AN14881

FlexGauge

Rev. 1.0 — 12 January 2026 | Application note

Document information

Information	Content
Keywords	PCA9422, FLEXGAUGE.
Abstract	This application note provides product guidelines and performance results for FlexGauge.

1 Introduction

1.1 General description

FLEXGAUGE is a software-based fuel gauging solution that combines the efficiency of a voltage-based algorithm with the accuracy of a hybrid gauge. Operating directly on the system MCU, it applies the PCA9422 PMIC to provide precise battery state-of-charge (SOC) estimation. FLEXGAUGE runs on the host MCU, eliminating discrete gauging ICs and sense resistors, reducing the bill of materials and overall system cost. This integration also lowers power consumption, making FLEXGAUGE suitable for energy-sensitive applications.

1.2 Features and benefits

1.2.1 Battery fuel-gauging

A battery fuel gauge is a system or component designed to estimate and display the remaining charge percentage of a battery with high accuracy. Its primary function is to give users and systems real-time battery SOC insight, enabling efficient power management and preventing unexpected shutdowns. Unlike simple voltage-based methods, advanced fuel gauges use algorithms that consider factors like current flow and temperature to deliver precise SOC readings. This capability is especially critical in portable electronics and IoT devices, where reliable battery performance is essential for both user experience and operational efficiency.

1.2.2 Types of battery gauging

Battery gauging algorithms estimate SOC, health, and runtime using three approaches: voltage-only, current-only, and hybrid voltage-current with impedance correction. Voltage-only gauging is simple and cost-effective, relying on open-circuit voltage to estimate SOC. Current-only gauging, often based on coulomb counting, tracks charge entering and leaving the battery. Hybrid gauging combines voltage and current measurements, applying impedance correction to account for internal resistance and dynamic load effects. Selecting the appropriate algorithm depends on system complexity, accuracy requirements, and power profile.

1.2.3 Challenges in voltage-only fuel gauging

Voltage-only gauging estimates battery SOC using terminal voltage without current measurements or coulomb counting. Although simple and cost-effective, especially in compact systems, it faces significant limitations. Temperature, load conditions, aging, and reducing accuracy influence battery voltage. Under dynamic loads, voltage fluctuations from internal resistance and transient effects complicate correlation with charge level. Different battery chemistries also exhibit varying voltage profiles, limiting its universal application. Improving accuracy requires sophisticated modeling and calibration, yet voltage-only gauging remains less reliable than hybrid methods incorporating current sensing or impedance tracking.

1.2.4 Practical constraints of current-only SOC measurement

Current-only gauging estimates battery SOC by integrating current flow over time, a method known as coulomb counting. While this technique can be highly accurate under controlled conditions, it presents several challenges in real-world applications. Sensor drift, noise, and measurement inaccuracies accumulate error, causing SOC miscalculations unless corrected regularly. This method requires precise knowledge of full charge capacity, which changes with aging, temperature, and complicates accuracy. Without voltage or temperature data, current-only gauging fails to detect idle self-discharge or estimate SOC during rest. As a result, it must be paired with other techniques-like voltage or impedance tracking to maintain long-term reliability.

1.2.5 The IR drop at load

Impedance-based gauging provides one of the most sophisticated and accurate methods for estimating battery SOC. It applies simultaneous real-time voltage and current measurements, and interprets them using advanced algorithms or models. This approach enables systems to account for voltage drops caused by varying loads, which simpler methods often overlook. The core advantage of impedance gauging lies in its ability to dynamically adjust SOC estimates based on operating conditions:

- Voltage under light load provides a baseline estimate
- Coulomb counting under heavy load improves accuracy during high current draw
- Load prediction helps anticipate voltage sag and system performance under future conditions

2 Flexgauge host-based battery gauging with software-assisted load tracking

The algorithm uses voltage-based estimation, infers current instead of measuring directly, and eliminates the cost, complexity, and power overhead of coulomb counters. Software-assisted load tracking enables the micro control unit (MCU) to assert predefined load state indicators at runtime. These indicators inform the algorithm of active subsystems or operating modes and enable more accurate interpretation of voltage measurements under dynamic load conditions. Because the gauging logic resides within the MCU, the system schedules sampling intelligently to avoid transient noise or poor estimation periods, improving robustness and reliability. This architecture is well suited for low-power embedded systems where minimizing component count and energy consumption remains critical.

