

LM5164-Q1 EVM User Guide

The [LM5164-Q1 EVM](#) is a 100-V DC/DC buck regulator that employs synchronous rectification to achieve high conversion efficiency in a small footprint. The EVM operates over a wide input voltage range of 15 V to 100 V to provide a regulated 12-V output at 300-kHz switching frequency. The output voltage has better than 1.5% setpoint accuracy and is adjustable using an external resistor divider. The module design uses the [LM5164-Q1](#) synchronous buck converter with wide input voltage (wide V_{IN}) range, wide duty-cycle range, integrated high-side and low-side power MOSFETs, cycle-by-cycle overcurrent protection, and precision enable. With AEC-Q100 grade 1 automotive qualification, the LM5164-Q1 is rated to operate over a junction temperature range of -40°C to $+150^{\circ}\text{C}$. The LM5164-Q1 is available in an 8-pin SO PowerPAD™ package to enable high density, low component count DC/DC solutions. The LM5164-Q1EVM-041 evaluation module is qualified for the LM5164 as well as the LM5164-Q1 buck converter. See [Table 1](#) for package information.

Use the LM5164-Q1 with [WEBENCH® Power Designer](#) to create a custom regulator design. Furthermore, the user can download the LM5164-Q1 [Quickstart calculator](#) to optimize component selection and examine predicted efficiency performance across line and load ranges.

Table 1. Device and Package Configurations

CONVERTER	IC	PACKAGE
U1	LM5164-Q1	8-pin SO package with PowerPAD (4.89 mm × 3.90 mm)
	LM5164	

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Trademarks

PowerPAD is a trademark of Texas Instruments.
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1 General TI High Voltage Evaluation User Safety Guidelines



Always follow TI's set-up and application instructions, including use of all interface components within their recommended electrical rated voltage and power limits. Always use electrical safety precautions to help ensure your personal safety and the safety of those working around you. Contact TI's Product Information Center <http://support.ti.com> for further information.

Save all warnings and instructions for future reference.

Failure to follow warnings and instructions may result in personal injury, property damage, or death due to electrical shock and/or burn hazards.

The term TI HV EVM refers to an electronic device typically provided as an open framed, unenclosed printed-circuit board assembly. It is intended strictly for use in development laboratory environments, solely for qualified professional users having training, expertise, and knowledge of electrical safety risks in development and application of high-voltage electrical circuits. Any other use and/or application are strictly prohibited by Texas Instruments. If you are not suitably qualified, you should immediately stop from further use of the HV EVM.

- **Work Area Safety:**

- Maintain a clean and orderly work area.
- Qualified observer(s) must be present anytime circuits are energized.
- Effective barriers and signage must be present in the area where the TI HV EVM and its interface electronics are energized, indicating operation of accessible high voltages may be present, for the purpose of protecting inadvertent access.
- All interface circuits, power supplies, evaluation modules, instruments, meters, scopes, and other related apparatus used in a development environment exceeding 50 V_{RMS}/75 VDC must be electrically located within a protected Emergency Power Off (EPO) protected power strip.
- Use a stable and non-conductive work surface.
- Use adequately insulated clamps and wires to attach measurement probes and instruments. No freehand testing whenever possible.

- **Electrical Safety:**

- As a precautionary measure, it is always a good engineering practice to assume that the entire EVM may have fully accessible and active high voltages.
- De-energize the TI HV EVM and all its inputs, outputs, and electrical loads before performing any electrical or other diagnostic measurements. Confirm that TI HV EVM power has been safely de-energized.
- With the EVM confirmed de-energized, proceed with required electrical circuit configurations, wiring, measurement equipment hook-ups, and other application needs, while still assuming the EVM circuit and measuring instruments are electrically live.
- When EVM readiness is complete, energize the EVM as intended.


WARNING: While the EVM is energized, never touch the EVM or its electrical circuits as they could be at high voltages capable of causing electrical shock hazard.

- **Personal Safety:**
 - Wear personal protective equipment, for example, latex gloves and/or safety glasses with side shields or protect EVM in an adequate lucent plastic box with interlocks from accidental touch.
- **Limitation for Safe Use:**
 - EVMs are not to be used as all or part of a production unit.

Safety and Precautions


The EVM is designed for professionals who have received the appropriate technical training, and is designed to operate from an AC power supply or a high-voltage DC supply. Please read this user guide and the safety-related documents that come with the EVM package before operating this EVM.

CAUTION




Do not leave the EVM powered when unattended.

WARNING



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

WARNING



High Voltage! Electric shock is possible when connecting board to live wire. Board should be handled with care by a professional.

For safety, use of isolated test equipment with overvoltage and overcurrent protection is highly recommended.

2 Overview

2.1 LM5164-Q1 Synchronous Buck Converter

The LM5164-Q1 step-down switching converter features all the functions needed to implement a low-cost, high-efficiency buck regulator capable of supplying 1 A to the load. An adaptive constant on-time (COT) control scheme and diode emulation mode at light loads enable a no-load supply current as low as 24 μA at 48-V input. With integrated 100-V power MOSFETs, synchronous rectification achieves high conversion efficiency over a wide load current range. Various features incorporated for enhanced reliability and safety include cycle-by-cycle peak current limit, thermal shutdown protection, internal output voltage soft-start timer, 1.5-V precision enable threshold, and an open-drain PGOOD indicator for sequencing and fault reporting.

Figure 1 shows the pin configuration of the LM5164-Q1. Figure 2 presents the regulator schematic for quick reference.

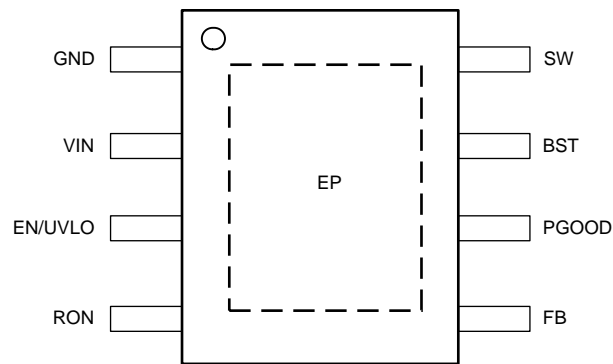
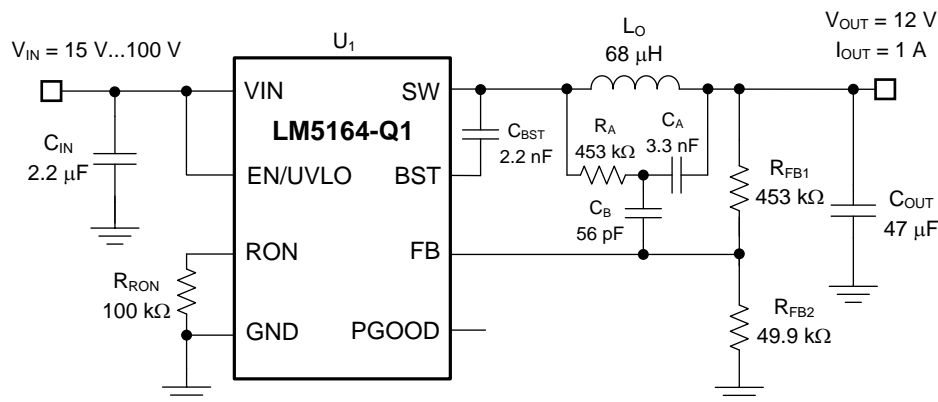


