Application Note, V1.0, June 2005

ICE1PCS02

300W PFC Evaluation Board with CCM PFC controller ICE1PCS02

Power Management & Supply

Never stop thinking.

Edition 2005-06-17

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ICE1PCS02

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Previous Version:	none	

Page	Subjects (major changes since last revision)

300W PFC Evaluation Board with CCM PFC controller ICE1PCS02
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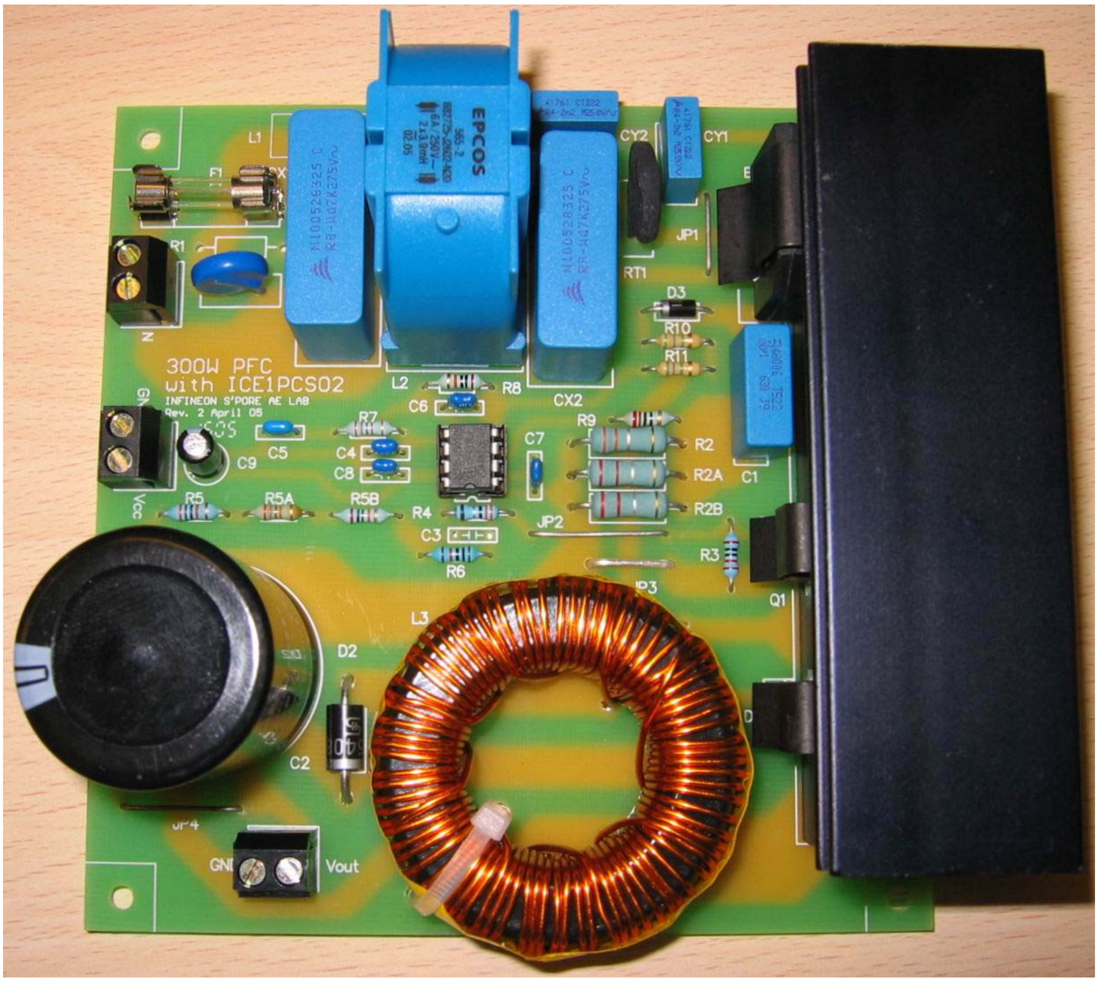
1 Content

The evaluation board presented here is a 300W power factor correction (PFC) circuit with 85~265VAC universal input and 390VDC fixed output. The continuous conduction mode (CCM) PFC controller **ICE1PCS02** is employed in this board to achieve the unity power factor. This **ICE1PCS02** is a design variant of ICE1PCS01 to incorporate the new input brown-out protection function and optimized to have a faster startup time with controlled peak startup current. Appreciated for its high integrated design, **ICE1PCS02** 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 65kHz due to internal oscillator of **ICE1PCS02**. In order to improve the power conversion efficiency, the **CoolMOS™ C3** series and high voltage silicon carbide (SiC) schottky diode **thinQ!™** are used into this boost type PFC circuit.

2 Evaluation Board



3 List of Features

Ease of use with few external components
Supports wide input range
Average current control
External current and voltage loop compensationfor greater user flexibility
Trimmed internal fixed switching frequency (65kHz±7.7% at 25□)
Direct sensing, input brown-out detection with hysteresis
Short startup (soft start) duration
Max duty cycle of 97% (typ)
Trimmed internal reference voltage (5V±2%)
VCC under voltage lockout
Cycle by cycle peak current limiting
Over voltage protection
Open loop detection
Soft over current protection
Enhanced dynamic response
Fulfills Class D requirements of IEC 1000-3-2

4 Technical Specifications

Input voltage	85VAC~265VAC
Input frequency	50Hz
Output voltage and current	390VDC, 0.76A
Output power	300W
Efficiency	>90% at full load
Switching Frequency	65kHz

5 Circuit Description

5.1 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.

5.2 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.

5.3 PWM Control of Boost Converter

The PWM control is realized by 8-Pin CCM PFC IC ICE1PCS02. It is a variant design of ICE1PCS01 with preserving most of the features. Unlike the conventional PFC controller, ICE1PCS02 does not need direct sine wave reference signal. The switching frequency is fixed at 65kHz 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 R5, R5A, R5B and R6 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.

