AND8246/D

A 160 W CRT TV Power Supply using NCP1337

Prepared by: Nicolas Cyr
ON Semiconductor

ON Semiconductor®

http://onsemi.com

APPLICATION NOTE

Introduction

Valley switching converters, also known as quasi−resonant (QR) converters, allow designing flyback Switch−Mode Power Supplies (SMPS) with reduced Electro−Magnetic Interference (EMI) signature and improved efficiency. Thanks to the low level of generated noise, valley switching SMPS converters are therefore very well suited to applications dealing with RF and video signals, such as TVs.

ON Semiconductor NCP1337 is a powerful valley switching controller, which eases the design of an EMI−friendly TV power supply with only a few surrounding components. Moreover, very low standby power (less than 1 W) can be achieved without any noise.

Main Features of the Controller

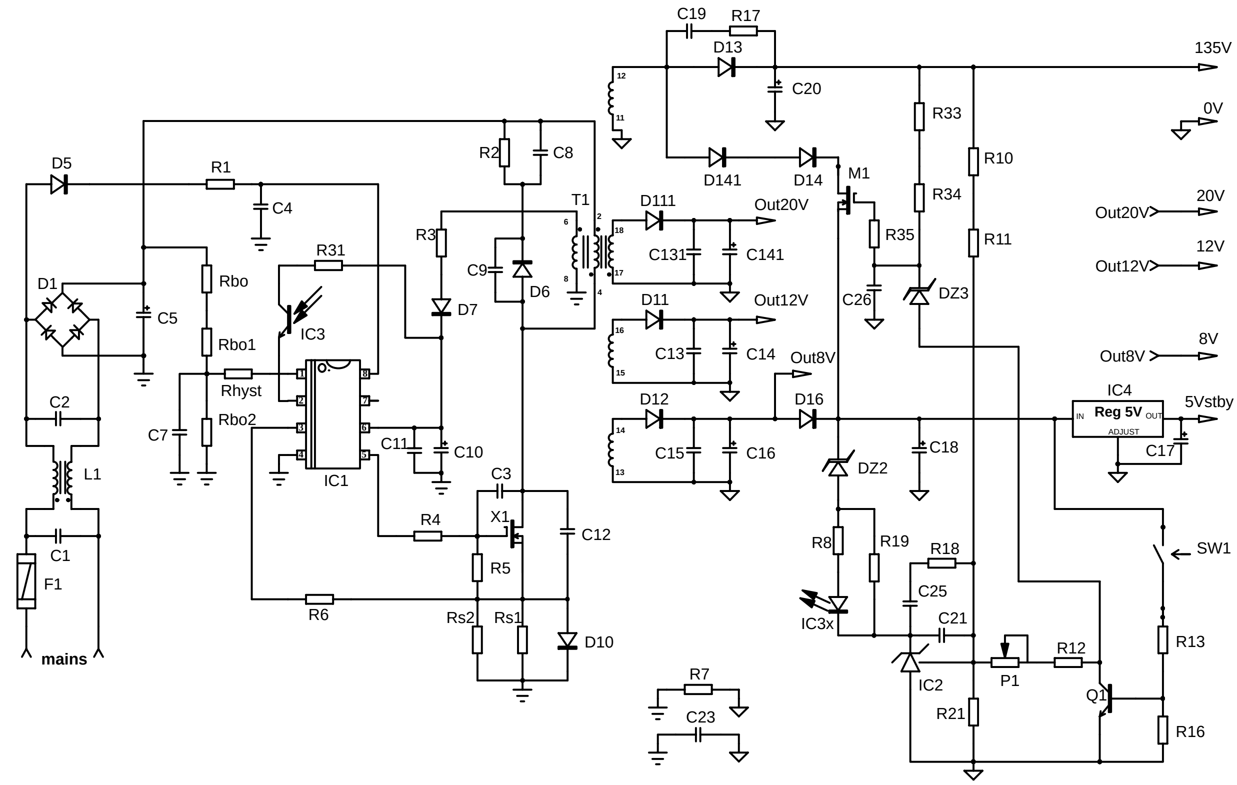
- Automatic Valley Switching
- Current−Mode
- Soft Ripple Mode with Minimum Switching Frequency for Noise−Free Standby
- Auto−Recovery Short−Circuit Protection Independent of Auxiliary Voltage
- Over Voltage Protection
- Brown−Out Protection
- 2 Externally Triggerable Fault Comparators (Auto−Recovery or Permanent Latch)
- Internal 5 ms Soft−Start
- 500 mA Peak Current Source/Sink Capability
- 130 kHz Max Frequency
- Internal Leading Edge Blanking
- Internal Temperature Shutdown
- Direct Optocoupler Connection
- Dynamic Self−Supply

A 160 W TV Power Supply Design

Power Supply Specification

Input Voltage	Universal input 90 Vac to 265 Vac
Output Power	160 W
Outputs	+135 V, 1 A max (135 W) regulated +20 V, 800 mA max (16 W) +12 V, 500 mA max (6 W) +8 V, 500 mA max (4 W) Standby output : +5 V, 100 mA derived from +8 V through a regulator
Protections	Short−circuit, over−power, over−voltage and brown−out
Standby Power	below 1 W

