USB PD-integrated 1 to 12-cell battery charger using EZ-PD™ PMG1-B2 MCU

About this document

Scope and purpose

This application note explains how to implement a USB Power Delivery (PD)-integrated 1 to 12-cell Lithium-ion (Li-ion) battery charger system using EZ-PD™ PMG1-B2 MCU.

EZ-PD™ PMG1-B2 is a high-voltage USB-C PD microcontroller with an integrated buck-boost controller for battery charging. The MCU includes an Arm® Cortex® CPU core, USB-C PD controller, buck-boost controller, fault protections, gate drivers, and configurable integrated analog and digital peripherals.

EZ-PD™ PMG1-B2 MCU offers a highly integrated solution with reduced BOM cost for battery-powered applications and is targeted for applications powered by USB-C PD, such as cordless power-tool chargers, wireless speakers, and portable electronics.

The firmware described in this application note is available as a code example with the ModusToolbox™ software development kit (SDK).

Intended audience

This document is intended for design and application engineers who are familiar with Li-ion batteries and want to integrate 1 to 12-cell Li-ion battery charging with USB PD and battery-monitoring functions using EZ-PD™ PMG1-B2 MCU.

Attention: ***When testing with Li-ion battery cells, all safety precautions for handling and using Li-ion batteries must be strictly followed. Do not use old or previously used battery cells. Always use new, identical battery cells to minimize risk.***

Keypoints

- Summarizes how to design a complete USB-PD-integrated 1 to 12-cell Li-ion charger using the EZ-PD™ PMG1-B2 MCU and its configurator tools
- Provides step-by-step guidance for creating, configuring, and building the charger application using ModusToolbox™ and evaluating the application on REF_PMG1_B2_DRP solution board
- Explains the hardware architecture, including buck-boost power stage design, sensing circuits, and hardware protection circuitry
- Describes the firmware flow implementing PD negotiation, charging algorithms, firmware protections, and safety timers for robust battery-charge control
- Provides hardware and firmware adaptation methods to support different battery-pack configurations for scalable end-application designs

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1 EZ-PD™ PMG1 MCU introduction

EZ-PD™ PMG1 from Infineon is a family of high-voltage microcontrollers with USB-C Power Delivery (PD). These devices include an Arm® Cortex®-M0/M0+ CPU, a USB-C PD controller, high-voltage protection features, gate drivers, and a range of analog and digital peripherals.

EZ-PD™ PMG1 is targeted at embedded systems that either provide power to or consume power from a high-voltage USB-C PD port, while using the MCU to enable additional control capabilities.

The EZ-PD™ PMG1 MCU family is fully compliant with the USB PD and Type-C standards. For a detailed overview of various features of PMG1 devices, see USB-C high voltage MCUs webpage.

2 Introduction to USB-C PD-integrated battery charging system

In recent years, the USB-C connector has become widely popular and now dominates applications such as mobile phones, laptops, tablets, PCs, and other consumer electronic devices. The USB Type-C and Power Delivery specification enable USB-C connectors to deliver up to 100 W (20 V at 5 A). With the latest USB Power Delivery 3.2 specification, USB-C power adapters can now provide up to 240 W (48 V at 5 A) on the Type-C connector. This standardization enabled many PC, notebook, and mobile phone vendors to replace proprietary chargers with USB-C power adapters as their primary charging solution. This has resulted in reduced electronic waste and the elimination of in-box chargers.

The USB-C revolution has led many other consumer applications, such as smart speakers, power tools, cameras, media players, and smart home appliances, to adopt USB-C as their primary connector for charging and data communication. The USB-C port on battery-operated devices, such as smart speakers, can be a dual-role port (DRP) device. This allows the speaker to charge its battery when connected to a USB-C charger and can also charge a phone when connected to it.

2.1 Traditional battery charging system

A battery charger works by supplying an electrical current at a voltage higher than the battery's current voltage, which forces the battery to accept the charge and causes its voltage to increase. As current is pushed into the battery, it triggers reverse chemical reactions, restoring the battery's stored energy and causing its terminal voltage to rise, a process that continues until the battery is full.

Figure 1 shows a traditional battery charger system block diagram.

- Buck-boost/battery charging IC to enable the charging of battery packs. These ICs typically support various battery charging modes, such as trickle charging, pre-charging, constant current, and constant voltage mode, among others. The battery charging IC also supports safety timers for protection against prolonged battery charging
- Battery management MCU is responsible for monitoring and cutting off charging if the primary battery charging IC fails. Additionally, temperature sensors are included to monitor the system and battery temperatures
- Finally, battery protection and monitoring circuits are included to ensure that the voltage of each individual cell does not exceed safe limits

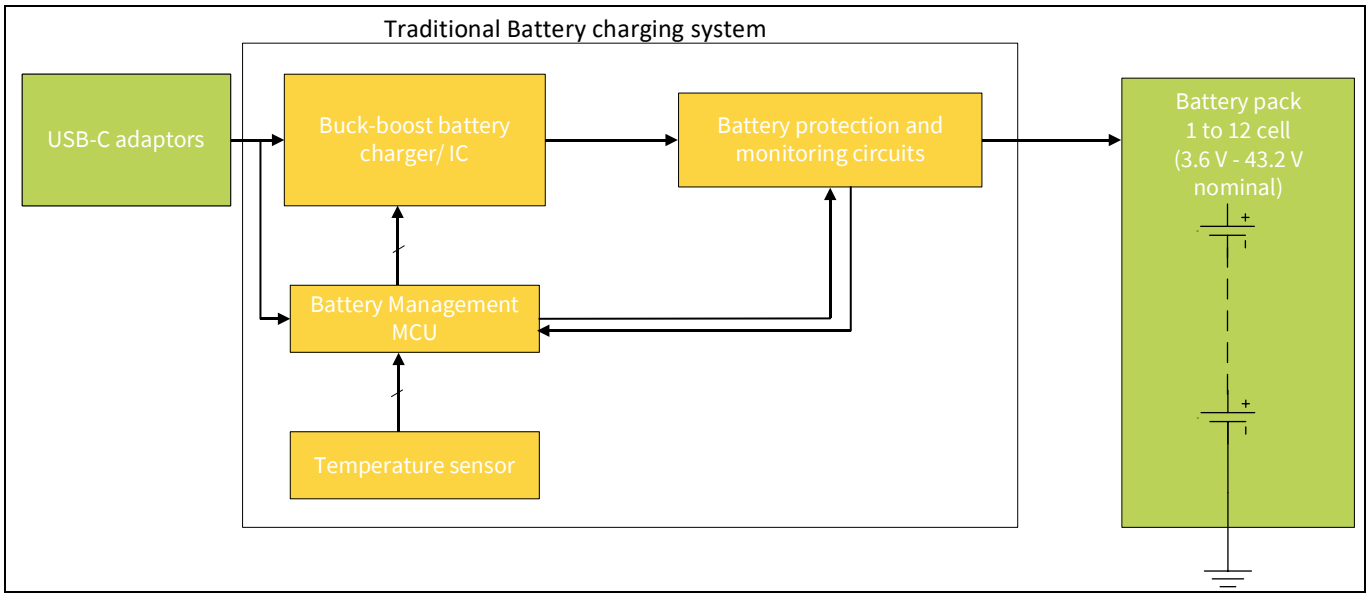


Figure 1 Traditional battery charger system

2.2 USB PD-integrated battery charger system

By replacing proprietary connectors in battery-powered applications with USB-C connectors, the device can be charged with any USB-C adapter. In the battery charger system shown in Figure 2, the USB-C PD controller is responsible for negotiating the USB Type-C and PD contract with the USB-C power adapters and delivering the power to the battery charger IC for charging the battery pack. In dual-role power applications, the USB-C controller can also take battery power and make it available on the USB-C connector to charge devices such as phones and laptops.

EZ-PD™ PMG1-B2 MCU from Infineon offers an integrated single chip solution for USB PD-integrated 1 to 12-cell Li-ion battery charging system with battery protection features. Figure 2 shows a USB-C PD powered system using EZ-PD™ PMG1-B2 MCU for battery charging.

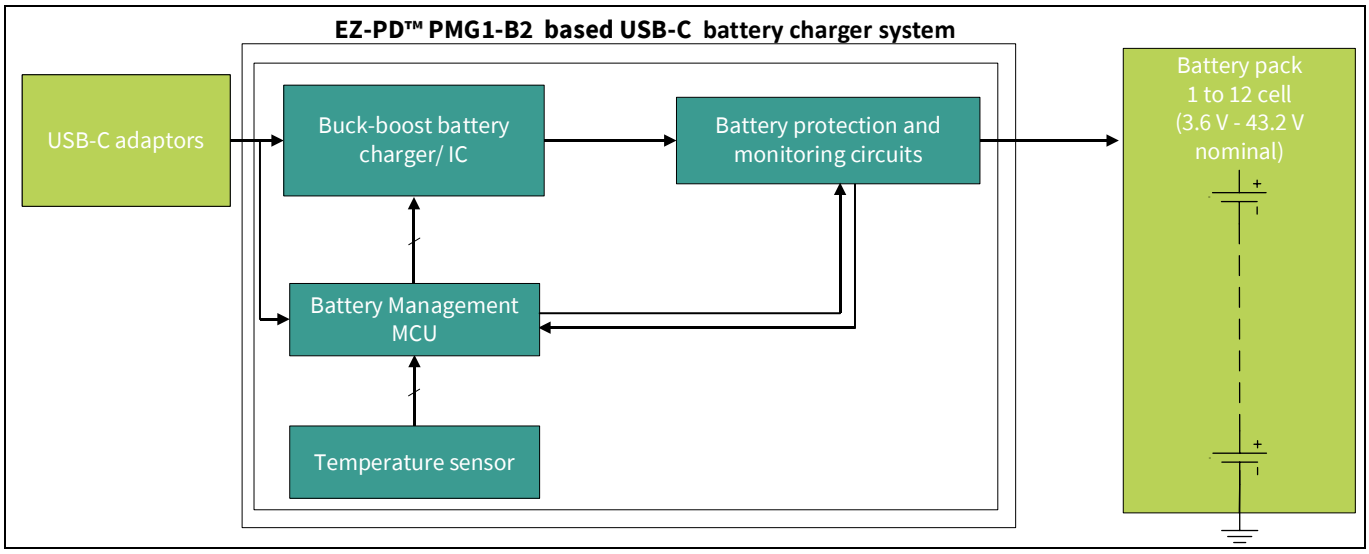


Figure 2 EZ-PD™ PMG1-B2-based USB-C battery charger system

3 EZ-PD™ PMG1-B2 controller for USB PD-integrated battery charging system

EZ-PD™ PMG1-B2 MCU is a highly integrated single-port USB Type-C PD solution with an integrated buck-boost controller for battery charger applications and is from the portfolio of EZ-PD™ PMG1 high-voltage USB-C PD microcontrollers. These MCUs include an Arm® Cortex® CPU core, a USB-C PD controller, and configurable integrated analog and digital peripherals.

The EZ-PD™ PMG1-B2 MCU includes integrated NFET gate drivers for the buck-boost FETs. It provides hardware and software-controlled protection features on the VBUS and VBAT paths. It has an integrated 5 V LDO. It complies with the latest USB Type-C and USB PD specifications.

EZ-PD™ PMG1-B2 device is targeted at embedded systems that are powered from a high-voltage USB-C port and require an MCU to implement the product features.

3.1 Feature integration

This section lists the key features of the EZ-PD™ PMG1-B2 device which are critical for the implementation of the USB PD integrated 1 to 12-cell Li-ion battery charging solution.

- 32-bit Arm® Cortex®-M0 CPU
- 8 KB SRAM, 8 KB SROM, and 128 KB flash memory
- Type-C and USB PD block
- Integrated 5 V LDO
- Integrated buck-boost controller with four integrated NFET gate drivers for the buck-boost operation
- Configurable switching frequency (200 kHz to 700 kHz) for the buck-boost controller
- Analog block with two 8-bit SAR ADC
- Programmable digital blocks such as SCB and TCPWM
- Ten programmable GPIO pins including two Fail-Safe GPIOs and nine fixed function I/O pins
- Two high-side current sense amplifiers (CSA) for current monitoring
- OVP, input overvoltage/undervoltage lockout protection features at the input USB-C port and OVP, OCP, SCP protection features at the output battery terminal
- On-chip temperature sensor

3.2 EZ-PD™ PMG1-B2-based 240 W Li-ion battery charger solution

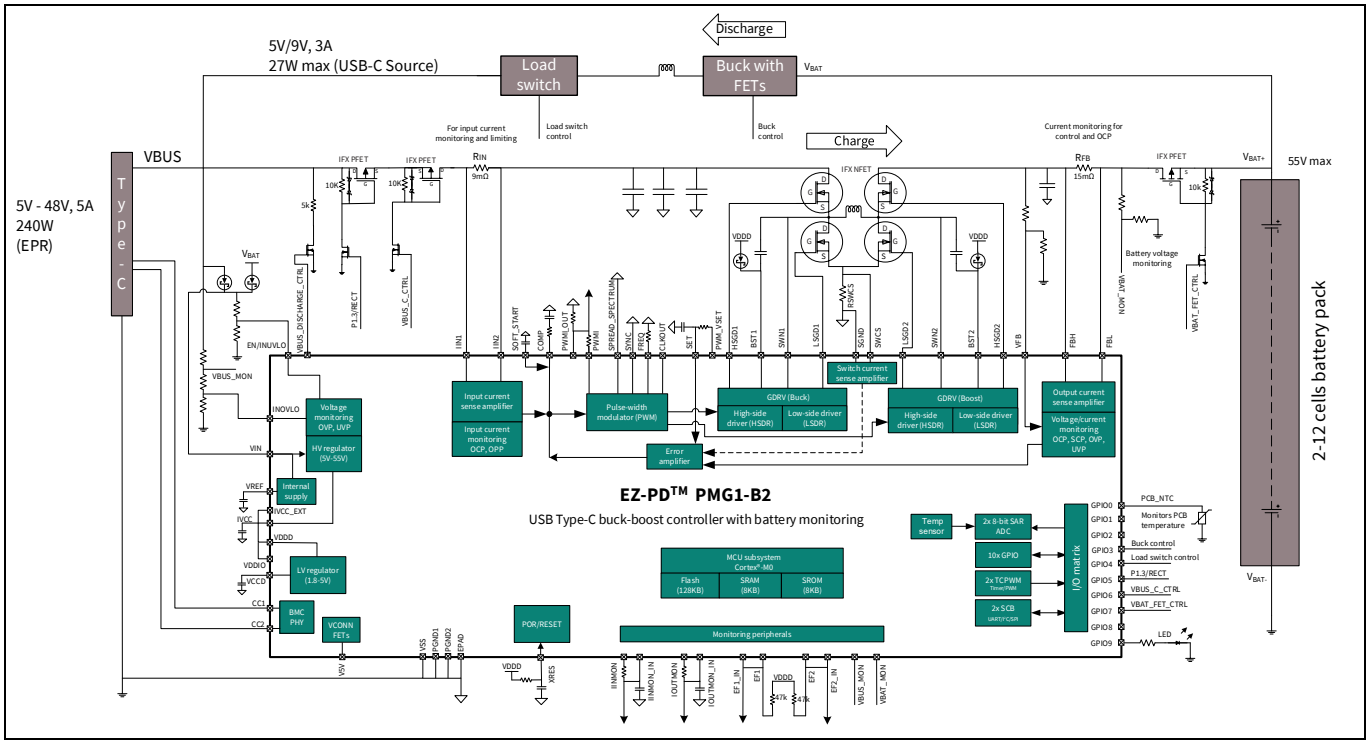


Figure 3 EZ-PD™ PMG1-B2 DRP battery charging solution diagram

The EZ-PD™ PMG1-B2 MCU-based 240 W battery charger solution provides monitoring, charging, and protection of batteries. It consists of a USB PD block and a built-in buck-boost block that allows the MCU to negotiate up to a 240 W power delivery contract over the USB-C connector with the USB-C power adapter. This makes the power easily accessible for charging the battery pack. The CSA blocks and voltage-monitoring circuits provide fault-protection features, ensuring safe and efficient charging of the batteries.

EZ-PD™ PMG1-B2 system supports USB PD-based battery charging for 1 to 12-cell batteries in Sink mode and 2 to 12-cell batteries in DRP mode. It offers three battery-charging modes throughout the battery charging process, such as pre-charge, normal charge, and top-off charge modes to enable efficient and safe charging of the batteries. It has high-voltage analog signal sensing peripherals such as a current sense amplifier (CSA) for monitoring the battery charging current and 8-bit SAR ADC for monitoring the total battery voltage as well as for VBUS overvoltage fault protection (OVP) handling. Based on the monitored battery voltage, the MCU firmware initiates the appropriate charging mode. The MCU's timer block provides additional layer of protection by enabling the implementation of battery-charging safety timers. These timers prevent the battery from overcharging because of unexpected conditions, thereby increasing the overall battery life.

EZ-PD™ PMG1-B2 device provides the functionality of a traditional MCU through software programmability. This feature enables developers to configure a wide range of battery-charging parameters through firmware, including battery cell count, charging mode configurations, battery voltage and current thresholds, temperature thresholds, battery protection features, and more. Additionally, EZ-PD™ PMG1-B2 MCU includes peripherals such as I2C and UART, enabling communication of battery status to an external embedded host controller and supporting the implementation of custom features.

4 Targeted applications

A growing number of battery-operated products in the consumer, industrial, and communications segments are adopting USB-C ports as their power source. The EZ-PD™ PMG1-B2-based battery charger solution targets many battery-operated applications, such as battery chargers for cordless power tools, vacuum cleaners, drones, E-bikes and E-Scooters, garden robot, smart speakers, cameras, headphones, game consoles, VR headsets, home appliances, and other portable electronics.

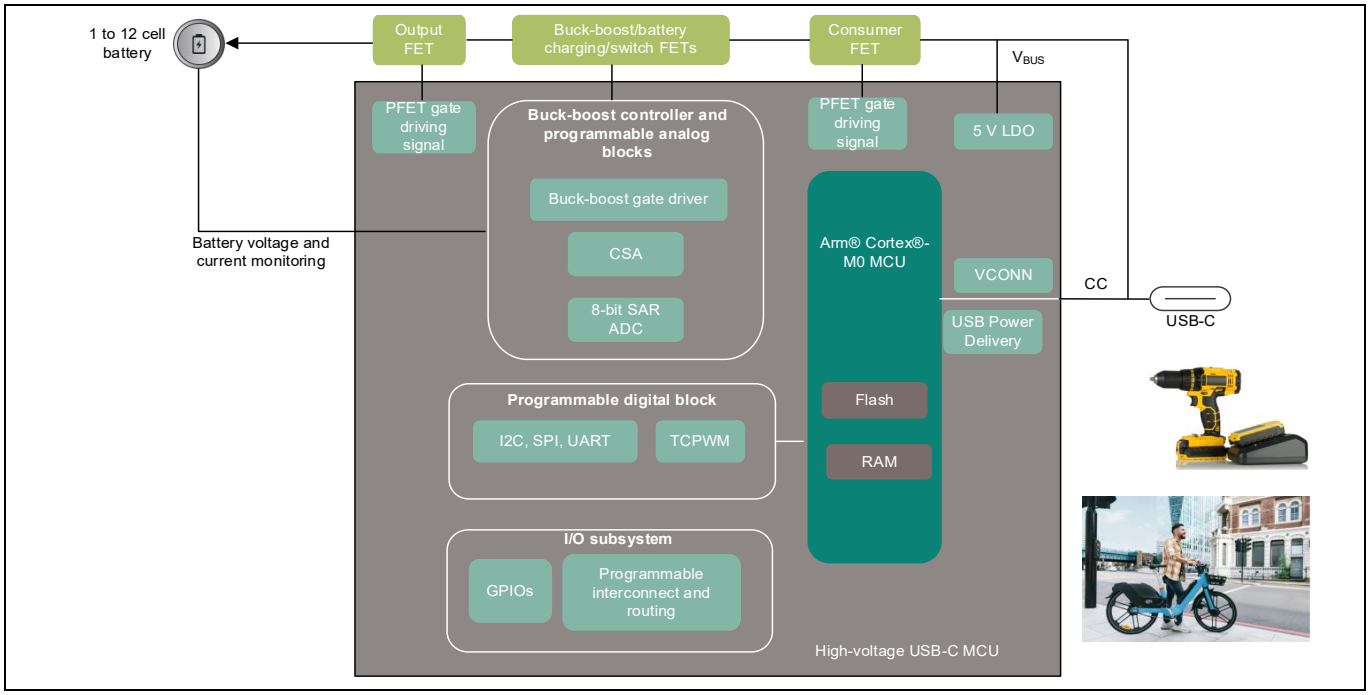


Figure 4 Application diagram

5 EZ-PD™ PMG1-B2 battery charger application development

5.1 REF_PMG1_B2_DRP solution board

The REF_PMG1_B2_DRP is a solution board with EZ-PD™ PMG1-B2 USB-PD MCU and the board can be used for 1 to 12 cell battery charging application (see Section 9.1 for the hardware changes required on the solution board for each cell configuration). The REF_PMG2_B2_DRP solution board can be used to sink or source power through the USB-C PD port in applications such as the cordless power tool charger, wireless speakers, and portable electronics. The solution board can be used to sink up to 240 W or source up to 27 W.

The solution in USB PD Sink mode can be used to charge 1 to 12-cell batteries based on the hardware and firmware configurations as discussed in Section 8 of this document. In USB PD Source mode, the solution supports 2 to 12-cell batteries. The code examples ([6], [7], [8]) for REF_PMG1_B2_DRP board are implemented as part of the EZ-PD™ PMG1-B2 SDK within the ModusToolbox™ software.

- REF_PMG1_B2_DRP solution board user guide [5] provides detailed information about the hardware capabilities of the board and how to set up the board for various demos such as charging a 12-cell battery
- Hardware design guidelines [2] and design calculator [3] for REF_PMG1_B2_DRP Solution board provide comprehensive and easy-to-follow guidelines for designing the power stage for 1 to 12-cell battery systems based on the EZ-PD™ PMG1-B2 MCU

Figure 5 shows the top view of the solution board with critical components.

