# bq24220 High-Voltage Charger Evaluation Module

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# 1 Introduction

This user's guide describes the bq24220 evaluation module (EVM). The EVM provides a convenient method for evaluating the performance of the bq24220 integrated circuit (IC), a high-voltage input, single-cell, Li-ion charge management solution for portable applications. A completely designed and tested charger is presented. The output of the DC-DC buck converter is designed to deliver up to 2 A which can be used as an input to the charger and also a independent power source. The charger is designed to deliver up to 1.25 A of continuous charge current for single-cell Li-ion or Li-polymer applications using a DC power supply.

## 1.1 Background

The bq24220 IC consists of a high-voltage input DC-DC buck converter followed by a low-voltage, single-cell integrated Li-ion and Li-polymer linear charger, targeted at space-limited portable applications. The bq24220 provides the ability to efficiently charge a single-cell Li-Ion battery with a high-voltage input. The battery is charged in three phases: conditioning, constant or thermally regulated current, and constant voltage. Charge is terminated based on minimum current. An internal charge timer provides a backup safety feature for charge termination. The bq24220 automatically restarts the charge if the battery voltage falls below the refresh threshold; sleep mode is set when the external input supply is removed. The DC-DC buck converter also can independently supply power to the system.

## 1.2 Performance Specification Summary

This section summarizes the performance specifications of the EVM. Table 1 gives the performance specifications of the EVM.

**Table 1. Performance Specification Summary**

| SPECIFICATION | | TEST CONDITIONS | MIN | TYP | MAX | UNIT |
|---|---|---|---|---|---|---|
| $V_{I(DC)}$ | Input DC Voltage | $V_{(DC-OUT)}$ = Ichg × 350 mΩ, Ohms + 4.2 V | 5 | 20 | 45 | V |
| $I_{O(CHG)}$ | Battery Charge Current | See [(1)] | | | 1.25 | A |
| | IC Power Dissipation Estimate+ | $(V_{(IN)} \times I_{(IN)}) \times 0.15 + (1\ V \times I_{(BAT+)})$ for $V_{DC-OUT}$ = 4.47 V | | | 3 | W |

(1) The IC power dissipation in the IC consists of two power conversions and is only a thermal concern at higher loads where the efficiency of the buck converter is approximately 85%. The linear charger efficiency is a function of its input voltage and the battery voltage. The thermal response of most PCBs is relatively slow ( >2 min) and typically the charge voltage of the battery reaches ~3.4 V during this time. Therefore, the peak IC temperatures are reached once the system board has reached its maximum temperature. The battery will be ~3.4 V and the input is ~4.4 V which explains the 1-V drop times the charge current for worst-case power. The converter has 15% total dissipation, which is mostly dissipated in the IC, and what is not can be considered a thermal margin of safety.

# 2 Test Summary

This section shows the test setups used and the tests performed in evaluating the EVM.

## 2.1 Equipment

| | |
|---|---|
| Power Sources: | DC+ Input: 50-VDC adjustable supply with adjustable current limit ≥2 A |
| | USB input: 5-V supply with adjustable current limit ≥1 A. |
| Three Fluke 75 — | Equivalent or better |
| Oscilloscope — | TDS220 or better, minimum of 2 channels/probes |
| | Single-cell Li-ion/polymer battery (4.2 Vreg) |

### 2.2 Equipment Setup

1. Preset the DC+ input power source to 25 V ±0.25 VDC, a current limit of 2 A ±0.1 ADC, and turn off the supply. Connect the power supply's positive lead to J1-DC+ and the negative lead to J1-GND.
2. Preset the USB input power source to 5 V ±0.1 VDC, a current limit of 1 A ±0.1 ADC, and turn off the supply. Connect the power supply's positive lead to J2-USB and the negative lead to J2-GND.
3. Connect a discharged single-cell Li-ion/polymer battery to J3-BAT+ and J3-BAT–. A 0.1-Ω sense resistor can be added (optional) to the return of the battery lead in order to measure charge current.
4. Connect a switch (set to open) and 10-Ω, 5-W power resistor between J3-DC-OUT and BAT– as shown in Figure 1.
5. Connect:
   - DVM#1-DCV: Red-JMP5 (DC-OUT), Blk-J3-BAT–
   - DVM#2-DCV: Red-J3-BAT+, Blk-J2-BAT–
   - DVM#3-DCmV: Red-right side of sense resistor, Blk-left side of sense resistor, as shown in Figure 1 .
6. Use the scope probes when called for in the test procedure. Note: There is only one ground plane, so GND = BAT–. Choose the closest ground connection for a given signal's ground lead.

