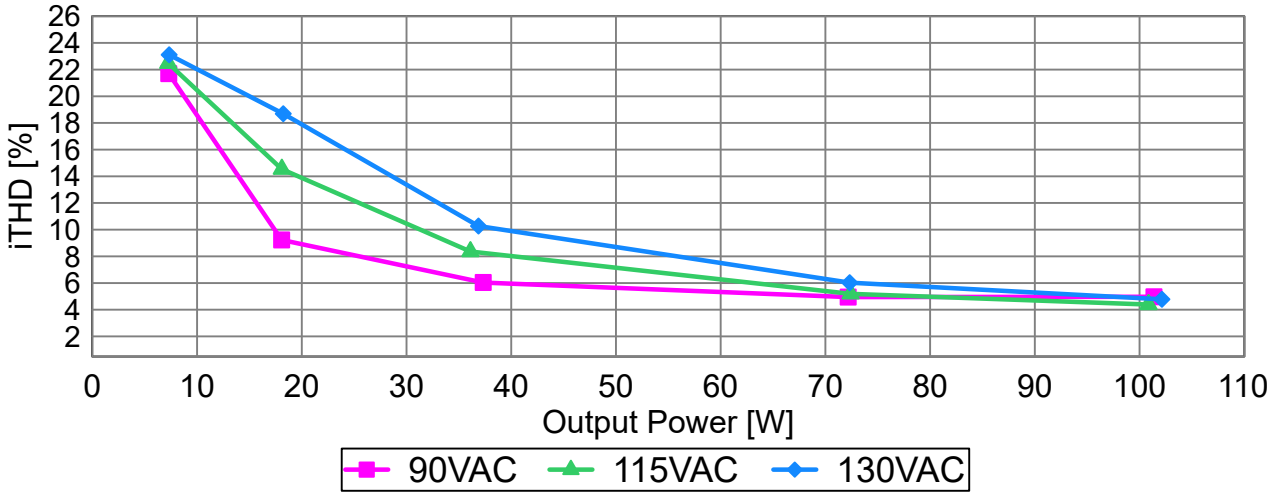


Figure 2-7. Total Harmonic Distortion (iTHD) at 800Hz

2.5 Static Output Voltage Variation versus Load

The output voltage regulation of the converter versus load current with frequency is shown in Figure 2-8 (400Hz) and Figure 2-9 (800Hz).

