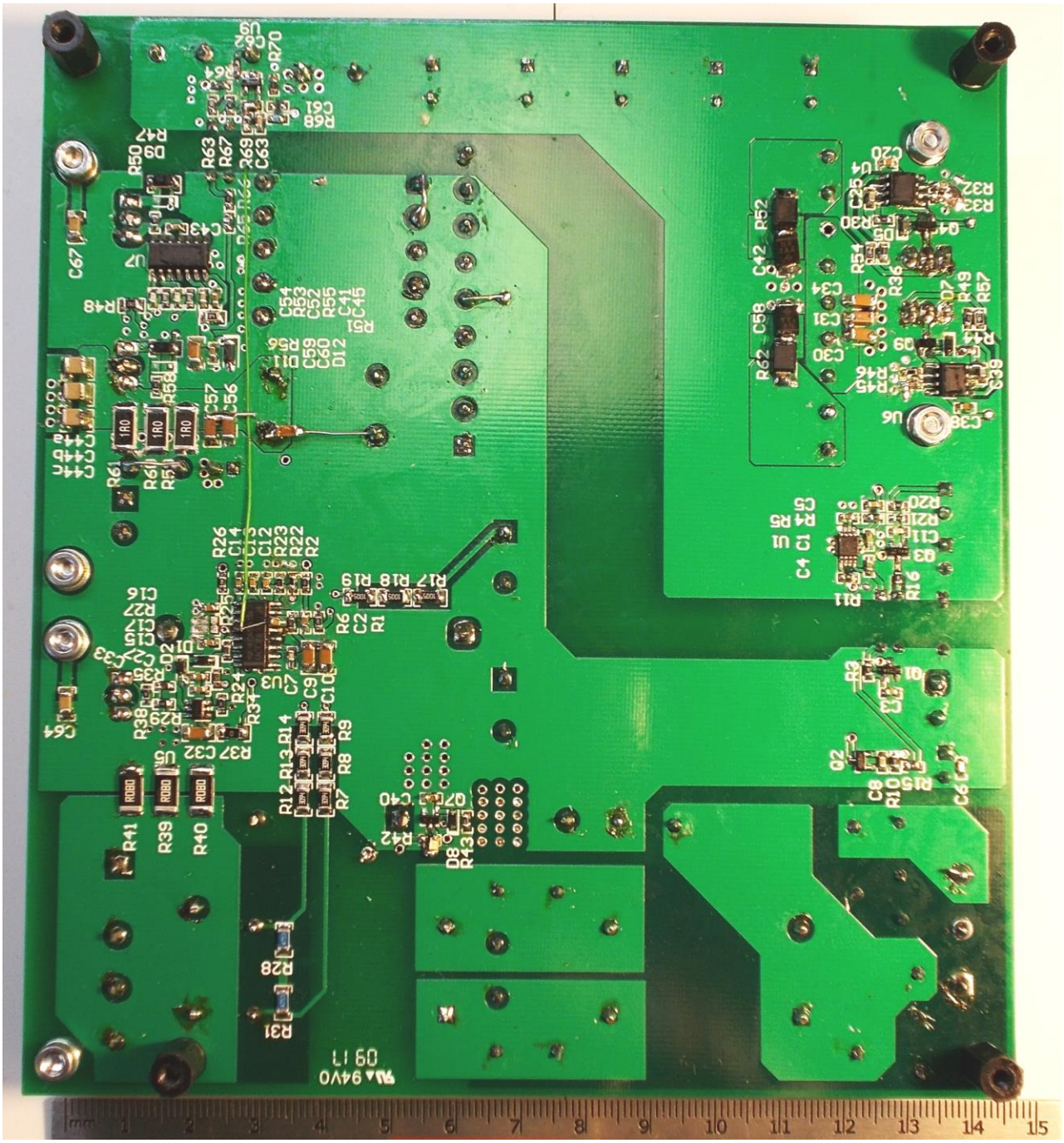
PHOTO OF THE PROTOTYPE

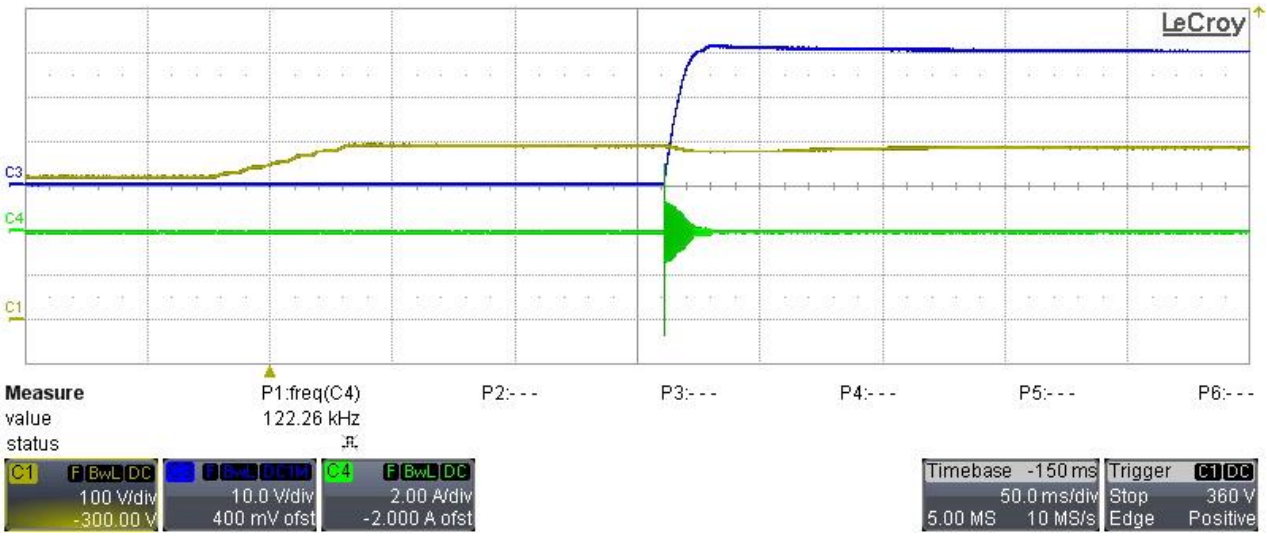


1 Startup

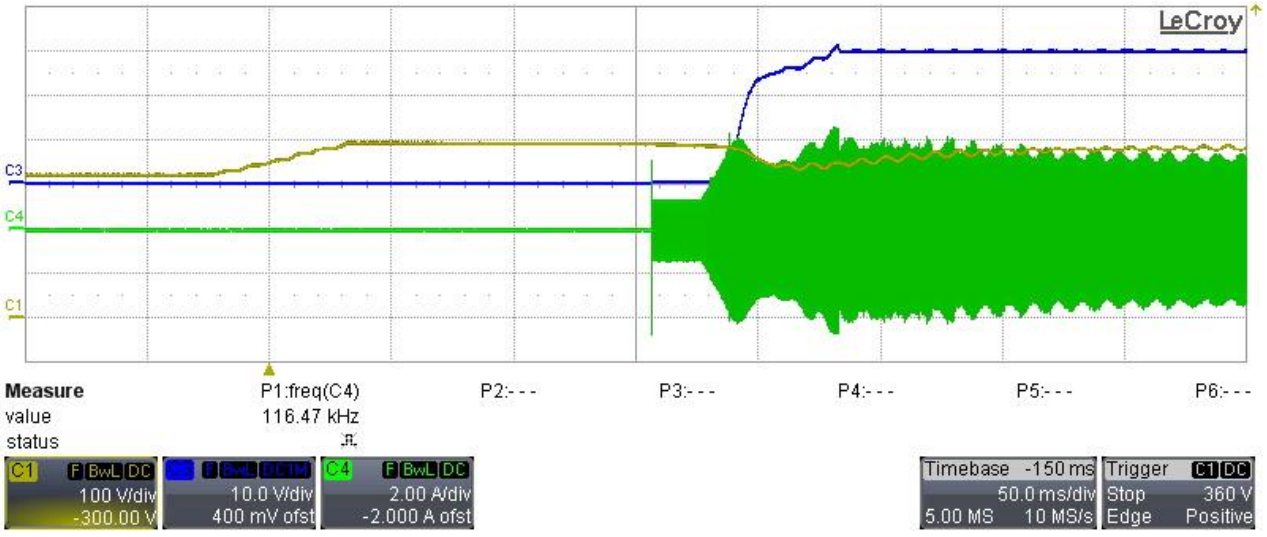
The behavior of the converter at startup is shown in the images below. The input voltage has been set to 230Vac, 50Hz and 120Vac, 60Hz in both loaded and unloaded conditions. After applying the AC source, 7V isolated supply has been connected to pin 5 of J5, which enables the power stage.