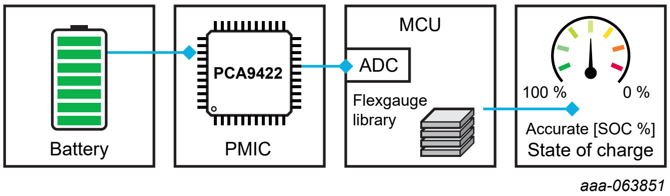

Figure 1. System flow

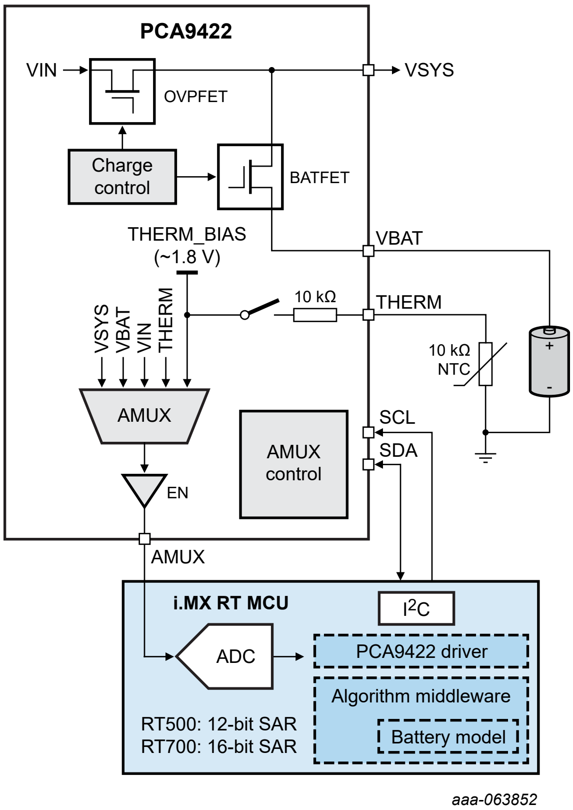

Figure 2. Hardware connection

3 Battery characterization

Lithium-ion battery technology has evolved significantly, producing diverse chemistries optimized for size, weight, cost, energy density, and performance. Lithium facilitates ion exchange, while cathode composition varies across battery types. Common cathode chemistries include nickel cobalt aluminum oxide (NCA), lithium cobalt oxide (LCO), lithium manganese oxide (LMO), and lithium titanate oxide (LTO).

Manufacturers introduce proprietary variations in chemical composition and cell construction, creating distinct open-circuit voltage (OCV) and impedance characteristics critical for accurate SOC estimation.

Developing a custom battery model tailored to specific cell chemistry and behavior ensures optimal performance of the FLEXGAUGE algorithm. Battery samples undergo controlled charge-discharge cycles under varying loads and temperatures at NXP facilities. Collected data generates model files capturing OCV and impedance profiles, which serve as foundational inputs for FLEXGAUGE SOC estimation across operating conditions.

Most fuel gauge algorithms rely on data collected at three temperature points: room, cold, and hot. Lithium-ion batteries exhibit nonlinear impedance behavior across the full temperature spectrum, especially at lower temperatures where performance degradation increases. NXP incorporates an additional temperature characterization point beyond the conventional three, improving visibility into battery behavior across the full operational range. By capturing granular data, especially under extreme conditions, FLEXGAUGE reduces extrapolation errors and delivers more accurate SOC estimations in challenging thermal environments.

