USB-C 240W Power Delivery 3.1 Extended Power Range Protocol

Introduction

The USB-C Power Delivery (PD) 3.1 Extended Power Range (EPR) is a wall-to-battery, full system design solution for USB-C PD charged battery-powered applications. The EPR protocol revolutionizes modern charging by enabling up to 240W power delivery. This advancement supports a wide range of high-power devices, improving efficiency and reducing charging time.

This document provides a complete USB-C PD 3.1 EPR system. It consists of a high-efficiency AC/DC adapter using GaN power switches, a bi-directional 48V charger (sink/source), and a Battery Management System (BMS) including the fuel-gauge firmware.

Key performance indicators, electrical specifications, and bill-of-materials (BoM) are shown for each Renesas sub-system, enabling a fast product design cycle and shorter time-to-market.

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1. Overview

USB Power Delivery (PD) technology is crucial for fast charging and powering modern devices. The USB PD specification (see section 1.2) allows Type-C cables to deliver up to 240W of power, with a maximum voltage of 48V and a current of 5A. This advancement represents a significant milestone, offering a more convenient, efficient, and environmentally friendly power supply solution.

1.1 Terms and Definitions

Term	Definition
USB-C PD	Universal Serial Bus Type-C Power Delivery
EPR	Extended Power Range
TCPC	Type-C Port Controller
TCPM	Type-C Port Manager
PFC	Power Factor Correction
GaN	Gallium Nitride
ZVS	Zero Voltage Switching
SR	Synchronous Rectifier
BMS	Battery Management System
BMIC	Battery Management Integrated Circuit
FGIC	Fuel-Gauge Integrated Circuit
MCU	Micro-Controller Unit
ESS	Energy-Storage System

1.2 USB PD Specifications

- **USB PD 1.0**: 5V/2A
- **USB PD 2.0**: 5V, 9V, 15V, 20V/2A
- **USB PD 3.0**: 5V, 9V, 15V, 20V/3A
- **USB PD 3.1**: 5V, 9V, 15V, 20V, 48V/5A

The most common applications for USB PD EPR technology are:

- **Travel Adapters**: Charging from appliances to power banks.
- **Portable Power Stations**: Ideal for outdoor activities like camping, hiking, or job sites where access to traditional power grids may be limited.
- **Portable LEV Chargers**: USB PD EPR could be adapted for future portable charging solutions with high power delivery for electric vehicles through a Type-C connection.
- **Power Supply for High-Performance Laptops**: Many high-performance laptops, specifically gaming laptops or professional devices with powerful architecture and graphics.
- **Power Delivery to Large Displays**: USB PD EPR can be used to power large computer monitors or TVs, by using a single USB Type-C cable for both power and video transmission.
- **Portable Power Banks**: USB PD EPR can be used to deliver sufficient power to portable Power banks capable of charging large devices, such as laptops and high-performance tablets.

To meet these market needs, Renesas offers a comprehensive suite of solutions designed to maximize efficiency and reliability while minimizing power loss. These include an advanced USB-C PD 3.1 Extended Power Range (EPR) charger and a GaN-powered high-efficiency AC/DC USB-C 240W adapter (EBC10286), ensuring optimal power delivery across the system.

Together, these cutting-edge technologies provide a unified solution for building next-generation USB-C PD 3.1 EPR systems with scalability, supporting a wide range of devices and applications.

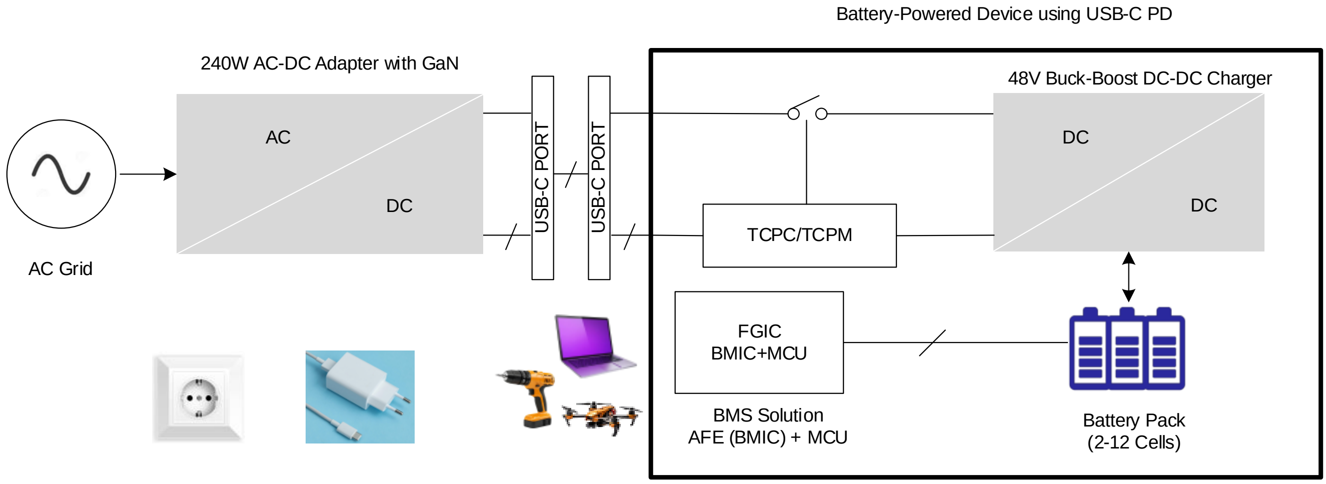

Figure 1. USB-C PD 3.1 EPR Wall-to-Battery Conceptual Block Diagram

2. Design Challenges with Sourcing USB-C 240W Power

USB PD technology plays a significant role in simplifying power delivery for a wide range of devices such as charging laptops, smartphones, tablets, even e-bikes, while improving charging speed, convenience, and energy efficiency. However, the implementation of USB PD with advancements in Photovoltaic power conversion technology presents more design challenges. To achieve the smooth power flow from source to load, several design challenges need to be addressed as detailed below.