Ch1: PFC output voltage, J1-1 (100V/div, 50ms/div), 20MHz BWL for all waveforms.
Ch3: Vout voltage, TP5 (10V/div)
Ch4: Resonant current (through L4) (2A/div)

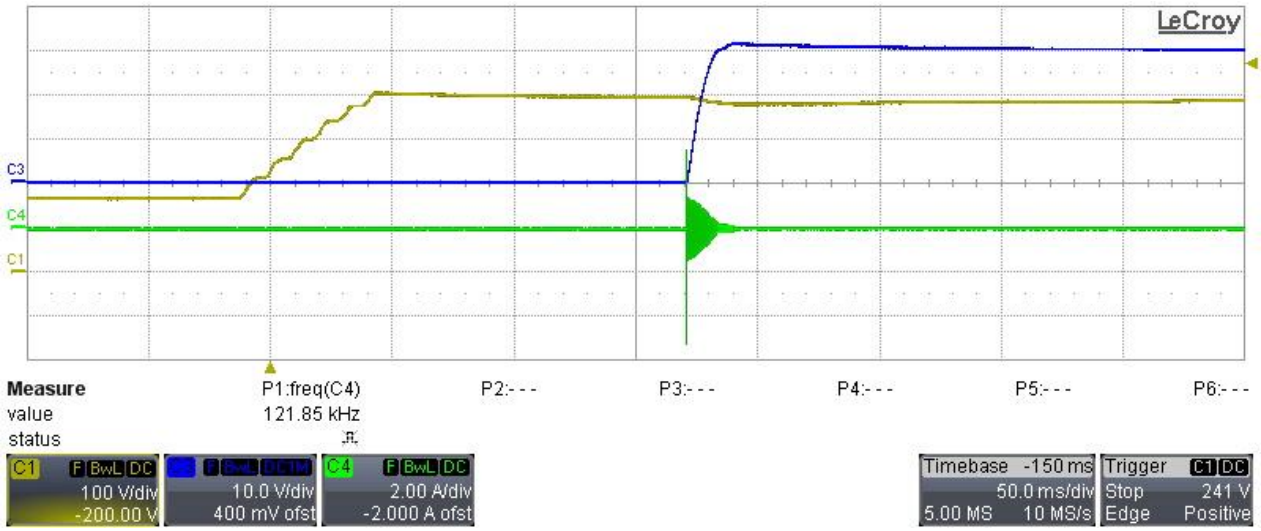
Vin = 230Vac, 50Hz, Iout = 0



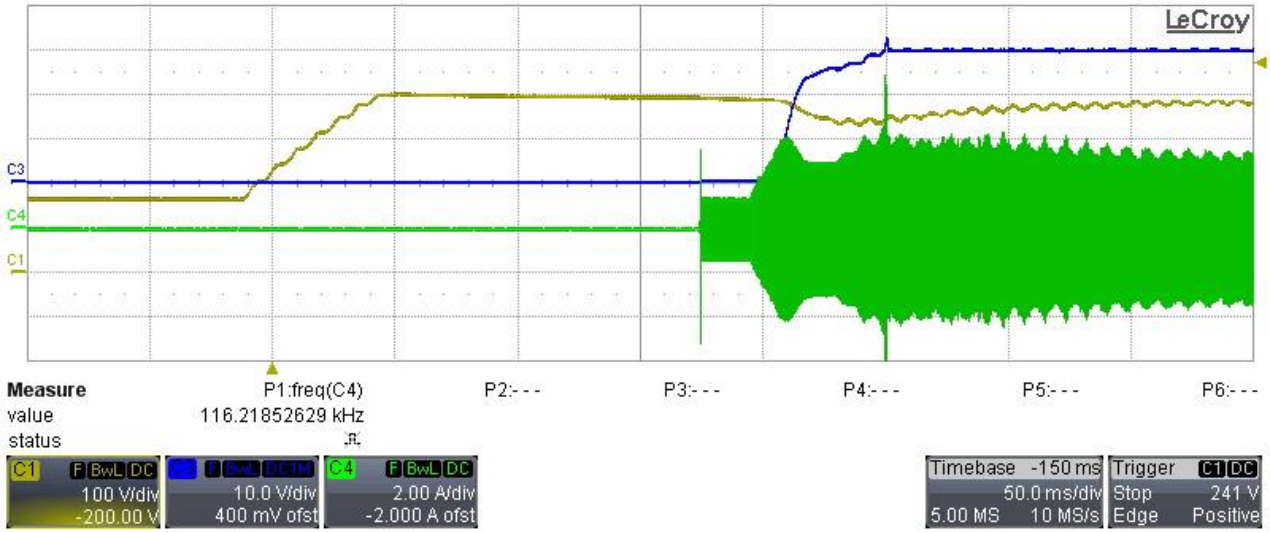
Vin = 230Vac, 50Hz, Iout = 12.5A



Vin = 120Vac, 60Hz, Iout = 0



Vin = 120Vac, 60Hz, Iout = 12.5A



2 Shut down

The AC source has been switched off and the behavior of the converter measured. The input voltage has been set to 230Vac, 50Hz and 120Vac, 60Hz, in both cases with the output fully loaded.

Ch1: PFC output voltage, J1-1 (100V/div, 50ms/div), 20MHz BWL for all waveforms.
Ch3: Vout voltage, TP5 (10V/div)
Ch4: Input AC current (J6 1-3) (2A/div)

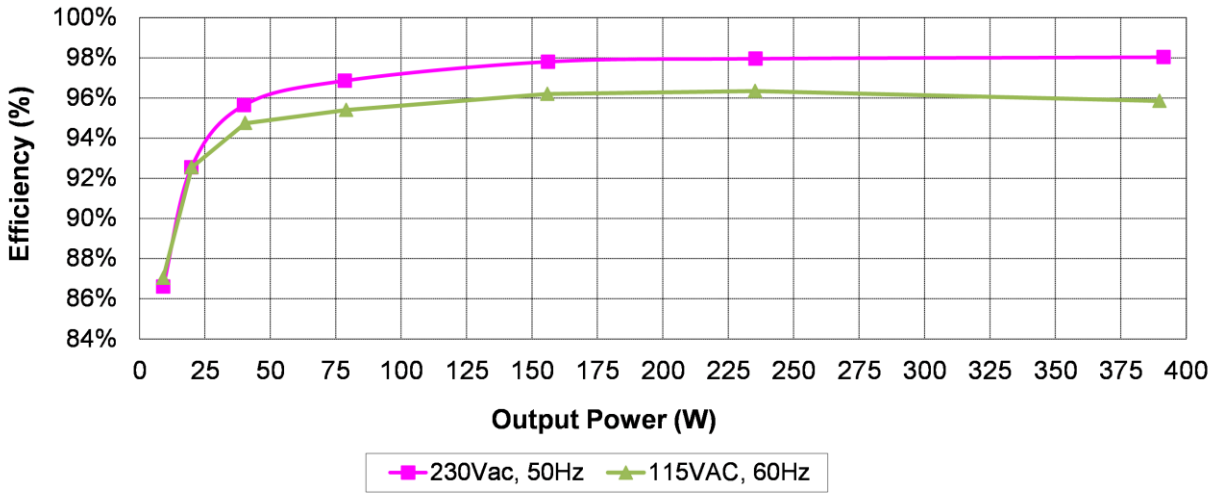
Vin = 230Vac, 50Hz

Vin = 120Vac, 60Hz

3 Efficiency

The efficiency data are shown in the tables and graphs below. The data show the PFC + AUX section, the LLC power stage (only) efficiency and the total plug-to-plug. The Auxiliary power supply was feeding only the housekeeping for this measurement.

PFC + Auxiliary Flyback section, supplied by PMP30191 Flyback

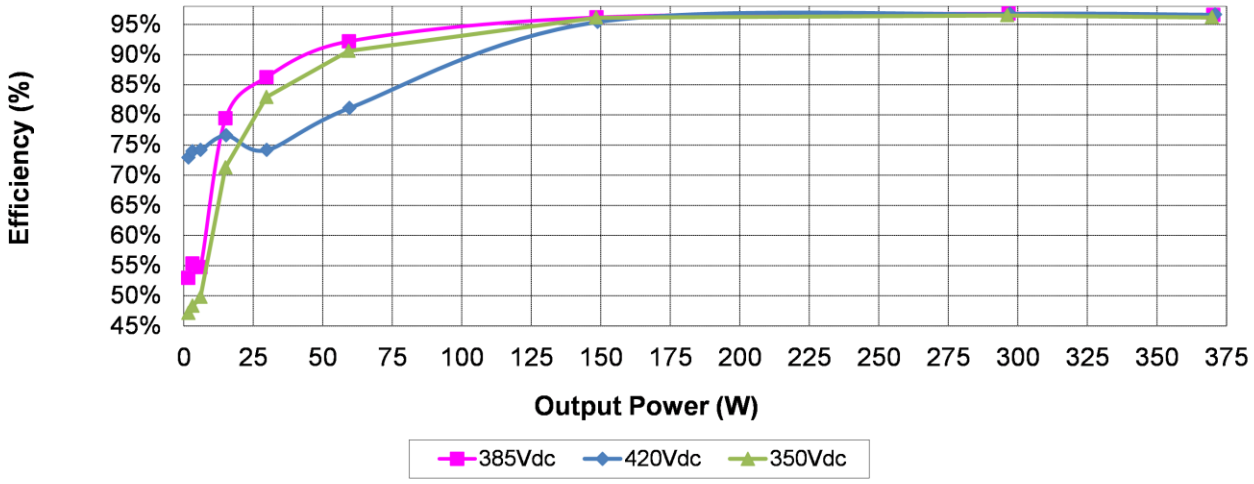


PFC + Auxiliary Flyback section efficiency data:

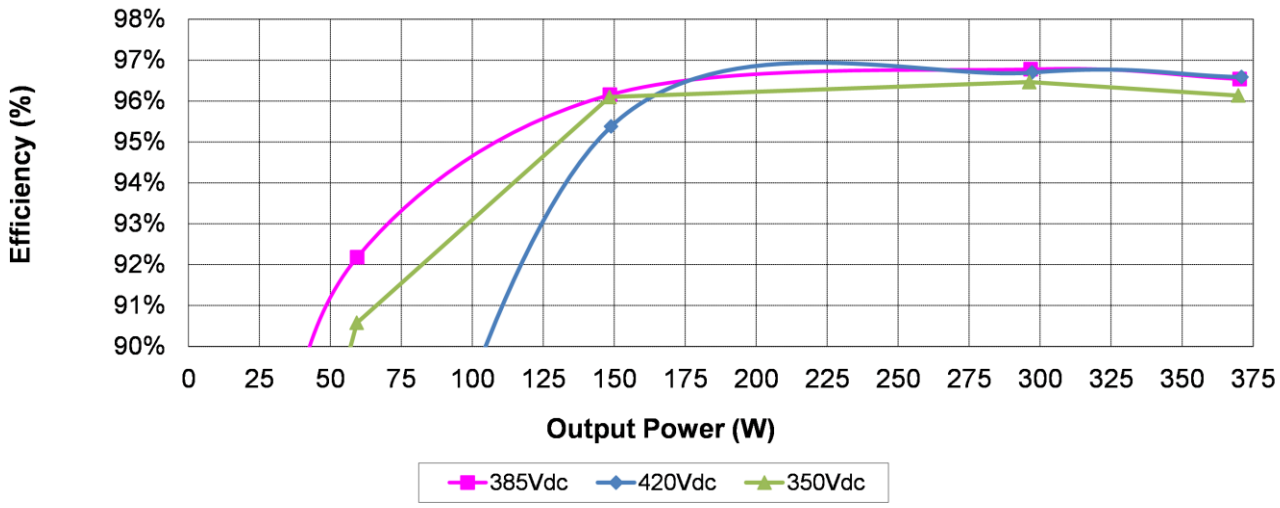
Vin (AC)	Pin(W)	PF	Vout (V)	Iout (mA)	Pout (W)	Efficiency (%)
230	0.436	0	389.3	0	0	0%
230	10.42	0.472	388.9	23.2	9.02	86.59%
230	21.41	0.708	389.2	50.9	19.81	92.53%
230	41.70	0.862	389.8	102.3	39.88	95.63%
230	80.98	0.938	389.8	201.2	78.43	96.85%
230	159.6	0.973	389.8	400.4	156.08	97.79%
230	240.3	0.984	389.8	603.8	235.36	97.94%
230	399.2	0.992	389.7	1004.1	391.30	98.02%

