

LM5165EVM-HD-C50X EVM

User's Guide



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1	High Density EVM Description	5
1.1	Typical Applications	5
1.2	Features and Electrical Performance	6
2	EVM Performance Specifications	7
3	Application Circuit Diagrams	8
4	EVM Photo	8
5	Test Setup and Procedure	9
5.1	Test Setup	9
5.2	Test Equipment	10
5.3	Recommended Test Setup	10
5.4	Test Procedure	10
6	Test Data and Performance Curves	11
6.1	Conversion Efficiency	11
6.2	Load Regulation	11
6.3	Operating Waveforms	12
6.4	CISPR 22 and CISPR 25 EMI Performance	22
7	EVM Documentation	24
7.1	Schematic	24
7.2	Bill of Materials	25
7.3	PCB Layout	26
8	Reference Designs	29
8.1	Schematics	29
8.2	Bill of Materials	30
9	Device Support	32
9.1	Development Support	32
9.2	Documentation Support	32
	Revision History	33

List of Figures

1	LM5165 COT-controlled Buck Converter Schematics, (a) Fixed Output 3.3 V or 5 V, (b) Adjustable Output...	8
2	LM5165 EVM Photo	8
3	EVM Test Setup.....	9
4	Converter Efficiency.....	11
5	Load Regulation	11
6	SW Node Voltage, $I_{OUT} = 150$ mA; (a) $V_{IN} = 12$ V, (b) $V_{IN} = 24$ V (Ch2: SW)	12
7	SW Node Voltage, $I_{OUT} = 150$ mA; (a) $V_{IN} = 48$ V, (b) $V_{IN} = 65$ V (Ch2: SW)	12
8	SW Node Voltage, $I_{OUT} = 20$ mA; (a) $V_{IN} = 12$ V, (b) $V_{IN} = 24$ V (Ch2: SW).....	13
9	SW Node Voltage, $I_{OUT} = 20$ mA; (a) $V_{IN} = 48$ V, (b) $V_{IN} = 65$ V (Ch2: SW) ⁽¹⁾	13
10	V_{OUT} ripple: $V_{IN} = 12$ V; (a) $I_{OUT} = 0$ mA, (b) $I_{OUT} = 150$ mA	14
11	V_{OUT} ripple: $V_{IN} = 24$ V; (a) $I_{OUT} = 0$ mA, (b) $I_{OUT} = 150$ mA	14
12	V_{OUT} ripple: $V_{IN} = 65$ V; (a) $I_{OUT} = 0$ mA, (b) $I_{OUT} = 150$ mA	15
13	Load Transient Response, $V_{IN} = 12$ V, 20 mA to 150 mA at 2 A/ μ s; (a) Load-on transient, (b) Load-off transient	15
14	Load Transient Response, $V_{IN} = 24$ V, 20 mA to 150 mA at 2 A/ μ s; (a) Load-on transient, (b) Load-off transient	16
15	Startup: $V_{IN} = 12$ V; (a) $I_{OUT} = 0$ mA, (b) $I_{OUT} = 150$ mA (Ch2: V_{IN} , Ch3: V_{OUT} , Ch4: I_{OUT}).....	16
16	Startup: $V_{IN} = 24$ V; (a) $I_{OUT} = 0$ mA, (b) $I_{OUT} = 150$ mA (Ch2: V_{IN} , Ch3: V_{OUT} , Ch4: I_{OUT}).....	17
17	Startup with 1.2 V Output Pre-bias: $I_{OUT} = 0$ mA; (a) $V_{IN} = 12$ V, (b) $V_{IN} = 24$ V (Ch2: V_{IN} , Ch3: V_{OUT} , Ch4: I_{OUT})	17
18	Startup with 2.5 V Output Pre-bias, $I_{OUT} = 0$ mA; (a) $V_{IN} = 12$ V, (b) $V_{IN} = 24$ V (Ch2: V_{IN} , Ch3: V_{OUT} , Ch4: I_{OUT})	18
19	Startup with 1 V Output Pre-bias, $I_{OUT} = 150$ mA; (a) $V_{IN} = 12$ V, (b) $V_{IN} = 24$ V (Ch2: V_{IN} , Ch3: V_{OUT} , Ch4: I_{OUT})	18
20	ENABLE On and Off: $V_{IN} = 24$ V; (a) $I_{OUT} = 0$ mA, (b) $I_{OUT} = 150$ mA (Ch2: V_{ENABLE} , Ch3: V_{OUT} , Ch4: I_{OUT})	19
21	ENABLE On and Off: $V_{IN} = 24$ V, $I_{OUT} = 0$ mA; (a) 1.8 V Output Pre-bias, (b) 3.3 V Output Pre-bias (Ch2: V_{ENABLE} , Ch3: V_{OUT} , Ch4: I_{OUT})	19
22	ENABLE On: $V_{IN} = 24$ V, $I_{OUT} = 150$ mA; (a) 1.8 V Output Pre-bias, (b) 3.3 V Output Pre-bias (Ch2: V_{ENABLE} , Ch3: V_{OUT} , Ch4: I_{OUT})	20
23	Typical automotive cold-crank input voltage transient; $I_{OUT} = 150$ mA; (a) Profile 1, (b) Profile 2 (Ch2: V_{IN} , Ch3: V_{OUT} , Ch4: I_{OUT})	21
24	Typical automotive cold-crank input voltage transient; $I_{OUT} = 150$ mA; (a) Profile 3, (b) Profile 3 zoomed to show dropout operation when $V_{IN} < 5$ V (Ch2: V_{IN} , Ch3: V_{OUT} , Ch4: I_{OUT})	21
25	CISPR 25 Class 5 Conducted Emissions Plot, 150 kHz to 30 MHz, $V_{IN} = 13.5$ V, $I_{OUT} = 100$ mA, (a) Unfiltered, (b) Filtered.....	22
26	CISPR 25 Class 5 Conducted Emissions Plot, 30 MHz to 108 MHz, $V_{IN} = 13.5$ V, $I_{OUT} = 100$ mA, (a) Unfiltered, (b) Filtered.....	22
27	CISPR 22 Class B Conducted Emissions Plot, $V_{IN} = 13.5$ V, $I_{OUT} = 100$ mA, (a) Unfiltered, (b) Filtered	23
28	5V, 150mA COT Schematic (Fixed 5V Output Version)	24
29	Top Copper (Top View).....	26
30	Layer 2 (Top View).....	26
31	Layer 3 (Top View).....	27
32	Bottom Copper (Bottom View).....	27
33	Top Assembly.....	28
34	Bottom Assembly.....	28
35	3.3V, 50mA COT Schematic (Fixed 3.3V Output Version)	29
36	5V, 25mA PFM Schematic (Adjustable Output Version)	29

⁽¹⁾ Pulse skipping and diode emulation are evident at light loads to increase efficiency and decrease power losses.

List of Tables

1	Electrical Performance Specifications.....	7
2	EVM Connections.....	9
3	Bill of Materials (COT, 5 V, 150 mA, Fixed Output Version)	25
4	Bill of Materials (COT, 3.3 V, 50 mA, Fixed Output Version).....	30
5	Bill of Materials (COT, 12 V, 100 mA, Adjustable Output Version)	30
6	Bill of Materials (PFM, 5 V, 25 mA, Adjustable Output Version)	31
7	Bill of Materials (PFM, 3.3 V, 50 mA, Fixed Output Version).....	31

LM5165EVM-HD-C50X EVM

The LM5165EVM-HD-C50X high density evaluation module (EVM) is designed to showcase the LM5165 high performance, exceptionally small, synchronous buck DC/DC buck converter with ultra-low no-load supply current. The module-style design is packaged in a miniature footprint with low component count. It operates over a wide input voltage range of 3 V to 65 V to deliver a fixed 5-V output with better than 2% setpoint accuracy. Low-dropout performance whenever the input voltage decreases below the output voltage setpoint is available with 100% duty cycle conduction of the high-side MOSFET. By virtue of the LM5165's constant on-time (COT) control scheme and diode emulation mode at light loads, the no-load supply current is only 12 μ A at 24-V input.

With integrated power MOSFETs, the LM5165 uses synchronous rectification to achieve high conversion efficiency over a wide load current range. Various features incorporated for enhanced reliability and safety include programmable cycle-by-cycle peak current limit, thermal shutdown protection, configurable soft-start, 1.212-V precision enable threshold, and open-drain PGOOD indicator for sequencing and fault reporting. With AEC-Q100 Q1 grade automotive qualification, the LM5165 is rated to operate over a junction temperature range of -40°C to $+150^{\circ}\text{C}$. Input UVLO turn-on/off thresholds are set internally at 2.75 V and 2.45 V to protect the circuit at low input voltage conditions, and it is possible to tailor the minimum operating input voltage and hysteresis to the application requirements by suitable choice of input UVLO components.

The LM5165 and LM5165-Q1 are available in VSON-10 PowerPAD™ package with 3 x 3-mm² footprint to enable high density, low component count DC/DC solutions. Please consult the [LM5165 datasheet](#) for more information. The LM5165 is supported by WEBENCH® Power Designer and numerous PSPICE simulation models. Furthermore, the reader can use the [LM5165 Quick-start calculator](#) to optimize component selection and examine predicted efficiency performance across wide line and load ranges.

1 High Density EVM Description

The LM5165EVM-HD-C50X high density EVM is designed to use a regulated or non-regulated high-voltage input rail ranging from 3 V to 65 V to produce a tightly regulated output voltage of 5 V at load currents up to 150 mA. The wide input voltage range (“wide V_{IN} ”) DC/DC solution offers outsized voltage rating and operating margin to deal with supply rail transient voltages. The output voltage is fixed at 5V using the LM5165's integrated high-resistance feedback divider to reduce circuit footprint, improve noise immunity, and achieve a lower no-load supply current. The power train passive components selected for this EVM, including filter inductor and ceramic input and output capacitors, are available with AEC-Q200 qualification for automotive applications.

1.1 Typical Applications

- 2-/3-/4-wire sensor power
- High voltage LDO replacement
- Process control
- Building automation and HVAC systems
- General-purpose bias supplies
- Automotive and battery powered equipment

1.2 Features and Electrical Performance

- Tightly-regulated output voltage of 5 V with 2% setpoint accuracy
- Wide input voltage operating range of 3 V to 65 V
- Full load current of 150 mA
- Ultra-high power conversion efficiency across wide load current range
 - Full load efficiency of 91% and 88.5% at $V_{IN} = 12\text{ V}$ and 24 V , respectively
 - Greater than 85% efficiency at load currents above 1 mA, $V_{IN} = 12\text{ V}$
- 12- μA no-load supply current at $V_{IN} = 24\text{ V}$
- Constant on-time (COT) control architecture provides fast load transient response
 - Low component count – no loop compensation components
 - Almost-constant switching frequency set by resistor
 - Natural, automatic duty cycle extension to 100% to maintain regulation in low-dropout applications
- Integrated high-side and low-side power MOSFETs
 - 2- Ω PMOS buck switch supports 100% duty cycle for low dropout voltage
 - 1- Ω NMOS synchronous rectifier eliminates external Schottky diode
- Peak inductor current limit set to 240 mA (ILIM pin tied to GND)
- Monotonic pre-bias output voltage startup
- User-adjustable soft-start ramp time set to 6 ms by 47-nF capacitor at the SS pin
 - Option for internal 0.9-ms soft-start time by leaving SS open circuit
 - Option for no soft-start for fast startup capability using 100-k Ω resistor connected from SS to GND
- ENABLE and PGOOD terminals with 10-M Ω and 10-k Ω pullups to VIN and VOUT, respectively
- Resistor-programmable input UVLO with customizable hysteresis for applications with wide turn-on / turn-off voltage difference
 - Input UVLO internally set to turn on and off at 2.75 V and 2.45 V, respectively
- Input circuit shunt RC damping accommodates high-Q inductive supply lines
- Fully assembled, tested and proven PCB layout with 15-mm x 12-mm total footprint

2 EVM Performance Specifications

Table 1. Electrical Performance Specifications

Parameter	Test Conditions	MIN	TYP	MAX	UNITS	
INPUT CHARACTERISTICS						
Input voltage range, V_{IN}	Operating	3	12	65	V	
Input voltage turn on, $V_{IN(ON)}$	Set internally, adjusted by populating EN/UVLO resistors	2.75			V	
Input voltage turn off, $V_{IN(OFF)}$		2.45			V	
Input voltage hysteresis, $V_{IN(HYS)}$		0.3			V	
Input current, no load, $I_{IN(NL)}$	$I_{OUT} = 0$ mA	$V_{IN} = 12$ V	14.5		μ A	
		$V_{IN} = 24$ V	12.5		μ A	
		$V_{IN} = 65$ V	11.5		μ A	
Input current, disabled, $I_{IN(OFF)}$	$V_{ENABLE} = 0$ V	$V_{IN} = 12$ V	5		μ A	
OUTPUT CHARACTERISTICS						
Output voltage, $V_{OUT}^{(1)}$	V_{OUT} tracks V_{IN} for $V_{IN} < 5.2$ V		4.9	5.0	5.1	V
Output current, I_{OUT}	$V_{IN} = 3$ V to 65 V		0		150	mA
Output voltage regulation, ΔV_{OUT}	Load Regulation	$I_{OUT} = 0$ mA to 150 mA	0.5%			
	Line Regulation	$V_{IN} = 5.5$ V to 65 V	0.5%			
Output voltage ripple, $V_{OUT(AC)}$	$V_{IN} = 12$ V, $I_{OUT} = 150$ mA		25		mVrms	
Output overcurrent protection, I_{OCP}	$V_{IN} = 12$ V		200		mA	
Soft-start time, t_{SS}			6		ms	
SYSTEM CHARACTERISTICS						
Switching frequency, $F_{SW(nom)}$	$V_{IN} = 12$ V		240		kHz	
Half-load efficiency, $\eta_{HALF}^{(1)}$	$I_{OUT} = 75$ mA	$V_{IN} = 12$ V	92.0%			
Full load efficiency, η_{FULL}	$I_{OUT} = 150$ mA	$V_{IN} = 8$ V	91.3%			
		$V_{IN} = 10$ V	91.1%			
		$V_{IN} = 12$ V	90.7%			
		$V_{IN} = 24$ V	88.4%			
		$V_{IN} = 36$ V	85.7%			
		$V_{IN} = 65$ V	80.4%			
LM5165 junction temperature, T_J			-40	150	$^{\circ}$ C	

⁽¹⁾ The default output voltage of this EVM is 5 V (fixed). Efficiency and other performance metrics will change based on operating input voltage, load current, externally-connected output capacitance, and other parameters.

3 Application Circuit Diagrams

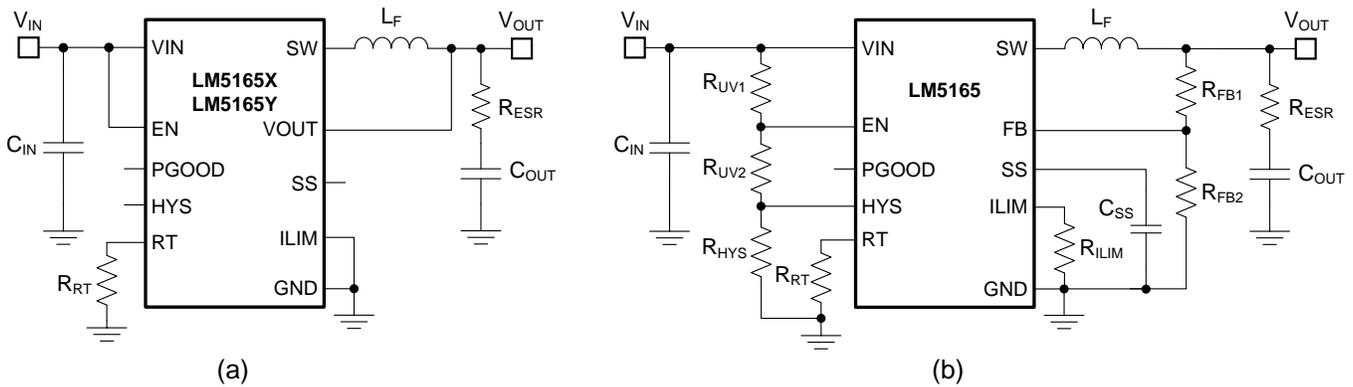


Figure 1. LM5165 COT-controlled Buck Converter Schematics, (a) Fixed Output 3.3 V or 5 V, (b) Adjustable Output

Figure 1(a) shows the schematic of a minimum parts count, fixed output voltage (3.3 V or 5 V), COT converter with continuous output current capability up to 150 mA. Figure 1(b) shows the schematic of a similar COT converter with output voltage adjustable using feedback resistors. Soft-start (SS), current limit (ILIM) and UVLO (EN and HYS) components are shown that are configurable as required by the specific application. The ripple voltage required at the FB pin is established using resistor R_{RIPPLE1} in series with the output capacitor.

