

# LM5166EVM-C50A Evaluation Module

## User's Guide



Literature Number: SNVU485  
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|          |                                         |           |
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## **LM5166EVM-C50A User's Guide**

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The LM5166EVM-C50A evaluation module (EVM) is designed to showcase the performance and all features of the LM5166, wide-VIN, synchronous buck DC/DC buck converter with ultra-low no-load supply current. The 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 LM5166's constant-on-time (COT) control scheme and diode emulation, the no-load supply current is only 14  $\mu$ A 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, over-temperature protection, configurable soft-start, 1.22-V precision enable threshold, and open-drain PGOOD flag. With AEC-Q100 Q1 grade automotive qualification, the LM5166 is rated to operate over a junction temperature range of  $-40^{\circ}\text{C}$  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 module 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 LM5166 is available in VSON-10 PowerPAD™ package with 3 x 3-mm<sup>2</sup> body size to enable high density, low component count DC/DC solutions. Please consult the LM5166 datasheet for more information. The LM5166 is supported by [WEBENCH®](#) Designer and numerous SPICE simulation models. Furthermore, the reader can avail of the [LM5166 Quick-Start Design Tool](#) to optimize component selection and examine predicted efficiency performance across wide line and load ranges.

## **1 EVM Description**

The LM5166EVM-C50A EVM is designed to use a regulated or non-regulated high-voltage input rail (3.0 V to 65 V) to produce a tightly regulated output voltage of 5 V at continuous current levels up to 500 mA. In particular, the current limit is set to one of two pre-defined levels to optimize inductor size and maximize efficiency. The EVM's maximum output current is configured by default to 500 mA but can be changed to 300 mA by suitable component selection.

ENABLE and PGOOD connections are provided to facilitate upstream and downstream sequencing of the LM5166-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**

- 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 with 1.5% setpoint accuracy, adjustable from 1.223 V to  $V_{IN}$
- Wide input voltage operating range of 3 V to 65 V
- Ultra-high power conversion efficiency:
  - >90% at an output voltage of 5 V and load current above 1 mA (input voltage 12 V)
- No-load supply current as low as 12  $\mu$ A
- Integrated 1- $\Omega$  PMOS buck switch supports 100% duty cycle for low dropout voltage
- Integrated 0.5- $\Omega$  NMOS synchronous rectifier eliminates external Schottky diode
- Output voltage level and inductor current limit set with the ILIM pin
- User-adjustable soft-start ramp time set to 4 ms by 33-nF capacitor at the SS pin
- ENABLE and PGOOD terminals with 10-M $\Omega$  and 10-k $\Omega$  pullups to  $V_{IN}$  and  $V_{OUT}$ , respectively
- Monotonic pre-bias output voltage startup
- Programmable input UVLO (internally set to turn on and off at 2.75 V and 2.45 V, respectively)
- Fully assembled, tested and proven PCB layout with 31.75-mm x 25.4-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            | 16    |     |     | $\mu$ A      |
|                                             |                                                                         | $V_{IN} = 24$ V            | 14    |     |     | $\mu$ A      |
|                                             |                                                                         | $V_{IN} = 65$ V            | 12    |     |     | $\mu$ A      |
| Input current, disabled, $I_{IN(OFF)}$      | $V_{ENABLE} = 0$ V                                                      | $V_{IN} = 12$ V            | 6     |     |     | $\mu$ A      |
| OUTPUT CHARACTERISTICS                      |                                                                         |                            |       |     |     |              |
| Output voltage, $V_{OUT}^{(1)}$             | $V_{OUT}$ follows $V_{IN}$ for $V_{IN} < 5$ V + $1.3\ \Omega * I_{OUT}$ |                            | 4.9   | 5.0 | 5.1 | V            |
| Output current, $I_{OUT}$                   | $V_{IN} = 3$ V to 65 V                                                  |                            | 0     |     | 500 | mA           |
| Output voltage regulation, $\Delta V_{OUT}$ | Load Regulation                                                         | $I_{OUT} = 0$ mA to 500 mA | 1%    |     |     | mVp-p        |
|                                             | Line Regulation                                                         | $V_{IN} = 6$ V to 65 V     | 1%    |     |     |              |
| Output voltage ripple, $V_{OUT(AC)}$        | $V_{IN} = 12$ V, $I_{OUT} = 250$ mA                                     |                            | 25    |     |     | mVp-p        |
| Output overcurrent protection, $I_{OCP}$    | $V_{IN} = 12$ V, ILIM setting of 750 mA                                 |                            | 750   |     |     | mA           |
| Soft-start time, $t_{SS}$                   |                                                                         |                            | 4     |     |     | ms           |
| SYSTEM CHARACTERISTICS                      |                                                                         |                            |       |     |     |              |
| Pulse switching frequency, $F_{SW(nom)}$    | $V_{IN} = 12$ V                                                         |                            | 100   |     |     | kHz          |
| Half-load efficiency, $\eta_{HALF}^{(1)}$   | $I_{OUT} = 250$ mA                                                      | $V_{IN} = 12$ V            | 93.5% |     |     |              |
| Full load efficiency, $\eta_{FULL}$         | $I_{OUT} = 500$ mA                                                      | $V_{IN} = 8$ V             | 89.7% |     |     |              |
|                                             |                                                                         | $V_{IN} = 12$ V            | 90.0% |     |     |              |
|                                             |                                                                         | $V_{IN} = 24$ V            | 89.6% |     |     |              |
|                                             |                                                                         | $V_{IN} = 36$ V            | 88.7% |     |     |              |
|                                             |                                                                         | $V_{IN} = 65$ V            | 86.0% |     |     |              |
| LM5166 junction temperature, $T_J$          |                                                                         |                            | -40   |     | 150 | $^{\circ}$ C |

<sup>(1)</sup> 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 Diagram

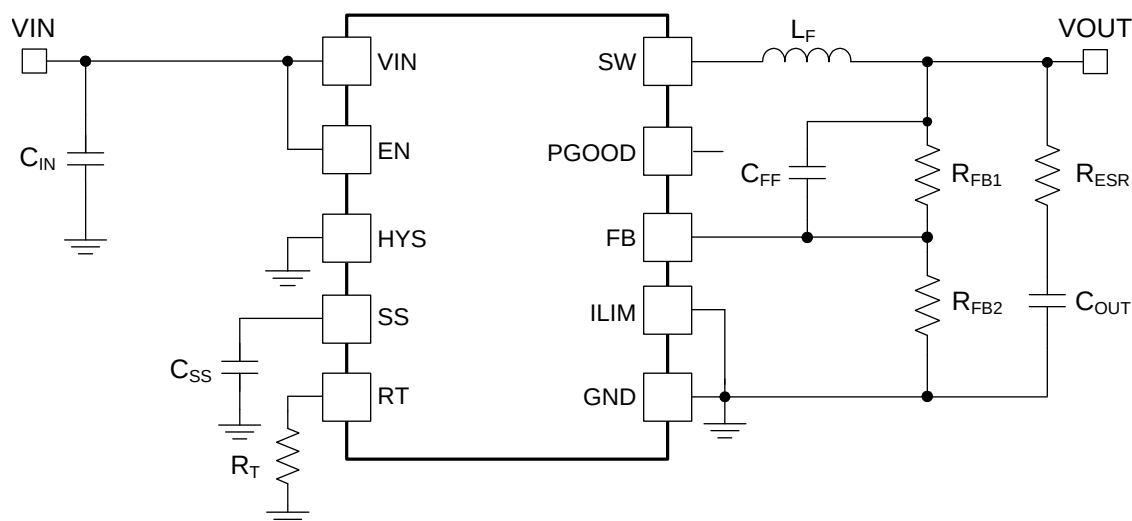


Figure 1. LM5166 Buck Converter Default Schematic: Adjustable Output COT

### 4 EVM Photo

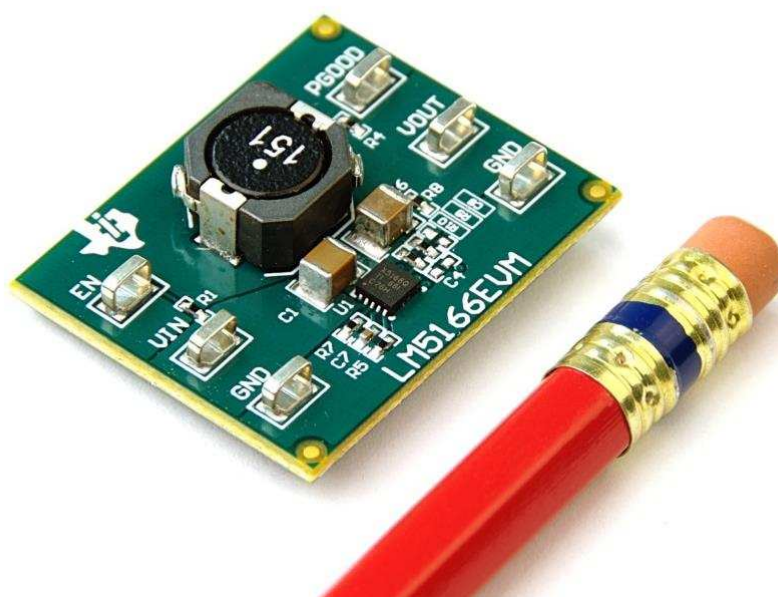


Figure 2. LM5166 EVM Photo



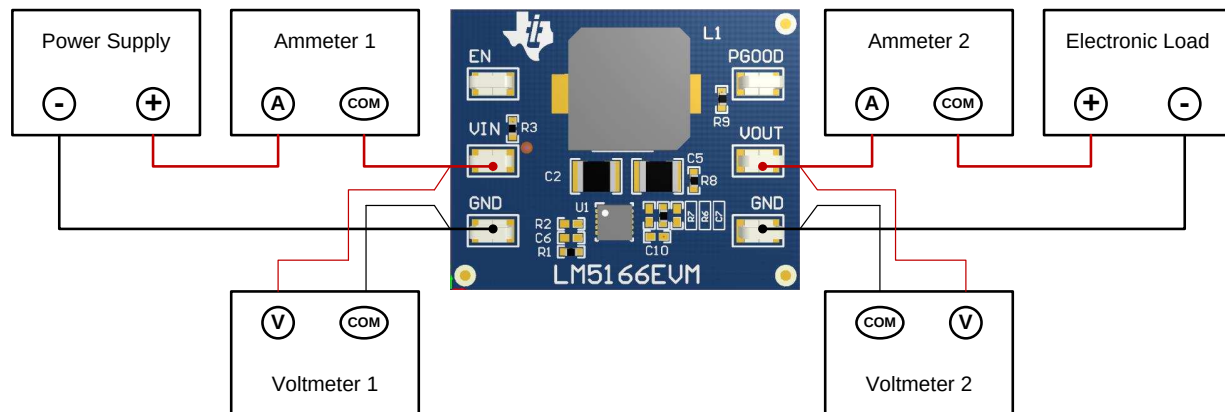
## 5 Test Setup and Procedure

### 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](#), [Figure 3](#) shows the recommended test setup to evaluate the LM5166EVM. 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 [LM5166](#) datasheet, [Quick-Start Design 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 0–70-V variable dc source capable of supplying 1A.

