参考資料

TI Designs: TIDA-01582
USB PD PPS用、スイッチト・キャパシタ高速充電のリファレンス・デザイン

TEXAS INSTRUMENTS

概要

このリファレンス・デザインは、スマートフォン・アプリケーションでスイッチト・キャパシタ高速充電トポロジを使用するときの全体的なシステム性能を示すことを目的としています。システムには、USBパワー・デリバリ(PD)のPPS (Programmable Power Supply)仕様をサポートするスマートACアダプタを使用して、充電ケーブル上の損失と、スマートフォン内での損失および温度上昇を減らす手法が採用されています。bq25970は、バッテリへ最大8Aの充電電流を供給可能な、TIで初めてのスイッチト・キャパシタ充電器です。このデザインは、bqStudio GUIソフトウェアを使用してbq25970およびbq25890デバイスの性能を評価するために使用できます。また、このデザインではUSB PDコントローラと、制御ソフトウェアを実行する MSP430™マイクロコントローラ(MCU)を含む、スマートフォン上の完全なシステムを紹介しています。このスイッチト・キャパシタ充電器のデザインには、USB PD PPS対応のACアダプタでデバイスを使用するときの回路図、ソフトウェア・フロー図、効率、電力損失、完全な充電サイクルのデータが含まれています。

リソース

TIDA-01582	デザイン・フォルダ
bq25970	プロダクト・フォルダ
bq25890	プロダクト・フォルダ
TUSB422	プロダクト・フォルダ
TS3USB221	プロダクト・フォルダ

TI E2E™ Community

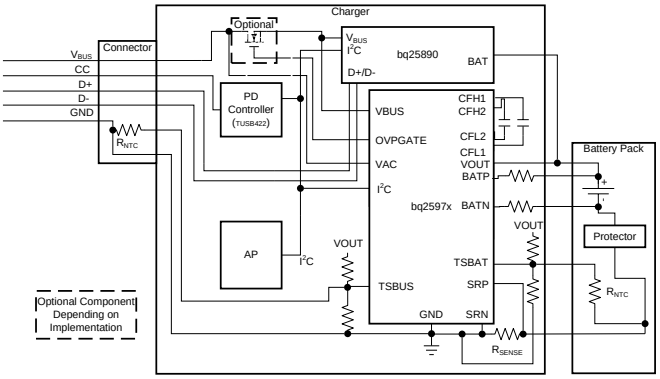
E2Eエキスパートに質問

特長

- 高い充電効率: 6Aで96.6%
- USB PD PPSの電圧および電流制御用の完全なシステム例
- スマートフォンおよびACアダプタのソフトウェア・フロー・チャート
- bq25890によるプリチャージ、テーパー・チャージ、終了
- bq25970による3Aケーブル電流での6A充電
- TUSB422 USB PDコントローラによりスマートACアダプタと通信

アプリケーション

- スマートフォン
- 外部バッテリ
- タブレット



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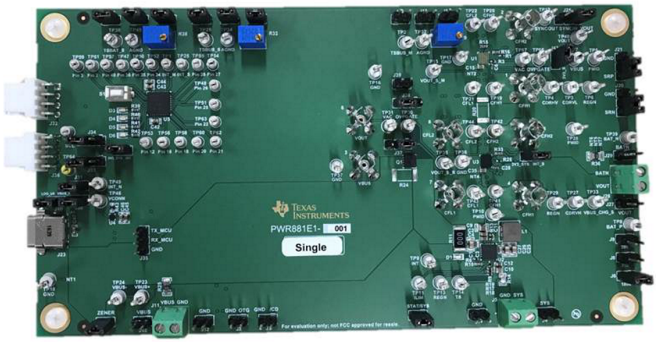

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1 System Description

This design uses the PWR881 System Evaluation Board as part of the total phone and wall adapter solution example. The PWR881 board schematic includes the bq25890 as the primary switching charger, the bq25970 switched-capacitor charger for fast charging, the TUSB422 PD controller, and an MSP430™ MCU to execute the control algorithm. This reference design is applicable to any system that requires charging a 1S battery device up to 8 A.

1.1 Key System Specifications

表 1. Key System Specifications

PARAMETER	SPECIFICATIONS
Input power source	USB PD PPS compliant wall adapter capable of 20-mV steps and 50-mA steps
Battery specification	Type of battery can be from 3.5-V to 4.65-V charge voltage and up to 8-A charge current
Total charging power dissipation at 6 A	Less than 850 mW
Efficiency at 6-A charging	Greater than 96%

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2 System Overview

2.1 Block Diagram

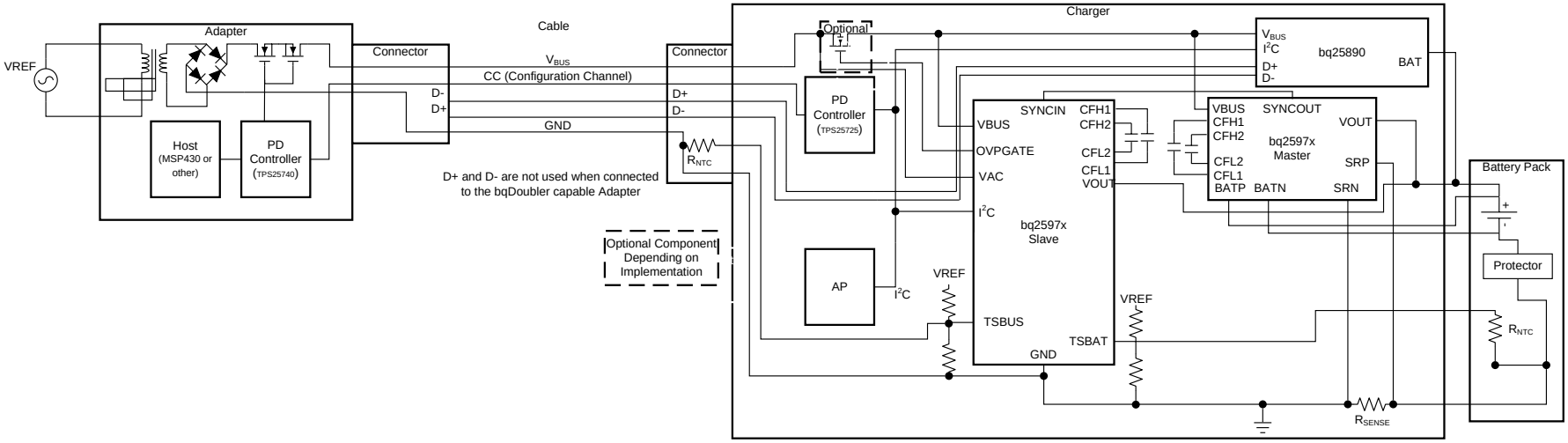

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図 1. TIDA-01582 Block Diagram

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2.2 Design Considerations

This reference design is useful for a wide variety of applications that require high-current battery charging but are limited in the amount of power they can dissipate. One such example is smartphones, which must be able to charge quickly and do not have active cooling. To achieve fast charging with the bq25970 device, the designer must use it along with a switching charger (or power management multichannel IC (PMIC) with charger, or even linear charger) for the trickle, precharge, taper charge, and termination portions of the charge cycle. 図 2 shows the charge cycle and which device takes control during each portion.

