LM5046 Based Eighth Brick Reference Design

National Semiconductor
Application Note 2126
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July 26, 2011

Introduction

The LM5046 reference board is designed in the telecom industry standard one-eighth brick footprint based on the phase-shifted full-bridge topology. This board is for reference only and is intended to demonstrate the capability of the LM5046. Hardware is not provided for evaluation. Please refer to AN2115 for LM5046 evaluation board.

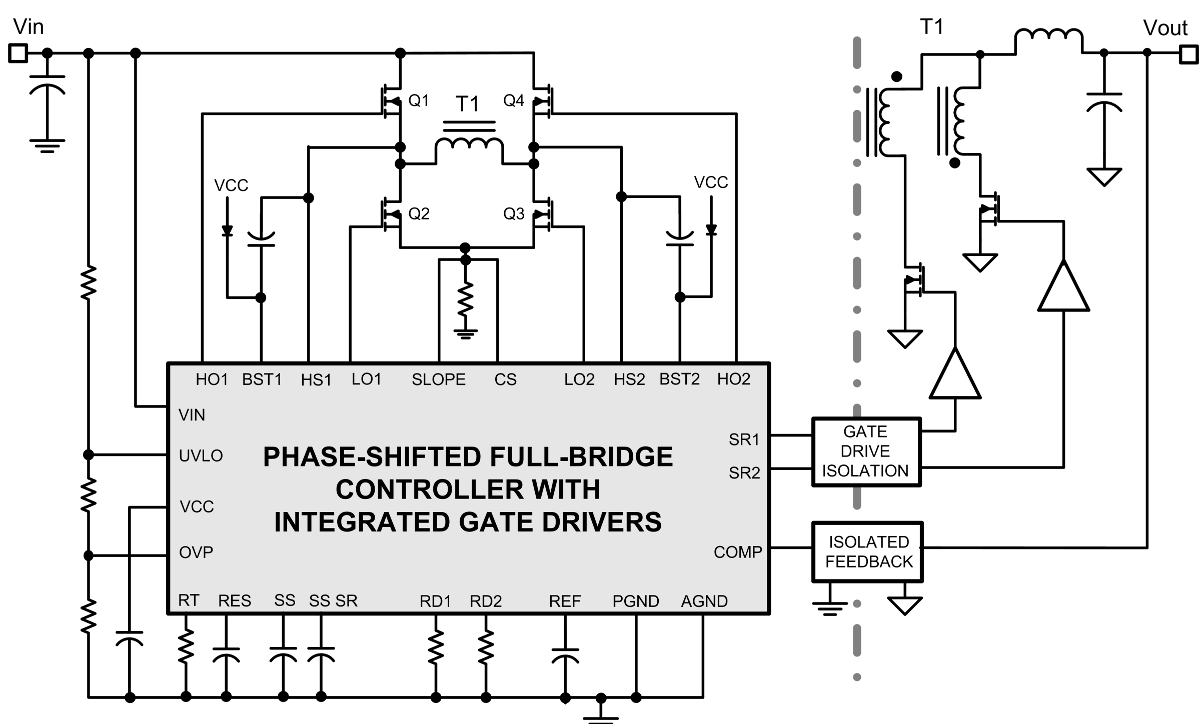
The performance of the reference board is as follows:

- Input operating range: 36V to 75V
- Output voltage: 12V
- Measured efficiency at 48V: 92% @ 10A
- Frequency of operation: 420kHz
- Board size: 2.28 x 0.89 x 0.4 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 10 layers; 2 ounce copper outer layers and 3 ounce copper inner layers on FR4 material with a total thickness of 0.12 inches. The unit is designed for continuous operation at rated load at <40°C and a minimum airflow of 300 LFM at full load.

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. The figure below illustrates the circuit arrangement for the PSFB topology. The power transfer mode of the PSFB topology is similar to the hard switching full-bridge i.e., when the FETs in the diagonal of the bridge are turned-on (Q1 & Q3 or Q2 & Q4), a power transfer cycle is initiated. 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.



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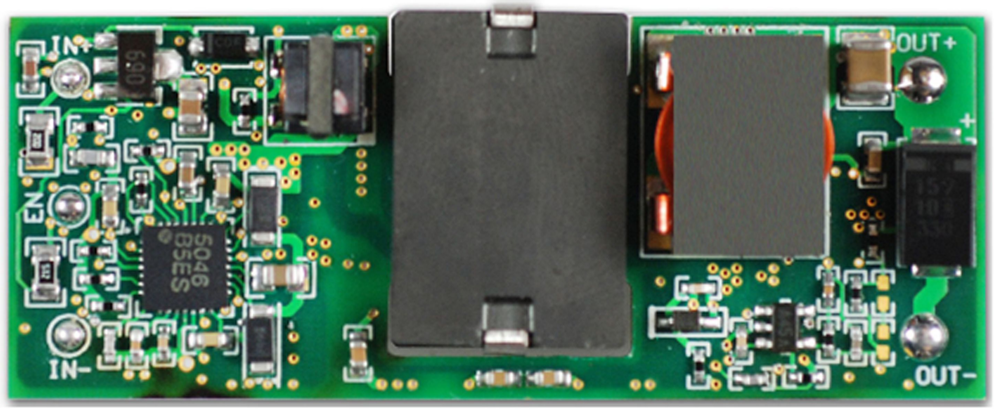
Simplified Phase-Shifted Full-Bridge Converter



