AND8324/D

300 W, Wide Mains, PFC Stage Driven by the NCP1654

Prepared by: Patrick Wang
ON Semiconductor

ON Semiconductor®

http://onsemi.com

Introduction

The NCP1654 is a Power Factor Controller to efficiently drive Continuous Conduction Mode (CCM) step−up pre−converters. As shown by the ON Semiconductor application note AND8322, “Four Key Steps to Design a Continuous Conduction Mode PFC Stage Using the NCP1654”, which details the four key steps to design a NCP1654 driven PFC stage, this circuit represents a major leap towards compactness and ease of implementation.

Housed in a SO−8 package, the circuit minimizes the external components count without sacrificing performance and flexibility. In particular, the NCP1654 integrates all the key protections to build robust PFC stages like an effective input power runaway clamping circuitry.

When needed or wished, the NCP1654 also allows operation in Follower Boost mode(1) to drastically lower the pre−converter size and cost, in a straight−forward manner. For more information on this device, please refer to the ON Semiconductor data sheet NCP1654/D.

The board illustrates the circuit capability to effectively drive a high power, universal line application. More specifically, it is designed to meet the following specifications:

- Maximum output power: 300 W
- Input voltage range: from 85 V_{RMS} to 265 V_{RMS}
- Regulation output voltage: 390 V
- Switching frequency: 65 kHz

This application was tested using an active load. As in many applications, the PFC controller is fed by an output of the downstream converter, there is generally no need for an auto−supply circuitry. Hence, in our demo board, the NCP1654 V_{CC} is to be supplied by a 15 V external power supply.

The external voltage source that is to be applied to the NCP1654 V_{CC}, should exceed 10.5 V typical, to allow the circuits start up. After start up, the V_{CC} operating range is from 9 V to 20 V.

The voltage applied to the NCP1654 V_{CC} must NOT exceed 20 V.

The NCP1654 is a continuous conduction mode and fixed frequency controller (65 kHz). The coil (650 uH) is selected to limit the peak to peak current ripple in the range of 36 % at the sinusoid top, in full load and low line conditions. Again, for details on how the application is designed, please refer to the ON Semiconductor application note AND8322, ”Four Key Steps to Design a Continuous Conduction Mode PFC Stage Using the NCP1654”.

As detailed in the document, the board yields very nice Power Factor ratios and effectively limits the Total Harmonic Distortion (THD).

