LM5165EVM-HD-P50A EVM

User's Guide

Literature Number: SNVU474
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Contents

List of Figures

List of Tables

LM5165EVM-HD-P50A EVM

The LM5165EVM-HD-P50A 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 an adjustable 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 pulse-frequency-modulation (PFM) control scheme and diode emulation, the no-load supply current is only 12 µA at 24-V input.

With integrated high- and low-side power MOSFETs, the design uses synchronous rectification to achieve high conversion efficiency over a wide load current range. The selectable PFM or COT control architecture simplifies the implementation while giving the option for optimization depending on the target application. Key features include programmable cycle-by-cycle peak current limit, thermal shutdown protection, configurable soft-start, 1.212-V precision enable threshold with hysteresis, and open-drain PGOOD flag. With AEC-Q100 Q1 grade automotive qualification, the LM5165 is rated to operate over a junction temperature range of –40°C to +150°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. The minimum operating input voltage and hysteresis are tailored to the application requirements by suitable choice of input UVLO components.

The LM5165 is available in VSON-10 package with 3 x 3-mm^2 body size to enable high density, low component count DC/DC solutions. Please consult the LM5165 Datasheet for more information. The LM5165 is supported by WEBENCH® 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 LM5165 high density EVM is designed to convert a widely-ranging input voltage supply (3 V to 65 V) to produce a tightly regulated output voltage of 5 V at currents up to 25 mA. Even though the LM5165 is available with fixed output versions (3.3V and 5 V), the adjustable version of the LM5165 is used here for added flexibility in setting the output voltage. Also, the peak inductor current is limited to one of four pre-defined levels to optimize inductor size and maximize efficiency. The EVM's maximum output current is configured by default to 25 mA but can be changed to 50mA, 75mA, 100 mA (in PFM mode) or 150 mA (in COT mode) by suitable component selection (see Section 7).

ENABLE and PGOOD connections are provided to facilitate upstream and downstream sequencing of the LM5165-based converter. The output voltage is user-adjustable by modification of the feedback resistors as appropriate. The power train passive components selected in this design, including filter inductor and ceramic input and output capacitors, are available with AEC-Q200 qualification for automotive applications.

1.1 Typical Applications

- 4–20 mA current-loop powered sensors
- High voltage LDO replacement
- Process control
- Building automation and HVAC
- General-purpose bias supplies
- Automotive and battery powered equipment

1.2 Features and Electrical Performance

- Tightly-regulated output voltage of 5 V, adjustable from 1.23 V to VIN
- Wide input voltage operating range of 3 V to 65 V
- Ultra-high power conversion efficiency over a wide load current range
  - >90% at an output voltage of 5 V and load current above 1 mA (input voltage 12 V)
- No-load supply current of 12 µA at V_{IN} = 24 V
- 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
- Pulse frequency modulation (PFM) control architecture supports all-ceramic output capacitor design
  - Low component count
  - Natural duty cycle extension to 100% for low dropout applications
- Peak inductor current level set to 60 mA by open-circuit or 100-kΩ external resistor from ILIM 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-kΩ external resistor connected from SS to GND
- ENABLE and PGOOD terminals with 10-MΩ and 10-kΩ pull-ups 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		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		15		µA
		V_{IN} = 24 V		12		µA
Input current, disabled, $I_{IN(OFF)}$	V_{ENABLE} = 0 V	V_{IN} = 12 V		5		µA
OUTPUT CHARACTERISTICS						
Output voltage, V_{OUT} [(1)]	V_{OUT} tracks V_{IN} when V_{IN} < 5 V		4.9	5.0	5.1	V
Output current, I_{OUT}	V_{IN} = 3 V to 65 V		0		25	mA
Output voltage regulation, ΔV_{OUT}	Load Regulation	I_{OUT} = 0 mA to 25 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} = 12.5 mA			20		mVrms
Output overcurrent protection, I_{OCP}	V_{IN} = 12 V, ILIM setting of 60 mA peak current			30		mA
Soft-start time, t_{SS}				6		ms
SYSTEM CHARACTERISTICS						
Switching frequency, $F_{SW(nom)}$	V_{IN} = 12 V			100		kHz
Half-load efficiency, η_{HALF} [(1)]	I_{OUT} = 12.5 mA	V_{IN} = 12 V		91.7%		
Full load efficiency, η_{FULL}	I_{OUT} = 25 mA	V_{IN} = 8 V		94.5%		
		V_{IN} = 10 V		92.8%		
		V_{IN} = 12 V		92.4%		
		V_{IN} = 24 V		87.6%		
		V_{IN} = 65 V		76.9%		
LM5165 junction temperature, T_J			-40		150	ºC

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

3 Application Circuit Diagrams

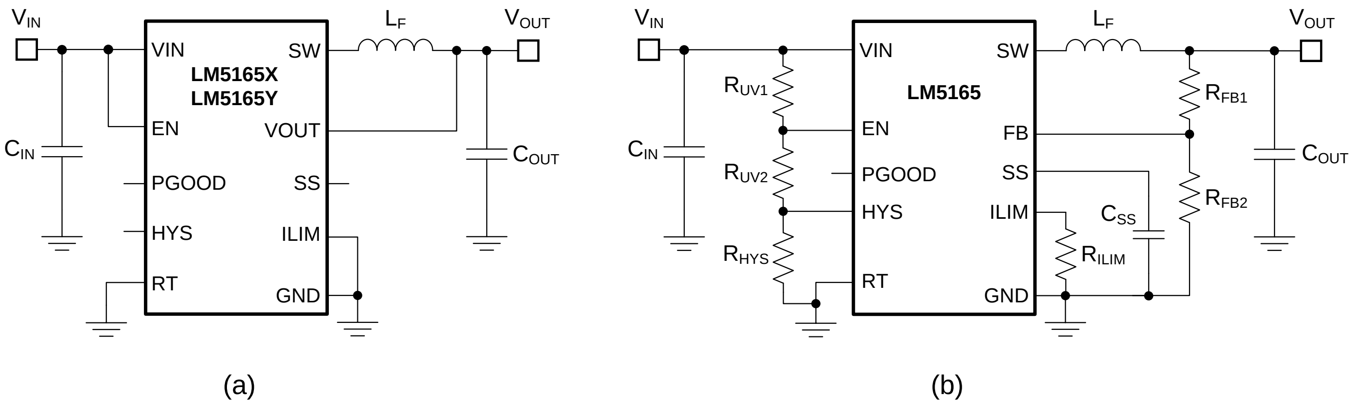


Figure 1. LM5165 PFM-controlled Buck Converter Schematics, (a) Fixed Output of 3.3 V or 5 V, (b) Adjustable Output with Soft-start, Current Limit and Input UVLO Components

Figure 1(a) shows the schematic of a minimum parts count, fixed output, PFM mode converter with continuous output current capability up to 100 mA. Figure 1(b) shows the schematic of a similar PFM converter with output voltage adjustable using feedback resistors. Additional components for soft start (SS), current limit (ILIM) and UVLO (EN and HYS) are shown to demonstrate that the converter is configurable as required to meet the specific application requirements.

The LM5165EVM-HD-P50A uses the adjustable version of the LM5165 so that the user can adjust the output voltage as needed using the feedback resistors, R_{FB1} and R_{FB2}.

4 EVM Photo

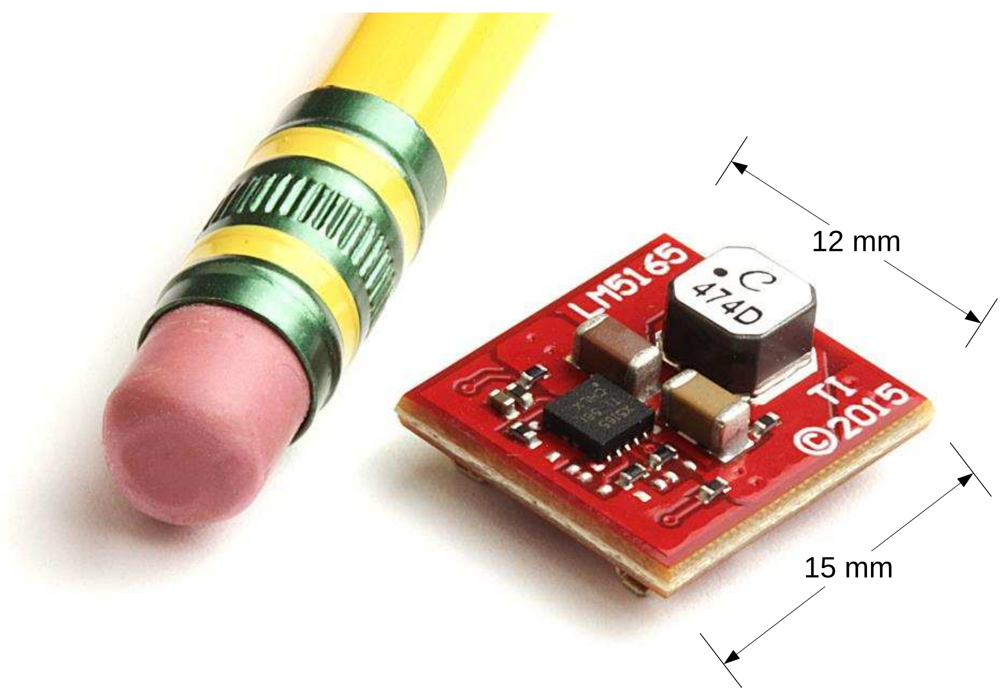


Figure 2. LM5165 EVM Photo

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 flag indicator

Referencing the EVM connections described in Table 2, the recommended test setup to evaluate the LM5165EVM-HD-P50A 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.