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LM5046 Based Eighth Brick Reference Board

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.

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 420 kHz, which is a good comprise between board size and efficiency. Please refer to the *Figure 1* for efficiency curves.

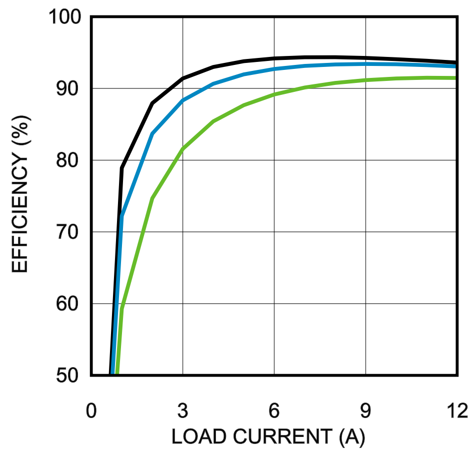

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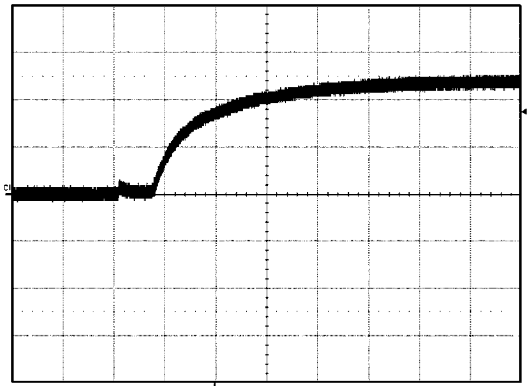
FIGURE 1. Reference Board Efficiency

Figure 2 shows the output voltage during a typical start-up with a 48V input and a load of 12A. There is no overshoot during start-up.



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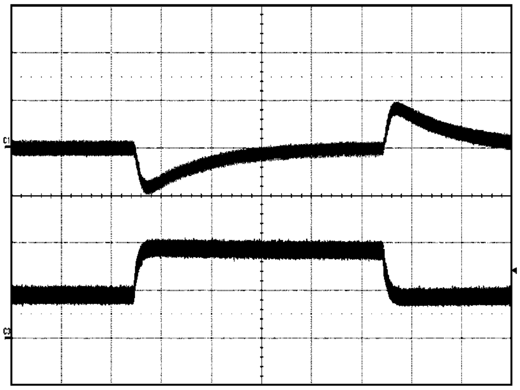
Conditions: Input Voltage=48V
Output Current=12A
Trace 1: Output Voltage Volts/div=5V
Horizontal Resolution =1.0 ms/div

FIGURE 2. Soft-Start

Figure 3 shows typical transient response on the reference board when the load current is switched from 5A to 10A and back to 5A. There is minimal output voltage droop and overshoot during the sudden change in output current shown by the lower trace.



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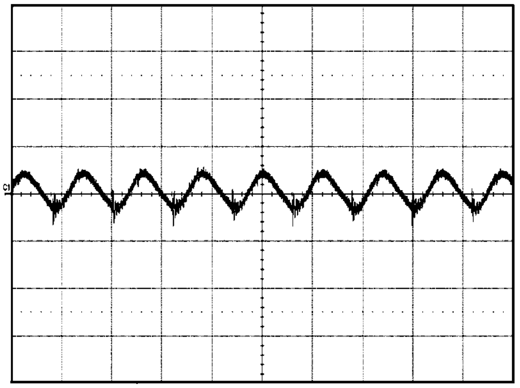
Conditions: Input Voltage=48V
Output Current=5A to 10A to 5A
Upper Trace: Output Voltage Volts/div=500mV
Horizontal Resolution=200 µs/div

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 12A. This waveform is typical of most loads and input voltages.