October, 2009 − Rev. 2

Publication Order Number:
AND8324/D

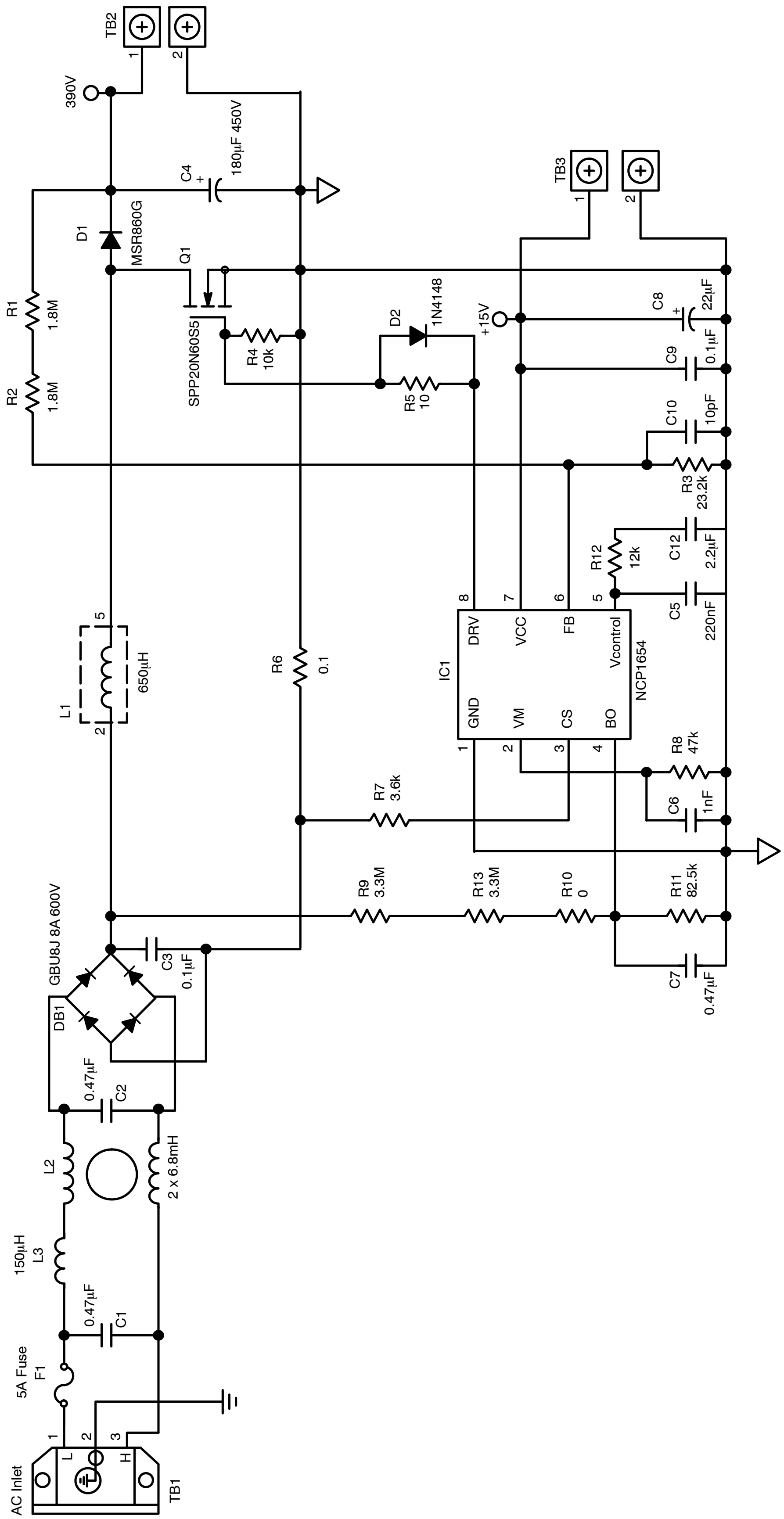

Figure 1. Application Schematic

Table 1. BILL OF MATERIAL

Reference	Description	Part Number	Manufacturer
C1	0.47 uF / 275 V type X2	F1772−447−2000	VISHAY
C2	0.47 uF / 275 V type X2	F1772−447−2000	VISHAY
C3	0.1u, 400V, High Ripple, Polypropylene Cap	ECWF4104JL	Matsushita
C4	180 μF 450 V	2222 159 47181	BC Components
C5	0.22 μF / 50V	K224K20X7RF53H5	VISHAY
C7	0.47 μF / 50V	K474K20X7RF53H5	VISHAY
C9	0.1 μF / 50V	K104K15X7RF53H5	VISHAY
C6	1 nF / 50 V	K102K15X7RF53H5	VISHAY
C10	100 pF / 50 V	K101K15X7RF53H5	VISHAY
C8	22 μF / 25 V	2222 013 36229	BC Components
C12	2.2 μF / 50 V	B32529D5225J	EPCOS
DB1	600 V, 8.0 A Bridge Dode	GBU8J	VISHAY
D1	8.0 A, 600 V	MSR860G	ON Semiconductor
D2	1N4148	1N4148	VISHAY
F1	5 A Fuse, Time Delay Fuse (FST 5x20)	0034.3124	SCHURTER
IC1	CCM PFC Controller	NCP1654	ON Semiconductor
L1	650 μH	GA3199−AL	CoilCraft
□		2702.0010A	Pulse
L2	4 A, 2 x 6.8 mH, CM Choke	B82725−J2402−N20	EPCOS
L3	150 uH, 5A, WE−FI Series, DM Choke	7447055	Wurth Elektronik
Q1	20 A 600 V MOSFET	SPP20N60C3	Infineon
R1	Resistor, Axial Lead, 1.8 M, 1/4 W, 1%	CCF501M80FKE36	VISHAY
R2	Resistor, Axial Lead, 1.8 M, 1/4 W, 1%	CCF501M80FKE36	VISHAY
R9	Resistor, Axial Lead, 3.3 M, 1/4 W, 1%	CCF503M30FKE36	VISHAY
R13	Resistor, Axial Lead, 3.3 M, 1/4 W, 1%	CCF503M30FKE36	VISHAY
R10	Jumper	Jumper	
R3	Resistor, Axial Lead, 23.2 k, 1/4 W, 1%	CCF5023K2FKE36	VISHAY
R4	Resistor, Axial Lead, 10 k, 1/4 W	CCF5010K0FKE36	VISHAY
R5	Resistor, Axial Lead, 10, 1/4 W	CCF5010R0FKE36	VISHAY
R6	Resistor, Axial Lead, 0.1, 3 W, 1% LVR3 Series	LVR03 R1000 F E12	VISHAY
R7	Resistor, Axial Lead, 3.6 k, 1/4 W 1%	CCF503K60FKE36	VISHAY
R8	Resistor, Axial Lead, 47 k, 1/4 W	CCF5047K0FKE36	VISHAY
R11	Resistor, Axial Lead, 82.5 k, 1/4 W, 1%	CCF5082K5FKE36	VISHAY
R12	Resistor, Axial Lead, 12 k, 1/4 W, 1%	CCF5012K0FKE36	VISHAY
TB1	AC Inlet Connector	GSF1.1201.31	SCHURTER
TB2	DC Output Plug Socket	20.101/2 (Order Code 3044531)	IMO
TB3	V_{CC} Connector Plug Socket	PM5.08/2/90. (Order Code 5015571)	WEIDMULLER
HS1	Heatsink(2.9°C/W)	SK481 100mm	Fischer Elektronik
Q1	Isolator TO−220	3223−07FR−43	BERGQUIST
D1	Isolator TO−220	3223−07FR−43	BERGQUIST
DB1	Clip for heatsink (TO−220)	THFU 1	Fischer Elektronik
Q1	Clip for heatsink (TO−220)	THFU 1	Fischer Elektronik
D1	Clip for heatsink (TO−220)	THFU 1	Fischer Elektronik
PCB			
	Board Legs	TCBS−801	RICHCO
	Board Legs	TCBS−801	RICHCO
	Board Legs	TCBS−801	RICHCO
	Board Legs	TCBS−801	RICHCO