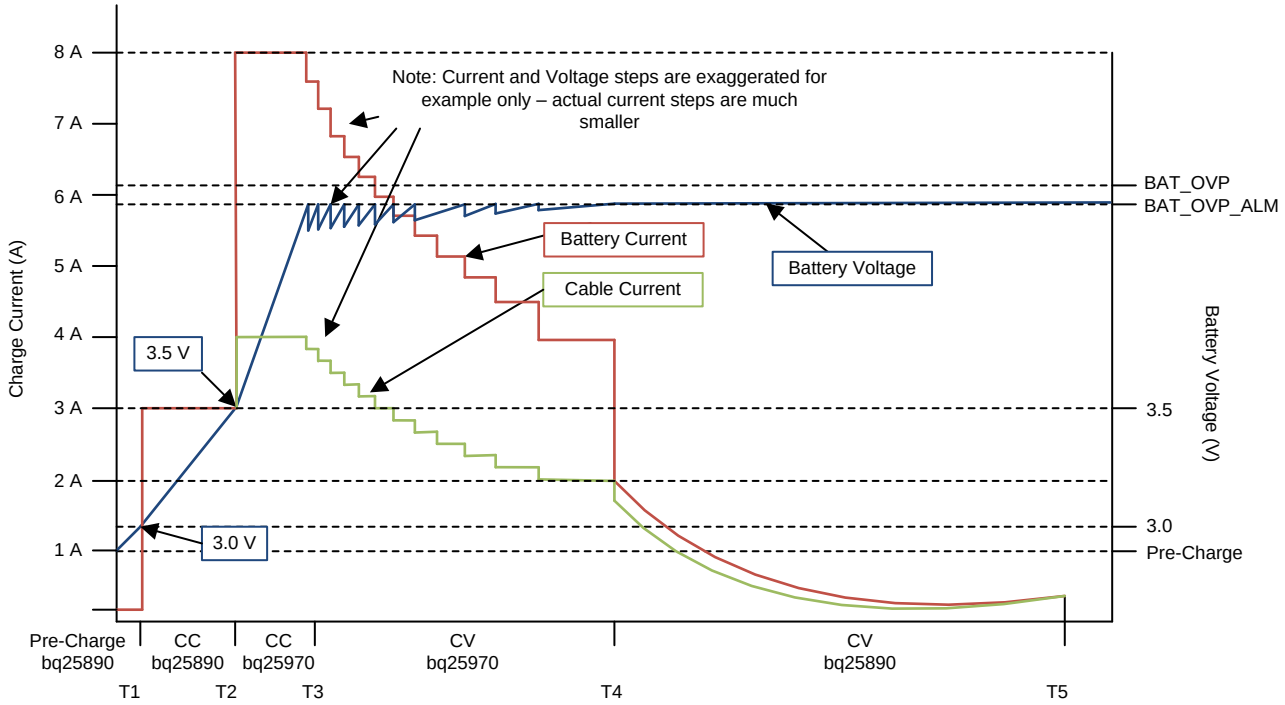

図 2. Ideal Charge Cycle Operation

The reference design board uses a USB Type-C™ 3-A cable and connector to connect to a wall supply that is USB PD PPS capable. After connecting the wall adapter to the PWR881 board with the USB cable, the software flow commences to allow the different stages of the charging cycle (see 図 6).

2.3 Highlighted Products

This reference design uses the bq25980 as the primary switching charger, the bq25970 as the fast charger, the TUSB422 as the USB PD controller, and the MSP430 MCU to run the code, control the system, and approximate the function of the application processor in a smartphone.

2.3.1 bq25970

The bq25970 is a high-efficiency switched-cap converter that can deliver up to 8 A to a battery. The switched cap architecture and the integrated field-effect transistors (FETs) are optimized to enable a 50% duty cycle, which allows the cable current to be half of the current delivered to the battery, reducing the losses over the charging cable as well as limiting the temperature rise in the application. The dual-phase architecture reduces the input cap requirements in addition to reducing the output voltage ripple. The

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device integrates all the necessary protection features to ensure safe charging, including input overvoltage and overcurrent protection, output overvoltage and overcurrent protection, temperature sensing for the battery and cable, and monitoring the die temperature. The device includes a 15-bit effective analog-to-digital converter (ADC) to provide bus voltage, bus current, output voltage, battery voltage, battery current, bus temperature, battery temperature, and die temperature.

2.4 System Design Theory

2.4.1 Theory of Operation

A typical buck-converter charger can achieve greater than 90% efficiency at 6 A; however, this means over 2 W must be dissipated in the phone. A typical thermal budget for a smartphone allows less than 1 W to be dissipated in the phone to meet the temperature rise limits. The switched cap architecture can achieve up to 97% efficiency at 6 A, which is less than 800-mW dissipation in the phone and requires less than 3 A on a standard USB-C cable. The switched cap architecture relies on a smart wall adapter to regulate the voltage and current at the input to the charger. Achieve this regulation with a voltage-limited constant-current source or a current-limited voltage source. The performance of the switched cap solution depends on which type of source is used. The switched cap architecture uses four switches to alternately charge and discharge capacitors (CFLY). 図 3 shows the simplified circuit, along with the equations for voltage and current during the charging and discharging of the CFLY caps.

