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EVALPFC2-ICE2PCS04

300W PFC Evaluation Board with CCM PFC controller ICE2PCS04

Power Management & Supply

Never stop thinking.

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1 Content

The evaluation board presented here is a 300W power factor correction (PFC) circuit with 85~265VAC universal input and 393VDC fixed output. The continuous conduction mode (CCM) PFC controller **ICE2PCS04** is employed in this board to achieve the unity power factor. This **ICE2PCS04** is a design variant of ICE2PCS01 to incorporate the new input brown-out protection function. Appreciated for its high integrated design, **ICE2PCS04** can achieve full requirements of the PFC application implemented in the 8-pin DIP8 and SO8 packages. At the same time the number of peripheral components is minimized. The operation frequency is fixed at 133kHz due to internal oscillator of **ICE2PCS04**. In order to improve the power conversion efficiency, the **CoolMOS^{TM} C3** series and high voltage silicon carbide (SiC) schottky diode **thinQ!^{TM}** are used into this boost type PFC circuit.

2 Evaluation Board

3 Technical Specifications

Input voltage	85VAC~265VAC
Input frequency	50Hz
Output voltage and current	393VDC, 0.75A
Output power	~ 300W
Efficiency	>91% at full load
Switching Frequency	133kHz

4 Circuit Description

Line Input

The AC line input side comprises the input fuse F1 as over-current protection. The high frequency current ripple is filtered by R1, L1 and CX1. The choke L2, X2-capacitors CX1 and CX2 and Y1-capacitor CY1 and CY2 are used as radio interference suppressors. RT1 is placed in series to limit inrush current during each power on.

Power Stage – Boost Type PFC Converter

After the bridge rectifier BR1, there is a boost type PFC converter consisting of L3, Q1, D1 and C2. The third generation CoolMOS™ SPP20N60C3 is used as the power switch Q1. BR1, Q1 and SiC Diode D1 share the same heat sink so that the system heat can be equably spread. Output capacitor C2 provides energy buffering to reduce the output voltage ripple (100Hz) to the acceptable level.

PWM Control of Boost Converter

The PWM control is realized by 8-Pin CCM PFC IC ICE2PCS04. It is a variant design of ICE2PCS01 with preserving most of the features. Unlike the conventional PFC controller, ICE2PCS04 does not need direct sine wave reference signal. The switching frequency is fixed at 133kHz by the IC internal oscillator. There are two control loops in the circuit, voltage loop and current loop. The output voltage is sensed by the voltage divider of R5A, R5B, R6A and R6B and sent to internal error amplifier. The output of error amplifier is used to control current in the inner current loop. The compensation network C4, C5, R7 constitutes the external circuitry of the error amplifier. This circuitry allows the feedback to be matched to various load conditions, thereby providing stable control. In order not to make the response for 100Hz ripple, the voltage loop compensation is implemented with low bandwidth. The inner loop, current control loop, is implemented with average current mode strategy. The instant current is adjusted to be proportional to both of MOSFET off duty DOFF and the error amplifier output voltage of voltage loop. The current is sensed by shunt resistors R2, R2A and R2B and fed into IC through R9. The current sense signal is averaged by an internal operating amplifier and then processed in the PWM generator which drives the gate drive. The averaging is realized by charging and discharging an external capacitor C7 at pin ICOMP.

The IC supply is provided by external voltage source and filtered and buffered by C8 and C9. The IC output gate driver is a fast totem pole gate drive. It has a built-in cross conduction current protection and a Zener diode to protect the external transistor switch against undesirable over voltages. The gate drive resistor R4 is selected to limit and gate pulse current and drive MOSFET for fast switching.

5 Circuit Operation

Soft Startup

When Vcc pin is higher than turn-on threshold, typical 11V, PFC is going to start. The unique soft start is integrated. Input current keeps sinusoidal and is increasing gradually until output voltage reaches 80% of rating. The boost diode is not stressed with large diode duty cycle under high current.

Enhanced Dynamic Response

Due to inherent low bandwidth of PFC dynamic, in case of load jump, regulation circuit can not response fast enough and it will lead to large output voltage overshoot or drop. To solve this problem in PFC application, enhanced dynamic response is implemented in the IC. Whenever output voltage exceeds by ±5%, it will bypass the slow compensation operating amplifier and act on the nonlinear gain block to affect the duty cycle directly. The output voltage can be recovered in a short time.