6 Circuit Operation

6.1 Soft Startup

When Vcc pin is higher than turn-on threshold, typical 11.2V, 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. Because the peak current limit is not activated, the boost diode is not stressed with large diode duty cycle under high current.

6.2 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.

6.3 Protection Features

6.3.1 Input brown-out protection

The dedicated input voltage brown-out VINS pin is the most distinct new feature brought by ICE1PCS02. 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.

6.3.2 Open loop protection

The open loop protection is available for this IC to safe-guard the output. Whenever VSENSE voltage falls below 0.8V, or equivalently VOUT falls below 16% 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 0.8V.

6.3.3 Output over-voltage protection

Output over-voltage protection is also available by the same integrated blocks of enhanced dynamic response. Whenever VOUT exceeds the rated value by 5%, the over-voltage protection OVP is active. This is implemented by sensing the voltage at pin VSENSE with respect to a reference voltage of 5.25V. A VSENSE voltage higher than 5.25V will immediately reduce the output duty cycle even down to zero, bypassing the normal voltage loop control. This results in a lower input power and the output voltage VOUT is reduced.

6.3.4 Soft over current control (SOC) and peak current limit

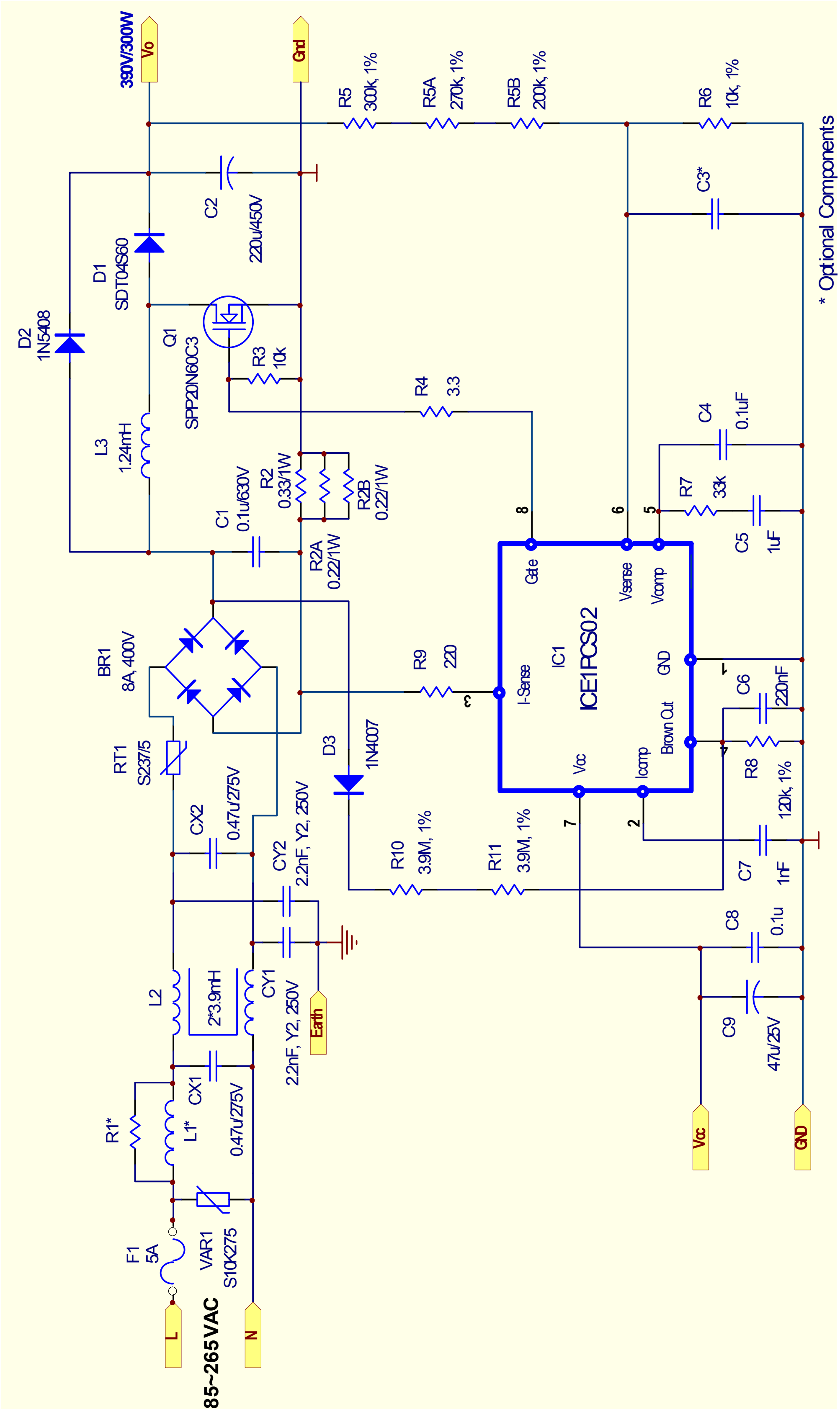
When the amplitude of current sense voltage reaches 0.73V, Soft Over Current Control (SOC) is activated. This is a soft control does not directly switch off the gate drive but acts on the internal blocks to result in a reduced PWM duty cycle.

The IC also provides a cycle by cycle peak current limitation (PCL). It is active when the voltage at current sense voltage reaches -1.08V. The gate output is immediately off after 300ns blanking time.

