User's Guide

LMQ644A2-Q1 6-Phase Buck Regulator Design for Automotive ADAS Applications

ABSTRACT

The LMQ644A2-Q1 is a dual channel 36-V synchronous buck DC/DC converter which supports maximum 6 A per channel. The device is stackable up to 6 phases for higher output currents up to 36-A without external clocks. The device uses current-mode control architecture for easy loop compensation, fast transient response, and excellent load and line regulation.

LMQ644xx series also provides 4A channel and 5A channel versions. Please refer Table 1-1 for more information.

Table 1-1. LMQ644xx Series Synchronous Buck DC/DC Converter

Part Number	V_{IN} Range	Start-up Voltage	Maximum I_{OUT} (Single-phase, dual-output)	Maximum I_{OUT} (Dual-phase, single-output)
LMQ64480-Q1	3.0 V to 36 V	3.8 V	4 A	8 A
LMQ644A0-Q1	3.0 V to 36 V	3.8 V	5 A	10 A
LMQ644A2-Q1	3.0 V to 36 V	3.8 V	6 A	12 A

The LMQ644A2-Q1 6-phase reference design is a high-density automotive synchronous buck DC/DC regulator that employs synchronous rectification to achieve high conversion efficiency. It requires minimum 3.8 V to start up and works down to 3.0 V after start up. The regulator supports up to 36 A output current, and allows maximum 36 V input for a short time operation. The regulator provides three fixed output voltage options (2.5 V, 3.3 V and 5.0 V). The default configuration is 3.3V when J1 #1 - #2 are short. For 5 V output, short J1 #2 - #3. For 2.5 V output, open J1 and short J7.

The regulator design uses the LMQ644A2-Q1 36-V low I_Q dual synchronous buck DC/DC converter, having the following features:

- Wide input voltage range with a dropout mode at low VIN
- Low shutdown and standby I_Q
- Programmable switching frequency from 100 kHz to 2.2 MHz
- Integrated low R_{DSON} MOSFETs
- Selectable spread spectrum modulation
- Integrated VIN capacitors
- Cycle-by-cycle current limit with hiccup-mode overload protection

The LMQ644A2-Q1 is available in a 25-pin WQFN package with 5-mm × 4-mm footprint. See the *LMQ644A2-Q1 3-V to 36-V, 12-A Low IQ Dual Synchronous Buck DC/DC Converter* data sheet for more information.

Table of Contents

List of Figures

List of Tables

Trademarks

All trademarks are the property of their respective owners.

1 Introduction

The LMQ644A2QEVM-S400-6PH is designed to use a high-voltage input rail from 3 V to 36 V (Please see Table 2-1 for more information) to produce a regulated output voltage at a load current up to 36 A. This wide V_{IN} range solution covers a 12-V car battery input and offers an operating margin to withstand battery voltage transients. The per-phase switching frequency is 400 kHz and is synchronizable to a higher or lower frequency if required.

1.1 Features and Electrical Performance

- Provides three output voltage options (2.5 V, 3.3 V and 5.0 V)
- Wide input operating range of 3 V to 36 V (requires minimum 3.8 V to start up)
- Small input and output voltage ripple with 6-phase configuration
- Supports external clock synchronization
- High efficiency across wide input voltage ranges
  - Peak 95.2% at V_{IN} = 12 V, V_{OUT} = 3.3 V
  - Peak 93.4% at V_{IN} = 24 V, V_{OUT} = 3.3 V
- Optional power supply input for EMI filter evaluation
- Selectable Forced PWM (FPWM) or Auto mode
- Selectable spread spectrum modulation
- Integrated low R_{DSON} MOSFETs
- Peak current limit with hiccup mode overload protection
- User-adjustable soft-start time
- User-programmable loop compensation
- Power Good indicator with 100-kΩ pullup resistors to VCC
- Proven 6-layer PCB layout
- Passes CISPR-25 Class5 CE

2 Design Specifications

Table 2-1. Electrical Performance Characteristics

PARAMETER	TEST CONDITIONS		MIN	TYP	MAX	UNIT
INPUT CHARACTERISTICS						
Input voltage range, V_{IN} [3]	Operating[2]		3	12	20	V
	Transients		3		36	
Input current, no load, $I_{IN(NL)}$	I_{OUT} = 0 A, AUTO mode (Resistive leak paths are removed)	V_{IN} = 9 V		49		uA
		V_{IN} = 12 V		38		
		V_{IN} = 16 V		28		
Input current, disabled, $I_{IN(OFF)}$	V_{EN} = 0 V (Resistive leak paths are removed)	V_{IN} = 12 V		2.8		μA
OUTPUT CHARACTERISTICS						
Output voltage, V_{OUT} [1]			3.135	3.3	3.465	V
Output current, I_{OUT}	V_{IN} = 3.8 V to 20 V		0		36	A
Output voltage regulation, ΔV_{OUT}	Load regulation	I_{OUT} = 0 A to 36 A		0.5%		
	Line regulation	V_{IN} = 9 V to 16 V		0.5%		
Output voltage ripple, $V_{OUT(AC)}$	V_{IN} = 12 V, I_{OUT} = 36 A			20		mVrms
Soft-start time, t_{SS}	C_{SS} = 100 nF			4		ms
SYSTEM CHARACTERISTICS						
Switching frequency, F_{SW}	V_{IN} = 12 V		320	400	480	kHz
Full load efficiency, η_{FULL}	I_{OUT} = 36 A	V_{IN} = 8 V		91.6%		
		V_{IN} = 12 V		91.5%		
		V_{IN} = 16 V		90.9%		

(1) The default output voltage of this design is 3.3 V. Efficiency and other performance metrics can be changed based on operating input voltage, load current, externally-connected output capacitors, and other parameters.
(2) The recommended airflow when operating is 200 LFM.
(3) Minimum 3.85V V_{IN} for 2.5V V_{OUT}, 4.23V V_{IN} for 3.3V V_{OUT}, 5.45V V_{IN} for 5V V_{OUT}

3 Application Circuit Diagram and Operating Configuration Table

Figure 3-1 shows the typical diagram of 6-phase synchronous buck regulator using LMQ644A2-Q1. SS, COMP and MODE/SYNC of each devices are connected together to share the same information. The SYNC_OUT of primary device is connected to the SYNC of secondary device, and the SYNC_OUT of secondary device is connected to the SYNC of tertiary device to synchronize three devices with phase interleaving.

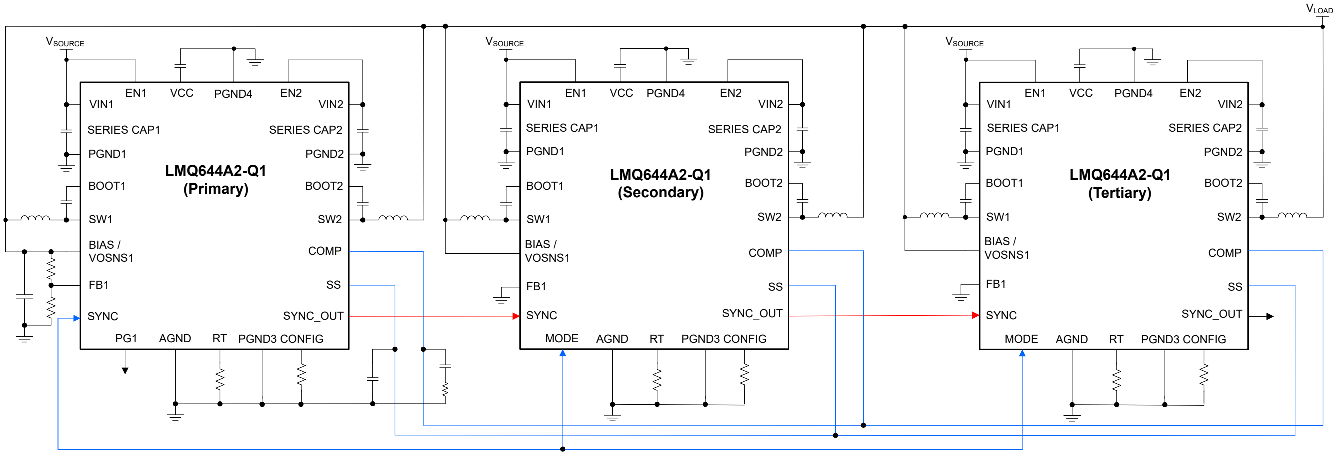


Figure 3-1. LMQ644A2-Q1 6-Phase Synchronous Buck Regulator Diagram

Table 3-1 describes the jumper and input terminal configurations of the LMQ644A2-Q1 6-phase reference design

Table 3-1. Operating Configuration Table

Operating Condition	Configuration
3.3 V output	J1 #1-#2 short, J7 open
5.0 V output	J1 #2-#3 short, J7 open
2.5 V output	J1 open, J7 short
Dither Enable	J4 #2-#3 short
Dither Disable	J4 #1-#2 short
AUTO Mode	J2 #1-#2 short
FPWM Mode	J2 #2-#3 short
Global Enable	J8 #2-#3 short
Global Disable	J8 #1-#2 short
EMI Bypass	Positive supply input to T3, Negative supply input to T4
EMI Input	Disconnect T3 and T4, Connect LISN(+) to VIN_EMI pad on the bottom, Connect LISN(-) to GND pad on the bottom

4 Top and Bottom Board Views

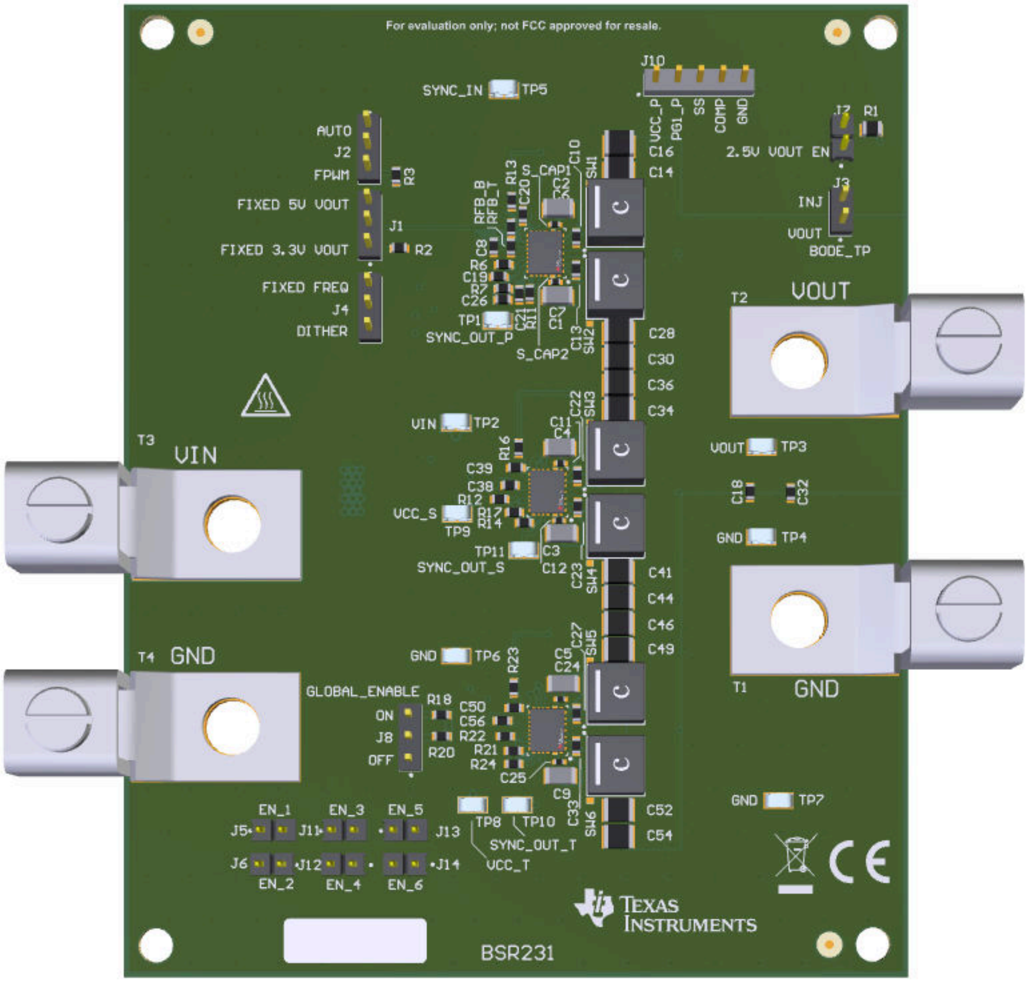


Figure 4-1. Top View (113mm x 90mm)

