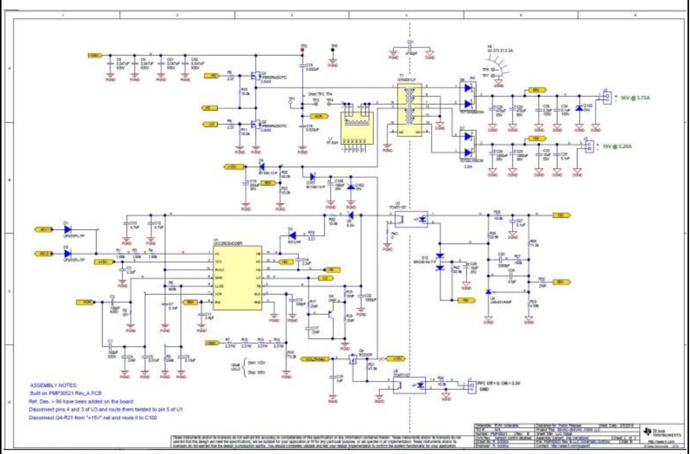
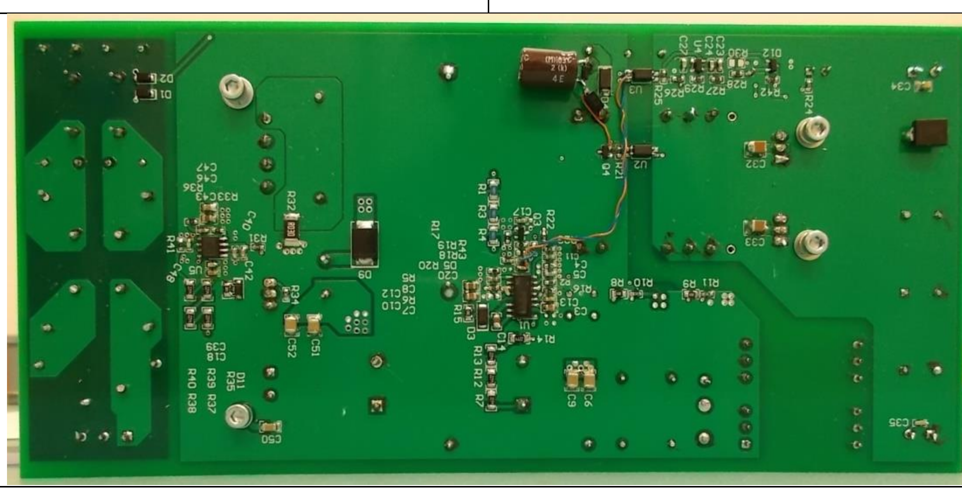
Test Report: PMP30521
93% Full-Load Efficiency (60% at 125 mW), 310-W Industrial AC/DC Reference Design

Description

This reference design is a compact and high efficient two-stage power supply. The front-end stage is a CCM power factor correction (PFC) based on UCC28180.The second stage is based on UCC256304, which drives a resonant 310 W LLC converter with two outputs, 19 V and 56 V. The board does not need any auxiliary supply and draws only 250 mW from mains (with PFC off), while supplying 150 mW load.

The reference design PMP30521 Rev_B has been built on PMP30521 Rev_A PCB.





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1 Test Prerequisites

1.1 Voltage and Current Requirements

Table 1. Voltage and Current Requirements

PARAMETER	SPECIFICATIONS
Input Voltage	90 VAC – 264 VAC
Output #1, Voltage:	19 VDC
Output #1, Current:	5.26 A
Output #2, Voltage:	56 VDC
Output #2, Current:	3.75 A

1.2 Required Equipment

- 0…270 VAC, (minimum current limit 5 Arms), AC constant voltage source (VS1)
- 2 x Electronic loads, (constant current range 0…6 A)
- Oscilloscope (min. 100 MHz bandwidth)
- Current probe (min. 100 KHz bandwidth)
- Optional: infrared camera

1.3 Testing Conditions

The power supply has two outputs and the feedback loop is closed to 19Vout (Output #1). It has been designed to work also from zero to 100 W with only 19Vout loaded and the 56Vout (Output #2) unloaded. A minimum load (≥ 150 mW) on 19Vout, for correct Vout regulation, should be always present. From 10 W up to full load, the PFC should be enabled by supplying a voltage > 3.3 V on J1; this can be done by adding a switch connecting pin 1 of J1 to 19Vout, or connecting pin 1of J1 to a digital output of a microcontroller. In order to improve the efficiency at light load, the PFC stage can be kept off from 150 mW to 10 W load.

a) Connect the source VS1 to J4-3 and J4-1; earth connection to J4-2.
b) Connect the loads to J2 (1-2) and J3 (2-1)
c) Attach current probe to the jumper that connects TP3 and TP4, to measure the resonant current.
d) Connect a 150 mW minimum load to 19Vout
e) Turn on Vs1 (accepted range: 90 VAC…264 VAC).
f) Increase the load on the outputs.
g) Turn on the PFC stage if total output power is higher than 10 W.
h) After turn off, wait ~ 5 minutes until C44 and C45 PFC capacitors are completely discharged (warning: HIGH VOLTAGE)

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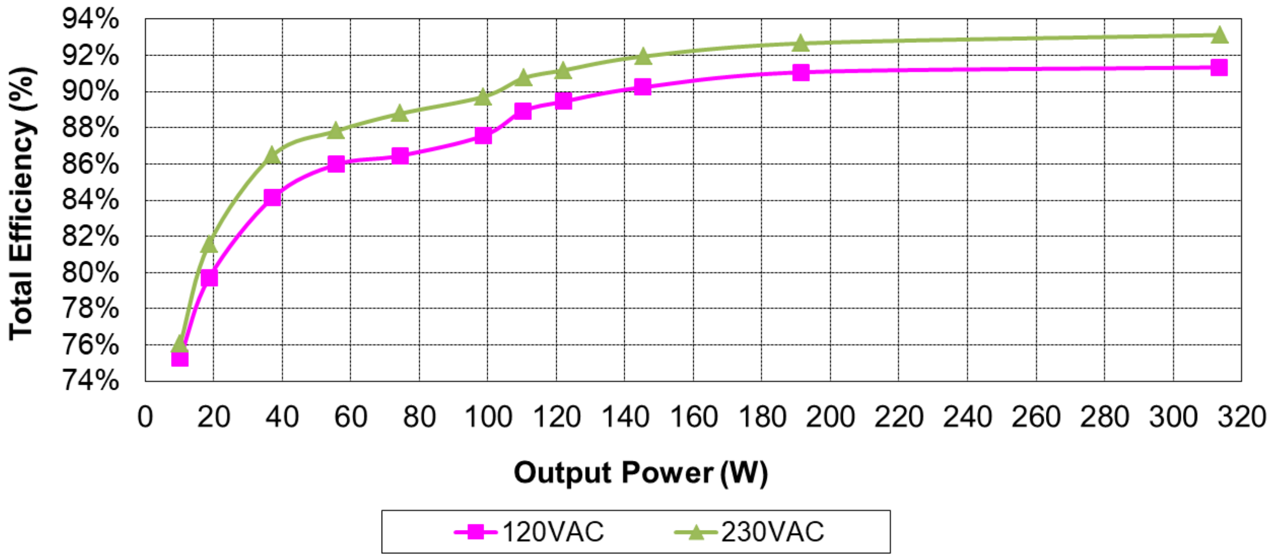
2 Testing and Results

2.1 Efficiency Graph and Data

2.1.1 Efficiency Graph:

The efficiency graph (plug to plug), versus output power, is shown below.
The input voltage has been set to 120 VAC, 60 Hz and 230 VAC, 50 Hz.



2.1.2 Efficiency Data:

The efficiency graph reports the data from the table shown below, in output power range 10 W…310 W:

Vin (AC)	Pin (W)	V_19V (V)	I_19V (mA)	V_56V (V)	I_56V (mA)	Vpfc (V)	Power Factor (%)	Pout (W)	Efficiency (%)
120	13.63	18.60	551.7	64.53	0	389.6	90.04	10.26	75.29%
120	23.41	18.60	1003	64.67	0	389.6	95.78	18.66	79.69%
120	44.26	18.61	2001	64.90	0	389.6	97.95	37.24	84.14%
120	64.88	18.61	2997	65.35	0	389.5	99.22	55.77	85.97%
120	86.02	18.61	3996	65.69	0	389.6	99.48	74.37	86.45%
120	112.65	18.62	5292	65.92	1.4	389.6	99.69	98.63	87.55%
120	124.07	18.62	5292	58.79	200.4	389.7	99.73	110.3	88.92%
120	136.48	18.63	5292	58.50	401.5	389.8	99.77	122.1	89.45%
120	161.05	18.63	5292	58.16	803.6	389.8	99.82	145.3	90.24%
120	210.26	18.65	5292	57.77	1606	390.0	99.88	191.5	91.07%
120	343.26	18.68	5292	57.08	3761	390.0	99.93	313.5	91.34%