Vin (AC)	Pin(W)	PF	Vout (V)	Iout (mA)	Pout (W)	Efficiency (%)
115	0.573	0	389.1	0	0	0%
115	10.34	0.868	389.5	23.1	9.00	87.02%
115	21.51	0.946	389.5	51.1	19.90	92.53%
115	42.60	0.984	389.5	103.6	40.35	94.73%
115	82.79	0.985	389.2	202.9	78.97	95.39%
115	162.0	0.996	389.3	400.2	155.80	96.18%
115	244.2	0.999	389.2	604.4	235.23	96.33%
115	406.6	1.000	389.1	1001.6	389.72	95.84%

LLC only, supplied by DC external source



Same graph as above, but expanded in efficiency range 90%...98%



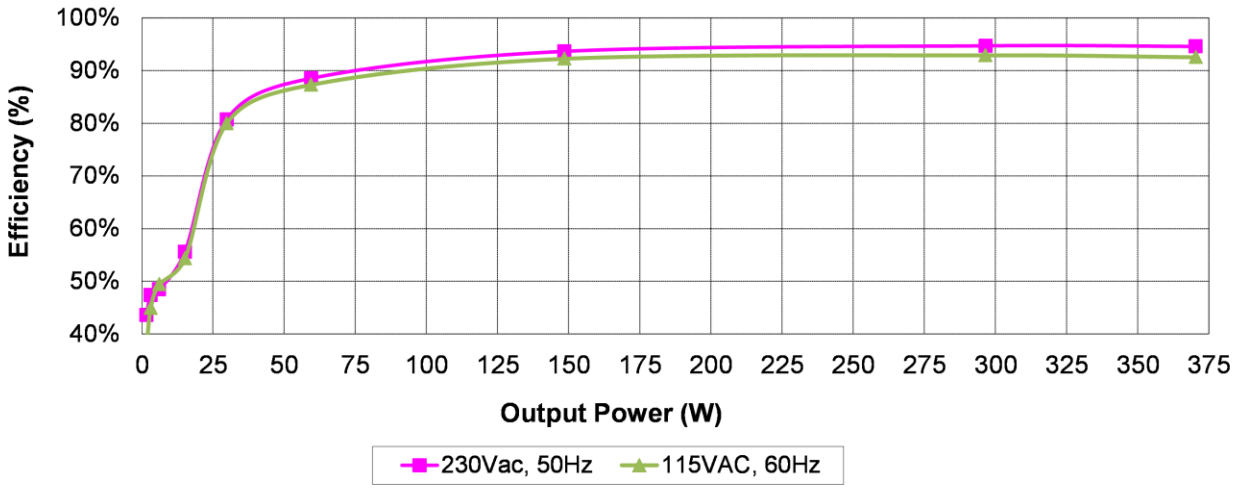
LLC efficiency data:

Vin (V)	Iin(mA)	Pin (W)	Vout (V)	Iout(A)	Pout (W)	Efficiency (%)
384.9	0.553	0.213	29.88	0	0.00	0.0%
384.9	7.92	3.048	29.87	0.054	1.61	52.9%
384.9	14.86	5.721	29.84	0.106	3.16	55.3%
384.9	28.61	11.01	29.83	0.202	6.03	54.7%
384.9	49.2	18.94	29.48	0.510	15.0	79.4%
384.9	89.6	34.49	29.44	1.01	29.7	86.2%
384.9	167.4	64.43	29.43	2.02	59.4	92.2%
384.7	401.2	154.34	29.42	5.04	148.4	96.1%
384.5	797.2	306.52	29.41	10.09	296.6	96.8%
384.5	997.6	383.58	29.41	12.59	370.3	96.5%

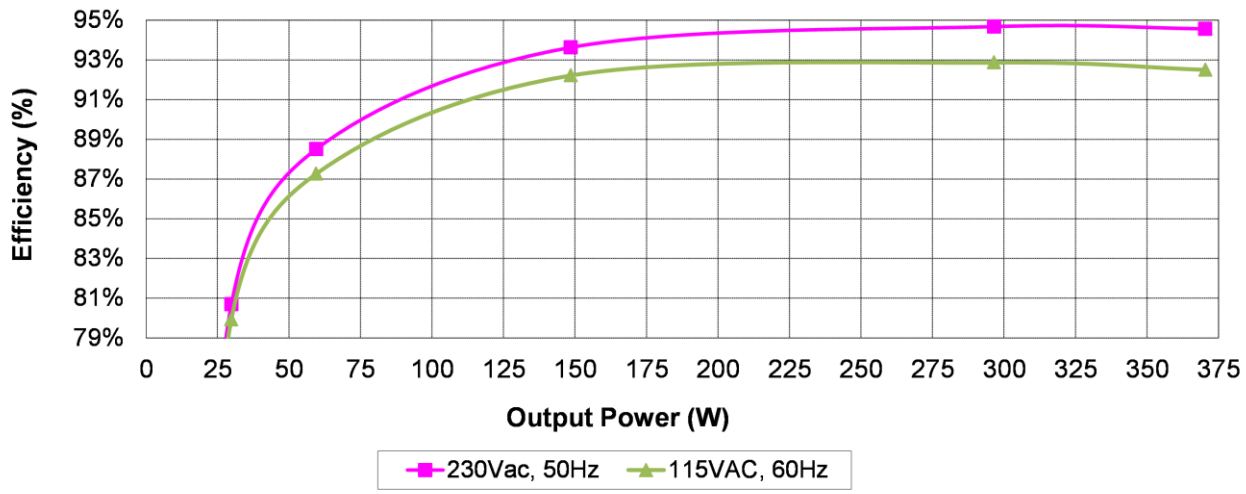
Vin (V)	Iin(mA)	Pin (W)	Vout (V)	Iout(A)	Pout (W)	Efficiency (%)
420.0	0.462	0.194	29.94	0	0.00	0.0%
420.0	5.47	2.296	29.88	0.056	1.67	72.9%
420.0	10.19	4.280	29.84	0.106	3.16	73.9%
420.0	19.53	8.20	29.80	0.204	6.08	74.1%
420.0	47.3	19.87	29.81	0.510	15.2	76.5%
419.9	95.9	40.27	29.55	1.01	29.8	74.1%
419.7	175.0	73.46	29.55	2.02	59.6	81.1%
420.0	371.5	156.03	29.49	5.05	148.8	95.4%
419.9	731.8	307.28	29.47	10.08	297.1	96.7%
419.9	914.6	384.04	29.46	12.59	370.9	96.6%

Vin (V)	Iin(mA)	Pin (W)	Vout (V)	Iout(A)	Pout (W)	Efficiency (%)
350.2	0.653	0.229	30.06	0	0.00	0.0%
349.2	10.18	3.555	29.89	0.056	1.67	47.1%
349.7	18.76	6.562	29.88	0.106	3.17	48.3%
350.0	34.64	12.13	29.86	0.202	6.03	49.7%
350.3	60.1	21.04	29.38	0.510	15.0	71.2%
350.2	102.4	35.86	29.38	1.01	29.7	82.9%
350.0	187.0	65.46	29.38	2.02	59.3	90.6%
350.3	440.6	154.34	29.38	5.05	148.3	96.1%
350.2	876.6	306.99	29.37	10.08	296.1	96.5%
350.2	1098.4	384.66	29.37	12.59	369.8	96.1%

Total efficiency (PFC + LLC + aux. Flyback), plug-to-plug



Total efficiency (PFC + LLC + aux. Flyback), plug-to-plug, expanded in range 79%...95%



Total efficiency (PFC + LLC + aux. Flyback), plug-to-plug data:

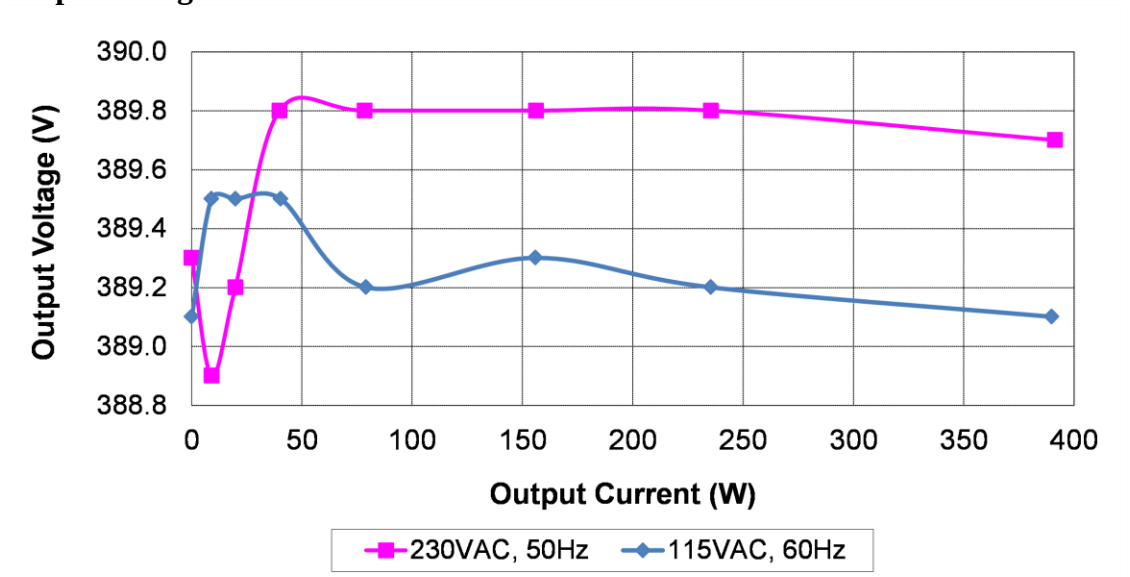
Vin (AC)	Pin(W)	Vout (V)	Iout (A)	Pout (W)	Efficiency (%)
230	0.595	29.89	0	0	0%
230	3.650	29.87	0.053	1.589	43.54%
230	6.477	29.87	0.103	3.065	47.32%
230	12.49	29.87	0.202	6.046	48.40%
230	27.17	29.90	0.505	15.09	55.53%
230	36.93	29.45	1.012	29.80	80.69%
230	67.22	29.43	2.021	59.49	88.50%
230	158.6	29.43	5.045	148.5	93.62%
230	313.2	29.42	10.08	296.5	94.67%
230	391.6	29.42	12.59	370.3	94.56%

