Sense Resistor Selection for Optimum Battery Gauge Performance

Abstract

Selection of a sense resistor to be used for battery gauging should be made with the recognition that various tradeoffs are to be weighed. Gauging performance may be evaluated and weighted by a mix of factors. These include gauge accuracy, sensor cost, gauge sense resistor load on system (others?). Analysis of these factors provides input for the resistor selection guide table presented below.

Analysis

Accuracy

Accuracy depends on the characteristics of the analog signal conversion circuit. Two primary considerations are the precision and linearity of that circuit. However, it must be recognized that selection of the sense resistor for gauging will impact accuracy. Signals of interest must not saturate the conversion circuit. To achieve maximum precision it is best to take advantage of the full range of the conversion circuit. Consider that a circuit capable of 15 bits of precision will not deliver the available performance if the sense resistor is chosen such that only 10% of the useful range is utilized. At 10% of the range the precision of a 16 bit converter is reduced to an effective 13 bits. At 1% precision is effectively dropped to 10 bits.

Evaluation of accuracy must also consider the resolution of the arithmetic performed by the gauge. Most arithmetic is performed using 16 bit integers. Data reporting from the gauge uses 16 bit integers and for gauging accuracy this provide a range a values that are reported to better than 1% precision. However, there are two situations where this can break down. Capacities exceeding about 14500 mAh can cause power and energy related computations to overflow. On the other hand, capacities below 200 mAh begin to lose resolution and therefore accuracy. These issues can be easily overcome by scaling. Scaling places a small additional burden on the host system as it must recognize that capacity, power and current reading will be scaled. Scaling can be applied in either direction. For cells that are large capacity, scaling is used to reduce the possibility of arithmetic overflow. For small capacity cells values can be scaled up in order to improve resolution ad accuracy.

When scaling is applied, it will also need to be applied to the impedance tables. Depending on the gauge this will be done in one of two ways. Many newer gauges provide auto-scaling of a default impedance table. On these gauges there are two capacities that are configured in data flash. One is the Default Design Capacity. The Default Capacity is matched to the impedance table. The second capacity, the Design Capacity, is the capacity of the cell that the gauge will monitor. The ratio of these capacities is used to scale values from the impedance table. On gauges where there is no Default Design Capacity, then the impedance table must be manually adjusted for the scaling.

Dead Band

At low currents noise has the potential to impact gauge performance. This is especially true in scenarios where current may be low for extended periods of time. The output of A/D circuit at the sense resistor is used in two ways. It provides the current and directly measures charge removed or added charge to a cell at each second. Change in charge is used in two important ways. One is in determining impedance measurement. The other is in determining Qmax. Both of these determinations need to use accurate accumulations of charge over time.

Low level currents do not need to be reported by the gauge and can cause the gauge to perform unnecessary computations. To avoid this gauge firmware used a constant called Current Deadband. Currents below this dead band are not reported or acted upon by gauge firmware.

However, over an extended period of time it may be the case that there is a signal in the noise at low current levels. So accumulation of charge related to this is needed for accurate gauging. The parameter that is used to pull signal out of noise is the CC Dead Band. The algorithm for signal detection, then is explicitly removing capacity accumulation below the CC Dead Band. Noise theory suggests that there is an accumulation of error over time from separating the signal from the noise. Gauge firmware adheres to that and so based on the CC Dead Band there is a point in time where the accumulation is declared to have too much error to be used for capacity and impedance measurements. The mathematics of this disqualification are fairly complex. The selection table will provide disqualification times based on the parameter in the table that effect that time. The effecting parameters are Design Capacity, Minimum Capacity Error (a data flash constant), CC Dead Band (a data flash constant), and the Capacity Gain which is a function of the sense resistor.

For gauges using the capacity smoothing algorithm and where the sense resistor has a small value it is often necessary to increase the CC Dead Band to avoid accumulating phantom currents over time. There are configurations of smoothing in all our gauges that can avoid the issue. But, some customers prefer to avoid those configurations. In that case, the only option to avoid phantom current accumulation is with CC Dead Band.

