LM5045 Based 720W Power Converter Utilizing Current-Doubler Topology on the Secondary

Texas Instruments
Application Note 2222
Ajay Hari
January 27, 2012

Introduction

The LM5045 based 720W reference board is designed to evaluate the performance of the current doubler topology the secondary side. The reference board is designed in an industry standard half brick footprint. This reference board design is for reference only and hardware is not provided.

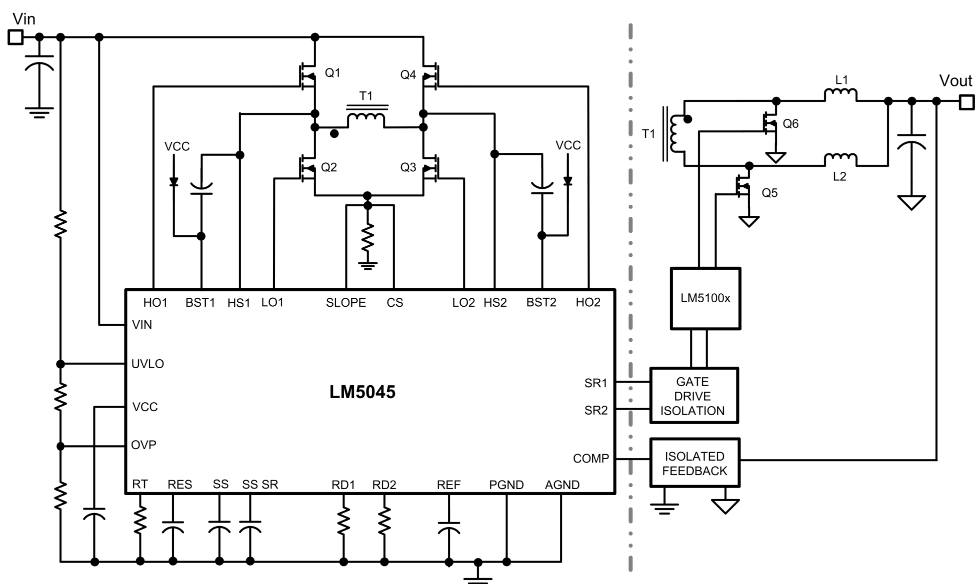
The performance of the evaluation board is as follows:

- Input Operating Range: 36V to 75V
- Output Voltage: 12V
- Output Current: 60A
- Measured Efficiency at 48V: 95.6% @ 58A with a Peak Efficiency of 97.1% at 30A
- Frequency of Operation: 400 kHz
- Board Size: 2.28 x 2.4 inches
- Load Regulation: 0.2%
- Line Regulation: 0.1%
- Line UVLO (34V/32V On/Off)
- Hiccup Mode Current Limit

The printed circuit board consists of 8 layers, 3 ounce copper on all layers on FR4 material with a total thickness of 0.064 inches. The unit is designed for continuous operation at rated load at <40°C and a minimum airflow of 500 LFM.

Theory of Operation

Power converters based on the full-bridge topology offer high-efficiency and good power handling capability up to 1kW. Figure 1 illustrates the circuit arrangement for the full-bridge topology with full-wave rectification. The switches, in the diagonal, Q1,Q3 and Q2,Q4 are turned alternatively with a pulse width determined by the input and output voltages and the transformer turns ratio. Each diagonal (Q1 and Q3 or Q2 and Q4), when turned ON, applies input voltage to the primary of the transformer. The resulting secondary voltage is then full-wave rectified and filtered with an LC filter to provide a smoothened output voltage. The current doubler topology on the secondary is a good alternative to the center-tapped and classical full-wave rectification schemes. The current doubler topology results in current sharing between the two output inductors L1 and L2. This makes it suitable for high load current applications such as this application note where a single bulky inductor would be an unattractive solution. Further in a full-bridge topology, the primary switches are turned on alternatively energizing the windings in such a way that the flux swings back and forth in the first and the third quadrants of the B-H curve. The use of two quadrants allows better utilization of the core resulting in a smaller core volume compared to the single-ended topologies such as a forward converter.