Figure 1. LM5164-Q1 Pin Configuration (8-Pin SO Package with PowerPAD, Top View)



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Figure 2. LM5164-Q1 Buck Regulator Simplified Schematic

2.2 Typical Applications

- Automotive 48-V Mild Hybrid ECU Bias Supplies
- Automotive DC/DC Converter, PTC Heater, HVAC Compressors
- High Cell Count Battery Packs for E-Bikes, E-Scooters and Drones
- General-Purpose Bias Supplies
- Automotive and Industrial Battery-Powered Equipment

2.3 EVM Performance Specifications

- Tightly-regulated output voltage of 12 V with 1% setpoint accuracy, adjustable from 1.2 V to VIN
- Wide input voltage operating range of 15 V to 100 V
- Ultra-high power conversion efficiency:
 - >90% at an output voltage of 12 V and load current above 3 mA (input voltage 24 V)
- No-load supply current as low as 24 μ A (without EN/UVLO resistor divider)
- Integrated 0.7- Ω NMOS buck switch supports 99% duty cycle for low dropout voltage
- Integrated 0.3- Ω NMOS synchronous rectifier eliminates external Schottky diode
- ENABLE and PGOOD terminals with 1-M Ω and 100-k Ω pullups to VIN and VOUT, respectively
- Monotonic pre-bias output voltage startup
- Programmable input UVLO via precision enable (internally set to turn on and off at 1.5 V and 1.4 V, respectively)
- Fully assembled, tested and proven PCB layout

3 EVM Characteristics

Table 2. EVM Electrical Performance Characteristics

Parameter	Test Conditions	MIN	TYP	MAX	UNITS
INPUT CHARACTERISTICS					
Input voltage range, V_{VIN}	EVM input voltage operating range	15	48	100	V
Input voltage turn on, $V_{IN(ON)}$	Adjusted by EN/UVLO resistors	6.0			V
Input voltage turn off, $V_{IN(OFF)}$		5.6			V
Input voltage hysteresis, $V_{IN(HYS)}$		0.4			V
Input current, no load, $I_{IN(NL)}$	$I_{OUT} = 0$ A	$V_{IN} = 24$ V	44		μ A
		$V_{IN} = 48$ V	60		μ A
Input current, disabled, $I_{IN(OFF)}$	$V_{EN/UVLO} = 0$ V	$V_{IN} = 24$ V	29		μ A
OUTPUT CHARACTERISTICS					
Output voltage, $V_{OUT}^{(1)}$	V_{OUT} follows V_{IN} for $V_{IN} < 12$ V	12.0			V
Output current, I_{OUT}	$V_{IN} = 15$ V to 100 V	0	1		A
Output voltage regulation, ΔV_{OUT}	Load regulation	$I_{OUT} = 0.1$ A to 1 A	0.75%		
	Line regulation	$V_{IN} = 15$ V to 100 V	1.5%		
Output voltage ripple, $V_{OUT(AC)}$	$V_{IN} = 48$ V, $I_{OUT} = 1$ A	30			mVp-p
Output overcurrent protection, I_{OCP}	$V_{IN} = 48$ V	1.4			A
Soft-start time, t_{SS}		3			ms
SYSTEM CHARACTERISTICS					
Switching frequency in CCM, $F_{SW(nom)}$	$V_{IN} = 48$ V	300			kHz
Half-load efficiency, $\eta_{HALF}^{(1)}$	$I_{OUT} = 0.5$ A	$V_{IN} = 24$ V	95%		
Full load efficiency, η_{FULL}	$I_{OUT} = 1$ A	$V_{IN} = 15$ V	93.2%		
		$V_{IN} = 24$ V	93.4%		
		$V_{IN} = 48$ V	92.1%		
		$V_{IN} = 100$ V	86%		

⁽¹⁾ The default output voltage of this EVM is 12 V. Efficiency and other performance metrics will change based on the operating input voltage, output voltage, load current, output capacitance, and other parameters.

4 LM5164-Q1 Evaluation Module

The LM5164-Q1 EVM is configured to deliver 12 V and 1 A at a switching frequency of 300 kHz. As shown in [Figure 2](#), a type 3 ripple generation circuit is used to generate the appropriate voltage ripple on FB. This circuit uses an RC network (consisting of R_A and C_A) between SW and V_{OUT} to create a triangular ramp. This triangular ramp is then AC coupled into the feedback node with capacitor C_B . This method is best suited for applications where low output voltage ripple is required and where ceramic output capacitors are used (since it is not using the output voltage to generate the ripple signal).

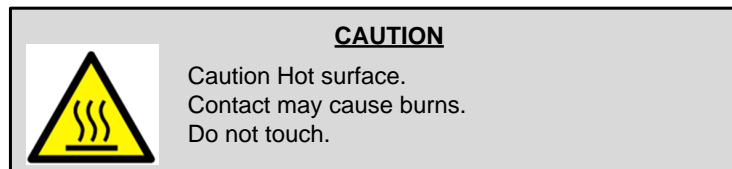
4.1 Quick Start Procedure

1. Connect the voltage supply between VIN and GND connectors using short wires.
2. Connect the load of the converter between VOUT and GND connectors using short wires.
3. Set the supply voltage (V_{VIN}) at an appropriate level between 15 V to 100 V. Set the current limit of the supply to an appropriate level as well.
4. Turn on the power supply. The EVM powers up and provides $V_{OUT} = 12$ V.
5. Monitor the output voltage while increasing the load current to 1 A max.

See [Figure 3](#) for the location of the connectors.



Figure 3. LM5164-Q1 EVM Top View



4.2 Detailed Descriptions

This section describes the connectors and the test points on the EVM and how to properly connect, set up and use the LM5164-Q1 EVM. See [Figure 3](#) for a top view of the EVM.

VOUT — Output voltage of the converter.

VOUT connector and test point connected to the power inductor and the output capacitors. Connect the loading device between VOUT and GND connectors to provide loading to the regulator. Connect the loading device to the board with short wires to handle the DC output current.

GND — Ground of the converter.

It is connected to the LM5164-Q1 GND as well as the return terminals of the input and output capacitors. GND is the current return path for both supply voltage and load. Connect to supply and load grounds with short wires.

VIN — Input voltage to the converter.

VIN connector and test point connects to the input capacitors and the VIN pin of the LM5164-Q1. Connect the supply voltage from a power supply or a battery between the VIN and GND connectors. The voltage range should be higher than 6 V for the device to be active. V_{VIN} higher than 15 V provides a regulated 12 V output voltage. To avoid damaging the device V_{VIN} should be no greater than 100 V. The current limit on the supply should be high enough to provide the needed supply current when the output is fully loaded. The supply voltage should be connected to the board with short wires. If long cables are used to power up the board, add a damping capacitor C_8 to avoid oscillation between the cable parasitic inductance and the low-ESR input ceramic capacitors.

