Application Report
SLVA161 - June 2004

126-Watt SMPS for TAS511x Applications

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ABSTRACT

The switch-mode power supply (SMPS) featured in this application report is designed for 5.1 bridge-tied load (BTL) digital audio amplifiers using the TAS3103/TAS5111 and TAS5026, with up to 50 W/channel. There are actually two sepatate power supplies on the board, one working at 72 kHz to power the discrete amplifiers and the other working at 60 Khz to power the integrated PWM and switching controller section. The board operates from an ac input voltage of 110 Vac or 220 Vac, chosen by operating a voltage selector switch. The controllers for both power supplies operate using flyback topology. During conditions of no load or low power output, this supply uses a switch-skipping process to reduce power consumption, thereby increasing overall efficiency.

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1 Introduction

1.1 Flyback Topology

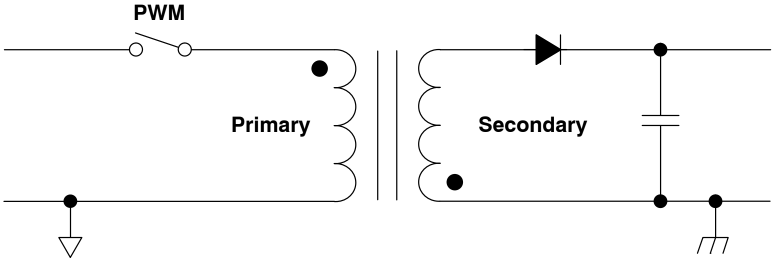


Figure 1. Flyback Transformer

The primary and secondary windings of the first converter transformer have opposite polarities. When the switch is closed, primary current increases, but during this time the output rectifer is reverse−biased and no secondary current flows. When the switch opens, the secondary voltage reverses. The energy stored in the transformer core (or gap) is released, and current flows through the diode to the output. The secondary voltage relative to the primary voltage is in direct proportion to the turns ratio of the transformer. The use of a transformer provides line isolation and allows the designer to select the turns ratio to optimize the duty cycle or switching frequency and to minimize peak primary current.

The flyback topology is amenable to multiple outputs by including additional secondaries with the appropriate turns ratios. The dynamic cross−regulation between these multiple outputs is theoretically good. However, leakage inductance between the secondaries can severely impair the cross-regulation, and considerable care must be applied to the design of the transformer in this respect.

The single-ended flyback circuit is popular at low power levels because of its simplicity and low cost. Its big disadvantage in the discontinuous operating mode is the high peak current in the switch and in the output capacitor, which can overload these components. The continuous mode reduces the peak current almost in half, but brings in other problems, compensation methods, and poor transient response. Many application designers use the flyback technique up to 150–250 W.

1.2 Transformer Design

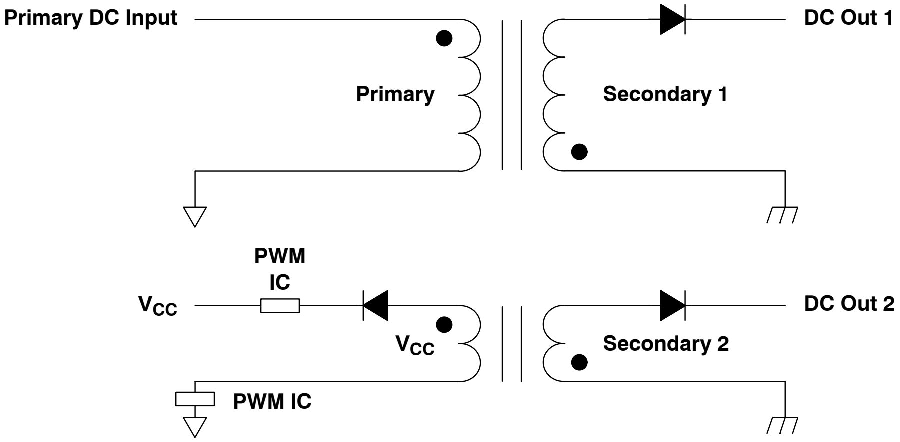


Figure 2. Flyback Schematic Diagram

The normal design method for calculating flyback–transformer turn ratios in the case of 110-Vac to 220-Vac input is as follows. The first step is to determine the total output wattage (total output voltage × current). Second, estimate the input ac line voltage regulation and voltage drop due to resistance in the etch pattern, connector terminals, etc.

Total output: *a* W = (output voltage × output current)

AC input voltage: The input line voltage tolerance is 220 Vac ±20%. The minimum input to the board is therefore 220 Vac –20% = 176 Vac. Allowing another 10% voltage drop (worst case) due to resistance in connectors and pattern etch yields 176 Vac –10% ≈ 158 Vac.

Main transformer input voltage (B+): The rectifier diode voltage drop for a half-wave bridge is –0.8 V and for a full-wave bridge is –1.6 V. The calculation also must account for the primary capacitor ripple factor, *b* Vp–p.

$$\text{B+} = (158\ \text{Vac} \times \sqrt{2}) - 2.6\ \text{V} - b\ \text{Vp–p}.$$

Switching frequency and maximum on-time: For a switching frequency *c* kHz and maximum on-duty *d*%,

$$t = \frac{1}{c\ \text{kHz}}\ \text{maximum on–time, and}$$

$$\frac{1}{c\ \text{kHz}} \times d\%\ \text{(on–time duty)} = e\ \text{maximum duty.}$$

$$\text{Energy input current: For a maximum efficiency } f\,\% = \left(\frac{\text{P}_{out}\ \text{(total power output)}}{\text{P}_{in}\ \text{(total power input)}}\right),$$

$$\text{the total power input } \text{P}_{in} = \frac{\text{P}_{out}\ \text{(total power output)}}{\text{Efficiency } f\,\%},$$

$$\text{The average current can now be calculated: } \text{I}_{avg} = \frac{\text{P}_{in}}{\text{B+ min}}.$$

$$\text{Maximum input current, } \text{I}_{peak} = \frac{2 \times \text{I}_{avg}}{e\ \text{maximum duty}}.$$

Then, we can get the primary inductance value

$$L_p = \frac{\text{B+ min (min primary input voltage)} \times e\ \text{max sec/cycle (maximum duty)}}{I_{max}\ \text{(max current)} \times c\ \text{kHz (switching frequency)}}$$

and the switching-off-time flyback voltage

$$V_{fb} = \text{B+ min (min primary input voltage)}\ \frac{e\ \text{max sec/cycle (maximum duty)}}{1 - e\ \text{max sec/cycle (maximum duty)}}$$

$$\text{Turns ratio} = \frac{N_p/N_s}{V_{fb}\big/V_{out} + V_{dp}}$$

where N_p = primary turns, N_s = secondary turns, V_{fb} = flyback voltage, and V_{dp} = secondary-side diode drop.

After that, we need to calculate primary turns and secondary turns using the core section area, core volume, and material. Hence, if we put $N_p =$ P turns, we can obtain the turns count for each secondary winding by multiplying its output turns ratio times the number of primary turns.

