# LM5045 Evaluation Board

Texas Instruments Application Note 2111 Ajay Hari February 20, 2012



### Introduction

The LM5045 evaluation board is designed to provide the design engineer with a fully functional power converter based on the full-bridge topology to evaluate the LM5045 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 x 1.45 x 0.5 inches

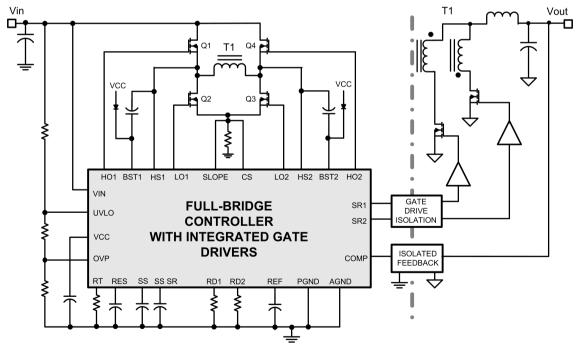
Load Regulation: 0.2% Line Regulation: 0.1% Line UVLO (34V/32V on/off)

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.

## **Theory of Operation**

Power converters based on the full-bridge topology offer highefficiency and good power handling capability up to 500W. Figure 1 illustrates the circuit arrangement for the full-bridge topology. 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 across the primary of the transformer. The resulting secondary voltage is then rectified and filtered with an LC filter to provide a smoothened output voltage. 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. Further, in a half-bridge topology, during power transfer when one of the primary switches is active, the voltage across the primary of the power transformer is 1/2 the input voltage (VIN) compared to a full VIN in a full-bridge topology. Therefore, for a given power, the primary current will be half as much for the full-bridge as compared to the half-bridge. The reduced primary current enables higher efficiency as compared to a halfbridge at high load currents.



Simplified Full-Bridge Converter

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The secondary side employs synchronous rectification scheme, which 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 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. Once the soft-start is finished, the synchronous rectifiers are engaged with a nonoverlap 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.

# Powering and Loading Considerations

When applying power to the LM5045 evaluation board certain precautions need to be followed. A misconnection can damage the assembly.

## **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. Monitor the voltage directly at the output terminals of the evaluation board. The voltage drop across the load connecting wires

will give inaccurate measurements. This is especially true for accurate efficiency measurements.

#### **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 LM5045 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.

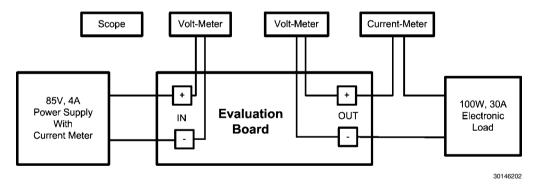
The power supply and cabling must present low impedance to the evaluation board. Insufficient cabling or a high impedance power supply will droop during power supply application with the evaluation board inrush current. If large enough, this droop will cause a chattering condition upon power up. This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

## Loading

An appropriate electronic load, with specified operation down to 3.0V minimum, is desirable. The resistance of a maximum load is  $0.11\Omega$ . 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

#### 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.



# **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.

#### **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.

### **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. Please refer to the figure 1. for efficiency curves.

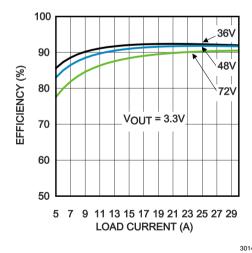
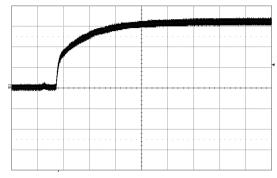


FIGURE 1. Application Board Efficiency

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 startup with a 48V input and a load of 25A. There is no overshoot during start-up.