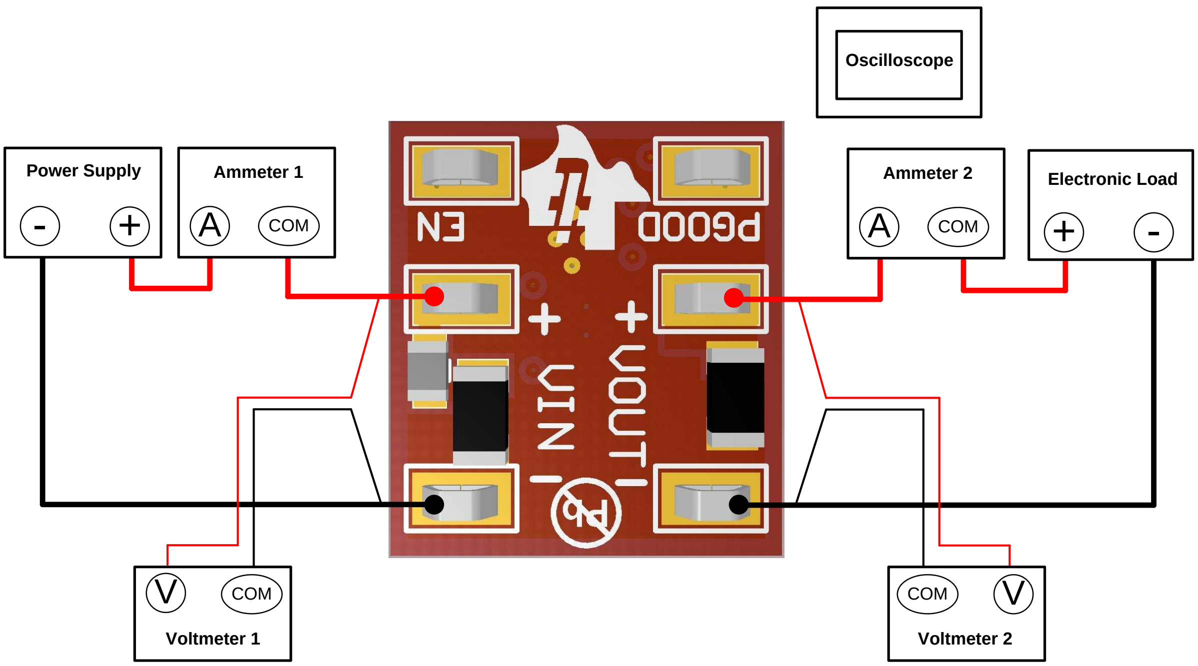


Figure 3. EVM Test Setup

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 100 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 250 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 25 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 12 present typical performance curves for the LM5165EVM-HD-P50A EVM. 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

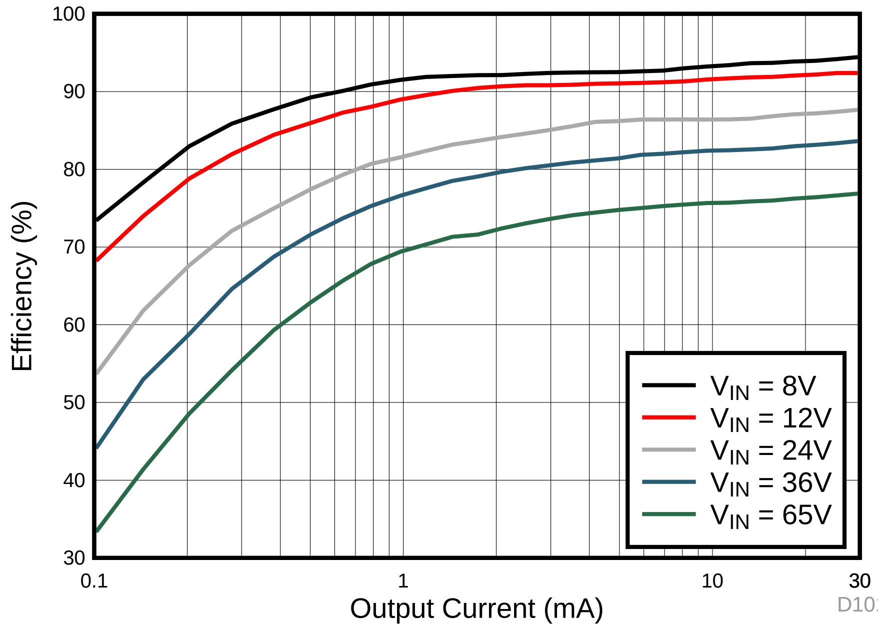
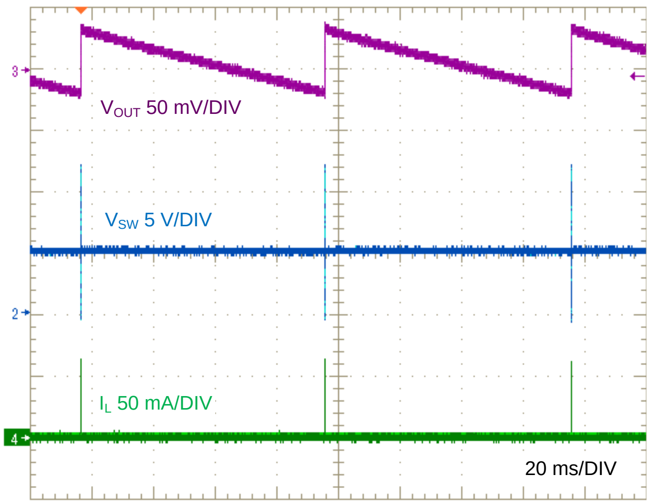


Figure 4. PFM Converter Efficiency, V_{OUT} = 5 V

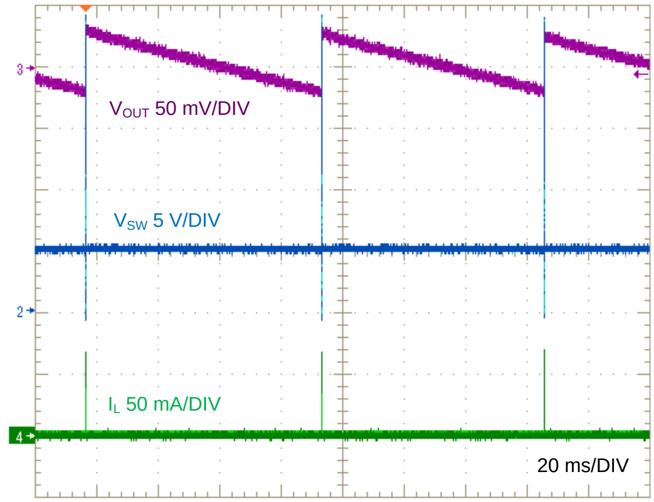
6.2 Operating Waveforms

6.2.1 Switching

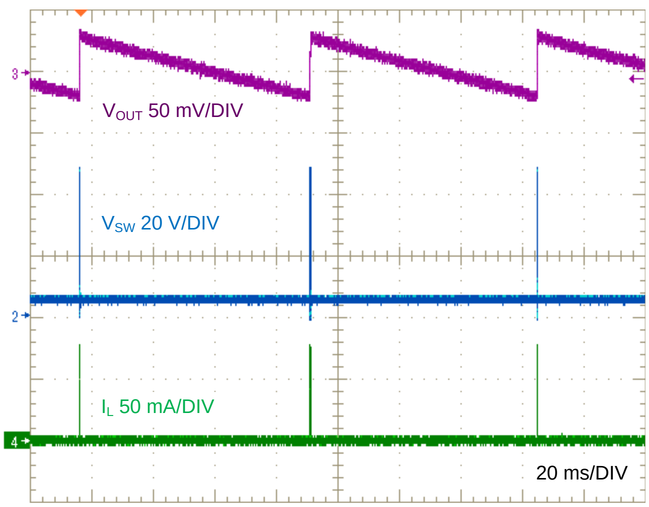
6.2.1.1 No Load



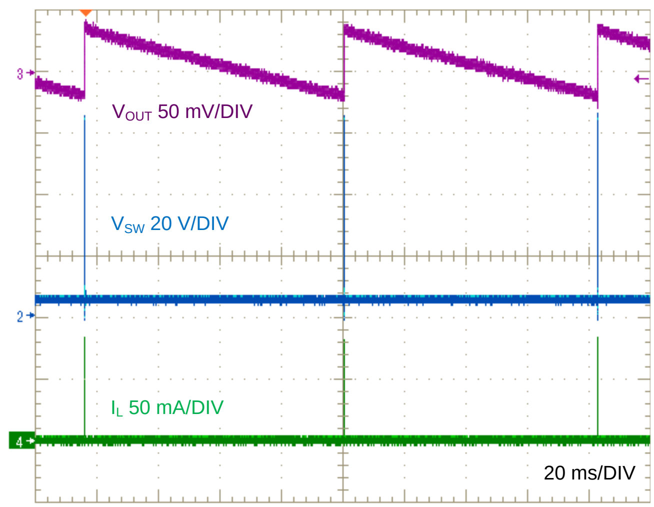
(a)