**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 750 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 1 A 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 (e.g. 47-μF, 100-V Electrolytic 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 500 mAdc;  $V_{OUT}$  should remain within the load regulation specification.
- Vary input source voltage from 6 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 presents typical efficiency curves for the LM5166EVM-C50A. Since actual efficiency 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

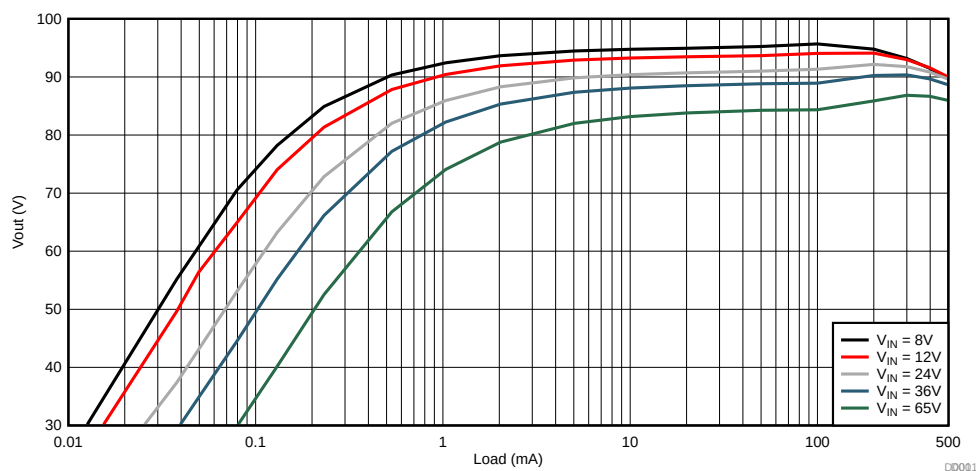


Figure 4. COT Converter Efficiency (5 V, 500 mA Output)

### 6.2 Line and Load Regulation

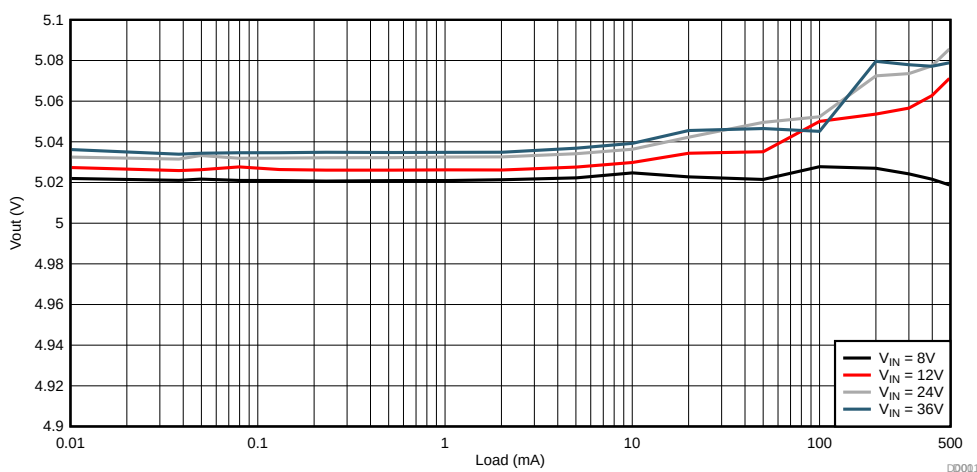
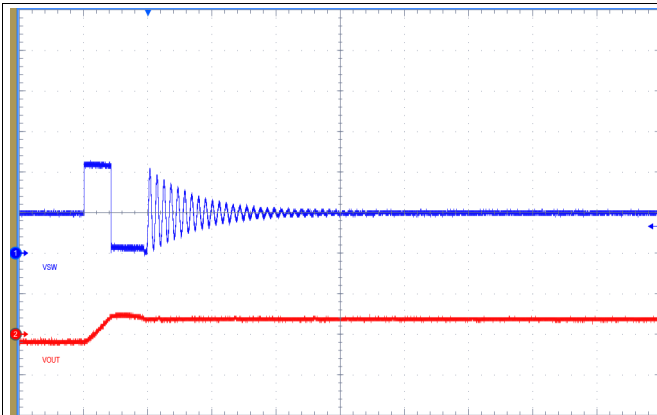


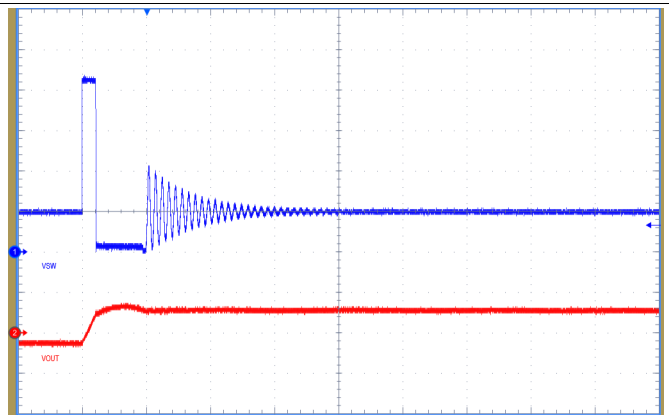
Figure 5. Line and Load Regulation

## 6.3 Operating Waveforms

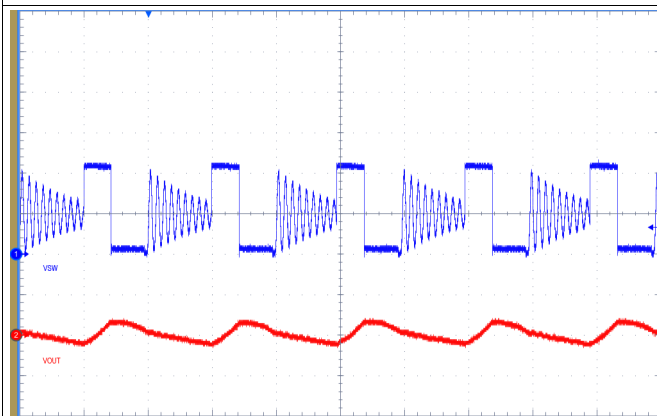
### 6.3.1 Switching



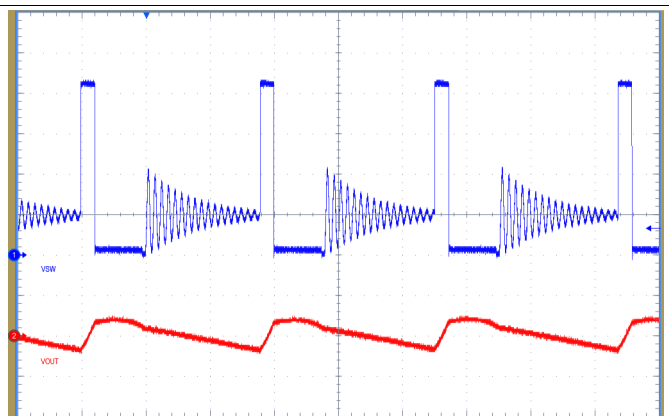
**Figure 6. COT Mode SW Node and  $V_{OUT}$  Waveforms:**  
 $V_{IN} = 12\text{ V}$ ,  $V_{OUT} = 5\text{ V}$ ,  $I_{OUT} = 0\text{ mA}$   
 (10µs/div, Ch1: SW, 5V/div; Ch2:  $V_{OUT}$ , 50mV/div)



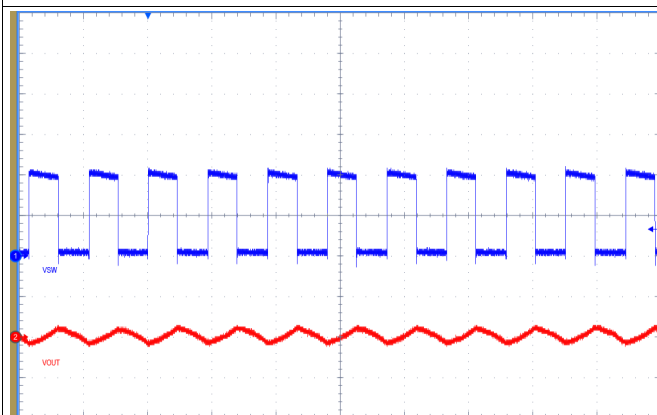
**Figure 7. COT Mode SW Node and  $V_{OUT}$  Waveforms:**  
 $V_{IN} = 24\text{ V}$ ,  $V_{OUT} = 5\text{ V}$ ,  $I_{OUT} = 0\text{ mA}$   
 (10µs/div, Ch1: SW, 5V/div; Ch2:  $V_{OUT}$ , 50mV/div)



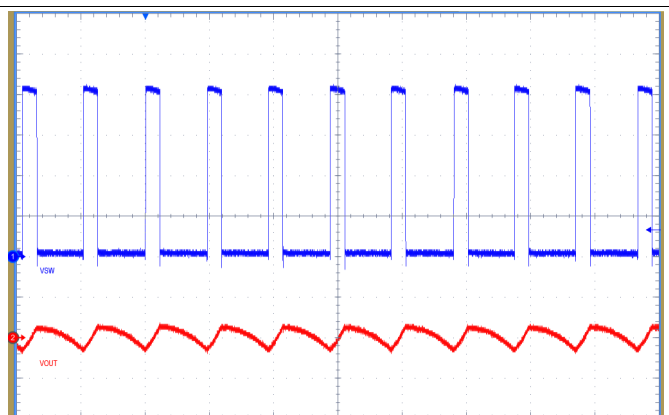
**Figure 8. COT Mode SW Node and  $V_{OUT}$  Waveforms:**  
 $V_{IN} = 12\text{ V}$ ,  $V_{OUT} = 5\text{ V}$ ,  $I_{OUT} = 50\text{ mA}$   
 (10µs/div, Ch1: SW, 5V/div; Ch2:  $V_{OUT}$ , 50mV/div)



**Figure 9. COT Mode SW Node and  $V_{OUT}$  Waveforms:**  
 $V_{IN} = 24\text{ V}$ ,  $V_{OUT} = 5\text{ V}$ ,  $I_{OUT} = 50\text{ mA}$   
 (10µs/div, Ch1: SW, 5V/div; Ch2:  $V_{OUT}$ , 50mV/div)

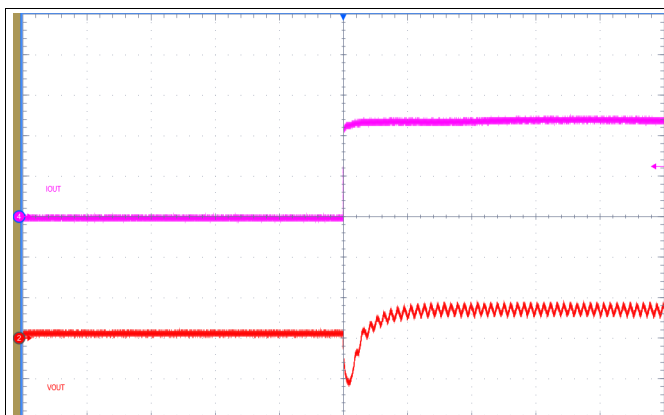


**Figure 10. COT Mode SW Node and  $V_{OUT}$  Waveforms:**  
 $V_{IN} = 12\text{ V}$ ,  $V_{OUT} = 5\text{ V}$ ,  $I_{OUT} = 500\text{ mA}$   
 (10µs/div, Ch1: SW, 5V/div; Ch2:  $V_{OUT}$ , 50mV/div)

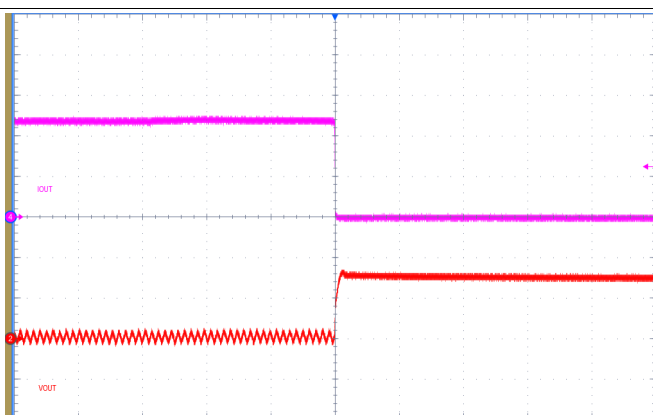


**Figure 11. COT Mode SW Node and  $V_{OUT}$  Waveforms:**  
 $V_{IN} = 24\text{ V}$ ,  $V_{OUT} = 5\text{ V}$ ,  $I_{OUT} = 500\text{ mA}$   
 (10µs/div, Ch1: SW, 5V/div; Ch2:  $V_{OUT}$ , 50mV/div)

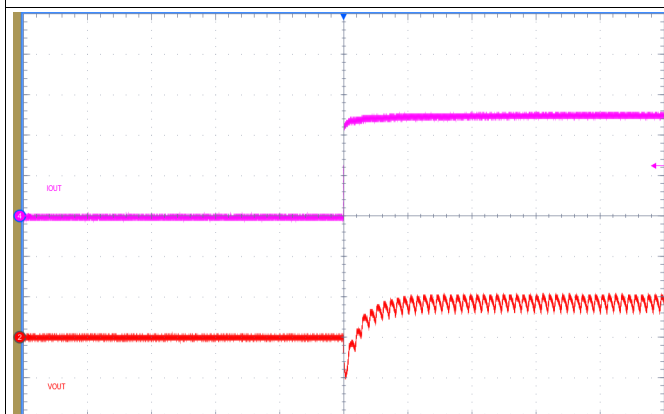
### 6.3.2 Load Transient Response



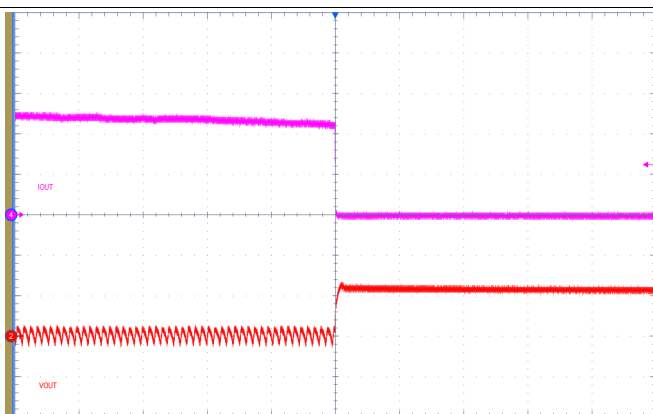
**Figure 12. Load-ON Transient Response**  
 $V_{IN} = 12\text{ V}$ ,  $V_{OUT} = 5\text{ V}$ , 0 mA to 500 mA at 2 A/ $\mu$ s  
 (100 $\mu$ s/div, Ch4:  $I_{OUT}$ , 200mA/div; Ch2:  $V_{OUT}$ , 100mV/div)