2.5.1 400Hz Mains Frequency

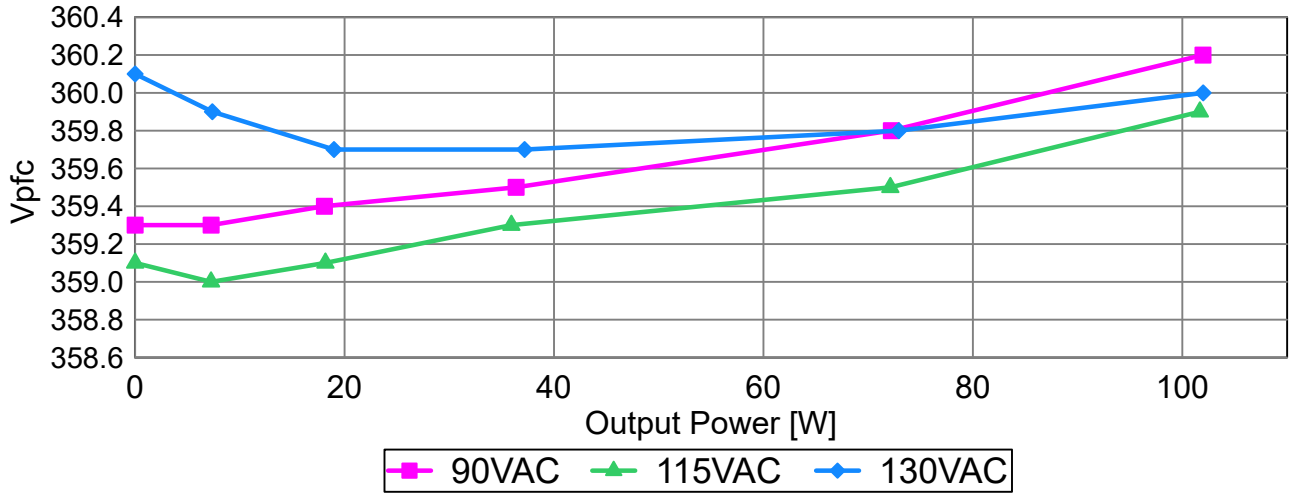


Figure 2-8. V_{pfc}; 400Hz

2.5.2 800Hz Mains Frequency

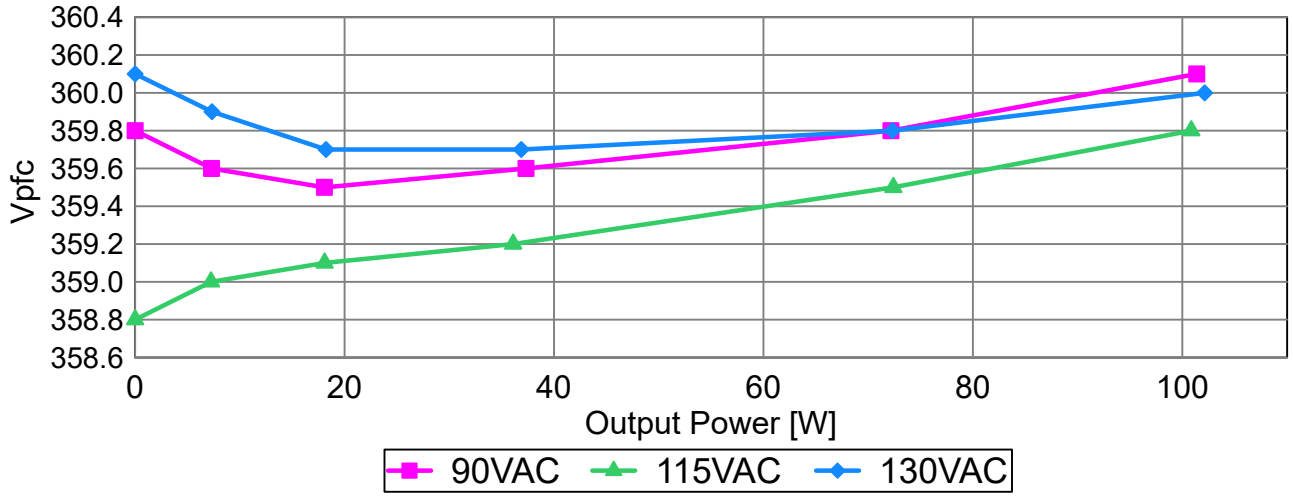


Figure 2-9. V_{pfc}; 800Hz

3 Waveforms

3.1 Switching Waveform on the Main FET at Full Load

The switching waveform was measured by supplying the converter at $115V_{AC}$, 400Hz, and full load.

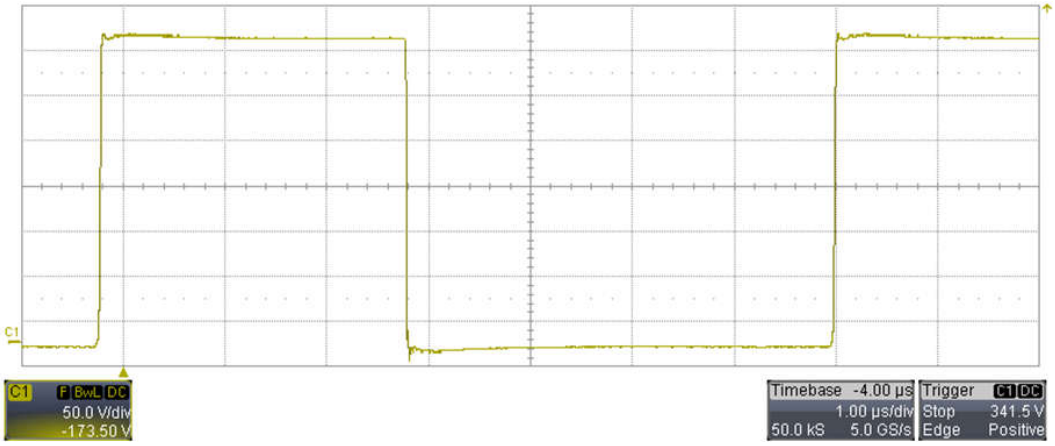


Figure 3-1. Q1 Drain to Source (50V/div, 1µs/div, 200MHz BWL)

3.2 AC Waveforms (Input Voltage and Current)

The screenshots show the input voltage and current of the PFC stage, at $90V_{AC}$, $115V_{AC}$, and $130V_{AC}$, with mains frequency = 400Hz and 800Hz in full load condition (all waveforms with 20MHz BWL).