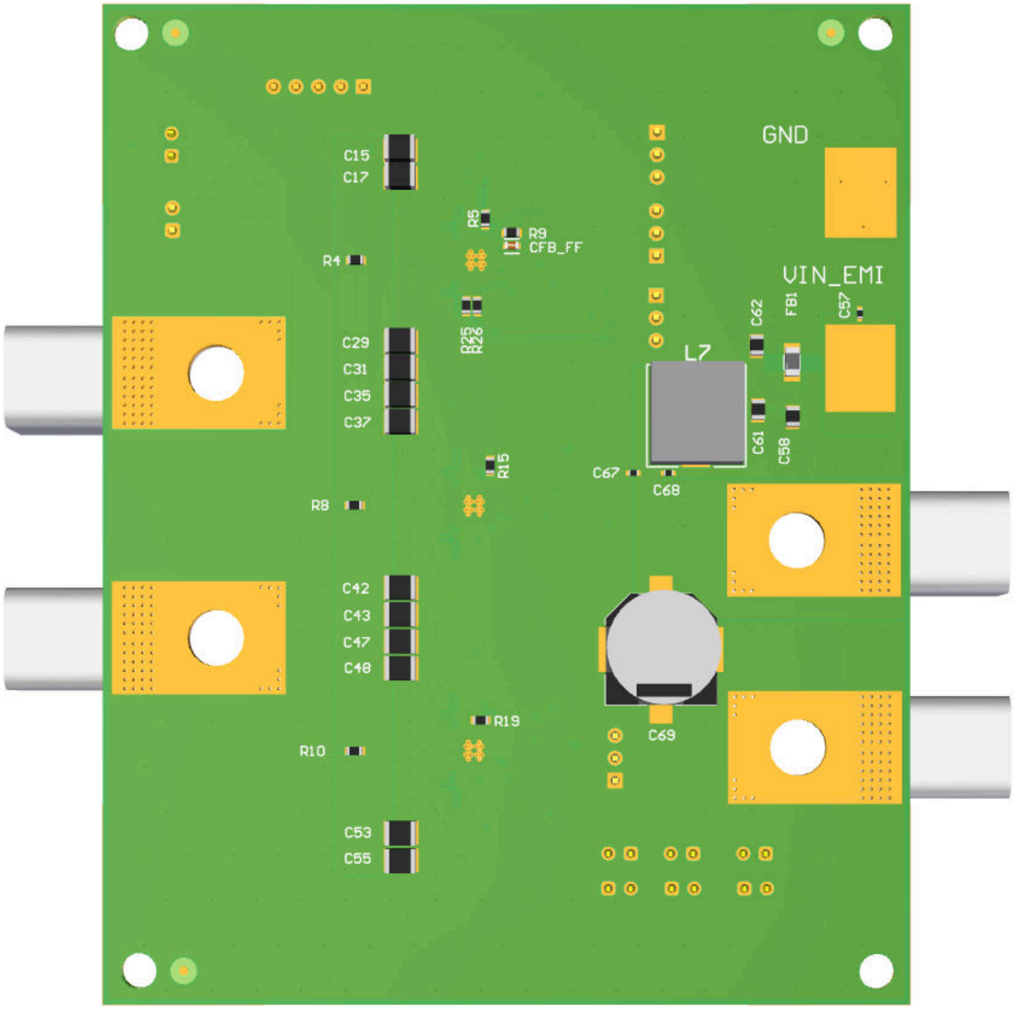


Figure 4-2. Bottom View (113mm x 90mm)

CAUTION

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

5 Test Data and Performance Curves

5.1 Conversion Efficiency

Efficiencies are measured at room temperature with external UVLO resistor dividers.

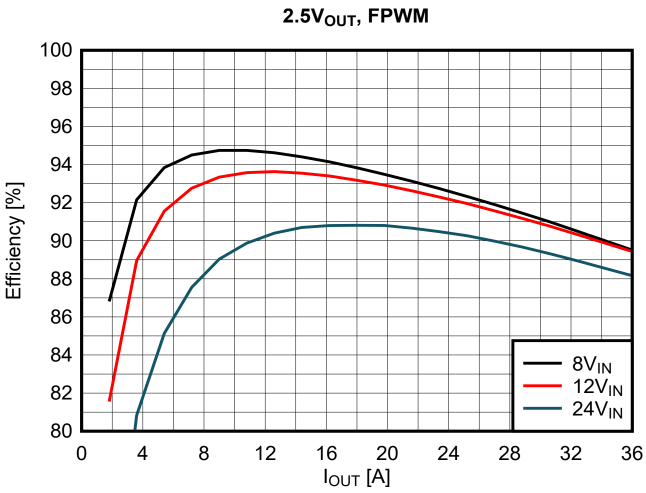


Figure 5-1. Efficiency, V_{OUT} = 2.5 V (FPWM mode)

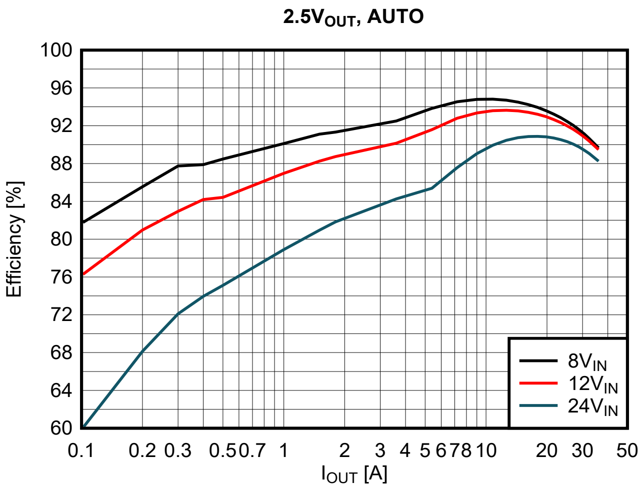


Figure 5-2. Efficiency, V_{OUT} = 2.5 V (Auto mode)

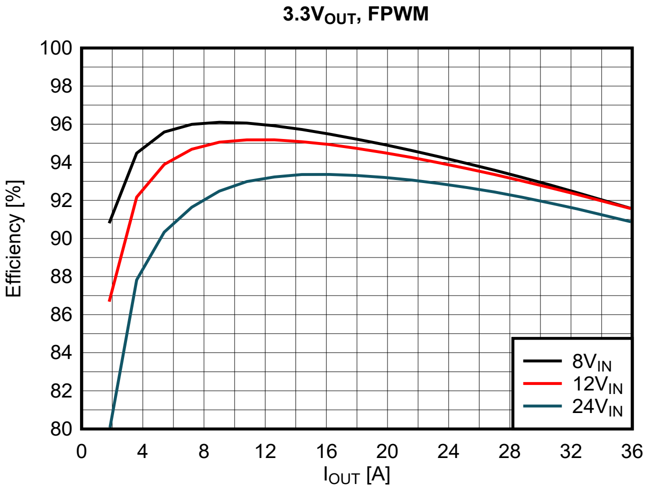


Figure 5-3. Efficiency, V_{OUT} = 3.3 V (FPWM mode)

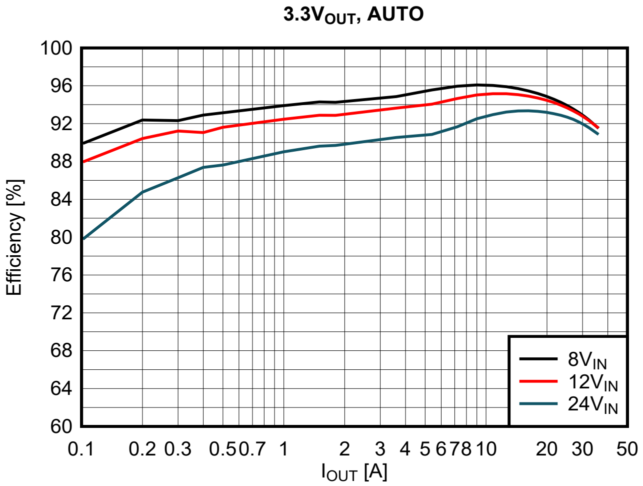


Figure 5-4. Efficiency, V_{OUT} = 3.3 V (Auto mode)

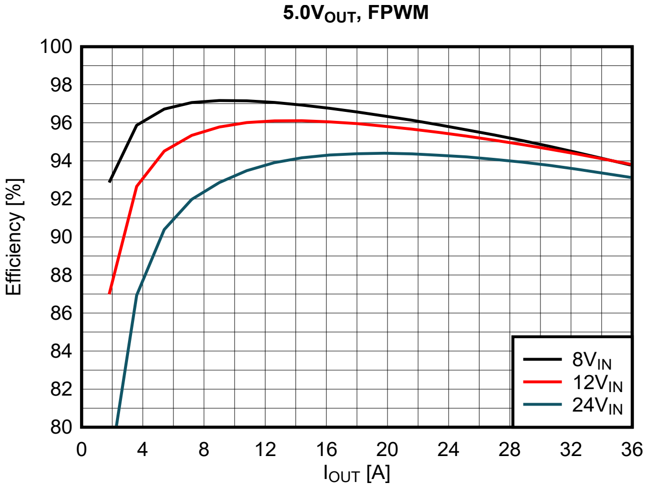


Figure 5-5. Efficiency, V_{OUT} = 5.0 V (FPWM mode)

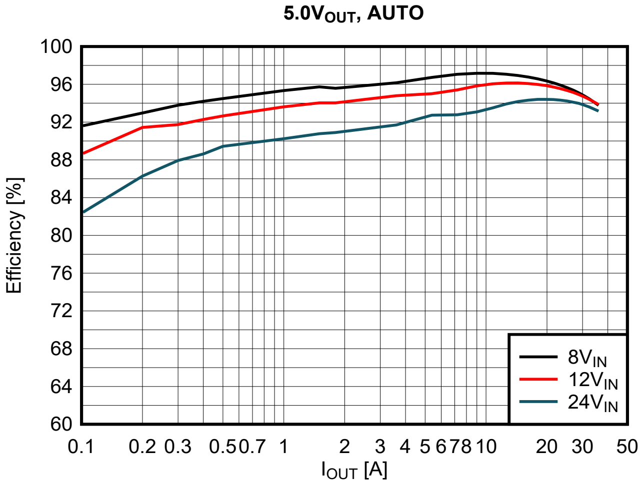
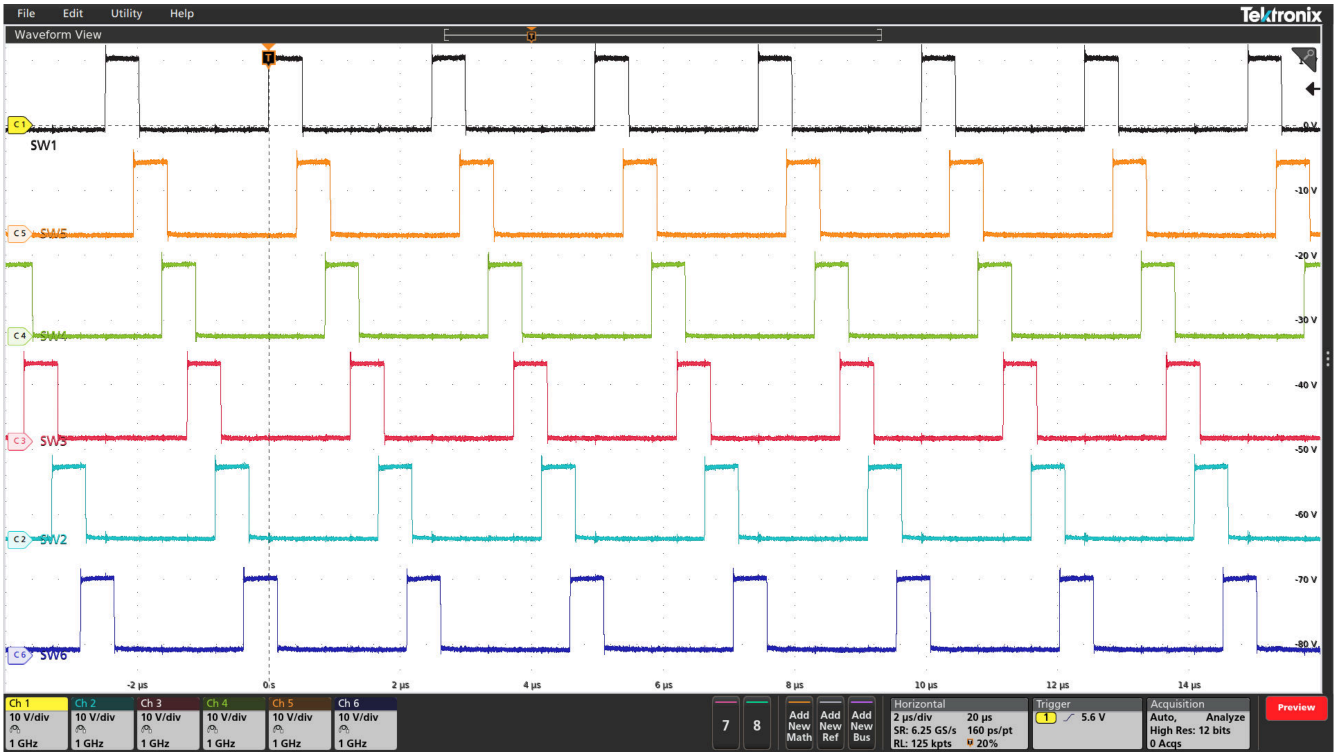


Figure 5-6. Efficiency, V_{OUT} = 5.0 V (Auto mode)