**Figure 13. Load-OFF Transient Response**  
 $V_{IN} = 12\text{ V}$ ,  $V_{OUT} = 5\text{ V}$ , 500 mA to 0 mA at 2 A/ $\mu$ s  
 (100 $\mu$ s/div, Ch4:  $I_{OUT}$ , 200mA/div; Ch2:  $V_{OUT}$ , 100mV/div)

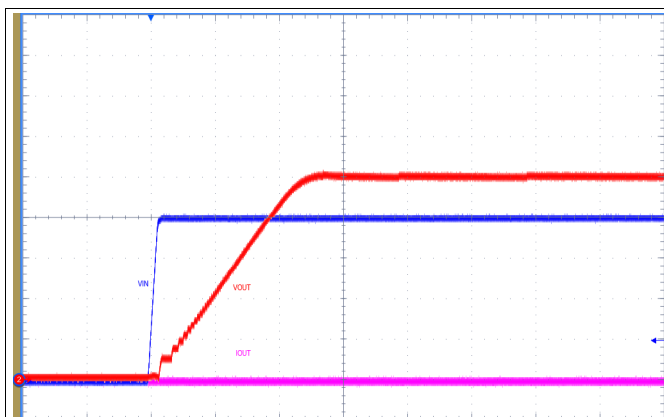


**Figure 14. Load-ON Transient Response**  
 $V_{IN} = 24\text{ V}$ ,  $V_{OUT} = 5\text{ V}$ , 0 mA to 500 mA at 2 A/ $\mu$ s  
 (100 $\mu$ s/div, Ch4:  $I_{OUT}$ , 200mA/div; Ch2:  $V_{OUT}$ , 100mV/div)

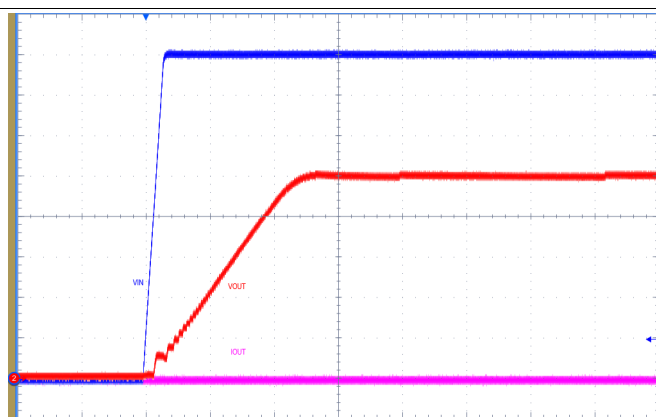


**Figure 15. Load-OFF Transient Response**  
 $V_{IN} = 24\text{ V}$ ,  $V_{OUT} = 5\text{ V}$ , 500 mA to 0 mA at 2 A/ $\mu$ s  
 (100 $\mu$ s/div, Ch4:  $I_{OUT}$ , 200mA/div; Ch2:  $V_{OUT}$ , 100mV/div)

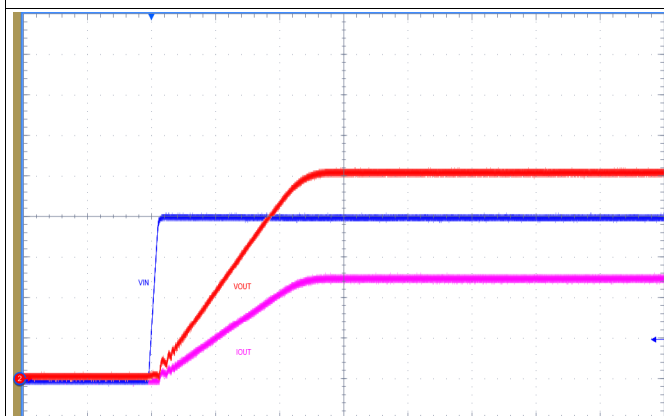
### 6.3.3 Startup



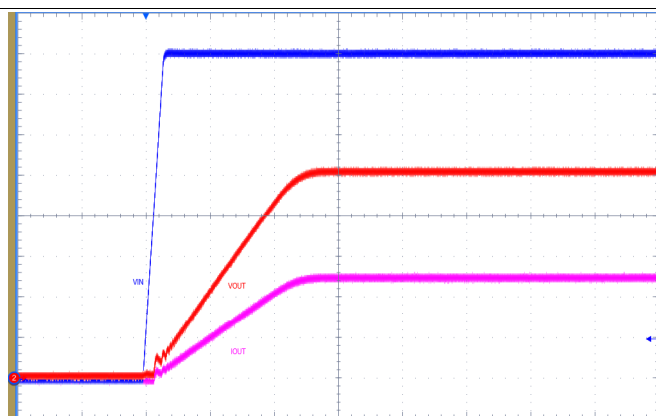
**Figure 16. Startup with  $V_{IN}$  Ramping to 12 V, No Load**  
(2ms/div, Ch1:  $V_{IN}$ , 3V/div; Ch2:  $V_{OUT}$ , 1V/div;  
Ch4:  $I_{OUT}$ , 200mA/div)



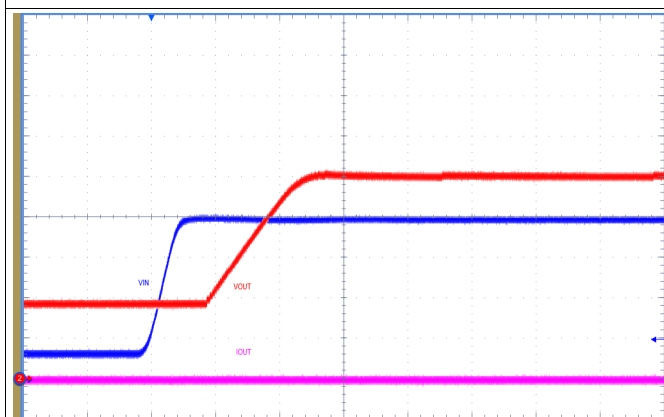
**Figure 17. Startup with  $V_{IN}$  Ramping to 24 V, No Load**  
(2ms/div, Ch1:  $V_{IN}$ , 3V/div; Ch2:  $V_{OUT}$ , 1V/div;  
Ch4:  $I_{OUT}$ , 200mA/div)



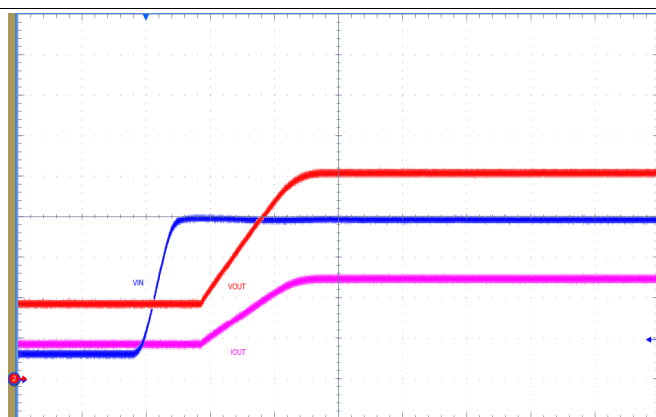
**Figure 18. Startup with  $V_{IN}$  Ramping to 12 V, 500 mA Load**  
(2ms/div, Ch1:  $V_{IN}$ , 3V/div; Ch2:  $V_{OUT}$ , 1V/div;  
Ch4:  $I_{OUT}$ , 200mA/div)



**Figure 19. Startup with  $V_{IN}$  Ramping to 24 V, 500 mA Load**  
(2ms/div, Ch1:  $V_{IN}$ , 3V/div; Ch2:  $V_{OUT}$ , 1V/div;  
Ch4:  $I_{OUT}$ , 200mA/div)

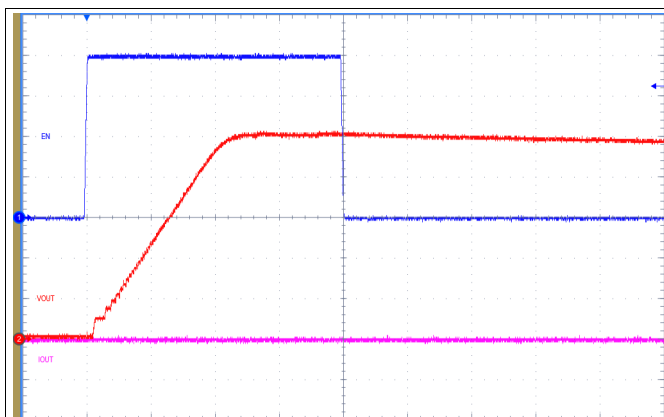


**Figure 20. Startup with  $V_{OUT}$  Pre-biased to 1.8 V;  $V_{IN}$  = 12 V, No Load**  
(2ms/div, Ch1:  $V_{IN}$ , 3V/div; Ch2:  $V_{OUT}$ , 1V/div;  
Ch4:  $I_{OUT}$ , 200mA/div)

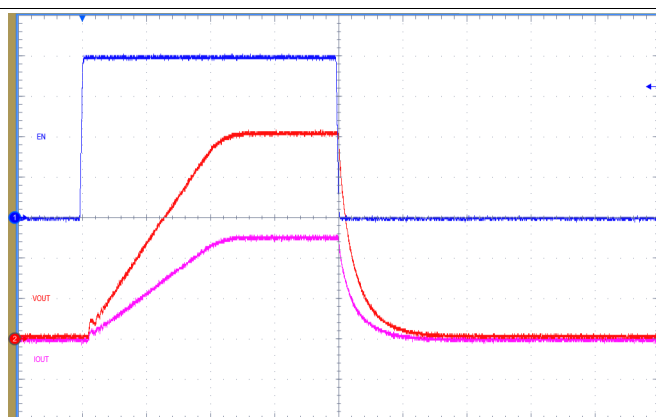


**Figure 21. Startup with  $V_{OUT}$  Pre-biased to 1.8 V;  $V_{IN}$  = 12 V, 500 mA Load**  
(2ms/div, Ch1:  $V_{IN}$ , 3V/div; Ch2:  $V_{OUT}$ , 1V/div;  
Ch4:  $I_{OUT}$ , 200mA/div)

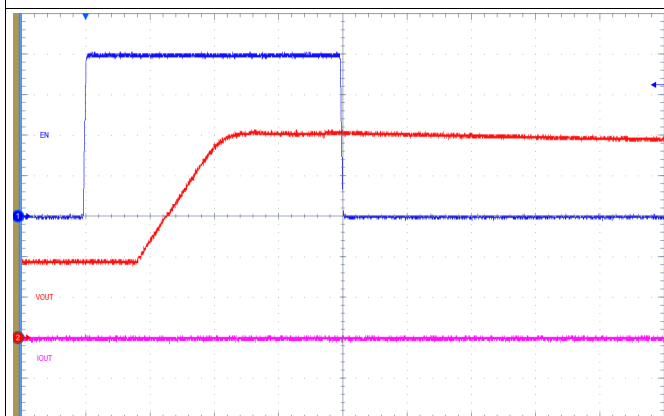
### 6.3.4 ENABLE On and Off



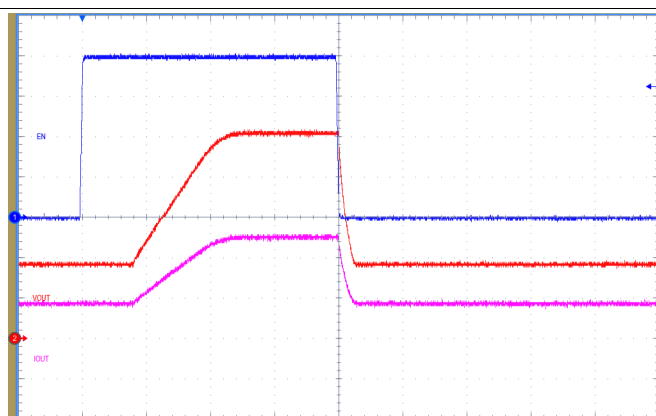
**Figure 22. ENABLE On and Off;  $V_{IN} = 24\text{ V}$ , No Load**  
(2ms/div, Ch1:  $V_{EN}$ , 1V/div; Ch2:  $V_{OUT}$ , 1V/div;  
Ch4:  $I_{OUT}$ , 200mA/div)



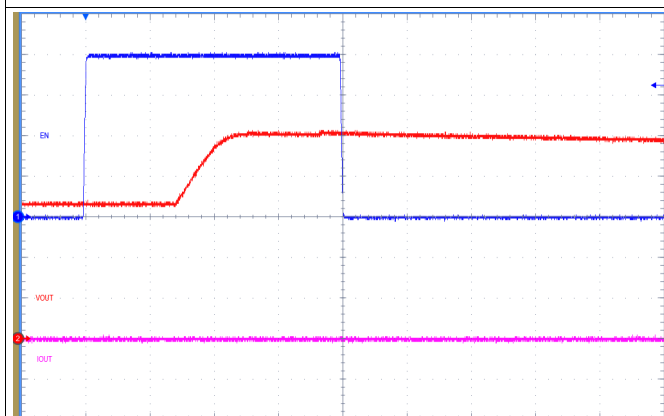
**Figure 23. ENABLE On and Off;  $V_{IN} = 24\text{ V}$ , 500 mA Load**  
(2ms/div, Ch1:  $V_{EN}$ , 1V/div; Ch2:  $V_{OUT}$ , 1V/div;  
Ch4:  $I_{OUT}$ , 200mA/div)



