



NCP1351 16 V/32 V – 40 W Printer Power Supply Evaluation Board User's Manual

ON Semiconductor®

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EVAL BOARD USER'S MANUAL

Description

The present document describes a printer power supply operated by the NCP1351, a fixed t_{on} /variable t_{off} time controller. The board can deliver 10 W average on a 16 V output and 30 W average on a 32 V output with a transient peak power capability of 80 W. It however exhibits a low standby power: below 150 mW at no load whatever the input voltage. Let us first review the benefit of using the NCP1351:

The NCP1351 at a Glance

Fixed t_{on} , Variable t_{off} Current-mode Control:

Implementing a fixed peak current mode control (hence the more appropriate term “quasi-fixed” t_{on}), the NCP1351 modulates the off time duration according to the output power demand. In high power conditions, the switching frequency increases until a maximum is hit. This upper limit depends on an external capacitor selected by the designer. In light load conditions, the off time expands and the NCP1351 operates at a lower frequency. As the frequency reduces, the contribution of all frequency-dependent losses accordingly goes down (driver current, drain capacitive losses, switching losses), naturally improving the efficiency at various load levels.

Peak Current Compression at Light Loads:

Reducing the frequency will certainly force the converter to operate into the audible region. To prevent the transformer mechanical resonance, the NCP1351 gradually reduces – compresses – the peak current setpoint as the load becomes lighter. When the current reaches 30% of the nominal value, the compression stops and the off duration keeps expanding towards low frequencies.

Low Standby-power:

The frequency reduction technique offers an excellent solution for designers looking for low standby power converters. Also, compared to the skip-cycle method, the smooth off time expansion does not bring additional ripple in no-load conditions: the output voltage remains quiet.

Natural Frequency Dithering:

The quasi-fixed t_{on} mode of operation improves the EMI signature since the switching frequency varies with the natural bulk ripple voltage.

Extremely Low Start-up Current:

Built on a proprietary circuitry, the NCP1351 startup section does not consume more than 10 μ A during the startup sequence. The designer can thus easily combine startup time and standby consumption.

Overload Protection Based on Fault Timer:

Every designer knows the pain of building converters where a precise over current limit must be obtained. When the fault detection relies on the auxiliary V_{CC} , the pain even increases. Here, the NCP1351 observes the lack of feedback current and starts a timer to countdown. At the end of its charge, the timer either triggers an auto-recovery sequence (auto-restart, B and D versions) or permanently latches-off (A and C). On C and D versions the fault timer is started at an output power corresponding to 60% of the maximum deliverable power; to allow transient peak power delivery.

Latch Fault Input:

A dedicated input lets the designer externally trigger the latch to build additional protections such as over-voltage (OVP) or over-temperature (OTP).

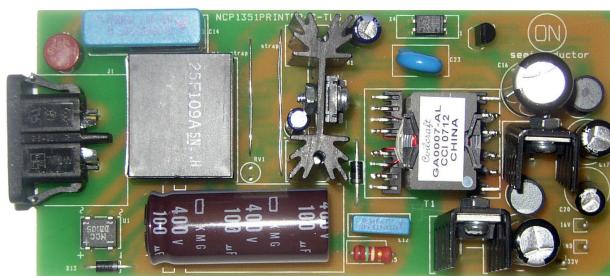


Figure 1. NCP1351 Evaluation Board

The Schematic

The design must fulfill the following specifications:

- Input Voltage: 88 – 265 Vac
- Output Voltage: 16 V @ 0.625 A and 32 V @ 1 A Nominal (40 W); with Transient 80 W Peak Power Capability during 40 ms, and 62 W Peak during 400 ms
- Over Power Protection below 100 W for the Whole Input Voltage Range (LPS)
- Latched Short-circuit Protection
- Latched Over-voltage Protection
- Latch Recovery Time below 3 s
- Brown-out Protection
- Start-up Time below 3 s

In order to deliver the peak output power, the NCP1351 will increase its switching frequency up to the upper limit set by the C_T capacitor. To not jeopardize the EMI test compliance, the switching frequency should be kept below 150 kHz. We will choose 100 kHz to have a good margin. As a result the switching frequency at nominal load will be around 50 kHz. Since we need to deliver 80 W of transient peak power while ensuring the power will never be above 100 W, we will use the C version of NCP1351, specially tailored for this kind of application. When the controller

detects a need for a frequency higher than 60 kHz, implying an overload condition, it will start to charge the timer capacitor: if the overload disappears, the timer capacitor goes back to zero. If the fault remains, the timer capacitor voltage reaches 5 V and latches off the controller. During the fault condition, the power supply will anyway deliver the output power while the switching frequency is below its maximum value of 100 kHz.

The transformer has been derived using the Excel® spreadsheet available from the ON Semiconductor website which also gives transformer parameters. We came up to the following values:

$$\begin{aligned}L_p &= 270 \mu\text{H} \\N_p:N_s &= 1:0.2 \\N_p:N_{aux} &= 1:0.2 \\I_{pk} &= 3 \text{ A}\end{aligned}$$

The transformer has been manufactured by Coilcraft (www.coilcraft.com). The leakage inductance is kept around 3% of the primary inductance, leading to a good efficiency and reduced losses in no-load conditions. The schematic appears on Figure 2. The converter operates in DCM at nominal power; and for peak power it goes CCM with close to 50% duty-cycle at low mains and stays CCM at high line.