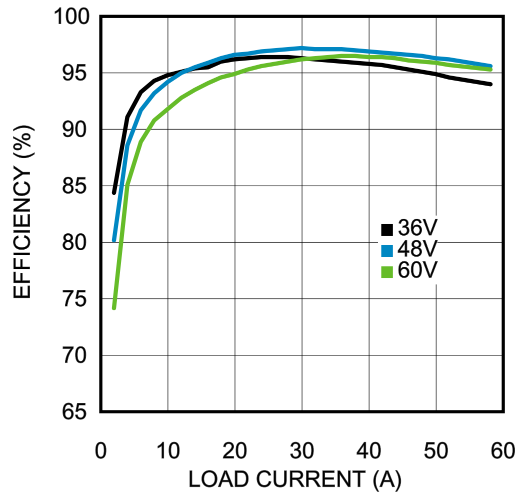
30184201

Simplified Full-Bridge Converter with a Current-Doubler Scheme on the Secondary

The current doubler topology on the secondary side is controlled by the LM5045. In addition to the basic soft-start already described, the LM5045 contains a second soft-start function that gradually turns on the synchronous rectifiers to their steady-state duty cycle. This function keeps the synchronous rectifiers off during the basic soft-start allowing a linear start-up of the output voltage even into pre-biased loads. Then the SR output duty cycle is gradually increased to prevent output voltage disturbances due to the difference in the voltage drop between the body diode and the channel resistance of the synchronous MOSFETs. Once, the soft-start is finished, the synchronous rectifiers are engaged with a non-overlap time programmed by the RD1 and RD2 resistors. Feedback from the output is processed by an amplifier and reference, generating an error voltage, which is coupled back to the primary side control through an opto-coupler. The LM5045 evaluation board employs peak current mode control and a standard “type II” network is used for the compensator.

Performance Characteristics

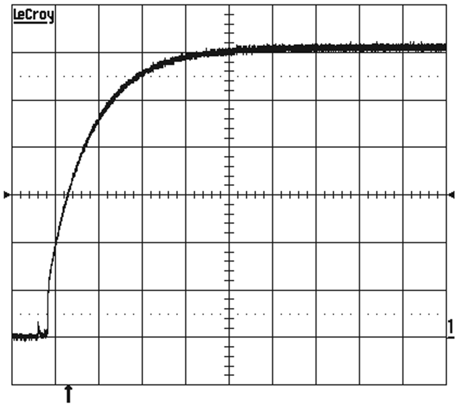
Once the circuit is powered up and running normally, the output voltage is regulated to 12V with the accuracy determined by the feedback resistors and the voltage reference. The frequency of operation is selected to be 400 kHz, which is a good comprise between board size and efficiency. Please refer to the figure 1. for efficiency curves.



30184203

FIGURE 1. Application Board Efficiency

When applying power to the LM5045 evaluation board a certain sequence of events occurs. Soft-start capacitor values and other components allow for a minimal output voltage for a short time until the feedback loop can stabilize without overshoot. Figure 2 shows the output voltage during a typical start-up with a 48V input and a load of 25A. There is no overshoot during start-up.

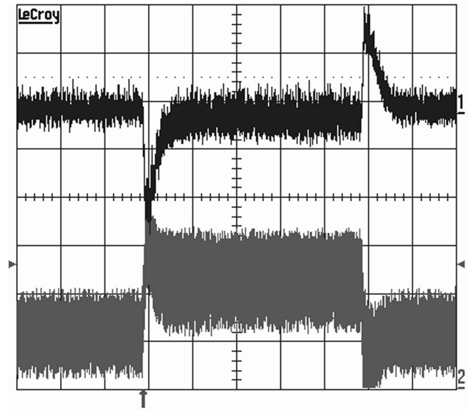


30184204

Conditions: Input Voltage = 48V
Output Current = 60A
Trace 1: Output Voltage Volts/div = 2V
Horizontal Resolution = 5.0 ms/div

FIGURE 2. Soft-Start

Figure 3 shows minimal output voltage droop and overshoot during the sudden change in output current represented by the current sense voltage in the lower trace.

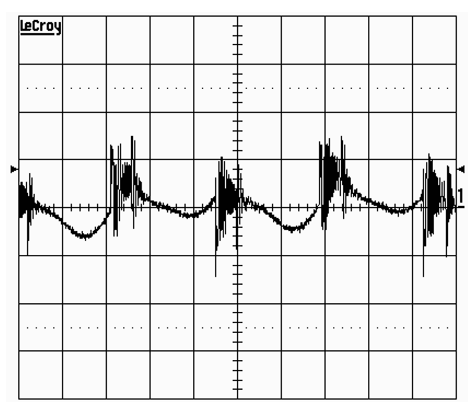


30184205

Conditions: Input Voltage = 48V
Upper Trace: Output Voltage Volts/div = 100mV
Lower Trace: Current Sense Voltage = 200mV
Horizontal Resolution = 200 µs/div

FIGURE 3. Transient Response

Figure 4 shows output ripple measured at 60A of load current.

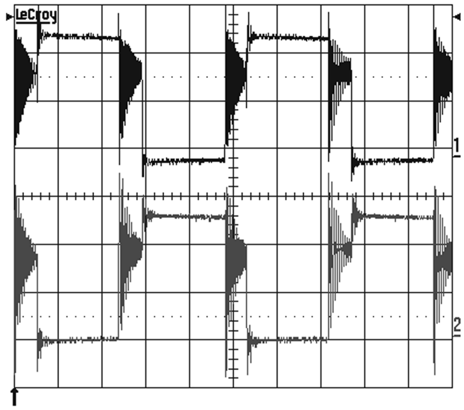


30184206

Conditions: Input Voltage = 48V
Output Current = 60A
Output Voltage Volts/div = 50mV AC Coupled
Horizontal Resolution = 1 µs/div

FIGURE 4. Output Ripple

Figures 5 shows the typical SW node voltage waveforms with a 30A load at 48V input.

