Prototype Report

High Power Factor LED Ballast using FSFR2100 Fairchild Power Switch (FPS^{TM}) for Resonant Half-Bridge Converter and FAN7529 PFC Controller

- Universal AC Input Voltage (90 – 265 V_{RMS})
- Total Output Power 200 W
- Six DC Outputs with Constant Current:

  0.7A / 48V max. each

  (can be changed to 0.35A / 96V max.)

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………………………………….

Name: ………………………….
Date: …………………………..

2 Warning

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3 Introduction

This document describes the proposed solution for a 200 W Power Supply using the FSFR2100 Fairchild Power Switch (FPS). The input voltage range is 90 – 265 V_{RMS} and there are six outputs with 0.7A / 48V max. each. The board consists of a high power factor pre-regulator based on the FAN6961 voltage mode PFC controller and an isolated DC/DC converter based on a resonant LLC topology.
This document contains the power supply specification, schematic, bill of materials and transformer documentation.

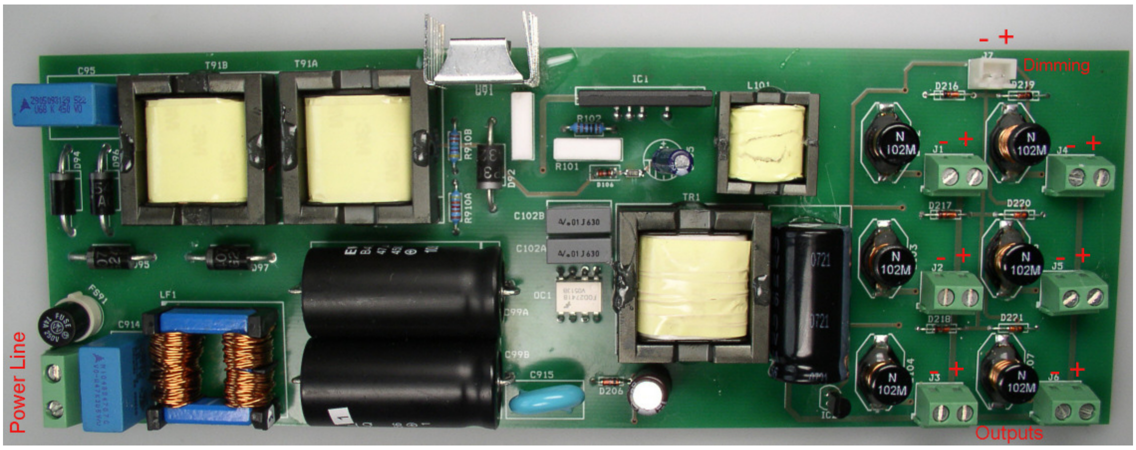
4 PSU Specification

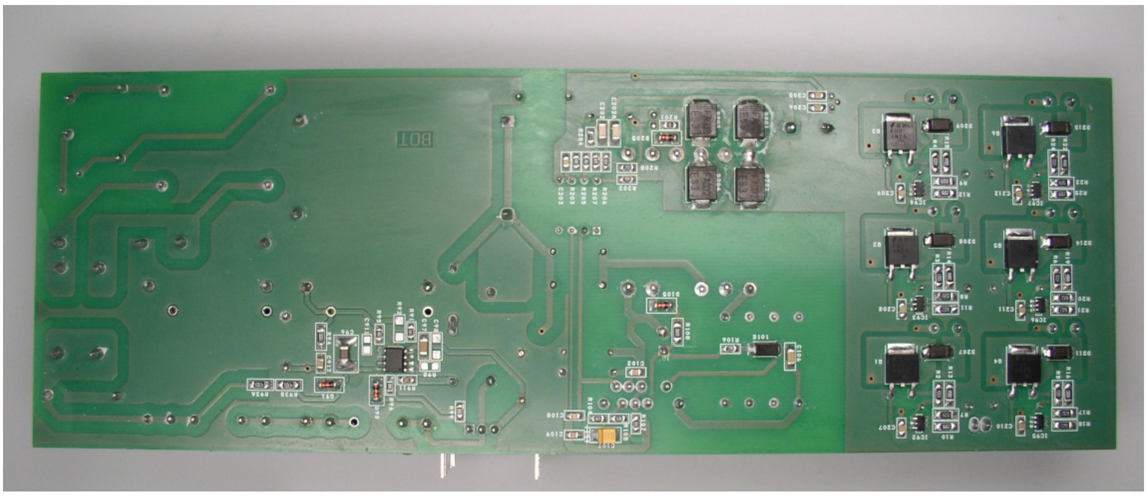
4.1 Electrical Specification

Minimum Line Voltage	90 V_{RMS}
Maximum Line Voltage	265 V_{RMS}
Line Frequency	50 to 60Hz
Six Outputs	0.7A / 48V max.