Key challenges of USB PD technology include:

- **High-efficiency Power Conversion**: As per today's market trends, the solution must have high-power density power converters with minimum losses. The wide-band gap GaN and SiC devices with high-frequency operation are preferred in achieving higher power conversion efficiency.
- **Higher Power Output**: USB PD allows devices to deliver significantly more power than traditional USB standards. It supports up to 100W with USB PD 2.0, and up to 240W with USB PD 3.1 using Type-C cables, enabling faster charging of power-hungry devices like laptops and gaming systems.
- **Voltage and Current Flexibility**: USB PD can dynamically adjust the voltages (5V to 48V) and current (5A maximum) to match the power requirements of different devices, providing efficient energy transfer and better heat management.
- **Bidirectional Power**: USB PD supports bidirectional power flow, meaning that power can flow both ways, allowing devices like laptops to charge peripherals, or enabling power-sharing between devices.
- **Safety and Protection**: The USB PD 3.1 EPR introduces new challenges to ensure safety and protection of connected devices. Due to the requirement of higher voltage levels, system design involves robust and powerful protection circuitry to protect sensitive components for PD controllers against abnormalities such as overvoltage, overcurrent, and other fault conditions. The system responds well to rapid changes in load requirements and variable output voltages.
- **Smart Communication**: Devices using USB PD 3.1 communicate with each other to transfer the optimal voltage and current levels, ensuring safe and efficient charging.
- **Modular and Scalable Solution**: The solution should be modular and scalable to various power levels to reduce customers' R&D time, reduce testing and validation time, and improve reusability of power solutions across multiple projects.

Apart from the above important challenges, some of the other design considerations have been considered for a reliable USB-C 240W EPR, such as:

- Grid compatibility, such as 90V to 264V, 50Hz/60Hz
- Various regulatory guidelines such as IEEE 1679.1, IEC 62933-5-2, UL 9540, etc.
- Integration feasibility with existing energy infrastructure
- Support for complete conversion chain including latest USB PD EPR protocol
- Mitigate hardware/software integration at customer side by providing FW and GUI for each sub-system

Considering the above challenges, the Renesas solution is built with cutting-edge technology that enables a modular and scalable and customer friendly USB-C PD EPR system.

Renesas strategy adds more flexibility for customers:

- **Reference design**: Containing datasheet, schematics, BOM and Gerber files
- **Assembled module**: Offer a standard assembled module for USB-C connector
- **Custom Assembled Module**: Offer an assembled module as per customer requirements with their own specifications

See Figure 2 for a high-level block diagram for the USB-C PD charging solution.

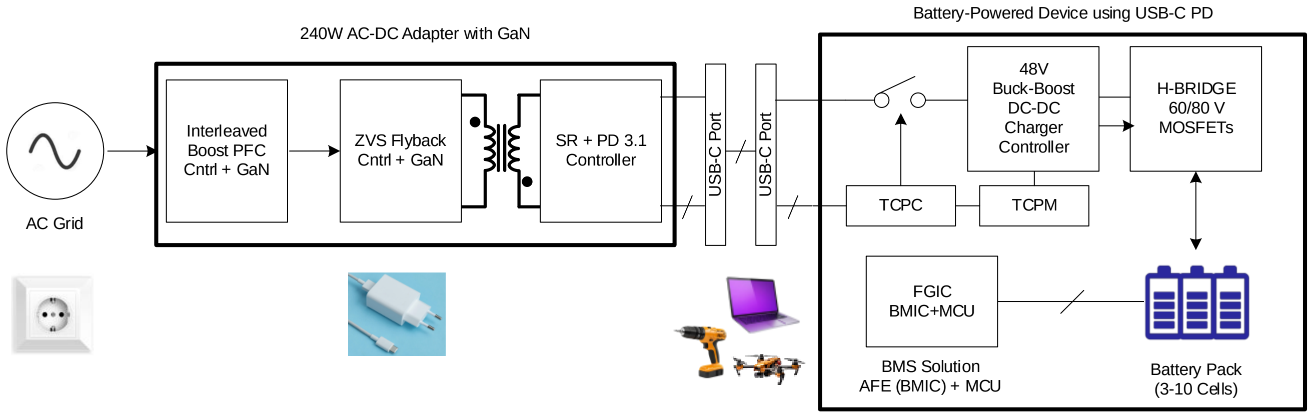

Figure 2. Block Diagram for the Renesas USB-C PD Wall-to-Battery Complete Solution

3. Solution for USB-C 240W Wall-to-Battery System

USB PD technology plays a key role in simplifying power delivery for a wide range of devices while improving charging speed, convenience, and energy efficiency. To meet the growing market demands, Renesas provides a range of solutions designed for maximum efficiency, reliability, and minimal power loss, including:

- **GaN-Powered High-Efficiency AC/DC USB-C 240W Adapter**: This adapter leverages Gallium Nitride (GaN) technology to deliver high efficiency while converting AC to DC, supporting up to 240W of power. It ensures optimal power delivery, enhancing the charging experience for power-hungry devices.
- **USB-C PD 3.1 Extended Power Range (EPR) Charger**: This advanced charger enables rapid and versatile charging, supporting the higher power delivery capabilities of the USB PD 3.1 EPR standard. It ensures quick charging while maintaining efficiency across devices.
- **Battery Management System (BMS)**: fully integrated Fuel-Gauge IC (FGIC), consisting of a Battery Management IC (BMIC) and MCU with Renesas gauging and monitor firmware, provides compact and cost-effective BMS solutions for 3-to-10 cell battery pack.