4 EVM Photo

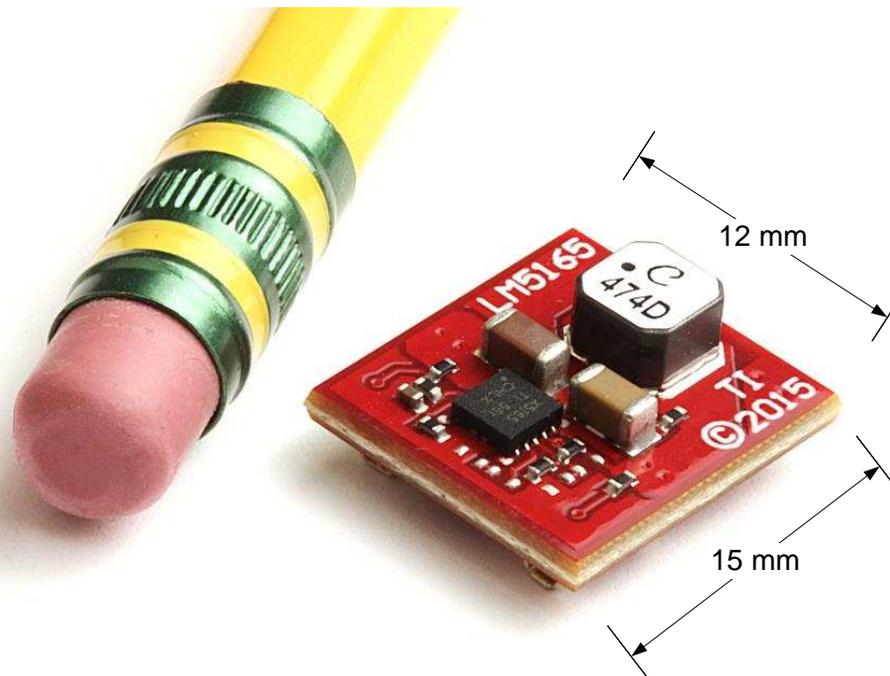


Figure 2. LM5165 EVM Photo

5 Test Setup and Procedure

5.1 Test Setup

Table 2. EVM Connections

LABEL	DESCRIPTION
VIN	Positive input voltage power and sense connection
GND	Negative input voltage negative power and sense connection
VOUT	Positive output voltage positive power and sense connection
GND	Negative output voltage negative power and sense connection
ENABLE	ENABLE input – tie to GND to disable converter
PGOOD	Power Good output

Referencing the EVM connections described in Table 2, the recommended test setup to evaluate the LM5165EVM-HD-C50X is shown in Figure 3. Working at an ESD workstation, make sure that any wrist straps, boot straps or mats are connected referencing the user to earth ground before power is applied to the EVM.

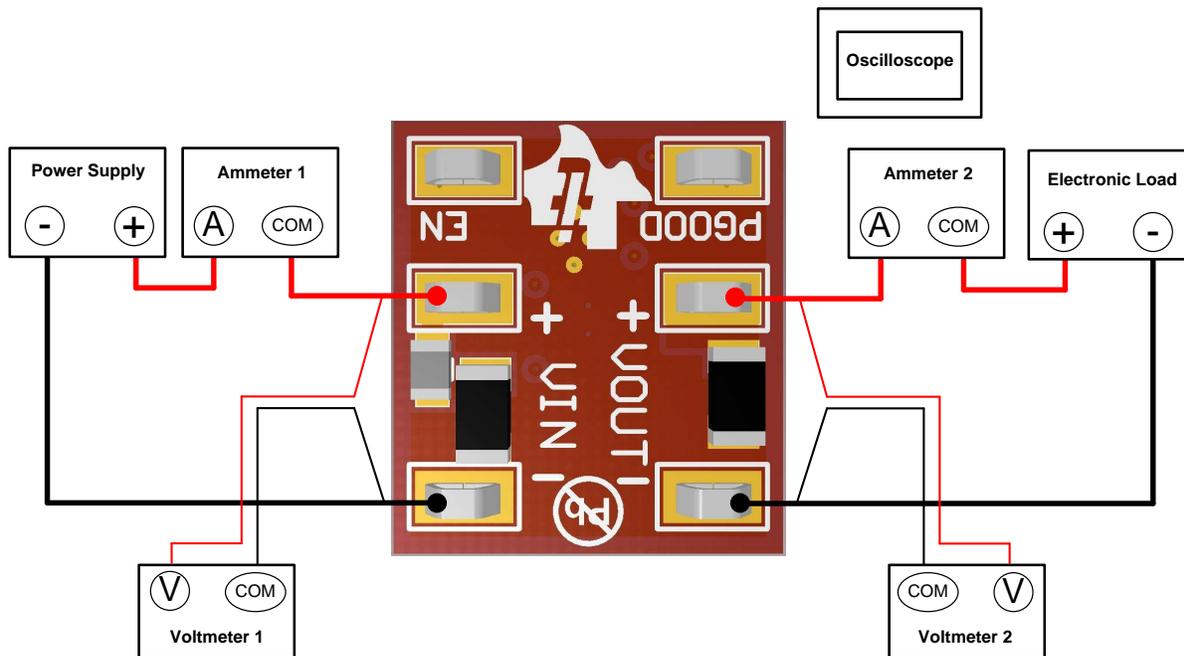


Figure 3. EVM Test Setup

CAUTION

Please refer to the [LM5165](#) and [LM5165-Q1](#) datasheets, LM5165 [Quick-start tool](#) and WEBENCH® Power Designer for additional guidance pertaining to component selection and converter operation.

5.2 Test Equipment

Voltage Source: The input voltage source VIN should be a 0–65-V variable dc source capable of supplying 200 mA.

Multimeters:

- **Voltmeter 1:** Input voltage at VIN to GND. Set voltmeter to input impedance of 1 GΩ .
- **Voltmeter 2:** Output voltage at VOUT to GND. Set voltmeter to input impedance of 1 GΩ.
- **Ammeter 1:** Input current. Set ammeter to 1-second aperture time.
- **Ammeter 2:** Output current. Set ammeter to 1-second aperture time

Electronic Load: The load should be an electronic constant-resistance (CR) or constant-current (CC) mode load capable of 0 mAdc to 300 mAdc at 5 V. For a no-load input current measurement, disconnect the electronic load as it may draw a small residual current.

Oscilloscope: With the scope set to 20-MHz bandwidth and AC coupling, measure the output voltage ripple directly across an output capacitor with a short ground lead normally provided with the scope probe. Place the oscilloscope probe tip on the positive terminal of the output capacitor, holding the probe's ground barrel through the ground lead to the capacitor's negative terminal. It is not recommended to use a long-leaded ground connection because this may induce additional noise given a large ground loop. To measure other waveforms, adjust the oscilloscope as needed.

Safety: Always use caution when touching any circuits that may be live or energized.

5.3 Recommended Test Setup

5.3.1 Input Connections

- Prior to connecting the DC input source, it is advisable to limit the source current to 200 mA maximum. Ensure the input source is initially set to 0 V and connected to the VIN and GND connection points as shown in [Figure 3](#). An additional high-ESR, low leakage, input bulk capacitor is recommended if long input lines are used.
- Connect voltmeter 1 at VIN and GND connection points to measure the input voltage.
- Connect ammeter 1 to measure the input current and set to at least 1-second aperture time.

5.3.2 Output Connections

- Connect an electronic load to VOUT and GND connections. Set the load to constant-resistance mode or constant-current mode at 0 mAdc before applying input voltage.
- Connect voltmeter 2 at VOUT and GND connection points to measure the output voltage.
- Connect ammeter 2 to measure the output current.

5.4 Test Procedure

5.4.1 Line and Load Regulation, Efficiency

- Setup the EVM as described above.
- Set load to constant resistance or constant current mode and to sink 0 mAdc.
- Increase input source from 0 V to 12 V, using voltmeter 1 to measure the input voltage.
- Using voltmeter 2 to measure the output voltage, V_{OUT} , vary the load current from 0 to 150 mAdc; V_{OUT} should remain within the load regulation specification.
- Vary input source voltage from 5.5 V to 65 V; V_{OUT} should remain within the line regulation specification.
- Decrease load to 0 mA. Decrease input source voltage to 0 V.

6 Test Data and Performance Curves

Figure 4 through Figure 24 present typical performance curves for the LM5165EVM-HD-C50X based on the BOM presented in Table 3. Since actual performance data may be affected by measurement techniques and environmental variables, these curves are presented for reference and may differ from actual field measurements.

6.1 Conversion Efficiency

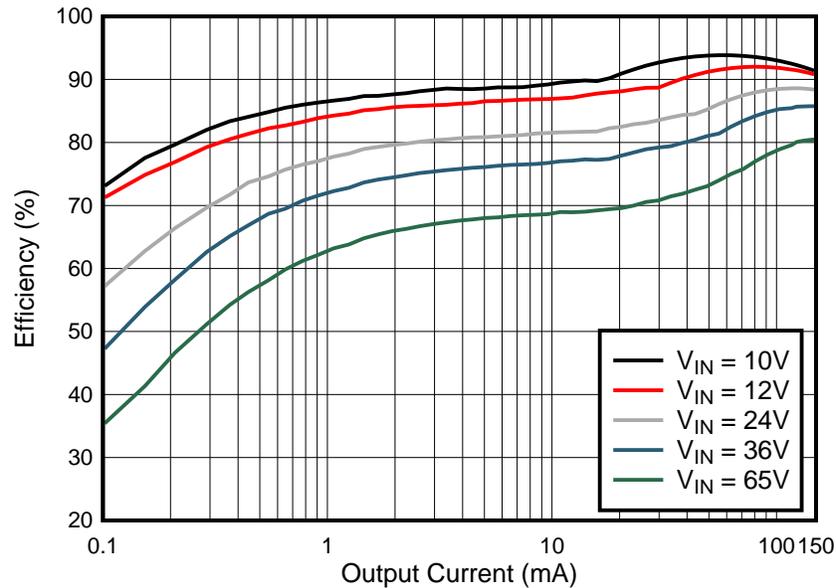


Figure 4. Converter Efficiency

6.2 Load Regulation

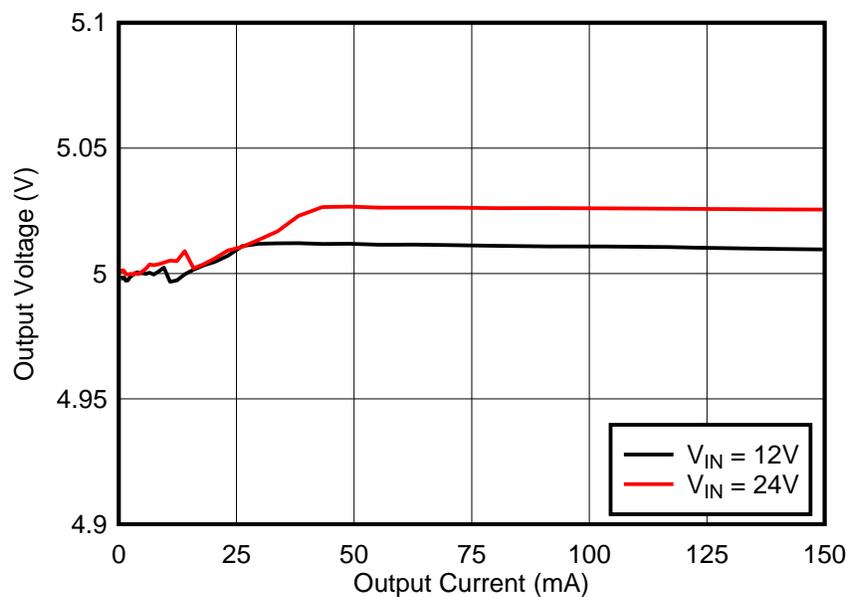
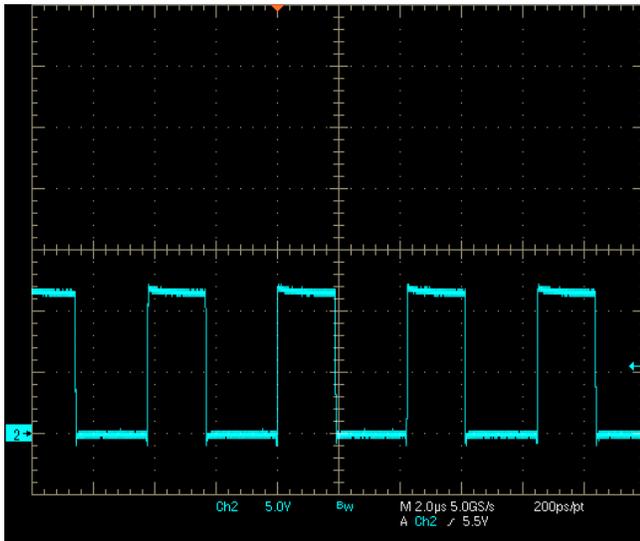


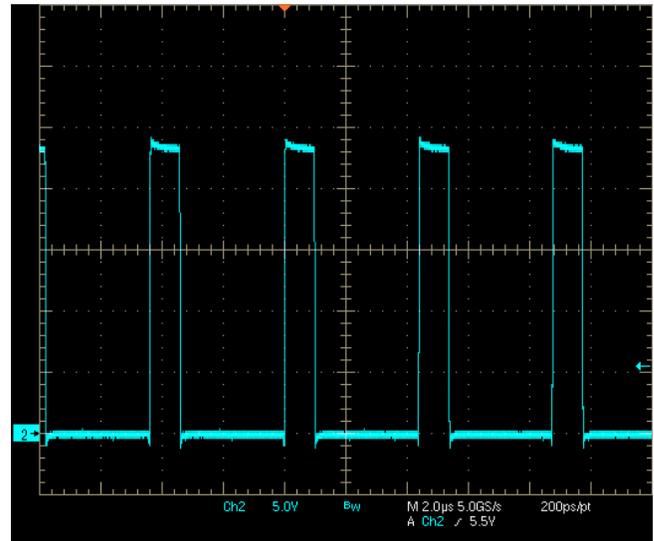
Figure 5. Load Regulation

6.3 Operating Waveforms

6.3.1 Switching

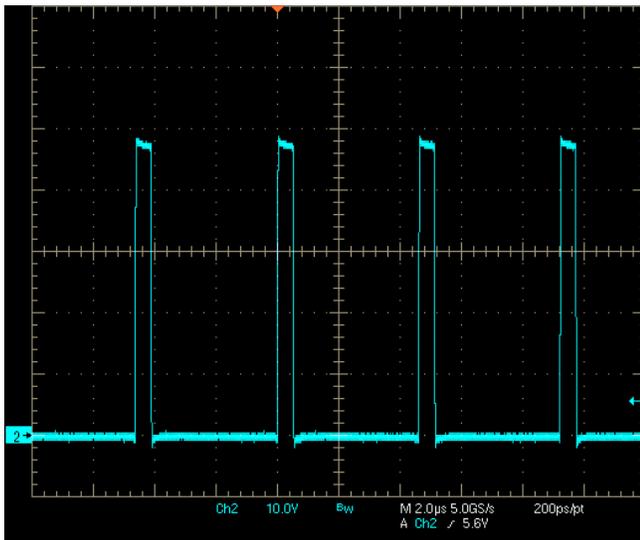


(a)

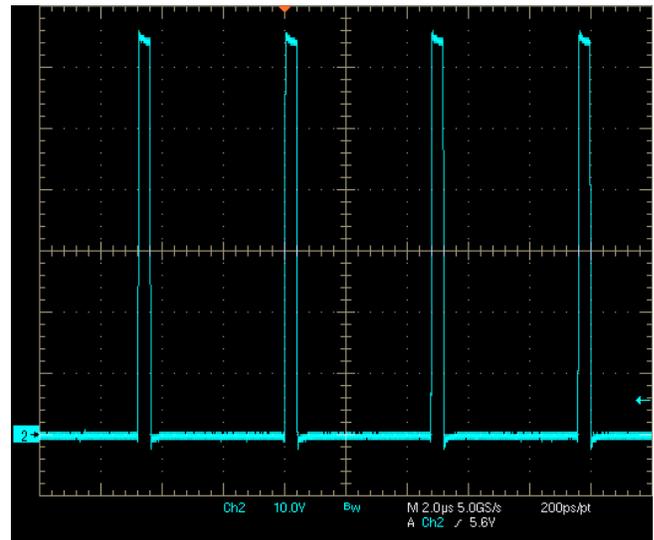


(b)