4.2 Mechanical Specification

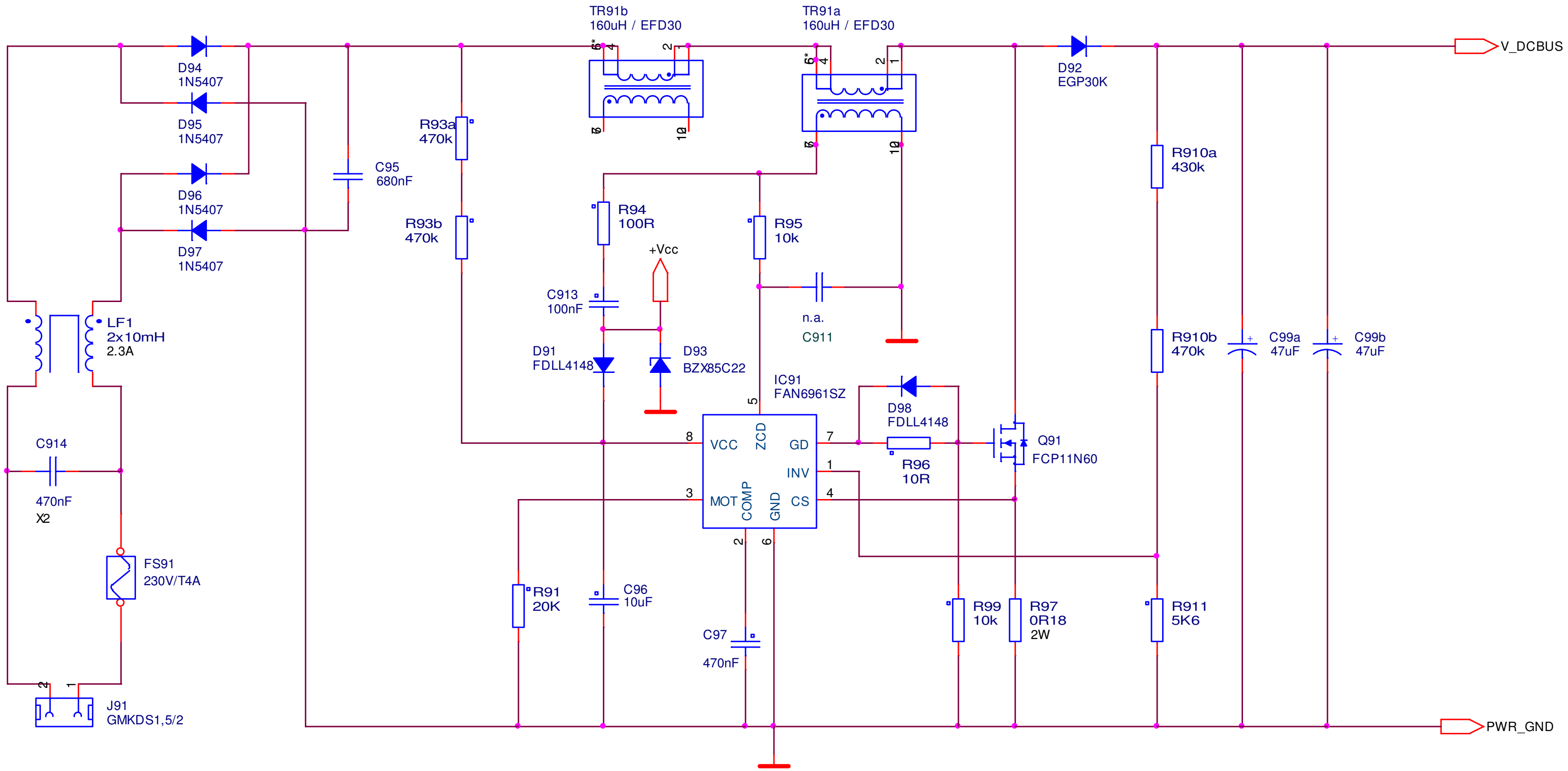
The board size is 201mm x 79mm x 20mm (L x W x H)