Protection Features

a. Input brown-out protection

The dedicated input voltage brown-out VINS pin is the most distinct new feature brought by ICE2PCS04. This VINS pin senses a filtered input voltage divider and detects for the input voltage brown-out condition. If the detected VINS is below 0.8V, then IC output will be shut down. Only when VINS voltage reaches 1.5V can awake the IC again. Be informed that it will still have the soft start property when the IC is recovered from brown-out situation.

b. Open loop protection

The open loop protection is available for this IC to safe-guard the output. Whenever VSENSE voltage falls below 0.6V, or equivalently VOUT falls below 20% of its rated value, it indicates an open loop condition (i.e. VSENSE pin not connected). In this case, most of the blocks within the IC will be shutdown. It is implemented using a comparator with a threshold of 0.6V.

c. Output over-voltage protection

Whenever VOUT exceeds the rated value by 8%, the over-voltage protection OVP is active. This is implemented by sensing the voltage at pin VSENSE with respect to a reference voltage of 3.25V. A VSENSE voltage higher than 3.25V will immediately block the gate signal.

d. Soft over current control (SOC) and peak current limit

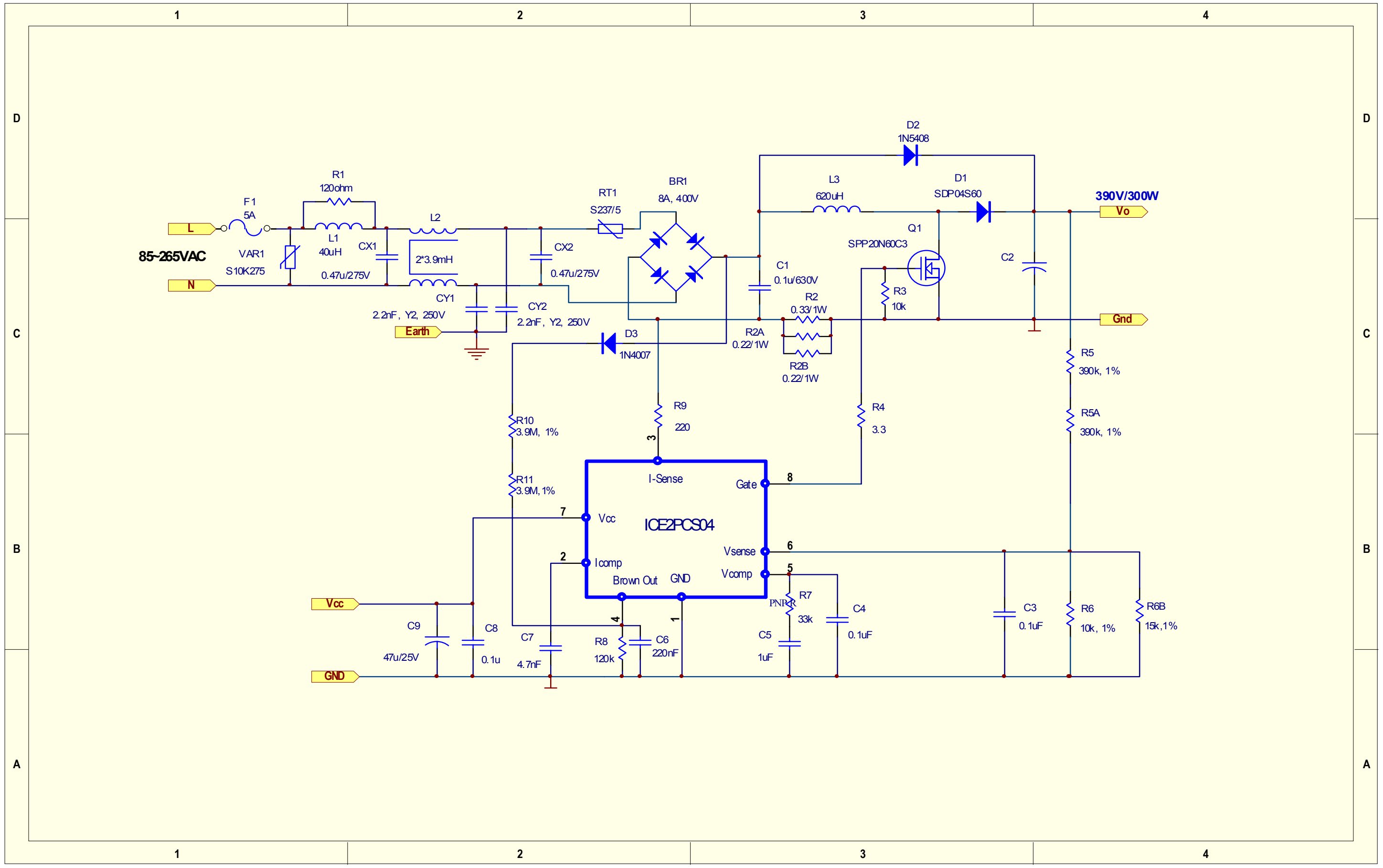
When the amplitude of current sense voltage reaches 0.68V, Soft Over Current Control (SOC) is activated. This is a soft control does not directly switch off the gate drive but acts on the internal blocks to result in a reduced PWM duty cycle.