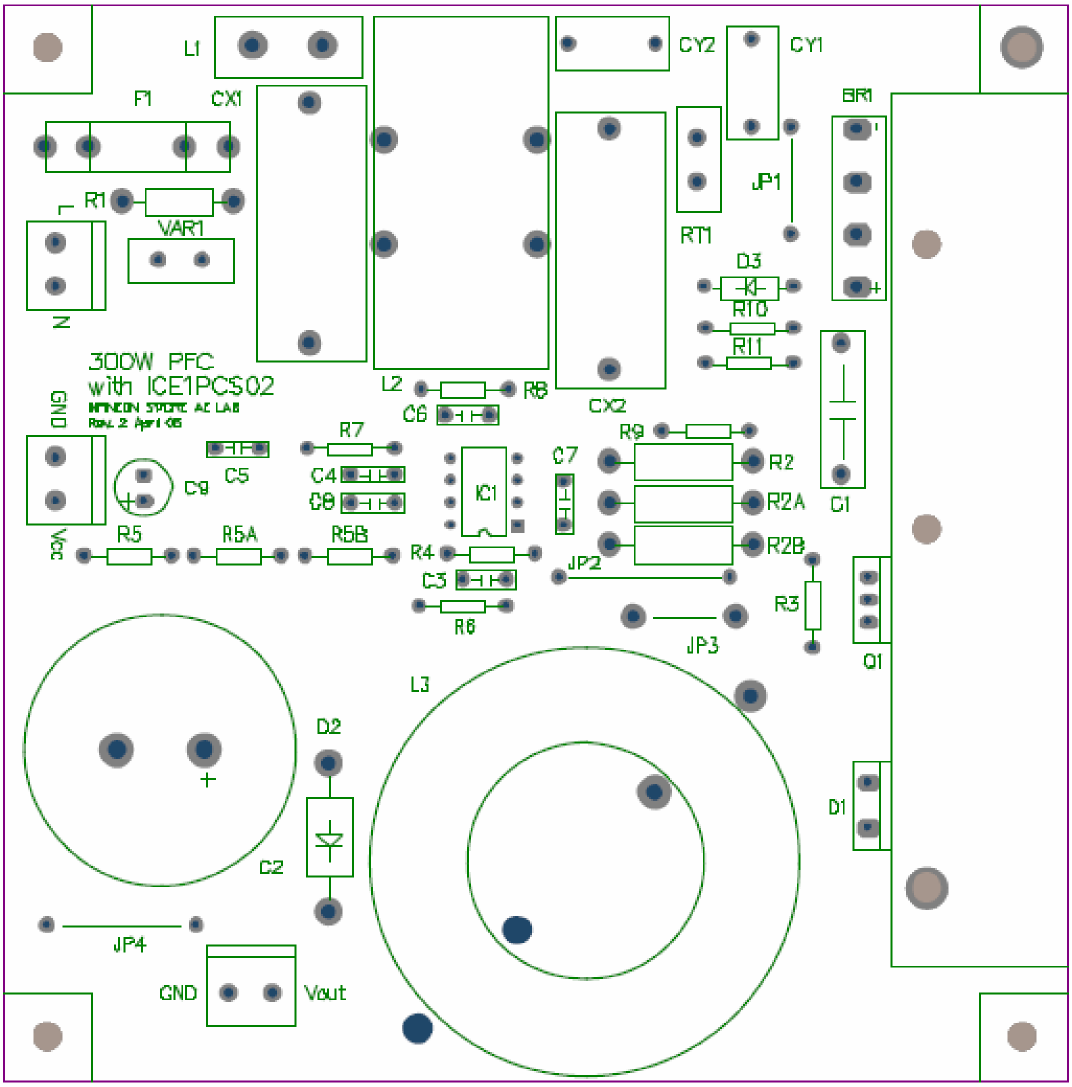
6.3.5 IC supply under voltage lockout

When VCC voltage is below the under voltage lockout threshold VCCUVLO, typical 10.2V, IC is off the gate drive is internally pull low to maintain the off state. The current consumption is down to 200uA only.

