Application Report
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Alternative Gauging Techniques for Flow Meters and the Benefits of the bq35100

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ABSTRACT

This paper discusses the different methods applied in gauging lithium primary cells used in flow meters-their advantages, disadvantages and the value which the bq35100 adds to a design when compared to these other methods.

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1 Introduction

There are two major types of lithium primary cells used in flow meters: Lithium manganese dioxide ($LiMnO_2$) and Lithium thionyl chloride ($LiSOCl_2$). Due to the peculiarities of these cells being non-rechargeable and possessing certain characteristics such as a flat open circuit voltage as in the case of $LiSOCl_2$, gauging their capacity can be challenging. Figure 1 and Figure 2 show the discharge profiles of both types of cells. Different approaches has been used for tracking the remaining capacity of these cells, however, TI's bq35100 is the first gauge developed primarily for these kind of cells and offers the combined advantage of the existing methods and more, providing additional value and reducing the overall cost of the system. The major existing approaches for gauging lithium primary cells has been the use of discrete components for either coulomb counting or direct voltage measurement. The bq35100 offers the advantage of these two methods and introduces a new advanced and innovative method where the state of health can be determined by the resistance profile of the cell with the ability to tell when the cells are at end of service. Typical applications where these cells are used are smart meters, flow meters and building automation. The different architectures of which most employ discrete solutions are real time clock method, voltage detection method (ADC), voltage detection (comparator method), host system coulomb accumulator method (Measurement and Math method), and rechargeable gas gauge method (voltage measurement method).

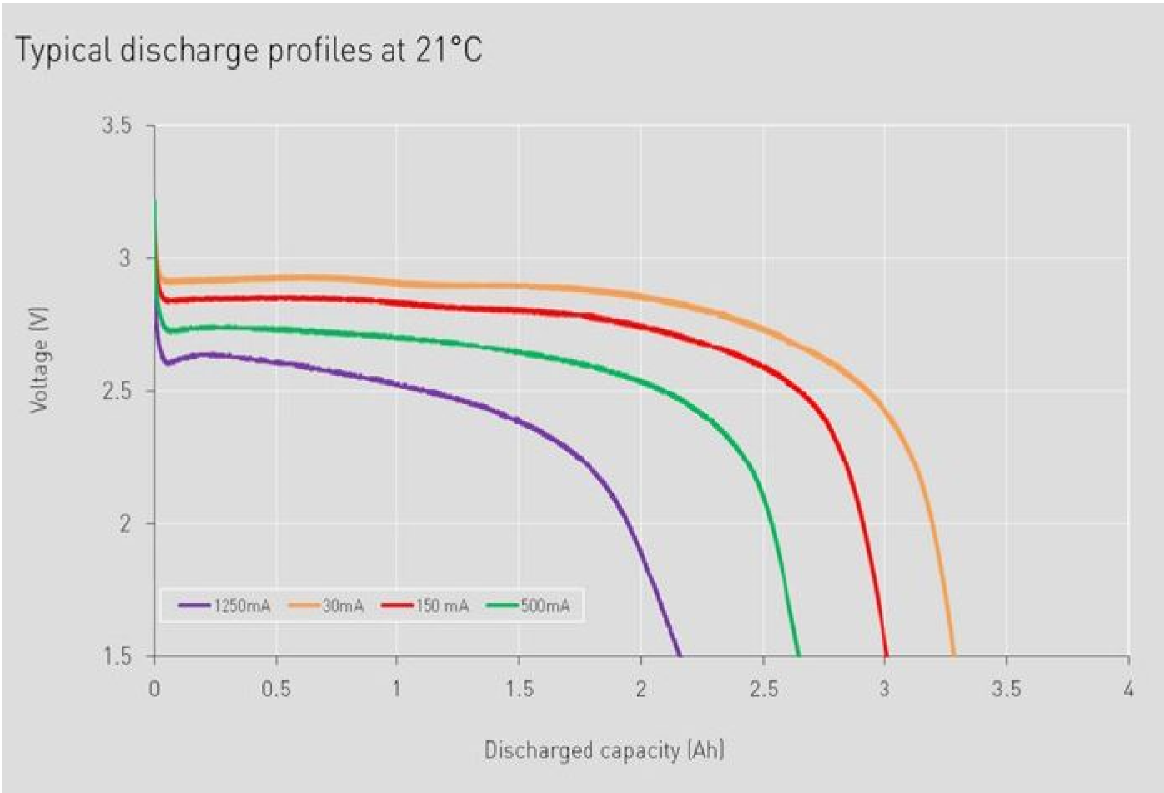

Figure 1. Discharge Profiles of a Lithium Manganese Dioxide Cell (Source: SAFT)