Vin (AC)	Pin(W)	Vout (V)	Iout (A)	Pout (W)	Efficiency (%)
115	0.866	29.99	0	0	0%
115	4.235	29.94	0.053	1.593	37.61%
115	6.877	29.95	0.103	3.085	44.86%
115	12.32	29.95	0.203	6.080	49.35%
115	27.91	29.97	0.506	15.15	54.29%
115	37.24	29.45	1.010	29.76	79.90%
115	68.13	29.43	2.020	59.44	87.25%
115	161.0	29.43	5.043	148.4	92.20%
115	319.3	29.42	10.08	296.5	92.85%
115	400.4	29.42	12.59	370.3	92.49%

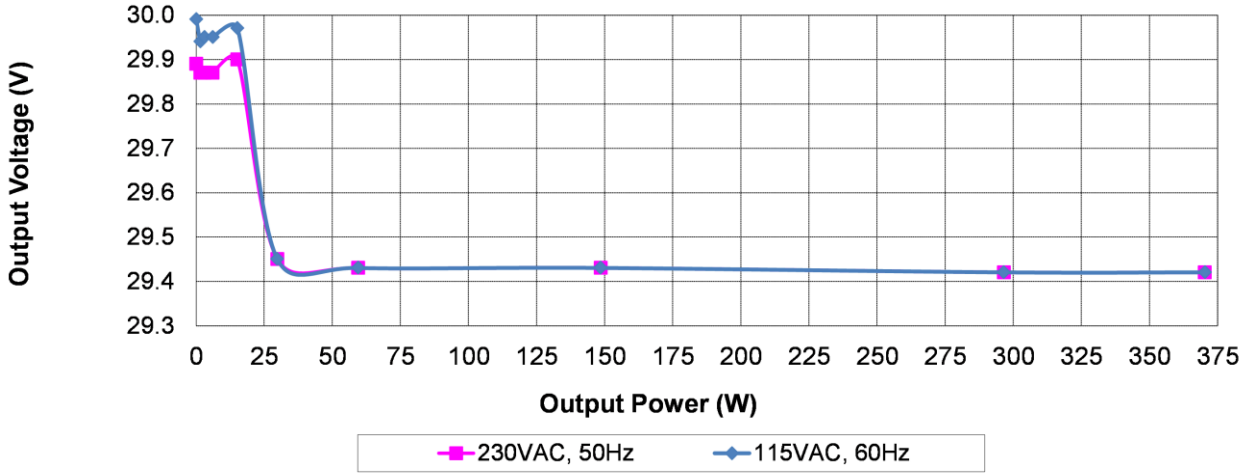
4 Output voltage regulation (PFC and 29Vout) vs. load

The graphs below show the static variation of output voltage versus load regarding PFC output (top picture, taken at different input AC voltages) and LLC (29Vout) output.

PFC output voltage vs. load and VAC:

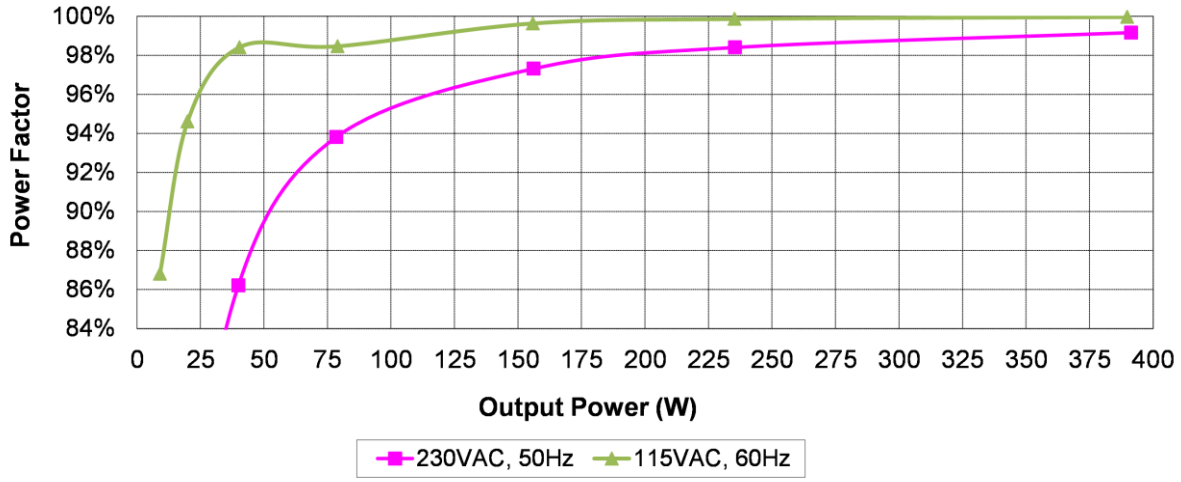


LLC output voltage vs. load:



5 Power factor

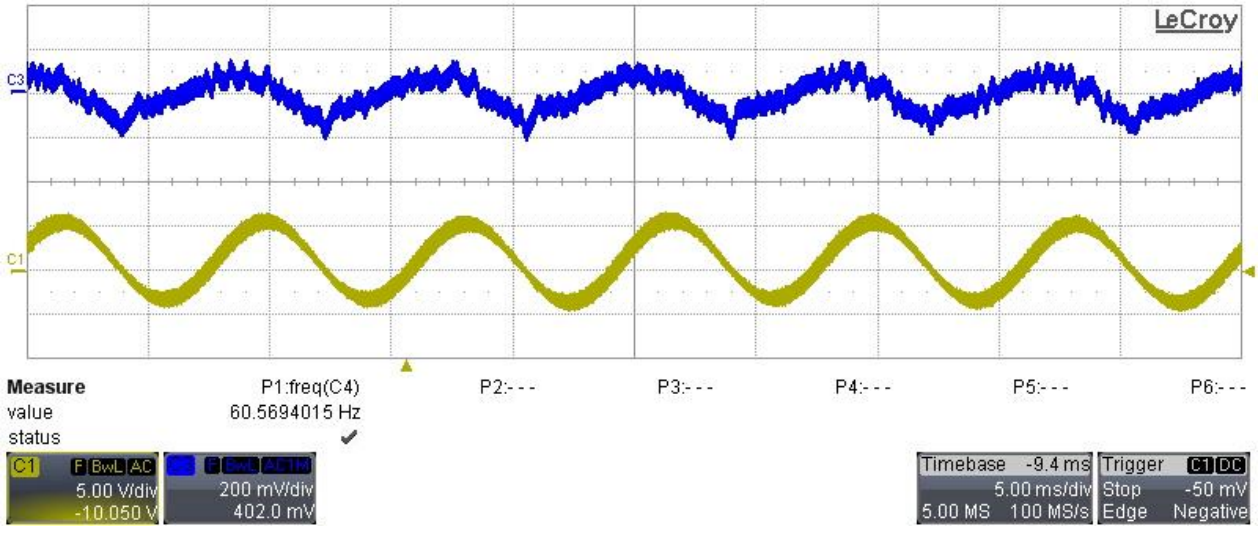
The Power Factor graph versus Vin and PFC Stage output power is shown below.



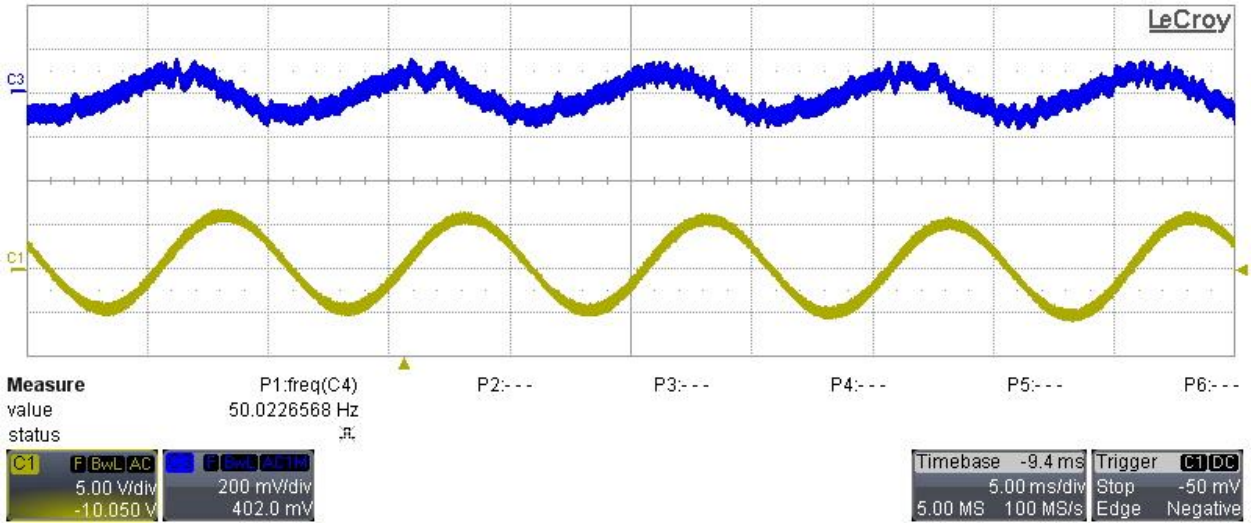
6 Output ripple voltage

The output ripple voltages for PFC and LLC stage are shown in the plots below. The input was set respectively to 120VAC, 60Hz and 230Vac, 50Hz with 29V output fully loaded.