To design for a reference value of new core application, the following equations are needed:

$$L_p = \frac{\text{B+ min} \times e\ \text{max (max on duty)}}{I_{pk}\ \text{(max current)} \times f_{sw}\ \text{(switching frequency)}}$$

$$N_p = \sqrt{\frac{L_p\ \text{(primary L)} \times 10^9}{\text{AL} - \text{V (inductance index)}}}, \text{ and}$$

$$N_s = \frac{N_p\ \text{(primary turns)} \times V_{out}\ \text{(output voltage)}}{V_{in}\ \text{(input voltage)}}, \text{ where}$$

V_{in} (input voltage) is at 50% maximum duty.

The last item is the transformer coil diameter calculation method,

$$D_{coil} = \sqrt{2 \times \frac{I_{rms}}{3.14 \times J}}, \text{ where J = current density, flyback topology 4 or 5.}$$

The secondary side calculations are the same as for the primary side.

1.2.1 Full-Wave Bridge Operation

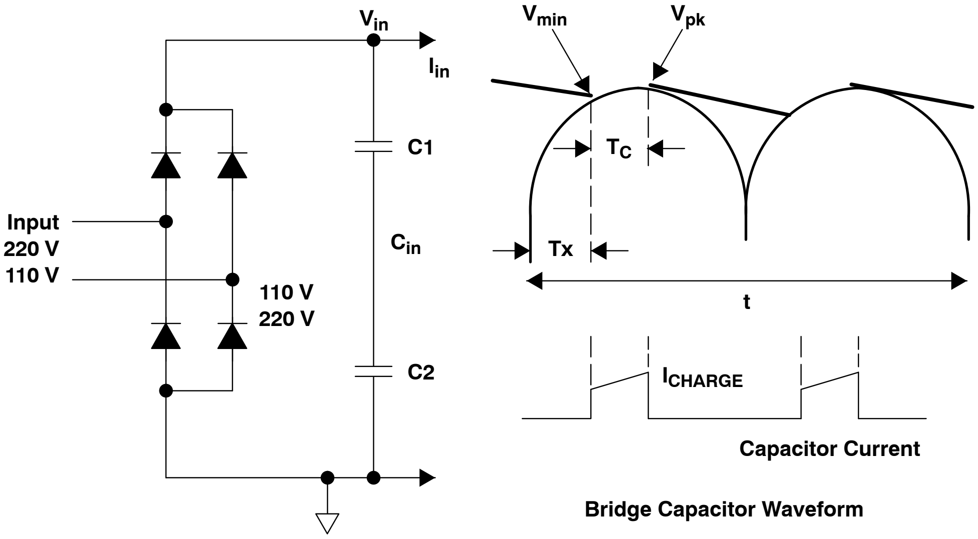


Figure 3. Full-Wave Bridge Operation

In Figure 3, C_{in} (C1 in series with C2) charges to peak line voltage each half-cycle. C_{in} then discharges, providing all the energy required by the switching supply until it recharges during the next half-cycle. Energy from C_{in} each half-cycle is:

$$W_{in} = \frac{P_{in}\ \text{(power input)}}{f\ \text{(AC input frequency)}},\ \text{Joules (watt} - \text{seconds)},\ f = 60\ \text{Hz},\ \text{worst case}\ f = 50\ \text{Hz}.$$

$$\frac{W_{in}}{2} = \frac{1}{2} C_{in} \left(V_{pk}^{2} - V_{min}^{2}\right),\ \text{Hence,}\ C_{in} = \frac{W_{in}}{V_{pk}^{2} - V_{min}^{2}}$$

The recharge time, tc, is fixed by the voltage waveform of the rectified ac line across the capacitor.

$$V_{min} = V_{pk} \cos\left(2\pi f \cdot tc\right),\ tc = \frac{\cos^{-1}\left(\frac{V_{min}}{V_{pk}}\right)}{2\pi f},$$

assuming a rectangular charging current pulse of peak amplitude $\Delta Q = \text{Ichg}\Delta t = C\Delta V$,

$$\text{Hence,}\ I_{chg} = \frac{C\left(V_{pk} - V_{min}\right)}{tc},\ \text{peak charging current.}$$

1.2.2 Voltage Doubler Operation

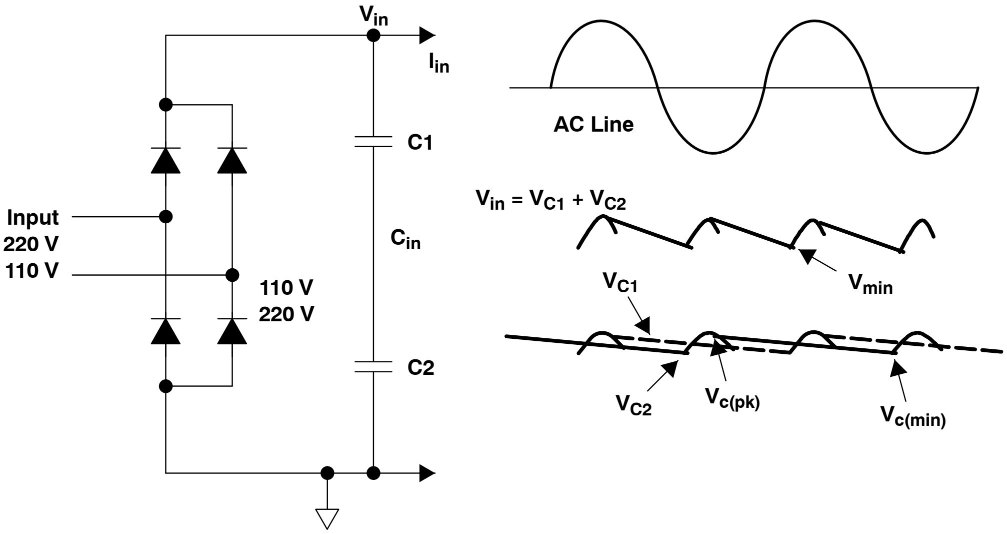


Figure 4. Voltage Doubler Configuration Waveforms

C1 and C2 alternately charge to peak line voltage. Whenever the input voltage,Vin, is at instantaneous minimum, one capacitor is at its minimum, but the other capacitor is halfway between peak and minimum voltage.The minimum voltage on each capacitor corresponding to an overall minimum voltage of 200 V can be approximated as follows. Normally V_{c1} and V_{c2} minimum line voltage is 90 V and maximum voltage is 135 V.

$$V\,\mathrm{min} = V_{c1}\,\mathrm{min} + V_{c2}\mathrm{avg} = V_c\,\mathrm{min} + \frac{V_c\,\mathrm{min} + V_c\mathrm{pk}}{2}$$

C1 and C2 each discharge for a complete cycle. Each capacitor must supply half the energy required by the switching regulator for an entire line cycle.

$$\frac{W}{2} = \frac{1}{2}C1\,(V_c\mathrm{pk}^2 - V_c\,\mathrm{min}^2),\ C1 = C2 = \frac{W}{V_c\mathrm{pk}^2 - V_c\,\mathrm{min}^2}.$$

C_{in}, the series combination of C1 and C2, $\frac{1}{C_{in}} = \frac{1}{C1} + \frac{1}{C2}$

