AND8209/D

90 W, Single Stage, Notebook Adaptor

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APPLICATION NOTE

General Description

The 90 W demo board demonstrates the wide range of features found in the NCP1651. It provides an 18.5 V, 4.86 A isolated output, foldback current limit which is ideal for low−cost battery charger and notebook adaptor applications.

This unit will provide an isolated 18.5 V output from an input source with a frequency range from 47 Hz to 63 Hz, and a voltage range of 90 V_{rms} to 265 V_{rms}. It is fully self−contained and includes an internal high voltage startup circuit, and bias supply that operates of f of the Flyback transformer auxiliary winding.

In addition to excellent power factor, this chip offers fixed frequency operation in continuous and discontinuous modes of operation. It has a wide variety of protection features, including instantaneous current limiting, average current limiting, and an accurate secondary side power limit.

Features

- Fixed Frequency Operation
- Operation Over the Universal Input Range
- Multiple Protection Schemes
- Single Power Stage with Isolated Output
- Startup and Bias Circuits Included

Table 1. Demonstration Board Specifications

Requirements	Symbol	Min	Max
Input	Vac	90	265
Frequency	Hz	47	63
Vo (Static Regulation)	Vdc	18.4	18.6
Io	Adc	0	4.86
Output Power	W	−	90
Efficiency	%	84	−
Standby Power Vin 230 Vac	mW	−	500

Detailed Circuit Description

The detailed operational description and design equations are contained in the NCP1651 data sheet and in application note AND8124/D. This application note relates to this 18.5 Vdc 90 W adaptor design.

The 18.5 Vdc 90 W adaptor was designed using the Excel Design Spreadsheet which can be downloaded from the ON Semiconductor website (www.onsemi.com). The design steps for the adaptor are listed below. The schematic for the 90 W demo board, Figure 7, is located at the end of the technical write up.

Design Steps

1. Specifications, refer to Table 1 (90−265 V, 18.5 Vout, 90 W).
2. Determine primary inductance.
3. Determine turns ratio.
4. Select the MOSFET.
5. Select the output rectifier.
6. Build transformer with the lowest leakage inductance.
7. Select the output capacitor for ripple and transient response.
8. Complete control circuit design.
9. Build and test!

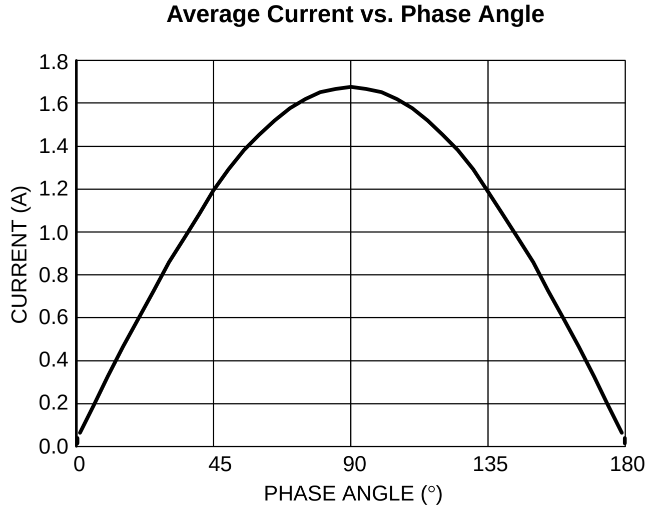
Figure 1 shows a sample of the System Input parameters from the NCP1651 Design Excel Spreadsheet. In the “Limits” column you enter your System Requirements. Below this is a column labeled “Evaluation”. This is where you would like to evaluate your design. Normally this is done at full load and with the minimum input AC line voltage. To the right you have the spreadsheet plot with the average input current with respect to phase angle.

Limits info should not change for a given design. Evaluation data may be changed as desired for various line and load conditions.