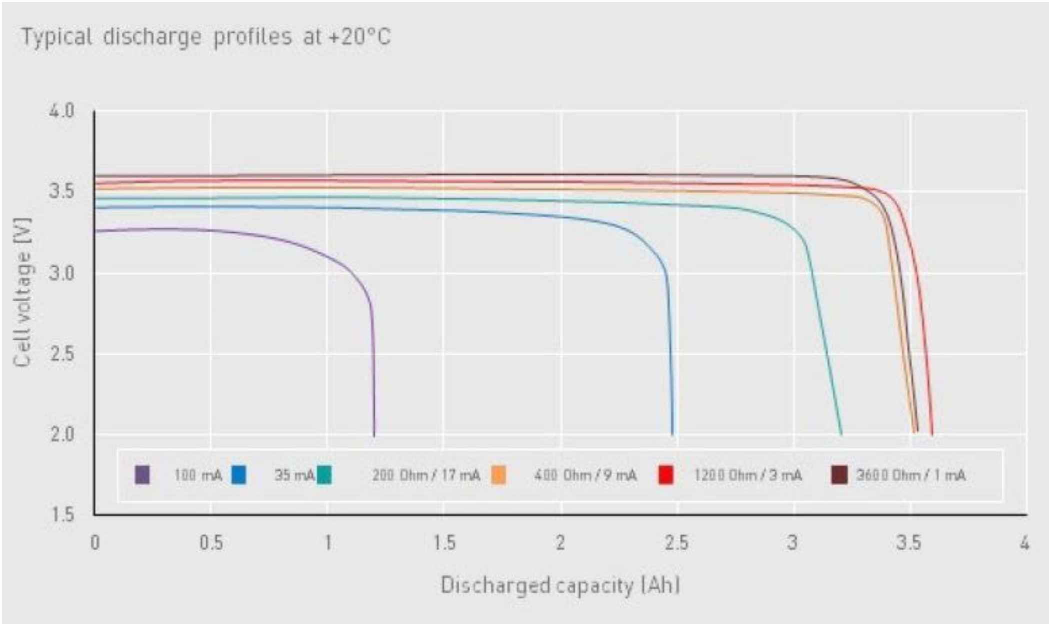

Figure 2. Discharge Profiles of a Lithium Thionyl Choloride Cell (Source: SAFT)

2 Real Time Clock Method

This is a fairly basic method where the load is known and the cell's performance is characterized under the expected load condition. In this case, you assume the worst case conditions and determine what the minimum time the cells can support under these conditions. Given these known conditions, one can count the time in service using a real time clock in the system.

The advantages of this system are:

- It is very easy to implement
- It only costs a small amount of memory and CPU utilization
- Time can be updated if system load configuration is changed (for example: firmware update)

The disadvantages of this system are:

- There is no ability to account for cell to cell or temperature variation so this must be built into the original cell capacity and time selection
- This is a very conservative approach to ensure run time. If the cell used is nominal, then several percentage of capacity is lost
- Any premature cell degradation cannot be detected
- Usually needs to be combined with a low battery voltage detection method

3 Voltage Detection (ADC method)

This method requires the use of an ADC for voltage measurement. The cell's performance is characterized under the anticipated load conditions and then one or more suitable voltage thresholds are determined. Typically the host ADC is used which often have 10-bit resolution with a 7-bit accuracy .This therefore means 36-mV resolution for measuring voltage. There are some hosts that have 12-bit resolution as well and a tad better accuracy can be achieved with those. For $LiSOCl_2$ cells this is less than ideal due to the flat nature of their open circuit voltage curve. Errors here could be significantly high depending on the resolution of the ADC and could be as bad as 40%. A better separate ADC and/or a different reference voltage could be used but that will result in additional current draw and increased costs.