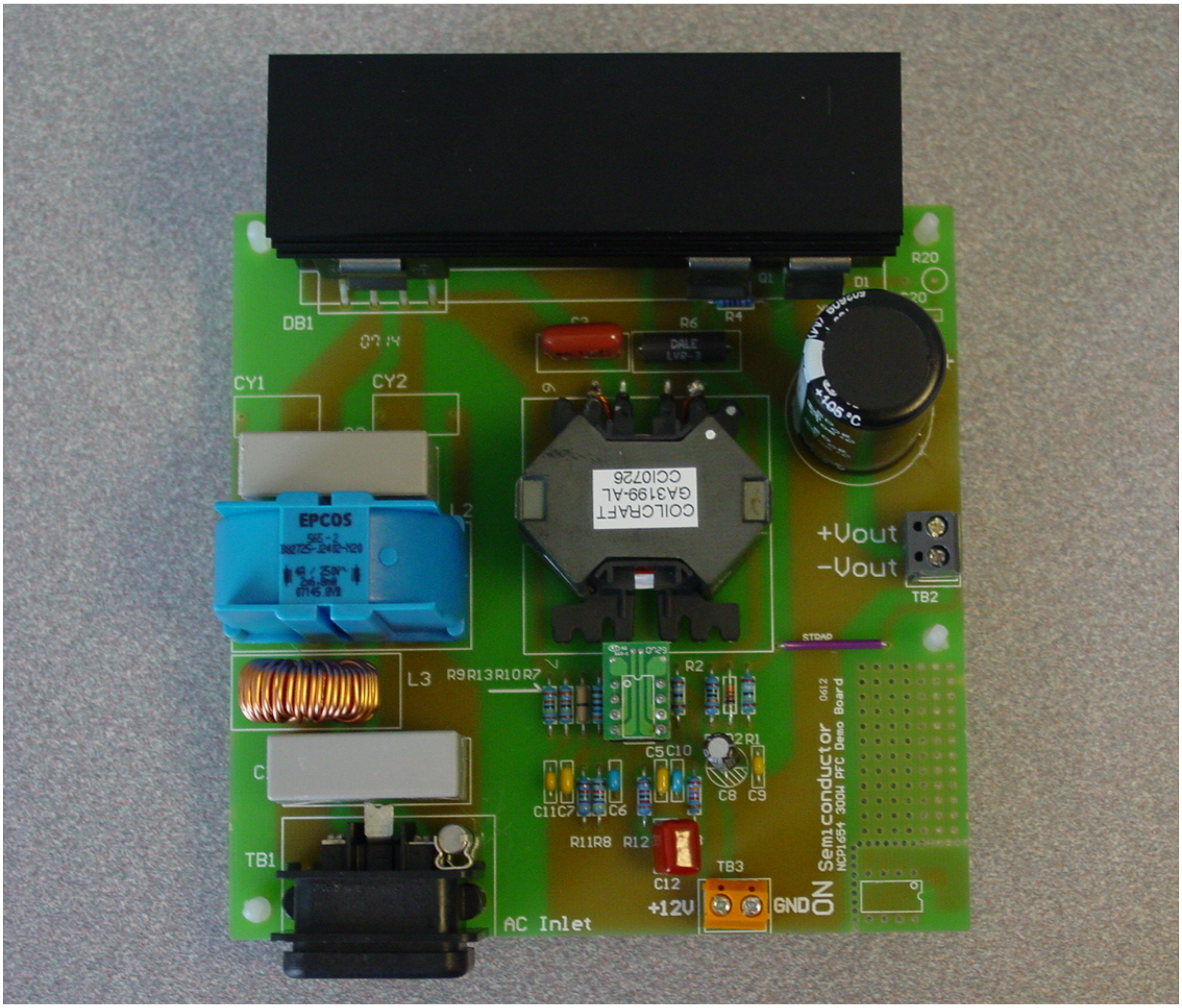

Figure 2. The Board

Two coils from two different vendors have been validated on this board:

- GA3199−AL from Coil Craft
- 2702.0010A from Pulse

For the sake of consistency, this application note reports the performance and results that were obtained using the CoilCraft. However, it has been checked that the other coil yield high performance too.

PCB LAYOUT

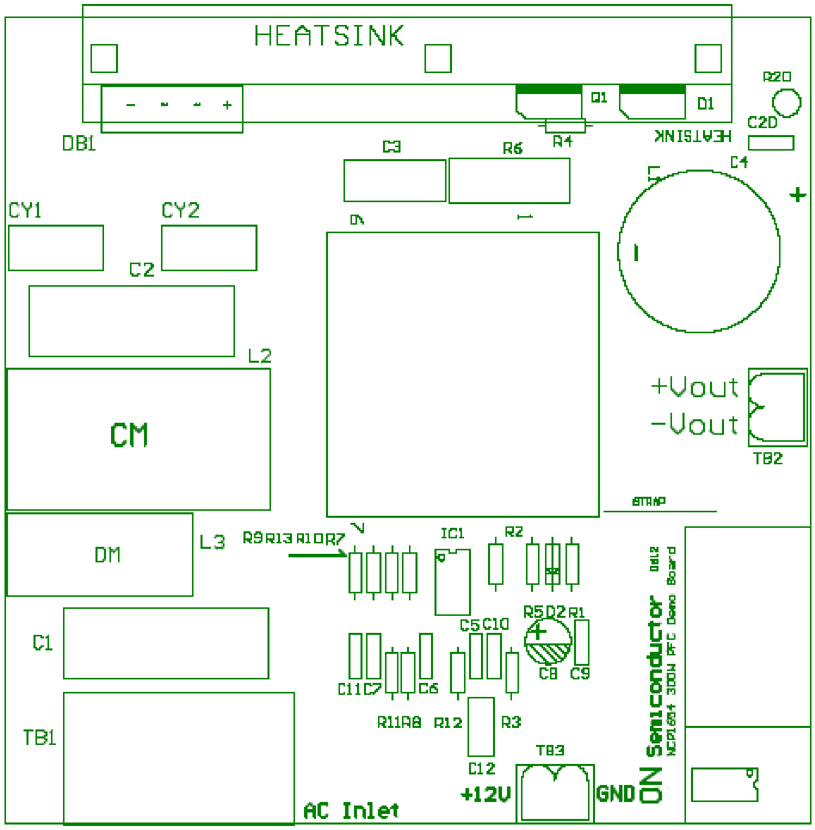

Figure 3. Components Placement (Component Side)