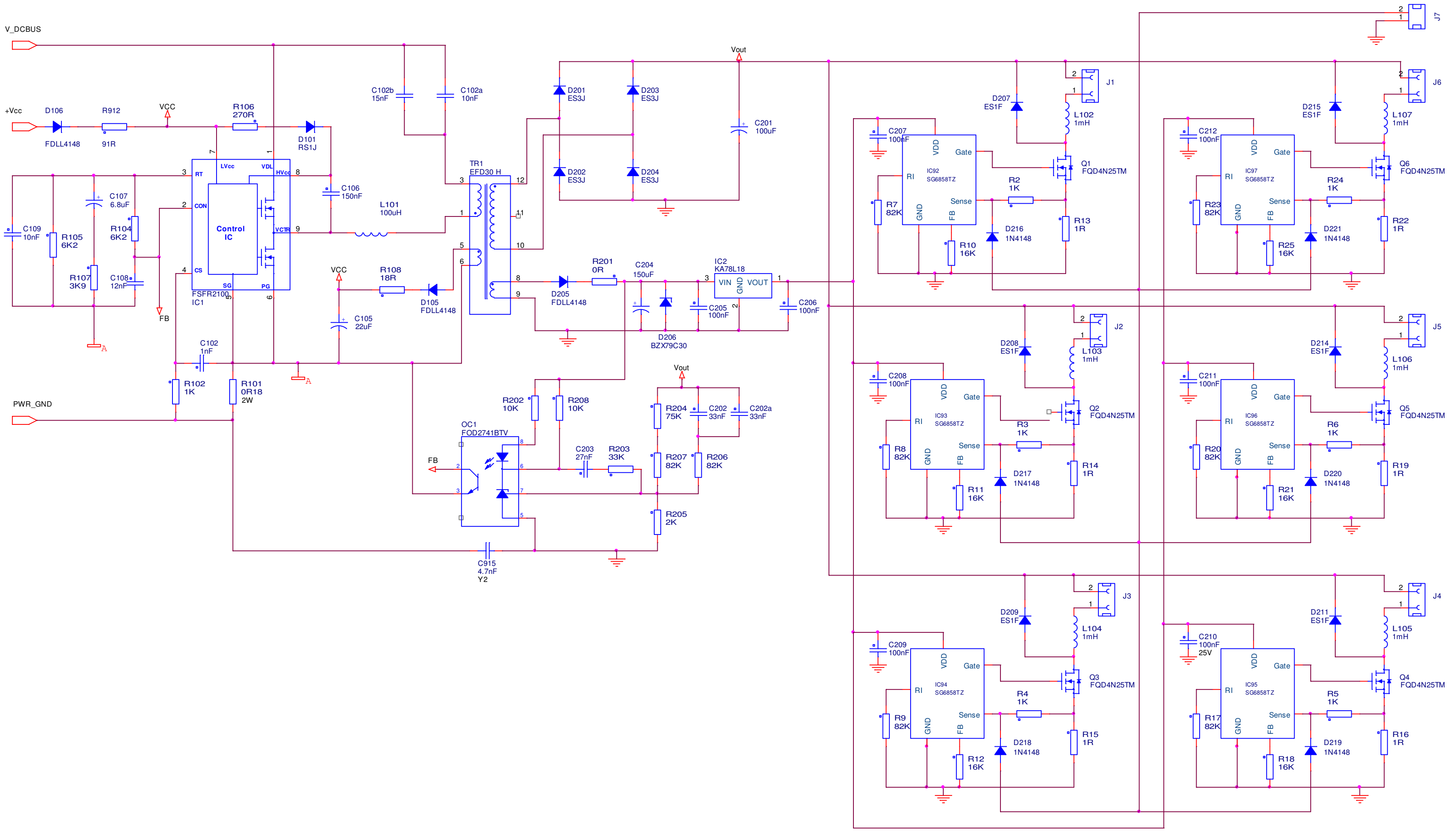




5 Schematic Diagram and Circuit Description

5.1 Schematic Diagram





V_DCBUS
+Vcc
D106
FDLL4148
R912
91R
VCC
R106
270R
D101
RS1J
C106
150nF
L101
100uH
C102b
15nF
C102a
10nF
TR1
EFD30 H
D201
ES3J
D203
ES3J
D202
ES3J
D204
ES3J
Vout
C201
100uF
C109
10nF
R105
6K2
C107
6.8uF
R104
6K2
R107
3K9
C108
12nF
FB
Control
IC
FSFR2100
IC1
R108
18R
D105
FDLL4148
C105
22uF
D205
FDLL4148
R201
0R
C204
150uF
IC2
KA78L18
VIN
GND
VOUT
C205
100nF
C206
100nF
D206
BZX79C30
C102
1nF
R102
1K
R101
0R18
2W
PWR_GND
R202
10K
R208
10K
OC1
FOD2741BTV
C203
27nF
R203
33K
R204
75K
C202
33nF
C202a
33nF
R207
82K
R206
82K
R205
2K
C915
4.7nF
Y2
C207
100nF
VDD
Gate
RI
IC92
SG6858TZ
Sense
GND
FB
R7
82K
R10
16K
D207
ES1F
L102
1mH
J1
Q1
FQD4N25TM
R2
1K
R13
1R
D216
1N4148
C212
100nF
IC97
SG6858TZ
R23
82K
R25
16K
D215
ES1F
L107
1mH
J6
J7
Q6
FQD4N25TM
R24
1K
R22
1R
D221
1N4148
C208
100nF
IC93
SG6858TZ
R8
82K
R11
16K
D208
ES1F
L103
1mH
J2
Q2
FQD4N25TM
R3
1K
R14
1R
D217
1N4148
C211
100nF
IC96
SG6858TZ
R20
82K
R21
16K
D214
ES1F
L106
1mH
J5
Q5
FQD4N25TM
R6
1K
R19
1R
D220
1N4148
C209
100nF
IC94
SG6858TZ
R9
82K
R12
16K
D209
ES1F
L104
1mH
J3
Q3
FQD4N25TM
R4
1K
R15
1R
D218
1N4148
C210
100nF
25V
IC95
SG6858TZ
R17
82K
R18
16K
D211
ES1F
L105
1mH
J4
Q4
FQD4N25TM
R5
1K
R16
1R
D219
1N4148

