AN-2115 LM5046 Evaluation Board

1 Introduction

The LM5046 evaluation board is designed to provide the design engineer with a fully functional power converter based on the phase-shifted full-bridge topology to evaluate the LM5046 PWM controller. The evaluation board is provided in an industry standard quarter brick footprint.

The performance of the evaluation board is as follows:

- Input operating range: 36V to 75V
- Output voltage: 3.3V
- Measured efficiency at 48V: 92% @ 30A
- Frequency of operation: 420kHz
- Board size: 2.28 × 1.45 × 0.5 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 6 layers; 2 ounce copper outer layers and 3 ounce copper inner layers on FR4 material with a total thickness of 0.062 inches. The unit is designed for continuous operation at rated load at <40°C and a minimum airflow of 200 LFM.

2 Theory of Operation

The Phase-Shifted Full-Bridge (PSFB) topology is a derivative of the classic full-bridge topology. When tuned appropriately the PSFB topology achieves zero voltage switching (ZVS) of the primary FETs while maintaining constant switching frequency. The ZVS feature is highly desirable as it reduces both the switching losses and EMI emissions. Figure 1 illustrates the circuit arrangement for the PSFB topology. The power transfer mode of the PSFB topology is similar to the hard switching full-bridge, that is, when the FETs in the diagonal of the bridge are turned-on (Q1 and Q3 or Q2 and Q4), it initiates a power transfer cycle. At the end of the power transfer cycle, PWM turns off the switch Q3 or Q4 depending on the phase with a pulse width determined by the input and output voltages and the transformer turns ratio. In the freewheel mode, unlike the classic full-bridge where all the four primary FETs are off, in the PSFB topology the primary of the power transformer is shorted by activating either both the top FETs (Q1 and Q4) or both the bottom FETs (Q2 and Q3) alternatively. In a PSFB 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. Further, the ZVS of the primary FETs results in low EMI compared to the conventional hard-switching full-bridge topology.

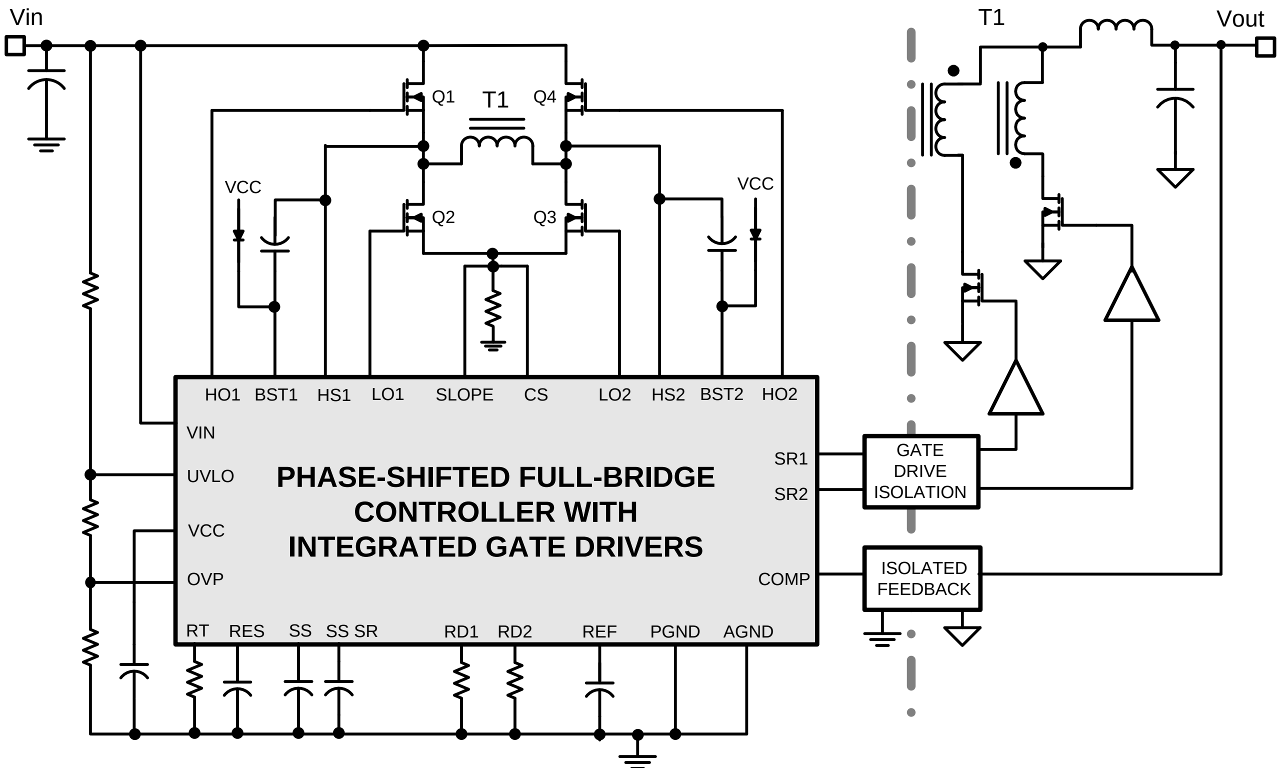


Figure 1. Simplified Full-Bridge Converter

The secondary side employs synchronous rectification scheme, which is controlled by the LM5046. In addition to the basic soft-start already described, the LM5046 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 until the error amplifier on the secondary side soft-starts, 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. 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 LM5046 evaluation board employs peak current mode control and a standard “type II” network is used for the compensator.

3 Powering and Loading Considerations

When applying power to the LM5046 evaluation board certain precautions need to be followed. A misconnection can damage the assembly.

4 Proper Connections

When operated at low input voltages the evaluation board can draw up to 3.5A of current at full load. The maximum rated output current is 30A. Be sure to choose the correct connector and wire size when attaching the source supply and the load. Monitor the current into and out of the evaluation board and monitor the voltage directly at the output terminals of the evaluation board, see Figure 2. The voltage drop across the load connecting wires will give inaccurate measurements. This is especially true for accurate efficiency measurements.

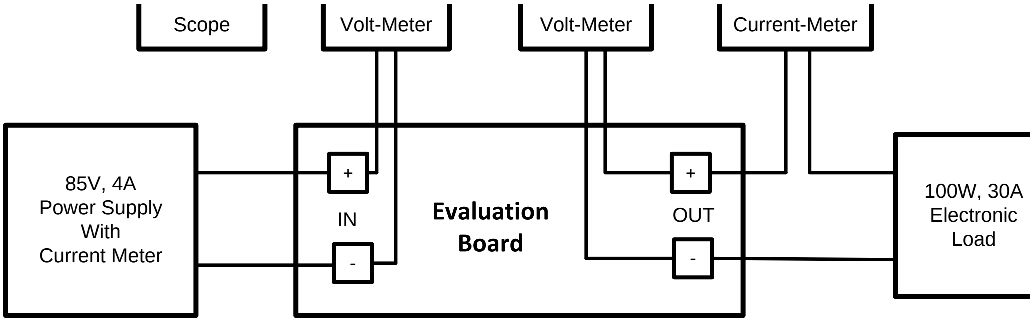


Figure 2. Evaluation Board Monitoring

5 Source Power

The evaluation board can be viewed as a constant power load. At low input line voltage (36V) the input current can reach 3.5A, while at high input line voltage (72V) the input current will be approximately 1.5A. Therefore, to fully test the LM5046 evaluation board a DC power supply capable of at least 85V and 4A is required. The power supply must have adjustments for both voltage and current.