Limits

PO_{max}	= 90 W
Vin_{max}	= 265 V_{rms}
Vin_{min}	= 90 V_{rms}
Vo	= 18.5 V
Lp	= 600 μH
f_{switch}	= 100 kHz
Np/Ns	= 8.43

Peek switch voltage is approximately (V). 560.7



Evaluation

Pout	= 90 W
Vi	= 90 V
Effic	= 0.85
f_{LINE}	= 60 Hz
T	= 10 μs
P_{in}	= 106 W

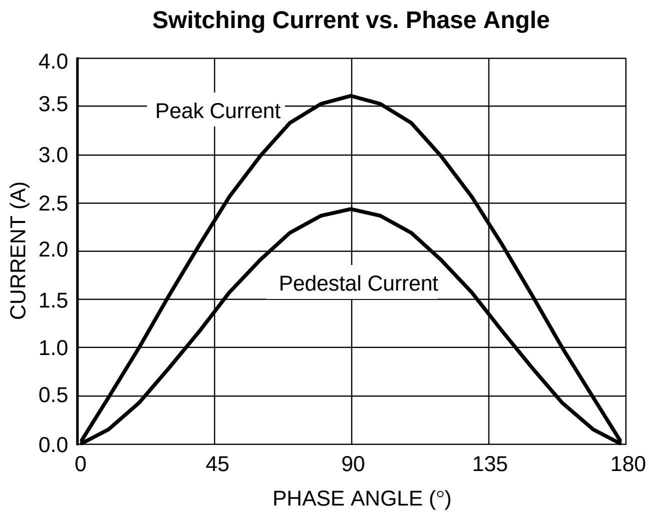


Figure 1.

Primary Inductance Selections

To determine the required primary inductance you must first determine if you want to operate in the continuous or discontinuous mode.

- CCM Operation
  - Lower peak and rms currents
  - Smaller input filter
  - Requires higher primary inductance (more turns)
- DCM Operation
  - Higher peak and rms currents
  - Larger input filter
  - Smaller inductor size

For most applications ON Semiconductor recommends CCM operation at low line and full load to minimize losses (deciding on the boundary conditioned from CCM to DCM depending on your magnetics size trade−of fs). Using the Design Spreadsheet we selected a primary inductance of 600 μH. Using 600 μH the input current is CCM at low line and full load, and starts to go discontinuous at 230 Vac near the zero crossing of the line. Selecting this operating mode allows for a lower Total Harmonic Distortion (THD) and a high Power Factor (PF), and lower peak current. A lower primary inductance can be used to reduce the size of the Flyback transformer, understanding that it will result in a higher THD, lower PF, and higher peak current which results in higher losses. Refer to the section labeled “Demo Board Test Result” for final Demo Board performance.

Transformer Turns Ratio

There are several tradeoffs that must be considered when selecting the transformer turns ratio (n). The first is the peak primary current, the second is the maximum voltage stress on the Flyback MOSFET (for more details refer to application note AND8124/D), and the third is the output diode reverse voltage. Figure 2 graphical shows the relationships, on the left axis is the MOSFET Drain to Source voltage (VDS). The horizontal axis is the transformer turns ratio, and the right vertical axis is the output diode reverse voltage. For an 18.5 Vdc output the graph shows that the transformer turns ratio can be between 4.6 and 9.4 (operating from the universal AC input).

The MOSFET in our design has a VDS rating of 800 V, this is the peak voltage across the device at turn−off (excluding the leakage inductance spike) is:

VDS = Vinmax • 1.414 + (Vo + Vf) n

Where:

Vinmax = 265 Vac

Vo = 18.5 Vdc

To provide some margin for the leakage inductance spike, the design goal is to keep VDS below 550 V. Based on the above design goals and the requirement to keep the peak current as low as possible, our turns ratio was selected to be 8.4. This will limit the MOSFET VDS to approximately 525 V (excluding the turn−off leakage inductance spike), and the output diode reverse voltage to approximately 55 V.