The following setup of the scope was used for all waveforms in this section which are:

- **C1: AC input voltage (50V/div, DC coupling)**
- **C2: AC input current (500mA/div, DC coupling)**

3.2.1 400Hz Mains Frequency

3.2.1.1 $90V_{AC}$ Input Voltage

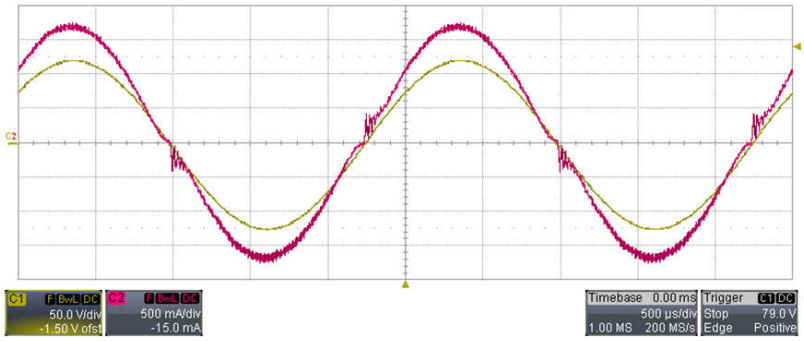


Figure 3-2. $90V_{AC}$ Input Voltage, 400Hz, 500µs/div

3.2.1.2 $115V_{AC}$ Input Voltage

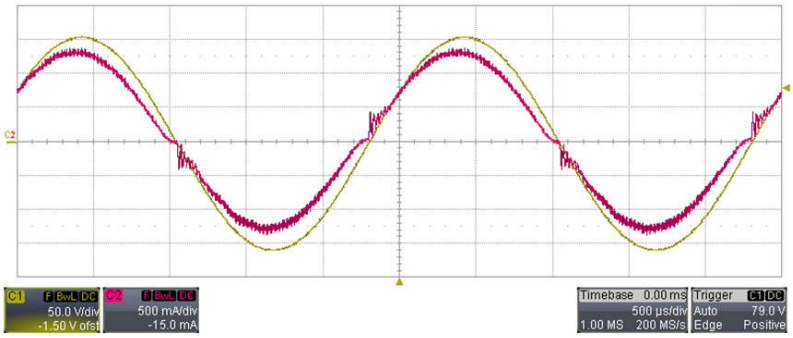


Figure 3-3. $115V_{AC}$ Input Voltage, 400Hz, 500µs/div

3.2.1.3 $134V_{AC}$ Input Voltage

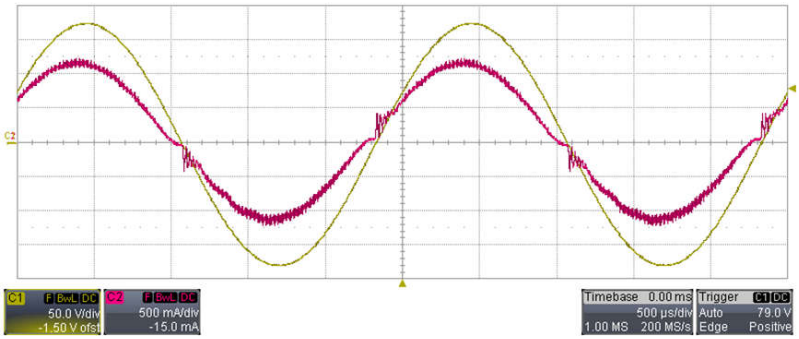


Figure 3-4. $134V_{AC}$ Input Voltage, 400Hz, 500µs/div

3.2.2 800Hz Mains Frequency

3.2.2.1 90V_{AC} Input Voltage