The power supply and cabling must present low impedance to the evaluation board. Insufficient cabling or a high impedance power supply will droop during power supply application with the evaluation board inrush current. If large enough, this droop will cause a chattering condition upon power up. This chattering condition is an interaction with the evaluation board under voltage lockout, the cabling impedance and the inrush current.

6 Loading

An appropriate electronic load, with specified operation down to 3.0V minimum, is desirable. The resistance of a maximum load is 0.11Ω. The high output current requires thick cables! If resistor banks are used there are certain precautions to be taken. The wattage and current ratings must be adequate for a 30A, 100W supply. Monitor both current and voltage at all times. Ensure that there is sufficient cooling provided for the load.

7 Air Flow

Full power loading should never be attempted without providing the specified 200 LFM of air flow over the evaluation board. A stand-alone fan should be provided.

8 Powering Up

It is suggested that the load be kept low during the first power up. Set the current limit of the source supply to provide about 1.5 times the wattage of the load. As soon as the appropriate input voltage is supplied to the board, check for 3.3 volts at the output.

A most common occurrence, that will prove unnerving, is when the current limit set on the source supply is insufficient for the load. The result is similar to having the high source impedance referred to earlier. The interaction of the source supply folding back and the evaluation board going into undervoltage shutdown will start an oscillation, or chatter, that may have undesirable consequences.

A quick efficiency check is the best way to confirm that everything is operating properly. If something is amiss you can be reasonably sure that it will affect the efficiency adversely. Few parameters can be incorrect in a switching power supply without creating losses and potentially damaging heat.

9 Over Current Protection

The evaluation board is configured with hiccup over-current protection. In the event of an output overload (approximately 38A) the unit will discharge the SS capacitor, which disables the power stage. After a delay, programmed by the RES capacitor, the SS capacitor is released. If the overload condition persists, this process is repeated. Thus, the converter will be in a loop of shot bursts followed by a sleep time in continuous overload conditions. The sleep time reduces the average input current drawn by the power converter in such a condition and allows the power converter to cool down.

10 Performance Characteristics

Once the circuit is powered up and running normally, the output voltage is regulated to 3.3V with the accuracy determined by the feedback resistors and the voltage reference. The frequency of operation is selected to be 420 kHz, which is a good comprise between board size and efficiency. See Figure 3 for efficiency curves.

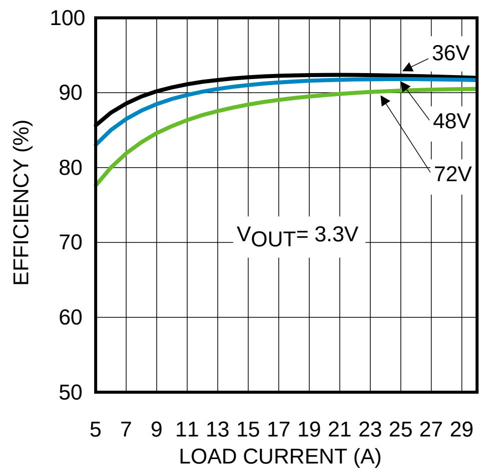
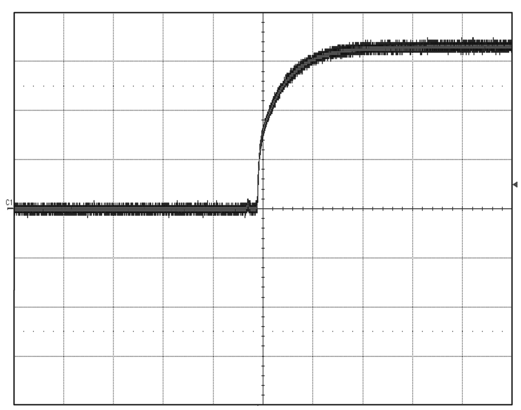


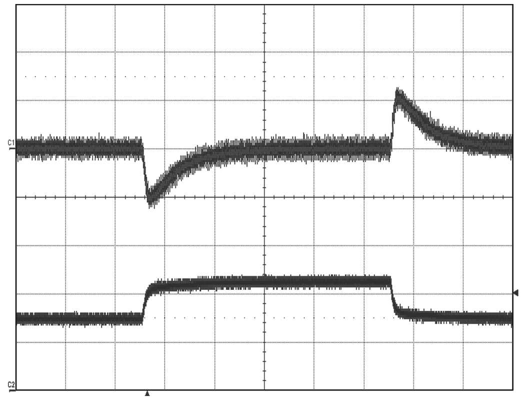
Figure 3. Application Board Efficiency

When applying power to the LM5046 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 4 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.



Conditions: Input Voltage = 48V
Output Current = 25A
Trace 1: Output Voltage Volts/div = 1V
Horizontal Resolution = 5.0 ms/div

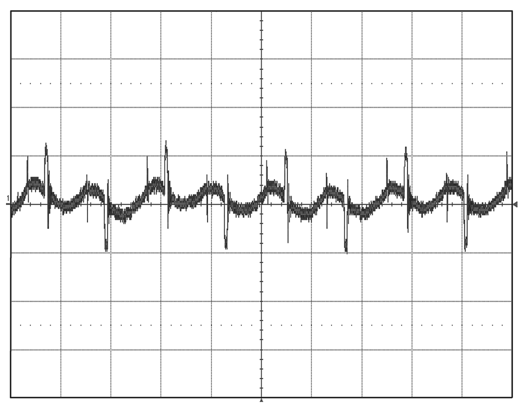
Figure 4. Soft-Start



Conditions: Input Voltage = 48V
Output Current = 15A to 22.5A to 15A
Upper Trace: Output Voltage Volts/div = 100mV
Lower Trace: Output Current = 10A/div
Horizontal Resolution = 200 µs/div

Figure 5. Transient Response

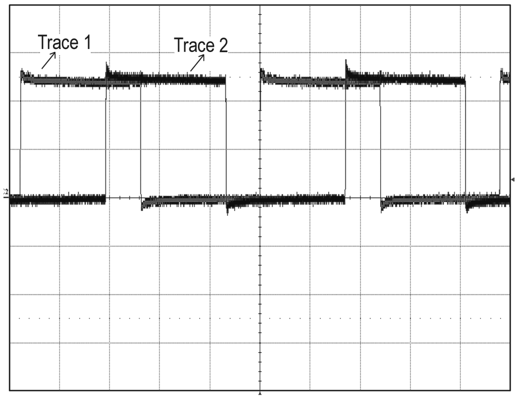
Figure 6 shows typical output ripple seen directly across the output capacitor, for an input voltage of 48V and a load of 30A. This waveform is typical of most loads and input voltages.



