NCP1351 Evaluation Board 16 V / 32 V – 40 W Printer Power Supply

Prepared by: Nicolas Cyr
ON Semiconductor

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APPLICATION NOTE

The present document describes a printer power supply operated by the NCP1351, a fixed t_{on} / variable *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 μA 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).

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:

L_p = 270 μH

N_p:N_s = 1:0.2

N_p:N_{aux} = 1:0.2

I_{pk} = 3 A

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 1. 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.

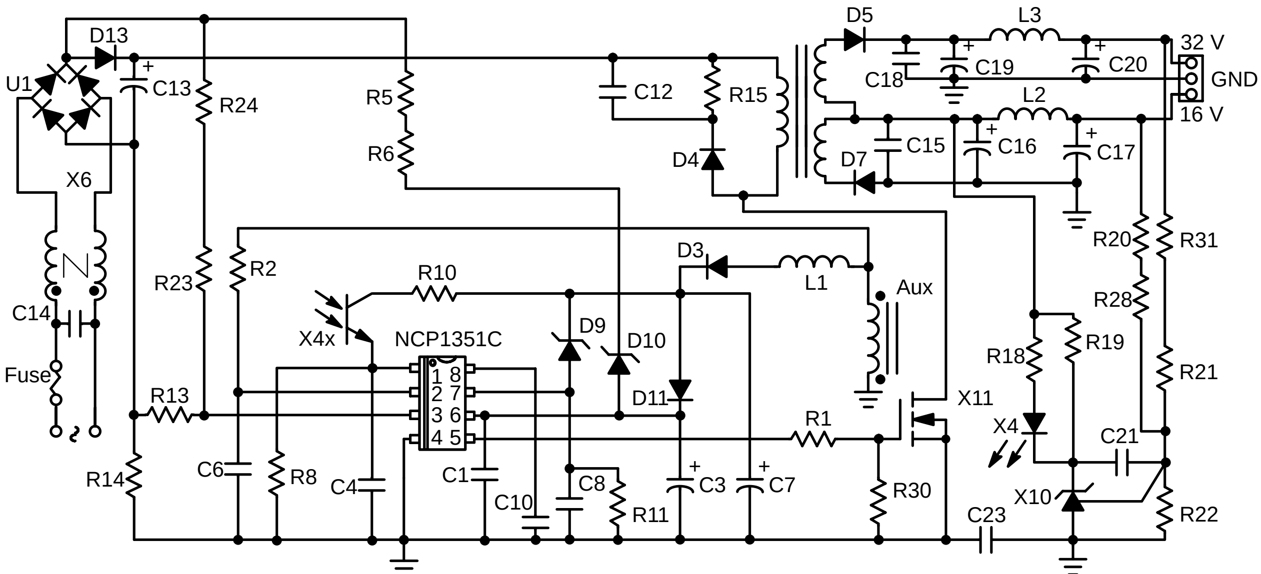

Figure 1. The Simplified 40 W Printer Board Featuring the NCP1351 Controller

Two 330 kΩ resistors in series with a 60 V zener diode ensure a clean start−up sequence with the 4.7 μF 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:

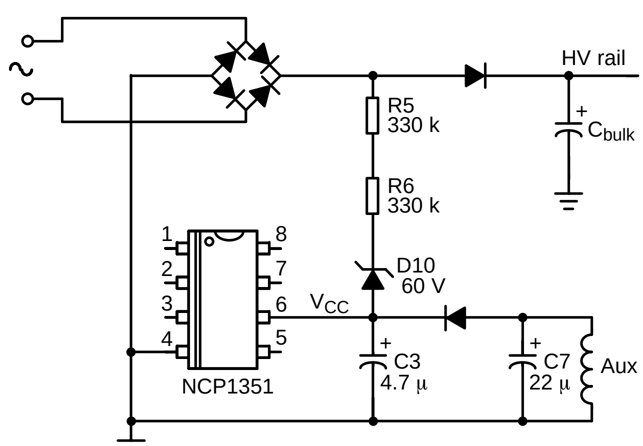

Figure 2. The split V_{CC} configuration helps to start−up in a small period of time (C3 to charge alone) but the addition of a second, larger capacitor (C7), ensures enough V_{CC} in standby.