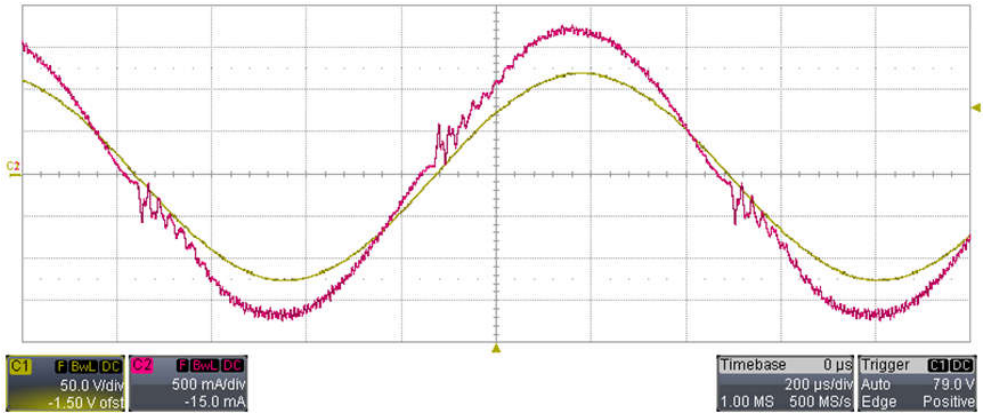


Figure 3-5. 90V_{AC} Input Voltage, 800Hz, 200µs/div

3.2.2.2 115V_{AC} Input Voltage

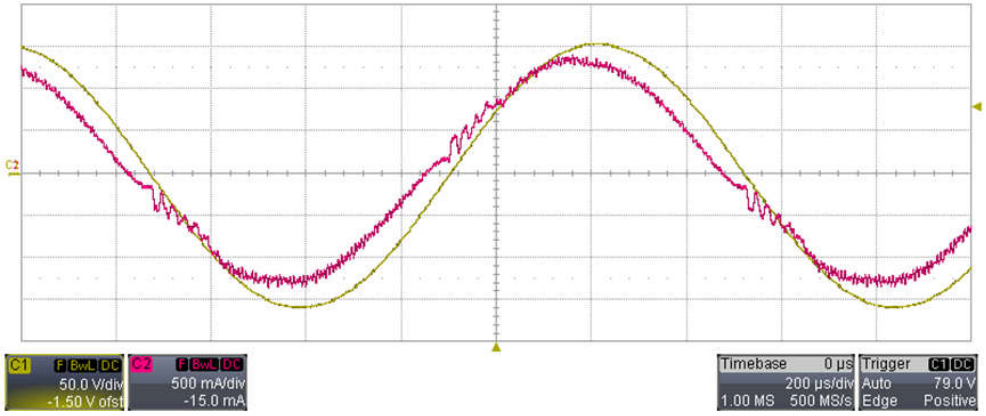


Figure 3-6. 115V_{AC} Input Voltage, 800Hz, 200µs/div

3.2.2.3 134V_{AC} Input Voltage

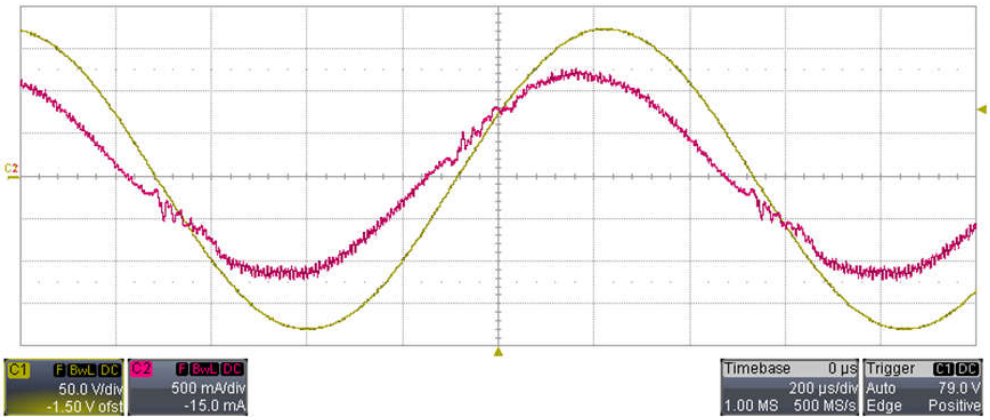


Figure 3-7. 134V_{AC} Input Voltage, 800Hz, 200µs/div

3.3 Output Voltage Ripple

The PFC output voltage ripple was measured by supplying the converter at $115V_{AC}$, 400Hz at full load; the bandwidth limit of the scope (BWL) was set to 20MHz.

- **C1: AC input voltage (100V/div, 1ms/div, DC coupling)**
- **C3: DC output voltage (200mV/div, AC coupling)**