3.1 AC/DC USB-C 240W Adapter

The Renesas AC/DC power supply design (EBC10286) consists of a two-stage configuration containing AC/DC interleaved boost as PFC stage and ZVS flyback converter with synchronous rectification as DC-DC stage as shown in Figure 3, Figure 4, and Figure 5 (schematic and hardware prototype). The design is based on 240W

(48V/5A) output power and operates from universal input AC voltage range (90V to 264V, 50Hz/60Hz). The design uses the R2A20132SP Renesas CrCM PFC controller for interleaved boost converter and the iW9801 Renesas ZVS flyback controller with DCM operation for flyback converter. This solution supplies the maximum power of 240W for the emerging USB PD 3.1 extended power range (EPR) specification. It can be used for a wide variety of power supply designs and complies with European regulations mandating USB Type-C common charger usage across many small- and medium-sized portable electronics.

3.1.1 System Benefits

- The design is based on the GaN Technology (TP65H150G4LSG) to obtain high power density and efficiency. Higher power density reduces size and weight while also achieving increased thermal performance.
- It supplies maximum power as defined by USB-C PD 3.1 requirements (48V/5A).
- It operates at Zero Voltage Switching (ZVS) with minimum switching losses and high efficiency >94% at full load (28V, 5A).
- Power factor obtained as >0.96.
- The PFC+ZVS flyback design is simple, with lower components count and cost.
- Synchronous rectification of flyback output further improves the efficiency of the system.

3.1.2 Target Applications

AC-DC Charger with USB-C PD adapter suitable for:

- Laptops
- Non-mobile Type-C powered handhelds
- Power tools
- E-bikes

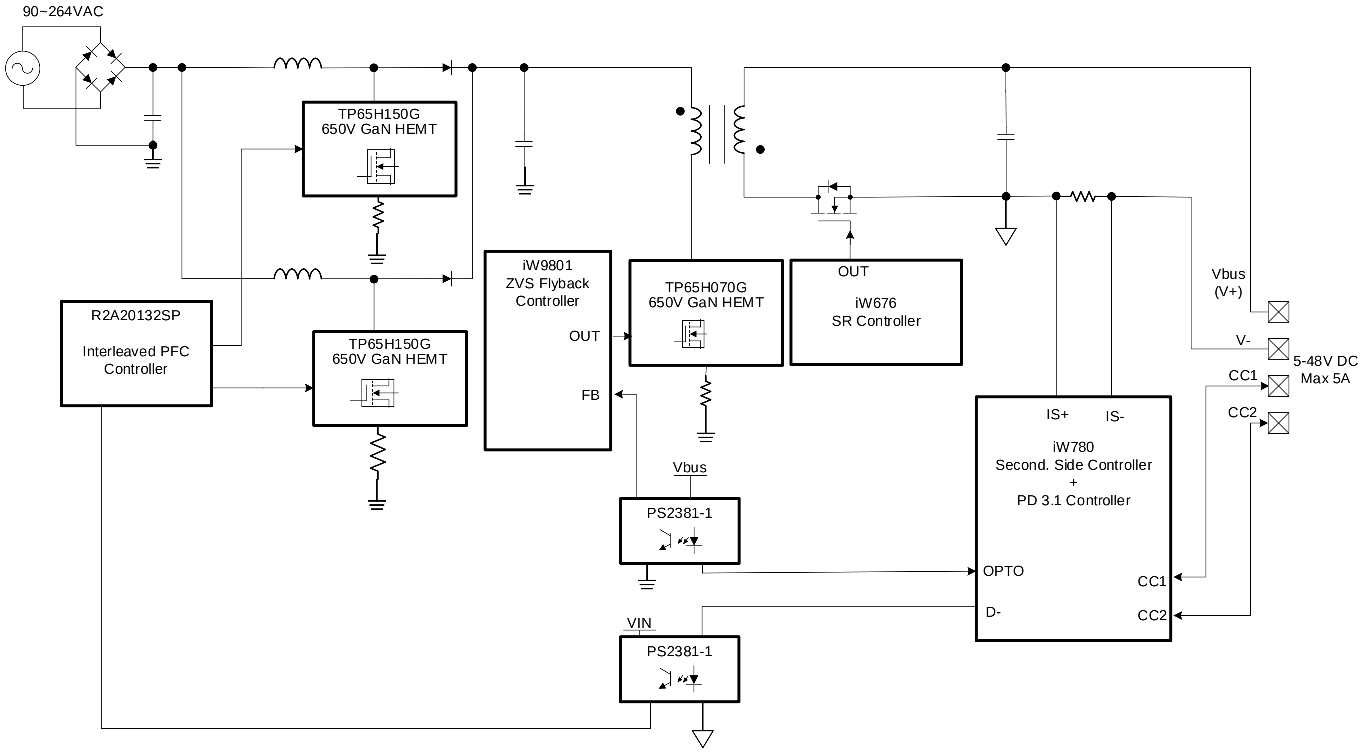

Figure 3. AC/DC Extended Power Range Adapter Block Diagram

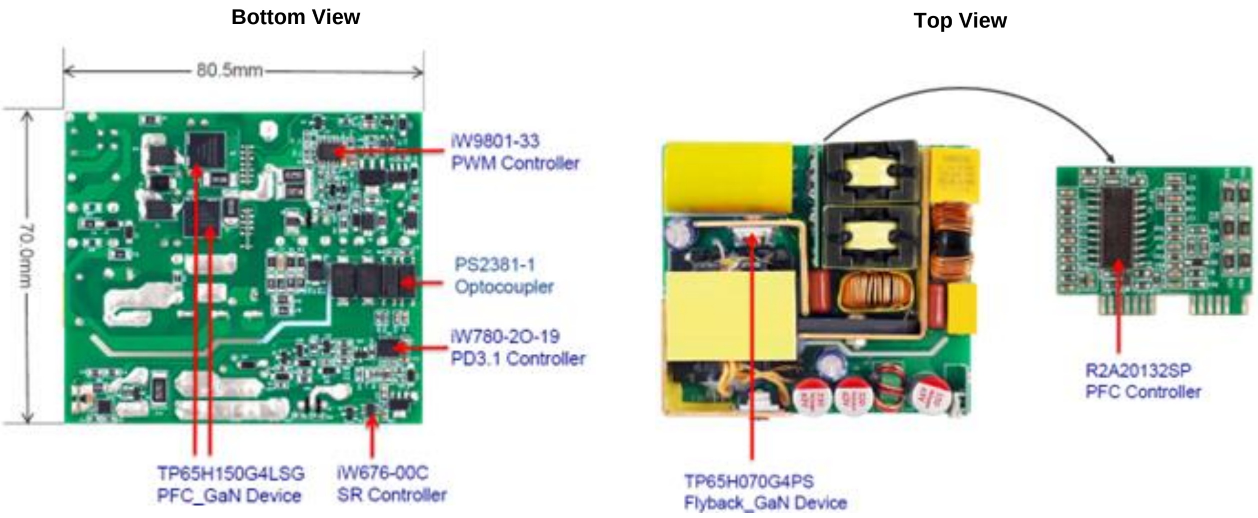

Figure 4. AC/DC Extended Power Range Adapter: Hardware Prototype

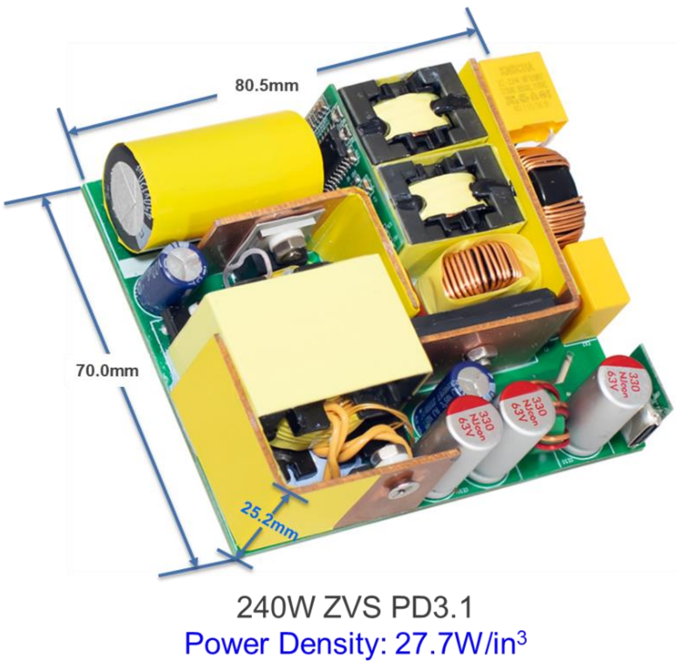

Figure 5. AC/DC Extended Power Range Adapter: Power Density 27.7W/in^3

The power components and controller used for the design are listed in Table 1. The technical key specification is shown in Table 2. The design achieves maximum power conversion efficiency of 92.74% at minimum input voltage and 94.97% at maximum input voltage with full load power (see Figure 6). The nominal power factor achieved is >0.98 for 110V supply voltage and >0.96 for 230V supply voltage (see Figure 7).

Table 1. 240W AC/DC Adapter Key Components

Renesas Part Number	Description
iW9801-00	Digital Zero Voltage Switching RapidCharge™ AC/DC Controller
TP65H150G4LSG	650V 150mΩ SuperGaN® FET in PQFN88
TP65H070G4PS	650V 70mΩ SuperGaN® FET in TO-220
R2A20132SP#W0	Critical Conduction Mode Interleave PFC Control IC

Renesas Part Number	Description
iW676-00C	Digital Synchronous Rectifier
iW780-2O-19	Secondary-Side USB Power Delivery 3.1 Protocol and Interface IC for Single and Multi-port Adapters up to 240W
PS2381-1	4-PIN LSOP Photocoupler Operating Ambient Temperature 115°C

Table 2. 240W AC/DC Adapter Key Specifications

Parameter	Minimum	Typical	Maximum	Unit
Input AC Voltage Range (rms)	90	110/230	264	V
Input AC Frequency	47	50/60	63	Hz
Output Voltage	45.60	48	50.4	V
Output Current	0	-	5	A
Output Power	-	240	-	W
Ripple and Noise (Vpp)	-	-	500	mV
Switching Frequency	-	-	-	
Average Efficiency at Full Load	89	-	94.79	%
Power Factor	-	-	0.99	