The primary−side feedback current is fixed to roughly 300 μA 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 kΩ 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 μA, 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 2).

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 C10 must be 1.5 μF. 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 3). 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.

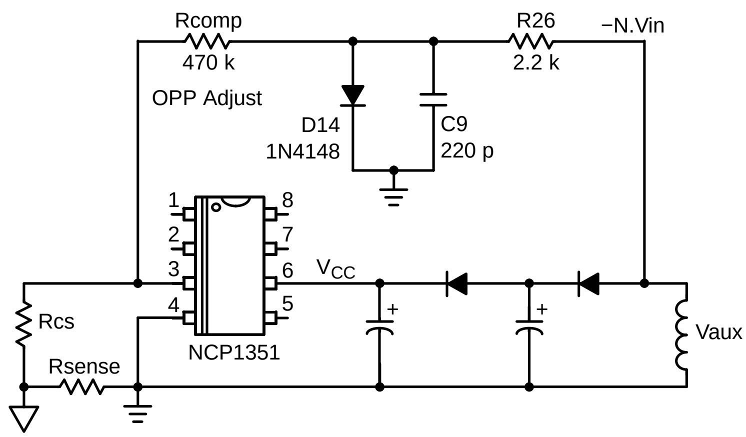

Figure 3. A Simple Arrangement Provides an Adjustable Overpower Power Compensation

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 μF 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 BVdss 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.

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%

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.

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.

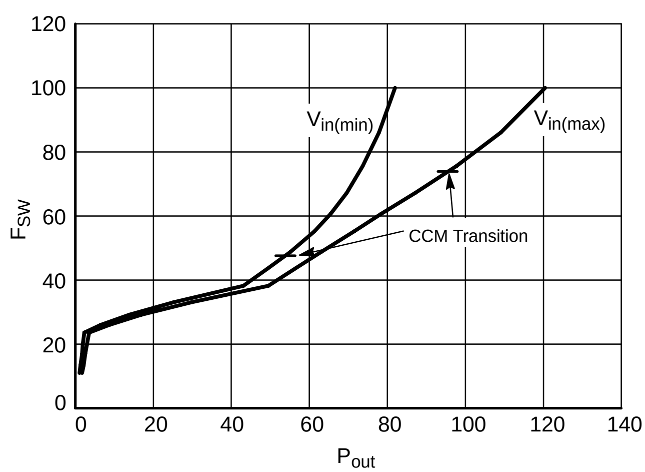

Figure 4. Switching Frequency Variations vs. Output Load

Scope Shots

Below are some oscilloscope shots gathered on the demoboard:

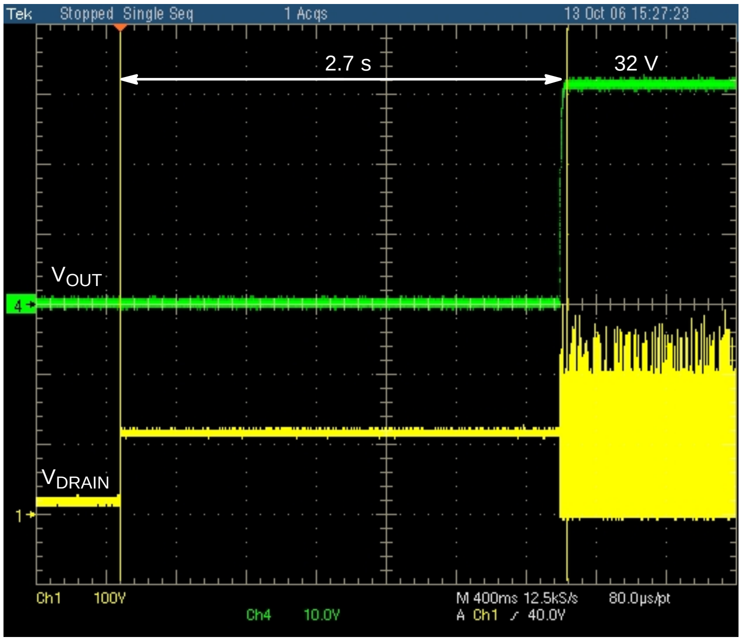

Figure 5. Startup Time, V_{IN} = 85 Vac

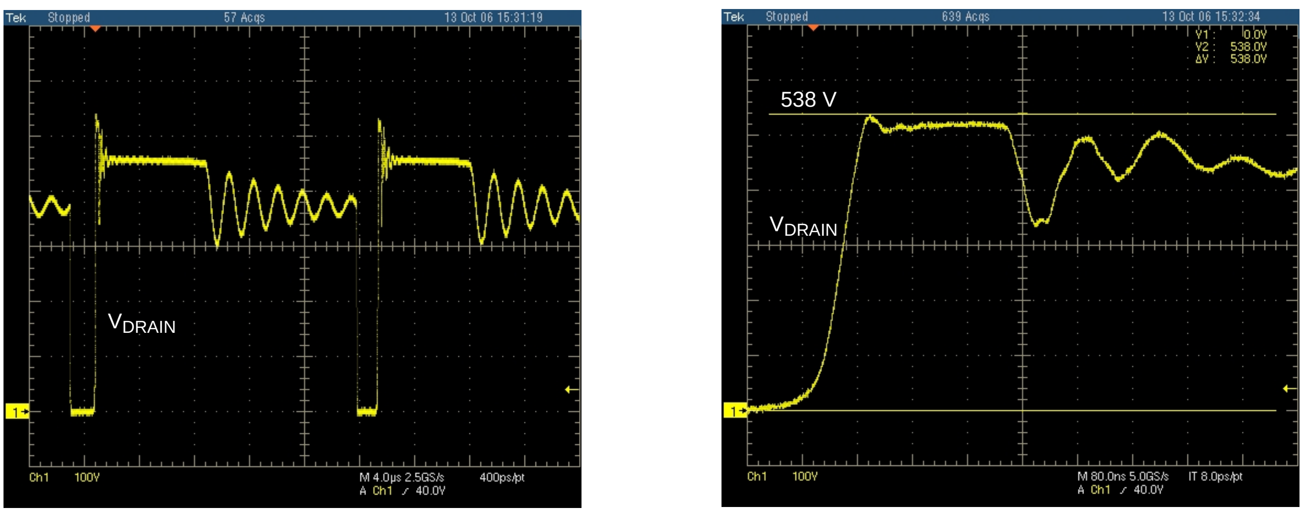

Figure 6. Maximum Output Power, V_{IN} = 265 Vac

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.

Bill of Materials

Designator	Qty	Description	Value	Tol.	Footprint
C1, C4, C15, C18, C21	5	SMD capacitor	100 nF / 50 V	5%	SMD 1206
C3	1	electrolytic capacitor	4.7 μF / 50 V	20%	radial
C5	0	SMD capacitor	−	5%	SMD 1206
C6	1	SMD capacitor	180 pF / 50 V	5%	SMD 1206
C7	1	electrolytic capacitor	47 μF / 50 V	20%	radial
C8	1	SMD capacitor	10 nF / 50 V	5%	SMD 1206
C9	0	SMD capacitor	−	5%	SMD 1206
C10	1	SMD capacitor	1.5 μF		SMD 1206
C12	1	Film capacitor	10 nF / 630 V	10%	radial
C13	1	electrolytic capacitor	100 μF / 400 V	20%	radial
C14	1	x2 capacitor	330 nF / 250 Vac	20%	radial
C16	1	electrolytic capacitor	1000 μF / 50 V	20%	radial
C17	1	electrolytic capacitor	100 μF / 50 V	20%	radial
C19	1	electrolytic capacitor	1000 μF / 25 V	20%	radial
C20	1	electrolytic capacitor	100 μF / 25 V	20%	radial
C23	1	y1 capacitor	2.2 nF / 250 Vac	20%	radial
C101	0	SMD capacitor	−	5%	SMD 1206
D1	1	SMD resistor	0 Ω / 0.25 W	5%	SMD 1206
D2	0	Zener diode	−	5%	SOD−123
D3	1	High−voltage switching diode BAS20	200 mA / 200 V	−	SOT−23
D4	1	Fast−recovery rectifier 1N4937	1 A / 600 V	−	axial
D5, D7	2	Schottky rectifier MBR20100CT	20 A / 100 V	−	TO−220
D9	1	Zener diode	17 V / 0.5 W	5%	SOD−123
D10	1	Zener diode	60 V / 0.5 W	5%	SOD−123
D11	1	Switching diode	200 mA / 75 V	−	SOD−123
D12	1	Zener diode	6.2 V / 0.5 W	5%	SOD−123
D13	1	Standard rectifier	1 A / 1000 V	−	axial
D14	0	Switching diode	−	−	SOD−123
HS1	1	Heatsink	6.2°C / W	−	radial
HS2, HS3	2	TO−220 heatsink	27°C / W	−	−
U1	1	Rectifier bridge DB105	1A / 600 V	−	DIP−4
U2	1	CMOS IC NCP1351A	−	−	SOIC−8
X4	1	Optocoupler SFH615	−	−	DIP−4
X6	1	Common−mode choke Panasonic ELF−25F108A	2 * 15 mH/ 1 A	−	radial
X10	1	shunt regulator TL431	2.5 – 36 V	5%	TO−92
X11	1	Power MOSFET N−Channel	3 A / 600 V	−	TO−220