(b)



(c)



(d)

Figure 5. SW Node, V_{OUT} and I_L Waveforms at I_{OUT} = 0 mA: (a) V_{IN} = 12 V, (b) V_{IN} = 24 V, (c) V_{IN} = 36 V, (d) V_{IN} = 65 V

6.2.1.2 Half Load

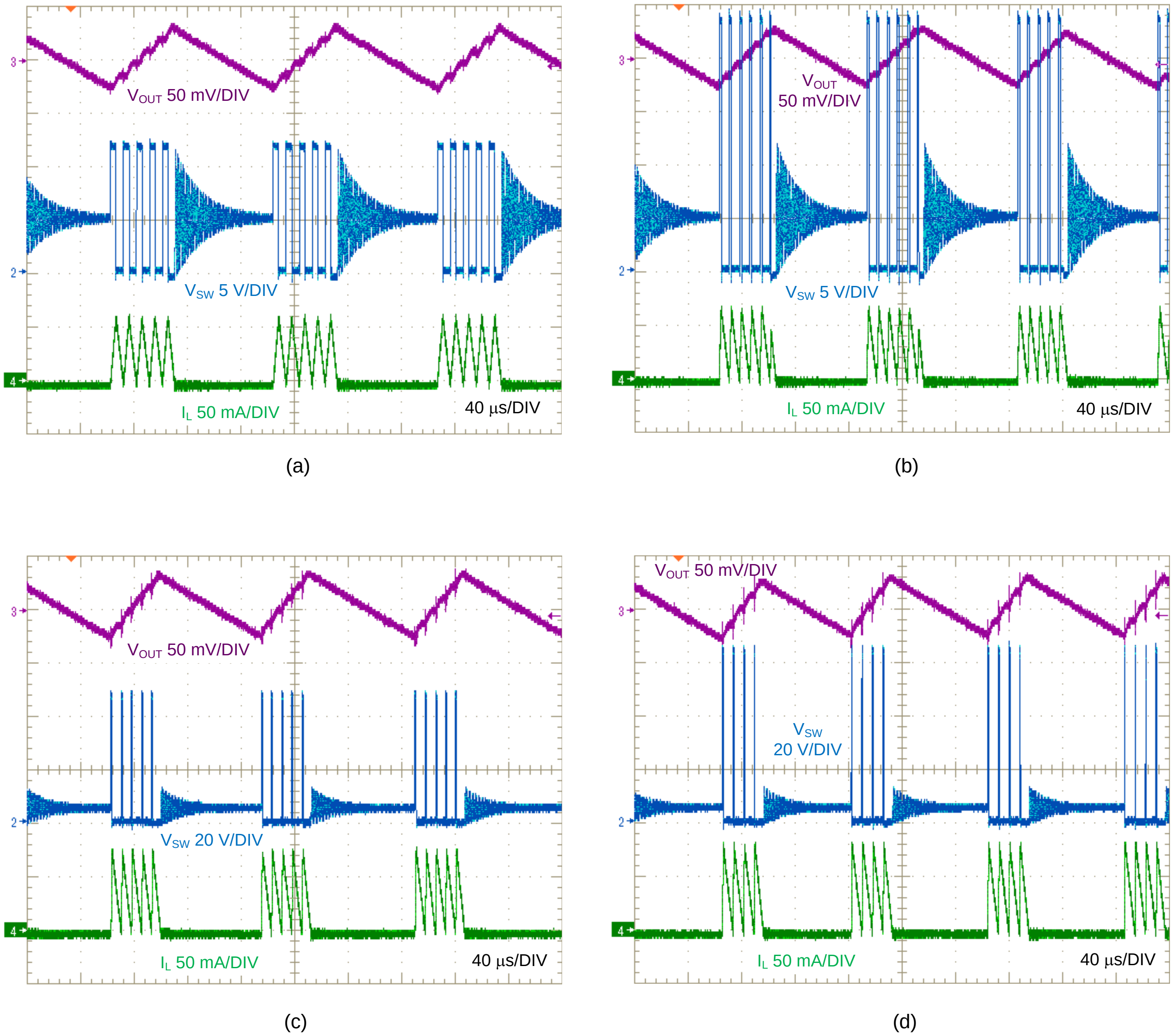


Figure 6. SW Node, V_{OUT} and I_L Waveforms at I_{OUT} = 12.5 mA: (a) V_{IN} = 12 V, (b) V_{IN} = 24 V, (c) V_{IN} = 36 V, (d) V_{IN} = 65 V

6.2.1.3 Full Load

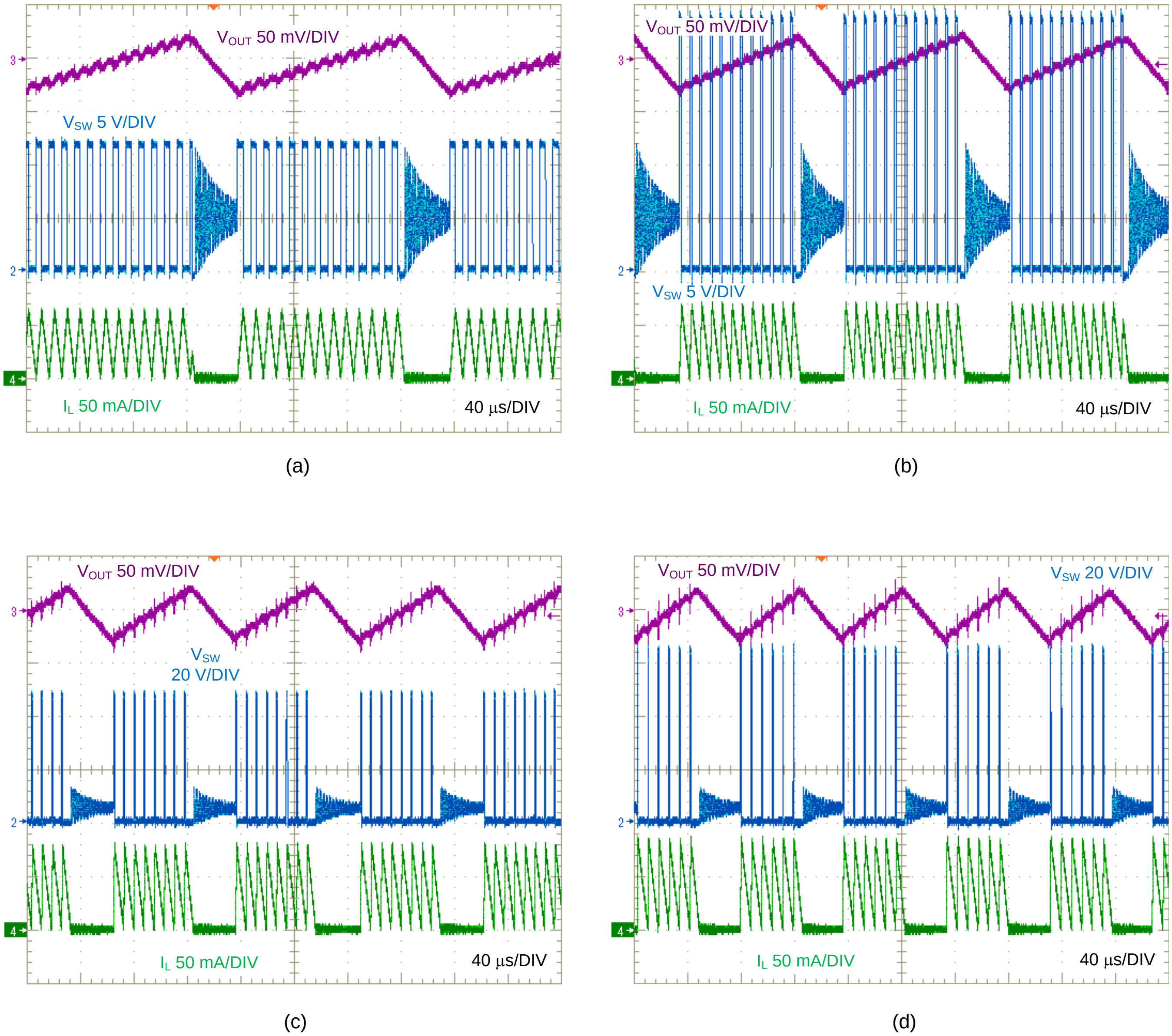
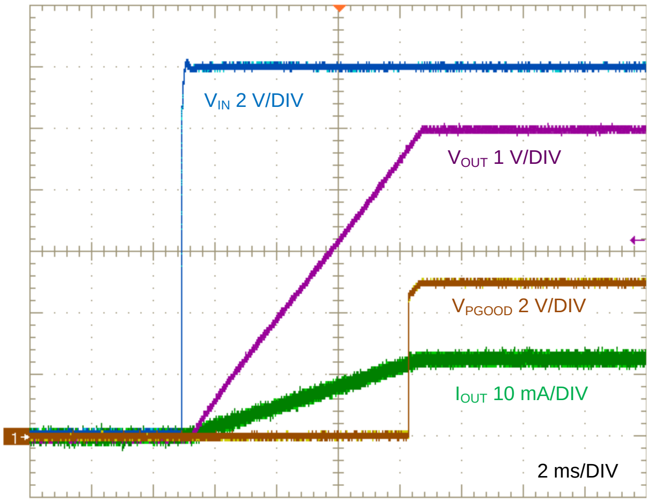
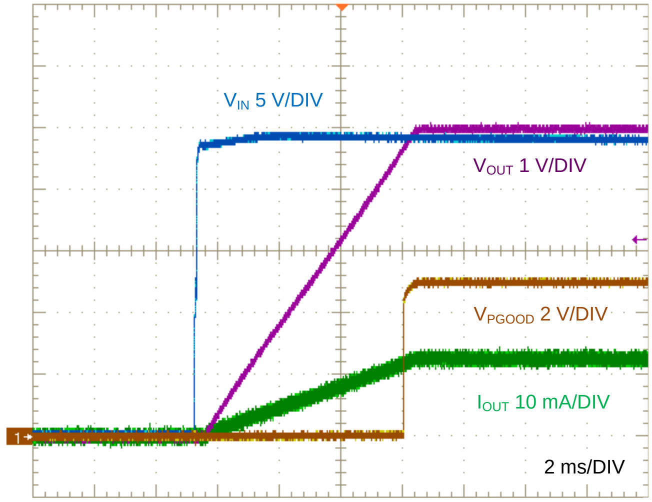