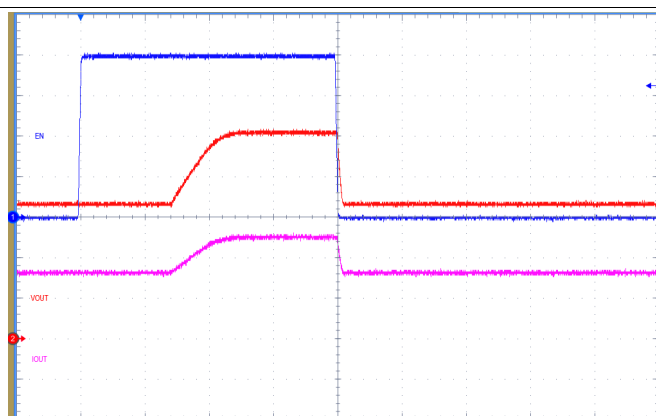
**Figure 24. ENABLE On and Off;  $V_{OUT}$  Pre-biased to 1.8V;  
 $V_{IN} = 24\text{ V}$ , No Load**  
(2ms/div, Ch1:  $V_{EN}$ , 1V/div; Ch2:  $V_{OUT}$ , 1V/div;  
Ch4:  $I_{OUT}$ , 200mA/div)



**Figure 25. ENABLE On and Off;  $V_{OUT}$  Pre-biased to 1.8V;  
 $V_{IN} = 24\text{ V}$ , 500 mA Load**  
(2ms/div, Ch1:  $V_{EN}$ , 1V/div; Ch2:  $V_{OUT}$ , 1V/div;  
Ch4:  $I_{OUT}$ , 200mA/div)

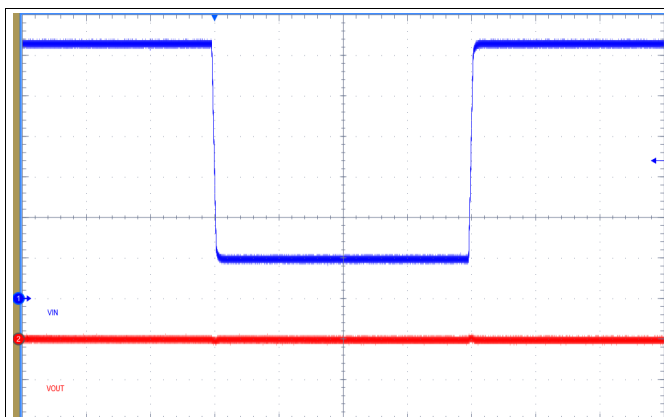


**Figure 26. ENABLE On and Off;  $V_{OUT}$  Pre-biased to 3.3V;  
 $V_{IN} = 24\text{ V}$ , No Load**  
(2ms/div, Ch1:  $V_{EN}$ , 1V/div; Ch2:  $V_{OUT}$ , 1V/div;  
Ch4:  $I_{OUT}$ , 200mA/div)

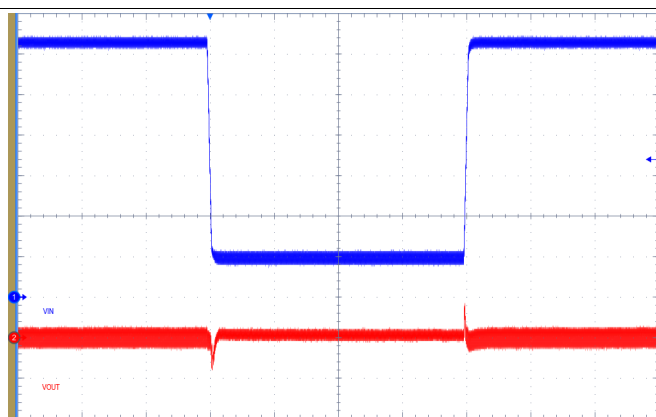


**Figure 27. ENABLE On and Off;  $V_{OUT}$  Pre-biased to 3.3V;  
 $V_{IN} = 24\text{ V}$ , 500 mA Load**  
(2ms/div, Ch1:  $V_{EN}$ , 1V/div; Ch2:  $V_{OUT}$ , 1V/div;  
Ch4:  $I_{OUT}$ , 200mA/div)

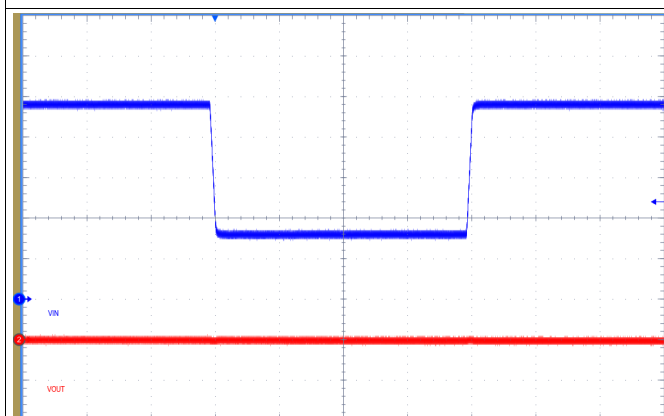
### 6.3.5 Line Transient Response



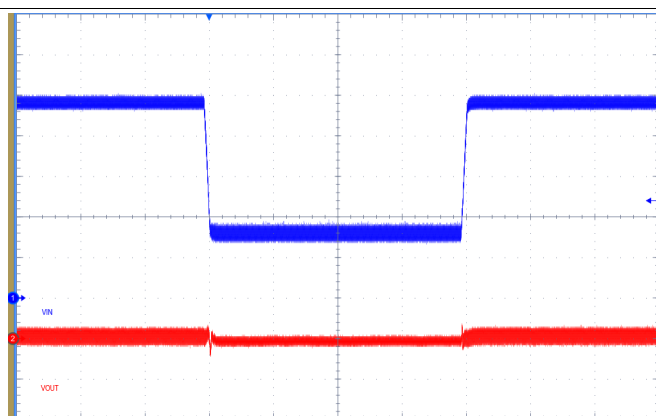
**Figure 28. Line Transient Response, No Load**  
65 V to 12 V to 65 V Transient at 1 V/μs  
(1ms/div, Ch1: V<sub>IN</sub>, 10V/div; Ch2: V<sub>OUT</sub>, 100mV/div)



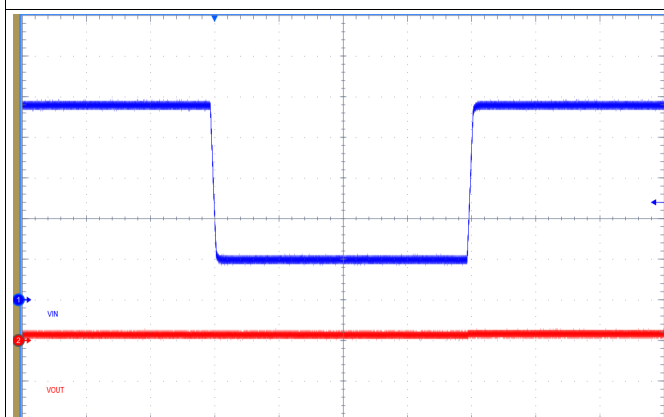
**Figure 29. Line Transient Response, 500 mA Load**  
65 V to 12 V to 65 V Transient at 1 V/μs  
(1ms/div, Ch1: V<sub>IN</sub>, 10V/div; Ch2: V<sub>OUT</sub>, 100mV/div)



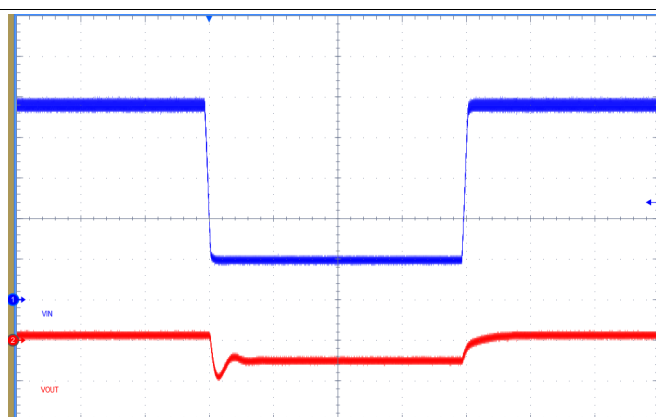
**Figure 30. Line Transient Response, No Load**  
24 V to 8 V to 24 V Transient at 0.1 V/μs  
(1ms/div, Ch1: V<sub>IN</sub>, 5V/div; Ch2: V<sub>OUT</sub>, 100mV/div)



**Figure 31. Line Transient Response, 500 mA Load**  
24 V to 8 V to 24 V Transient at 0.1 V/μs  
(1ms/div, Ch1: V<sub>IN</sub>, 5V/div; Ch2: V<sub>OUT</sub>, 100mV/div)

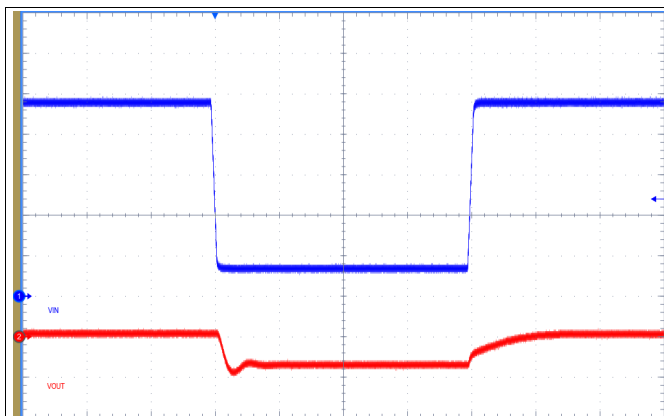


**Figure 32. Line Transient Response, No Load**  
24 V to 5 V (Dropout) to 24 V Transient at 0.1 V/μs  
(1ms/div, Ch1: V<sub>IN</sub>, 5V/div; Ch2: V<sub>OUT</sub>, 1V/div)

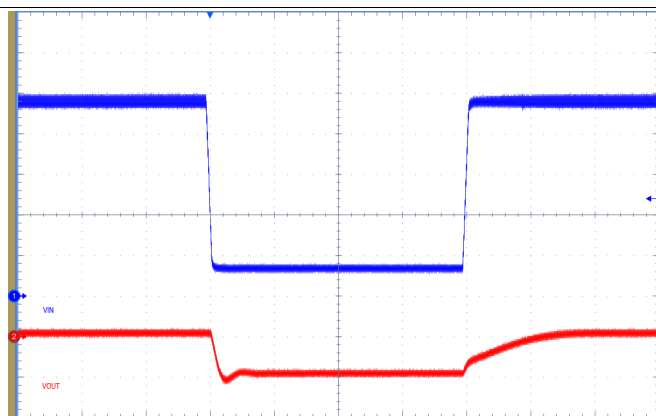


**Figure 33. Line Transient Response, 500 mA Load**  
24 V to 5 V (Dropout) to 24 V Transient at 0.1 V/μs  
(1ms/div, Ch1: V<sub>IN</sub>, 5V/div; Ch2: V<sub>OUT</sub>, 1V/div)





**Figure 34. Line Transient Response, No Load**  
24 V to 3.5 V (Dropout) to 24 V Transient at 0.1 V/μs  
(1ms/div, Ch1:  $V_{IN}$ , 5V/div; Ch2:  $V_{OUT}$ , 2V/div)

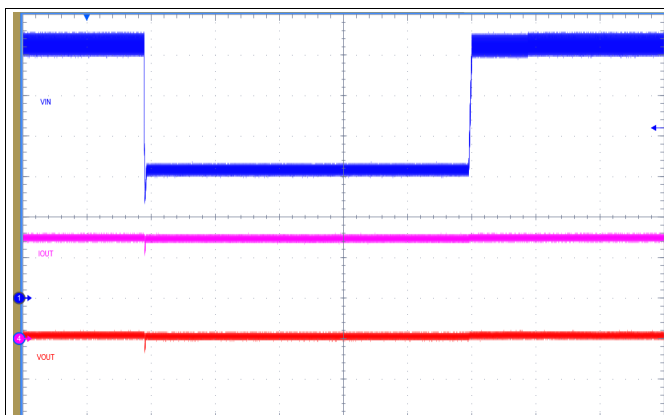


**Figure 35. Line Transient Response, 500 mA Load**  
24 V to 3.5 V (Dropout) to 24 V Transient at 0.1 V/μs  
(1ms/div, Ch1:  $V_{IN}$ , 5V/div; Ch2:  $V_{OUT}$ , 2V/div)

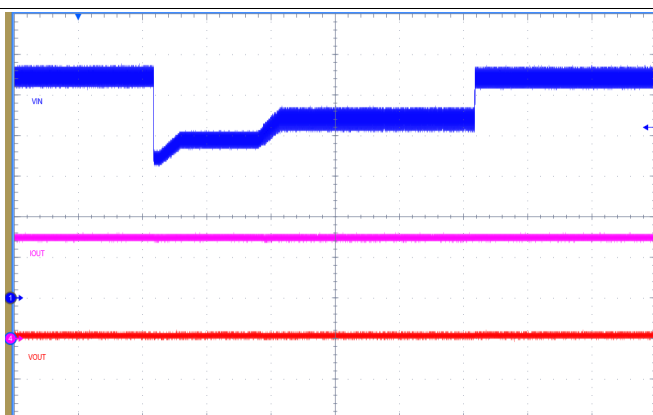
### 6.3.6 Line Transients - Automotive Cold-Crank

Various automotive cold-crank voltage profiles are applied to the input of the LM5166 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.