Bill of Materials

Designator	Qty	Description	Value	Tol.	Footprint
Q1	0	PNP transistor	−	−	TO−92
T1	1	Transformer Coilcraft GA0007−AL	−	−	radial
J1	1	connector	230 Vac		radial
F1	1	Fuse	2 A / 250 Vac	T	radial
L1	1	SMD inductor Coilcraft	10 μH		SMD DO1605T
L2, L3	1	inductor	4.7 μH / 10 A	−	radial
R1	1	SMD resistor	15 Ω / 0.25 W	5%	SMD 1206
R2	1	resistor	4.7 MΩ / 0.33 W	5%	axial
R5, R6	2	SMD resistor	330 kΩ / 0.25 W	1%	SMD 1206
R7	1	SMD resistor	0 Ω / 0.25 W	5%	SMD 1206
R8, R19	2	SMD resistor	2.7 kΩ / 0.25 W	5%	SMD 1206
R9, R12	2	SMD resistor	0 Ω / 0.25 W	5%	SMD 1206
R10, R11, R18	3	SMD resistor	1 kΩ / 0.25 W	5%	SMD 1206
R13	1	SMD resistor	3.4 kΩ / 0.25 W	1%	SMD 1206
R14	1	SMD resistor	0.33 W / 0.5 W	1%	SMD 2010
R15	1	resistor	150 kΩ / 2 W	5%	axial
R16	0	SMD resistor	−	−	SMD 2010
R17	0	SMD resistor	−	−	SMD 1206
R20	1	SMD resistor	100 kΩ / 0.25 W	1%	SMD 1206
R21	1	SMD resistor	56 kΩ / 0.25 W	1%	SMD 1206
R22	1	SMD resistor	10 kΩ / 0.25 W	1%	SMD 1206
R23, R24	2	SMD resistor	3.3 MΩ / 0.25 W	5%	SMD 1206
R25	0	SMD resistor	−	1%	SMD 1206
R26	1	SMD resistor	0 Ω / 0.25 W	1%	SMD 1206
R28	1	SMD resistor	8.2 kΩ / 0.25 W	1%	SMD 1206
R30	1	SMD resistor	47 kΩ / 0.25 W	1%	SMD 1206
R31	1	SMD resistor	180 kΩ / 0.25 W	1%	SMD 1206
RV1	1	NTC	−	−	Radial