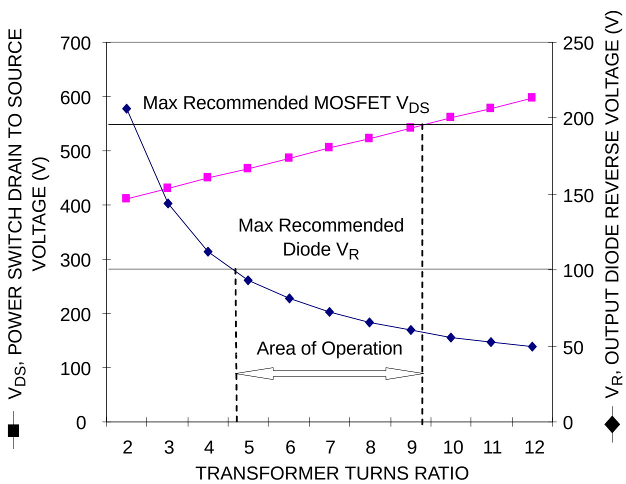


Figure 2. Turns Ratio Tradeoff

Transformer Turns Ration Summary

- Higher N leads to lower Iprim, Vsec
- Lower N allows lower Vds, lower leakage inductance, and capacitor ripple current

MOSFET Selection

For our application one of the primary concerns is the system efficiency. To reduce the conduction losses two low RDSON Infineon SP A11N80C MOSFETs were used. In addition to reduce the switching loses the oscillator frequency of the NCP1651 controller is set to run at 70 kHz.

Output Diode Selection

For this application we selected an ON Semiconductor MBR20100CT Schottky diode. The MBR20100CT diode has a peak inverse voltage rating of 100 V and an average forward current rating of 10 A.

Leakage Inductance

To minimize the effect of the leakage inductance spike, the coupling between the primary and secondary of the transformer needs to be as high as possible. This can be accomplished, if your transformer requires a primary with multiple layers, by interleaving the primary secondary windings. In our 18.5 Vdc application, the transformer primary has fifty−nine turns, and the secondary has seven turns. The manufacturer of the transformer , TDK, wound one layer of the primary with thirty turns and then the seven turn secondary (two seven turns secondary in parallel), and the remaining twenty−nine turns of the primary The results were a leakage inductance of approximately 8.5 μH. Refer to application note AND8147/D where a comparison of transformer winding techniques versus leakage inductance was preformed.

Output Voltage Ripple

The output voltage ripple (ΔV) on the secondary of the transformer has two components, the traditional high frequency ripple associated with a flyback converter, and the low frequency ripple associated with the line frequency (50 or 60 Hz).

$$\Delta V = \sqrt{\Delta Vcap^2 + \Delta Vesr^2}$$

The high frequency ripple can be calculated by:

$$\Delta Vcap = \frac{Ioavg \cdot dt}{Co}$$

$$Ioavg = \frac{Ipk + Iped}{2}$$

$$\Delta Vesr = Ipk \cdot esr$$

If we divided the output ripple into 10° increments over one cycle (180°) the sinusoidal ripple voltage with respect to phase angle is:

The low frequency ripple can be calculated by:

$$\Delta V = \left(\left(\frac{Po}{2 \cdot Co \cdot Vo \cdot 2 \cdot \pi \cdot f_{line}}\right) \cdot \sin\Theta\right)$$

Where:

Ipk = Peak current (secondary)

Iped = Pedestal of the secondary current

Co = Output capacitance

esr = Output capacitor equivalent series resistance

T = Switching frequency

Using the NCP1651 Excel Design Spreadsheet the output voltage ripple is plotted versus phase angle in Figure 3 and is approximately 800 mV pk–pk with an output capacitance of 15,600 μF.

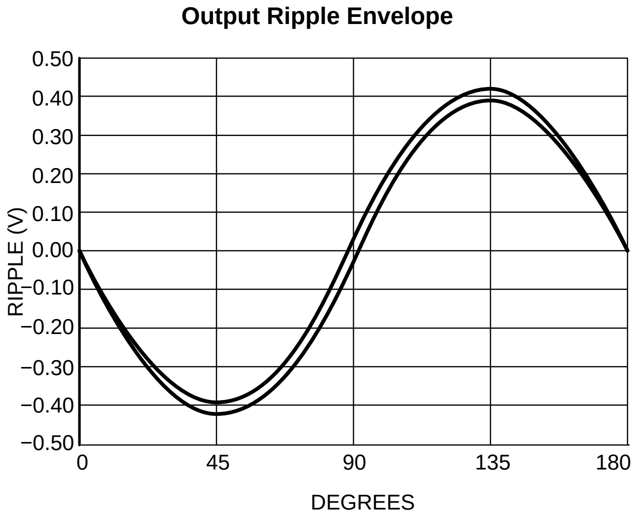


Figure 3. Excel Spreadsheet Output Voltage Ripple

For a comparison, Figure 4 shows the measured output voltage ripple from the NCP1651 Demo Board. The results show that the Excel Design Spreadsheets provide very accurate results.