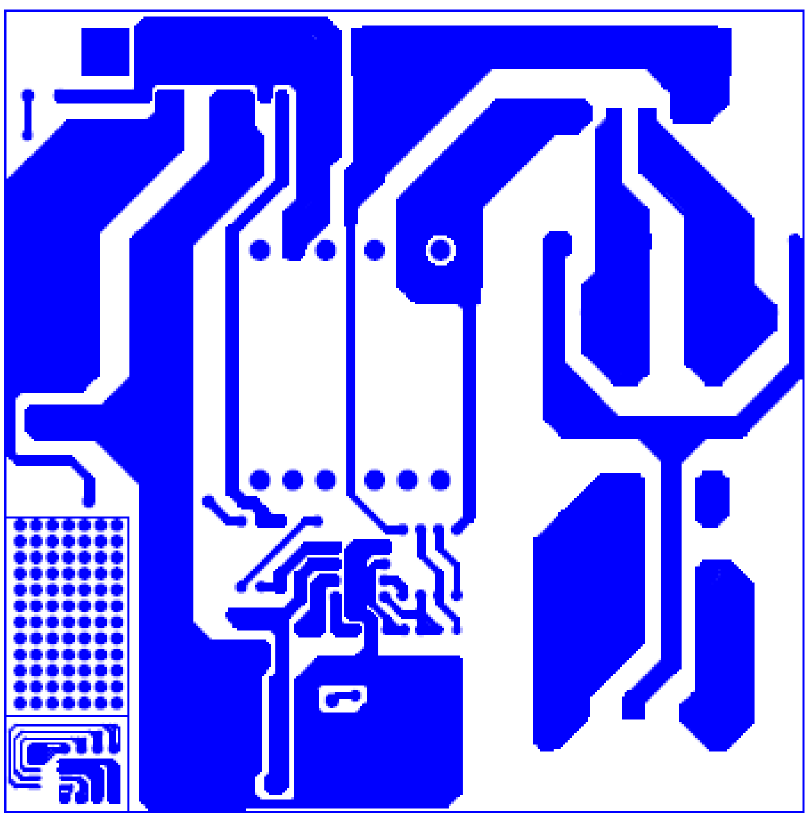

Figure 4. PCB Layout (Solder Side)

GENERAL BEHAVIOR

EFFICIENCY AND PF AT 85 VAC AND 110 VAC

Table 2. EFFICIENCY, PF AT DIFFERENT LOAD AND LINE CONDITIONS

Vin	I_{in} (A)	P_{in} (W)	Vo (V)	Io (A)	Po (W)	PF	Efficiency	THD
85 Vac 60 Hz	3.87	326.5	392.6	0.77	302.3	0.999	92.6%	3.7%
	3.50	295.4	392.6	0.70	274.6	0.999	93.0%	3.6%
	3.00	253.1	392.7	0.60	236.2	0.999	93.3%	3.6%
	2.48	210.1	392.8	0.50	196.8	0.999	93.7%	3.4%
	1.98	167.5	392.9	0.40	157.4	0.999	94.0%	3.2%
	1.48	125.5	392.8	0.30	118.4	0.999	94.3%	3.6%
	1.00	84.5	393.1	0.20	79.6	0.998	94.3%	6.6%
	0.49	41.2	393.7	0.10	39.2	0.998	95.2%	8.7%
	0.25	21.0	397.1	0.05	19.5	0.991	93.0%	11.9%
110 Vac 60 Hz	2.93	319.5	392.7	0.77	302.9	0.999	94.8%	3.3%
	2.65	289.9	392.8	0.70	275.4	0.999	95.0%	3.2%
	2.27	248.0	392.8	0.60	236.1	0.999	95.2%	3.2%
	1.89	206.4	392.9	0.50	196.8	0.999	95.4%	3.3%
	1.51	165.0	392.9	0.40	157.5	0.998	95.5%	4.0%
	1.13	123.9	393.0	0.30	118.4	0.998	95.5%	6.3%
	0.76	82.5	393.1	0.20	79.0	0.998	95.8%	7.6%
	0.38	41.6	394.3	0.10	39.8	0.993	95.6%	8.6%
	0.20	20.9	397.4	0.05	19.6	0.973	93.6%	11.1%

Table 3. EFFICIENCY AND PF AT 230 VAC AND 265 VAC

Vin	I_{in} (A)	P_{in} (W)	Vo (V)	Io (A)	Po (W)	PF	Efficiency	THD
230 Vac 50 Hz	1.36	309.4	393	0.77	303.0	0.996	97.9%	6.1%
	1.23	281.0	393	0.70	275.1	0.995	97.9%	6.3%
	1.05	240.7	393.1	0.60	235.5	0.994	97.9%	7.1%
	0.89	201.5	393.2	0.50	197.1	0.992	97.8%	7.1%
	0.71	161.3	393.2	0.40	157.7	0.990	97.8%	7.2%
	0.54	121.1	393.3	0.30	118.2	0.983	97.6%	7.4%
	0.37	81	393.7	0.20	78.8	0.966	97.3%	7.3%
	0.20	41.1	394.6	0.10	39.6	0.892	96.5%	13.0%
	0.12	20.6	395.4	0.05	19.4	0.752	94.5%	15.8%
265 Vac 50 Hz	1.18	308.2	393	0.77	302.3	0.993	98.1%	6.9%
	1.07	281.1	393.1	0.70	275.8	0.992	98.1%	6.8%
	0.92	241.2	393.1	0.60	236.5	0.991	98.0%	6.7%
	0.77	201.2	393.2	0.50	197.1	0.988	98.0%	7.0%
	0.62	161.2	393.2	0.40	157.8	0.982	97.9%	6.9%
	0.47	121.1	393.4	0.30	118.4	0.972	97.8%	7.3%
	0.33	81.4	393.8	0.20	79.0	0.943	97.1%	11.8%
	0.19	41.1	394.5	0.10	39.7	0.840	96.6%	22.6%
	0.13	21.5	395	0.05	20.4	0.650	94.7%	23.0%