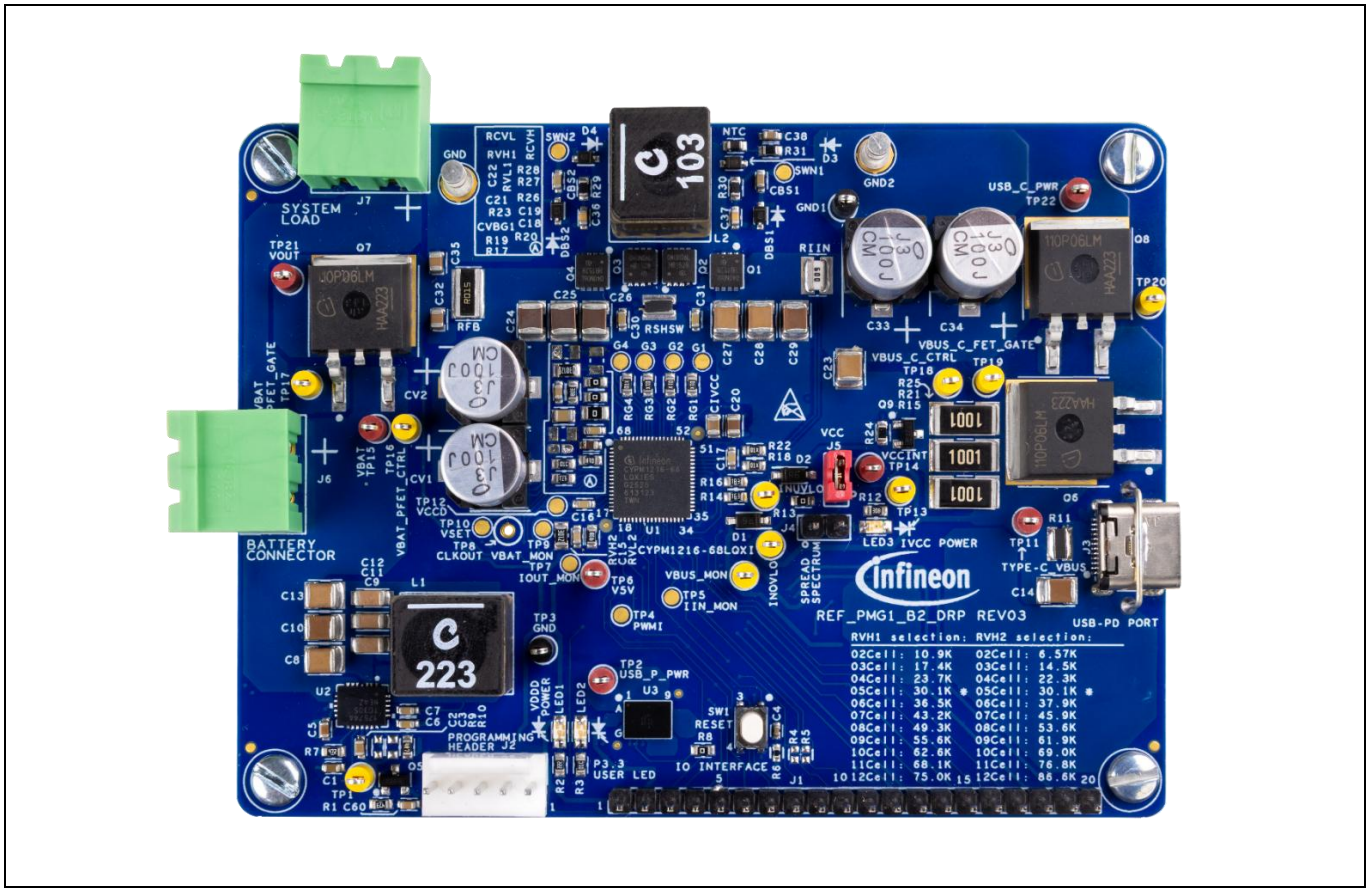


Figure 5 REF_PMG1_B2_DRP solution board (top view)

5.2 Creating EZ-PD™ PMG1-B2 Li-ion battery charger application using ModusToolbox™

This code example [6] is developed using the ModusToolbox™ software development environment. The ModusToolbox™ package provides a set of integrated configuration tools along with the Eclipse IDE, enabling easy development of embedded applications. The following sections discuss the process of creating and programming this code example using the REF_PMG1_B2_DRP solution board.

5.2.1 Creating the EZ-PD™ PMG1-B2 battery charger application

Install ModusToolbox™ package on your PC (version 3.8 and above) and click on Eclipse IDE for ModusToolbox™ from the start menu to open the IDE.

1. In the Eclipse IDE for ModusToolbox™, provide the appropriate directory path and folder name to create a workspace for the project
2. In the Quick Panel, click **New Application** to launch the Project Creator tool
3. In **PMG BSPs**, select REF_PMG1_B2_DRP board support package (BSP) and click **Next**, as shown in Figure 6

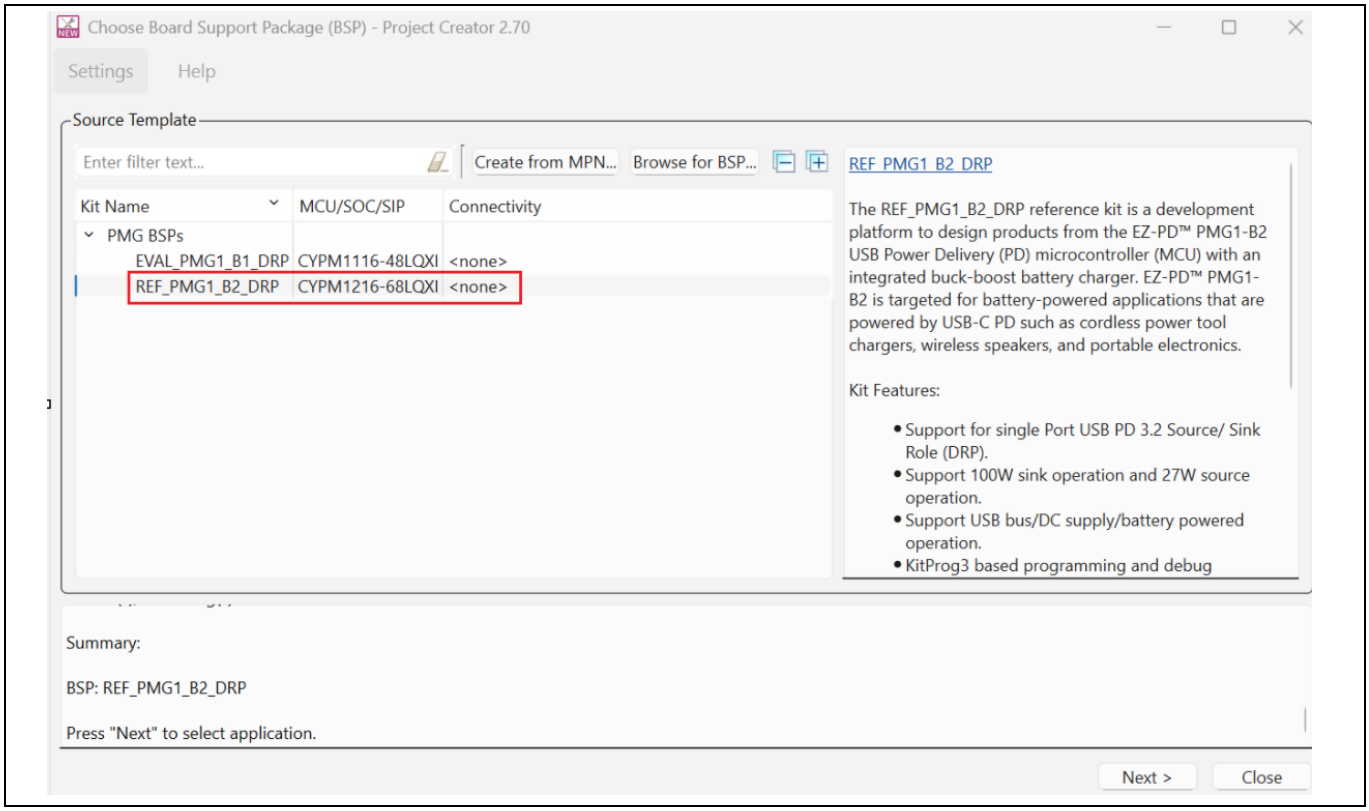


Figure 6 Creating a new application in ModusToolbox™

4. Select **USBPD Li-ion Battery Charger** and click **Create**, as shown in Figure 7 to launch the application

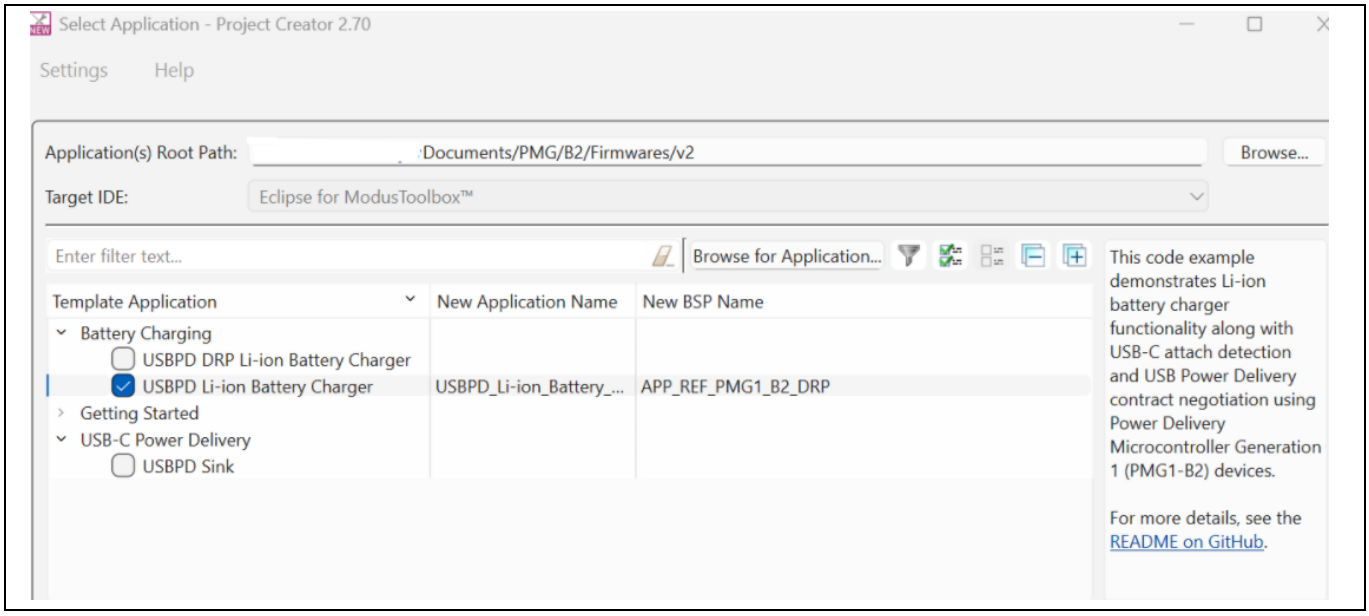


Figure 7 Selecting Templating Application in Project Creator

5. The application will be created in the new workspace and all the related files and libraries will be listed under the **Project Explorer**, as shown in Figure 8

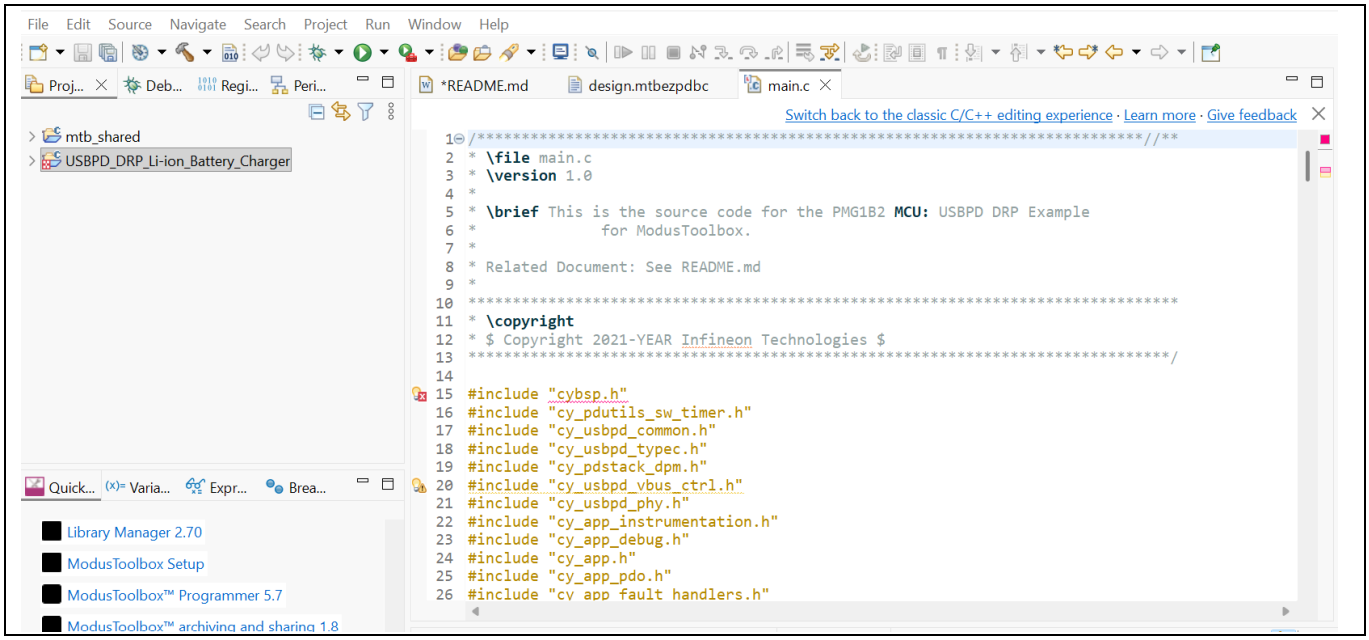


Figure 8 Creating a new application in the workspace

5.2.2 Device Configurator for peripheral configuration

The Device Configurator enables and configures device peripherals, such as ADC, USB PD, clocks, pins, and standard MCU peripherals that do not require their own configurator tool. This configurator generates the initialization code used in the battery charger application.

The template folder contains the target files and includes the *design.modus* file.

1. Double-click the *design.modus* file to open the design configuration defined by the BSP, or select **Device Configurator** under **BSP Configurators** in the **Quick Panel** to view and modify the design configuration

2. Device Configurator GUI contains Resource Categories Pane, List of resources, Parameters Pane, and Notice Pane sections, as shown in Figure 9

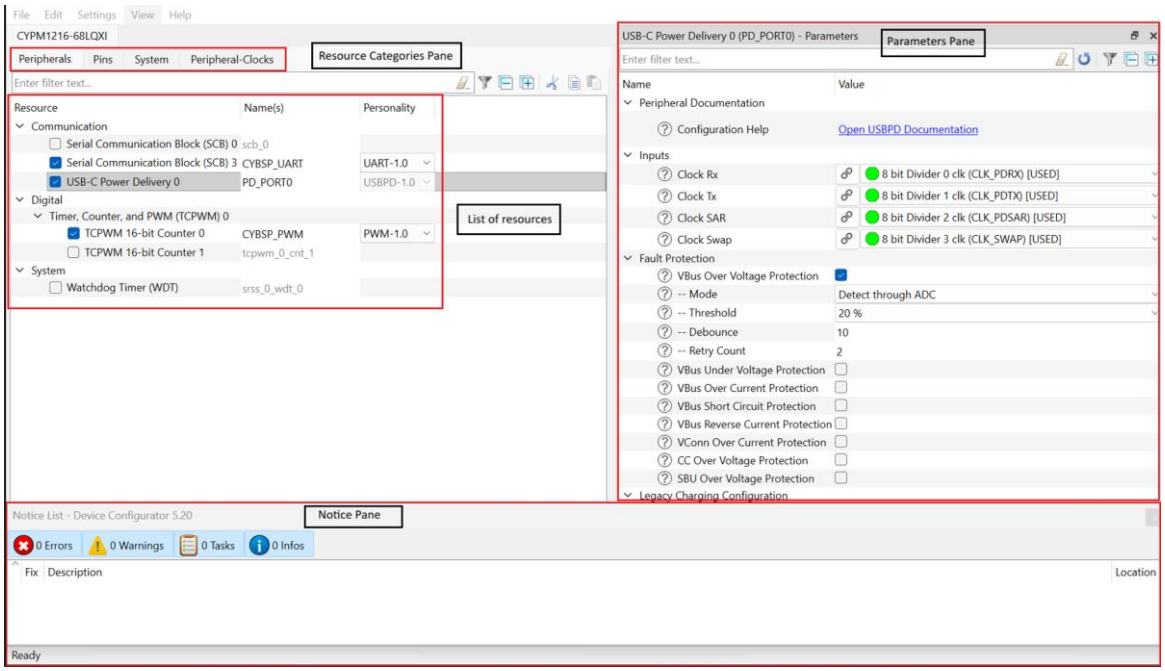


Figure 9 Device Configurator GUI

3. From the list of resources in the **Resource Categories Pane** of **Device Configurator**, choose from the different resources available on the device, such as peripherals, pins, and clocks
   - You can configure how a resource behaves by selecting a personality for that resource. For example, a Serial Communication Block (SCB) resource can have EZI2C, I2C, SPI, or UART personalities
4. In the **Parameters** window, enter the configuration parameters for each enabled resource and the selected personality
   - The code **Preview** pane displays the configuration code generated based on the selected configuration parameters. This code is populated in the "*mtbcfg_ezpd.c*" file located in the *GeneratedSource* folder
   - The **Notices** pane displays the errors, warnings, and information messages arising out of the configuration

5.2.3 EZ-PD™ Configurator for configuring the USB PD parameters

The EZ-PD™ Configurator enable and configure USB PD parameters, such as VID/PID, Type-C port role, port power, port supported PDOs, EPR PDOs, and port PDP. This configurator generates the configuration code used in the battery charger application.

1. Double-click the *design.mtbezpd* file to open the EZ-PD™ configuration defined by the BSP or select **EZ-PD™ Configurator** under **BSP Configurators** in the **Quick Panel** to view and modify the USB PD configuration
   - **EZ-PD™ Configurator GUI** contains Port information, Sink PDOs, Source PDOs, EPR PDOs, and SKEDB Configuration, as shown in Figure 10

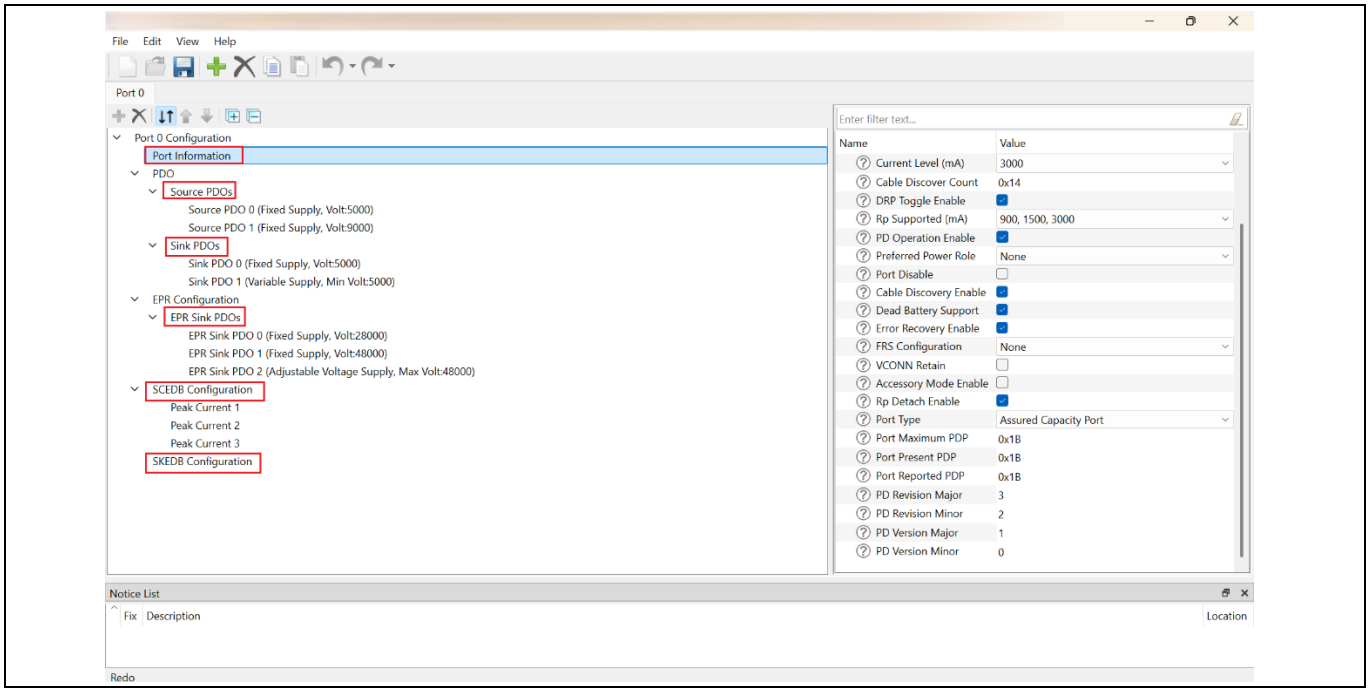


Figure 10 EZ-PD™ Configurator GUI

2. In the **Port information** section, configure the solution's VID/PID, supported PD revision and version, supported port power and port PDPD parameters for the desired output
   - In **Sink PDO** section, configure standard power range (SPR) fixed PDOs, variable AVS, and PPS PDOs
   - In **EPR PDO** section, configure extended power range (EPR) fixed PDOs, variable AVS, and PPS PDOs

Once the Port Information and supported PDOs are configured, the port's maximum SPR PDP and EPR PDP can be configured in the **SKEDB Configuration**, as shown in Figure 11.

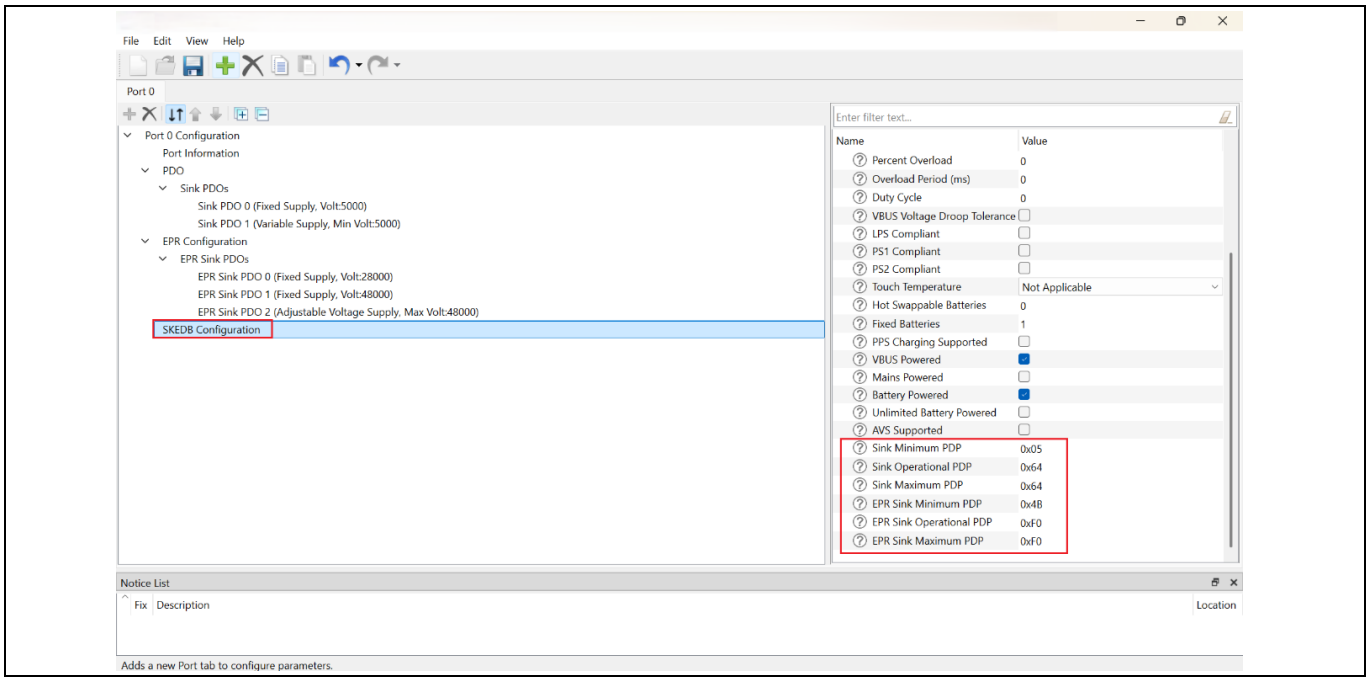


Figure 11 SKEDB Configuration

5.2.4 EZ-PD™ Battery Charger Configurator for configuring the battery parameters

The EZ-PD™ Battery Charger Configurator enables and configures the battery charging parameters, such as battery voltage, current, charging safety timers, and temperature sensor parameters that do not require their own configurator tool. This configurator generates the source code that is used in the battery charger application.