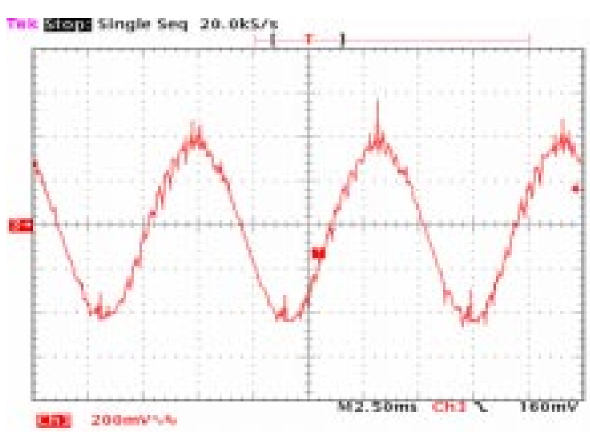


Figure 4. Measured Output Voltage Ripple

Control Loop

The control loop is set up to limit the loop bandwidth at high line (230 Vac) to approximately 15 Hz with a minimum phase margin of 45°. The simplest way do this is with the Excel Design Spreadsheet. In our application the final components selected were based on cost and standard components values. The loop crosses 0 dB at 12 Hz at high line with a phase margin of 50° (refer to Figures 5 and 6). Step 5, the "Error Amplifier Loop Design", below , is a captured screen from the Excel Design Spreadsheet. The spreadsheet will recommend the compensation values to provide a stable control loop, but the user typically should select the closest standard value. For this application, the 18.5 Vdc Demo Board, the spreadsheet recommended values were not used so we could reduce the loop bandwidth to provide a higher power factor and lower distortion.

Step 5 − Error Amplifier Loop Design

NCP1651 Design Spreadsheet
Provided by ON Semiconductor

Loop Stability

	Suggested Value		
CTR_{opto} =		2.5	Optocoupler Current Transfer Ratio (I_{coll}/I_{diode})
V_{CC} =		12 V	Bias Voltage for Secondary Operational Amplifier
R_{opto} =	**8,333**	4,700 Ω	Optocoupler Series Resistor
R_{fb} =	**455**	560 Ω	Volt Error Amp Stability (suggested value for 10 Hz crossover)
C_{fb} =	**70.6**	22 μF	Volt Error Amp Stability (see bode plots for C_{fb} and R_{fb})
$f_{z\ error\ amp}$ =		12.92 Hz	
$f_{p\ output}$ =		2.68 Hz	