Gauge Load

Gauging creates a load on the power system. First there is the power that gauge requires. Second is the power loss through the sense resistor (transducer) that the gauge uses.

During discharge a single cell gauge uses an average of around 100 uA current. For very low capacity cells this may contribute significantly to a loss of run time. During idle times the gauge averages only 20 uA. In use scenarios of the most interest, it is the gauge’s current during active discharge that is most significant. Still, assuming a C/2 discharge the loss of capacity to the gauge is only .2 mAh. For a 1 Ah cell the run-time loss is just 1.5 seconds at the C/2 discharge rate.

Power loss through the sense resistor is determined as follows. Consider that the average power is based on a nominal operating point for C/t , t in hours, C in Ah, discharge. Then power loss across the sense resistor is (C/t)^2 * R. Energy dissipation over the discharge is then (C/t)^2 *R*t =(C^2 /t) *R. From the example above we can plug in the numbers to see the energy loss; 1 /2 * .01 = .005 Wh. The nominal cell energy is 3.6 * 1 = 3.6 Wh. The run time loss estimate is then (.005/3.6) * 2h = 10 seconds. From the power loss formula, the motivation to reduce value of the sense resister as a cell size increases becomes clear. Still it is important to keep a good perspective on the effect. 10 seconds is a pretty small percentage of the 7200 second run-time.

Cost

Cost should be considered. Some situations may require a higher cost sense resistor, but in most situations the higher cost would not be chosen without a demonstrable benefit. The selection table below should help with this decision.

End User Experience

This is what gauging is all about. Probably the most disappointing end user experience is an unexpected shutdown; the case where a device is indicating available capacity when none is present. Preventing that experience is the goal of optimizing the gauge performance. Sense resistor selection is a key element of that optimization.

Selection Guide Table

The selection table provides recommended selection and calibration for sense resistor selection and provides perspective on accuracy run-time loss related to power dissipation across the sense resistor.

milliohm	Scale	Max Capacity - mAh	Min Capacity - mAh	Max Current Range - mA	Min Current Range - mA	Current Precision	SR Run-time Loss - s	Dead Band - mA	Cap Err Time - hour
20	1	14600	200	5000	200	.238 mA	292	5	30
20	2	7300	100	3900	100	.119 mA	146	5	15
10	1	14600	400	7800*	400	.4768 mA	146	5	30
10	.5	29200	800	15600*	800	.954 mA	292	5	60
5	1	14600	800	7800*	800	.954 mA	73	10	15
5	.5	29200	1600	15600*	1600	1.59 mA	146	10	30
3	.5	29200	1600	15600*	1600	1.59 mA	87.6	20	9
3	.25	58400	3200	31200*	3200	3.18 mA	175.2	20	18
2.5	1	14600	1600	7800*	1600	1.9 1 mA	36.5	20	7.4
2.5	.5	29200	3200	15600*	3200	3.82 mA	73	20	15

Explanation of columns:

Scale – indicates the multiplicative factor from scaling the sense resistor gain. For instance, the 2x scaling for the 20 milliOhm means the gauge is reporting current and capacity at twice their actual value. A host system would then divide by 2 to get true capacity or current value.

Max Capacity – is max capacity of the actual cell, for which scaling is accounted.

Min Capacity – indicate minimum capacity supported, scaling is accounted for and compare with Current Accuracy to determine if SR is workable for the application.

Max Current Range – determined by minimum of available range on conversion circuit or prevention of overflow of integer math. *These currents can be doubled on gauges with Design Energy Scaling.

Min Current Range – is a recommendation.

> The current ranges are the actual range limits in mA. For instance, using the 20 milliOhm SR and a scaling of 2, the gauge will report 200 mA when the actual current is 100 mA. This improves the resolution for a 100 mAh low capacity cell.

Current Precision - the assumed 1 LSB error in mA of 4.768 microV across the sense resistor.

SR Run-time loss – for comparison purposes assume the C/2 rate loss at Max Capacity as described in the Analysis section. Units are in seconds.

Dead Band – in mA the value used to determine Cap Err Time

Cap Err Time - # hours allowed after an OCV measurement before impedance and Qmax measurements will be disabled. Used Min Capacity as this is worst case.