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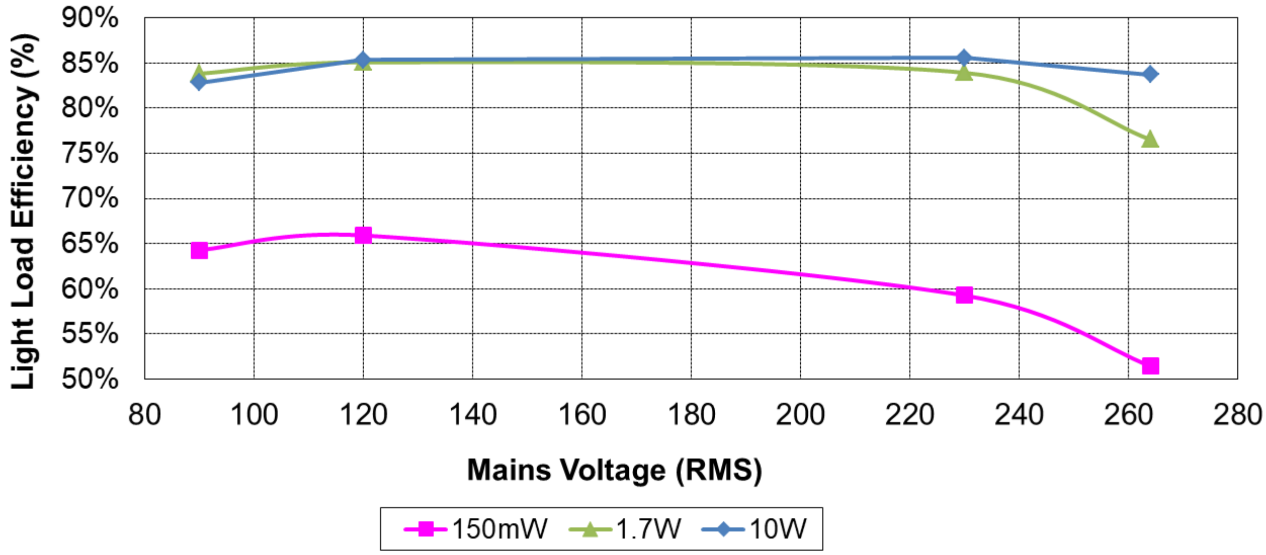
Vin (AC)	Pin (W)	V_19V (V)	I_19V (mA)	V_56V (V)	I_56V (mA)	Vpfc (V)	Power Factor (%)	Pout (W)	Efficiency (%)
230	13.50	18.60	551.7	64.66	0	389.7	58.27	10.26	76.04%
230	22.87	18.60	1003	64.77	0	389.7	74.32	18.66	81.57%
230	43.04	18.60	2001	64.95	0	389.7	90.16	37.22	86.47%
230	63.49	18.61	2996	65.38	0	389.7	93.11	55.76	87.82%
230	83.77	18.61	3996	65.77	0	389.7	95.20	74.37	88.77%
230	110.07	18.63	5291	66.05	2.7	389.7	97.21	98.75	89.72%
230	121.76	18.64	5291	58.83	201.7	390.1	97.52	110.5	90.74%
230	134.01	18.64	5291	58.54	402.6	390.1	97.84	122.2	91.18%
230	158.24	18.65	5291	58.19	804.6	390.1	98.50	145.5	91.95%
230	206.73	18.66	5291	57.80	1606	390.1	99.23	191.6	92.66%
230	336.72	18.69	5291	57.10	3760	390.1	99.58	313.6	93.13%

2.1.3 Light load Efficiency graph and data:

As anticipated, the light load performance can be improved by turning off the PFC stage. After doing that, we measured the efficiency versus load and VAC, at three fixed load levels: 150 mW, 1.7 W and 10 W, all applied to 19Vout only (therefore the 56Vout has been kept unloaded).



Vin (AC)	Pin (W)	V_19V (V)	I_19V (mA)	V_56V (V)	I_56V (mA)	Pout (W)	Efficiency (%)
90	0.2241	18.59	7.75	58.35	0	0.144	64.25%
120	0.2178	18.56	7.73	58.41	0	0.144	65.90%
230	0.2410	18.51	7.71	59.94	0	0.143	59.24%
264	0.2774	18.50	7.71	63.27	0	0.143	51.41%

Vin (AC)	Pin (W)	V_19V (V)	I_19V (mA)	V_56V (V)	I_56V (mA)	Pout (W)	Efficiency (%)
90	2.080	18.51	94.2	58.63	0	1.744	83.83%
120	2.048	18.50	94.2	58.80	0	1.743	85.09%
230	2.073	18.51	94.0	63.80	0	1.740	83.93%
264	2.286	18.59	94.1	64.06	0	1.749	76.52%

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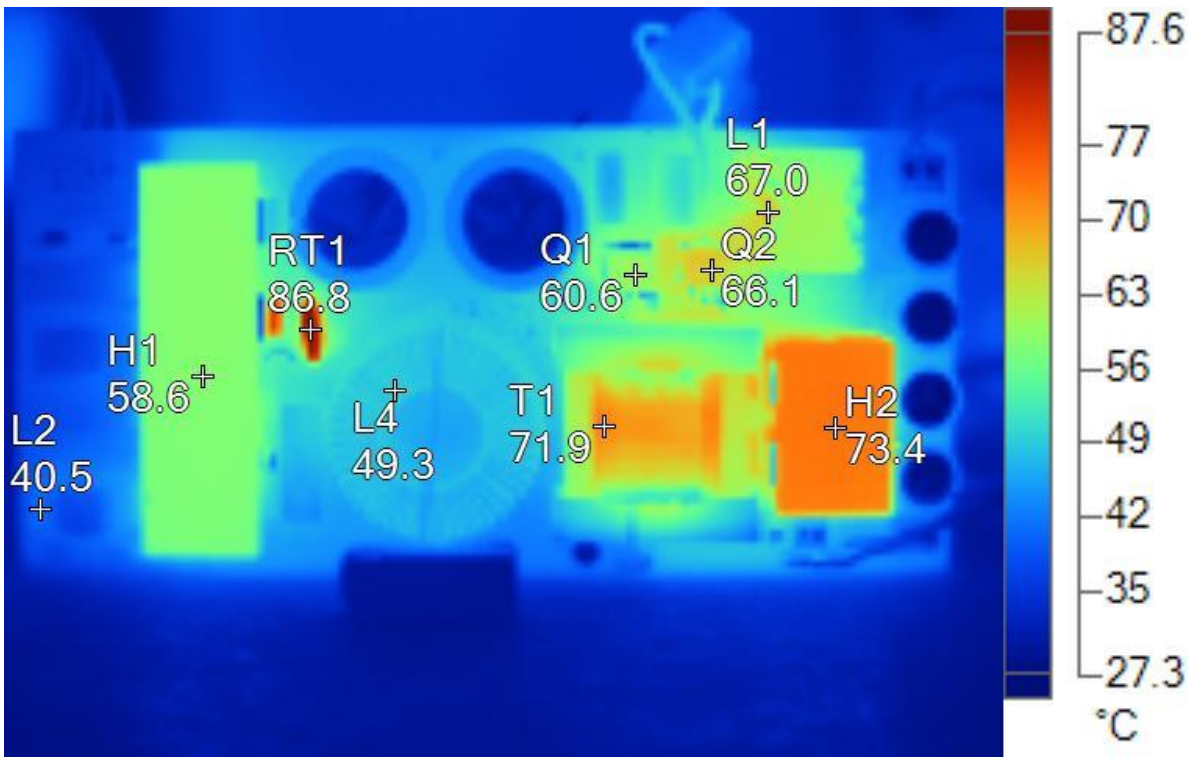
Vin (AC)	Pin (W)	V_19V (V)	I_19V (mA)	V_56V (V)	I_56V (mA)	Pout (W)	Efficiency (%)
90	12.440	18.68	551.6	58.96	0	10.304	82.83%
120	12.050	18.64	551.6	63.18	0	10.282	85.33%
230	11.995	18.61	551.6	64.04	0	10.265	85.58%
264	12.253	18.60	551.6	64.39	0	10.260	83.73%

2.2 Thermal Images

The graphs and tables below show the thermal pictures of the converter supplied respectively at 230 VAC, 50 Hz and 120 VAC, 60 Hz. The images have been taken after the board was running for 40 minutes (first image) and 1 hour (second image), placed vertical on the bench, at full load, with ambient temperature of 26.5°C (and 26.8°C) and in still air condition.

Conditions: mains voltage = 230 VAC, 50 Hz; image taken after 40 minutes at full load.



Main Image Markers

Name	Temperature	Emissivity	Background
H1	58.6°C	0.96	26.5°C
RT1	86.8°C	0.96	26.5°C
L2	40.5°C	0.96	26.5°C
L4	49.3°C	0.96	26.5°C
T1	71.9°C	0.96	26.5°C
H2	73.4°C	0.96	26.5°C
Q2	66.1°C	0.96	26.5°C
Q1	60.6°C	0.96	26.5°C
L1	67.0°C	0.96	26.5°C

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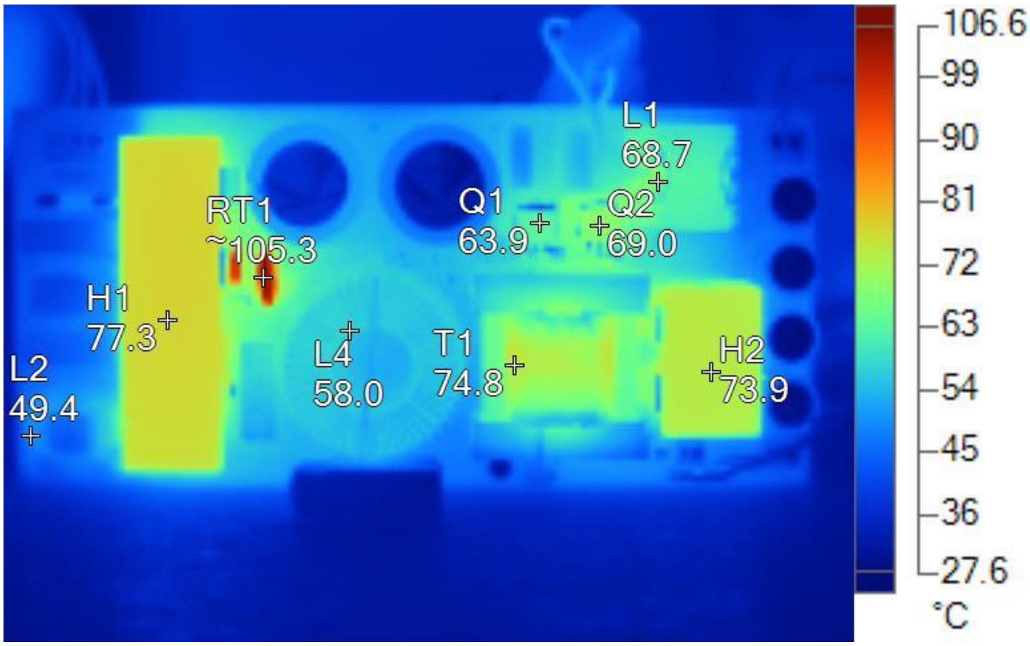
Conditions: mains voltage = 120 VAC, 60 Hz; image taken after 1 hour at full load.