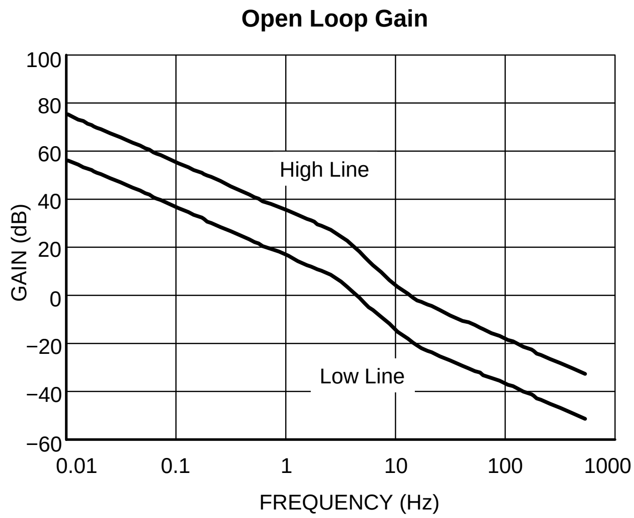


Figure 5. Loop Gain

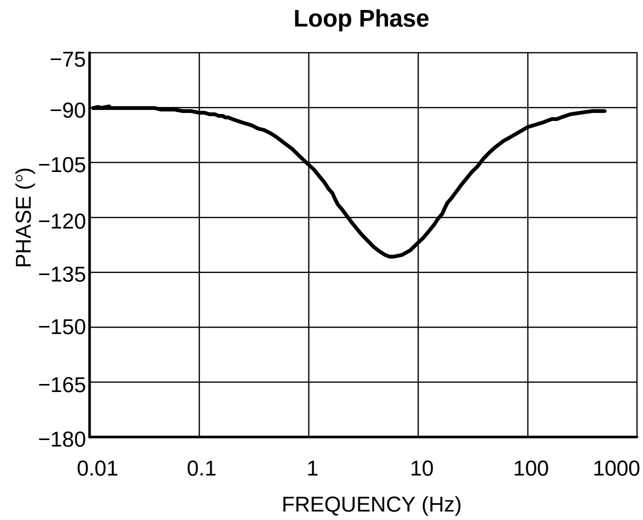


Figure 6. Phase Margin

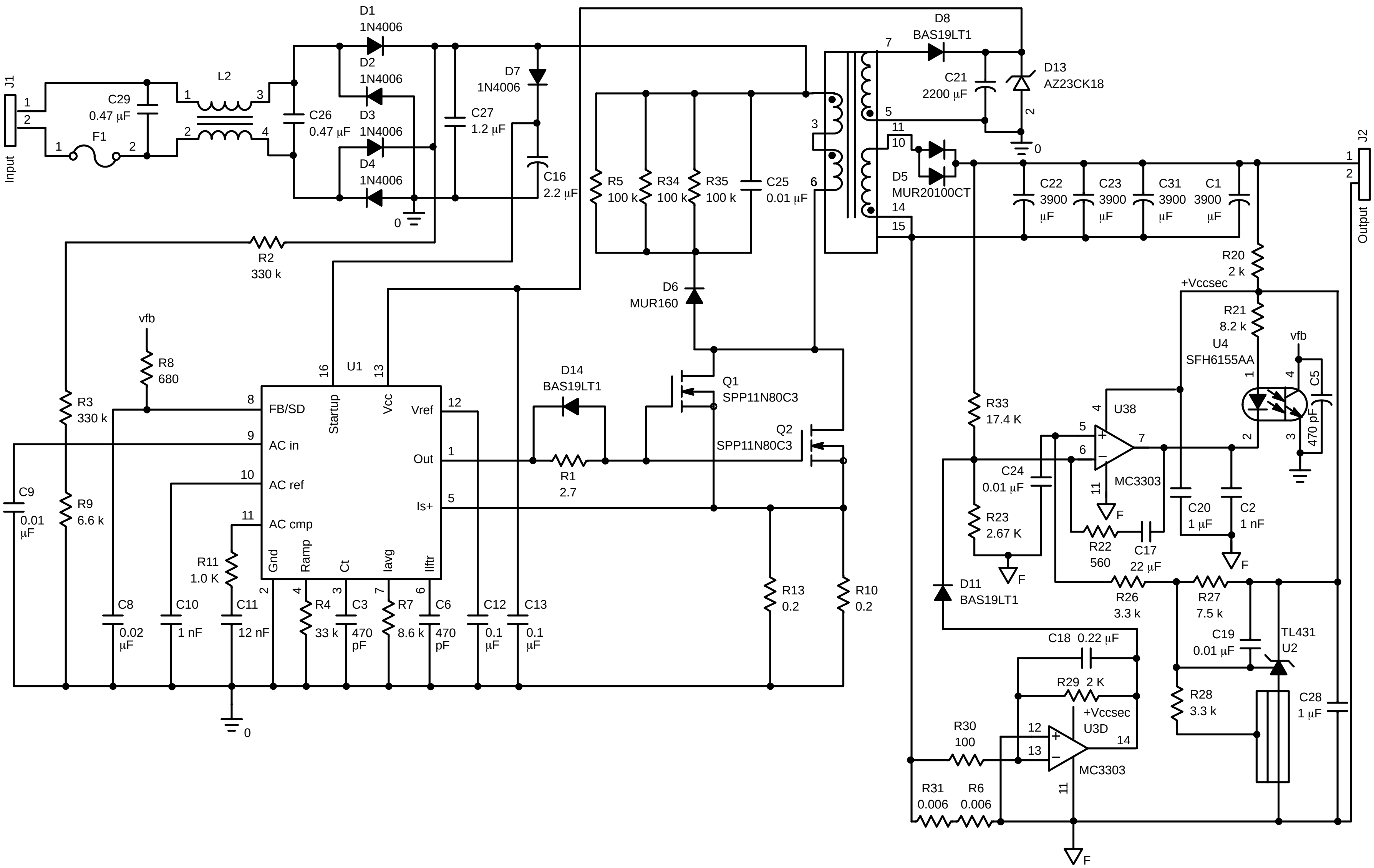


Figure 7. NCP1651 Applications Circuit Schematic

DEMO BOARD TEST PROCEDURE

Table 2. Test Equipment

AC Source 85−265 Vac, 47−64 Hz	Variable Electronic Load
Digital Multimeter	Voltec Precision Power Analyzer

1. Connect the AC source to the input terminals J1.
2. Connect a variable electronic load to the output terminals J2, the PWB is marked +, for the positive output, and − for the return.
3. Set the variable electronic load to 45 W.
4. Turn on the AC source and set it to 115 Vac at 60 Hz.
5. Verify that the NCP1651 provides 18.5 Vdc to the load.
6. Vary the load and input voltage. Verify output voltage as shown in Table 3.

Table 3. Expected Values for Varying Input Voltages and Loads

Vin (Vac)	Vo (Vdc) @ No Load	Vo (Vdc) @ 45 W	Vo (Vdc) @ 90 W	THD (%)	PF 90 W
90	18.7	18.6	18.5	8.0	0.995