The IC also provides a cycle by cycle peak current limitation (PCL). It is active when the voltage at current sense voltage reaches -1.04V. The gate output is immediately off after 300ns blanking time.

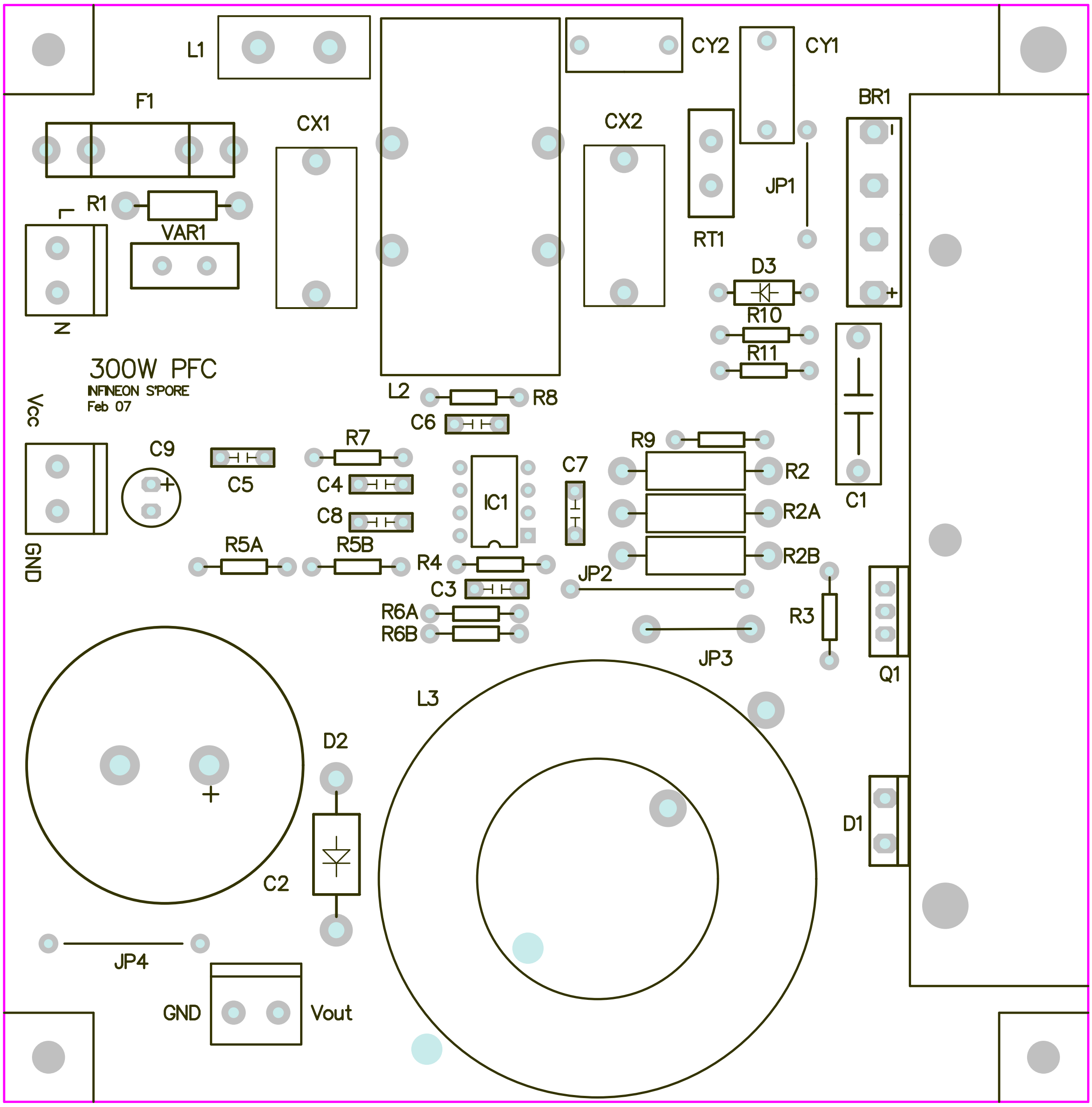
e. IC supply under voltage lockout

When VCC voltage is below the under voltage lockout threshold VCCUVLO, typical 11, IC is off the gate drive is internally pull low to maintain the off state. The current consumption is down to 200uA only.

