

bq2083 and bq2085 Board Offset Characterization and Compensation

Portable Power Products/Battery Management

ABSTRACT

The bq208x (bq2083, bq2084, and bq2085) products are high-precision advanced gas gauge products for battery monitoring and management. Because the current signal is measured through a small sense resistor ($< 20\text{ m}\Omega$) to minimize power loss, compensation for the ADC input offset is critical for the accuracy of the measurement. This application note discusses common issues associated with board offset characterization, data analysis, and data flash configuration. The article uses bench data in the step by step description. Layout guidelines for low board offset are discussed at the end of the article.

1 The Need for Board Offset Compensation

The sigma delta ADC of bq208x, used as a coulomb counter (CC), integrates battery current to report important battery status, such as remaining capacity, state of charge, current, and learned full capacity. The current signal is small due to the small sense resistor used in series with batteries. For example, 10-mA current produces only 100 μV across a 10-m Ω sense resistor. Therefore, offset (internal and external) to the IC all need to be calibrated and compensated.

Failure to compensate offset can result in an inaccurate current and battery capacity report. For example, gas gauge (GG) can falsely report current and capacity change (more than self-discharge) when the battery pack is removed from the system or has no load attached.

The bq208x automatically calibrates internal CC offset each time the device enters the sleep mode. During calibration, bq208x places an internal short across the differential current inputs and measures the CC output. The resulting offset value is saved in the data flash for compensation. See application note SLVA148 for a detailed description.

Board offset is system-level offset, often caused by component mismatch and noise coupling. Like any other offset, board offset varies from system to system and has dependency on temperature. Board offset needs to be characterized in the product development phase. The number of boards and measurement samples should be of sufficient quantity to adequately represent the distribution of board offset. Data analysis yields programming values for **Digital Filter** (DF 0x2C) and **Board Offset** (DF 0xd7 in bq2084 and DF 0xC6 in bq2083/5).

2 Board Offset Characterization and Data Analysis

The bq208x evaluation software (EVSW) provides board offset measurement under Options → Special Options → Calculate Board Offset. The board offset calculation window appears in Figure 1.

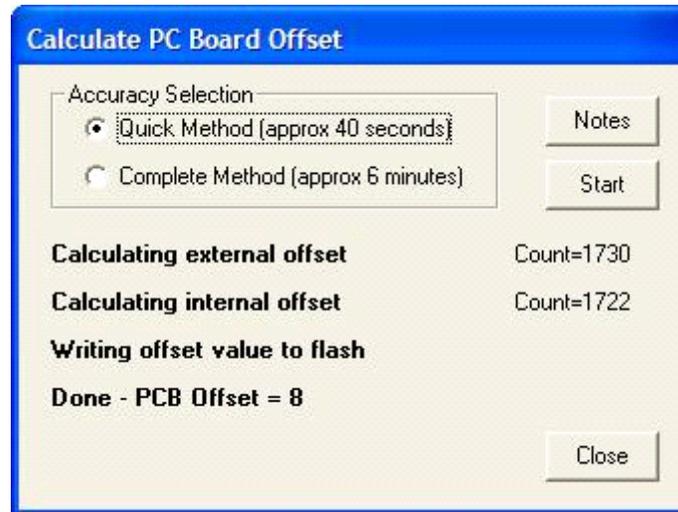


Figure 1. Board Offset Window in bq208x Evaluation Software

The two methods for board offset capture based on the number of CC samples are quick method and the complete method. The quick method, which usually takes 40 seconds, averages 64 CC samples. The complete method takes approximately 6 minutes, but uses 640 samples for much better accuracy. The board offset calculation procedure starts with external offset measurement, followed by internal offset, which is the CC offset. The difference of the two offset numbers is written to **Board Offset** flash location by EVSW. The engineering unit for offset is $0.584 \mu\text{V}/\text{count}$ for the bq2083 and bq2085, and $0.146 \mu\text{V}/\text{count}$ for the bq2084. The positive sign indicates offset as charge current. The offset shown in Figure 1 can be calculated to $4.672 \mu\text{V}$ ($= 8 \times 0.584 \mu\text{V}$) in charging direction.

To have an accurate board offset measurement, it is important that absolutely no current flows through the sense resistor during offset measurement. A common mistake is taking measurements after the battery is connected. As shown in Figure 2, the operating current of the AFE and Gas Gauge are treated as offset current and subtracted from reporting current and capacity. As a result, the IC current is counted as discharge current. We recommend measuring board offset on the module level, before the battery pack has been assembled. Connect a voltage to Pack+ and Pack- on the module as shown in Figure 3. This allows operating current of the IC to bypass the sense resistor.

