Application Report
SNVA870A – March 2019 – Revised April 2020

LM5143-Q1 4-phase Buck Regulator Design for Automotive ADAS Applications

Timothy Hegarty

ABSTRACT

With an input operating voltage as low as 3.5 V and up to 100 V as specified in Table 1, the LM5140-Q1, LM5141-Q1, LM5143-Q1, and LM5146-Q1 family of automotive synchronous buck controllers from TI provides flexibility, scalability, and optimized solution size for a range of applications. These controllers enable DC/DC solutions with high density, low EMI, and increased flexibility. All controllers are rated for a maximum operating junction temperature of 150°C and have AEC-Q100 grade 1 qualification.

Table 1. Automotive Synchronous Buck DC/DC Controller Family

DC/DC CONTROLLER	SINGLE or DUAL	V_{IN} RANGE	CONTROL METHOD	GATE DRIVE VOLTAGE	SYNC OUTPUT	PROGRAMMABLE DITHER
LM5140-Q1	Dual	3.8 V to 65 V	Peak current mode	5 V	180° phase shift	N/A
LM5141-Q1	Single	3.8 V to 65 V	Peak current mode	5 V	N/A	Yes
LM25141-Q1	Single	3.8 V to 42 V	Peak current mode	5 V	N/A	Yes
LM5143-Q1	Dual	3.5 V to 65 V	Peak current mode	5 V	90° phase shift	Yes
LM5146-Q1	Single	5.5 V to 100 V	Voltage mode	7.5 V	180° phase shift	N/A

The LM5143-Q1 4-phase reference design is an automotive synchronous buck DC/DC regulator that employs synchronous rectification to achieve high conversion efficiency in a small footprint. It operates over a wide input voltage range of 8 V to 18 V, providing a regulated output of 5 V. The output voltage has better than 1% setpoint accuracy and is adjustable by installing appropriate feedback resistor values, letting you customize the output voltage from 1.8 V to 8 V as needed.

The module design uses the LM5143-Q1 65-V synchronous buck controller and has the following:

- Wide input voltage (wide V_{IN}) range
- Wide duty cycle range
- Peak current-mode PWM control loop
- Integrated high-side and low-side MOSFET gate drivers
- Cycle-by-cycle overcurrent protection
- Configurable hiccup-mode protection
- Spread spectrum modulation features

The free-running switching frequency is 2.1 MHz and is synchronizable to a higher or lower frequency if required. A synchronization output signal (SYNCOUT) from the master controller is 90° phase-shifted relative to its internal clock and drives the DEMB/SYNCIN pin of the slave controller. VCC voltage rail UVLO protects the converter at low input voltage conditions, and EN pins for each phase support application specific power-up and power-down requirements.

The LM5143-Q1 is available in a 40-pin VQFN package with 6-mm × 6-mm footprint to enable DC/DC solutions with high density and low component count. See the *LM5143-Q1 3.5-V to 65-V dual synchronous buck DC/DC controller data sheet* for more information. Use the LM5143-Q1 with the WEBENCH® Power Designer to create a custom regulator design. You can download the *LM5143-Q1 Quickstart Calculator* to optimize component selection and examine predicted efficiency performance across line and load ranges.

Contents

List of Figures

List of Tables

Trademarks

1 High Density Reference Design Description

The LM5143-Q1EVM-2100 high-density EVM is designed to use a regulated or non-regulated high-voltage input rail ranging from 8 V to 18 V to produce a tightly-regulated output voltage of 5 V at a load current up to 30 A. This wide V_{IN} range DC/DC solution offers outsized voltage rating and operating margin to withstand supply rail voltage transients.

The free-running switching frequency is 2.1 MHz and is synchronizable to an external clock signal at a higher or lower frequency. The selected power-train passive components, including buck inductors and ceramic input and output capacitors, are automotive AEC-Q200 rated and are available from multiple component vendors.

1.1 Typical Applications

- High-current automotive DC/DC regulators using 2-, 3-, and 4-phase implementations
- Dual outputs for ADAS and body electronics
- Power supplies for HEV/EV compliant to LV-124

1.2 Features and Electrical Performance

- Tightly-regulated output voltage of 5 V with better than ±1% setpoint accuracy
- Wide input voltage operating range of 8 V to 18 V (with transients from 6 V to 36 V)
- Single--output configurations
  - Single output, four-phase solution provides 30 A
- Switching frequency of 2.1 MHz externally synchronizable up or down by 20%
- Ultra-high power conversion efficiency across wide load current ranges
  - Half-load efficiency of 92.3% at V_{IN} = 12 V
  - Full-load efficiency of 91.75% at V_{IN} = 12 V
- Input π-stage EMI filter with electrolytic capacitor for parallel damping
  - Two-stage differential-mode EMI filter
  - Meets CISPR 25 and UNECE Reg 10 EMI standards
- Peak current-mode control architecture provides fast line and load transient response
  - Integrated slope compensation adaptive with switching frequency
  - Forced PWM (FPWM) or diode emulation mode (DEM) operation
- Integrated high-side and low-side power MOSFET gate drivers
  - 3.25-A and 4.25-A sink/source gate drive current capability
  - Independent source and sink gate driver pins for adjustable switch (SW) voltage slew rate
  - 14-ns adaptive dead-time control reduces power dissipation and MOSFET temperature rise
- Overcurrent protection (OCP) with shunt or inductor DCR current sensing
- Monotonic prebias output voltage startup
- User-adjustable soft-start time set to 3 ms by 100-nF capacitors connected between SS pins and AGND
- SYNCOUT signal 90° out-of-phase with internal clock
- Power Good indicator with 100-kΩ pullup resistors to VCC
- Fully assembled, tested, and proven PCB layout with 105-mm × 75-mm total footprint