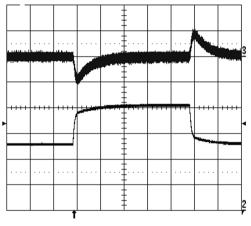
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Conditions: Input Voltage = 48V

Output Current = 25A

Trace 1: Output Voltage Volts/div = 1V Horizontal Resolution = 2.0 ms/div

#### FIGURE 2. Soft-Start



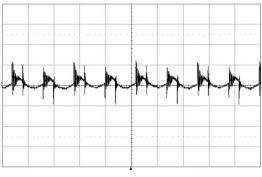
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Conditions: Input Voltage = 48V Output Current = 15A to 22.5A to 15A Upper Trace: Output Voltage Volts/div = 100mV

Lower Trace: Output Current = 5A/divHorizontal Resolution =  $200 \mu s/div$ 

**FIGURE 3. Transient Response** 

Figure 4 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.

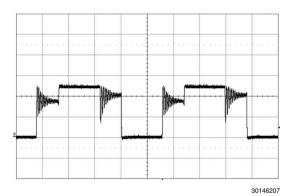


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Conditions: Input Voltage = 48V, Output Current = 30A Trace 1: Output Voltage Volts/div = 50mV Bandwidth Limit = 20MHz Horizontal Resolution = 2 µs/div

#### FIGURE 4. Output Ripple

Figures 5 and 6 show the typical SW node voltage waveforms with a 25A load. Figure 5 shows an input voltage represents an input voltage of 48V and Figure 6 represents an input voltage of 72V.



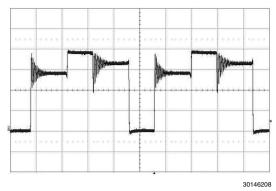
Conditions: Input Voltage = 48V

Output Current = 30A

Trace 1: SW1 Node (Q2 Drain) Voltage Volts/div = 20V

Horizontal Resolution = 1µs/div

#### FIGURE 5. Switch Node Waveforms



Conditions: Input Voltage = 72V

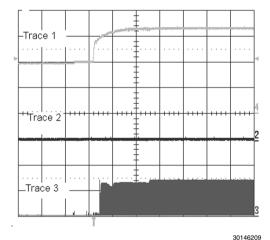
Output Current = 30A

Trace 1: SW1 Node (Q2 Drain) Voltage Volts/div = 20V

Horizontal Resolution = 1 µs/div

#### FIGURE 6. Switch Node Waveforms

Figure 7 shows a typical startup of the LM5045 into a 2V prebiased 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 MOSFET's do not sink any current during the power-up into pre-biased load.



Conditions: Input Voltage = 48V, Output Pre-Bias = 2V

Trace 1 (Channel 4): Output Voltage Volts/div = 1V

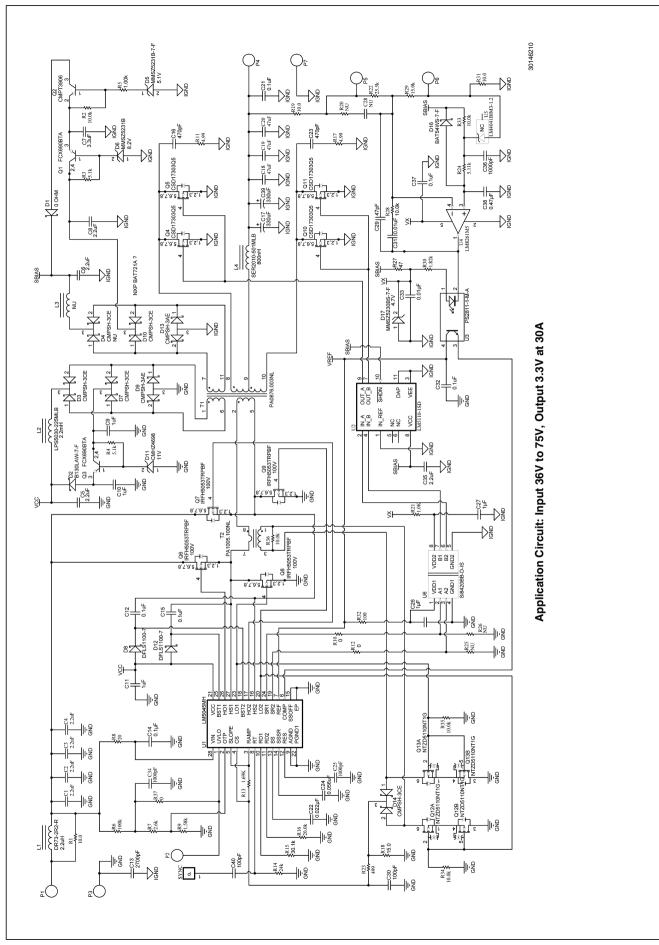
Trace 2 (Channel 2): Output Current Amps/div = 200mA