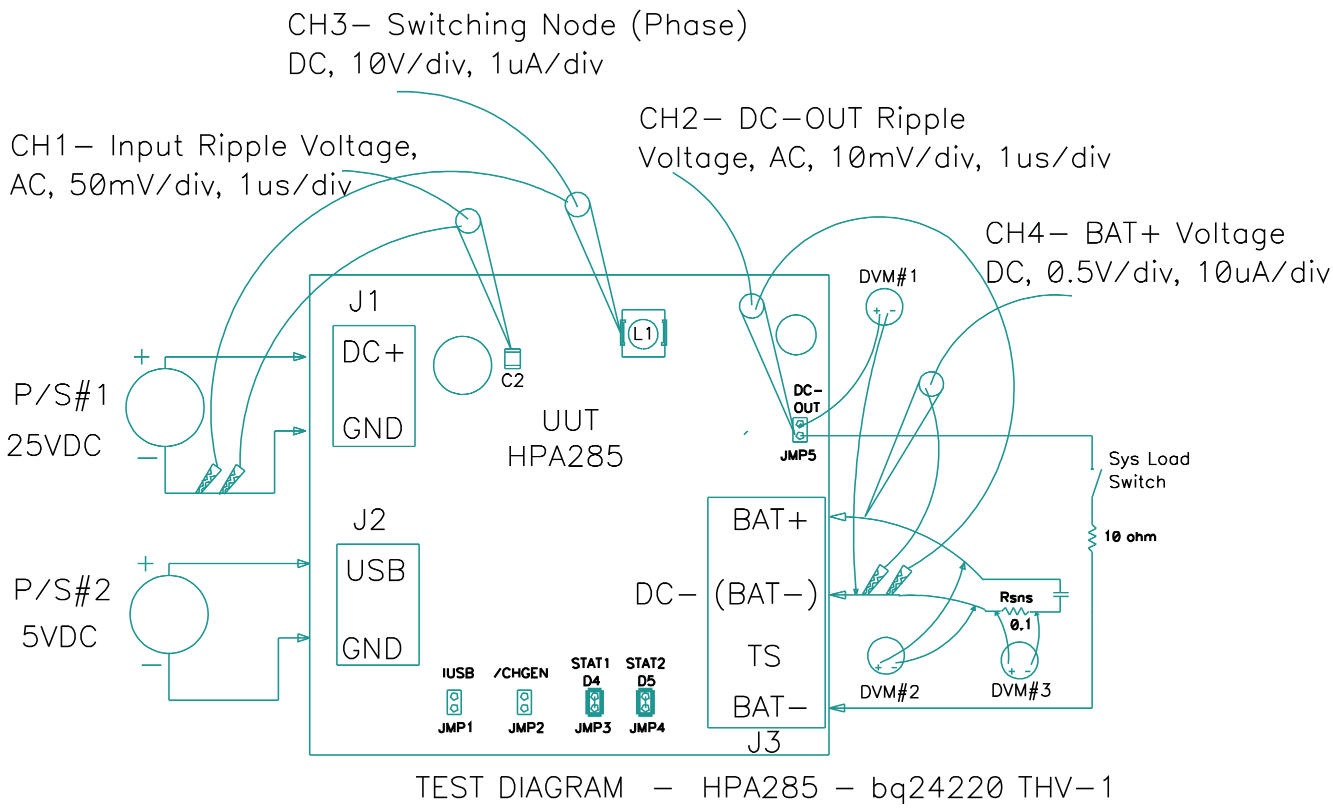


**Figure 1. Test Diagram — HPA285 — bq24220 THV-1**

**Table 2. I/O and Jumper Connections (Factory Jumper Selections are shown in BOLD)**

| Jack | Connect To: |
|---|---|
| J1-DC+ | Input Power Supply (+) to DC-DC buck converter, preset to +25 VDC (Range is from 5-to-45 VDC, 1.5- A current limit. |
| J1-GND | Input Power Supply (converter) Return |
| J2-USB | USB Power Supply Input (+5 V). Add a 1-µF ceramic capacitor from J2 pin 1 to pin 2 on back of PCB. |
| J2-GND | USB Power Supply Return (–). Although unit passed test without capacitor, it is recommended. |

**Table 2. I/O and Jumper Connections (Factory Jumper Selections are shown in BOLD) (continued)**

| **Jack** | **Connect To:** |
|---|---|
| J3-BAT+ | Positive (4.2 Vreg) battery pack single-cell terminal |
| J3-BAT– | Negative battery pack single-cell terminal |
| J3-TS | UUT has fixed 10-kΩ resistor to indicate a fixed 25°C temperature. If external 10-kΩ thermistor is used, R19 on the EVM should be removed. |
| J3-GND | |
| JMP1-IUSB | USB Input Current Limit Set Threshold – Hi (shunt) –500 mA, Low (**no-shunt**) –100 mA |
| JMP2 - $\overline{\text{CHGEN}}$ | Charge Enable – Hi (shunt)–Charge Disabled, |
| | Low (**no shunt**)–Charge Enabled |
| JMP3 - STAT1 | JMP3-1 pin is at the edge of the PCB and connects to the STAT1 pin. |
| | JMP3-2 connects to the LED (D4)/Resistor – Shunt connects STAT1 to |
| | the LED. **Shunt installed.** |
| JMP4 - STAT2 | JMP4-1 pin is at the edge of the PCB and connects to the STAT2 pin.<br>JMP4-2 connects to the LED (D5)/Resistor – Shunt connects STAT2 to the LED. **Shunt installed.** |
| JMP5 - VDC-OUT | JMP5 - 1 and 2 ($V_{DC\text{-}OUT}$) Easy access for testing or system load connection. |

## 2.3 Test Procedure

Set up the evaluation board as previously described by making the necessary I/O connections and jumper selections. Prior to test and evaluation, it is important to verify that the maximum power dissipation on the IC is not exceeded, $P_{(MAX)}$ = 3 Watts.

1. Turn on PS#1 (+25 VDC, and 1.5-A current limit setting).
2. Turn on the System Load Switch to connect the 10-Ω load.
3. Verify that the input ripple on C2 (CH1) is ≤150 mVpp and output ripple on JMP5 (CH2) is ≤30 mVpp; CH1: AC, 50 mV/div; CH2: AC, 10 mV/div; 1 µs/div, CH1 trigger, respectively. Exclude noise spikes, see Figure 2