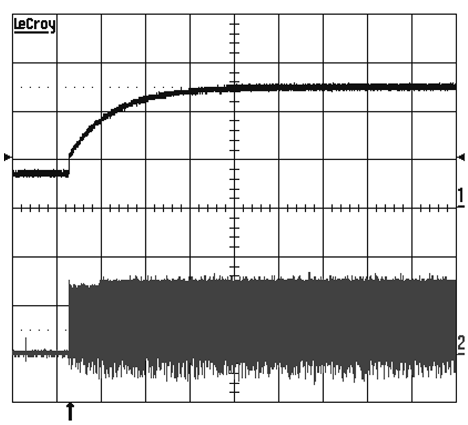


30184207

Conditions: Input Voltage = 48V
Output Current = 30A
Trace 1: Q1 Drain Voltage Volts/div = 20V
Horizontal Resolution = 1 μs/div

FIGURE 5. Switch Node Waveforms

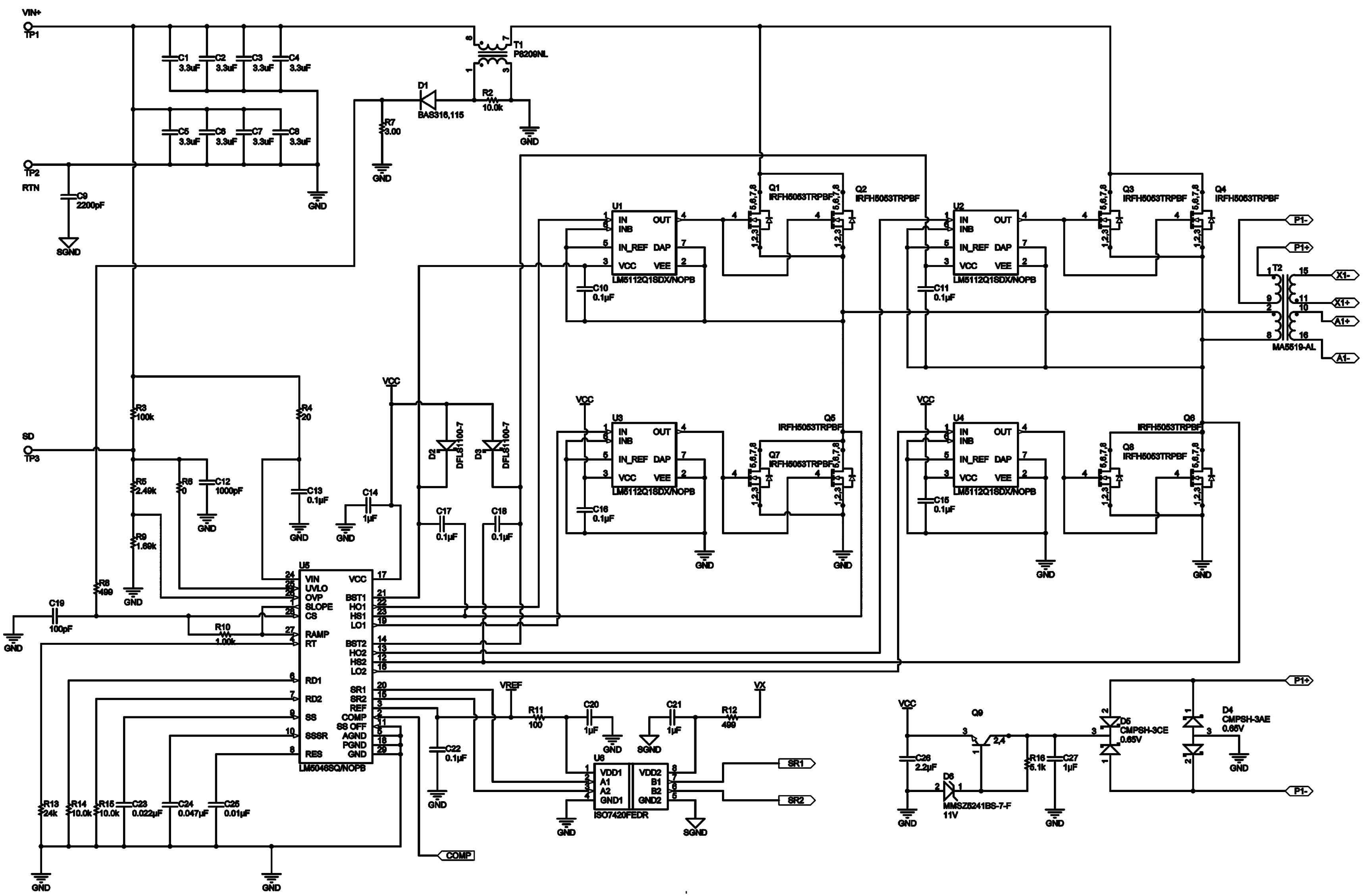
Figure 6 shows a typical startup of the reference into a 4V pre-biased load.