2 Electrical Specification

1. Input voltage: 110 Vac, 220 Vac

   Option): Input range: 90 Vac~130 Vac (CN83: SHORT) or 165 Vac–265 Vac (CN83: OPEN)

2. UC3844 switching frequency: 72 kHz (transformer T81).

Output Voltage	Current	Tolerance	Output Ripple Voltage
25 V	50 mA–3.5 A	±5%	100 mA p-p max
12 V	0 mA–100 mA	±5%	
5 V	10 mA–500 mA	±5%	

3. Efficiency at full load 85%.

4. STR-G6352 switching frequency : 60 kHz(transformer T71).

Output Voltage	Current	Tolerance	Output Ripple Voltage
5 V (analog)	50 mA–3.0 A	±5%	100 mA p-p max.
5 V (digital)	0 mA–500 mA	±5%	
12 V (analog)	0 mA–500 mA	±5%	
12 V (digital)	0 mA–300 mA	±5%	
–12 V	50 mA–100 mA	±10%	
–16 V	10 mA–100 mA	±10%	
–20 V	10 mA–100 mA	±10%	
–26 V	10 mA–100 mA	±10%	

5. Current saturation point

   I pk = 3.3 A at R_{cs} 0.3 Ω, I saturation = 6.4 A. Using a 25% high-temperature derating factor, I saturation = 4.8 A, current margin = 45%.

3 Transformer Winding Specifications

1. Digital video display (DVD) audio amplifier

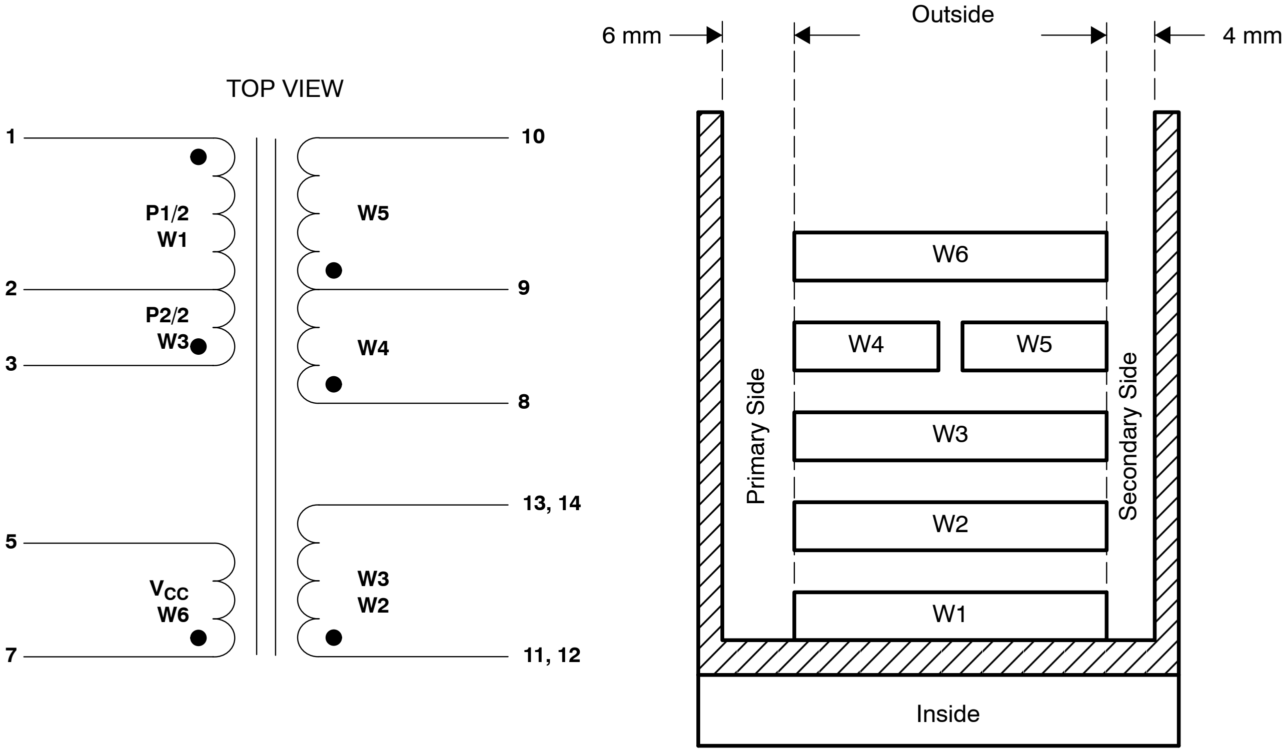


Figure 5. Schematic Diagram

2. Winding specification

WINDING		TERMINAL		WIRE DIAMETER (mm)	TURNS	INSULATION	
NO.	RATING	START	FINISH			TURNS	MATERIAL
W1	P1	1	2	0.5	22T	3T	Polyester film tape
W2	25 V/3.5 A	11,12	13,14	3.5 A Litz	8T	3T	Polyester film tape
W3	P2	2	3	0.5	22T	3T	Polyester film tape
W4	5 V/0.5 A	8	9	0.45	2T	3T	Polyester film tape
W5	12 V/ 0.1A	8	10	0.45	4T	3T	Polyester film tape
W6	VCC	7	5	0.22	5T	3T	Polyester film tape

3. Core size: EER – 40/42/15 H-type (pin bobbin)

4. Electrical characeristic

CLOSURE	PIN	SPEC.	REMARKS
INDUCTANCE	1 – 4	400 µH ± 5%	1 kHz, 1 V
LEAKAGE INDUCTANCE	1 – 4	±10 µH, max.	All secondary pins shorted together