2 Design Specifications

Table 2. Electrical Performance Characteristics

PARAMETER	TEST CONDITIONS		MIN	TYP	MAX	UNIT
INPUT CHARACTERISTICS						
Input voltage range, V_{IN}	Operating		8	12	18	V
	Transients		6		36	
Input current, no load, $I_{IN(NL)}$	I_{OUT} = 0 A, FPWM mode	V_{IN} = 8 V		132		mA
		V_{IN} = 12 V		130		
		V_{IN} = 18 V		125		
Input current, disabled, $I_{IN(OFF)}$	V_{EN} = 0 V	V_{IN} = 12 V		16		µA
OUTPUT CHARACTERISTICS						
Output voltage, V_{OUT} (1)			4.95	5.0	5.05	V
Output current, I_{OUT}	V_{IN} = 8 V to 18 V, Airflow = 100 LFM (2)		0		30	A
Output voltage regulation, ΔV_{OUT}	Load regulation	I_{OUT} = 0 A to 30 A		0.5%		
	Line regulation	V_{IN} = 8 V to 18 V		0.5%		
Output voltage ripple, $V_{OUT(AC)}$	V_{IN} = 12 V, I_{OUT} = 30 A			10		mVrms
Output overcurrent protection, I_{OCP}	V_{IN} = 12 V			40		A
Soft-start time, t_{SS}	C_{SS} = 100 nF			3		ms
Hiccup time, t_{RES}	C_{RES} = 220 nF			13		ms
SYSTEM CHARACTERISTICS						
Switching frequency, F_{SW}	V_{IN} = 12 V			2.1		MHz
Half-load efficiency, η_{HALF} (1)	I_{OUT} = 15 A	V_{IN} = 8 V		93.5%		
		V_{IN} = 12 V		92.3%		
		V_{IN} = 18 V		89.5%		
Full load efficiency, η_{FULL}	I_{OUT} = 30 A	V_{IN} = 8 V		91.3%		
		V_{IN} = 12 V		91.75%		
		V_{IN} = 18 V		90%		
LM5143-Q1 junction temperature, T_J			–40		150	ºC

(1) The default output voltages of this design is 5 V. Efficiency and other performance metrics can change based on operating input voltage, load current, externally-connected output capacitors, and other parameters.
(2) The recommended airflow when operating at input voltages greater than 15 V is 100 LFM.

3 Application Circuit Diagram

Figure 1 shows the schematic of an LM5143-Q1 based synchronous buck regulator (EMI filter stage not shown). Soft start (SS), restart (RES), and dither (DITH) components are shown that are configurable as required by the specific application.

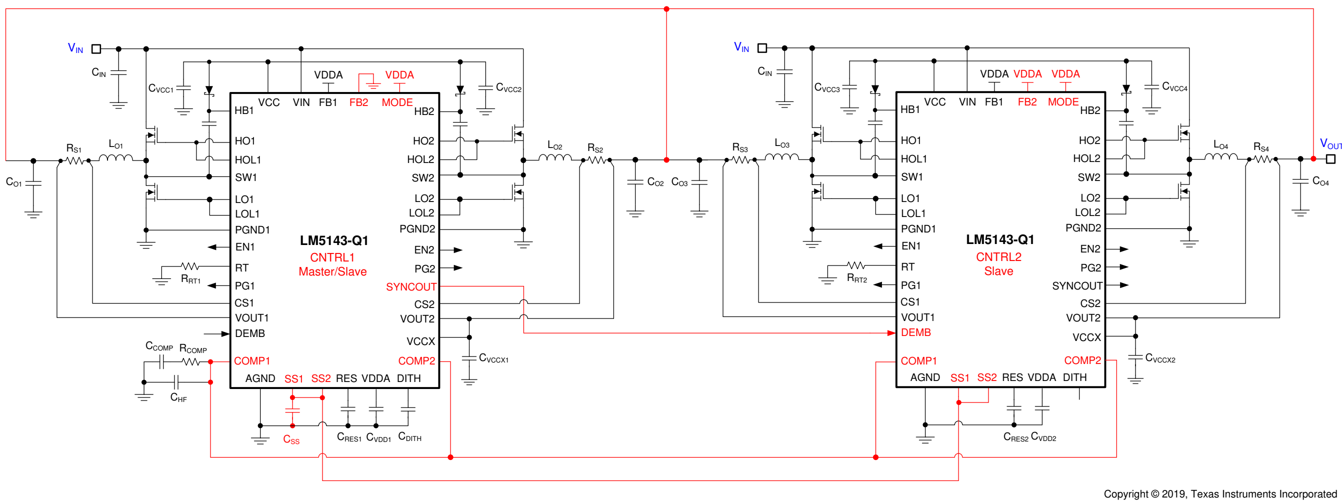

Figure 1. LM5143-Q1 4-Phase Synchronous Buck Regulator Schematic

4 Photo

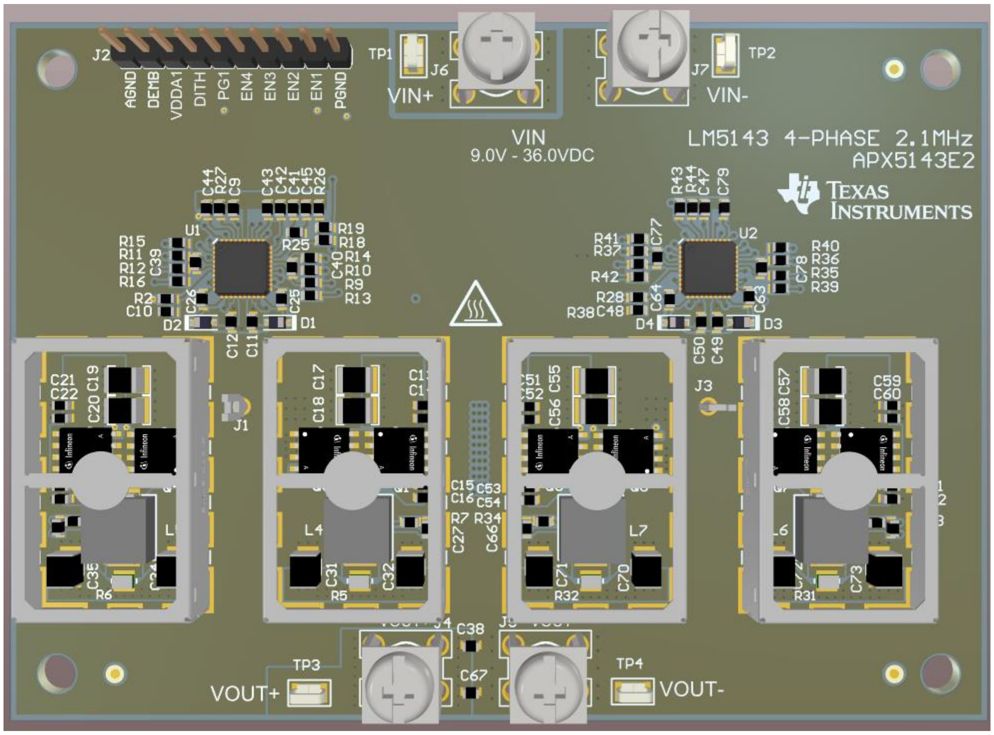

Figure 2. Board Photo, 105 mm × 75 mm

CAUTION

Caution Hot surface.
Contact may cause burns.
Do not touch.