Table 3. 240W AC/DC Adapter Grid to USB-C VBUS Efficiency

Vin rms (V)	Pin (W)	Vout (V)	Iout (A)	Vripple (mV p-p)	Po (W)	Efficiency (%)
90	65.84	48.065	1.25	196	60.01	91.14
	130.05	47.993	2.5	228	119.98	92.26
	194.3	47.99	3.75	208	179.96	92.62
	258.7	47.982	5	200	239.91	92.74
115	65.6	48.006	1.25	196	60.01	91.47
	129.11	47.994	2.5	200	119.99	92.93
	192.9	47.986	3.75	196	179.95	93.29
	256.55	47.974	5	204	239.87	93.5
230	65.92	48.01	1.25	196	60.01	91.04
	128.25	48.004	2.5	156	120.01	93.58
	190.66	47.99	3.75	204	179.96	94.39
	253.1	47.983	5	192	239.92	94.79
264	65.95	48.012	1.25	192	60.02	91
	128.1	48.008	2.5	156	120.02	93.69
	190.3	47.99	3.75	160	179.96	94.57
	252.6	47.978	5	188	239.89	94.97

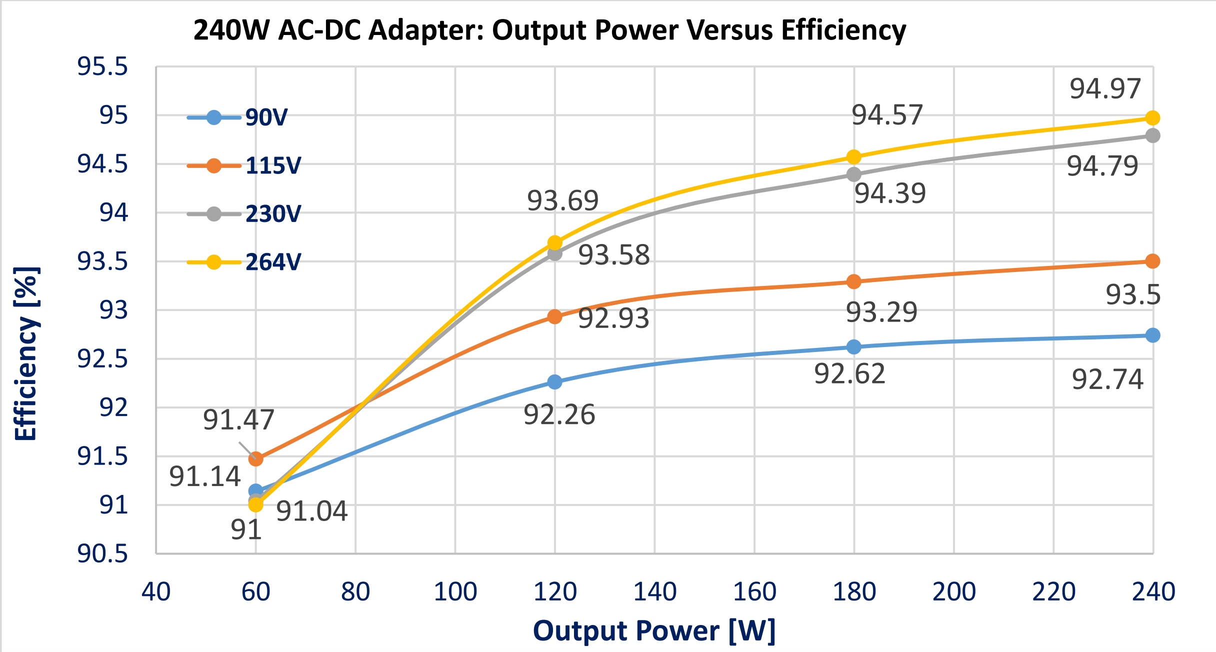

Figure 6. 240W AC/DC Adapter – Efficiency vs Output Power

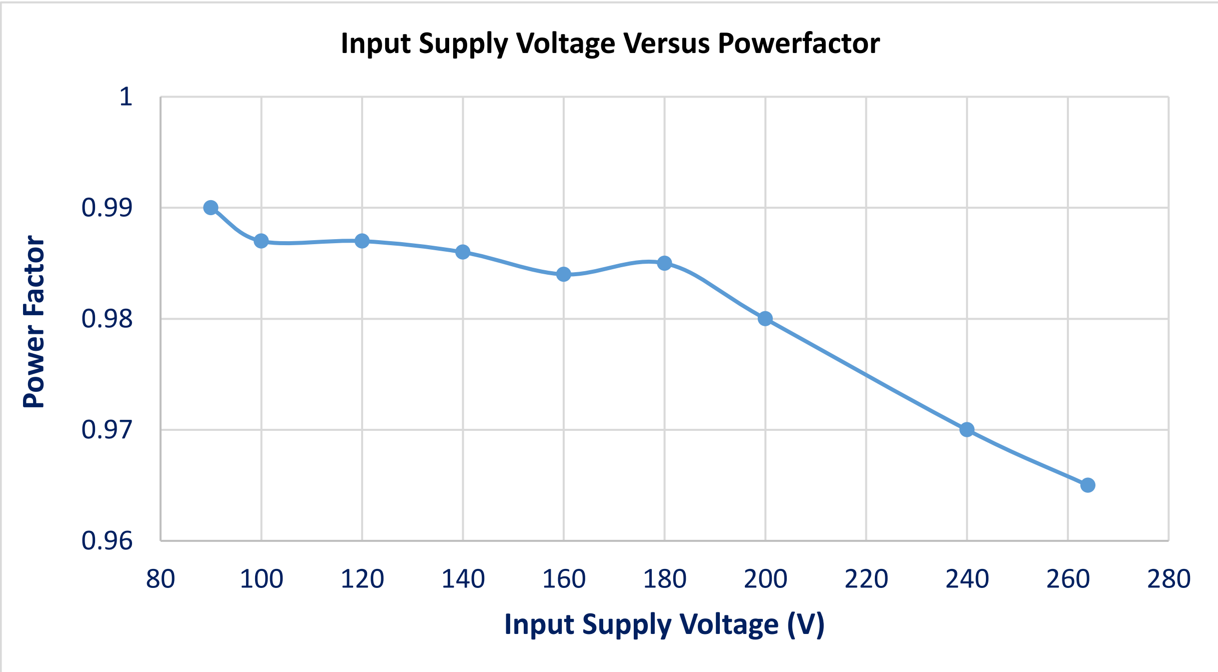

Figure 7. 240W AC/DC Adapter – Input Supply Voltage Versus Power Factor

3.2 USB-C PD 3.1 EPR Solution

The USB-C PD 3.1 Extended Power Range (EPR) charging solution is designed to deliver up to 240W of power in both sinking and sourcing operating modes. The Renesas solution for EPR is shown in Figure 8. This solution operates with a bus voltage up to 48V and a maximum current of 5A.

3.2.1 System Benefits

- Wide number of cells support
- Supports both source and sink modes
- Multiport support with single TCPM
- Simplified implementation of digital control through buck-boost charge controller
- Short development time-to-market by reusing the USB PD solution

3.2.2 Target Applications

- Battery-powered mobile devices
- Electric bikes, robots, and drones
- Power tools, battery packs
- Home appliances such as vacuum cleaners
- Notebooks, tablets, power banks, and desktop PCs

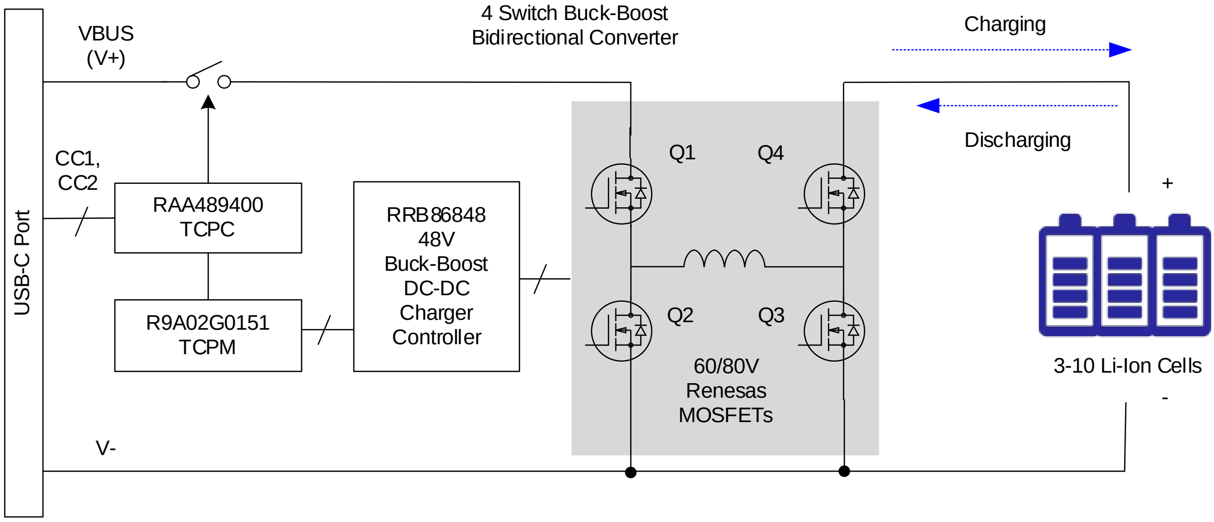

Figure 8. USB-C PD 3.1 Extended Power Range (EPR) Charger