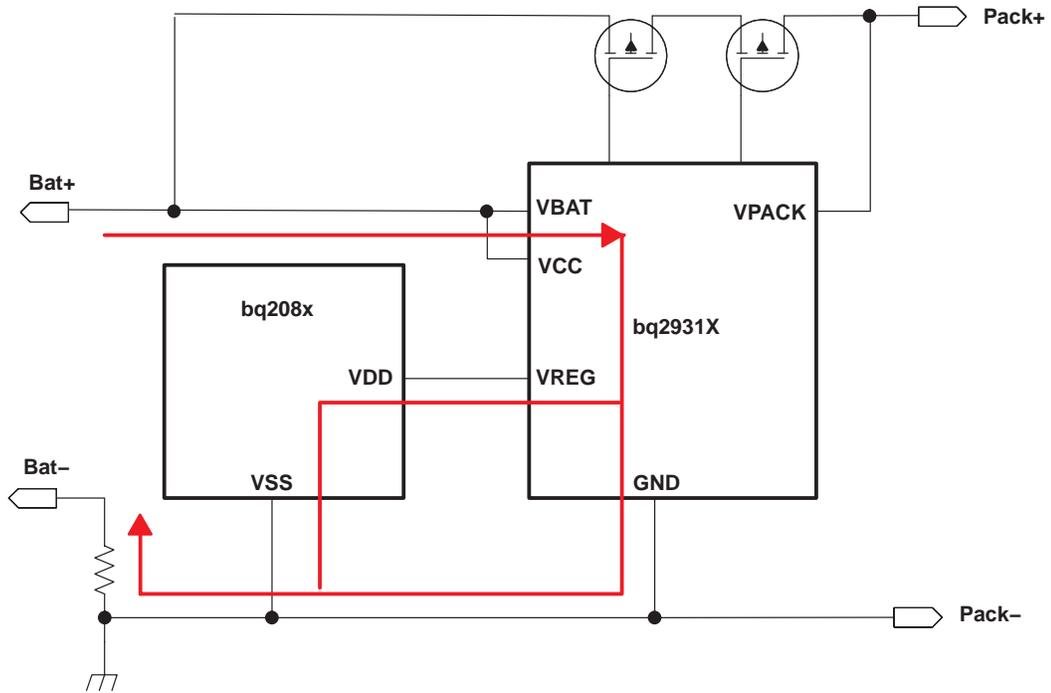


Figure 2. Measuring Board Offset With Power on Bat+ and Bat- Introduces Error From IC Operation Current

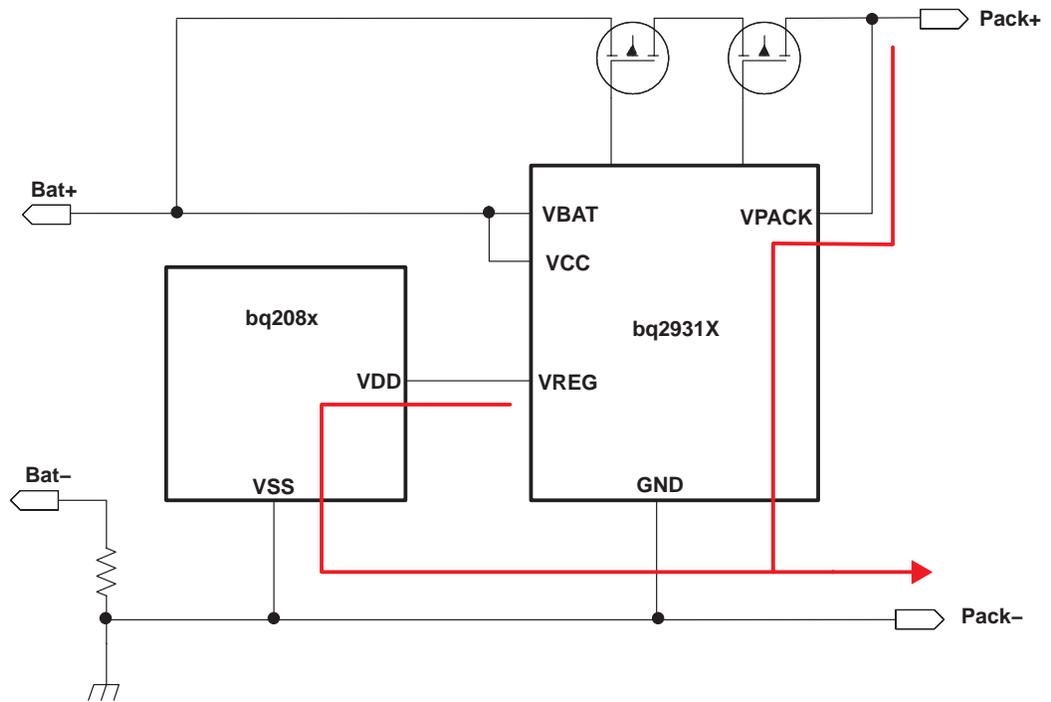


Figure 3. Powering ICs From Pack+ and Pack- Allows the IC Current to Bypass the Sense Resistor