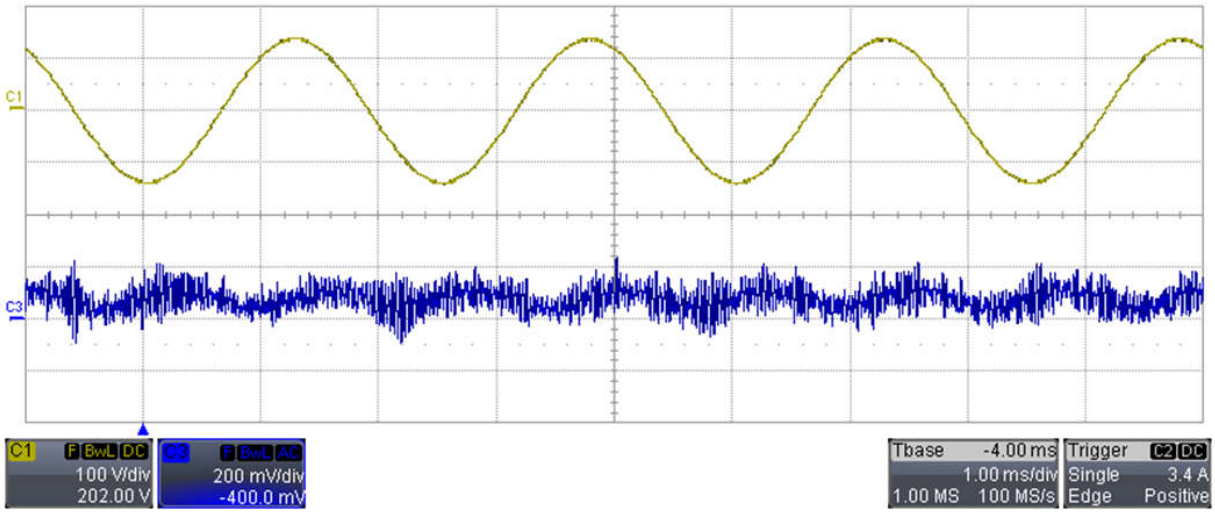


Figure 3-8. C3 DC Output Voltage, C1 AC Input Voltage

3.4 Load Transients

The output voltage variation, during load transients, was measured by supplying the converter at $115V_{AC}$ with F_{MAINS} = 400Hz. The load was switched between 100mA and 280mA (35.7% to 100% of the nominal load). This test was performed by connecting a fixed 3.6kΩ resistor (100mA fixed load) to the output and switching a 2kΩ on and off in parallel to the first resistor. For all waveforms the bandwidth limit of the oscilloscope was set to 20MHz.

- **C3: Output voltage (10V/div, 20ms/div, AC coupling)**
- **C2: Output current (100mA/div, DC coupling)**