Conditions: Input Voltage = 48V, Output Current = 30A
Trace 1: Output Voltage Volts/div = 20mV
Bandwidth Limit = 20MHz
Horizontal Resolution = 2µs/div

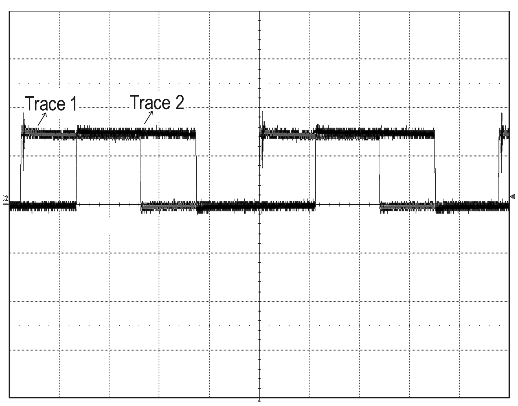
Figure 6. Output Ripple

Figure 7 and Figure 8 show the typical SW node voltage waveforms with a 30A load. Figure 7 shows an input voltage represents an input voltage of 48V and Figure 8 represents an input voltage of 72V. When one SW node is at the input voltage and the other SW node at the GND, it implies power transfer cycle, that is, FETs in the diagonal, Q1 and Q3, or Q2 and Q4, are activated. Further, when both the SW nodes are the same potential, that is, either at the input voltage or at the GND, it implies freewheeling mode.



Conditions: Input Voltage = 48V
Output Current = 30A
Trace 1: SW1 Node (Q2 Drain) Voltage Volts/div = 20V
Trace 2: SW2 Node (Q3 Drain) Voltage Volts/div = 20V
Horizontal Resolution = 1µs/div

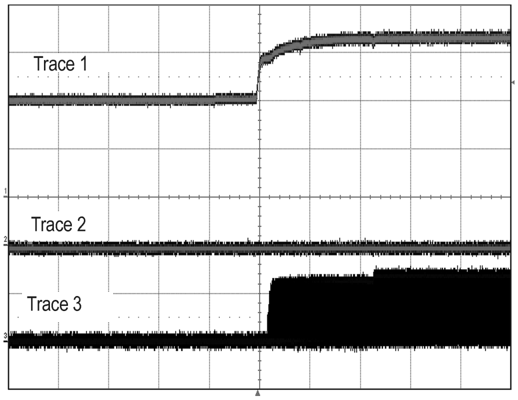
Figure 7. 48V Switch Node Waveforms



Conditions: Input Voltage = 72V
Output Current = 30A
Trace 1: SW1 Node (Q2 Drain) Voltage Volts/div = 50V
Trace 1: SW2 Node (Q3 Drain) Voltage Volts/div = 50V
Horizontal Resolution = 1 µs/div

Figure 8. 72V Switch Node Waveforms

Figure 9 shows a typical startup of the LM5046 evaluation board into a 2V pre-biased load. Trace 2 represents the output current that is monitored between the output caps of the power converter and the 2V pre-bias voltage supply. It can be inferred from the Trace 2 that the SR MOSFETs do not sink any current during the power-up into pre-biased load.



Conditions: Input Voltage = 48V, Output Pre-Bias = 2V
Trace 1 (Channel 1): Output Voltage Volts/div = 1V
Trace 2 (Channel 2): Output Current Amps/div = 200mA
Trace 3 (Channel 3): SR Gate Voltage Volts/div = 5V

Figure 9. Soft-Start into 2V Pre-Biased Load

11 Bill of Materials

Item	Designator	Description	Manufacturer	Part Number
1	AA	Printed Circuit Board	TBD	
2	C1, C2, C3, C4	Ceramic 2.2uF X7R 100V 10% 1210	MuRata	GRM32ER72A225KA35L
3	C35	Ceramic 4.7uF X7R 16V 10% 0805	MuRata	GRM21BR71C475KA73L
4	C5	Ceramic 2.2uF X7R 16V 10% 0805	MuRata	GRM21BR71C225KA12L
5	C7, C8	Ceramic 2.2uF X5R 25V 10% 0805	TDK	GRM21BR71E225KA73L
6	C9	CAP CERM 1uF X7R 50V 10% 0805	MuRata	GRM21BR71H105KA12L
7	C10, C11	Ceramic 1uF X7R 16V 10% 0603	TDK	C1608X7R1C105K
8	C12, C15, C21, C32	Ceramic 0.1uF X7R 25V 10% 0603	AVX	06033C104KAT2A
9	C13	CAP CERM X7R 2000V 2700pF 10%	Kemet	C1808C272KGRACTU
10	C14	CAP CERM 0.1uF 100V +/- 10% X7R 0603	MuRata	GRM188R72A104KA35D
11	C16, C23	Ceramic C0G/NP0 470pF 100V 10% 1206	AVX	12061A471KAT2A
12	C17, C39	CAP 330uF 4V AL 4V 20% 0.012 Ohm ESR	Panasonic	EEF-UE0G331R
13	C18, C19, C20	CAP CERM 47uF X7R 6.3V 10%	MuRata	GCM32ER70J476KE19L
14	C22	Ceramic 0.022uF 16V +/-10% X7R 0402	TDK	C1005X7R1C223K

