*EVM User's Guide: LM67680-Q1EVM*

# *LM67680-Q1 $60V_{IN}$, $–12V_{OUT}$, –6A, Inverting Buck-Boost DC/DC Regulator Evaluation Module*

## Description

The LM67680-Q1EVM evaluation module (EVM) is designed to showcase the LM67680-Q1 DC/DC converter configured in an inverting buck-boost (IBB) implementation. The EVM operates over an input voltage range of 3.8V to 60V to deliver a –12V output at up to 6A.

## Get Started

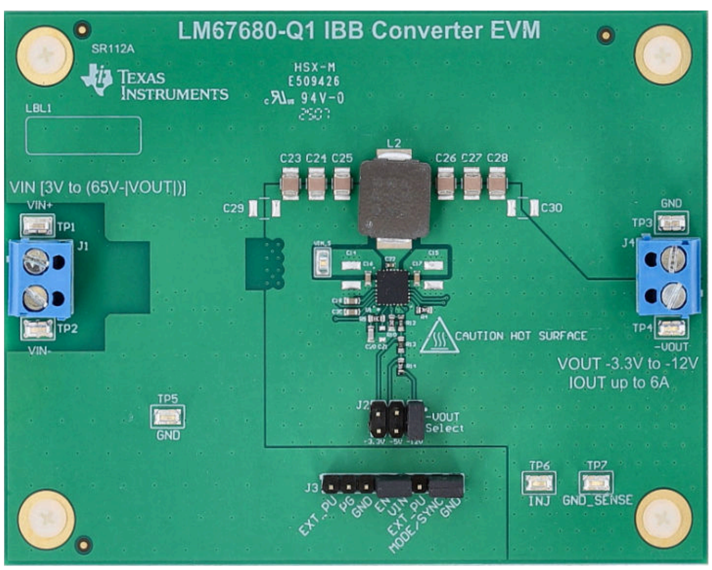
1. Order the LM67680-Q1EVM.
2. Refer to the LM67680-Q1 product folder.
3. Review the Altium PCB layout source files.
4. Use the LM67680-Q1 quickstart calculator to assist with component selection in the design.
5. Simulate the design using PSPICE or SIMPLIS.

## Features

- 65V synchronous IBB converter with high efficiency over a wide load current range: 93% at $48V_{IN}$, $–12V_{OUT}$, –6A
- Integrated level-shifters on MODE/SYNC, EN, and PG allow easy interface to system control signals
- Switching frequency of 400kHz synchronizable ±20% with an external clock signal
- ZEN 1 switcher technology
  - Spread spectrum (DRSS) and switching slew-rate control reduce peak emissions
  - Input π-stage EMI filter helps meet CISPR 25 Class 5 and UNECE Reg 10 EMI standards
- Integrated protection features for robust design: Overcurrent protection (OCP); Power-Good (PG) indicator with 100kΩ pullup to external voltage source; internal 5.3ms soft-start (SS) timer
- Fully assembled, tested, and proven PCB layout

## Applications

- LIDAR, ADAS, automotive display
- Automotive infotainment and cluster
- Hybrid, electric, and powertrain systems
- Industrial automation, test and measurement
- Medical imaging systems
- Wireless infrastructure systems



# 1 Evaluation Module Overview

## 1.1 Introduction

The LM67680-Q1EVM evaluation module (EVM) uses the LM67680-Q1, which comes from a family of converters that demonstrate high conversion efficiency, flexibility, scalability, and small design size – therefore designed to a wide range of applications. With an input voltage up to (65V – |$V_{OUT}$|) for IBB applications and an inductor current up to 8A, the IC enables designs with high power density and low conducted and radiated emissions. Available EMI mitigation options includes dual-random spread spectrum (DRSS) and slew rate (SR) control to reduce peak emissions.

The EVM design has selectable output voltages of –3.3V, –5V, or –12V and a switching frequency of 400kHz. Also supported are remote enable for application-specific power-up and power-down requirements, external clock synchronization to mitigate beat frequencies in noise-sensitive applications, power good (PG) indicator for sequencing and output voltage monitoring, pin-selectable MODE control for light-load performance in AUTO mode or fixed switching frequency in forced pulse width modulation (FPWM) mode, external compensation, and internal soft start (SS).

The selected power-train passive components, including the 6.8µH IBB inductor, 4.7µF/100V/X7R/1210 ceramic input capacitors, and 22µF/25V/X7S/1210 ceramic output capacitors, are available from multiple component vendors. To optimize component selection and examine predicted efficiency performance across line and load ranges, download the LM67680-Q1 quickstart calculator.

## 1.2 Kit Contents

- LM67680-Q1EVM Circuit Board
- EVM Disclaimer Read Me

### 1.3 Specifications

Table 1-1 lists the EVM specifications. $V_{IN}$ = 48V, $V_{OUT}$ = –12V, $I_{OUT}$ = –6A, $F_{SW}$ = 400kHz, unless otherwise indicated.

**Table 1-1. Electrical Performance Characteristics**

| PARAMETER | TEST CONDITIONS | | MIN | TYP | MAX | UNIT |
|---|---|---|---|---|---|---|
| **INPUT CHARACTERISTICS** | | | | | | |
| Input voltage range, $V_{IN}$ | Steady-state operating range | | 5 | 48 | 60 | V |
| Input current, no load, $I_{IN-NL}$ | $I_{OUT}$ = 0A, MODE/SYNC tied low to SGND | $V_{IN}$ = 12V | | 420 | | µA |
| | | $V_{IN}$ = 24V | | 233 | | |
| | | $V_{IN}$ = 48V | | 146 | | |
| Input current, shutdown, $I_{IN-OFF}$ | $V_{EN}$ = 0V | $V_{IN}$ = 12V | | 65 | | µA |
| **OUTPUT CHARACTERISTICS** | | | | | | |
| Output voltage, $V_{OUT}$ (1) | | | –12.1 | –12 | –11.9 | V |
| Output current, $I_{OUT}$ | $V_{IN}$ = 48V to (65V – \|$V_{OUT}$\|), airflow = 100 LFM(2) | | | | –6 | A |
| Output voltage regulation, $\Delta V_{OUT}$ | Load regulation | $I_{OUT}$ = 0A to –6A | | 0.2% | | |
| | Line regulation, $I_{OUT}$ = 2A | $V_{IN}$ = 9V to (65V – \|$V_{OUT}$\|) | | 0.2% | | |
| Output voltage ripple, $V_{OUT-AC}$ | | | | 20 | | $mV_{RMS}$ |
| Soft-start time, $t_{SS}$ | Internal soft start | | | 5.3 | | ms |
| **SYSTEM CHARACTERISTICS** | | | | | | |
| Switching frequency, $F_{SW}$ | | | | 400 | | kHz |
| Synchronization frequency range, $F_{SYNC}$ | | | 320 | | 480 | kHz |
| Light-load efficiency, AUTO mode, $\eta_{LIGHT}$ | $I_{OUT}$ = –1A | $V_{OUT}$ = –12V | | 90.5 | | % |
| | | $V_{OUT}$ = –5V(1) | | 89 | | % |
| | | $V_{OUT}$ = –3.3V | | 86 | | % |
| Half-load efficiency, $\eta_{HALF}$ | $I_{OUT}$ = –3A | $V_{OUT}$ = –12V | | 93.3 | | % |
| | | $V_{OUT}$ = –5V | | 91 | | % |
| | | $V_{OUT}$ = –3.3V | | 87.5 | | % |
| Full-load efficiency, $\eta_{FULL}$ | $I_{OUT}$ = –6A | $V_{OUT}$ = –12V | | 93 | | % |
| | | $V_{OUT}$ = –5V | | 89.5 | | % |
| | | $V_{OUT}$ = –3.3V | | 88 | | % |
| LM67680-Q1 junction temperature, $T_J$ | | | –40 | | 150 | °C |

(1) The default output voltage of this EVM is –5V. Efficiency and other performance metrics can change based on operating input voltage, load current, externally-connected output capacitors, and other parameters.
(2) Caution: touchable components and surfaces on the EVM can exceed 55°C (normalized for 25°C ambient). High ambient temperatures can require forced cooling or other thermal management steps to keep the IC junction temperature below 150°C. Refer to Section 3.1.5.

## 1.4 Device Information

The EVM design uses the LM67680-Q1 65V, 8A IBB converter IC, which enables high conversion efficiency and incorporates the following key features:

- Versatile synchronous IBB converter family
  - Wide input voltage range of 3.8V to (65V – $|V_{OUT}|$)
  - 4A, 6A, and 8A inductor current options
  - Monolithically integrated power MOSFETs and controller
    - Optimized near-zero dead-time switching minimizes power loss and temperature rise
  - Ultra-low shutdown and sleep quiescent currents
  - Dual-input VCC subregulator with BIAS option
  - EN input supports application-specific power-up and power-down requirements
- ZEN 1 switcher technology
  - Facilitates CISPR 25 Class 5 compliance
  - Enhanced HotRod™ QFN (eQFN) package with symmetrical pinout design and minimal parasitic loop inductance for clean switching waveforms
  - Optional dual-random spread spectrum (DRSS) modulation and switch-voltage slew-rate (SR) control for lower EMI
  - AUTO, FPWM, or SYNC operation
- Improved reliability with optimized pinout design and clearance spacing for short-circuit-to-adjacent-pin test
  - VIN to PGND pin clearance of 1.1mm
  - Material group I insulation per IEC 60664-1
  - Butterfly (VIN1, PGND1) and (VIN2, PGND2) pinout arrangement for improved current distribution

The LM67680-Q1 comes in a 4.5mm × 4.5mm, thermally enhanced, 26-pin eQFN package using a flip-chip routable leadframe (FCRLF) packaging technique. The integrated level-shifters allow direct interface to EN, PG, and MODE/SYNC pins, which reference to system ground (SGND) in IBB designs. Leveraging integrated power MOSFETs, EMI mitigation features, and small design size, the LM67680-Q1 represents an excellent point-of-load regulator choice for IBB applications requiring the most efficient design with useable current, lifetime reliability, and cost advantages.