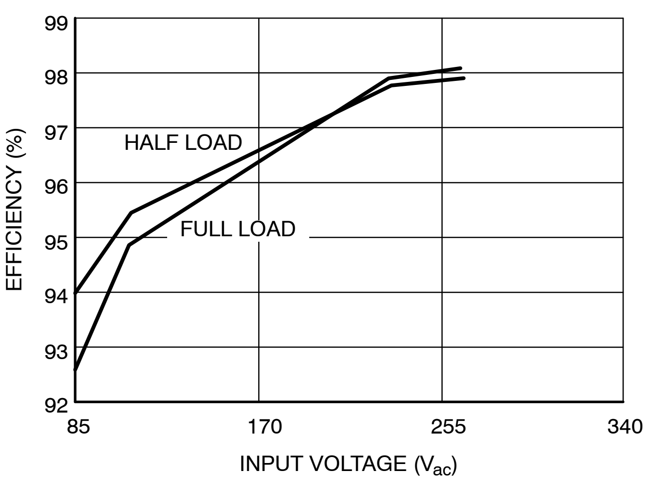

Figure 5. Efficiency vs. Input Voltage

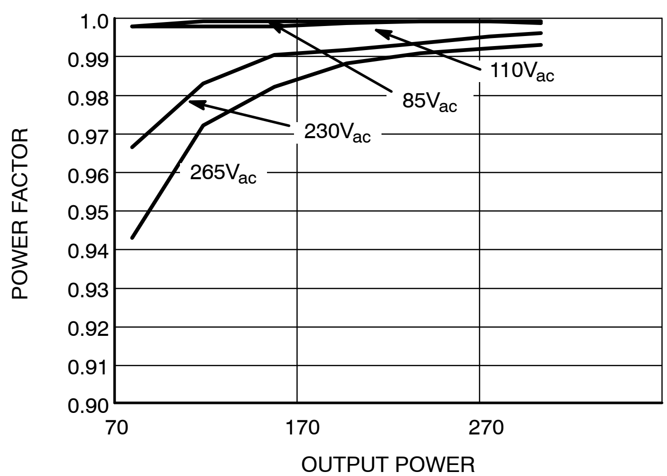

Figure 6. Power Factor vs. Output Power

TYPICAL WAVEFORMS

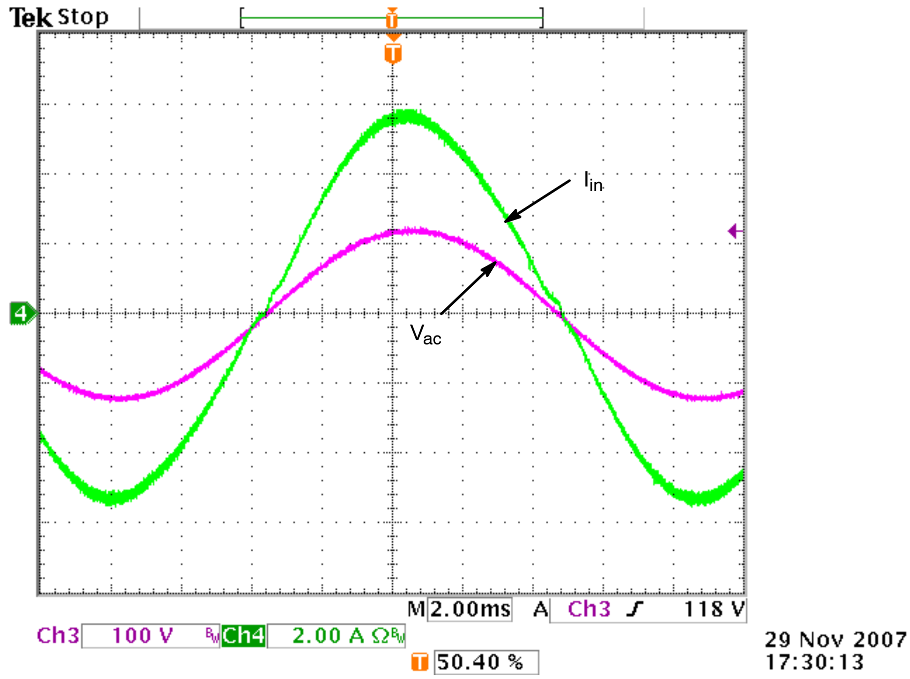

Figure 7. V_{ac} = 85 Vac, P_{in} = 326.5 W, V_{out} = 392.6 V, I_{out} = 0.77 A, PF = 0.999, THD = 3.74%

