Application Note

ADC Current Sense

AN-CM-291

Abstract

This application note describes how to implement an analog-to-digital converter (ADC) in the SLG46855V to measure current drawn by a load. The correlating ADC code can be read from the counter data via I2C. It also details some accuracy analysis of the read ADC value.

This application note comes complete with design files which can be found in the References section.

Contents

Figures

Tables

1 Terms and Definitions

ADC   Analog to digital converter
DAC   Digital to analog converter
PWM   Pulse width modulation

2 References

For related documents and software, please visit:

https://www.dialog-semiconductor.com/configurable-mixed-signal.

Download our free GreenPAK™ Designer software [1] to open the .gp files [2] and view the proposed circuit design. Use the GreenPAK development tools [3] to freeze the design into your own customized IC in a matter of minutes. Dialog Semiconductor provides a complete library of application notes [4] featuring design examples as well as explanations of features and blocks within the Dialog IC.

[1]   GreenPAK Designer Software, Software Download and User Guide, Dialog Semiconductor

[2]   AN-CM-291 ADC Current Sense.gp, GreenPAK Design File, Dialog Semiconductor

[3]   GreenPAK Development Tools, GreenPAK Development Tools Webpage, Dialog Semiconductor

[4]   GreenPAK Application Notes, GreenPAK Application Notes Webpage, Dialog Semiconductor

[5]   SLG46855V, Datasheet, Dialog Semiconductor.

[6]   AN-1177, Flexible Range ADC with I2C Interface, Application Note, Dialog Semiconductor. https://www.dialog-semiconductor.com/AN-1177.

Author: Gino Castillo, Applications Engineer, Dialog Semiconductor

3   Introduction

In this application note we will describe how to implement an 8-bit analog-to-digital converter (ADC) in the SLG46855V [5] that can sense load current and interface with an MCU via I2C. This design can be used for various current sensing applications such as ammeters, fault detection systems, and fuel gauges.

4   ADC Architecture

The ADC is essentially comprised of an analog comparator and a Digital-to-Analog Converter (DAC). The comparator senses the input voltage vs. the DAC output voltage, and subsequently controls whether to increment or decrement the DAC input code, such that the DAC output converges to the input voltage. The resulting DAC input code becomes the ADC digital output code.

In our implementation, we create a DAC using a pulse-width modulation (PWM) controlled resistor network. We can easily create a precise digitally controlled PWM output using GreenPAK. The PWM when filtered becomes our analog voltage and thus serves as an effective DAC. A distinct advantage of this approach is that it is easy to set the voltages which corresponds to zero code and full scale (equivalently offset and gain) by simply adjusting resistor values. For example, a user wants to ideally read zero code from a temperature sensor with no current (0 µA) corresponding to 4.3 V, and full-scale code at 1000 µA corresponding to 3.9 V (Table 1). This is easily implemented by simply setting a few resistor values. By having the ADC range match the sensor range of interest, we make greatest use of the ADC resolution.

Table 1: Example Code to Current Comparison

Code (Dec)	Current (µA)	V_{SENSE} (V)
0	0	4.3
125	500	4.1
255	1000	3.9

A design consideration for this architecture is that an internal PWM frequency needs to be much faster than the ADC update rate to prevent underdamped behavior of its control loop. At the very least it should be longer than the ADC data counter clock divided by 256. In this design, the ADC update period is set to 1.3312 ms.

5   Internal Circuit

The flexible ADC is based on the design presented in Dialog Semiconductor AN-1177 [6]. The clock speed is increased from 1 MHz to 12.5 MHz in order to clock the ADC counter since the SLG46855 has a 25 MHz clock available. This allows a much faster update rate for finer sample resolution. The LUT clocking the ADC data clock is changed so it will pass through the 12.5 MHz signal when the PWM DFF is low.
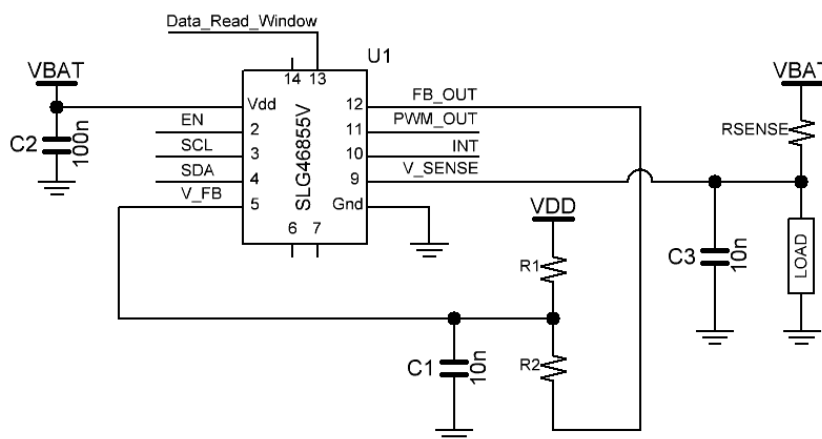
Figure 1: External Circuit Schematic