**Table 1-2. Orderable Part Numbers**

| GENERAL PART NUMBER | ORDERABLE PART NUMBER | INPUT VOLTAGE RANGE | RATED CURRENT | TI FUNCTIONAL-SAFETY CLASSIFICATION[(2)] | LEVEL SHIFTERS FOR IBB |
|---|---|---|---|---|---|
| LM67680-Q1 | LM67680RZYRQ1 | 3.8V to 65V | 8A | Functional safety-capable | Yes |
| LM67660-Q1[(1)] | LM67660RZYRQ1 | | 6A | | |
| LM67640-Q1 | LM67640RZYRQ1 | | 4A | | |
| LM65680-Q1 | LM65680RZYRQ1 | 3.5V to 65V (70V transient) | 8A | Functional safety-capable | No |
| LM65660-Q1[(1)] | LM65660RZYRQ1 | | 6A | | |
| LM65640-Q1[(1)] | LM65640RZYRQ1 | | 4A | | |
| LM68680-Q1[(1)] | LM68680FRZYRQ1 | 3.5V to 65V | 8A | ASIL C functional safety-compliant | No |
| LM68660-Q1[(1)] | LM68660FRZYRQ1 | | 6A | | |
| LM68640-Q1[(1)] | LM68640FRZYRQ1 | | 4A | | |
| LM68580-Q1[(1)] | LM68580FRZYRQ1 | 3.5V to 42V | 8A | | |
| LM68580-Q1[(1)] | LM68560FRZYRQ1 | | 6A | | |

(1) Preview information (not Production Data). For more information, please contact TI.
(2) Refer to the functional safety homepage to understand the TI functional safety classifications (in terms of the development process, analysis report, and diagnostics description).

### *1.4.1 Application Circuit Diagram*

Figure 1-1 shows the schematic of an LM67680-Q1 IBB converter with output voltage set by feedback resistors designated as $R_{FB1}$ and $R_{FB2}$. Defined by components $R_{COMP}$, $C_{COMP}$, and $C_{HF}$, a type-II compensation network sets the voltage-loop crossover frequency and phase margin to meet a target load transient response specification.

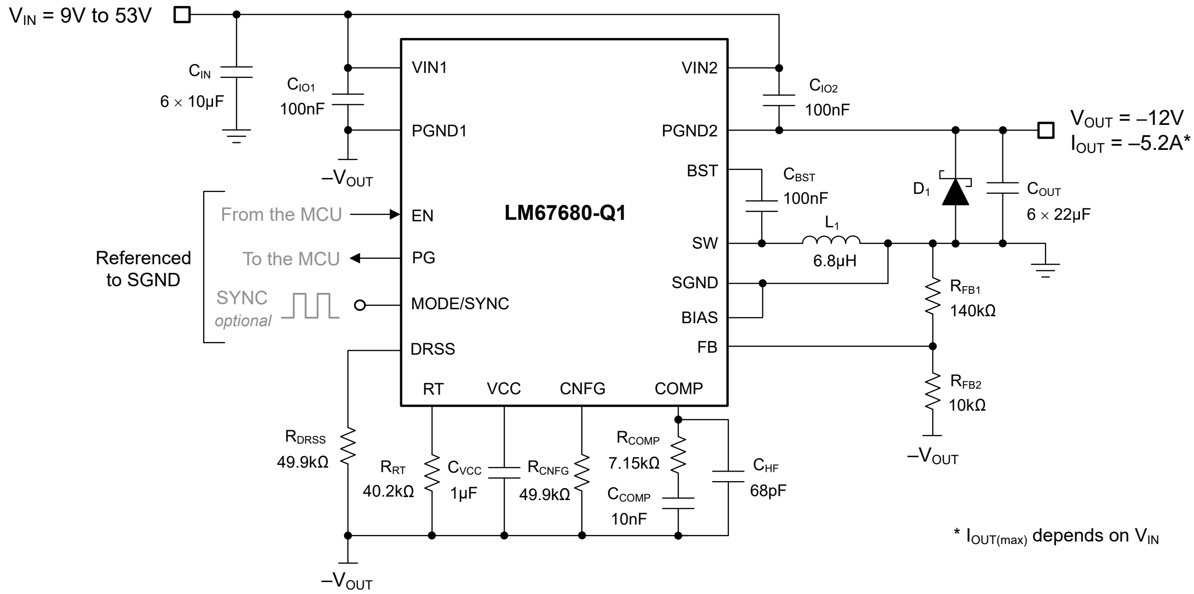



**Figure 1-1. Typical Schematic**

The BIAS input derives current from the output (at voltages above the 4V switchover threshold) to achieve lower IC power loss and improved efficiency at light loads in particular. Not shown in Figure 1-1 is an EMI filter stage at the input.

### *1.4.2 IBB Maximum Output Current*

Similar to a boost or flyback topology, the inductor in an IBB converter stores energy during the PWM on time (or D interval) of each cycle and transfers energy to the output only during the off time (or 1 – D interval). As a result, Equation 1 gives the achievable output current with an IBB design as

$$I_{OUT(max)} = I_{L,DC(max)} \times (1 - D) \tag{1}$$

where $I_{L,DC(max)}$ for the LM67680-Q1 is the rated current of 8A and D is the IBB duty cycle given by

$$D = \frac{|V_{OUT}|}{|V_{OUT}| + V_{IN}} \tag{2}$$

Figure 1-2 plots the maximum output current capability of the LM67680-Q1 as a function of input voltage for output voltages of –3.3V, –5V, and –12V. The available output current is lowest at minimum input voltage.

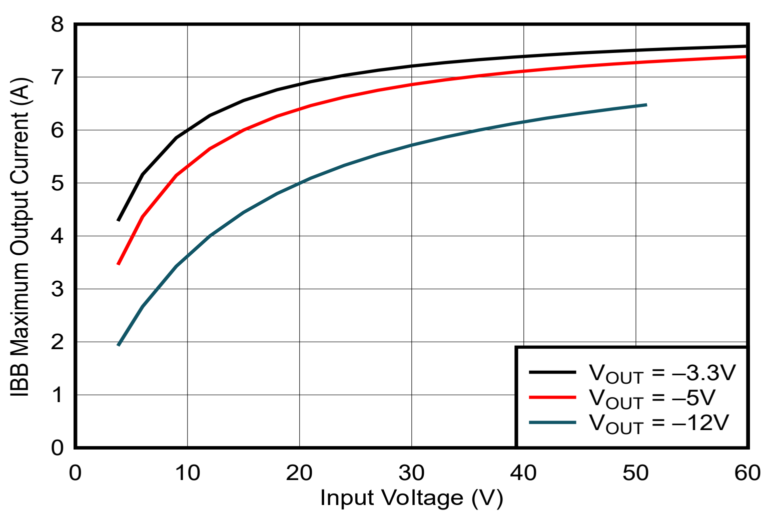



**Figure 1-2. IBB Maximum Output Current**

# 2 Hardware

## 2.1 Test Setup and Procedure

### *2.1.1 EVM Connections*

Referencing the EVM connections described in Table 2-1, Figure 2-1 shows the recommended test setup to evaluate the LM67680-Q1. Working at an ESD-protected workstation, make sure that any wrist straps, boot straps, or mats are connected and referencing the user to earth ground before handling and applying power to the EVM.

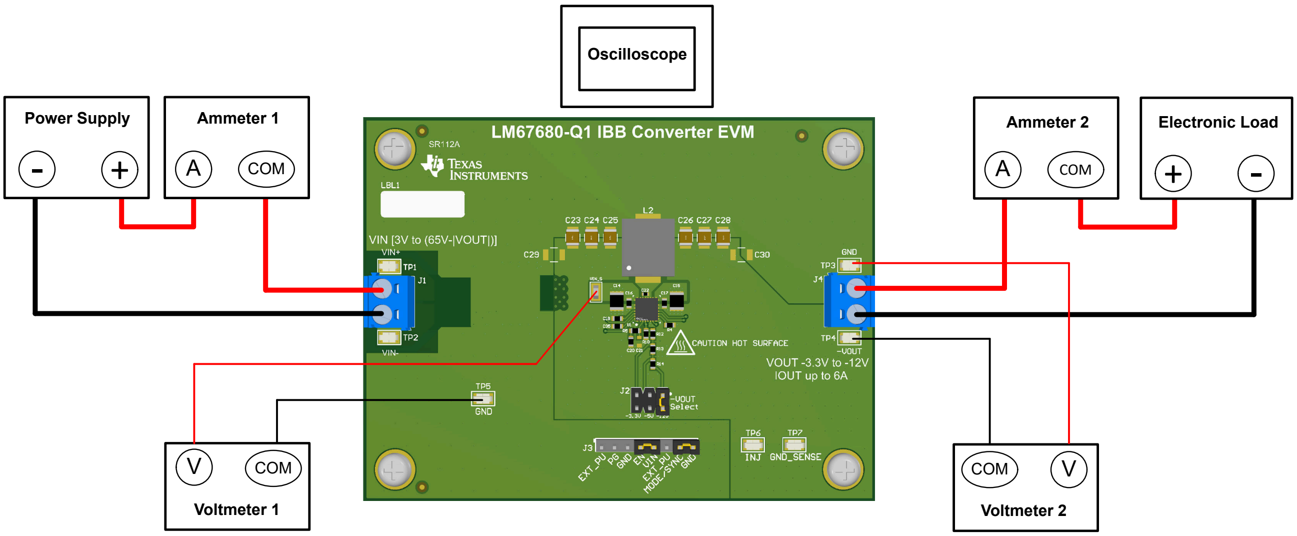



**Figure 2-1. EVM Test Setup**

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**Note**

Refer to the *LM67680/60/40-Q1 Automotive, 65V, 8A/6A/4A, Inverting Buck-Boost Converter Family With ZEN 1 Low-EMI Switcher Technology* data sheet and WEBENCH® Power Designer for additional guidance pertaining to component selection and converter operation.