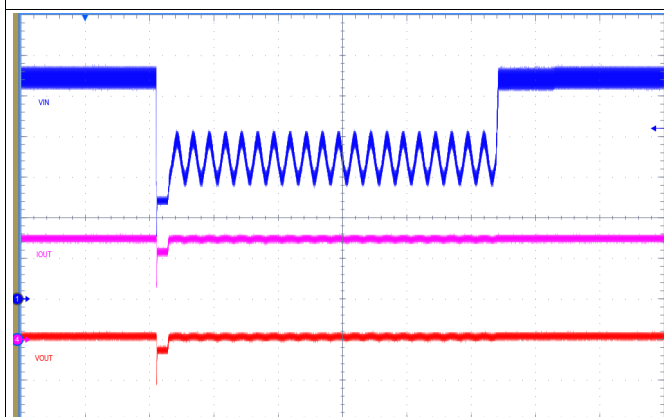
The test pulses shown in Figure 36 through Figure 39 represent the drop in battery voltage and subsequent recovery. These waveforms are readily generated using the TI [PMP7233](#) automotive cranking simulator design. Please consult the *Automotive Cranking Simulator User's Guide* [SLVU984](#) for more detail.



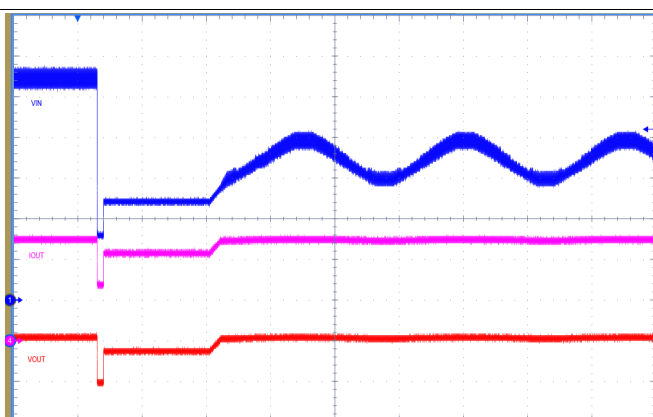
**Figure 36. Typical Automotive Cold-Crank VIN Transient, Profile 1, 500 mA Load**  
(2s/div, Ch1:  $V_{IN}$ , 2V/div; Ch2:  $V_{OUT}$ , 2V/div;  
Ch4:  $I_{OUT}$ , 200mA/div)



**Figure 37. Typical Automotive Cold-Crank VIN Transient, Profile 2, 500 mA Load**  
(200ms/div, Ch1:  $V_{IN}$ , 2V/div; Ch2:  $V_{OUT}$ , 2V/div;  
Ch4:  $I_{OUT}$ , 200mA/div)



**Figure 38. Typical Automotive Cold-Crank VIN Transient, Profile 3, 500 mA Load**  
(2s/div, Ch1:  $V_{IN}$ , 2V/div; Ch2:  $V_{OUT}$ , 2V/div;  
Ch4:  $I_{OUT}$ , 200mA/div)

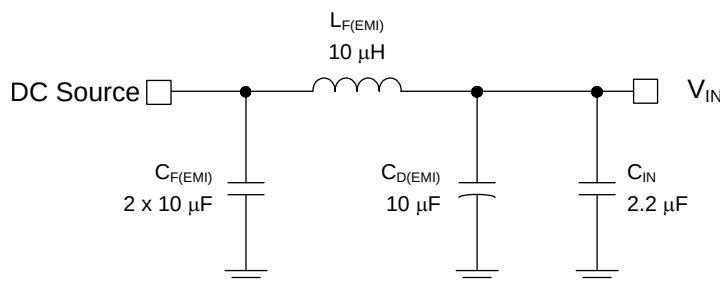


**Figure 39. Zoom-in on a Typical Automotive Cold-Crank VIN Transient, Profile 3, 500 mA Load**  
(200ms/div, Ch1:  $V_{IN}$ , 2V/div; Ch2:  $V_{OUT}$ , 2V/div;  
Ch4:  $I_{OUT}$ , 200mA/div)

## 6.4 EMI Performance - CISPR 25

Figure 41 and Figure 42 represent the LM5166EVM-C50A converter's unfiltered and filtered EMI performance for conducted emissions over a frequency range of 150 kHz to 30 MHz using a 5- $\mu$ H LISN according to the CISPR 25 specification. Figure 43 and Figure 44 show 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.

A suitable EMI input filter to meet the specification limits is represented by an LC filter and a damping electrolytic capacitor is shown in Figure 40. The required components are listed in Table 3.

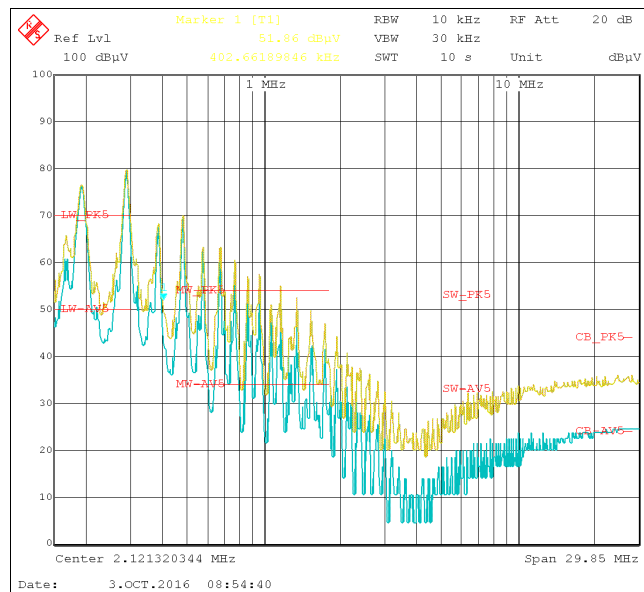


**Figure 40. EMI Filter**

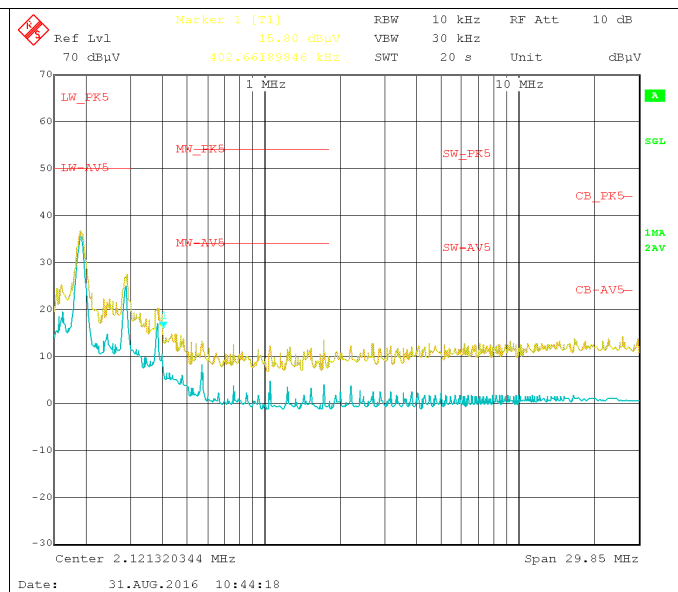
**Table 3. List of Components for EMI Filter <sup>(1)</sup>**

| Count | Ref Des             | Description                                                      | Part Number         | MFR       |
|-------|---------------------|------------------------------------------------------------------|---------------------|-----------|
| 2     | C <sub>F(EMI)</sub> | Capacitor, Ceramic, 10 $\mu$ F, 63 V, X7R, 10%, 1210             | GRM32ER71J106KA12   | Murata    |
| 1     | C <sub>D(EMI)</sub> | Capacitor, Electrolytic, 10 $\mu$ F, 63 V, 2.2 $\Omega$ ESR      | EEE-TG1J100P        | Panasonic |
| 1     | L <sub>F(EMI)</sub> | Inductor, 10 $\mu$ H, 0.136 $\Omega$ typ, 0.9 A Isat, 2.4 mm max | VLCF4024T-100MR90-2 | TDK       |

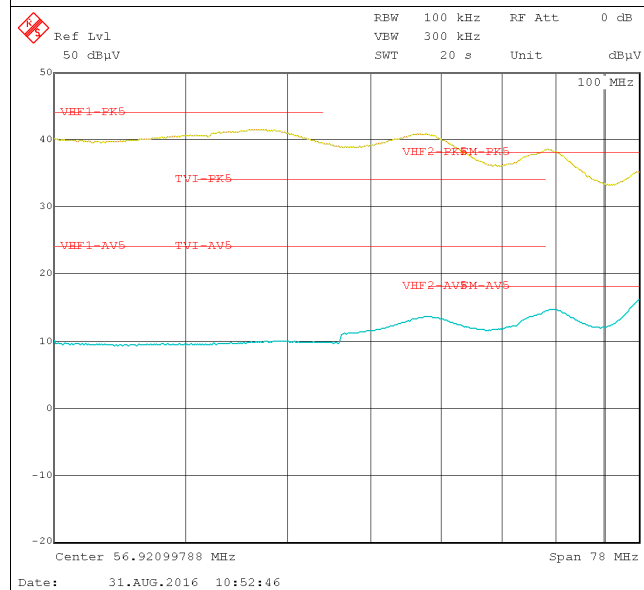
<sup>(1)</sup> This EMI filter is rated for the maximum input voltage of 42 V.



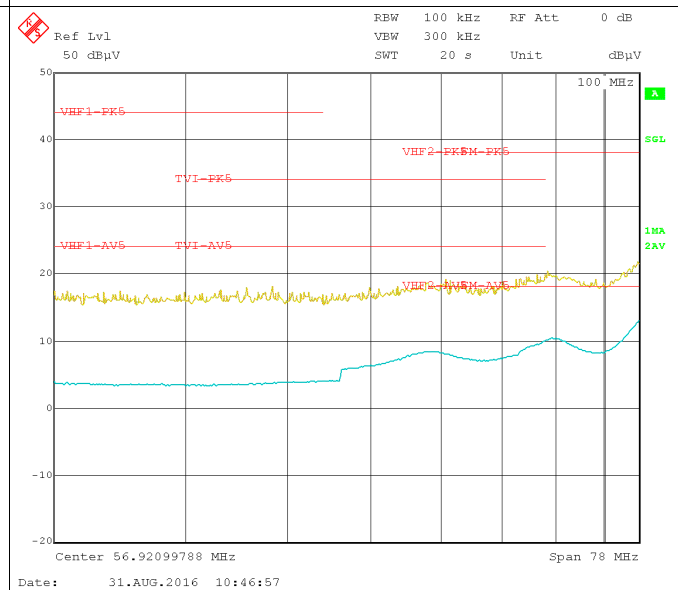
**Figure 41. CISPR25 Class 5 Conducted Emissions Plot, 150 kHz to 30 MHz, VIN = 13.5 V, Load = 500 mA, UNFILTERED**  
(Yellow: Peak Detector, Blue: Average Detector)



**Figure 42. CISPR25 Class 5 Conducted Emissions Plot, 150 kHz to 30 MHz, VIN = 13.5 V, Load = 500 mA, FILTERED**  
(Yellow: Peak Detector, Blue: Average Detector)



**Figure 43. CISPR25 Class 5 Conducted Emissions Plot, 30 MHz to 108 MHz, VIN = 13.5 V, Load = 500 mA, UNFILTERED**  
(Yellow: Peak Detector, Blue: Average Detector)



**Figure 44. CISPR25 Class 5 Conducted Emissions Plot, 30 MHz to 108 MHz, VIN = 13.5 V, Load = 500 mA, FILTERED**  
(Yellow: Peak Detector, Blue: Average Detector)