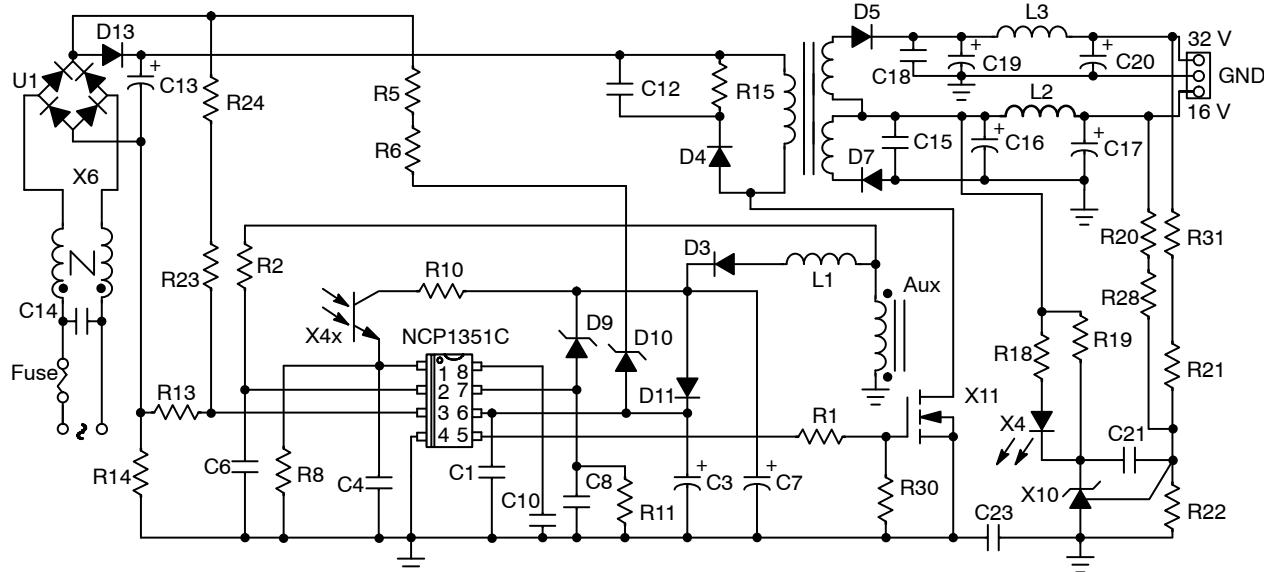


Figure 2. The Simplified 40 W Printer Board Featuring the NCP1351 Controller

Two 330 k Ω resistors in series with a 60 V zener diode ensure a clean start-up sequence with the 4.7 μ F capacitor (C_3), not from the bulk capacitor as it is usually done; but from the fully rectified, unfiltered haversine. This configuration allows for a quick release time after the

controller is latched (a direct connection to the AC line would also work). Despite a small value for C_3 , the V_{CC} still maintains in no-load conditions thanks to the split configuration:

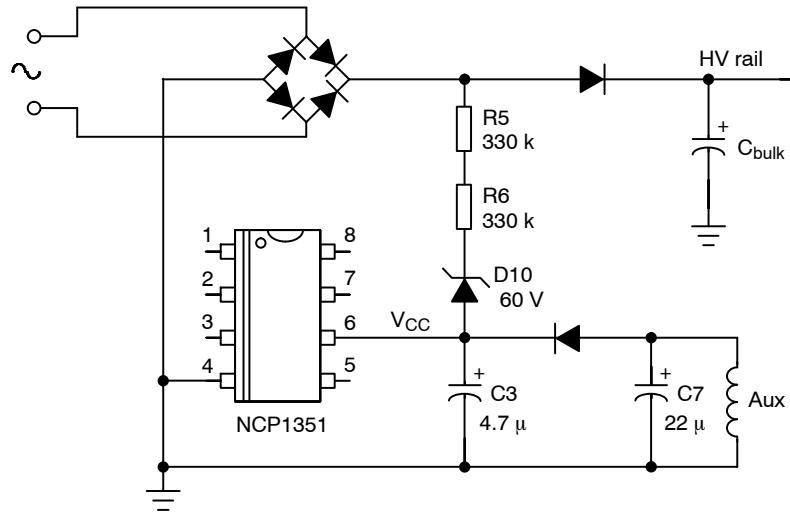


Figure 3. The split V_{CC} configuration helps to start-up in a small period of time (C_3 to charge alone) but the addition of a second, larger capacitor (C_7), ensures enough V_{CC} in standby.

The primary-side feedback current is fixed to roughly 300 μ A via R_8 and an additional bias is provided for the TL431. 1 mA at least must flow in the TL431 in worse case conditions (full load). Failure to respect this will degrade the power supply output impedance and regulation will suffer. A 2.7 k Ω value for R_{19} has proven to do just well, without degrading the standby power.

The overvoltage protection uses a 17 V zener diode (D_9) connected to the auxiliary V_{CC} . When the voltage on this rail exceeds 17 V plus the NCP1351 5 V latch trip point (total is thus 22 V), the circuit latches-off and immediately pulls the V_{CC} pin down to 6 V. The reset occurs when the injected current into the V_{CC} pin falls below a few μ A, that is to say when the power supply is disconnected from the mains outlet. To speed-up this reset phase, a connection to the fully rectified haversine resets the system faster (Figure 3).