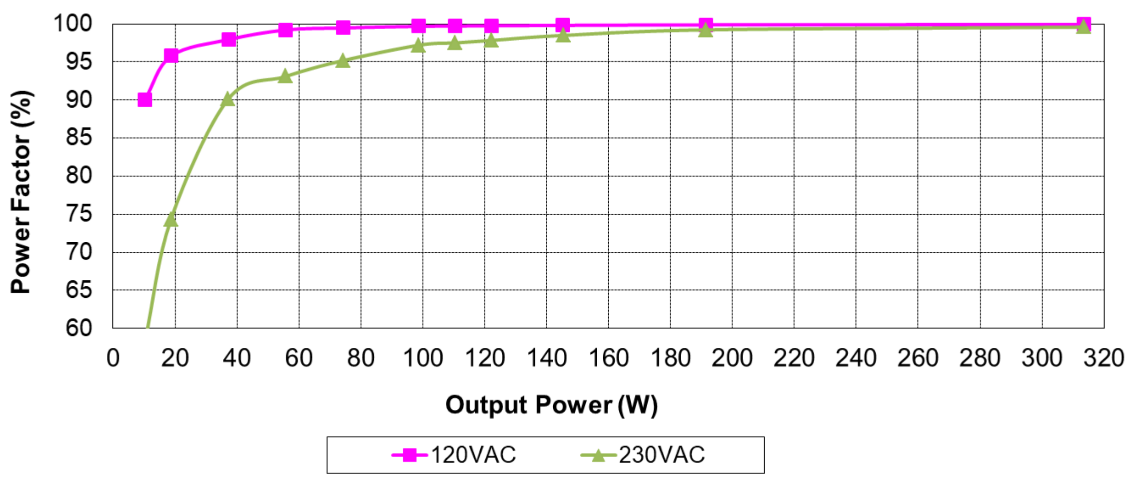


Main Image Markers

Name	Temperature	Emissivity	Background
L2	49.4°C	0.96	26.8°C
H1	77.3°C	0.96	26.8°C
RT1	~105.3°C	0.96	26.8°C
Q1	63.9°C	0.96	26.8°C
Q2	69.0°C	0.96	26.8°C
L1	68.7°C	0.96	26.8°C
H2	73.9°C	0.96	26.8°C
T1	74.8°C	0.96	26.8°C
L4	58.0°C	0.96	26.8°C

2.3 *Power Factor versus Load and VAC*

The power factor value has been measured by varying the total load power from 10 W to full load; below 10 W the PFC stage has been turned off.



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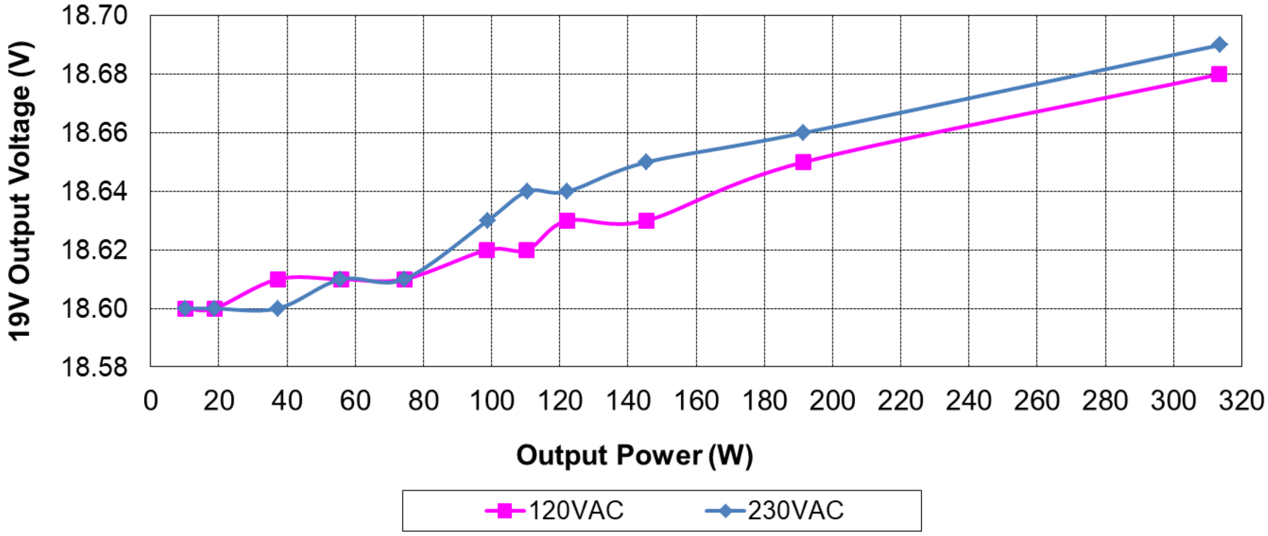
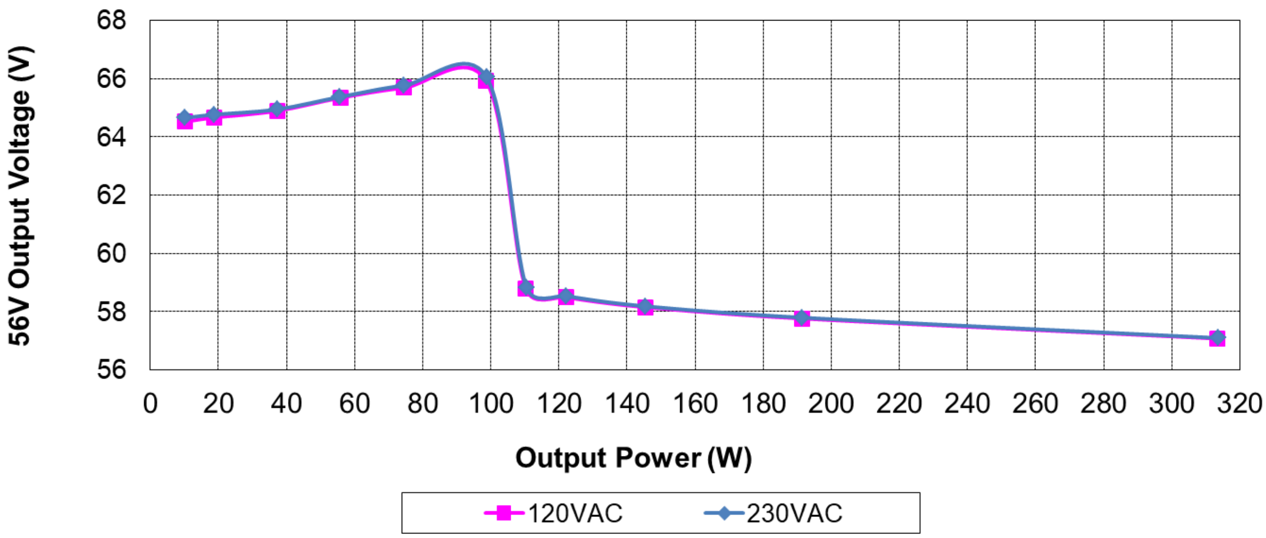
2.4 Static Output Voltage Variation versus Load

The output voltage regulation versus load current is shown in the graphs below.





2.5 Dimensions

The board dimensions are 102.2 mm x 214.6 mm, height 40 mm.

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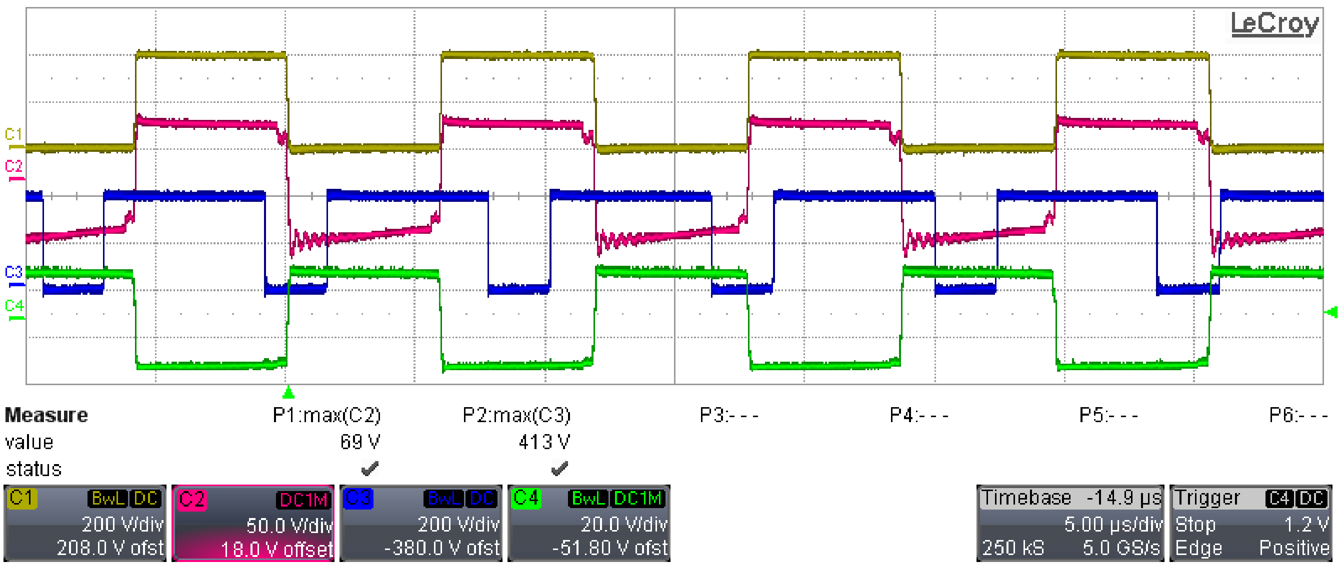
3 Waveforms

3.1.1 Switching Waveforms on Drain of Main FETs, and Diodes, at Full Load

The switching waveforms have been measured by supplying the converter at 230 VAC, 120 VAC (60 Hz), with both outputs fully loaded.