Figure 6. SW Node Voltage, $I_{OUT} = 150 \text{ mA}$; (a) $V_{IN} = 12 \text{ V}$, (b) $V_{IN} = 24 \text{ V}$ (Ch2: SW)

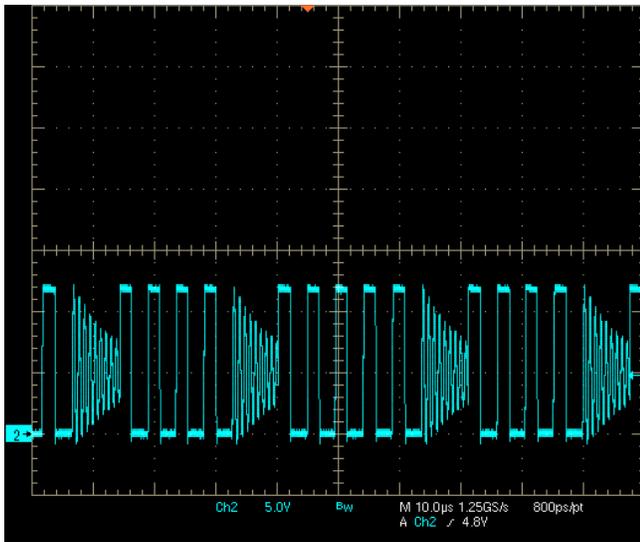


(a)

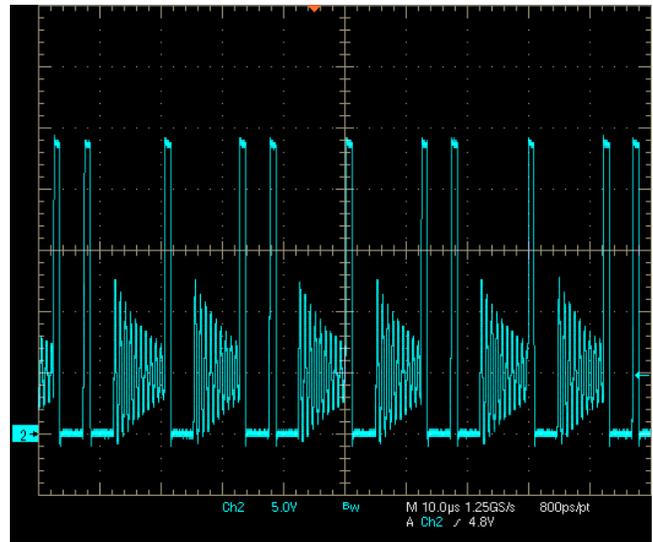


(b)

Figure 7. SW Node Voltage, $I_{OUT} = 150 \text{ mA}$; (a) $V_{IN} = 48 \text{ V}$, (b) $V_{IN} = 65 \text{ V}$ (Ch2: SW)

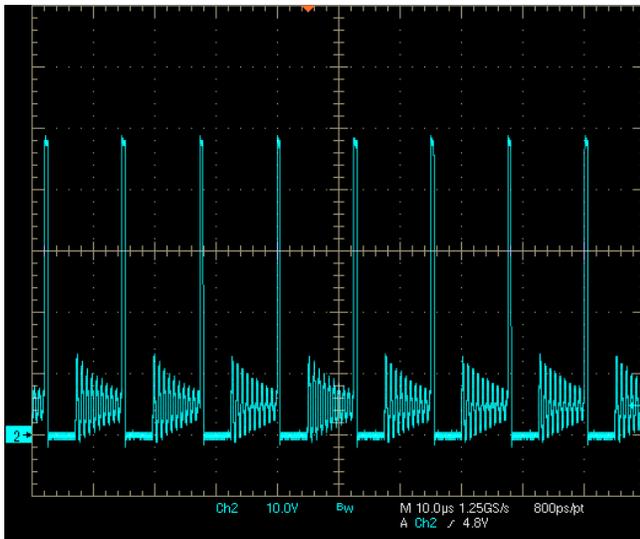


(a)

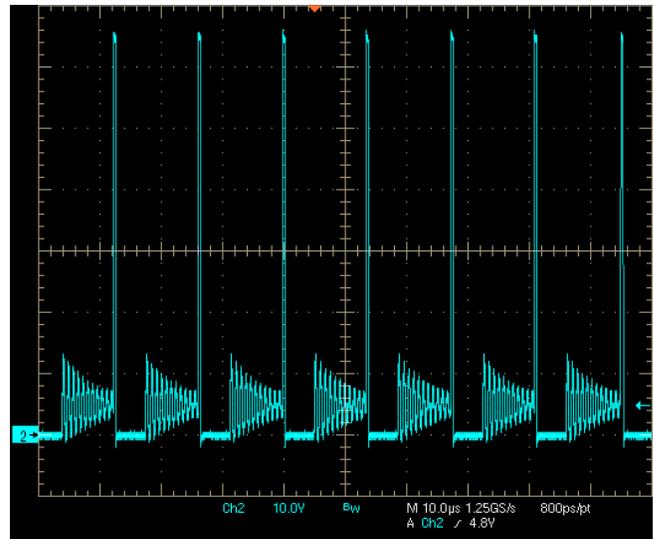


(b)

Figure 8. SW Node Voltage, $I_{OUT} = 20\text{ mA}$; (a) $V_{IN} = 12\text{ V}$, (b) $V_{IN} = 24\text{ V}$ (Ch2: SW)



(a)

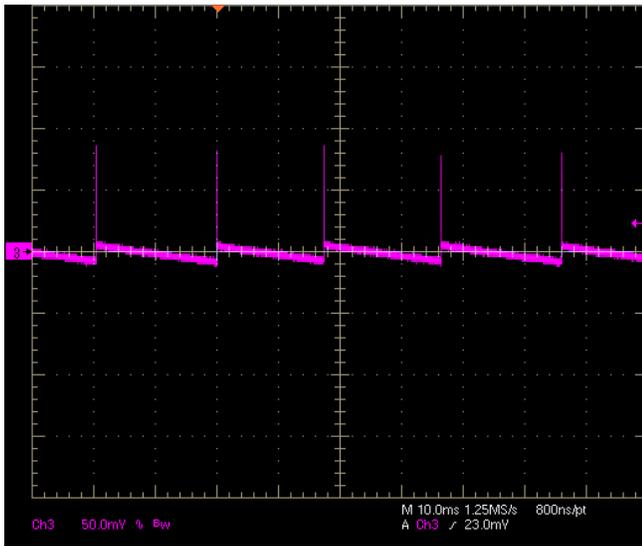


(b)

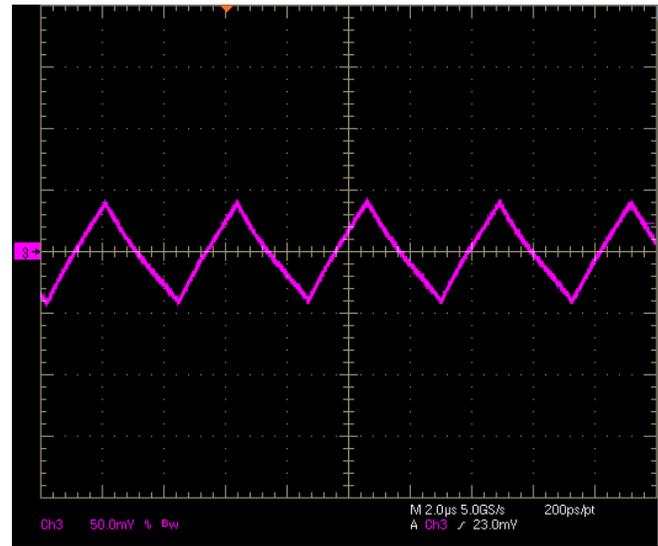
Figure 9. SW Node Voltage, $I_{OUT} = 20\text{ mA}$; (a) $V_{IN} = 48\text{ V}$, (b) $V_{IN} = 65\text{ V}$ (Ch2: SW) ⁽¹⁾

⁽¹⁾ Pulse skipping and diode emulation are evident at light loads to increase efficiency and decrease power losses.

6.3.2 Output Voltage Ripple, 20-MHz Bandwidth

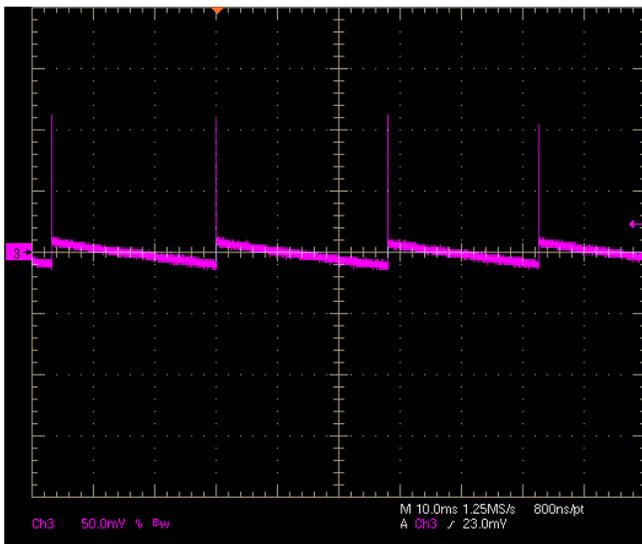


(a)

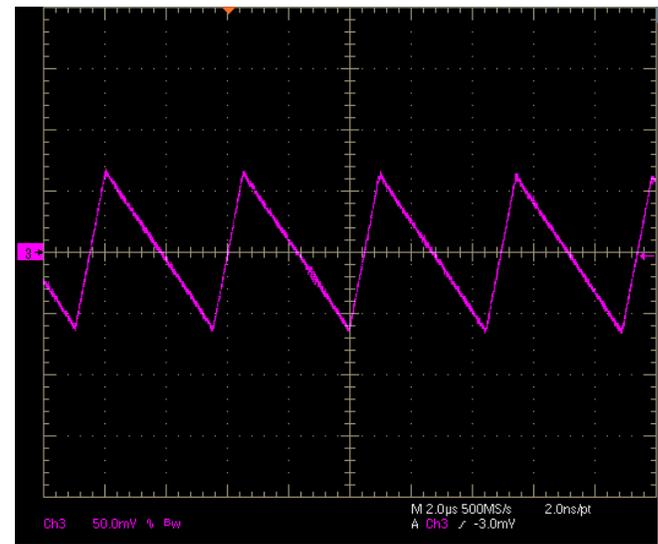


(b)

Figure 10. V_{OUT} ripple: $V_{IN} = 12\text{ V}$; (a) $I_{OUT} = 0\text{ mA}$, (b) $I_{OUT} = 150\text{ mA}$

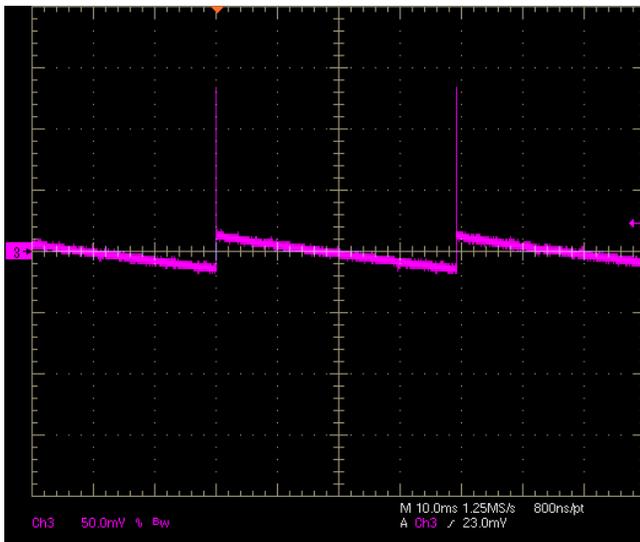


(a)

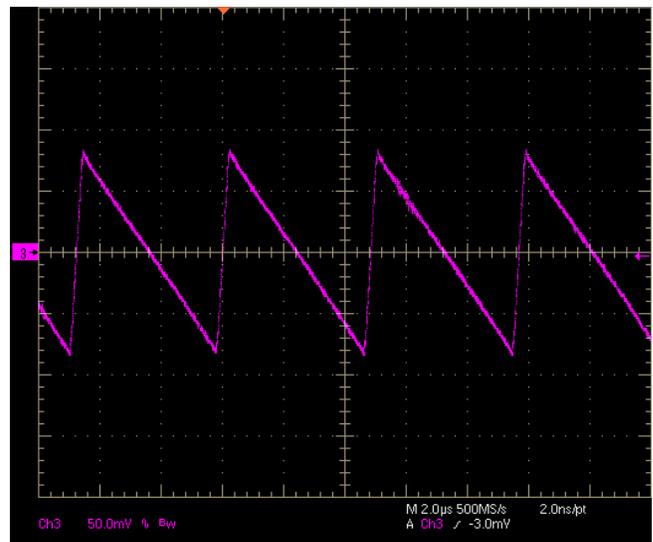


(b)

Figure 11. V_{OUT} ripple: $V_{IN} = 24\text{ V}$; (a) $I_{OUT} = 0\text{ mA}$, (b) $I_{OUT} = 150\text{ mA}$



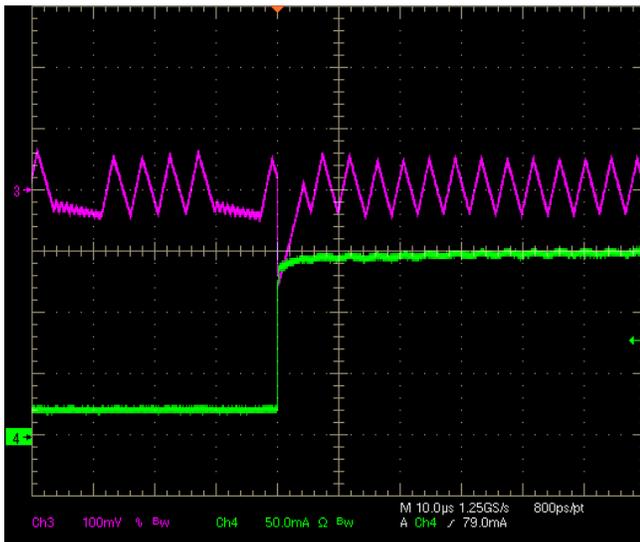
(a)



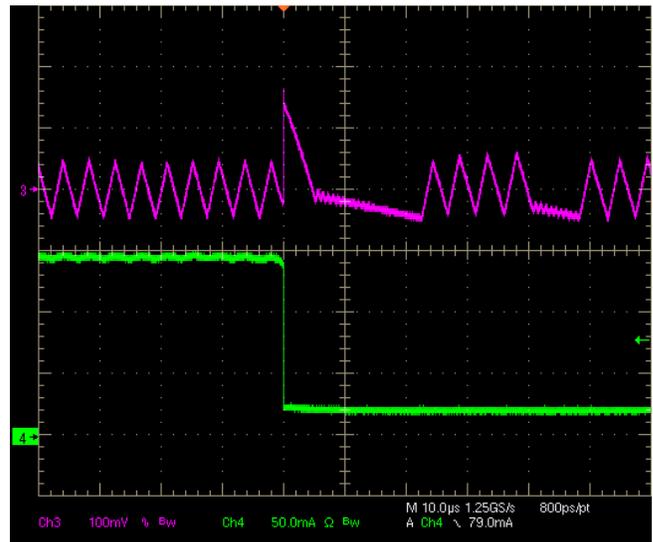
(b)

Figure 12. V_{OUT} ripple: $V_{IN} = 65\text{ V}$; (a) $I_{OUT} = 0\text{ mA}$, (b) $I_{OUT} = 150\text{ mA}$