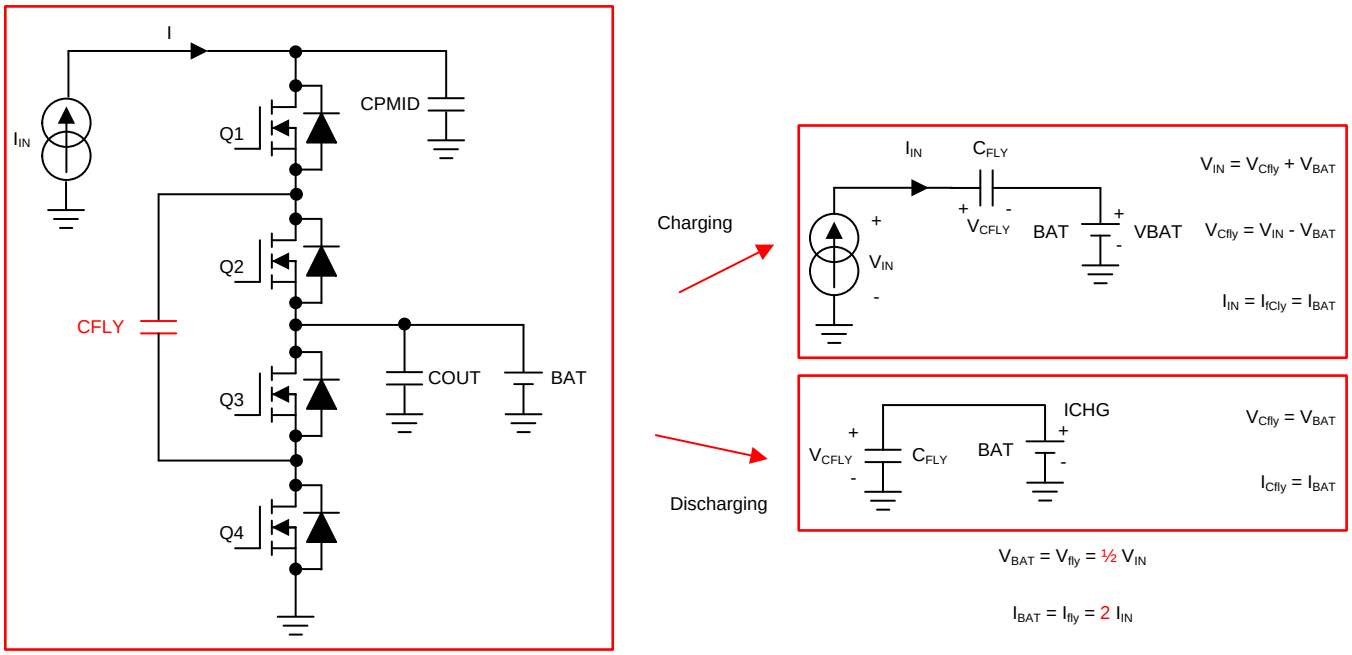

図 3. Simplified Switched Cap Circuit (Single Phase)

In the charging phase (t1), Q1 and Q3 are turned on and Q2 and Q4 are turned off. This action allows the switched-cap charger to charge CFLY while delivering current to the battery. During the discharge phase (t2), Q1 and Q3 are turned off while Q2 and Q4 are turned on. During this time the CFLY caps provide the charging current to the battery. The duty cycle is 50%, the battery current is half of the input voltage, and the current delivered to the battery is twice the input current. 図 4 shows the waveforms of the battery current and voltage. This figure shows models of the equivalent series resistance (ESR) of the fly cap as well as the resistances of the switches.

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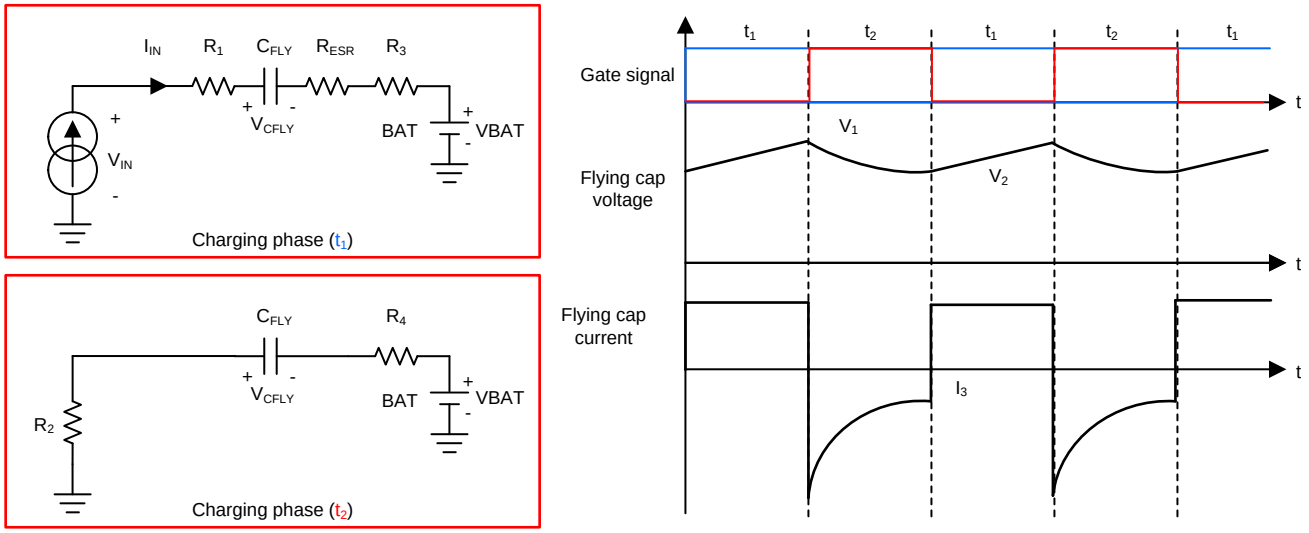

図 4. Switching Waveforms With Current Source

When using a constant current source, the CFLY current is constant. If using a constant voltage source, the CFLY current follows the RC constant curve as 図 5 shows. Although not significant, the effect of using a voltage source instead of a current source is increased ripple current, increased root mean square (RMS) current, and reduced efficiency due to higher conduction losses.