5.2 Circuit Description

The power supply consists of a high power factor pre-regulator, a DC/DC converter and three current sources.
D94 - 97 act as a rectifier that supplies positive half-waves to the following boost-converter. C914, LF1, C95 and C915 form an EMI filter.
The PFC is based on IC91, the voltage mode PFC controller FAN6961. At start-up of the application, C96 is charged by R93a and R3b to the start voltage of IC91. As soon as the IC begins to operate, current is drawn and C96 starts to discharge. Since the circuit is switching now, the voltage across the secondary winding of TR91a supplies current via R94, C913 and D91. Since the latter voltage varies with the input voltage it is clamped with D93 to a suitable level. IC91 generates the gate voltage for the boost switch Q91. The on-time of Q91 is (almost) constant during one half-wave of the power line voltage while the off-time is variable and determined by the de-magnetization of TR91a & TR91b. The latter is determined by detection of the zero crossing of the voltage at the pin 'ZCD' of IC91. The output voltage of 405V is fed back via the divider R910a/b and R911. C97 determines the crossover frequency that has to be less than half the line frequency in order to get a high power factor.
The DC/DC converter is based on the Fairchild Power Switch (FPS™) FSFR2100. At start-up C105 is charged via D105 and R9155 to the start voltage of the IC. When this voltage is reached, the device starts to operate with the frequency determined by R107 and drops - since C107 is charged by and by - to the nominal operating frequency with a slope that is determined by C107 (Soft-Start).
The half-bridge of IC1 drives a LLC network consisting of L101, TR1 and C102a & b. On the secondary side the transformed voltage is rectified by D201 - D204 and filtered with C201.A second output voltage that supplies the optocoupler and error amplifier OC1 is generated with D201, R201, C201 and D206. R204, C202, R207 etc. together with OC1 form the feedback loop to regulate the output voltage. The BJT of the optocoupler together with R104 form a variable resistor that is parallel to R105, that sets the minimum operating frequency, and adjust the operating frequency accordingly.
D105, R108, C105 and D102 deliver the supply current for IC1 during normal operation The supply voltage for the high-side driver of the half bridge is generated with the bootstrap circuit consisting of R106, D101 and C106.
The current through the lower MOSFET is measured with R101, the signal is filtered by the network R102/C102 and fed to the 'CS' pin. This pin accepts a signal that is negative respect to the ground-pin of the chip. If a level of -0.6V is met at this pin, the half-bridge is switched of until the next cycle.
If -0.9V are met, the device is shut down (AOCP). The latter mode is latched and only reset after the Vcc of the chip fell below 5V typical.
The three current sources use the SG6859 current mode PWM controller in a buck topology. The peak current through the inductors L102 .. 104 is measured with the hunt resistors R13, 14, 15 16, 19 and 22 and fed to the current sense of the corresponding controller. The controller keeps the peak inductor current and in turn the output current constant. R10 .. 12 set the current sense level and R7 .. 9 determine the operating frequency of the current source. In order to set an output current of 350mA the resistors R13, 14, 15 16, 19 and 22 have to be doubled.
The current sources can be dimmed with a PWM signal of approx. 200Hz applied to J7.

5.3 FAN7529 Critical Conduction Mode PFC Controller

The FAN6961 is an 8-pin, boundary-mode, PFC controller IC intended for controlling PFC pre-regulators. The FAN6961 provides a controlled on-time to regulate the output DC voltage and achieve natural power factor correction. The maximum on-time of the external switch is programmable to ensure safe operation during AC brownouts. An innovative multi-vector error amplifier is built in to provide rapid transient response and precise output voltage clamping. A built-in circuit disables the controller if the output feedback loop is opened. The start-up current is lower than 20µA and the operating current has been reduced to under 6mA. The supply voltage can be up to 25V, maximizing application flexibility.

5.4 FSFR2100 Fairchild Power Switch (FPS™) for Resonant Half-Bridge Converter

FSFR-series is a highly integrated power switch specially designed for high efficiency half-bridge resonant converter. Offering every thing necessary to build a reliable and robust resonant converter, the FSFR-series simplifies designs and improves productivity while improving performance. The FSFR-series combines power MOSFETs with fast recovery type body diodes, a high-side gate drive circuit, an accurate current controlled oscillator, frequency limit circuit, soft-start and built-in protection functions. The high side drive circuit has a common mode noise cancellation capability, which guarantees stable operation with excellent noise immunity. The fast recovery body diode of the MOSFETs improves reliability against abnormal operation condition while minimizing the effect of the reverse recovery. Using the zero-voltage-switching (ZVS) technique, the switching losses are dramatically reduced and therefore the efficiency also has been significantly improved. The zero-voltage-switching also reduces the switching noise noticeably, which allows using small size EMI filter. The FSFR-series can be applied to various resonant converter topologies such as series resonant, parallel resonant and LLC resonant converter.

5.5 FOD2741 Optically Isolated Error Amplifier

The FOD2741 Optically Isolated Amplifier consists of the popular KA431 precision programmable shunt reference and an optocoupler. The optocoupler is a gallium arsenide (GaAs) light emitting diode optically coupled to a silicon phototransistor. It comes in 3 grades of reference voltage tolerance = 2%, 1%, and 0.5%.

The Current Transfer Ratio (CTR) ranges from 100% to 200%. It also has an outstanding temperature coefficient of 50 ppm/°C. It is primarily intended for use as the error amplifier/reference voltage/optocoupler function in isolated ac to dc power supplies and dc/dc converters.

When using the FOD2741, power supply designers can reduce the component count and save space in tightly packaged designs. The tight tolerance reference eliminates the need for adjustments in many applications. The device comes in a 8-pin dip white package.