6.3.3 Load Transient Response

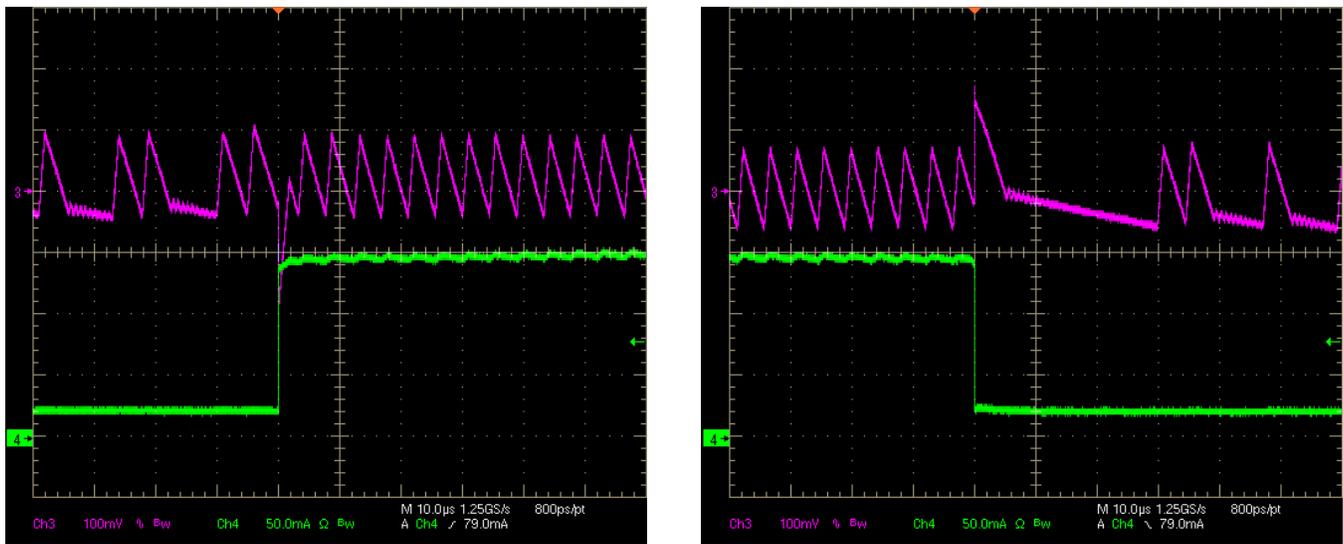


(a)



(b)

Figure 13. Load Transient Response, $V_{IN} = 12\text{ V}$, 20 mA to 150 mA at 2 A/μs; (a) Load-on transient, (b) Load-off transient

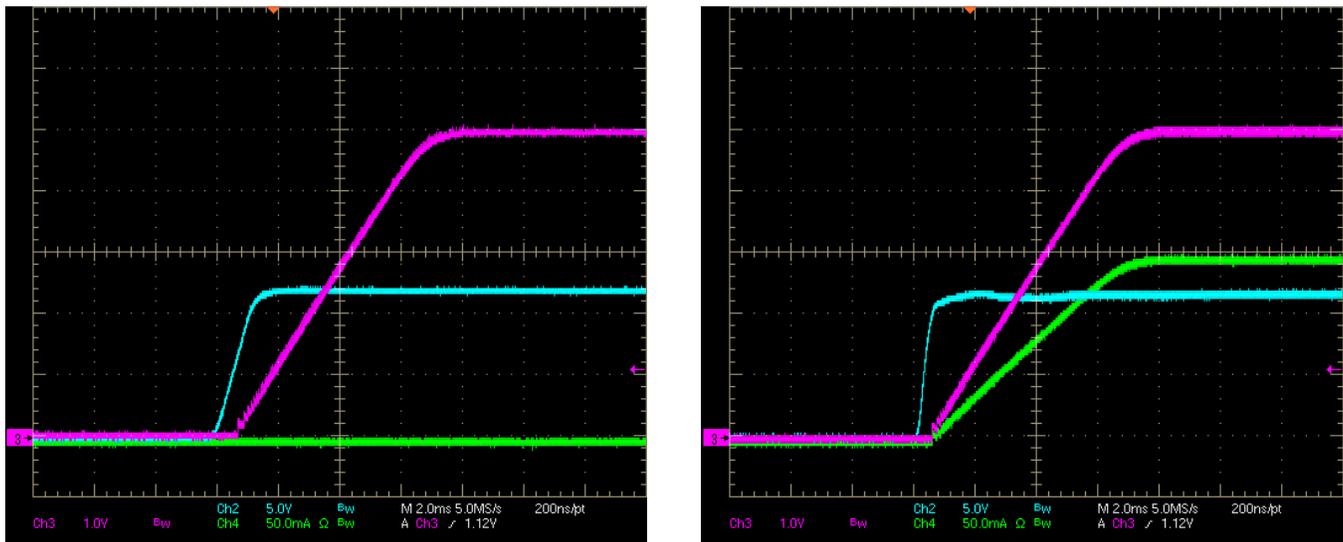


(a)

(b)

Figure 14. Load Transient Response, $V_{IN} = 24\text{ V}$, 20 mA to 150 mA at $2\text{ A}/\mu\text{s}$; (a) Load-on transient, (b) Load-off transient

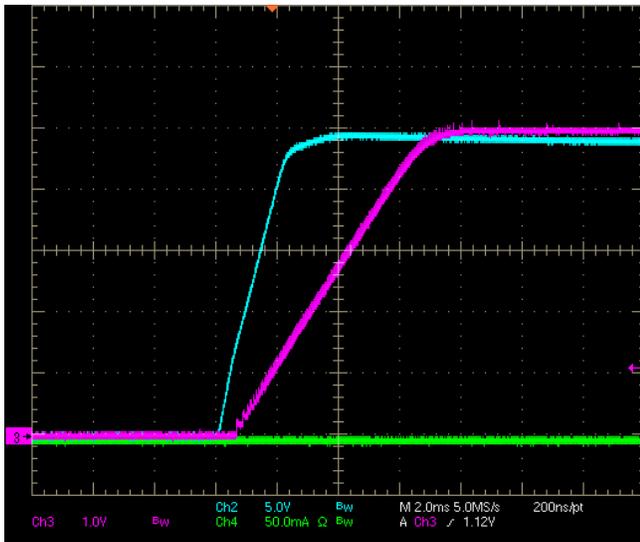
6.3.4 Startup



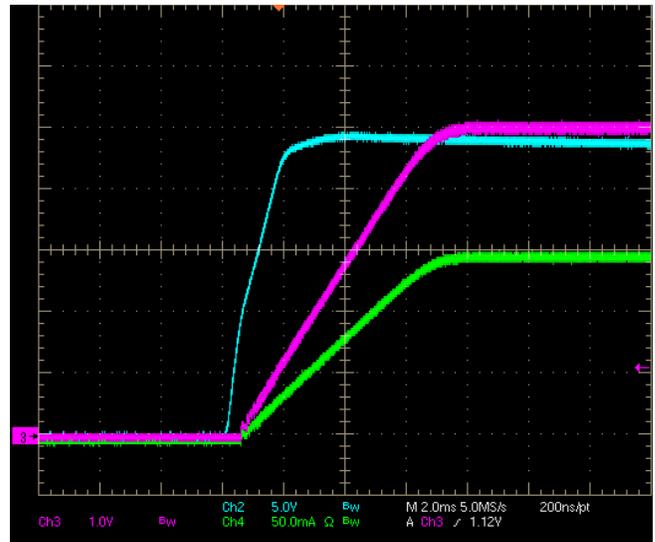
(a)

(b)

Figure 15. Startup: $V_{IN} = 12\text{ V}$; (a) $I_{OUT} = 0\text{ mA}$, (b) $I_{OUT} = 150\text{ mA}$ (Ch2: V_{IN} , Ch3: V_{OUT} , Ch4: I_{OUT})

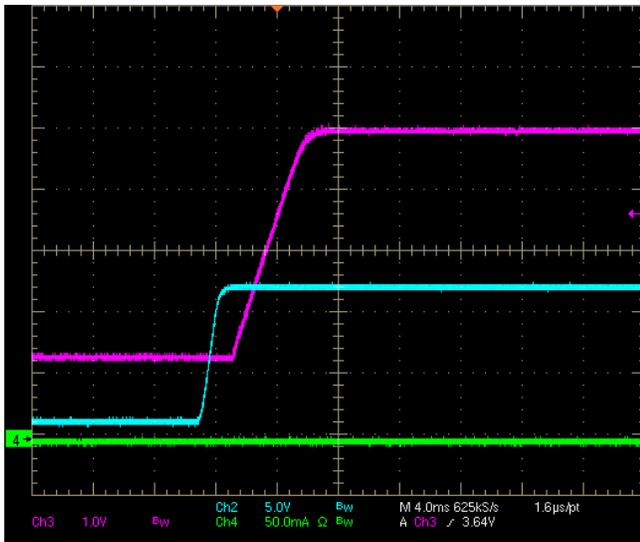


(a)

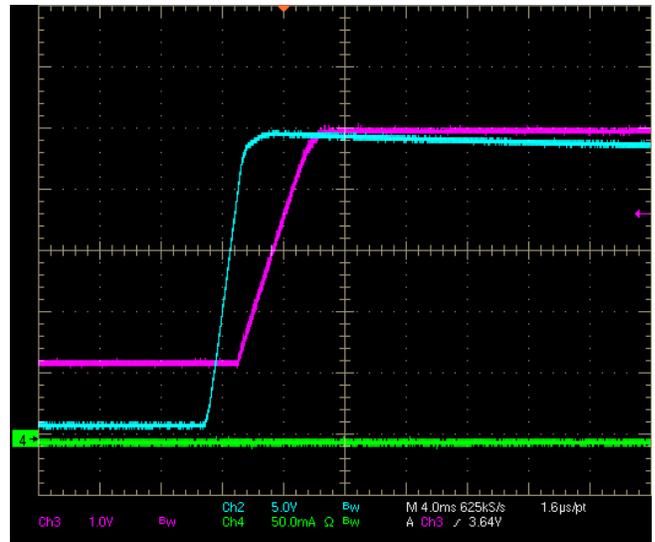


(b)

Figure 16. Startup: $V_{IN} = 24\text{ V}$; (a) $I_{OUT} = 0\text{ mA}$, (b) $I_{OUT} = 150\text{ mA}$ (Ch2: V_{IN} , Ch3: V_{OUT} , Ch4: I_{OUT})

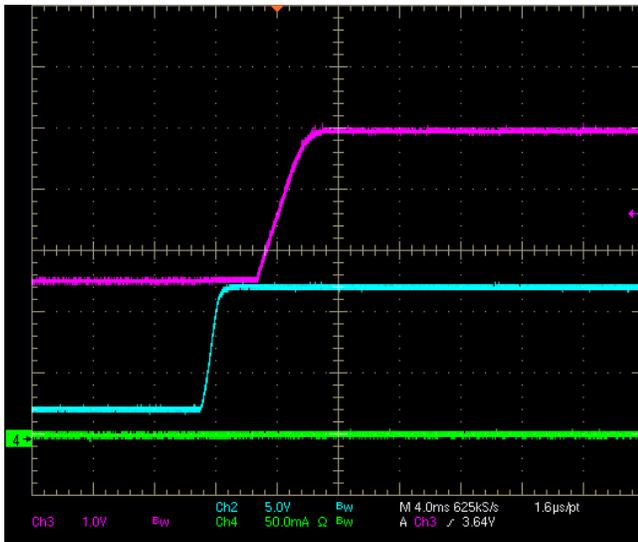


(a)

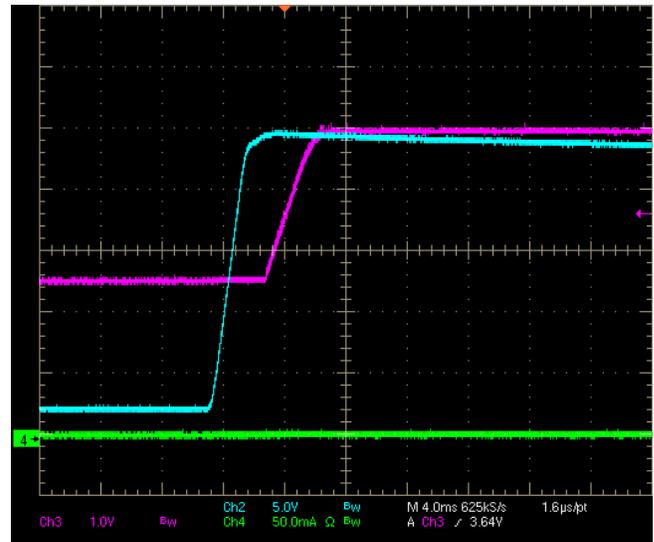


(b)

Figure 17. Startup with 1.2 V Output Pre-bias: $I_{OUT} = 0\text{ mA}$; (a) $V_{IN} = 12\text{ V}$, (b) $V_{IN} = 24\text{ V}$ (Ch2: V_{IN} , Ch3: V_{OUT} , Ch4: I_{OUT})



(a)

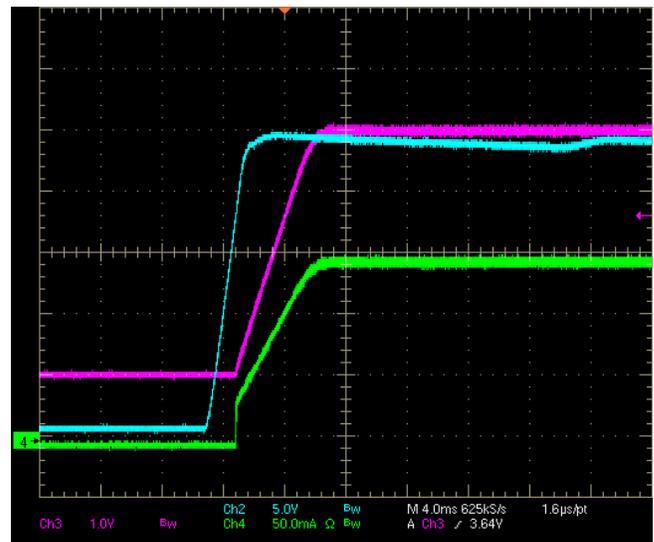


(b)

Figure 18. Startup with 2.5 V Output Pre-bias, $I_{OUT} = 0$ mA; (a) $V_{IN} = 12$ V, (b) $V_{IN} = 24$ V (Ch2: V_{IN} , Ch3: V_{OUT} , Ch4: I_{OUT})



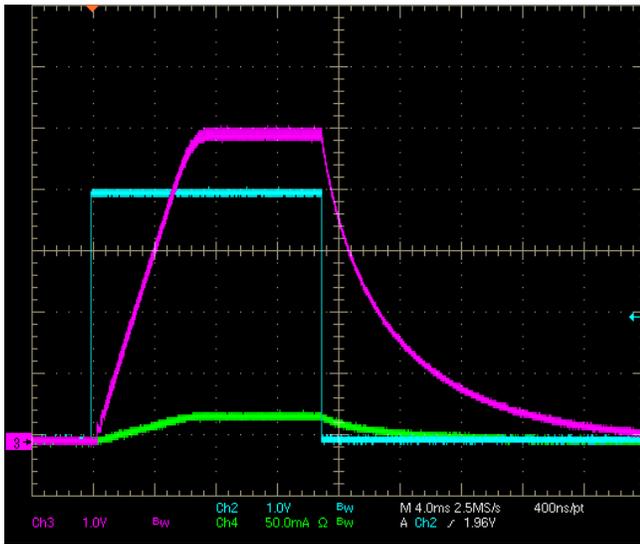
(a)



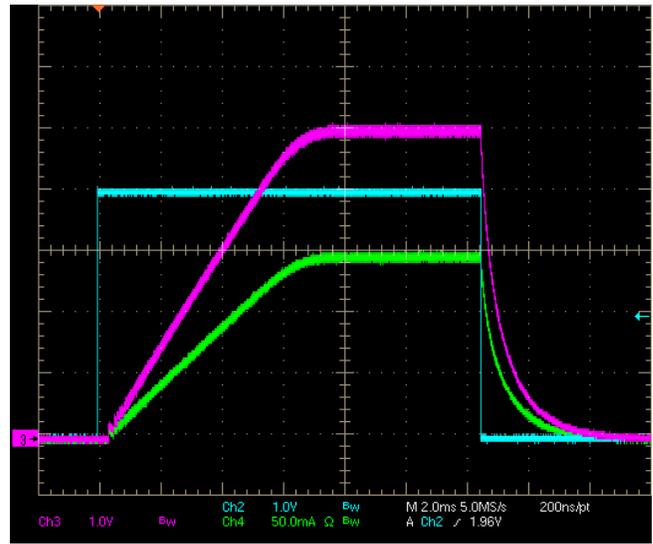
(b)