To satisfy the maximum power limit, we don't need to add a true Over Power Protection (OPP) circuit since our

NCP1351C transiently authorizes higher power, but safely latches off if the overpower lasts too long. To ensure a fault timer duration of at least 500 ms (to be able to deliver the 62 W power peak during 400 ms), the timer capacitor C_{10} must be 1.5 μ F. This value will be adjusted depending on the specification, according to the maximum peak power duration the adapter must sustain.

If anyway a constant overpower protection is needed over the whole input voltage range, a simple arrangement can be used: given the negative sensing technique, we can use a portion of the auxiliary signal during the on time, as it also swings negative. However, we don't want this compensation for short T_{ON} durations since standby power can be affected. For this reason, we can insert a small integrator made of C_9 - R_{26} (see Figure 4). To avoid charging C_9 during the flyback stroke, D_{14} clamps the positive excursion and offers a stronger negative voltage during the on time.

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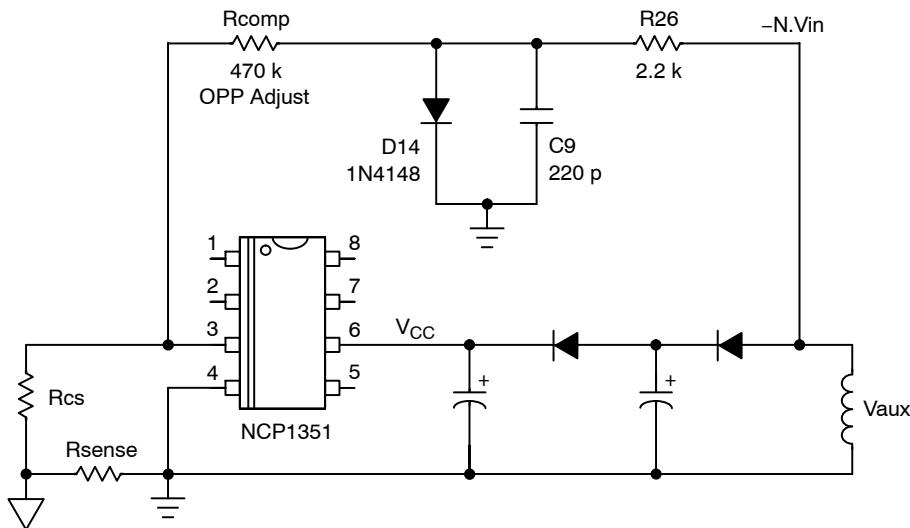


Figure 4. A Simple Arrangement Provides an Adjustable Overpower Power Compensation

A simple resistor connected between the auxiliary winding (that swings negative during the ON time) and the CT capacitor ensure a stable operation in CCM despite the duty cycle above 50% at very low line, due to the ripple on the bulk capacitor. The unique features of NCP1351C allow using a 100 μ F bulk capacitor while delivering the transient peak power and ensuring the output is still regulated during line drop-outs.

Finally, the clamping network maintains the drain voltage below 520 V at high-line (375 Vdc) which provides 85% derating for the 600 V BV_{dss} device.

Measurements

Once assembled, the board has been operated during 15 min at full power to allow some warm-up time. We used a WT210A from Yokogawa to perform all power related measurements coupled to an electronic ac source.

Table 1. EFFICIENCY

V_{IN} (P_{OUT})	120 Vac	230 Vac
40 W	84.4%	85.4%
25 W	85.9%	85.9%
10 W	86.0%	85.1%
5 W	85.5%	83.2%
2 W	83.4%	79.5%
1 W	77.7%	73.3%
0.5 W	70.0%	66.3%

Table 2. NO-LOAD POWER

V_{IN} (P_{OUT})	120 Vac	230 Vac
No-load	75 mW	140 mW

Overpower Protection Level:

The power supply is able to deliver a peak power of 85 W during 500 ms from 85 Vac to 270 Vac.

It can deliver a constant output power of more than 40 W, but less than 80 W over the same input voltage range.

Table 3. START-UP TIME

V_{IN} ($P_{OUT} = 40$ W)	85 Vac	230 Vac
Start-up Duration	2.7 s	0.5 s

In the above tables, we can see the excellent efficiency, especially at light load conditions thanks to the natural frequency foldback of the NCP1351.

The no-load standby power stays below 150 mW at high line, a good performance for a dual output power supply able to deliver 80 W. Please note that the high-voltage probe observing the drain was removed and the load totally disconnected to avoid leakage.

Despite operation in the audible range, we did not notice any noise problems coming from either the transformer or the RCD clamp capacitor.