6   External Circuit

An external resistor and capacitor network are used to convert a PWM into an analog voltage as shown in the circuit schematic in Figure 1. The values are calculated for maximum resolution for the maximum current the device will sense. To achieve this flexibility, we add resistors R1 and R2 in parallel to VDD and ground. A resistor divider divides down VBAT to the low side of voltage range. The divider ratio for an expected minimum VBAT can be solved using the following equation:

Equation 1:

$$Divider = 1 - \frac{I_{MAX} \times R_{SENSE}}{V_{BAT\ MIN}}$$

7   I2C Read Instructions

Table 1 describes the I2C command structure to read back the data stored in CNT0. The I2C commands require a start bit, control byte, word address, read bit, and stop bit.

Table 2: I2C Structure

Information	Data (Hex)
Start Bit	[
Control Byte/Slave Address	0x10 (Write); 0x11 (Read)
Word Address/CNT0 Counted Value	0xA5
Read Bit	R
Stop Bit	]

An example I2C command to read back the CNT0 counted value is written below:

[0x10 0xA5] [0x11 R]

The counted value that is read back will be the ADC code value. As an example, an Arduino code is included in the ZIP file of this application note on Dialog's website.

8   Results

To test the accuracy of the ADC current sense design, the measured values at a given load current and VDD level were compared to a theoretical value. The theoretical ADC values were calculated with the following equation:

Equation 2:

$$ADC\ Value = \left(1 - \frac{I_{LOAD} \times R_{SENSE} - V_{BAT} + V_{BAT} \times Divider}{V_{BAT} \times (Divider - 1)}\right) \times 256$$

The I_{LOAD} that correlates with an ADC value is found with the following equation:

Equation 3:

$$I_{LOAD} = \frac{V_{BAT}\ (Div - 1)\left(1 - \frac{ADC\ Value}{256}\right) + V_{BAT} - V_{BAT} \times Div}{R_{SENSE}}$$

For the following results I used these component values:

Table 3: Component Values for Test Circuit

Component	Nominal Value	Measured Value
R_{SENSE}	400Ω	381Ω
R_1	10kΩ	11.87kΩ
R_2	100kΩ	89.94kΩ
R_{LOAD}	50kΩ (potentiometer)	N/A
C_1	10nF	9.26nF
C_2	10nF	9.47nF

The resolution of the ADC value to I_{LOAD} conversion can be calculated by using equation 3 with the measured values in Table 2 and the ADC value set to 1. With a V_{BAT} of 3.9 V the resolution is 4.96 µA/div.

In order to optimize the ADC current sense circuit to a minimum VDD level of 3.6 V with a maximum current of 1100 µA and a 381 Ω sense resistor, the ideal divider coefficient would be 0.884, based on equation 1. With the values given in Table 2, the actual divider has a divider coefficient of 0.876. Since this is slightly less, it will allow for a slightly larger load current range so the ADC values are close to the full range but will not overflow. The actual divider value is calculated with the following equation:

Equation 4:

$$Divider = \frac{R2}{R1 + R2}$$

Below are the measurements taken of the circuit at three voltage levels: 4.3 V, 3.9 V, and 3.6 V. Each level displays a graph displaying the difference between the measured and theoretical ADC values. Theoretical values are rounded to the closest whole integer. There is a summary graph to compare the differences at the three voltage levels. Afterwards there is a graph displaying the correlation between the theoretical ADC values and load current at the different voltage levels.
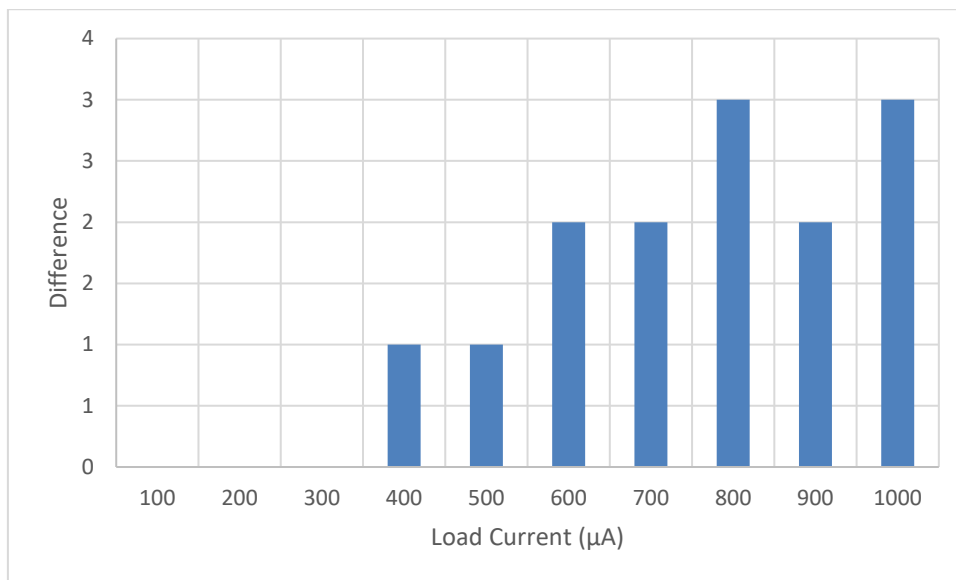
ADC Current Sense

Figure 2: Difference Between Measured and Theoretical ADC Values, VDD = 4.3 V

Table 4: Measured Values with VDD = 4.3 V

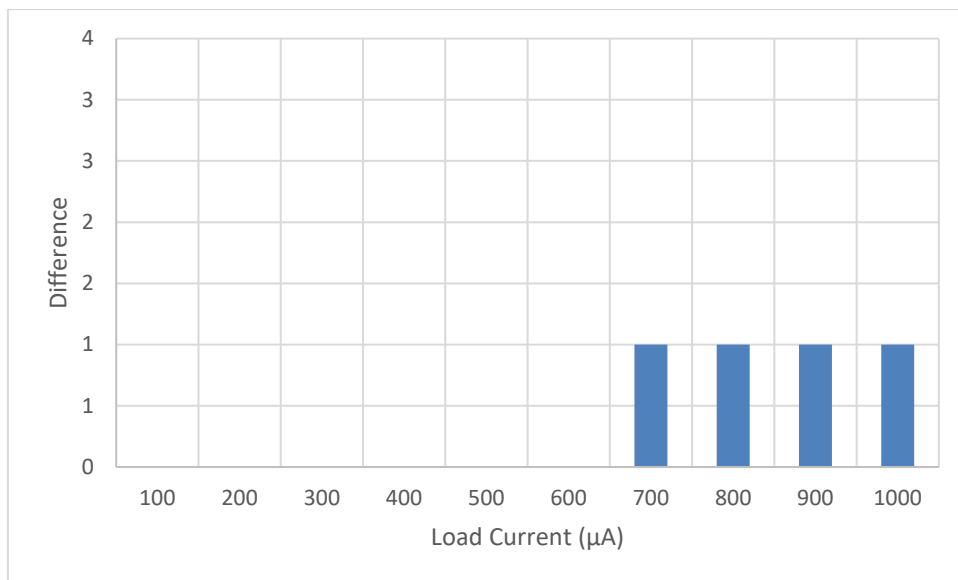| Load Current (µA)	ADC Code Measured	ADC Code Theoretical	Difference	Expected V_{SENSE}
100	18	18	0	4.2619
200	37	37	0	4.2238
300	55	55	0	4.1857
400	74	73	1	4.1476
500	93	92	1	4.1095
600	112	110	2	4.0714
700	130	128	2	4.0333
800	149	146	3	3.9952
900	167	165	2	3.9571
1000	186	183	3	3.919