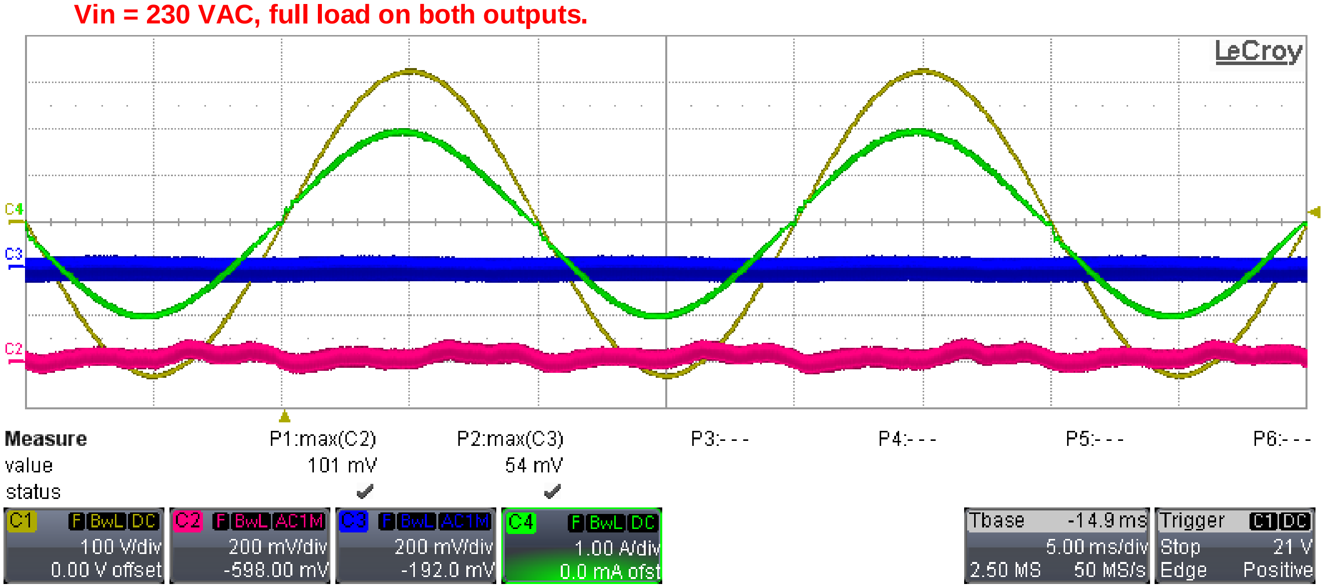
C1: Q2-Vds (200 V/div, 5 usec/div, 200 MHz BWL), C2: D6 (Anode to GND) voltage (50 V/div, no BWL)
C3: Q5-Vds (200 V/div, 200 MHz BWL), C4: D7 (Anode to GND) voltage (20 V/div, 200 MHz BWL)
Vin = 230 VAC, full load on both outputs.



3.1.2 AC waveforms (Input Voltage and Input PFC Stage Current)

The screenshots shown below show the input voltage and current of the PFC stage, at 120 VAC and 230 VAC, in full load condition (all waveforms with 20 MHz BWL).

C1: Input AC voltage (100 V/div, 5 msec/div, DC coupling), C2: 56Vout (200 mV/div, AC coupling)
C3: 19Vout (200 mV/div, AC coupling), C4: Input AC current (1 A/div, DC coupling)
Vin = 230 VAC, full load on both outputs.



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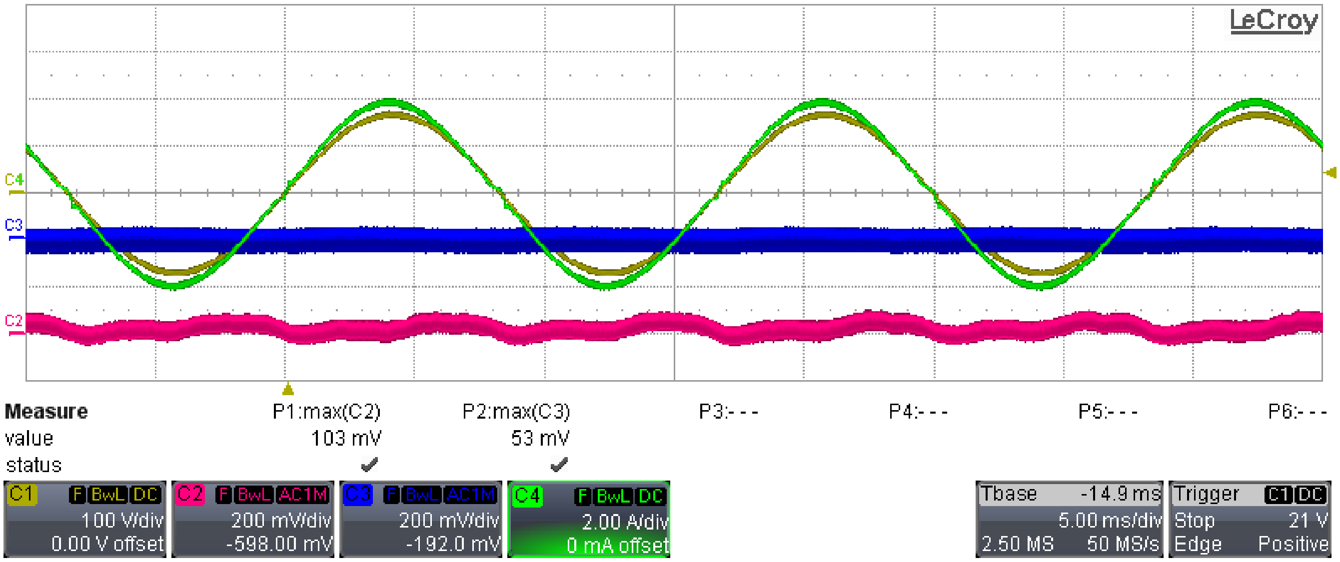
C1: Input AC voltage (100 V/div, 5 msec/div, DC coupling), C2: 56Vout (200 mV/div, AC coupling)
C3: 19Vout (200 mV/div, AC coupling), C4: Input AC current (2 A/div, DC coupling)
Vin = 120 VAC, full load on both outputs.



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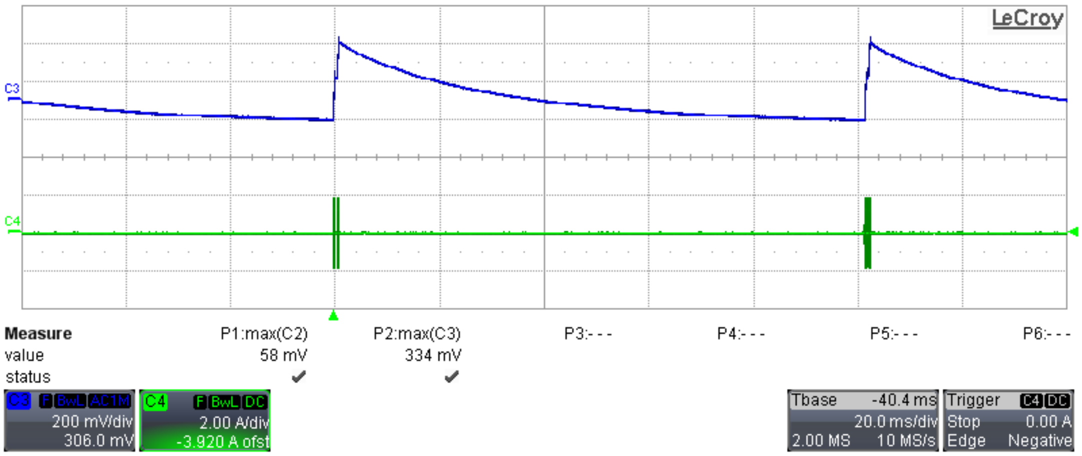
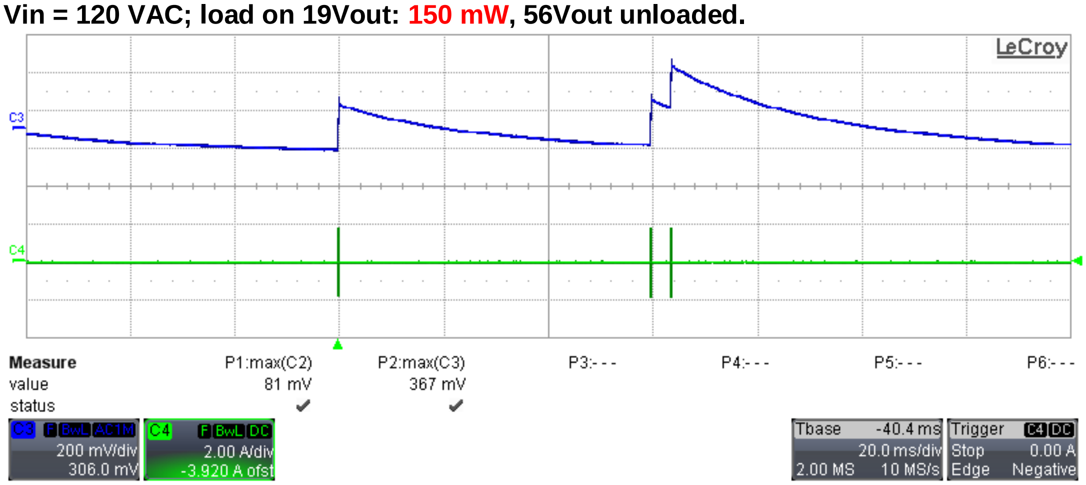
3.2 Output Voltage Ripple

The 19Vout output voltage ripple has been measured by supplying the converter at 90 VAC, 120 VAC (60 Hz), 230 VAC and 264 VAC (50 Hz) at 150 mW, 1.7 W and 10 W load (BWL set to 20 MHz).