Figure 7. SW Node, V_{OUT} and I_L Waveforms at I_{OUT} = 25 mA: (a) V_{IN} = 24 V, (b) V_{IN} = 24 V, (c) V_{IN} = 36 V, (d) V_{IN} = 65 V

6.2.2 Startup



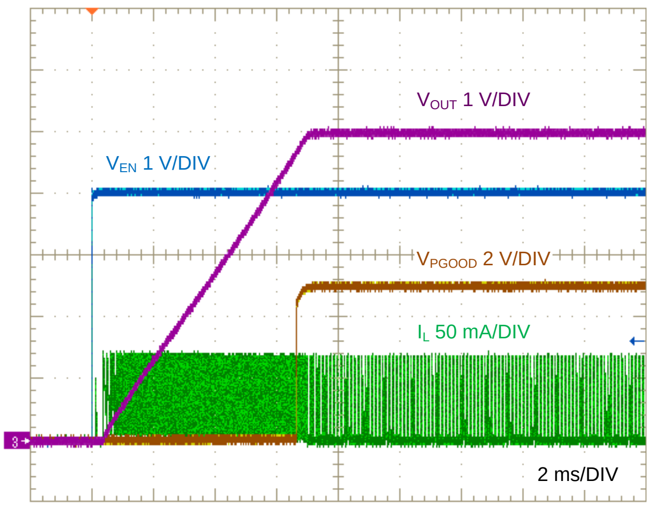
(a)



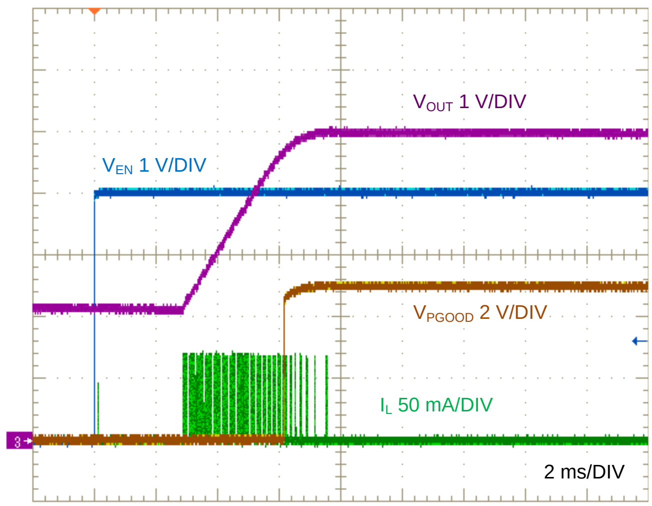
(b)

Figure 8. Startup at I_{OUT} = 12.5 mA: (a) V_{IN} = 12 V, (b) V_{IN} = 24 V

6.2.3 Enable ON



(a)



(b)

Figure 9. Enable ON at V_{IN} = 24 V: (a) I_{OUT} = 12.5 mA, (b) No Load, 2-V Output Pre-bias

6.2.4 Short Circuit Recovery

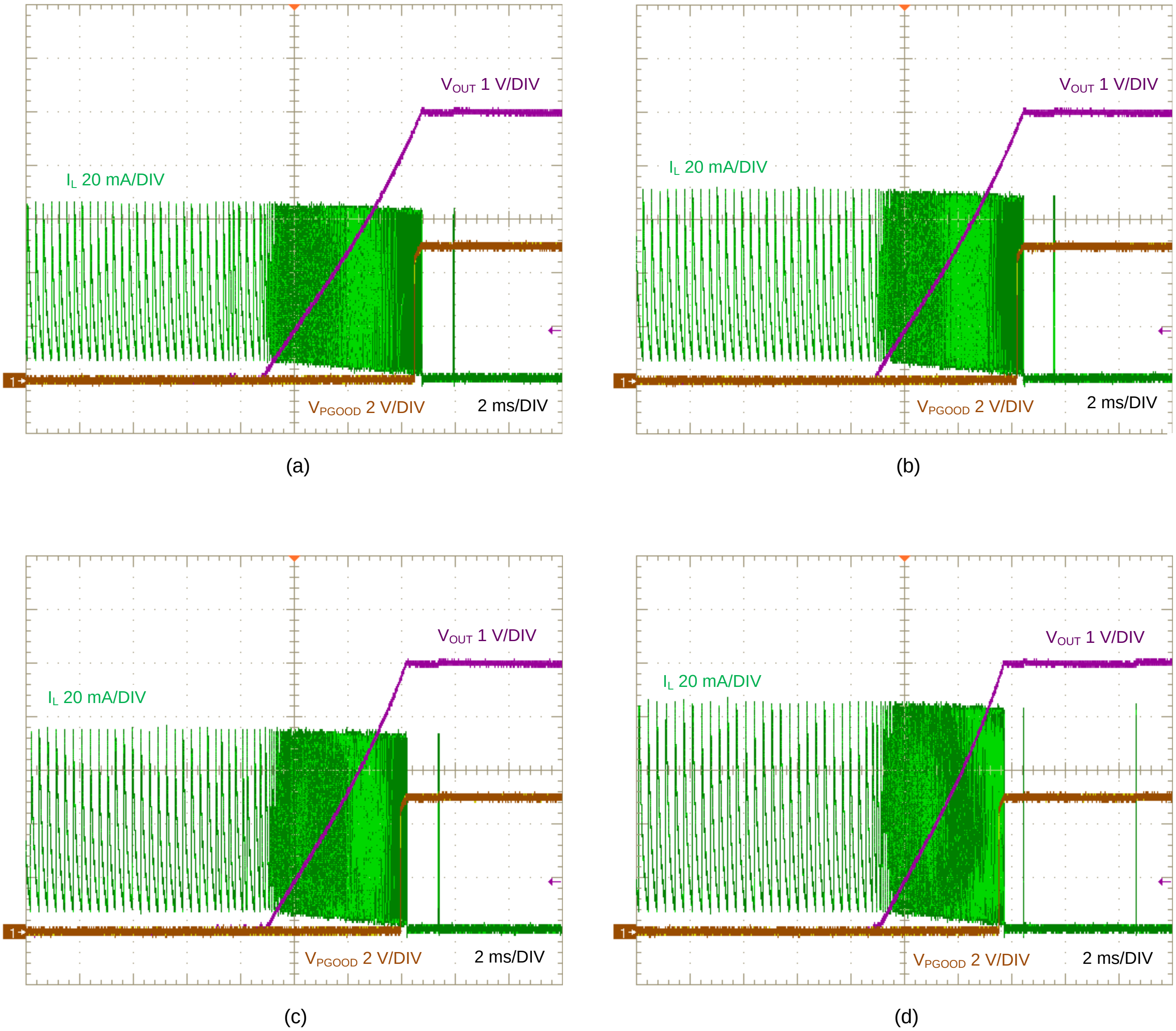
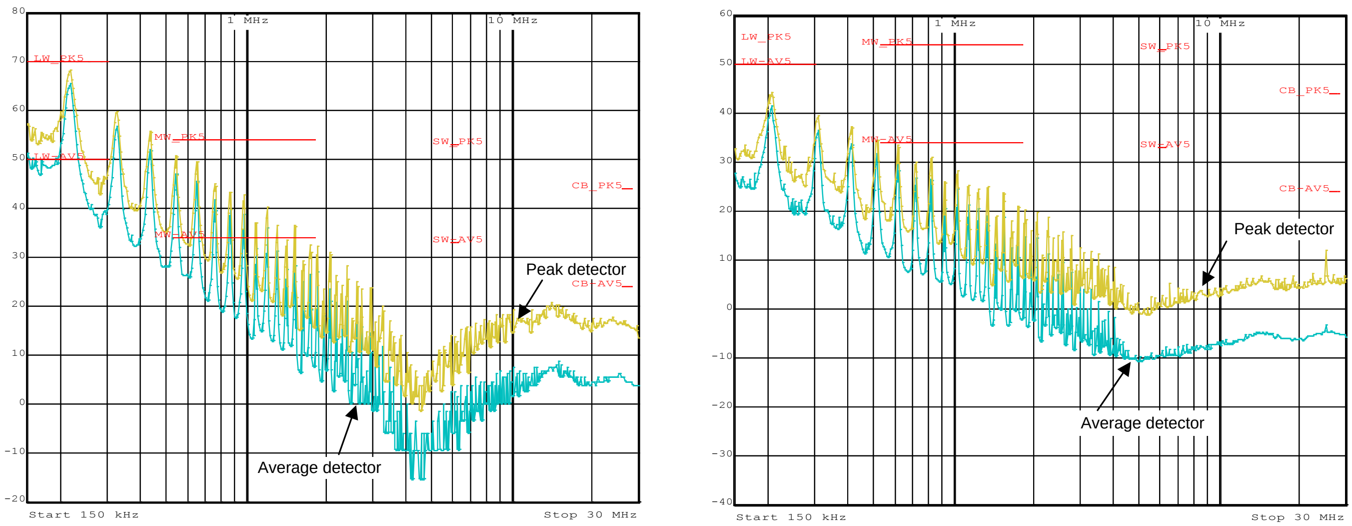