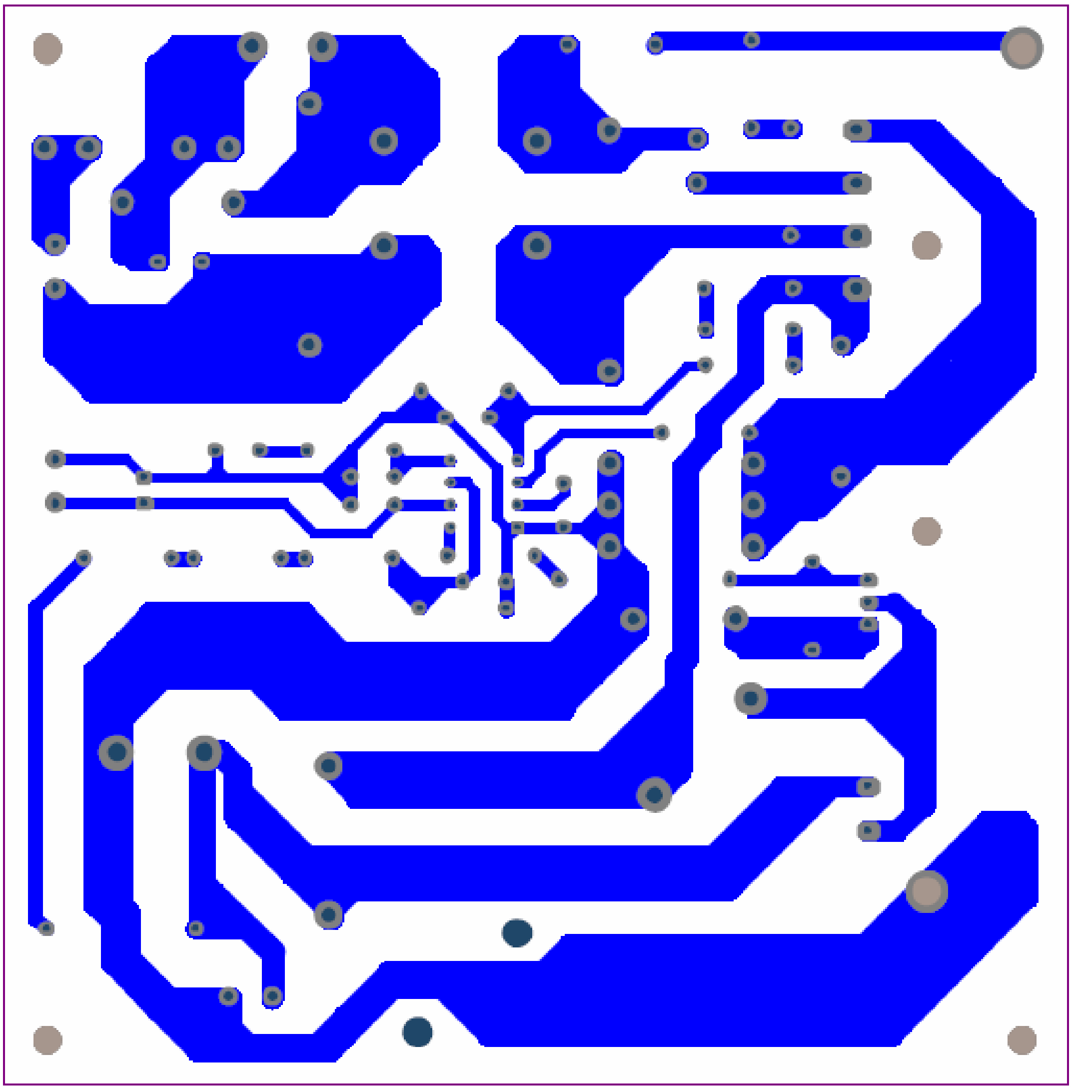
7 Circuit Diagram



8 PCB Layout Top Layer



9 PCB layout Bottom Layer



10 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*	Not Connected		0
C4	0.1uF/50V	Ceramic Cap	1
C5	1uF/50V	Ceramic Cap	1
C6	220nF/50V	Ceramic Cap	1
C7	1nF/50V	Ceramic Cap	1
C8	0.1uF/50V	Ceramic Cap	1
C9	47uF/25V	Electrolytic Cap	1
CX1	0.47uF, X1, 275V	Ceramic Cap	1
CX2	0.47uF, X1, 275V	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	ICE1PCS02		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	1.24mH	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
R5	300k/0.25W, 1%	Carbon Film Resistor	1
R5A	270k/0.25W, 1%	Carbon Film Resistor	1
R5B	200k/0.25W, 1%	Carbon Film Resistor	1
R6	10k/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