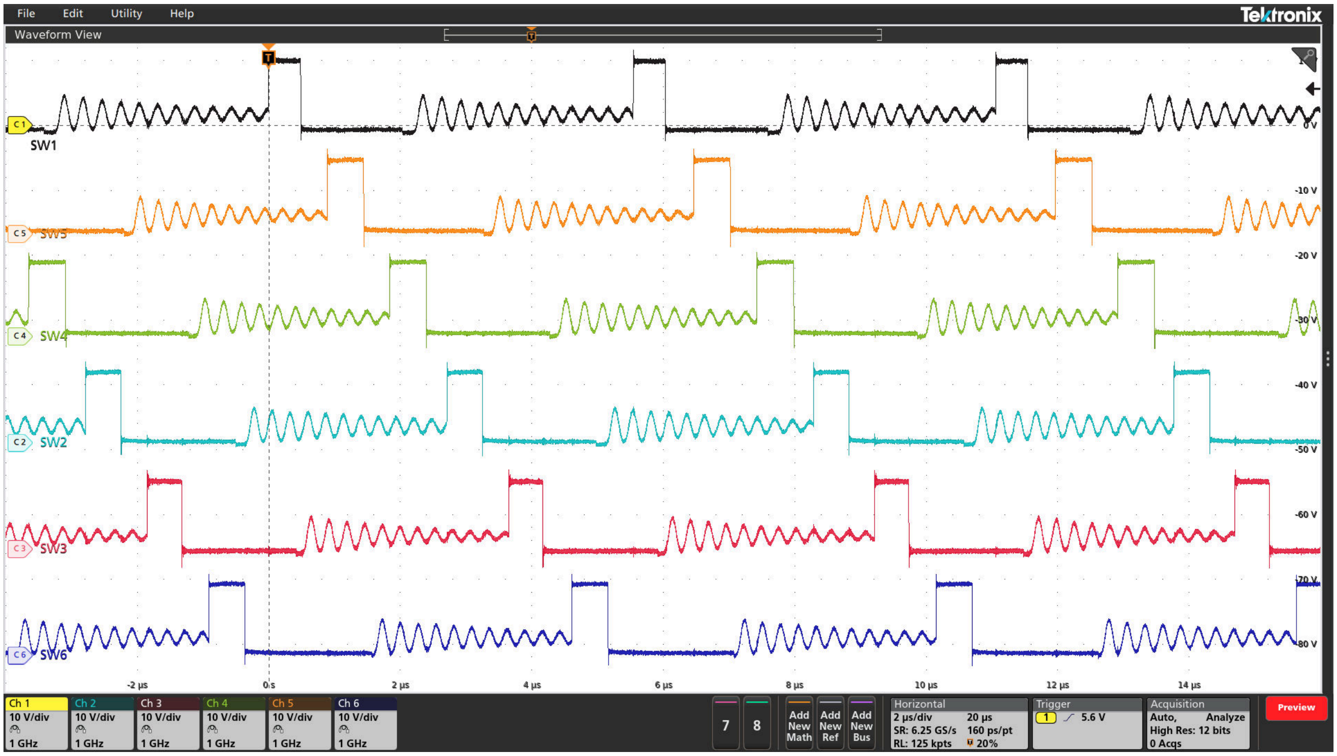
5.2 Operating Waveforms

5.2.1 6-phase Switching



Ch 1 10 V/div 1 GHz
Ch 2 10 V/div 1 GHz
Ch 3 10 V/div 1 GHz
Ch 4 10 V/div 1 GHz
Ch 5 10 V/div 1 GHz
Ch 6 10 V/div 1 GHz
Horizontal 2 µs/div 20 µs SR: 6.25 GS/s 160 ps/pt RL: 125 kpts 20%
Trigger 1 5.6 V
Acquisition Auto, Analyze High Res: 12 bits 0 Acqs

Figure 5-7. SW Node Voltage, V_{IN} = 12 V, V_{OUT} = 3.3 V, I_{OUT} = 2 A, FPWM mode



Ch 1 10 V/div 1 GHz
Ch 2 10 V/div 1 GHz
Ch 3 10 V/div 1 GHz
Ch 4 10 V/div 1 GHz
Ch 5 10 V/div 1 GHz
Ch 6 10 V/div 1 GHz
Horizontal 2 µs/div 20 µs SR: 6.25 GS/s 160 ps/pt RL: 125 kpts 20%
Trigger 1 5.6 V
Acquisition Auto, Analyze High Res: 12 bits 0 Acqs

Figure 5-8. SW Node Voltage, V_{IN} = 12 V, V_{OUT} = 3.3 V, I_{OUT} = 0 A, AUTO mode

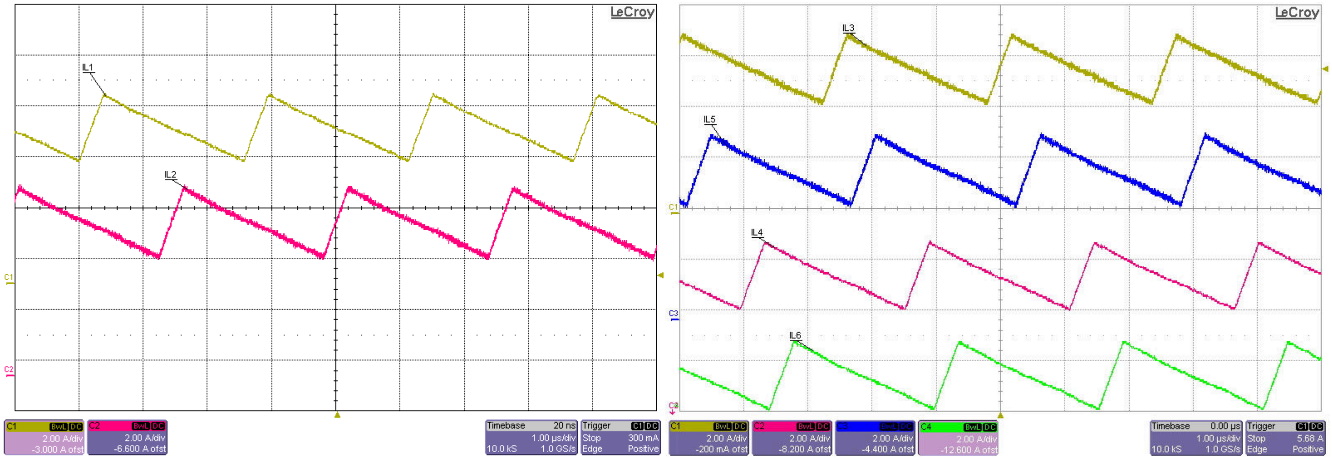


Figure 5-9. Inductor current, V_{IN} = 24 V, V_{OUT} = 3.3 V, I_{OUT} = 36 A, FPWM mode

5.2.2 Load Transient Response

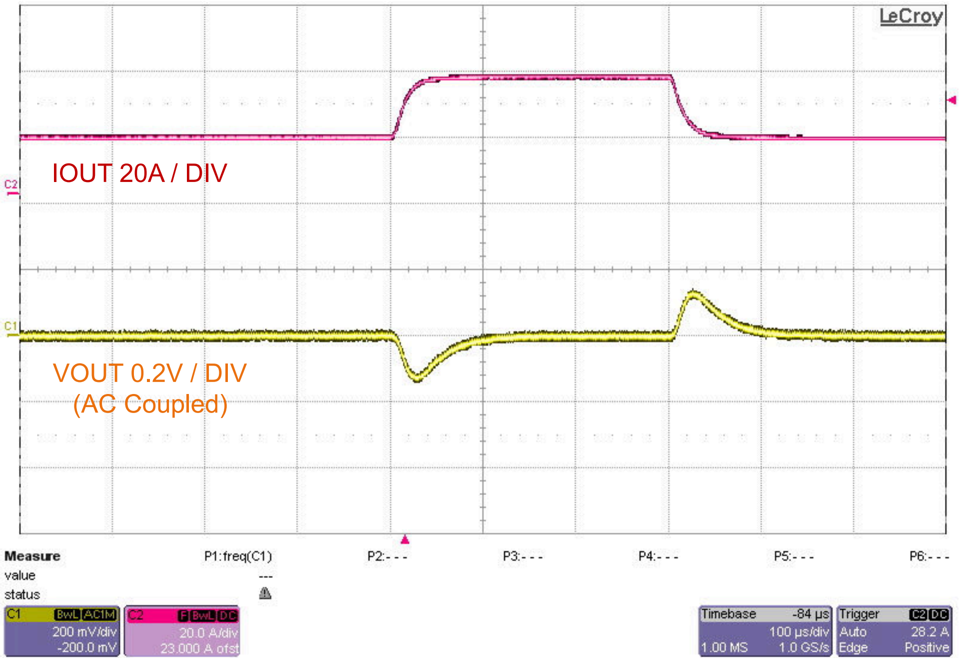


Figure 5-10. V_{IN} = 12 V, V_{OUT} = 2.5 V, FPWM, 18 A to 36 A (1A/us)

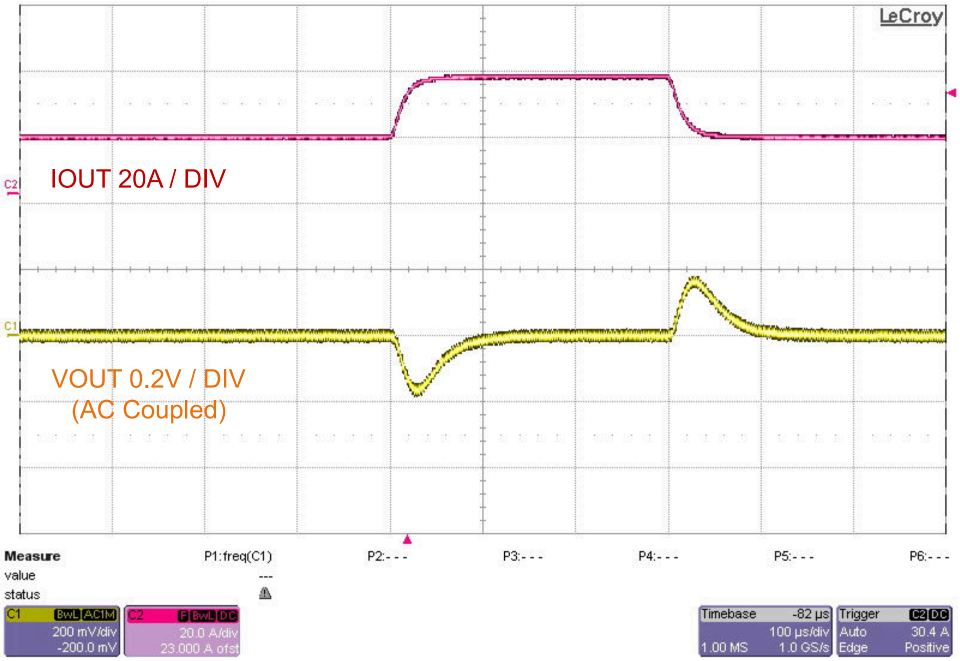


Figure 5-11. V_{IN} = 12 V, V_{OUT} = 3.3 V, FPWM, 18 A to 36 A (1A/us)

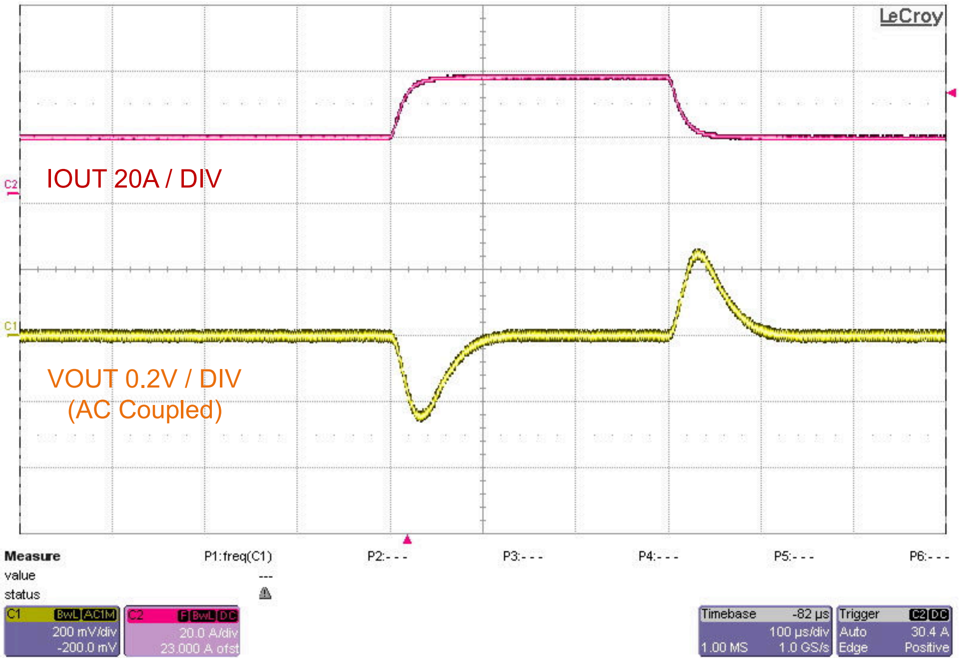
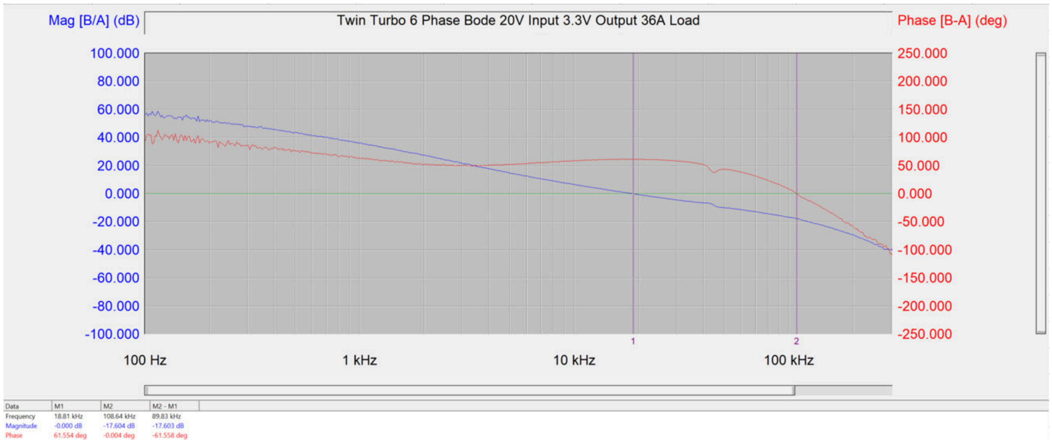