VIN-EMI — Input voltage to input filter of the converter.

If an input filter is desired between the supply voltage and the LM5164-Q1, connect the supply voltage between VIN-EMI and GND-EMI. The supply voltage should be connected to the board with short wires.

GND-EMI — Ground connection near the input filter.

This is the current return path for the supply connected to VIN-EMI. It provides a direct connection to the input filter capacitors to filter conducted noise generated by the converter. Use VIN-EMI and GND-EMI connections at the input filter to minimize EMI.

Input Filter— EMI mitigation.

The input filter consists of a filter inductor, ferrite bead and ceramic capacitors. An electrolytic capacitor is included for bulk energy storage and input parallel damping. To include the input filter in the power path, connect the supply voltage between VIN-EMI and GND-EMI. The output side of the filter is connected to the VIN net, which is connected to the LM5164-Q1 VIN pin and input capacitors.

Conducted EMI arises from the turn-on and turn-off transition of power switches that generate large discontinuous currents at the input of the buck converter, resulting in voltage ripple. The input filter helps smooth out this voltage ripple at the regulator input.

EN/UVLO — Test point to monitor the EN/UVLO pin of the device.

This test point is to monitor the voltage on the device EN/UVLO pin.

EN/UVLO Jumper — Set EN/UVLO pin options.

Use this jumper to enable/disable the LM5164-Q1. PIN-1 is connected to GND and PIN-2 is connected to EN/UVLO.

1. Connect PIN-1 to PIN-2 to disable the device.
2. Leave PIN-1 and PIN-2 open for EN/UVLO to be connected to VIN through a resistor divider. PIN-1 and PIN-2 are not connected in the default setting. Calculate the lower UVLO resistor, R_{UV2} , based on the desired turn-on voltage of 6 V and the selected upper UVLO resistor, R_{UV1} , of 1 M Ω using [Equation 1](#).

$$R_{UV2} = \frac{1.5\text{ V}}{V_{IN(on)} - 1.5\text{ V}} \cdot R_{UV1} = \frac{1.5\text{ V}}{6\text{ V} - 1.5\text{ V}} \cdot 1\text{ M}\Omega = 332\text{ k}\Omega \quad (1)$$

If a resistor divider is not required, R_{UV2} can be removed such that the EN/UVLO voltage pulls up to the input voltage.

PGOOD — PGOOD jumper.

PGOOD jumper with PIN-1 connected to PGOOD and PIN-2 connected to GND. PIN-1 can be used as a test point to monitor the power-good indicator. This flag indicates whether the output voltage has reached its regulation level. The LM5164-Q1 PGOOD is an open-drain output that is tied to V_{OUT} through resistor R_{10} .

Edge Connector — Additional connector to attach the EVM to a cable harness.

The edge connector provides the option of connecting the EVM to a cable harness if available. It includes the power connections: VIN, VIN-EMI, GND, GND-EMI and VOUT. It also has Kelvin sense connections for VIN, VOUT, and GND. See the schematic in [Figure 4](#) for all signals connected to the edge connector.

5 Schematic

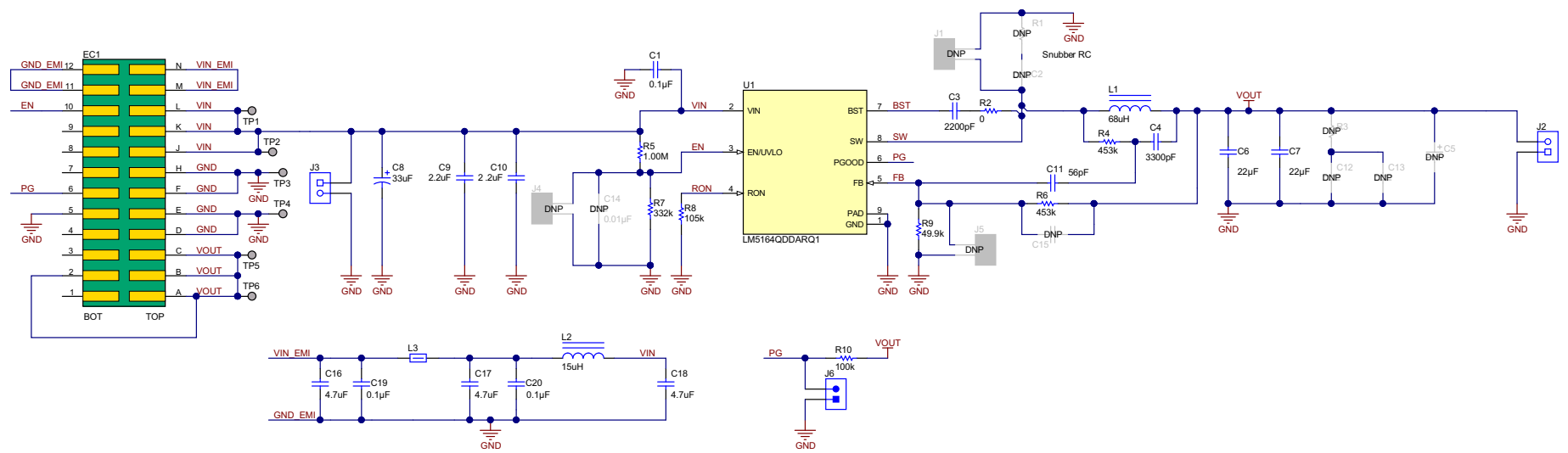


Figure 4. LM5164-Q1 EVM Schematic

6 PCB Layout

Figure 5 through Figure 8 show the board layout for the LM5164-Q1EVM-041. The EVM offers resistors, capacitors, and test points to configure the output voltage, precision enable, and switching frequency.

The 8-pin SO PowerPAD™ package offers an exposed thermal pad, which must be soldered to the copper landing on the PCB for optimal thermal performance. The PCB consists of a 4-layer design. There are 2-oz copper planes on the top and bottom and 1-oz copper mid-layer planes to dissipate heat with an array of thermal vias under the thermal pad to connect to all four layers.

Test points have been provided for ease of use to connect the power supply, required load, and to monitor critical signals. The 12-pin edge connector can also be used to facilitate the use of a cable harness if required.