Table 4. 48V, 240W Bi-Directional USB-C PD Solution – Key Components

Renesas Part number	Description
RRB86848	48V Buck-Boost DC-DC Charge Controller
RAA489400	USB Type-C Port Controller
R9A02G0151	USB Type-C Port Manager
RBE0xxN0xR1S	60V / 80V MOSFETs

Table 5. 48V, 240W Bi-Directional USB-C PD Solution – Key Specifications

Parameters	Minimum	Typical	Maximum	Unit
Type-C Input Range	5	-	48	V
Battery Voltage Range	5.632	-	48.96	V
Input Current	-	-	5	A
Charging Current	-	-	12	A
Input Power	-	-	240	W
Switching Frequency	-	377	-	kHz

To mitigate potential thermal issues by maximizing the system efficiency, a high efficiency Bi-Directional Buck-Boost DC-DC converter is exploited. It typically consists of a four control loops controller (input and output CC/CV loops) driving four discrete 60/80V MOSFETs in an H-bridge configuration. A TCPC controller is used to control the bus switches, read the CC signals, and to send and receive the messages from/to the TCPM microcontroller. The key components and key specifications for the EPR solution are listed in Table 4 and Table 5, respectively.

The Renesas portfolio offers a cutting edge Buck-Boost controller: the RRB86848 supports bi-directional current flow and guarantee robust operation withstanding both input and output voltages up to 54V. The new Renesas Split-Gate MOSFET technology enables low RDS (on) and switching capability operation for high-power and high-frequency applications.

A single USB Type-C Port Manager, the R9A02G0151, combines with multiple RAA489400 Type-C Port Controller devices to implement all USB PD functions (such as power negotiation and Alternate Mode support) for the management of multiple USB Type-C ports. This feature minimizes the overall solution size and cost by reducing the number of Port Managers in the design. A typical block diagram for a single TCPM and single TCPC is shown in Figure 9.