Item	Designator	Description	Manufacturer	Part Number
15	C34, C36	Ceramic 1000pF 25V +/-5% C0G/NP0 0402	TDK	C1005C0G1E102J
16	C26, C27	Ceramic 1uF 16V +/-20% X7R 0805	MuRata	GRM21BR71C105MA01L
17	C28, R20, D4, L3	NU	NU	NU
18	C29	Ceramic 47pF 50V +/-5% C0G/NP0 0402	MuRata	GRM1555C1H470JZ01
19	C30, C40	Ceramic 100pF C0G/NP0 50V 5% 0603	TDK	C1608C0G1H101J
20	C24	CAP CERM 0.056uF 6.3V +/-10% X7R 0402	Kemet	C0402C563K9RACTU
21	C25, C31, C37, C33	CAP CERM 0.01uF 16V +/-10% X7R 0402	TDK	C1005X7R1C1103K
22	C38	CAP CERM 0.47uF 6.3V +/-20% X5R 0402	TDK	C1005X5R0J474K
23	D1	Vr=100V Ir=150mA Vf=0.7V Schottky	Vishay	BAT46JFILM
24	D2	Vr=30V Io=1A Vf=0.38V	Diodes Inc	B130LAW-7-F
25	D3, D7, D10	Vr=40V Io=0.2A Vf=0.65V Common Cathode	Central Semiconductor	CMPSH-3CE
26	D5	SMT 5.1V Zener Diode	Diodes Inc	MMSZ5231B
27	D6	SMT 8.2V Zener Diode	Central Semiconductor	CMHZ4694
28	D8, D12	Vr=100V Io=1A Vf=0.77V Schottky diode	Diodes Inc	DFLS1100-7
29	D9, D13	Vr=40V Io=0.2A Vf=0.65V Common Anode	Central Semiconductor	CMPSH-3AE
30	D11	SMT 11V Zener Diode	Central Semiconductor	CMHZ4698
31	D16	Vr=30V Io=0.2A Vf=0.7V Schottky	Diodes Inc	BAT54WS-7-F
32	D17	Zener Diode 4.7V 250mW SOD-323	Central Semiconductor	CMDZ4L7
33	L1	Shielded Drum Core 2.2uH 4.15A 0.0165 Ohm	Coiltronics	DR73-2R2-R
34	L2	Shielded Drum Core 0.08A 11 Ohm	Coilcraft Inc	LPS5030-225MLB
35	L4	Inductor, Shielded E Core, Ferrite, 800nH 45A 0.0009 Ohm SMD	Coilcraft	SER2010-801MLB
36	P1, P3, P5, P6	PCB Pin	Mill-Max	3104-2-00-34-00-00-08-0
37	P2	Test Point, SMT, Miniature	Keystone Electronics	5015
38	P4, P7	PCB Pin	Mill-Max	3231-2-00-34-00-00-08-0
39	Q1, Q3	NPN 2A 45V	Diodes Inc	FCX690BTA
40	Q2	PNP 0.2A 40V	Central Semiconductor	CMPT3906
41	Q4, Q5, Q10, Q11	32A 18nC rDS(on) @ 4.5V = .002 Ohms	Texas Instruments	CSD17303Q5
42	Q6, Q7, Q8, Q9	MOSFET N-CH 100V 9.3A PQFN 8L 5x6 A	International Rectifier	IRFH5053TRPBF
43	R1	RES 10 Ohm 1% 0.125W 0805	Vishay-Dale	CRCW080510R0FKEA
44	R2, R28, R33, R36	RES 10K Ohm 1% 0.063W 0402	Vishay-Dale	CRCW040210K0FKED
45	R3, R4	RES 5.1K Ohm 5% 0.125W 0805	Panasonic	ERJ-6GEYJ512V
46	R5	RES 1.0K Ohm 5% 0.125W 0805	Vishay-Dale	CRCW08051K00FKEA
47	R6	RES 100K Ohm 1% 0.125W 0805	Vishay-Dale	CRCW0805100KFKEA

Item	Designator	Description	Manufacturer	Part Number
48	R7	RES 2.61K Ohm1% 0.063W 0402	Vishay-Dale	CRCW04022K61KFKED
49	R8	RES 20 Ohm 1/8W 5% 0805 SMD	Panasonic	ERJ-6GEYJ200V
50	R9	RES 1.58K Ohm, 1% 0.063W 0402	Vishay-Dale	CRCW04021K58FKED
51	R10, R12	RES 0 Ohm, 5% 0.063W 0402	Yageo America	RC0402JR-070RL
52	R11, R17	RES 4.99 Ohm, 1% 0.25W 1206	Vishay-Dale	CRCW12064R99FNEA
53	R13	RES 3.4K Ohm, 1% 0.063W 0402	Vishay-Dale	CRCW0402340FKED
54	R14	RES 24K 5% 0.063W 0402	Vishay-Dale	CRCW040224K0JNED
55	R15, R16	RES 20K Ohm, 1% 0.063W 0402	Vishay-Dale	CRCW040220K0FKED
56	R18	RES 15.0 Ohm 1% 0.063W 0402	Vishay-Dale	CRCW040215R0FKED
57	R19, R31	RES 10.0 Ohm, 1% 0.063W 0402	Vishay-Dale	CRCW040210R0FKED
58	R21	RES 1.0K Ohm 1/16W 5% 0402 SMD	Vishay-Dale	CRCW04021K00JNED
59	R22	RES 25.5K Ohm,1% 0.063W 0402	Vishay-Dale	CRCW040225K5FKED
60	R23	RES 499 Ohm, 1% 0.063W 0402	Vishay-Dale	CRCW0402499RFKED
61	R24	RES 5.11K Ohm, 1% 0.063W 0402	Vishay-Dale	CRCW04025K11FKED
62	R25, R26	NU	Vishay-Dale	NU
63	R27	RES 47 Ohm .25W 5% 0603 SMD	Vishay-Dale	CRCW060347R0JNEAHP
64	R32	RES 100 Ohm, 1% 0.063W 0402	Vishay-Dale	CRCW0402100RFKED
65	R29	RES 15K Ohm,1% 0.063W 0402	Vishay-Dale	CRCW040215K0FKED
66	R30	RES 1.82K Ohm,1% 0.063W 0402	Vishay-Dale	CRCW04021K82FKED
67	R37	RES 0.0 Ohm, 5% 0.063W 0402	Vishay-Dale	CRCW04020000Z0ED
68	T1	High Frequency Planar Transformer	Pulse Engineering	PA0876.003NL
69	T2	SMT Current Sense Transformer	Pulse Engineering	PA1005.100NL
70	U1	Phase Shifted Full-Bridge PWM Controller	Texas Instruments	LM5046
71	U2	Dual 5A Compound Gate Driver with Negative Output Voltage Capability	Texas Instruments	LM5110
72	U3	Low Input Current, High CTR Photocoupler	NEC	PS2811-1-M-A
73	U4	RRIO, High Output Current & Unlimited Cap Load Op Amp in SOT23-5	Texas Instruments	LM8261
74	U5	Precision Micropower Shunt Voltage Reference	Texas Instruments	LM4041
75	U6	ISOPro Low-Power Dual-Channel Digital Isolator	Silicon Laboratories Inc	Si8420BB-D-IS