ADC Current Sense

Figure 3: Difference Between Measured and Theoretical ADC Values, VDD = 3.9 V

Table 5: Measured Values with VDD = 3.9 V

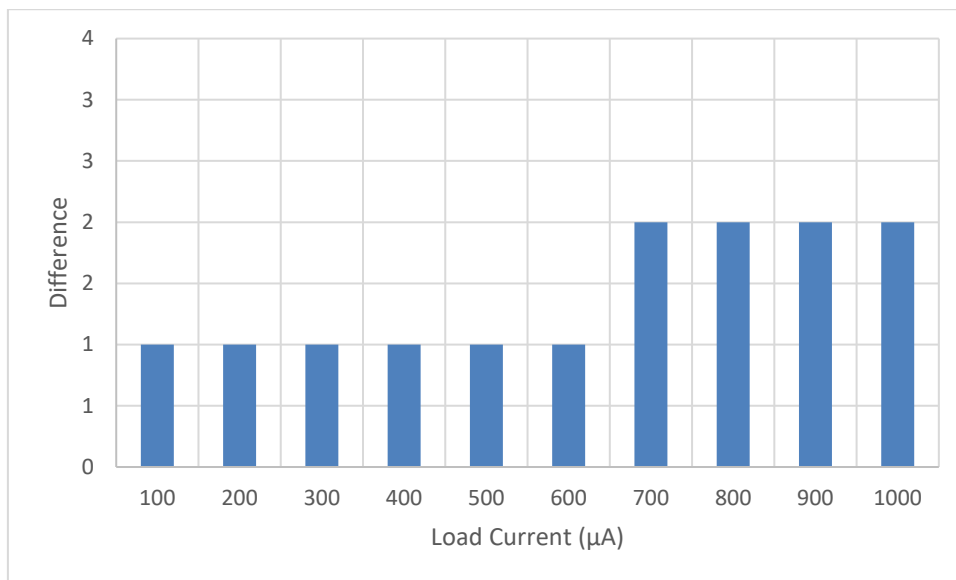| Load Current (µA)	ADC Code Measured	ADC Code Theoretical	Difference	Expected ACMP VIN
100	20	20	0	3.8619
200	40	40	0	3.8238
300	61	61	0	3.7857
400	81	81	0	3.7476
500	101	101	0	3.7095
600	121	121	0	3.6714
700	142	141	1	3.6333
800	162	161	1	3.5952
900	183	182	1	3.5571
1000	203	202	1	3.519

Figure 4: Difference Between Measured and Theoretical ADC Values, VDD = 3.6 V

Table 6: Measured Values with VDD = 3.6 V

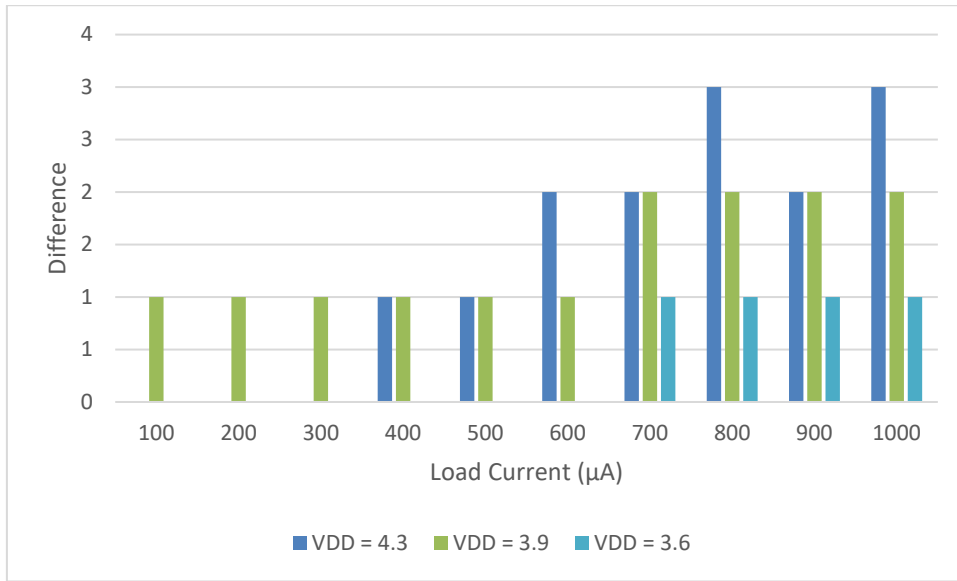| Load Current (µA)	ADC Code Measured	ADC Code Theoretical	Difference	Expected ACMP VIN
100	23	22	1	3.5619
200	45	44	1	3.5238
300	67	66	1	3.4857
400	88	87	1	3.4476
500	110	109	1	3.4095
600	132	131	1	3.3714
700	155	153	2	3.3333
800	177	175	2	3.2952
900	199	197	2	3.2571
1000	221	219	2	3.219