Trace 3 (Channel 3): SR Gate Voltage Volts/div = 5V

FIGURE 7. Soft-Start into 2V Pre-Biased Load

#### **5V Evaluation Board**

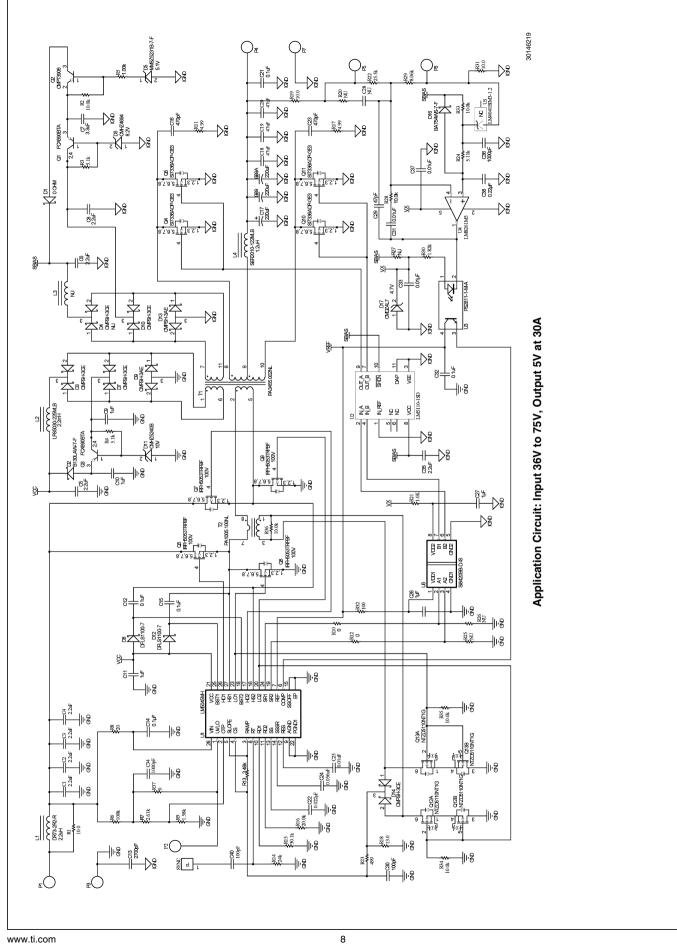
The LM5045 evaluation board can be easily modified to achieve a 5V output at 30A load. The 5V board schematic and the Bill of Materials change required to achieve it are shown on Pages 8 and 9. A peak efficiency of 93% was observed at 48V input and 5V out at 30A.