12 PCB Layouts

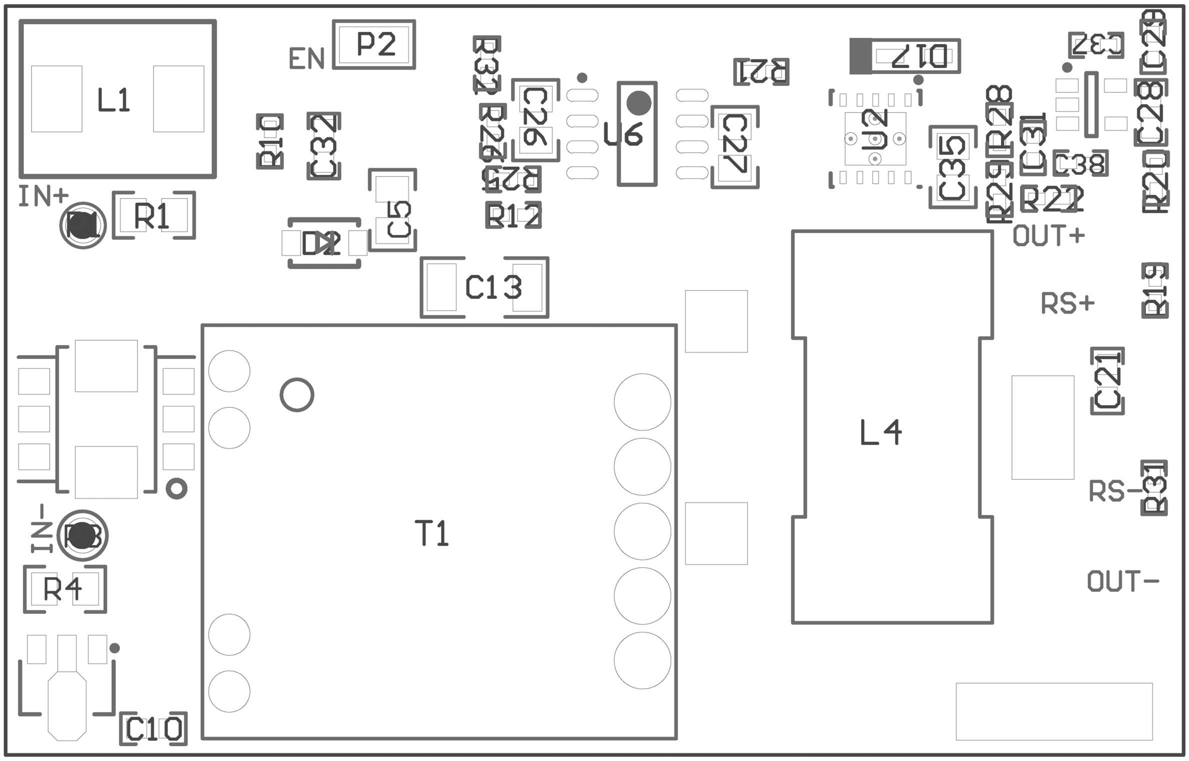


Figure 10. Top Side Assembly

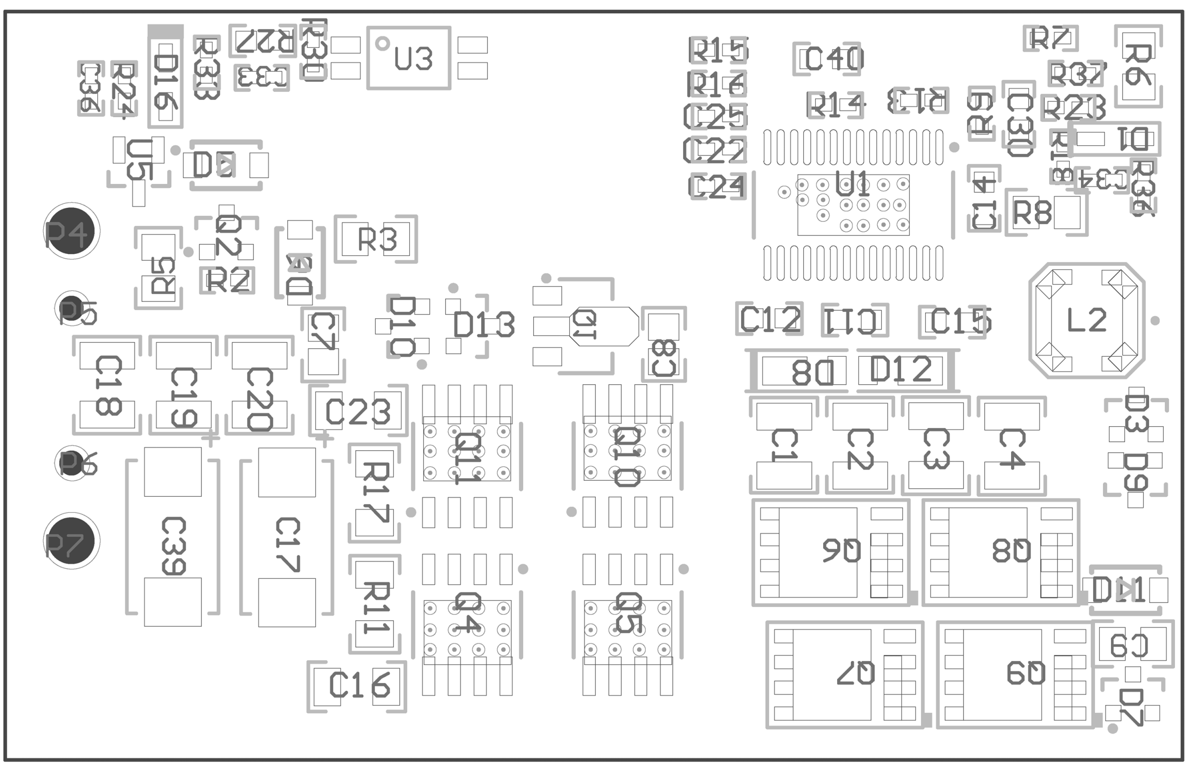


Figure 11. Bottom Side Assembly

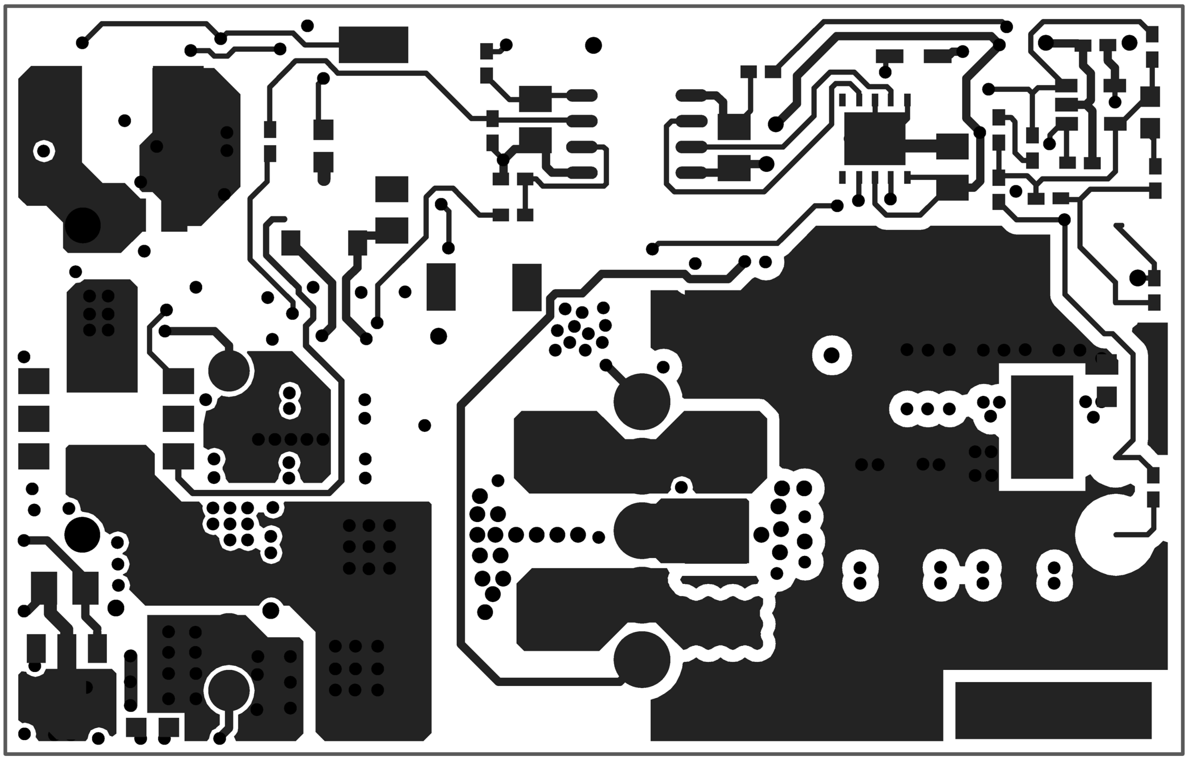


Figure 12. Layer 1 (Top Side)