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**Table 2-1. EVM Power Connections**

| LABEL | DESCRIPTION |
|---|---|
| VIN+ | Positive input power connection |
| VIN– | Negative input power connection |
| GND | Positive output power connection |
| –VOUT | Negative output power connection |

**Table 2-2. EVM Signal Connections**

| LABEL | DESCRIPTION |
|---|---|
| EXT_PU | External pullup voltage for PG |
| PG | Power-Good indicator |
| GND | GND connection |
| EN | ENABLE input – tie to GND to disable the device |
| VIN | Input voltage |
| EXT_PU | External pullup voltage for MODE/SYNC |
| MODE/SYNC | FPWM/AUTO mode selection and synchronization input. Connect MODE/SYNC to GND for AUTO mode or to EXT_PU for FPWM mode. Connect an external clock signal (320kHz to 480kHz) to MODE/SYNC to synchronize the device and operate in FPWM mode. |
| GND | GND connection |

**Table 2-3. EVM Output Voltage (–VOUT) Select Options**

| LABEL | DESCRIPTION |
|---|---|
| –12V | Jumper across pins 1 – 2 on J2 sets the output voltage to –12V |
| –5V | Jumper across pins 3 – 4 on J2 sets the output voltage to –5V |
| –3.3V | Jumper across pins 5 – 6 on J2 sets the output voltage to –3.3V |

**Table 2-4. EVM Test Point Connections**

| LABEL | DESCRIPTION |
|---|---|
| VIN_S | Input supply voltage monitoring point |
| GND_SENSE | GND_SENSE voltage monitoring point for –VOUT and INJ |
| INJ | 50Ω injection point for loop response |

### 2.1.2 Test Equipment

**Voltage Source:** The input voltage source $V_{IN}$ must be an 80V variable DC source capable of supplying 8A.

**Multimeters:**

- **Voltmeter 1:** Measure the input voltage at VIN_S to GND test point (TP3).
- **Voltmeter 2:** Measure the output voltage at GND (TP3) to –VOUT (TP4).
- **Ammeter 1:** Measure the input current.
- **Ammeter 2:** Measure the output current.

**Electronic Load:** The load must be an electronic constant-resistance (CR) or constant-current (CC) mode capable of 0A to 6A. For a no-load input current measurement, disconnect the electronic load as the load can draw a small residual current.

**Oscilloscope:** With the scope set to 20MHz 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 ground barrel of the probe through the ground lead to the negative terminal of the capacitor. TI does not recommend using a long-leaded ground connection because this can induce additional noise given a large ground loop. To measure other waveforms, adjust the oscilloscope as needed.

**Safety:** Use caution when touching any circuits that can be live or energized. Always have ESD protection.

### 2.1.3 Recommended Test Setup

#### 2.1.3.1 Input Connections

- Prior to connecting the DC input source, set the current limit of the input source to 0.1A. Make sure the input source is initially set to 0V and connected to the VIN+ and VIN– connection points as shown in Figure 2-1.
- Connect voltmeter 1 at VIN_S and GND (TP3) connection points to measure the input voltage.
- Connect ammeter 1 to measure the input current.

#### 2.1.3.2 Output Connections

- Connect an electronic load to GND and –VOUT connections as shown in Figure 2-1. Set the load to constant-resistance mode or constant-current mode at 0A before applying input voltage.
- Connect voltmeter 2 at GND_SENSE (TP7) and –VOUT (TP4) sense points to measure the output voltage.
- Connect ammeter 2 to measure the output current.

### 2.1.4 Test Procedure

#### 2.1.4.1 Line and Load Regulation and Efficiency

- Set up the EVM as described in *EVM Connections*.
- Place a jumper on J2 (–VOUT select) to set the output voltage to –12V.
- Set the load to constant resistance or constant current mode to sink 0A.
- Increase the input voltage source from 0V to 65V – $|V_{OUT}|$; use voltmeter 1 to measure the input voltage.
- Increase the current limit of the input supply to 8A.
- Use voltmeter 2 to measure the output voltage. With an input voltage of 48V, vary the load current from 0A to 6A. $V_{OUT}$ must remain within the load regulation specification.

- Set the load current to 2A and vary the input voltage source from 12V to (65V – |$V_{OUT}$|). $V_{OUT}$ must remain within the line regulation specification.
- Set the load current to 3.8A, 5.2A and 6A and measure the efficiency at typical input voltages of 12V, 24V, and 48V, respectively.
- Decrease the load to 0A. Decrease the input voltage source to 0V.

**WARNING**

Extended operation at high output current can raise component and EVM board temperatures above 55°C. To avoid risk of a burn injury, do not touch the components and the EVM board until cooled sufficiently after disconnecting power.

# 3 Implementation Results

## 3.1 Performance Data and Results

Figure 3-1 through Figure 3-11 show the typical performance curves for the EVM. Because actual performance data can be affected by measurement techniques and environmental variables, these curves are presented for reference and can differ from actual field measurements.