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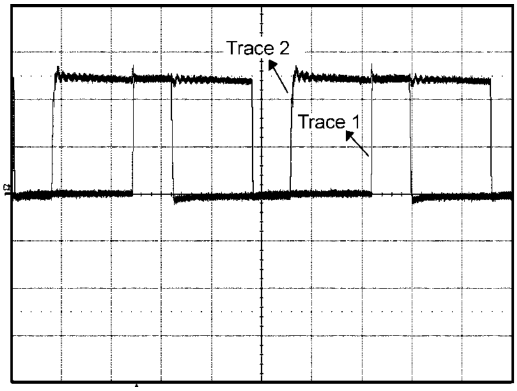
Conditions: Input Voltage=48V
Output Current=12A
Bandwidth Limit=20 MHz
Trace 1: Output Voltage 100 mV/div
Horizontal Resolution=2 µs/div

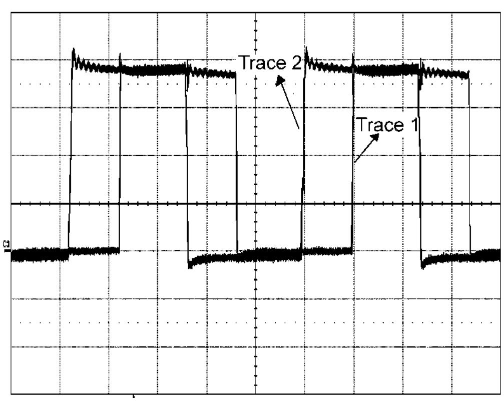
FIGURE 4. Output Ripple

Figure 5 and *Figure 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 75V.



Conditions: Input Voltage=48V
Output Current=10A
Trace 1: SW1 Node Q2 Drain Voltage Volts/div=20V
Trace 2: SW2 Node Q3 Drain Voltage Volts/div=20V
Horizontal Resolution=1 µs/div

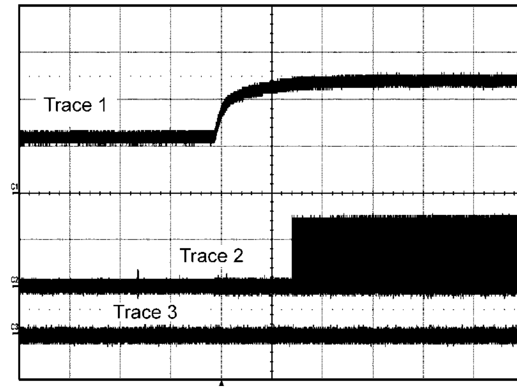
FIGURE 5. 48V Switch Node Waveforms



Conditions: Input Voltage=75V
Output Current=10A
Trace 1: SW1 Node Q2 Drain Voltage Volts/div=20V
Trace 2: SW2 Node Q3 Drain Voltage Volts/div=20V
Horizontal Resolution=1 µs/div

FIGURE 6. 75V Switch Node Waveforms

Figure 7 shows a typical startup of the LM5045 into a 6V pre-biased load.



Conditions: Input Voltage=48V, Output Pre-Bias=6V
Trace 1 (Channel 1): Output Voltage Volts/div=5V
Trace 2 (Channel 2): SR gate Volage Volts/Div=5V
Trace 3 (Channel 3): Output Current Amps/div=200mA
Horizontal Resolution=2.0 ms/div

FIGURE 7. Soft-Start into a 6V Pre-Biased Output

Figure 8 shows the output current de-rating on the reference board at 48V input.