11 Boost Choke Layout

Core: CS468125 toriod

Turns: 83

Wire: 1 x Φ1.0mm, AWG19

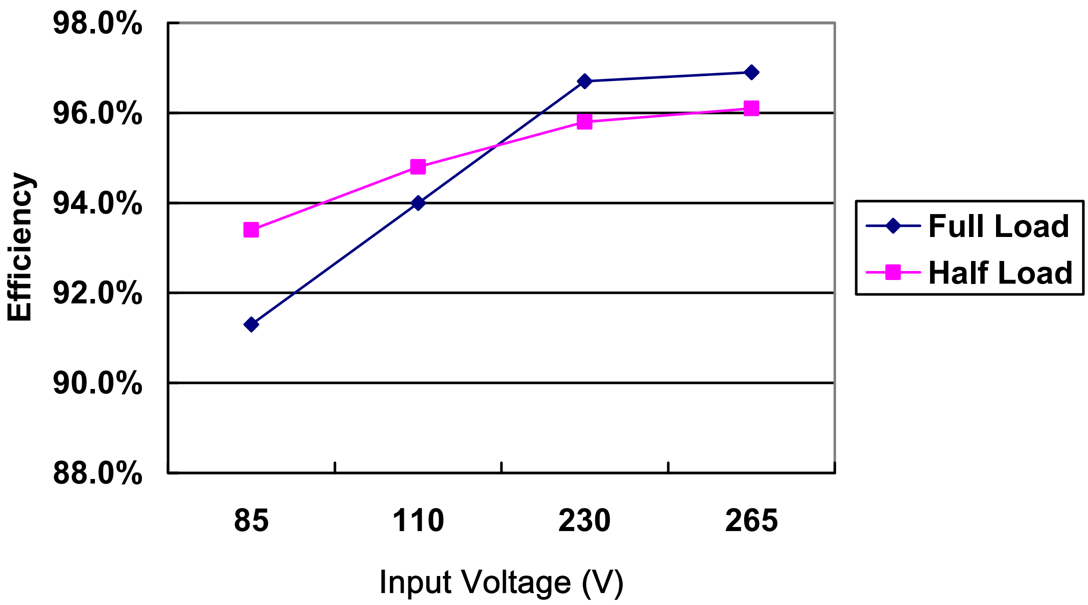
Inductance: L=1.24mH

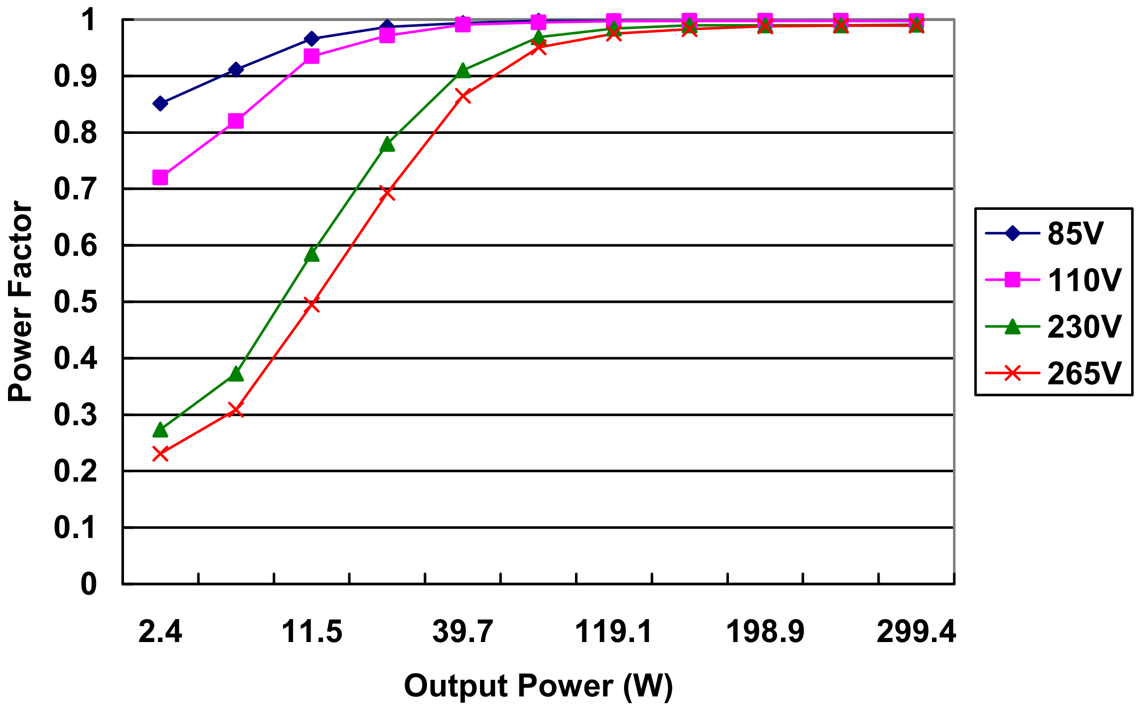
12 Test report

12.1 Load test (table and figure)

Vin (VAC)	Iin (A)	Pin (W)	Vo (V)	Io (A)	Po (W)	PF	Efficiency (%)
85	3.866	327.9	397.1	0.754	299.4	0.998	91.3%
	3.043	258.1	397.1	0.600	238.3	0.998	92.3%
	2.517	213.4	397.1	0.501	198.9	0.998	93.2%
	2.000	169.7	397.1	0.399	158.4	0.998	93.4%
	1.495	126.9	397.0	0.300	119.1	0.998	93.9%
	0.996	84.4	397.0	0.199	79.0	0.998	93.6%
	0.506	42.7	397.0	0.100	39.7	0.994	93.0%
	0.267	22.4	397.0	0.052	20.6	0.987	92.2%
	0.151	12.5	397.1	0.029	11.5	0.966	92.1%
	0.083	6.4	397.1	0.014	5.6	0.911	86.9%
	0.062	4.5	397.0	0.006	2.4	0.851	52.9%
110	2.906	318.9	396.9	0.755	299.7	0.997	94.0%
	2.302	252.5	397.0	0.600	238.2	0.998	94.3%
	1.913	209.9	397.0	0.501	198.9	0.998	94.8%
	1.526	167.5	397.0	0.400	158.8	0.998	94.8%
	1.145	125.5	397.0	0.300	119.1	0.997	94.9%
	0.767	84.0	397.0	0.200	79.4	0.995	94.5%
	0.389	42.4	397.1	0.100	39.7	0.991	93.7%
	0.210	22.4	397.1	0.053	21.0	0.972	94.0%
	0.122	12.5	397.1	0.029	11.5	0.935	92.1%
	0.071	6.4	397.0	0.014	5.6	0.820	86.8%
	0.058	4.6	397.0	0.006	2.4	0.720	51.8%
230	1.360	309.9	397.0	0.755	299.7	0.991	96.7%
	1.085	247.1	397.0	0.600	238.2	0.990	96.4%
	0.905	206.2	397.1	0.501	198.9	0.990	96.5%
	0.726	165.4	397.1	0.399	158.4	0.990	95.8%
	0.551	124.7	397.1	0.300	119.1	0.984	95.5%
	0.376	83.8	397.1	0.200	79.4	0.969	94.8%
	0.205	42.8	397.1	0.100	39.7	0.910	92.8%
	0.130	23.3	397.0	0.052	20.6	0.780	88.6%
	0.099	13.4	397.0	0.029	11.5	0.585	85.9%
	0.085	7.3	397.0	0.014	5.6	0.373	76.1%
	0.082	5.3	397.0	0.006	2.4	0.274	44.9%

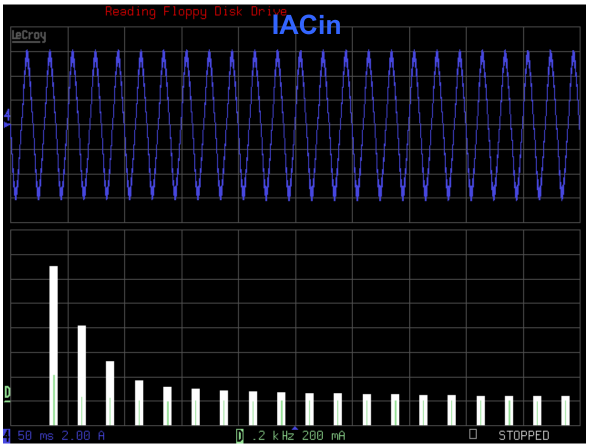
Vin (VAC)	Iin (A)	Pin (W)	Vo (V)	Io (A)	Po (W)	PF	Efficiency (%)
265	1.180	309.2	397.0	0.755	299.7	0.989	96.9%
	0.942	246.7	397.0	0.601	238.6	0.989	96.7%
	0.787	206.0	397.1	0.501	198.9	0.988	96.6%
	0.635	165.3	397.0	0.400	158.8	0.983	96.1%
	0.482	124.6	397.0	0.300	119.1	0.975	95.6%
	0.333	84.0	397.0	0.199	79.0	0.951	94.1%
	0.190	43.5	397.0	0.100	39.7	0.865	91.3%
	0.129	23.8	396.9	0.053	21.0	0.693	88.4%
	0.106	13.8	396.9	0.029	11.5	0.495	83.4%
	0.095	7.7	396.9	0.014	5.6	0.309	72.2%
	0.093	5.7	396.9	0.005	2.0	0.231	34.8%