### *3.1.1 Conversion Efficiency*

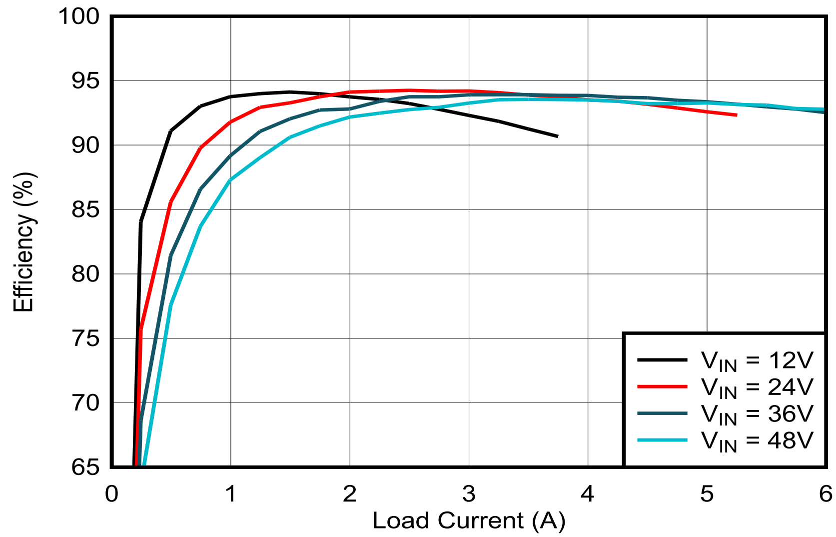


**Figure 3-1. Efficiency, $V_{OUT}$ = –12V, FPWM Mode**

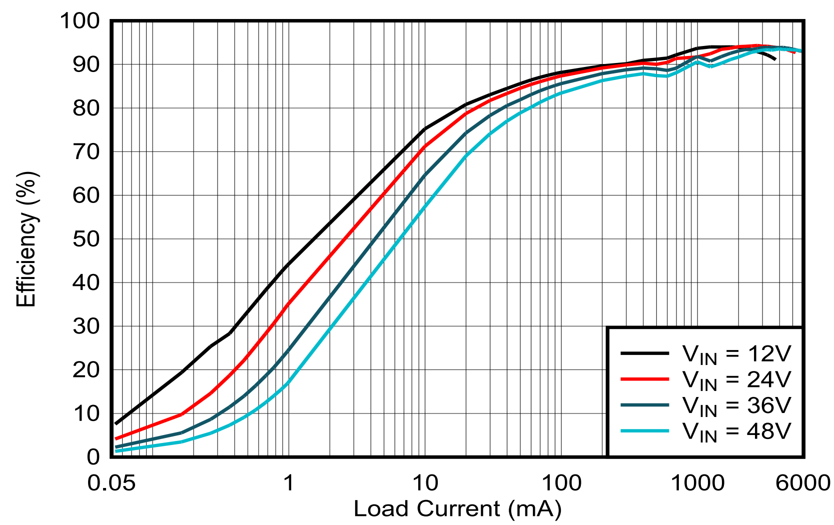


**Figure 3-2. Efficiency, $V_{OUT}$ = –12V, AUTO Mode**

### 3.1.2 Operating Waveforms

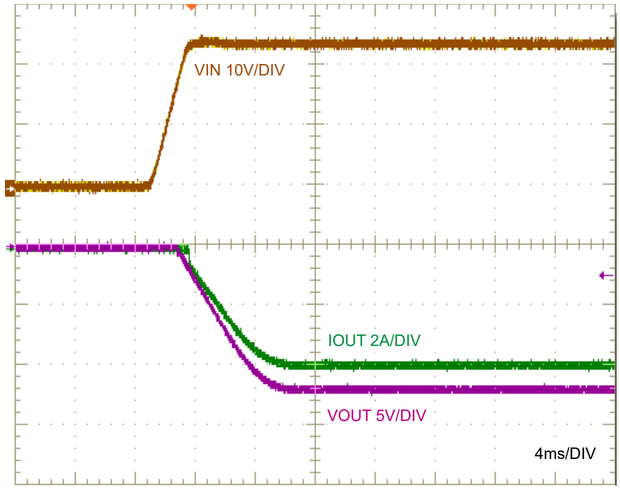


**Figure 3-3. Start-Up Characteristic, $V_{IN}$ = 48V, $V_{OUT}$ = –12V, 3Ω Resistive Load**

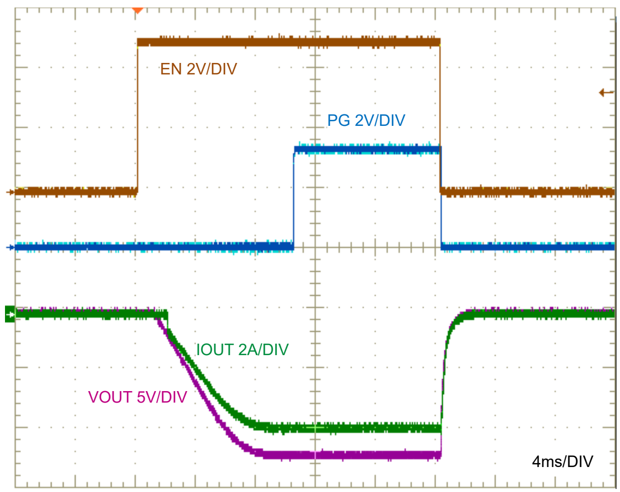


**Figure 3-4. Enable On/Off Characterisitc, $V_{IN}$ = 48V, $V_{OUT}$ = –12V, 3Ω Resistive Load**

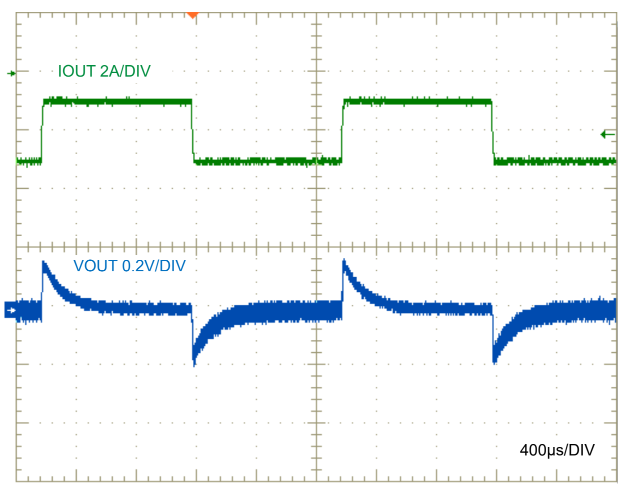


**Figure 3-5. Load Transient Response, $V_{IN}$ = 48V, $V_{OUT}$ = –12V, $I_{OUT}$ = –1A to –3A, FPWM**

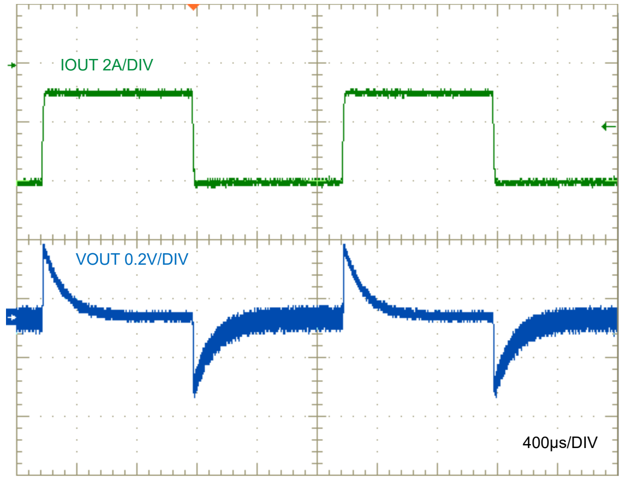


**Figure 3-6. Load Transient Response, $V_{IN}$ = 48V, $V_{OUT}$ = –12V, $I_{OUT}$ = –1A to –4A, FPWM**

### *3.1.3 Bode Plot*

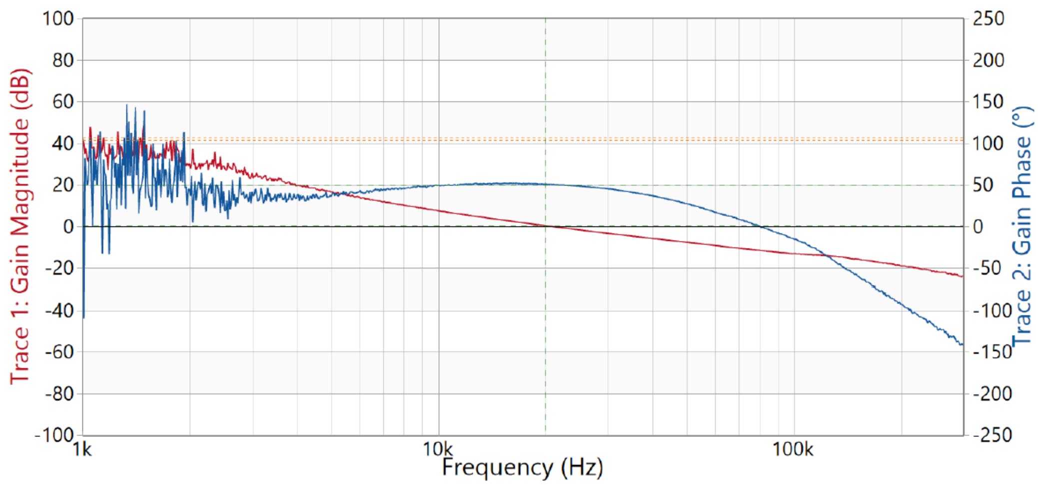


**Figure 3-7. Bode Plot, $V_{IN}$ = 24V, $V_{OUT}$ = –12V, $I_{OUT}$ = 5.2A Resistive Load, $f_C$ = 20kHz, PM = 50°**

### 3.1.4 CISPR 25 EMI Performance

Figure 3-8 and Figure 3-9 shows the radiated and conducted emissions performance of the LM67680-Q1 EVM at 24V input with DRSS enabled. Conducted emissions were measured over a frequency range of 150kHz to 108MHz using a 5μH LISN according to the CISPR 25 specification. CISPR 25 Class 5 peak and average limit lines are denoted in red. The purple and green spectra are measured using peak and average detectors, respectively. Radiated emissions were measured over a frequency range of 30MHz to 6GHz. CISPR 25 Class 5 peak and average limit lines are denoted in orange and green respectively. The orange and green spectra are measured using peak and average detectors, respectively

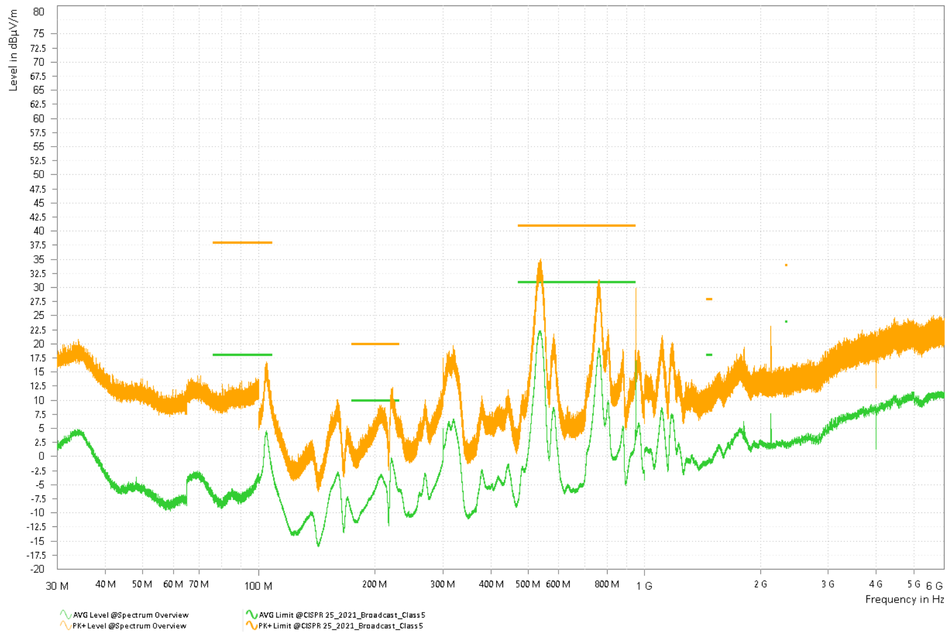


**Figure 3-8. Typical CISPR 25 Class 5 Radiated Emissions, 30MHz to 6GHz, DRSS on, $V_{IN}$ = 24V, $V_{OUT}$ = –12V, $I_{OUT}$ = –4A Resistive Load, $F_{SW}$ = 400kHz**

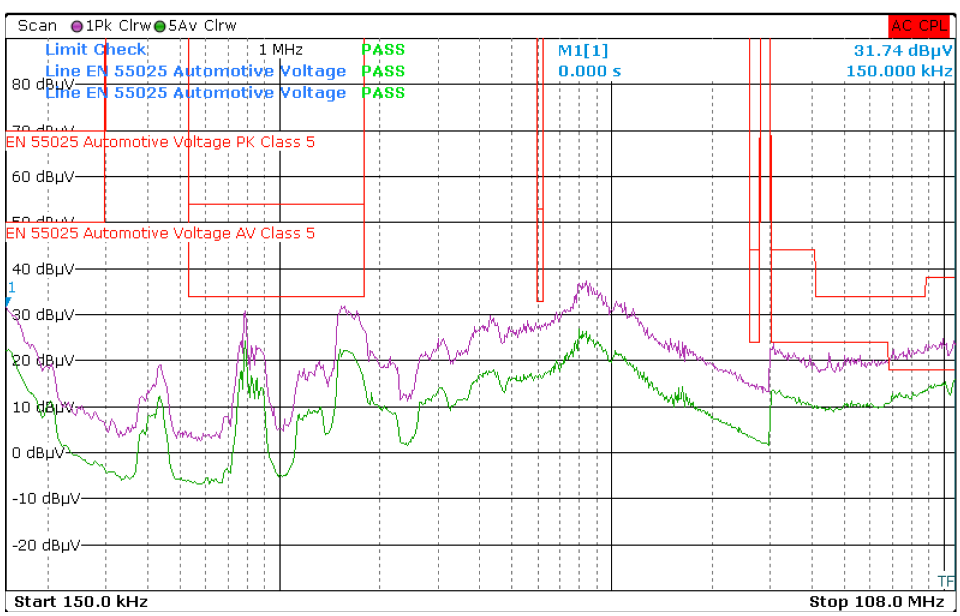


**Figure 3-9. CISPR 25 Class 5 Conducted Emissions Plot, 150kHz to 108MHz, DRSS on, $V_{IN}$ = 24V, $V_{OUT}$ = –12V, $I_{OUT}$ = –4A Resistive Load, $F_{SW}$ = 400kHz**

### 3.1.5 Thermal Performance

Figure 3-10 and Figure 3-11 show the thermal performance with –12V and –5V output, respectively.