It is also recommended to take at least 10 boards for board-offset characterization, and make at least 5 measurement samples on each board. Of course, more samples always yield better data quality. Table 1 is an example of offset collected from bq2083/bq29311 gas gauge board using EVSW. As the data shows, there are variations from board to board, and even on repeated measurements on each board. The average of all the numbers is calculated and programmed into **Board Offset** data flash location.

Table 1. Example of Data From Bench Characterization of Board Offset

	1	2	3	4	5	TOTAL	AVERAGE
1	12	14	8	14	7	55	11
2	11	13	-3	7	6	34	6.8
3	7	-4	-3	14	7	21	4.2
4	-6	-3	6	2	3	2	0.4
5	12	16	8	0	9	45	9
6	16	17	9	11	19	72	14.4
7	11	10	10	13	5	49	9.8
8	10	3	0	14	3	30	6
9	2	7	6	3	1	19	3.8
10	3	15	16	4	13	46	10.2
Total σ							6.14
TOTAL AVERAGE							7.56

In addition to the mean value, the standard deviation of the board offset also needs to be calculated to cover the variance of the offset. Standard deviation (σ) is a statistic measurement of how spread out the distribution is. It is defined as

$$\sigma^2 = \frac{\sum(x - \mu)^2}{n}$$

where μ is the mean and n is the number of samples. Microsoft™ Excel uses function *stdev()* to calculate standard deviation. Input all the numbers into this function.

Digital Filter, also referred to as **Deadband**, is a programmable parameter in bq208x to prevent false signal detection with no charge or discharge current through the sense resistor. Gas gauge does not measure charge or discharge counts below this threshold. This threshold needs to be selected based on the standard deviation of the board offset. So, how do we link the standard deviation to the program value of **Digital Filter**?

Typically, offset distribution can be described as Gaussian distribution, shown in Figure 4. The Y axis represents the probability density function, and x is the offset measurement with mean normalized to 0. The peak value of the distribution occurs when $X = \text{mean value}$. It is also shown that the probability of the offset having values in a certain range is just equal to the area under the curve of Figure 4 in that range. Our interest is how to program the **Digital Filter** threshold so that the probability of having offset outside the range is statistically small. Table 2 provides the area outside the number of σ . For example, if the **Digital Filter** uses $6x\sigma$, the probability of counting capacity due to board offset is equal to 4.3 ppm. The adopted industry-wide standard for quality control is 6σ and therefore is recommended in this case. Using the data in Table 1 as an example, the **Digital Filter** = $6.14 \times 0.584 \mu\text{V} \times 6 = 21.5 \mu\text{V}$.

For current reporting, bq2083/5 has a fixed 3-mA deadband, while bq2084 has a programmable data flash location **Current Deadband** (DF 0x7b). To avoid reporting current when there is no load, the 6σ value divided by the sense resistor needs to be less than the current deadband. For a 10-m Ω sense resistor, the 6σ needs to be less than 30 μ V.

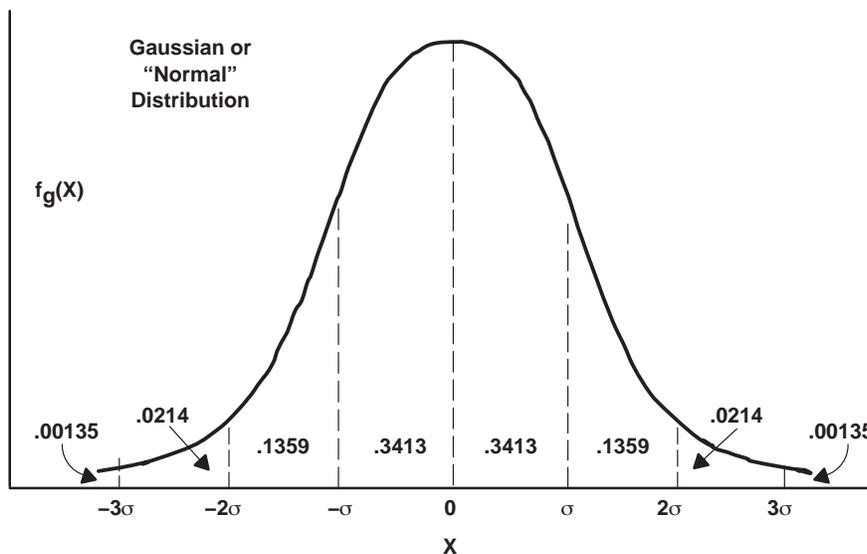


Figure 4. Gaussian Distribution Function

Table 2. Area Outside $\pm K\sigma$ Represents the Probability of $|x|$ Greater than $K\sigma$