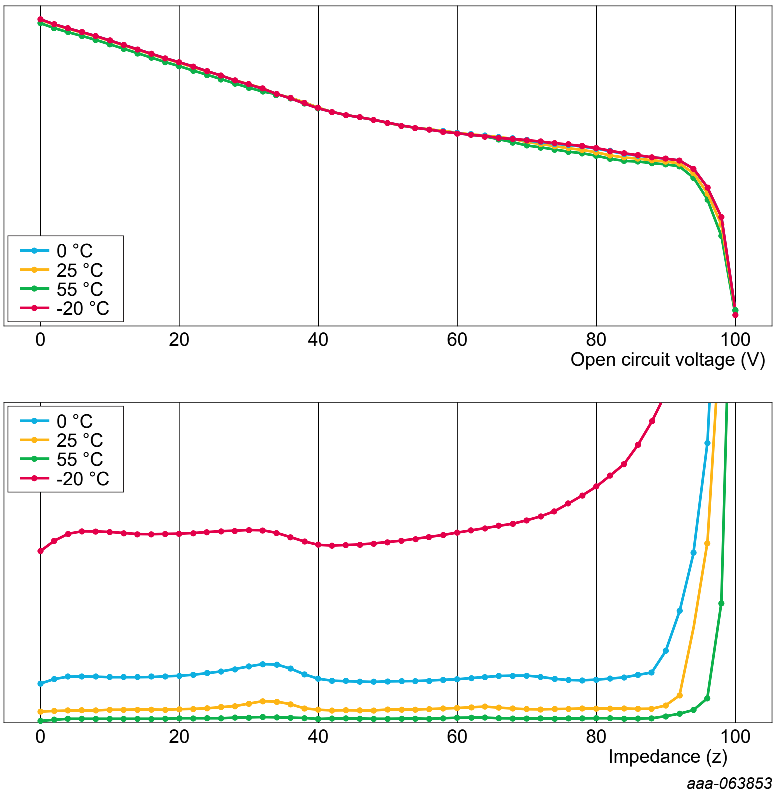

Figure 3. Battery Characterization Visualization

For more information about how to generate a custom battery model, contact Flexgauge.support@nxp.com.

4 Host MCU integration and load list-based predictive gauging

Conventional battery fuel gauges operate reactively, estimating remaining capacity based only on historical current measurements and usage patterns. This approach lacks predictive insight into future load conditions and often relies on averaged load profiles that fail to reflect upcoming usage scenarios accurately.

Figure 4 illustrates this limitation using data collected from constant current discharge of the same battery under three load conditions: 50 mA (~C/4), 125 mA (~C/2), and 250 mA (~C rate). Discharging at higher loads produces an apparent capacity reduction of about 7 %. This discrepancy requires evaluating how the end application can model, predict, and mitigate potential loss factors within its operational framework.