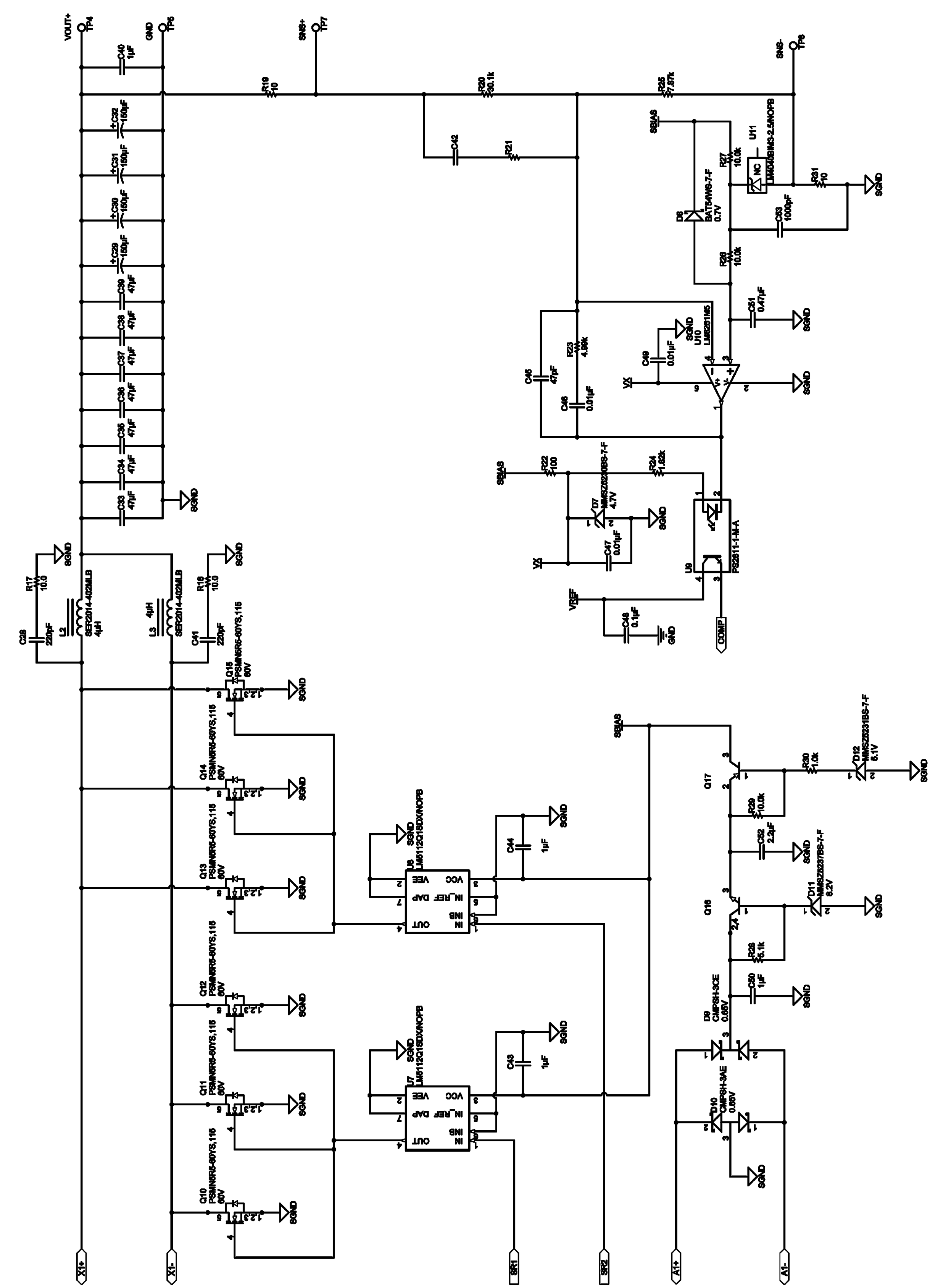
30184208

Conditions: Input Voltage = 48V
Trace 1: V_{OUT} with Pre-Bias of 4V Volts/div = 5V
Trace 2: SR Gate Waveforms, Volts/div = 5V
Horizontal Resolution = 5 ms/div

FIGURE 6. Soft-Start into 5V Pre-Biased Load



Application Circuit: Input 36V to 75V, Output 12V at 60A (Page 1)



30184226

Application Circuit: Input 36V to 75V, Output 12V at 60A (Page 2)