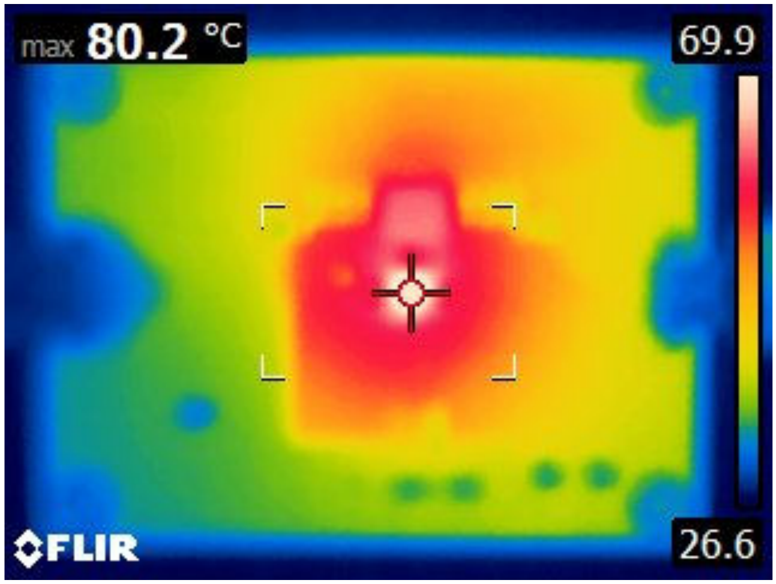


**Figure 3-10. Thermal Performance, $V_{IN}$ = 24V, $V_{OUT}$ = –12V, $I_{OUT}$ = –4A, $T_A$ = 25°C, No Airflow**

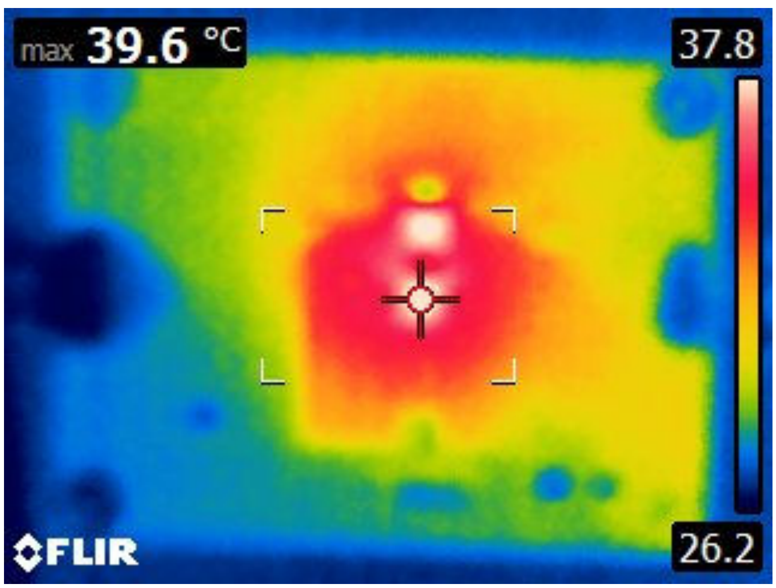


**Figure 3-11. Thermal Performance, $V_{IN}$ = 12V, $V_{OUT}$ = –5V, $I_{OUT}$ = –2.7A, $T_A$ = 25°C, No Airflow**

# 4 Hardware Design Files

## 4.1 Schematic

Figure 4-1 provides the EVM schematic.

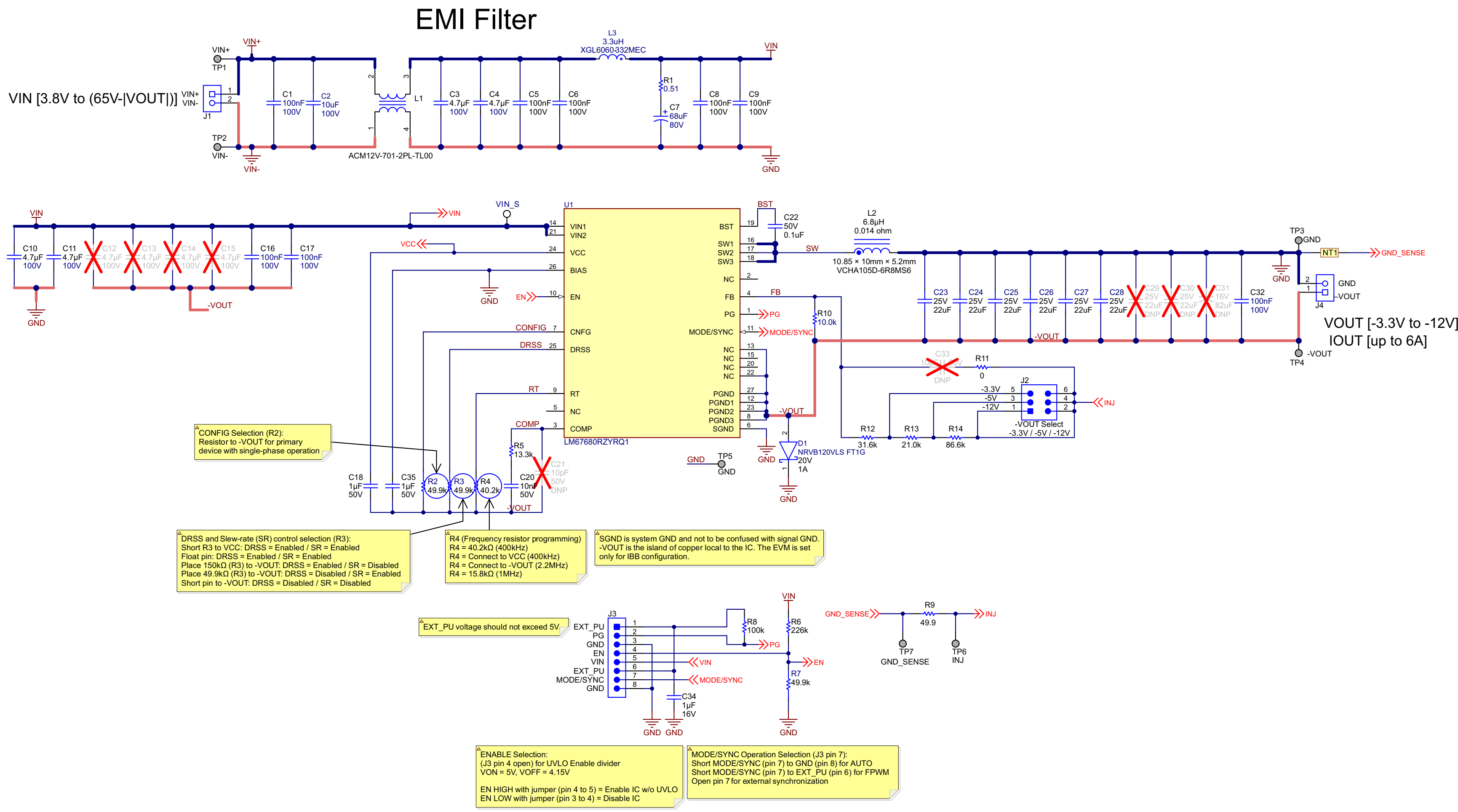


**Figure 4-1. EVM Schematic**

## 4.2 PCB Layout

Figure 4-2 through Figure 4-9 show the design of the LM67680-Q1 EVM using a four-layer PCB with 62mils standard thickness and 2oz copper on all layers.