Figure 10. Short Circuit Recovery into No Load: (a) V_{IN} = 12 V, (b) V_{IN} = 24 V, (c) V_{IN} = 36 V, (d) V_{IN} = 65 V

6.3 EMI Performance

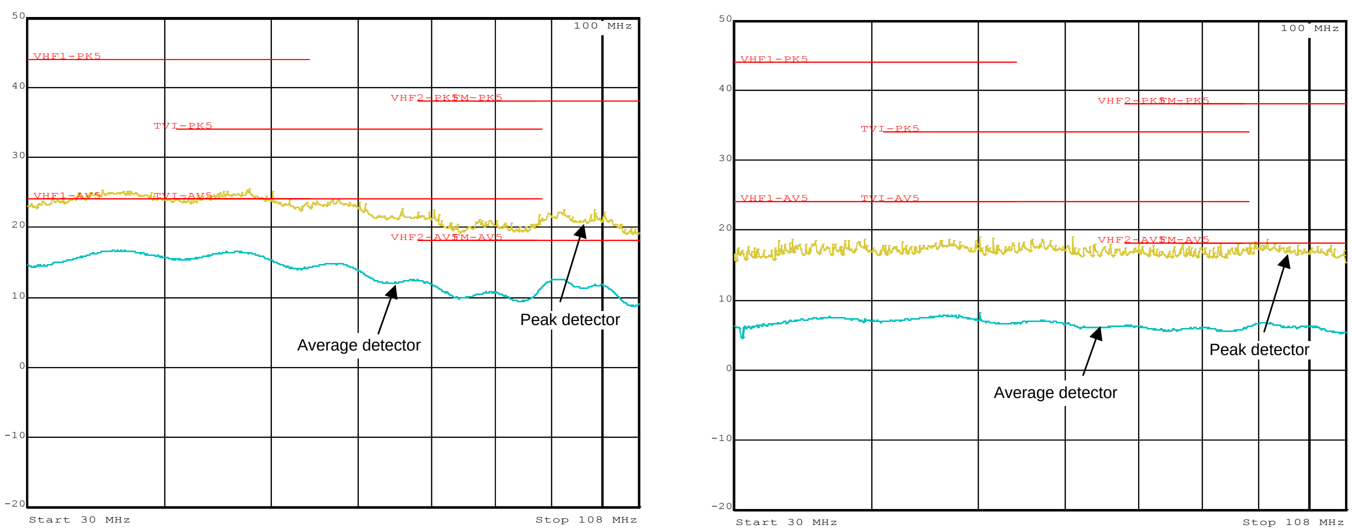
Figure 11 represents the LM5165 PFM converter's EMI performance for conducted emissions over a frequency range of 150 kHz to 30 MHz. Figure 12 shows the measurement over a frequency range of 30 MHz to 108 MHz. CISPR 25 class 5 peak and average limits are denoted in red. The yellow and blue spectra are measured using peak and average detection settings, respectively.

The EMI input filter is simply a series resistance of 110 Ω together with the on-board capacitance of two 1 µF (100 V, X7R, 1206 ceramic) capacitors.



(a) (b)

Figure 11. CISPR 25 Class 5 Conducted Emissions Plot, 150 kHz to 30 MHz, V_{IN} = 13.5 V, I_{OUT} = 25 mA: (a) Unfiltered, (b) Filtered



(a) (b)

Figure 12. CISPR 25 Class 5 Conducted Emissions Plot, 30 MHz to 108 MHz, V_{IN} = 13.5 V, I_{OUT} = 25 mA: (a) Unfiltered, (b) Filtered

7 EVM Documentation

7.1 Schematic

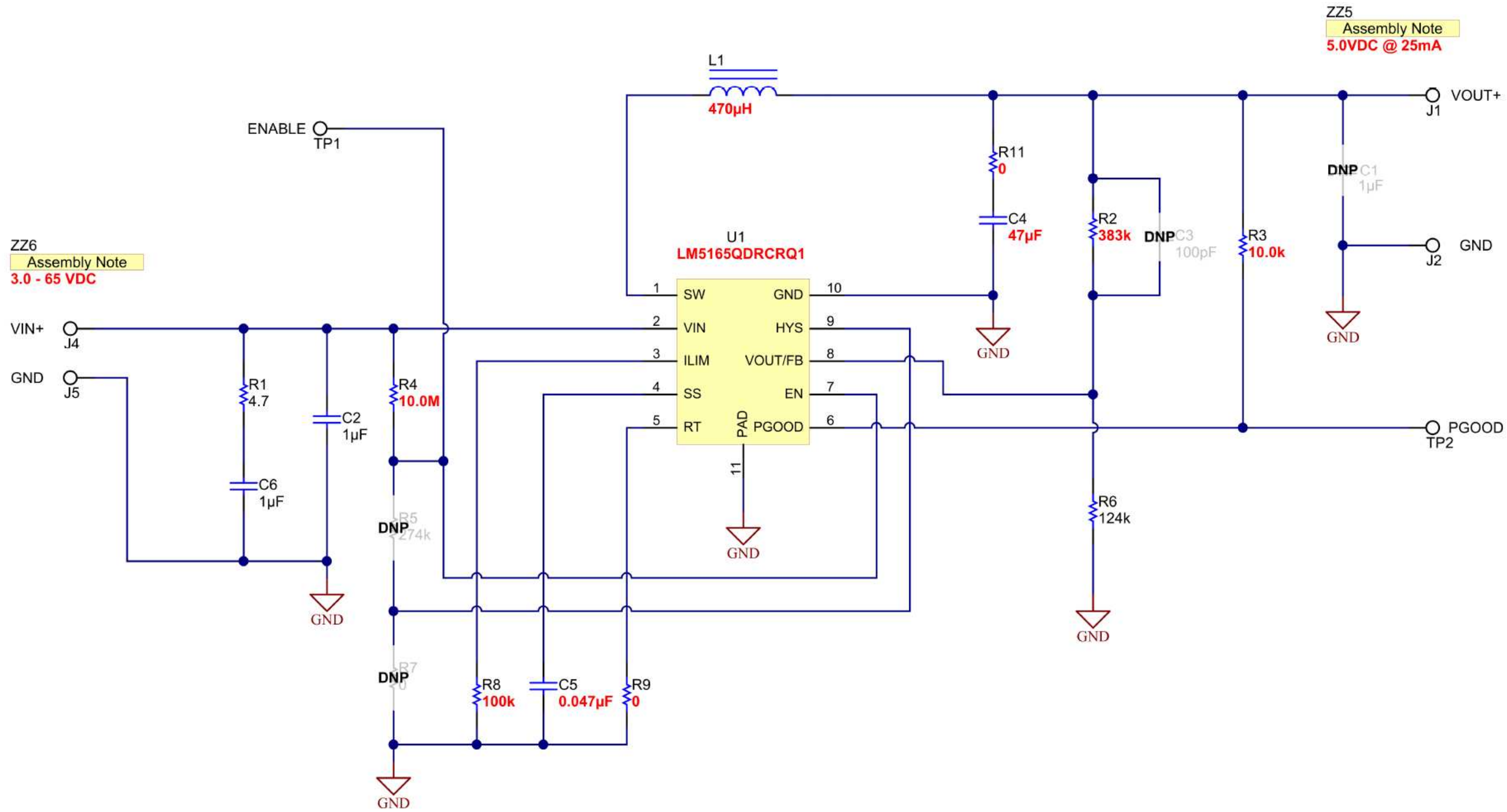


Figure 13. 5V, 25mA PFM Schematic (Adjustable Output Version)