Schematic


C19
R17
D13
135V
C20
0V
R33
R10
R2
C8
D5
R1
D141
D14
M1
C4
T1
D111
Out20V
R34
20V
Out20V
R31
R3
C9
C131
C141
R35
R11
12V
Out12V
D1
Rbo
IC3
D6
D7
D11
Out12V
C26
DZ3
C5
Rbo1
C13
C14
Out8V
8V
Out8V
Rhyst
D12
D16
IC4
5Vstby
C2
Rbo2
Reg 5V
C7
C11
C10
C15
C16
C18
C17
L1
IC1
DZ2
C3
X1
R4
C12
R8
R19
R18
SW1
C1
R5
C25
F1
R6
Rs2
Rs1
D10
IC3x
C21
R13
R12
R7
IC2
P1
mains
Q1
C23
R21
R16

Design Steps

1. Reflected Voltage

Let us first start the design by selecting the amount of secondary voltage we want to reflect on the primary side, which will give us the primary to secondary turn ratio of the transformer. If we decide that we want to use a rather cheap and common 600 V MOSFET, we will select the turn ratio by:

$$V_{INmax} + N \cdot (V_{OUT} + V_F) < 600\ V$$

V_{INmax} is 375 V and ($V_{OUT} + V_F$) is about 135.5 V. If we decide to keep a 100 V safety margin, it gives N < 0.92. We will choose a turn ratio of N = 0.91, which will give a reflected voltage of 123 V.

2. Peak Current

Knowing the turn ratio, we can now calculate the peak primary current needed to supply the 75 W of output power. If we neglect the delay T_W between the zero of the current and the valley of the drain voltage, we can calculate I_{Pmax} by:

$$I_{Pmax} = 2 \cdot P_{OUT} \cdot \frac{V_{INmin} + N \cdot (V_{OUT} + V_F)}{\eta \cdot N \cdot V_{INmin} \cdot (V_{OUT} + V_F)}$$

V_{INmin} is 110 V and η is 85%. Plugging the other values gives us a maximum peak current of I_{Pmax} = 6.5 A. NCP1337 max current sense setpoint is 500 mV, so we should put a sense resistor R_S = 0.5 V / 6.5 A = 0.077 Ω. We will use two standard 0.15 Ω resistors in parallel, that will allow I_{Pmax} = 6.67 A.

3. Primary Inductance

To calculate the primary inductance L_P, we need to decide the switching frequency range in which we allow the controller to operate. There are two constraints: at low line, maximum power, the switching frequency should be above the audible range (higher than 20 kHz). At high line, 50% nominal power, the switching period should be higher than 7.5 μs, to prevent the controller from jumping between valleys (because these discrete jumps between 2 valleys can generate noise in the transformer as well). If we still neglect T_W, L_P is then given by:

$$L_P \le \frac{1}{2 \cdot F_{SWmin} \cdot P_{OUTmax}\left(\frac{V_{INmin} + N \cdot (V_{OUT} + V_F)}{\eta \cdot N \cdot V_{INmin} \cdot (V_{OUT} + V_F)}\right)^2}$$

If we choose 20 kHz min for 160 W of output power at 110 Vdc, we obtain: $L_P \le 380\ \mu H$.

To take tolerances into account, we can choose L_P = 330 μH, and verify if it satisfies the second condition:

For 80 W output power at 375 Vdc, T_{SW} = 9 μs, i.e. F_{SW} = 112 kHz.

4. Clamp

We can calculate the overvoltage due to the leakage inductance: $V_{OV_{LEAK}} = I_P \sqrt{\frac{L_{LEAK}}{C_{TOT}}}$.

At this time we don't know the value of L_{LEAK}, but we can choose a value of 3% of the primary inductance (i.e. 10 μH), which would not be too far from the final value. Considering 330 pF on the drain, at 375 V input voltage and 160 W of output power, which gives I_P = 4.2 A, we obtain: $V_{OV_{LEAK}} = 730\ V$.

But we only have 100 V available before reaching the MOSFET breakdown voltage. So we will need to add a clamp to limit the spike at turn−off.

Please refer to application note AN1679 (available at www.onsemi.com) to calculate this clamp. You can also use a SPICE simulator to test the right values for the components.

We chose to use an RCD clamp, using a 1N4937 diode, a 47 kΩ resistor and a 10 nF capacitor: it is an aggressive design (the maximum drain voltage will be very close to the maximum voltage allowable for the MOSFET), but it gives enough protection without degrading the efficiency too much.

5. Brown−Out Protection

We want the power supply to turn on at 90 Vac, and turn off at 70 Vac.

Start−up level is directly given by the resistor divider connected between high input voltage and BO pin, knowing that the threshold of the internal comparator is 500 mV. 90 Vac means 127 Vdc, so the ratio of the divider must be 254.

Once the controller has started, an internal 10 μA current source is activated and flows out of BO pin, creating hysteresis. 70 Vac means 99 Vdc, so we want a 28 V hysteresis, corresponding to 22% of the start−up level. The corresponding threshold for the comparator is 390 mV, so the 10 μA current must create an offset of 110 mV across the equivalent resistance of the resistor divider.

Those 2 conditions lead to 2 equations:

$$\frac{R_{BOhigh} + R_{BOlow}}{R_{BOlow}} = 254$$

and

$$\frac{R_{BOhigh} \cdot R_{BOlow}}{R_{BOhigh} + R_{BOlow}} \cdot 10^{-5} = 0.11$$

Solving these equations gives R_{BOhigh} = 2.8 MΩ and R_{BOlow} = 11 kΩ.

But in reality there will be a non−negligible ripple on the DC input voltage, and the hysteresis should be increased in order to obtain the desired turn−on and turn−off levels.

Final value for R_{BOlow} is 15k (R_{BO2} in schematic), and 3.9 MΩ for R_{BOhigh} (split in R_{BO} = 2.7 MΩ and R_{BO1} = 1.2 MΩ to sustain the high voltage).