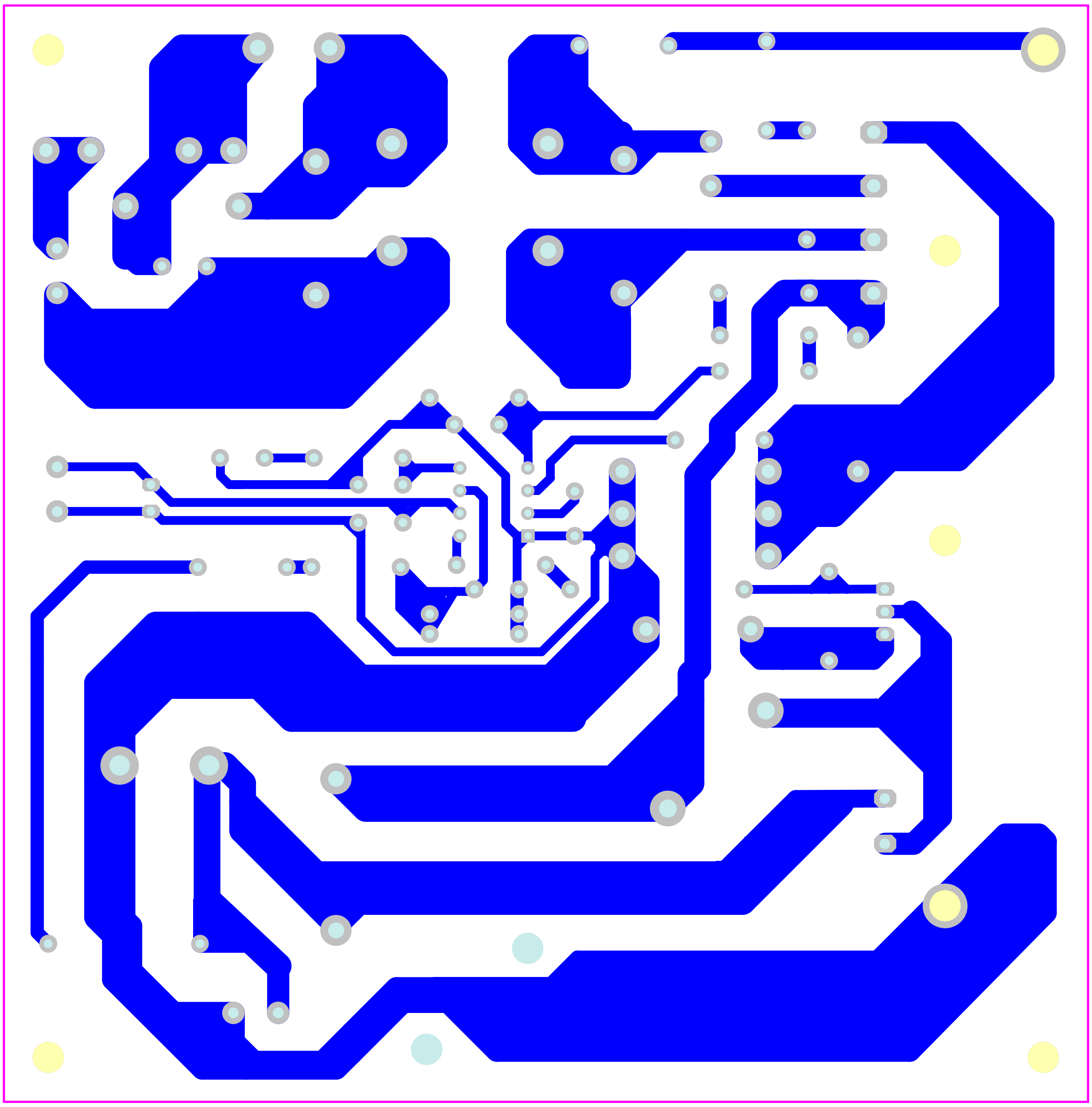
6 Circuit Diagram



7 PCB Layout Top Layer



8 PCB layout Bottom Layer



9 Component List

Designator	Part Type	Description	Quantity
BR1	8A, 400V	Bridge Rectifier	1
C1	0.1uF/630V	Ceramic Cap	1
C2	220uF/450V	Electrolytic Cap	1
C3*	0.1uF/50V	Ceramic Cap	1
C4	0.1uF/50V	Ceramic Cap	1
C5	1uF/50V	Ceramic Cap	1
C6	220nF/50V	Ceramic Cap	1
C7	4.7nF/50V	Ceramic Cap	1
C8	0.1uF/50V	Ceramic Cap	1
C9	47uF/25V	Electrolytic Cap	1
CX1	0.47uF, X1, 305V	Ceramic Cap	1
CX2	0.47uF, X1, 305V	Ceramic Cap	1
CY1	2.2nF, Y2, 250V	Ceramic Cap	1
CY2	2.2nF, Y2, 250V	Ceramic Cap	1
		Connector	3
D1	SDT04S60	Diode	1
D2	1N5408	Diode	1
D3	1N4007	Diode	1
F1	5A	Fuse	1
		Fuse Holder	2
IC1	ICE2PCS04		1
JP1	12.5mm, Φ0.7mm	Jumper	1
JP2	20mm, Φ0.7mm	Jumper	1
JP3	12mm, Φ1.2mm	Jumper	1
JP4	17.5mm, Φ0.7mm	Jumper	1