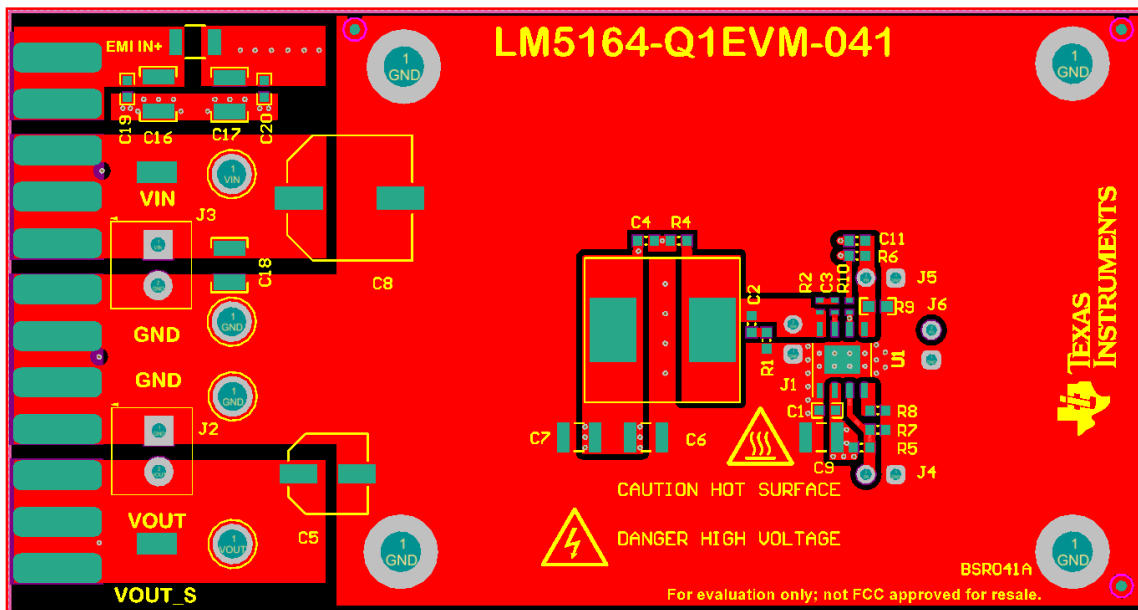


Figure 5. Top Layer and Silkscreen Layer

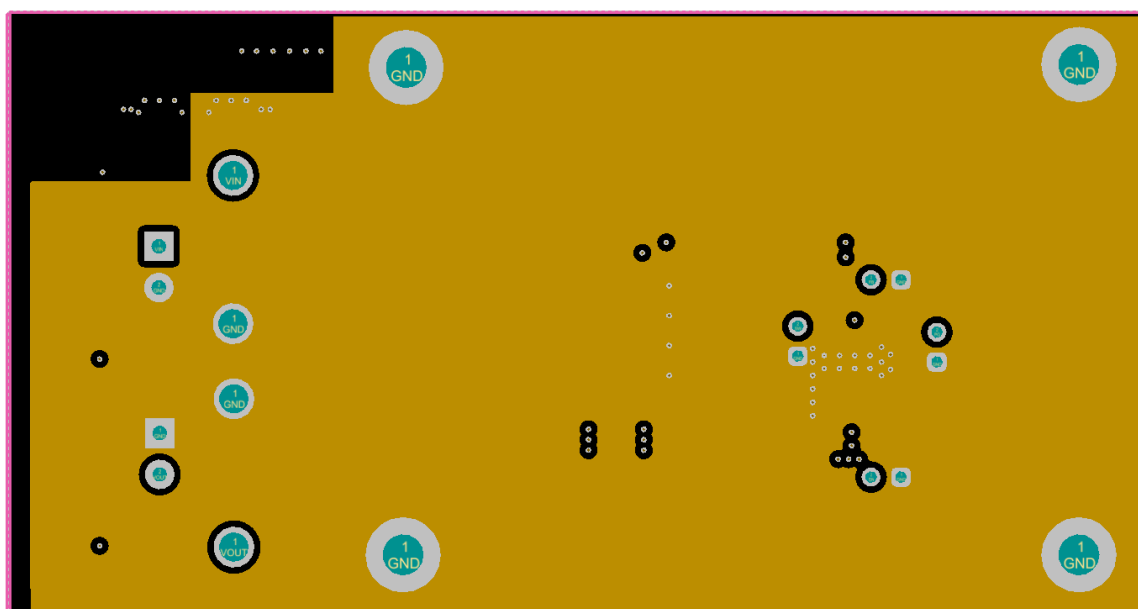


Figure 6. Mid-Layer 1 Ground Plane

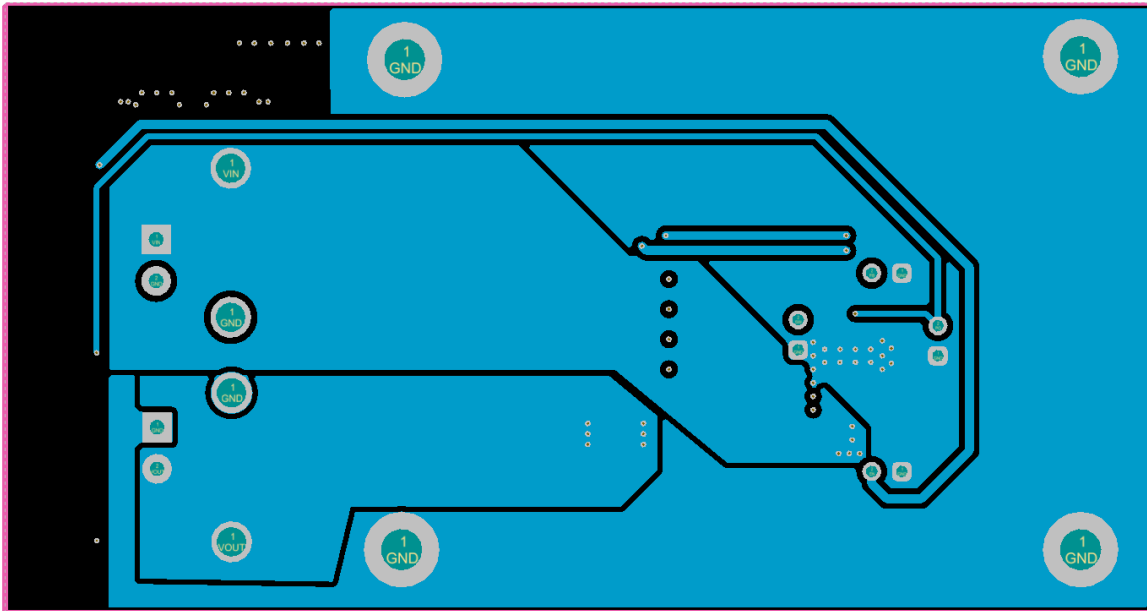


Figure 7. Mid-Layer 2 Routing

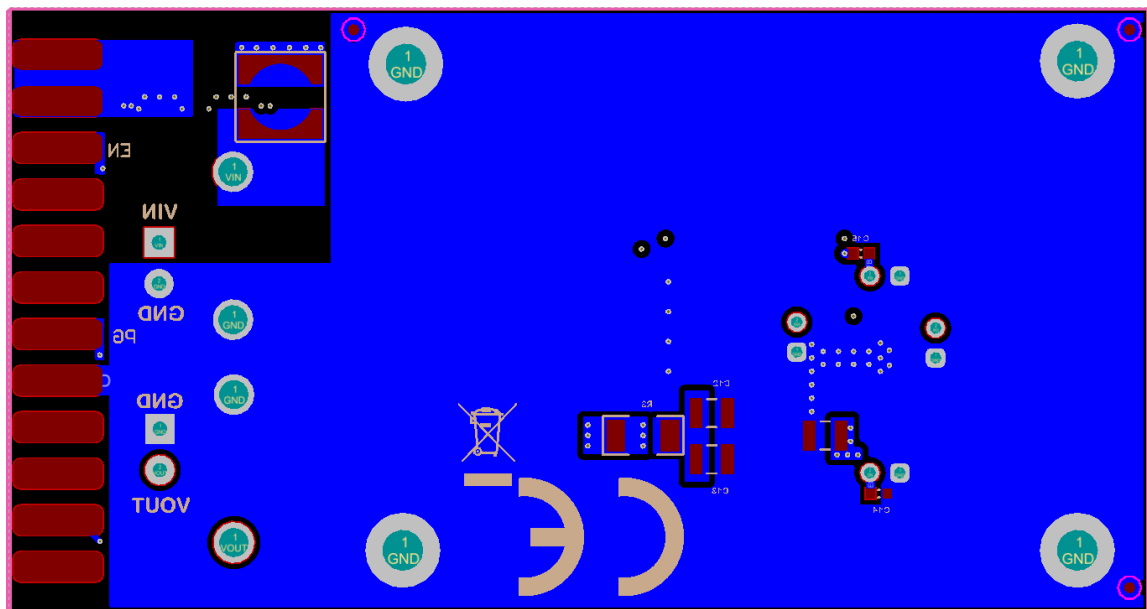


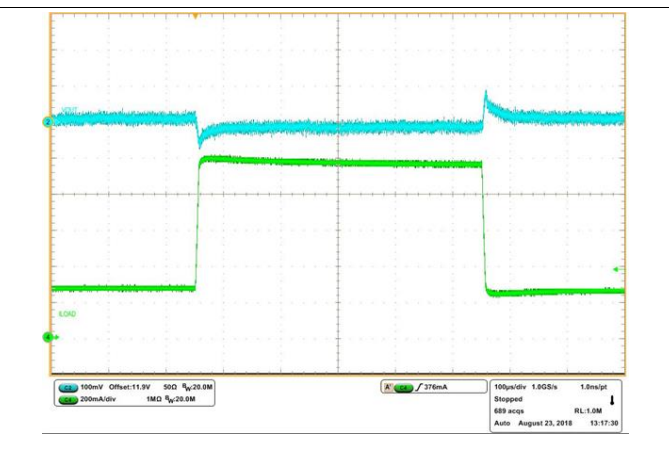