# Bill of Materials

Item	Designator	Description	Part Number
1	AA	Printed Circuit Board	
2	C1, C2, C3, C4	Ceramic 2.2uF, X7R, 100V, 10%, 1210	GRM32ER72A225KA35L
3	C5, C35	Ceramic 2.2uF, X7R, 16V, 10%, 0805	GRM21BR71C225KA12L
4	C7, C8	Ceramic, 2.2uF, X5R, 25V, 10%, 0805	GRM21BR71E225KA73L
5	C9	Ceramic, 1uF, X7R, 50V, 10%, 0805	GRM21BR71H105KA12L
6	C6	Ceramic 2.2uF 10V X7R 0603	GRM188R71A225KE15D
7	C10, C11	Ceramic, 1uF, X7R, 16V, 10%, 0603	C1608X7R1C105K
8	C12, C15, C21, C32	Ceramic,0.1uF, X7R, 25V, 10%, 0603	06033C104KAT2A
9	C13	Ceramic, X7R,2000V, 2700pF,10%	C1808C272KGRACTU
10	C14	Ceramic 0.1uF, 100V, +/-10%, X7R, 0603	GRM188R72A104KA35D
11	C16, C23	Ceramic, C0G/NP0 470pF, 100V, 10%, 1206	12061A471KAT2A
12	C17, C39	Cap 330uF, 4V, AL, 4V, 20%, 0.012 ohm ESR	EEF-UE0G331R
13	C18, C19, C20	Ceramic 47uF, X7R, 6.3V, 10%	GCM32ER70J476KE19L
14	C22	Ceramic 0.022uF, 16V, +/-10%, X7R, 0402	C1005X7R1C223K
15	C34, C36	Ceramic 1000pF, 25V, +/-5%, C0G/NP0, 0402,	C1005C0G1E102J
16	C26, C27	Ceramic 0.47uF, 16V, +/-20%, X7R, 0805	GRM21BR71C474KCO1D
17	C28, R20, D4, L3	NU	NU
18	C29	Ceramic 47pF, 50V, +/-5%, C0G/NP0, 0402	GRM1555C1H470JZ01
19	C30, C40	Ceramic 100pF, C0G/NP0, 50V, 5%, 0603	C1608C0G1H101J
20	C24	CAP, CERM, 0.056uF, 6.3V, +/-10%, X7R, 0402	C0402C563K9RACTU
21	C25, C31, C37, C33	CAP, CERM, 0.01uF, 16V, +/-10%, X7R, 0402	C1005X7R103K
22	C38	CAP, CERM, 0.47uF, 6.3V, +/-10%, X5R, 0402	C1005X5R0J474K
23	D2	Vr = 30V, Io = 1A, Vf = 0.38V	B130LAW-7-F
24	D3, D7, D10, D14	Vr = 40V, Io = 0.2A, Vf = 0.65V, Common Cathode	CMPSH-3CE
25	D5	SMT 5.1V Zener Diode	MMSZ5231B
26	D6	SMT 8.2V Zener Diode	CMHZ4694
27	D8, D12	Vr = 100V, Io = 1A, Vf = 0.77V, Schottky diode	DFLS1100-7
28	D9, D13	Vr = 40V, Io = 0.2A, Vf = 0.65V, Common Anode	CMPSH-3AE
29	D11	SMT 11V Zener Diode	CMHZ4698
30	D16	Vr = 30V, Io = 0.2A, Vf = 0.7V, Schottky	BAT54WS-7-F
31	D17	Diode, Zener, 4.7V, 250mW, SOD-323	CMDZ4L7
32	L1	Shielded Drum Core, 2.2uH 4.15A, 0.0165 ohm	DR73-2R2-R
33	L2	Shielded Drum Core, 0.08A, 11 ohm	LPS5030-225MLB
34	L3	NU	NU
35	L4	Inductor, Shielded E Core, Ferrite, 800nH, 45A, 0.0009 ohm, SMD	SER2010-801MLB