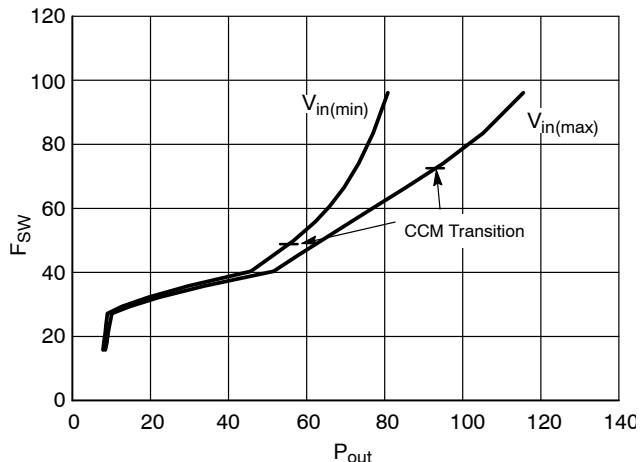


Figure 5. Switching Freq. Variations vs. Output Load

Scope Shots

Below are some oscilloscope shots gathered on the evaluation board:

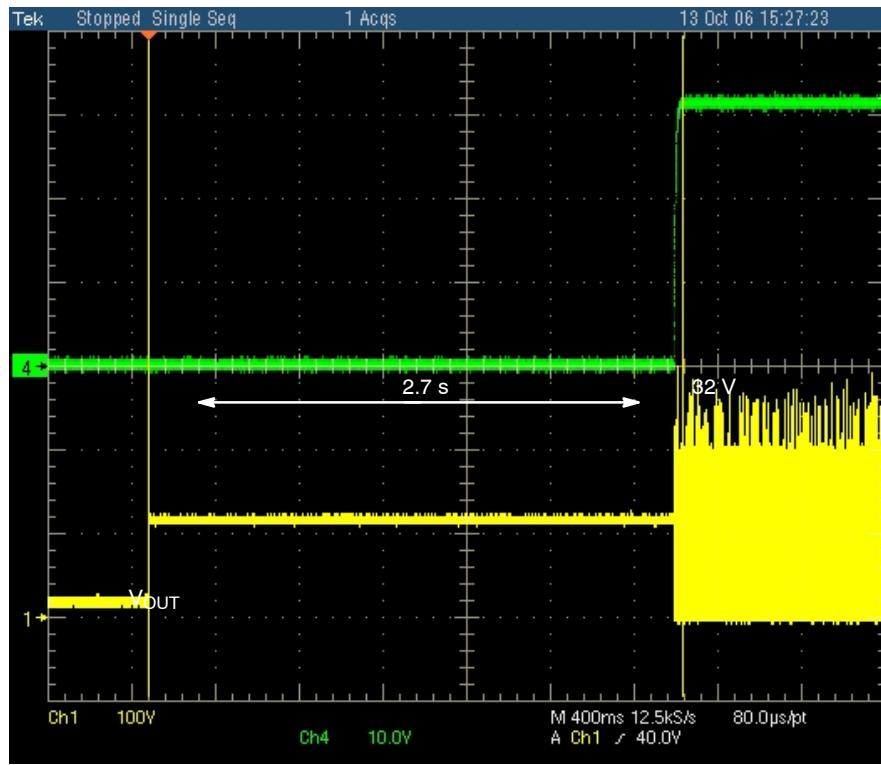


Figure 6. Start-up Time, $V_{IN} = 85$ Vac

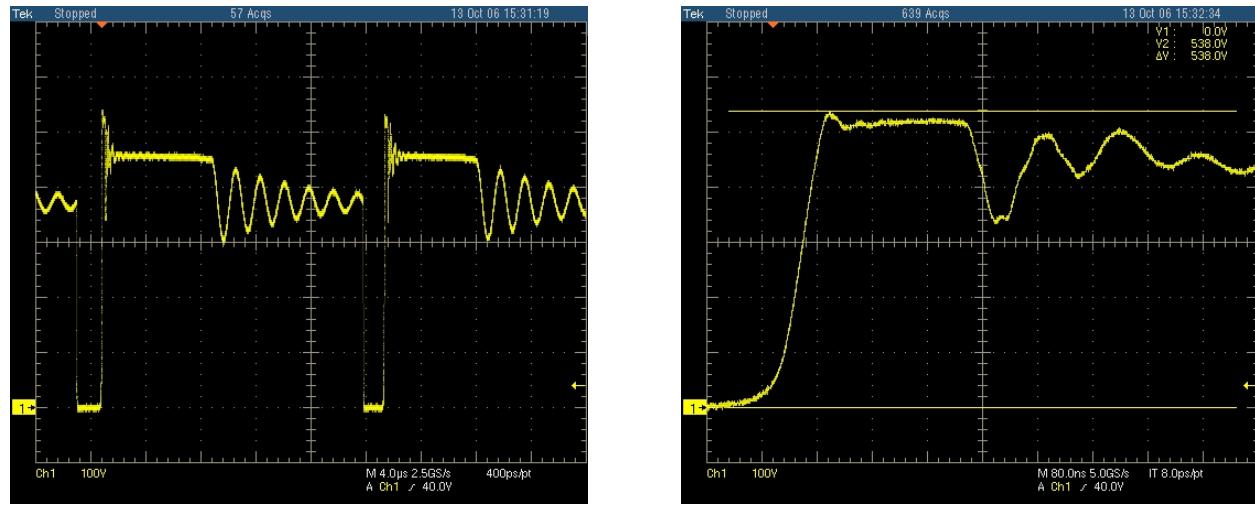


Figure 7. Maximum Output Power, $V_{IN} = 265$ Vac

Conclusion

The printer power supply built with the NCP1351 exhibits an excellent performance on several parameters like the efficiency and the low-load standby. The transient switching frequency increase allows to deliver peak power during a limited time; but if the overpower lasts longer than the set fault timer, the controller safely latches off.