5 Test Data and Performance Curves

5.1 Conversion Efficiency

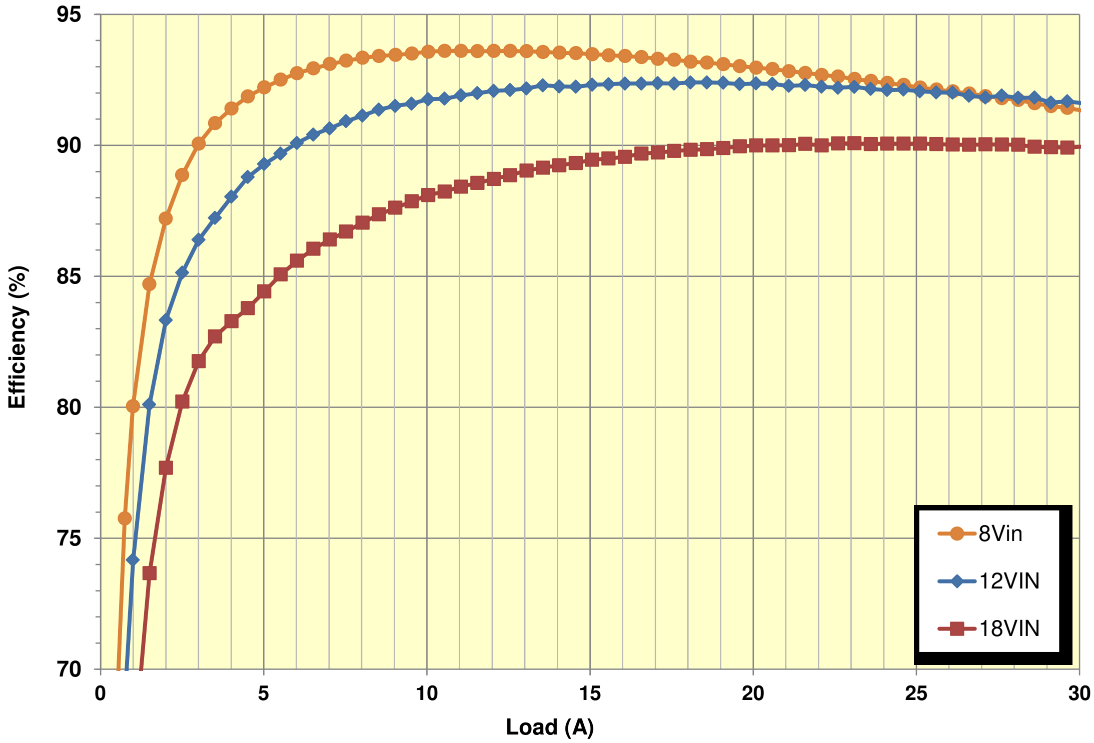

Figure 3. Conversion Efficiency, V_{OUT} = 5 V

6 EVM Documentation

6.1 Schematic

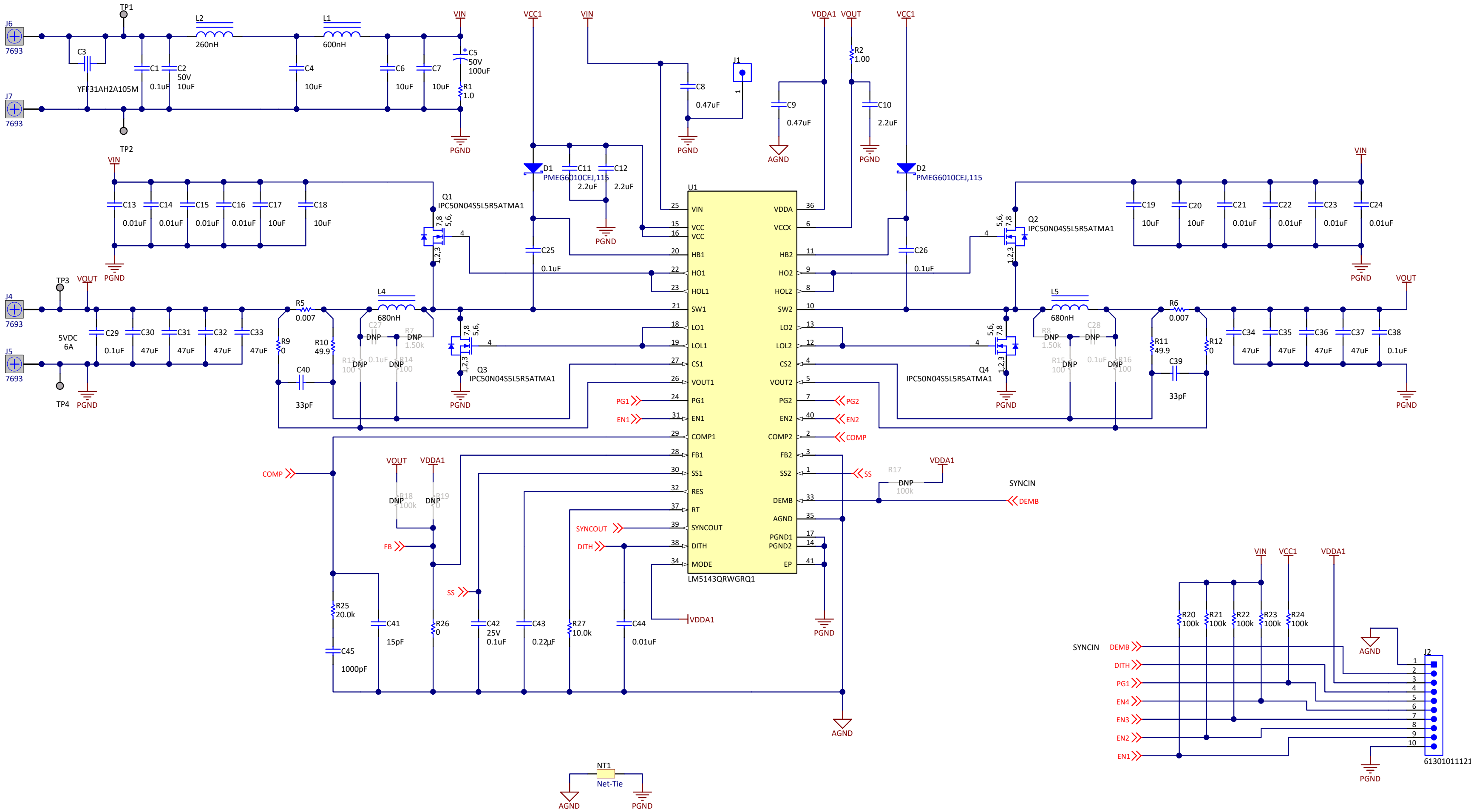

Figure 4. Schematic – Master Controller

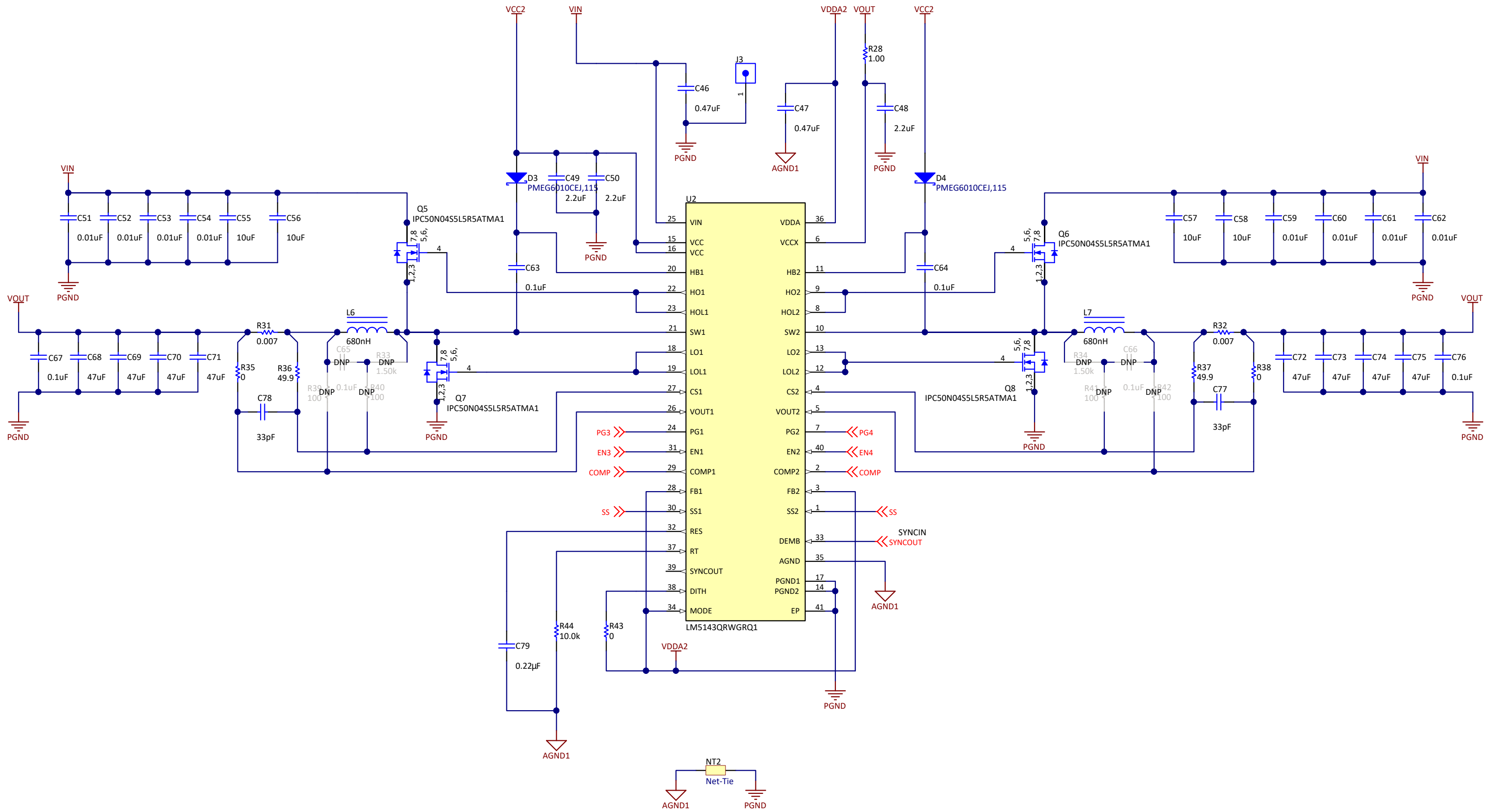

Figure 5. Schematic – Slave Controller

6.2 Bill of Materials

Table 3. Bill of Materials

COUNT	REF DES	DESCRIPTION	PART NUMBER	MFR
1	C1	Capacitor, Ceramic, 0.1μF, 100 V, X7R, 0603		
12	C2, C4, C6, C7, C17, C18, C19, C20, C55, C56, C57, C58	Capacitor, Ceramic, 10 μF, 50 V, X7R, 1210, AEC-Q200	UMJ325KB7106KMHT	Taiyo Yuden
			CNA6P1X7R1H106K250AE	TDK
		Capacitor, Ceramic, 10 μF, 50 V, X7R, 1206, AEC-Q200	CGA5L1X7R1H106K160AC	TDK
1	C3	Capacitor, Ceramic, 1 μF, 100 V, X7R, 1206, AEC-Q200	YFF31AH2A105M	TDK
1	C5	Capacitor, Aluminum, 100 μF, 50 V, AEC-Q200	EEE-FC1H101P	Panasonic
2	C8, C46	Capacitor, Ceramic, 0.47 μF, 100 V, X7R, 0805	Std	Std
2	C9, C47	Capacitor, Ceramic, 0.47 μF, 16 V, X7R, 0805	Std	Std
6	C10, C11, C12, C48, C49, C50	Capacitor, Ceramic, 2.2 μF, 16 V, X7R, 0603	Std	Std
16	C13, C14, C15, C16, C21, C22, C23, C24, C51, C52, C53, C54, C59, C60, C61, C62	Capacitor, Ceramic, 0.01 μF, 100 V, X7R, 0603	GRM188R72A103KA01D	Murata