Figure 19. Startup with 1 V Output Pre-bias, $I_{OUT} = 150$ mA; (a) $V_{IN} = 12$ V, (b) $V_{IN} = 24$ V (Ch2: V_{IN} , Ch3: V_{OUT} , Ch4: I_{OUT})

6.3.5 ENABLE On/Off

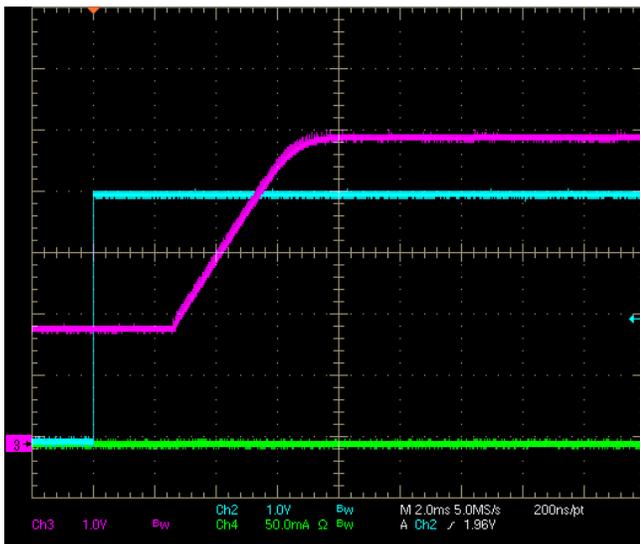


(a)

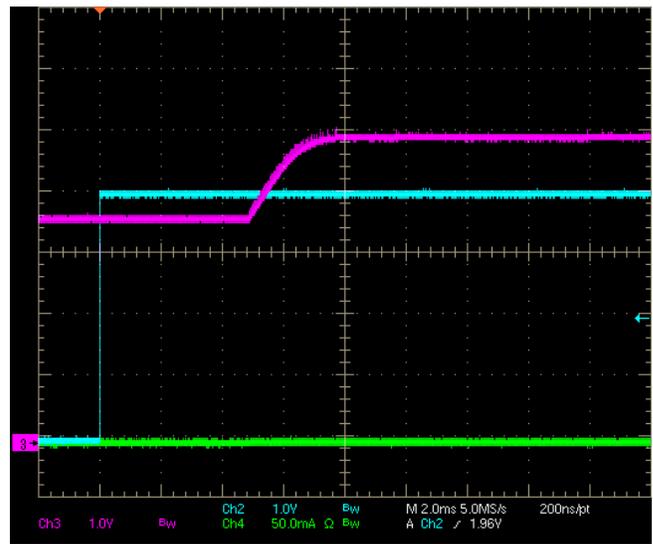


(b)

Figure 20. ENABLE On and Off: $V_{IN} = 24\text{ V}$; (a) $I_{OUT} = 0\text{ mA}$, (b) $I_{OUT} = 150\text{ mA}$ (Ch2: V_{ENABLE} , Ch3: V_{OUT} , Ch4: I_{OUT})

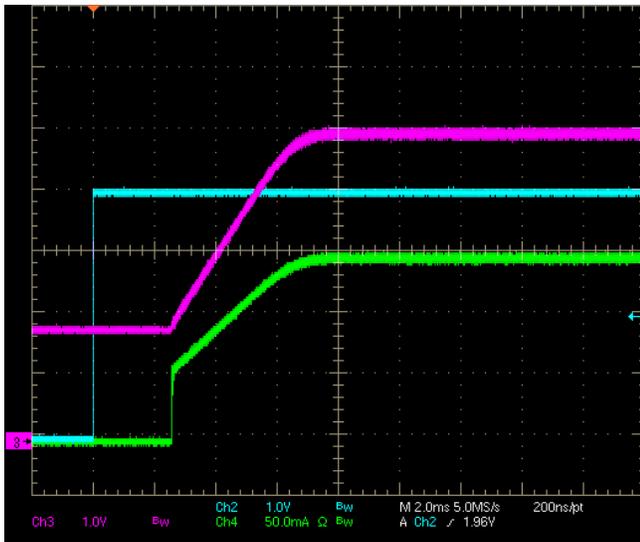


(a)

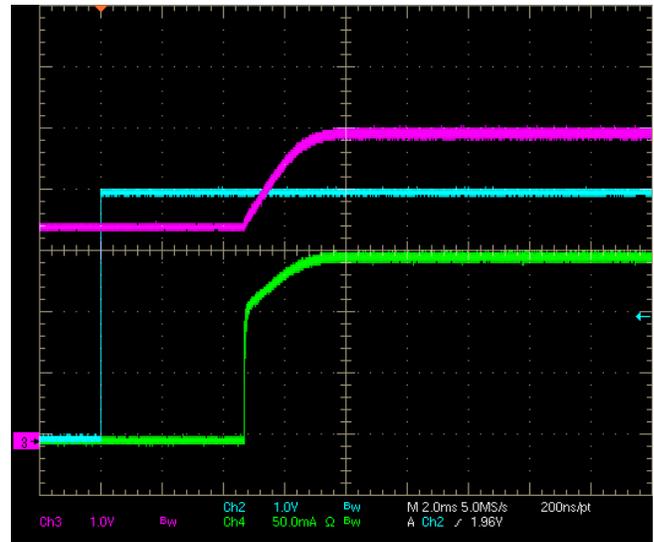


(b)

Figure 21. ENABLE On and Off: $V_{IN} = 24\text{ V}$, $I_{OUT} = 0\text{ mA}$; (a) 1.8 V Output Pre-bias, (b) 3.3 V Output Pre-bias (Ch2: V_{ENABLE} , Ch3: V_{OUT} , Ch4: I_{OUT})



(a)



(b)

Figure 22. ENABLE On: $V_{IN} = 24\text{ V}$, $I_{OUT} = 150\text{ mA}$; (a) 1.8 V Output Pre-bias, (b) 3.3 V Output Pre-bias
(Ch2: V_{ENABLE} , Ch3: V_{OUT} , Ch4: I_{OUT})

6.3.6 Line Transients – Automotive Cold-Crank

Various automotive cold-crank voltage profiles are applied to the input of the LM5165 converter. A cranking condition causes the battery voltage to drop to a low value when the battery is supplying current to an electric starter motor. The test pulses describe the drop of the battery voltage during cranking and subsequent recovery to the nominal operating voltage. Each automotive manufacturer has its own applicable standard.

The test pulses shown in [Figure 23](#) and [Figure 24](#) represent the drop in battery voltage and subsequent recovery. These waveforms are readily generated using the TI [PMP7233](#) automotive cranking simulator design. Please consult the *Automotive Cranking Simulator User's Guide* [SLVU984](#) for more detail.

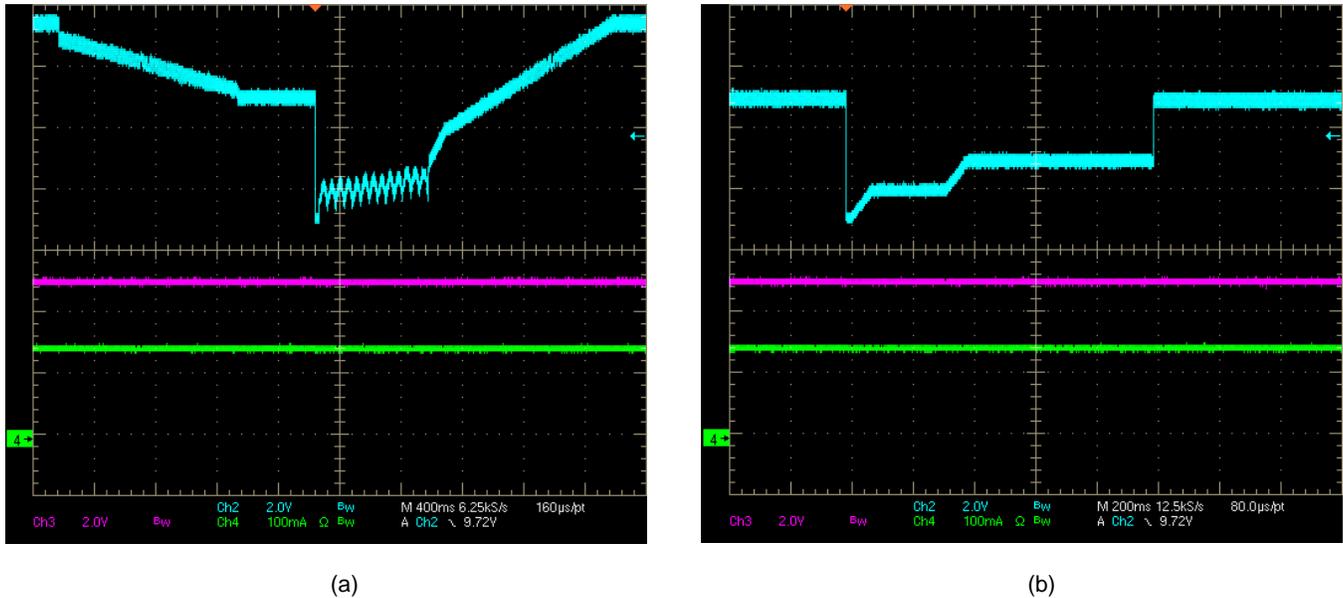


Figure 23. Typical automotive cold-crank input voltage transient; $I_{OUT} = 150\text{ mA}$; (a) Profile 1, (b) Profile 2 (Ch2: V_{IN} , Ch3: V_{OUT} , Ch4: I_{OUT})

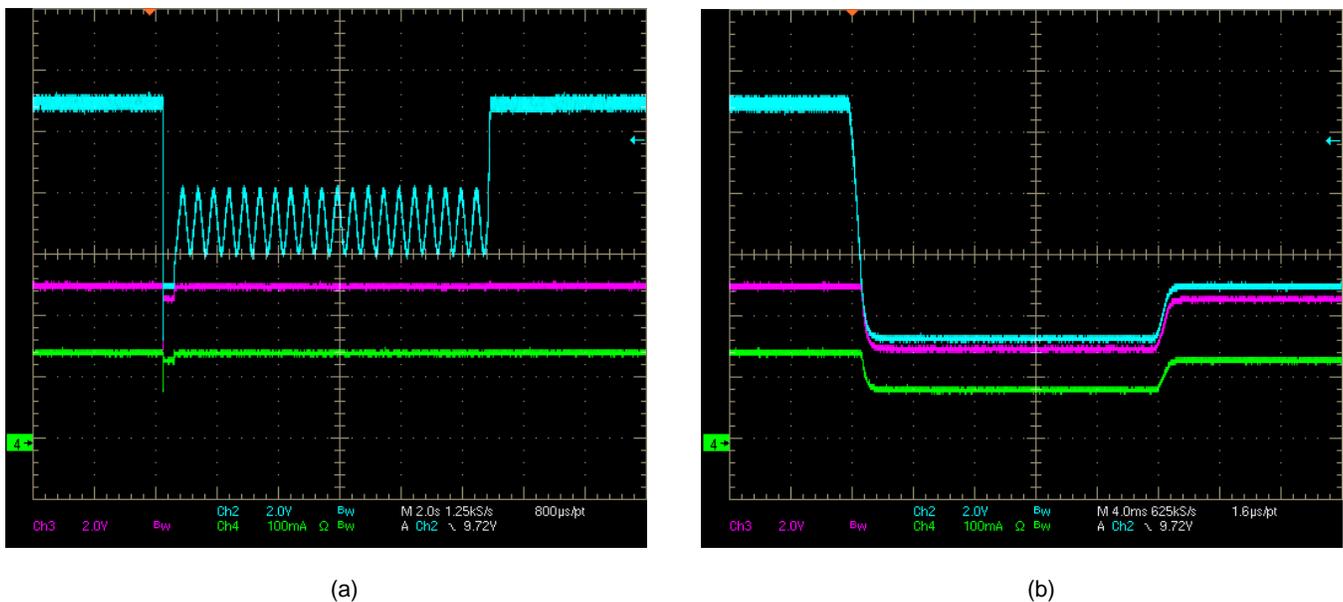


Figure 24. Typical automotive cold-crank input voltage transient; $I_{OUT} = 150\text{ mA}$; (a) Profile 3, (b) Profile 3 zoomed to show dropout operation when $V_{IN} < 5\text{ V}$ (Ch2: V_{IN} , Ch3: V_{OUT} , Ch4: I_{OUT})

6.4 CISPR 22 and CISPR 25 EMI Performance

Figure 25 represents the LM5165 COT converter's unfiltered and filtered EMI performance for conducted emissions over a frequency range of 150 kHz to 30 MHz using a 5- μ H LISN according to the CISPR 25 specification. Figure 26 shows the measurement over a frequency range of 30 MHz to 108 MHz. CISPR 25 Class 5 peak and average limits are denoted in red. The yellow and blue spectra are measured using peak and average detection, respectively.

Figure 27 shows the measurement over a frequency range of 150 kHz to 30 MHz using a 50- μ H LISN according to the CISPR 22 specification. CISPR 22 Class B limits are denoted in red.

A suitable EMI input filter to meet the specification limits is represented by a series inductor of 22 μ H together with an external input capacitance of 10 μ F (100 V, X7R, 1206 ceramic).

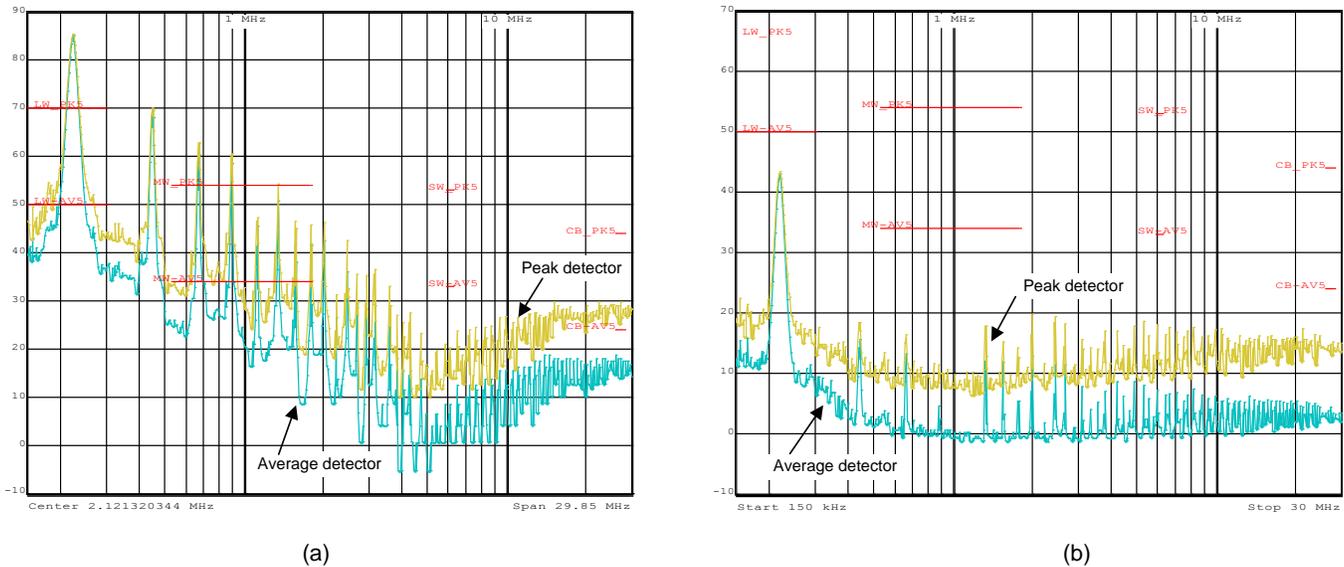


Figure 25. CISPR 25 Class 5 Conducted Emissions Plot, 150 kHz to 30 MHz, $V_{IN} = 13.5$ V, $I_{OUT} = 100$ mA, (a) Unfiltered, (b) Filtered