5. Cut pin: pin 2 (primary side) is not used and is cut from the coil form.

6. DVD receive

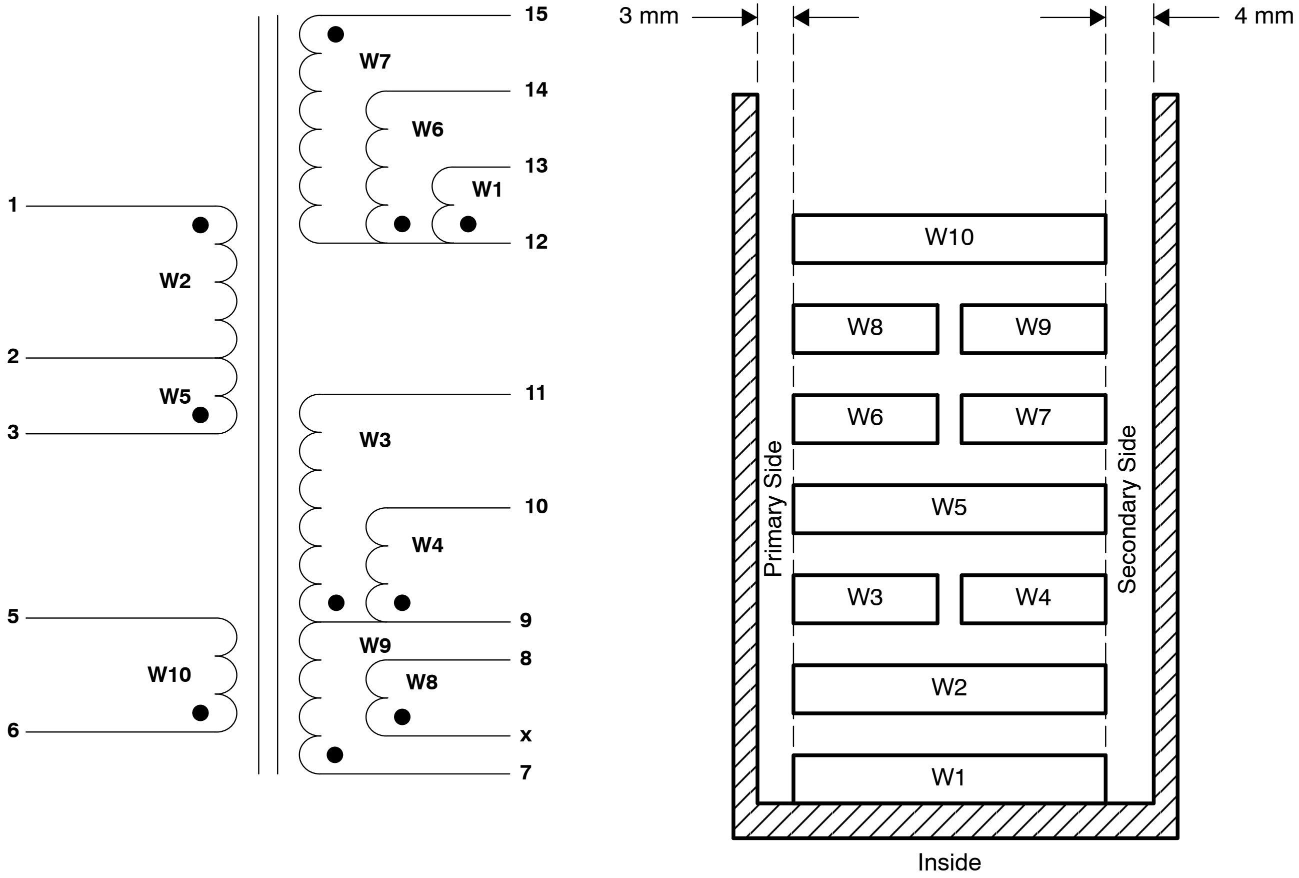


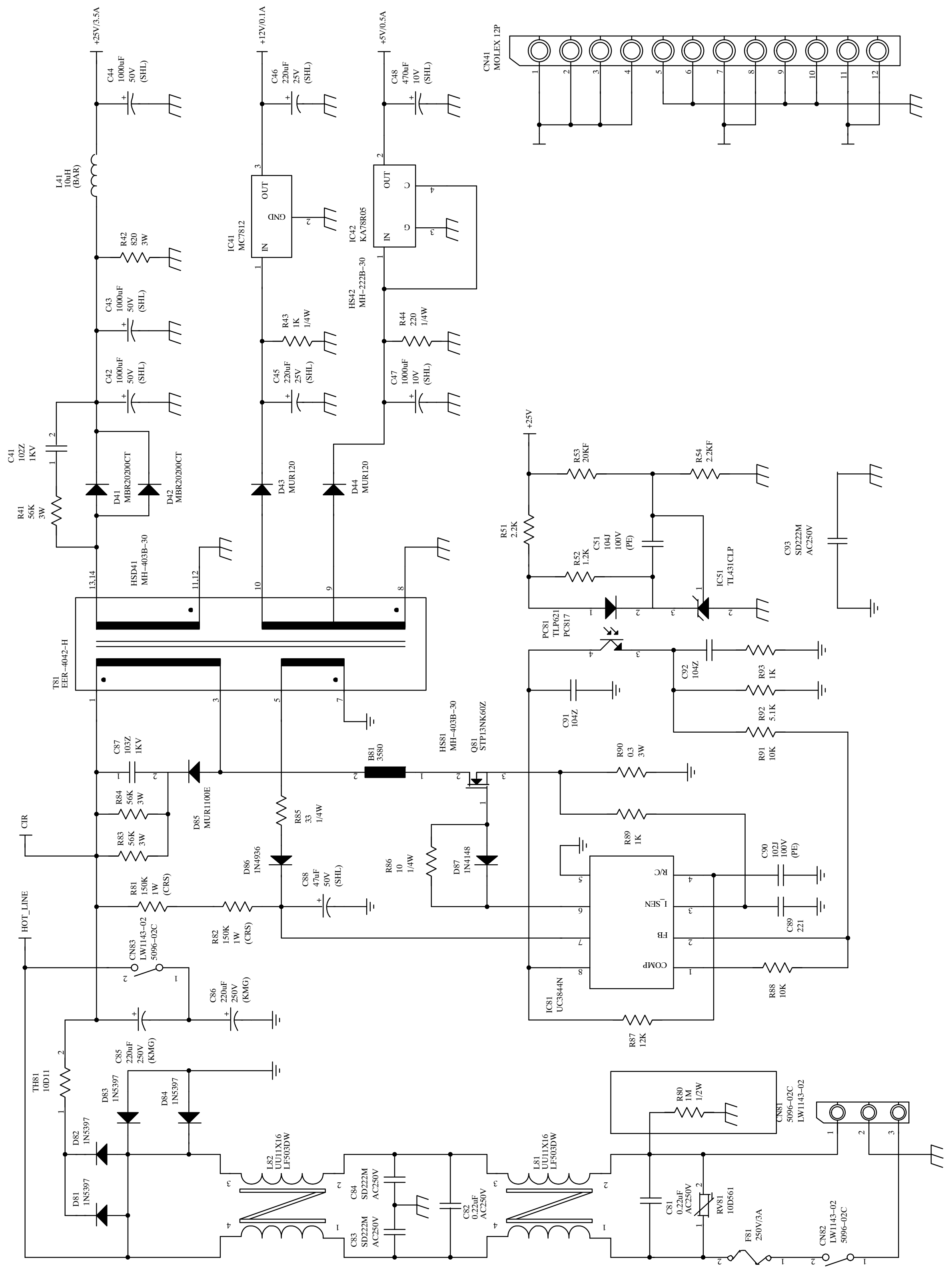
Figure 6. Schematic Diagram

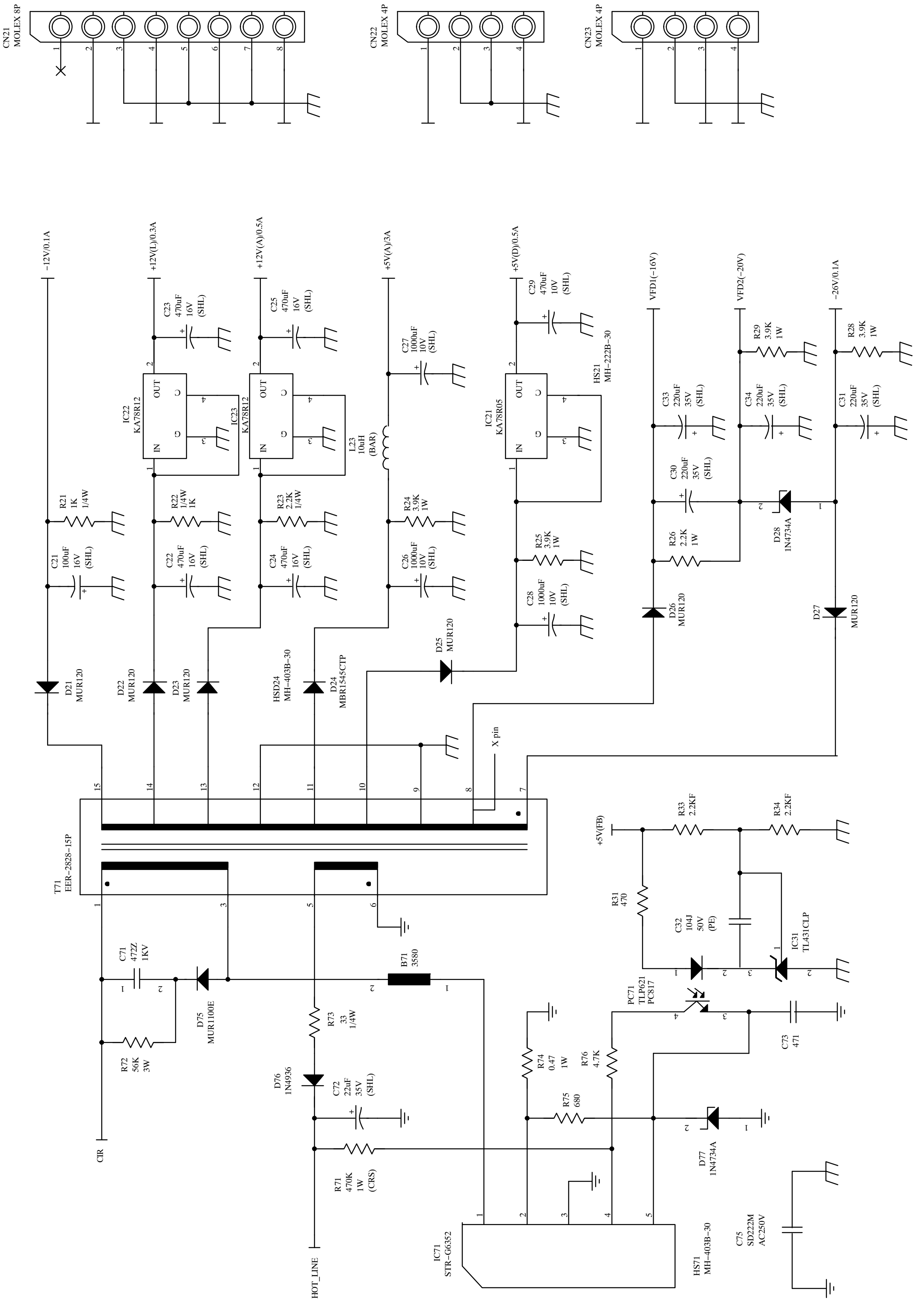
7. Winding specification
8. Core size: EER – 28/28 (5/11 pin bobbin)
9. ELECTRICAL CHARACERISTIC

CLOSURE	PIN	SPEC.	REMARKS
Inductance	1 – 4	880 µH ± 5%	1 kHz, 1 V
Leakage inductance	1 – 4	±20 µH, max.	All secondary pins shorted together

10. Cut Pin: Pin 2 and pin 4 (primary side) are not used and are cut from the coil form.
11. I_{sat} = 4.8 A

4 Schematic


+25V/3.5A
C44 1000uF 50V (SHL)
L41 10uH (BAR)
R42 820 3W
C43 1000uF 50V (SHL)
C42 1000uF 50V (SHL)
C41 102Z 1KV
R41 56K 3W
D41 MBR20200CT
D42 MBR20200CT
HSD41 MH–403B–30
+12V/0.1A
C46 220uF 25V (SHL)
IC41 MC7812
IN
OUT
GND
R43 1K 1/4W
C45 220uF 25V (SHL)
D43 MUR120
+5V/0.5A
C48 470uF 10V (SHL)
IC42 KA78R05
HS42 MH–222B–30
C
G
R44 220 1/4W
C47 1000uF 10V (SHL)
D44 MUR120
CN41 MOLEX 12P
T81 EER–4042–H
C87 103Z 1KV
D85 MUR1100E
R84 56K 3W
R83 56K 3W
CIR
R85 33 1/4W
B81 3580
HS81 MH–403B–30
Q81 STP13NK60Z
D86 1N4936
C88 47uF 50V (SHL)
R86 10 1/4W
D87 1N4148
R81 150K 1W (CRS)
R82 150K 1W (CRS)
HOT_LINE
CN83 LW1143–02 5096–02C
C86 220uF 250V (KMG)
C85 220uF 250V (KMG)
TH81 10D11
D83 1N5397
D84 1N5397
D82 1N5397
D81 1N5397
L82 UU11X16 LF503DW
C84 SD222M AC250V
C83 SD222M AC250V