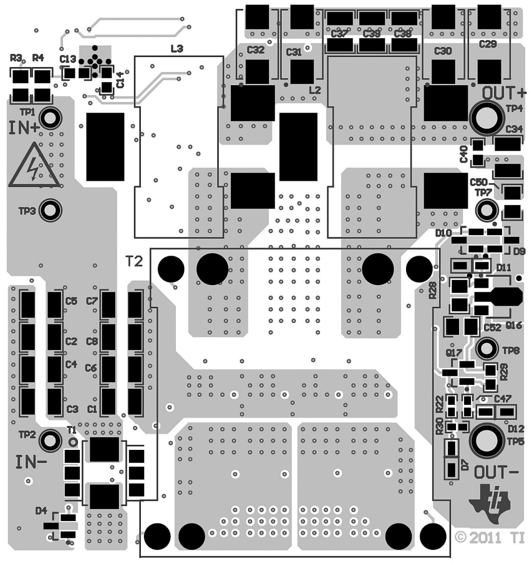
Bill of Materials

Item	Designator	Description	Manufacturer	Part Number	Qty
1	C1, C2, C3, C4, C5, C6, C7, C8	CAP CER 3.3UF 100V X7S 1210	TDK	C3225X7S2A335K	8
2	C9	CAP, CERM, 2200pF, 2000V, +/-10%, X7R, 1812	TDK	C4532X7R3D222K	1
3	C10, C11, C15, C16, C17, C18, C22, C48	CAP, CERM, 0.1uF, 16V, +/-10%, X7R, 0402	MuRata	GRM155R71C104KA88D	8
4	C12	CAP, CERM, 1000pF, 25V, +/-5%, C0G/NP0, 0402	TDK	C1005C0G1E102J	1
5	C13	CAP, CERM, 0.1uF, 100V, +/-10%, X7R, 0603	MuRata	GRM188R72A104KA35D	1
6	C14, C20, C21	CAP, CERM, 1uF, 16V, +/-10%, X7R, 0603	Taiyo Yuden	EMK107B7105KA-T	3
7	C19	CAP, CERM, 100pF, 50V, +/-5%, C0G/NP0, 0402	MuRata	GRM1555C1H101JA01D	1
8	C23	CAP, CERM, 0.022uF, 16V, +/-10%, X7R, 0402	TDK	C1005X7R1C223K	1
9	C24	CAP, CERM, 0.047uF, 16V, +/-10%, X7R, 0402	TDK	C1005X7R1C473K	1
10	C25, C46, C47, C49	CAP, CERM, 0.01uF, 16V, +/-10%, X7R, 0402	TDK	C1005X7R1C103K	4
11	C26, C52	CAP, CERM, 2.2uF, 16V, +/-10%, X7R, 0805	MuRata	GRM21BR71C225KA12L	2
12	C27, C50	CAP, CERM, 1uF, 25V, +/-10%, X7R, 0805	MuRata	GRM21BR71E105KA99L	2
13	C28, C41	CAP, CERM, 220pF, 100V, +/-5%, C0G/NP0, 0805	Kemet	C0805C221J1GACTU	2
14	C29, C30, C31, C32	CAP, TANT, 150uF, 16V, +/-20%, 0.085 ohm, 7343-31 SMD	Kemet	T495D157M016ATE085	4
15	C33, C34, C35, C36, C37, C38, C39	CAP, CERM, 47uF, 16V, +/-20%, X5R, 1210	MuRata	GRM32ER61C476ME15L	7
16	C40, C43, C44	CAP, CERM, 1uF, 16V, +/-10%, X7R, 0603	TDK	C1608X7R1C105K	3
17	C45	CAP, CERM, 47pF, 50V, +/-5%, C0G/NP0, 0402	MuRata	GRM1555C1H470JA01D	1
18	C51	CAP, CERM, 0.47uF, 16V, +/-10%, X5R, 0603	MuRata	GRM188R61C474KA93D	1
19	C53	CAP, CERM, 1000pF, 50V, +/-5%, C0G/NP0, 0603	MuRata	GRM1885C1H102JA01D	1
20	D1	Diode, Ultrafast, 100V, 0.25A, SOD-323	NXP Semiconductor	BAS316,115	1
21	D2, D3	Diode, Schottky, 100V, 1A, PowerDI123	Diodes Inc.	DFLS1100-7	2