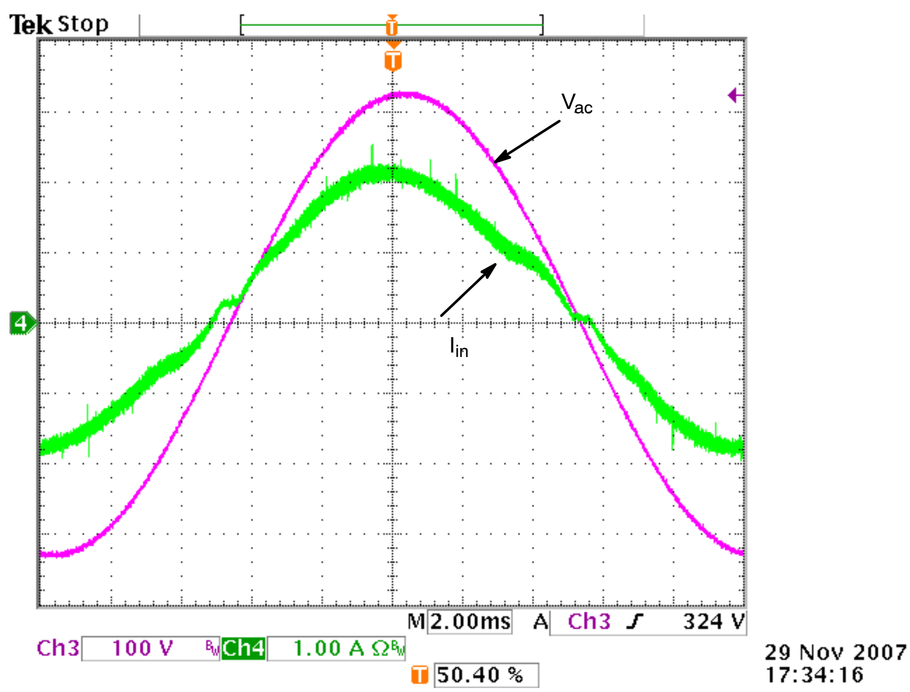

Figure 8. V_{ac} = 230 Vac, P_{in} = 309 W, V_{out} = 393 V, I_{out} = 0.77 A, PF = 0.996, THD = 6.1%

NO LOAD OPERATION

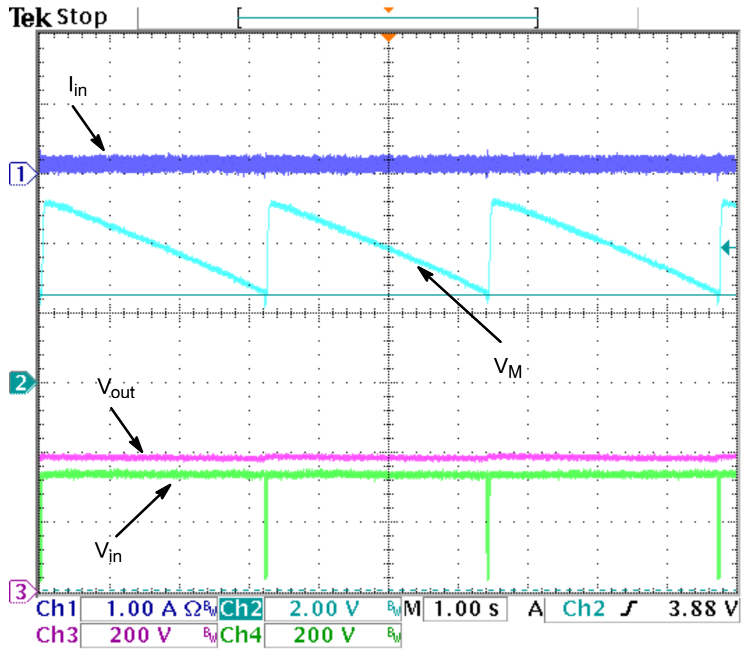

Figure 9. V_{ac} **= 230 Vac,** P_{in} **= 147 mW,** V_{out} **= 396 V,** I_{out} **= 0 A**

When in light load, the circuit enters a welcome burst mode that enables the circuit to keep regulating. V_M pin oscillates around its internal reference voltage (2.5 V).

The power losses @ 230 V_{ac} are nearly 147 mW. This result was obtained by using a W.h. meter (measure duration: 1 sec)

Soft−Start

The NCP1654 grounds the "$V_{control}$" capacitor when it is off, i.e., before each circuit active sequence ("$V_{control}$" being the regulation block output). Only charging by the 28−μA internal current source of the error amplifier (the 200 μA of the dynamic response enhancer being disabled during the start−up phase), "$V_{control}$" ramps up slowly. As a result, the power delivery rises gradually and the PFC pre−regulator starts up smoothly and noiselessly.