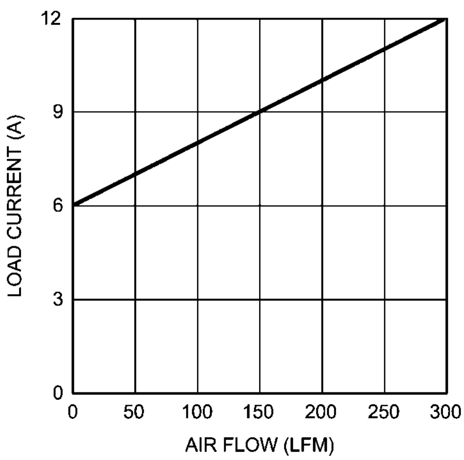
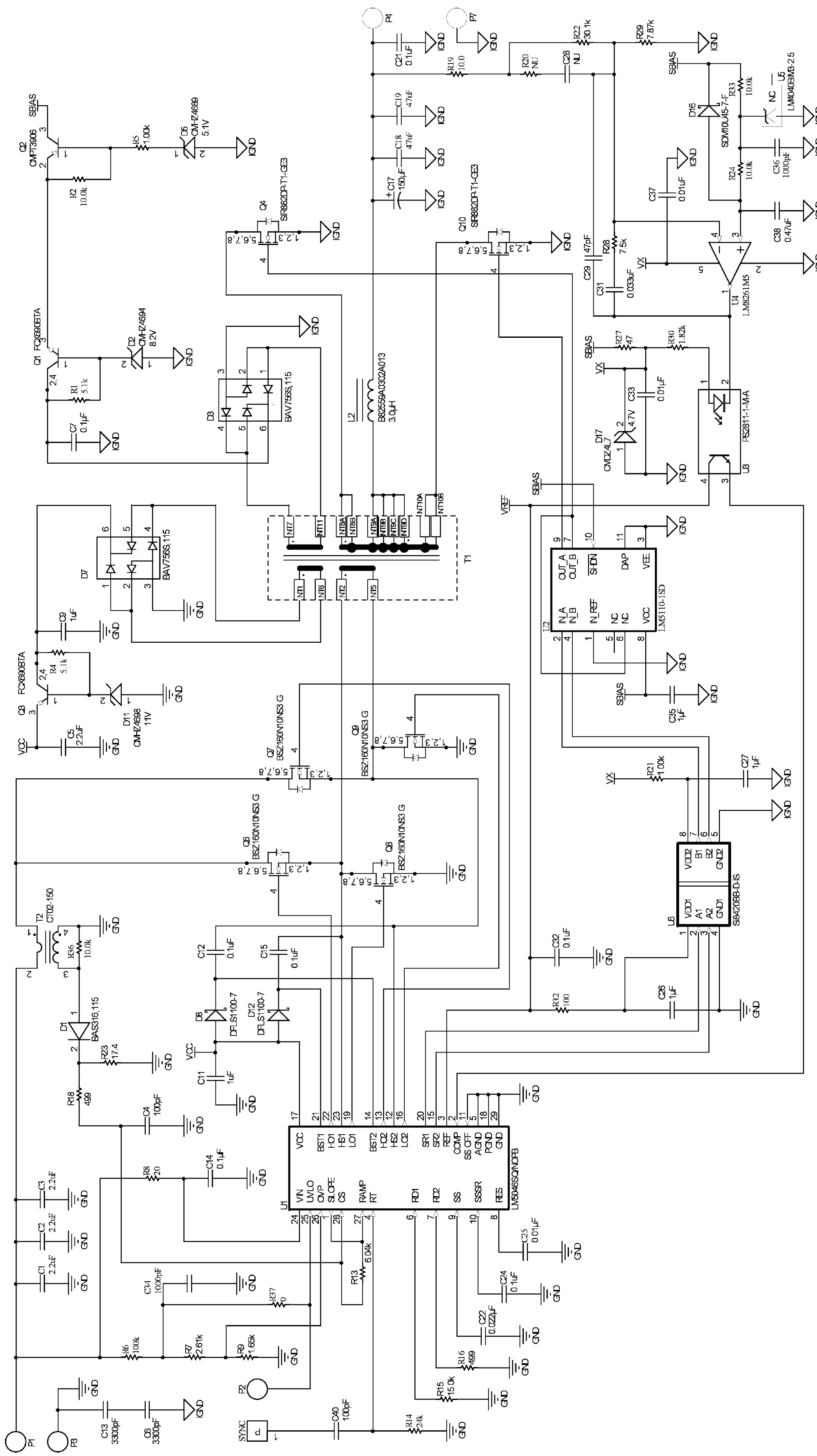


FIGURE 8. Load Current vs. Air Flow



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LM5046 Based Eight Brick Reference Board Schematic