Item	Designator	Description	Part Number	
36	P1, P3, P5, P6	PCB Pin	3104-2-00-34-00-00-08-0	
37	P2	Test Point, SMT, Miniature	5015	
38	P4, P7	PCB Pin	3231-2-00-34-00-00-08-0	
39	Q1, Q3	NPN, 2A, 45V	FCX690BTA	
40	Q2	PNP, 0.2A, 40V	CMPT3906	
41	Q4, Q5, Q10, Q11	32A, 18nC, rDS(on) @ 4.5V = .002 ohm	CSD17303Q5	
42	Q6, Q7, Q8, Q9	MOSFET, N-CH, 100V, 9.3A, PQFN 8L 5x6 A	IRFH5053TRPBF	
43	Q12, Q13	0.31A, 0.7nC, rDS(on) @ 4.5V =2.5 ohm	NTZD5110NT1G	
44	R1	RES 10 ohm 1%, 0.125W, 0805	CRCW080510R0FKEA	
45	R2, R28, R33, R34, R35, R36	RES 10K ohm 1%, 0.063W, 0402	CRCW040210k0FKED	
46	R3, R4	RES 5.1K ohm 5%, 0.125W, 0805	ERJ-6GEYJ512V	
47	R5	RES 1K ohm, 5.1, 0.125W, 0805	CRCW08051K00FKEA	
48	R6	RES 100K ohm,1%, 0.125W, 0805	CRCW0805100KFKEA	
49	R7	RES, 2.61k ohm, 1%, 0.063W, 0402	CRCW04022K61FKED	
50	R8	RES 20 ohm 1/8W 5% 0805 SMD	ERJ-6GEYJ200V	
51	R9	RES, 1.58k ohm, 1%, 0.063W, 0402	CRCW04021K58FKED	
52	R10, R12	RES, 0 ohm, 5%, 0.063W, 0402	RC0402JR-070RL	
53	R11, R17	RES 4.99 ohm,1%, 0.25W, 1206	CRCW12064R99FNEA	
54	R13	RES, 1.69k ohm, 1%, 0.063W, 0402	CRCW04021K69FKED	
55	R14	RES 24K, 5%, 0.063W, 0402	CRCW040224k0JNED	
56	R15	RES, 30.1k ohm, 1%, 0.063W, 0402	CRCW040230K1FKED	
57	R16	RES 20k ohm,1%, 0.063W, 0402	CRCW040220k0FKED	
58	R18	RES, 15.0 ohm, 1%, 0.063W, 0402	CRCW040215R0FKED	
59	R19, R31	RES 10.0 ohm, 1%, 0.063W, 0402	CRCW0402750RFKED	
60	R21	RES 750 ohm 1/16W 5% 0402 SMD	CRCW04021K00JNED	
61	R22	RES 25.5k ohm,1%, 0.063W, 0402	CRCW040225k5FKED	
62	R23	RES 499 ohm, 1%, 0.063W, 0402	CRCW0402499RFKED	
63	R24	RES 5.11k ohm, 1%, 0.063W, 0402	CRCW04025k11FKED	
64	R25, R26	NU	NU	
65	R27	RES 47 ohm .25W 5% 0603 SMD	CRCW060347R0JNEAHP	
66	R32	RES 100 ohm, 1%, 0.063W, 0402	CRCW0402100RFKED	
67	R29	RES 15k ohm,1%, 0.063W, 0402	CRCW040215k0FKED	
68	R30	RES 1.82k ohm,1%, 0.063W, 0402	CRCW04021k82FKED	
69	R37	RES 0.0 ohm, 5%, 0.063W, 0402	CRCW04020000Z0ED	
70	D1	RES 0.0 ohm, 5%, 0.063W, 1206	CRCW12060000Z0EA	
71	T1	High Frequency Planar Transformer	PA0876.003NL	
72	T2	SMT Current Sense Transformer	PA1005.100NL	
73	U1	Full-Bridge PWM Controller	LM5045MH	
74	U2	Dual 5A Compound Gate Driver with	LM5110-1SD	
		Negative Output Voltage Capability		
75	U3	Low Input Current, High CTR Photo- coupler	PS2811-1-M-A	
76	U4	RRIO, High Output Current & Unlimited Cap Load Op Amp in SOT23-5	LM8261M5	
77	U5	Precision Micro-power Shunt Voltage Reference	LM4041BIM3-1.2	
78	U6	Dual-Channel Digital Isolator	ISO742OFED	

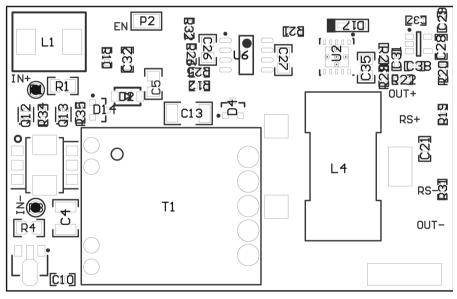


# **Bill of Materials\***

Item	Designator	Description	Manufacturer	Part Number
1	C17, C39,C39A	Cap 220uF, 6.3V, AL, 4V, 20%, 0.012 ohm ESR	Panasonic	EEF-UE0G331R
2	L4	Inductor, Shielded E Core, Ferrite, 1.2uH, 36A, 0.0009 ohm, SMD	Coilcraft	SER2010-122MLB
3	R13	RES, 3.48k ohm, 1%, 0.063W, 0402	Vishay-Dale	CRCW04023K48FKED
4	R18	RES, 13.0 ohm, 1%, 0.063W, 0402	Vishay-Dale	CRCW040213R0FKED
5	R29	RES 8.06k ohm,1%, 0.063W, 0402	Vishay-Dale	CRCW040280k6FKED
6	T1	High Frequency Planar Transformer	Pulse Engineering	PA3455.002NL
7	D11	SMT10V Diode	Central Semiconductor	CMHZ5240B
8	C38	CAP Ceramic 0.22uF 6.3V +/-10% X5R 0402	TDK Corporation	C1005X5R0J224K