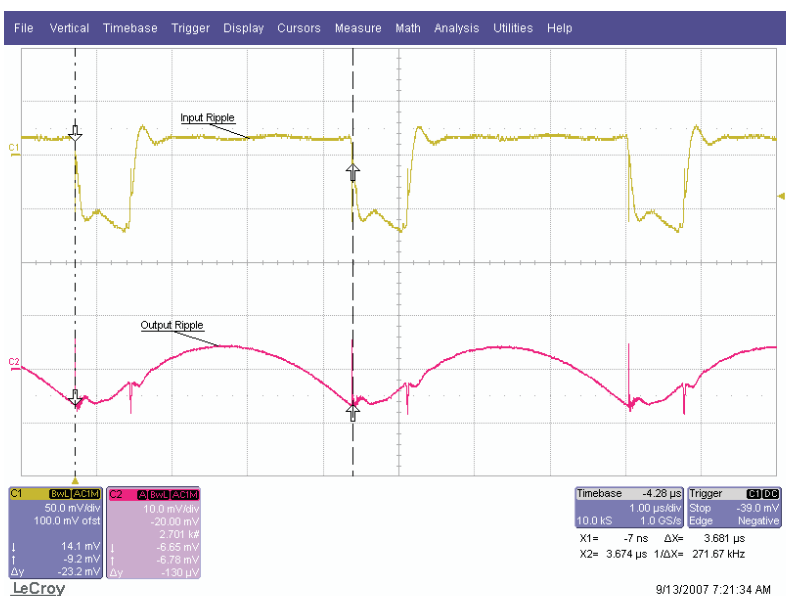


**Figure 2. Input and Output Ripple of DC-DC Converter**

4. Verify that the switching phase node at L1-1 looks similar to Figure 3: CH3: DC, 10 V/div, 1 µs/div, 25 MHz BW filtering.


**Figure 3. Phase Switching Node of DC-DC Converter**

5. The bq24220 enters preconditioning mode if the battery is below the V(LOWV) threshold. In this mode, the bq24220 precharges the battery with a low current (typically $I_{O(CHG)}$ /10 = 0.7 A/10 = 70 mA) until the battery voltage reaches the $V_{(LOWV)}$ threshold or until the precharge timer expires. If the timer expires, then the charge current is terminated and the bq24220 enters fault mode. Both LEDs turn off when in fault mode. Toggling input power (system load may need to be reduce to power up converter output) or battery replacement resets fault mode.
6. Once the battery voltage is above the $V_{(LOWV)}$ threshold, the battery enters fast-charge mode. This EVM is programmed for 0.7 A of fast-charging current.
7. Once the battery reaches voltage regulation (4.2 V) the current tapers down as the battery reaches its full capacity.
8. The battery remains at the fast-charge mode until either the charge timer expires or the charge termination current threshold is reached.
9. Once the charge terminates, if the battery discharges down to the recharge threshold, the charger start fast charging.

## *2.4 Alternative Methods of Testing the EVM*

Note: Due to the precharge, fast charge, and battery detection circuit, it is difficult to test the different charge phases without a battery, using just resistors. The following are two alternative tests.

**Alternative Method 1):** A source meter, that can sink/source current, can easily be adjusted to test each mode in place of a battery. No test procedure is suggested.

**Alternative Method 2):** Connect a load board in place of a battery. See the following sections on equipment, setup, and procedure. The sequence of the test procedure is important due to the active battery detection circuit, refresh feature, precharge, and fast-charge current levels (switching in/out load in different modes have different results). No damage should occur but one might get different results than anticipated if procedure sequence is altered. This procedure was used to check out the design of the EVM and may not demonstrate all the features of the IC.

### 2.4.1 Equipment

| | |
|---|---|
| Power Sources: | DC+ Input: 50-VDC Adjustable supply with adjustable current limit ≥2 A |
| | USB input: 5-V Supply with adjustable current limit ≥1A. |
| Three Fluke 75 — | Equivalent or better |
| Oscilloscope — | TDS220 or better, minimum of 2 channels/probes |
| Load test board | |

### 2.4.2 Equipment Setup

1. Preset the DC+ input power source to 25 V± 0.25 VDC, a current limit of 2±0.1 ADC and turn off the supply. Connect the power supply's positive lead to J1-DC+ and negative lead to J1-GND.
2. Preset the USB input power source to 5 V ±0.1 VDC, a current limit of 1 A ±0.1 ADC and turn off the supply. Connect the power supply's positive lead to J2-USB and the negative lead to J2-GND.
3. Connect the HPA285-PR736 load board to the UUT: Red to J3-BAT+ and Black to J3-BAT–. Place SW#1 in the on position and SW#2 in the off position (see Figure 4).
4. Connect DVM#1-DCV: Red-JMP5 (DC-OUT), Blk-J3-BAT–; DVM#2-DCV: Red-J3-BAT+, Blk-J2-BAT–; DVM#3-DCmV: Red-left side of sense resistor on load board, Blk-Right side of sense resistor, as shown.
5. Connect the scope probes as needed in the test procedure.
   Note: There is only one ground plane, so GND = BAT–. Choose the closest ground connection for a given signal's ground lead.