The limited number of surrounding components around the controller associated to useful features (timer-based protection, latch input...) makes the NCP1351 an excellent choice for cost-sensitive printer adapter designs.

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PCB LAYOUT

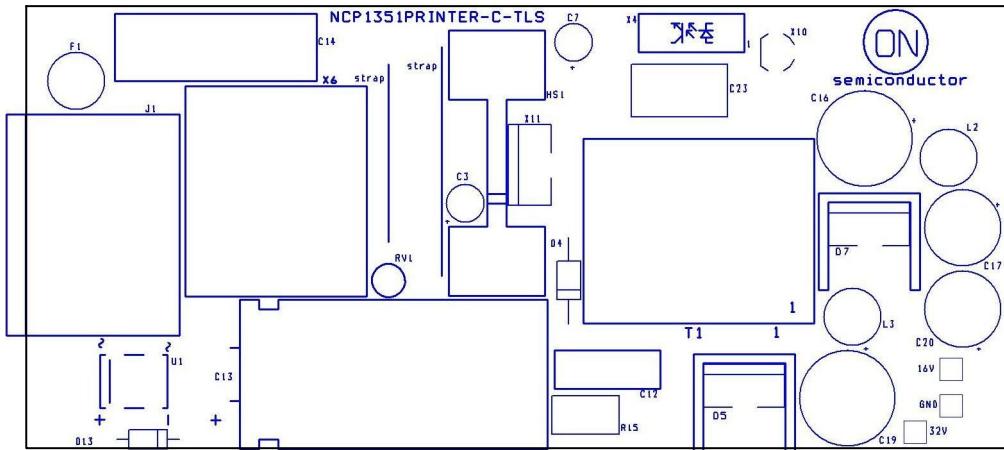


Figure 8. Top Side Components

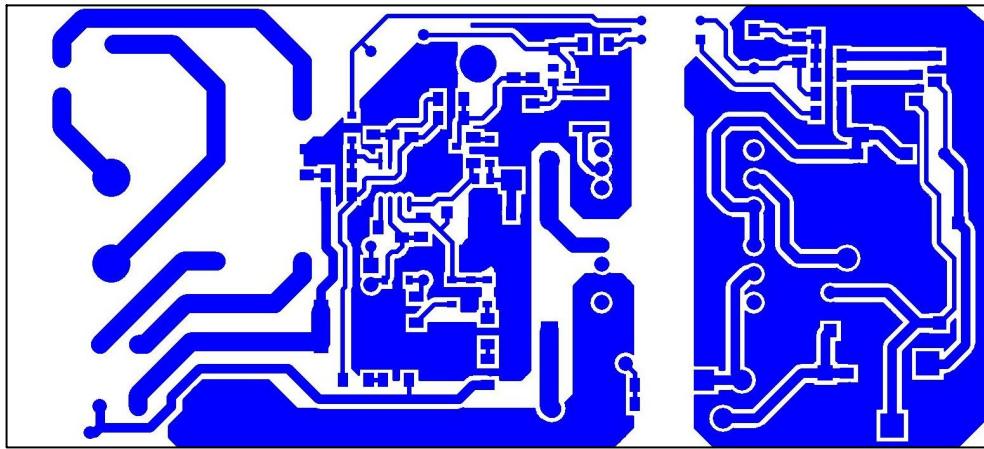