98.0%
96.0%
94.0%
92.0%
90.0%
88.0%
Efficiency
85
110
230
265
Input Voltage (V)
Full Load
Half Load


1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Power Factor
2.4
11.5
39.7
119.1
198.9
299.4
Output Power (W)
85V
110V
230V
265V

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

12.2.1 85VAC, full load (300W output)



26-Apr-05
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Harmonic	Frequency[Hz]	Measurement[mA]	Limit[mA]
3	150.00	217.90	1087.94
5	250.00	36.01	607.97
7	350.00	28.92	319.98
9	450.00	4.76	159.99
11	550.00	1.43	111.99
13	650.00	6.16	94.76
15	750.00	5.07	82.13
17	850.00	2.71	72.47
19	950.00	11.86	64.84
21	1050.00	5.89	58.66
23	1150.00	10.87	53.56
25	1250.00	10.59	49.28
27	1350.00	7.99	45.63
29	1450.00	7.44	42.48
31	1550.00	5.75	39.74
33	1650.00	11.09	37.33
35	1750.00	5.32	35.20
37	1850.00	2.85	33.30
39	1950.00	6.47	31.59

LINE POWER

Class D
Frequency
50.00Hz

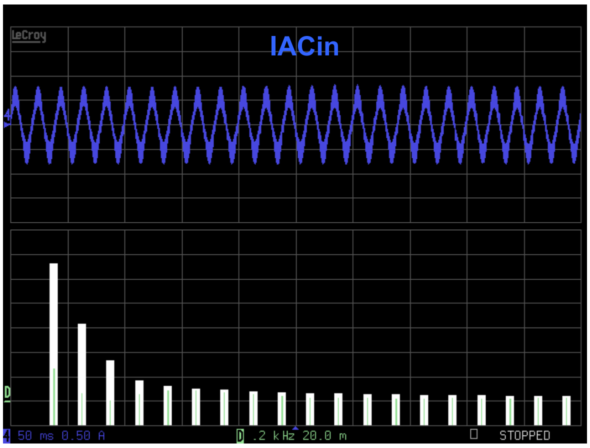
Show Graph

Units
A dBuA

50 kS/s

STOPPED

12.2.2 85VAC, 9.3% of full load (28W output)



26-Apr-05
14:38:21

Harmonic	Frequency[Hz]	Measurement[mA]	Limit[mA]
3	150.00	26.81	111.29
5	250.00	6.59	62.19
7	350.00	0.94	32.73
9	450.00	5.92	16.37
11	550.00	8.69	11.46
13	650.00	8.92	9.69
15	750.00	7.49	8.40
17	850.00	6.12	7.41
19	950.00	4.70	6.63
21	1050.00	2.88	6.00
23	1150.00	3.12	5.48
25	1250.00	3.36	5.04
27	1350.00	2.18	4.67
29	1450.00	2.43	4.35
31	1550.00	2.93	4.07
33	1650.00	2.06	3.82
35	1750.00	2.33	3.60
37	1850.00	2.94	3.41
39	1950.00	2.78	3.23

LINE POWER

Class D
Frequency
50.00Hz

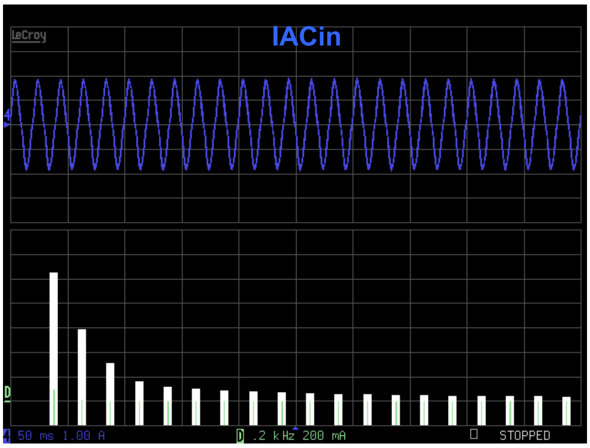
Show Graph

Units
A dBuA

50 kS/s

STOPPED

12.2.3 265VAC, full load (300W output)



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14:49:32

LINE POWER

Harmonic	Frequency[Hz]	Measurement[mA]	Limit[mA]
3	150.00	98.44	1036.15
5	250.00	14.06	579.03
7	350.00	2.99	304.75
9	450.00	2.72	152.38
11	550.00	2.35	106.66
13	650.00	2.78	90.25
15	750.00	2.77	78.22
17	850.00	2.76	69.02
19	950.00	2.44	61.75
21	1050.00	1.76	55.87
23	1150.00	0.43	51.01
25	1250.00	0.31	46.93
27	1350.00	0.64	43.46
29	1450.00	0.96	40.46
31	1550.00	1.31	37.85
33	1650.00	1.70	35.55
35	1750.00	1.76	33.52
37	1850.00	1.97	31.71
39	1950.00	1.90	30.08

Class D
Frequency
50.01Hz

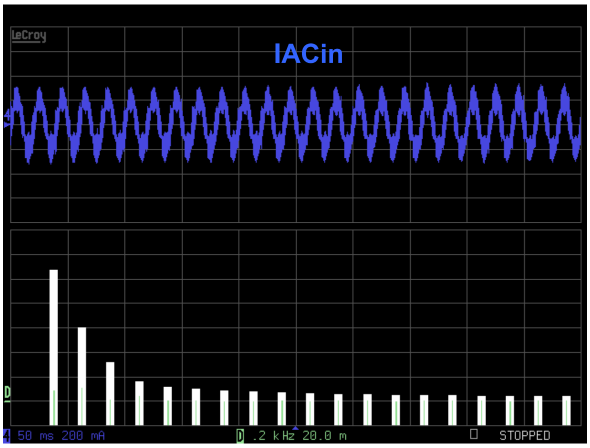
Show Graph

Units: A dBuA

50 kS/s

STOPPED

12.2.4 265VAC, 9.3% of full load (28W output)