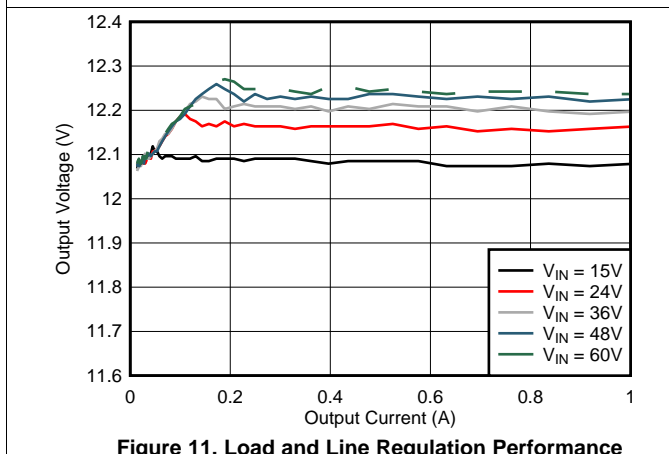
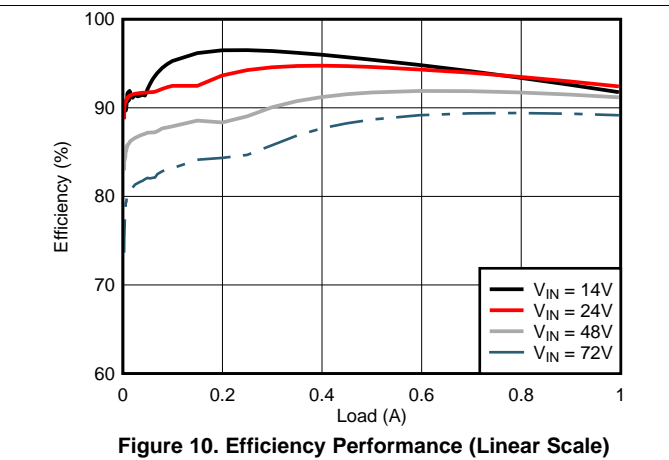
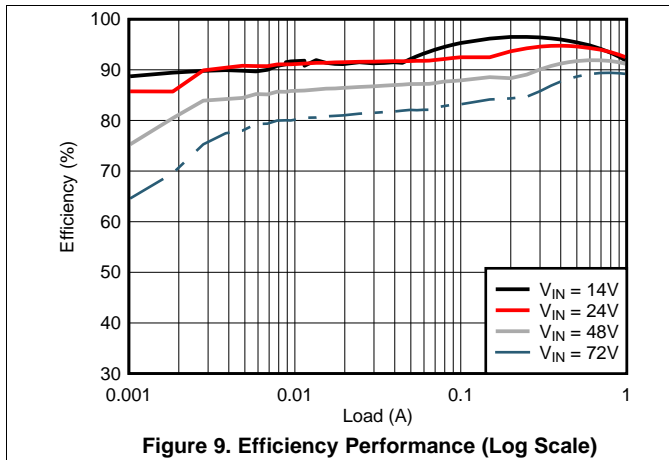
Figure 8. Bottom Layer Routing

7 Bill of Materials

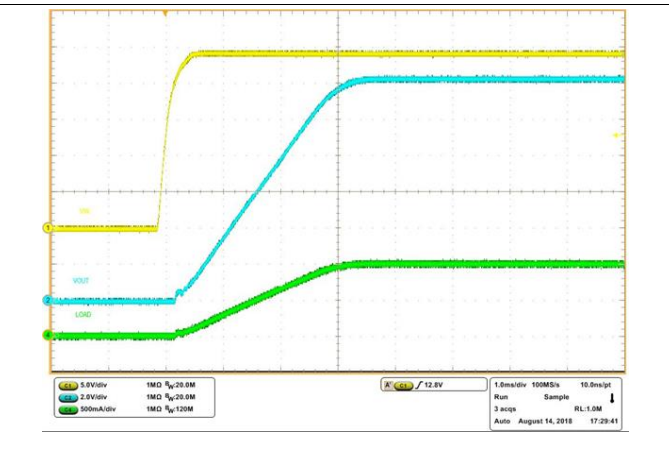
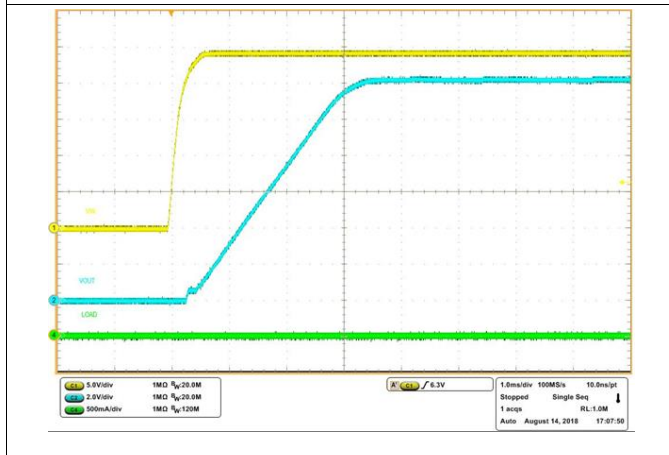
Table 3. LM5164-Q1 EVM Bill of Materials