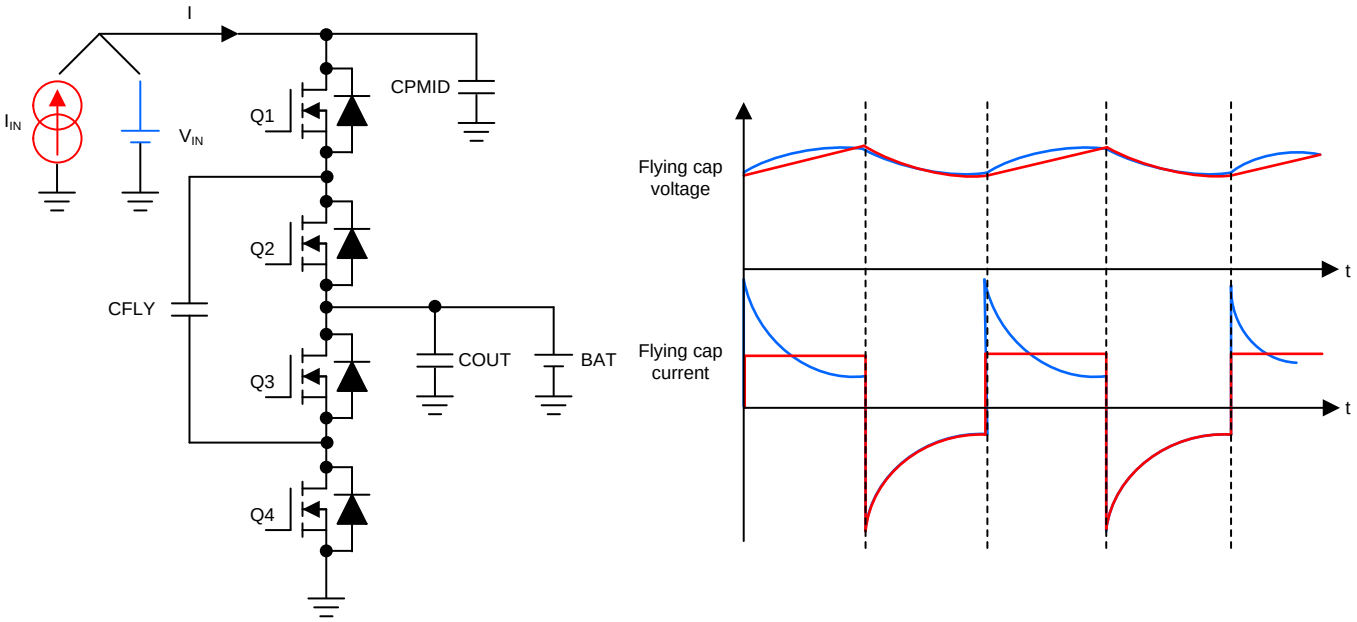

図 5. Switching Waveforms Difference With Current versus Voltage Source

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2.4.2 Software Flow Chart

As described in the bq25970 data sheet, this reference design is capable of executing the software flow chart shown in 図 6. The designer can modify the software flow based on the desired measurements, protections, and alarm thresholds based on the system constraints and goals.

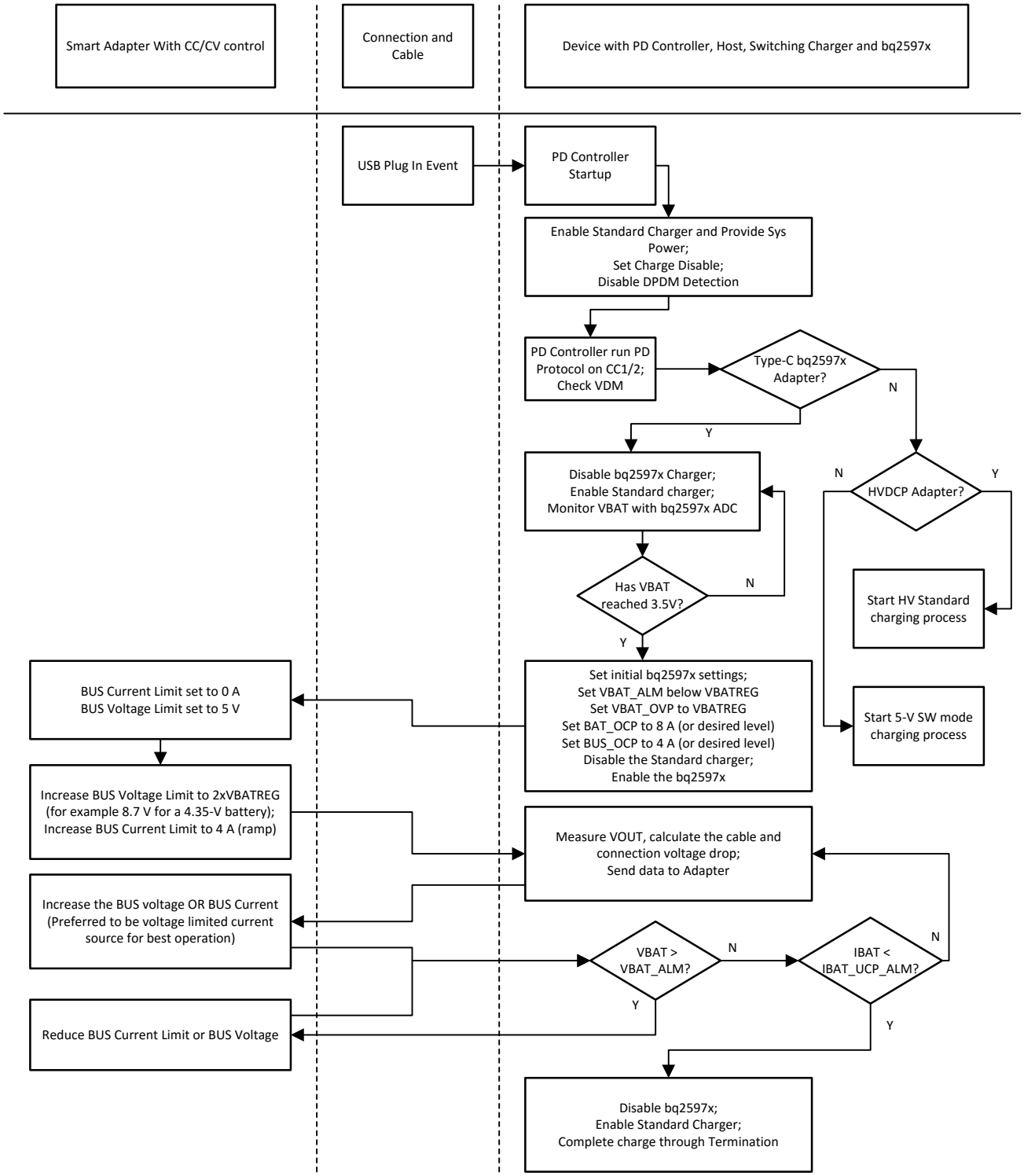

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図 6. Total System Software Flow Chart

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3 Hardware, Software, Testing Requirements, and Test Results

3.1 Required Hardware and Software

3.1.1 Hardware

The designer can use this reference design in two ways. The first way is as a development platform for code to run on the phone and wall adapter. The second way is to use the PWR881 board as a stand-alone development and evaluation platform.