115	18.7	18.6	18.5	10	0.990
230	18.7	18.6	18.5	20	0.920

Table 3 shows typical values, the initial set point (18.5 Vdc may vary).

7. To verify total harmonic distortion (THD) first, shut off the AC power supply.
8. Connect the Voltec Precision Power Analyzer as shown in Figure 1.
9. Turn on the AC source to 115 Vac at 60 Hz and set the electronic load to 90 W (only measure the THD at full load).
10. Verify the voltage and current Harmonics of the circuit as shown in Table 3.
11. Shut off the power AC power supply.
12. Set the variable electronic load to 90 W.
13. Turn on the AC source and set it to 230 Vac at 60 Hz.
14. Verify the voltage and current Harmonics of the circuit as shown in Table 3.

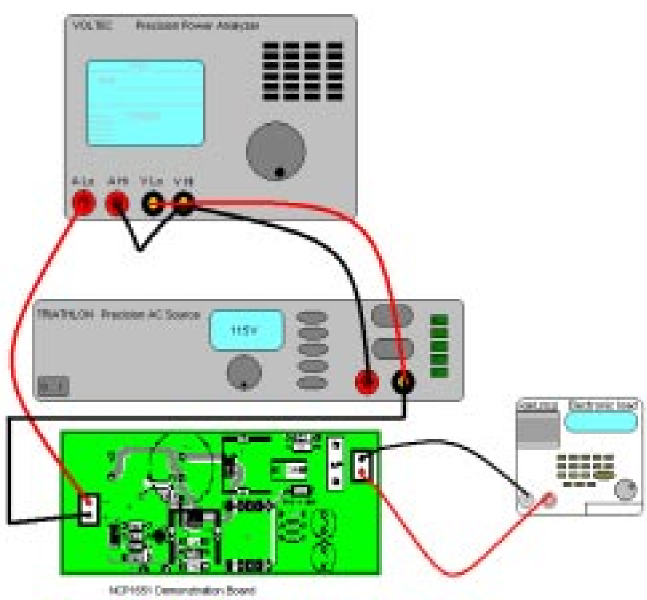


Figure 8. NCP1651 Test Setup

NCP1651 DEMO BOARD TEST RESULTS PERFORMANCE DATA

Regulation

Vin (Vac)	Pin (W)	Vo (Vdc)	IO (Adc)	PO (W)	Eff (%)
90	106.03	18.55	4.85	89.97	84.85
115	105.21	18.55	4.85	89.85	85.40
230	105.1	18.57	4.85	90.1	85.69