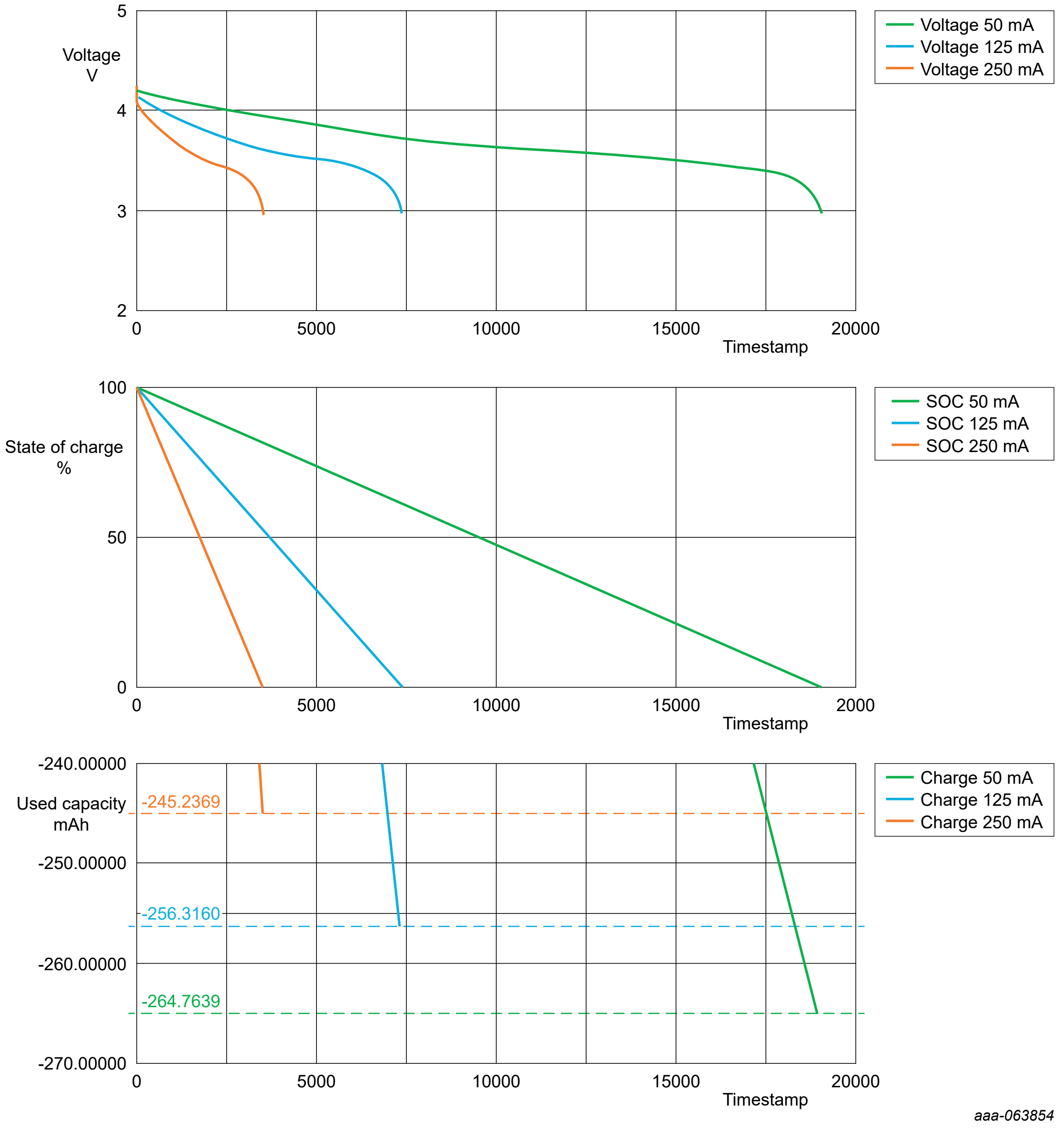

Figure 4. Battery discharge curves

Consider a smartwatch application. Smartwatches operate in low-power Standby mode for extended periods, producing minimal average current draw and reducing internal resistance (IR) losses. This condition increases usable capacity and extends runtime. When users initiate high-activity modes such as workouts with heart rate monitoring, GPS tracking, and music playback, the load increases significantly. Under these conditions, available capacity drops sharply. Traditional fuel gauges respond reactively, accelerating SOC decay and causing abrupt drops that result in a suboptimal user experience.

5 FLEXGAUGE: predictive and adaptive SOC estimation

FLEXGAUGE uses the host MCU's awareness of device activity states to SOC. The approach relies on a configuration register called *Load List*, which contains precharacterized load profiles representing possible future operating conditions.

The host MCU compiles load estimates into the *Load List* register. FLEXGAUGE calculates individual SOC values for each profile in the Load List. These SOC values are treated as supplementary data rather than primary indicators. FLEXGAUGE transfers the values into its core SOC register, *Reported SOC*. An NXP-developed SOC engine generates this register.