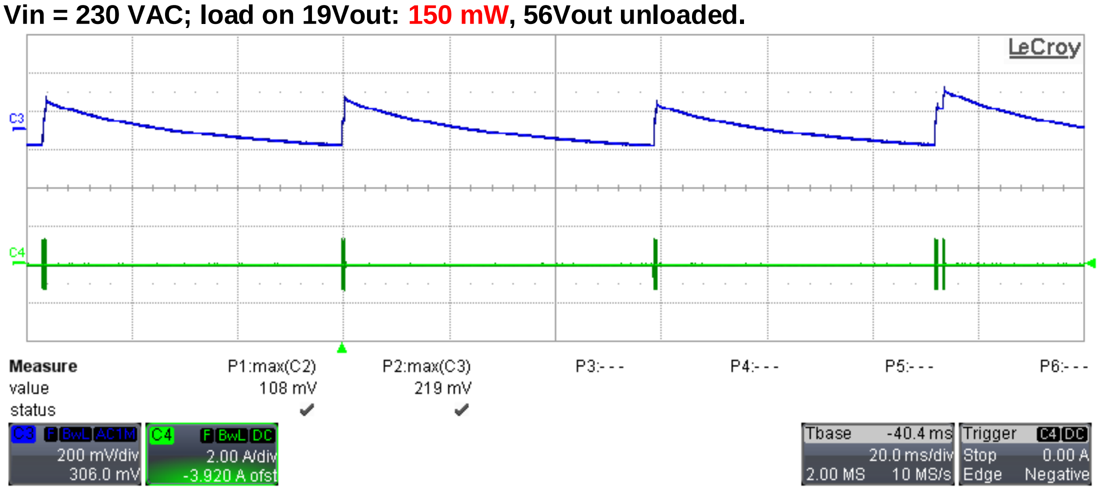
C3: 19Vout (200 mV/div, 20 msec/div, AC coupling), C4: Resonant current (TP3-TP4) (2 A/div)
Vin = 90 VAC; load on 19Vout: 150 mW, 56Vout unloaded.



C3: 19Vout (200 mV/div, 20 msec/div, AC coupling), C4: Resonant current (TP3-TP4) (2 A/div)
Vin = 120 VAC; load on 19Vout: 150 mW, 56Vout unloaded.



C3: 19Vout (200 mV/div, 20 msec/div, AC coupling), C4: Resonant current (TP3-TP4) (2 A/div)
Vin = 230 VAC; load on 19Vout: 150 mW, 56Vout unloaded.



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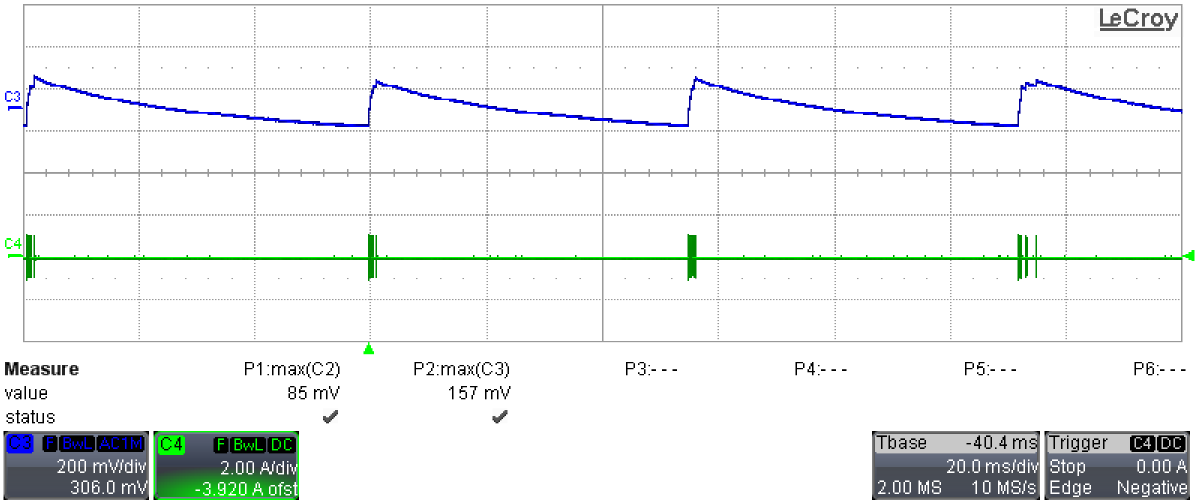
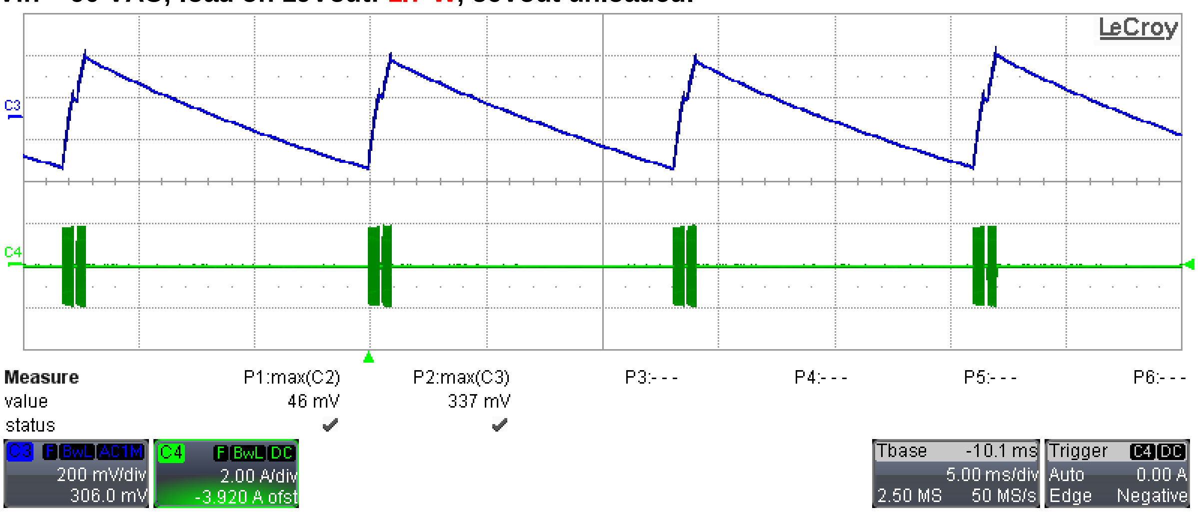
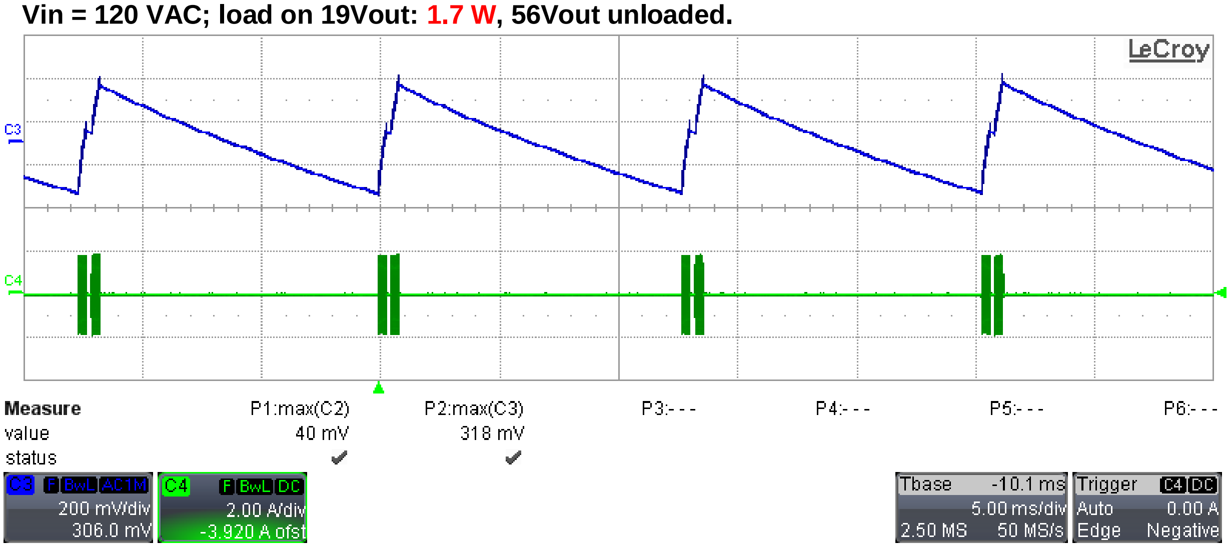
C3: 19Vout (200 mV/div, 20 msec/div, AC coupling), C4: Resonant current (TP3-TP4) (2 A/div)
Vin = 264 VAC; load on 19Vout: 150 mW, 56Vout unloaded.