Figure 5-12. V_{IN} = 12 V, V_{OUT} = 5.0 V, FPWM, 18 A to 36 A (1A/us)

5.2.3 Loop Response

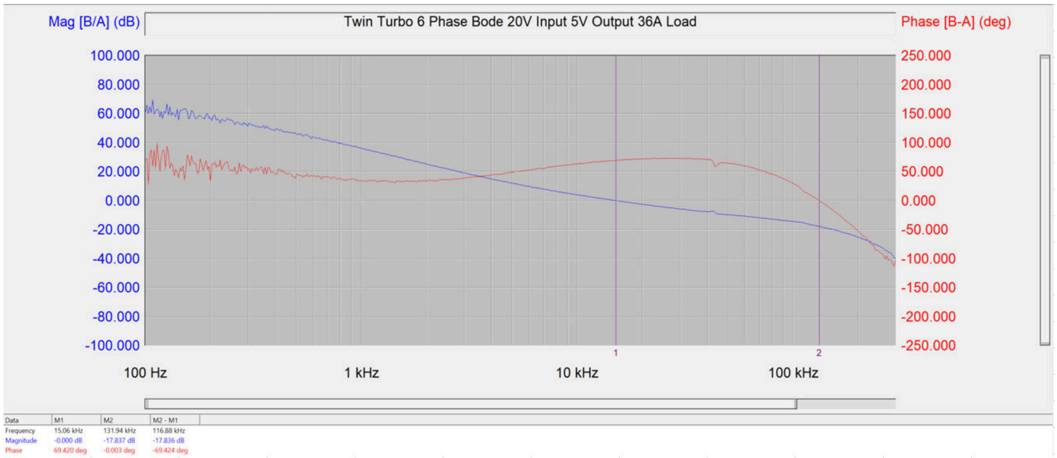
Data	M1	M2	M2 - M1
Frequency	21.75 kHz	104.23 kHz	82.48 kHz
Magnitude	-0.000 dB	-15.990 dB	-15.990 dB
Phase	59.481 deg	-0.001 deg	-59.482 deg

Figure 5-13. V_{IN} = 20 V, V_{OUT} = 2.5 V, I_{OUT} = 36 A



Data	M1	M2	M2 - M1
Frequency	18.81 kHz	108.64 kHz	89.83 kHz
Magnitude	-0.000 dB	-17.604 dB	-17.603 dB
Phase	61.554 deg	-0.004 deg	-61.558 deg

Figure 5-14. V_{IN} = 20 V, V_{OUT} = 3.3 V, I_{OUT} = 36 A



Data	M1	M2	M2 - M1
Frequency	15.06 kHz	131.94 kHz	116.88 kHz
Magnitude	-0.000 dB	-17.837 dB	-17.836 dB
Phase	69.420 deg	-0.003 deg	-69.424 deg

Figure 5-15. V_{IN} = 20 V, V_{OUT} = 5.0 V, I_{OUT} = 36 A

5.2.4 Startup/Shutdown

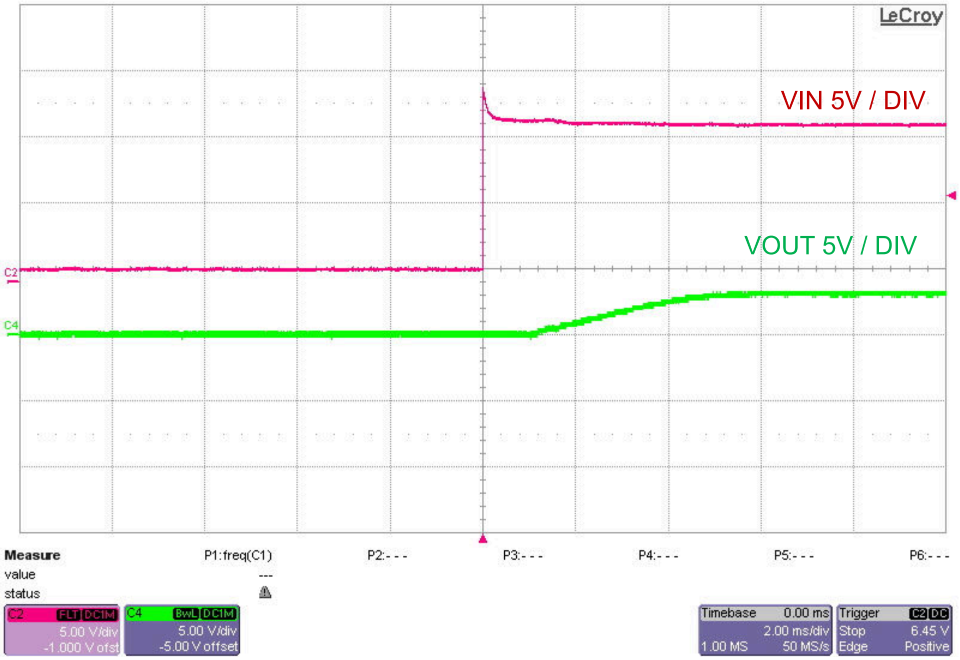


Figure 5-16. Startup, V_{IN} = 12 V, V_{OUT} = 3.3 V, I_{OUT} = 36 A Electric Load

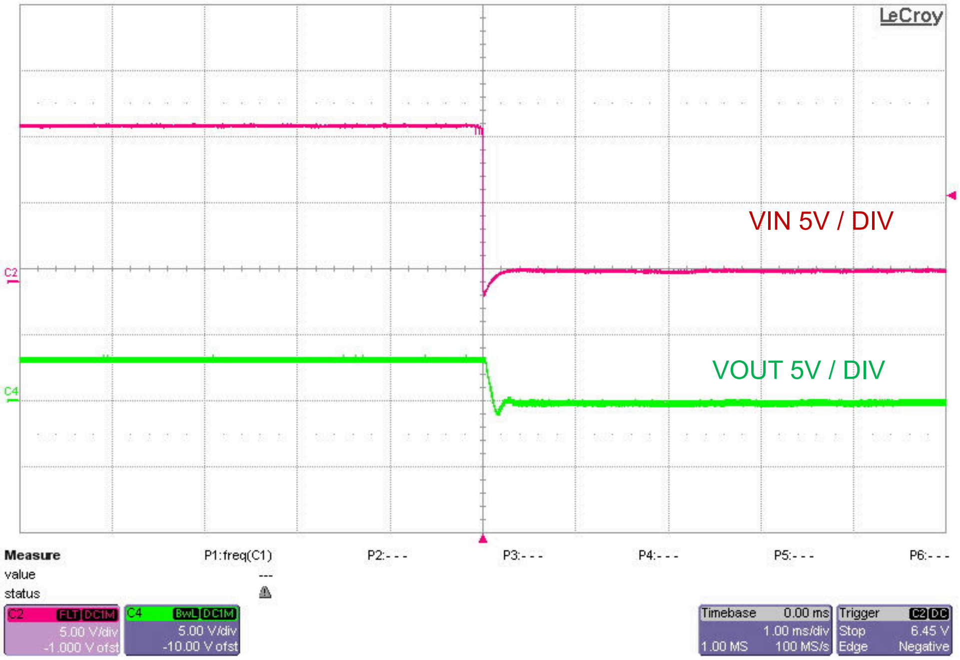


Figure 5-17. Shutdown, V_{IN} = 12 V, V_{OUT} = 3.3 V, I_{OUT} = 36 A Electric Load

5.3 Thermal Performance

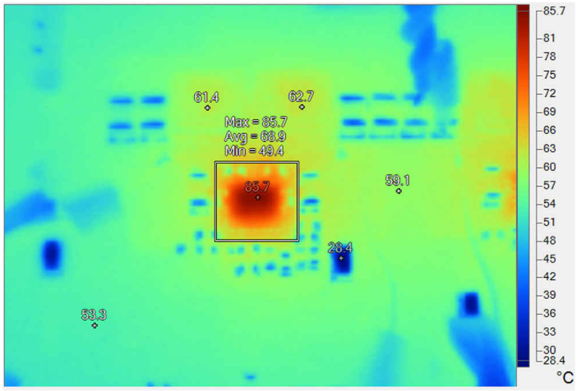


Figure 5-18. U1 Thermal Performance, V_{IN} = 12 V, V_{OUT} = 2.5 V, I_{OUT} = 36 A, Free Convection Airflow

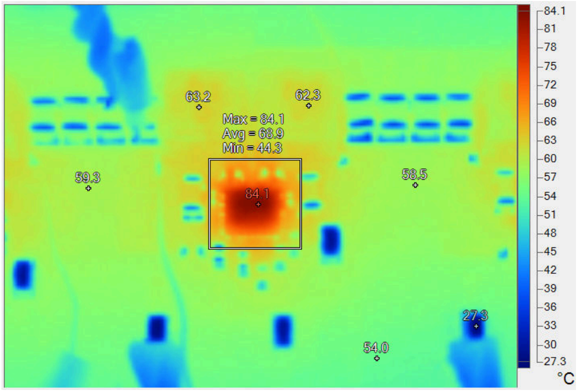


Figure 5-19. U2 Thermal Performance, V_{IN} = 12 V, V_{OUT} = 2.5 V, I_{OUT} = 36 A, Free Convection Airflow

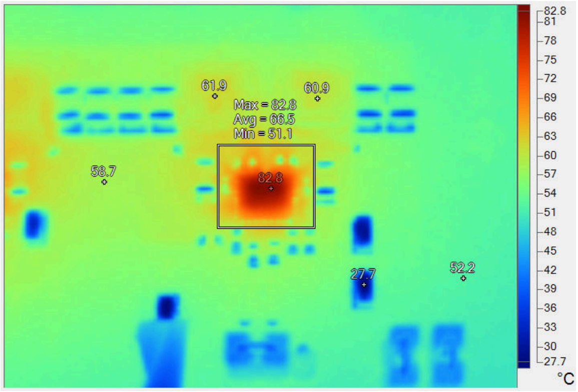


Figure 5-20. U3 Thermal Performance, V_{IN} = 12 V, V_{OUT} = 2.5 V, I_{OUT} = 36 A, Free Convection Airflow

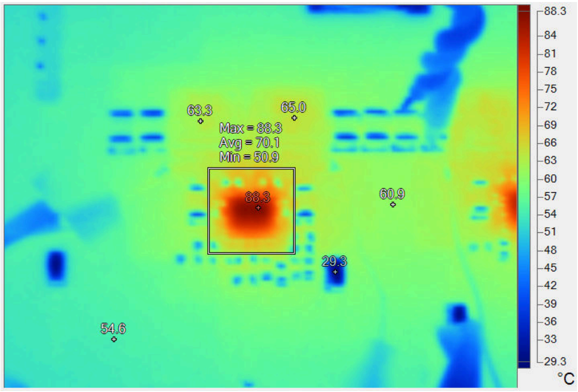


Figure 5-21. U1 Thermal Performance, V_{IN} = 12 V, V_{OUT} = 3.3V, I_{OUT} = 36 A, Free Convection Airflow

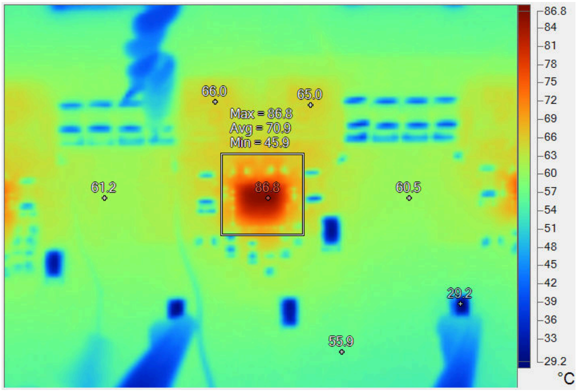


Figure 5-22. U2 Thermal Performance, V_{IN} = 12 V, V_{OUT} = 3.3 V, I_{OUT} = 36 A, Free Convection Airflow