3.1.1.1 Total System Hardware Configuration

When using the reference design in this manner, plug the wall adapter into the wall outlet, connect the battery to the VOUT and BATN terminal block, and then connect the wall adapter to the PWR881 board with a USB Type-C cable. After completing these steps, the USB PD controller on the PWR881 board negotiates with the USB PD controller on the wall adapter and charging commences per the software flow chart.

3.1.2 System Evaluation Board With bqStudio GUI

When using the reference design in this manner, use it with a power supply and battery emulator to evaluate the basic functions and system efficiency. This case uses the bqStudio GUI to control the devices on the board. 図 9 shows the setup. The designer can control the bq25890 and bq25970 devices through the bqStudio GUI.

3.1.3 Software

Two levels of software are provided for this reference design. The total system software executes on the MSP430 MCU and works with a USB PD PPS smart wall adapter. The system evaluation board software runs along with bqStudio and allows evaluation of the bq25970 device. The following subsections describe both levels of software.

3.1.3.1 Total System Software

For the total system solution, run the software on the PWR881 board and on the USB PD PPS wall adapter.

The example code for the PWR881 board installed using the MSP430 F5529 LaunchPad™ Evaluation Kit. To update the code on the PWR881 board, connect the MSP430 LaunchPad GND, RST, TEST, and 3V3 connections. After downloading and unzipping the files, download and install the Code Composer Studio™ (CCS) software. Import the files into CCS by clicking *File → Import*, select *CCS → CCS Project*, then browse to the project directory. After selecting, click the *Finish* button to import the project. After importing, the project should be in the *Project Explorer*. Right click on the project and select *Build Project*. If no issues arise, click on the green bug in the icon menu to program the MCU. After programming the PWR881 board, the designer can disconnect the connector and the MSP430 will retain the code and continue to run.

The example code for the wall adapter is installed on the wall adapter control board. To do this, connect the MPS430 LaunchPad to the header on the board as follows: PIN1: 3V3, PIN2: TEST, PIN3: RST, and PIN4: GND. Follow a similar process as before to install the code on the wall adapter control board.

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3.1.3.2 System Evaluation Board Software With bqStudio GUI Software

The board contains all the necessary devices to fully test the bq2597x device. The board can be configured in several ways:

1. Single bq25970 evaluation (with external overvoltage protection (OVP)) – Variant 001
2. Single bq25971 evaluation (without external OVP) – Variant 001 with R24 populated and J38 pins 1 and 2 shorted together
3. Dual bq25970 evaluation (with external OVP) – Variant 002
4. Dual bq25971 evaluation (without external OVP) – Variant 002 with R24 populated and J38 pins 1 and 2 shorted together

The system evaluation board requires an EV2400 interface board, which the designer must order separately. The EV2400 USB-based PC interface board is required to communicate with the bq25890 device and both bq25970 devices on the board (see http://www.ti.com/tool/EV2400).

Ensure proper installation of the PWR881 System Evaluation Board (SEB) evaluation software. Also, check to be sure that the following three files are located in the *\BatteryManagementStudio\config* directory and choose Charger_1_05- bq25970_SEB.bqz:

- Charger_1_05-bq25970_SEB.bqz
- Charger_1_05-bq25970_S.bqz
- Charger_1_05-bq25970_M.bqz

3.2 Testing and Results

3.2.1 Test Setup

3.2.1.1 Total System Test Setup

When using the reference design in this manner, plug the wall adapter into the wall outlet, connect the battery to the VOUT and BATN terminal block, and then connect the wall adapter to the PWR881 board with a USB Type-C cable. After completing these steps, the USB PD controller on the PWR881 board negotiates with the USB PD controller on the wall adapter and charging commences per the software flow chart.

図 7 shows the charge cycle data for the total system setup.

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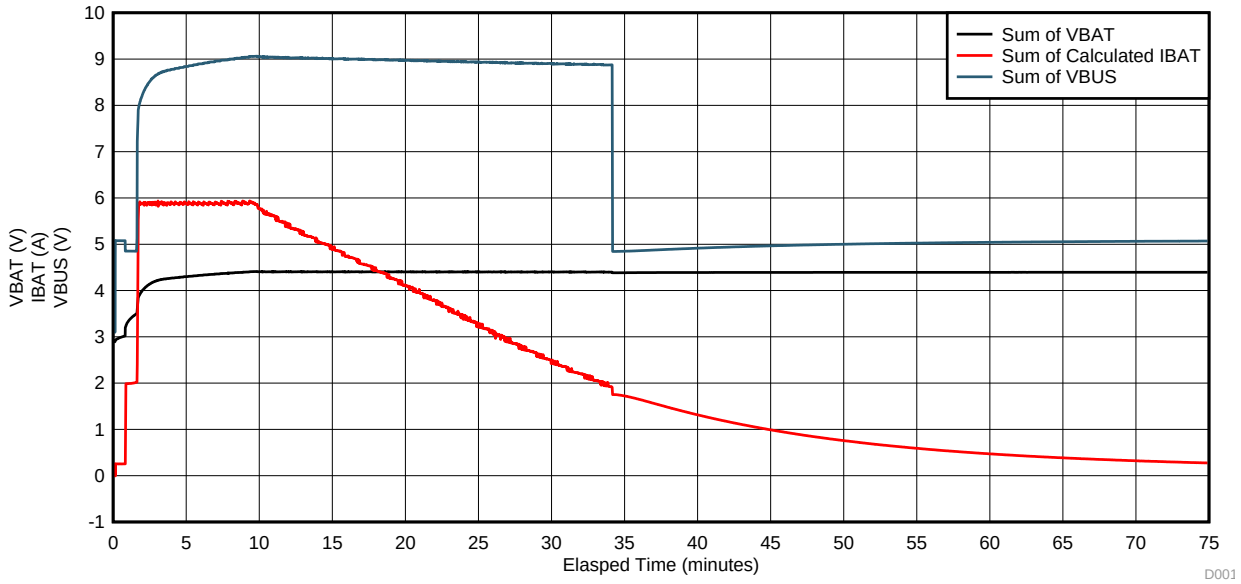

図 7. Total System Charge Cycle Data

図 8 shows the total charge time when charging a 4.4-V, 3200-mAh, I^2C capable battery. The battery is 50% charged after 17 minutes and 80% charged in a little more than half an hour.