Ref Des	Value	Description	Package	Part Number	Vendor	Qty
C1, C19, C20	0.1μF	CAP, CERM, 0.1 μF, 100 V, ±10%, X7R, AEC-Q200 Grade 1, 0603	0603	HMK107B7104KAHT	Taiyo Yuden	3
C3	2200pF	CAP, CERM, 2200 pF, 50 V, ±10%, X7R, AEC-Q200 Grade 1, 0402	0402	GCM155R71H222KA37D	MuRata	1
C4	3300pF	CAP, CERM, 3300 pF, 100 V, ±10%, X7R, AEC-Q200 Grade 1, 0603	0603	CGA3E2X7R2A332K080 AA	TDK	1
C6, C7	22uF	CAP, CERM, 22 μF, 25 V, ±10%, X5R, AEC-Q200 Grade 3, 1210	1210	GRT32ER61E226KE13L	MuRata	2
C8	33μF	CAP, AL, 33 μF, 100 V, ±20%, 0.7 ohm, AEC-Q200 Grade 2, SMD	SMT Radial G	EEE-FK2A330P	Panasonic	1
C9, C10	2.2μF	CAP, CERM, 2.2 μF, 100 V, ±10%, X7R, AEC-Q200 Grade 1		CGA6N3X7R2A225K230 AB	TDK	2
C11	56pF	CAP, CERM, 56 pF, 50 V, ±5%, C0G/NP0	0603	C0603C560J5GACTU	Kemet	1
C16, C17, C18	4.7μF	CAP, CERM, 4.7 μF, 100 V, ±10%, X7S, AEC-Q200 Grade 1, 1210	1210	CGA6M3X7S2A475K200 AB	TDK	3
J2, J3		Terminal Block, 3.5mm Pitch, 2x1, TH	7.0 × 8.2 × 6.5mm	ED555/2DS	On-Shore Technology	2
J6		Header, 100mil, 2x1, Gold, TH	2x1 Header	TSW-102-07-G-S	Samtec	1
L1	68μH	Inductor, Shielded Drum Core, Ferrite, 68 μH, 1.8 A, 0.17 ohm, AEC-Q200 Grade 1	MSS1246T	MSS1246T-683MLB	Coilcraft	1
		Inductor, Shielded Drum Core, Ferrite, 68 μH, 2.1 A, 0.11 ohm, AEC-Q200 Grade 1	SRR1260A	SRR1260A-680M	Bourns	
		Inductor, Shielded, 68uH, 1.9A, 0.11ohm AEC-Q200 Grade 1	7447714680	7447714680	Würth	
		Inductor, Shielded, Powdered Iron, 68uH, 2.3 A, 0.18 ohm	MPT1040-H1	MPT1040-680H1	Delta	
L2	15μH	Inductor, Shielded Drum Core, Ferrite, 15 μH, 1.8 A, 0.05 ohm, AEC-Q200 Grade 3	MSS7341	MSS7341T-153MLB	Coilcraft	1
		Inductor, Shielded Drum Core, Ferrite, 15 μH, 1.5 A, 0.1 ohm, AEC-Q200 Grade 1	744778115	744778115	Würth	
L3	2000 Ω	Ferrite Bead, 2000 Ω @ 100 MHz, 1.2 A	1210	FBMH3225HM202NT	Taiyo Yuden	1
R2	0	RES, 0, 5%, 0.063 W, AEC-Q200 Grade 0	0402	CRCW04020000Z0ED	Vishay	1
R4, R6	453k	RES, 453 k, 1%, 0.1 W, 0603	0603	RC0603FR-07453KL	Yageo	2
R5	1.00Meg	RES, 1.00 M, 1%, 0.1 W, 0603	0603	RC0603FR-071ML	Yageo	1
R7	332k	RES, 332 k, 1%, 0.1 W, 0603	0603	RC0603FR-07332KL	Yageo	1
R8	105k	RES, 105 k, 0.1%, 0.1 W, 0603	0603	RG1608P-1053-B-T5	Susumu Co Ltd	1
R9	49.9k	RES, 49.9 k, 0.1%, 0.1 W, 0603	0603	RG1608P-4992-B-T5	Susumu Co Ltd	1
R10	100k	RES, 100 k, 1%, 0.1 W, 0402	0402	ERJ-2RKF1003X	Panasonic	1
SH-J4	1x2	Shunt, 100mil, Gold plated, Black	Shunt	SNT-100-BK-G	Samtec	1
TP1, TP6		Test Lead clips and hooks, SMT	Test Point	S1751-46	Harwin	2
TP2, TP3, TP4, TP5	Triple	Terminal, Turret, TH, Triple		1598-2	Keystone	4
U1		100-V, Low I _Q Synchronous Buck Converter	SO-8	LM5164QDDARQ1	TI	1