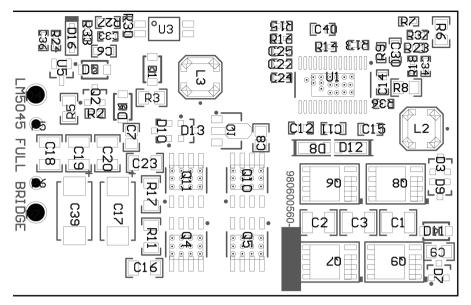
<sup>\*</sup>Note: All the other parts are the same as 3.3V evaluation board.

# **PCB Layouts**



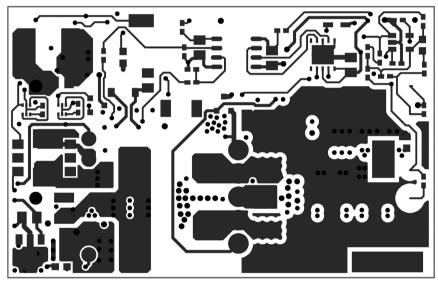
**Top Side Assembly** 

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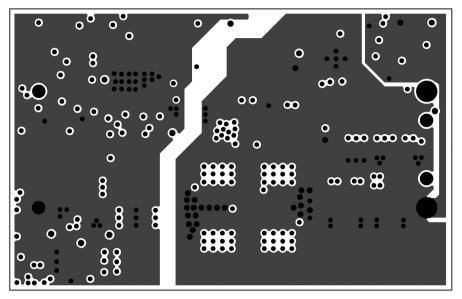
**Bottom Side Assembly** 

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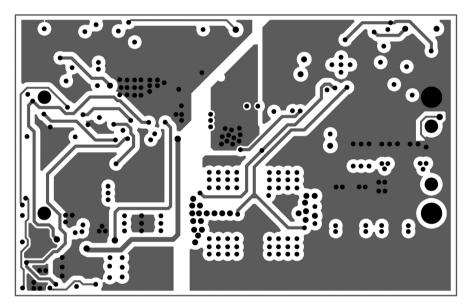
Layer 1 (Top Side)

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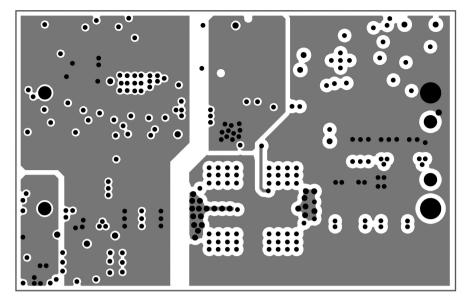
Layer 2

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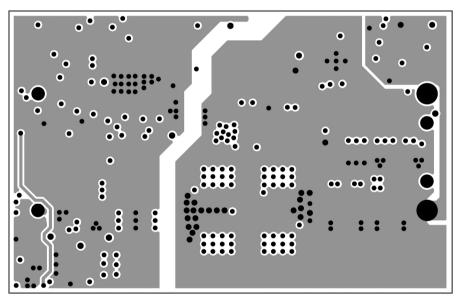
Layer 3

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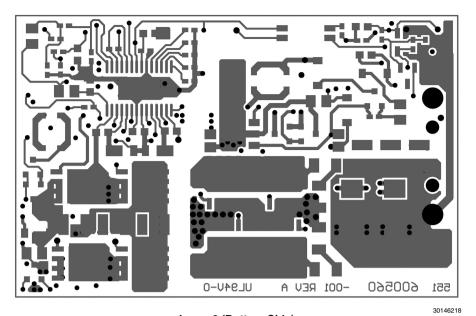
Layer 4





Layer 5

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Layer 6 (Bottom Side)

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