Bill of Materials

Designator	Description	Manufacturer	Part Number
C1, C2, C3	Ceramic, 2.2uF, X7R, 100V, 10%	MuRata	GRM32ER72A225KA35L
C4, C40	Ceramic, 100pF,C0G/NP0, 50V, 5%	TDK	C1608C0G1H101J
C5	Ceramic, 2.2uF, X7R, 16V, 10%	MuRata	GRM21BR71C225KA12L
C6, C13	CAP, CERM, 3300pF, 250V, +/-10%, X7R, 0603	MuRata	GRM188R72A332MA01D
C7, C9	Ceramic, 1uF, X7R, 50V, 10%	MuRata	GRM21BR71H105KA12L
C11	Ceramic,1uF, X7R, 16V, 10%	TDK	C1608X7R1C105K
C12, C15, C21, C32	Ceramic, 0.1uF,X7R, 25V, 10%	AVX	06033C104KAT2A
C14	CAP, CERM, 0.1uF, 100V, +/-10%, X7R, 0603	MuRata	GRM18872A104KA
C17	CAP, TANT, 150uF, 16V, +/-10%, 0.085 ohm, 7343-31 SMD	Kemet	T495D157K016ATE085
C18, C19	Ceramic, 47uF,X5R, 16V, 20%	MuRata	GRM32ER61C476ME15L
C22	CAP, CERM, 0.022uF, 16V, +/-10%, X7R, 0402	TDK	C1005X7R1C223K
C24	Ceramic, 0.1uF, X5R, 6.3V, 10%	TDK	C1005X5R0J104K
C25, C33, C37	CAP, CERM, 0.01uF, 16V, +/-10%, X7R, 0402	TDK	C1005X7R1C103K
C26	CAP, CERM, 1uF, 16V, +/-20%, X7R, 0805	MuRata	GRM21BR71C105MA01L
C27, C35	CAP, CERM, 1uF, 16V, +/-10%, X7R, 0603	MuRata	GRM188R71C105KA12D
C29	CAP, CERM, 47pF, 50V, +/-5%, C0G/NP0, 0402	MuRata	GRM1555C1H470JZ01
C31	CAP CER 33000PF 16V X7R 0402	TDK	C1005X7R1C333K
C34, C36	Ceramic, 1000pF, C0G/NP0, 25V, 5%	TDK	C1005C0G1E102J
C38	CAP CER .47uF 6.3V X5R 0402	TDK	C1005X5R0J474M
D1	Diode, Ultrafast, 100V, 0.25A, SOD-323	NXP Semiconductor	BAS316,115
D2	Diode, Zener, 8.2V, 500mW, SOD-123	Central Semiconductor	CMHZ4694
D3, D7	Diode Switching Array 90V SOT363	NXP	BAV756S,115
D5	Diode, Zener, 5.1V, 500mW, SOD-123	Central Semiconductor	CMHZ4689
D8, D12	Vr = 100V, Io = 1A, Vf = 0.77V	Diodes Inc.	DFLS1100-7
D11	11V SMT Zener Diode	Central Semiconductor	CMHZ4698
D16	Diode, Schottky, 45V, 0.1A, SOD-523	Diodes Inc.	SDM10U45-7-F
D17	Diode, Zener, 4.7V, 200mW, SOD-323	Central Semiconductor	CMDZ4L7
L2	Inductor, Flat Wire, Ferrite, 3.0uH, 12A, 0.0048 ohm, SMD	Epcos Inc	B82559A0302A013
P1, P2, P3	PCB Pin	Mill-Max	3104-2-00-34-00-00-08-0
P4, P7	Conn Pin Nail-Head L =.610" GOLD	Mill-Max	6142-0-00-15-00-00-33-0
Q1, Q3	NPN, 1A, 45V, Transistor, NPN, 45V, 1A, SOT-89	Diodes Inc.	FCX690BTA
Q2	PNP, 0.2A, 40V	Central Semiconductor	CMPT3906
Q4, Q10	MOSFET N-CH D-S 100V 8-SOIC	Vishay	SIR882DP-T1-GE3
Q6, Q7, Q8, Q9	MOSFET, N-CH, 100V, 28A, PG-TSDSON-8	Infineon Technologies	BSZ160N10NS3 G
R1, R4	RES 0805, 5.1k, 5%, 0.125W	Panasonic	ERJ-6GEYJ512V
R2, R24, R33, R36	RES 0402, 10k,1%, 0.063W	Vishay-Dale	CRCW040210k0FKED
R5	RES, 1.00k ohm, 1%, 0.1W, 0603	Vishay-Dale	CRCW06031K00FKEA
R6	RES 100k, 1%, 0.125W	Vishay-Dale	CRCW0805100KFKEA
R7	RES, 2.61k ohm, 1%, 0.063W, 0402	Vishay-Dale	CRCW04022K61FKED
R8	RES 20 ohm, 0805, 5%, 0.125W	Panasonic	ERJ-6GEYJ200V
R9	RES, 1.65k ohm, 1%, 0.063W, 0402	Vishay-Dale	CRCW04021K65FKED
R13	RES, 6.04k ohm, 1%, 0.063W, 0402	Vishay-Dale	CRCW04026K04FKED
R14	RES 24k, 5%, 0.063W	Vishay-Dale	CRCW040224k0JNED
R15	RES, 30.1k ohm, 1%, 0.063W, 0402	Vishay-Dale	CRCW040230K1FKED
R16, R18	RES, 499 ohm, 1%, 0.063W, 0402	Vishay-Dale	CRCW0402499RFKED
R37	RES 0 ohm 5%, 0.063W	Vishay-Dale	CRCW04020000Z0ED