Ch1: PFC voltage, J1-1 (5V/div, AC coupling, 20 MHz BWL)
Ch3: 29Vout, TP5 (200mV/div, AC coupling, 20 MHz BWL)
Vin = 120VAC, 60Hz



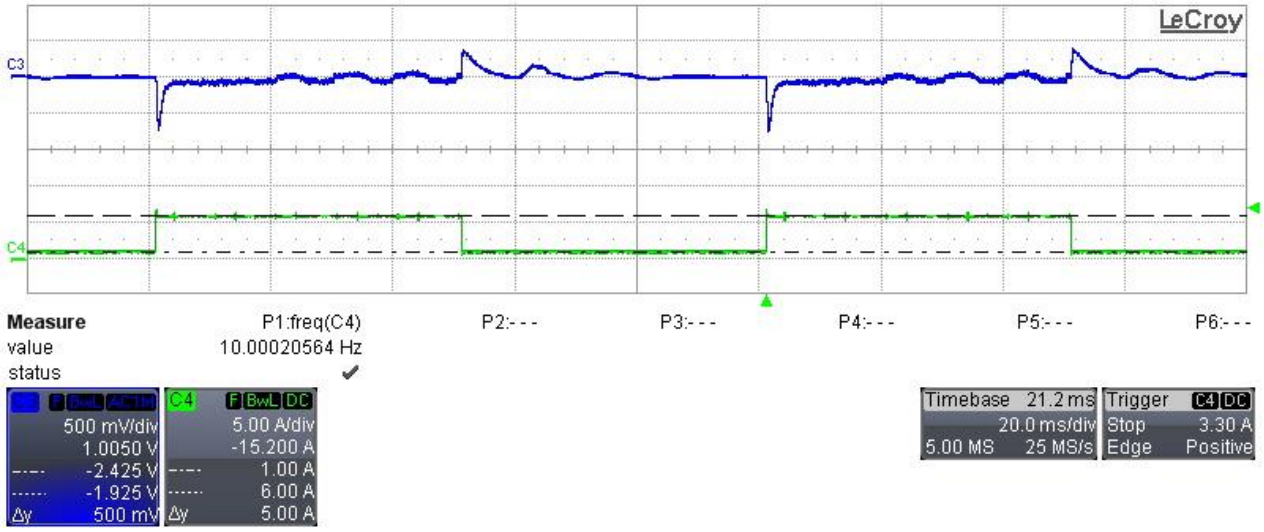
Vin = 230VAC, 50Hz
Ch1: PFC voltage, J1-1 (5V/div, AC coupling, 20 MHz BWL)
Ch3: 29Vout, TP5 (200mV/div, AC coupling, 20 MHz BWL)



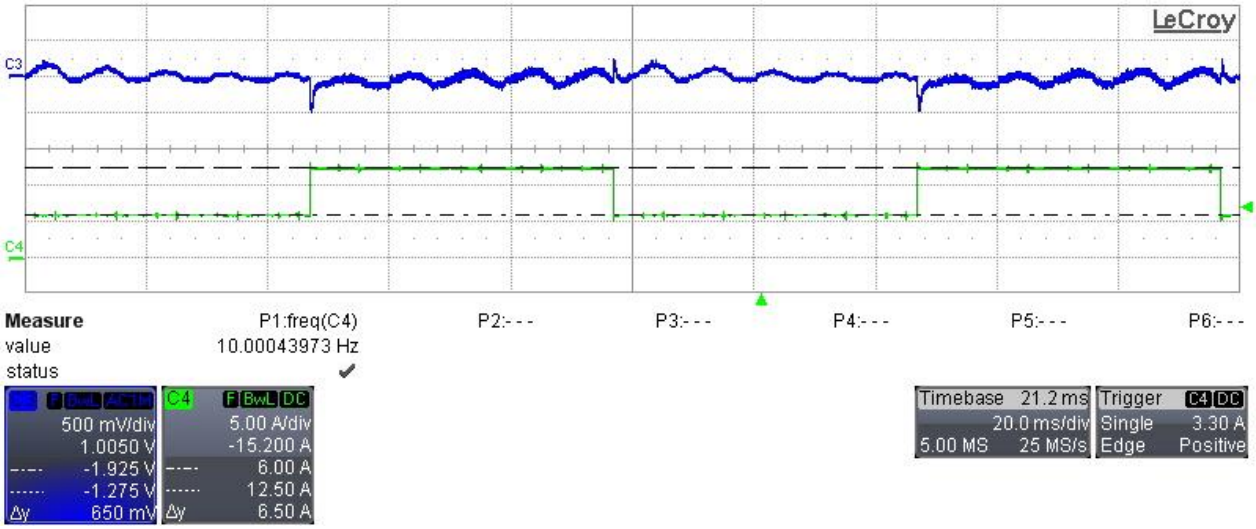
7 Transient response

The graphs below show the responses of the main output (29Vout) during output current variation respectively between 1A & 6A and 6A to 12.5A, measured at 230VAC input.

Ch3: 29Vout, TP5 (500mV/div, 20ms/div, AC coupling, 20MHz BWL)
Ch4: Output current (5A/div, DC coupling, 20MHz BWL)
Vin = 230VAC, 50Hz, Iout 1A → 6A transients



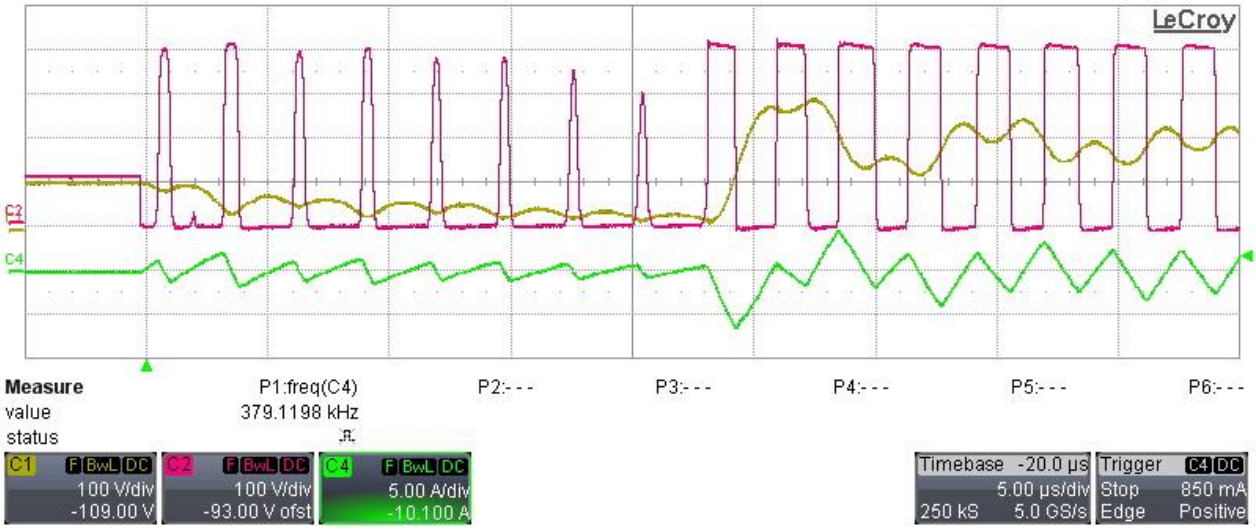
Ch3: 29Vout, TP5 (500mV/div, 20ms/div, AC coupling, 20MHz BWL)
Ch4: Output current (5A/div, DC coupling, 20MHz BWL)
Vin = 230VAC, 50Hz, Iout 6A → 12.5A transients



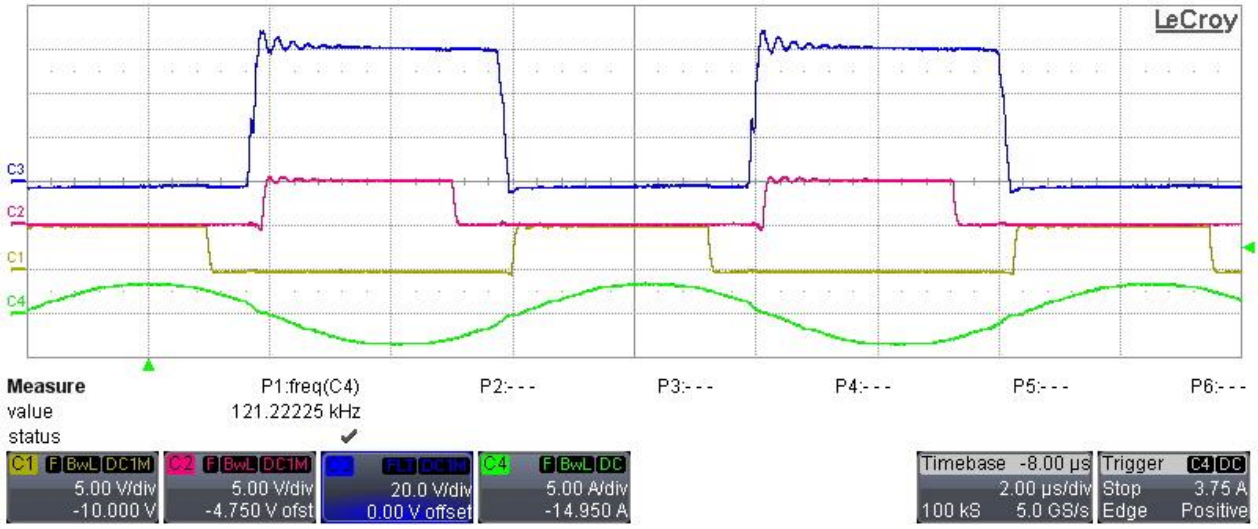
8 Switching node waveforms

The image below shows the LLC switch node (Drain-Source of Q11), the voltage across C53 and the current trough L4 (resonant current I_R) at full load and Vin = 230Vac, 50Hz (all waveforms taken @ 20MHz BWL)

Ch1: V_{C53} (100V/div, 5us/div)
Ch2: V_{DS}(Q11) (100V/div)
Ch4: I_R(L4) (5A/div)