The advantages of this system are:

- It is easy to implement
- Cell degradation can be accounted for based on voltage
- Most system host micro controllers have spare ADC channel, therefore there is not a need for a separate ADC
- It only costs a small amount of memory and CPU utilization
- The thresholds can be updated if system load configuration is changed (for example: FW update)

The disadvantages of this system are:

- There is no ability to account for cell to cell or temperature variation so this must be built into the original cell capacity and voltage selection
- Cell voltage is very flat for $LISOCl_2$ cells so a small voltage measurement error is a very large capacity error.
- An external ADC and reference can be used to maximize precision but that increase supply current and cost. There will also be a need to enable and disable such additional circuitry.

4 Voltage Detection (Comparator method)

This method is identical to the ADC method already mentioned, but instead of using an ADC, comparators can be used. The cell's performance is characterized under the anticipated load conditions and then one or more suitable voltage thresholds are determined. Then one comparator can be used per threshold. An example is the flash ADC architecture as seen in Figure 3. This architecture requires a large number of comparators compared to the ADC method especially if higher precision is needed. This translates into higher current consumption and reduced scalability.

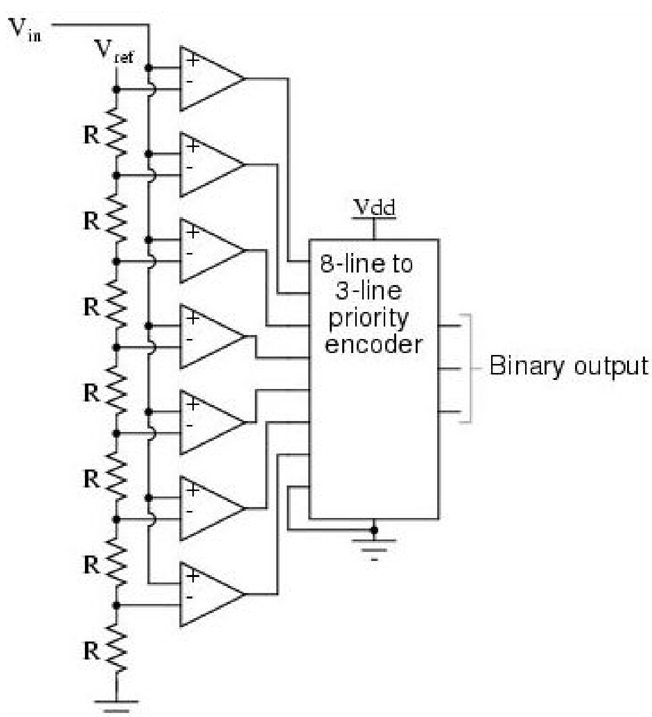

Figure 3. Flash ADC Architecture

The advantages of this system are:

- Cell degradation can be accounted for using this method

- Has better precision than using host ADC
- Only requires a small amount of memory and CPU utilization to enable and disable it.

The disadvantages of this system are:

- There is no ability to account for cell to cell or temperature variation so this must be built into the original cell capacity and voltage selection
- Cell voltage is very flat for $LISOCl_2$ cells so a small voltage measurement error could be a very large capacity error
- To maximize precision, supply current and cost of the comparator increases.
- There is a need to enable and disable circuitry to conserve battery energy

5 Host System Coulomb Accumulation (Math method)

This is similar to the real clock method. The amount of current flowing out of the battery is measured in the different load/power modes. Each power mode that the device will be used in can be characterized and tabulated in the host. Based on this table and the host knowing which power mode is functional at a given time and for how long, the current consumption can be calculated and the state of health of the battery determined. This approach obviously requires definitive exact known profiles in order to be accurate but will not account for the 3-5% cell to cell variation which may exist.

The advantages of this system are:

- Easy to implement for simple systems with two or three power modes
- Only requires a small amount of memory and CPU utilization to enable and disable it.

The disadvantages of this system are:

- There is no ability to account for cell to cell or temperature variation so this must be built into the original cell capacity
- Complex systems require a lot of characterization
- Any system changes, radio distance, FW updates need to be accounted for in the accumulation math
- Premature cell degradation cannot be detected.
- Usually needs to be combined with a low battery voltage detection method.

6 Host System Coulomb Accumulation (Measurement method)

Here the host accumulates the measured current over the counted time to determine when the battery is empty and needs to be replaced. For this method, an ADC is required for coulomb counting and the host ADC could be used just like in the voltage measurement method. The sense resistor used for current measurement could have drifts and offsets which could introduce errors in measurements. This is a reliable method that works for complex systems with different power modes.