L1*	Shorted		0
L2	2*3.9mH	CM Choke	1
L3	620uH	Choke	1
Q1	SPP20N60C3	Power MOSFET	1
		Heat Sink	1
		TO220 Clip	2
		TO247 Clip	1
		TO220 Isolation Pad	2
		3mm Screw	3
R1*	Not Connected		0
R2	0.33/1W, 5%	Metal Film Resistor	1
R2A	0.22/1W, 5%	Metal Film Resistor	1
R2B	0.22/1W, 5%	Metal Film Resistor	1
R3	10k/0.25W, 5%	Carbon Film Resistor	1
R4	3.3/0.25W, 5%	Carbon Film Resistor	1
R5A	390k/0.25W, 1%	Carbon Film Resistor	1
R5B	390k/0.25W, 1%	Carbon Film Resistor	1
R6A	10k/0.25W, 1%	Carbon Film Resistor	1
R6B	15k/0.25W, 1%	Carbon Film Resistor	1
R7	33k/0.25W, 5%	Carbon Film Resistor	1
R8	120k/0.25W, 1%	Carbon Film Resistor	1

R9	220/0.25W, 5%	Carbon Film Resistor	1
R10	3.9M/0.25W, 1%	Carbon Film Resistor	1
R11	3.9M/0.25W, 1%	Carbon Film Resistor	1
RT1	S237/5	NTC Thermistor	1
VAR1	S10K275	Varistor	1