3.4.1 100mA to 280mA

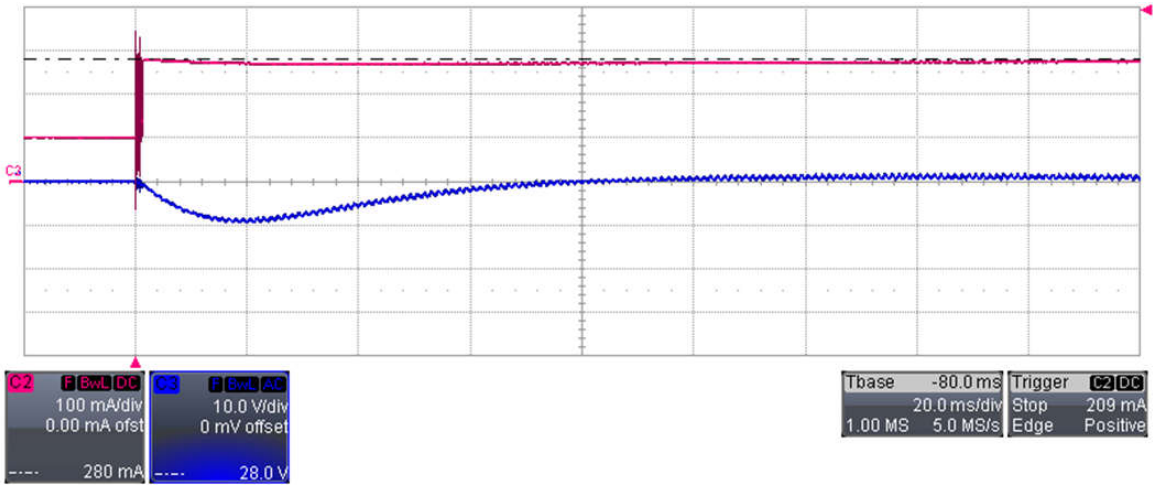


Figure 3-9. Output Current Switched From 100mA to 280mA

3.4.2 280mA to 100mA

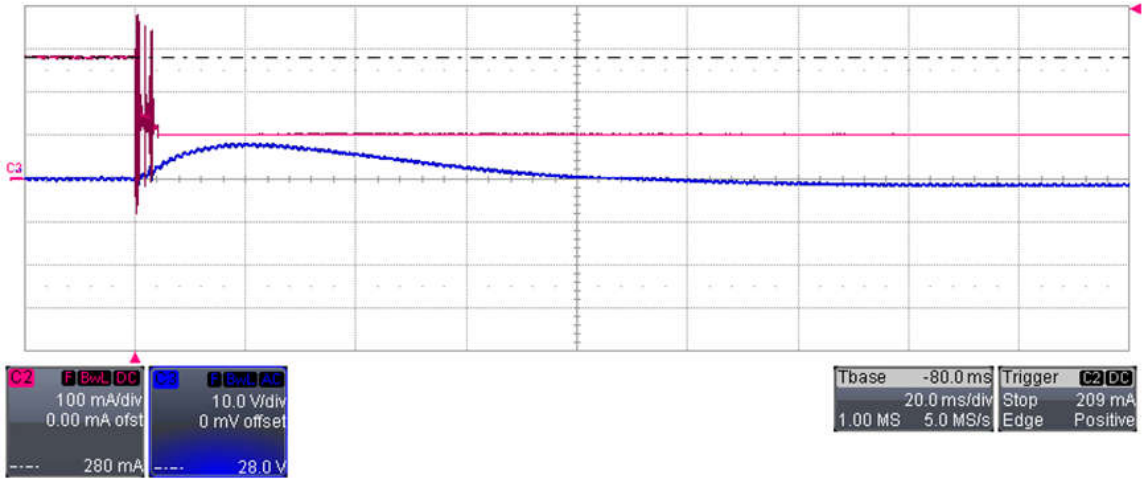


Figure 3-10. Output Current Switched From 280mA to 100mA

3.5 Inrush Current and Start-Up

During this test, the AC source was turned on with bias voltage already on. Both input current and voltage, as well as the output voltage, were measured (with 20MHz BWL). VAC and frequency were set respectively to 115V_{AC} and 400Hz.

- **C3: Output voltage (100V/div, 20ms/div, DC coupling)**
- **C1: Input AC voltage (100V/div, DC coupling)**
- **C2: Input AC current (10A/div, DC coupling)**