Item	Designator	Description	Manufacturer	Part Number	Qty
22	D4, D10	Diode, Schottky, 40V, 0.2A, SOT-23	Central Semiconductor	CMPSH-3AE	2
23	D5, D9	Diode, Schottky, 40V, 0.2A, SOT-23	Central Semiconductor	CMPSH-3CE	2
24	D6	Diode, Zener, 11V, 200mW, SOD-323	Diodes Inc.	MMSZ5241BS-7-F	1
25	D7	Diode, Zener, 4.7V, 200mW, SOD-323	Diodes Inc.	MMSZ5230BS-7-F	1
26	D8	Diode, Schottky, 30V, 0.2A, SOD-323	Diodes Inc.	BAT54WS-7-F	1
27	D11	Diode, Zener, 8.2V, 200mW, SOD-323	Diodes Inc.	MMSZ5237BS-7-F	1
28	D12	Diode, Zener, 5.1V, 200mW, SOD-323	Diodes Inc.	MMSZ5231BS-7-F	1
29	L2, L3	Inductor, Shielded E Core, Ferrite, 4uH, 25A, 0.00194 ohm, SMD	Coilcraft	SER2014-402MLB	2
30	Q1, Q2, Q3, Q4, Q5, Q6, Q7, Q8	MOSFET, N-CH, 100V, 9.3A, PQFN 8L 5x6 A	International Rectifier	IRFH5053TRPBF	8
31	Q9, Q16	Transistor, NPN, 45V, 1A, SOT-89	Diodes Inc.	FCX690BTA	2
32	Q10, Q11, Q12, Q13, Q14, Q15	MOSFET N-CH 60V 100A LFPAK	NXP	PSMN5R5-60YS,115	6
33	Q17	Transistor, PNP, 40V, 0.2A, SOT-23	Central Semiconductor	CMPT3906 LEAD FREE	1
34	R2, R29	RES, 10.0k ohm, 1%, 0.1W, 0603	Vishay-Dale	CRCW060310K0FKEA	2
35	R3	RES, 100k ohm, 1%, 0.125W, 0805	Vishay-Dale	CRCW0805100KFKEA	1
36	R4	RES, 20 ohm, 5%, 0.125W, 0805	Vishay-Dale	CRCW080520R0JNEA	1
37	R5	RES, 2.49k ohm, 1%, 0.063W, 0402	Vishay-Dale	CRCW04022K49FKED	1
38	R6	RES, 0 ohm, 5%, 0.063W, 0402	Vishay-Dale	CRCW04020000Z0ED	1
39	R7	RES, 3.00 ohm, 1%, 0.25W, 1206	Yageo America	RC1206FR-073RL	1
40	R8, R12	RES, 499 ohm, 1%, 0.063W, 0402	Vishay-Dale	CRCW0402499RFKED	2
41	R9	RES, 1.69k ohm, 1%, 0.063W, 0402	Vishay-Dale	CRCW04021K69FKED	1
42	R10	RES, 1.00k ohm, 1%, 0.063W, 0402	Vishay-Dale	CRCW04021K00FKED	1
43	R11	RES, 100 ohm, 1%, 0.1W, 0603	Vishay-Dale	CRCW0603100RFKEA	1
44	R13	RES, 24k ohm, 5%, 0.063W, 0402	Vishay-Dale	CRCW040224K0JNED	1
45	R14, R15, R26, R27	RES, 10.0k ohm, 1%, 0.063W, 0402	Vishay-Dale	CRCW040210K0FKED	4
46	R16, R28	RES, 5.1k ohm, 5%, 0.125W, 0805	Panasonic	ERJ-6GEYJ512V	2
47	R17, R18	RES, 10.0 ohm, 1%, 1W, 1218	Vishay-Dale	CRCW121810R0FKEK	2

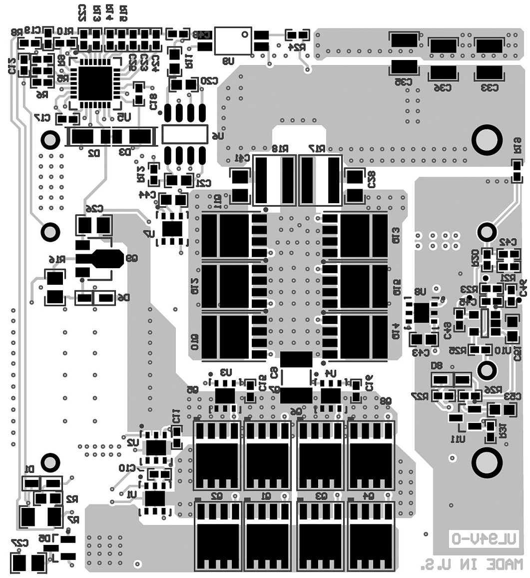
Item	Designator	Description	Manufacturer	Part Number	Qty
48	R19, R31	RES, 10 ohm, 5%, 0.063W, 0402	Vishay-Dale	CRCW040210R0JNED	2
49	R20	RES, 30.1k ohm, 1%, 0.063W, 0402	Vishay-Dale	CRCW040230K1FKED	1
50	R22	RES, 100 ohm, 1%, 0.063W, 0402	Vishay-Dale	CRCW0402100RFKED	1
51	R23	RES, 4.99k ohm, 1%, 0.063W, 0402	Vishay-Dale	CRCW04024K99FKED	1
52	R24	RES, 1.82k ohm, 1%, 0.063W, 0402	Vishay-Dale	CRCW04021K82FKED	1
53	R25	RES, 7.87k ohm, 1%, 0.063W, 0402	Vishay-Dale	CRCW04027K87FKED	1
54	R30	RES, 1.0k ohm, 5%, 0.063W, 0402	Vishay-Dale	CRCW04021K00JNED	1
55	T1	SMT Current Sense Transformer	Pulse Engineering	P8209NL	1
56	T2		CoilCraft	MA5519-AL	1
57	TP1, TP2, TP3, TP7, TP8	PCB Pin, TH	Mill-Max	3125-2-00-34-00-00-08-0	5
58	TP4, TP5	PCB Pin, Swage Mount, TH	Mill-Max	3231-2-00-34-00-00-08-0	2
59	U1, U2, U3, U4, U7, U8	Tiny 7A MOSFET Gate Driver, 6-pin LLP, Pb-Free	National Semiconductor	LM5112Q1SDX/NOPB	6
60	U5	100V Full-Bridge PWM Controller with Integrated MOSFET Drivers	National Semiconductor	LM5046SQ/NOPB	1
61	U6	ISOPro Low-Power Dual-Channel Digital Isolator	Texas Instruments	ISO7420FEDR	1
62	U9	Low Input Current, High CTR Photocoupler	California Eastern Laboratories	PS2811-1-M-A	1
63	U10	Single RRIO, High output Current and High Capacitive Load Op Amp	National Semiconductor	LM8261M5	1
64	U11	Precision Micropower Shunt Voltage Reference, 3-pin SOT-23, Pb-Free	National Semiconductor	LM4040BIM3-2.5/NOPB	1