R23	RES, 17.4ohm, 1%, 0.063W, 0402	Vishay-Dale	CRCW040217R4FKED
R27	RES, 47 ohm, 5%, 0.25W, 0603	Vishay-Dale	CRCW060347R0JNEA
R28	RES, 7.5k ohm, 5%, 0.063W, 0402	Vishay-Dale	CRCW04027K50JNED
R30	RES 1.82k ohm, 1%, 0.063W	Vishay-Dale	CRCW04021k82FKED
R32	RES 100 ohm, 1%, 0.063W	Vishay-Dale	CRCW0402100RFKED
R22	RES 30.1k ohm, 1%, 0.063W	Vishay-Dale	CRCW040230k1FKED
R29	RES 7.87k ohm, 1%, 0.063W	Vishay-Dale	CRCW04027k87FKED
R21	RES 1.0k ohm, 1%, 0.063W	Vishay-Dale	CRCW04021k00FKED
T2	Current Sense Transformer	Ice Components	CT02-150
U1	100V Full-Bridge PWM Controller with Integrated MOSFET Drivers	National Semiconductor	LM5046SQ/NOPB
U2	Dual 5A Compound Gate Driver with Negative Output Voltage Capability	National Semiconductor	LM5110-1SD
U3	Low Input Current, High CTR Photocoupler	NEC	PS2811-1-M-A
U4	RRIO, High Output Current & Unlimited Cap Load Op Amp in SOT23-5	National Semiconductor	LM8261M5
U5	Precision Micropower Shunt Voltage Reference	National Semiconductor	LM4040BIM3-2.5
U6	ISOPro Low-Power Dual-Channel Digital Isolator	Silicon Laboratories	Si8420BB-D-IS

PCB Layouts

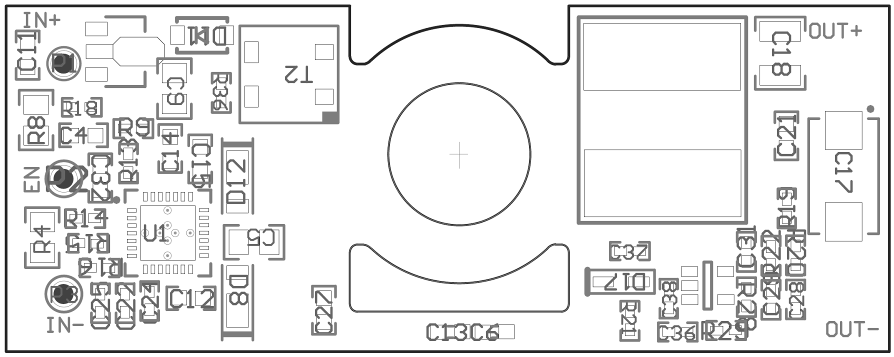

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FIGURE 9. Top Layer Assembly

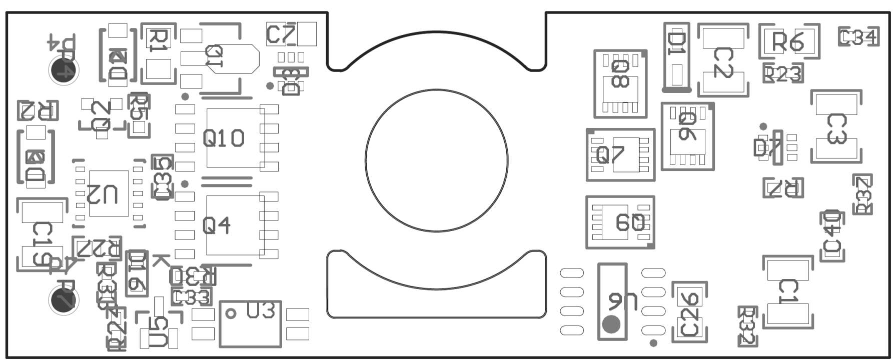

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FIGURE 10. Bottom Layer Assembly

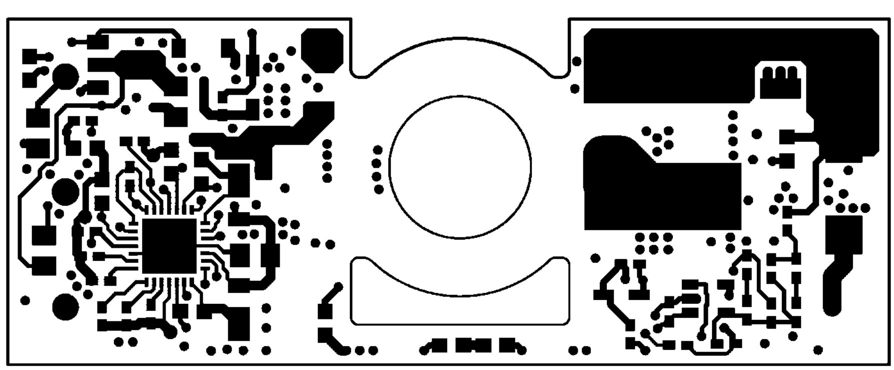

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FIGURE 11. Top Layer (Layer 1)