7.2 Bill of Materials

Table 3. Bill of Materials (PFM, 5 V, 25 mA, Adjustable Output Version)

Count	Ref Des	Description	Part Number	MFR
2	C2, C6	Capacitor, Ceramic, 1µF, 100V, X7R, 1206	C3216X7R2A105K160AA	TDK
		Capacitor, Ceramic, 1µF, 100V, X7R, 1206, AEC-Q200	CGA5L2X7R2A105K	TDK
1	C4	Capacitor, Ceramic, 47µF, 6.3V, X7R, 1206	LMK316BJ476ML-T	Taiyo Yuden
		Capacitor, Ceramic, 47µF, 10V, X5R, 1206	C1206C476M8PACTU	Kemet
			GRM31CR61A476ME15L	Murata
1	C5	Capacitor, Ceramic, 47nF, 16V, X7R, 10%, 0402	Std	Std
1	L1	Inductor, 470µH, 2.8Ω max DCR, 146mA Isat, 3.0mm max	LPS5030-474MLD	Coilcraft
		Inductor, 470µH, 2.6Ω max DCR, 125mA Isat, 3.0mm max	WE-TPC 4828 744043471	Würth
		Inductor, 470µH, 3.1Ω max DCR, 140mA Isat, 2.8mm max	VLCF5028T-471MR14-2	TDK
		Inductor, 470µH, 2.6Ω max DCR, 155mA Isat, 3.0mm max	SRR4028-471Y	Bourns
1	R1	Resistor, Chip, 4.7Ω, 1/8W, 1%, 0805	Std	Std
1	R2	Resistor, Chip, 383kΩ, 1/16W, 1%, 0402	Std	Std
1	R3	Resistor, Chip, 10kΩ, 1/16W, 1%, 0402	Std	Std
1	R4	Resistor, Chip, 10MΩ, 1/16W, 1%, 0402	Std	Std
2	R6, R8	Resistor, Chip, 124kΩ, 1/16W, 1%, 0402	Std	Std
2	R9, R11	Resistor, Chip, 0Ω, 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	–
6	VIN, VOUT, GND (x2), ENABLE, PGOOD	Connector, SMT	5015	Keystone

7.3 PCB Layout

Figure 14 through Figure 19 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).

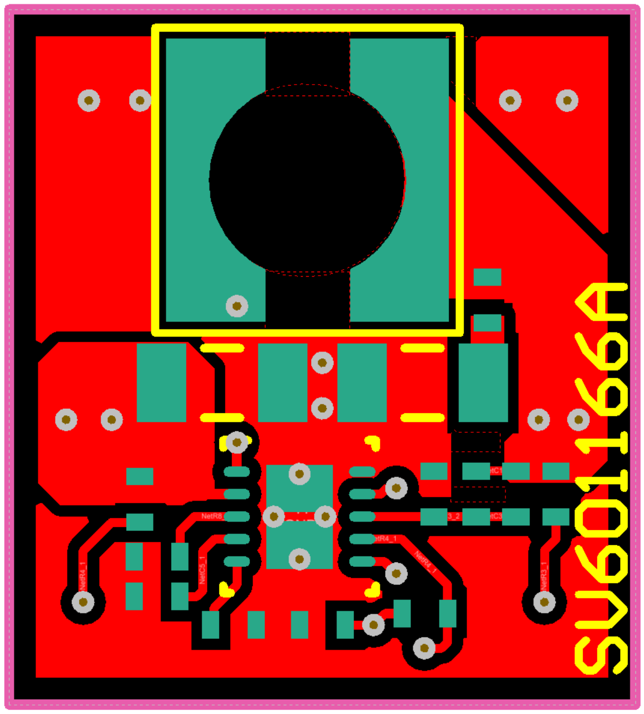


Figure 14. Top Copper (Top View)

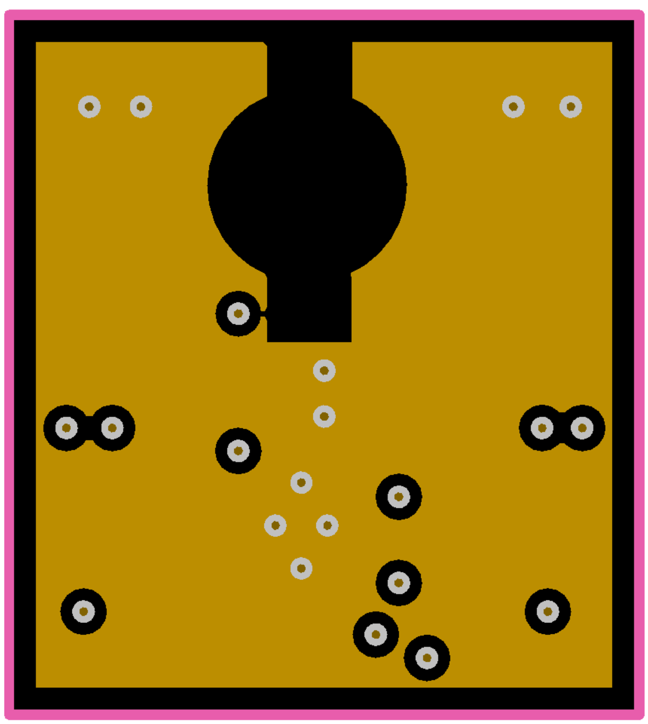


Figure 15. Layer 2 (Top View)

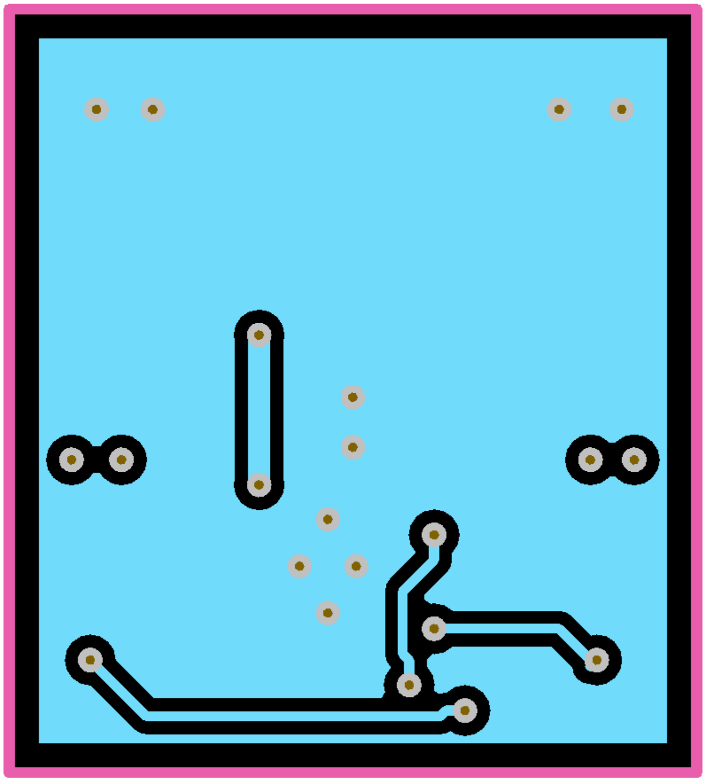


Figure 16. Layer 3 (Top View)

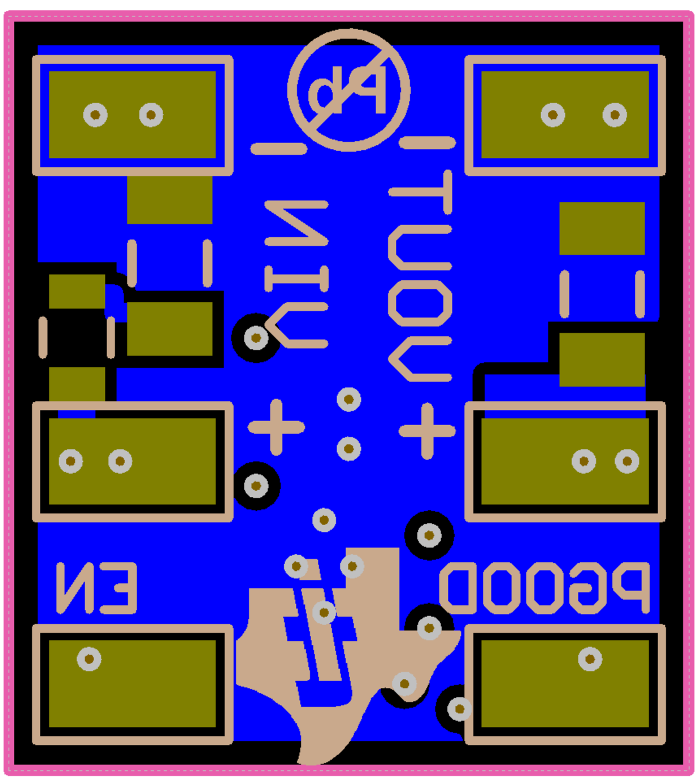


Figure 17. Bottom Copper (Bottom View)