10 Boost Choke Layout

Core: CS400125 toriod

Turns: 60

Wire: 1 x Φ1.0mm, AWG19

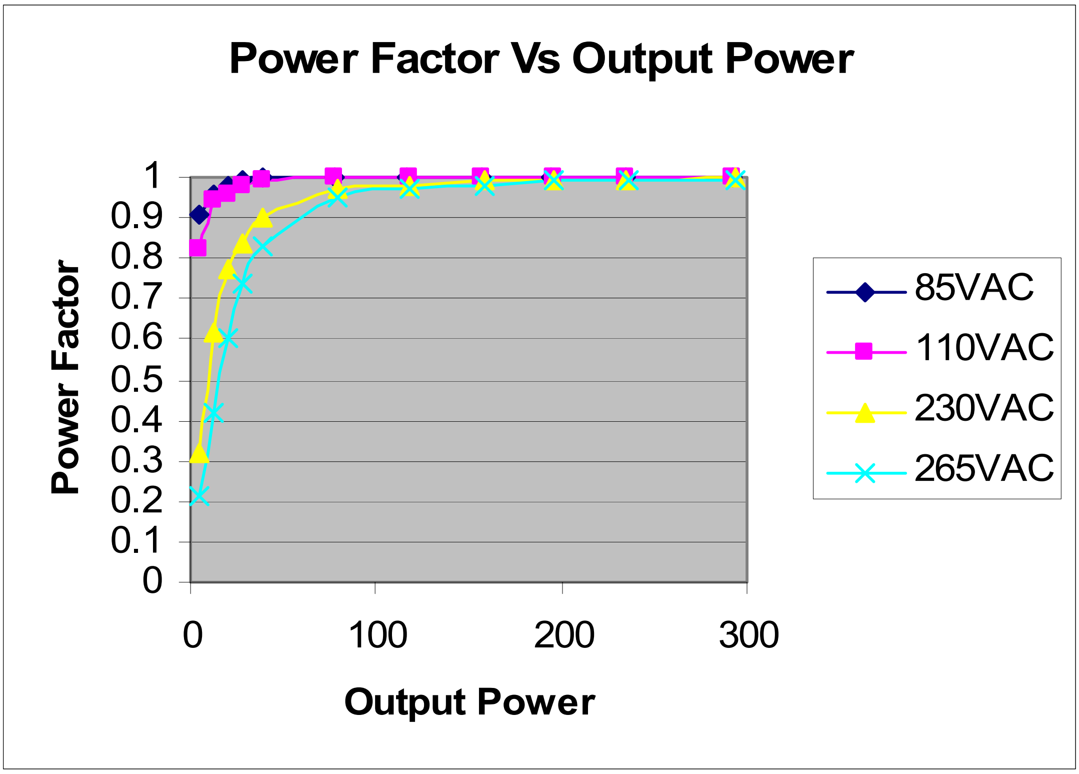
Inductance: L=620uH

11 Test report

11.1 Load test (table and figure)

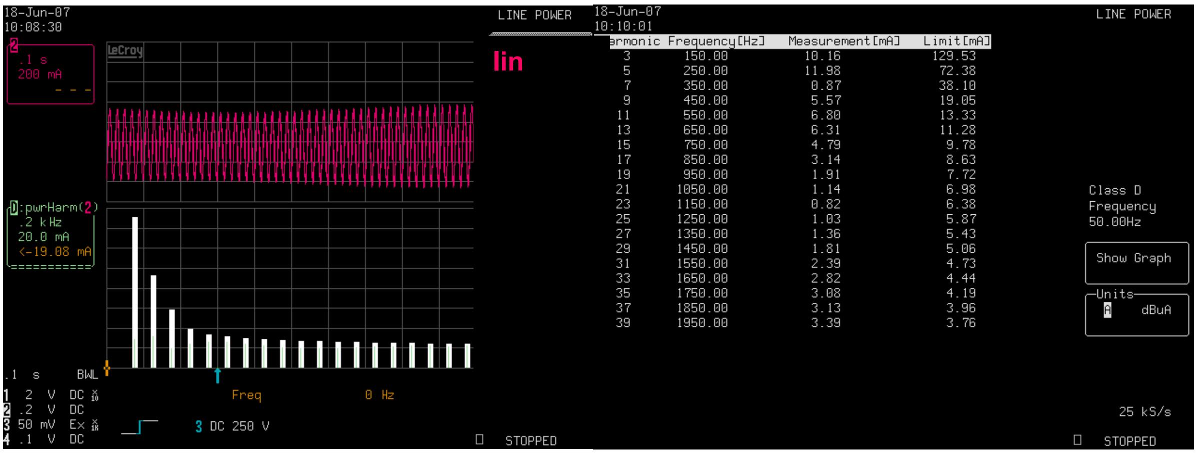
Vin(VAC)	Pin	Iin	Vout	Iout	Pout	Efficiency	PF
	317	3.82	389	0.75	291.75	92%	1
	252	3.02	390	0.6	234	93%	1
	209	2.49	390	0.5	195	93%	1
	168	1.99	390	0.4025	156.975	93%	1
	126.5	1.5	391	0.3	117.3	93%	1
	84	1	391.4	0.2	78.28	93%	1
	43.2	0.51	392	0.0987	38.6904	90%	1
	31.2	0.37	393	0.0706	27.7458	89%	0.99
	22.7	0.27	393	0.0512	20.1216	89%	0.98
	14.7	0.18	394	0.0318	12.5292	85%	0.96
85VAC	6.6	0.085	394	0.0125	4.925	75%	0.91
	310	2.85	390	0.75	292.5	94%	1
	247	2.27	390.5	0.6	234.3	95%	1
	206	1.89	391	0.5	195.5	95%	1
	166	1.52	391	0.4025	157.3775	95%	1
	125	1.15	391.5	0.3	117.45	94%	1
	83.6	0.765	392	0.2	78.4	94%	1
	42.7	0.39	393	0.0987	38.7891	91%	0.99
	30.4	0.28	394	0.0706	27.8164	92%	0.98
	22.5	0.21	394	0.0512	20.1728	90%	0.96
	14.5	0.141	394	0.0318	12.5292	86%	0.94
110VAC	6.5	0.072	394	0.0125	4.925	76%	0.82
230VAC	302	1.32	392	0.75	294	97%	1
	242	1.06	392.4	0.6	235.44	97%	0.99
	202	0.89	392.5	0.5	196.25	97%	0.99
	163	0.72	393	0.4025	158.1825	97%	0.99
	123	0.54	393	0.3	117.9	96%	0.98