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LINE POWER

Harmonic	Frequency[Hz]	Measurement[mA]	Limit[mA]
3	150.00	9.25	106.23
5	250.00	11.12	59.36
7	350.00	1.39	31.24
9	450.00	4.28	15.62
11	550.00	1.01	10.94
13	650.00	1.04	9.25
15	750.00	0.38	8.02
17	850.00	0.26	7.08
19	950.00	0.48	6.33
21	1050.00	0.26	5.73
23	1150.00	0.56	5.23
25	1250.00	0.59	4.81
27	1350.00	0.37	4.46
29	1450.00	0.52	4.15
31	1550.00	0.73	3.88
33	1650.00	0.58	3.65
35	1750.00	0.12	3.44
37	1850.00	0.89	3.25
39	1950.00	1.16	3.08

Class D
Frequency
50.00Hz

Show Graph

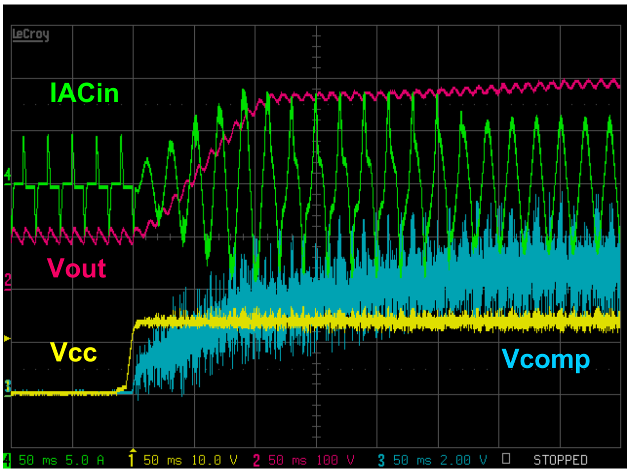
Units: A dBuA

50 kS/s

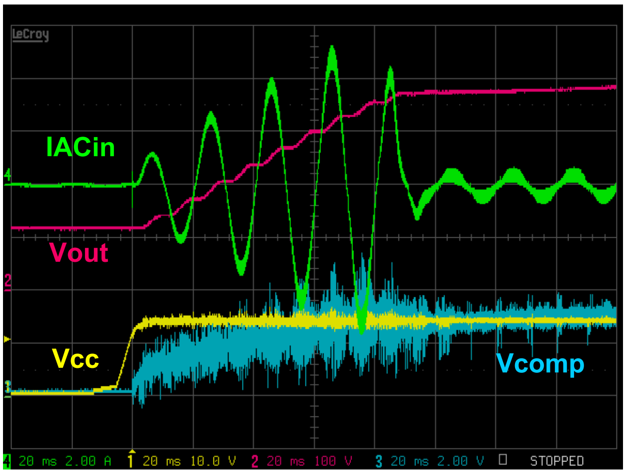
STOPPED

12.3 Test Waveforms

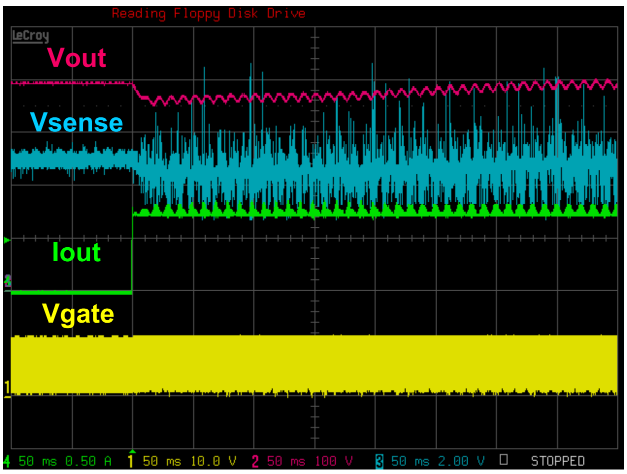
12.3.1 Startup test at 85VAC, full load (300W)



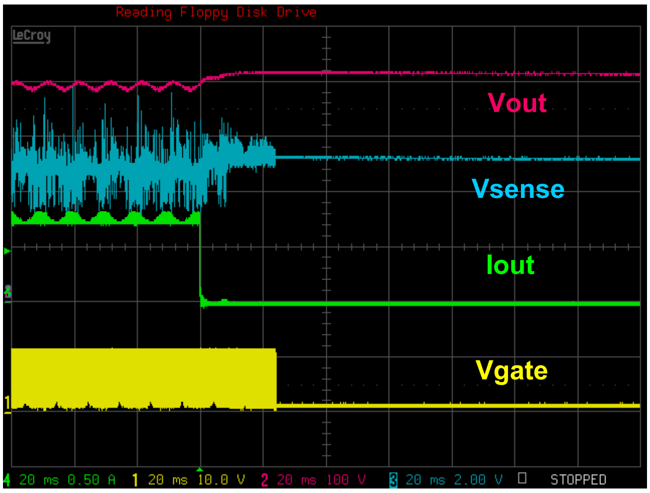
12.3.2 Startup test at 85VAC, open load



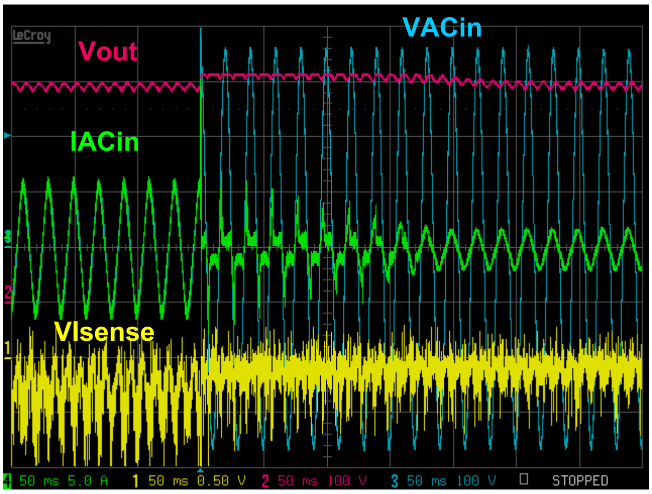
12.3.3 Load jump test at 85VAC, Iout from 0A to 0.75A