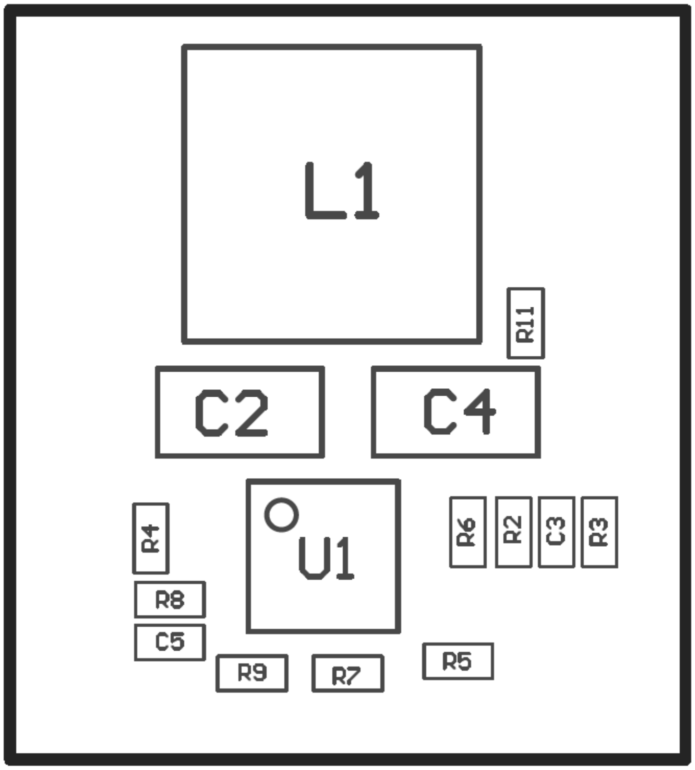


Figure 18. Top Assembly

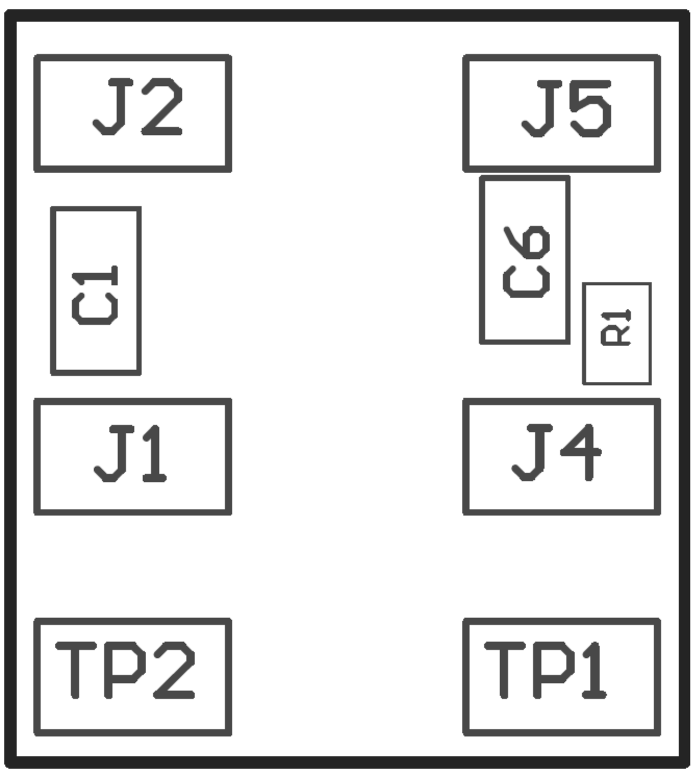


Figure 19. Bottom Assembly

8 Reference Designs

Shown below are several designs that can be realized on the same PCB as that used for this EVM. The reader is also encouraged to review the *LM5165EVM-HD-C50X EVM User's Guide*, SNVU511.

8.1 Schematics

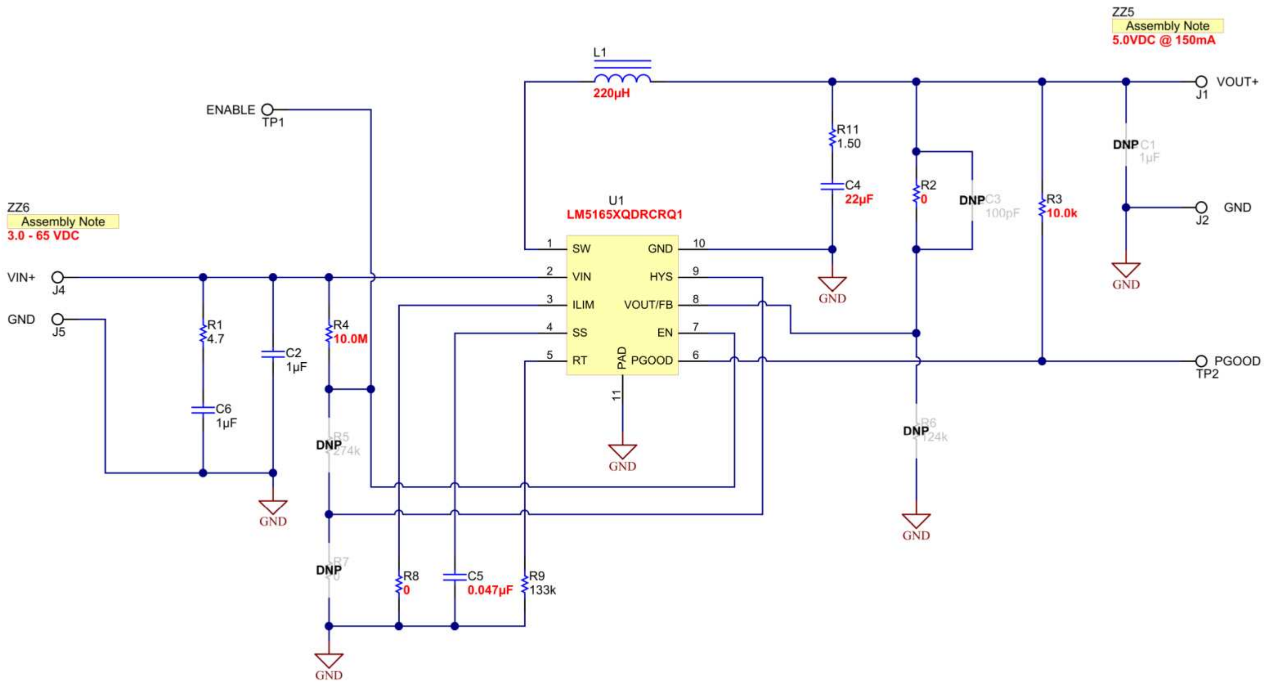


Figure 20. COT, 5V, 150mA Schematic (Fixed 5V Output Version)

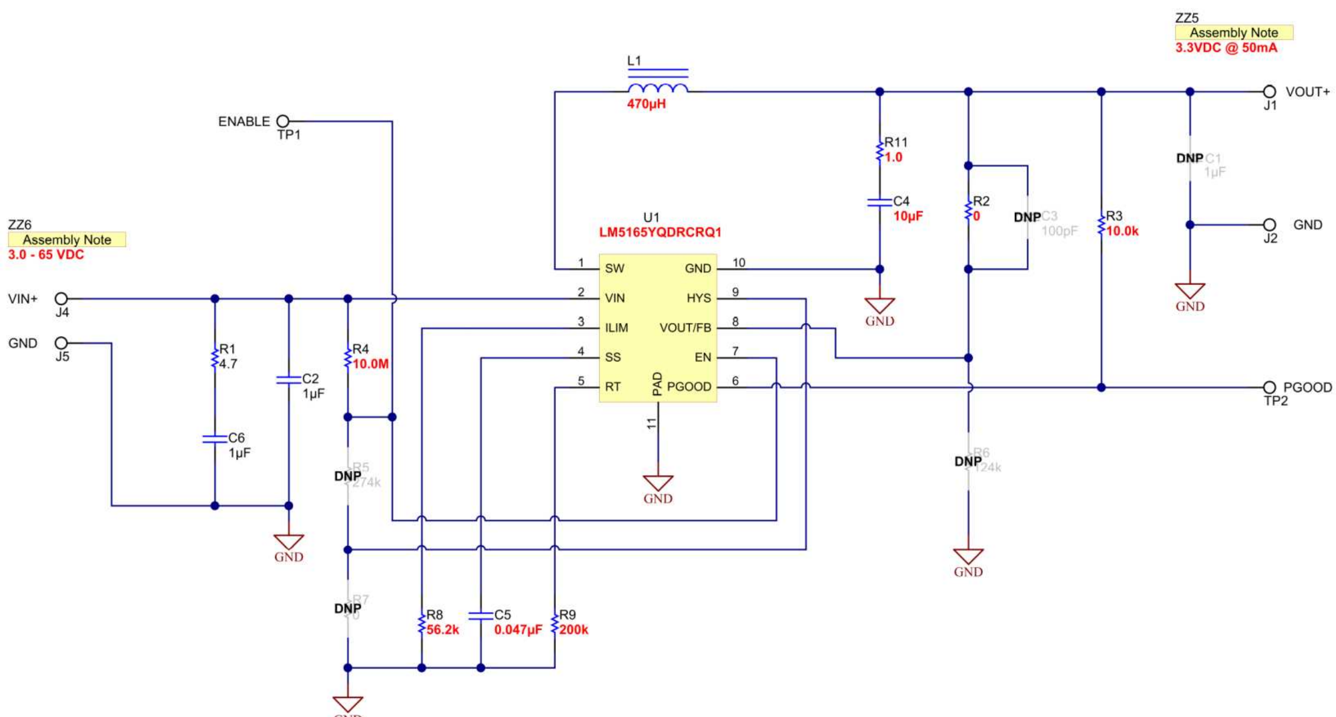


Figure 21. COT, 3.3V, 50mA Schematic (Fixed 3.3V Output Version)