C3: 19Vout (200 mV/div, 5 msec/div, AC coupling), C4: Resonant current (TP3-TP4) (2 A/div)
Vin = 90 VAC; load on 19Vout: 1.7 W, 56Vout unloaded.



C3: 19Vout (200 mV/div, 5 msec/div, AC coupling), C4: Resonant current (TP3-TP4) (2 A/div)
Vin = 120 VAC; load on 19Vout: 1.7 W, 56Vout unloaded.



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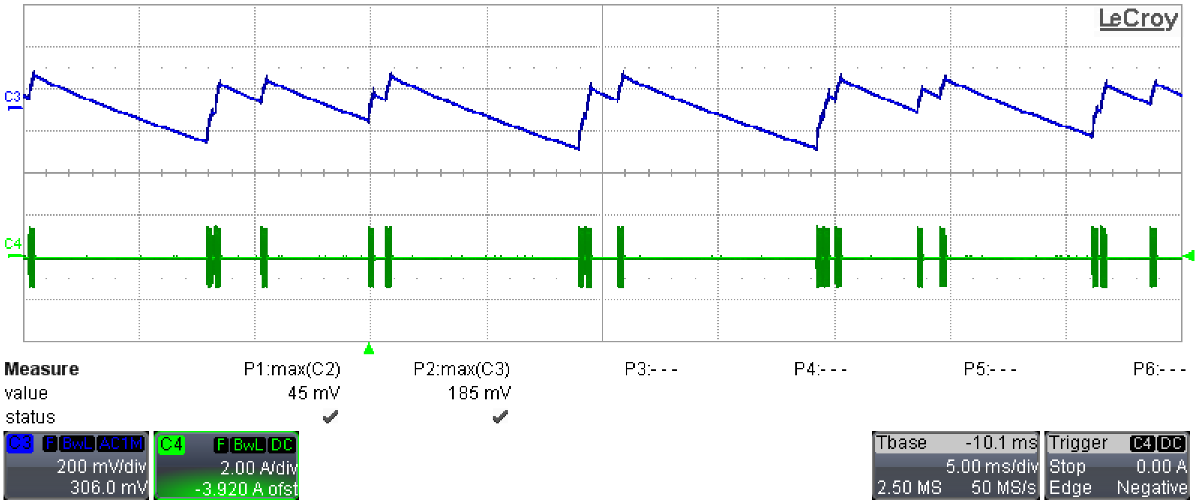
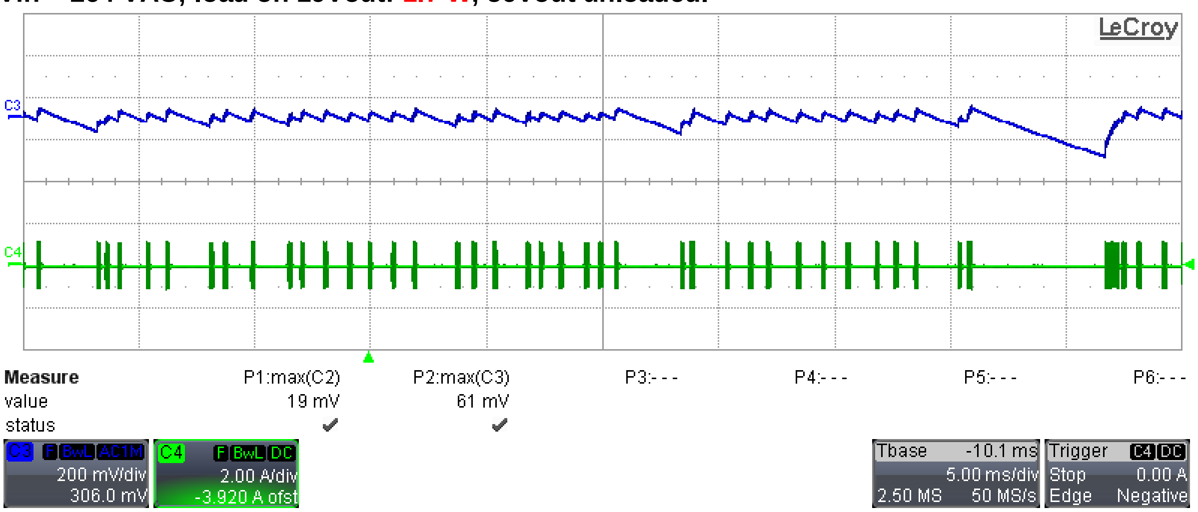
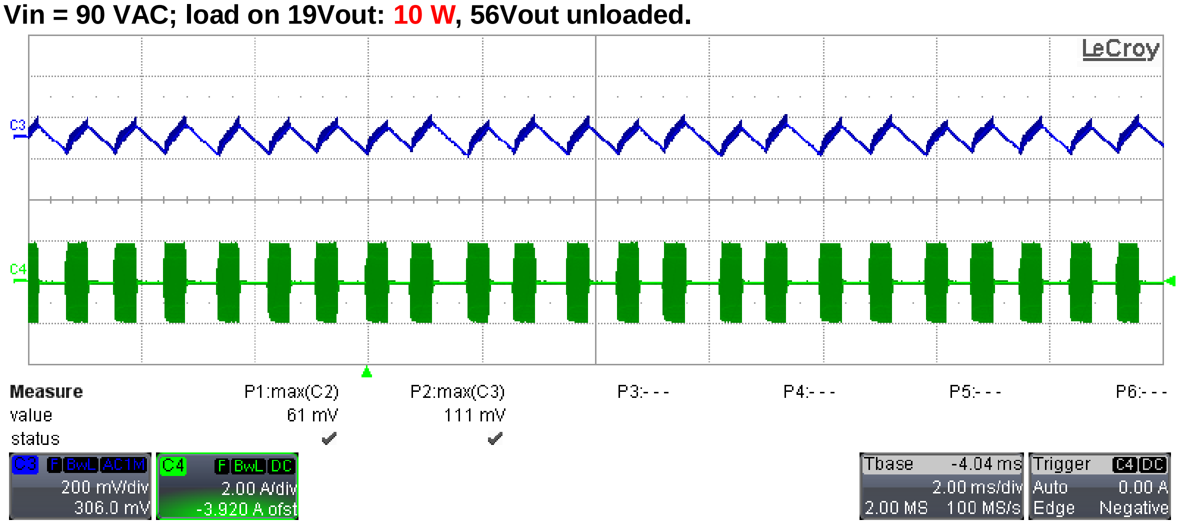
C3: 19Vout (200 mV/div, 5 msec/div, AC coupling), C4: Resonant current (TP3-TP4) (2 A/div)
Vin = 230 VAC; load on 19Vout: 1.7 W, 56Vout unloaded.



C3: 19Vout (200 mV/div, 5 msec/div, AC coupling), C4: Resonant current (TP3-TP4) (2 A/div)
Vin = 264 VAC; load on 19Vout: 1.7 W, 56Vout unloaded.



C3: 19Vout (200 mV/div, 2 msec/div, AC coupling), C4: Resonant current (TP3-TP4) (2 A/div)
Vin = 90 VAC; load on 19Vout: 10 W, 56Vout unloaded.