PCB Layouts



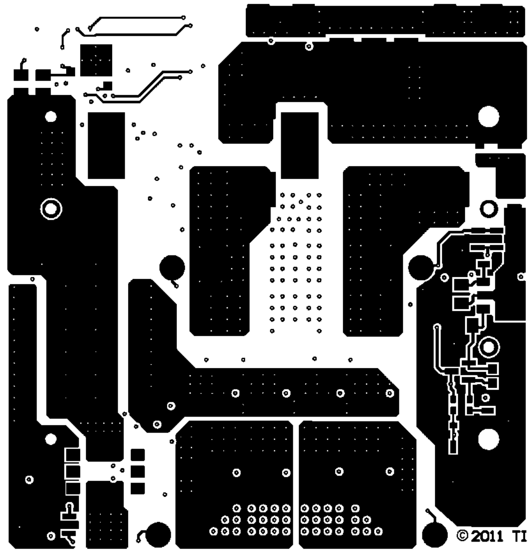
30184211

Top Side Assembly



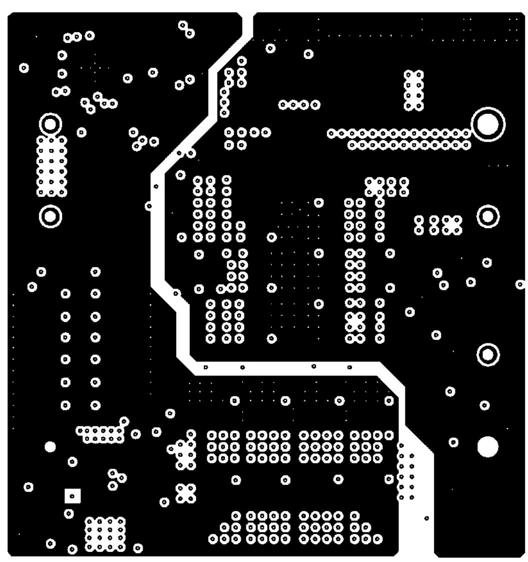
30184212

Bottom Side Assembly



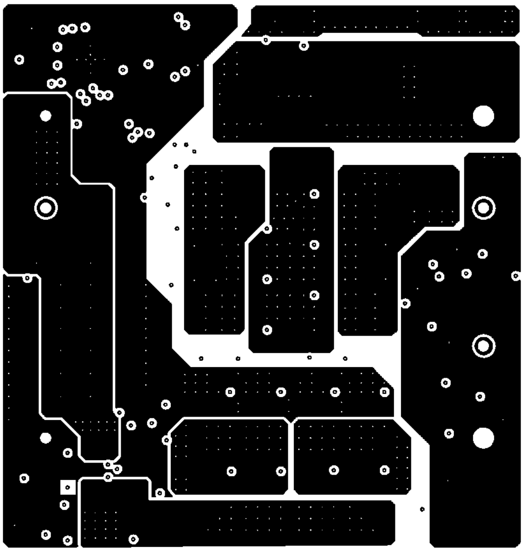
30184213

Top Layer 1



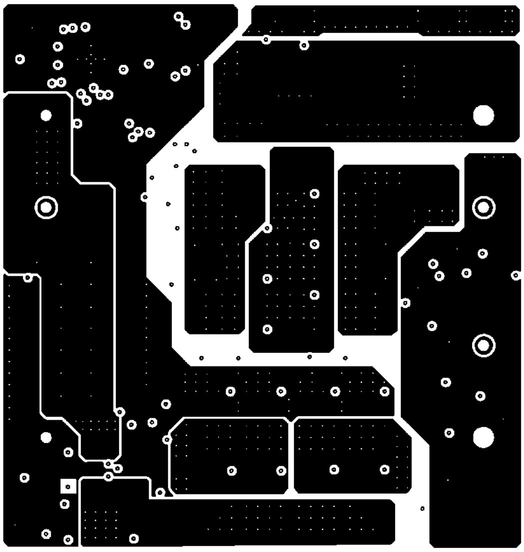
30184214

Layer 2