8 Performance Curves

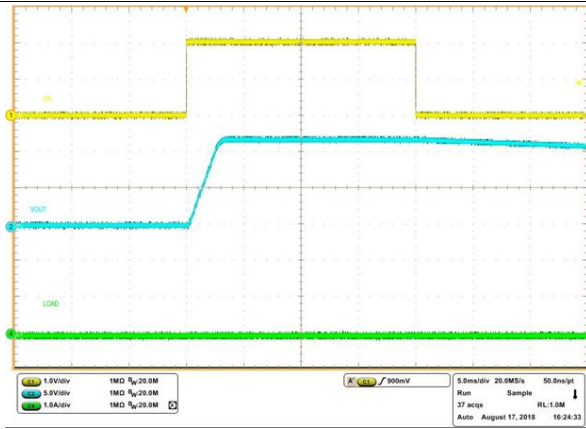


$V_{IN} = 24\text{ V}$ Load = 0.25 A to 1 A, 0.1A/ μs



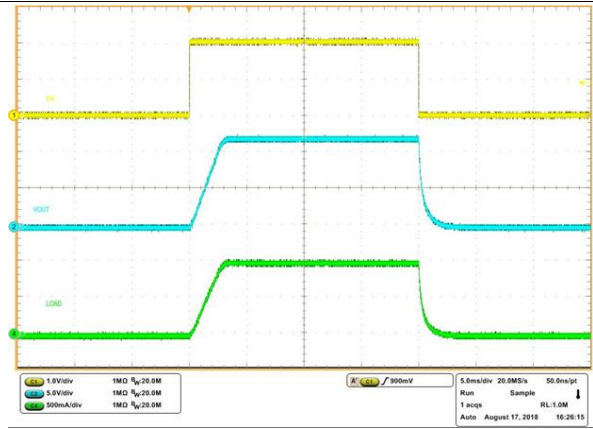
$V_{IN} = 24\text{ V}$ Load = 0 A

$V_{IN} = 24\text{ V}$ Load = 1 A



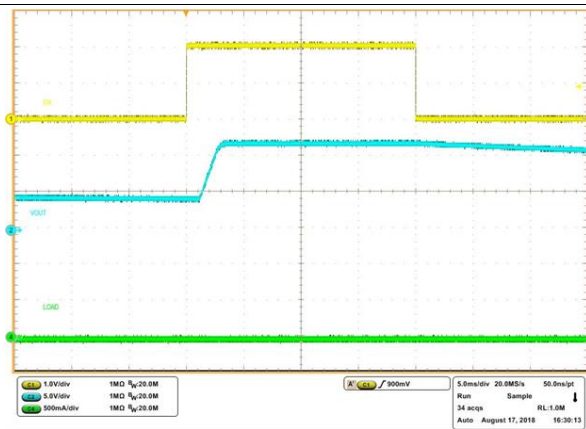
$V_{IN} = 24\text{ V}$ Load = 0 A

Figure 15. No Load Start-up with EN/UVLO



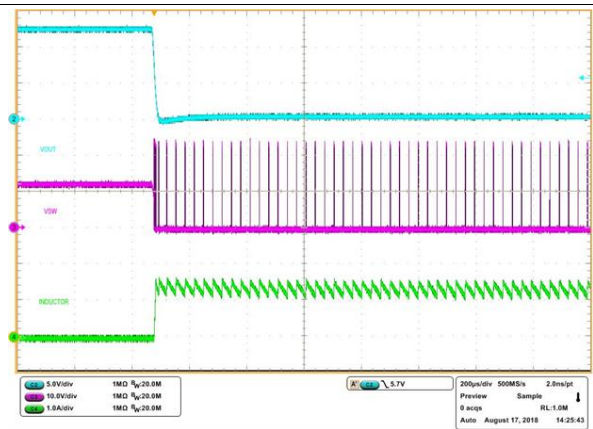
$V_{IN} = 24\text{ V}$ Load = 1 A

Figure 16. Full Load Start-up/Shutdown with EN/UVLO



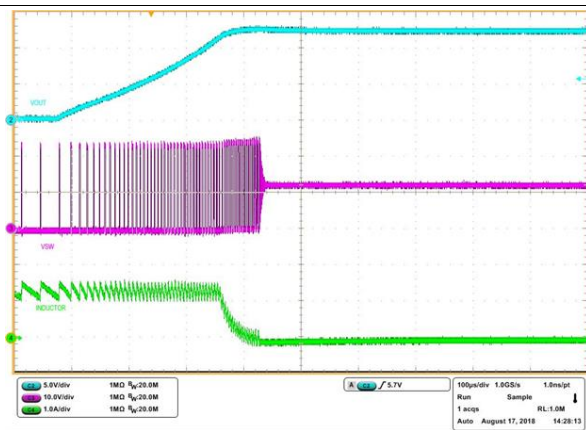
$V_{IN} = 24\text{ V}$ Load = 0 A

Figure 17. EN/UVLO Start-up in Prebias



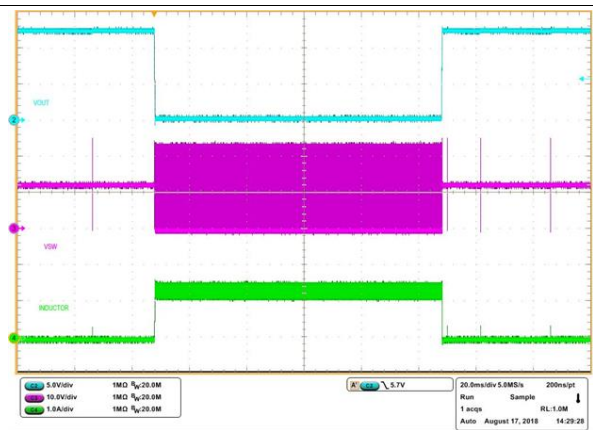
$V_{IN} = 24\text{ V}$ Load = 0 A to short

Figure 18. Short Circuit



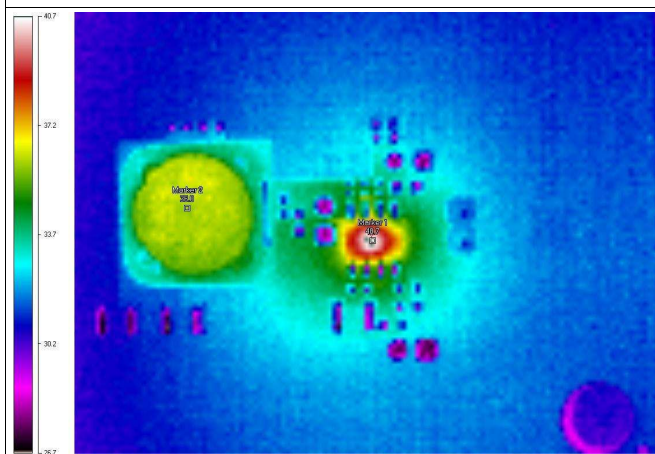
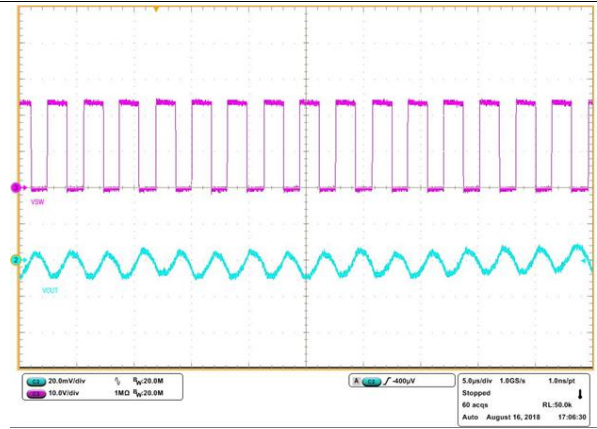
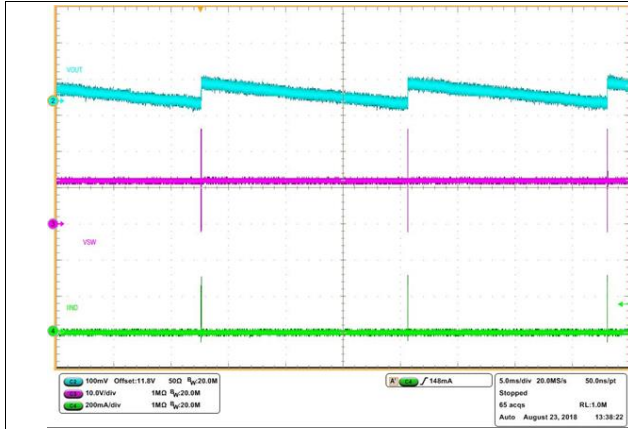
$V_{IN} = 24\text{ V}$ Load = Short to 0 A

Figure 19. Short-Circuit Recovery



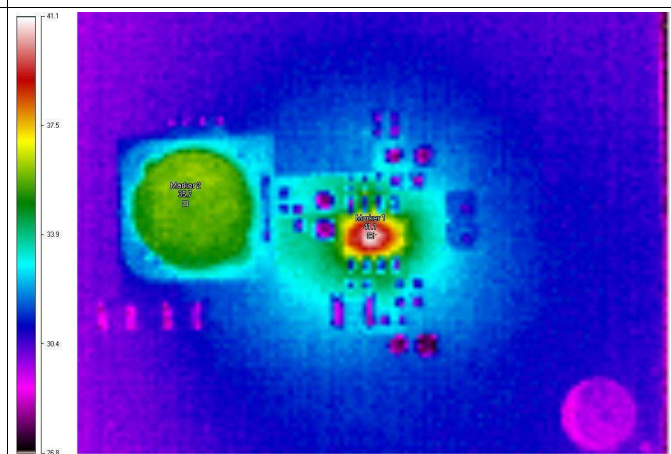
$V_{IN} = 24\text{ V}$ Load = 0 A to Short to 0 A