1. Select **EZ-PD™ Battery Charger Configurator** under **BSP Configurators** (in the **Quick Panel** to view and modify the design configuration. See Figure 12

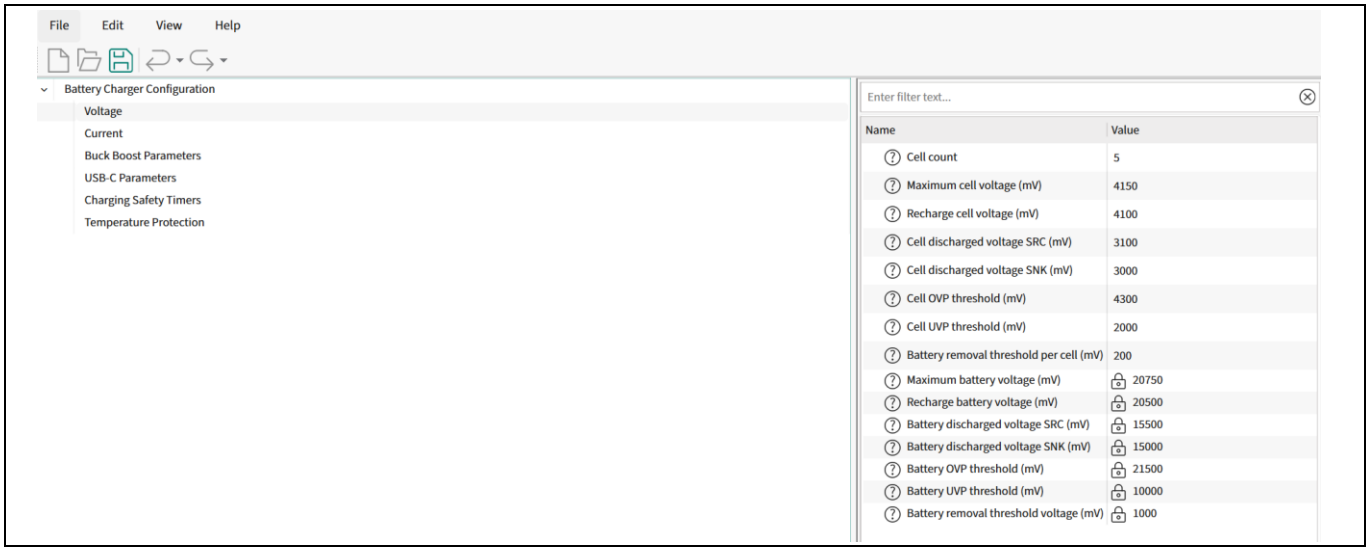


Figure 12 EZ-PD™ Battery Charger Configurator GUI

5.3 Building and programming the application

Building of the application involves generating the source files corresponding to the configurator design files, compiling, and linking the C code to generate the programmable hex file.

Building the application: Follow the steps to build the application:

1. Select the application by clicking the project file in the **Project Explorer**
2. Navigate to the **Quick Panel** and click **Build Application** to start the build process
3. Follow the updates in the **Console** window to observe the final result after the build is complete. Ensure that there are no errors or warnings listed in the console
4. After the build is complete, the generated programmable hex file will be located at: **Application-name** > **build** > **APP _REF_PMG1_B2_DRP** > **Debug**

Programming the MCU: To program the target EZ-PD™ PMG1-B2 MCU, use ModusToolbox™ and a MiniProg4.

1. Connect **MiniProg4** from the PC to the J2 header on the board
2. Go to **Run** > **External Tools** > **External Tool Configuration** > **Main**
3. Add the following script to enable MiniProg to supply power, as shown in Figure 13:

```
-j12 program _MTB_RECIPE__OPENOCD_INTERFACE="source [find interface/kitprog3.cfg];
set ENABLE_POWER_SUPPLY 5000
```

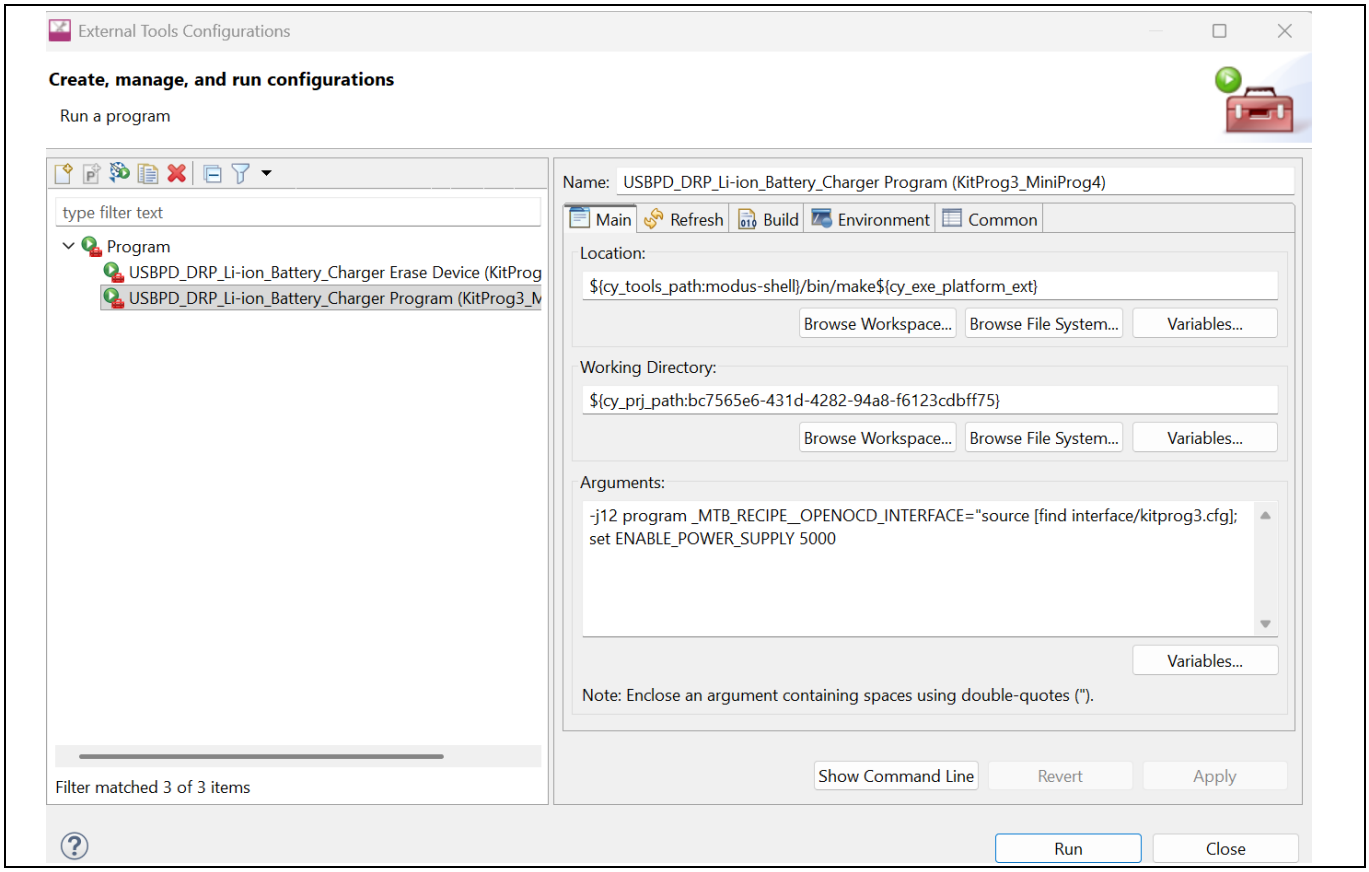


Figure 13 Configure MiniProg to supply power while programming the target REF_PMG1_B2_DRP solution board

Note: The MiniProg4 power supply configuration shown in Figure 13 is a one-time setup procedure. For subsequent programming, steps 2 and 3 can be bypassed

4. In ModusToolbox™, use “USBPD_Li-ion_Battery_Charger Program” (as shown in Figure 14) option for programming the firmware into EZ-PD™ PMG1-B2 MCU

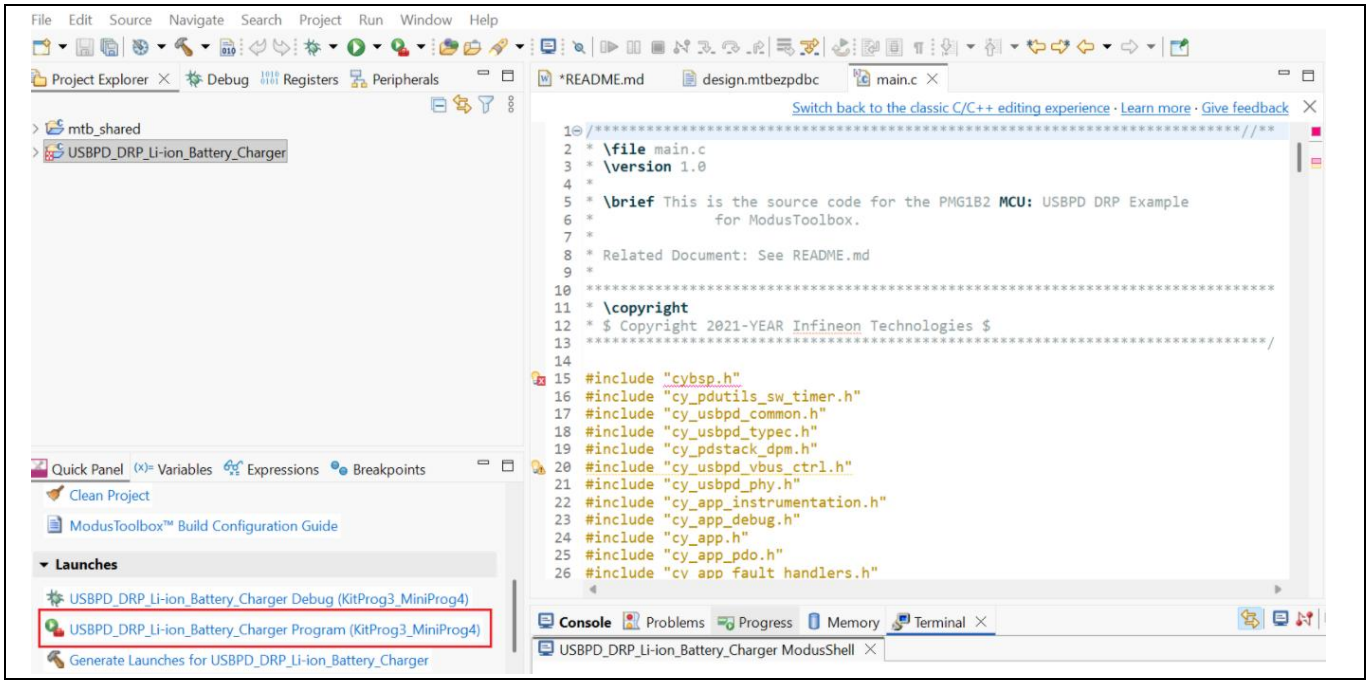


Figure 14 Programming the application to the target REF_PMG1_B2_DRP solution board

5.4 Evaluating the battery charger application

Connect the battery to the battery terminal (J6) and connect the USB-C adaptor to the J3 terminal of the REF_PMG1_B2_DRP solution board. If a faulty battery is connected, EZ-PD™ PMG1-B2 device can detect the fault and will not start the charging.

If the connected battery is functional, the battery charging algorithm in EZ-PD™ PMG1-B2 MCU firmware activates, and the battery starts charging. The V-I charging profile is shown in Figure 15.

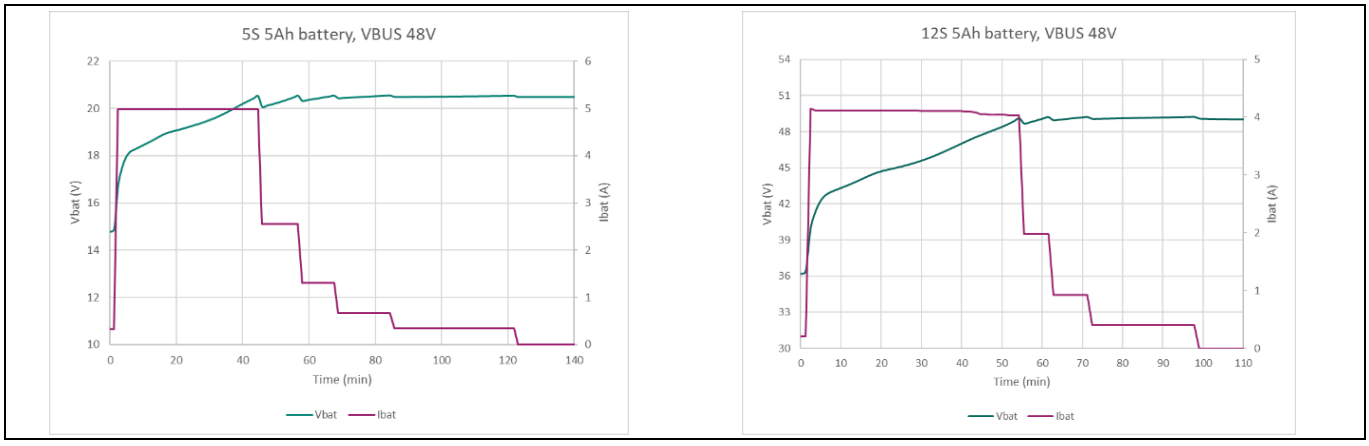


Figure 15 Typical Li-ion battery charging V-I characteristics

The charging status of the connected battery can be identified using the LED state on the REF_PMG1_B2_DRP solution board. When the battery is charging in pre-charge, normal or top-off charging mode, the LED blinks with 5 Hz frequency. When the battery is fully charged, LED is turned off. When fault occurs, LED is turned on. When the temperature increases or decreases, LED brightness increases or decreases.

Table 1 User LED (on REF_PMG1_B2_DRP solution board) status

Condition	LED2 status
EZ-PD™ PMG1-B2 device is in pre-charge/normal charge/top-off charging mode	Blinks with 5 Hz frequency
Battery is fully charged	OFF
Fault condition	ON
System/EZ-PD™ PMG1-B2 device is in cooling mode (after hitting the OTP threshold)	In breathing mode (brightness increases and decreases)

6 Hardware architecture

6.1 Design specifications

6.1.1 System specifications for REF_PMG1_B2_DRP solution board

Table 2 System specification of the hardware

Parameter	Minimum	Typical	Maximum	Unit
Total number of Li-ion battery cells supported	1[1]	–	12	–
USB-C PDO contact voltage for battery charging	5	–	48	V
USB-C PDO contract current for battery charging	0.9	–	5	A
USB-C Sink port power for battery charging	15	–	240	W
Buck-boost PWM frequency	200	206	700	kHz
Battery charger output voltage	5	–	50.4	V
Battery charging current	0.3	–	10	A
Voltage regulation mode output	–	24	–	V
Maximum output power (with 240 W EPR USB-C power supply)	–	–	230	W
USB-C Source port power	–	–	27	W
Thermal protection (based on board temperature measured using NTC)	5	–	85	°C

6.2 EZ-PD™ PMG1-B2 MCU-based USB PD-integrated battery charger system hardware architecture

Figure 16 shows hardware blocks of the EZ-PD™ PMG1-B2 MCU used in the battery charging system. The EZ-PD™ PMG1-B2 MCU provides efficient battery charging and protection with USB-C support, integrating key features such as the USBPD block, integrated buck-boost block, timer block, high-voltage regulator, and standby or low-power regulator.

[1] For USB PD DRP application, 1-cell charging is not supported.

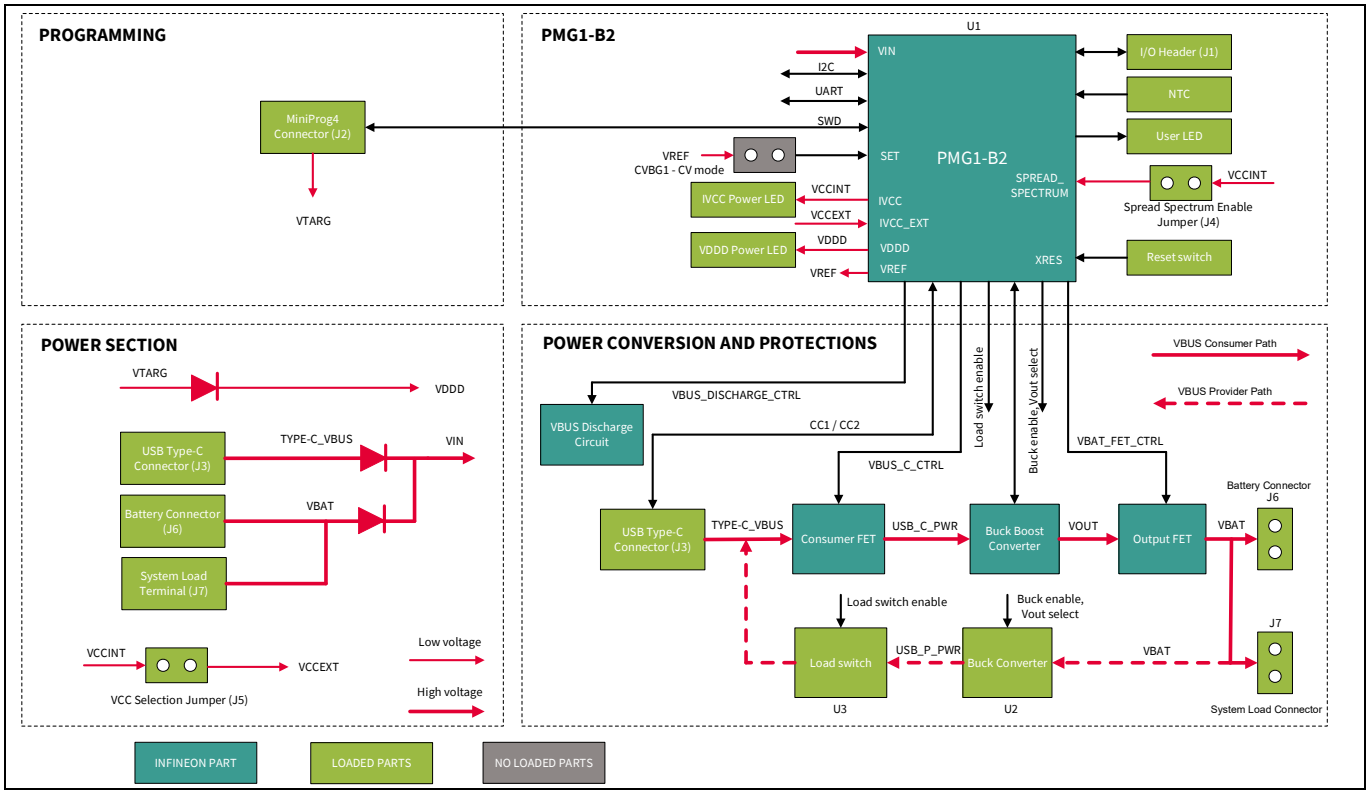


Figure 16 EZ-PD™ PMG1-B2 MCU system hardware blocks for DRP battery charging system

6.3 EZ-PD™ PMG1-B2 battery charger system components

This section explains external hardware components or system components used for EZ-PD™ PMG1-B2 battery charger application.

6.3.1 Hardware components at the input Type-C end

6.3.1.1 Consumer FET

EZ-PD™ PMG1-B2 devices provide a gate driving signal on pin VBUS_C_CTRL for turning on or off the consumer FET (Q8) placed to disconnect or connect the Type-C VBUS from the buck-boost input as shown in Figure 17. The hardware circuitry connected to the gate of Q8 helps in the soft turn-on, which helps limit inrush current The FET is turned on only when a Type-C adapter is connected to the USB-C port.

FET Q6 is added in series to Q8 to block any reverse current flowing into the Type-C VBUS during start-up. It is controlled through GPIO P1.3. The gate circuit associated with Q6 is enabled for a short time interval during buck-boost converter startup.

The considerations for selecting the consumer FETs Q6 and Q8 include low $R_{DS(ON)}$ to minimize conduction losses, and ensuring that the V_{DS} rating (minimum blocking voltage) is at least 60 V.

See hardware design guidelines [2] for a detailed description of the component selection process.

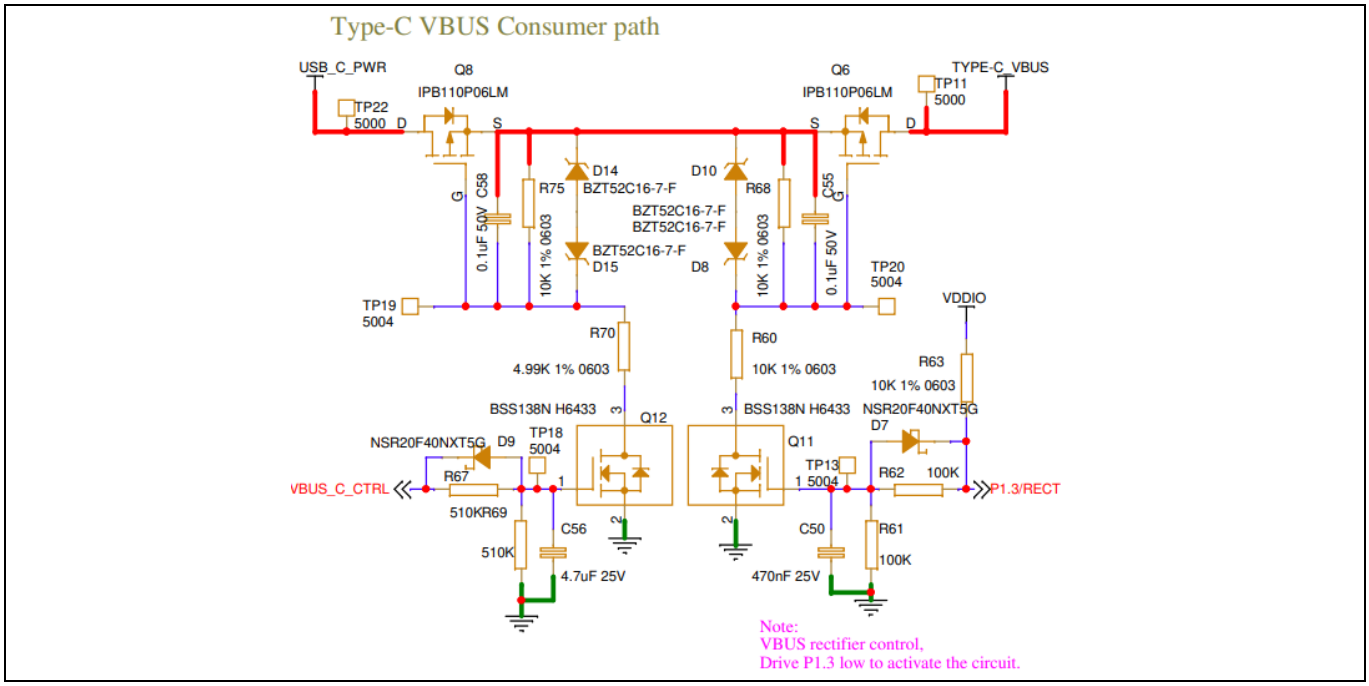


Figure 17 Consumer path PFETs and gate drives

6.3.1.2 Type-C VBUS discharge circuit

EZ-PD™ PMG1-B2 devices provide a Type-C VBUS discharge signal to discharge VBUS when the VBUS is disconnected from the Type-C adapter. Figure 18 shows the burn in resistor circuit to discharge the capacitors energy and reduce the VBUS voltage to a safe level in the required time.

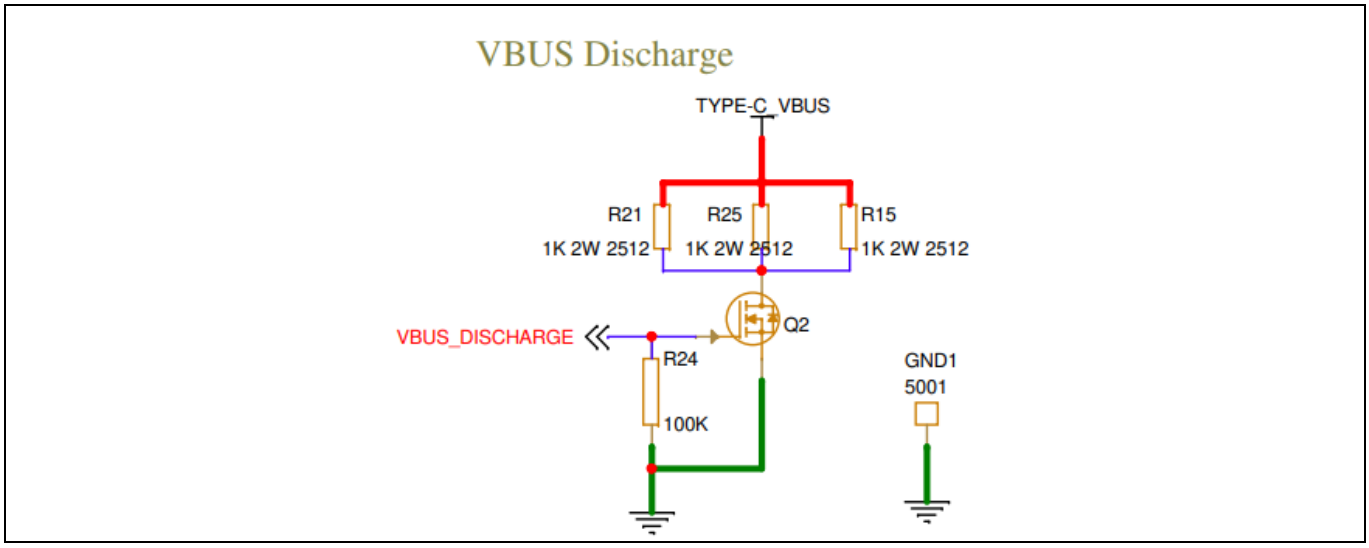


Figure 18 Input side Type-C VBUS discharge circuit

6.3.2 Buck-boost power stage

6.3.2.1 Buck-boost controller

The EZ-PD™ PMG1-B2 device has an integrated buck-boost controller with integrated gate drivers for both high-side and low-side N-MOSFETs for the buck-boost converter. The buck-boost can support 5 V to 55 V input voltage range and can provide up to 55 V output voltage with a maximum efficiency utilizing synchronous switching scheme.