C82 0.22uF AC250V
L81 UU11X16 LF503DW
C81 0.22uF AC250V
R80 1M 1/2W
RV81 10D561
F81 250V/3A
CN82 LW1143–02 5096–02C
CN81 5096–02C LW1143–02
+25V
R53 20KF
R54 2.2KF
R51 2.2K
R52 1.2K
C51 104J 100V (PE)
IC51 TL431CLP
C93 SD222M AC250V
PC81 TLP621 PC817
C92 104Z
R93 1K
C91 104Z
R92 5.1K
R91 10K
R90 0.3 3W
R89 1K
C90 102J 100V (PE)
C89 221
IC81 UC3844N
R/C
I_SEN
FB
COMP
R88 10K
R87 12K


CN21
MOLEX 8P
CN22
MOLEX 4P
CN23
MOLEX 4P
-12V/0.1A
+12V(L)/0.3A
+12V(A)/0.5A
+5V(A)/3A
+5V(D)/0.5A
VFD1(-16V)
VFD2(-20V)
-26V/0.1A
IC22
KA78R12
IC23
KA78R12
IC21
KA78R05
HS21
MH-222B-30
C23
470uF
16V
(SHL)
C25
470uF
16V
(SHL)
C27
1000uF
10V
(SHL)
C29
470uF
10V
(SHL)
L23
10uH
(BAR)
R21
1K
1/4W
R22
1/4W
1K
R23
2.2K
1/4W
R24
3.9K
1W
R25
3.9K
1W
R26
2.2K
1W
R29
3.9K
1W
R28
3.9K
1W
C21
100uF
16V
(SHL)
C22
470uF
16V
(SHL)
C24
470uF
16V
(SHL)
C26
1000uF
10V
(SHL)
C28
1000uF
10V
(SHL)
C30
220uF
35V
(SHL)
C33
220uF
35V
(SHL)
C34
220uF
35V
(SHL)
C31
220uF
35V
(SHL)
D28
1N4734A
D21
MUR120
D22
MUR120
D23
MUR120
HSD24
MH-403B-30
D24
MBR1545CTP
D25
MUR120
D26
MUR120
D27
MUR120
X pin
T71
EER-2828-15P
+5V(FB)
R33
2.2KF
R34
2.2KF
R31
470
C32
104J
50V
(PE)
IC31
TL431CLP
C71
472Z
1KV
B71
3580
D75
MUR1100E
R72
56K
3W
R73
33
1/4W
PC71
TLP621
PC817
C73
471
D76
1N4936
C72
22uF
35V
(SHL)
R74
0.47
1W
R76
4.7K
R75
680
D77
1N4734A
R71
470K
1W
(CRS)
CIR
HOT_LINE
IC71
STR-G6352
HS71
MH-403B-30
C75
SD222M
AC250V