9	C25, C26, C29, C38, C42, C63, C64, C67, C76	Capacitor, Ceramic, 0.1 μF, 25 V, X7R, 0603	Std	Std
16	C30, C31, C32, C33, C34, C35, C36, C37, C68, C69, C70, C71, C72, C73, C74, C75	Capacitor, Ceramic, 47 μF, 6.3 V, X7R, 1210, AEC-Q200	CGA6P1X7S0J476M250AC	TDK
			JMK325B7476KMHTR	Taiyo Yuden
			GCM32ER70J476KE19L	Murata
4	C39, C40, C77, C78	Capacitor, Ceramic, 33 pF, 100 V, C0G, 5%, 0603	Std	Std
1	C41	Capacitor, Ceramic, 15 pF, 50 V, C0G, 5%, 0603	Std	Std
2	C43, C79	Capacitor, Ceramic, 0.22 μF, 16 V, X7R, 0603	Std	Std
1	C44	Capacitor, Ceramic, 0.01 μF, 25 V, X7R, 0603	Std	Std
1	C45	Capacitor, Ceramic, 1 nF, 50 V, X7R, 10%, 0603	Std	Std
4	D1, D2, D3, D4	Schottky Diode, 60 V, 1 A, SOD-323	PMEG6010CEJ	Nexperia
0	H1, H2, H11, H12	Surface Mount Shield, 29.4-mm × 18.5-mm, Height: 7 mm	BMI-S-205-F	Laird
0	H7, H8, H17, H18	Shield Cover, 29.4-mm × 18.5-mm	BMI-S-205-C	Laird
2	J1, J3	Test Point Slotted, 0.118", TH	1040	Keystone
1	J2	Header, 2.54 mm, 10×1, Au, TH	PBC10SABN	Sullins
4	J4, J5, J6, J7	Terminal screw, vertical, snap-in	PC Screw Terminal	Keystone
1	L1	Inductor, 0.6 μH, 3 mΩ typ, 36 A Isat, 7.5-mm × 7.5-mm typ, 72 MHz SRF, AEC-Q200	XAL7030-601	Coilcraft
1	L2	Inductor, 0.26 μH, 2.16 mΩ typ, 31 A Isat, 5.48-mm × 5.28-mm typ, 117 MHz SRF, AEC-Q200	XEL5030-261	Coilcraft