The Buck-boost topology is an H-bridge topology which supports buck, boost, and buck-boost operations. It provides wide range of outputs ranging from 5 V to 55 V output voltage. The transition between each mode is seamless.

The regulator function is implemented by a peak current mode (PCM) control. An external compensation network (R_{COMP}, C_{COMP}) is used to adjust the control loop response for various applications. The inductor current for the current mode loop is sensed by the R_{SWCS} resistor. The inductor value selection is based on the maximum ripple current and the frequency of the converter. A higher inductor value will result in a lower ripple current in the output current. See Figure 19.

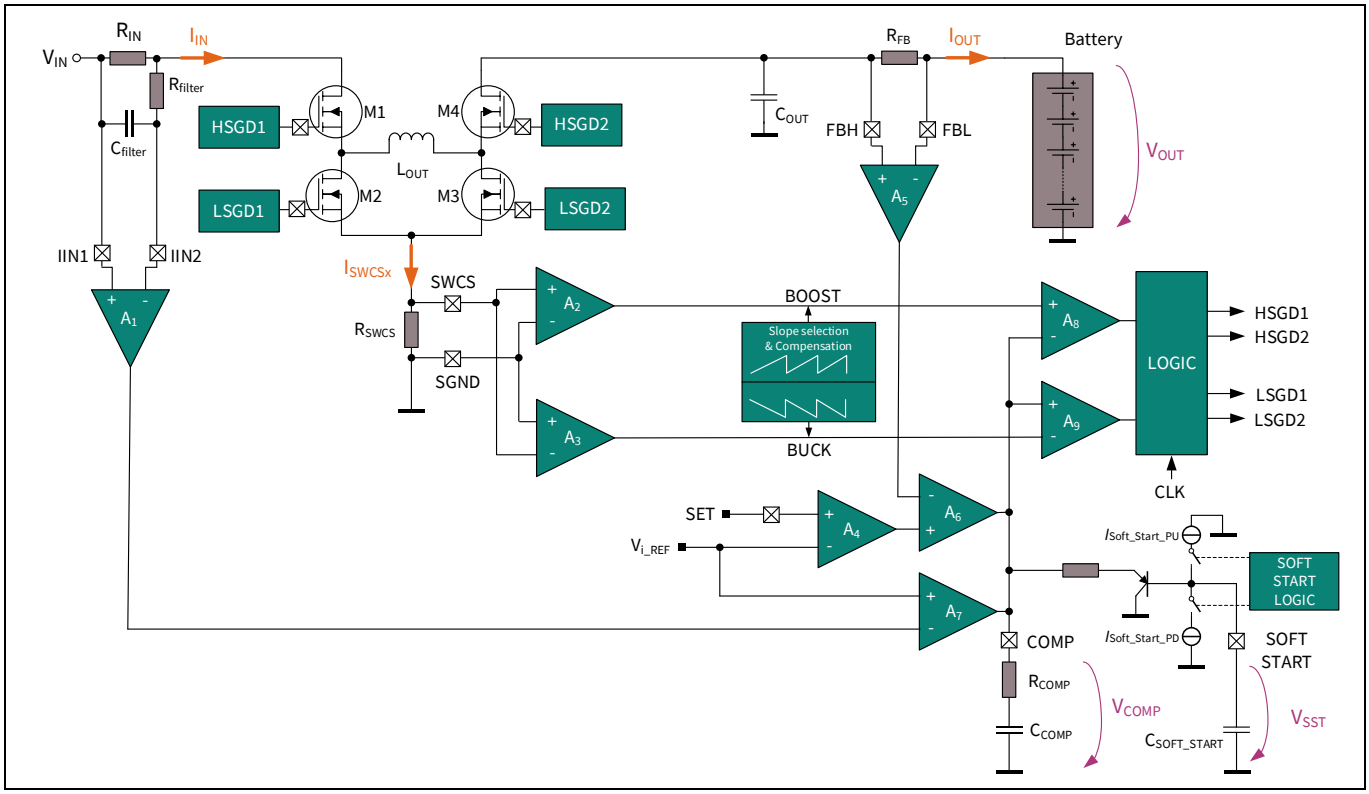


Figure 19 Buck-boost control system block diagram

The two differential analog current sensing inputs (IIN1, IIN2) at R_{IN} are used to limit the maximum input current. A second differential analog current sensing inputs pins FBL and FBH sense the output current through the R_{FB} and the control loop is using this feedback to regulate the output current. The R_{IN} value selection is based on limiting the input current to ($50\ mV/I_{IN_MAX}$), where 50 mV is the maximum allowed voltage drop across R_{IN}. If the input current goes beyond ($50\ mV/R_{IN}$), then the system limits this current by reducing the VCOMP voltage (at the output of A7) resulting in limiting the output power The input current monitoring signal is generated on IINMON pin following the equation below:

$$V_{IINMON} = 20 . I_{IN} . R_{IN}$$

Equation 1 V_{INMON} equation

The R_{FB} value selection is based on the maximum output current. Controller will limit the current to maintain the maximum voltage drops across R_{FB} to 150 mV.

The IOUTMON pin provides a linear indication of the current flowing through the output feedback shunt resistor R_{FB}, as shown in Equation 2:

$$V_{IOUTMON} = 200\ mV + 8 . I_{OUT} R_{FB}$$

Equation 2 $V_{IOUTMON}$ equation

The input capacitors cater to the varying switching current resulted during the buck-boost switching. The capacitors should be capable of tolerating 50 V. The output capacitors are required to filter out the output ripple current (ideally less than 10% current) and provide smooth battery charging currents. The output capacitor and the inductor decide the response of the control system.

See power-stage design calculator [3] for exact values of R_{IN}, R_{FB}, R_{SWCS}, input capacitors, output capacitors, and inductor for the specific design criteria.

6.3.2.2 Buck-boost soft start

The soft-start routine limits the input inrush current (injected from the Type-C input side to the buck-boost power stage) and output overshoots by limiting the V_{COMP} in the boost mode.

The soft-start routine is applied under the following conditions:

- At the first turn ON (first PWMI rise after EN/INUVLO = HIGH)
- After an output short-to-GND or open-load detection
- After an input overvoltage detection

Note: REF_PMG1_B2_DRP has 100 nF capacitor (on the SOFT_START pin) resulting in 6.7 ms soft-start ramp time.

6.3.2.3 Compensator design

An external compensation network (R_{COMP}, C_{COMP}) is used to adjust the control loop performance based on the application requirement. It prevents sub-harmonic oscillations. System uses Type-1 compensator network for stability. See datasheet [1] for more details on the compensator design.

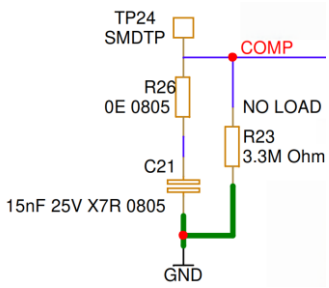


Figure 20 Compensator circuit

The selection of R_{COMP} and C_{COMP} depends on the system requirements. See hardware design guidelines [2] document for detailed instructions on choosing the right compensation circuit component values.

6.3.2.4 Switching frequency

The switching frequency for the buck-boost converter can be set from 200 kHz to 700 kHz defined by an external pull-down resistor (R_{FREQ}) connected from the FREQ pin to GND or by supplying a synchronization signal to the SYNC pin (not used in this kit).

A lower switching frequency is recommended for minimizing power loss. Select the switching frequency with an external resistor according to the graph in Figure 21 or the following approximate formulas:

$$f_{SW}[kHz] = 5375 \,.\, (R_{FREQ}[k\Omega])^{-0.8}$$

$$R_{FREQ}[k\Omega] = 46023 \,.\, (f_{SW}[kHz])^{-1.25}$$

Equation 3 Switching frequency equations

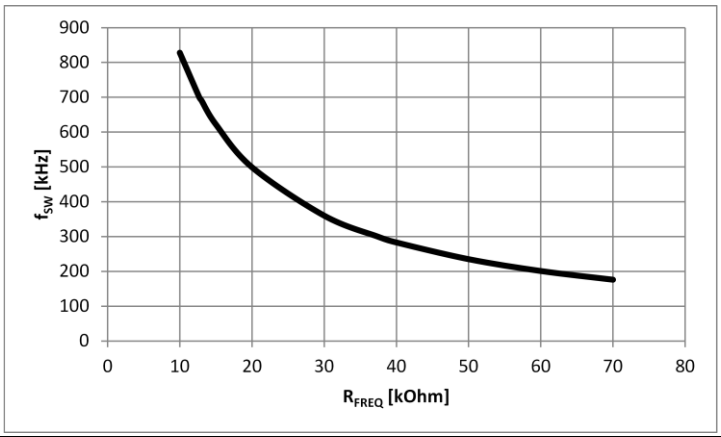


Figure 21 Switching frequency (f_{SW}) vs. frequency select resistor (R_{FREQ}) value

Note: The switching frequency on the EZ-PD™ PMG1-B2 solution board is fixed to 200 kHz to minimize the switching losses and thermal dissipation.

6.3.3 Hardware components at the output battery end

6.3.3.1 Output FET

EZ-PD™ PMG1-B2 devices provide a gate driving signal on pin VBAT_PFET_CTRL for turning on or turning off the output FET (Q4) which connects or disconnects the battery from the buck-boost output. The hardware circuitry connected to the gate of Q4 helps in the soft turn on that limits inrush current. The purpose of the FET is to disconnect the battery from the system during the fault condition and to prevent the leakage current when the battery is not charging.

The considerations for selecting the output FET include low $R_{DS(ON)}$ to minimize conduction losses and ensuring that the minimum blocking voltage (V_{DS}) is higher than the maximum battery-pack voltage (that is, 12 cell × 4.2 V). The gate driver circuit (Figure 22) is identical to the consumer FET gate driver circuit explained in Section 6.3.1.1.

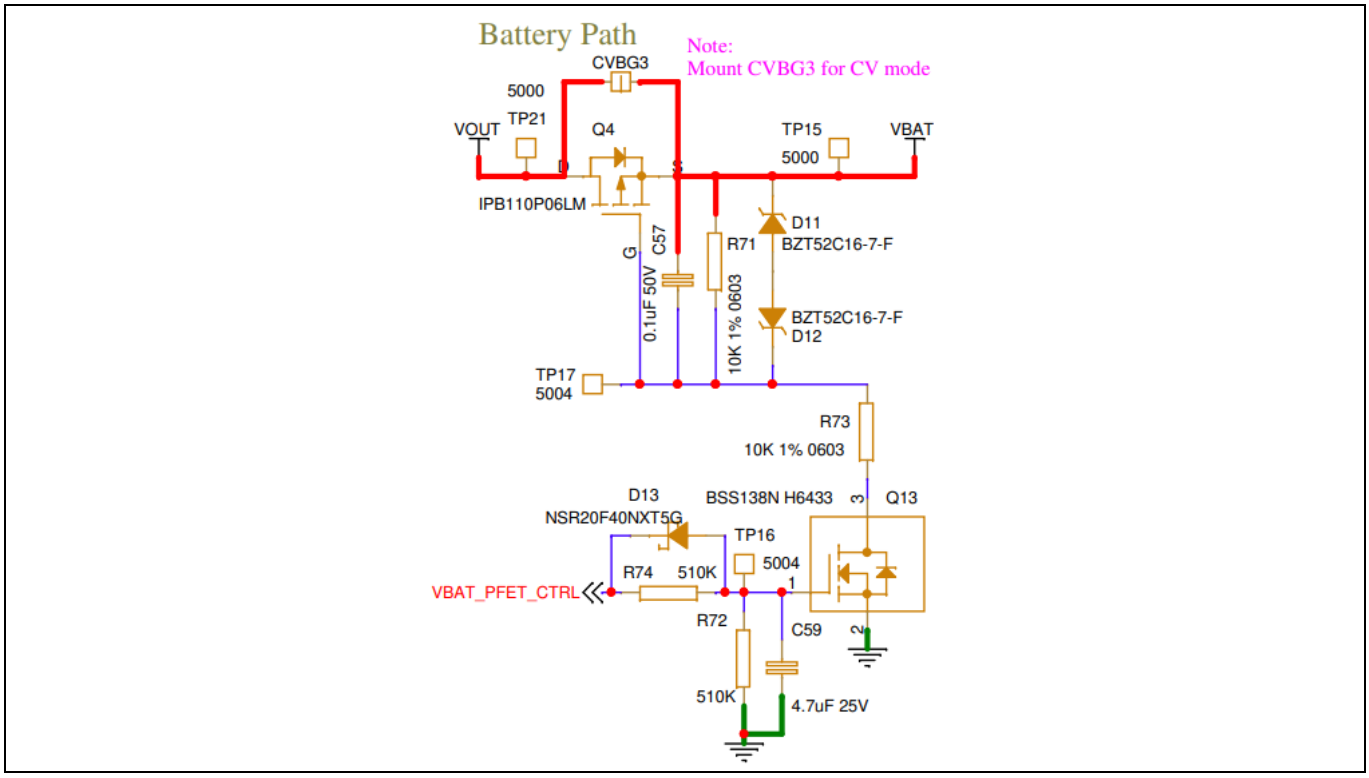


Figure 22 Circuit showing output FET path with its gate driving signal

6.3.4 Setting the battery charging current

EZ-PD™ PMG1-B2 devices control the output current based on PWM signal duty applied at PWM_VSET pin of the MCU, as shown in Figure 23. The PWM signal from the PWM_VSET pin is filtered through an external RC filter to produce an analog voltage at SET pin which is the reference signal for the analog current control.

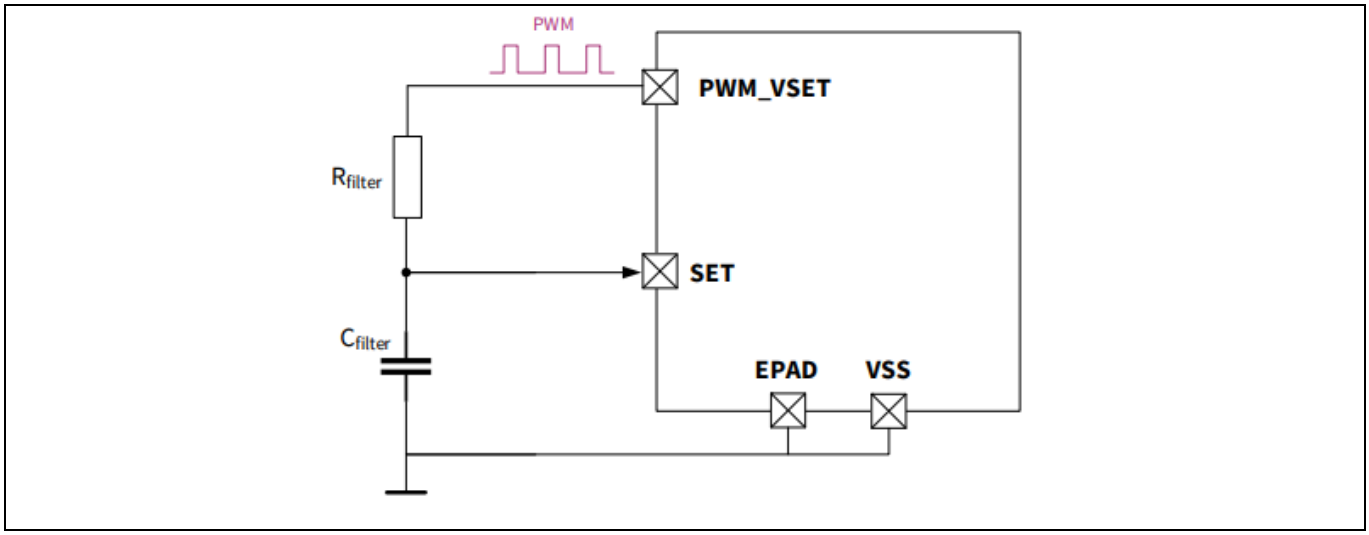


Figure 23 Analog current control

The output current I_{OUT} is related to the feedback voltage $V_{FBH-FBL}$ and the feedback shunt resistor R_{FB}, as shown in Equation 4:

$$I_{OUT} = \frac{V_{FBH} - V_{FBL}}{8\ R_{FB}}$$

Equation 4 I_{OUT} equation

Hence, the output current is directly proportional to the feedback voltage $V_{FBH-FBL}$.

The SET pin is used to adjust the mean output current. The analog control range is enabled for V_{SET} input voltages between 0.2 V to 1.5 V, with an approximately linear relationship throughout this range, as shown in Figure 24.

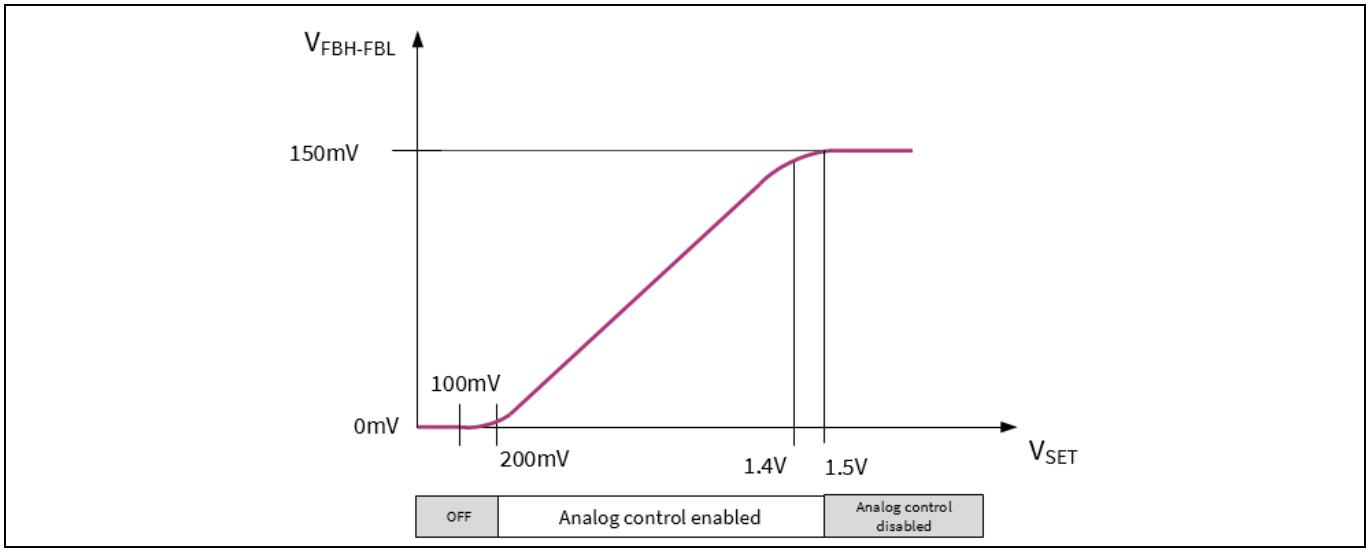


Figure 24 Analog control using external reference input voltage

Note: If V_{SET} is 200 mV (typical), then the output current is only determined by the internal offset voltages of the comparators. Therefore, to ensure the switching activity is stopped and I_{OUT} = 0, V_{SET} must be less than 100 mV, as shown in Figure 24.

6.3.5 Input and output voltage and current monitoring circuits

6.3.5.1 Input voltage (VBUS) monitoring circuit

The EZ-PD™ PMG1-B2 MCU monitors VBUS voltage using an internal 8-bit SAR ADC and a voltage divider circuit on the pin VBUS_MON, as shown in Figure 25.

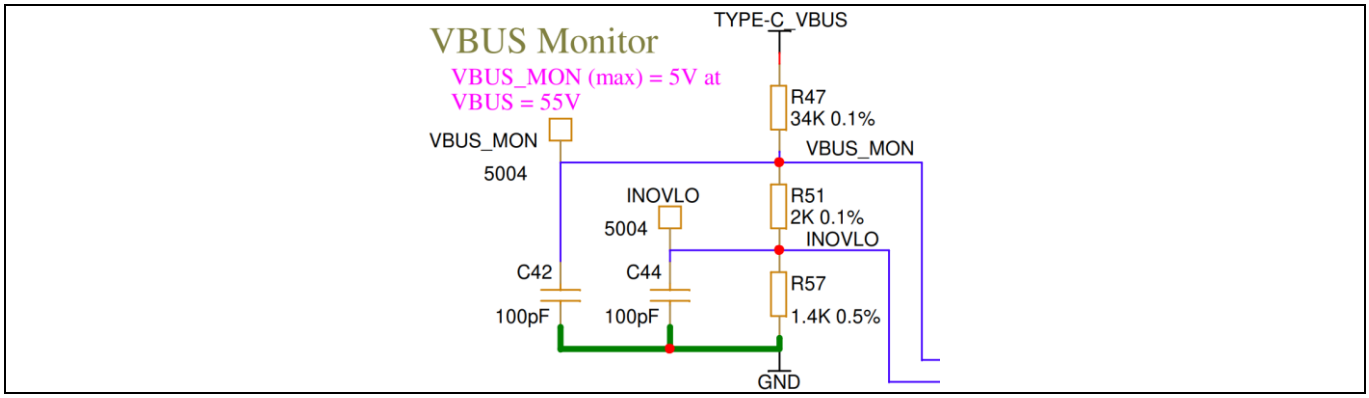


Figure 25 Input voltage (VBUS) monitoring circuit

The monitored voltage is used in the firmware for the VBUS overvoltage fault protection (OVP) implementation.

6.3.5.2 Input current monitoring circuit

EZ-PD™ PMG1-B2 devices provide an analog output pin (IINMON) that can be used to monitor the input current. The pin routes the output of current-sense amplifier, which corresponds to a scaled-up value of the input current-sense voltage. The microcontroller can read the analog voltages using the internal 8-bit ADC by connecting the analog pin to the IINMON_IN pin of the device.

The two inputs (IIN1, IIN2) are used to monitor and limit the input current (shown in Figure 26). The control loop reduces the compensation voltage (V_{COMP}) when the voltage across the pins reaches input current-sense threshold $V_{(IIN1-IIN2)_th}$ to keep the input current below I_{IN_MAX}, as shown in Equation 5.

$$I_{IN_{MAX}} = \frac{V_{(IN1-IN2)TH}}{RIN}$$

Equation 5 I_{INMAX} equation

Note: If the R_{IN} value is chosen in a way that the current limitation is much higher than the nominal input current in the application, the current measurement becomes inaccurate.

R_{IN} value chosen on REF_PMG1_B2_DRP solution board is 9 mΩ to limit the input Type-C current to 5.5 A.