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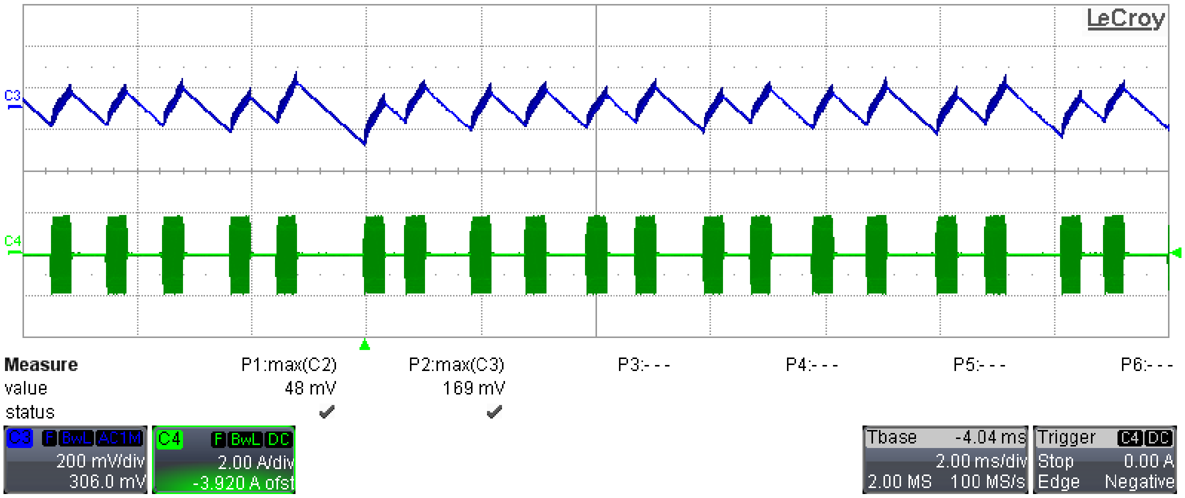
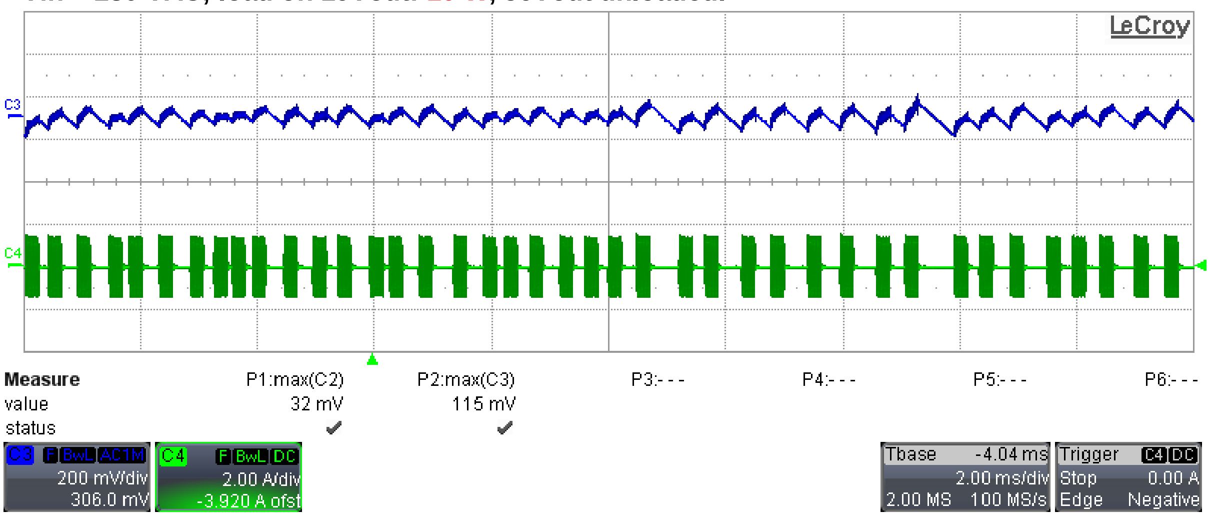
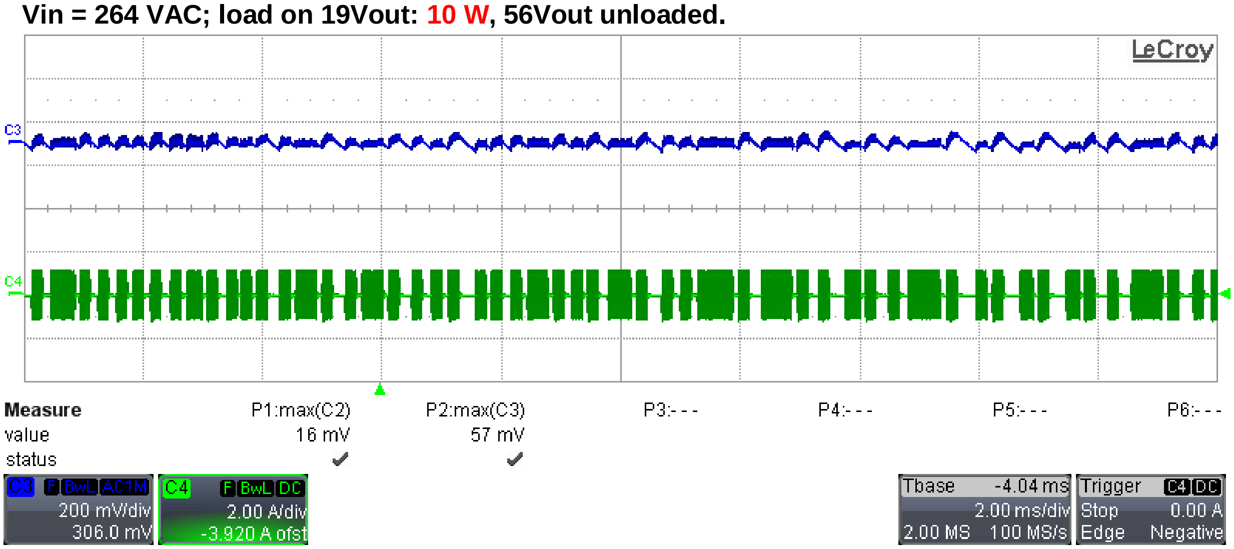
C3: 19Vout (200 mV/div, 2 msec/div, AC coupling), C4: Resonant current (TP3-TP4) (2 A/div)
Vin = 120 VAC; load on 19Vout: 10 W, 56Vout unloaded.



C3: 19Vout (200 mV/div, 2 msec/div, AC coupling), C4: Resonant current (TP3-TP4) (2 A/div)
Vin = 230 VAC; load on 19Vout: 10 W, 56Vout unloaded.



C3: 19Vout (200 mV/div, 2 msec/div, AC coupling), C4: Resonant current (TP3-TP4) (2 A/div)
Vin = 264 VAC; load on 19Vout: 10 W, 56Vout unloaded.



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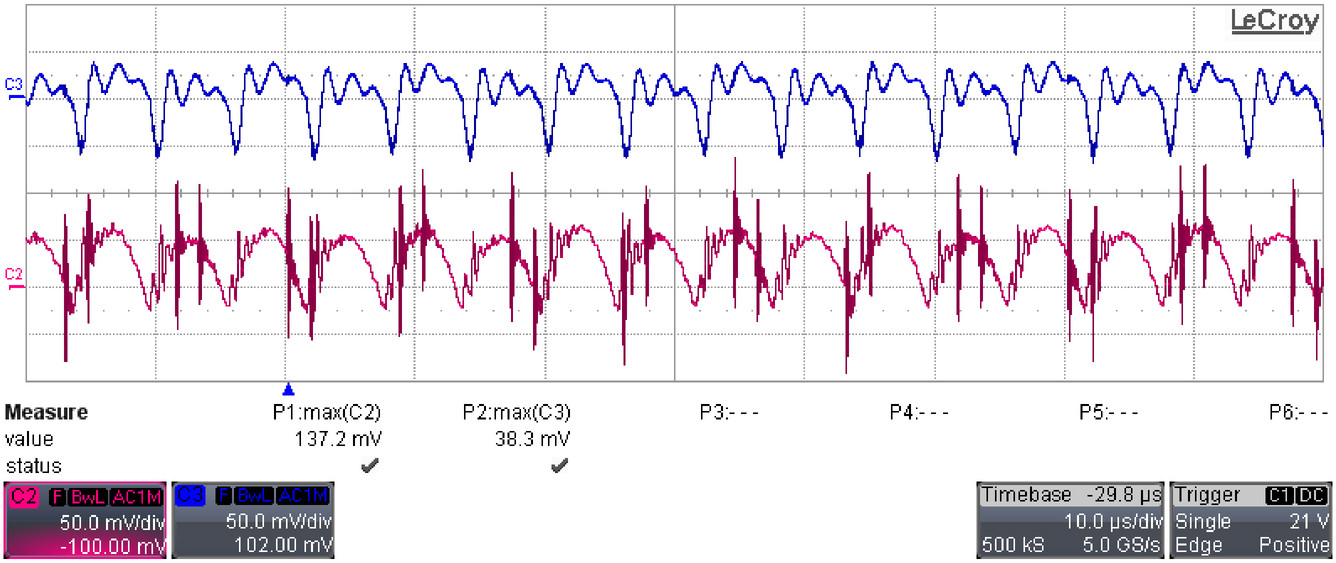
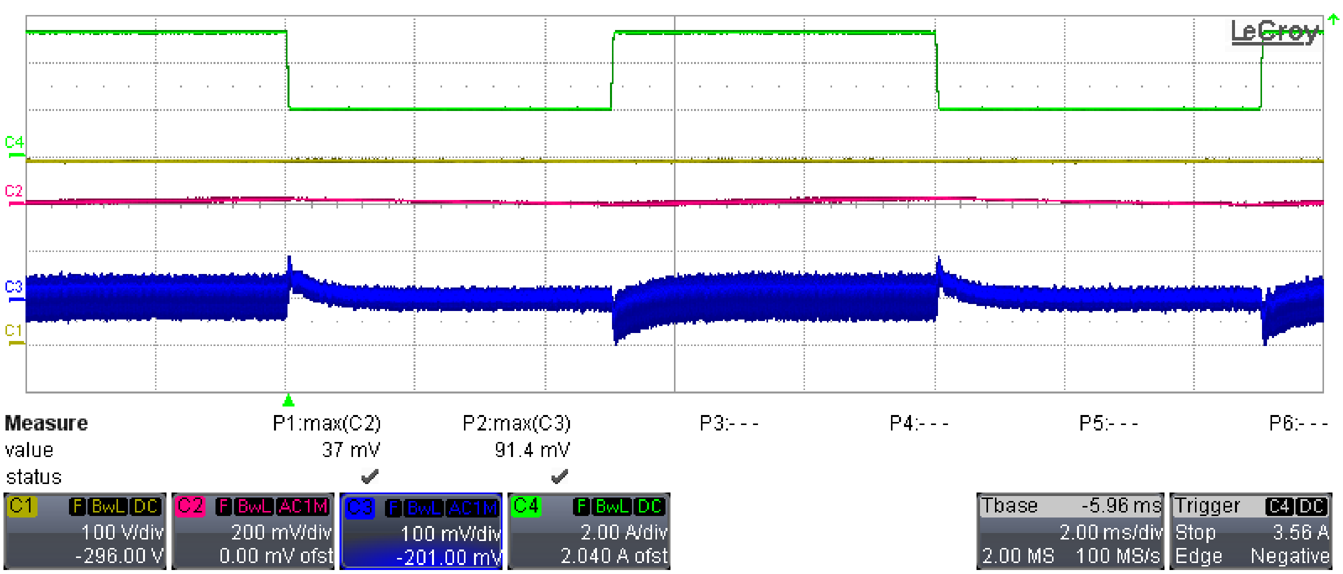
C2: 56Vout (50 mV/div, 10 usec/div, AC coupling)
C3: 19Vout (50 mV/div, AC coupling)
Vin = 230 VAC; full load on both outputs, PFC on.