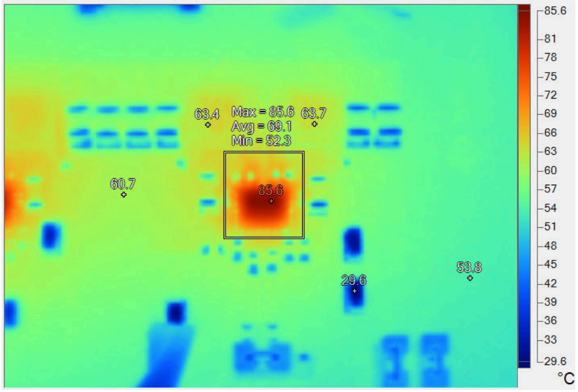


Figure 5-23. U3 Thermal Performance, V_{IN} = 12 V, V_{OUT} = 3.3 V, I_{OUT} = 36 A, Free Convection Airflow

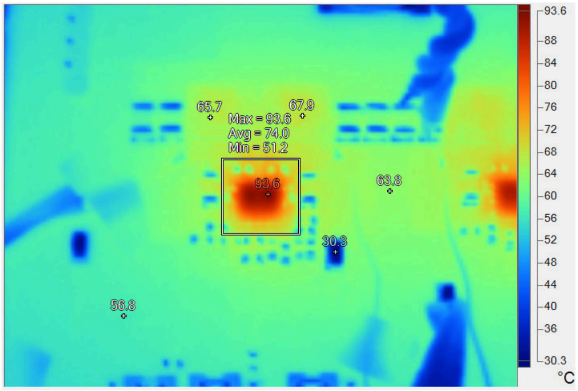


Figure 5-24. U1 Thermal Performance, V_{IN} = 12 V, V_{OUT} = 5.0 V, I_{OUT} = 36 A, Free Convection Airflow

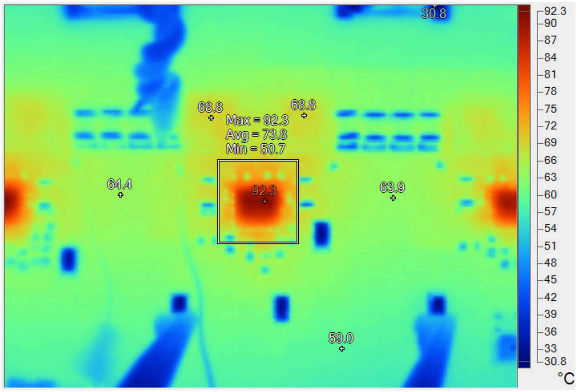


Figure 5-25. U2 Thermal Performance, V_{IN} = 12 V, V_{OUT} = 5.0 V, I_{OUT} = 36 A, Free Convection Airflow

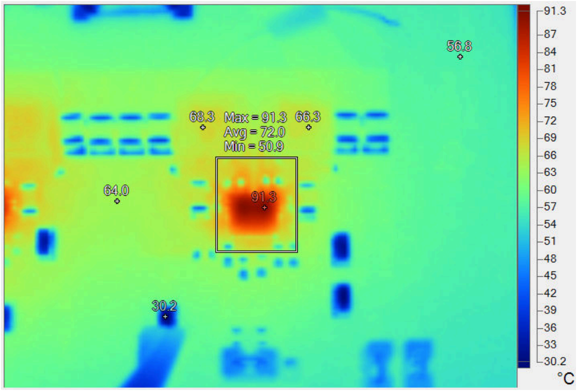
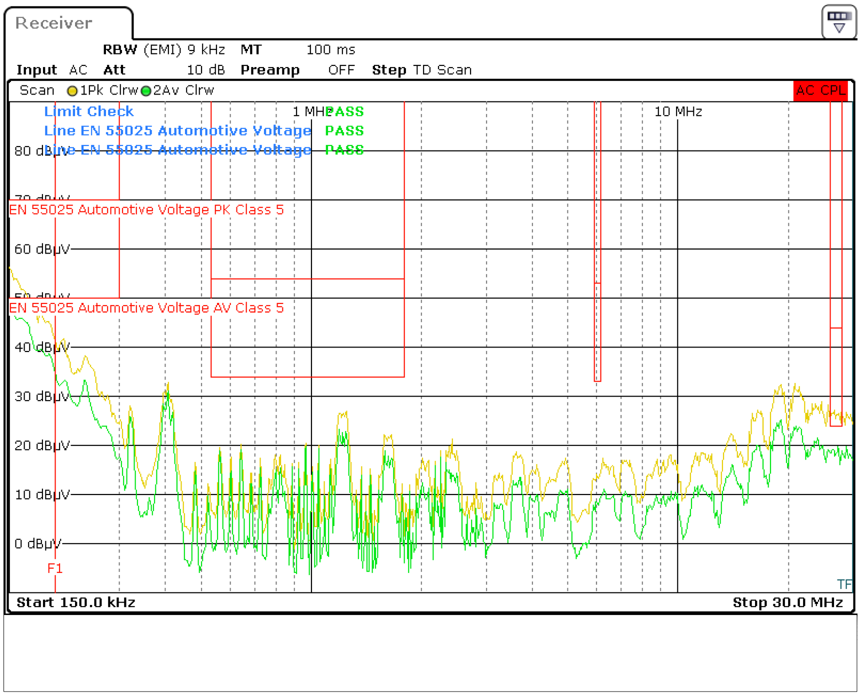


Figure 5-26. U3 Thermal Performance, V_{IN} = 12 V, V_{OUT} = 5.0 V, I_{OUT} = 36 A, Free Convection Airflow

5.4 CISPR 25 EMI Performance

EMI filter (GCM155R71H104KE2D(C57,C67,C68),C2012X7R1V225K085AC(C58,C61,C620), 7427930(FB1), SER1052-102MLB(L7)) is used when testing



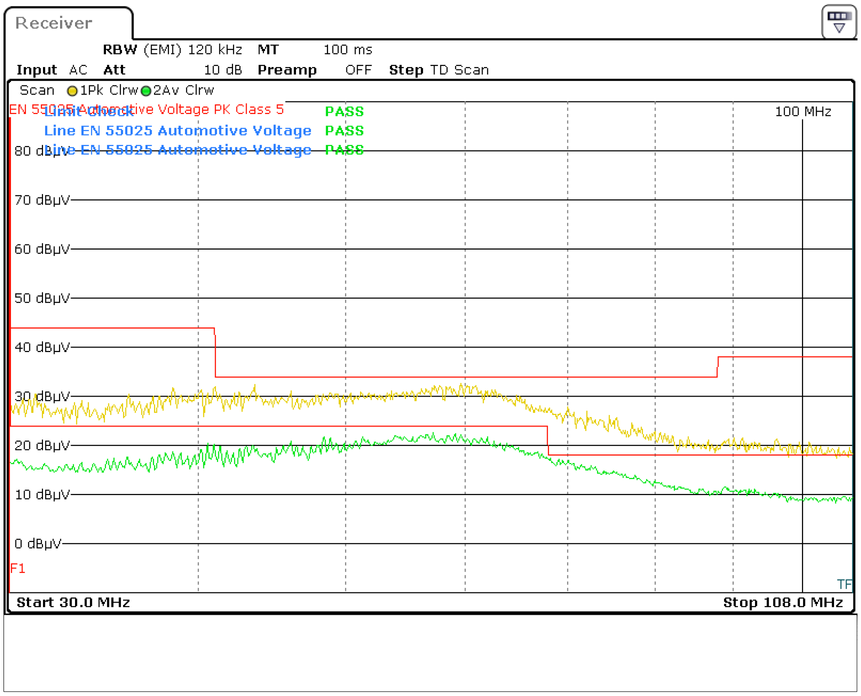
Receiver

RBW (EMI) 9 kHz **MT** 100 ms
Input AC **Att** 10 dB **Preamp** OFF **Step** TD Scan

Scan ●1Pk Clrw ●2Av Clrw

Limit Check PASS
Line EN 55025 Automotive Voltage PASS
Line EN 55025 Automotive Voltage PASS

Figure 5-27. CISPR 25 Class 5 Conducted Emissions Plot, 150 kHz to 30 MHz (RBW =9kHz) , V_{IN} = 24 V, V_{OUT} = 3.3 V, I_{OUT} = 36 A, Spread Spectrum enabled



Receiver

RBW (EMI) 120 kHz **MT** 100 ms
Input AC **Att** 10 dB **Preamp** OFF **Step** TD Scan

Scan ●1Pk Clrw ●2Av Clrw

Limit Check PASS
Line EN 55025 Automotive Voltage PASS
Line EN 55025 Automotive Voltage PASS

Figure 5-28. CISPR 25 Class 5 Conducted Emissions Plot, 30 MHz to 108 MHz (RBW=120kHz) , V_{IN} = 24 V, V_{OUT} = 3.3 V, I_{OUT} = 36 A, Spread Spectrum enabled