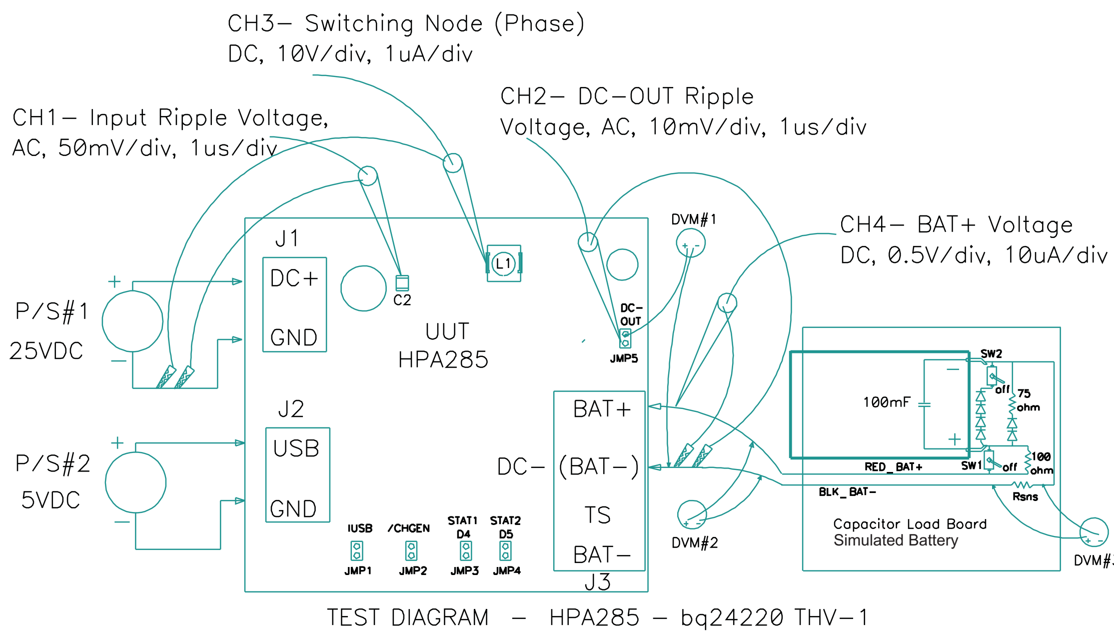


**Figure 4. Test Diagram — HPA285 — bq24220 THV-1**

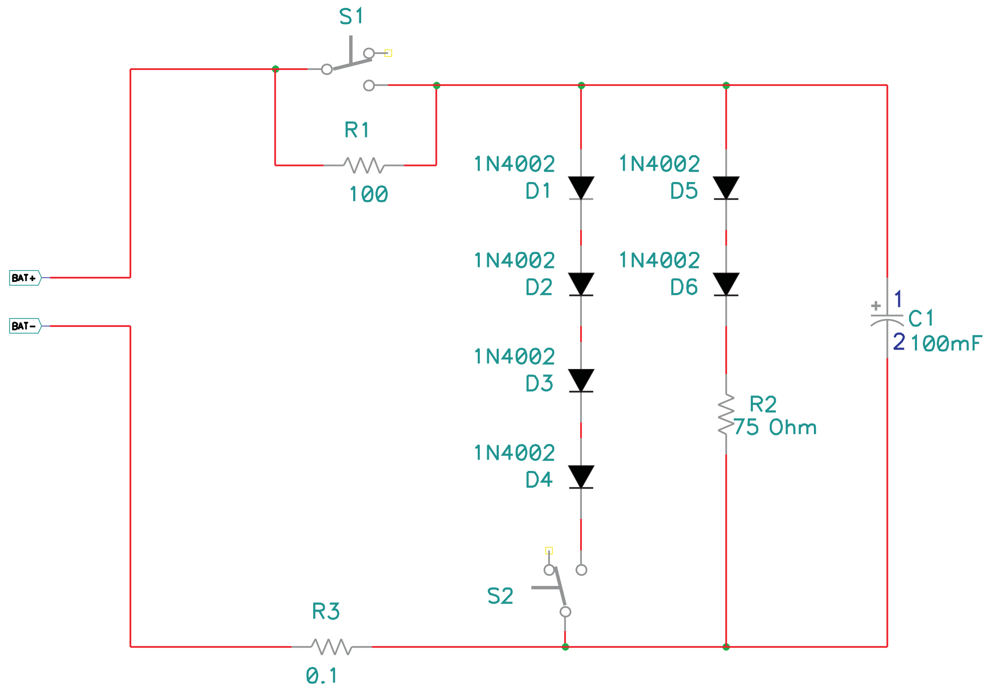


**Figure 5. HPA, bq24200 Load Test Board Schematic**

### 2.4.3 Procedure

1. Verify that equipment is set up per Section 2.4.2: J1-DC+:25 VDC input; UUT: JMP1-no shunt, JM2-no shunt, JMP3-shunt, JMP4-shunt; load board: SW1-on, SW2-off
2. Power up P/S#1 (DC+ Input), preset to 25 VDC.
3. Verify that STAT1 (D4) and STAT 2 (D5) are flashing (alternating). This can take a few seconds if the capacitor was discharged.
4. Turn switch SW2 on, and verify that STAT1 (D4) is on and STAT2 (D5) is off.
5. Verify that DVM#1, DC_OUT is between 4.5 to 5 VDC.
6. Verify that the input ripple on C2 (CH1) is ≤150 mVpp and output ripple on JMP5 (CH2) is ≤≤30 mVpp; CH1: AC, 50 mV/div; CH2: AC, 10 mV/div; 1 µs/div, CH1 trigger, respectively. Exclude noise spikes; see Figure 2.
7. Verify that the switching phase node at L1-1 looks similar to Figure 3: CH3: DC, 10 V/div, 1 µs/div, 25 MHz BW filtering. Amplitude of pulse is between 23 and 27 V, pulse duration is 0.55 to 0.85 µs, period is between 3.4 to 3.9 µs.
8. Verify that DVM#2, Vbat is between 3.05 V and 4 V.
9. Verify that DVM#3 is between 72.5 to 87.5 mV (i.e., charge current is between 725 to 875 mA).
10. Place shunt on JMP2 ($\overline{\text{CHGEN}}$) and verify that LED D4 (STAT1) is turned off and DVM#3 is less than 1 mV (no charge current).
11. Remove the shunt on JMP2 (place on just one of the pins so that it does not get lost).
12. Short between J3-TS and BAT– and verify that LEDs D4 (STAT1) and D5 (STAT2 are off.
13. Remove short, and verify that LED D4 (STAT1) turns on (D5 turns on if it is in precharge).
14. Turn SW#2 off, and then back on to get D5 LED to turn off.
15. Adjust P/S#`1, the input supply, from 25 V to 48 V and down to 6 V while viewing CH2 (output ripple) and trigger off of CH3 (phase node at 5 VDC). The amplitude changes as the input is varied, but ensure that the waveform is stable (no large DC level shifting).
16. Set P/S#1, the input supply, back to 25 V ±0.5 V and power down the P/S#1 input DC+ supply.
17. Turn on P/S#2, the +5-VDC USB input source.
18. Verify that DVM#3 is between 9 and 10 mV or a charging current of 90 to 100 mA.