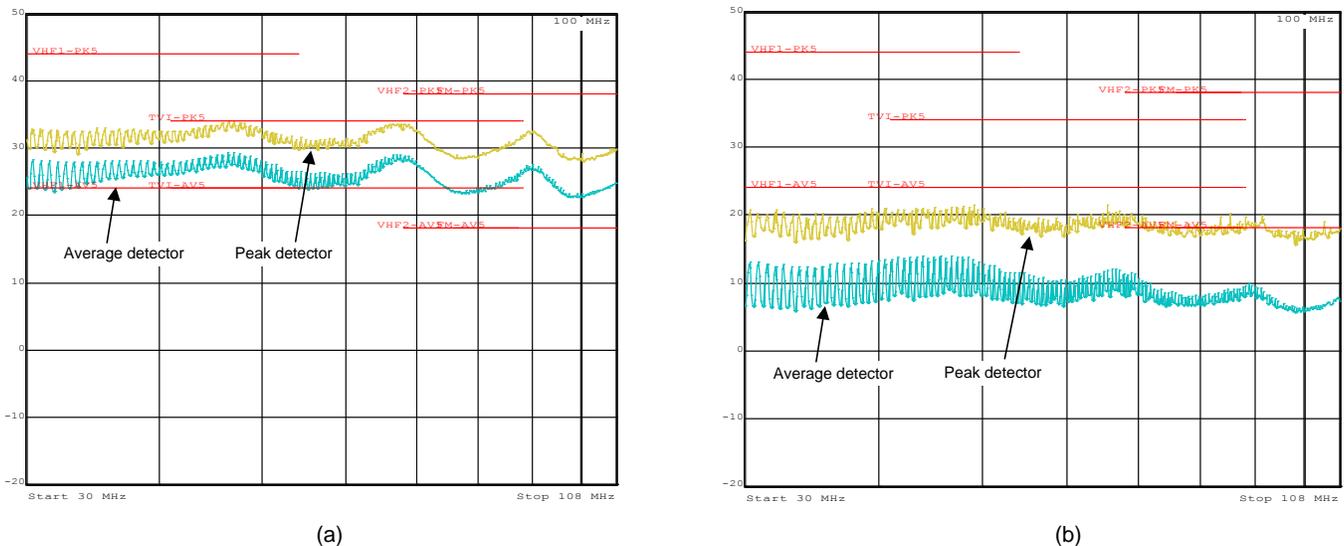


Figure 26. CISPR 25 Class 5 Conducted Emissions Plot, 30 MHz to 108 MHz, $V_{IN} = 13.5$ V, $I_{OUT} = 100$ mA, (a) Unfiltered, (b) Filtered

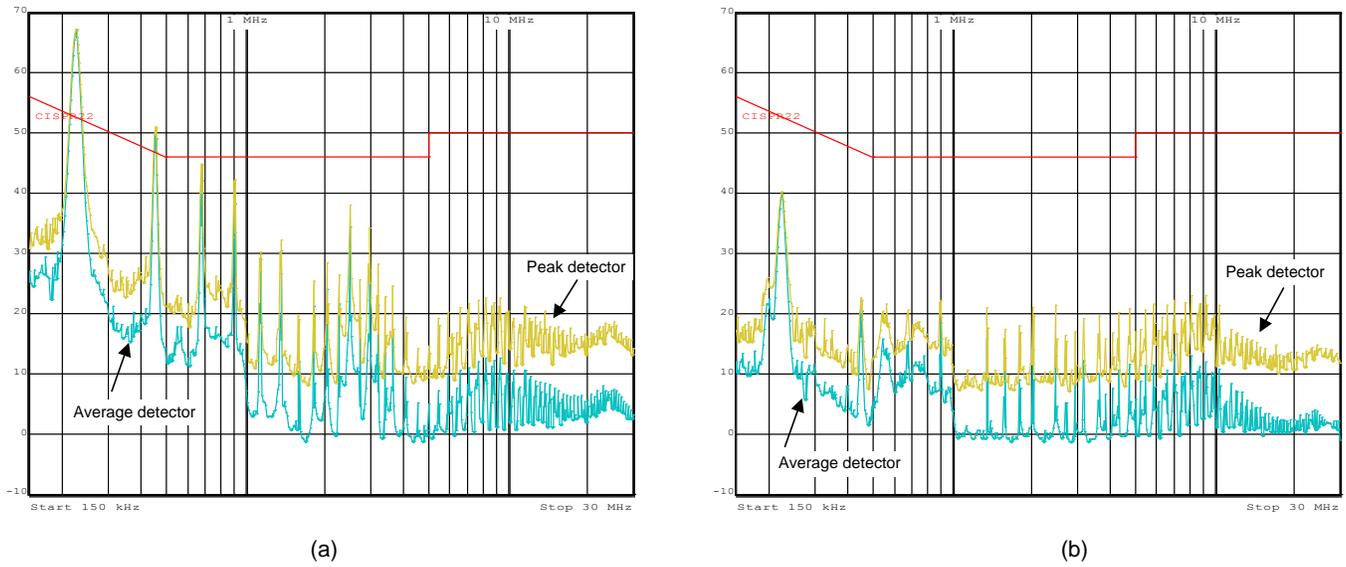


Figure 27. CISPR 22 Class B Conducted Emissions Plot, $V_{IN} = 13.5\text{ V}$, $I_{OUT} = 100\text{ mA}$, (a) Unfiltered, (b) Filtered

7 EVM Documentation

7.1 Schematic

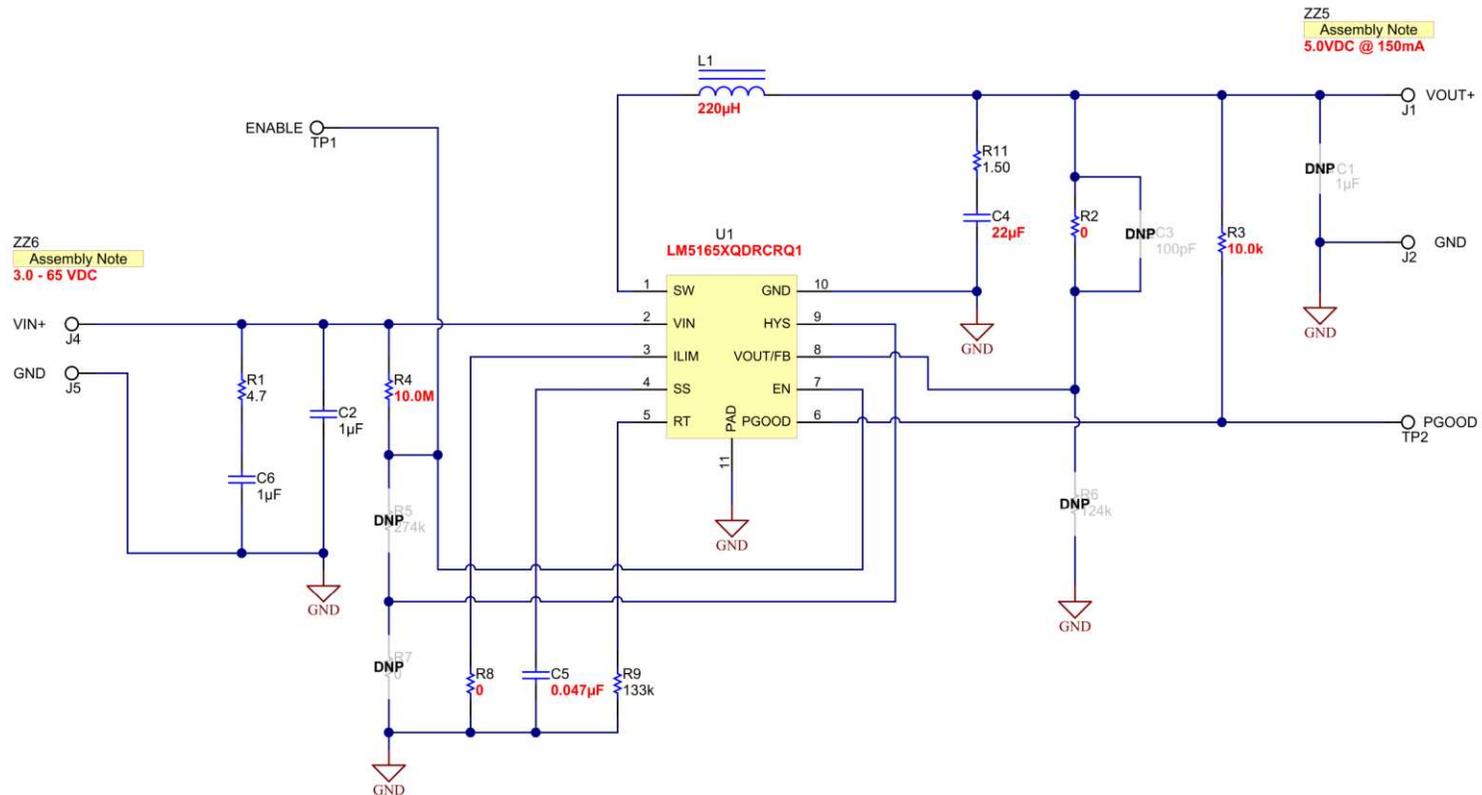


Figure 28. 5V, 150mA COT Schematic (Fixed 5V Output Version)

7.2 Bill of Materials

Table 3. Bill of Materials (COT, 5 V, 150 mA, Fixed Output Version)

Count	Ref Des	Description	Part Number	MFR
2	C2, C6	Capacitor, Ceramic, 1 μ F, 100V, X7R, 1206, AEC-Q200	HMJ316BB7105KLHT	Taiyo Yuden
		Capacitor, Ceramic, 1 μ F, 100V, X7R, 1206	GRM31CR72A105KA01L	Murata
1	C4	Capacitor, Ceramic, 22 μ F, 10V, X7R, 1206, AEC-Q200	LMJ316BB7226KLHT	Taiyo Yuden
		Capacitor, Ceramic, 22 μ F, 10V, X7R, 1206	C1206C226K8RAC7800	Kemet
			GRM31CR71A226KE15L	Murata
1	C5	Capacitor, Ceramic, 47nF, 16V, X7R, 10%, 0402	Std	Std
1	L1	Inductor, 220 μ H, 0.92 Ω typ, 0.29A Isat, 3.0mm max	WE-TPC 5828 744053221	Würth
		Inductor, 220 μ H, 0.85 Ω typ, 0.75A Isat, 4.5mm max	WE-LQS 74404064221	Würth
		Inductor, 220 μ H, 0.87 Ω max, 0.328A Isat, 4.5mm max	VLS6045EX-221M	TDK
		Inductor, 220 μ H, 1.25 Ω max, 0.3A Isat, 3.0mm max	SRR5028-221Y	Bourns
		Inductor, 220 μ H, 0.83 Ω typ, 0.7A Isat, 4.5mm max, AEC-Q200	TYS6045221M-10	Laird
1	R1	Resistor, Chip, 4.7 Ω , 1/8W, 1%, 0805	Std	Std
1	R3	Resistor, Chip, 10k Ω , 1/16W, 1%, 0402	Std	Std
1	R4	Resistor, Chip, 10M Ω , 1/16W, 1%, 0402	Std	Std
1	R9	Resistor, Chip, 133k Ω , 1/16W, 1%, 0402	Std	Std
1	R11	Resistor, Chip, 1.5 Ω , 1/16W, 1%, 0402	Std	Std
2	R2, R8	Resistor, Chip, 0 Ω , 1/16W, 5%, 0402	Std	Std
1	U1	IC, Synchronous Buck Converter, VSON-10, 5V Fixed	LM5165XQDRCRQ1	TI
1	PCB1	PCB, FR4, 4 layer, 1 oz, 15 mm x 12 mm	PCB	–
6	VIN, VOUT, GND (2), ENABLE, PGOOD	Connector, SMT	5015	Keystone

7.3 PCB Layout

Figure 29 through Figure 34 show the design of the LM5165 4-layer PCB with 1-oz copper thickness. The EVM is a two-sided design, and it includes positions for additional input and output capacitors on the bottom side (if needed).

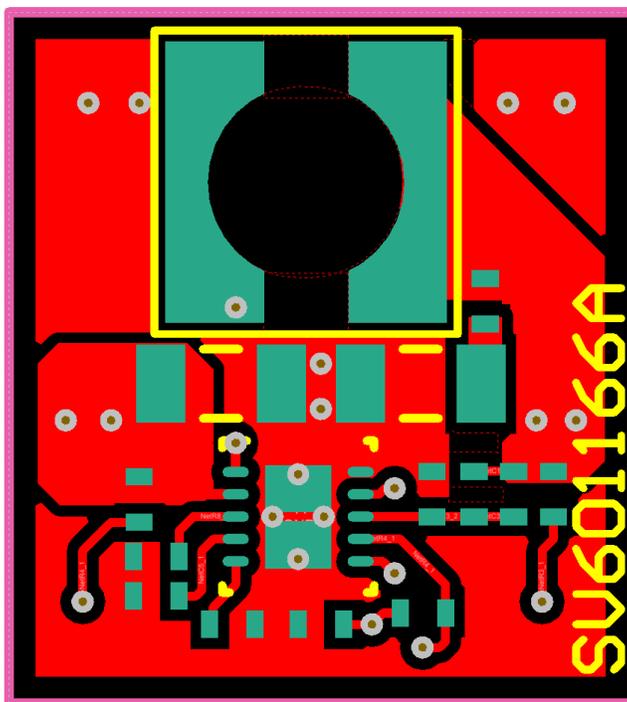


Figure 29. Top Copper (Top View)

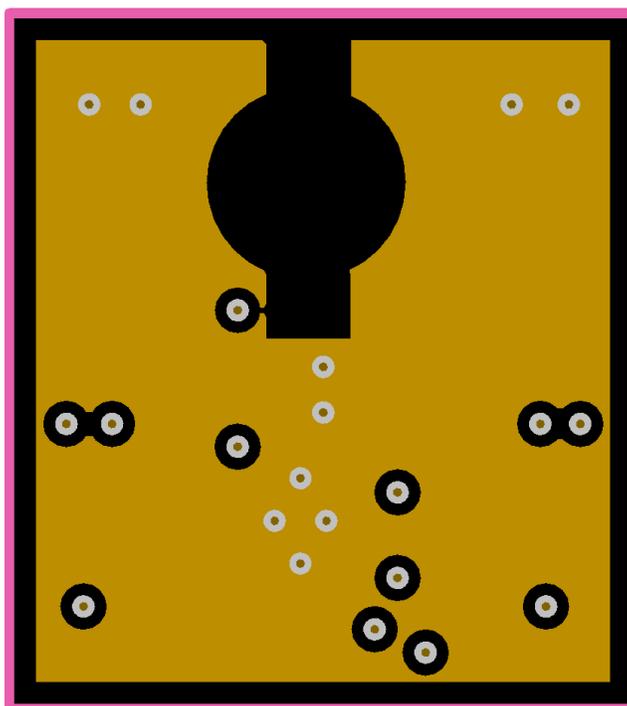


Figure 30. Layer 2 (Top View)

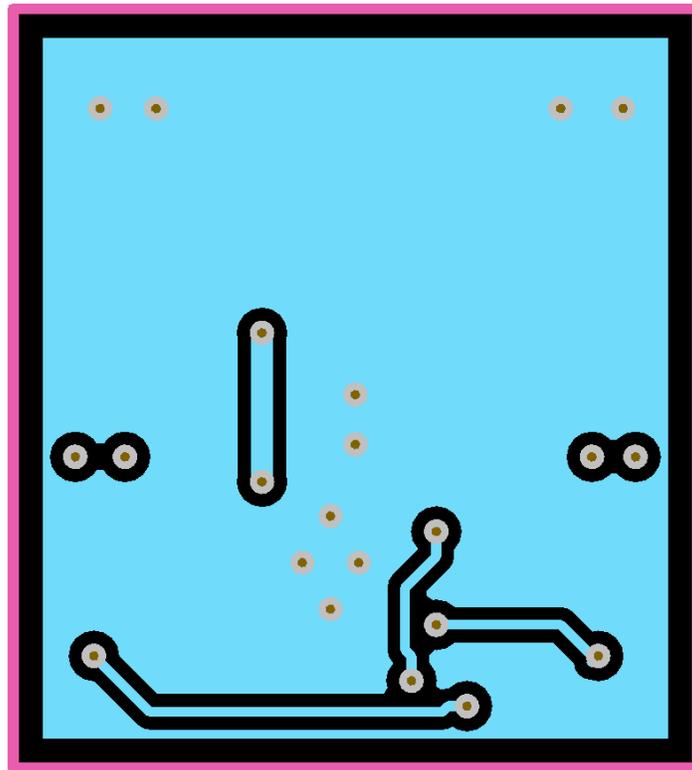


Figure 31. Layer 3 (Top View)