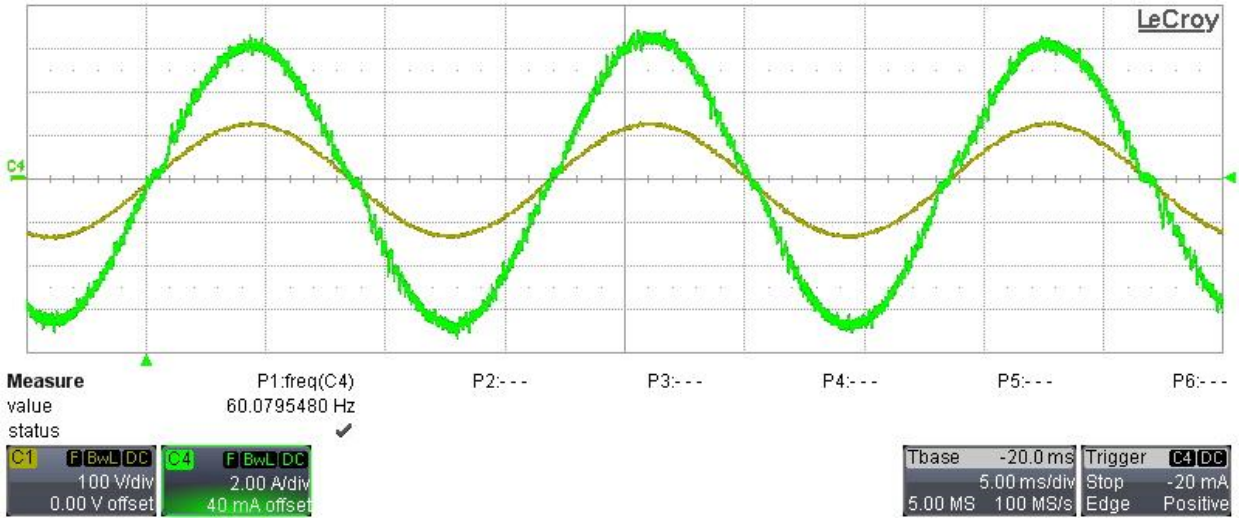
The image below shows the synchronous rectification V_{DS} voltage of Q10 and both gate waveforms of Q10 and Q12, as well as the resonant current I_R, at full load and Vin = 230Vac.
Ch1: V_{GS}(Q10) (5V/div, 2us/div, 20 MHz BWL)
Ch2: V_{GS}(Q12) (5V/div, 20 MHz BWL)
Ch3: V_{DS}(Q10) (20V/div, no BWL)
Ch4: I_R(L4) (5A/div, 20 MHz BWL)



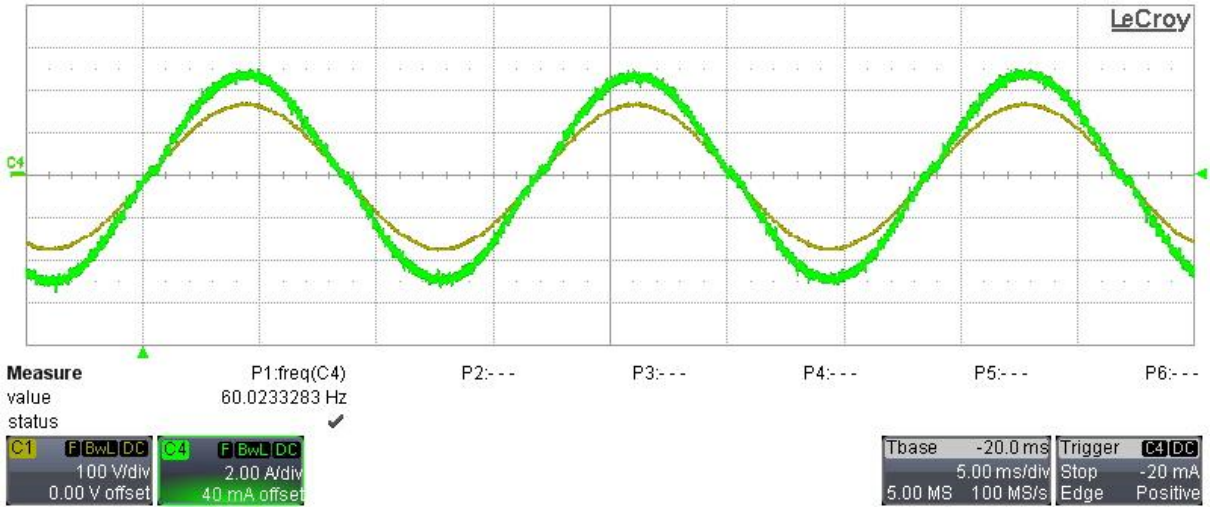
9 Input voltage and current waveforms

The images below show PFC input AC voltage and current (J6) respectively at 90VAC and 120VAC (60Hz) as well as 230VAC, and 264VAC (50Hz) in full load condition. Oscilloscope setup was the same for all four screenshots.

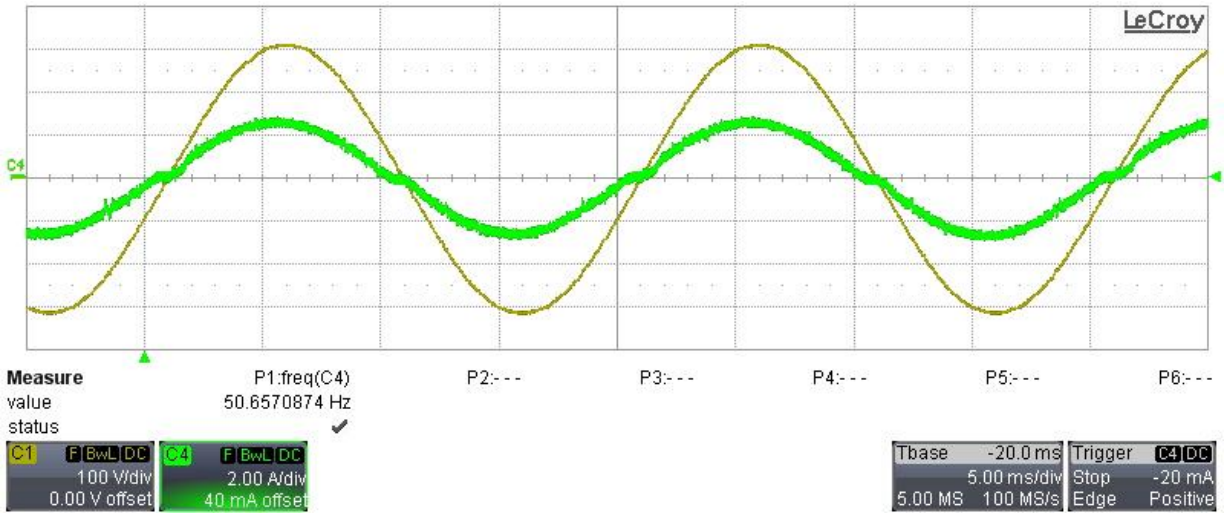
Ch1: Input AC voltage (100V/div, 5ms/div, 20MHz BWL)
Ch4: Input AC current (10V/div, 20MHz BWL)
Vin = 90VAC, 60Hz