5 PCB Gerber Files

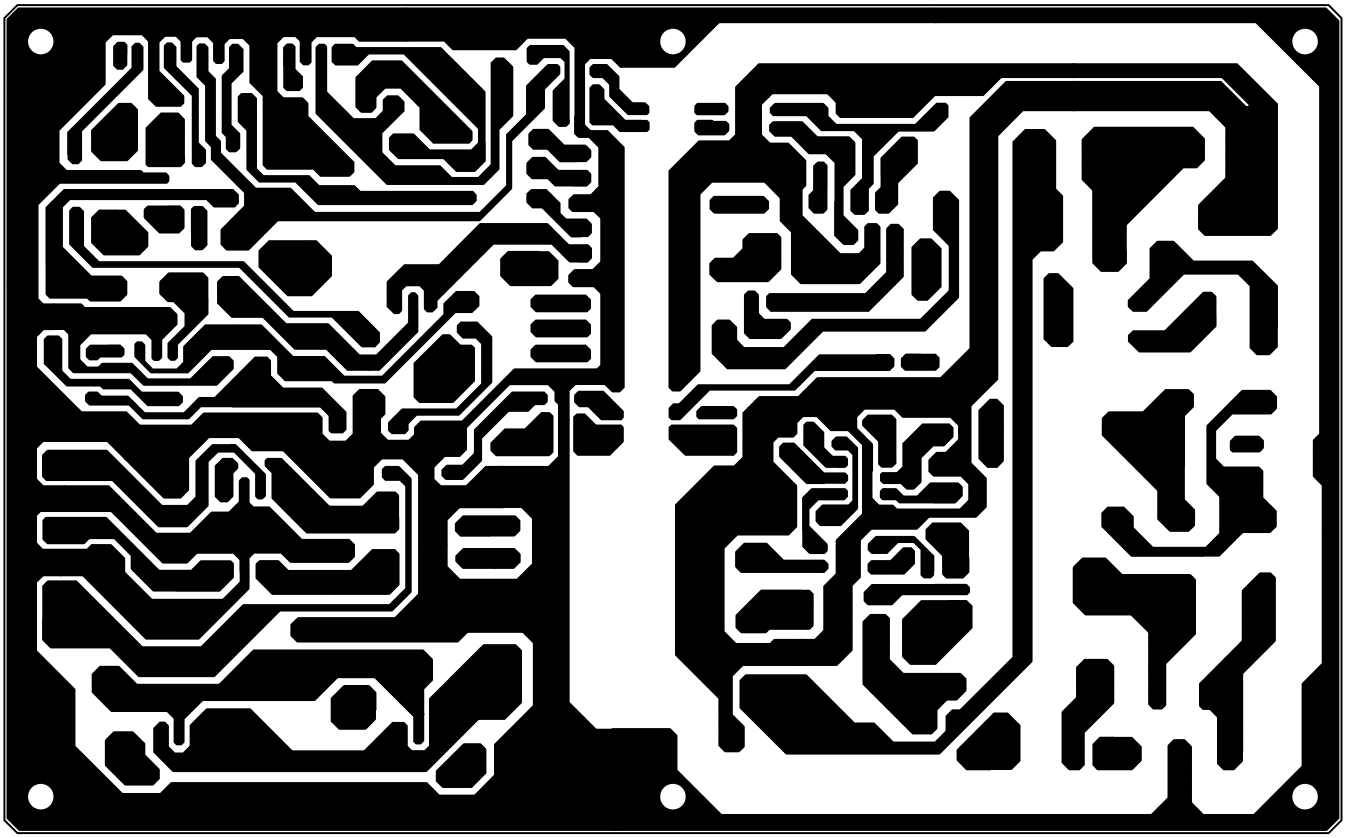


Figure 7. PCB Layout

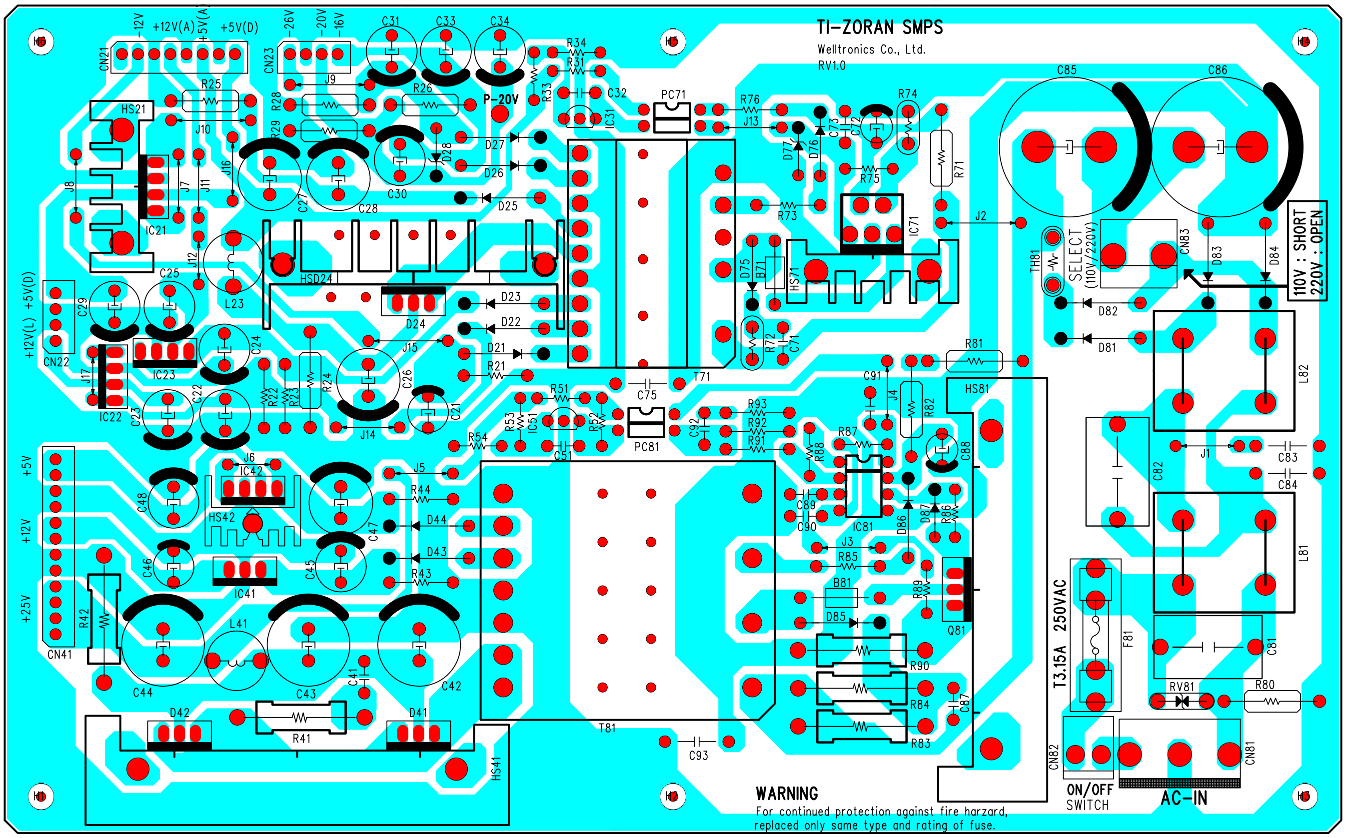


Figure 8. Component Layout

6 Bill of Materials

NO.	QTY	LOCATION	VALUE	PART NO.	DESCRIPTION
1	1	B71	3580		Bead
2	1	B81	3580		Bead
3	1	C21	100 µF/16 V		Capacitor, electrolytic
4	4	C22, C23, C24, C25	470 µF/16 V		Capacitor, electrolytic
5	3	C26, C27, C28	1000 µF/10 V		Capacitor, electrolytic
6	1	C29	470 µF/10 V		Capacitor, electrolytic
7	4	C30, C31, C33, C34	220 µF/35 V		Capacitor, electrolytic
8	1	C32		104J	Capacitor, ceramic
9	1	C41		102Z	Capacitor, ceramic
10	1	C42	1000 µF/50 V		Capacitor, electrolytic
11	1	C43	1000 µF/50 V		Capacitor, electrolytic
12	1	C44	1000 µF/50 V		Capacitor, electrolytic
13	2	C45, C46	220 µF/25 V		Capacitor, electrolytic
14	1	C47	1000 µF/10 V		Capacitor, electrolytic
15	1	C48	470 µF/10 V		Capacitor, electrolytic
16	1	C51		104J	Capacitor, ceramic
17	1	C71		472Z	Capacitor, electrolytic
18	1	C72	22 µF/35 V		Capacitor, electrolytic
19	1	C73		471	Capacitor, electrolytic
20	3	C75, C83, C84		SD222M	Capacitor, ceramic
21	2	C81, C82	0.22 µF		Capacitor, X2
22	2	C85, C86	220 µF/250 V		Capacitor, electrolytic
23	1	C87	0.01 µF/1 kV	103Z	Capacitor, ceramic
24	1	C88	47 µF/50 V		Capacitor, electrolytic
25	1	C89		221	Capacitor, ceramic
26	1	C90		102J	Capacitor, ceramic
27	2	C91, C92		104Z	Capacitor, ceramic
28	1	C93		SD222M	Capacitor, ceramic
29	1	CN21		MOLEX 8P	
30	1	CN22, CN23		MOLEX 4P	
31	1	CN41		MOLEX 12P	
32	1	CN81		5096−02C	AC−IN
33	2	CN82, CN83		LW1143−02	ON/OFF, 110/220
34	8	D21, D22, D23, D25, D26, D27, D43, D44	1 A, 200 V	MUR120	UFD
35	1	D24	15 A, 45 V	MBR1545CTP	SCHD