Figure 9. Copper Traces

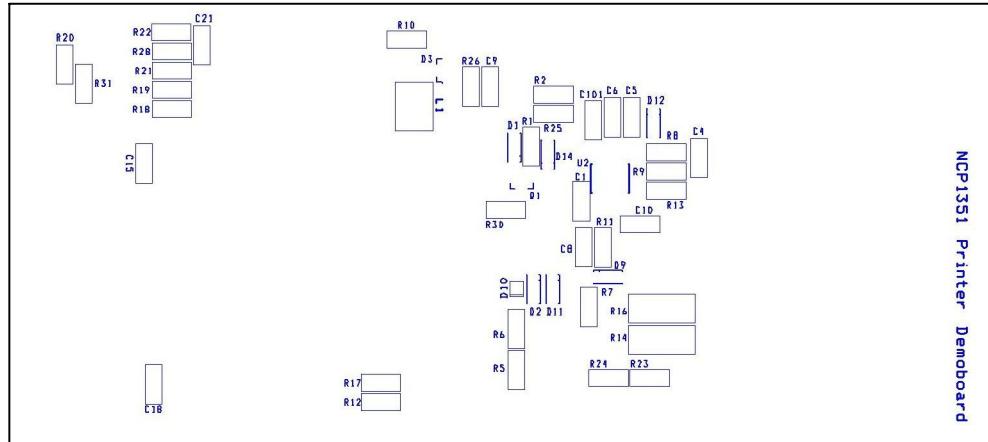


Figure 10. SMD Components

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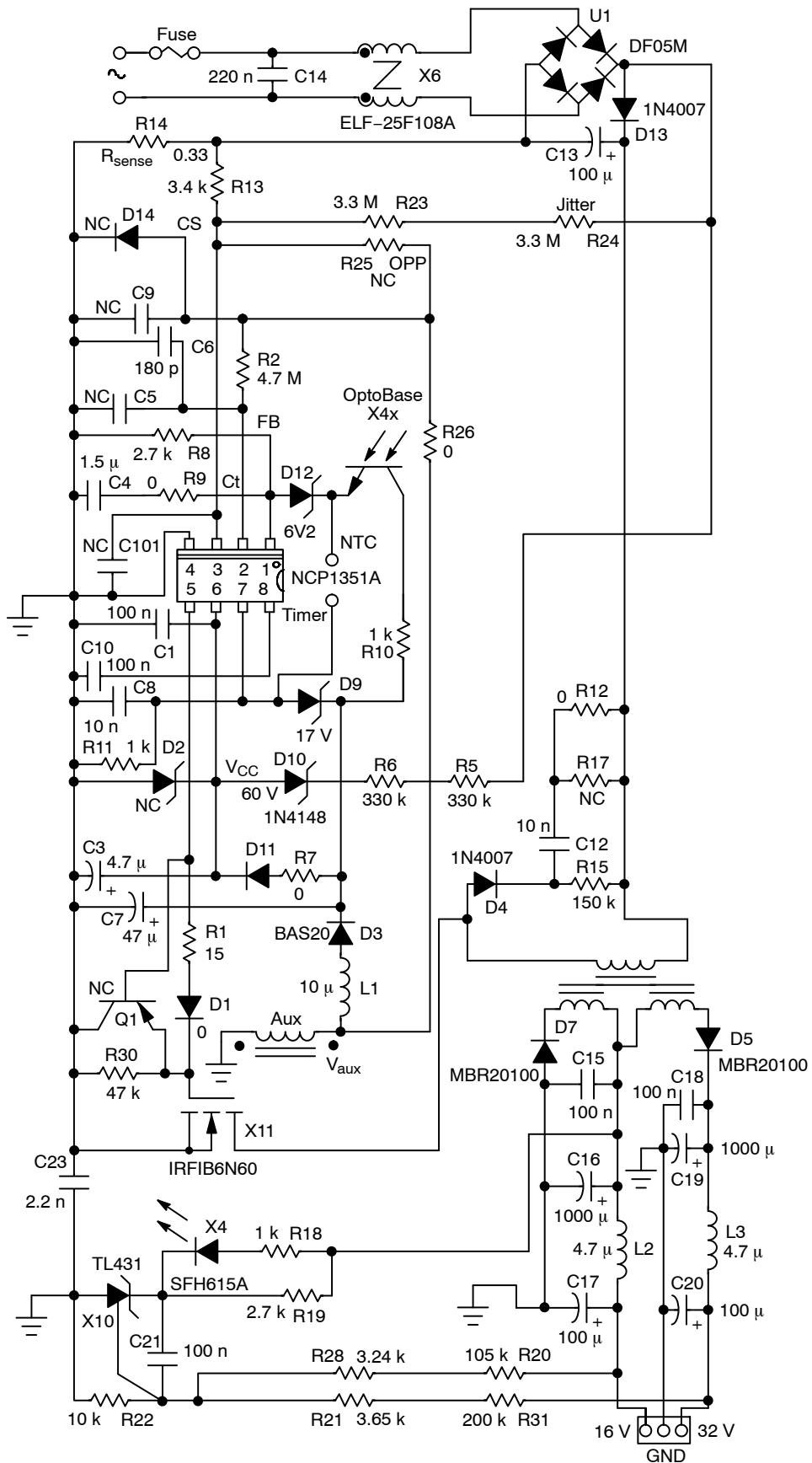


Figure 11. Schematic for the NCP1351 40 W Printer Evaluation Board

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Table 4. BILL OF MATERIAL FOR THE NCP1351 40 W PRINTER EVALUATION BOARD