## 7 EVM Documentation

## 7.1 Converter Schematics

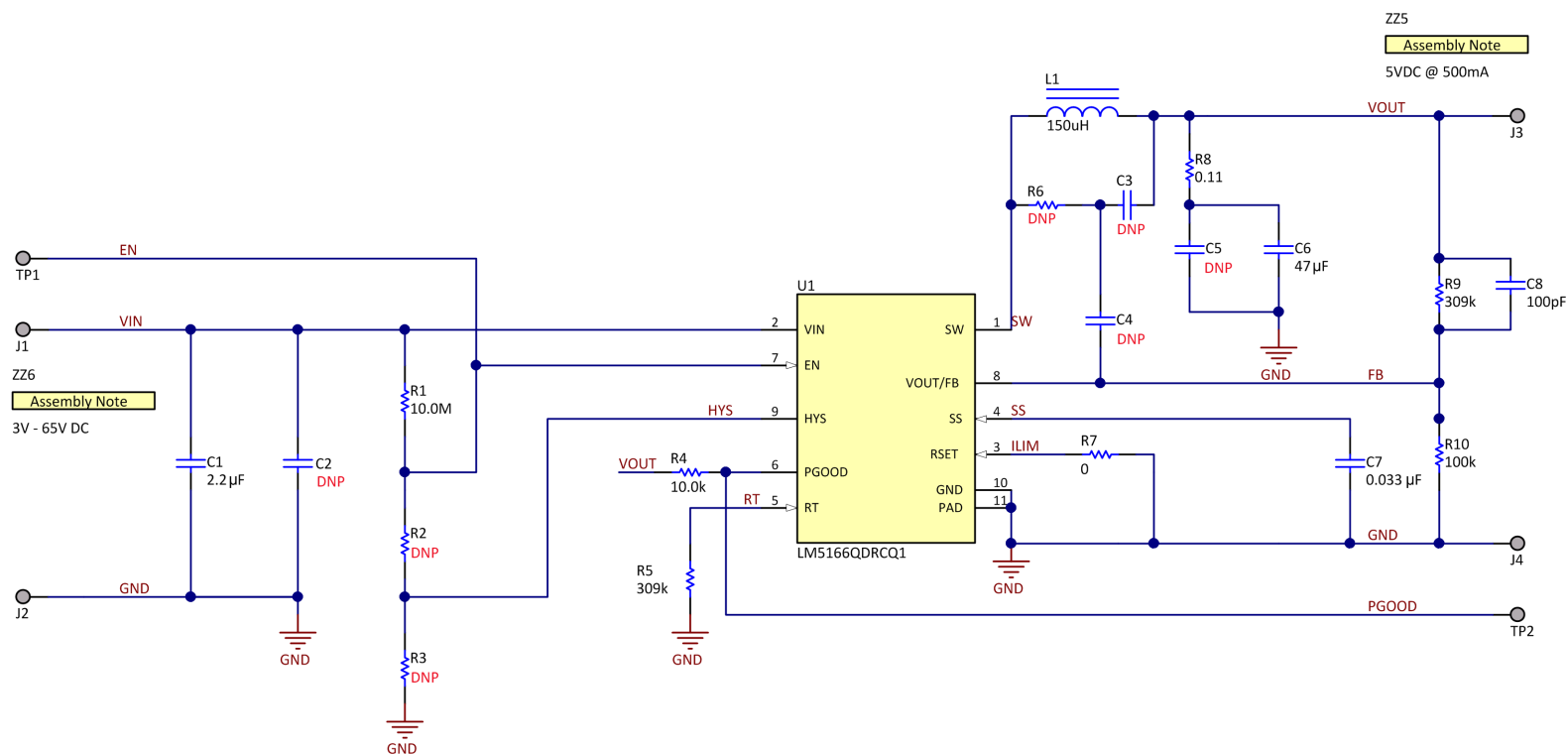


Figure 45. 5V, 500mA COT Schematic (Adjustable Output Version)

## 7.2 PCB Layout

Figure 46 through Figure 51 show the design of the LM5166 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).

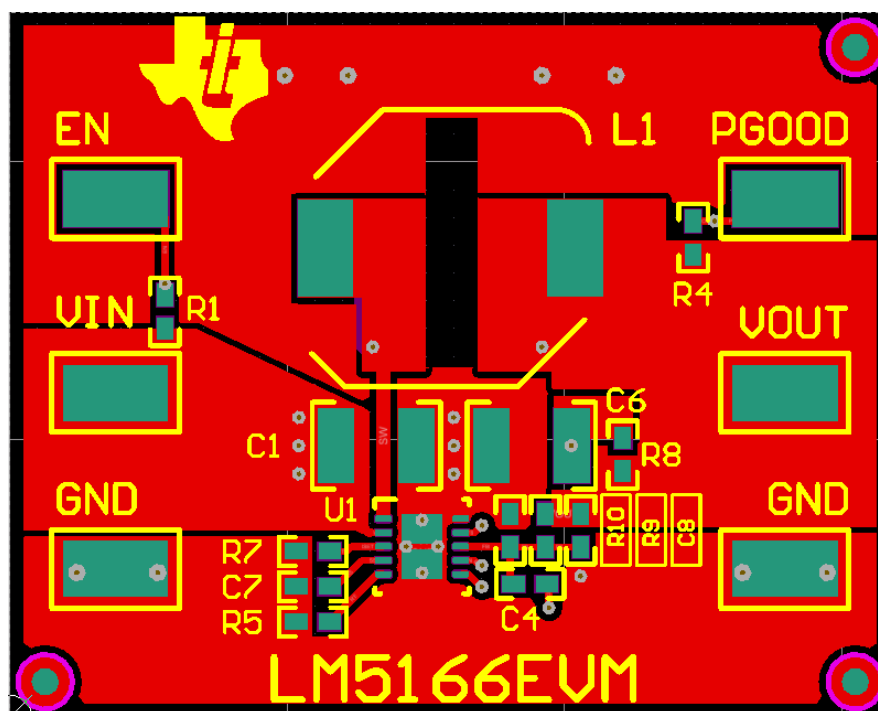


Figure 46. Top Copper (Top View)

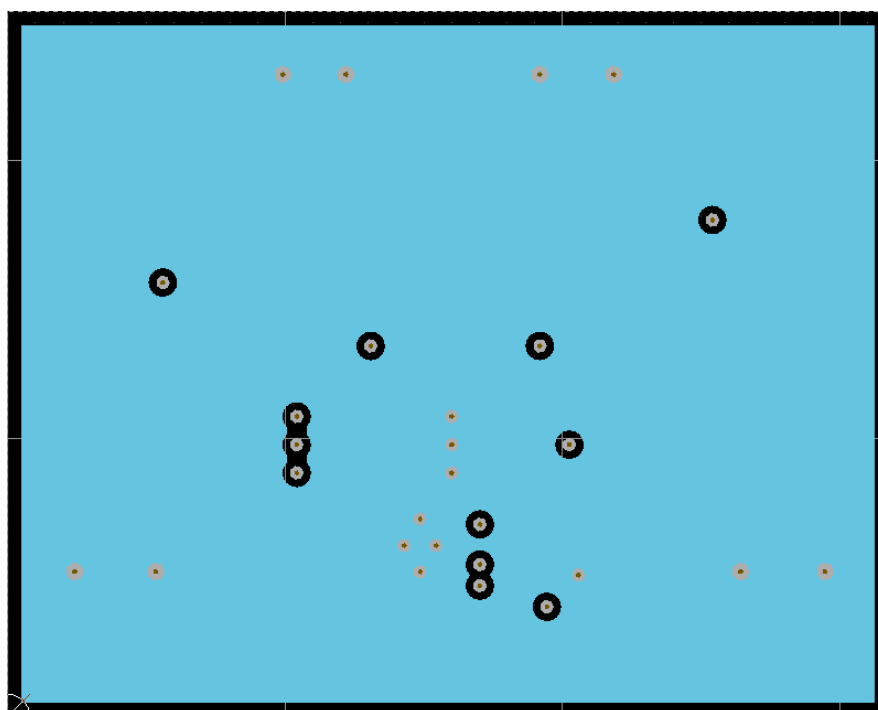


Figure 47. Layer 2 (Top View)

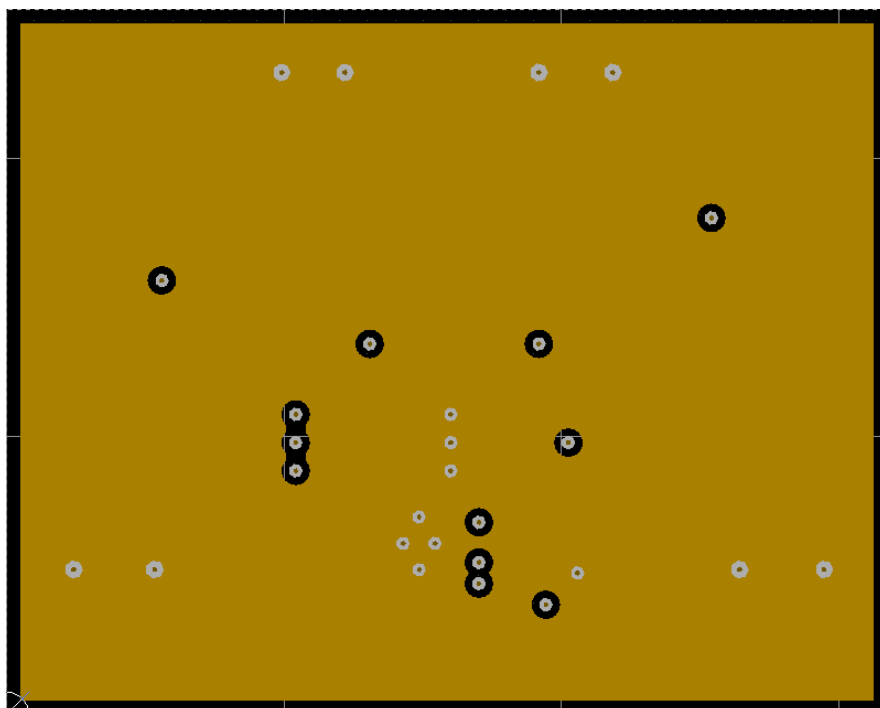


Figure 48. Layer 3 (Top View)

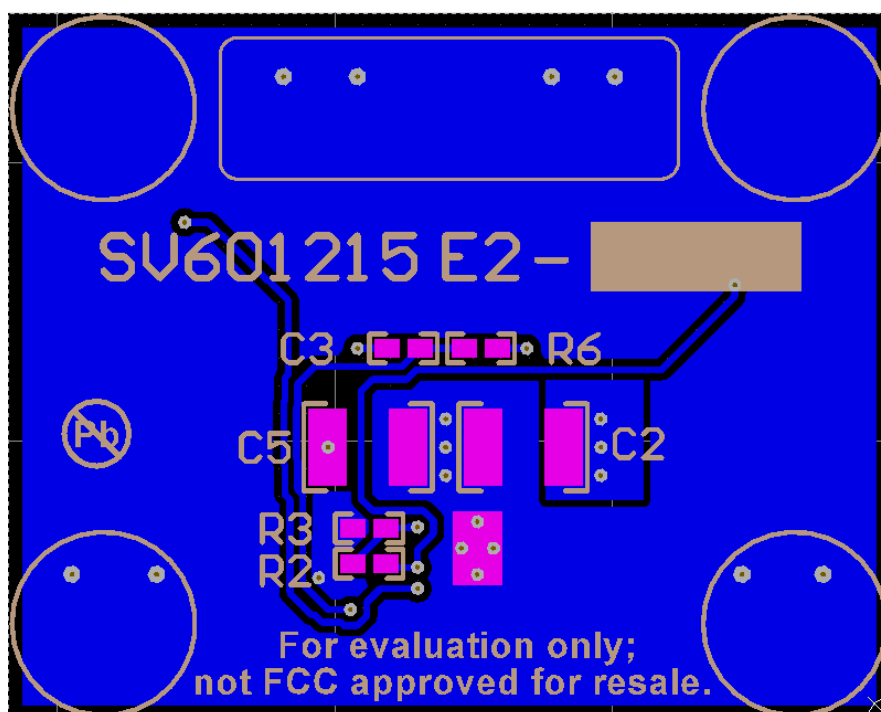


Figure 49. Bottom Copper (Bottom View)