3.5.1 Full Load

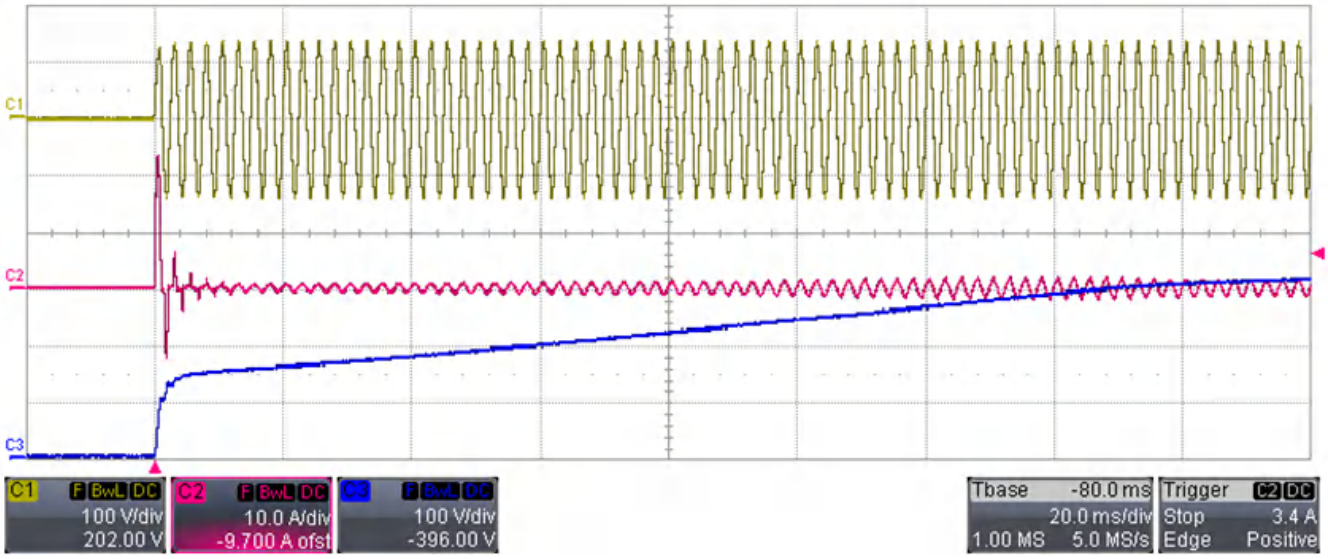


Figure 3-11. Start-Up With Full Load

3.5.2 Zero Load

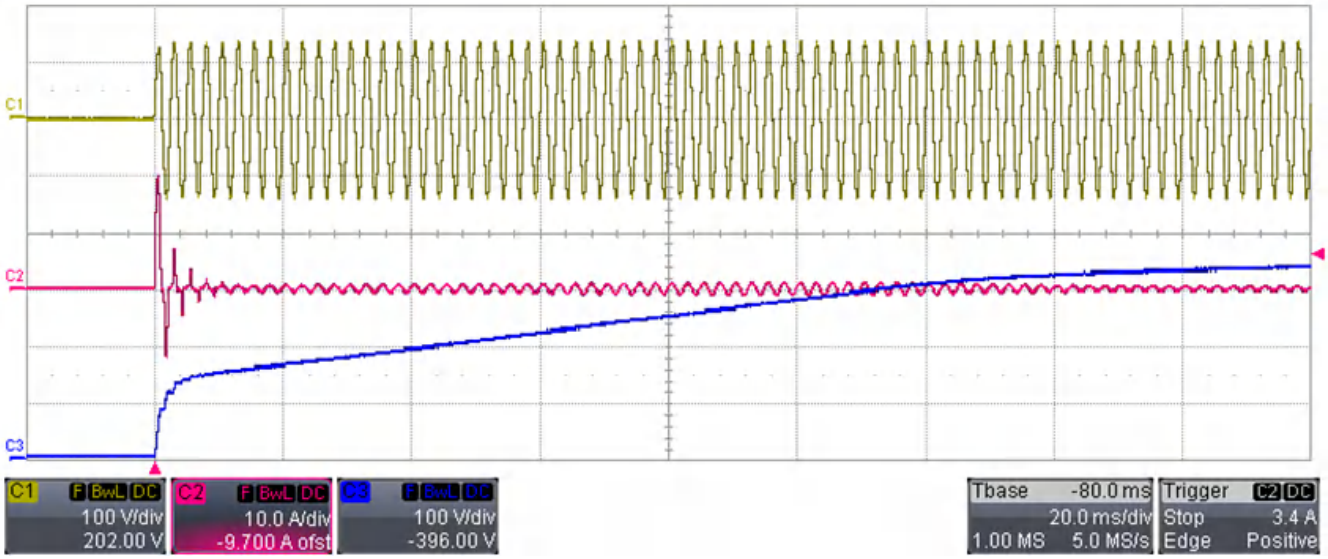


Figure 3-12. Start-Up With Zero Load

3.6 Input AC Current Measurements: Compliance to DO160 Harmonic Limits

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

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

For all even harmonics with order greater than 4, an absolute limit of 10mA was considered, regardless on the order number (DO-160-G limits). All graphs show each harmonic current (in mA) versus number of orders.