Designator	Qty.	Description	Value	Tolerance	Footprint	Manufacturer	Manufacturer Part Number	Substitution Allowed	Lead Free
C1, C4, C15, C18, C21	5	SMD Capacitor	100 nF/50 V	5%	SOD-1206	Vishay	VJ1206Y104KXAA	Yes	Yes
C3	1	Electrolytic Capacitor	4.7 μ F/50 V	20%	Radial – OD 5 mm	Panasonic	ECEA1HN100U	Yes	Yes
C6	1	SMD Capacitor	180 pF/50 V	5%	SOD-1206	Vishay	VJ1206A181KXAA	Yes	Yes
C7	1	Electrolytic Capacitor	47 μ F/50 V	20%	Radial – OD 5 mm	Panasonic	ECA1HM470	Yes	Yes
C8	1	SMD Capacitor	10 nF/50 V	5%	SOD-1206	Vishay	VJ1206Y103KXAA	Yes	Yes
C10	1	SMD Capacitor	1.5 μ F	10%	SOD-1206	Murata	GRM31MR71C155K	Yes	Yes
C12	1	Film Capacitor	10 nF/630 V	5%	Radial	Epcos	B32521N8103J	Yes	Yes
C13	1	Electrolytic Capacitor	100 μ F/400 V	20%	Radial – OD 20 mm	United chemicon	EKXG401ELL101MMN3S	Yes	Yes
C14	1	X2 Capacitor	330 nF/250 Vac	20%	Radial	Epcos	B32923A2334M	Yes	Yes
C16	1	Electrolytic Capacitor	1,000 μ F/50 V	20%	Radial – OD 12.5 mm	Panasonic	ECA1HHG102	Yes	Yes
C17	1	Electrolytic Capacitor	100 μ F/50 V	20%	Radial – OD 10 mm	Panasonic	EEUEB1H101S	Yes	Yes
C19	1	Electrolytic Capacitor	1,000 μ F/25 V	20%	Radial – OD 12.5 mm	Panasonic	ECA1EHG102	Yes	Yes
C20	1	Electrolytic Capacitor	100 μ F/25 V	20%	Radial – OD 10 mm	Panasonic	EEUEB1E101	Yes	Yes
C23	1	Y1 Capacitor	2.2 nF/250 Vac	20%	Radial	TDK	CD12-E2GA222MYNS	Yes	Yes
D1	1	SMD Resistor	0 Ω /0.25 W	5%	SOD-1206	Vishay	CRCW12060000Z0EA	Yes	Yes
D3	1	High-voltage Switching Diode	200 mA/200 V	–	SOT-23	ON Semiconductor	BAS20LT1G	No	Yes
D4	1	Fast-recovery Rectifier	1 A/600 V	–	Axial	ON Semiconductor	1N4937G	No	Yes
D5, D7	2	Schottky Rectifier	20 A/100 V	–	TO-220	ON Semiconductor	MBR20100CTG	No	Yes
D9	1	Zener Diode	17 V/0.5 W	5%	SOD-123	ON Semiconductor	MMSZ5247BT1G	No	Yes
D10	1	Zener Diode	60 V/0.5 W	5%	SOD-123	ON Semiconductor	MMSZ5264BT1G	No	Yes
D11	1	Switching Diode	200 mA/75 V	–	SOD-123	ON Semiconductor	MMSD4148T1G	No	Yes
D12	1	Zener Diode	6.2 V/0.5 W	5%	SOD-123	ON Semiconductor	MMSZ5234BT1G	No	Yes
D13	1	Standard Rectifier	1 A/1,000 V	–	Axial	ON Semiconductor	1N4007G	No	Yes
HS1	1	Heatsink	13.4°C/W	–	Radial	Aavid Thermalloy	531002B02500G	Yes	Yes
HS2, HS3	2	TO-220 Heatsink	24°C/W	–	–	Aavid Thermalloy	577202B00000G	Yes	Yes
U1	1	Rectifier Bridge	1 A/600 V	–	DIP-4	Micro Commercial Co.	DB105-BP	No	Yes
U2	1	CMOS IC	–	–	SOIC-8	ON Semiconductor	NCP1351CDR2G	No	Yes
X4	1	Optocoupler	–	–	DIP-4	CEL-NEC	PS2501-1-H-A	No	Yes
X6	1	Common-mode Choke	2 \times 15 mH/1 A	–	Radial	Panasonic	ELF-25F108A	No	Yes
X10	1	Shunt Regulator	2.5–36 V	5%	TO-92	ON Semiconductor	TL431CLPG	No	Yes
X11	1	Power MOSFET N-Channel	3 A/600 V	–	TO-220	Rohm	2SK2792	No	Yes
T1	1	Transformer	–	–	Radial	Coilcraft	GA0007-AL	No	Yes
J1	1	Connector	230 Vac	–	Radial	Qualtek	771W-X2/02	Yes	Yes
F1	1	Fuse	2 A/250 Vac	T	Radial	Wickmann	37212000411	Yes	Yes
L1	1	SMD Inductor	10 μ H	–	SMD	Coilcraft	DO1605T-ML	No	Yes
L2, L3	2	Inductor	4.7 μ H/4.3 A	20%	Radial	API Delevan Inc.	4554-4R7M	Yes	Yes
R1	1	SMD Resistor	15 Ω /0.25 W	5%	SOD-1206	Vishay	CRCW120615R0JNEA	Yes	Yes

Table 4. BILL OF MATERIAL FOR THE NCP1351 40 W PRINTER EVALUATION BOARD (continued)