Figure 5: Summary Graph of Differences between Measured and Theoretical ADC Values
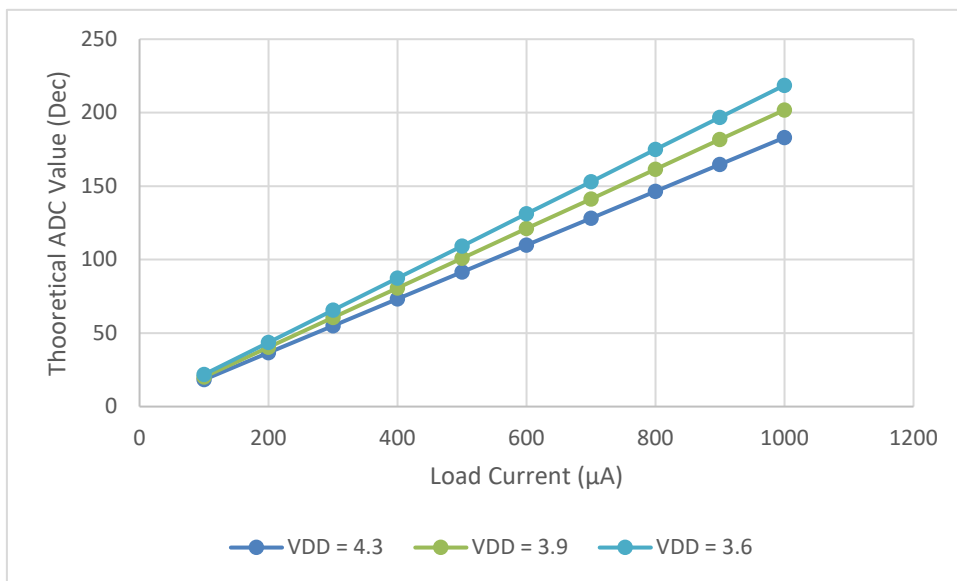

Figure 6: Graph of Correlation between Theoretical ADC values and Load Current

9   Conclusions

The device was tested at three voltage levels: 3.6 V, 3.9 V, and 4.3 V. The range of these voltages models a full lithium ion battery that discharges to its nominal level. Of the three voltage levels, it is observed that the device typically was more accurate at 3.9 V for the chosen external circuit. The difference between the measured and theoretical ADC values was only 1 decimal value off at load currents of 700 - 1000 µA. At the given voltage range, the measured ADC values were 3 decimal points above nominal conditions at the worst case. Further adjustments to the resistor divider can be made to optimize different VDD voltage levels.