19. Place a shunt on JMP1, and verify DVM#3 is between 40 to 50 mV or a charging current of 400 to 500 mA.
20. Remove shunt from JMP1 (place on one pin to avoid losing).
21. Turn SW#2 to the off position
22. Power down the P/S#2 USB input supply.

# 3 Schematic – EVM

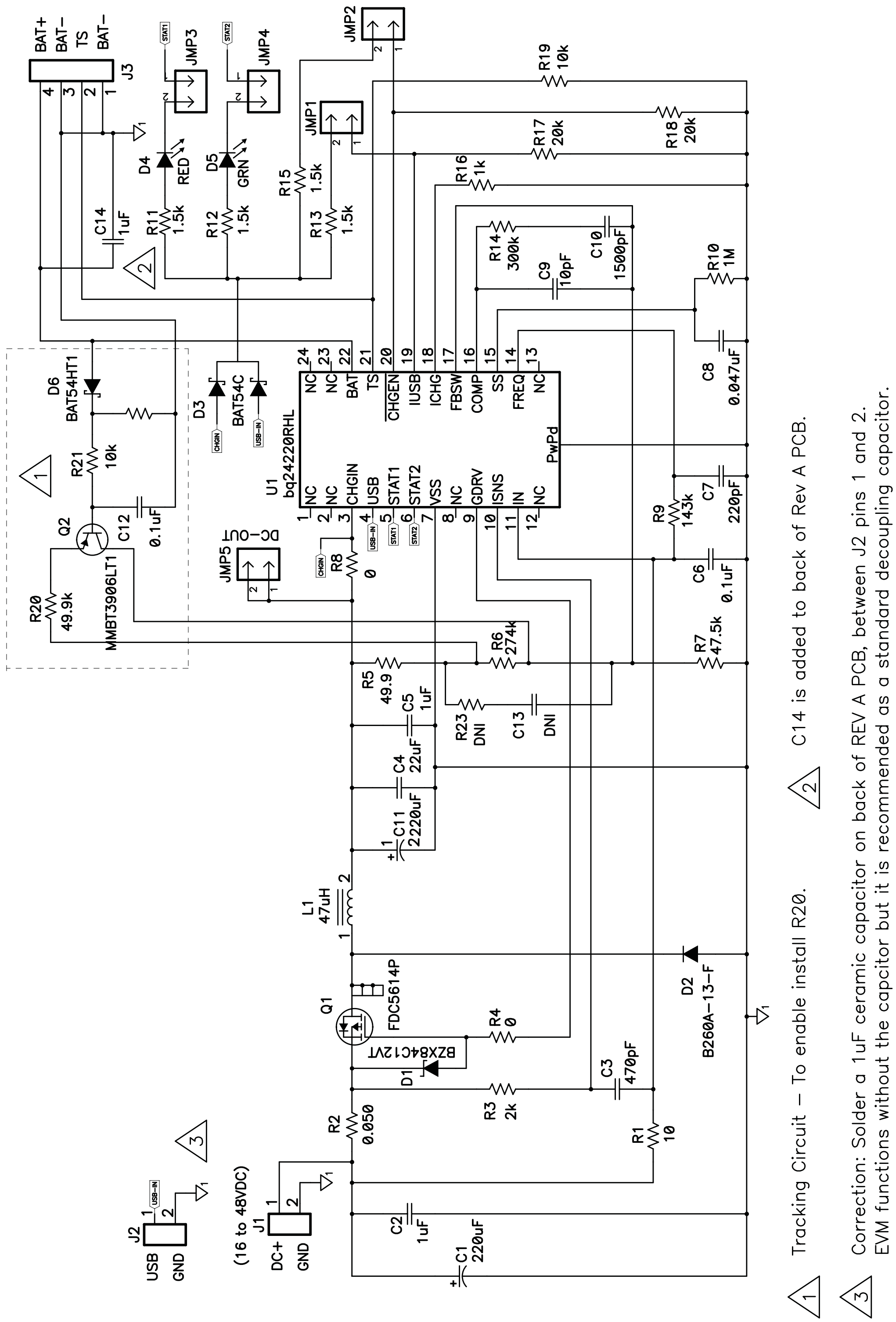


**Figure 6. Load Test Board Schematic**

# 4 Physical Layouts

Figure 7 shows the top assembly view, Figure 8 shows the top layer, Figure 9 shows the second layer, Figure 10 shows the third layer, and Figure 11 shows the bottom layer.