Designator	Qty.	Description	Value	Tolerance	Footprint	Manufacturer	Manufacturer Part Number	Substitution Allowed	Lead Free
R2	1	Resistor	4.7 MΩ/0.33 W	5%	Axial	–	–	Yes	Yes
R5, R6	2	SMD Resistor	330kΩ/0.25 W	1%	SOD-1206	Vishay	CRCW1206330RFKEA	Yes	Yes
R7	1	SMD Resistor	0 Ω/0.25 W	5%	SOD-1206	Vishay	CRCW12060000Z0EA	Yes	Yes
R8, R19	2	SMD Resistor	2.7 kΩ/0.25 W	5%	SOD-1206	Vishay	CRCW12062R70JNEA	Yes	Yes
R9, R12	2	SMD Resistor	0 Ω/0.25 W	5%	SOD-1206	Vishay	CRCW12060000Z0EA	Yes	Yes
R10, R11, R18	3	SMD Resistor	1 kΩ/0.25 W	5%	SOD-1206	Vishay	CRCW12061K00JNEA	Yes	Yes
R13	1	SMD Resistor	3.4 kΩ/0.25 W	1%	SOD-1206	Vishay	CRCW12063K40FKEA	Yes	Yes
R14	1	SMD Resistor	0.33 Ω/0.5 W	1%	SOD-1206	–	–	Yes	Yes
R15	1	Resistor	150 kΩ/2 W	5%	Axial	–	–	Yes	Yes
R20	1	SMD Resistor	100 kΩ/0.25 W	1%	SOD-1206	Vishay	CRCW1206100KFKEA	Yes	Yes
R21	1	SMD Resistor	56 kΩ/0.25 W	1%	SOD-1206	Vishay	CRCW120656K0FKEA	Yes	Yes
R22	1	SMD Resistor	10 kΩ/0.25 W	1%	SOD-1206	Vishay	CRCW120610K0FKEA	Yes	Yes
R23, R24	2	SMD Resistor	3.3 MΩ/0.25 W	5%	SOD-1206	Vishay	CRCW12063M30JNEA	Yes	Yes
R26	1	SMD Resistor	0 Ω/0.25 W	1%	SOD-1206	Vishay	CRCW12060000FKEA	Yes	Yes
R28	1	SMD Resistor	8.2 kΩ/0.25 W	1%	SOD-1206	Vishay	CRCW12068K20FKEA	Yes	Yes
R30	1	SMD Resistor	47 kΩ/0.25 W	1%	SOD-1206	Vishay	CRCW120647K0FKEA	Yes	Yes
R31	1	SMD Resistor	180 kΩ/0.25 W	1%	SOD-1206	Vishay	CRCW1206180KFKEA	Yes	Yes

TEST PROCEDURE

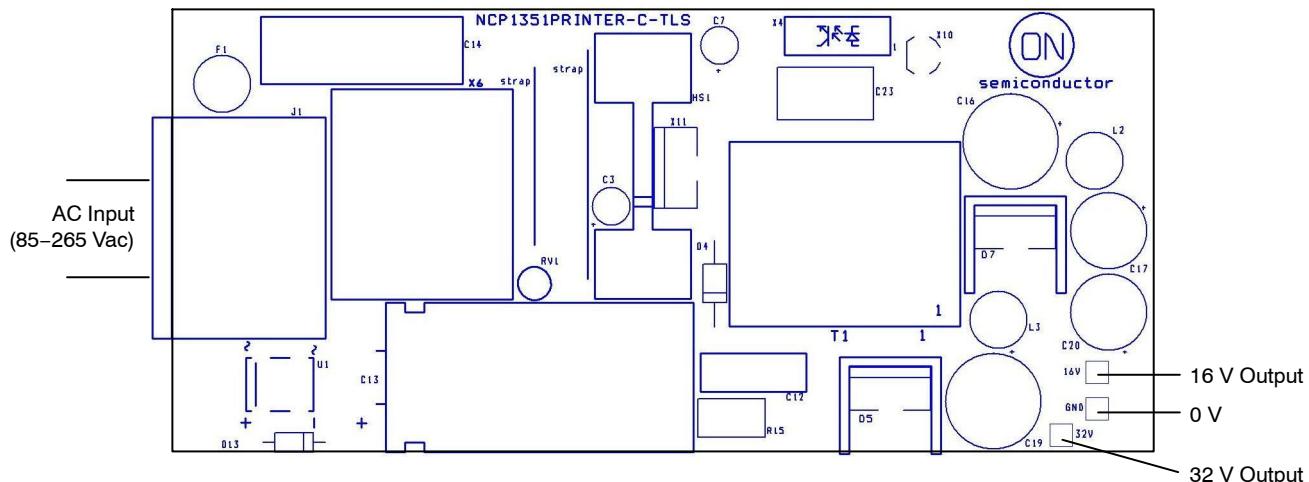


Figure 12. Test Procedure Schematic

WARNING: Be careful when manipulating the boards in operation, lethal voltages up to 600 V are present on the primary side. An isolation transformer is also recommended for safer manipulations.

Necessary Equipment

- 1 current limited 230 Vrms AC source (current limited to avoid board destruction in case of a defective part)
- 1 DC volt-meter able to measure up to 50 V DC
- 2 programmable electronic loads

Test Procedure

1. Apply 110 Vac on the Vin pins. Output pins are left floating.
2. Measure the output voltage between pins +16 V et GND and between +32 V and GND with a volt-meter on the 50 V range. The measurements should be respectively 16 and 32 volts ($\pm 10\%$).

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3. Connect an electronic load between pins +32 V and GND, and set up a current of 1 A. Connect another electronic load between pins +16 V and GND, and set up a current of 0.625 A. Measure the output voltages that should be respectively 16 and 32 volts ($\pm 10\%$).
4. Change the voltage applied on the Vin pins to 230 Vac. Measure the output voltages that should again be respectively 16 and 32 volts ($\pm 10\%$).
5. Change the current setpoint for the electronic load connected between pins +32 V and GND to 2.8 A.

The power supply should go to short-circuit protection. Measure the output voltages that should be 0 V.

6. Change the current setpoint for the electronic load connected between pins +32 V and GND back to 1 A. Turn off the AC voltage source. Wait 5 seconds. Apply it again, the outputs should rise again. Measure the output voltages that should again be respectively 16 and 32 volts ($\pm 10\%$).
7. If every step has gone well, the board is considered to be ok.

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