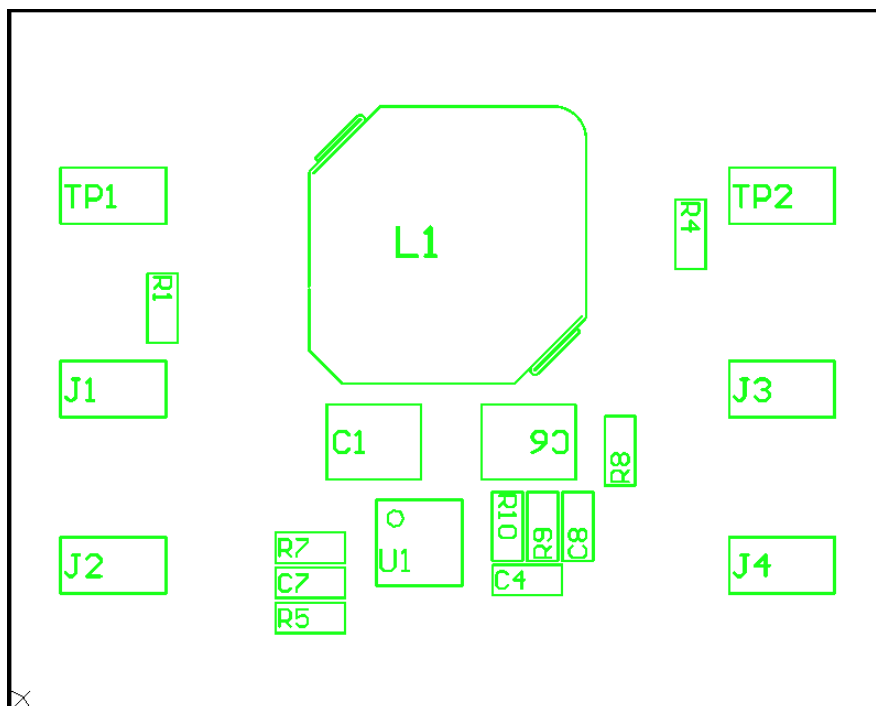


Figure 50. Top Assembly

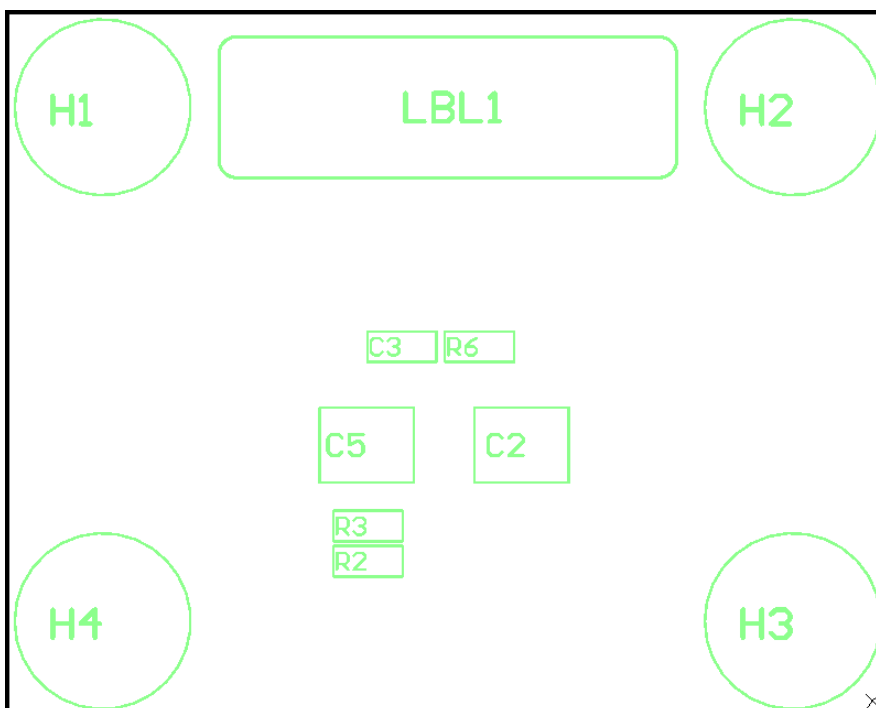


Figure 51. Bottom Assembly



### 7.3 Bill of Materials

**Table 4. Bill of Materials (COT, 5 V, 500 mA, Adjustable Output Version)**

| Count | Ref Des                  | Description                                                                | Part Number          | MFR         |
|-------|--------------------------|----------------------------------------------------------------------------|----------------------|-------------|
| 1     | C1                       | Capacitor, Ceramic, 2.2 $\mu$ F, 100V, X7R, 10%, 1210                      | GRM32ER72A225KA35L   | Murata      |
|       |                          | Capacitor, Ceramic, 2.2 $\mu$ F, 100V, X7R, 10%, 1210, AEC-Q200            | CGA6N3X7R2A225K230AB | TDK         |
| 1     | C6                       | Capacitor, Ceramic, 47 $\mu$ F, 10V, X7R, 10%, 1210                        | GRM32ER71A476KE15L   | Murata      |
|       |                          | Capacitor, Ceramic, 47 $\mu$ F, 6.3V, X7R, 10%, 1210, AEC-Q200             | JMK325B7476KMHTR     | Taiyo Yuden |
| 1     | C7                       | Capacitor, Ceramic, 0.033 $\mu$ F, 10V, X7R, 10%, 0402                     | Std                  | Std         |
| 1     | C8                       | Capacitor, Ceramic, 100pF, 50V, X7R, 10%, 0402                             | Std                  | Std         |
| 1     | L1                       | Inductor, 150 $\mu$ H, 0.240 $\Omega$ typ, 1.4A Isat, 5mm max              | 7447714151           | Würth       |
|       |                          | Inductor, 150 $\mu$ H, 0.285 $\Omega$ typ, 1.12A Isat, 5.1mm max           | CDRH105RNP-151NC     | Sumida      |
|       |                          | Inductor, 150 $\mu$ H, 0.330 $\Omega$ max, 1.16A Isat, 5.1mm max, AEC-Q200 | MSS1048T-154KL       | Coilcraft   |
| 1     | R1                       | Resistor, Chip, 10M $\Omega$ , 1/16W, 1%, 0402                             | Std                  | Std         |
| 1     | R4                       | Resistor, Chip, 10k $\Omega$ , 1/16W, 1%, 0402                             | Std                  | Std         |
| 2     | R5, R9                   | Resistor, Chip, 309k $\Omega$ , 1/16W, 1%, 0402                            | Std                  | Std         |
| 1     | R7                       | Resistor, Chip, 0 $\Omega$ , 1/16W, 1%, 0402                               | Std                  | Std         |
| 1     | R8                       | Resistor, Chip, 0.11 $\Omega$ , 1/16W, 1%, 0402                            | Std                  | Std         |
| 1     | R10                      | Resistor, Chip, 100k $\Omega$ , 1/16W, 1%, 0402                            | Std                  | Std         |
| 1     | U1                       | IC, Synchronous Buck Converter, VSON-10, ADJ                               | LM5166QDRCRQ1        | TI          |
| 1     | PCB1                     | PCB, FR4, 4 layer, 1 oz, 31.75-mm x 25.4-mm                                | PCB                  | –           |
| 6     | TP1, TP2, J1, J2, J3, J4 | Connector, SMT                                                             | 5019                 | Keystone    |

## 8 Reference Designs

Shown below are several designs that can be realized on the same PCB as that used for the LM5166EVM-C50A Evaluation Module.

## 8.1 Schematics

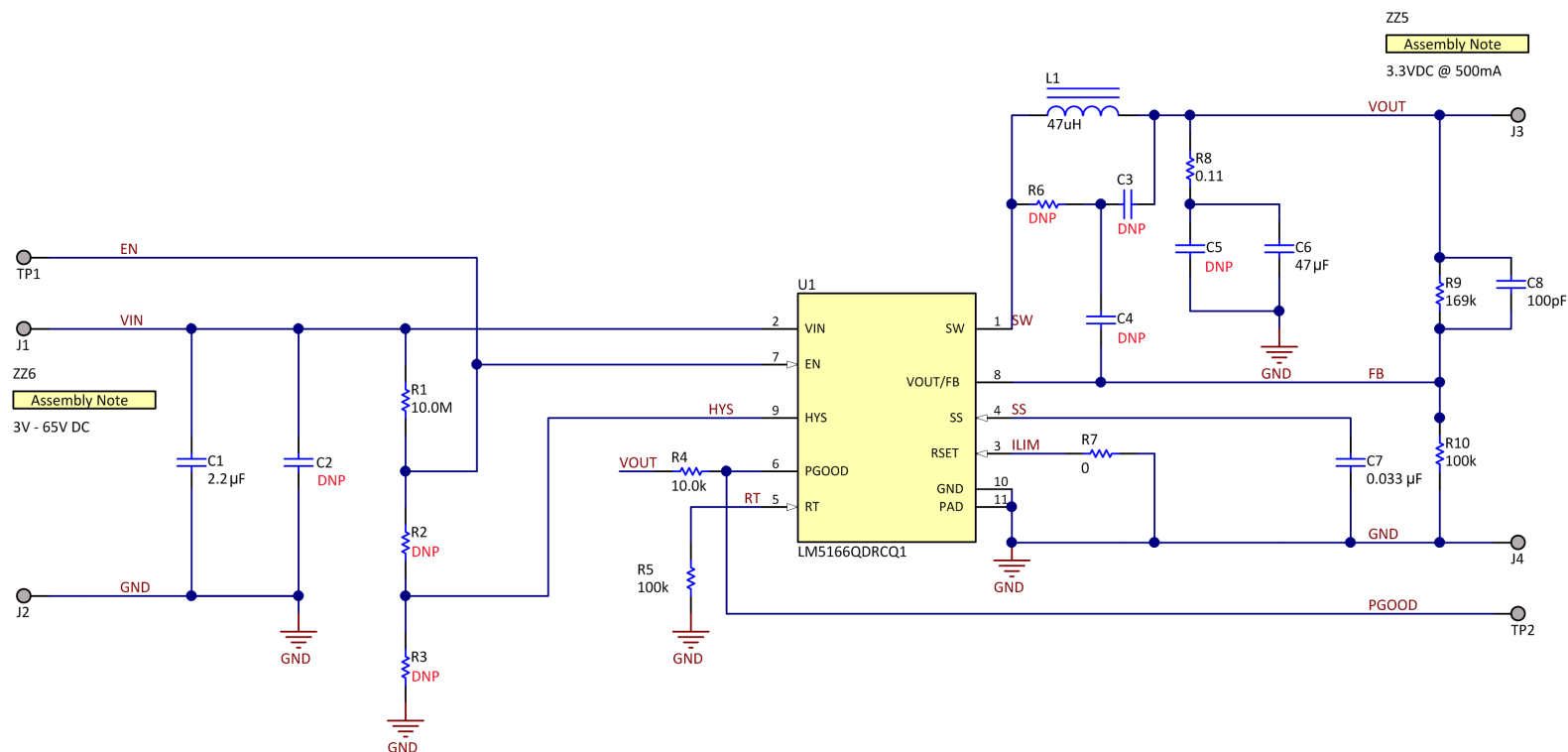
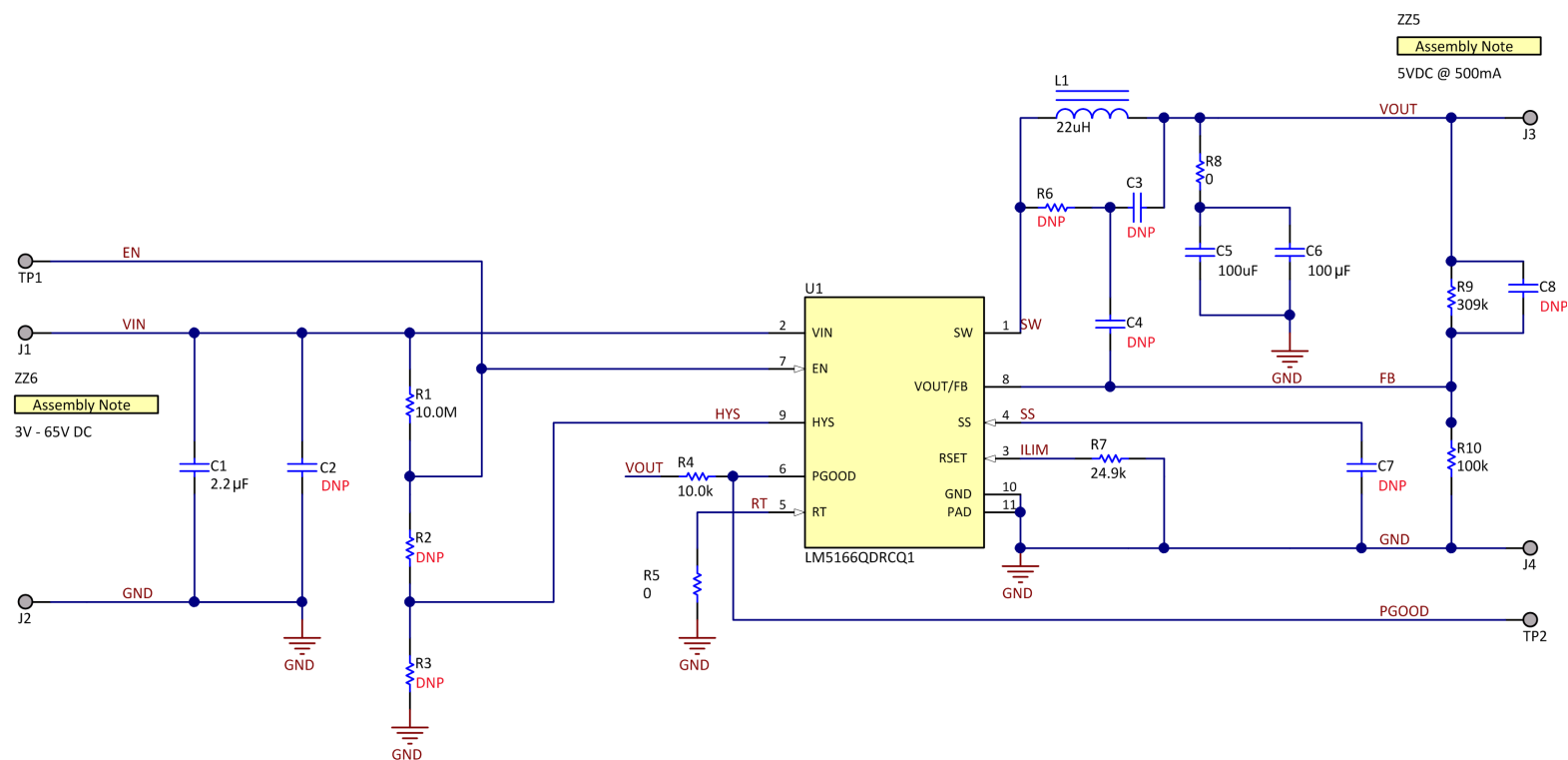