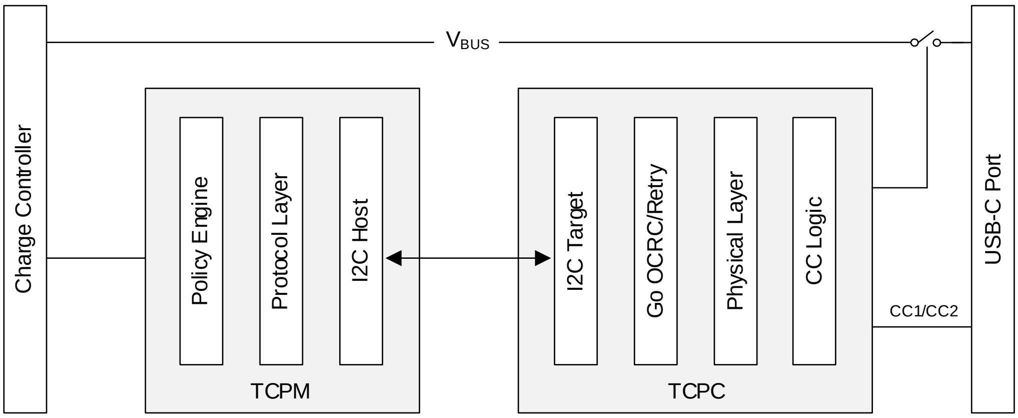

Figure 9. Block Diagram of TCPM and TCPC

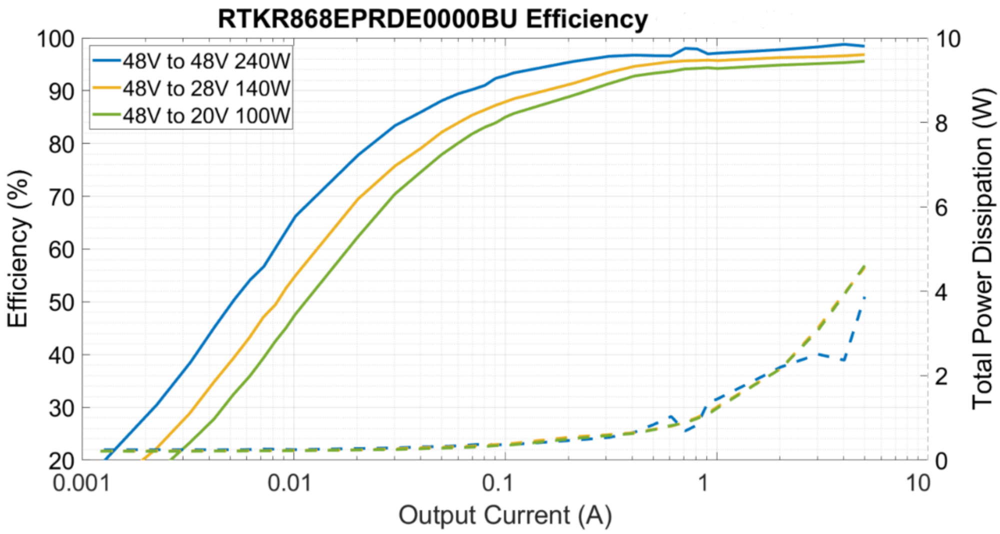

Figure 10. 240W Bi-Directional USB-C PD – Charger Efficiency

3.3 Battery Management System

The Battery Management System (BMS) is a crucial component in all battery-powered devices, ensuring the safe and efficient operation of the battery pack. The three primary functions of a BMS include monitoring, protection, and cell balancing. The BMS continuously monitors the status of individual cells within the battery pack for voltage, temperature, and state of charge. It also prevents conditions such as overcharging/discharging, short circuits, and thermal runaway. Finally, it ensures uniform charge distribution among cells to maximize battery life and performance. These functions can be done with discrete devices or a Battery Management Integrated Circuit (BMIC). Switches such as MOSFET transistors control the charging and discharging processes. They enable precise control over the current flow, which is essential for protecting battery cells and maintaining efficiency. Next, a method for obtaining and processing accurate data for voltage, current, and temperature measurements is done with Analog-to-Digital Converters. Finally, a stable power supply to the BMS and its components is critical to maintaining reliability and accuracy in monitoring and control.

The Renesas FGIC, RAJ240100, integrates all the blocks, reducing size and cost. It also includes an MCU and a dedicated 18b delta sigma ADC for fuel-gauging purposes. It supports 3-to-10 cell battery packs, widely used in power tools, high-performance drones, professional laptops, and many more. A block diagram can be found in Figure 11. Internally, the BMIC and MCU have multiple self-diagnostic functions to more easily realize safety and regulatory compliance. Fixed, validated firmware is available for the RAJ240100. This firmware provides all standard functions, including voltage, current, temperature protections with associated charge and discharge FET behaviors, cell balancing functions, a Coulomb counting based state of charge algorithm, state of health algorithm, and additional functions. In addition, though the firmware is fixed, the solution is flexible. Over 70 parameters can be entered to customize the solution for different cells or different conditions. The firmware provided allows designers to make a battery pack without battery firmware expertise and reduce both the Research and Development (R&D) time and the test and validation process, resulting in a lower cost and shorter time-to-market for the final product. The RAJ240100 Evaluation Kit is displayed in Figure 12.