A capacitor C7 is added between BO pin and ground to filter any noise, and to ensure a DC voltage. This capacitor value should be small enough, otherwise it may introduce a delay between input voltage collapsing and Power supply turn−off (a 10 nF ceramic capacitor gives good results).

6. Overpower Protection

We have seen that full load maximum peak current at low input voltage is 6.5 A, but only 4.2 A at high input voltage. We need to create an offset on the current sense signal. As 500 mV on CS pin corresponds to 6.67 A, 2.3 A corresponds to a 172 mV offset. At 375 Vdc input voltage, BO voltage is 1.55 mV: as a result a 73.5 μA current flows out of CS pin during ON time. To create the desired 172 mV offset, it is necessary to insert a 2.34 kΩ resistor R6 in series. We choose a standard 2.2 kΩ value.

7. Standby

In order to reduce as much as possible the power wasted during standby mode, NCP1337 enters an efficient and quiet soft−skip mode. But because of the high output voltage of 135 V, any leakage current will create a significant output power, preventing the power supply to reach the requirement of less than 1 W standby power. This demonstration board thus includes a simple patented circuit that allows collapsing all unused outputs, while still powering the 5 V standby rail. This circuit is made of a regulated rectifier (around M1) connected between the high voltage output winding and the input of the 5 V linear regulator IC4, and of a switch (Q1) that changes the regulation setpoint. DZ2 is added to prevent voltage drops during transition from normal to standby mode.

If the leakage current on the 135 V output is extremely low, this circuit can be omitted (see appendix schematic A).

8. Controller Supply

NCP1337 includes a DSS able to supply the controller without the help of any auxiliary supply. However this is possible only if the gate current is low, i.e. during standby in our case. So an auxiliary winding is necessary to supply the controller during normal mode, but DSS can be activated in standby, for instance in the case all voltages are decreased by the circuit described above. In order to minimize the power consumption of the DSS, HV pin can be connected to the half−wave rectified input voltage instead of the full−wave rectified bulk voltage.

To further decrease the power consumed by the controller during standby, it may be interesting to prevent the DSS to turn on: this can be achieved by inverting the coupling of the auxiliary winding (see appendix schematic B). By creating the auxiliary supply from a forward winding instead of a flyback winding, it is possible to ensure a sufficient supply voltage even in standby mode with all voltages reduced. V_{CC} voltage must then be clamped to protect the controller when the input voltage is high: as a result overvoltage protection on V_{CC} pin is lost.

Static Measurements

Brown−Out Protection

- Input voltage turn−ON level: 95 Vac
- Input voltage turn−OFF level: 80 Vac

Efficiency

- At 230 Vac, 148 W IN for 135 W OUT → 91%
- At 110 Vac, 154 W IN for 135 W OUT → 87%

Standby Power

- Noise−free
- All outputs are low (135 V output is 12.7 V), except 5 V standby output which is maintained. I_{OUT} consumption is taken on 5 V standby output. Controller is powered thanks to the Dynamic Self−Supply (DSS).

I_{OUT} / V_{IN}	0	10	20	30	40
230 Vac	390 mW	600 mW	780 mW	980 mW	1.18 W
110 Vac	230 mW	460 mW	700 mW	860 mW	975 mW

- All outputs are low (135 V output is 12.7 V), except 5 V standby output which is maintained. I_{OUT} consumption is taken on 5 V standby output. Controller is powered thanks to a forward−coupled auxiliary winding.

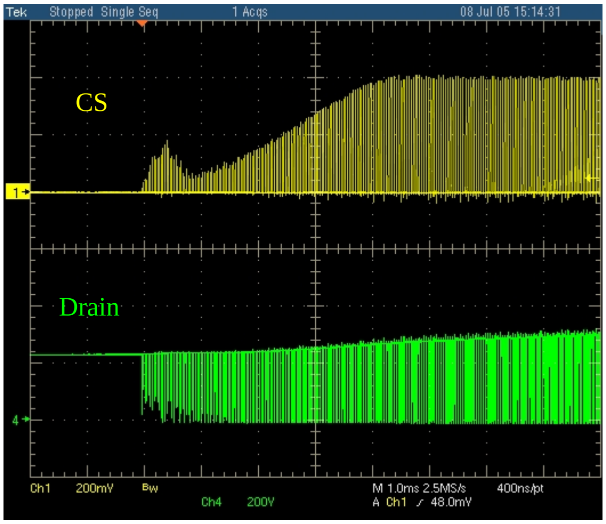
I_{OUT} / V_{IN}	0	10	20	30	40
230 Vac	340 mW	470 mW	580 mW	730 mW	900 mW
110 Vac	140 mW	350 mW	540 mW	700 mW	820 mW

- All outputs are at their nominal values. I_{OUT} consumption is taken on 5 V standby output. Controller is powered thanks to the auxiliary winding.