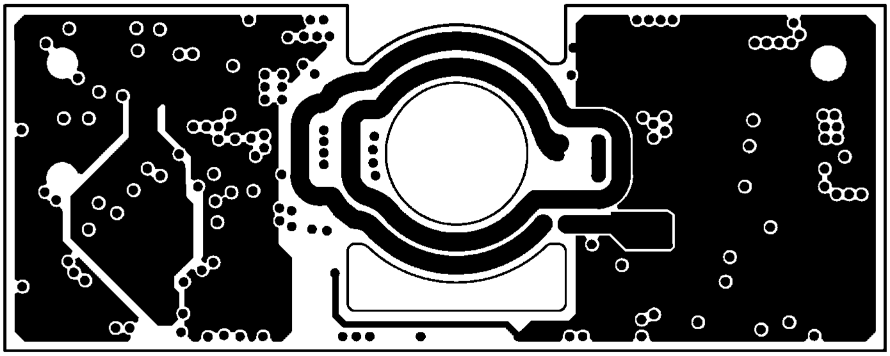

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FIGURE 12. Layer 2

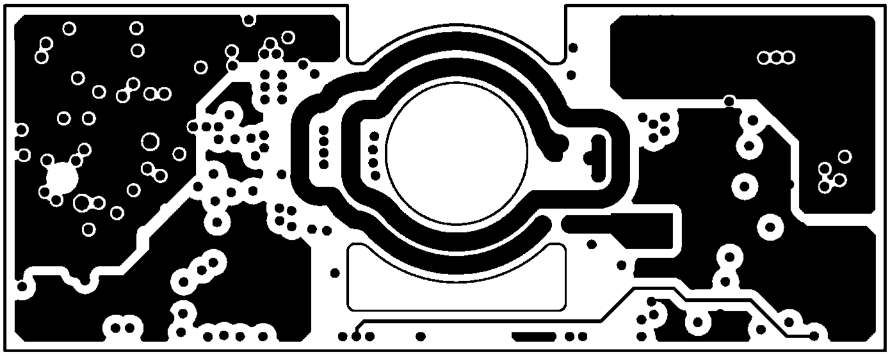

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FIGURE 13. Layer 3

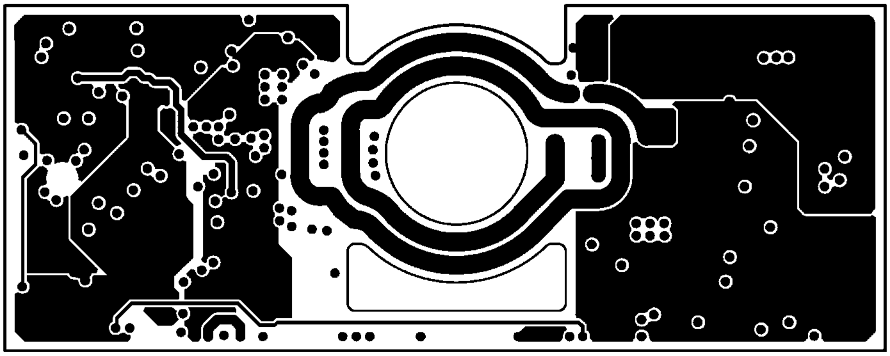

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FIGURE 14. Layer 4

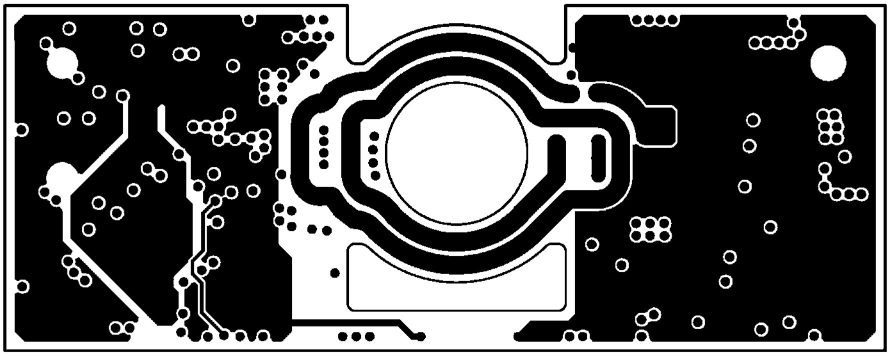

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FIGURE 15. Layer 5

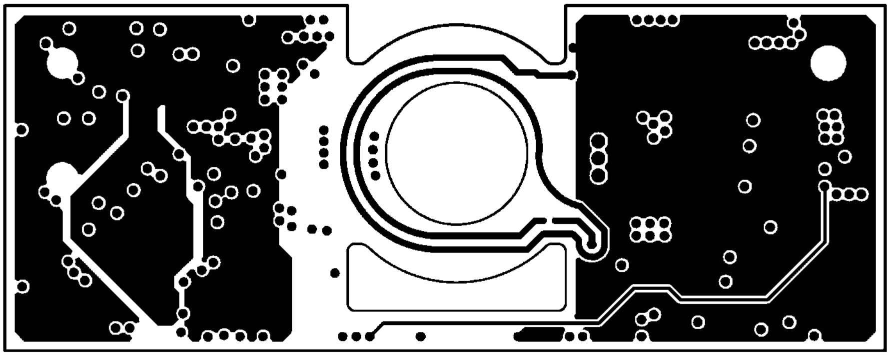

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FIGURE 16. Layer 6