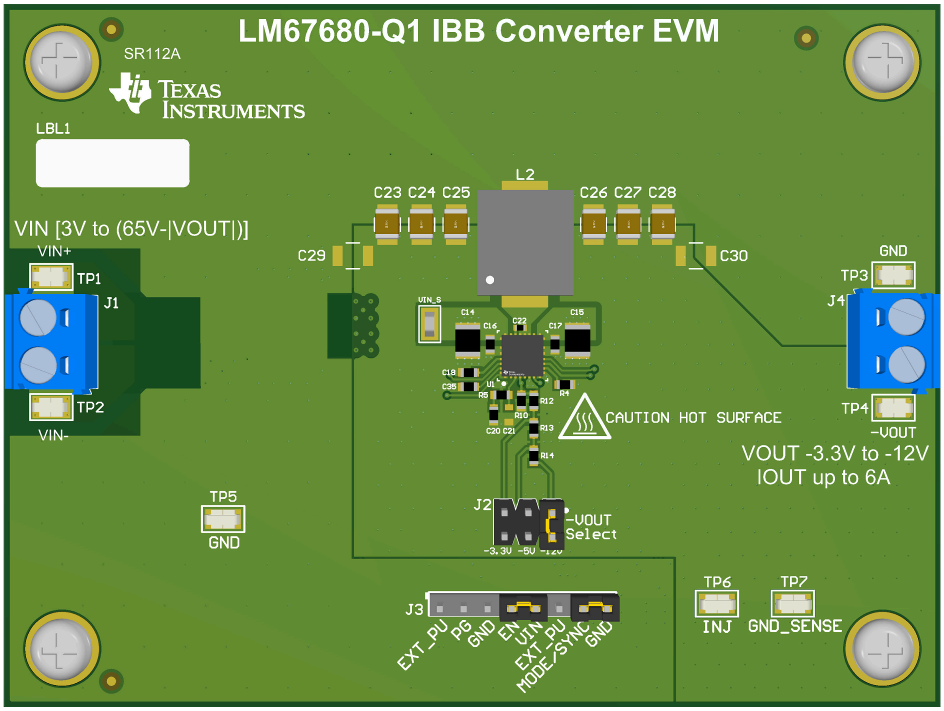


**Figure 4-2. Top 3D View**

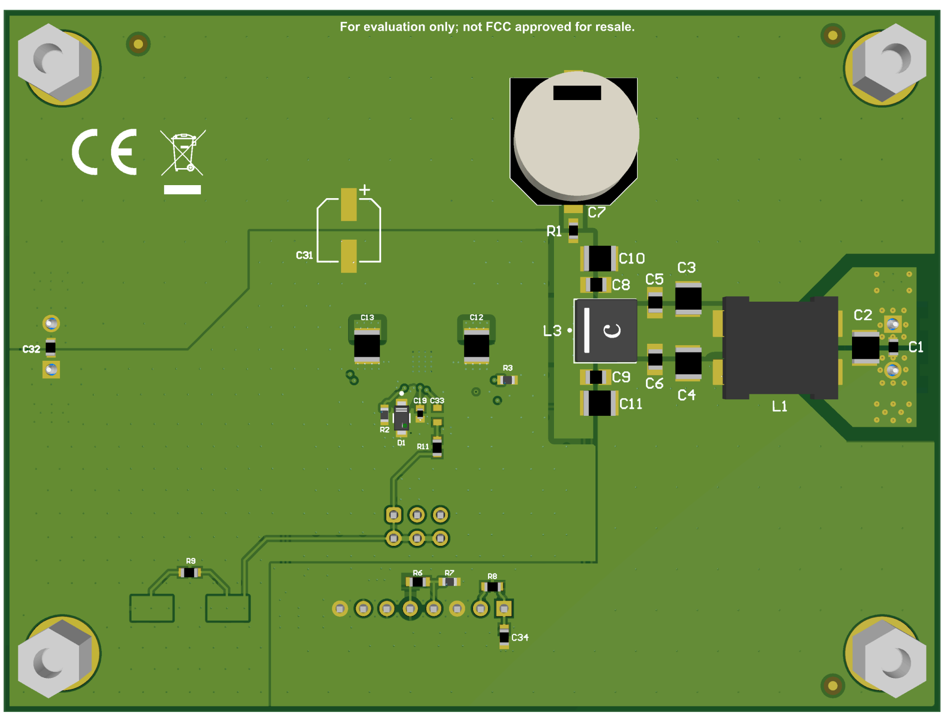


**Figure 4-3. Bottom 3D View (Viewed from Bottom)**

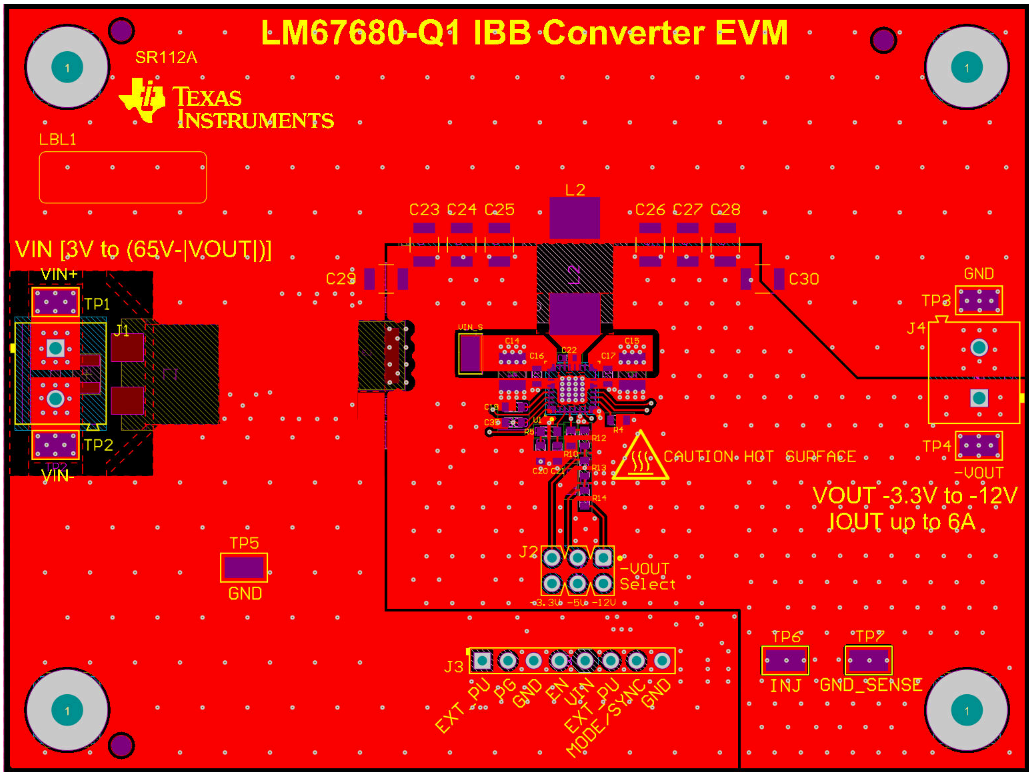


Figure 4-4. Top Layer Copper (Top View)

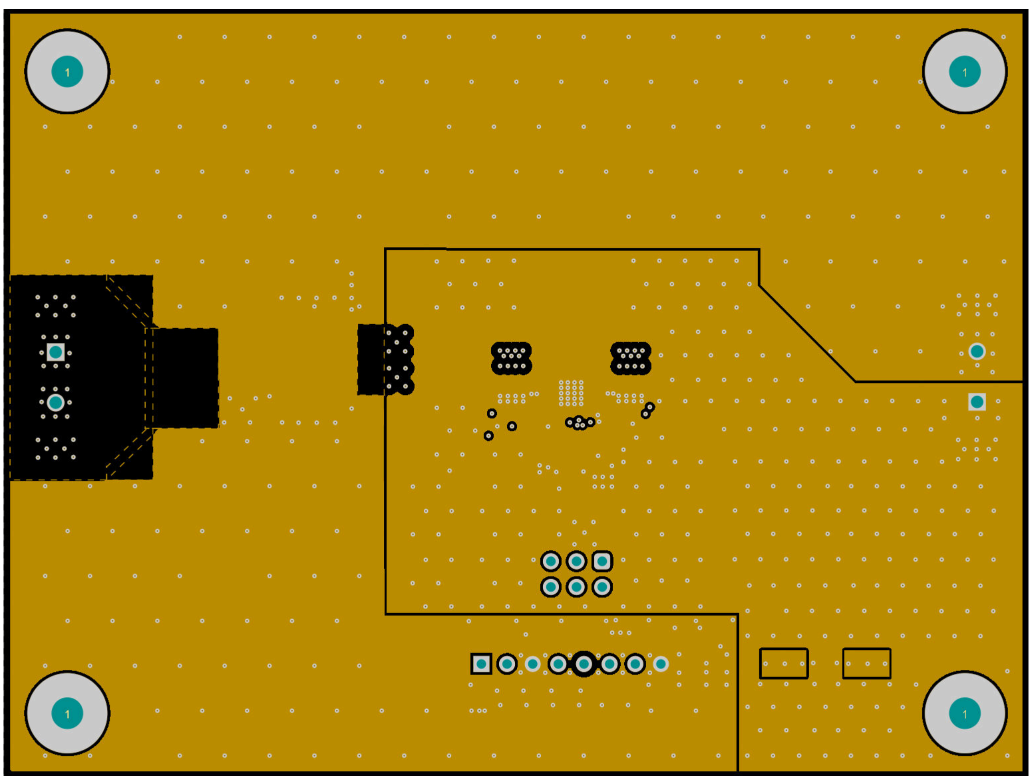

Figure 4-5. Layer 2 Copper (Top View)