The advantages of this system are:

- Easy to implement for complex systems.
- More precise than the math method and can account for system variations
- Only requires a small amount of memory and CPU utilization to enable and disable it.

The disadvantages of this system are:

- There is no ability to account for cell to cell or temperature variation so this must be built into the original cell capacity
- Any premature cell degradation cannot be detected
- The ADC and sense resistor measuring the current can have offset and drift issues.
- There is a need to enable and disable this method to conserve energy during low power states
- Usually needs to be combined with a low battery voltage detection method.

7 Rechargeable Gas Gauge (voltage measurement method)

Texas Instruments has a plethora of gas gauges designed for rechargeable batteries. These can be configured for a primary cell with some adjustments and used to provide state of health information. This approach is based off a look-up table preprogrammed on the gauge and SOC-Voltage correlation is used for gauging.

The advantages of this system are:

- Off the shelf voltage to SOC conversion.
- It accounts for early cell degradation
- It only requires a small amount of memory and CPU utilization to enable and disable it.

The disadvantages of this system are:

- Designed for the wrong chemistries and battery characteristic changes
- No accounting for cell-to-cell or temperature variation so this must be built into the original cell capacity
- Learning of capacity usually requires charging which is not possible
- Flat cell voltage could means a small voltage measurement error results in large capacity error.
- It needs to be enabled/ disabled to conserve battery energy

8 bq35100

This is TI's latest gauge for lithium primary batteries. It has the combined advantages of all aforementioned architectures and more. The gauge has the option to be used in state of health mode which is a voltage measurement mode with a high accuracy delta-sigma 16-bit ADC with 1-mV resolution. It also has the option to be used as an accumulator whereby the coulombs flowing out of the battery can be counted. Figure 4 shows that with the 16-bit ADC, the accuracy error which can be achieved for $LiMnO_2$ is less than 3%.