36	2	D28, D77	5.6 V	1N4734A	Zener diode
37	1	D41, D42		MBR20200CT	SCHD, 20 A, 200 V
38	2	D75, D85		MUR1100E	UFD, 1 A, 1000 V
39	2	D76, D86		1N4936	SD, 1 A, 400 V
40	4	D81, D82, D83, D84	1.5 A, 600 V	1N5397	SD
41	1	D87	0.15 A, 75 V	1N4148	SWD
42	1	F81	250 V/3 A		FUSE
43	2	HS21, HS42		MH−222B−30	
44	4	HS71, HS81, HSD24, HSD41		MH−403B−30	

NO.	QTY	LOCATION	VALUE	PART NO.	DESCRIPTION
45	1	IC21	5 V	KA78R05	REG
46	2	IC22, IC23	12 V	KA78R12	REG
47	1	IC31		TL431CLP	
48	1	IC41	12 V	MC7812	REG
49	1	IC42	5 V	KA78R05	REG
50	1	IC51	TL431CLP		
51	1	IC71		STR−G6352	PWM+FET
52	1	IC81		UC3844N	PWM CTRL
53	2	L23, L41	10 µH		
54	2	L81, L82		UU11X16	
55	2	PC71, PC81		TLP621	
56	1	Q81	13 A, 600 V	STP13NK60Z	N−channel FET
57	3	R21, R22, R43	¼ W, 1 kΩ		Resistor
58	1	R23, R51	¼ W, 2.2 kΩ		Resistor
59	4	R24, R25, R28, R29	1 W, 3.9 kΩ		Resistor
60	1	R26	1 W, 2.2 kΩ		Resistor
61	1	R31	¼ W, 470		Resistor
62	3	R33, R34, R54	1/8 W, 2.2 kΩ		Resistor
63	4	R41, R72, R83, R84	3W, 56 kΩ		Resistor
64	1	R42	3 W, 820		Resistor
65	1	R44	¼ W, 220 Ω		Resistor
66	1	R52	¼ W, 1.2 kΩ		Resistor
67	1	R53	1/8 W, 20 kΩ		Resistor
68	1	R71	1 W, 470 kΩ		Resistor
69	1	R73	¼ W, 33 Ω		Resistor
70	1	R74	1 W, 0.47 Ω		Resistor
71	1	R75	¼ W, 680 Ω		Resistor
72	1	R76	¼ W, 4.7 kΩ		Resistor
73	1	R80	1 W, 1 MΩ		Resistor
74	2	R81, R82	1 W, 150 kΩ		Resistor
75	1	R85	¼ W, 33 Ω		Resistor
76	1	R86	¼ W, 10 Ω		Resistor
77	1	R87	¼ W, 12 kΩ		Resistor
78	1	R88, R91	¼ W, 10 kΩ		Resistor
79	2	R89, R93	¼ W, 1 kΩ		Resistor
80	1	R90	3 W, 0.3 Ω		Resistor
81	1	R92	¼ W, 5.1 kΩ		Resistor
82	1	T71		EER−2828−15P	Transformer
83	1	T81		EER−4042−H	Transformer
84	1	TH81		10D11	Thermistor