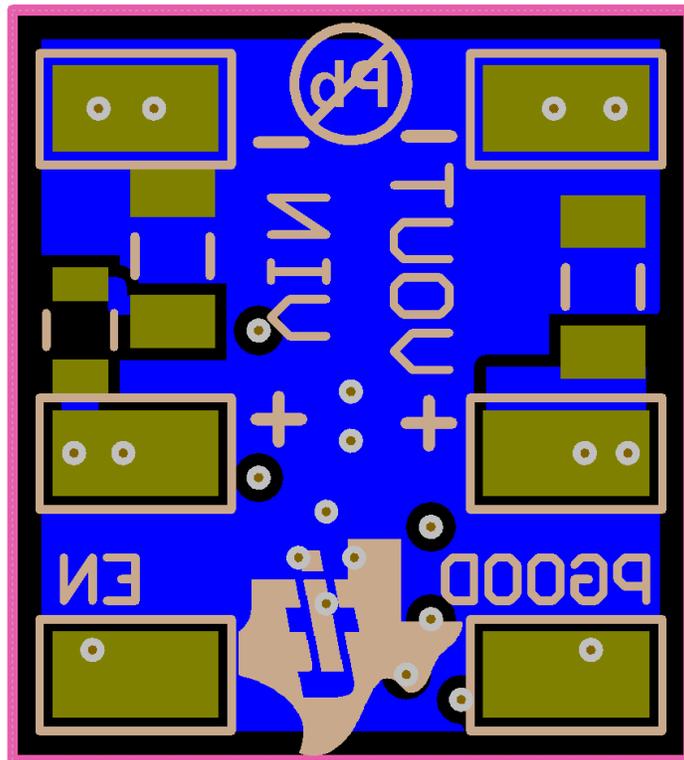


Figure 32. Bottom Copper (Bottom View)

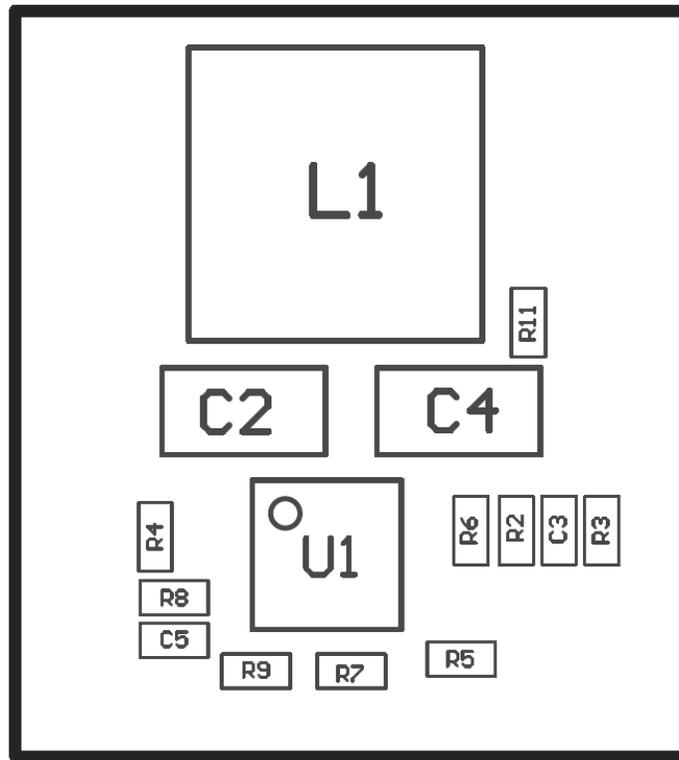


Figure 33. Top Assembly

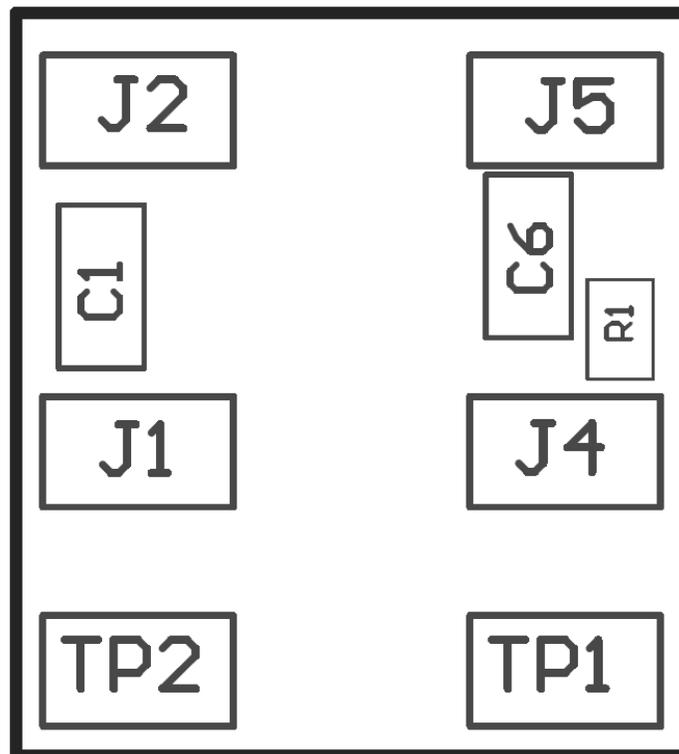


Figure 34. Bottom Assembly

8 Reference Designs

Shown below are several designs that can be realized on the same PCB as that used for the *LM5165EVM-HD-C50X* EVM. The reader is also encouraged to review the *LM5165EVM-HD-P50A* EVM User's Guide, [SNVU474](#).

8.1 Schematics

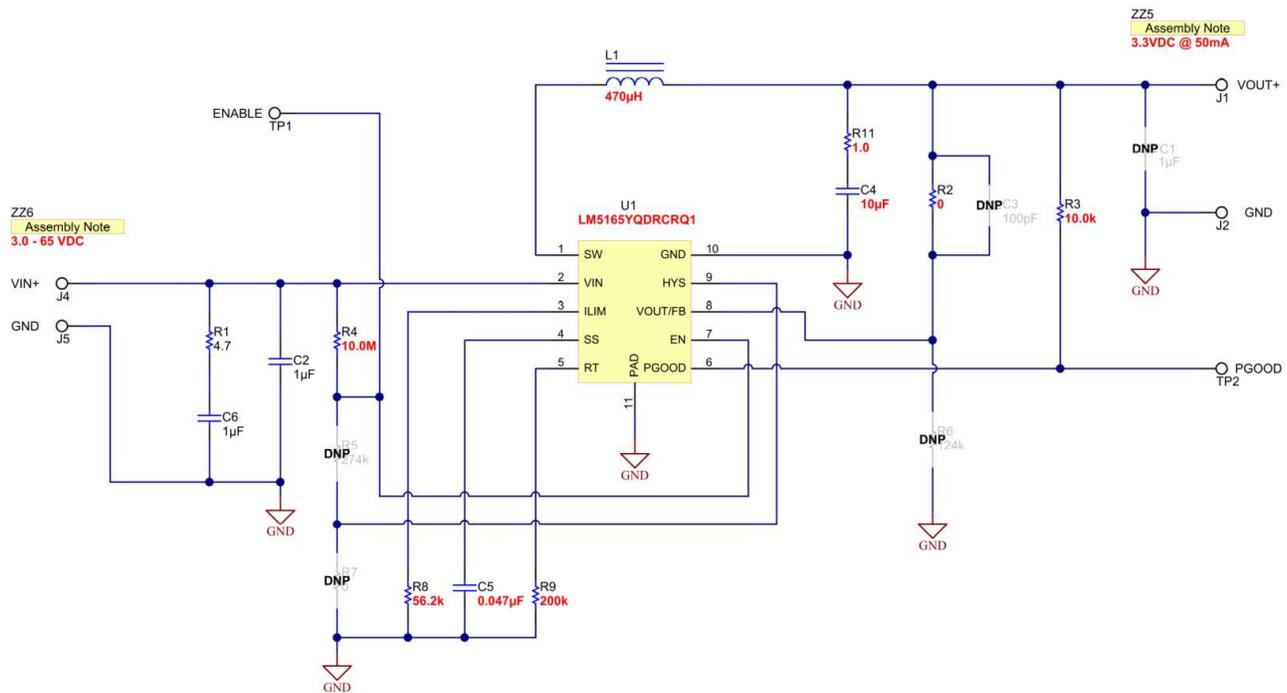


Figure 35. 3.3V, 50mA COT Schematic (Fixed 3.3V Output Version)

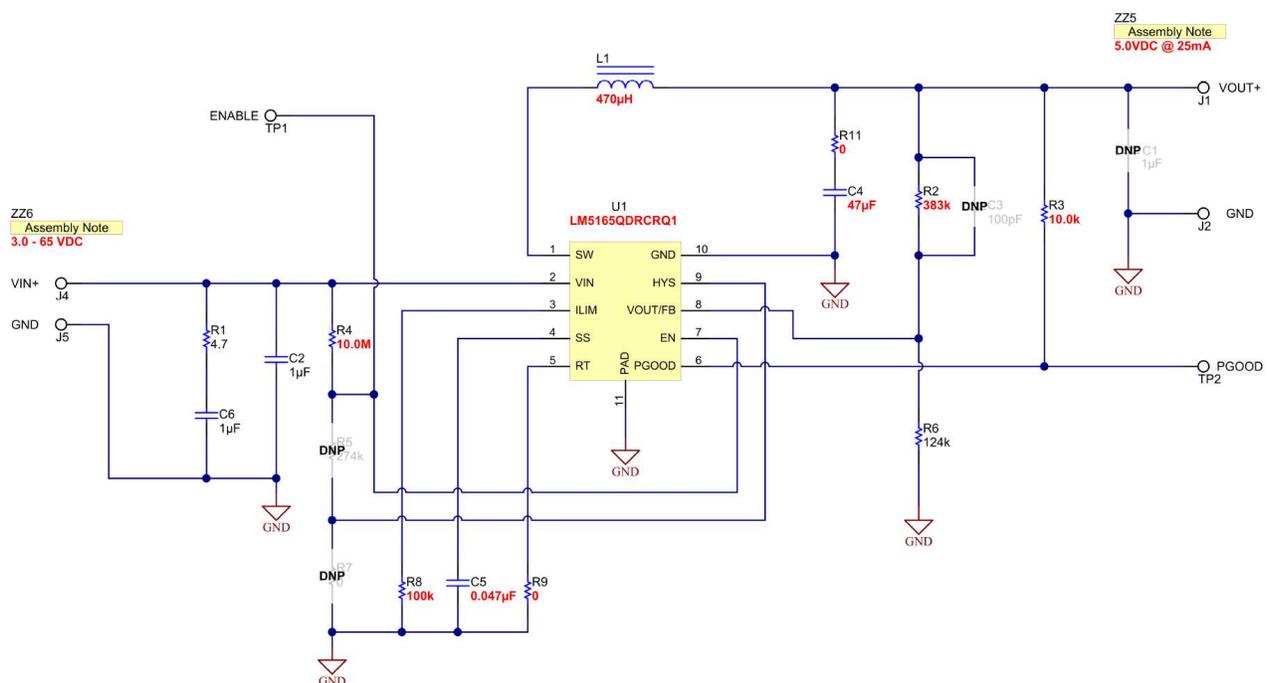


Figure 36. 5V, 25mA PFM Schematic (Adjustable Output Version)

8.2 Bill of Materials

8.2.1 Bill of Materials – COT Designs

Table 4. Bill of Materials (COT, 3.3 V, 50 mA, Fixed Output Version)

Count	Ref Des	Description	Part Number	MFR
2	C2, C6	Capacitor, Ceramic, 1 μ F, 100V, X7R, 1206, AEC-Q200	HMJ316BB7105KLHT	Taiyo Yuden
			CGA5L2X7R2A105K	TDK
			GCM31CR72A105KA03L	Murata
1	C4	Capacitor, Ceramic, 10 μ F, 6.3V, X7R, 1206, AEC-Q200	CGA5L1X7R1E106K160AC	TDK
			C1206C106K4RACAUTO	Kemet
1	C5	Capacitor, Ceramic, 22nF, 16V, X7R, 10%, 0402	Std	Std
1	L1	Inductor, 470 μ H, 2.8 Ω max, 0.146A Isat, 3.0mm max	LPS5030-474MLD	Coilcraft
		Inductor, 470 μ H, 2.6 Ω max, 0.125A Isat, 3.0mm max	WE-TPC 4828 744043471	Würth
1	R1	Resistor, Chip, 4.7 Ω , 1/8W, 1%, 0805	Std	Std
2	R2	Resistor, Chip, 0 Ω , 1/16W, 5%, 0402	Std	Std
1	R3	Resistor, Chip, 10k Ω , 1/16W, 1%, 0402	Std	Std
1	R4	Resistor, Chip, 10M Ω , 1/16W, 1%, 0402	Std	Std
1	R8	Resistor, Chip, 56.2k Ω , 1/16W, 1%, 0402	Std	Std
1	R9	Resistor, Chip, 200k Ω , 1/16W, 1%, 0402	Std	Std
1	R11	Resistor, Chip, 1.0 Ω , 1/16W, 5%, 0402	Std	Std
1	U1	IC, Synchronous Buck Converter, VSON-10, 3.3V Fixed	LM5165YQDRCRQ1	TI
1	PCB1	PCB, FR4, 4 layer, 1 oz, 15 mm x 12 mm	PCB	–

Table 5. Bill of Materials (COT, 12 V, 100 mA, Adjustable Output Version)

Count	Ref Des	Description	Part Number	MFR
2	C2, C6	Capacitor, Ceramic, 1 μ F, 100V, X7R, 1206	GRM31CR72A105KA01L	Murata
		Capacitor, Ceramic, 1 μ F, 100V, X7R, 1206, AEC-Q200	HMJ316BB7105KLHT	Taiyo Yuden
			CGA5L2X7R2A105K	TDK
1	C4	Capacitor, Ceramic, 22 μ F, 16V, X7R, 1206	EMK316BB7226KML-T	Taiyo Yuden
		Capacitor, Ceramic, 10 μ F, 25V, X7R, 1206, AEC-Q200	CGA5L1X7R1E106K160AC	TDK
			TMK316AB7106KLHT	Taiyo Yuden
1	C5	Capacitor, Ceramic, 47nF, 16V, X7R, 10%, 0402	Std	Std
1	L1	Inductor, 470 μ H, 1.6 Ω max, 0.26A Isat, 3.5mm max	LPS6235-474MRD	Coilcraft
		Inductor, 470 μ H, 1.56 Ω max, 0.28A Isat, 4.8mm max, AEC-Q200	CLF6045NIT-470M-D	TDK
1	R1	Resistor, Chip, 4.7 Ω , 1/8W, 1%, 0805	Std	Std
2	R2, R4	Resistor, Chip, 1M Ω , 1/16W, 1%, 0402	Std	Std
1	R3	Resistor, Chip, 10k Ω , 1/16W, 1%, 0402	Std	Std
1	R6	Resistor, Chip, 113k Ω , 1/16W, 1%, 0402	Std	Std
1	R8	Resistor, Chip, 0 Ω , 1/16W, 5%, 0402	Std	Std
1	R9	Resistor, Chip, 261k Ω , 1/16W, 1%, 0402	Std	Std
1	R11	Resistor, Chip, 4.7 Ω , 1/16W, 1%, 0402	Std	Std
1	U1	IC, Synchronous Buck Converter, VSON-10, ADJ	LM5165QDRCRQ1	TI
1	PCB1	PCB, FR4, 4 layer, 1 oz, 15 mm x 12 mm	PCB	–

8.2.2 Bill of Materials – PFM Designs

Table 6. Bill of Materials (PFM, 5 V, 25 mA, Adjustable Output Version)