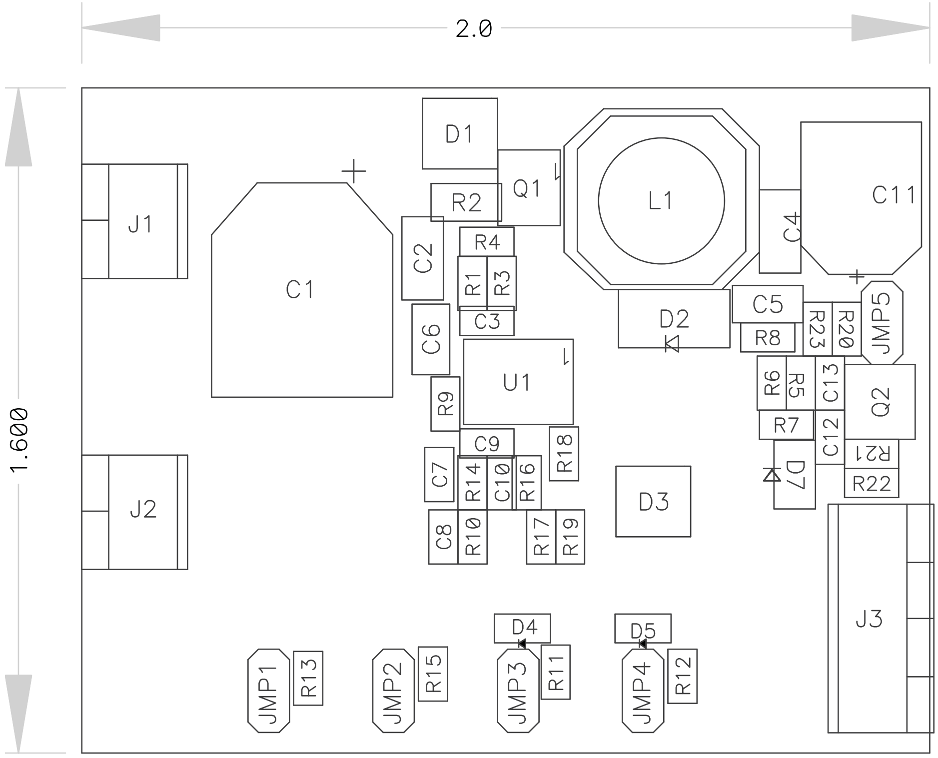


**Figure 7. Assembly Layer**

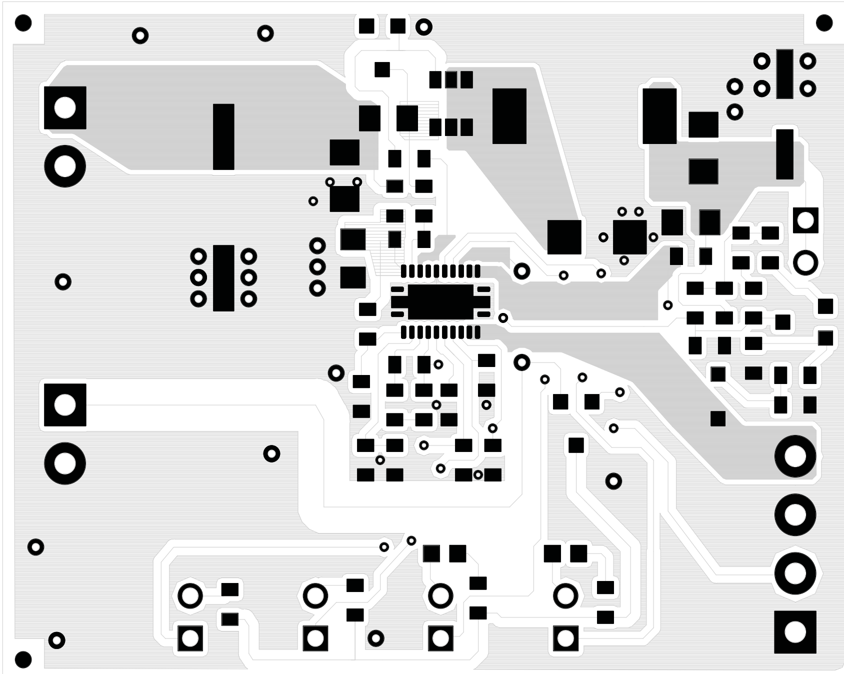

Figure 8. Top Layer

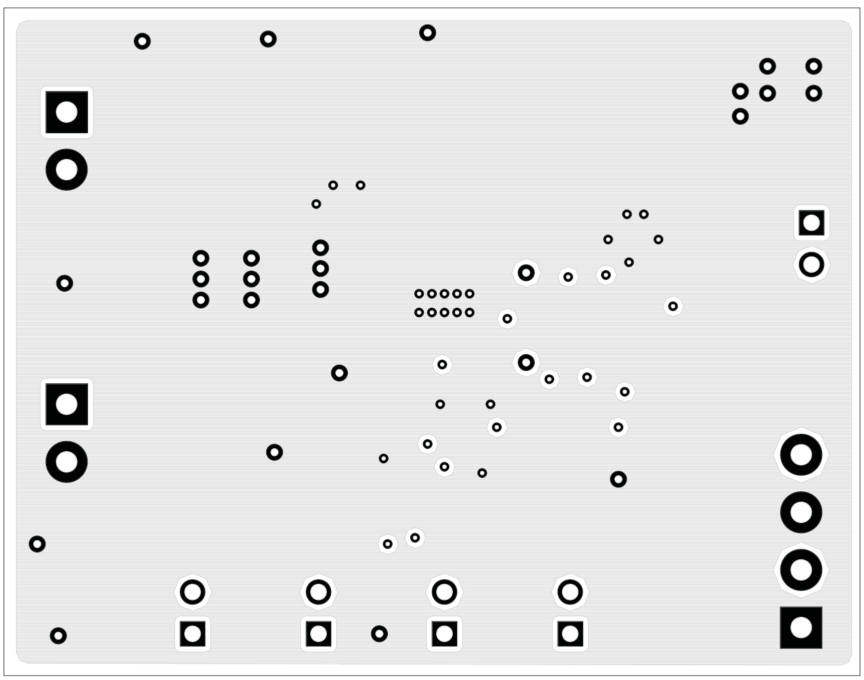

Figure 9. Second Layer