4	L4, L5, L6, L7	Inductor, 0.68 μH, 4.8 mΩ typ, 25 A, 2.8 mm typ, AEC-Q200	744373460068	Würth Electronik
		Inductor, 0.68 μH, 4.5 mΩ typ, 22 A, 2.8 mm typ, AEC-Q200	VCMV063T-R68MN2T	Cyntec
8	Q1, Q2, Q3, Q4, Q5, Q6, Q7, Q8	MOSFET, N-Channel, 40 V, 5.7 mΩ, AEC-Q101	IPC50N04S5L5R5	Infineon
1	R2	Resistor, Chip, 1 Ω, 1/4 W, 5%, 1206	Std	Std
6	R9, R12, R19, R35, R36, R43	Resistor, Chip, 0 Ω, 1/10 W, 1%, 0603	Std	Std
4	R5, R6, R31, R32	Resistor, Chip, 7 mΩ, 1 W, 1%, 0508, AEC-Q200	KRL2012M-R007-F-T1	Susumu
4	R10, R11, R36, R37	Resistor, Chip, 49.9 Ω, 1/10 W, 1%, 0603	Std	Std
1	R25	Resistor, Chip, 20 kΩ, 1/10 W, 1%, 0603	Std	Std
8	R17, R18, R20, R21, R22, R23, R24, R28	Resistor, Chip, 100 kΩ, 1/16 W, 1%, 0603	Std	Std
1	R26	Resistor, Chip, 22.1 kΩ, 1/10 W, 1%, 0603	Std	Std
2	R27, R44	Resistor, Chip, 10 kΩ, 1/10 W, 1%, 0603	Std	Std
4	TP1, TP2, TP3, TP4	Test Point, Miniature, SMT	5015	Keystone
1	U1	IC, LM5143-Q1, 65-V Dual Synchronous Buck Controller, VQFNP-40	LM5143QRGWRQ1	TI
1	PCB1	PCB, FR4, 6 layer, 2 oz, 105-mm x 75-mm	PCB	–

6.3 PCB Layout

Figure 6 through show the design using a 6-layer PCB with 2-oz copper thickness. The design is essentially a single-sided design except for certain input filtering and small-signal components located on the bottom side.