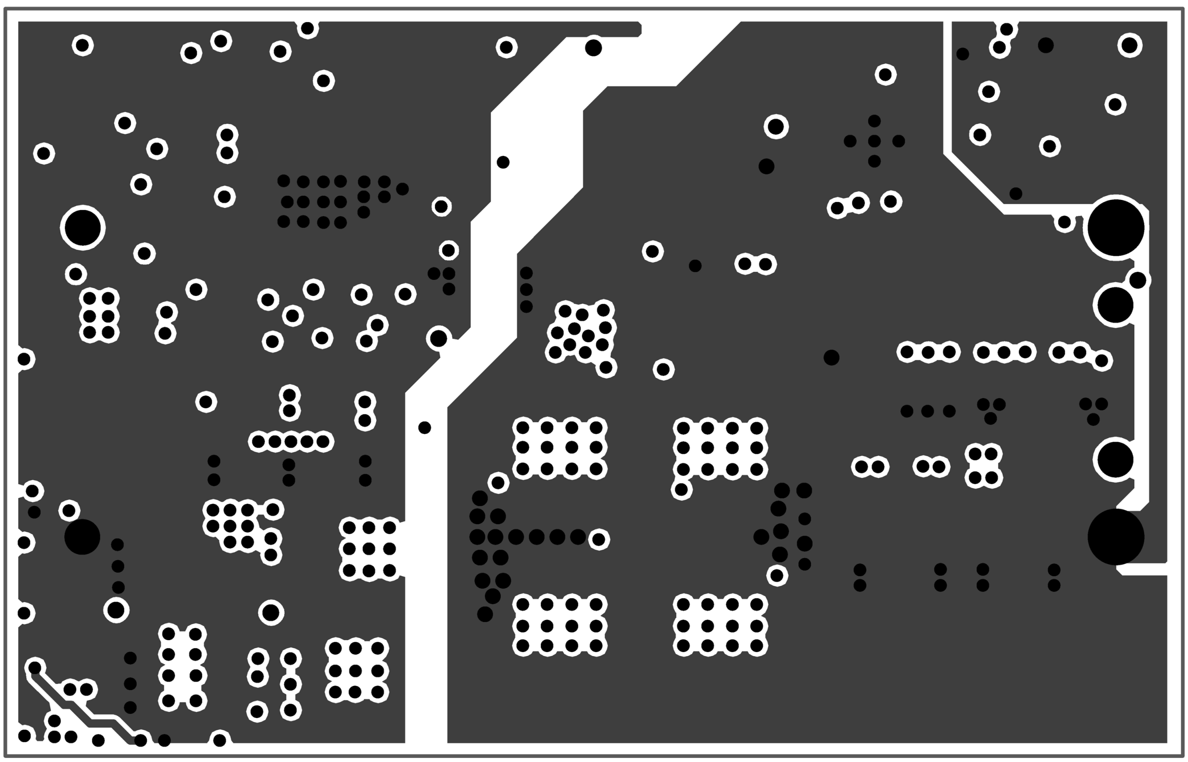


Figure 13. Layer 2

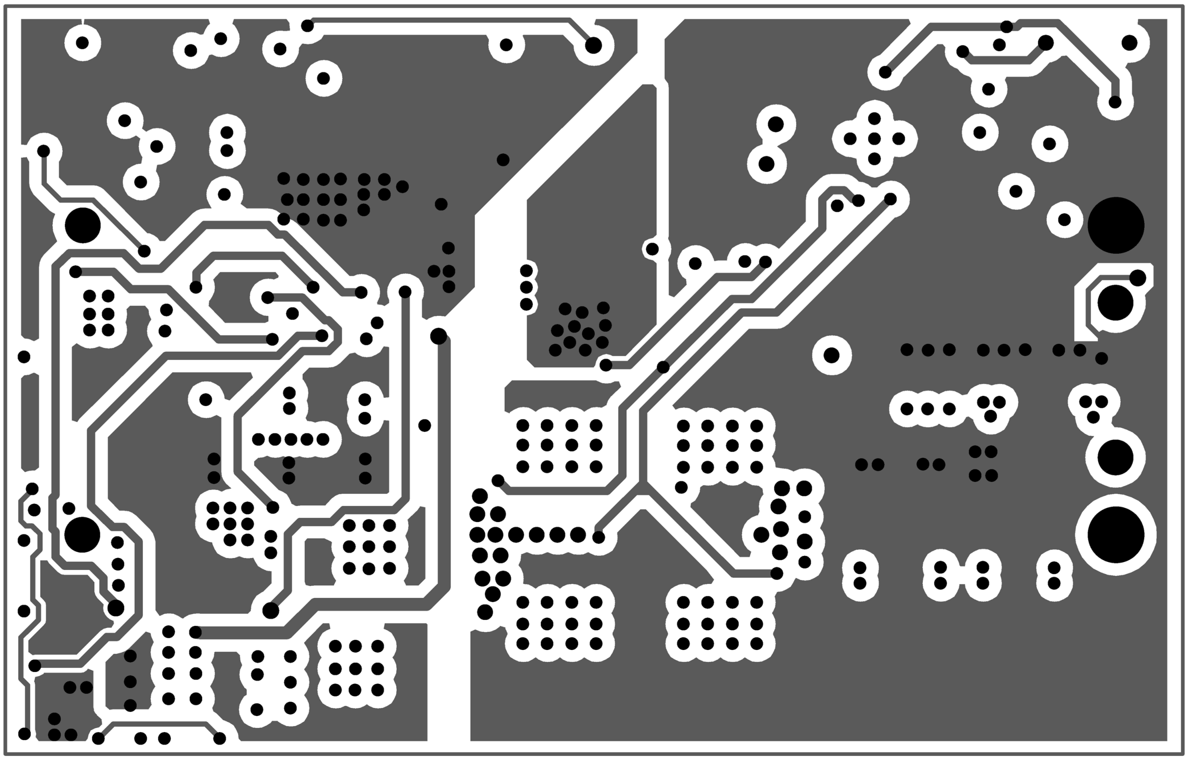


Figure 14. Layer 3

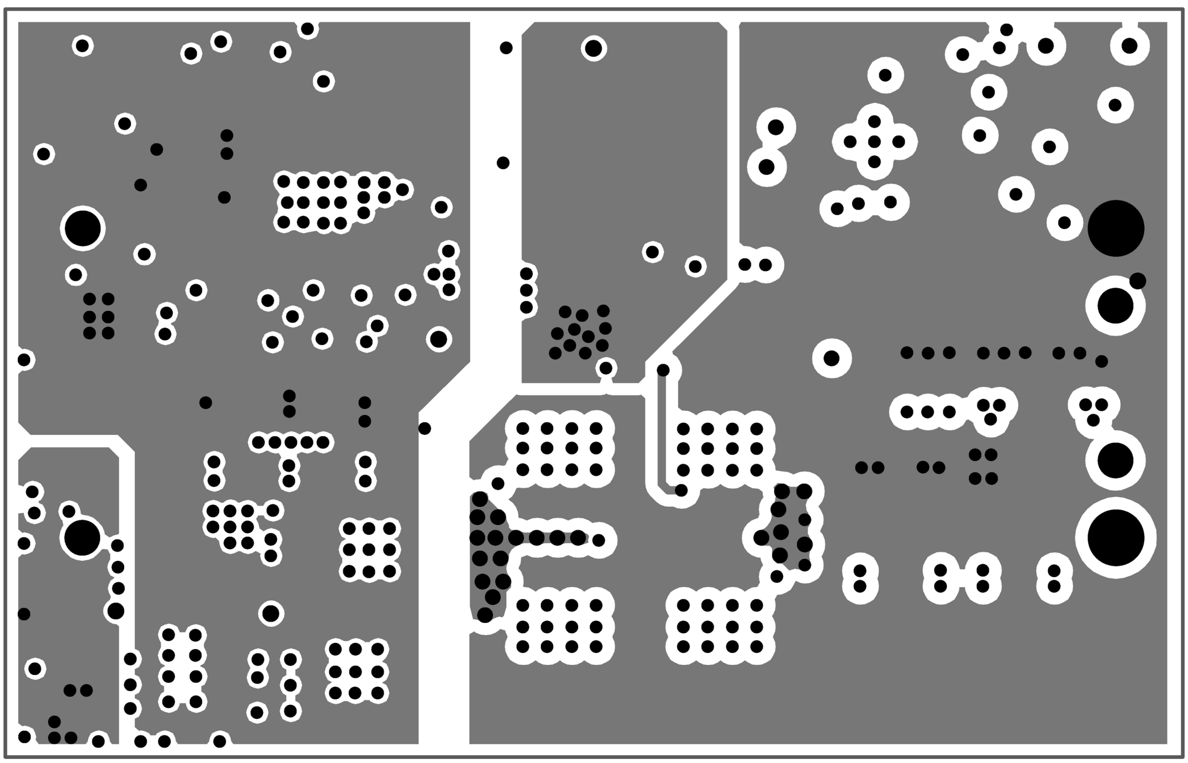