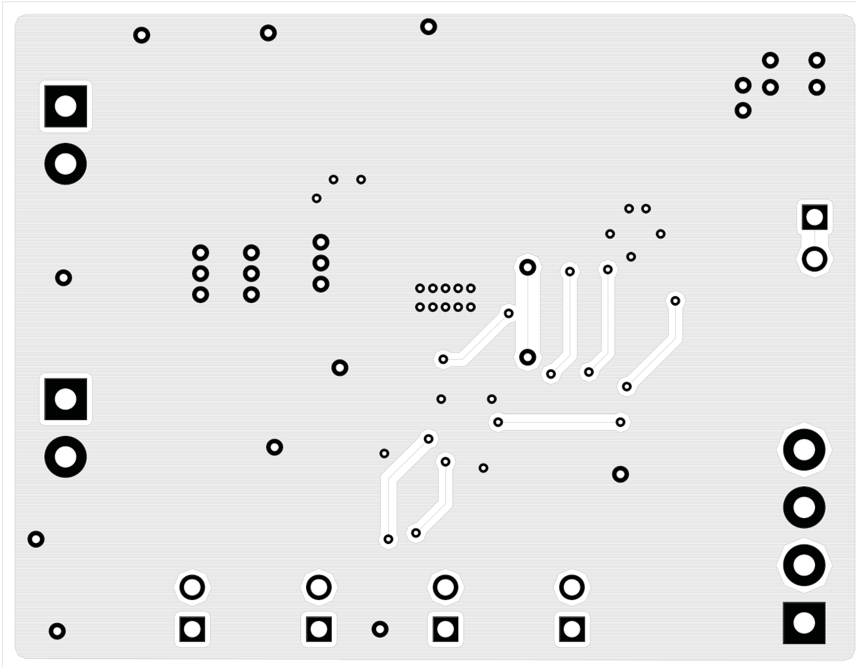

Figure 10. Third Layer

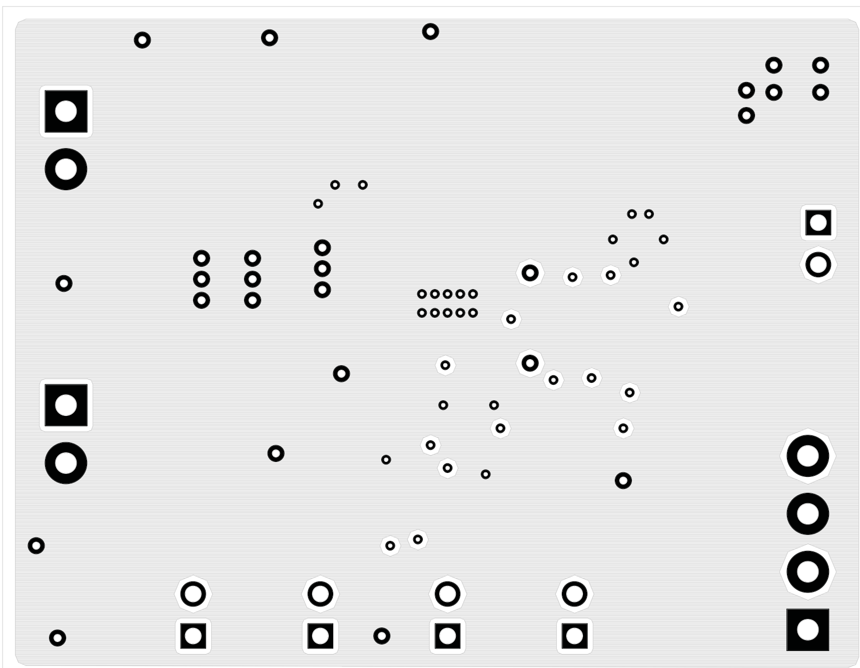

Figure 11. Bottom Layer

# 5 Bill of Materials

The bill of materials lists the materials required for the EVM.