Appendix A

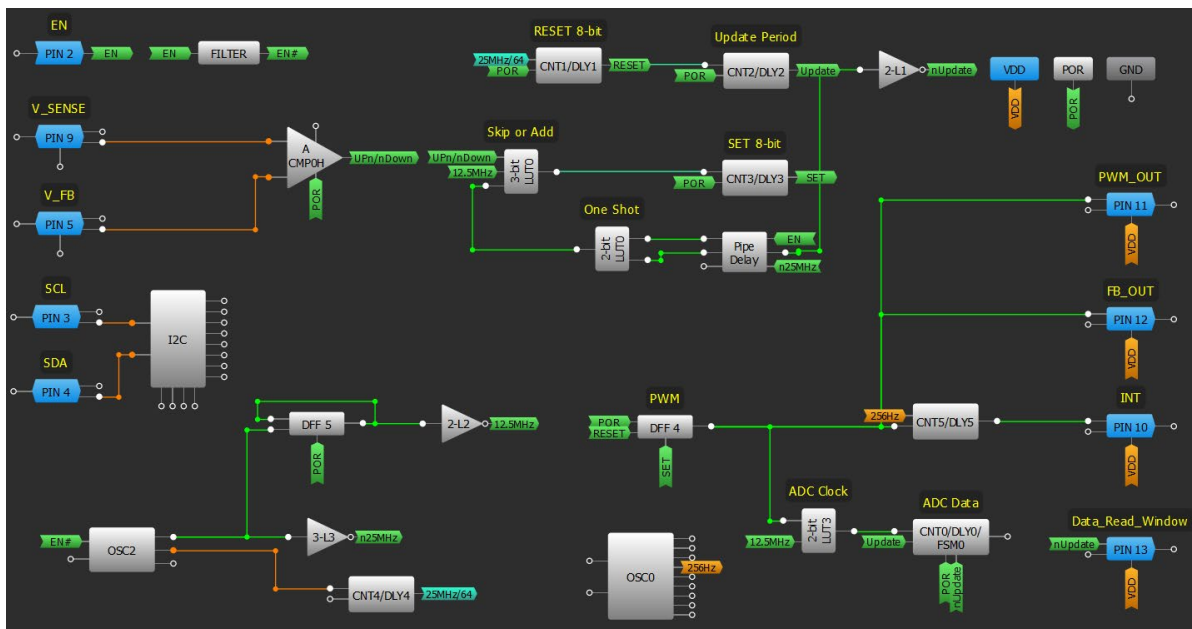**Figure 7: View in GreenPAK Designer**

Revision History

Revision	Date	Description
1.0	23-Oct-2019	Initial version

Status Definitions

Status	Definition
DRAFT	The content of this document is under review and subject to formal approval, which may result in modifications or additions.
APPROVED or unmarked	The content of this document has been approved for publication.

Disclaimer

Information in this document is believed to be accurate and reliable. However, Dialog Semiconductor does not give any representations or warranties, expressed or implied, as to the accuracy or completeness of such information. Dialog Semiconductor furthermore takes no responsibility whatsoever for the content in this document if provided by any information source outside of Dialog Semiconductor.

Dialog Semiconductor reserves the right to change without notice the information published in this document, including without limitation the specification and the design of the related semiconductor products, software and applications.

Applications, software, and semiconductor products described in this document are for illustrative purposes only. Dialog Semiconductor makes no representation or warranty that such applications, software and semiconductor products will be suitable for the specified use without further testing or modification. Unless otherwise agreed in writing, such testing or modification is the sole responsibility of the customer and Dialog Semiconductor excludes all liability in this respect.

Customer notes that nothing in this document may be construed as a license for customer to use the Dialog Semiconductor products, software and applications referred to in this document. Such license must be separately sought by customer with Dialog Semiconductor.

All use of Dialog Semiconductor products, software and applications referred to in this document are subject to Dialog Semiconductor's Standard Terms and Conditions of Sale, available on the company website (www.dialog-semiconductor.com) unless otherwise stated.

Dialog and the Dialog logo are trademarks of Dialog Semiconductor plc or its subsidiaries. All other product or service names are the property of their respective owners.

Contacting Dialog Semiconductor

United Kingdom (Headquarters)
Dialog Semiconductor (UK) LTD
Phone: +44 1793 757700

Germany
Dialog Semiconductor GmbH
Phone: +49 7021 805-0

The Netherlands
Dialog Semiconductor B.V.
Phone: +31 73 640 8822

Email:
enquiry@diasemi.com

North America
Dialog Semiconductor Inc.
Phone: +1 408 845 8500

Japan
Dialog Semiconductor K. K.
Phone: +81 3 5769 5100

Taiwan
Dialog Semiconductor Taiwan
Phone: +886 281 786 222

Web site:
www.dialog-semiconductor.com

Hong Kong
Dialog Semiconductor Hong Kong
Phone: +852 2607 4271

Korea
Dialog Semiconductor Korea
Phone: +82 2 3469 8200

China (Shenzhen)
Dialog Semiconductor China
Phone: +86 755 2981 3669

China (Shanghai)
Dialog Semiconductor China
Phone: +86 21 5424 9058