3.3 Load Transients

The output voltage variation, during load transients, has been measured by supplying the converter at 120 VAC, 60 Hz. Two different situations for the loads have been measured.
For all waveforms the bandwidth of the oscilloscope has been set to 20 MHz.

C1: PFC Voltage (100 V/div, 2 msec/div, DC coupling), C2: 56Vout (200 mV/div, AC coupling)
C3: 19Vout (100 mV/div, AC coupling), C4: Output current of 19Vout (2 A/div, DC coupling)
Vin = 120VAC, load on 56Vout = 0, load on 19Vout: switched between 2 A and 5.3 A



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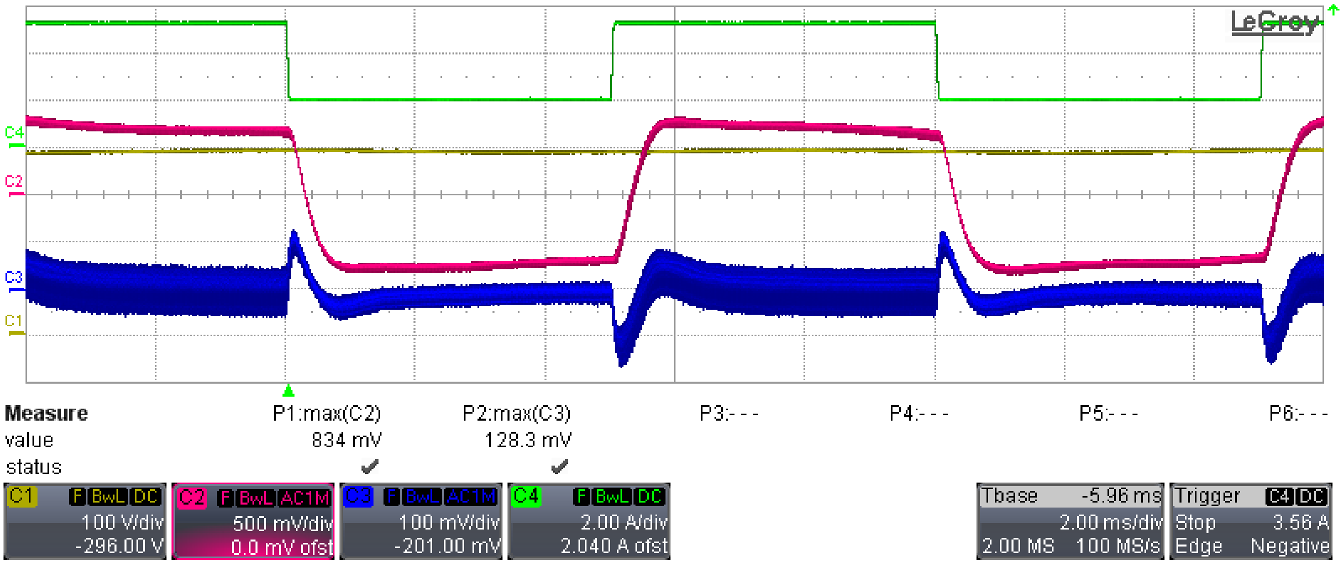
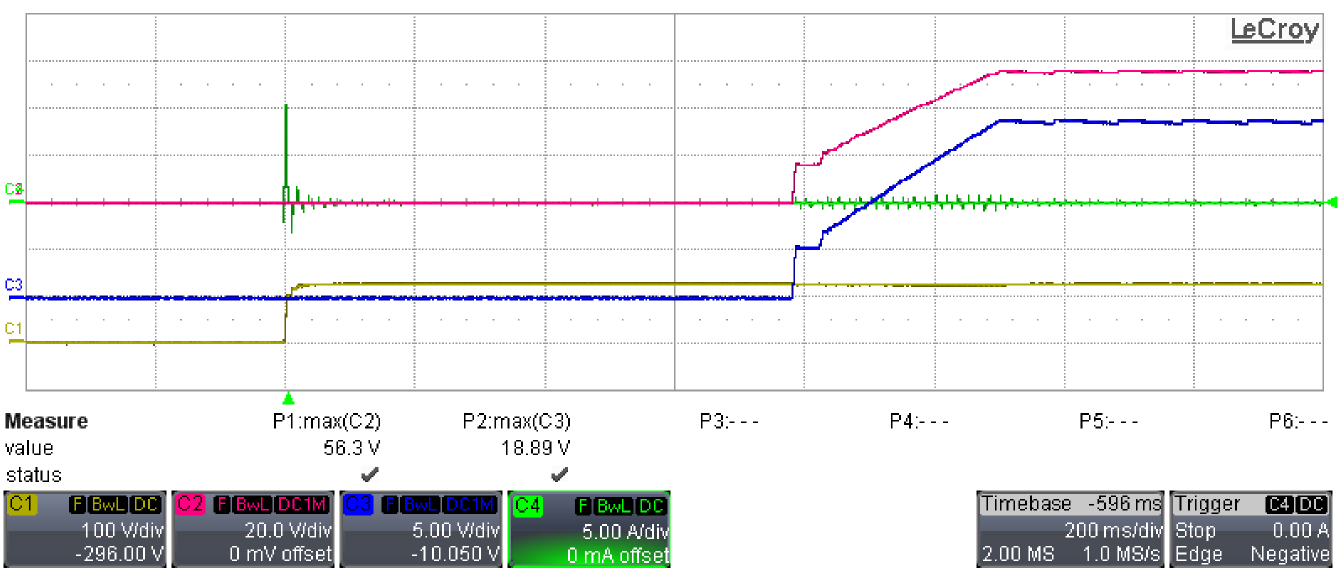
C1: PFC Voltage (100 V/div, 2 msec/div, DC coupling), C2: 56Vout (500 mV/div, AC coupling)
C3: 19Vout (100 mV/div, AC coupling), C4: Output current of 19Vout (2 A/div, DC coupling)
Vin = 120VAC, load on 56Vout = 3.75 A, load on 19Vout: switched between 2 A and 5.3 A



3.4 Start-up

During this test, the AC source has been turned on (while PFC stage was disabled) and the delay between AC and Vout startup has been measured.

C1: PFC Voltage (100 V/div, 200 msec/div, DC coupling), C2: 56Vout (20 V/div, DC coupling)
C3: 19Vout (5 V/div, DC coupling), C4: Input current (J4) (5 A/div, DC coupling)
Vin = 90VAC, load on 56Vout = 0 A, load on 19Vout: 150 mW



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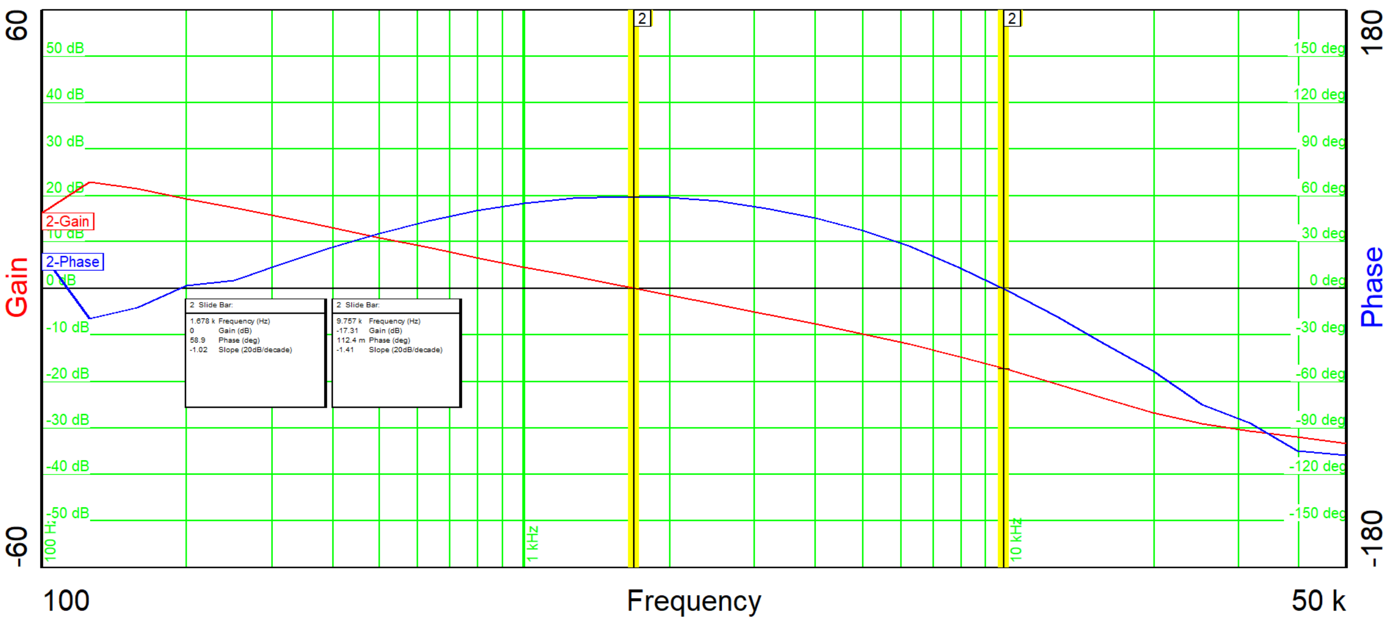
3.5 Bode Plot

The following graph shows the bode plot of the converter, when supplied at 230 VAC and fully loaded. Here is the result, in terms of crossover frequency, phase margin and gain margin:

Parameter	Value
Crossover frequency:	1.678 KHz
Phase margin:	58.9 deg.
Gain margin:	17.31 dB



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