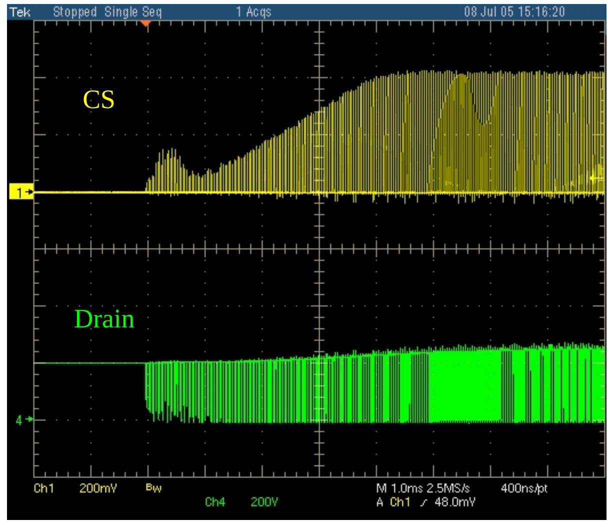
I_{OUT} / V_{IN}	0	10	20	30	40
230 Vac	260 mW	380 mW	620 mW	740 mW	880 mW
110 Vac	180 mW	280 mW	400 mW	540 mW	690 mW

Static Measurements

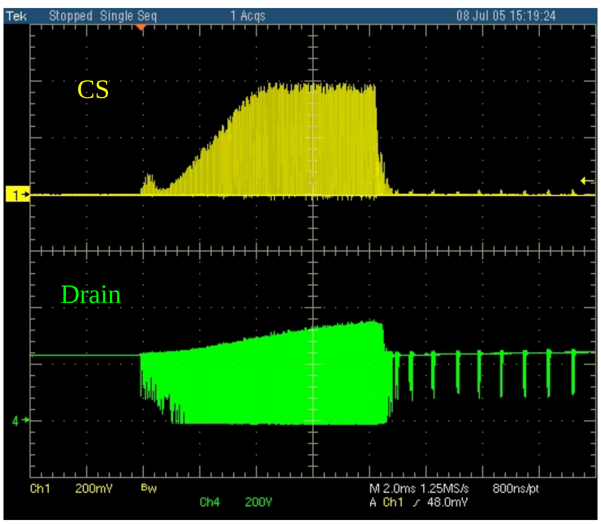
Soft−Start



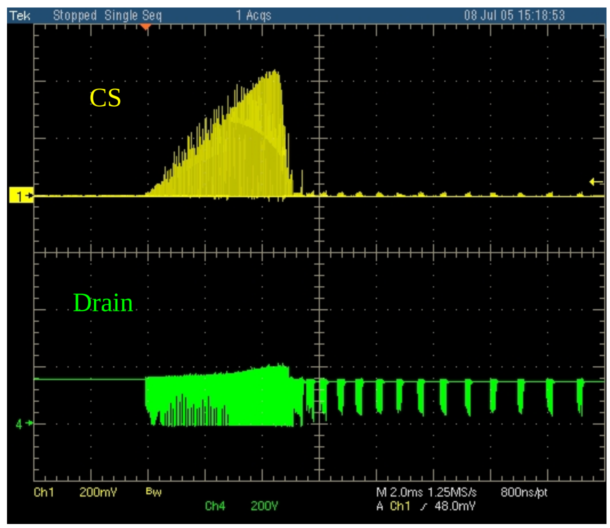
At 230 Vac, full load



At 110 Vac, no load

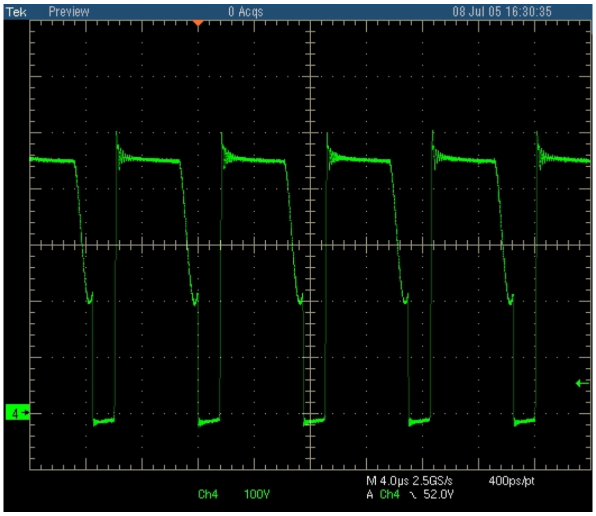


At 230 Vac, no load

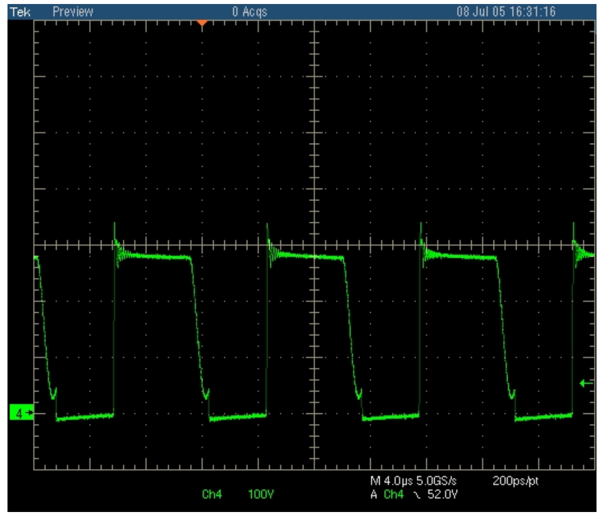


At 110 Vac, no load

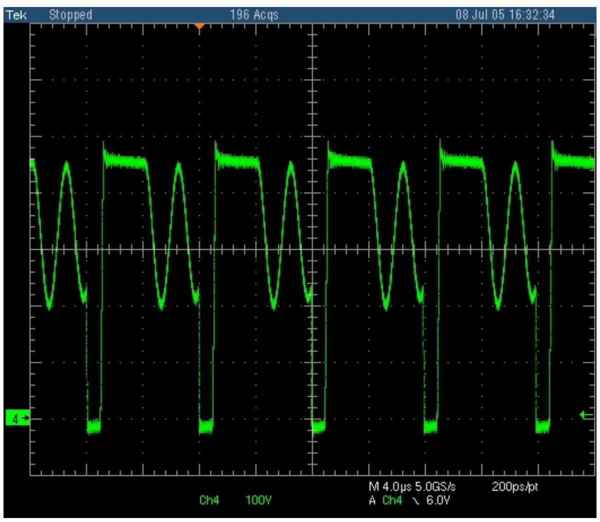
Valley Switching



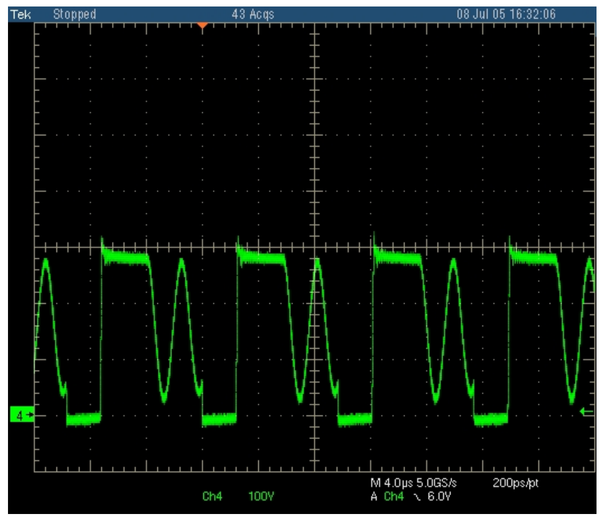