6 EVM Documentation

6.1 Schematic

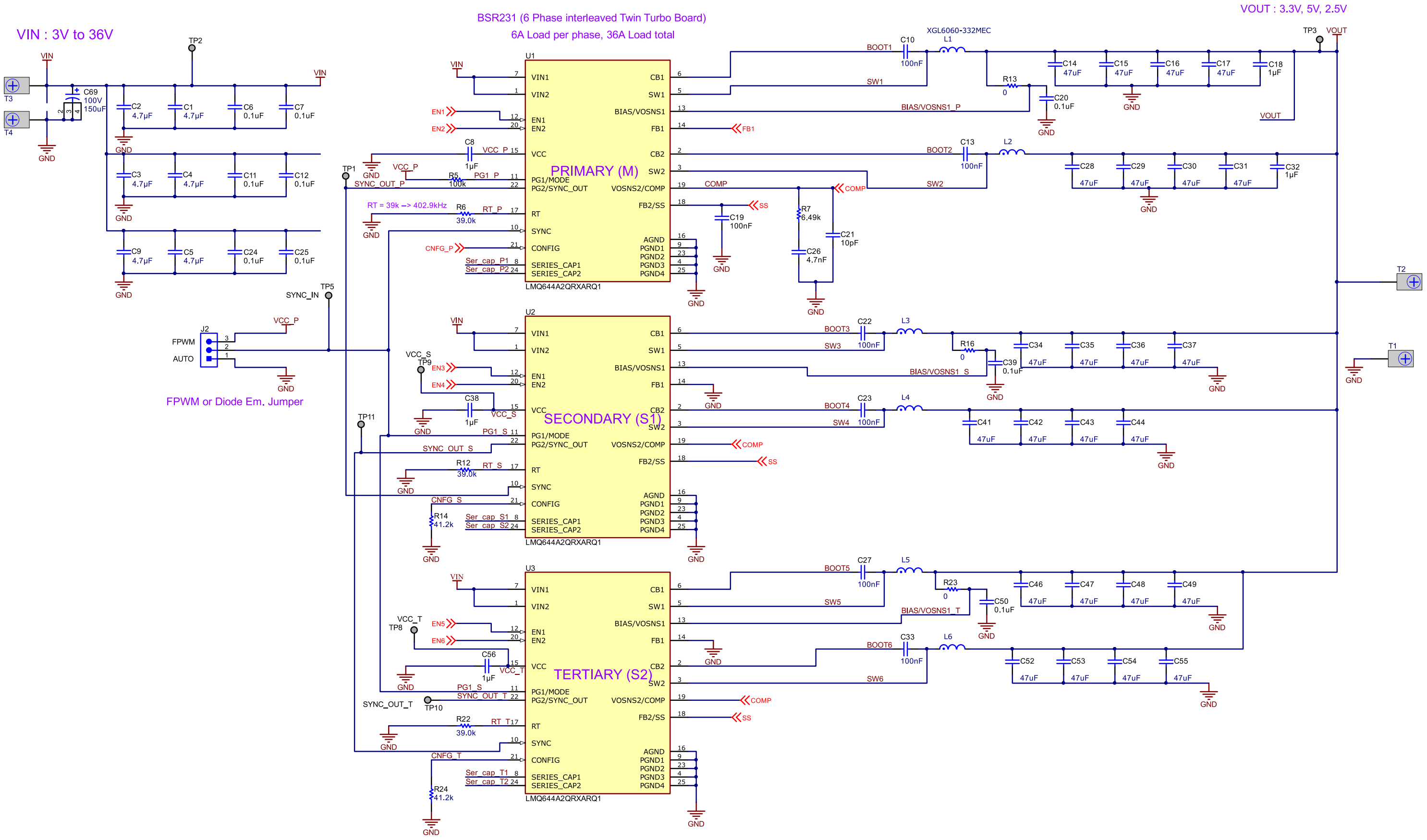


Figure 6-1. Schematic – Main

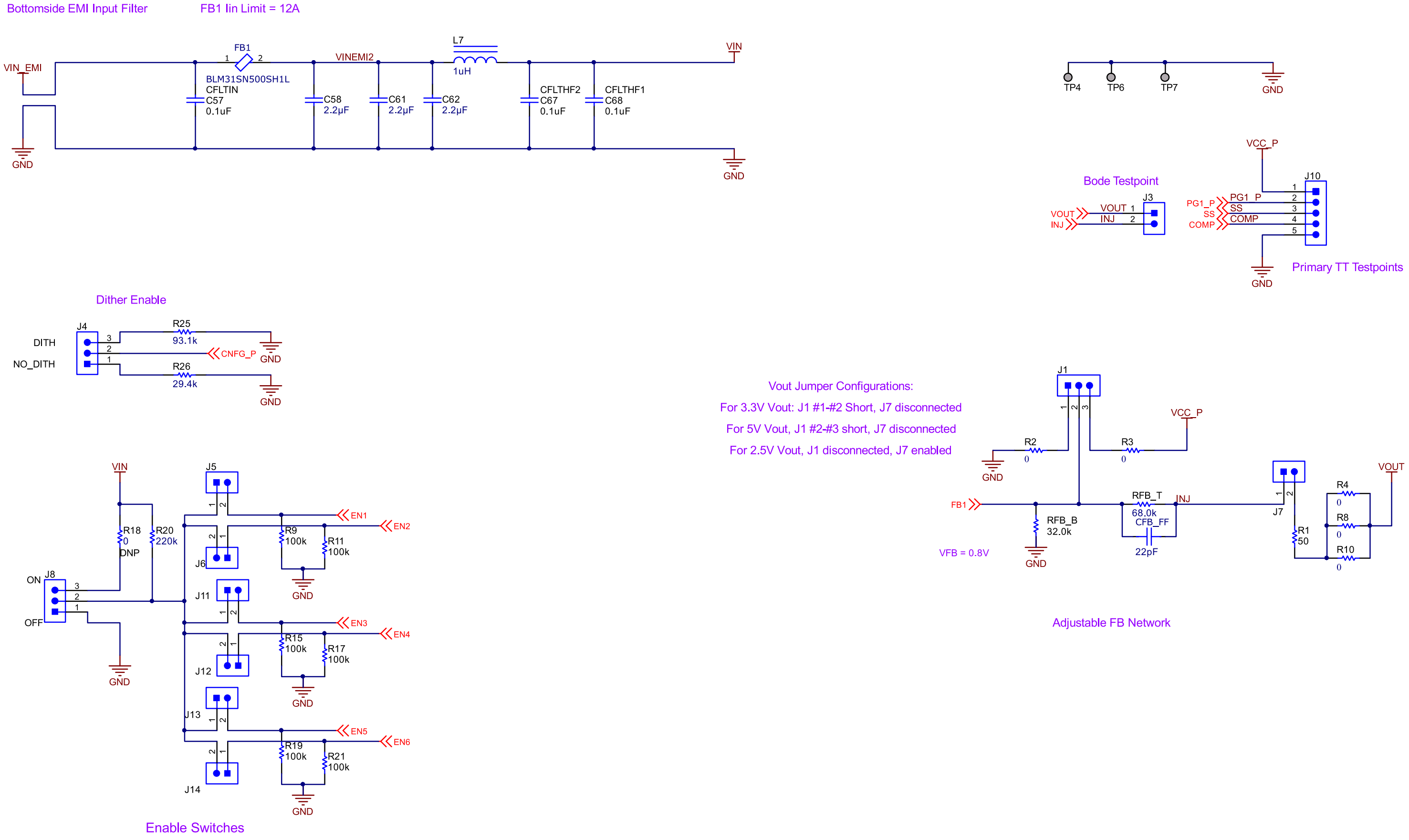


Figure 6-2. Schematic – Jumpers, Testpoints, EMI filter

6.2 Bill of Materials

Table 6-1. Bill of Materials

COUNT	REF DES	DESCRIPTION	PART NUMBER	MFR
6	C1, C2, C3, C4, C5, C9	CAP, CERM, 4.7 µF, 50 V,+/- 10%, X7R, 1206	C3216X7R1H475K160AE	TDK
9	C6, C7, C11, C12, C24, C25, C57, C67, C68	CAP, CERM, 0.1 uF, 50 V, +/- 10%, X7R, AEC-Q200 Grade 1, 0402	GCM155R71H104KE02D	MuRata
3	C8, C38, C56	CAP, CERM, 1 uF, 16 V, +/- 20%, X7R, AEC-Q200 Grade 1, 0603	GCM188R71C105MA64D	MuRata
6	C10, C13, C22, C23, C27, C33	CAP, CERM, 0.1 uF, 50 V, +/- 10%, X7R, AEC-Q200 Grade 1, 0603	CGA3E2X7R1H104K080AA	TDK
24	C14, C15, C16, C17, C28, C29, C30, C31, C34, C35, C36, C37, C41, C42, C43, C44, C46, C47, C48, C49, C52, C53, C54, C55	CAP, CERM, 47 uF, 10 V,+/- 20%, X7R, 1210	LMK325B7476MM-TR	Taiyo Yuden
2	C18, C32	CAP, CERM, 1 uF, 25 V, +/- 10%, X7R, AEC-Q200 Grade 1, 0603	GCM188R71E105KA64D	MuRata
1	C19	CAP, CERM, 0.1 uF, 16 V, +/- 10%, X7R, AEC-Q200 Grade 1, 0603	GCM188R71C104KA37J	MuRata
3	C20, C39, C50	CAP, CERM, 0.1 uF, 50 V, +/- 10%, X5R, 0603	C1608X5R1H104K080AA	TDK
1	C21	CAP, CERM, 10 pF, 100 V, +/- 5%, C0G/NP0, 0603	GRM1885C2A100JA01D	MuRata
1	C26	CAP, CERM, 4700 pF, 50 V, +/- 10%, X7R, AEC-Q200 Grade 1, 0603	GCM188R71H472KA37D	MuRata
3	C58, C61, C62	CAP, CERM, 2.2 uF, 35 V, +/- 10%, X7R, 0805	C2012X7R1V225K085AC	TDK
1	C69	CAP, AL, 100 uF, 100 V, +/- 20%, AEC-Q200 Grade 2, SMD	MAL215099907E3	Vishay-Bccomponents
1	CFB_FF	Cap Ceramic 22pF 100V C0G 5% Pad SMD 0603 125C Automotive T/R	GCM1885C2A220JA16D	Murata Electronics North America
1	FB1	Chip Ferrite Bead Array, 1206, 50Ω @ 100MHz, 0.0016Ω, 25%, 12A	BLM31SN500SH1L	Murata
8	H1, H2, H3, H4	Standoff, Hex, 0.5"L #4-40 Nylon	1902C	Keystone
8	H5, H6, H7, H8	Screw, Pan Head , 4-40, 3/8", Nylon	NY PMS 440 0038 PH	B&F Fastener Supply
4	J1, J2, J4, J8	Header, 100mil, 3x1, Gold, TH	PBC03SAAN	Sullins Connector Solutions
1	J3	Header, 100mil, 2x1, Gold, TH	TSW-102-07-G-S	Samtec
7	J5, J6, J7, J11, J12, J13, J14	Header, 2.54mm, 2x1, Tin, TH	TSW-102-23-T-S	Samtec
1	J10	Header, 100mil, 5x1, Gold, TH	HTSW-105-07-G-S	Samtec
6	L1, L2, L3, L4, L5, L6	Shielded Power Inductors 3.3uH 20% tol, 6.5mOhm 16.6A	XGL6060-332MEC	Coilcraft
1	L7	Inductor, Shielded E Core, Ferrite, 1 uH, 16.3 A, 0.004 ohm, SMD	SER1052-102MLB	Coilcraft
1	R1	RES, 49.9, 1%, 0.125 W, AEC-Q200 Grade 0, 0805	CRCW080549R9FKEA	Vishay-Dale
9	R2, R3, R4, R8, R10, R13, R16, R18, R23	RES, 0, 0%, 0.25 W, AEC-Q200 Grade 0, 0603	PMR03EZPJ000	Rohm
7	R5, R9, R11, R15, R17, R19, R21	RES, 100 k, 1%, 0.1 W, 0603	RC0603FR-07100KL	Yageo
3	R6, R12, R22	RES, 39.0 k, 0.1%, 0.1 W, 0603	RG1608P-393-B-T5	Susumu Co Ltd
1	R7	RES, 6.49 k, 1%, 0.1 W, AEC-Q200 Grade 0, 0603	CRCW06036K49FKEA	Vishay-Dale
2	R14, R24	RES, 41.2 k, 1%, 0.1 W, 0603	RC0603FR-0741K2L	Yageo
1	R20	RES, 220 k, 1%, 0.1 W, 0603	RC0603FR-07220KL	Yageo
1	R25	RES, 93.1 k, 1%, 0.1 W, 0603	RC0603FR-0793K1L	Yageo
1	R26	RES, 29.4 k, 0.1%, 0.1 W, 0603	RT0603BRD0729K4L	Yageo America
1	RFB_B	RES, 32.0 k, 0.1%, 0.1 W, 0603	RT0603BRD0732KL	Yageo America
1	RFB_T	RES, 68.0 k, 1%, 0.1 W, 0603	RC0603FR-0768KL	Yageo
11	SYNC_OUT_T, TP1, TP2, TP3, TP4, TP5, TP6, TP7, TP9, TP11, VCC_T	Test Lead clips and hooks, SMT	S1751-46	Harwin
4	T1, T2, T3, T4	Terminal 70A Lug	CXS70-14-C	Panduit
3	U1, U2, U3	LMQ644A2-Q1 3-V to 36-V, 12A, Low Iq dual buck converter	LMQ644A2QRXARQ1	Texas Instruments

6.3 PCB Layout

Top Copper through Bottom Copper show the design using a 6-layer PCB with 2-oz copper thickness.

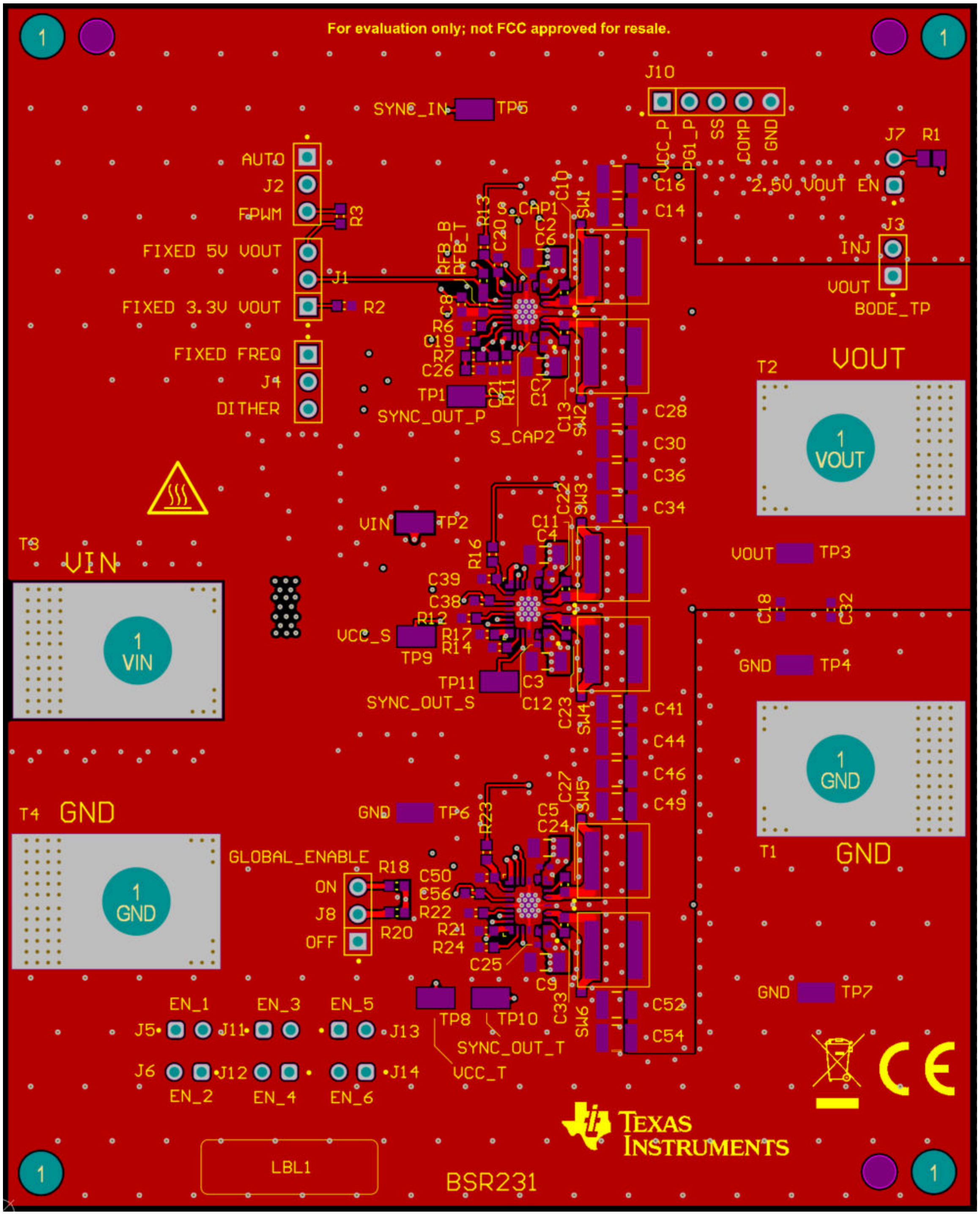


Figure 6-3. Top Copper (Top View)