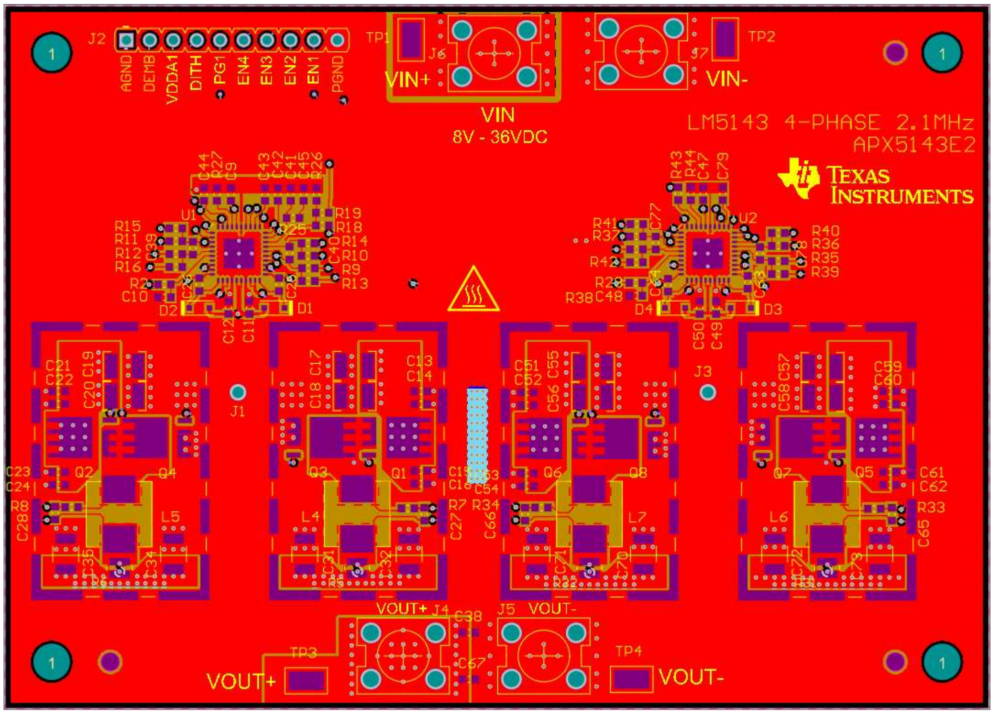

Figure 6. Top Copper (Top View)

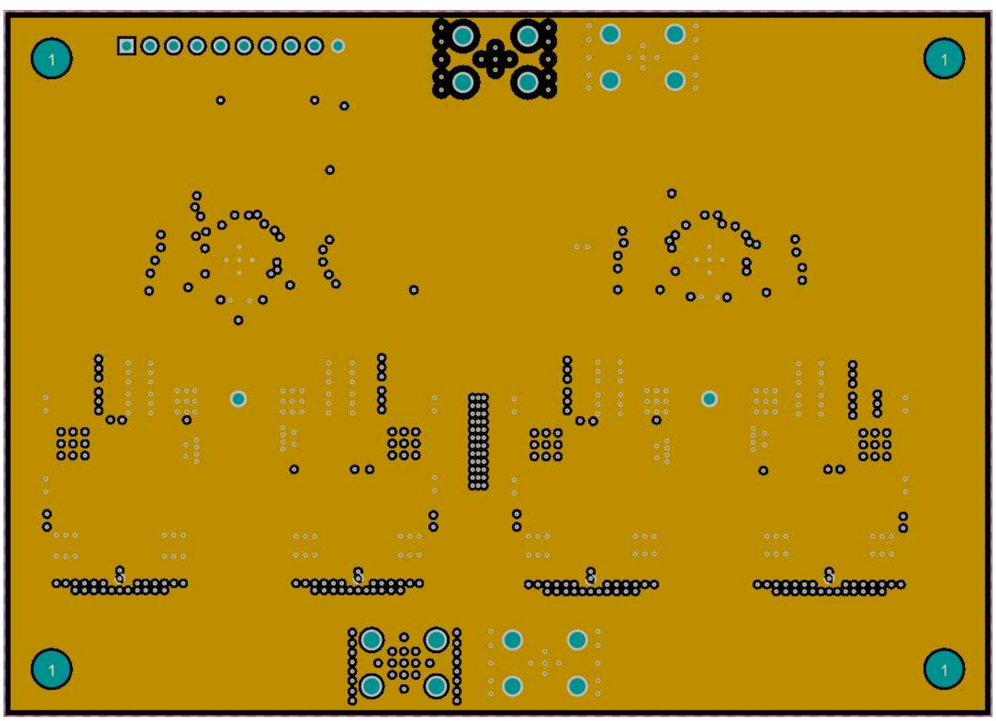

Figure 7. Layer 2 Copper (Top View)