Figure 52. 3.3V, 500mA COT Schematic (Adjustable Output Version)



**Figure 53. 5V, 500mA PFM Schematic (Adjustable Output Version)**

## 8.2 Bill of Materials - COT Designs

**Table 5. Bill of Materials (COT, 3.3 V, 500 mA, Adjustable Output Version)**

| Count | Ref Des                  | Description                                                               | Part Number          | MFR         |
|-------|--------------------------|---------------------------------------------------------------------------|----------------------|-------------|
| 1     | C1                       | Capacitor, Ceramic, 2.2 $\mu$ F, 100V, X7R, 10%, 1210                     | GRM32ER72A225KA35L   | Murata      |
|       |                          | Capacitor, Ceramic, 2.2 $\mu$ F, 100V, X7R, 10%, 1210, AEC-Q200           | CGA6N3X7R2A225K230AB | TDK         |
| 1     | C6                       | Capacitor, Ceramic, 22 $\mu$ F, 25V, X7R, 10%, 1206                       | GRM31CR71A226KE15L   | Murata      |
|       |                          | Capacitor, Ceramic, 47 $\mu$ F, 6.3V, X7R, 10%, 1210, AEC-Q200            | JMK325B7476KMHTR     | Taiyo Yuden |
| 1     | C7                       | Capacitor, Ceramic, 0.033 $\mu$ F, 10V, X7R, 10%, 0402                    | Std                  | Std         |
| 1     | C8                       | Capacitor, Ceramic, 100pF, 50V, X7R, 10%, 0402                            | Std                  | Std         |
| 1     | L1                       | Inductor, 47 $\mu$ H, 0.315 $\Omega$ typ, 1.3A Isat, 2.8mm max            | 74404063470          | Würth       |
|       |                          | Inductor, 47 $\mu$ H, 0.156 $\Omega$ max, 0.97A Isat, 4.8mm max, AEC-Q200 | CLF6045NIT-470M-D    | TDK         |
|       |                          | Inductor, 47 $\mu$ H, 0.245 $\Omega$ max, 1.2A Isat, 3.5mm max            | LPS6235-473MR        | Coilcraft   |
| 1     | R1                       | Resistor, Chip, 10M $\Omega$ , 1/16W, 1%, 0402                            | Std                  | Std         |
| 1     | R4                       | Resistor, Chip, 10k $\Omega$ , 1/16W, 1%, 0402                            | Std                  | Std         |
| 1     | R9                       | Resistor, Chip, 169k $\Omega$ , 1/16W, 1%, 0402                           | Std                  | Std         |
| 1     | R7                       | Resistor, Chip, 0 $\Omega$ , 1/16W, 1%, 0402                              | Std                  | Std         |
| 1     | R8                       | Resistor, Chip, 0.11 $\Omega$ , 1/16W, 1%, 0402                           | Std                  | Std         |
| 2     | R5, R10                  | Resistor, Chip, 100k $\Omega$ , 1/16W, 1%, 0402                           | Std                  | Std         |
| 1     | U1                       | IC, Synchronous Buck Converter, VSON-10, ADJ                              | LM5166QDRCRQ1        | TI          |
| 1     | PCB1                     | PCB, FR4, 4 layer, 1 oz, 31.75-mm x 25.4-mm                               | PCB                  | —           |
| 6     | TP1, TP2, J1, J2, J3, J4 | Connector, SMT                                                            | 5019                 | Keystone    |

**Table 6. Bill of Materials (COT, 3.3 V, 300 mA, Adjustable Output Version)**

| Count | Ref Des                  | Description                                                               | Part Number          | MFR       |
|-------|--------------------------|---------------------------------------------------------------------------|----------------------|-----------|
| 1     | C1                       | Capacitor, Ceramic, 2.2 $\mu$ F, 100V, X7R, 10%, 1210                     | GRM32ER72A225KA35L   | Murata    |
|       |                          | Capacitor, Ceramic, 2.2 $\mu$ F, 100V, X7R, 10%, 1210, AEC-Q200           | CGA6N3X7R2A225K230AB | TDK       |
| 1     | C6                       | Capacitor, Ceramic, 10 $\mu$ F, 6.3V, X7R, 10%, 0805                      | GRM21BR70J106KE76L   | Murata    |
|       |                          | Capacitor, Ceramic, 10 $\mu$ F, 6.3V, X7R, 10%, 0805, AEC-Q200            | GCM21BR70J106KE22L   | Murata    |
| 1     | C7                       | Capacitor, Ceramic, 0.033 $\mu$ F, 10V, X7R, 10%, 0402                    | Std                  | Std       |
| 1     | L1                       | Inductor, 33 $\mu$ H, 0.260 $\Omega$ max, 0.68A Isat, 3.0mm max, AEC-Q200 | SRU5028A-330Y        | Bourns    |
|       |                          | Inductor, 33 $\mu$ H, 0.240 $\Omega$ max, 0.62A Isat, 2.8mm max           | VLCF5028T-330MR62-2  | TDK       |
|       |                          | Inductor, 33 $\mu$ H, 0.260 $\Omega$ max, 0.64A Isat, 3.0mm max           | LPS5030-333ML        | Coilcraft |
| 1     | R1                       | Resistor, Chip, 10M $\Omega$ , 1/16W, 1%, 0402                            | Std                  | Std       |
| 1     | R4                       | Resistor, Chip, 10k $\Omega$ , 1/16W, 1%, 0402                            | Std                  | Std       |
| 1     | R9                       | Resistor, Chip, 169k $\Omega$ , 1/16W, 1%, 0402                           | Std                  | Std       |
| 1     | R5                       | Resistor, Chip, 49.9k $\Omega$ , 1/16W, 1%, 0402                          | Std                  | Std       |
| 1     | R8                       | Resistor, Chip, 0.3 $\Omega$ , 1/16W, 1%, 0402                            | Std                  | Std       |
| 2     | R7, R10                  | Resistor, Chip, 100k $\Omega$ , 1/16W, 1%, 0402                           | Std                  | Std       |
| 1     | U1                       | IC, Synchronous Buck Converter, VSON-10, ADJ                              | LM5166QDRCRQ1        | TI        |
| 1     | PCB1                     | PCB, FR4, 4 layer, 1 oz, 31.75-mm x 25.4-mm                               | PCB                  | —         |
| 6     | TP1, TP2, J1, J2, J3, J4 | Connector, SMT                                                            | 5019                 | Keystone  |

### 8.3 Bill of Materials - PFM Designs

**Table 7. Bill of Materials (PFM, 5V, 500 mA, Adjustable Output Version)**

| Count | Ref Des                  | Description                                                | Part Number          | MFR         |
|-------|--------------------------|------------------------------------------------------------|----------------------|-------------|
| 1     | C1                       | Capacitor, Ceramic, 2.2μF, 100V, X7R, 10%, 1210            | GRM32ER72A225KA35L   | Murata      |
|       |                          | Capacitor, Ceramic, 2.2μF, 100V, X7R, 10%, 1210, AEC-Q200  | CGA6N3X7R2A225K230AB | TDK         |
| 2     | C5, C6                   | Capacitor, Ceramic, 100μF, 10V, X5R, 20%, 1210             | GRM32ER61A107ME20K   | Murata      |
|       |                          | Capacitor, Ceramic, 100μF, 16V, X5R, 20%, 1210             | EMK325ABJ107MM-T     | Taiyo Yuden |
| 1     | L1                       | Inductor, 22μH, 0.139Ω typ, 2.0A Isat, 4.5mm max, AEC-Q200 | NRS6045T220MMGKV     | Taiyo Yuden |
|       |                          | Inductor, 22μH, 0.167Ω typ, 2.0A Isat, 4.8mm max, AEC-Q200 | MBH6045C-220MA=P3    | Murata      |
|       |                          | Inductor, 22μH, 0.145Ω max, 1.7A Isat, 3.5mm max           | LPS6235-223MR        | Coilcraft   |
| 1     | R1                       | Resistor, Chip, 10MΩ, 1/16W, 1%, 0402                      | Std                  | Std         |
| 1     | R4                       | Resistor, Chip, 10kΩ, 1/16W, 1%, 0402                      | Std                  | Std         |
| 1     | R9                       | Resistor, Chip, 309kΩ, 1/16W, 1%, 0402                     | Std                  | Std         |
| 2     | R5, R8                   | Resistor, Chip, 0Ω, 1/16W, 1%, 0402                        | Std                  | Std         |
| 1     | R7                       | Resistor, Chip, 24.9kΩ, 1/16W, 1%, 0402                    | Std                  | Std         |
| 1     | R10                      | Resistor, Chip, 100kΩ, 1/16W, 1%, 0402                     | Std                  | Std         |
| 1     | U1                       | IC, Synchronous Buck Converter, VSON-10, ADJ               | LM5166QDRCRQ1        | TI          |
| 1     | PCB1                     | PCB, FR4, 4 layer, 1 oz, 31.75-mm x 25.4-mm                | PCB                  | –           |
| 6     | TP1, TP2, J1, J2, J3, J4 | Connector, SMT                                             | 5019                 | Keystone    |

**Table 8. Bill of Materials (PFM, 3.3V, 300 mA, Adjustable Output Version)**

| Count | Ref Des                  | Description                                                | Part Number          | MFR         |
|-------|--------------------------|------------------------------------------------------------|----------------------|-------------|
| 1     | C1                       | Capacitor, Ceramic, 2.2μF, 100V, X7R, 10%, 1210            | GRM32ER72A225KA35L   | Murata      |
|       |                          | Capacitor, Ceramic, 2.2μF, 100V, X7R, 10%, 1210, AEC-Q200  | CGA6N3X7R2A225K230AB | TDK         |
| 2     | C5, C6                   | Capacitor, Ceramic, 100μF, 10V, X5R, 20%, 1210             | GRM32ER61A107ME20K   | Murata      |
|       |                          | Capacitor, Ceramic, 100μF, 16V, X5R, 20%, 1210             | EMK325ABJ107MM-T     | Taiyo Yuden |
| 1     | L1                       | Inductor, 22μH, 0.139Ω typ, 2.0A Isat, 4.5mm max, AEC-Q200 | NRS6045T220MMGKV     | Taiyo Yuden |
|       |                          | Inductor, 22μH, 0.167Ω typ, 2.0A Isat, 4.8mm max, AEC-Q200 | MBH6045C-220MA=P3    | Murata      |
|       |                          | Inductor, 22μH, 0.145Ω max, 1.7A Isat, 3.5mm max           | LPS6235-223MR        | Coilcraft   |
| 1     | R1                       | Resistor, Chip, 10MΩ, 1/16W, 1%, 0402                      | Std                  | Std         |
| 1     | R4                       | Resistor, Chip, 10kΩ, 1/16W, 1%, 0402                      | Std                  | Std         |
| 1     | R9                       | Resistor, Chip, 169kΩ, 1/16W, 1%, 0402                     | Std                  | Std         |
| 2     | R5, R8                   | Resistor, Chip, 0Ω, 1/16W, 1%, 0402                        | Std                  | Std         |
| 1     | R7                       | Resistor, Chip, 56.2kΩ, 1/16W, 1%, 0402                    | Std                  | Std         |
| 1     | R10                      | Resistor, Chip, 100kΩ, 1/16W, 1%, 0402                     | Std                  | Std         |
| 1     | U1                       | IC, Synchronous Buck Converter, VSON-10, ADJ               | LM5166QDRCRQ1        | TI          |
| 1     | PCB1                     | PCB, FR4, 4 layer, 1 oz, 31.75-mm x 25.4-mm                | PCB                  | –           |
| 6     | TP1, TP2, J1, J2, J3, J4 | Connector, SMT                                             | 5019                 | Keystone    |

## 9 Device Support

### 9.1 Development Support

- [LM5166 Quick-Start Design Tool](#)
- [TIDesigns](#) Reference Design Library
- [WEBENCH®](#) Designer

### 9.2 Documentation Support

- [LM5166 Datasheet SNVSA67](#)
- [LM5166-Q1 Datasheet SNVSAO1](#)
- [LM5166EVM-C33A User's Guide SNVU544](#)
- [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](#)

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### 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

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[http://www.tij.co.jp/llds/ti\\_ja/general/eStore/notice\\_01.page](http://www.tij.co.jp/llds/ti_ja/general/eStore/notice_01.page)

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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.

##### 4.3 *Safety-Related Warnings and Restrictions:*

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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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|                               |                                                                                          |
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