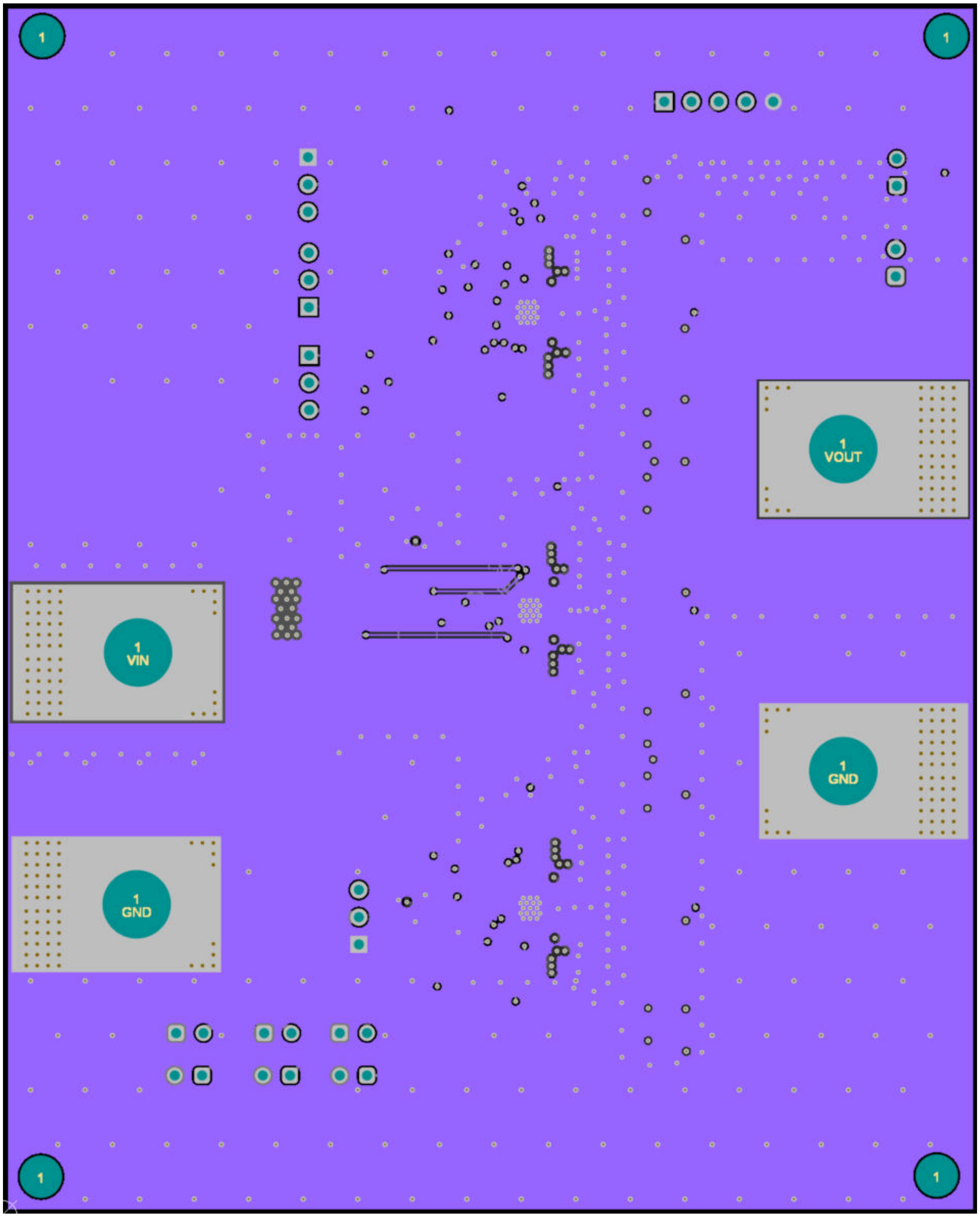


Figure 6-4. Layer 2 Copper (Top View)

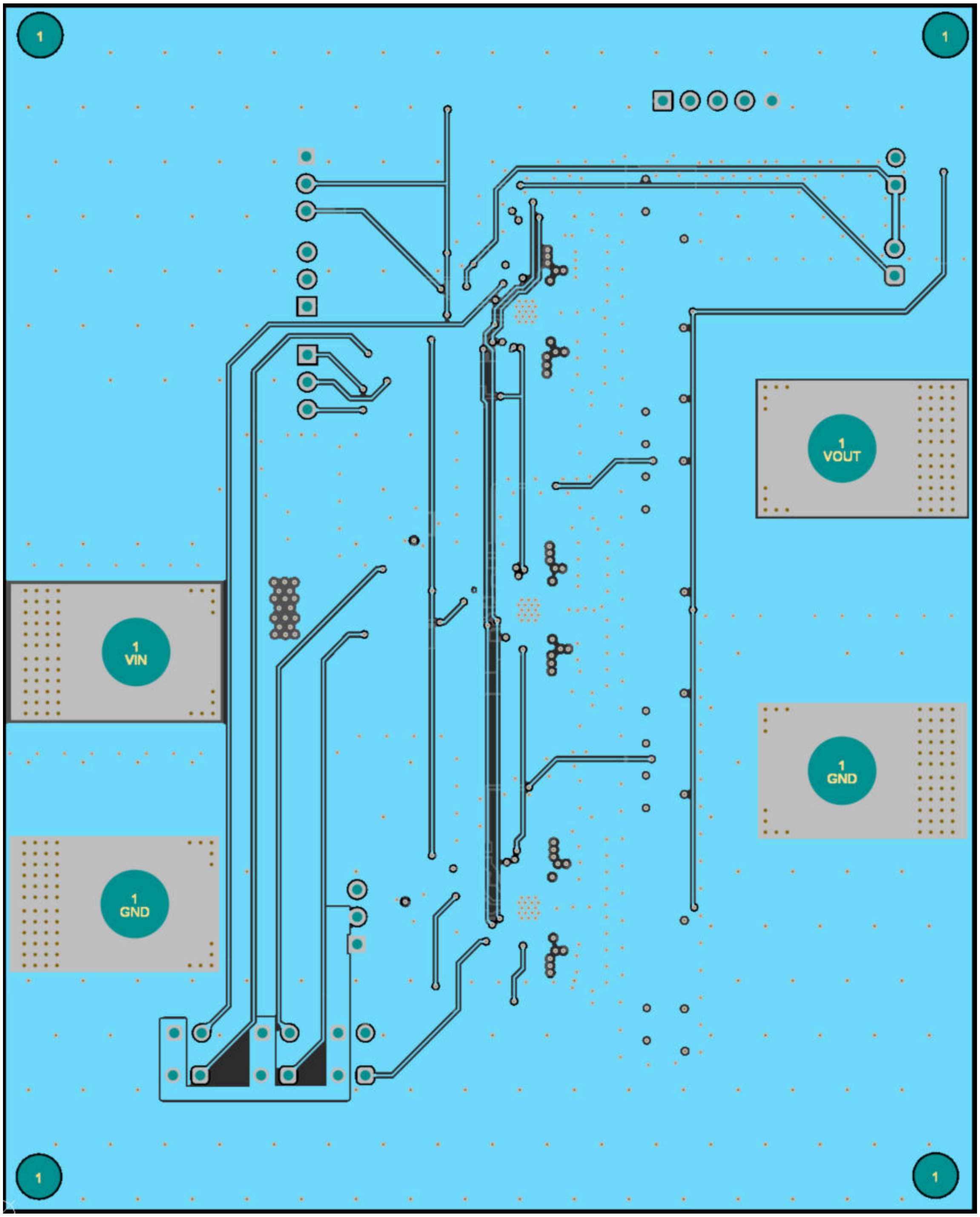


Figure 6-5. Layer 3 Copper (Top View)

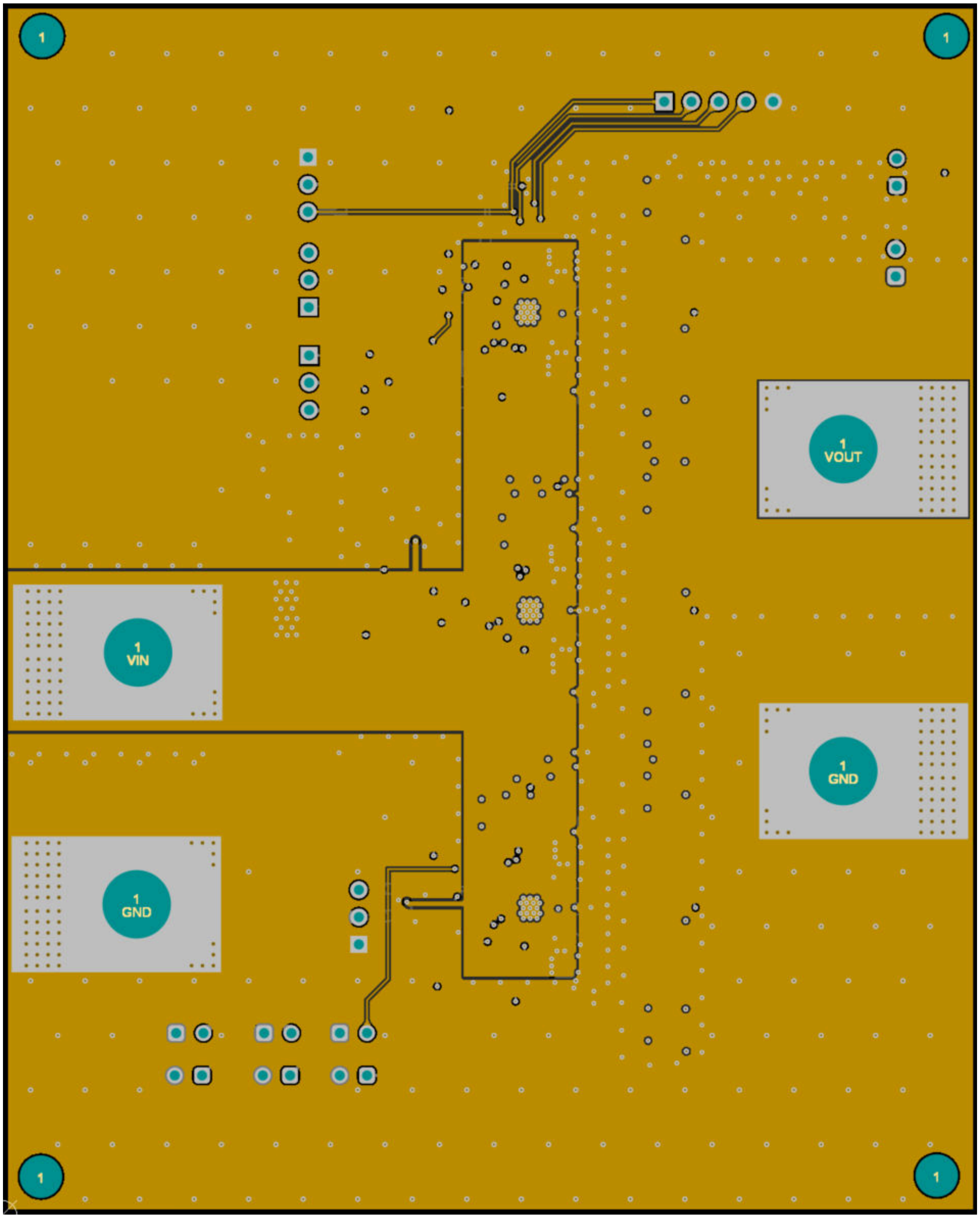


Figure 6-6. Layer 4 Copper (Top View)