Figure 15. Layer 4

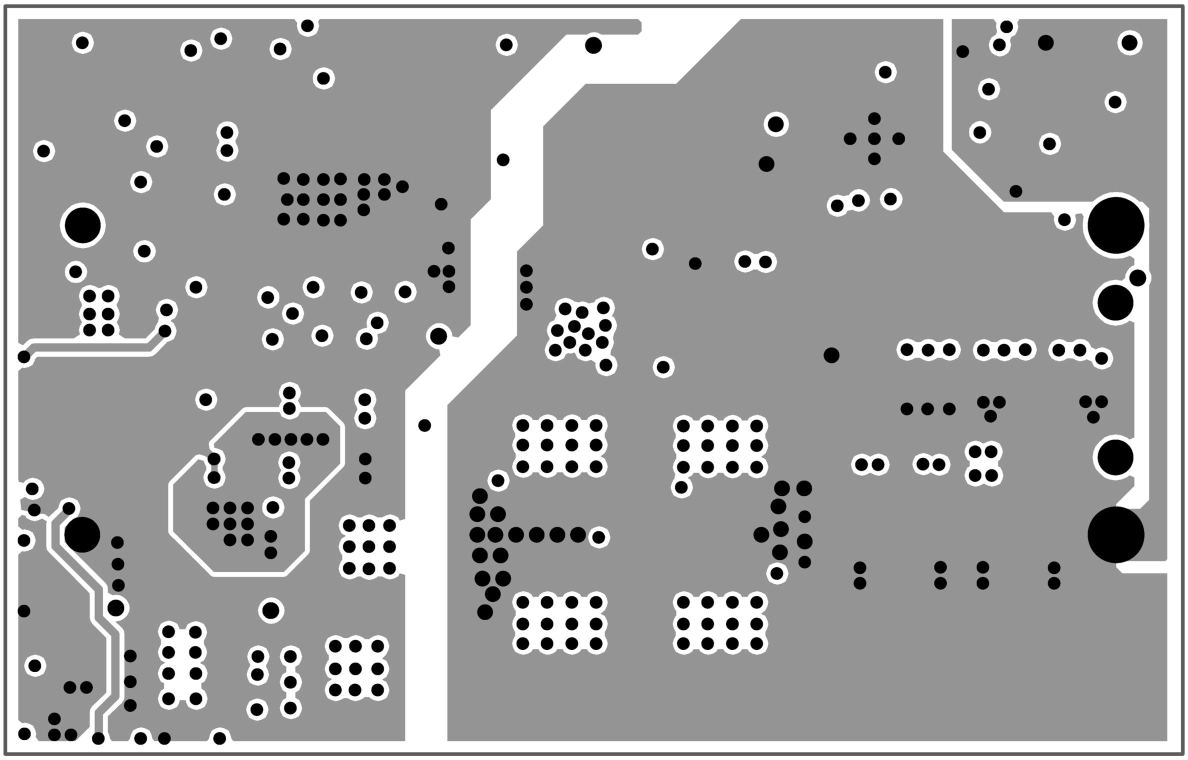


Figure 16. Layer 5

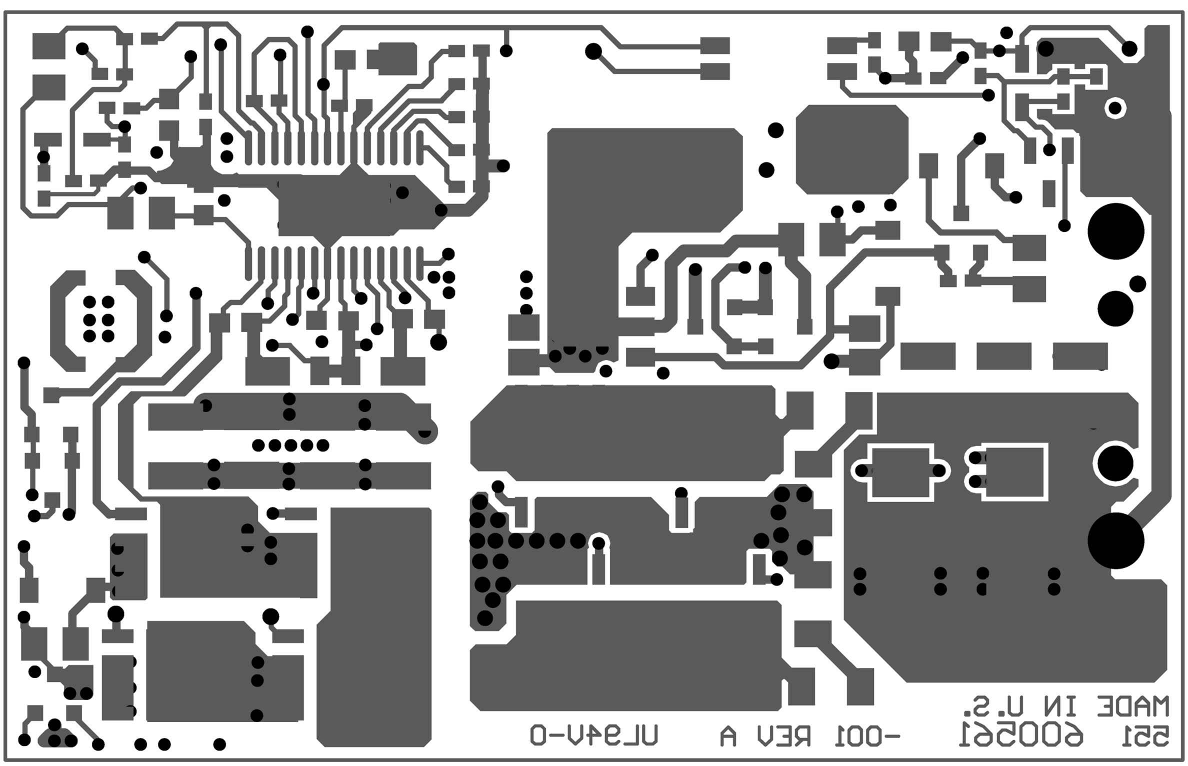


Figure 17. Layer 6 (Bottom Side)

13 Application Circuit