Figure 20. No-Load/Short Circuit and Short-Circuit Recovery



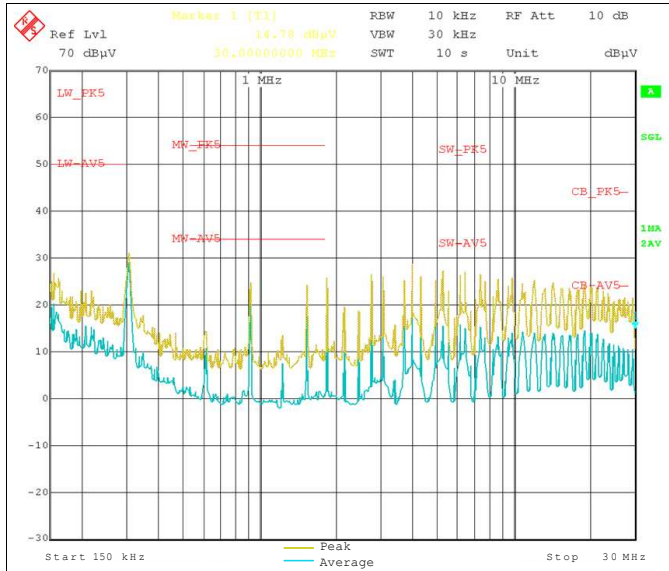
$V_{VIN} = 24\text{ V}$ Load = 1 A

Figure 23. Thermal Performance



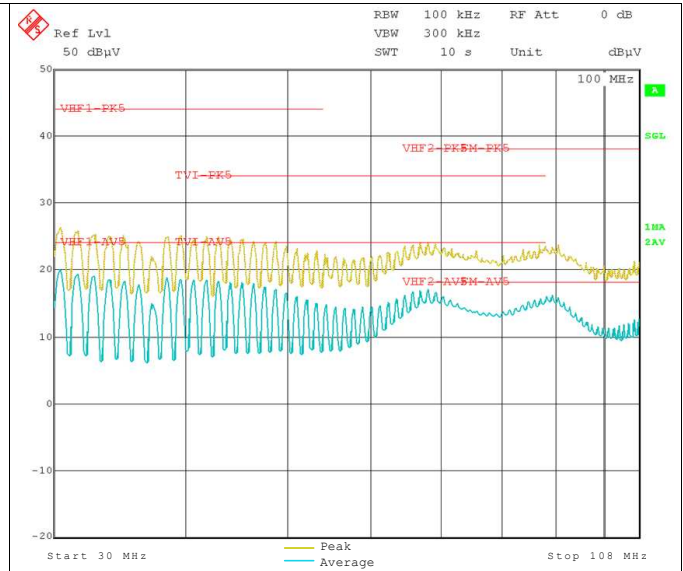
$V_{VIN} = 48\text{ V}$ Load = 1 A

Figure 24. Thermal Performance



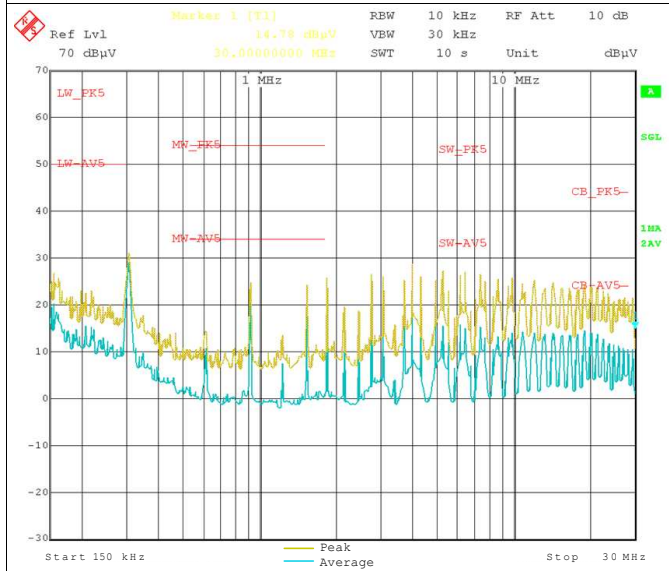
$V_{IN} = 48\text{ V}$ Load = 1 A $R_1 = 1\ \Omega$, $C_2 = 680\ \text{pF}$

Figure 25. CISPR 25 Class 5 Conducted Emissions Plot, 150 kHz to 30 MHz



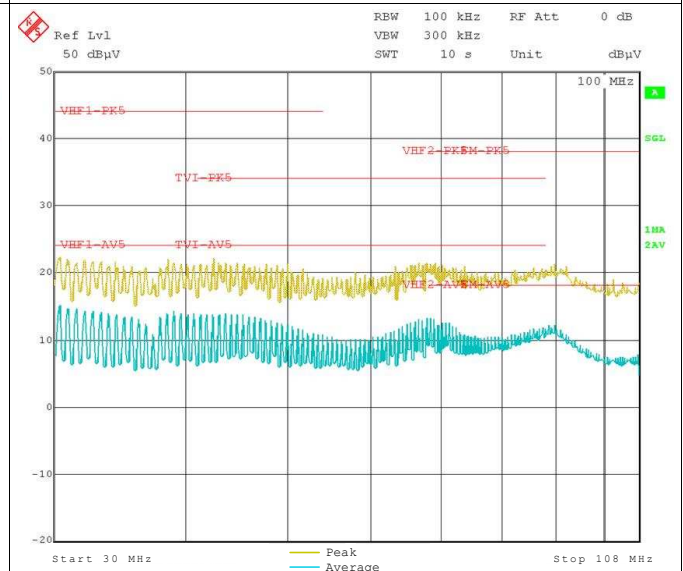
$V_{IN} = 48\text{ V}$ Load = 1 A $R_1 = 1\ \Omega$, $C_2 = 680\ \text{pF}$

Figure 26. CISPR 25 Class 5 Conducted Emissions Plot, 30 MHz to 108 MHz



$V_{IN} = 24\text{ V}$ Load = 1 A $R_1 = 1\ \Omega$, $C_2 = 680\ \text{pF}$

Figure 27. CISPR 25 Class 5 Conducted Emissions Plot, 150 kHz to 30 MHz



$V_{IN} = 24\text{ V}$ Load = 1 A $R_1 = 1\ \Omega$, $C_2 = 680\ \text{pF}$

Figure 28. CISPR 25 Class 5 Conducted Emissions Plot, 30 MHz to 108 MHz

Revision History

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

Changes from Original (September 2018) to A Revision	Page
• Updated EVM schematic	10
• Cleaned up BOM, added second sources.....	13
• Added CISPR 25 EMI figures	14

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