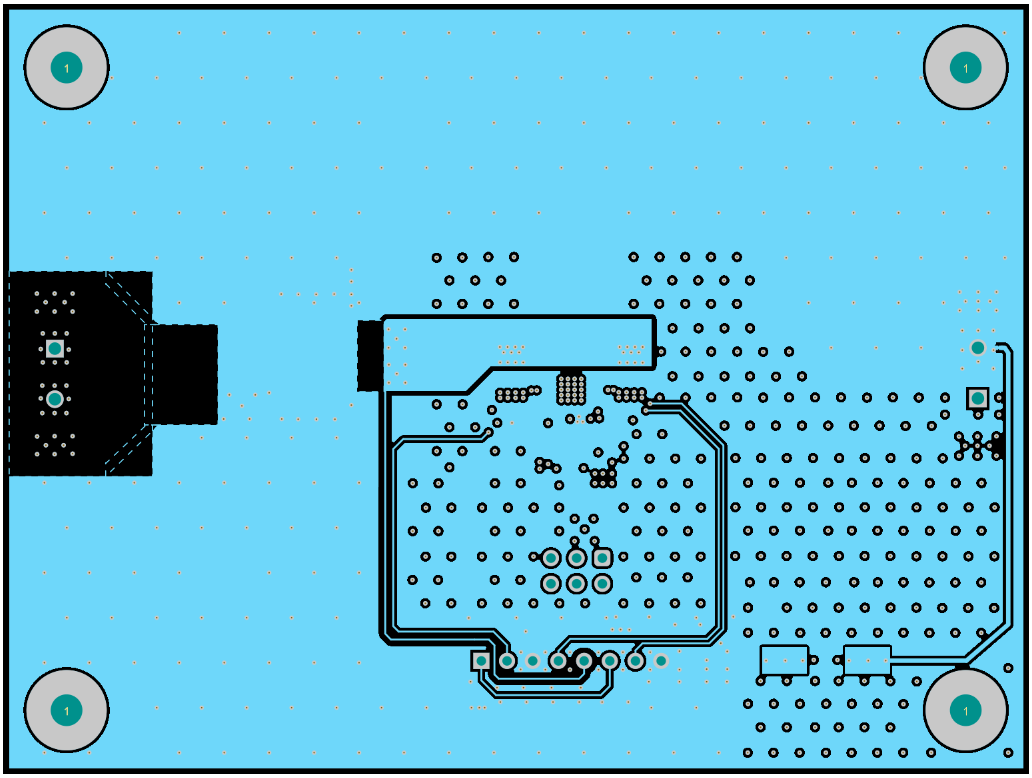

**Figure 4-6. Layer 3 Copper (Top View)**

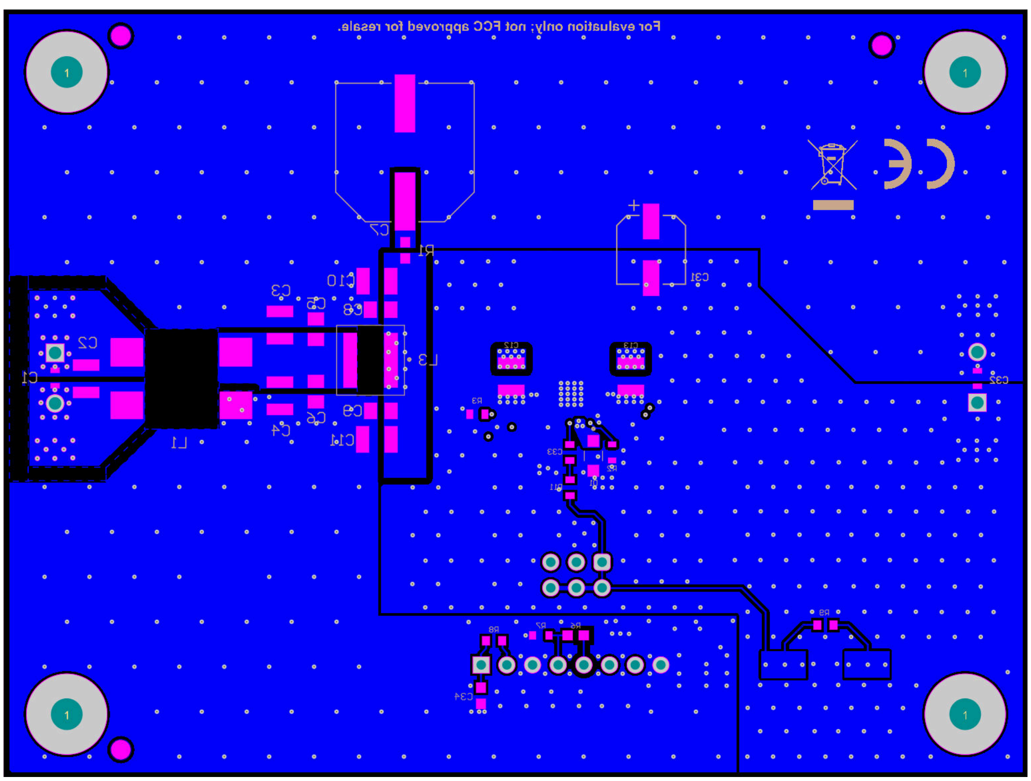

**Figure 4-7. Bottom Layer Copper (Top View)**

### 4.2.1 Component Drawings

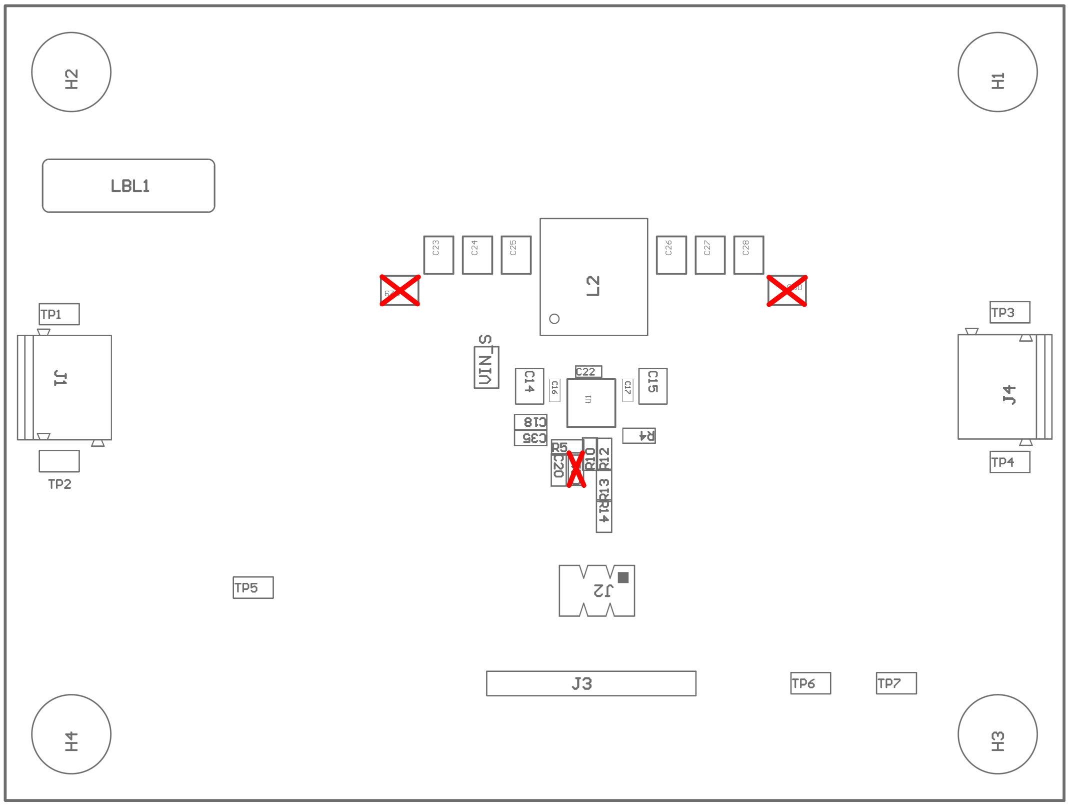


Figure 4-8. Top Component Drawing

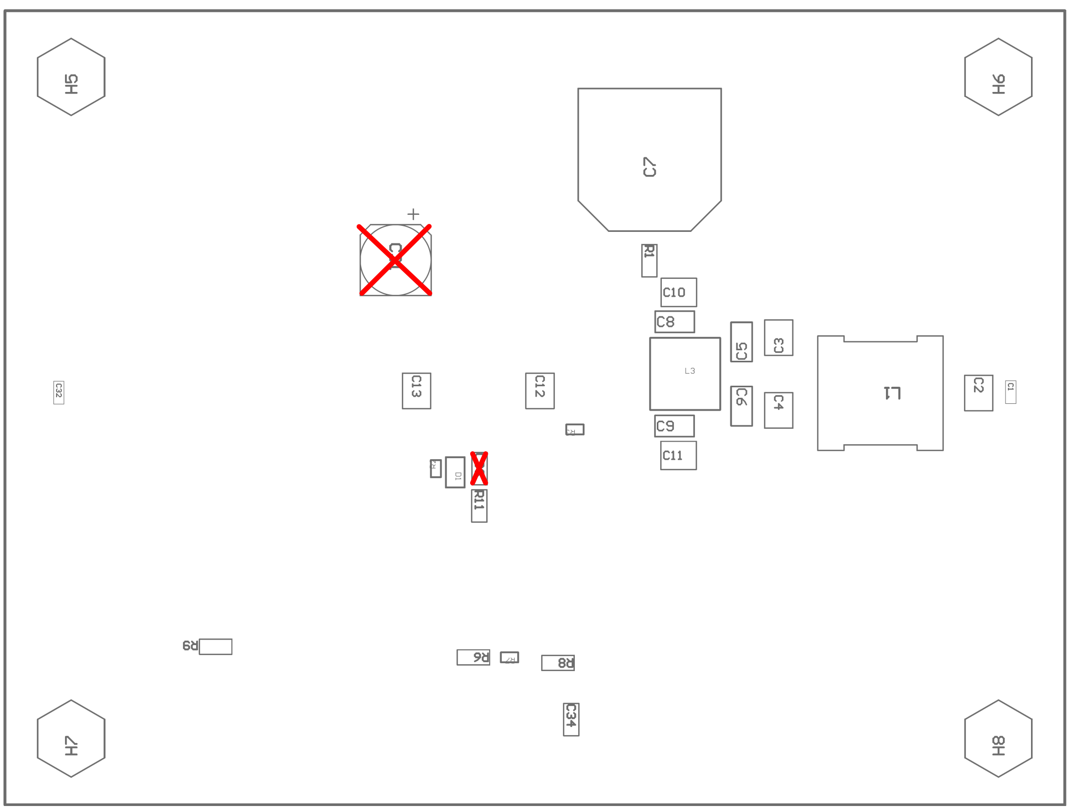


Figure 4-9. Bottom Component Drawing

### 4.2.2 Multi-Layer Stackup

| # | Name | Material | Type | Weight | Thickness | Dk | Df |
|---|---|---|---|---|---|---|---|
| | Top Overlay | | Overlay | | | | |
| | Top Solder | Solder Resist | Solder Mask | | 0.4mil | 3.5 | |
| 1 | Top Layer | | Signal | 2oz | 2.8mil | | |
| | Dielectric1 | FR-4 High Tg | Core | | 5mil | 4.2 | |
| 2 | Signal Layer 1 | | Signal | 2oz | 2.8mil | | |
| | Dielectric 2 | FR-4 High Tg | Prepreg | | 40mil | 4.2 | |
| 3 | Signal Layer 2 | | Signal | 2oz | 2.8mil | | |
| | Dielectric 3 | FR-4 High Tg | Core | | 5mil | 4.2 | |
| 4 | Bottom Layer | | Signal | 2oz | 2.8mil | | |
| | Bottom Solder | Solder Resist | Solder Mask | | 0.4mil | 3.5 | |
| | Bottom Overlay | | Overlay | | | | |