3.6.1 400Hz Mains Frequency

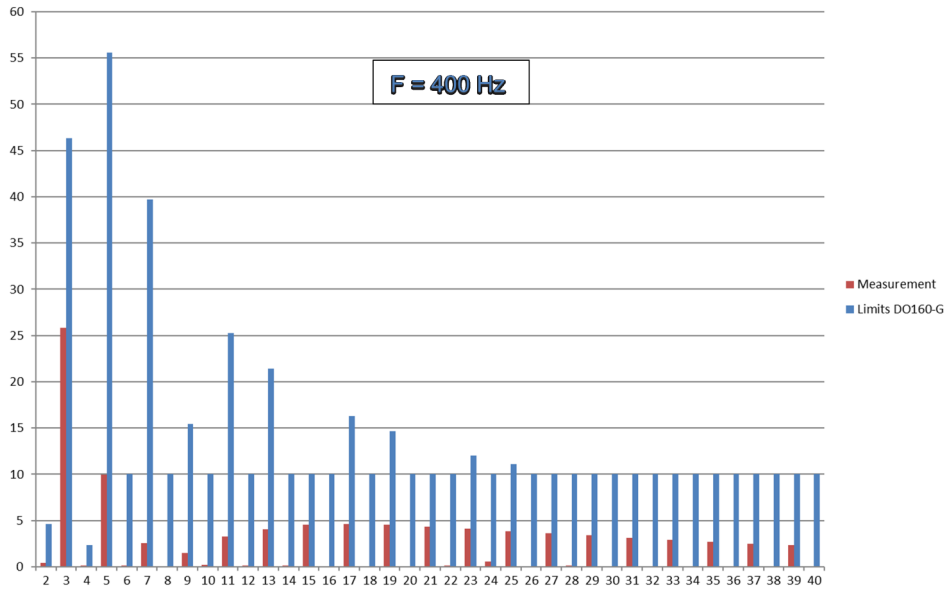


Figure 3-13. Harmonics of the Input Current at 400Hz Mains Frequency

3.6.2 600Hz Mains Frequency

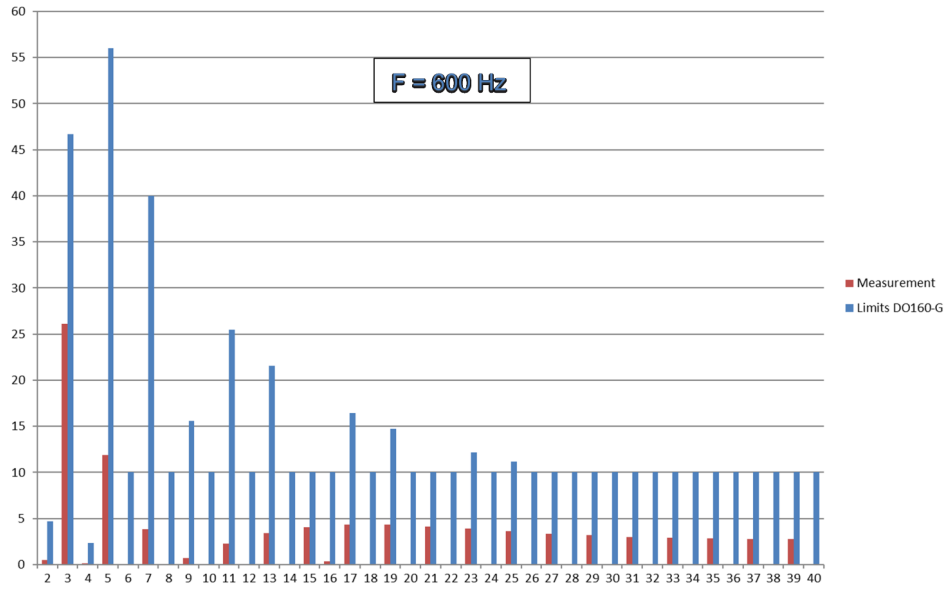


Figure 3-14. Harmonics of the Input Current at 600Hz Mains Frequency

3.6.3 800Hz Mains Frequency

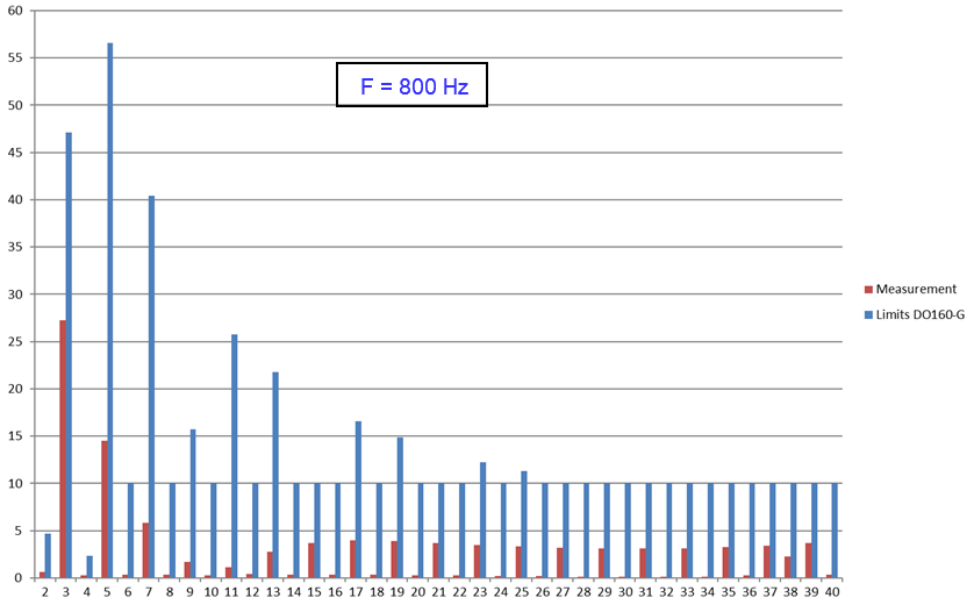


Figure 3-15. Harmonics of the Input Current at 800Hz Mains Frequency

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