At 230 Vac, full load



At 110 Vac, full load

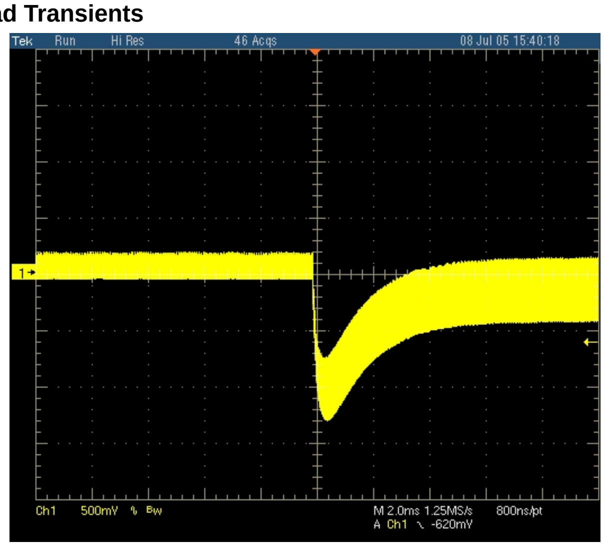


At 230 Vac, half load

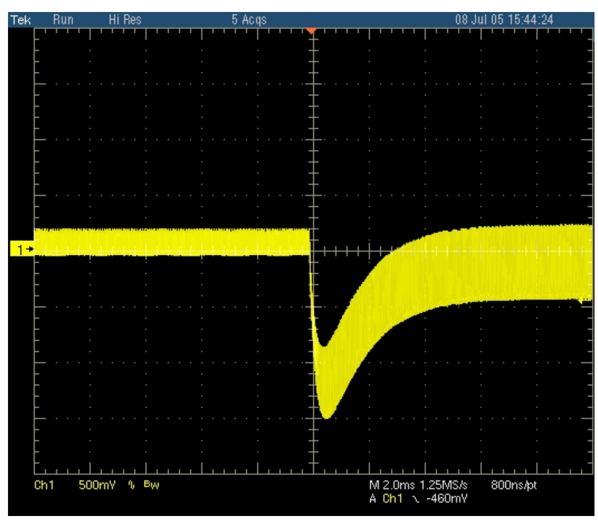


At 110 Vac, half load

Load Transients

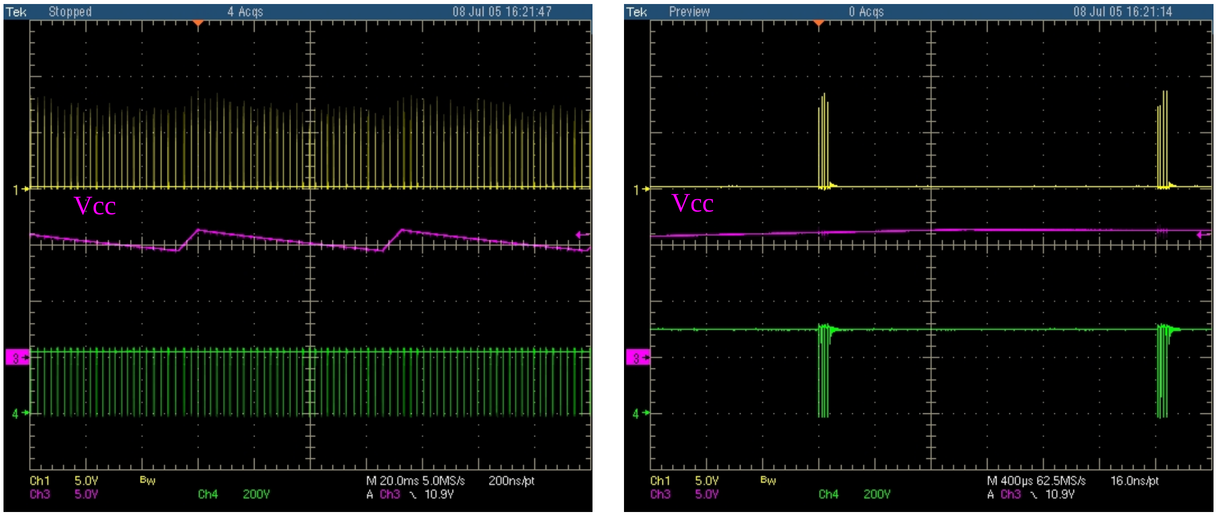


At 230 Vac, 20% to 80% load on 135 V output

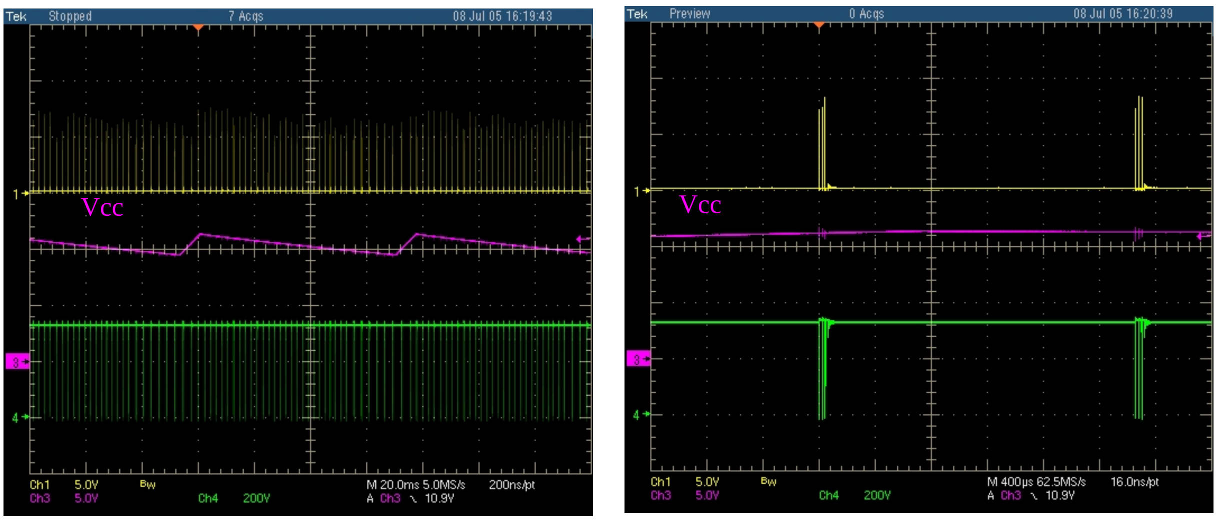


At 110 Vac, 20% to 80% load on 135 V output

Standby

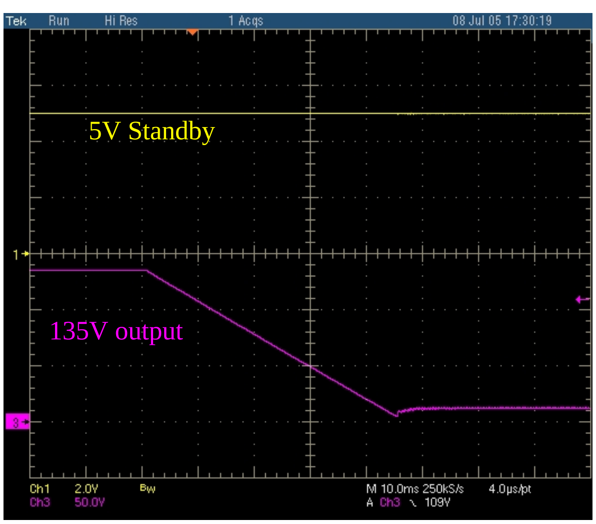


Standby burst at 110 Vac

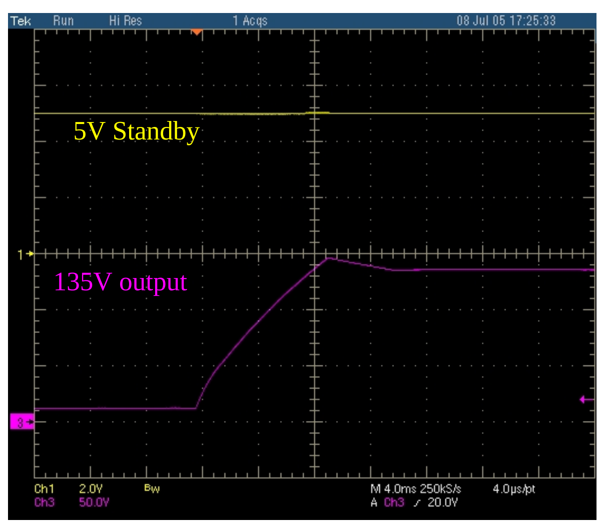


Standby burst at 230 Vac

Transitions Between Modes