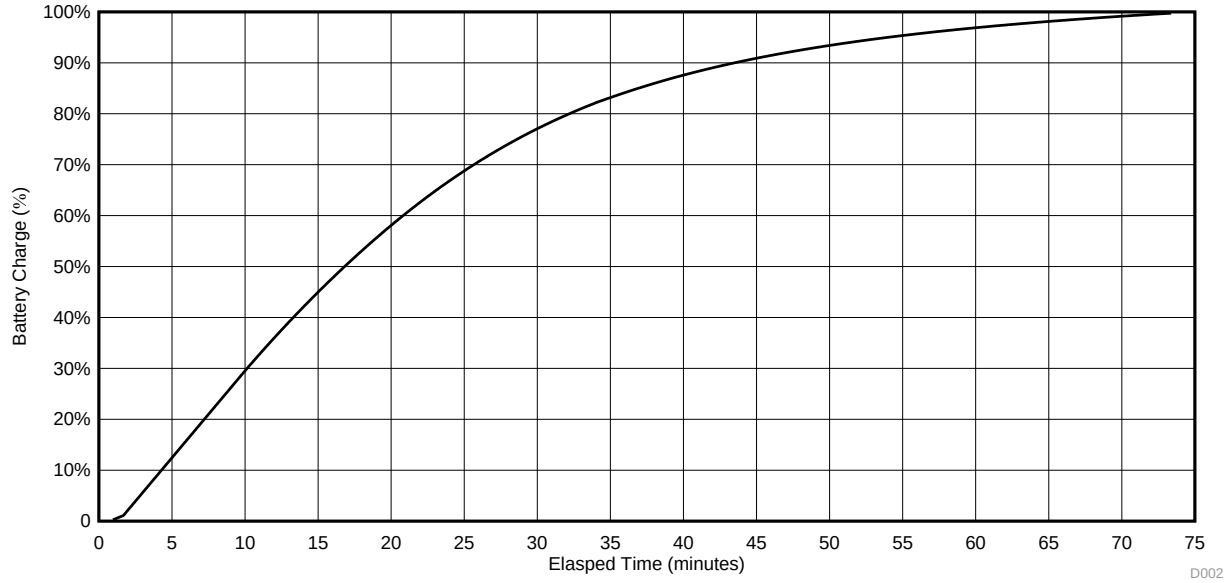

図 8. Charge Time

3.2.1.2 System Evaluation Board Test Setup

When using the reference design in this manner, use it with a power supply and battery emulator to evaluate the basic functions and system efficiency. This case uses the bqStudio GUI to control the devices on the board. 図 9 shows the setup. The designer can control the bq25890 and bq25970 devices through the bqStudio GUI.

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図 9. EV2400 and Cables

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Set up the equipment using the following steps:

1. Set the power supply for 7 V, DC output, 0.5-A current limit, and then turn off the supply.
2. Connect the output of the power supply to J11 (VBUS and GND). Note that when Q1 has been installed and the bq25970 is used, the VBUS is actually the VAC input. The VBUS voltage is after Q1 and can be measured at VBUS_CHG_SNS (TP33).
3. Turn on the battery simulator (load), set the battery simulator to constant voltage mode, and output to 3.5 V. Turn off (disable) the load. Connect the load to J28 (VOUT and BATN).
4. Connect the EV2400 USB interface board to the computer with a USB cable and from the I^2C port to J36 with the four-pin cable.
5. Connect the meters to measure VAC, VBUS, IBUS, VBAT, VOUT, and IBAT. Note that IBUS and IBAT are voltages to measure across the sense resistors. At this point, the system should appear similar to the setup in 図 10:

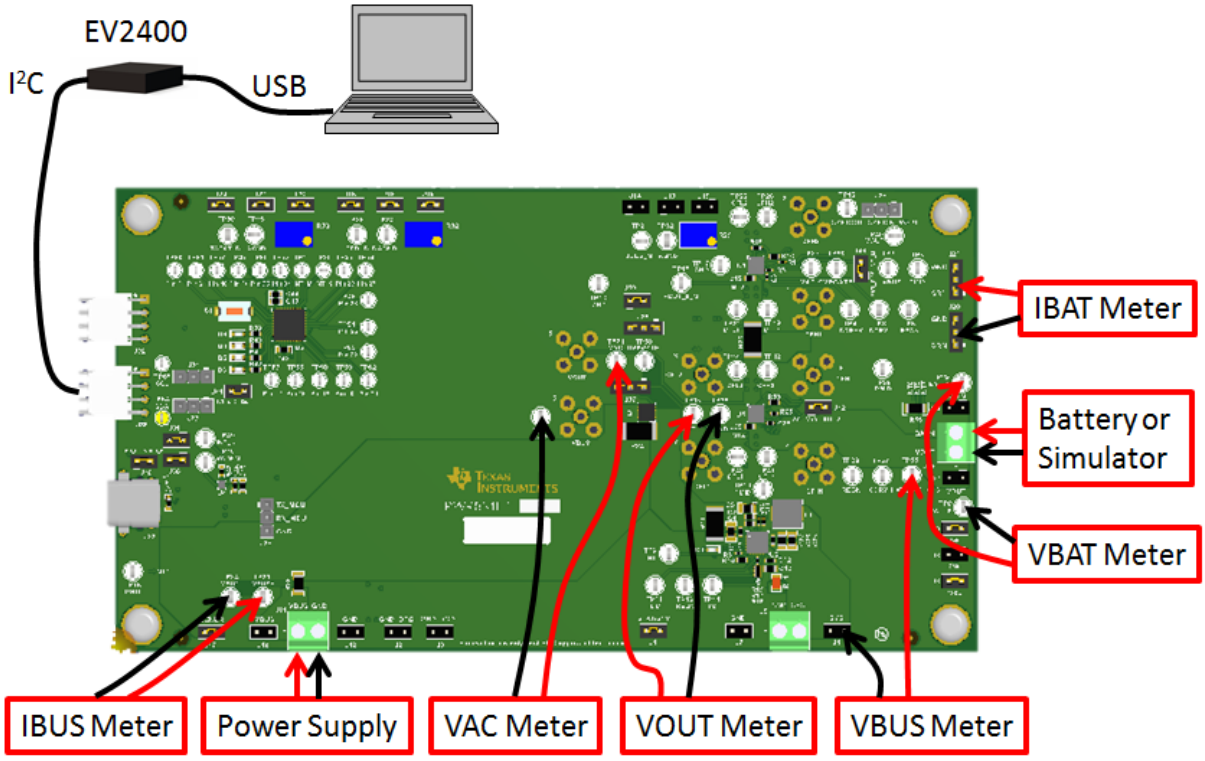

図 10. PWR881 Test Connections

6. Ensure that the jumpers and components have been installed for the version of the board for testing.
7. Turn on the computer. Launch the Battery Management Studio (bqStudio) software. Select *Charger* and *Charger_1_05-bq25970_SEB* as the following 図 11 shows (always choose the latest revision):