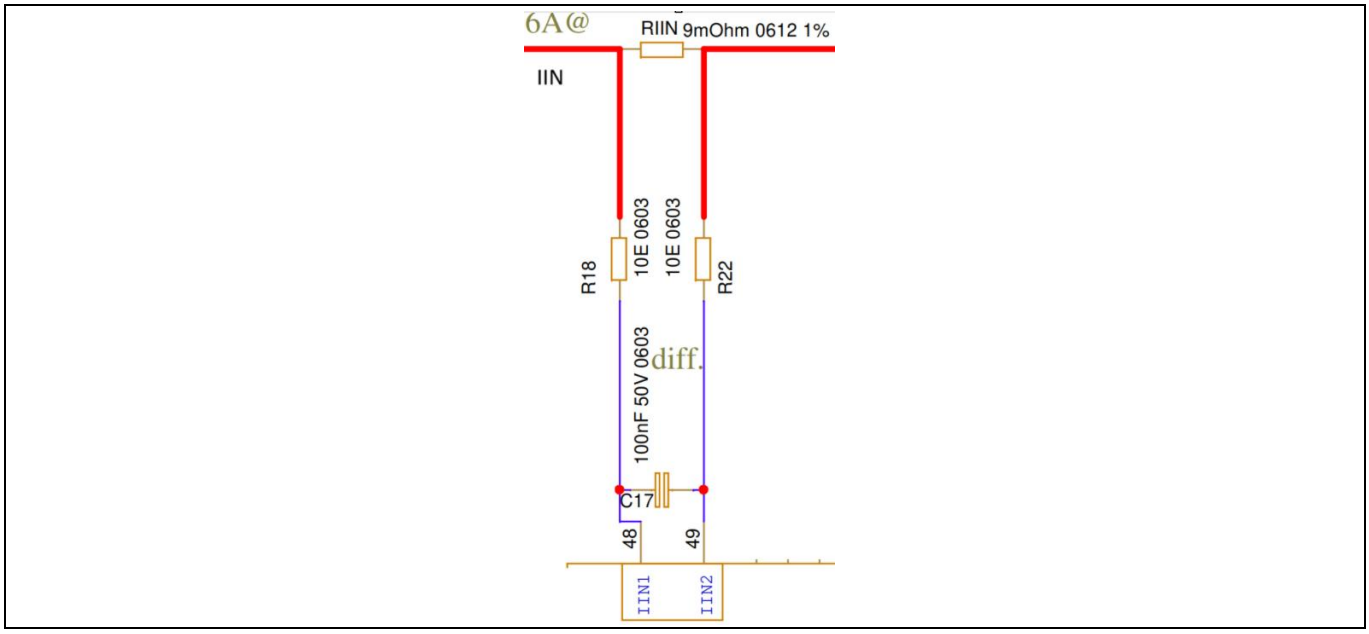


Figure 26 Input current monitoring circuit

6.3.5.3 Battery pack voltage monitoring circuit

The EZ-PD™ PMG1-B2 MCU monitors the battery pack voltage using an internal 8-bit SAR ADC and a “Voltage divider circuit on the pin VBAT_MON”. Based on the monitored battery pack voltage, the firmware enters a charging mode and adjusts the battery charging current. The EZ-PD™ PMG1-B2 MCU firmware has EZ-PD™ Battery Charge Configurator to configure the minimum and maximum battery pack voltage thresholds for the design requirements. See Section 5.2.4 for the configuration details.

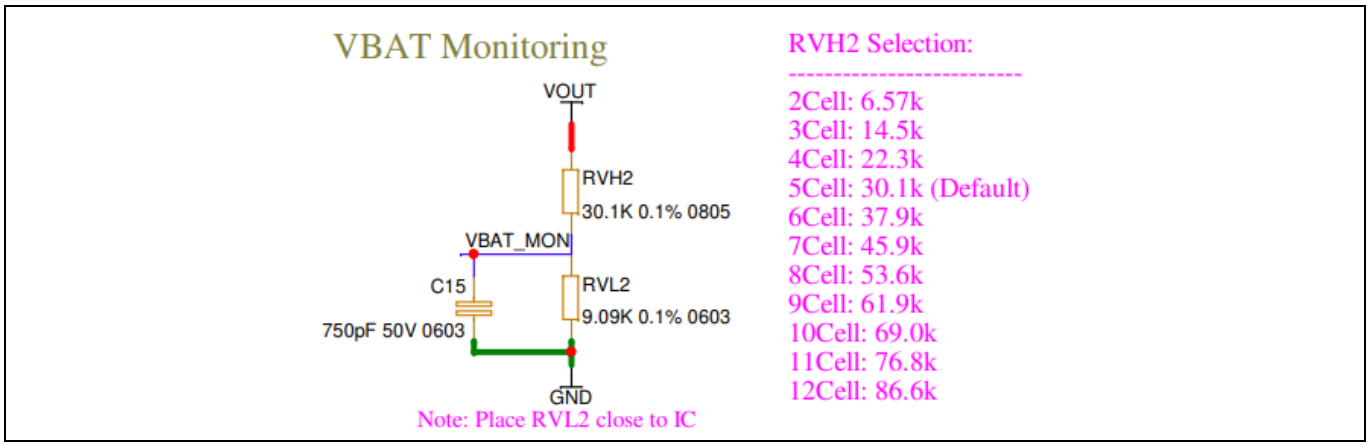


Figure 27 Battery pack voltage-monitoring circuit

6.3.5.4 Battery pack current-monitoring circuit

EZ-PD™ PMG1-B2 provides analog output pin IOUTMON which can be used to monitor the output current. The pin routes the output of the current sense amplifier which corresponds to a scaled-up value of output current-sense voltage. The microcontroller can read the analog voltage using the internal 8-bit ADC by connecting the analog pin to IOUTMON_IN pin of the device.

The output current-monitoring is achieved by scaling the current-sense voltage between FBH and FBL pins using the output current-sense amplifier.

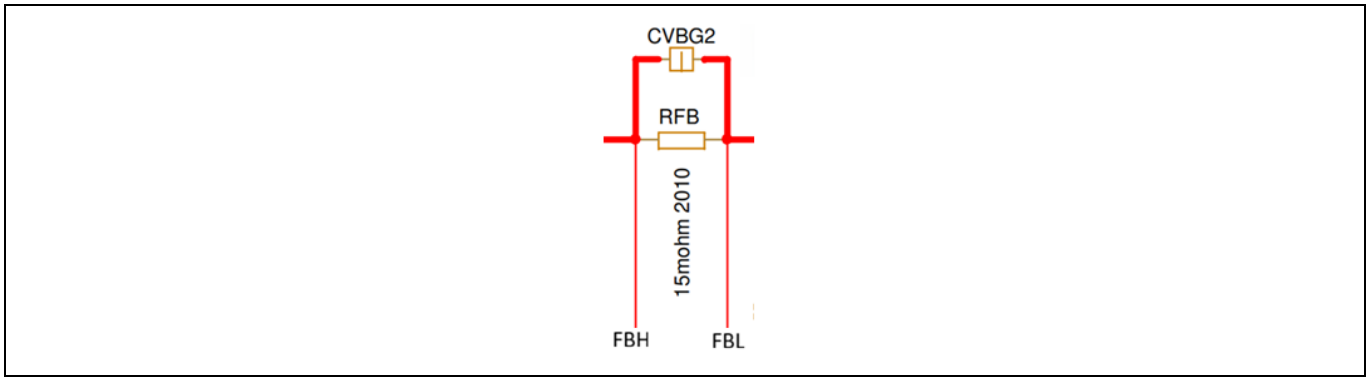


Figure 28 Battery pack current-monitoring circuit

R_{FB} value chosen on REF_PMG1_B2_DRP solution board is 15 mΩ to limit the output battery current to 10 A.

6.3.6 Board temperature monitoring circuit

The hardware has a temperature monitoring circuit (shown in Figure 29) based on the NTC device to monitor the board temperature. ADC_0 is used for reading the voltage level through GPIO P1.5. If the board temperature rises to a high threshold level, then the firmware shuts off the buck-boost converter, the output FET, and the consumer FET.

Also, before starting the battery charger algorithm, if the temperature is below or higher than the firmware-defined thresholds, the charging process will not begin due to low or high ambient temperature. If the MCU detects “over temperature” condition, then it will reduce the charging current. This way, the MCU protects the battery.

The circuit is designed to monitor temperatures from –20°C to 120°C with an approximate resolution of 1°C.

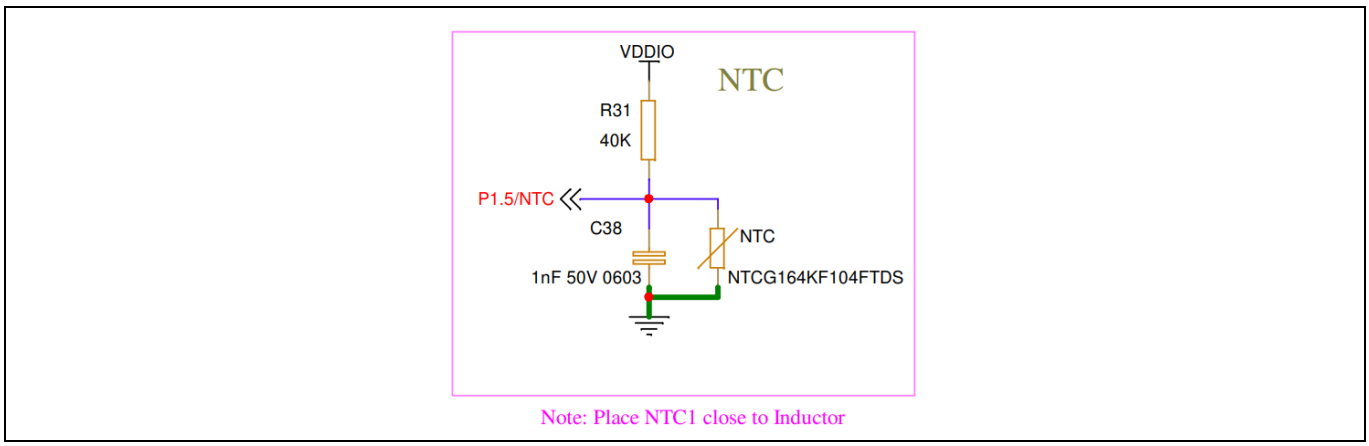


Figure 29 Temperature monitoring circuit

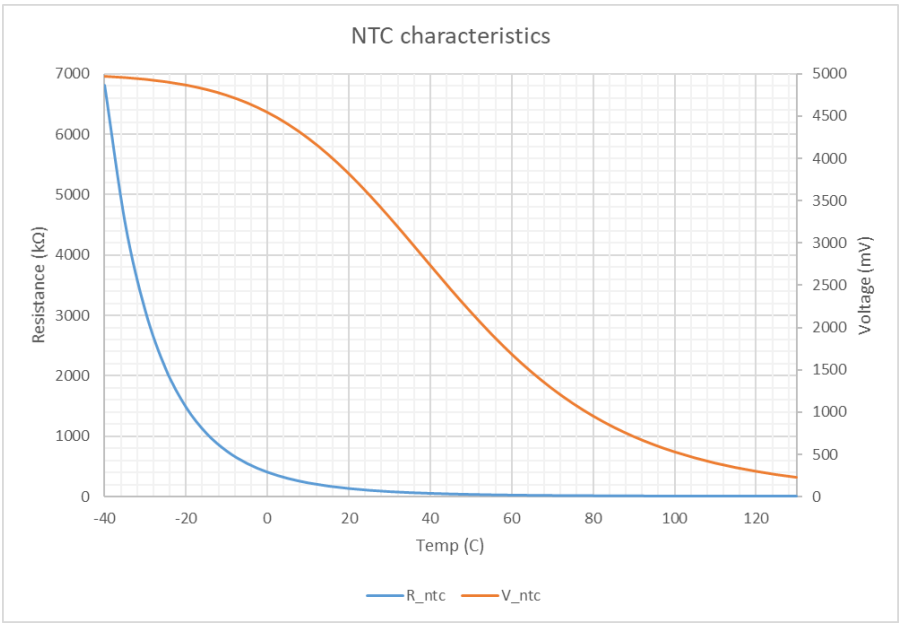


Figure 30 NTC characteristics

6.3.7 Fault protection

The EZ-PD™ PMG1-B2 MCU has integrated circuits to diagnose and protect against overvoltage, undervoltage and short-circuits of the load. The MCU contains two error-flags pins, EF1 and EF2, which change their state when a fault occurs. It also includes comparators that compare the voltage value with the threshold levels set for the faults.

When a fault occurs, comparator pulls the error-flag pin low, which triggers an interrupt on EF1 and EF2. The firmware handles this interrupt and takes the necessary action. The threshold levels set for the fault protection are constant.

6.3.7.1 Input fault protection

The device provides the following fault protections at the input side:

- Input overvoltage protection
- Input undervoltage protection

The input overvoltage and undervoltage shutdown levels can be defined using an external resistor divider, as shown in Figure 31 and Figure 32. The voltages on the INOVLO and EN/INUVLO pins are internally compared against their respective thresholds using hysteretic comparators. Whenever the comparator thresholds are crossed, the corresponding fault condition is triggered.

In the event of an input undervoltage condition, the EN/INUVLO pin detects the undervoltage condition and it will turn off the IVCC regulator and stops switching.

In the event of an input overvoltage condition, the open-drain status pin EF2 will toggle to LOW, while EF1 will stay at HIGH and the buck-boost MOSFET's switching is ceased.

The fixed threshold limits for the overvoltage and undervoltage faults are based on the resistor values chosen in the resistor-divider network.

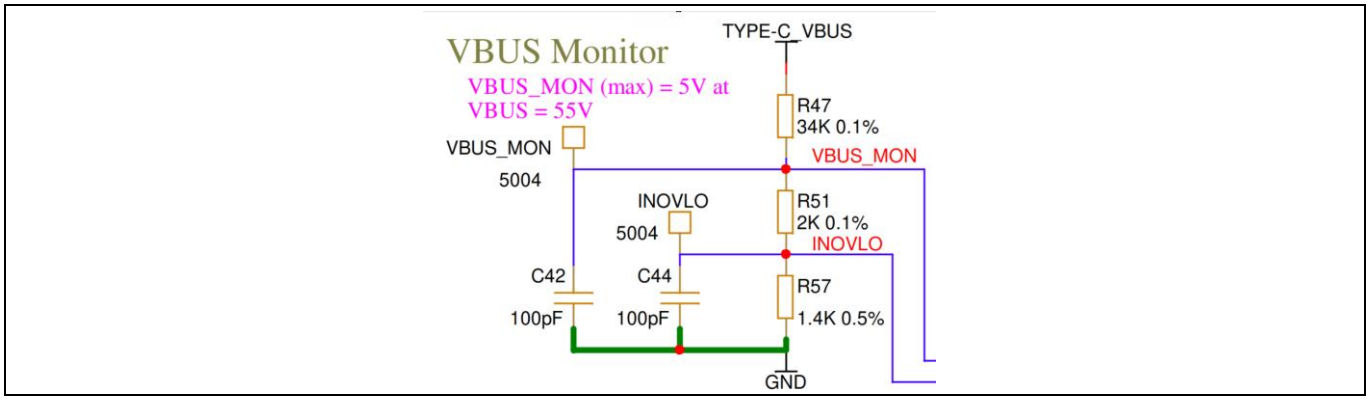


Figure 31 INOVLO voltage-divider network

$$V_{IN_OVth} = (1 + \frac{R_{47}+R_{51}}{R_{57}}).V_{INOVLOth}$$

Equation 6 V_{IN_OVth} equation

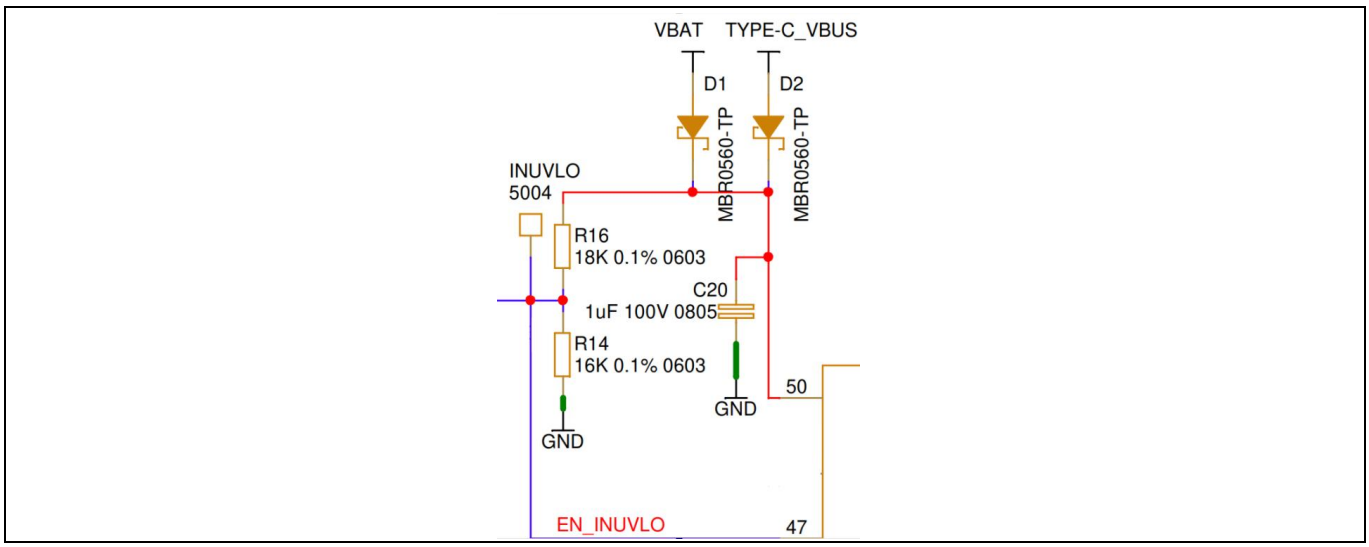


Figure 32 INUVLO circuit

$$V_{IN_UVth} = (1 + \frac{R_{16}}{R_{14}}).V_{EN_INUVLOth}$$

Equation 7 V_{IN_UVth} equation

6.3.7.2 Output fault protection

The MCU provides the following output-side fault protections:

- Output overvoltage
- Open load
- Short-circuit

The protection mechanism monitors the voltage at VFB using the “voltage divider network” shown in Figure 33 for overvoltage and short-to-ground protections. Different faults, such as short-to-ground, open load, and output overvoltage are triggered based on the internal thresholds set.

The device detects a short-circuit condition if the pin VFB falls below the threshold voltage V_{VFB_S2G} (short-to-ground voltage) for at least 8 clock cycles. A voltage divider between VOUT, VFB pin, and AGND is used to adjust the application short-circuit thresholds.

A voltage divider between VOUT, VFB pin, and AGND is used to adjust the overvoltage protection threshold.

$$V_{OUT_OVth} = \left(\frac{R_{VH1} + R_{VL1}}{R_{VL1}}\right).V_{VFB_OVth}$$

Equation 8 **V_{OUT_OVth} equation**

$$V_{OUT_Short} = \left(\frac{R_{VH1} + R_{VL1}}{R_{VL1}}\right).V_{VFB_S2G}$$

Equation 9 **V_{OUT_Short} equation**

Table 3 **Diagnostic truth table**

Input		Output		
Condition	**Level**	**EF1**	**EF2**	**Gate drivers**
Open load/overvoltage	False	1	1	Switching
	True	1	0	Both low-side MOSFETs ON
Output short-circuit	False	1	1	Switching
	True	0	1	Both low-side MOSFETs ON

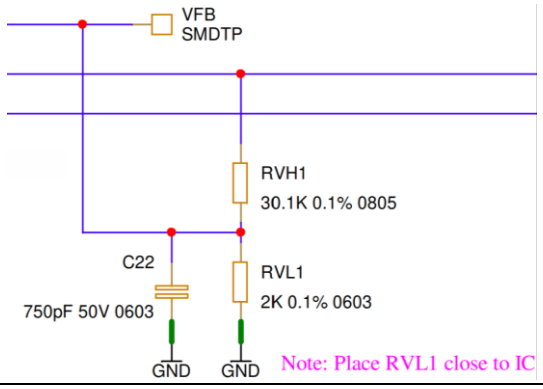


Figure 33 **VFB voltage-divider network**

6.3.7.3 Buck-boost control reset

The EN/INUVLO pin of EZ-PD™ PMG1-B2 device is also used to reset the buck-boost controller to re-initialize the internal states such as soft-start. This is done by driving the EN/INUVLO signal LOW momentarily (for 100us) using GPIO P1.2 signal in the firmware before startup.

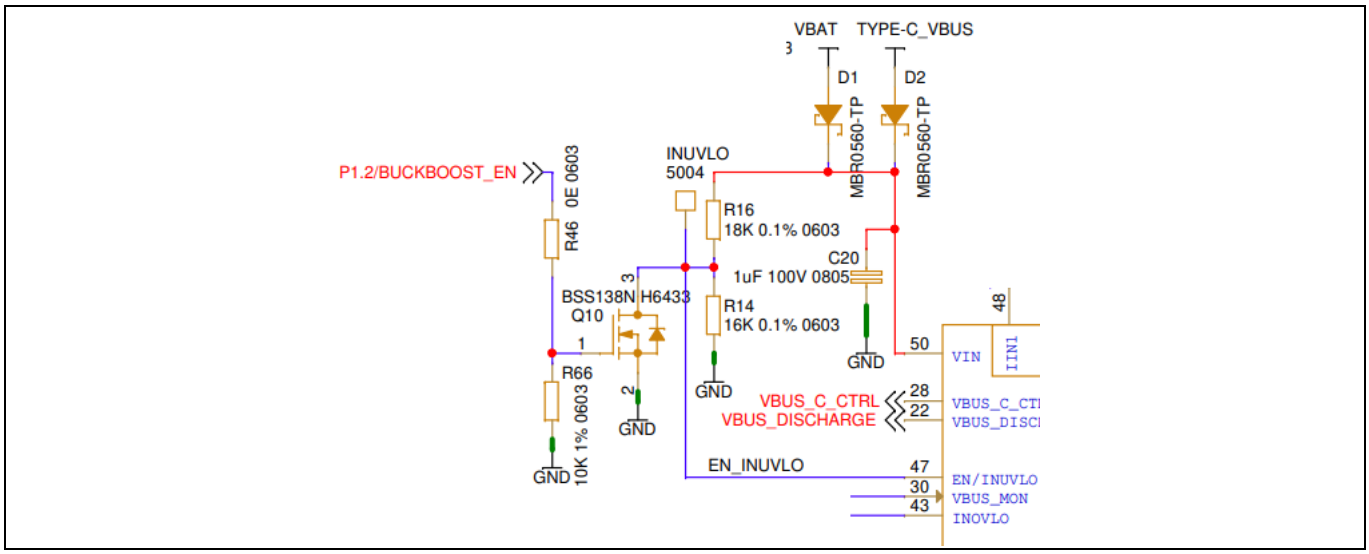


Figure 34 Buck-boost reset circuit

6.3.7.4 USB PD Source path circuits

The USB PD Source power path contains an external Buck converter (U2) and a load-switch (U3). In PD Source mode, EZ-PD™ PMG1-B2 device handles PD communication and commands the Buck converter to set the desired voltage (5 V or 9 V) using the '9V_SRC_SEL' GPIO. The load-switch has built in overcurrent protection (set to
3.6 A) and is used to disconnect the path during a fault event based on the command from EZ-PD™ PMG1-B2 device using GPIO P0.1.