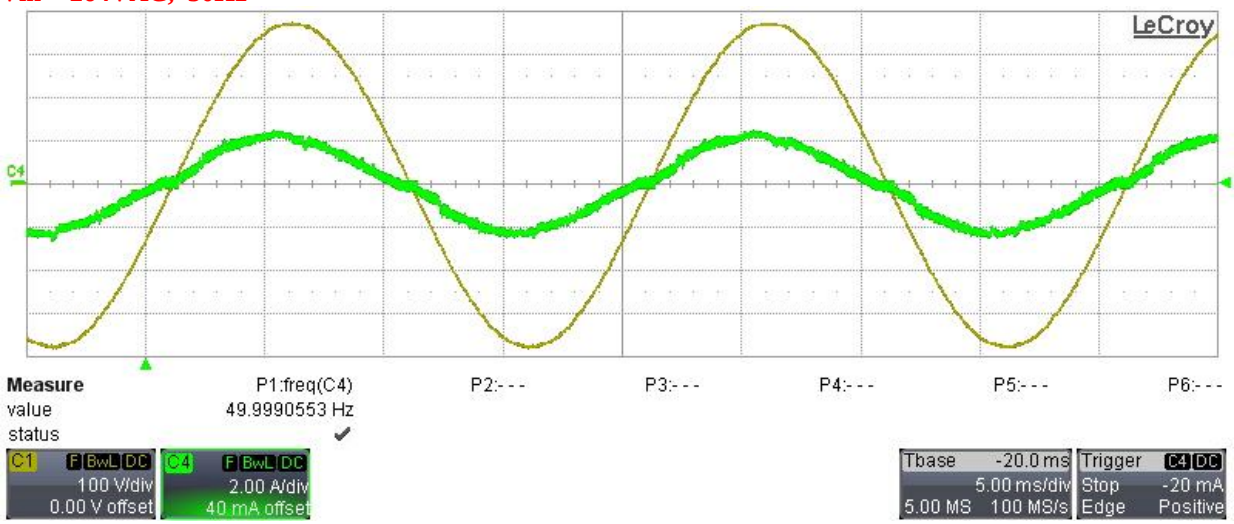
Vin = 120VAC, 60Hz



Vin = 230VAC, 50Hz

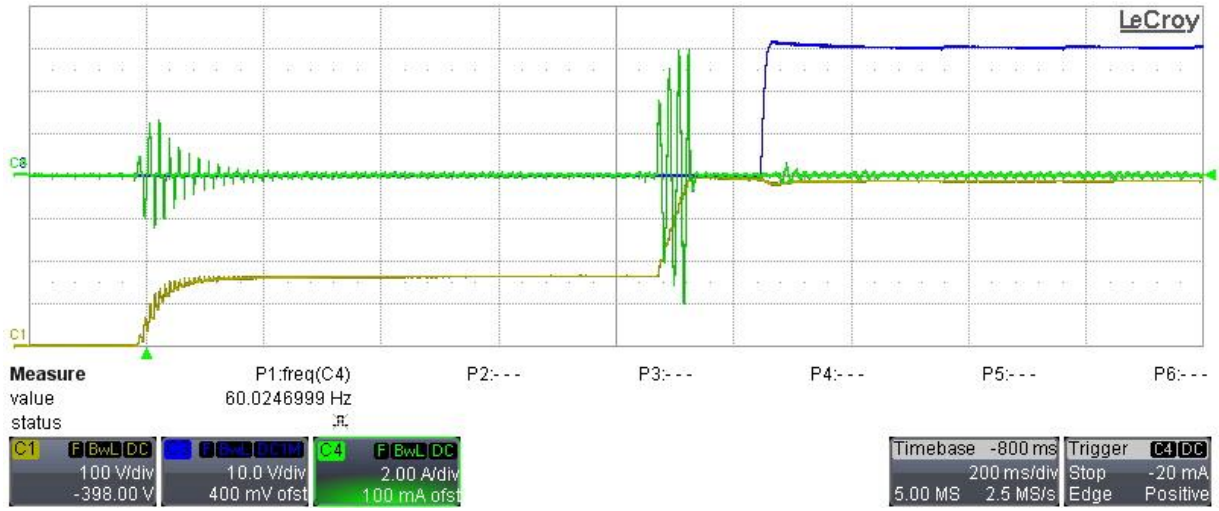


Vin = 264VAC, 50Hz

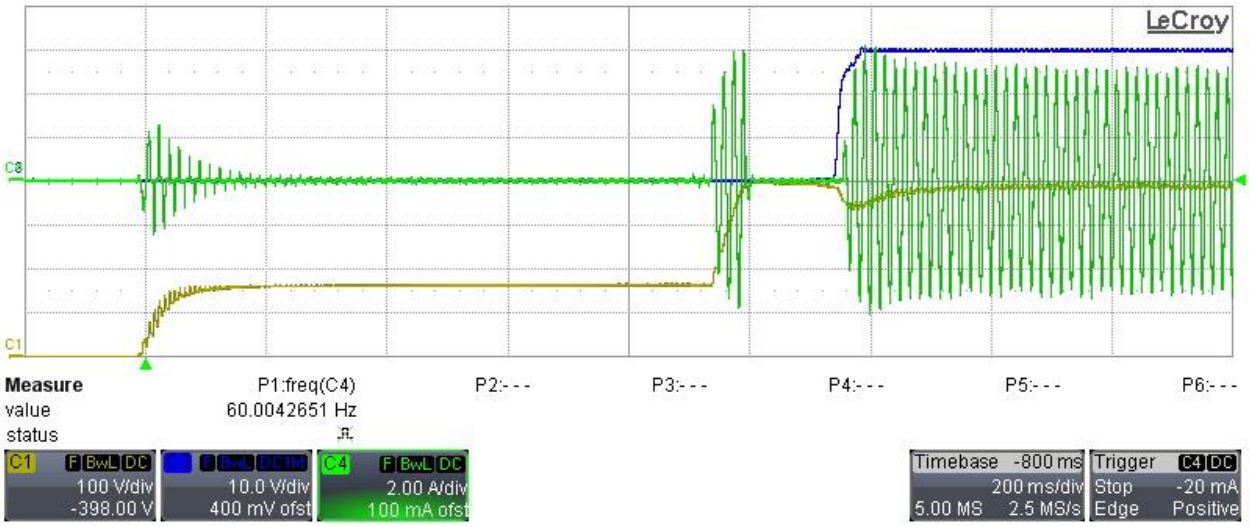


10 Input voltage and current waveforms during inrush

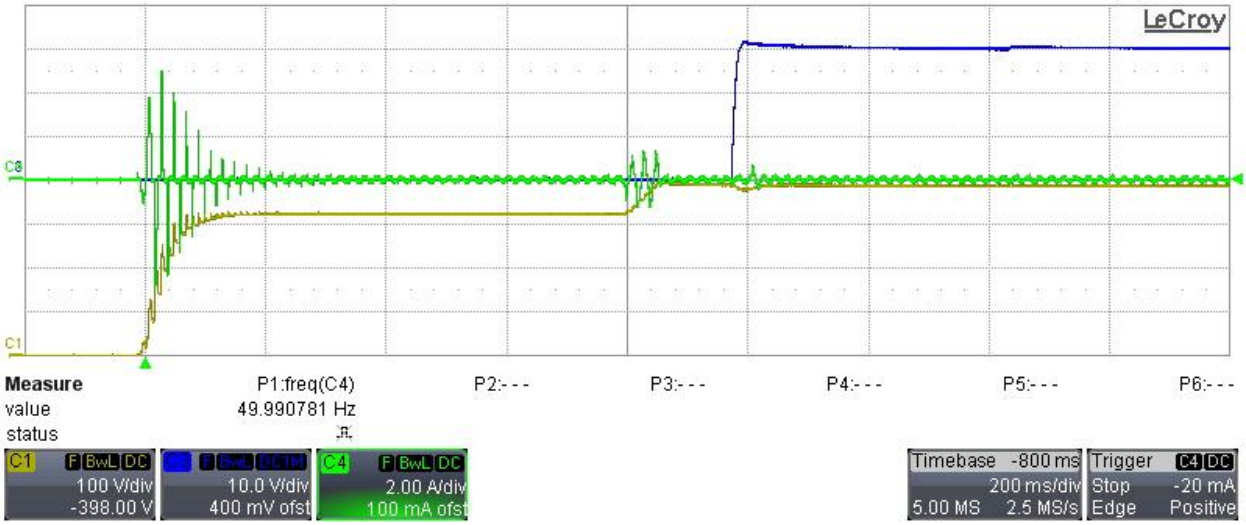
The images below show PFC output voltage, input AC current and 29Vout waveforms during AC source turn on; the source was set to 120Vac, 60Hz and 230Vac, 50Hz. The main 29V output voltage was fully loaded as well as unloaded.
Ch1: PFC output voltage (100V/div, 50ms/div, 20MHz BWL)
Ch2: 29Vout, TP5 (10V/div, 20MHz BWL)
Ch4: Input AC current (2A/div, 20MHz BWL)
Vin = 120Vac, 60Hz, no load



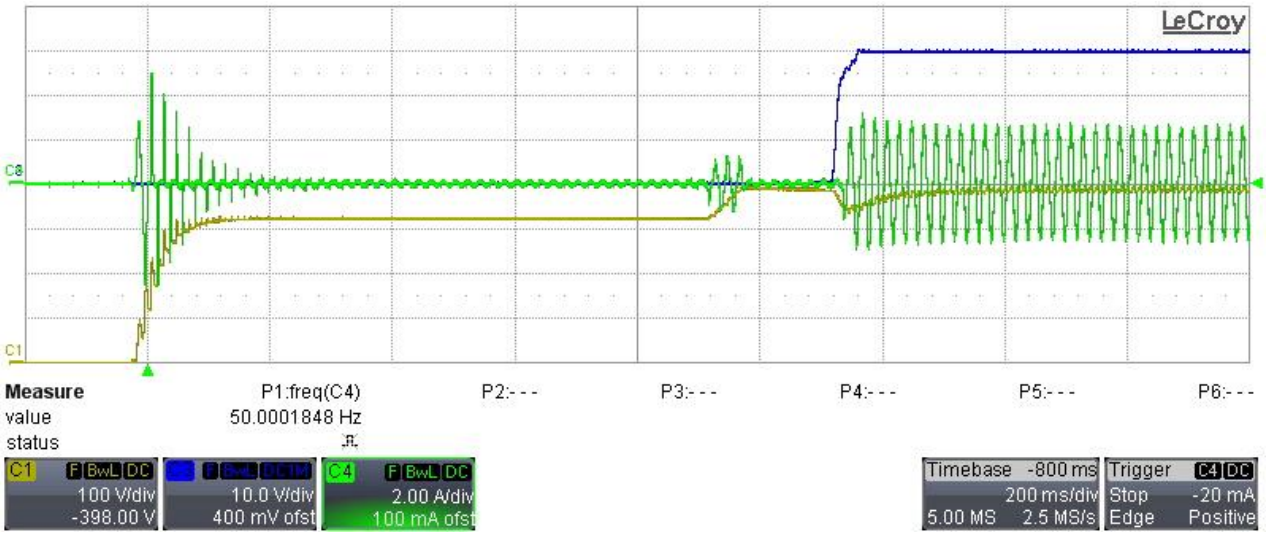
Same oscilloscope setup as above.
Vin = 120Vac, 60Hz, full load



Same oscilloscope setup as above.
Vin = 230Vac, 50Hz, no load



Same oscilloscope setup as above.
Vin = 230Vac, 50Hz, full load

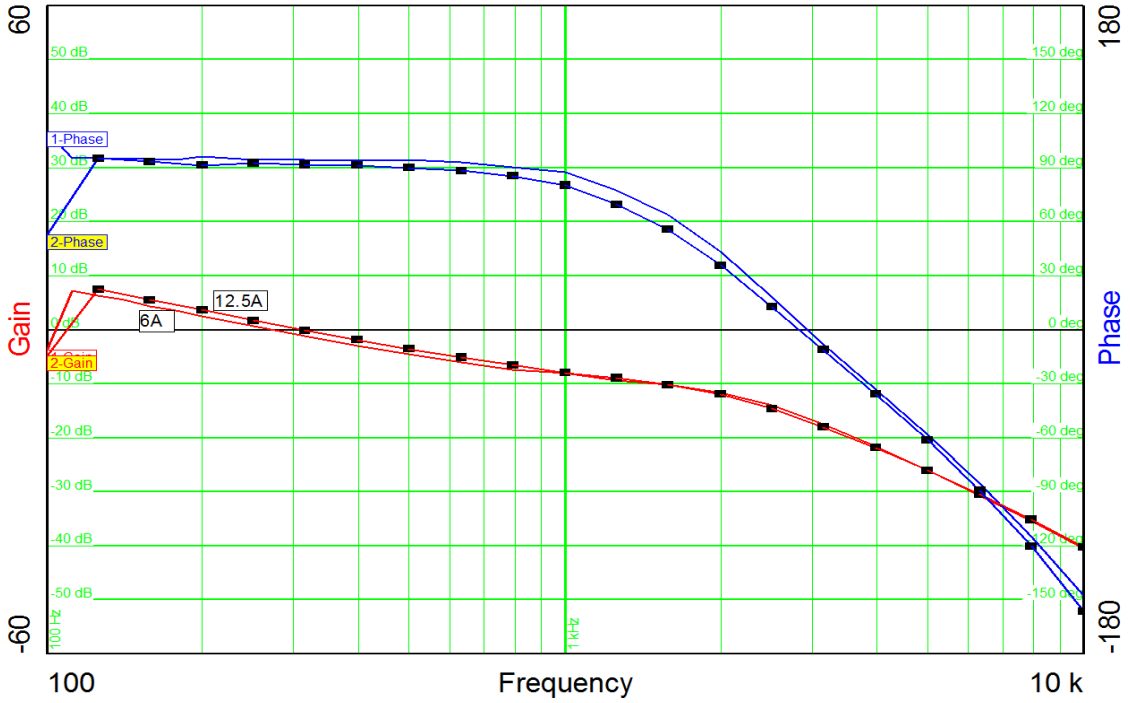


11 Feedback loop response of LLC converter

The graphs below show the bode plots of main LLC converter (29Vout) when loaded @ 6A and 12.5A. The input voltage was always 230Vac.