	82	0.37	394	0.2	78.8	96%	0.97
	41.5	0.2	394	0.0987	38.8878	94%	0.9
	30	0.15	394	0.0706	27.8164	93%	0.84
	22	0.12	394	0.0512	20.1728	92%	0.77
	14	0.99	394	0.0318	12.5292	89%	0.62
	6	0.084	395	0.0125	4.9375	82%	0.32
	301	1.15	392.5	0.75	294.375	98%	0.99
	241	0.921	393	0.6	235.8	98%	0.99
	201	0.77	393	0.5	196.5	98%	0.99
	162.5	0.62	393	0.4025	158.1825	97%	0.98
	122	0.47	393	0.3	117.9	97%	0.97
	82	0.324	394	0.2	78.8	96%	0.952
	41	0.185	394	0.0987	38.8878	95%	0.83
	29	0.15	394	0.0706	27.8164	96%	0.74
	21.5	0.137	394	0.0512	20.1728	94%	0.6
	13.9	0.125	395	0.0318	12.561	90%	0.42
265VAC	5.9	0.1	395	0.0125	4.9375	84%	0.21



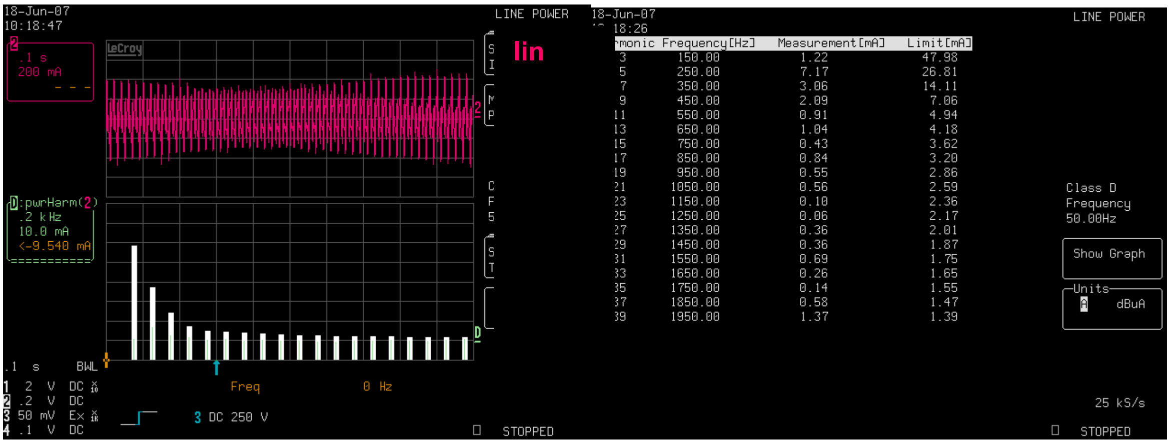
11.2 Harmonic test according to EN61000-3-2 Class D requirement

85VAC, 6% of full load (18W output)



Harmonic	Frequency[Hz]	Measurement[mA]	Limit[mA]
3	150.00	10.16	129.53
5	250.00	11.98	72.38
7	350.00	0.87	38.10
9	450.00	5.57	19.05
11	550.00	6.80	13.33
13	650.00	6.31	11.28
15	750.00	4.79	9.78
17	850.00	3.14	8.63
19	950.00	1.91	7.72
21	1050.00	1.14	6.98
23	1150.00	0.82	6.38
25	1250.00	1.03	5.87
27	1350.00	1.36	5.43
29	1450.00	1.81	5.06
31	1550.00	2.39	4.73
33	1650.00	2.82	4.44
35	1750.00	3.08	4.19
37	1850.00	3.13	3.96
39	1950.00	3.39	3.76

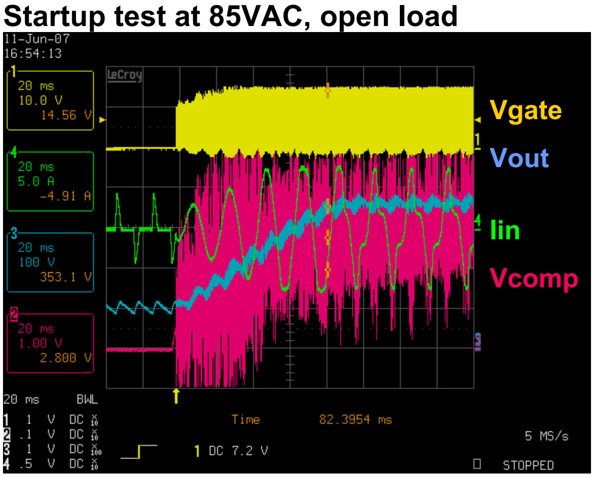
265VAC, 6% of full load (18W output)