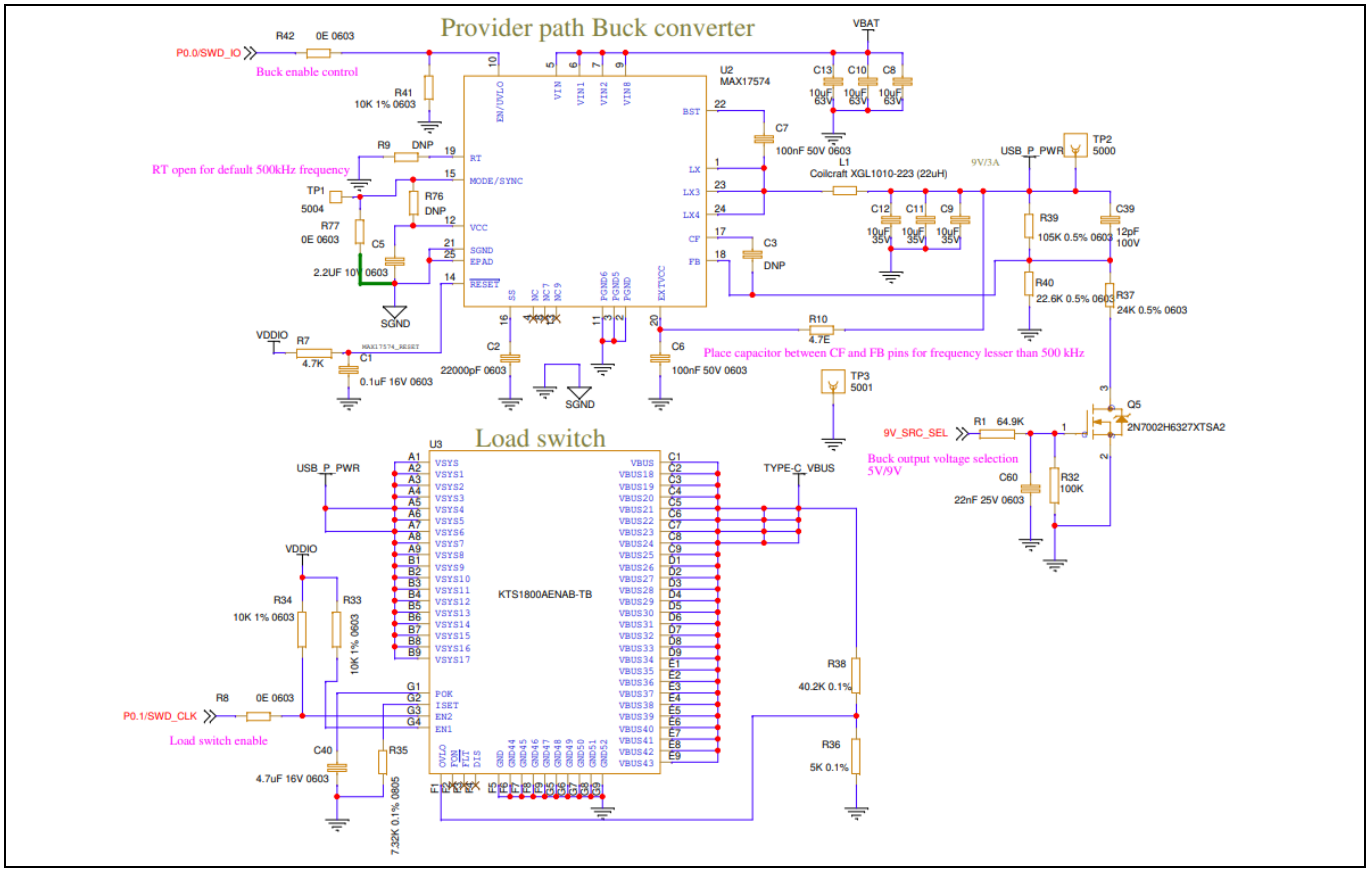


Figure 35 USB PD Source Buck converter and load-switch

7 Firmware architecture

EZ-PD™ PMG1-B2 MCU's Software Development Kit (SDK) consists of the following code examples under REF_PMG1_B2_DRP BSP which can be created using ModusToolbox™ IDE and downloaded into the MCU using a suitable programmer.

- USBPD Li-ion battery charger [6]
- USBPD DRP Li-ion battery charger [7]
- USBPD sink [8]

This section describes the firmware implementation of USB PD-integrated 1 to 12-cell Li-ion battery charging and battery monitoring system using the EZ-PD™ PMG1-B2 MCU within the ModusToolbox™ software development environment. The configuration of various EZ-PD™ PMG1-B2 MCU peripherals is easily achieved using various configurator tools provided in the ModusToolbox™ package.

7.1 Structure of the firmware

Firmware architecture is a layered architecture which improves code portability, maintainability, reusability, and testability.

After the project creation process (see Section 5.2 for project creation), the following two folders will be created:

- mtb_shared (middleware): This folder contains the middleware libraries that provide key features to the application along with few utilities for building and programming ModusToolbox™-based application. Table 4 lists the middleware layer components
- Application: This folder contains the header, source files, and utilities that provide user configurations, user hardware-specific functions, and custom code modules. It is expected that these files may be changed to match the hardware design and requirements for all customer implementations

Middleware layer consists of the following items:

Table 4 Middleware layer components

Middleware	Source/library
PdStack	Library
PdUtils	Source
mtb-pdl-cat2	Source
pmg-app-common	Source
pmg-battery-charger	Source

7.2 USB Power Delivery operation

The EZ-PD™ PMG1-B2 MCU with the integrated USBPD and buck-boost controller blocks enable a one-chip solution for USB PD-integrated Li-ion battery charging and battery monitoring applications. The USBPD block of the EZ-PD™ PMG1-B2 MCU implements the USB Type-C and Power Delivery Specification 3.2. The USBPD block enables the EZ-PD™ PMG1-B2 MCU to negotiate up to 240 W (48 V at 5 A) Extended Power Range (EPR) from the connected USB-C power adapters.

For enabling the EPR functionality, enable the macros `CY_PD_EPR_ENABLE` and `CY_PD_EPR_AVS_ENABLE` in the “Makefile” of the firmware, as shown in the Figure 36. The integrated buck-boost block then uses this negotiated power to charge the Li-ion battery pack.

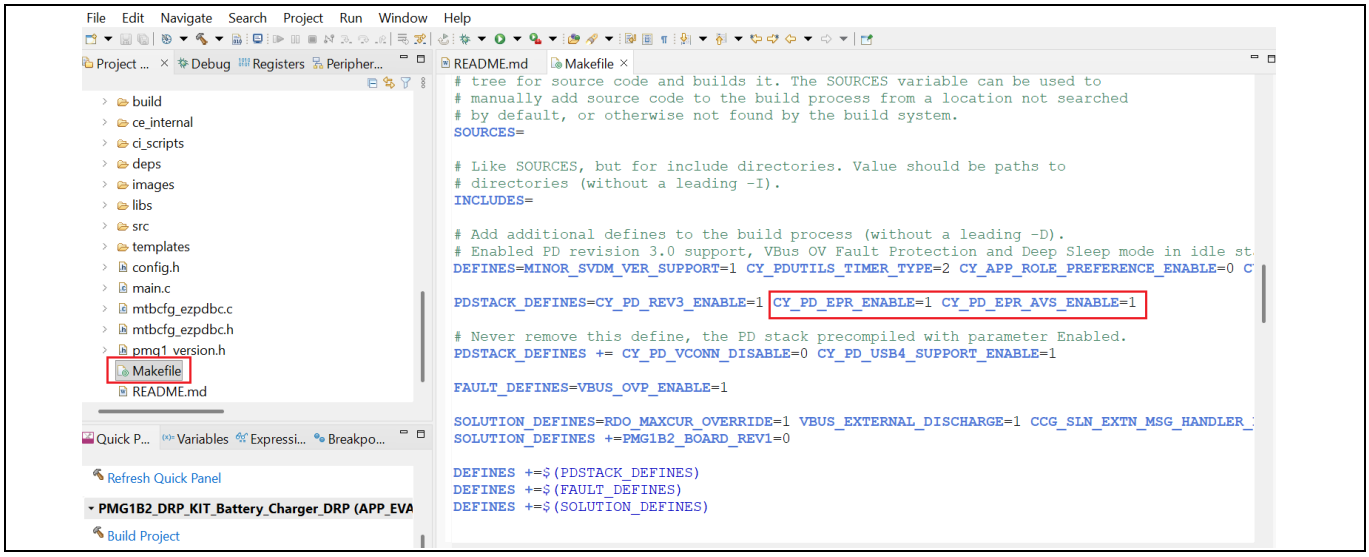


Figure 36 Enable/disable EPR functionality using Li-ion battery charger project Makefile

7.2.1 Sink PDOs supported on the input Type-C terminal

See Figure 37 for configuring the sink PDOs supported by the EZ-PD™ PMG1-B2 MCU battery charger. Table 5 lists the MCU minimum and maximum supported power levels.

Table 5 PDO specification of the firmware

Sink PDO type	Voltage	Operational current	Power
Fixed supply PDO	5 V	0.9 A	4.5 W (sink minimum PDP)
Variable supply PDO	5 V to 21 V	0.9 A	100 W (sink maximum PDP)
EPR sink PDO	28 V	5 A	140 W (sink EPR minimum PDP)
EPR sink PDO	36 V	5 A	180 W
EPR sink PDO	48 V	5 A	240 W (sink EPR maximum PDP)
EPR Adjustable supply PDO	15 V to 48 V	5 A	240 W (sink EPR maximum PDP)

Note: Battery charging functionality works only if the power on Type-C terminal is greater than or equal to 15 W (5 V/3 A).

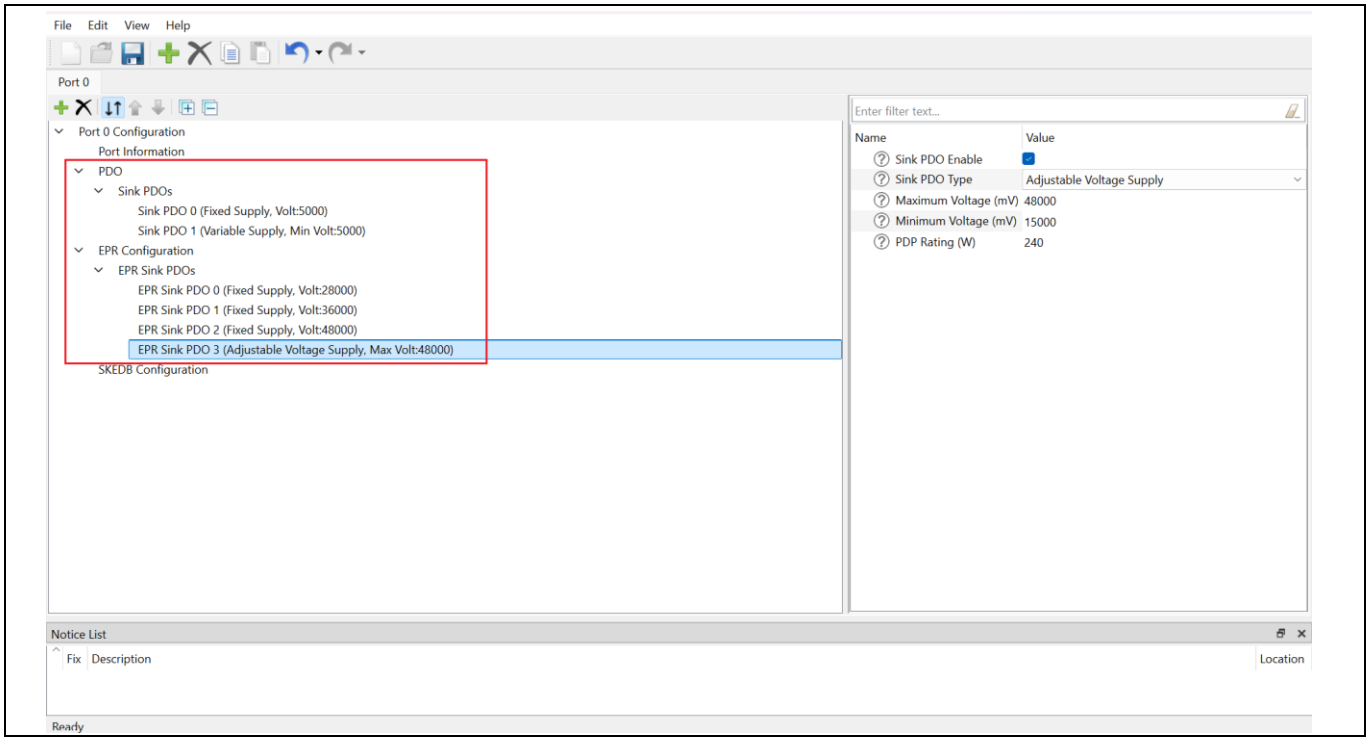


Figure 37 PDO configuration using EZ-PD™ Configurator tool of ModusToolbox™

7.2.2 USB PD Li-ion battery charger firmware flow-chart

- Examine the code in the *main.c* file of the application. For the firmware flowchart, see Figure 38
- Resource initialization is performed by the CM0 CPU. It configures the system clocks, pins, clock to peripheral connections, 8-bit SAR ADC, USB-C PD, buck-boost, and other platform resources required to implement the USB-C PD Li-ion battery charger application

See Section 7.3 for details on the EZ-PD™ PMG1-B2 firmware implementation for the USB PD-integrated Li-ion battery charger application.

Note: The application code uses BSP or middleware functions to execute the intended functionality.

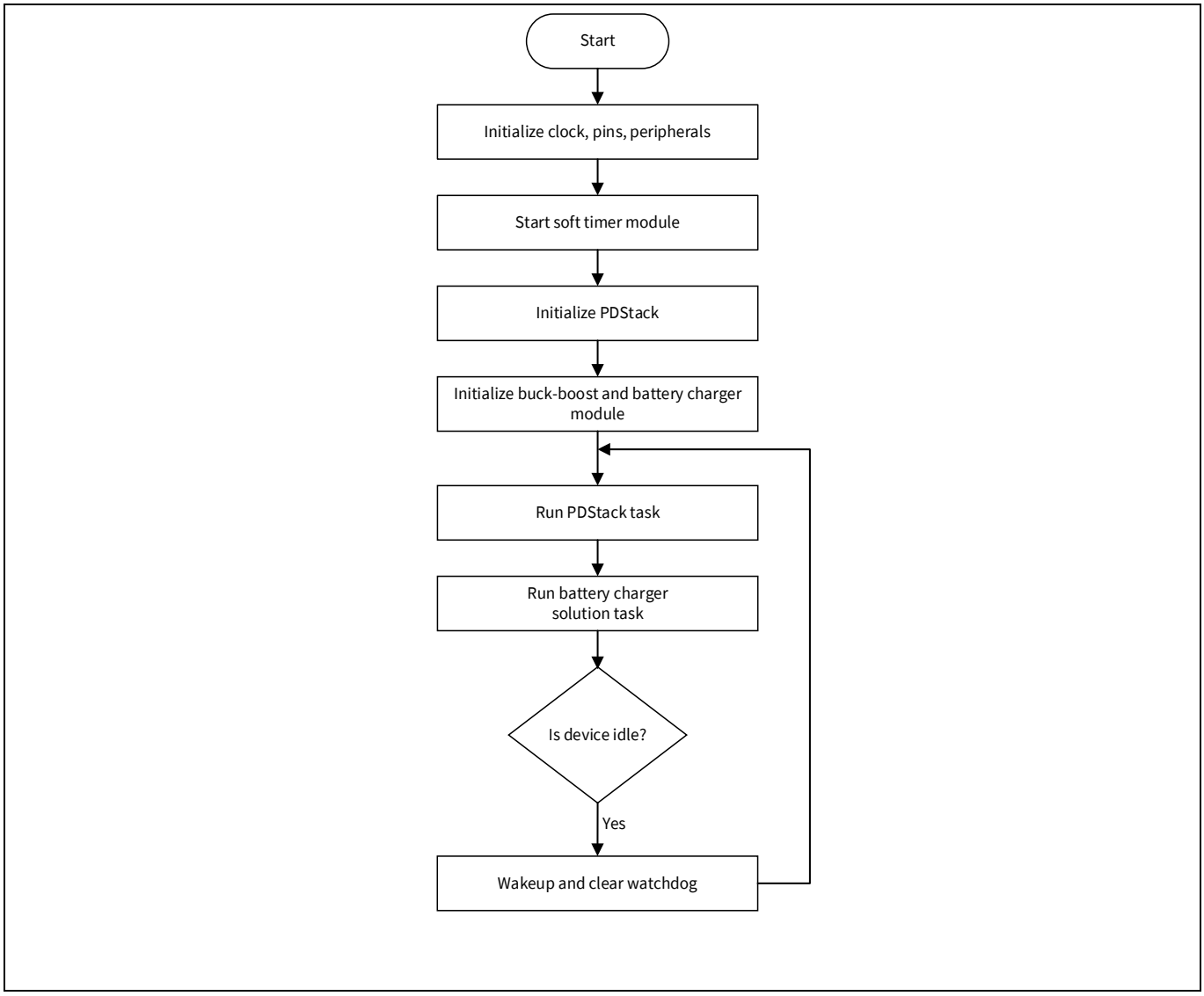


Figure 38 High-level firmware flowchart

7.3 Battery charging firmware flow

The firmware flow chart for the “initialization of buck-boost and battery charger module” works, as shown in Figure 39.

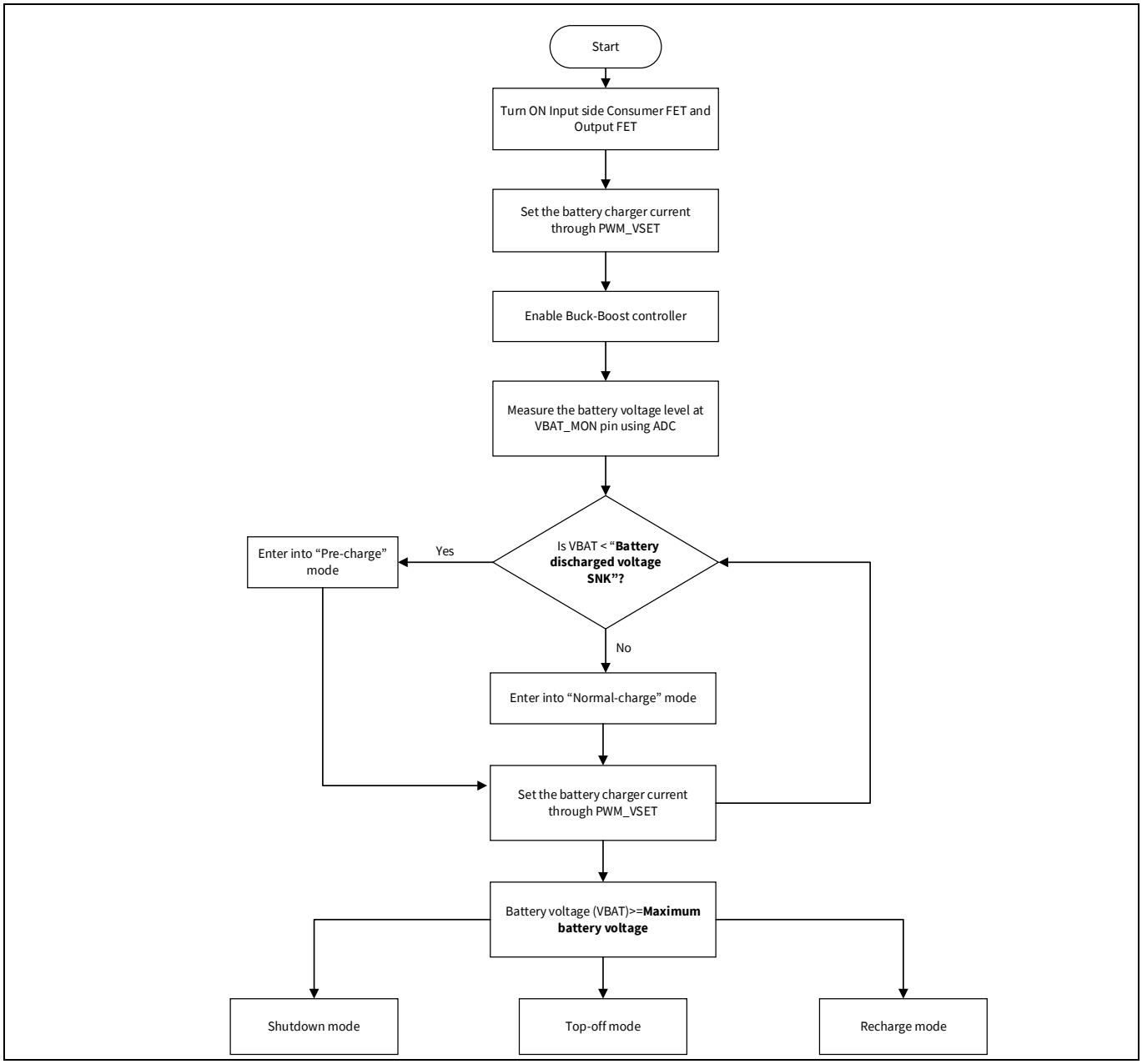


Figure 39 Firmware flowchart for enabling the buck-boost and initiating the battery charger module

7.3.1 Consumer FET

EZ-PD™ PMG1-B2 devices provide a digital high or low signal on VBUS_C_CTRL pin for turning on or off the consumer FET.

7.3.2 Output FET

EZ-PD™ PMG1-B2 devices provide digital high or low on VBAT_PFET_CTRL pin for turning on or off the output FET.

7.3.3 Setting the battery charging current

The EZ-PD™ PMG1-B2 firmware calculates the V_{SET} voltage using the Equation 11. It generates PWM pulses on PWM_VSET pin based on the compare value, which determines the ON duration of the generated PWM pulses and is computed using Equation 10.

$$\text{PWM Compare value} = \frac{V_{SET} * (PWM\ period\ count)}{V_{DDD}}$$

Equation 10 PWM period calculation equation

The relationship between the average output current (I_{OUT}) and the voltage at the SET pin (V_{SET}), for values between 0.2 V and 1.5 V, is mathematical expressed as:

$$I_{OUT} = \frac{V_{SET} - 0.2\ V}{8\ R_{FB}}$$

Equation 11 I_{OUT} equation

7.3.4 Buck-boost ON/OFF feature

The EZ-PD™ PMG1-B2 firmware enables the buck-boost functionality only after both the consumer FET and output FET are turned on. The PWMI pin of the MCU is used to start or stop the buck-boost operation of the controller. Setting the PWMI pin HIGH turns on the power stages of the buck-boost controller and initiates the switching operation. The PWMI_OUT pin should be externally connected to the PWMI pin of EZ-PD™ PMG1-B2 device (shown in Figure 40) to enable to firmware control of buck-boost switching operation by the MCU.

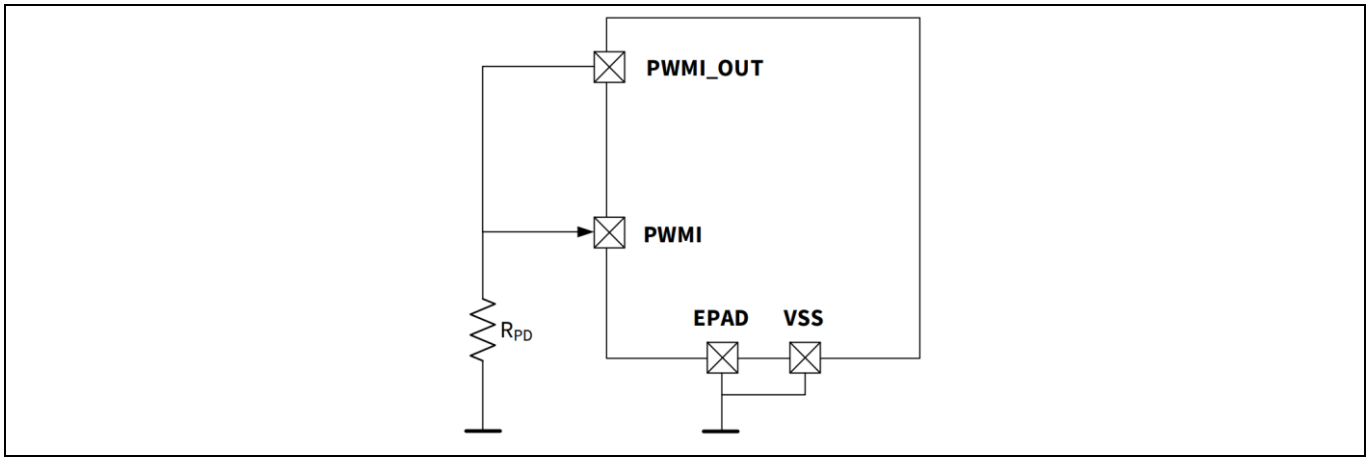


Figure 40 Buck-boost output control using PWMI pin

In the firmware, the buck-boost controller is enabled after setting the battery charging current.

7.3.5 Battery-charging algorithm

EZ-PD™ PMG1-B2 device implements a battery-charging algorithm that provides an efficient method for charging a battery. This helps extend battery life, maximize usable capacity, and prevent charging of a faulty battery. It implements the algorithm by monitoring various battery parameters, such as battery voltage, charge current, and board temperature to ensure that the battery pack is charged safely. Accurate sensing of these battery parameters is critical in any battery-charging application, as excessive charging or charging beyond the rated limits of a Li-ion battery pack can result in a thermal runaway and other serious safety concerns.