5.6 SG6858 / SG6859 PWM Controller

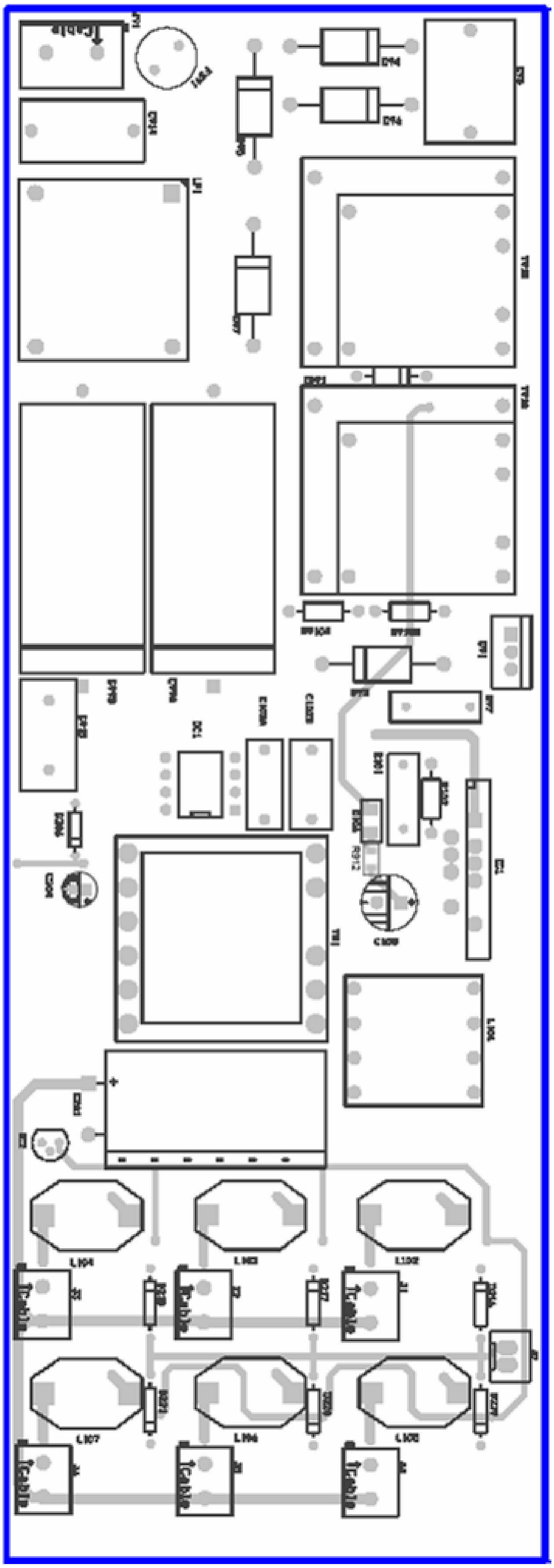
This highly integrated PWM controller provides several special enhancements designed to meet the low standby-power needs of low-power SMPS. To minimize standby power consumption, the proprietary green-mode function provides off-time modulation to linearly decrease the switching frequency under light-load conditions. This green-mode function enables the power supply to easily meet even the strictest power conservation requirements.

The BiCMOS fabrication process enables reducing the start-up current to 9uA, and the operating current to 3mA. To further improve power conservation, a large start-up resistance can be used. Built-in synchronized slope compensation ensures the stability of peak current mode control. Proprietary internal compensation provides a constant output power limit over a universal AC input range (90VAC to 264VAC). Pulse-by-pulse current limiting ensures safe operation even during short-circuits.

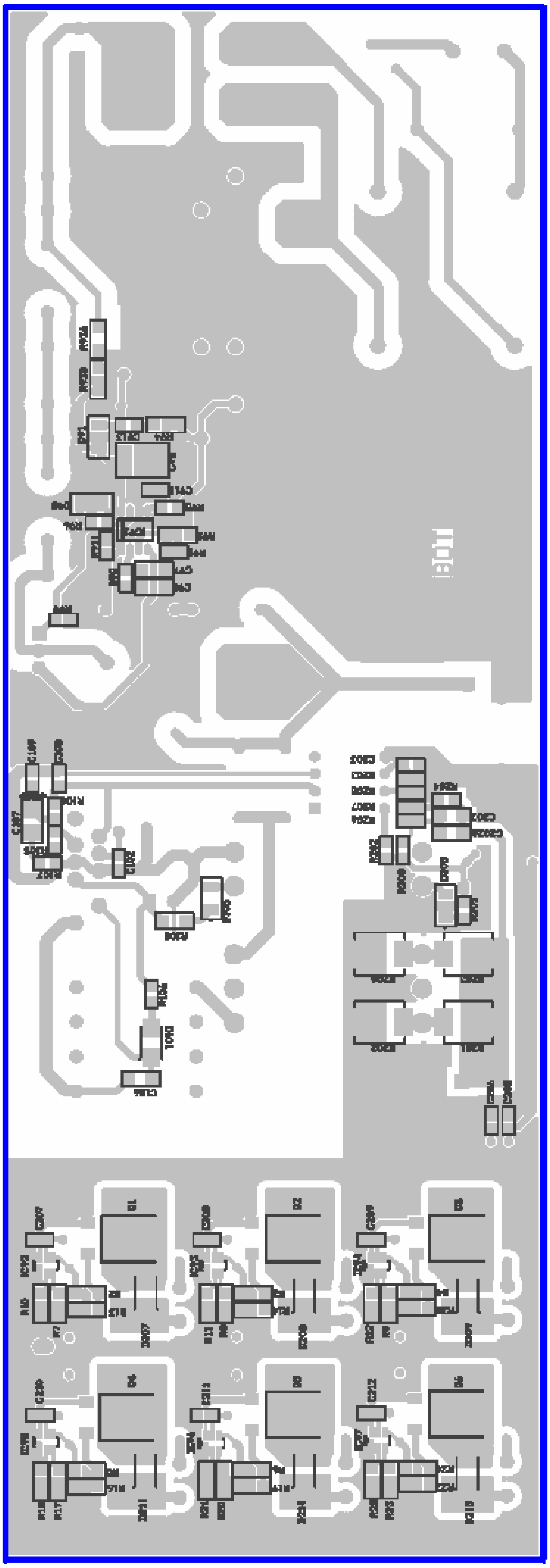
To protect the external power MOSFET from being damaged by supply over voltage, the SG6859's output driver is clamped at 17V. SG6859 controllers can be used to improve the performance and reduce the production cost of power supplies. The SG6859 is the best choice for replacing linear and RCC-mode power adapters. It is available in 8-pin DIP and 6-pin SOT-26 packages.