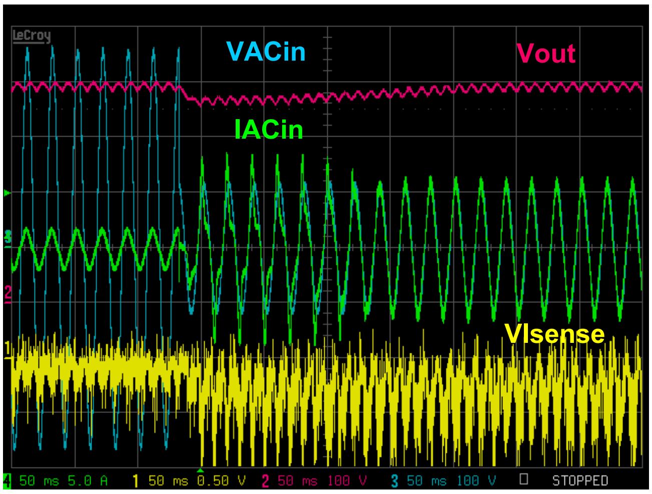
12.3.4 Load jump test at 85VAC, Iout from 0.75A to 0A



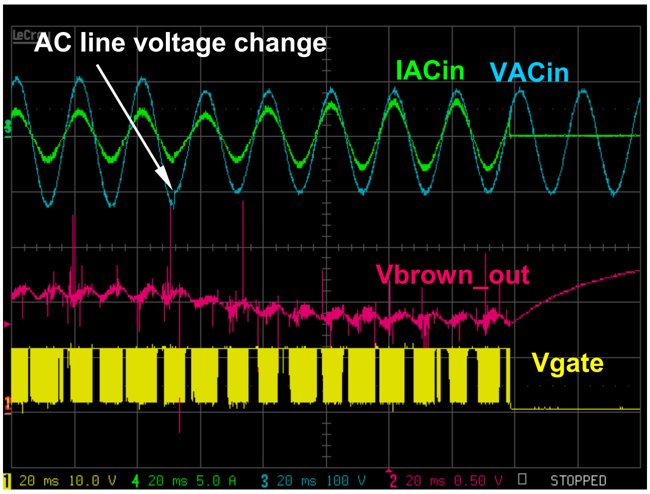
12.3.5 Voltage jump test at full load, from 85V to 265V



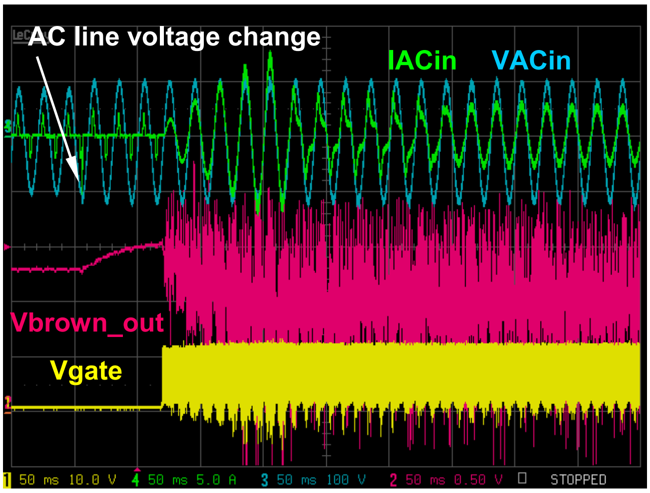
12.3.6 Voltage jump test at full load, from 265V to 85V



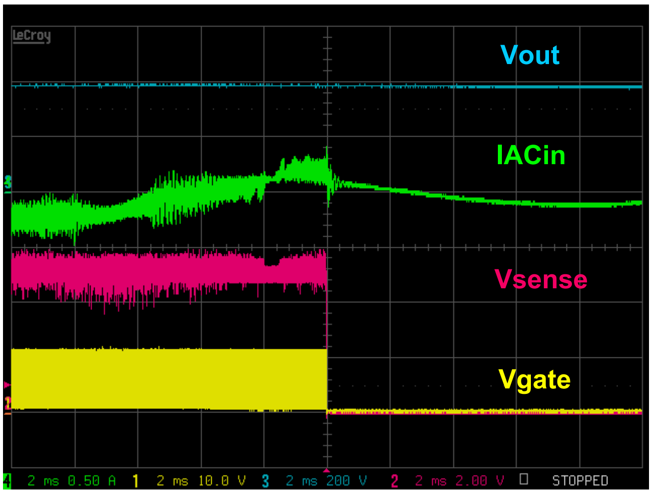
12.3.7 Enter brown-out at Iout=0.3A, 68VAC



12.3.8 Leave brown-out at Iout=0.3A, 80VAC



12.3.9 Open Loop protection at 265V, Iout=0.1A



13 References:

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[2] Luo Junyang, Jeoh Meng Kiat, ICE1PCS02 Based Boost Type CCM PFC Design Guide, Application Note, Infineon Technologies, Singapore, Oct. 2004

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