The MCU includes built-in analog peripherals, such as two 8-bit SAR ADC, CSA, and external sensing circuits to measure various battery parameters. See Section 6.3.5 and 6.3.6 for details.

The charging algorithm includes various charging stages, such as pre-charge, normal-charge and top-off charge, as shown in Figure 41. The voltage thresholds that trigger each charging mode can be configured using the EZ-PD™ Battery Charger Configurator. The MCU periodically monitors the battery voltage (VBAT) and based on the voltage limits configured in the battery charger configurator and the actual battery voltage measured at the VBAT_MON pin, the appropriate charging mode is activated and the corresponding output current is provided.

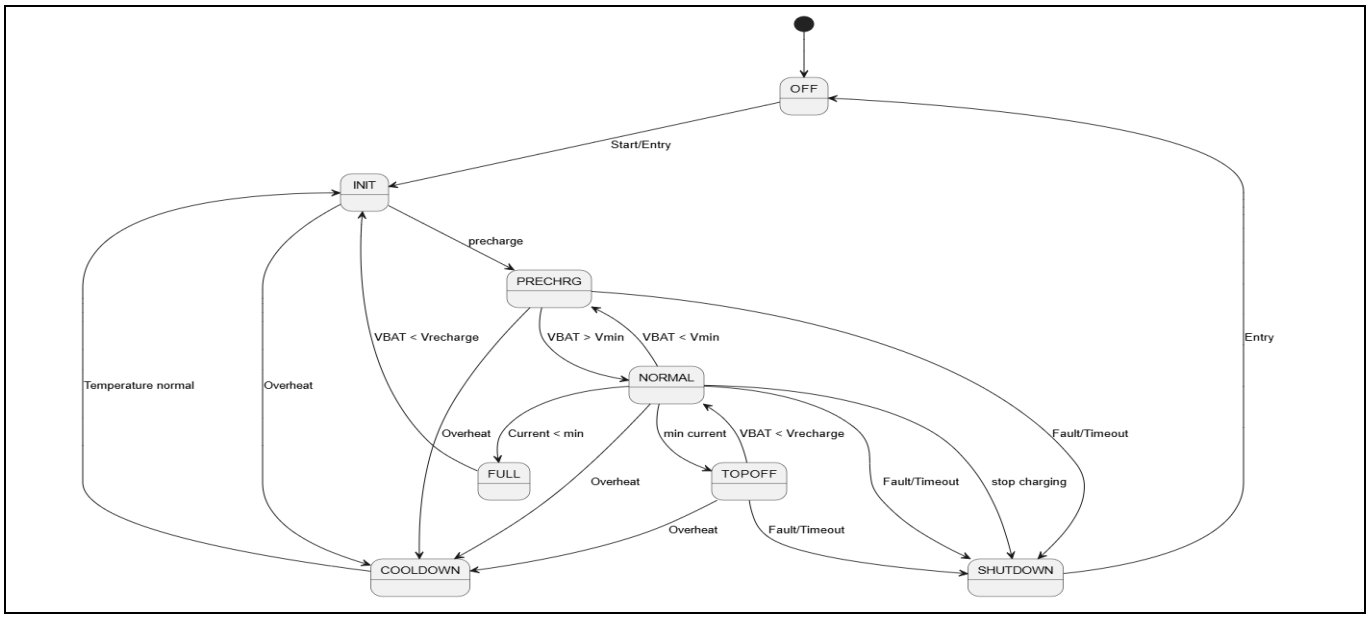


Figure 41 Battery charging modes in EZ-PD™ PMG1-B2 charger

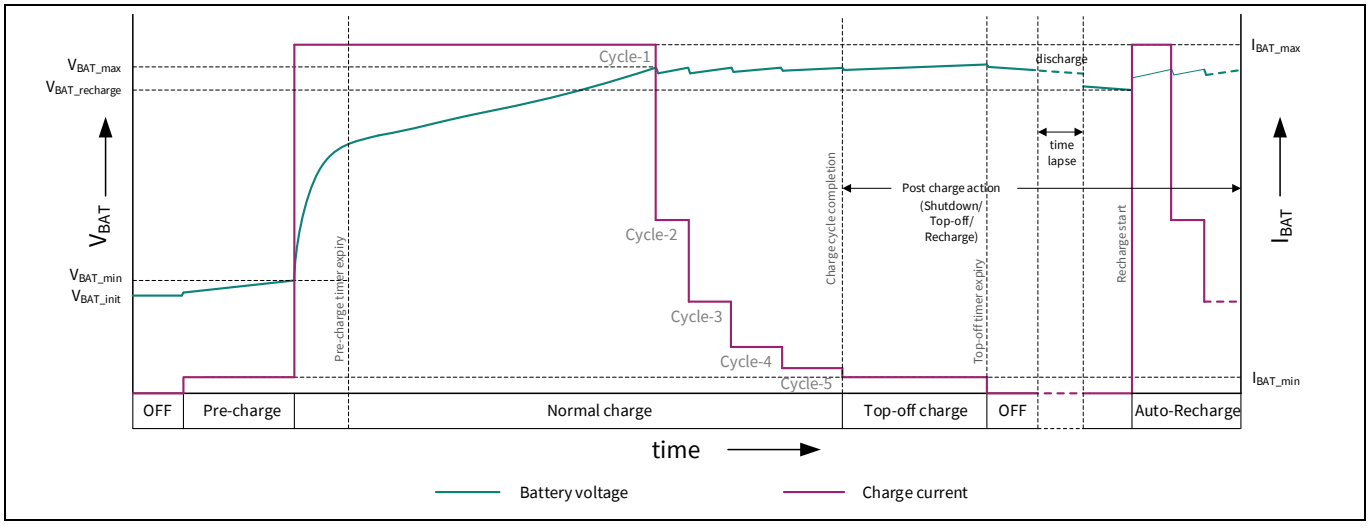


Figure 42 Battery charging cycles in EZ-PD™ PMG1-B2 charger

7.3.5.1 Pre-charging

The pre-charging mode becomes active when the measured battery voltage (VBAT) is lower than the “Battery discharged voltage SNK” value configured in the EZ-PD™ Battery Charger Configurator tool shown in Figure 43. In this mode, the MCU provides “pre-charge current” (configuration shown in Figure 44) to the battery until the battery voltage rises above the configured battery discharged voltage in SNK or until the pre-charge timeout occurs in the firmware. Hence, charging the battery with the minimal constant current (pre-charge current) helps prevent over-heating and potential damaging. If the battery voltage does not rise above the threshold even after the pre-charge timeout, the battery is considered as a faulty battery.

Pre-charge timeout can be configured in the EZ-PD™ Battery Charger Configurator, as shown in Figure 53.

The pre-charge voltage and current configurations for a 12-cell and 5 A battery charging are shown Figure 43 and Figure 44.

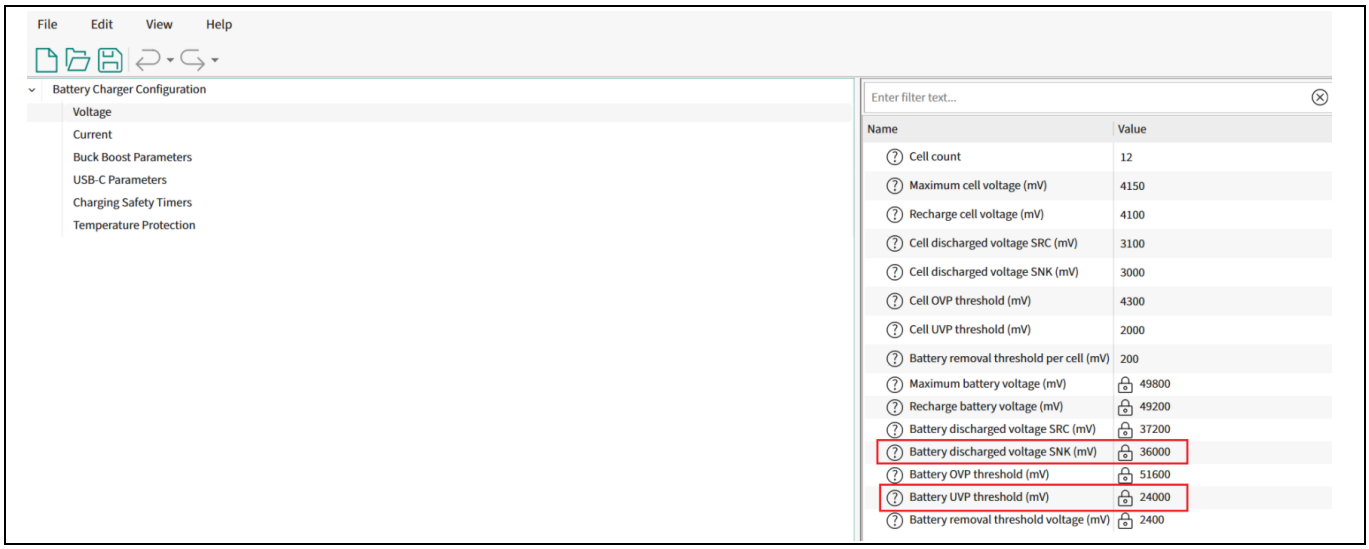


Figure 43 Pre-charge voltage configuration



Figure 44 Pre-charge current configuration

7.3.5.2 Normal charging

Normal-charging mode becomes active when the measured battery voltage (VBAT) is greater than the “Battery discharged voltage in SNK” configured in the EZ-PD™ Battery Charger Configurator tool. In this mode, the MCU performs standard constant-current (CC) charging, where the system supplies the maximum safe charging current referred to as the “Maximum charging current” (shown in Figure 46) to enable faster charging of the battery.

The normal-charging process is divided into multiple charge cycles, with each cycle using different current levels configured by the system. When the battery voltage reaches “Maximum battery voltage” value set in the EZ-PD™ Battery Charger Configurator (shown in Figure 45), the charging current is reduced to a lower value. This reduction causes the battery voltage to drop slightly, after which charging continues at the newly selected current level until the battery voltage rises and again reaches the maximum threshold. This process repeats in multiple cycles, as shown in Figure 42, until the charging current is reduced to a minimum predefined level to top-off the charge until the battery is fully charged. The entire process will also stop if the “normal charge timeout” occurs. See Figure 54 for normal-charge timer configuration.

The normal-charge configurations are shown Figure 45 and Figure 46.

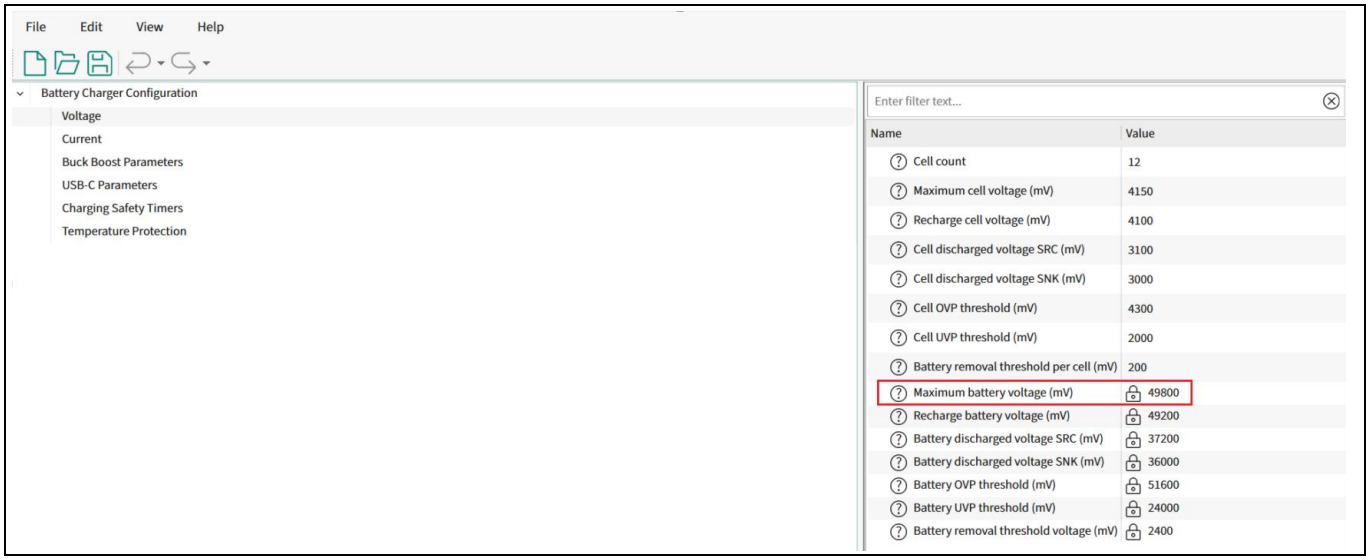


Figure 45 Normal-charge voltage configuration

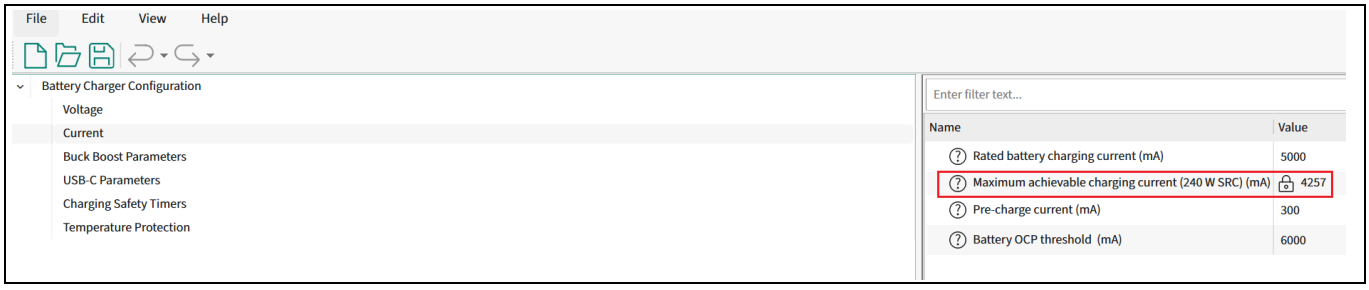


Figure 46 Normal-charge current configuration

7.3.5.3 Top-off charging

Top-off charging mode becomes active when the measured battery voltage reaches the configured “Maximum battery voltage” and the charging current has reduced to the minimum threshold after the normal-charging cycles, as shown in Figure 42.

When the battery voltage reaches “Maximum battery voltage”, the system can be configured to operate in one of the following three modes:

- Shutdown mode: The charging process stops indefinitely (until a USB Type-C reconnect occurs)
- Recharge mode: Charging is temporarily stopped until the battery voltage drops slightly due to self-discharge. The system then restores the lost charge using the minimum current until the terminal voltage reaches the maximum level again

- Top-off charge mode: The system initiates top-off charging for a pre-determined time to maintain the battery voltage at the maximum level. When configured in this mode, the system continues to supply a minimum defined current for the “top-off charge timer” duration. See Figure 55 for “top-off charger timeout” configuration

The system operates in the mode configured in the EZ-PD™ Battery Charger Configurator shown in Figure 47.



Figure 47 Top-off charging mode selection in the EZ-PD™ Battery Charger Configurator

This helps the battery to retain the maximum possible charge, allowing it to reach its full capacity and preventing self-discharge.

7.4 Firmware protections

The EZ-PD™ PMG1-B2 MCU firmware provides protection mechanisms such as input Type-C OVP and battery OVP, UVP, and OCP by monitoring the input and output voltage and current levels. The threshold values for each protection type are configurable in the firmware. When any threshold value is exceeded, the MCU firmware immediately stops the battery-charging process.

7.4.1 Type-C VBUS overvoltage protection (VBUS OVP)

The EZ-PD™ PMG1-B2 firmware implements VBUS overvoltage protection under the macro “`VBUS_OVP_ENABLE`” defined in “Makefile”, as shown in Figure 48. The macro must be enabled to enable the firmware implementation of OVP protection.

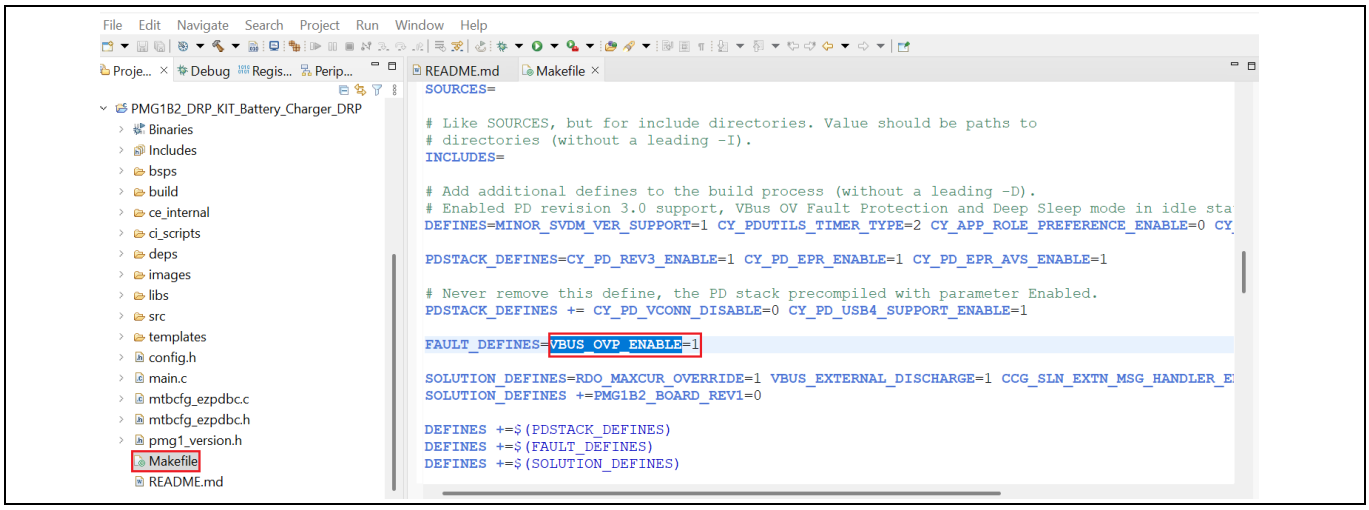


Figure 48 Enable or disable VBUS OVP functionality in the firmware

The VBUS overvoltage threshold limit, debounce period and the retry count parameters are configured in *design.modus*, as shown in Figure 49. Firmware uses internal ADC (ADC_1) comparator for OVP fault detection. If the voltage on VBUS_MON pin exceeds the OVP threshold, then the firmware disconnects the Type-C connection.

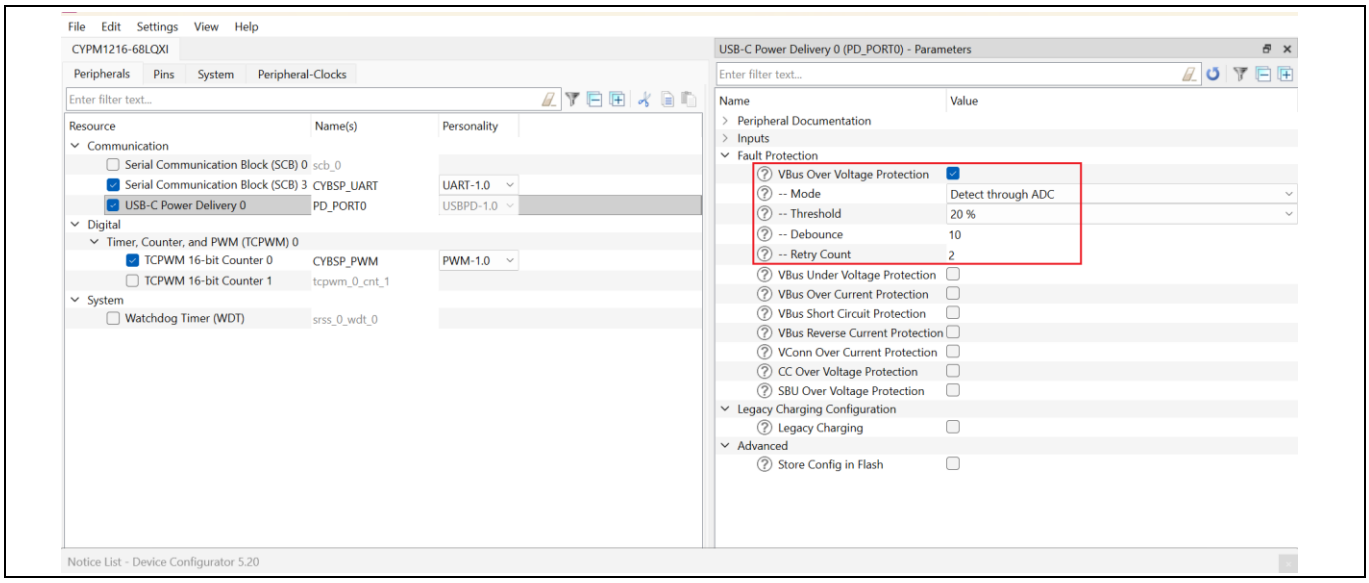


Figure 49 Configuring VBUS OVP threshold parameter in *design.modus* file

7.4.2 Battery overvoltage protection (OVP)

The EZ-PD™ PMG1-B2 firmware has battery overvoltage protection functionality enabled by default. Firmware monitors the battery voltage on VBAT_MON pin using internal 8-bit ADC (see Section 6.3.5.3 for details on battery voltage monitoring circuit).

The battery OVP threshold value is configured in the EZ-PD™ Battery Charger Configurator, as shown in Figure 50. If the monitored battery voltage exceeds the battery OVP threshold value, firmware stops the battery charging process and turns off the output FET.

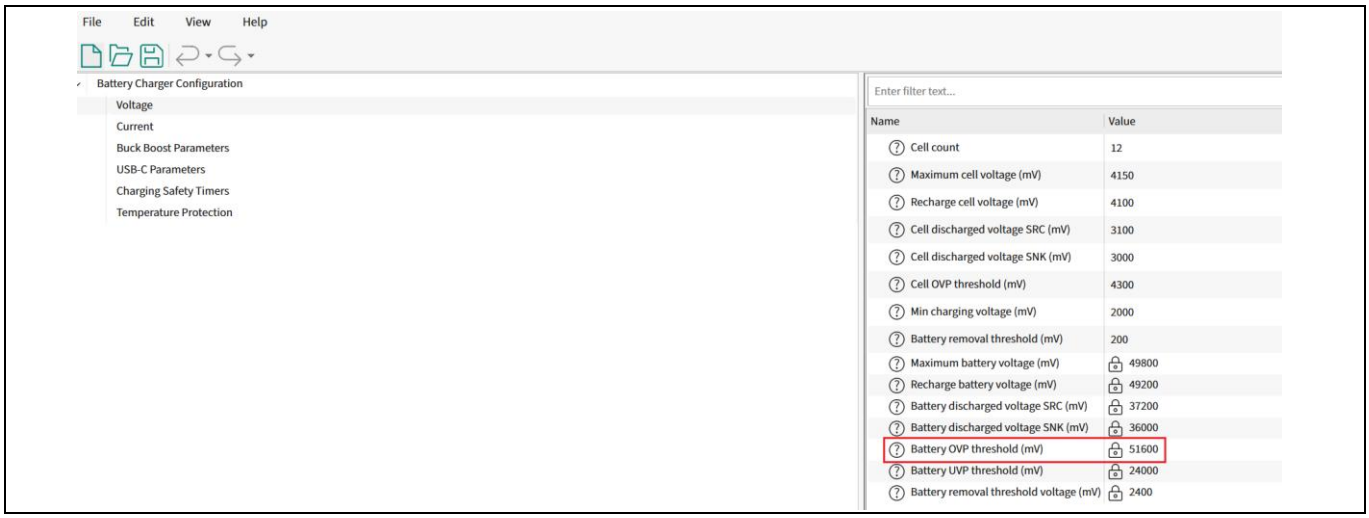


Figure 50 Configuring battery OVP threshold parameter in the EZ-PD™ Battery Charger Configurator

7.4.3 Battery undervoltage protection (UVP)

The EZ-PD™ PMG1-B2 firmware has battery undervoltage protection enabled by default.