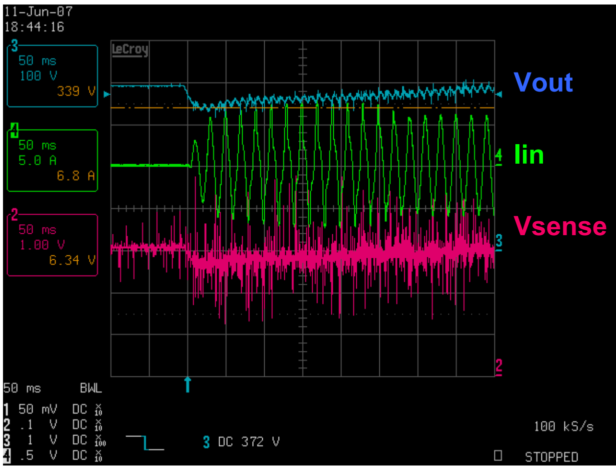
Harmonic	Frequency[Hz]	Measurement[mA]	Limit[mA]
3	150.00	1.22	47.98
5	250.00	7.17	26.81
7	350.00	3.06	14.11
9	450.00	2.09	7.06
11	550.00	0.91	4.94
13	650.00	1.04	4.18
15	750.00	0.43	3.62
17	850.00	0.84	3.20
19	950.00	0.55	2.86
21	1050.00	0.56	2.59
23	1150.00	0.10	2.36
25	1250.00	0.06	2.17
27	1350.00	0.36	2.01
29	1450.00	0.36	1.87
31	1550.00	0.69	1.75
33	1650.00	0.26	1.65
35	1750.00	0.14	1.55
37	1850.00	0.58	1.47
39	1950.00	1.37	1.39

Test Waveforms

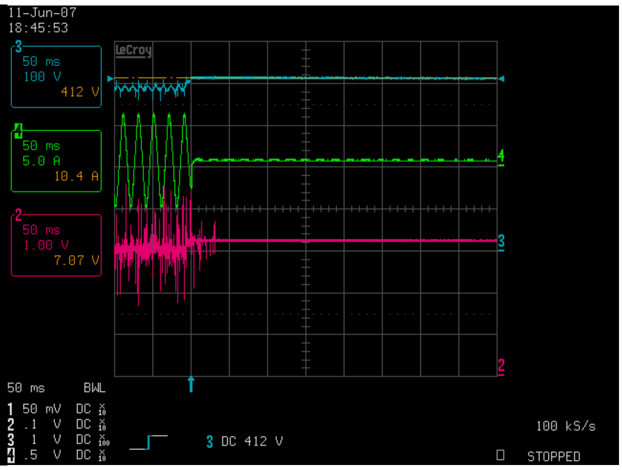
Startup test at 85VAC, open load



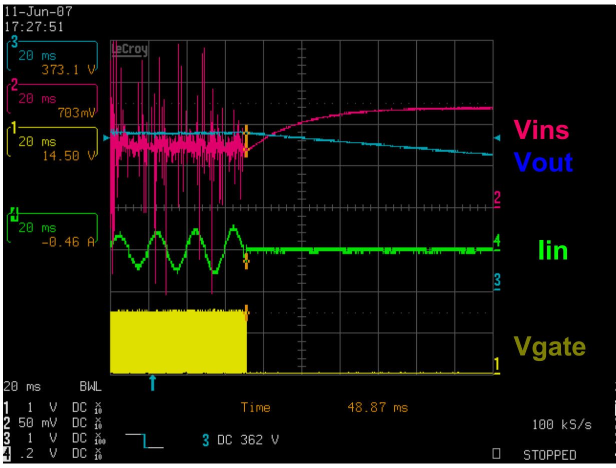
Load jump test at 85VAC, Iout from 0A to 0.75A



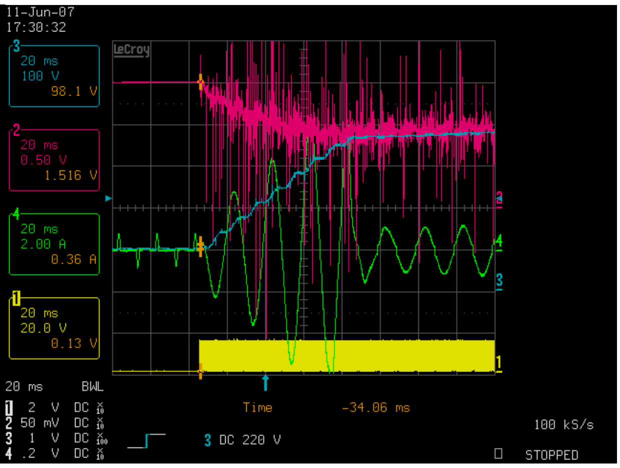
Load jump test at 85VAC, Iout from 0.75A to 0A



Enter brown-out at Iout=0.1A, 56VAC



Leave brown-out at Iout=0.1A, 74VAC



Open Loop protection at 265V, Iout=0.1A