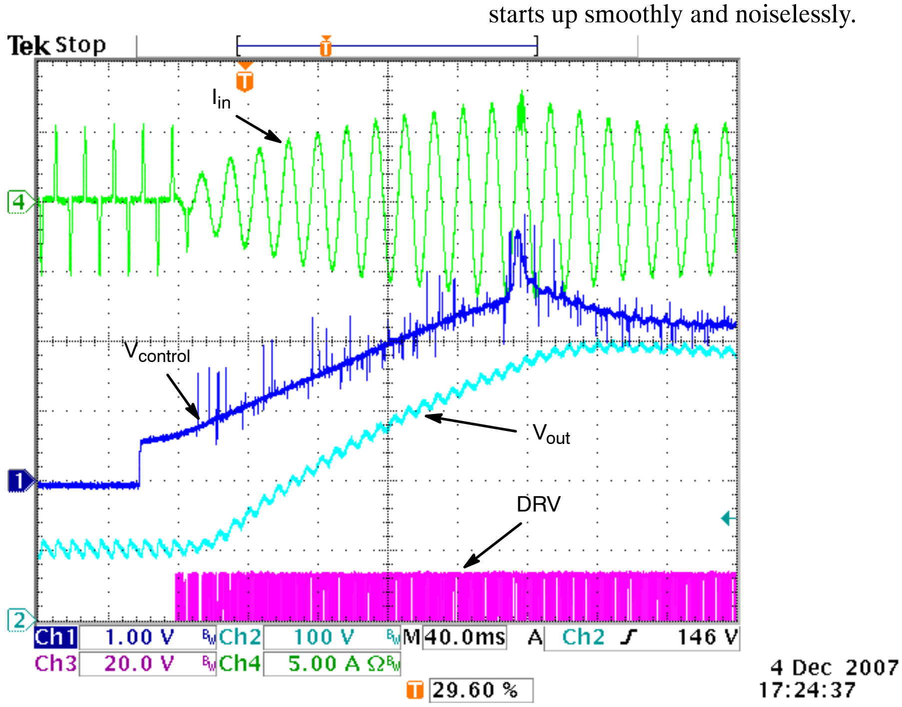

Figure 10. V_{ac} **= 85 Vac,** V_{out} **= 392.6 V,** I_{out} **= 0.77 A**

Transient Load

When output loading changes from full load to no load, the output voltage raises, and V_{fb} rises to activate the OVP function. The output voltage is clamped by the OVP function.

When output loading changes from no load to full load, the output voltage drops, V_{fb} drops below 95% of V_{ref}, $V_{control}$ is sharply pulled high by the internal 200 μA current source of the dynamic response enhancer. As a result, a higher power is delivered to output. Hence it prevents the output voltage from dropping deeply.

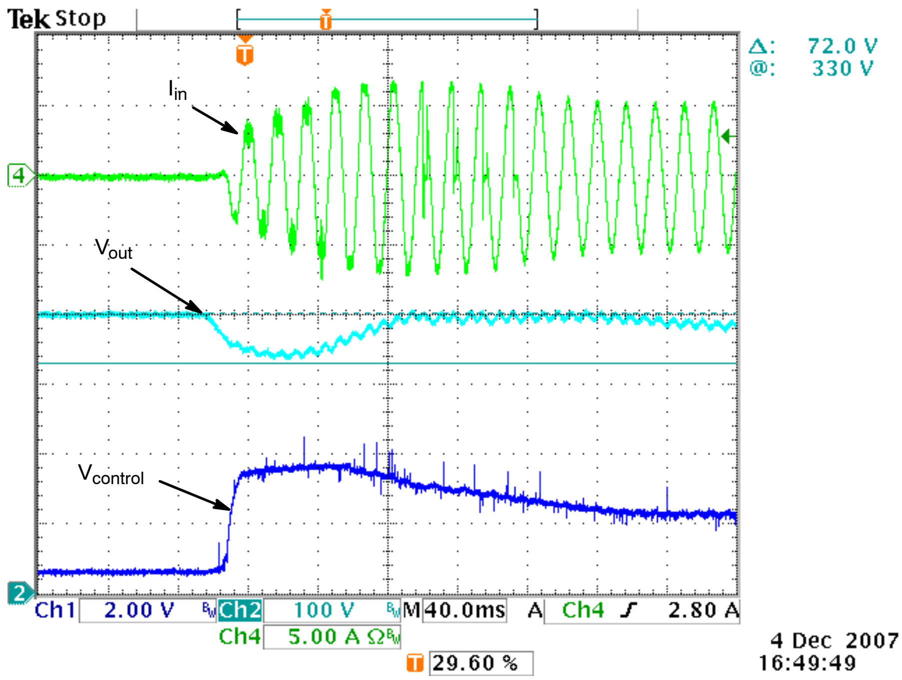

Figure 11. V_{ac} = 85 Vac, V_{out} = 392.6 V, I_{out} = 0 A ~ 0.77 A

Under Voltage Protection (UVP)

FB open test at 265 V_{ac}, I_{out} = 0.1 A. The PFC circuit operates first, then short the FB Pin to ground. As V_{fb} is lower than 8% of V_{ref}, UVP activates and shuts down the output. It is to protect the buck capacitor from damaging.

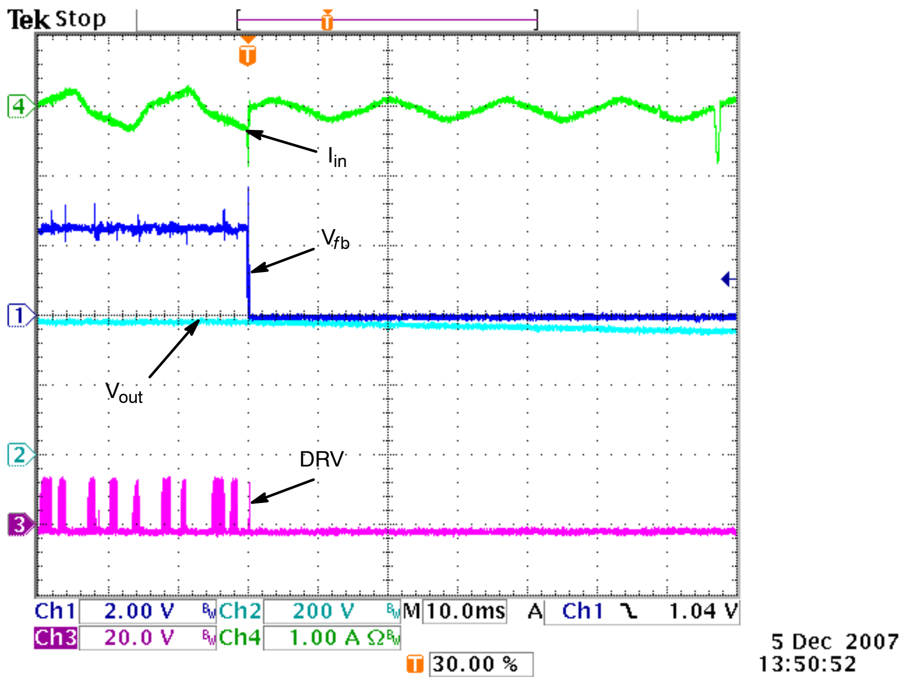

Figure 12. V_{ac} = 265 Vac, V_{out} = 394.5 V, I_{out} = 0.1 A

Brown Out Test

When the input voltage decreases to 68 V_{ac}, V_{BO} is below 0.7 V, brown out function is triggered and driver stops.