**Table 3. HPA285B Bill of Materials**

| Count | RefDes | Value | Description | Size | Part Number | MFR |
|---|---|---|---|---|---|---|
| 1 | C1 | 220 μF | Capacitor, Aluminum, SM, 20%, 50V, | 0.406 × 0.457 inch | EEEFK1H221P | Panasonic |
| 1 | C10 | 1500 pF | Capacitor, Ceramic, 50V, X7R, 10% | 0603 | std | Panasonic |
| 1 | C11 | 220 μF | Capacitor, Aluminum, 6.3V, 20% | 0.260 × 0.276 inch | EEV-FK0J221P | Panasonic |
| 1 | C12 | 0.1 μF | Capacitor, Ceramic, 16V, X7R, 10% | 0603 | std | Panasonic |
| 0 | C13 | DNI | Capacitor, Ceramic, 50V, X7R, 10% | 0603 | std | Panasonic |
| 1 | C2 | 1 μF | Capacitor, Ceramic, 50V, X5R, 10% | 1206 | std | Vishay |
| 1 | C3 | 470 pF | Capacitor, Ceramic, 50V, X7R, 10% | 0603 | std | Panasonic |
| 1 | C4 | 22 μF | Capacitor, Ceramic, 6.3V, X5R, 20% | 1206 | ECJ-HVB0J226M | Panasonic |
| 1 | C5 | 1 μF | Capacitor, Ceramic, 16V, X5R, 10% | 0805 | ECJ-2FB1C105K | Panasonic |
| 1 | C14 | 1 μF | Capacitor, Ceramic, 6.3V, X5R, 10% | 0805 | ECJ-1VB0J105K | Panasonic |
| 1 | C6 | 0.1 μF | Capacitor, Ceramic, 50V, X7R, 10% | 0805 | std | Panasonic |
| 1 | C7 | 220 pF | Capacitor, Ceramic, 50V, NPO, 5% | 0603 | ECJ-2VC1H221J | Panasonic |
| 1 | C8 | 0.047 μF | Capacitor, Ceramic, 50V, X7R, 10% | 0603 | std | std |
| 1 | C9 | 10 pF | Capacitor, Ceramic, 50V, NPO, 5% | 0603 | ECJ-1VC1H100D | Panasonic |
| 1 | D1 | BZX84C12VT | Diode, Zener, 12-V, 350-mW | SOT-23 | BZX84C12-7-F | Diodes Inc |
| 1 | D2 | B260A-13-F | Diode, Rectifier, 2A, 60V | SMA | B260A-13-F | Diodes Inc |
| 1 | D3 | BAT54C | Diode, Dual Schottky, 200-mA, 30-V | SOT23 | BAT54C | Vishay-Liteon |
| 1 | D4 | RED | Diode, LED, Red, 2.1-V, 20-mA, 6-mcd | 0603 | LTST-C190CKT | Lite On |
| 1 | D5 | GRN | Diode, LED, Green, 2.1-V, 20-mA, 6-mcd | 0603 | LTST-C190GKT | Lite On |
| 1 | D6 | BAT54HT1 | Diode, Schottky, 200-mA, 30-V | SOD323 | BAT54HT1 | On Semi |
| 2 | J1, J2 | ED1514 | Terminal Block, 2-pin, 6-A, 3,5mm | 0.27 × 0.25 inch | ED1514 | OST |
| 1 | J3 | ED1516 | Terminal Block, 4-pin, 6-A, 3,5mm | 0.55 × 0.25 inch | ED1516 | OST |
| 5 | JMP1–JMP5 | PTC36SAAN | Header, 2-pin, 100 mil spacing, (36-pin strip) | 0.100 inch × 2 | PTC36SAAN | Sullins |
| 1 | L1 | 47 μH | Inductor, SMT, 2.1A, 95 mΩ | 0.405 sq inch | CDRH104R-470 | Sumida |
| 1 | Q1 | FDC5614P | Transistor, MOSFET, Pch, –3A, –60V, 105 mΩ | SuperSOT-6 | FDC5614P | Fairchild |
| 1 | Q2 | MMBT3906LT1 | Bipolar, PNP, 40V, 200mA | SOT23 | MMBT3906LT1 | On Semi |
| 1 | R1 | 10 | Resistor, 1/16W, 1% | 0603 | std | std |
| 1 | R10 | 1M | Resistor, 1/16W, 1% | 0603 | std | std |
| 4 | R11–R13, R15 | 1.5k | Resistor, 1/16W, 1% | 0603 | std | std |
| 1 | R14 | 300k | Resistor, 1/16W, 1% | 0603 | std | std |
| 1 | R16 | 1k | Resistor, 1/16W, 1% | 0603 | std | std |
| 2 | R17, R18 | 20k | Resistor, 1/16W, 1% | 0603 | std | std |
| 2 | R19, R21 | 10k | Resistor, 1/16W, 1% | 0603 | std | std |
| 1 | R2 | 0.05 | Resistor, Chip, 1/8W, 1% | 0805 | WSL0805R0500FEA | Vishay |
| 0 | R20 | 49.9k | Resistor, 1/16W, 1% | 0603 | std | std |
| 1 | R22 | 100k | Resistor, 1/16W, 1% | 0603 | std | std |
| 0 | R23 | DNI | Resistor, 1/16W, 1% | 0603 | std | std |
| 1 | R3 | 2k | Resistor, 1/16W, 1% | 0603 | std | std |
| 2 | R4, R8 | 0 | Resistor, 1/16W, 1% | 0603 | std | std |
| 1 | R5 | 49.9 | Resistor, 1/16W, 1% | 0603 | std | std |
| 1 | R6 | 274k | Resistor, 1/16W, 1% | 0603 | std | std |
| 1 | R7 | 47.5k | Resistor, 1/16W, 1% | 0603 | std | std |
| 1 | R9 | 143k | Resistor, 1/16W, 1% | 0603 | std | std |
| 1 | U1 | bq24220RHL | IC, Single-Chip, 1 Cell Dual-Input Li-Ion Charger With High-Input Voltage | RHL-24 | bq24220RHL | TI |
| 1 | – | | PCB, 2 In x 1 In × 0.031 In | | HPA285 | Any |
| 4 | | 929950-00 | Shunts, 100 mill, Black | | std | 3M |

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Should this evaluation board/kit not meet the specifications indicated in the User's Guide, the board/kit may be returned within 30 days from the date of delivery for a full refund. THE FOREGOING WARRANTY IS THE EXCLUSIVE WARRANTY MADE BY SELLER TO BUYER AND IS IN LIEU OF ALL OTHER WARRANTIES, EXPRESSED, IMPLIED, OR STATUTORY, INCLUDING ANY WARRANTY OF MERCHANTABILITY OR FITNESS FOR ANY PARTICULAR PURPOSE.

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## EVM WARNINGS AND RESTRICTIONS

It is important to operate this EVM within the input voltage range of 5 V to 48 V and the output voltage range of 4.5 V to 5.5 V.

Exceeding the specified input range may cause unexpected operation and/or irreversible damage to the EVM. If there are questions concerning the input range, please contact a TI field representative prior to connecting the input power.

Applying loads outside of the specified output range may result in unintended operation and/or possible permanent damage to the EVM. Please consult the EVM User's Guide prior to connecting any load to the EVM output. If there is uncertainty as to the load specification, please contact a TI field representative.

During normal operation, some circuit components may have case temperatures greater than 75°C. The EVM is designed to operate properly with certain components above 75°C as long as the input and output ranges are maintained. These components include but are not limited to linear regulators, switching transistors, pass transistors, and current sense resistors. These types of devices can be identified using the EVM schematic located in the EVM User's Guide. When placing measurement probes near these devices during operation, please be aware that these devices may be very warm to the touch.

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