Count	Ref Des	Description	Part Number	MFR
2	C2, C6	Capacitor, Ceramic, 1 μ F, 100V, X7R, 1206	C3216X7R2A105K160AA	TDK
		Capacitor, Ceramic, 1 μ F, 100V, X7R, 1206, AEC-Q200	CGA5L2X7R2A105K	TDK
1	C4	Capacitor, Ceramic, 47 μ F, 6.3V, X7R, 1206	LMK316BJ476ML-T	Taiyo Yuden
		Capacitor, Ceramic, 47 μ F, 10V, X5R, 1206	C1206C476M8PACTU	Kemet
			GRM31CR61A476ME15L	Murata
1	C5	Capacitor, Ceramic, 47nF, 16V, X7R, 10%, 0402	Std	Std
1	L1	Inductor, 470 μ H, 2.8 Ω max, 0.146A Isat, 3.0mm max	LPS5030-474MLD	Coilcraft
		Inductor, 470 μ H, 2.6 Ω max, 0.125A Isat, 3.0mm max	WE-TPC 4828 744043471	Würth
		Inductor, 470 μ H, 3.1 Ω max, 0.14A Isat, 2.8mm max	VLCF5028T-471MR14-2	TDK
		Inductor, 470 μ H, 2.6 Ω max, 0.155A Isat, 3.0mm max	SRR4028-471Y	Bourns
1	R1	Resistor, Chip, 4.7 Ω , 1/8W, 1%, 0805	Std	Std
1	R2	Resistor, Chip, 383k Ω , 1/16W, 1%, 0402	Std	Std
1	R3	Resistor, Chip, 10k Ω , 1/16W, 1%, 0402	Std	Std
1	R4	Resistor, Chip, 10M Ω , 1/16W, 1%, 0402	Std	Std
2	R6, R8	Resistor, Chip, 124k Ω , 1/16W, 1%, 0402	Std	Std
2	R9, R11	Resistor, Chip, 0 Ω , 1/16W, 5%, 0402	Std	Std
1	U1	IC, Synchronous Buck Converter, VSON-10, ADJ	LM5165QDRCRQ1	TI
1	PCB1	PCB, FR4, 4 layer, 1 oz, 15 mm x 12 mm	PCB	–

Table 7. Bill of Materials (PFM, 3.3 V, 50 mA, Fixed Output Version)

Count	Ref Des	Description	Part Number	MFR
2	C2, C6	Capacitor, Ceramic, 1 μ F, 100V, X7S, 0805	C2012X7S2A105K125AB	TDK
			GRJ21BC72A105KE11L	Murata
		Capacitor, Ceramic, 1 μ F, 100V, X7S, 0805, AEC-Q200	CGA4J3X7S2A105K125AE	TDK
1	C4	Capacitor, Ceramic, 10 μ F, 6.3V, X7R, 0805, AEC-Q200	GCM21BR70J106KE22L	Murata
			JMK212AB7106KGHT	Taiyo Yuden
			CGA4J1X7R0J106K125AC	TDK
1	C5	Capacitor, Ceramic, 22nF, 16V, X7R, 10%, 0402	Std	Std
1	L1	Inductor, 47 μ H, 0.62 Ω typ DCR, 0.7A Isat, 1.8mm max	WE-LQS 4018 74404042470	Würth
		Inductor, 47 μ H, 0.65 Ω max, 0.55A Isat, 1.8mm max, AEC-Q200	LPS4018-473MRD	Coilcraft
		Inductor, 47 μ H, 1.05 Ω typ 0.41A Isat, 1.5mm max	WE-LQS 3015 74404032470	Würth
		Inductor, 47 μ H, 0.65 Ω typ, 0.57A Isat, 1.8mm max, AEC-Q200	TYS4018470M-10	Laird
		Inductor, 47 μ H, 0.65 Ω typ, 0.6A Isat, 1.8mm max, AEC-Q200	NRS4018T470M	Taiyo Yuden
		Inductor, 47 μ H, 0.78 Ω max, 0.62A Isat, 1.8mm max	SRN4018-470M	Bourns
		Inductor, 47 μ H, 0.66 Ω max, 0.2A Isat, 2.0mm max	CDRH2D18/LDNP-470NC	Sumida
		Inductor, 47 μ H, 0.594 Ω max, 0.48A Isat, 1.9mm max	IFSC1515AHER470M01	Vishay Dale
		Inductor, 47 μ H, 0.871 Ω max, 0.39A Isat, 2.7mm max	CBC3225T470KRV	Taiyo Yuden
1	R1	Resistor, Chip, 4.7 Ω , 1/8W, 1%, 0805	Std	Std
3	R2, R9, R11	Resistor, Chip, 0 Ω , 1/16W, 5%, 0402	Std	Std
1	R3	Resistor, Chip, 10k Ω , 1/16W, 1%, 0402	Std	Std
1	R4	Resistor, Chip, 10M Ω , 1/16W, 1%, 0402	Std	Std
1	R8	Resistor, Chip, 56.2k Ω , 1/16W, 1%, 0402	Std	Std
1	U1	IC, Synchronous Buck Converter, VSON-10, 3.3V Fixed	LM5165YQDRCRQ1	TI
1	PCB1	PCB, FR4, 4 layer, 1 oz, 15 mm x 12 mm	PCB	–

9 Device Support

9.1 Development Support

- LM5165 DC/DC Converter [Design Tool](#)
- [TIDesigns](#) Reference Design Library
- [WEBENCH® Designer](#)

9.2 Documentation Support

9.2.1 Related Documentation

- LM5165 datasheet, [SNVSA47](#)
- LM5165-Q1 datasheet, [SNVSAJ3](#)
- LM5165EVM-HD-P50A EVM User's Guide, [SNVU474](#)
- AN-2162: Simple Success with Conducted EMI from DC-DC Converters, [SNVA489](#)
- Automotive Cranking Simulator User's Guide, [SLVU984](#)
- Using New Thermal Metrics Application Report, [SBVA025](#)
- Semiconductor and IC Package Thermal Metrics, [SPRA953](#)

Revision History

DATE	REVISION	NOTES
March 2016	*	Initial release

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 - 1.2 EVMs are not intended for consumer or household use. EVMs may not be sold, sublicensed, leased, rented, loaned, assigned, or otherwise distributed for commercial purposes by Users, in whole or in part, or used in any finished product or production system.
2. *Limited Warranty and Related Remedies/Disclaimers:*
 - 2.1 These terms and conditions do not apply to Software. The warranty, if any, for Software is covered in the applicable Software License Agreement.
 - 2.2 TI warrants that the TI EVM will conform to TI's published specifications for ninety (90) days after the date TI delivers such EVM to User. Notwithstanding the foregoing, TI shall not be liable for any defects that are caused by neglect, misuse or mistreatment by an entity other than TI, including improper installation or testing, or for any EVMs that have been altered or modified in any way by an entity other than TI. Moreover, TI shall not be liable for any defects that result from User's design, specifications or instructions for such EVMs. Testing and other quality control techniques are used to the extent TI deems necessary or as mandated by government requirements. TI does not test all parameters of each EVM.
 - 2.3 If any EVM fails to conform to the warranty set forth above, TI's sole liability shall be at its option to repair or replace such EVM, or credit User's account for such EVM. TI's liability under this warranty shall be limited to EVMs that are returned during the warranty period to the address designated by TI and that are determined by TI not to conform to such warranty. If TI elects to repair or replace such EVM, TI shall have a reasonable time to repair such EVM or provide replacements. Repaired EVMs shall be warranted for the remainder of the original warranty period. Replaced EVMs shall be warranted for a new full ninety (90) day warranty period.
3. *Regulatory Notices:*
 - 3.1 *United States*
 - 3.1.1 *Notice applicable to EVMs not FCC-Approved:*

This kit is designed to allow product developers to evaluate electronic components, circuitry, or software associated with the kit to determine whether to incorporate such items in a finished product and software developers to write software applications for use with the end product. This kit is not a finished product and when assembled may not be resold or otherwise marketed unless all required FCC equipment authorizations are first obtained. Operation is subject to the condition that this product not cause harmful interference to licensed radio stations and that this product accept harmful interference. Unless the assembled kit is designed to operate under part 15, part 18 or part 95 of this chapter, the operator of the kit must operate under the authority of an FCC license holder or must secure an experimental authorization under part 5 of this chapter.
 - 3.1.2 *For EVMs annotated as FCC – FEDERAL COMMUNICATIONS COMMISSION Part 15 Compliant:*

CAUTION

This device complies with part 15 of the FCC Rules. Operation is subject to the following two conditions: (1) This device may not cause harmful interference, and (2) this device must accept any interference received, including interference that may cause undesired operation.

Changes or modifications not expressly approved by the party responsible for compliance could void the user's authority to operate the equipment.

FCC Interference Statement for Class A EVM devices

NOTE: This equipment has been tested and found to comply with the limits for a Class A digital device, pursuant to part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference when the equipment is operated in a commercial environment. This equipment generates, uses, and can radiate radio frequency energy and, if not installed and used in accordance with the instruction manual, may cause harmful interference to radio communications. Operation of this equipment in a residential area is likely to cause harmful interference in which case the user will be required to correct the interference at his own expense.

FCC Interference Statement for Class B EVM devices

NOTE: This equipment has been tested and found to comply with the limits for a Class B digital device, pursuant to part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference in a residential installation. This equipment generates, uses and can radiate radio frequency energy and, if not installed and used in accordance with the instructions, may cause harmful interference to radio communications. However, there is no guarantee that interference will not occur in a particular installation. If this equipment does cause harmful interference to radio or television reception, which can be determined by turning the equipment off and on, the user is encouraged to try to correct the interference by one or more of the following measures:

- Reorient or relocate the receiving antenna.
- Increase the separation between the equipment and receiver.
- Connect the equipment into an outlet on a circuit different from that to which the receiver is connected.
- Consult the dealer or an experienced radio/TV technician for help.

3.2 Canada

3.2.1 For EVMs issued with an Industry Canada Certificate of Conformance to RSS-210

Concerning EVMs Including Radio Transmitters:

This device complies with Industry Canada license-exempt RSS standard(s). Operation is subject to the following two conditions: (1) this device may not cause interference, and (2) this device must accept any interference, including interference that may cause undesired operation of the device.

Concernant les EVMs avec appareils radio:

Le présent appareil est conforme aux CNR d'Industrie Canada applicables aux appareils radio exempts de licence. L'exploitation est autorisée aux deux conditions suivantes: (1) l'appareil ne doit pas produire de brouillage, et (2) l'utilisateur de l'appareil doit accepter tout brouillage radioélectrique subi, même si le brouillage est susceptible d'en compromettre le fonctionnement.

Concerning EVMs Including Detachable Antennas:

Under Industry Canada regulations, this radio transmitter may only operate using an antenna of a type and maximum (or lesser) gain approved for the transmitter by Industry Canada. To reduce potential radio interference to other users, the antenna type and its gain should be so chosen that the equivalent isotropically radiated power (e.i.r.p.) is not more than that necessary for successful communication. This radio transmitter has been approved by Industry Canada to operate with the antenna types listed in the user guide with the maximum permissible gain and required antenna impedance for each antenna type indicated. Antenna types not included in this list, having a gain greater than the maximum gain indicated for that type, are strictly prohibited for use with this device.

Concernant les EVMs avec antennes détachables

Conformément à la réglementation d'Industrie Canada, le présent émetteur radio peut fonctionner avec une antenne d'un type et d'un gain maximal (ou inférieur) approuvé pour l'émetteur par Industrie Canada. Dans le but de réduire les risques de brouillage radioélectrique à l'intention des autres utilisateurs, il faut choisir le type d'antenne et son gain de sorte que la puissance isotrope rayonnée équivalente (p.i.r.e.) ne dépasse pas l'intensité nécessaire à l'établissement d'une communication satisfaisante. Le présent émetteur radio a été approuvé par Industrie Canada pour fonctionner avec les types d'antenne énumérés dans le manuel d'usage et ayant un gain admissible maximal et l'impédance requise pour chaque type d'antenne. Les types d'antenne non inclus dans cette liste, ou dont le gain est supérieur au gain maximal indiqué, sont strictement interdits pour l'exploitation de l'émetteur.

3.3 Japan

3.3.1 *Notice for EVMs delivered in Japan:* Please see http://www.tij.co.jp/lstds/ti_ja/general/eStore/notice_01.page 日本国内に輸入される評価用キット、ボードについては、次のところをご覧ください。
http://www.tij.co.jp/lstds/ti_ja/general/eStore/notice_01.page

3.3.2 *Notice for Users of EVMs Considered "Radio Frequency Products" in Japan:* EVMs entering Japan may not be certified by TI as conforming to Technical Regulations of Radio Law of Japan.

If User uses EVMs in Japan, not certified to Technical Regulations of Radio Law of Japan, User is required by Radio Law of Japan to follow the instructions below with respect to EVMs:

1. Use EVMs in a shielded room or any other test facility as defined in the notification #173 issued by Ministry of Internal Affairs and Communications on March 28, 2006, based on Sub-section 1.1 of Article 6 of the Ministry's Rule for Enforcement of Radio Law of Japan,
2. Use EVMs only after User obtains the license of Test Radio Station as provided in Radio Law of Japan with respect to EVMs, or
3. Use of EVMs only after User obtains the Technical Regulations Conformity Certification as provided in Radio Law of Japan with respect to EVMs. Also, do not transfer EVMs, unless User gives the same notice above to the transferee. Please note that if User does not follow the instructions above, User will be subject to penalties of Radio Law of Japan.

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4 *EVM Use Restrictions and Warnings:*

4.1 EVMS ARE NOT FOR USE IN FUNCTIONAL SAFETY AND/OR SAFETY CRITICAL EVALUATIONS, INCLUDING BUT NOT LIMITED TO EVALUATIONS OF LIFE SUPPORT APPLICATIONS.

4.2 User must read and apply the user guide and other available documentation provided by TI regarding the EVM prior to handling or using the EVM, including without limitation any warning or restriction notices. The notices contain important safety information related to, for example, temperatures and voltages.

4.3 *Safety-Related Warnings and Restrictions:*

4.3.1 User shall operate the EVM within TI's recommended specifications and environmental considerations stated in the user guide, other available documentation provided by TI, and any other applicable requirements and employ reasonable and customary safeguards. Exceeding the specified performance ratings and specifications (including but not limited to input and output voltage, current, power, and environmental ranges) for the EVM may cause personal injury or death, or property damage. If there are questions concerning performance ratings and specifications, User should contact a TI field representative prior to connecting interface electronics including input power and intended loads. Any loads applied outside of the specified output range may also result in unintended and/or inaccurate operation and/or possible permanent damage to the EVM and/or interface electronics. Please consult the EVM user guide prior to connecting any load to the EVM output. If there is uncertainty as to the load specification, please contact a TI field representative. During normal operation, even with the inputs and outputs kept within the specified allowable ranges, some circuit components may have elevated case temperatures. These components include but are not limited to linear regulators, switching transistors, pass transistors, current sense resistors, and heat sinks, which can be identified using the information in the associated documentation. When working with the EVM, please be aware that the EVM may become very warm.

4.3.2 EVMs are intended solely for use by technically qualified, professional electronics experts who are familiar with the dangers and application risks associated with handling electrical mechanical components, systems, and subsystems. User assumes all responsibility and liability for proper and safe handling and use of the EVM by User or its employees, affiliates, contractors or designees. User assumes all responsibility and liability to ensure that any interfaces (electronic and/or mechanical) between the EVM and any human body are designed with suitable isolation and means to safely limit accessible leakage currents to minimize the risk of electrical shock hazard. User assumes all responsibility and liability for any improper or unsafe handling or use of the EVM by User or its employees, affiliates, contractors or designees.

4.4 User assumes all responsibility and liability to determine whether the EVM is subject to any applicable international, federal, state, or local laws and regulations related to User's handling and use of the EVM and, if applicable, User assumes all responsibility and liability for compliance in all respects with such laws and regulations. User assumes all responsibility and liability for proper disposal and recycling of the EVM consistent with all applicable international, federal, state, and local requirements.

5. *Accuracy of Information:* To the extent TI provides information on the availability and function of EVMs, TI attempts to be as accurate as possible. However, TI does not warrant the accuracy of EVM descriptions, EVM availability or other information on its websites as accurate, complete, reliable, current, or error-free.

6. *Disclaimers:*
- 6.1 EXCEPT AS SET FORTH ABOVE, EVMS AND ANY WRITTEN DESIGN MATERIALS PROVIDED WITH THE EVM (AND THE DESIGN OF THE EVM ITSELF) ARE PROVIDED "AS IS" AND "WITH ALL FAULTS." TI DISCLAIMS ALL OTHER WARRANTIES, EXPRESS OR IMPLIED, REGARDING SUCH ITEMS, INCLUDING BUT NOT LIMITED TO ANY IMPLIED WARRANTIES OF MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE OR NON-INFRINGEMENT OF ANY THIRD PARTY PATENTS, COPYRIGHTS, TRADE SECRETS OR OTHER INTELLECTUAL PROPERTY RIGHTS.
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10. *Governing Law:* These terms and conditions shall be governed by and interpreted in accordance with the laws of the State of Texas, without reference to conflict-of-laws principles. User agrees that non-exclusive jurisdiction for any dispute arising out of or relating to these terms and conditions lies within courts located in the State of Texas and consents to venue in Dallas County, Texas. Notwithstanding the foregoing, any judgment may be enforced in any United States or foreign court, and TI may seek injunctive relief in any United States or foreign court.

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