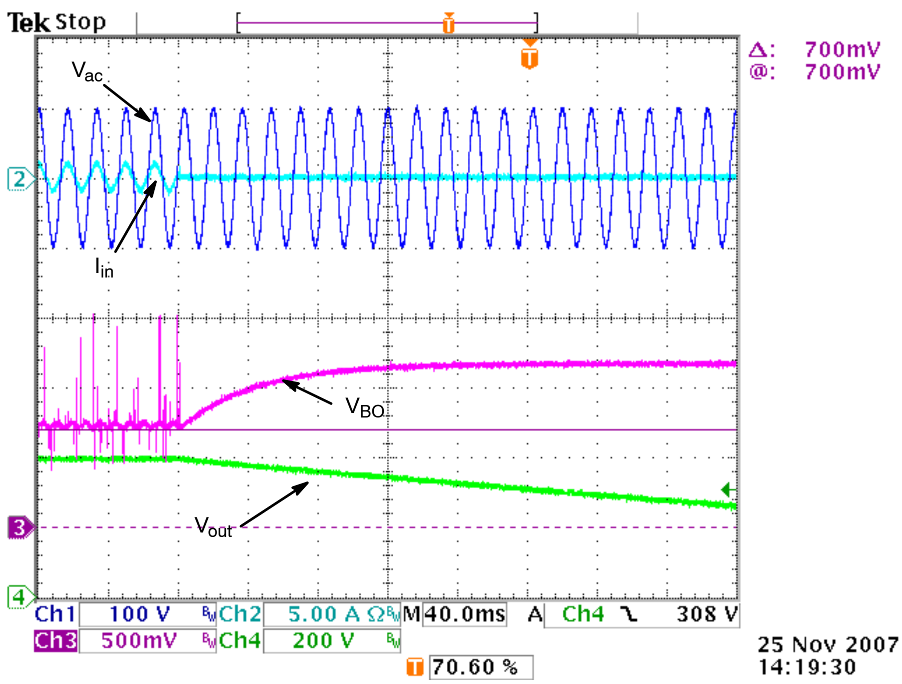

Figure 13. V_{ac} = 68 Vac, V_{out} = 393.7 V, I_{out} = 0.1 A

Brown Out Recovery Test

When the input voltage increases above 78.4 V_{ac}, V_{BO} is above 1.3 V and driver resumes operation.

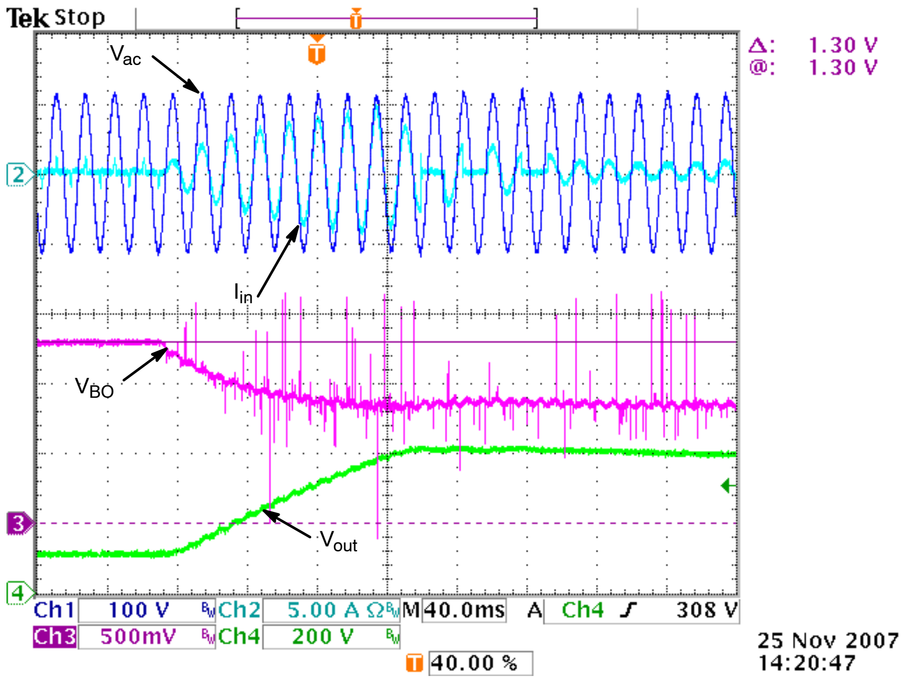

Figure 14. V_{ac} = 78.4 V_{ac}, V_{out} = 393.7 V, I_{out} = 0.1 A

PUBLICATION ORDERING INFORMATION

LITERATURE FULFILLMENT:
Literature Distribution Center for ON Semiconductor
P.O. Box 5163, Denver, Colorado 80217 USA
Phone: 303−675−2175 or 800−344−3860 Toll Free USA/Canada
Fax: 303−675−2176 or 800−344−3867 Toll Free USA/Canada
Email: orderlit@onsemi.com

N. American Technical Support: 800−282−9855 Toll Free USA/Canada
Europe, Middle East and Africa Technical Support:
Phone: 421 33 790 2910
Japan Customer Focus Center
Phone: 81−3−5773−3850

ON Semiconductor Website: **www.onsemi.com**

Order Literature: http://www.onsemi.com/orderlit

For additional information, please contact your local Sales Representative