6 PCB Layout

6.1 Top



6.2 Bottom



7 Bill of Materials

Item	Qtty.	RefDes	Part / Specification	Manufacturer / Series
1	1	C95	680nF / 450V	Epcos / B32522N
2	1	C96	10uF / 25V	TDK / C5750
3	1	C97	470nF / 25V	any X7R / 15% / 1206
4	2	C99b	47uF / 450V	Epcos / B43699
		C99a	47uF / 450V	Epcos / B43699
5	1	C102	1nF / 25V	any X7R / 15% / 0805
6	1	C102a	10nF / 630V	Arcotronics / R76
7	1	C102b	15nF / 630V	Arcotronics / R76
8	1	C105	22uF / 50V	any electrolytic
9	1	C106	150nF / 25V	any X7R / 15% / 1206
10	1	C107	6.8uF / 25V	AVX / TAP
11	1	C108	12nF / 25V	any X7R / 15% / 0805
12	1	C109	10nF / 25V	any X7R / 15% / 0805
13	1	C201	100uF / 250V	Panasonic / ED
14	2	C202a	33nF / 500V	Yageo / CC1206
		C202	33nF / 500V	Yageo / CC1206
15	1	C203	27nF / 25V	any X7R / 15% / 0805
16	1	C204	150uF / 35V	any electrolytic
17	8	C205	100nF / 25V	any X7R / 15% / 0805
		C206	100nF / 25V	any X7R / 15% / 0805
		C207	100nF / 25V	any X7R / 15% / 0805
		C208	100nF / 25V	any X7R / 15% / 0805
		C209	100nF / 25V	any X7R / 15% / 0805
		C210	100nF / 25V	any X7R / 15% / 0805
		C211	100nF / 25V	any X7R / 15% / 0805
		C212	100nF / 25V	any X7R / 15% / 0805
18	1	C911	n.a. / 200V	any MLC / X7R / 15%
19	1	C913	100nF / 50V	any X7R / 15% / 0805
20	1	C914	470nF / 305V	Epcos / B32922C
21	1	C915	4.7nF / 250V	Murata / DE
22	5	D91	FDLL4148	Fairchild Semiconductor
		D98	FDLL4148	Fairchild Semiconductor
		D105	FDLL4148	Fairchild Semiconductor
		D106	FDLL4148	Fairchild Semiconductor
		D205	FDLL4148	Fairchild Semiconductor
23	1	D92	EGP30K	Fairchild Semiconductor
24	1	D93	BZX85C22	Fairchild Semiconductor
25	4	D94	1N5407	Fairchild Semiconductor
		D95	1N5407	Fairchild Semiconductor
		D96	1N5407	Fairchild Semiconductor
		D97	1N5407	Fairchild Semiconductor
26	1	D101	RS1J	Fairchild Semiconductor
27	4	D201	ES3J	Fairchild Semiconductor
		D202	ES3J	Fairchild Semiconductor
		D203	ES3J	Fairchild Semiconductor
		D204	ES3J	Fairchild Semiconductor
28	1	D206	BZX79C30	Fairchild Semiconductor
29	6	D207	ES1F	Fairchild Semiconductor
		D208	ES1F	Fairchild Semiconductor
		D209	ES1F	Fairchild Semiconductor
		D211	ES1F	Fairchild Semiconductor
		D214	ES1F	Fairchild Semiconductor
		D215	ES1F	Fairchild Semiconductor