PCB Layout

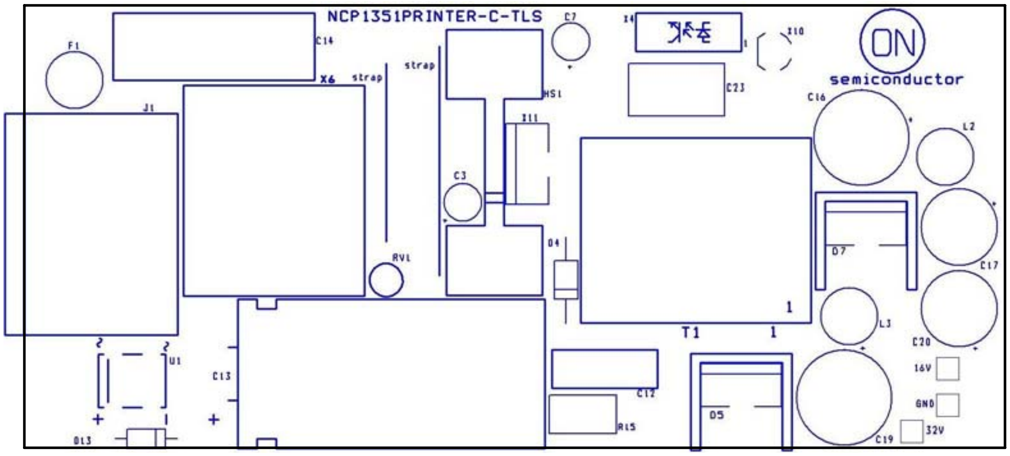

Figure 7. Top Side Components

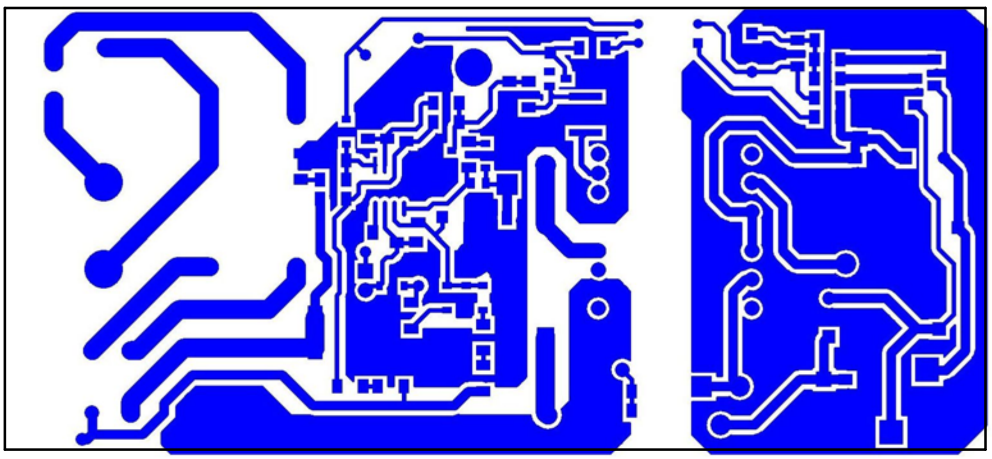

Figure 8. Copper Traces

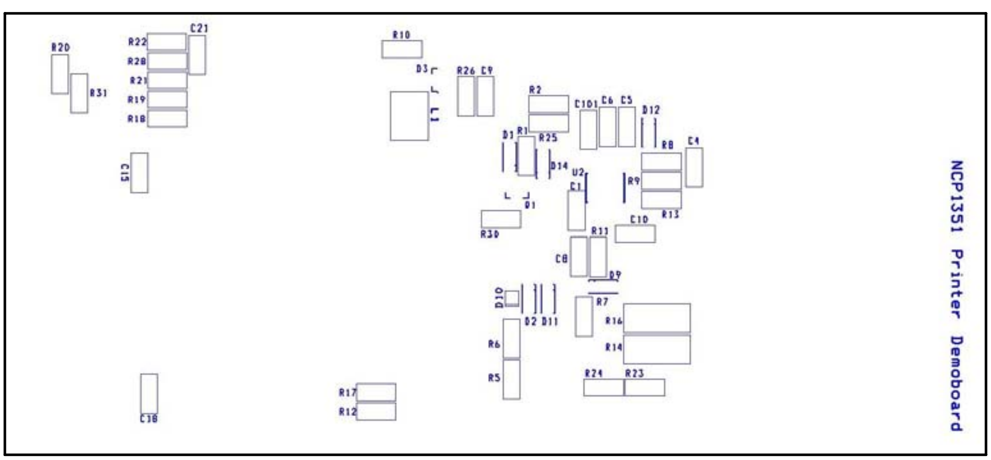