K	AREA OUTSIDE $\pm K\sigma$
1	0.317
2	0.046
3	0.003
6	4.3ppm

3 Layout to Minimize Board Offset

PCB layout plays a critical role in reducing board offset and its variants. The most important component is the decoupling capacitor on V_{dda}/V_{ssa}. As shown in Table 3, removing the V_{dda} capacitor increases the offset mean by 5 times, and standard deviation by almost 3 times. Although it may be the worst case scenario, bad component selection and/or bad layout can make the capacitor *disappear* from the circuit for high-frequency noise. To make the decoupling capacitor effective, the ESR (equivalent series resistor) and ESL (equivalent series inductance) need to be small. Ceramic capacitors usually meet this requirement. For high-frequency noise, it is beneficial to parallel a small capacitor, such as 68 pF, with a large-value capacitor like 0.1 μ F, since a small-value capacitor has better high-frequency performance. On the layout side, the designer usually pays greater attention to shorting the trace between the decoupling capacitor and V_{dd}. The connection between the capacitor and V_{ss} is often neglected, although it is equally important, and needs to follow the same guidelines. The bottom line is that ac impedance between the V_{dds} and V_{ssa} needs to be minimized in order to reduce noise coupling.

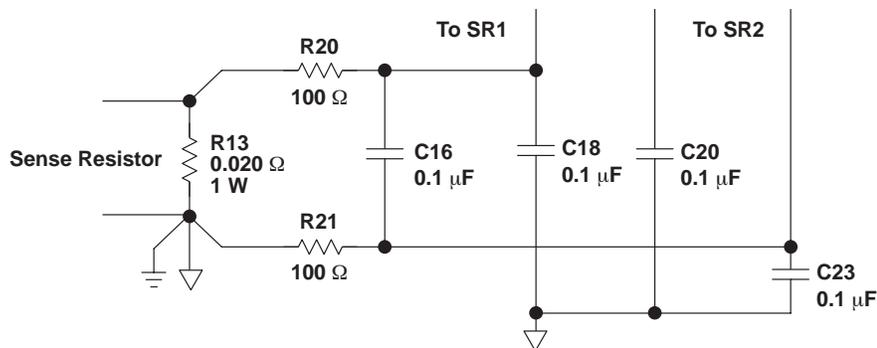
Table 3. Removing the Decoupling Capacitor Increases the Board Offset and its Variance

EVM	1	2	3	4	5	6	7	8	9	10	Mean
Board #1	9	8	9	11	10	9	8	7	8	8	8.78
Board #2	4	4	7	3	8	5	6	8	9	4	6.00
								Mean	7.25	σ	6.38

Vdda cap removed	1	2	3	4	5	6	7	8	9	10	Mean
Board #1	-28	-34	-26	-32	-37	-30	-32	-30	-33	-27	-30.9
Board #2	-40	-43	-42	-30	-37	-41	-24	-36	-45	-44	-38.2
								Mean	-34.55	σ	6.38

The routing between the current sense inputs and sense resistor also requires careful consideration. The key is to prevent any differential signal coupling into the current sense line. The following guidelines need to be followed.

1. Ensure that the current-sense leads to bq208x are good Kelvin connections.
2. Keep the three current-sense decoupling capacitors (C16, C18, and C23 in Figure 5) are very close to bq208x.
3. If the current-sense leads are long, ensure that the 100- Ω resistors (R20 and R21 in Figure 5) are near the IC in a symmetrical pattern with the three capacitors.
4. Route the signals from the sense resistor as a differential pair. Use the same length and number of vias for each line.

**Figure 5. Recommended Decoupling Circuit for Current Sense Lines**

4 Conclusion

Board offset is a common issue in gas gauge design. However, bq208x products provide automatic compensation for its effect, and the value can be programmed for individual design. The bench characterization can yield reliable data for the data flash program. A thoughtful layout provides an even further preventive measure in minimizing the board offset. If the offset still remains an issue, consider checking the CC offset and ADC offset calibration procedure, covered in application note SLVA148.

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