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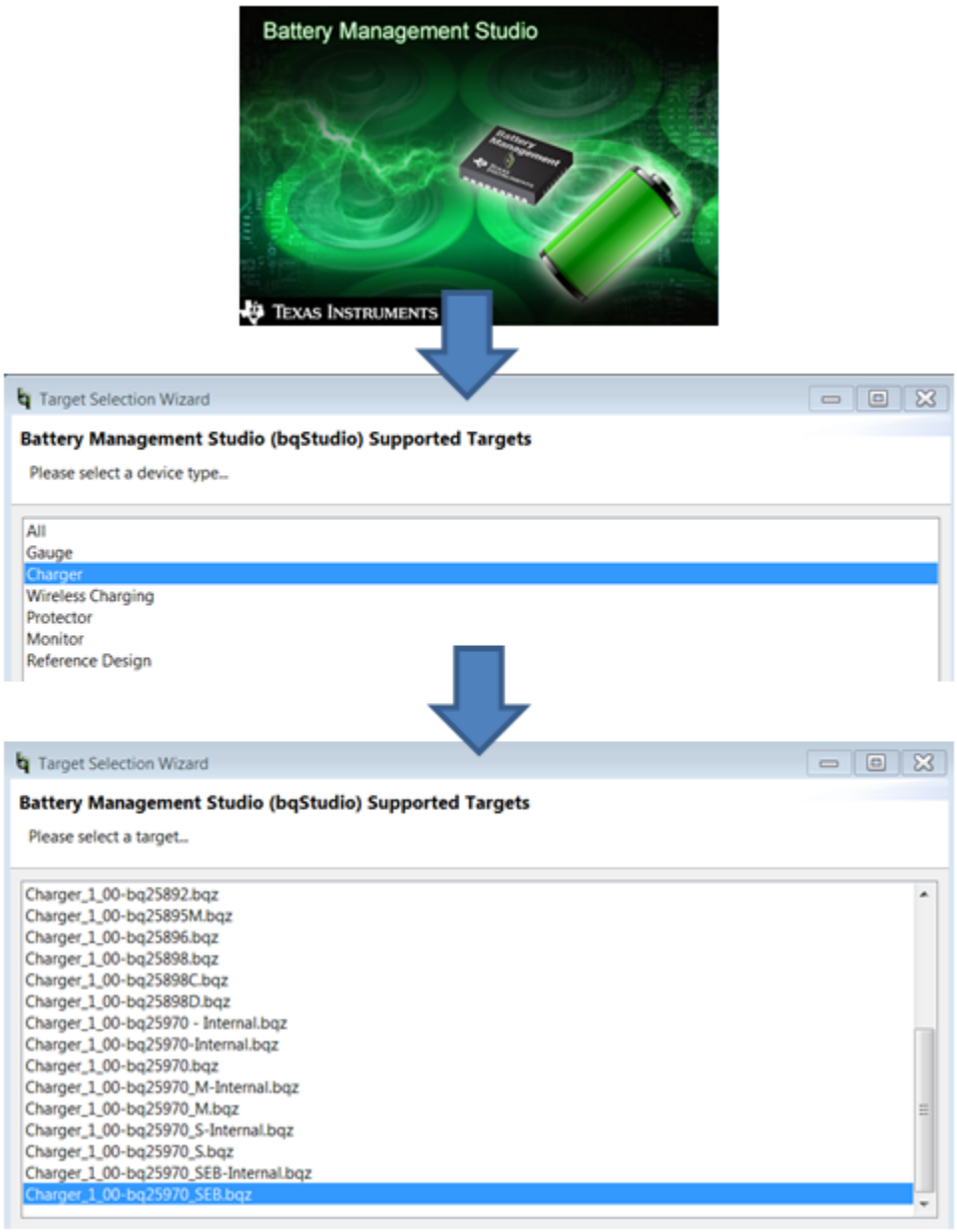

図 11. bqStudio GUI Selection

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3.2.2 Test Results

3.2.2.1 Total System Test Results

The following subsection shows the test results for the total system charge cycle using a 3200-mAh, 3.82-V (4.4-V charge voltage), I^2C capable battery.

3.2.2.2 System Evaluation Board Results

Use the following steps for the test procedure:

1. Check that all connections are as described in the previous 3.2.1.2.
2. Turn on the power supply.
3. Turn on the load (battery emulator).
4. Launch the bqStudio software (if not already done).
5. Measure the VAC, VBUS, IBUS, VBAT, VOUT, and IBAT. The device should not be switching and no charging current (only I_q) should be measured on IBUS and IBAT.

Use the following steps for communication verification:

1. In the EVM software, three devices should be available on different tabs in bqStudio. The bq25890, the bq25970_S (operates as stand-alone or slave), and the bq25970_M (operates as master when two bq25970 devices are used in parallel). Select the *Field View* for the device of interest; in most cases, this will be the bq25970_S. The default I^2C address for configuration with the jumpers on is CC(66).
2. Click the *Read Register* button. The *Device ACK OK* should then appear.
3. The registers for the bq25970 device are populated as shown in the previous 図 1.
4. In the software, make the following changes:
    1. On the bq25970_S, disable the watchdog timer by enabling register 0x0Bh, bit 2.
    2. On the bq25970_M, disable the watchdog timer by enabling register 0x0Bh, bit 2.
    3. On the bq25890, disable the watchdog timer by setting bits 5 and 4 in register 0x07h to ‘0’.
    4. Disable charging of the bq25890 by setting bit 4 in register 0x04h to ‘0’.