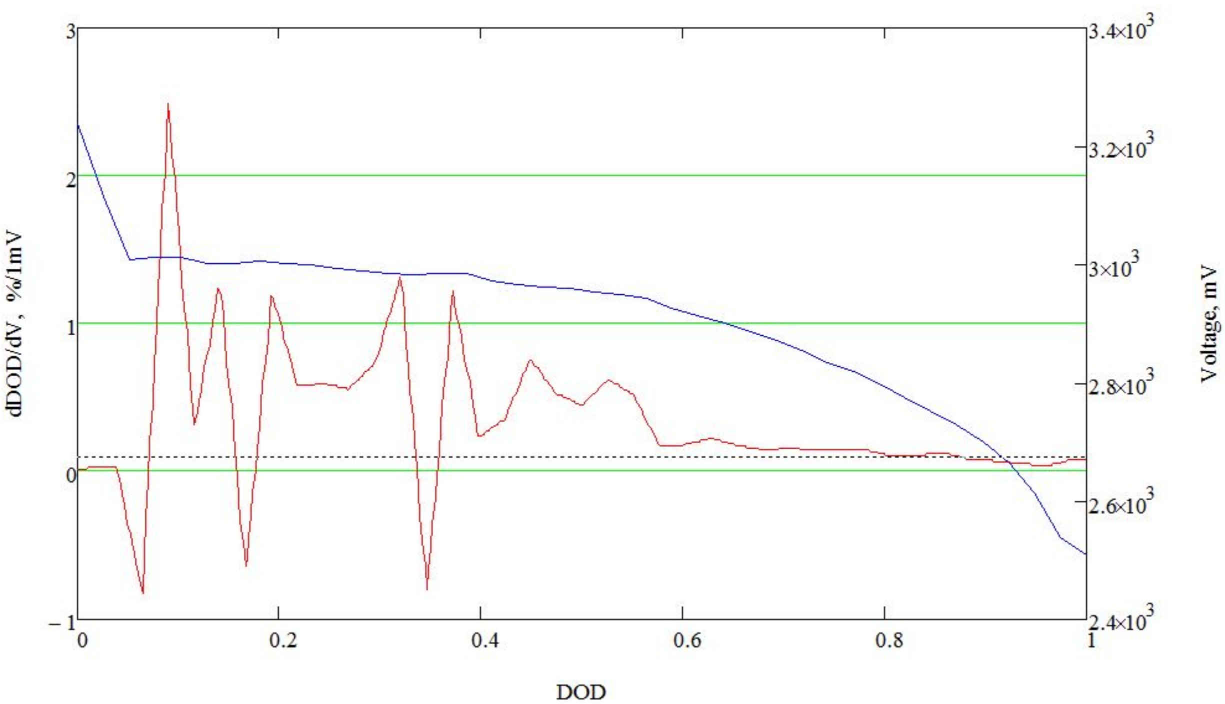

Figure 4. DOD vs OCV Error of the $LiMnO_4$ Cell with bq35100

Additionally, an innovative means of determining the SOH and end-of-service of a primary battery using its resistance profile adds a degree of functionality to this device. Figure 5 shows that the resistance can be correlated with DOD to determine the SOH. It further shows that the amount of error in this correlation is minimal especially towards the end of the discharge. Applying TI's innovative algorithm of looking at the rate of change of the resistance, the end of service of the battery is able to be predicted with high accuracy. Also, with the aid of a host this gauge can be enabled and disabled to reduce power consumption.

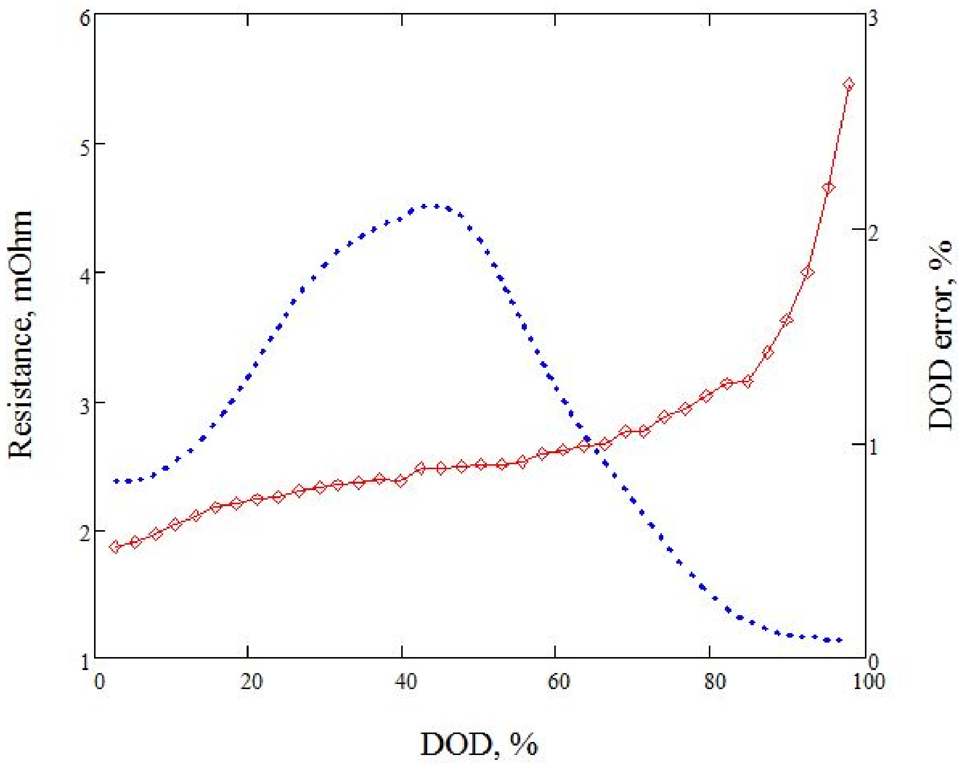

Figure 5. Resistance and DOD Error vs DOD Percentage

The advantages of this system are:

- Able to extract the maximum energy from the battery under all static or varying conditions
- Able to provide an accurate early warning of End-of-Service (EoS) enabling scheduled replacement rather than emergency replacement when the battery fails.
- Able to provide diagnostic data of how the battery is being used in the field.
- Ability to be used for voltage measurement or accumulation mode
- Does not require memory utilization
- No extra ADC is needed for functionality.
- Low current consumption using with the ability to enable and disable the chip to conserve energy.

9 Conclusion

While there are several techniques which can be applied to gauging lithium primary batteries used in flow meters, the bq35100 incorporates the benefits and advantages of all these techniques in one chip. It is a relatively simple to use gauge with low power consumption which can be further optimized by powering the chip down via the host during lower power modes of the application. The gauge is able to account for cell to cell variation and temperature changes making it an ideal fit for flow meters.

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