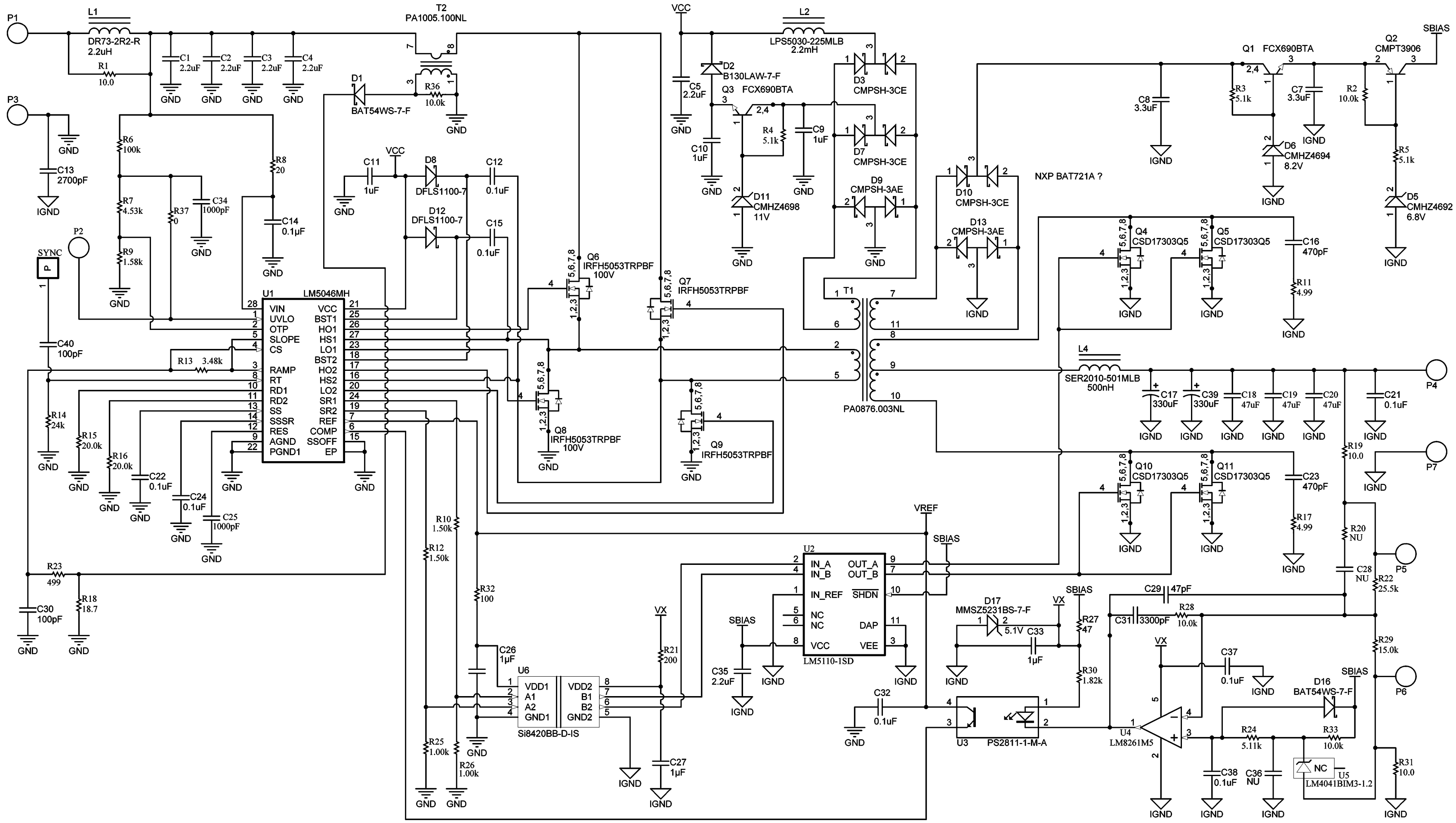


Figure 18. Application Circuit: Input 36V to 75V, Output 3.3V at 30A

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