Use the following steps for communication verification:

1. Ensure that the load is set to 3.5 V, constant voltage mode.
2. Ensure that the power supply is current limited to 0.5 A.
3. Ensure that the power is twice the desired battery voltage. For example, start with the power supply set to 8.7 V if the desired battery voltage is 4.35 V.
4. On the bq25970_S, set register 0x03h, bit 4 to ‘1’ to enable charge.
5. Charging then commences and the power supply is current limited at 0.5 A, with the voltage held near 7 V. The battery voltage should be 3.5 V and the battery current should be 1 A. 式 1 calculates the charging efficiency of the system. 式 2 calculates the charging efficiency of the bq25970 _S.

$$\eta_{system} = \left(\frac{(IBAT \times VBAT)}{(VAC \times IBUS)} \right) \times 100 \quad (1)$$

$$\eta_{bq25970_S} = \left(\frac{(IBAT \times VBAT)}{(VBUS \times IBUS)} \right) \times 100 \quad (2)$$

6. Measure other operating points by raising the power supply current limit for higher charging current, adjusting the VBAT voltage, and adjusting the power supply voltage (keeping it in constant current (CC) mode).
7. Deselect *Charge Enable* to stop charging.

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図 12 shows the efficiency of the bq25970.

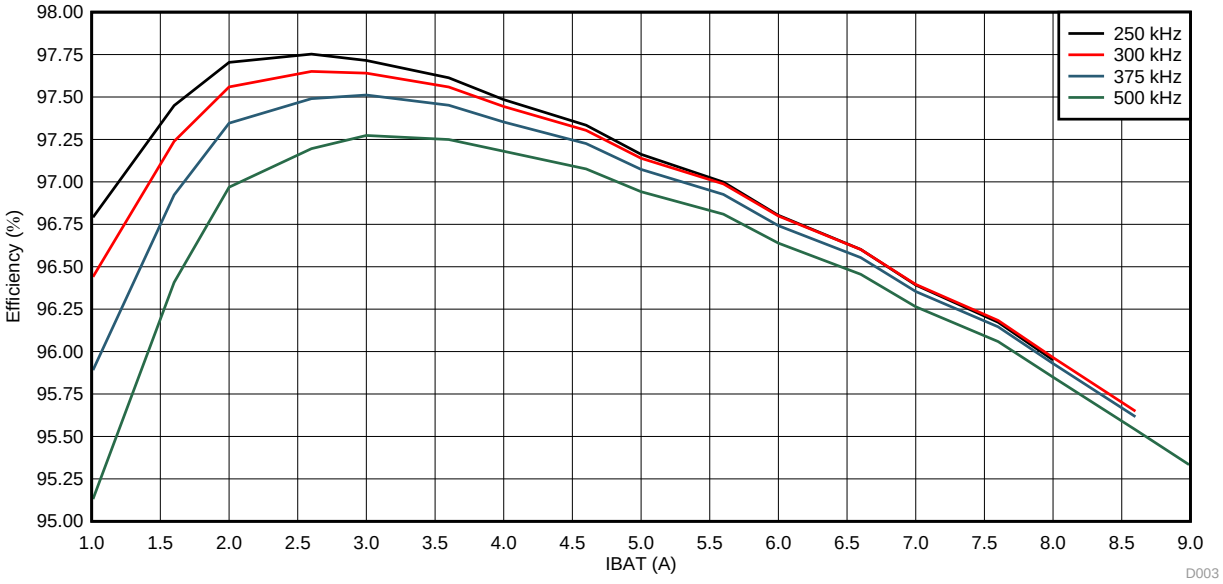

図 12. Efficiency of bq25970

図 13 shows the power loss of the bq25970.

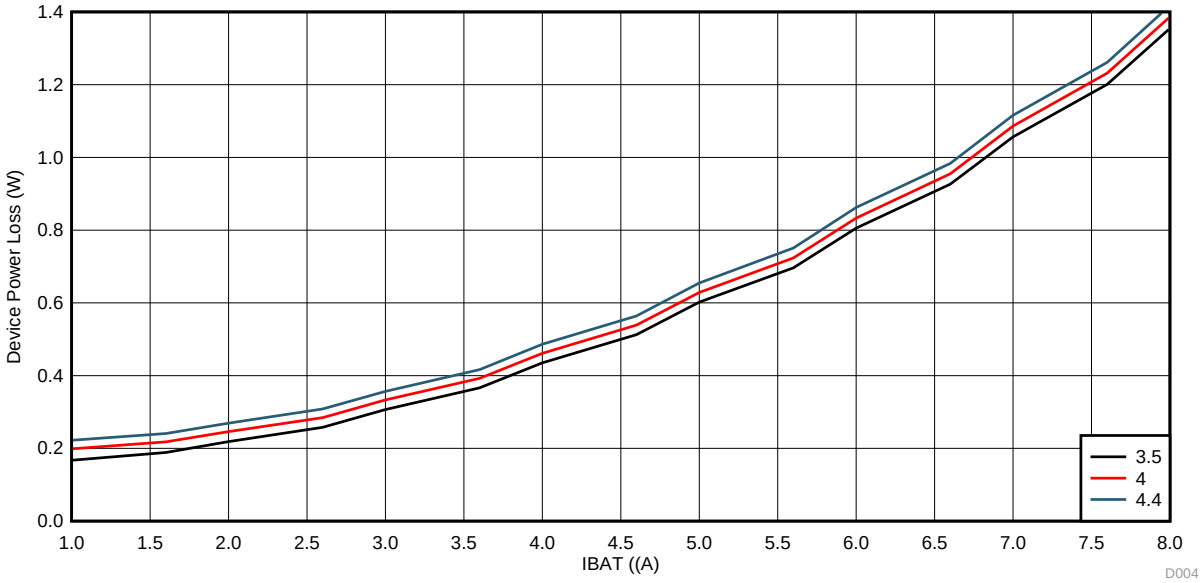

図 13. Power Loss of bq25970

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4 Design Files

4.1 Schematics

To download the schematics, see the design files at TIDA-01582.

4.2 Bill of Materials

To download the bill of materials (BOM), see the design files at TIDA-01582.

4.3 PCB Layout Recommendations

4.3.1 Layout Prints

To download the layer plots, see the design files at TIDA-01582.

4.4 Altium Project

To download the Altium project files, see the design files at TIDA-01582.

4.5 Gerber Files

To download the Gerber files, see the design files at TIDA-01582.

4.6 Assembly Drawings

To download the assembly drawings, see the design files at TIDA-01582.

5 Software Files

To download the software files, see the design files at TIDA-01582.

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6 Terminology

ADC— Analog-to-digital converter

CC— Constant current (mode)

CCS— Code Composer Studio™

ESR— Equivalent series resistance

FET— Field-effect transistor

GUI— Graphical user interface

MCU— Microcontroller

OVP— Overvoltage protection

PD— Power delivery

PMIC— Power management multichannel IC

PPS— Programmable power supply

RMS— Root mean square

SEB— System evaluation board

7 About the Author

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