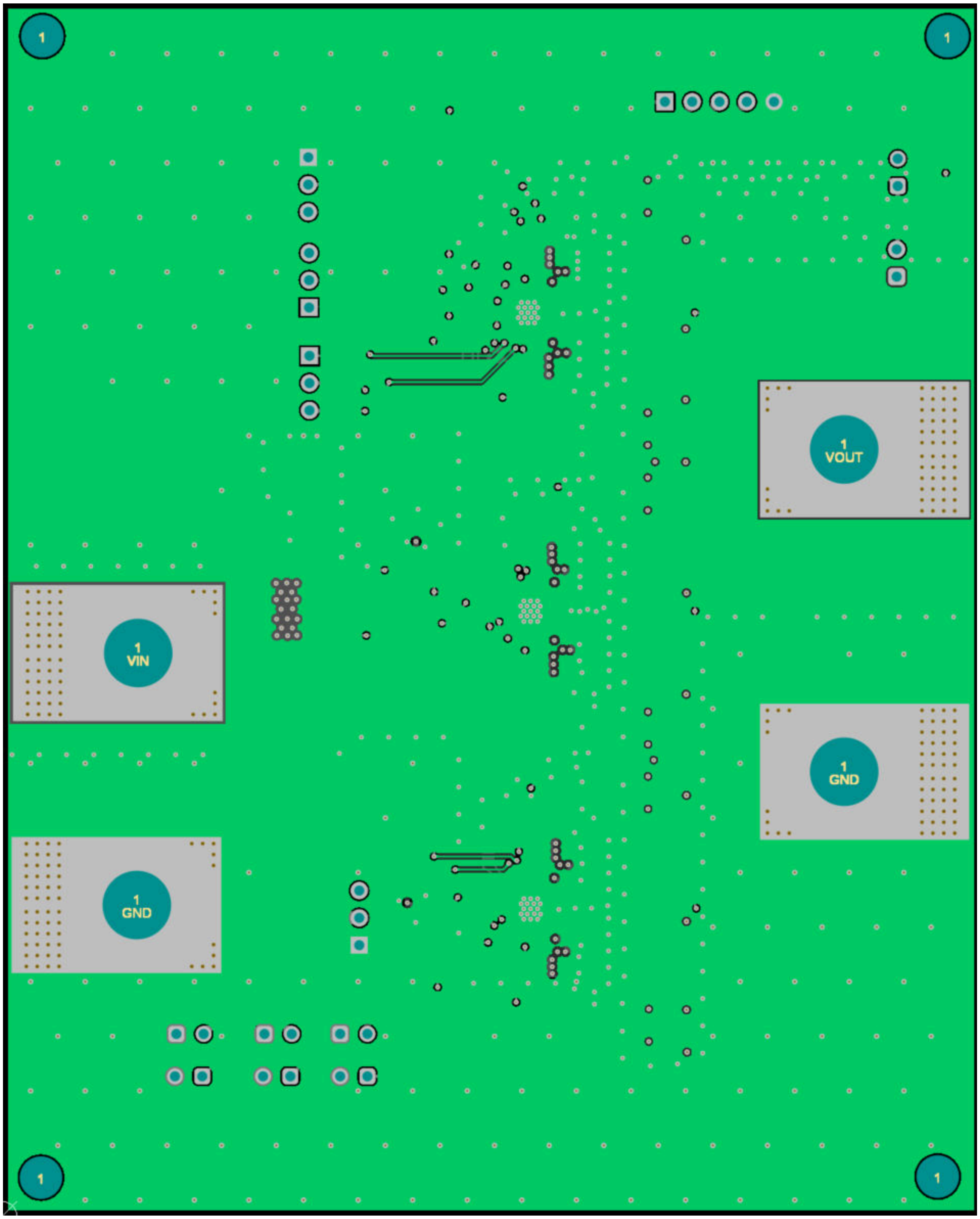


Figure 6-7. Layer 5 Copper (Top View)

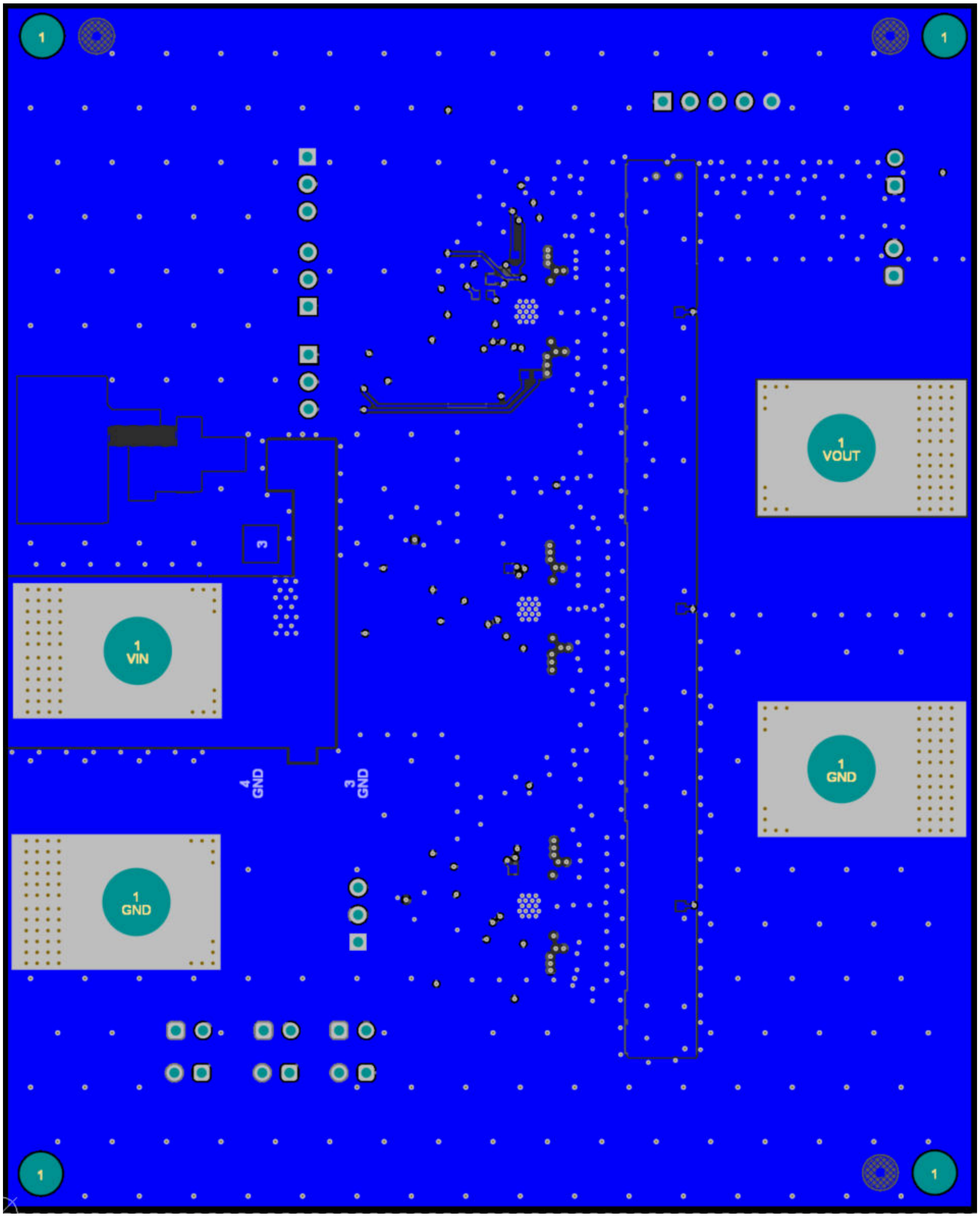


Figure 6-8. Bottom Copper (Top View)

7 4-Phase Configuration

7.1 4-Phase Switching

The 6-phase board can be used to evaluate the device in 4-phase configuration. The following changes need to be made to configure the 4-phase converter.

Table 7-1. Board Modification for 4-Phase Evaluation

Ref. Designator	Configuration
R25	73.2 kΩ
R26	19.1 kΩ
L5	Open
L6	Open
EN5	GND
EN6	GND
R23	Open

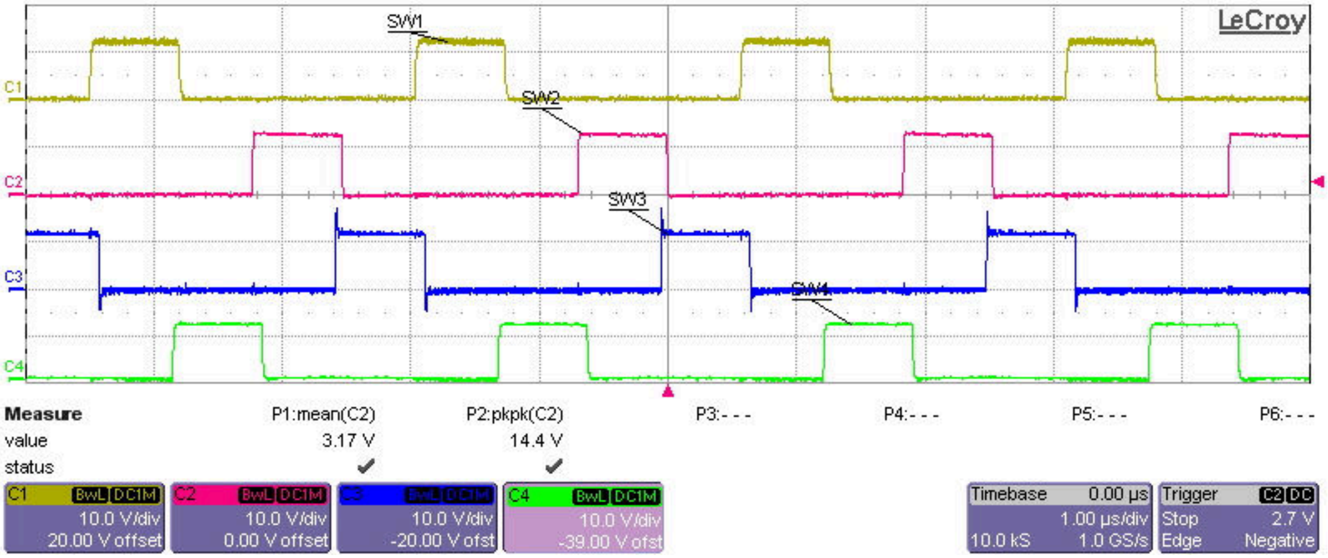


Figure 7-1. SW Node Voltage, V_{IN} = 12 V, V_{OUT} = 3.3 V, FPWM mode

8 Device and Documentation Support

8.1 Device Support

8.1.1 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 LMQ644A2-Q1 calculator, visit LMQ644A2-Q1 Product Folder

8.2 Documentation Support

8.2.1 References

- Texas Instruments, *LMQ644A2-Q1*, data sheet.
- Texas Instruments, *Improve High-current DC/DC Regulator Performance for Free with Optimized Power Stage Layout*, application brief.
- Texas Instruments, Reduce Buck Converter EMI and Voltage Stress by Minimizing Inductive Parasitics, analog applications journal.
- Texas Instruments, *AN-2162 Simple Success with Conducted EMI from DC-DC Converters* (SNVA489)
- Texas Instruments, *Valuing Wide V_{IN}, Low EMI Synchronous Buck Circuits for Cost-driven, Demanding Applications*, marketing white paper.
- Texas Instruments, *An Overview of Conducted EMI Specifications for Power Supplies*, marketing white paper.
- Texas Instruments, *An Overview of Radiated EMI Specifications for Power Supplies*, marketing white paper.

8.2.1.1 PCB Layout Resources

- Texas Instruments, *High-Density PCB Layout of DC-DC Converters*
- Texas Instruments, *AN-1149 Layout Guidelines for Switching Power Supplies*, application note.
- Texas Instruments, *AN-1229 Simple Switcher PCB Layout Guidelines*, application note.
- Texas Instruments, *Constructing Your Power Supply – Layout Considerations*, application note.
- Texas Instruments, *Low Radiated EMI Layout Made SIMPLE with LM4360x and LM4600x* , application note.

8.2.1.2 Thermal Design Resources

- Texas Instruments, *AN-2020 Thermal Design by Insight, Not Hindsight*, application note.
- Texas Instruments, *AN-1520 A Guide to Board Layout for Best Thermal Resistance for Exposed Pad Packages*, application note.
- Texas Instruments, *Semiconductor and IC Package Thermal Metrics*, application note.
- Texas Instruments, *Thermal Design Made Simple with LM43603 and LM43602*, application note.
- Texas Instruments, *PowerPAD Thermally Enhanced Package*, application note.
- Texas Instruments, *PowerPAD Made Easy*, application note.
- Texas Instruments, *Using New Thermal Metrics*, application note.

IMPORTANT NOTICE AND DISCLAIMER

TI PROVIDES TECHNICAL AND RELIABILITY DATA (INCLUDING DATA SHEETS), DESIGN RESOURCES (INCLUDING REFERENCE DESIGNS), APPLICATION OR OTHER DESIGN ADVICE, WEB TOOLS, SAFETY INFORMATION, AND OTHER RESOURCES “AS IS” AND WITH ALL FAULTS, AND DISCLAIMS ALL WARRANTIES, EXPRESS AND IMPLIED, INCLUDING WITHOUT LIMITATION ANY IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE OR NON-INFRINGEMENT OF THIRD PARTY INTELLECTUAL PROPERTY RIGHTS.

These resources are intended for skilled developers designing with TI products. You are solely responsible for (1) selecting the appropriate TI products for your application, (2) designing, validating and testing your application, and (3) ensuring your application meets applicable standards, and any other safety, security, regulatory or other requirements.

These resources are subject to change without notice. TI grants you permission to use these resources only for development of an application that uses the TI products described in the resource. Other reproduction and display of these resources is prohibited. No license is granted to any other TI intellectual property right or to any third party intellectual property right. TI disclaims responsibility for, and you will fully indemnify TI and its representatives against, any claims, damages, costs, losses, and liabilities arising out of your use of these resources.

TI’s products are provided subject to TI’s Terms of Sale or other applicable terms available either on ti.com or provided in conjunction with such TI products. TI’s provision of these resources does not expand or otherwise alter TI’s applicable warranties or warranty disclaimers for TI products.

TI objects to and rejects any additional or different terms you may have proposed.

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265

Copyright © 2023, Texas Instruments Incorporated