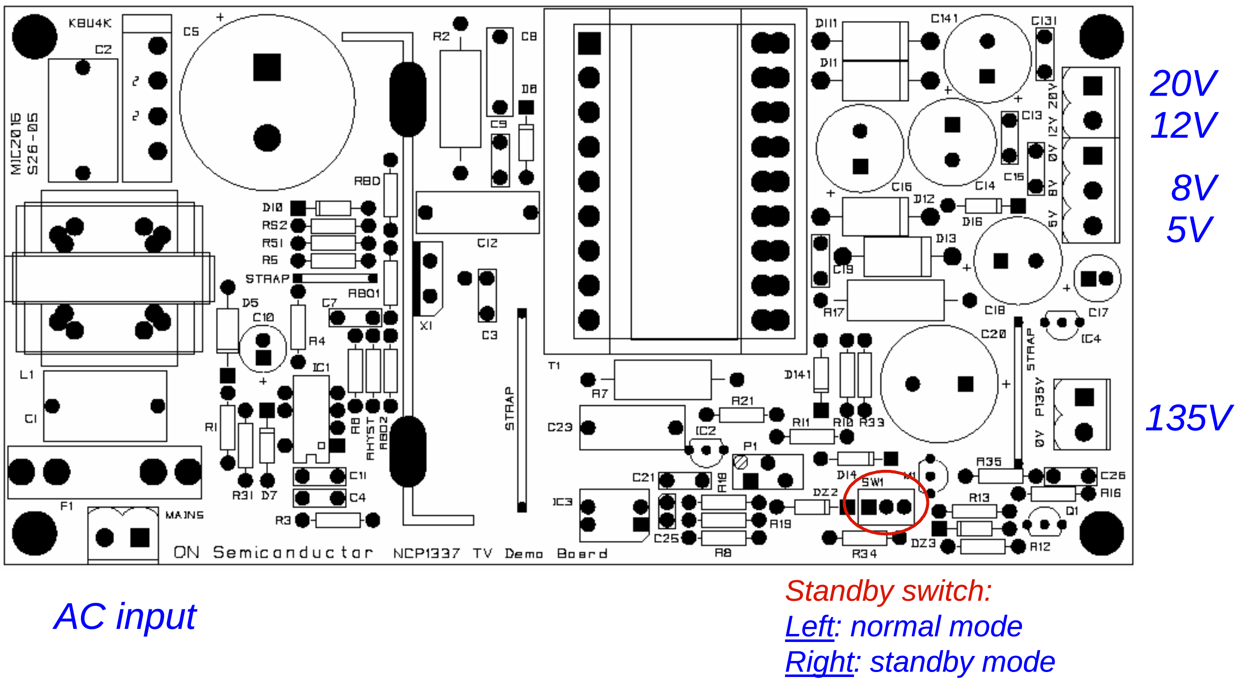


Normal to Standby Transition



Standby to Normal Transition

Board Layout

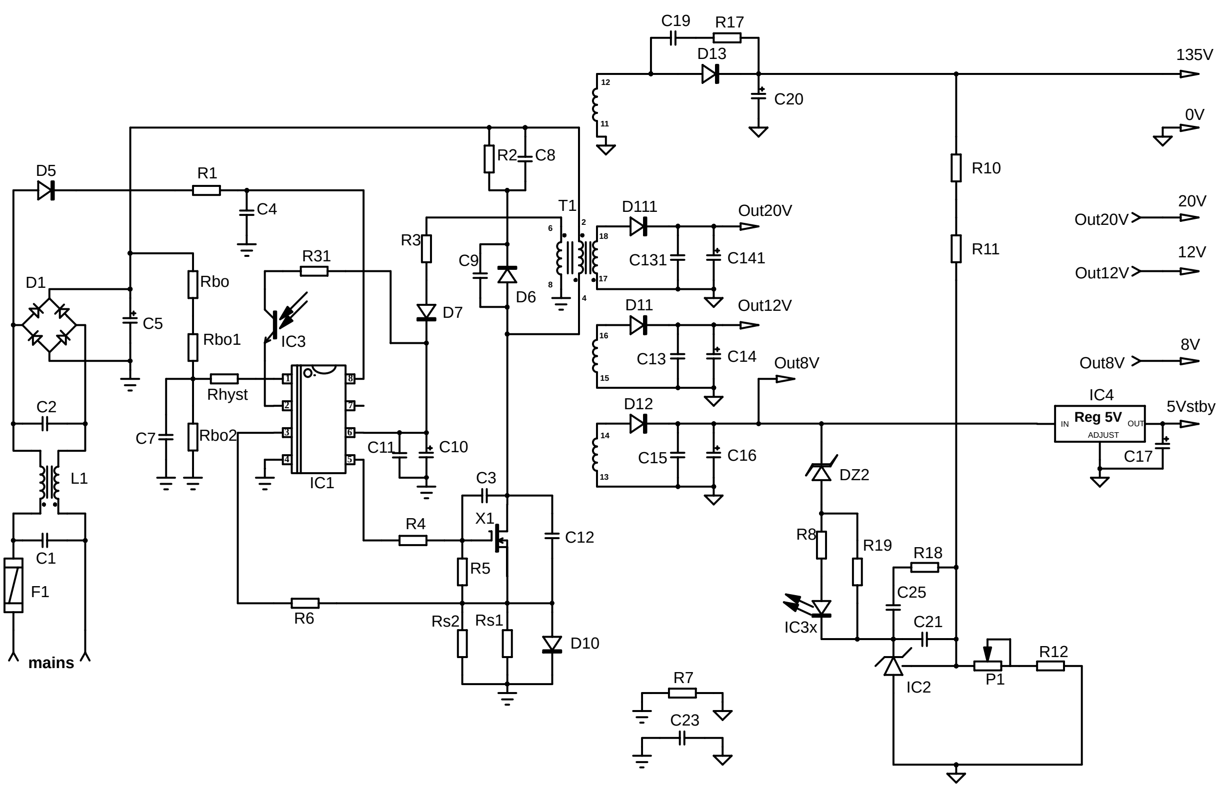


Bill of Material

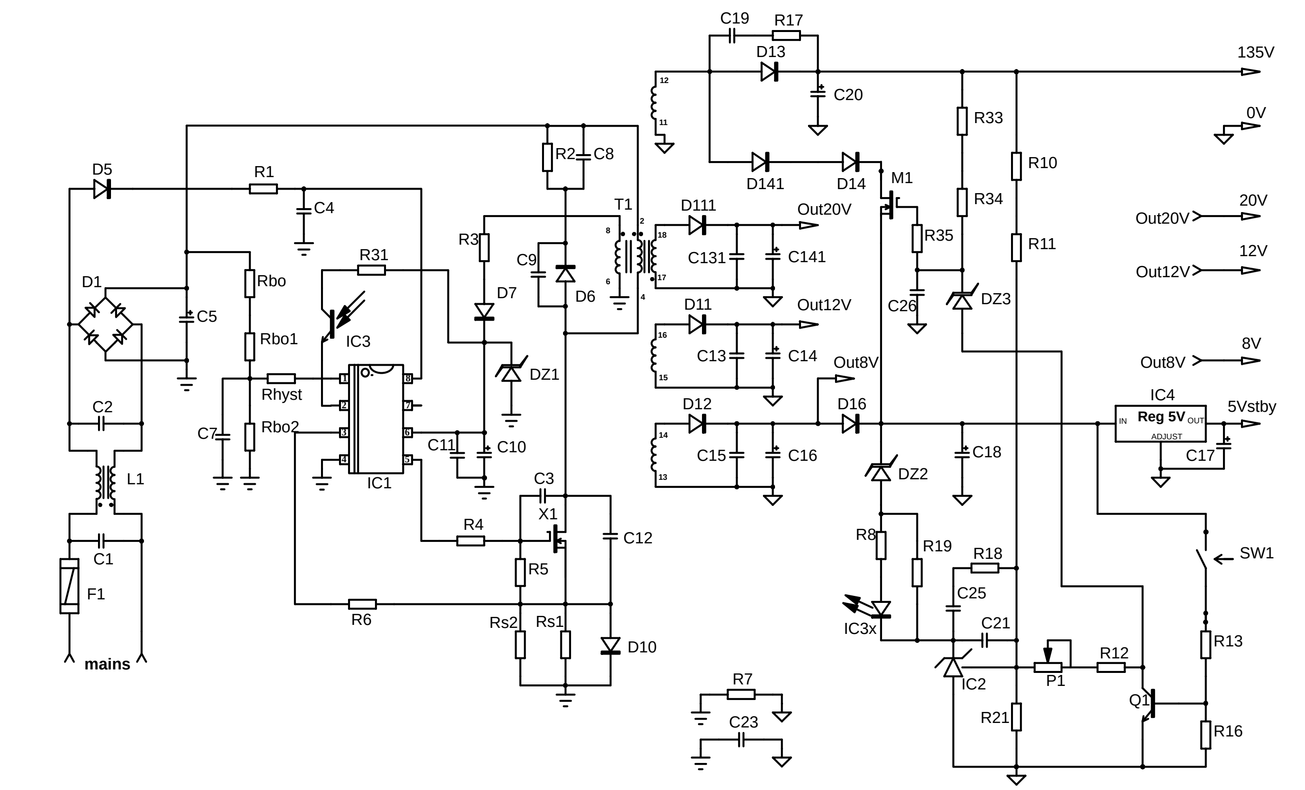
IC1	NCP1337	R7	10Meg−4kV
IC2	TL431	R8	330
IC3	SFH615A	R10	150k
IC4	MC78L05	R11	120k
X1	IRFIB6N60A	R12	5.6k
M1	BS108	R13, R16	100k
Q1	BC547	R17	–
T1	TDK SRW42/15EC−X21V017, CLICK BCK4201−304	R18, R31	18k
L1	OREGA 47283900 RM4	R19	1.5k
F1	2A 250V	R33,R34	47k
D1	KBU4K	P1	1k
D5, D10, D14, D16, D141	1N4007	C1, C2	330p −300Vac −X2
D6	1N4937	C3	10p −2kV