Figure 9. SMD Components

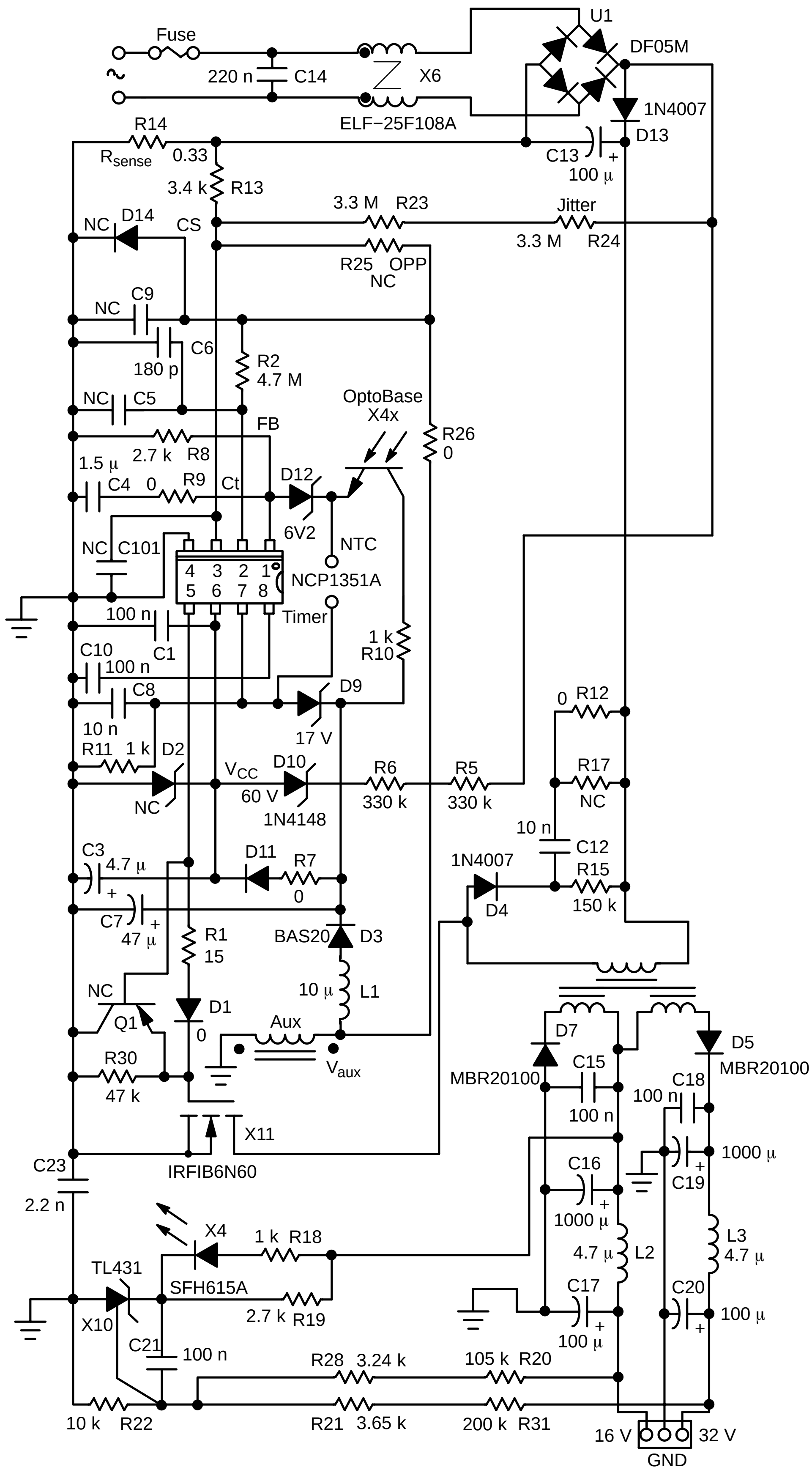

Figure 10. The 40 W Printer Board Featuring the NCP1351 Controller

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