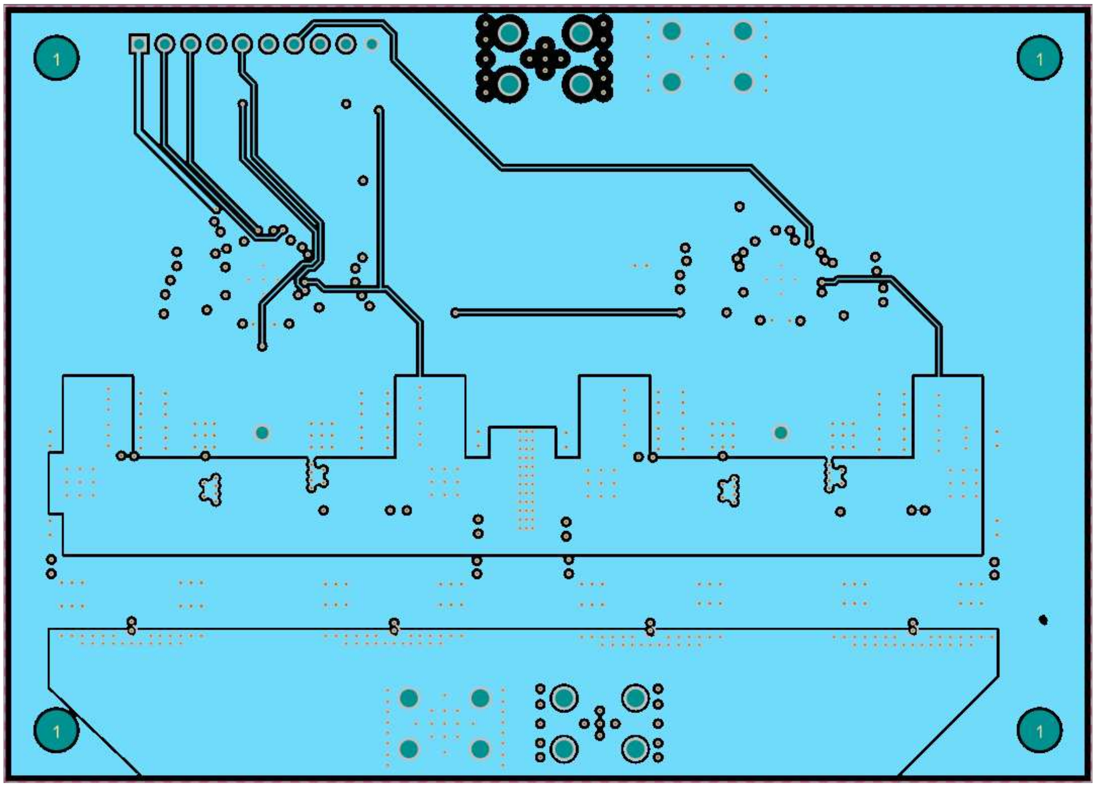

Figure 8. Layer 3 Copper (Top View)

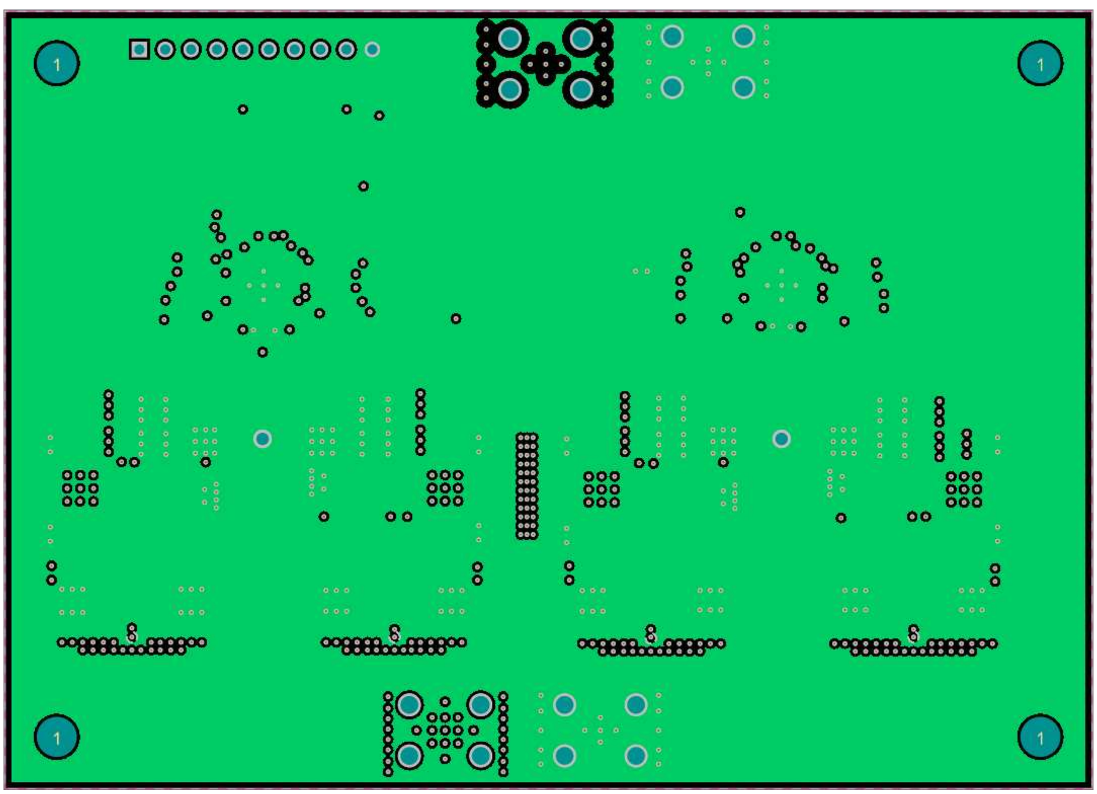

Figure 9. Layer 4 Copper (Top View)

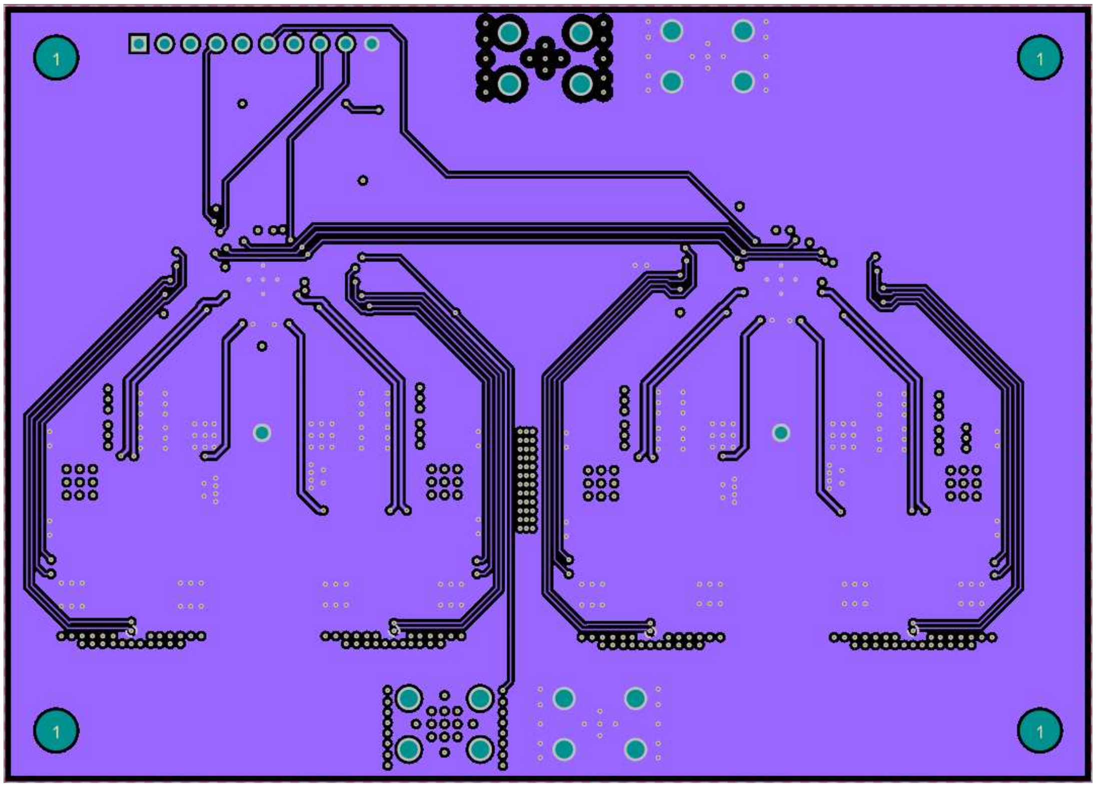

Figure 10. Layer 5 Copper (Top View)