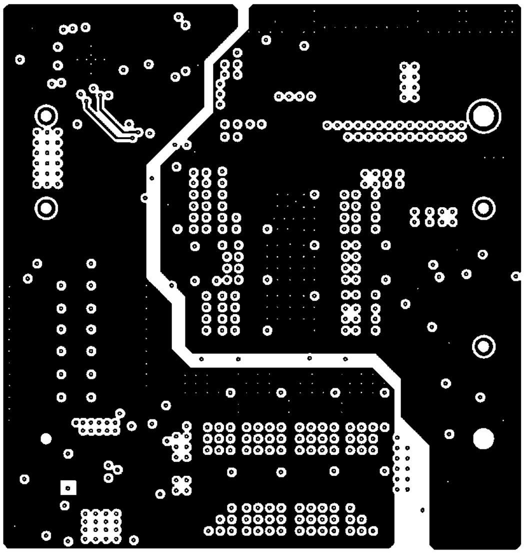
30184215

Layer 3



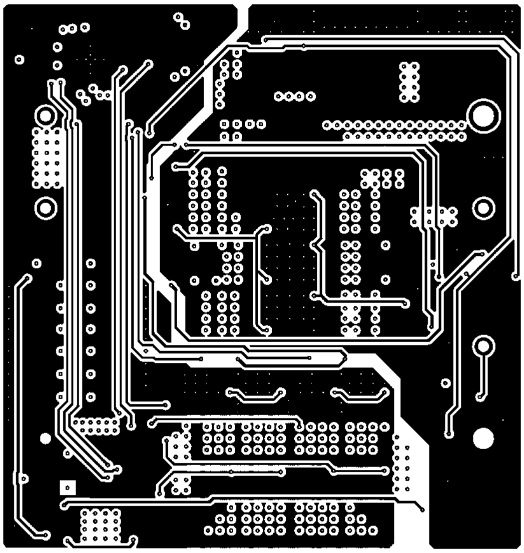
30184216

Layer 4



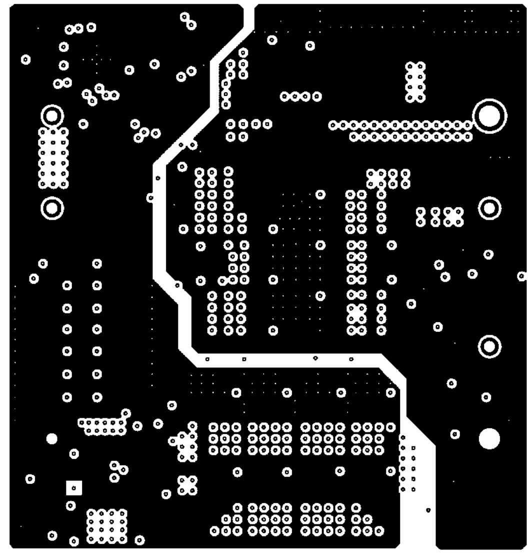
30184217

Layer 5



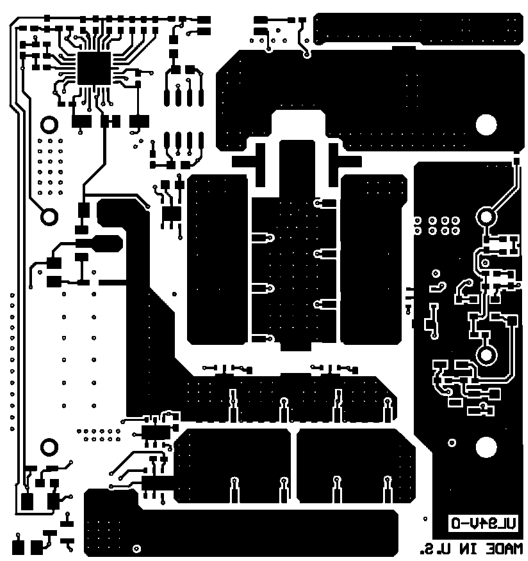
30184218

Layer 6



30184223

Layer 7



30184224

Bottom Layer

Notes

Notes