6A load: crossover frequency (F_{CO}) = 274Hz, phase margin = 94 deg, gain margin = 16.5dB.

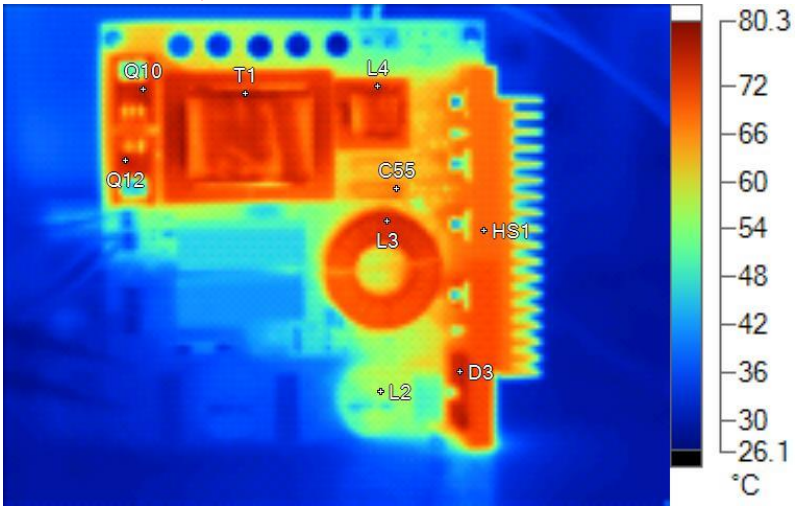
12.5A load: F_{CO} = 311Hz, phase margin = 91.6 deg, gain margin = 16.4dB.



12 Thermal analysis

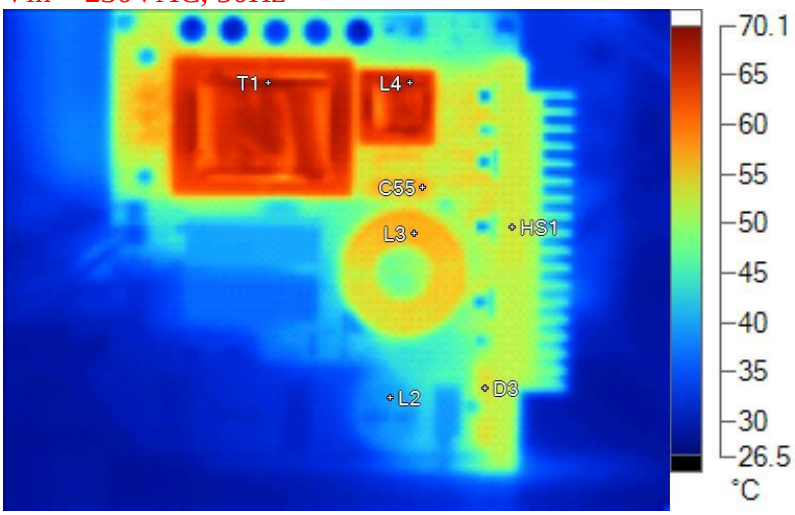
The thermal images have been taken after one hour in steady state condition, at full load and at 120VAC as well as 230VAC input voltage. The board was placed vertically on the bench without any forced convection. The ambient temperature was 25°C.

Vin = 120VAC, 60Hz



Name	Temperature	Background
Q10	75.7°C	25.0°C
Q12	75.9°C	25.0°C
T1	78.0°C	25.0°C
L4	72.3°C	25.0°C
L3	74.4°C	25.0°C
D3	75.1°C	25.0°C
HS1	68.6°C	25.0°C
L2	56.1°C	25.0°C
C55	66.7°C	25.0°C

Vin = 230VAC, 50Hz

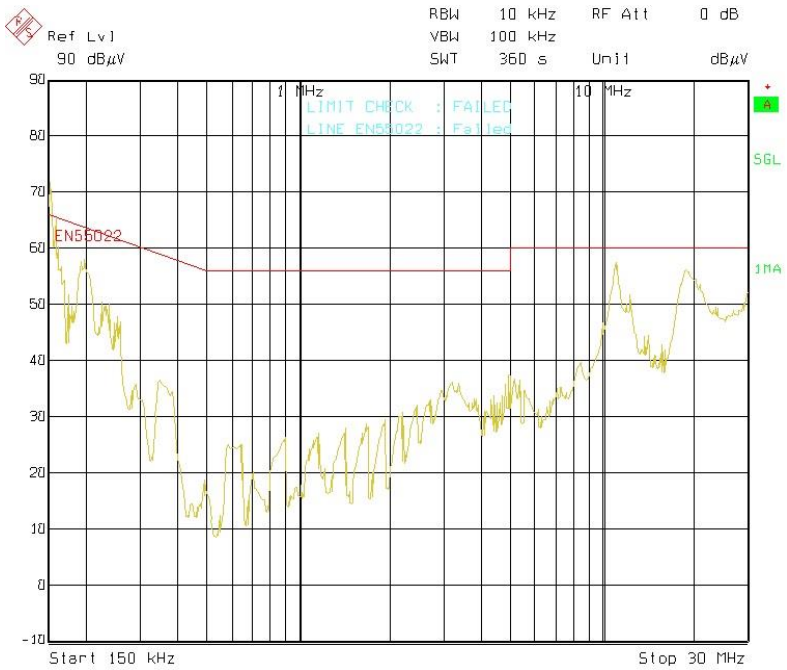


Name	Temperature	Background
T1	69.1°C	25.0°C
L4	68.3°C	25.0°C
L3	56.3°C	25.0°C
C55	56.9°C	25.0°C
D3	53.2°C	25.0°C
HS1	52.6°C	25.0°C
L2	39.1°C	25.0°C

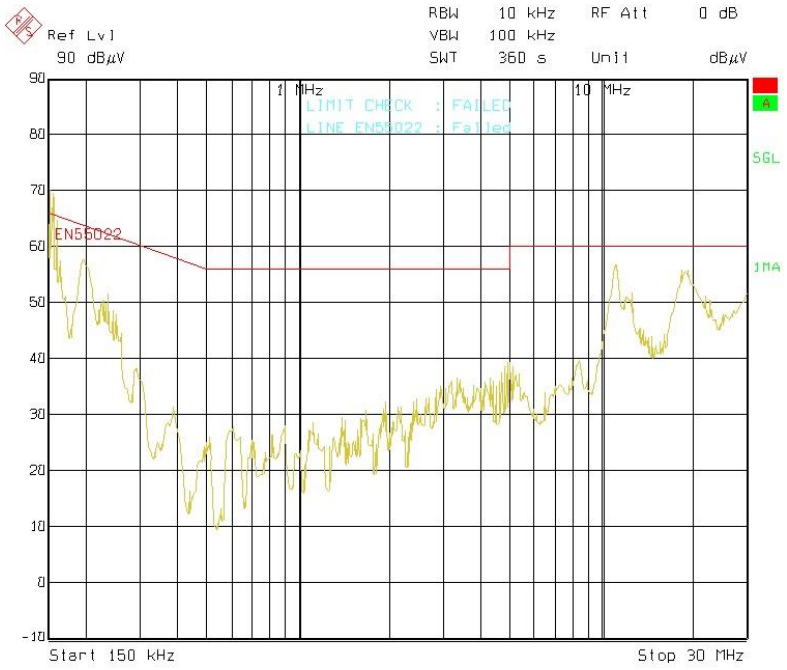
13 EMI measurement

The graphs below show the EMI measurements of the converter connected to an isolation transformer by means of a Hameg HM6050-2 LISN. The supply voltage was 230VAC. The converter has been loaded with an electronic load and fully loaded. The output negative terminal of the converter has been connected to the ground of the LISN. The detector of the receiver was set to "quasi-peak" and the limit is the equivalent EN55022 grade B.

Line:



Neutral:



IMPORTANT NOTICE AND DISCLAIMER

TI PROVIDES TECHNICAL AND RELIABILITY DATA (INCLUDING DATASHEETS), DESIGN RESOURCES (INCLUDING REFERENCE DESIGNS), APPLICATION OR OTHER DESIGN ADVICE, WEB TOOLS, SAFETY INFORMATION, AND OTHER RESOURCES “AS IS” AND WITH ALL FAULTS, AND DISCLAIMS ALL WARRANTIES, EXPRESS AND IMPLIED, INCLUDING WITHOUT LIMITATION ANY IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE OR NON-INFRINGEMENT OF THIRD PARTY INTELLECTUAL PROPERTY RIGHTS.

These resources are intended for skilled developers designing with TI products. You are solely responsible for (1) selecting the appropriate TI products for your application, (2) designing, validating and testing your application, and (3) ensuring your application meets applicable standards, and any other safety, security, or other requirements. These resources are subject to change without notice. TI grants you permission to use these resources only for development of an application that uses the TI products described in the resource. Other reproduction and display of these resources is prohibited. No license is granted to any other TI intellectual property right or to any third party intellectual property right. TI disclaims responsibility for, and you will fully indemnify TI and its representatives against, any claims, damages, costs, losses, and liabilities arising out of your use of these resources.

TI’s products are provided subject to TI’s Terms of Sale (https:www.ti.com/legal/termsofsale.html) or other applicable terms available either on ti.com or provided in conjunction with such TI products. TI’s provision of these resources does not expand or otherwise alter TI’s applicable warranties or warranty disclaimers for TI products.

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265
Copyright © 2021, Texas Instruments Incorporated