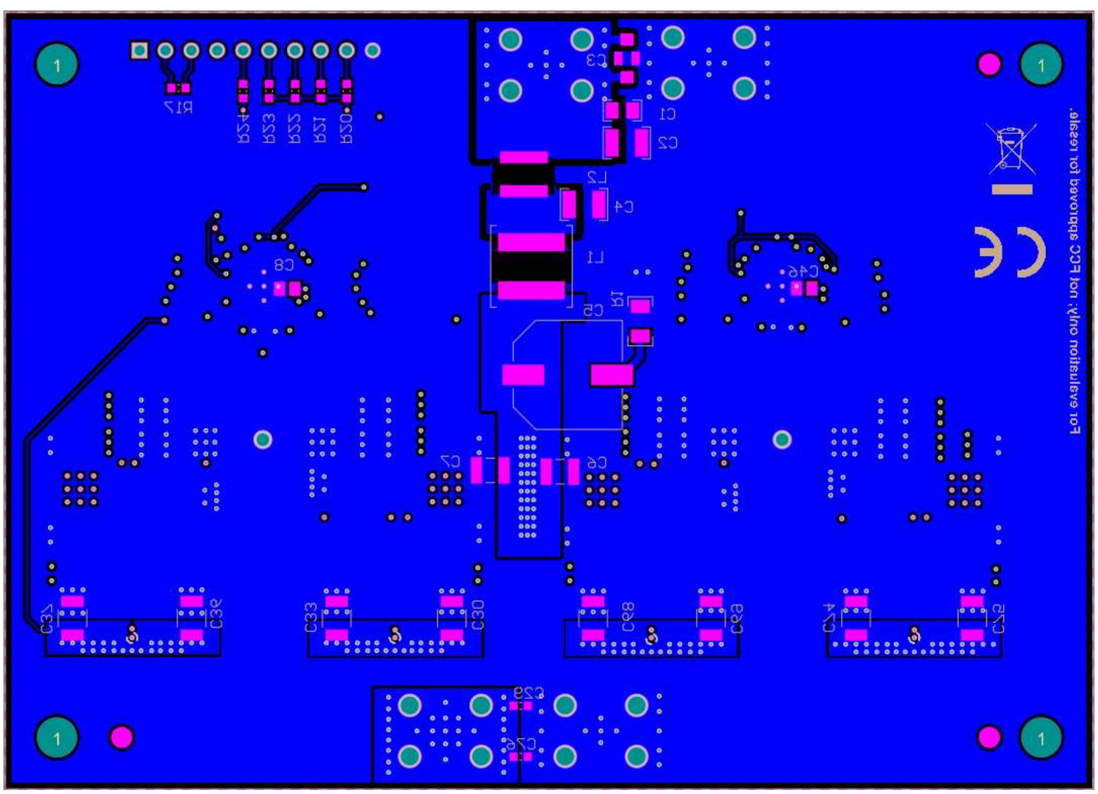

Figure 11. Bottom Copper (Top View)

7 Device and Documentation Support

7.1 Device Support

7.1.1 Development Support

For development support see the following:

- For TI's reference design library, visit TI Designs
- For TI's WEBENCH Design Environments, visit the WEBENCH® Design Center
- For the LM5143-Q1 DC/DC Controller Quickstart Calculator and PSPICE simulation models

7.2 Documentation Support

7.2.1 Related Documentation

- *LM5143-Q1 data sheet* (SNVSB29)
- *LM5143-Q1 EVM user's guide* (SNVU623)
- *Improve High-current DC/DC Regulator Performance for Free with Optimized Power Stage Layout* (SNVA803)
- *Reduce Buck Converter EMI and Voltage Stress by Minimizing Inductive Parasitics* (SLYT682)
- *AN-2162 Simple Success with Conducted EMI from DC-DC Converters* (SNVA489)
- White Papers:
  - *Valuing Wide V_{IN}, Low EMI Synchronous Buck Circuits for Cost-driven, Demanding Applications* (SLYY104)
  - *An Overview of Conducted EMI Specifications for Power Supplies* (SLYY136)
  - *An Overview of Radiated EMI Specifications for Power Supplies* (SLYY142)

7.2.1.1 PCB Layout Resources

- Technical Articles:
  - *High-Density PCB Layout of DC-DC Converters*
- *AN-1149 Layout Guidelines for Switching Power Supplies* (SNVA021)
- *AN-1229 Simple Switcher PCB Layout Guidelines* (SNVA054)
- *Constructing Your Power Supply – Layout Considerations* (SLUP230)
- *Low Radiated EMI Layout Made SIMPLE with LM4360x and LM4600x* (SNVA721)

7.2.1.2 Thermal Design Resources

- *AN-2020 Thermal Design by Insight, Not Hindsight* (SNVA419)
- *AN-1520 A Guide to Board Layout for Best Thermal Resistance for Exposed Pad Packages* (SNVA183)
- *Semiconductor and IC Package Thermal Metrics* (SPRA953)
- *Thermal Design Made Simple with LM43603 and LM43602* (SNVA719)
- *PowerPAD Thermally Enhanced Package* (SLMA002)
- *PowerPAD Made Easy* (SLMA004)
- *Using New Thermal Metrics* (SBVA025)

Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

Changes from Original (March 2019) to A Revision **Page**

- Added *Table 1* 1
- Updated *Table 3* 10