Standby Power

Vin (Vac)	Pin (mW)
115	372
230	455

Power Factor and THD

Vin (Vac)	PF (W)	THD (%)	PO (W)
90	0.995	8.5	90
115	0.990	9.18	90
230	0.940	19.45	90

Vendor Contact List

Vendor	U.S. Phone/Internet
ON Semiconductor	1−800−282−9855 www.onsemi.com/
TDK	1−847−803−6100 www.component.tdk.com/
Vishay	www.vishay.com/
Bussman (Cooper Ind.)	1−888−414−2645 www.cooperet.com/
Coiltronics (Cooper Ind.)	1−888−414−2645 www.cooperet.com/
Fairchild	www.fairchildsemi.com/
Panasonic	www.eddieray.com/panasonic/
Weidmuller	www.weidmuller.com/
Keystone	1−800−221−5510 www.keyelco.com/
HH Smith	1−888−847−6484 www.hhsmith.com/
Aavid Thermalloy	www.aavid.com/

Table 4. NCP1651 Application Circuit Parts List

Ref Des	Description	Part Number	Manufacturer
C2	Cap, Ceramic, Chip, 0.001 μF, 25 V	VJ0603Y102KXXET	VISHAY
C3	Cap, Ceramic, Chip, 470 pF, 25 V	VJ0603Y471JXXET	VISHAY
C4	Cap, Aluminum Elec., 100 μF, 35 V	EKB00BA310F00	VISHAY
C5	Cap, Ceramic, Chip, 470 pF, 25 V	VJ0603Y471JXXET	VISHAY
C6	Cap, Ceramic, Chip, 470 pF, 25 V	VJ0603Y471JXXET	VISHAY
C8	Cap, Ceramic, Chip, 0.022 μF, 25 V	VJ0603Y223KXXET	VISHAY
C9	Cap, Ceramic, Chip, 0.01 μF, 25 V	VJ0603Y103KXXET	VISHAY
C11	Cap, Ceramic, Chip, 0.012 μF, 25 V	VJ0603Y123KXXET	VISHAY
C10	Cap, Ceramic, Chip, 0.001 μF, 25 V	VJ0603Y102KXXET	VISHAY
C12, C13	Cap, Ceramic, Chip, 0.1 μF, 25 V	VJ0606Y104KXXET	VISHAY
C16	2.2 μF, Alum Elect, 450 V (0.394 dia x 0.492H) (0.394 dia x 0.492H)	ECA−2WHG2R2 EKA00DC122P00	Panasonic (Digi–P5873) Vishay Sprague (20)
C17	Cap, Ceramic, Chip, 22 μF, 10 V	C3225X5R0J226MT	TDK
C18	Cap, Ceramic, Chip, 0.22 μF, 25 V	VJ0603Y224KXXET	VISHAY
C19	Cap, Ceramic, Chip, 0.01 μF, 25 V	VJ0603Y103KXXET	VJ0603Y103KXAAT
C20	Cap, Ceramic, Chip, 1.0 μF, 25 V	C3216X7R1E105KT	TDK
C21	220 μF, Alum Elect, 25 V	ECA1EM331	Panasonic
C1, C22, C23, C31	Cap, Alum, 3900 μF, 25 V	25YXH3900M16X35.5 UHE1E392MHD	Rubycon Nichicon
C24	Cap, Ceramic, Chip, 0.01 μF, 50 V	VJ0603Y103KXAAT	VISHAY
C25	Cap, Ceramic, 0.01 μF, 1.0 KV	225261148036	Vishay
C27	Cap, 1.2 μF, 275 Vac	F1778−512K2KCT0	Vishay
C26, C29	Cap, Polypropylene, 0.47 μF, 400 VDC	MKP1841−447−3000	Vishay−Sprague
C28	Cap, Ceramic, Chip, 1.0 μF, 25 V	C3216X7R1E105KT	TDK
D1–D4	Diode, Rectifier, 800 V, 1.0 A	1N4006	ON Semiconductor
D5	Diode, Ultrafast, 200 V, 16 A	MUR20100CT	ON Semiconductor
D6	Diode, Ultrafast, 600 V, 1.0 A	MUR160	ON Semiconductor
D7	Diode, Rectifier, 800 V, 1.0 A	1N4006	ON Semiconductor
D8, D11, D14	Diode, Switching, 120 V, 200 mA, SOT−23	BAS19LT1	ON Semiconductor
D13	Zener Diode, 18 V	AZ23C18	VISHAY
F1	Fuse, 2.0 A, 250 Vac	1025TD2A	Bussman
L2	5.0 A Sat, 3.0 mH Inductor, Common Mode	Q4007−A	Coilcraft
Q1, Q2	FET, 11 A, 800 V, 0.45 ?, N−channel	SPA11N80C3	Infineon
R1	Resistor, SMT1206, 2.7	CRCW1206270JRE4	Vishey
R2	Resistor, Axial Lead, 270 k, 1/4 W	CMF−55−270K00FKRE	Vishey
R3	Resistor, Axial Lead, 270 k, 1/4 W	CMF−55−270K00FKRE	Vishey
R5	Resistor, 100 k, 3.0 W, 5%	CFP−3104JT−00K	VISHAY
R4	Resistor, SMT1206, 33 k	CRCW120633KOJNTA	Vishey
R7	Resistor, SMT1206, 8.66 k	CRCW12068661F	Vishey
R8	Resistor, SMT1206, 680	CRCW12066800F	Vishey
R10	Resistor, SMT, 0.2, 1.0 W	WSL2512 .20 1%	Vishey Dale