D7	1N4148	C4	–
D11, D12, D111	MUR420	C5	220u −450V
D13	MUR460	C7	1u −63V
DZ2	3V9	C8	10n −630V
DZ3	6V2	C9	–
R1, R35	1k	C10	33u −25V
R2	47k −2W	C11, C13, C15, C25, C131	100n
Rbo	2.7Meg	C12	330p −1.5kV
Rbo1	1.2Meg	C14, C16, C141	1000u −35V
Rbo2	15k	C17	100u −25V
Rhyst	–	C18	1000u −16V
R3	47	C20	100u −200V
R4	15	C21	1n
R5, R21	33k	C23	2.2n −Y1
Rs1, Rs2	0.15	C26	470n
R6	2.2k		

Board Picture

Appendix Schematic A



Appendix Schematic B



PUBLICATION ORDERING INFORMATION

LITERATURE FULFILLMENT:
Literature Distribution Center for ON Semiconductor
P.O. Box 61312, Phoenix, Arizona 85082−1312 USA
Phone: 480−829−7710 or 800−344−3860 Toll Free USA/Canada
Fax: 480−829−7709 or 800−344−3867 Toll Free USA/Canada
Email: orderlit@onsemi.com

N. American Technical Support: 800−282−9855 Toll Free USA/Canada

Japan: ON Semiconductor, Japan Customer Focus Center
2−9−1 Kamimeguro, Meguro−ku, Tokyo, Japan 153−0051
Phone: 81−3−5773−3850

ON Semiconductor Website: http://onsemi.com

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

For additional information, please contact your local Sales Representative.