7 SMPS Board

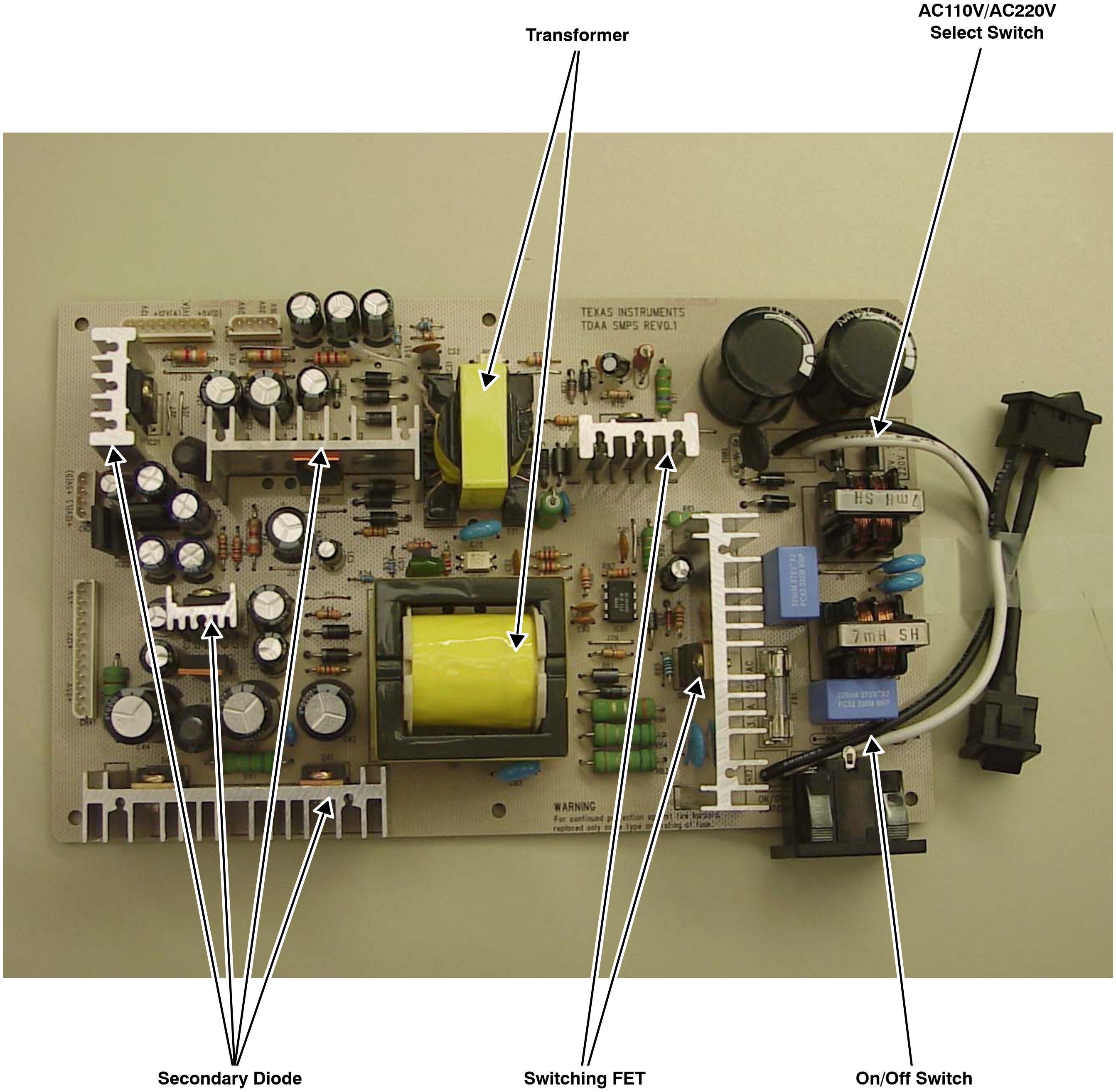
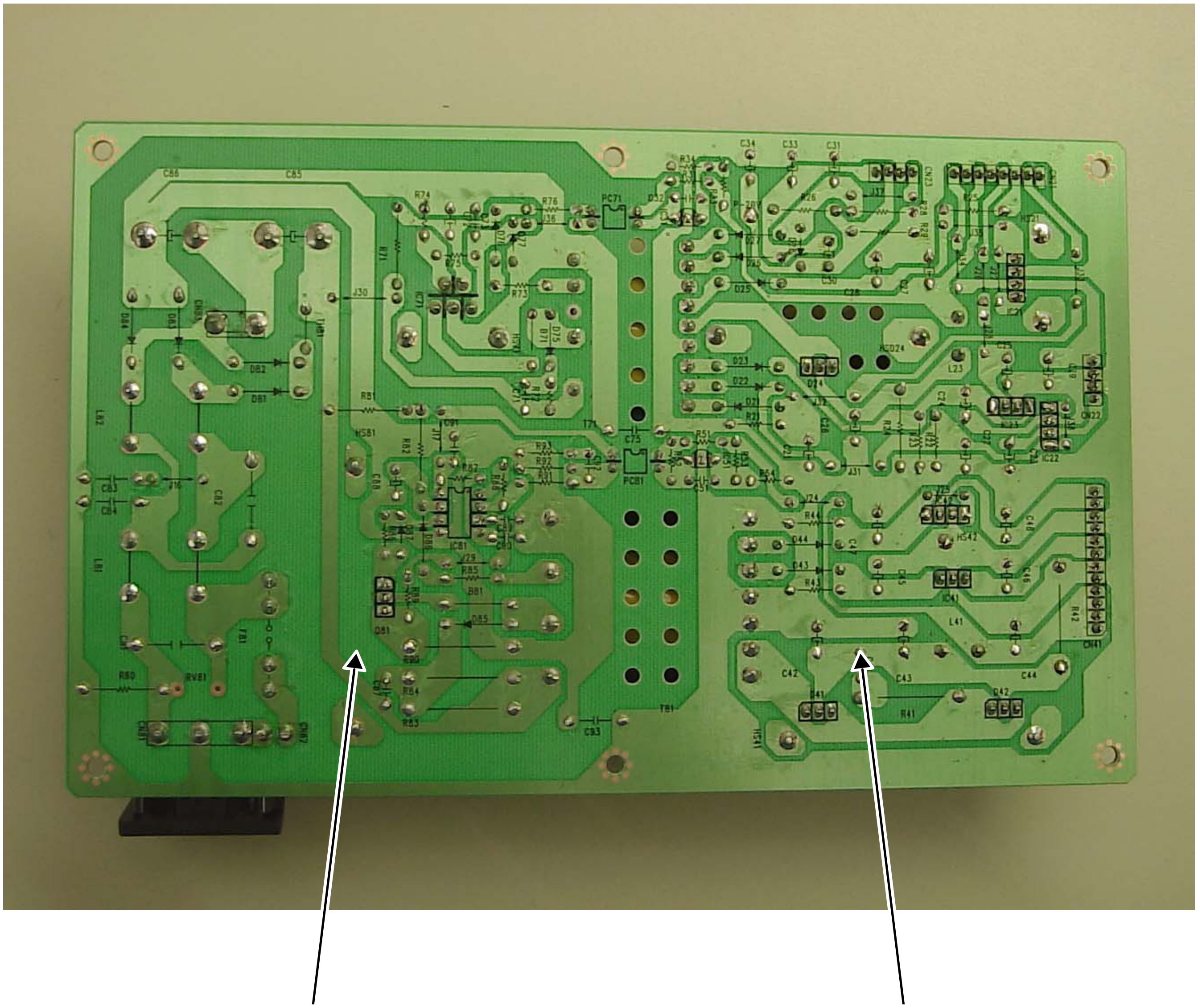


Figure 9. Component Side of Board



Primary Side

Secondary Side

Figure 10. Pattern Side of Board

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