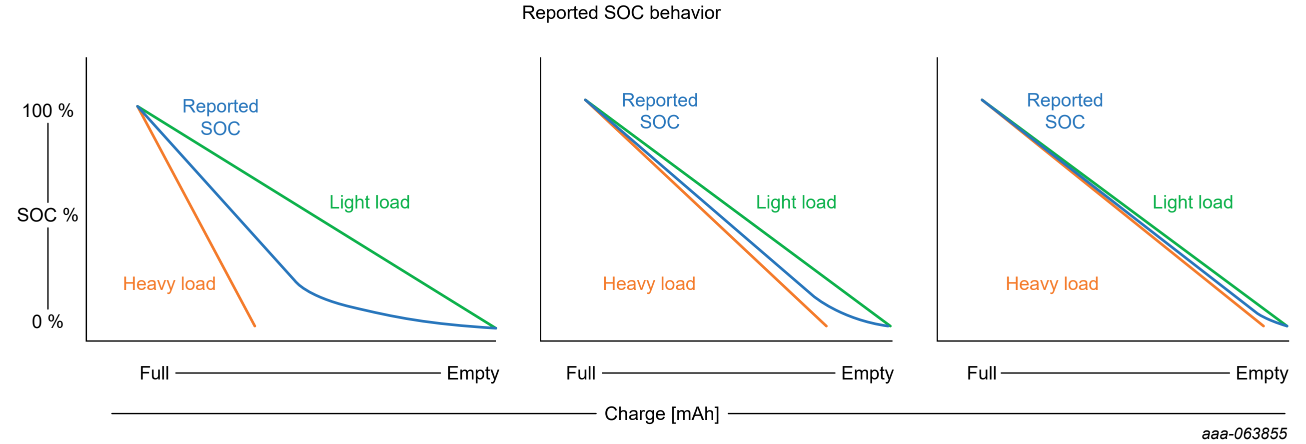

Figure 5. Reported SOC Behavior

The engine synthesizes predicted SOC values to produce a conservative estimate. The estimate accounts for any load state that the application may activate at any time. Unlike methods based on average current or time-weighted load profiles, Reported *SOC* assumes that any listed load could occur immediately. This conservative approach prevents sudden SOC drops and ensures stable performance for the user.

6 Safeguarding against sudden SOC collapse

A sudden drop to 0 % SOC represents a worst-case scenario for battery-powered devices. FLEXGAUGE mitigates this risk with an additional protective mechanism called *VOLT SOC*. *VOLT SOC* is derived from raw voltage measurements and disregards load conditions.

As battery voltage approaches the configured end-of-discharge threshold (*ENDV*), *VOLT SOC* converges with *Reported SOC*. This dual-layered approach-combining predictive load-based SOC estimation with voltage-based validation-provides robust protection against unexpected shutdowns and ensures consistent system reliability.

Benefits of FLEXGAUGE

- **High accuracy:** advanced algorithms ensure precise and reliable battery percentage reporting.
- **Zero hardware cost:** eliminates the need for a dedicated fuel-gauge IC, reducing BOM.
- **Ultra-low footprint:** consumes minimal MCU Flash and RAM.
- **Easy integration:** delivered as a portable Zephyr library with a simple API.
- **System-level awareness:** runs on the host MCU for intelligent power management.
- **Battery agnostic:** configurable for Li-ion and Li-Po battery profiles. .

Suitable for integration into upcoming projects

- IoT and edge devices
- Wearables and hearables
- Portable medical monitors
- Smart home sensors
- Handheld industrial tools
- Consumer electronics

Table 1. Technical snapshot

Number	Feature	Specification
1	**PMIC**	PCA9422
2	**MCU Requirements**	M-33 Core (RT500/RT700)
3	**Code Footprint**	< 12 kB code, < 7473 Bytes RAM
4	**Language**	ZephyrOS, FreeRTOS
5	**Deliverable**	Example Application code Static Library (.lib/.a) and Header Files

Get started in 3 simple steps.

1. **Route:** connect the PMIC’s buffered voltage output to the host MCU’s ADC input.
2. **Integrate:** add the FLEXGAUGE library to your project and call the simple API functions.
3. **Deploy:** enable precise battery monitoring and reduce the BOM.

7 Revision history

Table 2. Revision history

Document ID	Release date	Description
AN14881 v.1.0	12 January 2026	Initial release

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