30	6	D216	1N4148	Fairchild Semiconductor
		D217	1N4148	Fairchild Semiconductor
		D218	1N4148	Fairchild Semiconductor
		D219	1N4148	Fairchild Semiconductor
		D220	1N4148	Fairchild Semiconductor
		D221	1N4148	Fairchild Semiconductor
31	1	FS91	230V / T4A	Wickmann / TR5
32	1	IC1	FSFR2100	Fairchild Semiconductor
33	1	IC2	KA78L18	Fairchild Semiconductor
34	1	IC91	FAN6961SZ	Fairchild Semiconductor
35	6	IC92	SG6858TZ	Fairchild Semiconductor
		IC93	SG6858TZ	Fairchild Semiconductor
		IC94	SG6858TZ	Fairchild Semiconductor
		IC95	SG6858TZ	Fairchild Semiconductor
		IC96	SG6858TZ	Fairchild Semiconductor
		IC97	SG6858TZ	Fairchild Semiconductor
36	6	J1	MKDSN1,5/2	Phoenix Contact / MKDSN1,5
		J2	MKDSN1,5/2	Phoenix Contact / MKDSN1,5
		J3	MKDSN1,5/2	Phoenix Contact / MKDSN1,5
		J4	MKDSN1,5/2	Phoenix Contact / MKDSN1,5
		J5	MKDSN1,5/2	Phoenix Contact / MKDSN1,5
		J6	MKDSN1,5/2	Phoenix Contact / MKDSN1,5
37	1	J7	B2B-XH-A	JST / XH
38	1	J91	GMKDS1,5/2	Phoenix Contact / GMKDS 1,5
39	1	LF1	2x10mH / 2.3A	Epcos / B82733-F series
40	1	L101	100uH / 1.5A	EFD20 / Custom
41	6	L102	1mH / 0.85A	FASTRON / PISN
		L103	1mH / 0.85A	FASTRON / PISN
		L104	1mH / 0.85A	FASTRON / PISN
		L105	1mH / 0.85A	FASTRON / PISN
		L106	1mH / 0.85A	FASTRON / PISN
		L107	1mH / 0.85A	FASTRON / PISN
42	1	OC1	FOD2741BTV	Fairchild Semiconductor
43	6	Q1	FQD4N25TM	Fairchild Semiconductor
		Q2	FQD4N25TM	Fairchild Semiconductor
		Q3	FQD4N25TM	Fairchild Semiconductor
		Q4	FQD4N25TM	Fairchild Semiconductor
		Q5	FQD4N25TM	Fairchild Semiconductor
		Q6	FQD4N25TM	Fairchild Semiconductor
44	1	Q91	FCP11N60	Fairchild Semiconductor
45	7	R2	1K / 0.125W	any 1% / 0805
		R3	1K / 0.125W	any 1% / 0805
		R4	1K / 0.125W	any 1% / 0805
		R5	1K / 0.125W	any 1% / 0805
		R6	1K / 0.125W	any 1% / 0805
		R24	1K / 0.125W	any 1% / 0805
		R102	1K / 0.125W	any 1% / 0805
46	6	R7	82K / 0.25W	any 1% / 1206
		R8	82K / 0.25W	any 1% / 1206
		R9	82K / 0.25W	any 1% / 1206
		R17	82K / 0.25W	any 1% / 1206
		R20	82K / 0.25W	any 1% / 1206
		R23	82K / 0.25W	any 1% / 1206
47	6	R10	16K / 0.25W	any 1% / 1206
		R11	16K / 0.25W	any 1% / 1206
		R12	16K / 0.25W	any 1% / 1206

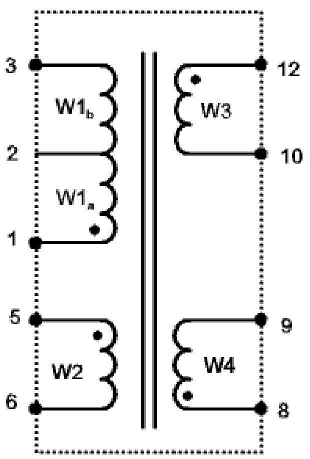
		R18	16K / 0.25W	any 1% / 1206
		R21	16K / 0.25W	any 1% / 1206
		R25	16K / 0.25W	any 1% / 1206
48	6	R13	1R / 0.25W	any 1% / 1206
		R14	1R / 0.25W	any 1% / 1206
		R15	1R / 0.25W	any 1% / 1206
		R16	1R / 0.25W	any 1% / 1206
		R19	1R / 0.25W	any 1% / 1206
		R22	1R / 0.25W	any 1% / 1206
49	1	R91	20K / 0.125W	any X7R / 15% / 0805
50	2	R93b	470k / 0.25W	any 1% / 0805
		R93a	470k / 0.25W	any 1% / 0805
51	1	R94	100R / 0.25W	any 1% / 0806
52	2	R95	10k / 0.125W	any X7R / 15% / 0805
		R99	10k / 0.125W	any X7R / 15% / 0805
53	1	R96	10R / 0.125W	any X7R / 15% / 0805
54	1	R97	0R18 / 2W	1% / low inductance
55	1	R101	0R18 / 2W	1% / low inductance
56	2	R104	6K2 / 0.125W	any 1% / 0805
		R105	6K2 / 0.125W	any 1% / 0805
57	1	R106	270R / 0.125W	any 1% / 0805
58	1	R107	3K9 / 0.125W	any 1% / 0805
59	1	R108	18R / 0.25W	any 1% / 1206
60	1	R201	0R / ?W	any 1% / 1206
61	1	R202	10K / o,125W	any 1% / 1206
62	1	R203	33K / 0.125W	any 1% / 0805
63	1	R204	75K / 0.125W	any 1% / 0805
64	1	R205	2K / 0.125W	any 1% / 0805
65	2	R206	82K / 0.125W	any 1% / 0805
		R207	82K / 0.125W	any 1% / 0805
66	1	R208	10K / 0.125W	any 1% / 1206
67	1	R910a	430k / 0.6W	any 1%
68	1	R910b	470k / 0.6W	any 1%
69	1	R911	5K6 / 0.125W	any X7R / 15% / 0805
70	1	R912	91R / 0.25W	any 1% / 1206
71	1	TR1	EFD30H	see specification
72	2	TR91b	160uH / EFD30H	see specification
		TR91a	160uH / EFD30H	see specification