8.2 Bill of Materials

8.2.1 Bill of Materials – COT Converters

Table 4. Bill of Materials (COT, 5 V, 150 mA, Fixed Output Version)

Count	Ref Des	Description	Part Number	MFR
2	C2, C6	Capacitor, Ceramic, 1µF, 100V, X7R, 1206, AEC-Q200	HMJ316BB7105KLHT	Taiyo Yuden
		Capacitor, Ceramic, 1µF, 100V, X7R, 1206	GRM31CR72A105KA01L	Murata
1	C4	Capacitor, Ceramic, 22µF, 10V, X7R, 1206, AEC-Q200	LMJ316BB7226KLHT	Taiyo Yuden
		Capacitor, Ceramic, 22µF, 10V, X7R, 1206	C1206C226K8RAC7800	Kemet
			GRM31CR71A226KE15L	Murata
1	C5	Capacitor, Ceramic, 47nF, 16V, X7R, 10%, 0402	Std	Std
1	L1	Inductor, 220µH, 0.92Ω typ, 0.29A Isat, 3.0mm max	WE-TPC 5828 744053221	Würth
		Inductor, 220µH, 0.85Ω typ, 0.75A Isat, 4.5mm max	WE-LQS 74404064221	Würth
		Inductor, 220µH, 0.87Ω max, 0.328A Isat, 4.5mm max	VLS6045EX-221M	TDK
		Inductor, 220µH, 1.25Ω max, 0.3A Isat, 3.0mm max	SRR5028-221Y	Bourns
		Inductor, 220µH, 0.83Ω typ, 0.7A Isat, 4.5mm max, AEC-Q200	TYS6045221M-10	Laird
1	R1	Resistor, Chip, 4.7Ω, 1/8W, 1%, 0805	Std	Std
1	R3	Resistor, Chip, 10kΩ, 1/16W, 1%, 0402	Std	Std
1	R4	Resistor, Chip, 10MΩ, 1/16W, 1%, 0402	Std	Std
1	R9	Resistor, Chip, 133kΩ, 1/16W, 1%, 0402	Std	Std
1	R11	Resistor, Chip, 1.5Ω, 1/16W, 1%, 0402	Std	Std
2	R2, R8	Resistor, Chip, 0Ω, 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	–

Table 5. Bill of Materials (COT, 3.3 V, 50 mA, Fixed Output Version)

Count	Ref Des	Description	Part Number	MFR
2	C2, C6	Capacitor, Ceramic, 1µF, 100V, X7R, 1206, AEC-Q200	HMJ316BB7105KLHT	Taiyo Yuden
			CGA5L2X7R2A105K	TDK
			GCM31CR72A105KA03L	Murata
1	C4	Capacitor, Ceramic, 10µF, 6.3V, X7R, 1206, AEC-Q200	CGA5L1X7R1E106K160AC	TDK
			C1206C106K4RACAUTO	Kemet
1	C5	Capacitor, Ceramic, 22nF, 16V, X7R, 10%, 0402	Std	Std
1	L1	Inductor, 470µH, 2.8Ω max, 0.146A Isat, 3.0mm max	LPS5030-474MLD	Coilcraft
		Inductor, 470µH, 2.6Ω max, 0.125A Isat, 3.0mm max	WE-TPC 4828 744043471	Würth
1	R1	Resistor, Chip, 4.7Ω, 1/8W, 1%, 0805	Std	Std
2	R2	Resistor, Chip, 0Ω, 1/16W, 5%, 0402	Std	Std
1	R3	Resistor, Chip, 10kΩ, 1/16W, 1%, 0402	Std	Std
1	R4	Resistor, Chip, 10MΩ, 1/16W, 1%, 0402	Std	Std
1	R8	Resistor, Chip, 56.2kΩ, 1/16W, 1%, 0402	Std	Std
1	R9	Resistor, Chip, 200kΩ, 1/16W, 1%, 0402	Std	Std
1	R11	Resistor, Chip, 1.0Ω, 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 6. Bill of Materials (COT, 12 V, 100 mA, Adjustable Output Version)

Count	Ref Des	Description	Part Number	MFR
2	C2, C6	Capacitor, Ceramic, 1µF, 100V, X7R, 1206	GRM31CR72A105KA01L	Murata
		Capacitor, Ceramic, 1µF, 100V, X7R, 1206, AEC-Q200	HMJ316BB7105KLHT	Taiyo Yuden
			CGA5L2X7R2A105K	TDK
1	C4	Capacitor, Ceramic, 22µF, 16V, X7R, 1206	EMK316BB7226KML-T	Taiyo Yuden
		Capacitor, Ceramic, 10µF, 25V, X7R, 1206, AEC-Q200	CGA5L1X7R1E106K160AC	TDK
			TMK316AB7106KLHT	Taiyo Yuden
1	C5	Capacitor, Ceramic, 47nF, 16V, X7R, 10%, 0402	Std	Std
1	L1	Inductor, 470µH, 1.6Ω max, 0.26A Isat, 3.5mm max	LPS6235-474MRD	Coilcraft
		Inductor, 470µH, 1.56Ω max, 0.28A Isat, 4.8mm max, AEC-Q200	CLF6045NIT-470M-D	TDK
1	R1	Resistor, Chip, 4.7Ω, 1/8W, 1%, 0805	Std	Std
2	R2, R4	Resistor, Chip, 1MΩ, 1/16W, 1%, 0402	Std	Std
1	R3	Resistor, Chip, 10kΩ, 1/16W, 1%, 0402	Std	Std
1	R6	Resistor, Chip, 113kΩ, 1/16W, 1%, 0402	Std	Std
1	R8	Resistor, Chip, 0Ω, 1/16W, 5%, 0402	Std	Std
1	R9	Resistor, Chip, 261kΩ, 1/16W, 1%, 0402	Std	Std
1	R11	Resistor, Chip, 4.7Ω, 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 Converter

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, 1µF, 100V, X7S, 0805	C2012X7S2A105K125AB	TDK
			GRJ21BC72A105KE11L	Murata
		Capacitor, Ceramic, 1µF, 100V, X7S, 0805, AEC-Q200	CGA4J3X7S2A105K125AE	TDK
1	C4	Capacitor, Ceramic, 10µF, 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, 47µH, 0.65Ω max, 0.55A Isat, 1.8mm max, AEC-Q200	LPS4018-473MRD	Coilcraft
		Inductor, 47µH, 0.62Ω typ DCR, 0.7A Isat, 1.8mm max	WE-LQS 4018 74404042470	Würth
		Inductor, 47µH, 1.05Ω typ 0.41A Isat, 1.5mm max	WE-LQS 3015 74404032470	Würth
		Inductor, 47µH, 0.65Ω typ, 0.57A Isat, 1.8mm max, AEC-Q200	TYS4018470M-10	Laird
		Inductor, 47µH, 0.65Ω typ, 0.6A Isat, 1.8mm max, AEC-Q200	NRS4018T470M	Taiyo Yuden
		Inductor, 47µH, 0.78Ω max, 0.62A Isat, 1.8mm max	SRN4018-470M	Bourns
		Inductor, 47µH, 0.66Ω max, 0.2A Isat, 2.0mm max	CDRH2D18/LDNP-470NC	Sumida
		Inductor, 47µH, 0.594Ω max, 0.48A Isat, 1.9mm max	IFSC1515AHER470M01	Vishay Dale
		Inductor, 47µH, 0.871Ω max, 0.39A Isat, 2.7mm max	CBC3225T470KRV	Taiyo Yuden
1	R1	Resistor, Chip, 4.7Ω, 1/8W, 1%, 0805	Std	Std
3	R2, R9, R11	Resistor, Chip, 0Ω, 1/16W, 5%, 0402	Std	Std
1	R3	Resistor, Chip, 10kΩ, 1/16W, 1%, 0402	Std	Std
1	R4	Resistor, Chip, 10MΩ, 1/16W, 1%, 0402	Std	Std
1	R8	Resistor, Chip, 56.2kΩ, 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	–
6	VIN, VOUT, GND (2), ENABLE, PGOOD	Connector, SMT	5015	Keystone

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-C50X EVM User's Guide*, SNVU511
- *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. *Delivery:* TI delivers TI evaluation boards, kits, or modules, including any accompanying demonstration software, components, or documentation (collectively, an “EVM” or “EVMs”) to the User (“User”) in accordance with the terms and conditions set forth herein. Acceptance of the EVM is expressly subject to the following terms and conditions.

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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/lsds/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/lsds/ti_ja/general/eStore/notice_01.page

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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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4.2 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.

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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.

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