The firmware monitors the battery voltage on the VBAT_MON pin (see Section 6.3.5.3 for the details) using the internal 8-bit ADC.

The “Battery UVP threshold value” is configured in the EZ-PD™ Battery Charger Configurator, as shown in Figure 51. If the monitored battery voltage falls below the battery UVP threshold, firmware stops the battery charging process and turns off the output FET.

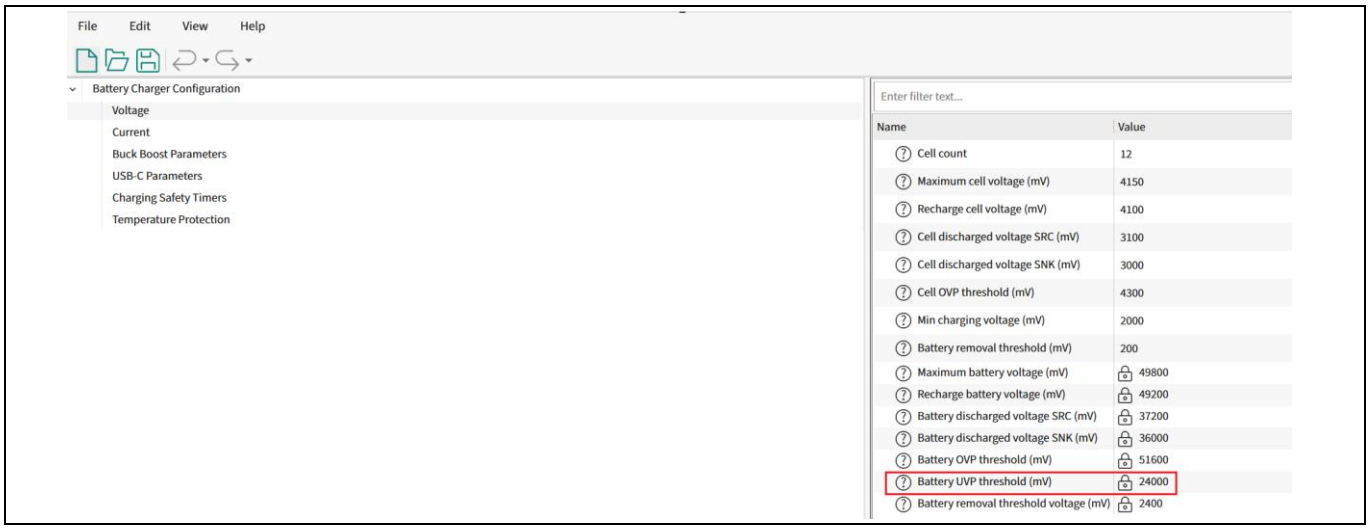


Figure 51 Configuring battery UVP threshold parameter in the EZ-PD™ Battery Charger Configurator

7.4.4 Battery overcurrent protection (OCP)

The EZ-PD™ PMG1-B2 firmware has “Battery overcurrent protection” enabled by default. The firmware measures the battery current across R_{FB} (at the FBH and FBL pins; see Section 6.3.5.4 for details on the current-monitoring circuit) using the in-built current sense amplifier (CSA). The OCP threshold value is configured in the EZ-PD™ Battery Charger Configurator, as shown in Figure 52. If the monitored battery current exceeds the OCP threshold value, the firmware stops the battery charging process and turns off the output FET.

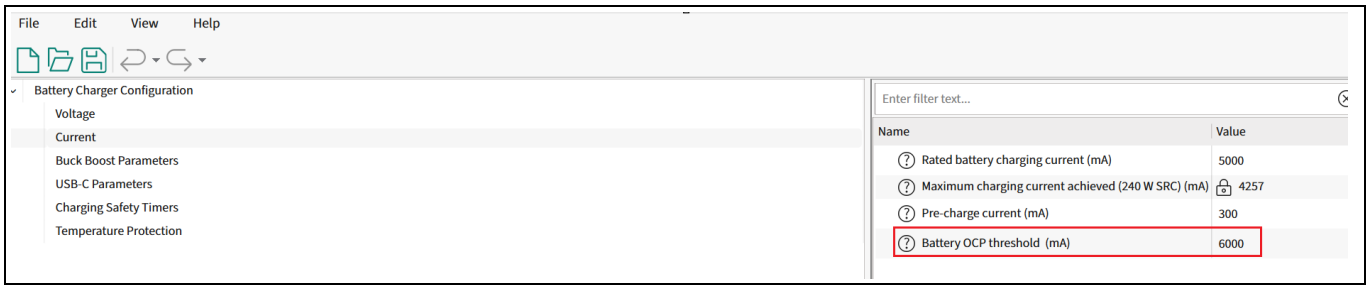


Figure 52 Configuring battery OCP threshold parameter in the EZ-PD™ Battery Charger Configurator

7.5 Battery-charging safety timers

The EZ-PD™ PMG1-B2 MCU battery charger firmware includes safety timers that prevent an extended charging cycles under abnormal battery conditions. The firmware provides the safety timers described in the following sections.

7.5.1 Pre-charge timer

The EZ-PD™ PMG1-B2 MCU firmware utilizes the pre-charge timer to monitor the time taken to pre-charge the battery pack when the battery cell voltage reading is less than the `BATTERY_DISCHARGED_VOLTAGE_SNK` threshold (for example, for a 12-cell battery pack, this threshold is 3 V × 12 = 36 V). This timer can be adjusted or disabled using the EZ-PD™ PMG1-B2 MCU firmware, which, by default sets the pre-charge time to 60 minutes (1 hour) and enables the timer. If the battery-pack voltage does not reach the `BATTERY_DISCHARGED_VOLTAGE_SNK` threshold before the timer expires, the EZ-PD™ PMG1-B2 MCU firmware will assert the battery as faulty and stops charging.

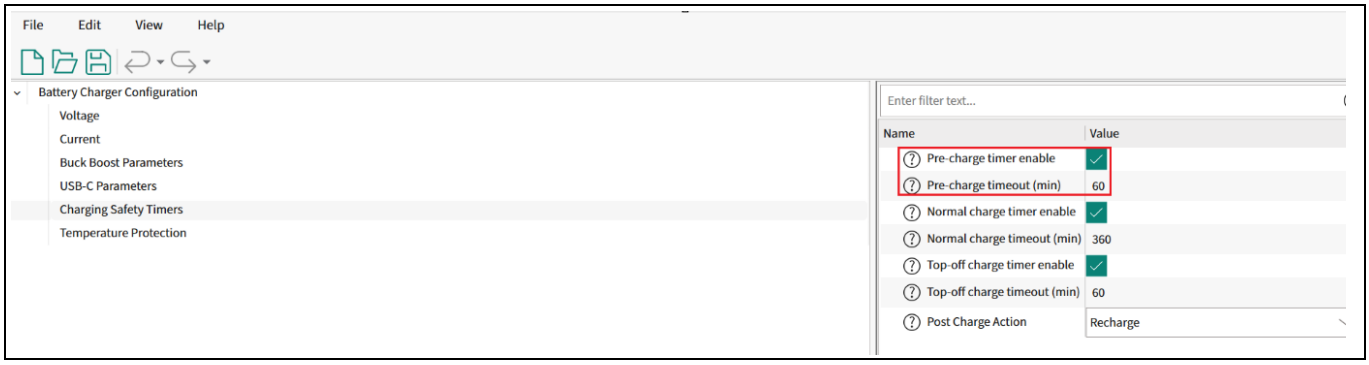


Figure 53 Enable or disable the pre-charge timer and change the timer value in the EZ-PD™ Battery Charger Configurator

7.5.2 Normal charge timer

If the measured battery pack voltage is higher than the `BATTERY_DISCHARGED_VOLTAGE_SNK` threshold (for example, for a 12-cell battery pack, this threshold is 3 V × 12 = 36 V), the firmware uses the normal charge timer to monitor the time required to charge the battery. This timer monitors the duration it takes for the full charging process. By default, this timer is enabled and the duration is set to 360 minutes (6 hours). If the battery-pack voltage does not reach the `MAXIMUM_BATTERY_VOLTAGE` threshold (for example, for a 12-cell battery pack, this threshold is 4.15 V × 12 = 49.8 V) before the timer expires, the firmware will assert the battery as faulty and stop charging.



Figure 54 Enable or disable normal charge timer and change the timer value in the EZ-PD™ Battery Charger Configurator

7.5.3 Top-off charge timer

Top-off charge timer starts when the battery voltage reaches the `MAXIMUM_BATTERY_VOLTAGE` threshold. During this stage, the firmware provides minimum charging current to prevent overheating and self-discharge. By default, this timer is enabled and the time is set to 60 minutes (1 hour).

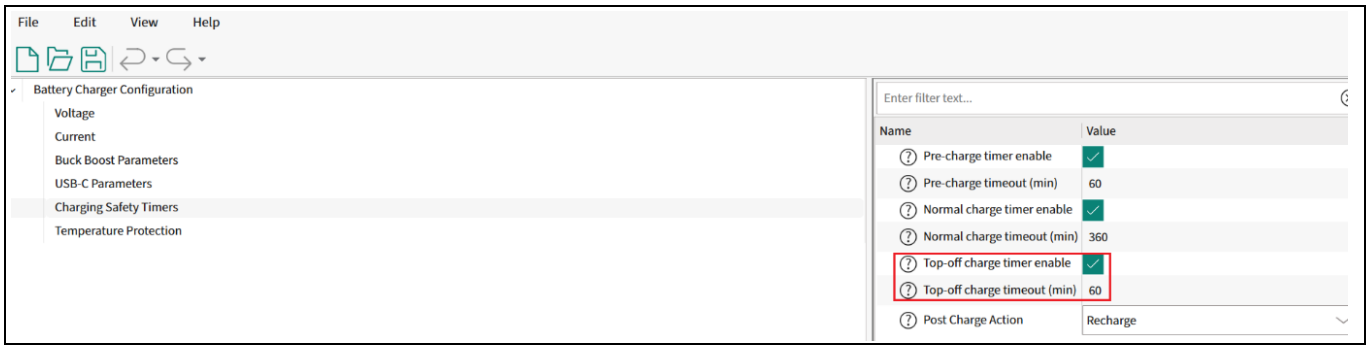


Figure 55 Enable or disable top-off charge timer and change the timer value in the EZ-PD™ Battery Charger Configurator

7.5.4 Watchdog timer (WDT)

The EZ-PD™ PMG1-B2 MCU offers a hardware-based watchdog timer to enhance the reliability and safety of the battery charging design. The watchdog timer (WDT) operates from the LFCLK (32 kHz), which is generated by the ILO. The EZ-PD™ PMG1-B2 MCU battery charger firmware has the WDT enabled by default, and the firmware periodically services the WDT to prevent timer expiration and an unintended device reset. The WDT ensures that the application firmware does not remain stuck due to unexpected code conditions during the firmware development and ensures safe charging of the battery pack.

The EZ-PD™ PMG1-B2 MCU battery charger firmware provides options to configure watchdog-related features. This includes enabling or disabling the watchdog and setting up the device's response when the watchdog timer expires. When WDT timer expires, the device can either reset or enter a hard-fault state. The following macro in the code shows how to configure these WDT-related parameters.

Code listing 1 Macro for enabling watchdog protection

```
/** Enable watchdog hardware reset for CPU lock-up recovery */
#define CY_APP_WATCHDOG_HARDWARE_RESET_ENABLE                    (1u)

/** Enable PMG1-B2 device reset on error (watchdog expiry or hard fault) */
#define CY_APP_RESET_ON_ERROR_ENABLE                             (1u)
```

In addition, EZ-PD™ PMG1-B2 MCU firmware also allows to select the WDT reset period in milliseconds (ms).

Code listing 2 Watchdog reset period configuration

```
/*
 * Watchdog reset period in ms. This should be set to a value greater than
 * 500 ms to avoid significant increase in power consumption.
 */
    #define WATCHDOG_RESET_PERIOD_MS                             (750u)
```

8 Constant voltage regulation

EZ-PD™ PMG1-B2 device supports constant voltage (CV) regulation mode using specific hardware and firmware configurations. In this mode, EZ-PD™ PMG1-B2 device operates as USB PD Sink to negotiate a desired power contract with the connected PD Source, and then the integrated buck-boost controller converts it into a fixed output voltage.

See EZ-PD™ PMG1-B2 MCU datasheet [1] for more details on constant voltage regulation.

REF_PMG1_B2_DRP solution board can be operated in voltage regulator mode by downloading USB PD Sink code example [8] into EZ-PD™ PMG1-B2 MCU after configuring the hardware in CV mode. The default configured value for the fixed output voltage is 24 V at the system load terminal (J7). It is set in the hardware by choosing the right values of resistors RCVH and RCVL in Figure 56.

Table 6 Hardware changes required on REF_PMG1_B2_DRP solution board for voltage regulation mode

S.No	Hardware components	Modifications	Description of change
1	CVBG1	Short CVBG1 solder bridge	Provides analog reference voltage to the internal error amplifier
2	CVBG2	Short CVBG2 solder bridge	Creates bypass path across RFB shunt resistor
3	CVBG3	Short CVBG3 terminals	Bypass the battery path FET Q7 as this is not required for the CV mode
4	RCVH RCVL R27	Populate RCVH, RCVL, and remove R27	Configures the output voltage feedback for CV mode
5	R64 C49	Populate R64 and C49	Secondary lead compensation circuit for CV mode
6	RVH1 RVH2	Change RVH1 to 43.2k and RVH2 to 45.9k	Set OVP/UVP protection thresholds for 24 V CV output

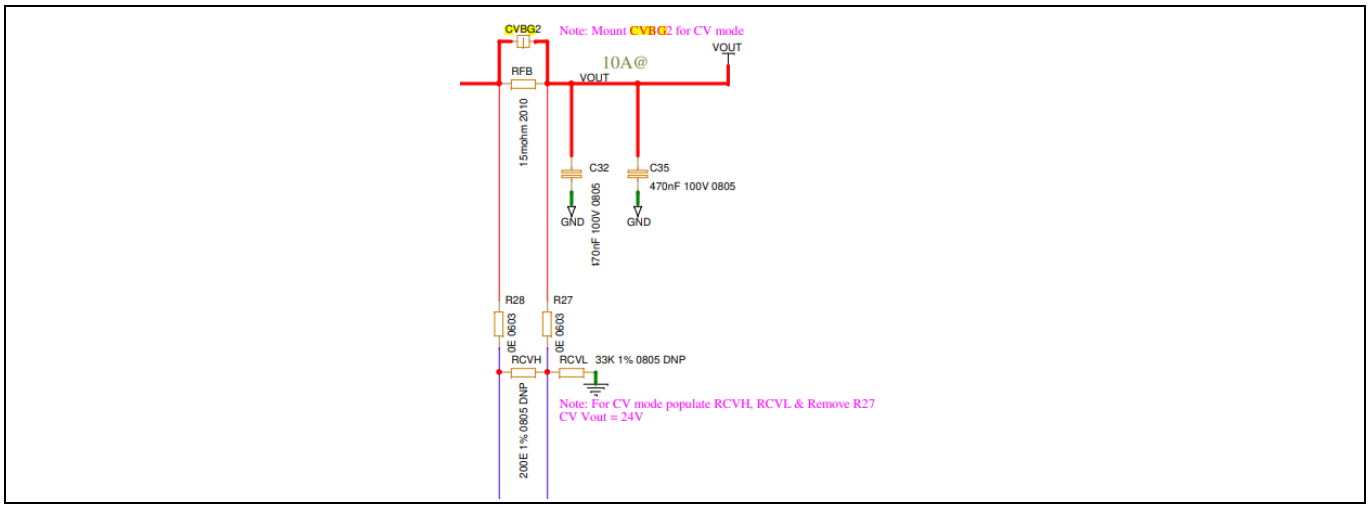


Figure 56 CV mode voltage feedback

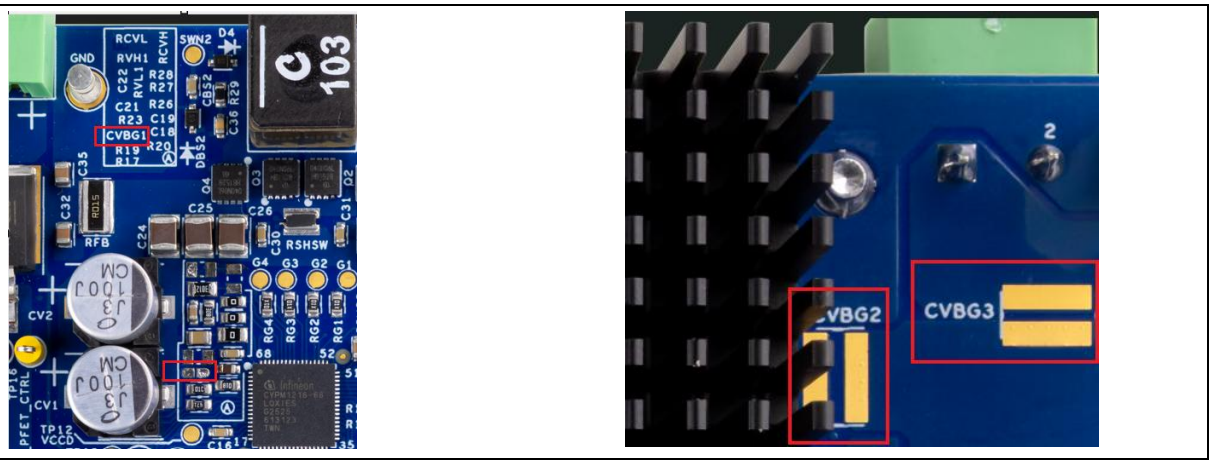


Figure 57 Onboard solder bridges for CV mode

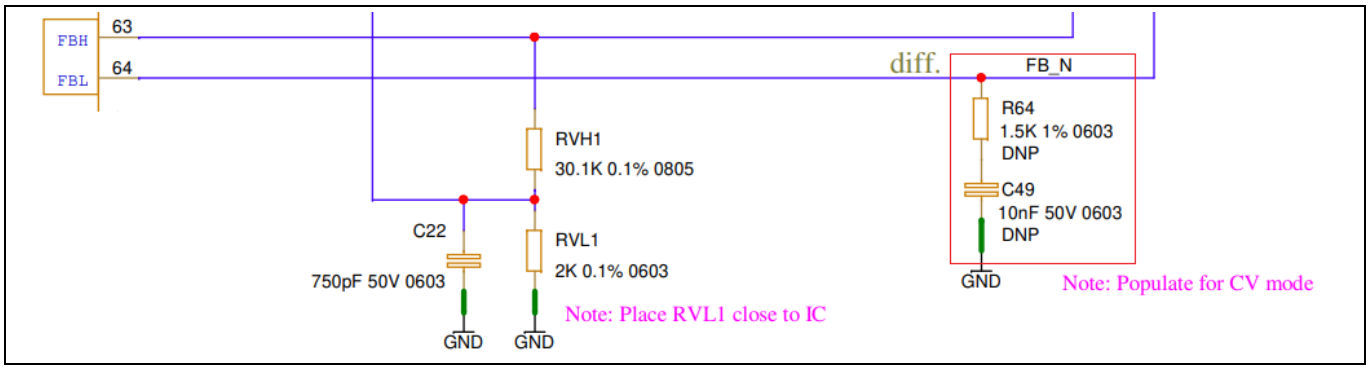


Figure 58 Secondary lead compensator for CV mode

8.1 Evaluation of constant voltage regulation

1. Ensure that the REF_PMG1_B2_DRP board is configured in CV mode referring to Table 6.
2. Download USB PD Sink code example into EZ-PD™ PMG1-B2 MCU following the steps below:
   a) In the Eclipse IDE for ModusToolbox™, provide the appropriate directory path and folder name to create a workspace for the project
   b) In the Quick Panel, click **New Application** to launch the Project Creator tool
   c) In **PMG BSPs**, select REF_PMG1_B2_DRP board support package (BSP) and click **Next**
   d) Select “USB-PD Sink” code example
   e) After selecting the code example, continue with the procedure listed in section 5.2.1 to create the project, build and program the board
3. Connect a USB PD Source to USB PD port (J3) on the board
4. Ensure that the user LED (LED2) is blinking indicating a normal PD Sink functionality
5. Measure the output voltage at the system load terminal (J7) and ensure that it is 24 V as expected
6. Connect a DC electronic load or resistor load at J7 to draw any current below 10 A

Note: *The maximum current that can be drawn at the output terminal (J7) is given by:*

$$I_{out_max} = (P_{in_max} * efficiency)/V_{out}$$

If the output current exceeds the maximum value, then the output voltage starts to drop such that input current is maintained at maximum configured value (5.5 A).

9 Hardware and firmware changes required for different battery-pack configurations

9.1 Hardware changes required for different battery-pack configuration

The hardware changes needed for a different battery-pack configuration are listed in Table 7.

Table 7 Hardware changes required for a different battery-pack configuration

Description of hardware change	Hardware component on REF_PMG1_B2_DRP solution board
VBAT Monitor circuit (on VBAT_MON pin)	RVH2
Output Voltage Protection circuit (on VFB pin)	RVH1

Table 8 RVH1 and RVH2 selection

Number of series cells in the battery	RVH1 (kΩ)	RVH2 (kΩ)
1[1]	4.4	0
2	10.9	6.57
3	17.4	14.5
4	23.7	22.3
5	30.1	30.1
6	36.5	37.9
7	43.2	45.9
8	49.3	53.6
9	55.6	61.9
10	62.6	69.0
11	68.1	76.8
12	75.0	86.6

See the power-stage design calculator [3] for exact values of each hardware component for different cell configuration.

[1] *1-cell support is possible only for USB PD Sink charging, and cannot work in DRP mode because of VIN_min = 4.5 V for PMG1-B2 IC.*

9.2 Firmware changes required for different battery-pack configuration

The firmware changes needed for a different battery-pack configuration are listed in Table 9.

Table 9 Firmware changes required for a different battery-pack configuration

EZ-PD™ Battery Charger Configurator parameters	Description of the change
Cell count	Total number of battery cells connected in series
Rated battery charger current	Maximum rated charging current limit for the battery. Set this as per battery specification
Maximum achievable charging current	Maximum charging current that can be achieved with 240 W USB-C Source power
Pre-charge current	Low charging current limit used for pre-charge and top-off charge
Battery OCP threshold	Overcurrent protection (OCP) threshold for the battery

10 Related resources

- USB PD high-voltage microcontrollers
- REF-PMG1-B2-DRP reference design
- USB PD-integrated 2 to 5-cell battery charger using EZ-PD™ PMG1-B1 MCU
- EZ-PD™ PMG1 MCU community forum

References

[1] Infineon Technologies AG: *002-41140: CYPM1216, EZ-PD™ PMG1-B2: 1 to 12-cell battery charger controller with USB-C PD MCU*; Available online

[2] Infineon Technologies AG: *002-42984: Hardware design guidelines for REF_PMG1_B2_DRP*; Available online

[3] Infineon Technologies AG: *002-42065: EZ-PD™ PMG1-B2 power stage design calculator for 1-12 cell Lithium-ion battery charging applications*; Available online

[4] Infineon Technologies AG: *002-43604: EZ-PD™ PMG1-B2 power stage design calculator for 240 W constant voltage power supply*; Available online

[5] Infineon Technologies AG: *002-41140: EZ-PD™ PMG1-B2 240 W 1 to 12-cell Lithium-ion battery charger solution board user guide*; Available online

[6] Infineon Technologies AG: *EZ-PD™ PMG1-B2 MCU: USB PD battery charger code example*; Available online

[7] Infineon Technologies AG: *EZ-PD™ PMG1-B2 MCU: USB PD DRP battery charger code example*; Available online

[8] Infineon Technologies AG: *EZ-PD™ PMG1-B2 MCU: USB PD sink code example*; Available online

Revision history

Document revision	Date	Description of changes
**	2026-04-15	Initial release
*A	2026-09-17	Updated Figure 1, Figure 2, and Figure 5, and added the ModusToolbox™ version in Section 5.2 Added constant voltage regulation in Section 8

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Edition: 2026-09-17

Published by
Infineon Technologies AG
Am Campeon 1-15
85579 Neubiberg, Germany

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Document reference:
002-42813 Rev. *A

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