3.3.1 System Benefits

- Reduced solution size and cost by integrating the BMIC and MCU into a single package
- Renesas BMIC firmware reduces the design time, validation process, and therefore, shorter time to market
- Internal and external cell balancing provision gives scalable solution

3.3.2 Target Applications

- E-bike, E-scooter, pedal-assist bicycle
- Power tool, vacuum cleaner
- Drone
- Battery backup system, Energy Storage System (ESS)

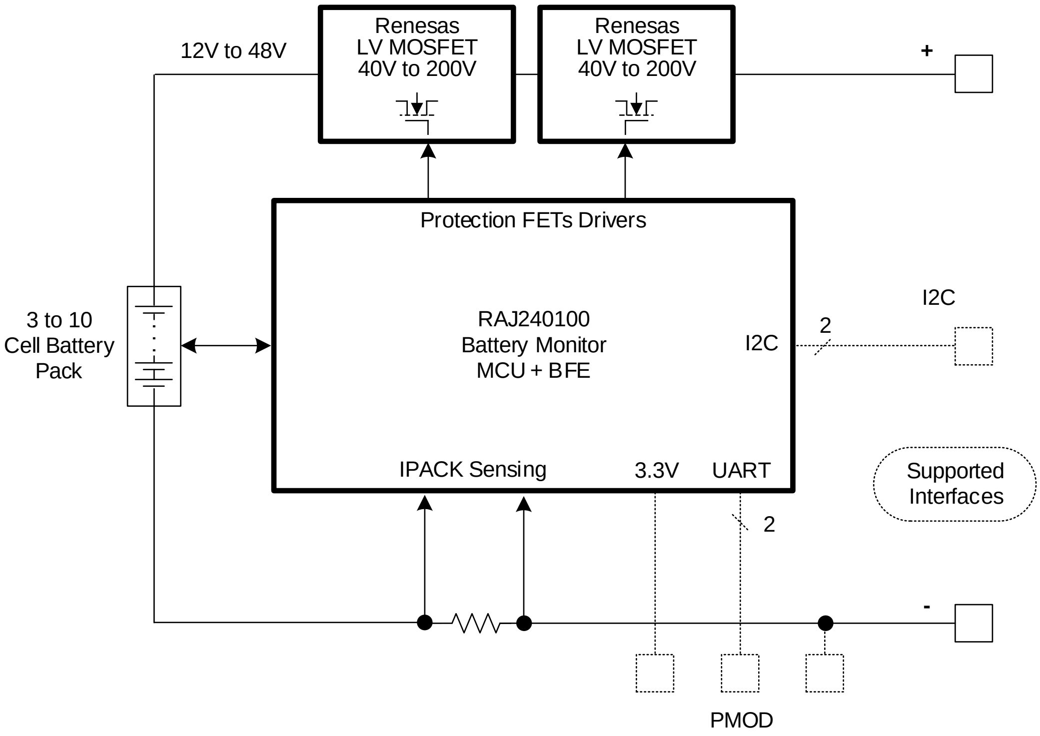

Figure 11. BMS Block Diagram

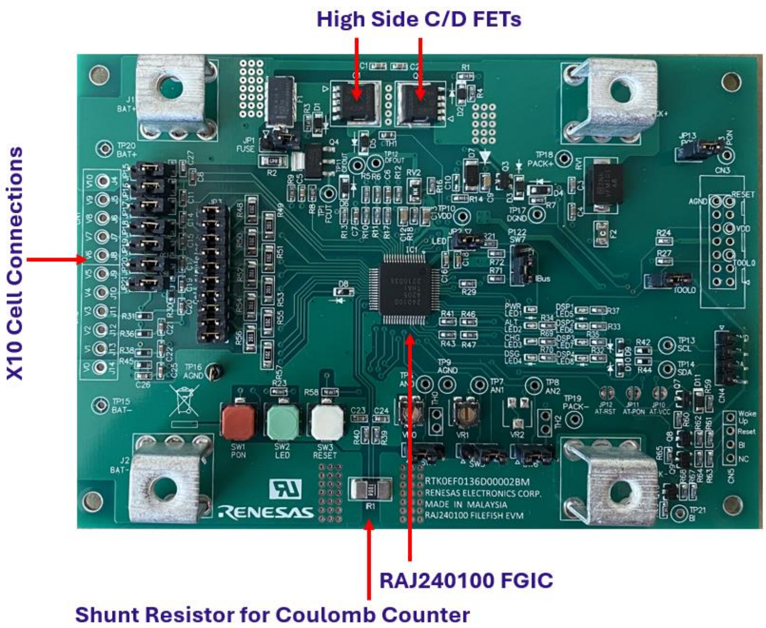

Figure 12. RAJ240100 FGIC Evaluation Board

Table 6. 3-to-10 Cell Battery Management – Key Components

Renesas Part Number	Description
RAJ240100	10S Battery monitor MCU + Battery Management IC (BMIC)
RBE0xxN0xR1S	60 V/80 V MOSFETs

Table 7. 3-to-10 Cell Battery Management – Key Specifications

Parameters	Typical	Units
Number of cells	2–12	-
MCU Flash	128	KB
GPIO	31	-
SPI	2	-
UART	2	-
I^2C	1	-
CAN	1	-
High-Side C/D FET Drive	Input Voltage + 9.5	V
BMIC ADC Resolution	15	bits
VCin Accuracy Across Temperature	±10	mV
Coulomb Counter ADC Resolution	18	bits
Internal Cell Balancing Rdson	200	Ohms

4. Conclusion

Renesas is the ideal design partner for systems and applications that require comprehensive expertise in power management, embedded processing, connectivity solutions, analog circuitry, and sensor integration.

Our diverse power portfolio includes DC-DC converters, AC-DC converters, and power discretes such as silicon MOSFETs and GaN HEMT, ensuring high efficiency and reliability tailored to diverse power requirements. This makes us an ideal partner for AC-DC adapter, USB-C PD charger, and Battery Management System designs across any application. We also offer extensive technical support and development tools, facilitating seamless integration of systems across a broad range of industries.

5. References

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6. Revision History

Revision	Date	Description
1.00	Mar 6, 2025	Initial release.

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