**Figure 4-10. Layer Stackup**

## 4.3 Bill of Materials

**Table 4-1. Component BOM**

| REF DES | QTY | DESCRIPTION | PART NUMBER | VENDOR |
|---|---|---|---|---|
| C1, C16, C17, C32 | 4 | Capacitor, ceramic, 0.1µF, 100V, X7R, 0603 | GCJ188R72A104K | MuRata |
| C2, C3, C4, C10, C11, C12, C13, C14, C15 | 9 | Capacitor, ceramic, 4.7µF, 100V, X7S, 1210 | GCM32DC72A475K | MuRata |
| | | | CGA6M3X7S2A475K | TDK |
| C5, C6, C8, C9 | 4 | Capacitor, ceramic, 0.1µF, 100V, X7R, 0805 | CGA4J2X7R2A104K | TDK |
| C7 | 1 | Capacitor, aluminum, 68µF, 80V, 0.32Ω, SMD | EEV-FK1K680Q | Panasonic |
| C18, C35 | 2 | Capacitor, ceramic, 1µF, 50V, X7R, 0603 | CGA3E3X7R1H105M | TDK |
| C20 | 1 | Capacitor, ceramic, 0.01µF, 50V, C0G/NP0, 0603 | CGA3E2C0G1H103J | TDK |
| C22 | 1 | Capacitor, ceramic, 0.1µF, 50V, X7R, 0402 | CGA2B3X7R1H104K | TDK |
| C23, C24, C25, C26, C27, C28 | 6 | Capacitor, ceramic, 22µF, 25V, X7R, 1210 | CGA6P3X7R1E226M | TDK |
| | | Capacitor, ceramic, 22µF, 25V, X7S, 1210 | GCM32EC71A476K | Murata |
| C34 | 1 | Capacitor, ceramic, 1µF, 16V, X7R, 0603 | GCM188R71C105M | MuRata |
| D1 | 1 | Diode, Schottky, 20V, 1A, SOD-123FL | NRVB120VLSFT1G | onsemi |
| H1, H2, H3, H4 | 4 | Machine screw, round, #4-40 × 1/4, nylon, Philips panhead | NY PMS 440 0025 PH | B&F Fastener Supply |
| H5, H6, H7, H8 | 4 | Standoff, hex, 0.5"L #4-40 nylon | 1902C | Keystone |
| J1, J4 | 2 | Terminal block, 5mm, 2 × 1, tin, TH | 691 101 710 002 | Würth Elektronik |
| J2 | 1 | Header, 100mil, 3 × 2, tin, TH | 5-146254-3 | TE Connectivity |
| J3 | 1 | Header, 100mil, 8 × 1, tin, TH | 5-146278-8 | TE Connectivity |
| L1 | 1 | Common-mode choke, 7.6µH, 700Ω, 12 × 11mm | ACM12V-701-2PL-TL00 | TDK |
| L2 | 1 | Inductor, 6.8µH, 7.1mΩ, 20A, 11.3 × 10 × 6mm | 744393665068 | Würth Elektronik |
| | | Inductor, 6.8µH, 14mΩ, 10.8A, 10.85 × 10 × 5.2mm | VCHA105D-6R8MS6 | Cyntec |
| L3 | 1 | Inductor, 3.3µH, 6mΩ, 15.6A, 6.6 × 6.4 × 6.1mm | 744393465033 | Würth Elektronik |
| | | Inductor, 3.3µH, 6.5mΩ, 16.6A, 6.7 × 6.5 × 6.1mm | XGL6060-332MEC | Coilcraft |
| | | Inductor, 3.3µH, 6.3mΩ, 16A, 6.6 × 6.4 × 6mm | XFHCL6060HC-3R3M | XFMRS |
| LBL1 | 1 | Thermal transfer printable labels, 0.65" W × 0.2" H | THT-14-423-10 | Brady |
| R1, R11 | 2 | RES, 0, 0.1W, 0603 | RMCF0603ZT0R00 | Stackpole |
| R2, R3, R7 | 3 | RES, 49.9kΩ, 1%, 0.1W, 0603 | CRCW060349K9FKEA | Vishay |
| R4 | 1 | RES, 40.2kΩ, 1%, 0.1W, 0603 | CRCW060340K2FKEA | Vishay |
| R5 | 1 | RES, 13.3kΩ, 1%, 0.1 W, 0603 | CRCW060313K3FKEA | Vishay |
| R6 | 1 | RES, 226kΩ, 1%, 0.1W, 0603 | CRCW0603226KFKEA | Vishay |
| R8 | 1 | RES, 100kΩ, 1%, 0.1W, 0603 | CRCW0603100KFKEA | Vishay |
| R9 | 1 | RES, 49.9Ω, 1%, 0.1 W, 0603 | CRCW060349R9FKEA | Vishay |
| R10 | 1 | RES, 10kΩ, 1%, 0.1W, 0603 | CRCW060310KFKEA | Vishay |
| R12 | 1 | RES, 31.6kΩ, 1%, 0.1 W, 0603 | CRCW060331K6FKEA | Vishay |
| R13 | 1 | RES, 21kΩ, 1%, 0.1 W, 0603 | CRCW060321K0FKEA | Vishay |
| R14 | 1 | RES, 86.6kΩ, 1%, 0.1 W, 0603 | CRCW060386K6FKEA | Vishay |
| SH-J1, SH-J2, SH-J3 | 3 | Shunt, 100mil, gold plated, black | SNT-100-BK-G | Samtec |
| TP1, TP2, TP3, TP4, TP5, TP6, TP7 | 7 | Test point, miniature, SMT | 5019 | Keystone |
| VIN_S | 1 | Test point, miniature, SMT | 5015 | Keystone |
| U1 | 1 | LM67680-Q1 65V, 8A, synchronous IBB converter | LM67680RZYRQ1 | Texas Instruments |
| PCB1 | 1 | PCB, FR4, 4 layer, 2oz | PCB | – |
| C21, C33 | 0 | Capacitor, ceramic, 10pF, 50V, C0G/NP0, 0603 | GRM1885C1H100JA01D | MuRata |
| C29, C30 | 0 | Capacitor, ceramic, 22µF, 25V, X7R, 1210 | CGA6P3X7R1E226M | TDK |
| C31 | 0 | Capacitor, aluminum polymer, 82µF, 16V, 0.03Ω | 875105344009 | Würth Elektronik |

# 5 Compliance Information

## 5.1 Compliance and Certifications

*LM67680-Q1EVM EU Declaration of Conformity (DoC) for Restricting the use of Hazardous Substances (RoHS)* certificate

# 6 Additional Information

## 6.1 Trademarks

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# 7 Related Documentation

For related documentation, see the following:

- Texas Instruments, *LM67680-Q1, LM67660-Q1 and LM67640-Q1 Automotive, 65V, 8A/6A/4A, Inverting Buck-Boost Converter Family With Low-EMI ZEN 1 Switcher Technology* data sheet
- Texas Instruments, *LM65680-Q1 65$V_{IN}$, 5$V_{OUT}$, 8A Synchronous Buck DC/DC Regulator Evaluation Module* user's guide

## 7.1 Supplemental Content

### *7.1.1 Development Support*

For development support, see the following:

- For TI's reference design library, visit TI reference designs.
- For TI's WEBENCH Design Environments, visit the WEBENCH® Design Center.
- LM67680-Q1 DC/DC Converter Quickstart Calculator.

### *7.1.2 IBB Design Resources*

- Texas Instruments, *Buck-boost and SEPIC* landing page
- Texas Instruments, *How to Modify a Step-down Converter to the Inverting Buck-boost Topology* technical article
- Texas Instruments, *Using a buck converter in an inverting buck-boost topology* analog design journal
- Texas Instruments, *Working with inverting buck-boost converters* application note
- Texas Instruments, *Using the TPSM53602/3/4 for negative-output, inverting buck-boost applications* application report

### *7.1.3 PCB Layout Resources*

- LM65680-Q1 buck regulator EVM *Altium layout* source files
- LM67680-Q1 IBB regulator EVM *Altium layout* source files
- Texas Instruments, *Laying Out an Inverting Buck-Boost Converter for Success* application note
- Texas Instruments, *Improve High-Current DC/DC Regulator EMI Performance for Free With Optimized Power Stage Layout* application brief
- Texas Instruments, *Constructing Your Power Supply – Layout Considerations* seminar

### *7.1.4 Thermal Design Resources*

- Texas Instruments, *Improving Thermal Performance in High Ambient Temperature Environments With Thermally Enhanced Packaging* white paper
- Applications notes:
  - Texas Instruments, *Thermal Design by Insight, Not Hindsight*
  - Texas Instruments, *A Guide to Board Layout for Best Thermal Resistance for Exposed Pad Packages*
  - Texas Instruments, *Semiconductor and IC Package Thermal Metrics*
  - Texas Instruments, *PowerPAD™ Thermally Enhanced Package*
  - Texas Instruments, *Using New Thermal Metrics*
- Texas Instruments, *PowerPAD™ Made Easy* application brief

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NOTE:

EXPOSURE TO ELECTROSTATIC DISCHARGE (ESD) MAY CAUSE DEGREDATION OR FAILURE OF THE EVALUATION KIT; TI RECOMMENDS STORAGE OF THE EVALUATION KIT IN A PROTECTIVE ESD BAG.

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3.1.1 *Notice applicable to EVMs not FCC-Approved:*

**FCC NOTICE:** 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 or RSS-247*

**Concerning EVMs Including Radio Transmitters:**

This device complies with Industry Canada license-exempt RSSs. 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。

https://www.ti.com/ja-jp/legal/notice-for-evaluation-kits-delivered-in-japan.html

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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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8. *Limitations on Damages and Liability:*

   8.1 *General Limitations*. IN NO EVENT SHALL TI BE LIABLE FOR ANY SPECIAL, COLLATERAL, INDIRECT, PUNITIVE, INCIDENTAL, CONSEQUENTIAL, OR EXEMPLARY DAMAGES IN CONNECTION WITH OR ARISING OUT OF THESE TERMS OR THE USE OF THE EVMS , REGARDLESS OF WHETHER TI HAS BEEN ADVISED OF THE POSSIBILITY OF SUCH DAMAGES. EXCLUDED DAMAGES INCLUDE, BUT ARE NOT LIMITED TO, COST OF REMOVAL OR REINSTALLATION, ANCILLARY COSTS TO THE PROCUREMENT OF SUBSTITUTE GOODS OR SERVICES, RETESTING, OUTSIDE COMPUTER TIME, LABOR COSTS, LOSS OF GOODWILL, LOSS OF PROFITS, LOSS OF SAVINGS, LOSS OF USE, LOSS OF DATA, OR BUSINESS INTERRUPTION. NO CLAIM, SUIT OR ACTION SHALL BE BROUGHT AGAINST TI MORE THAN TWELVE (12) MONTHS AFTER THE EVENT THAT GAVE RISE TO THE CAUSE OF ACTION HAS OCCURRED.

   8.2 *Specific Limitations.* IN NO EVENT SHALL TI'S AGGREGATE LIABILITY FROM ANY USE OF AN EVM PROVIDED HEREUNDER, INCLUDING FROM ANY WARRANTY, INDEMITY OR OTHER OBLIGATION ARISING OUT OF OR IN CONNECTION WITH THESE TERMS, , EXCEED THE TOTAL AMOUNT PAID TO TI BY USER FOR THE PARTICULAR EVM(S) AT ISSUE DURING THE PRIOR TWELVE (12) MONTHS WITH RESPECT TO WHICH LOSSES OR DAMAGES ARE CLAIMED. THE EXISTENCE OF MORE THAN ONE CLAIM SHALL NOT ENLARGE OR EXTEND THIS LIMIT.

9. *Return Policy.* Except as otherwise provided, TI does not offer any refunds, returns, or exchanges. Furthermore, no return of EVM(s) will be accepted if the package has been opened and no return of the EVM(s) will be accepted if they are damaged or otherwise not in a resalable condition. If User feels it has been incorrectly charged for the EVM(s) it ordered or that delivery violates the applicable order, User should contact TI. All refunds will be made in full within thirty (30) working days from the return of the components(s), excluding any postage or packaging costs.

10. *Governing Law:* These terms and conditions shall be governed by and interpreted in accordance with the laws of the State of Texas, without reference to conflict-of-laws principles. User agrees that non-exclusive jurisdiction for any dispute arising out of or relating to these terms and conditions lies within courts located in the State of Texas and consents to venue in Dallas County, Texas. Notwithstanding the foregoing, any judgment may be enforced in any United States or foreign court, and TI may seek injunctive relief in any United States or foreign court.

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# IMPORTANT NOTICE AND DISCLAIMER