8 Main Transformer

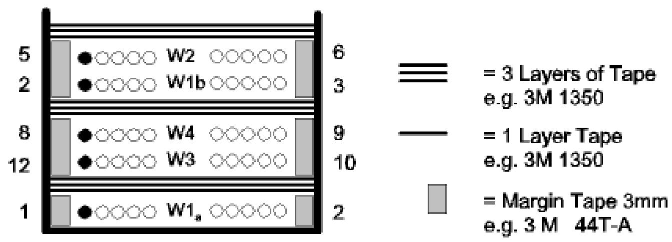
8.1 Winding Details

Name	Pins (Start → End)	# of Layers	Strands x Wire ø	Turns	Construction	Material
W1a	3 → 2	1	1 x 0.5 mm	28	perfect solenoid	CuLL
W3	12 → 10	2	1 x 0.5 mm	55	perfect solenoid	CuLL
W4	8 → 9	1	1 x 0.15 mm	6	spaced winding	CuLL
W1b	2 → 1	1	1 x 0.5 mm	28	perfect solenoid	CuLL
W2	5 → 6	1	1 x 0.15 mm	5	spaced winding	CuLL

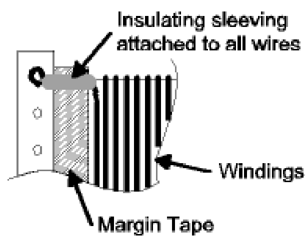
Schematic



Construction



Layers not to scale !



Bottom View

8.2 Electrical Characteristics

Parameter	Pins	Specification	Conditions
Primary Inductance	1 → 3	600 uH +/- 5%	100kHz, 100mV, all secondaries open
Leakage inductance	1 → 3	15 uH maximum	10kHz, 100mV, all other pins shorted

8.3 Core and Bobbin

Core: EFD 30
Material: N87 (EPCOS) or equivalent
Bobbin: EFD 30 horizontal / 12 pins e.g. EPCOS B66424W….
Gap in center leg: approx. 0.5 mm for A_L of 191 nH/Turns^2

8.4 Safety

High voltage test: 3000V_{rms} for 1 minute between primary (pins 1 to 5) and secondary (pins 6 to 9)

9 LLC Choke

9.1 Winding Details

Name	Pins (Start →End)	Layers	Strands x Wire ø	Turns	Construction	Material
W1	1 → 5	n.a.	30 x 0.1 mm	56	perfect solenoid	CuL

9.2 Electrical Characteristics

Parameter	Pins	Specification	Conditions
Inductance	1 → 5	100 uH +/- 5%	100kHz, 100mV

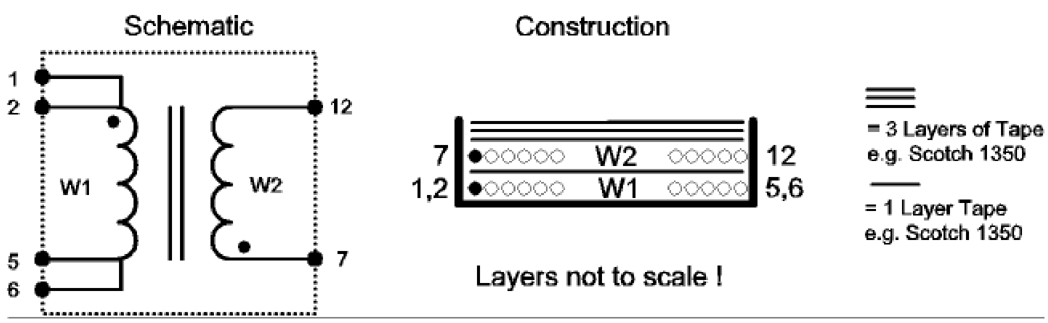
9.3 Core and Bobbin

Core: EFD20
Material: N87 (EPCOS) or equivalent
Bobbin: EFD20 / 8 Pin / Horizontal e.g. EPCOS B66418W…
Gap in center leg: aprox. 2.5 mm for an A_L of 32 nH/Turns^2

10 PFC Choke

10.1 Winding Details

Name	Pins (Start →End)	Layers	Strands x Wire ø	Turns	Construction	Material
W1	1,2 →5,6	n.a.	2 x 30 x 0.1 mm	49	perfect solenoid	CuL
W2	7 →12	1	1 x 0.15 mm	12	perfect solenoid	CuLL



10.2 Electrical Characteristics

Parameter	Pins	Specification	Conditions
Inductance	1 → 6	160 uH +/- 5%	100kHz, 100mV

10.3 Core and Bobbin

Core: EFD 30
Material: N87 (EPCOS) or equivalent
Bobbin: EFD 30 horizontal / 12 pins e.g. EPCOS B66424W….
Gap in Centre leg: aprox. 2.5 mm for an A_L of 64 nH/Turns^2