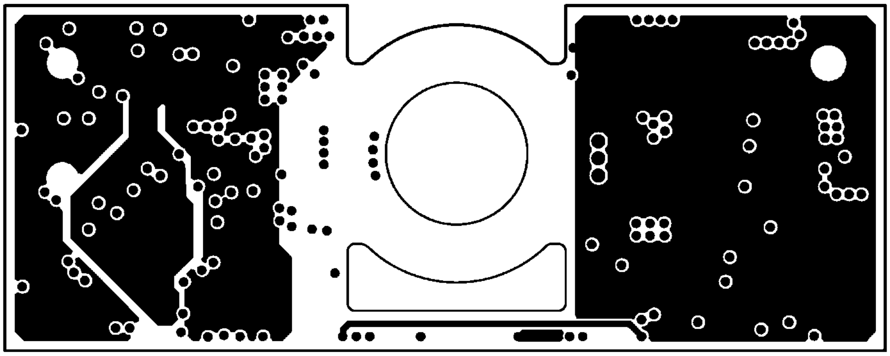

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FIGURE 17. Layer 7

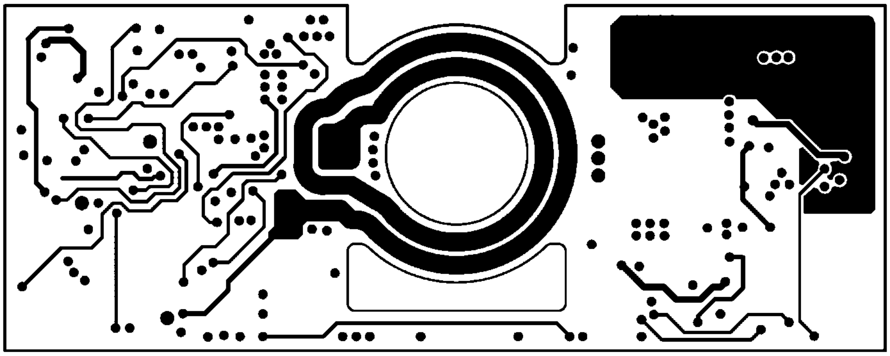

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FIGURE 18. Layer 8

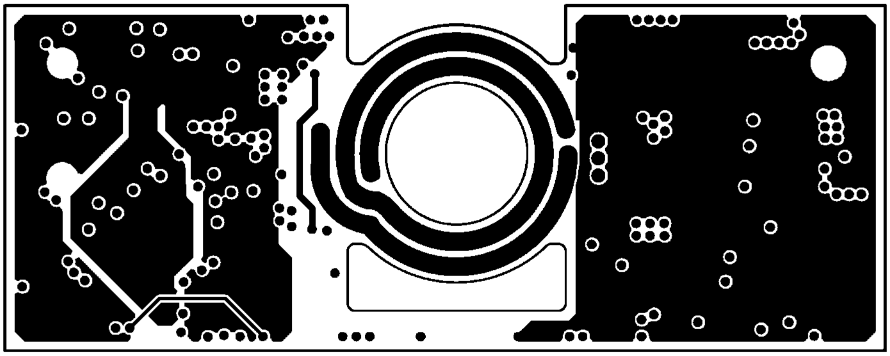

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FIGURE 19. Layer 9

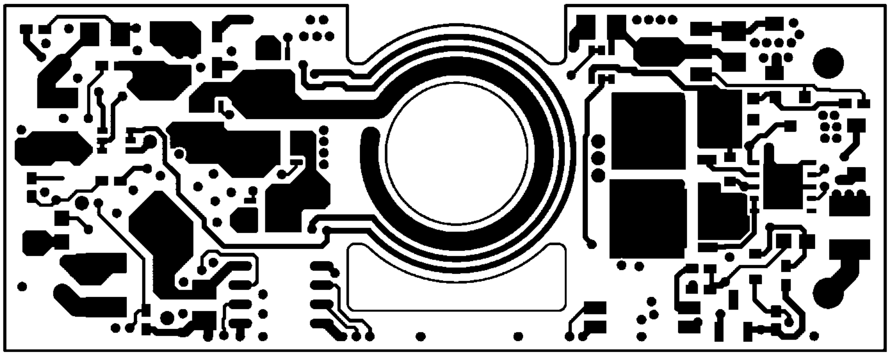

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FIGURE 20. Bottom Layer (Layer 10)

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