Table 4. NCP1651 Application Circuit Parts List (continued)

Ref Des	Description	Part Number	Manufacturer
R9	Resistor, Axial Lead, 5.4 k, 1/4 W	CMF−55−5K400FKBF	Vishey
R11	Resistor, SMT1206, 1.0 k	CRC12061K00JNTA	Vishey
R12	Resistor, 100 k, 3.0 W, 5%	CFP−3104JT−00K	VISHAY
R13	Resistor, SMT, 0.2, 1.0 W	WSL2512 .20 1%	Vishey Dale
R14	Resistor, SMT1206, 100	CRC12062K100JNTA	Vishey
R20	Resistor, SMT1206, 2.0 k	CRC12062K00JNTA	Vishey
R21	Resistor, SMT1206, 8.2 k	CRC12068K20JNTA	Vishey
R22	Resistor, SMT1206, 2.0 k	CRC12062K00JNTA	Vishey
R23	Resistor, SMT1206, 2.67 K, 1%	CRCW12062670F	Vishey
R26	Resistor, SMT1206, 3.3 k	CRC12063K30JNTA	Vishey
R27	Resistor, SMT1206, 7.5 k	CRC12067K50JNTA	Vishey
R28	Resistor, SMT1206, 3.3 k	CRC12063K30JNTA	Vishey
R29	Resistor, SMT1206, 2.0 k	CRC12062K00JNTA	Vishey
R30	Resistor, SMT1206, 100, 1%	CRCW12061000F	Vishey
R31	1.0 W, 0.006 Resistor	WSL251R006FTB	Vishey
R6	1.0 W, 0.006 Resistor	WSL251R006FTB	Vishey
R33	Resistor, SMT1206, 17.4 k, 1%	CRCW120617400F	Vishey
R34	Resistor, 100 k, 3.0 W, 5%	CFP−3104JT−00K	VISHAY
R35	Resistor, 100 k, 3.0 W, 5%	CFP−3104JT−00K	VISHAY
T1	Transformer, Flyback (Lp 600 μH)	SRW42EC−U10H014	TDK
U1	PFC Controller	NCP1651	ON Semiconductor
U2	2.5 V Programmable Ref, SOIC	TL431ACD	ON Semiconductor
U3	Quad Op A	MC3303D	ON Semiconductor
U4	Optocoupler, 1:1 CTR, 4 Pin	SFH615AA−X007	Vishay

Hardware

Ref Des	Description	Part Number	Manufacturer
H1	Printed Circuit Board		
H2	Connector	171602	Weidmuller (Digi 281−1435−ND)
H3	Connector	171602	Weidmuller (Digi 281−1435−ND)
	Insulator	4672	Keystone
H8, H9	Aluminum Heatsinks	4.1″ X 1.0″ X 0.05″	Manufactured

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