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1 Introduction

This document provides instructions for using the range zooming technique to compensate for a high offset in the input signal for the ZSC31150 or ZSSC3138 Sensor Signal Conditioner (SSC) ICs. It describes the configuration parameters and calibration procedures using the ZSC31150 Evaluation Kit as an example and gives an example of a memory configuration that can be directly programmed into the ZSC31150 registers. Comparable procedures can be performed for the ZSSC3138 using the ZSSC313x Evaluation Kit. Several of the configuration steps can be performed on the desktop using the kit.

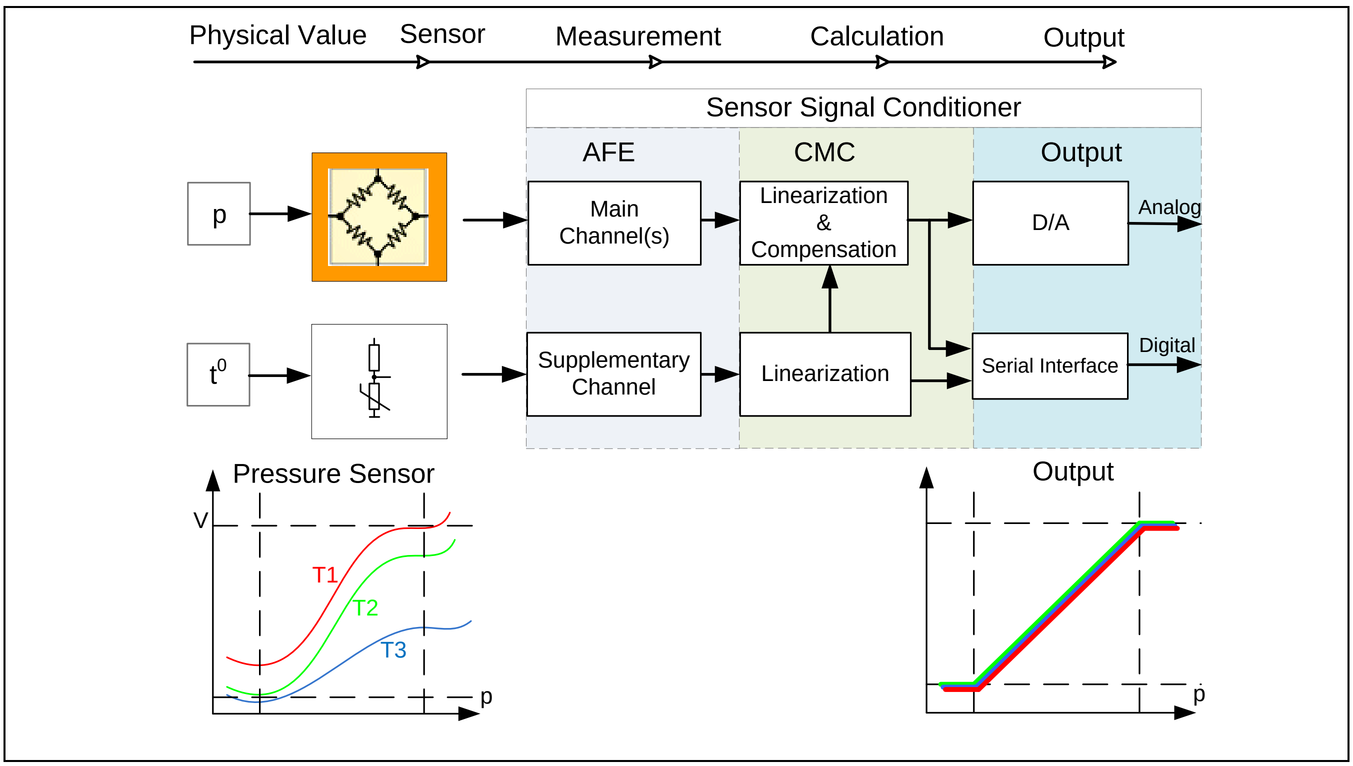
The focus is on compensating large offsets of non-calibrated and temperature-compensated sensor elements (no trimming or external components), such as low-cost pressure cells. A sensor offset is the actual deviation of the output signal from 0 when no mechanical force is applied to the sensor.

This document describes an example of an application for a measurement system with resistive sensor bridges (piezoresistive MEMS, thin/thick film on ceramic/steel, strain gauge elements, etc.). This reference application demonstrates several modifications that are possible for adapting an application to different sensor requirements.

In general, IDT's SSC ICs are used for sensor signal amplification, digital compensation, and linearization of the sensor's non-linearity and temperature dependence, which fits perfectly with the requirements of piezoresistive and ceramic thick-film-based sensor elements as well as strain gauges.

Reading the data sheet, functional description, and evaluation kit description documents for the ZSC31150 or ZSSC3138 before using these procedures is strongly recommended.

Figure 1.1 SSC Block Diagram and Signal Flow for Pressure Sensor Example



2 Offset Compensation

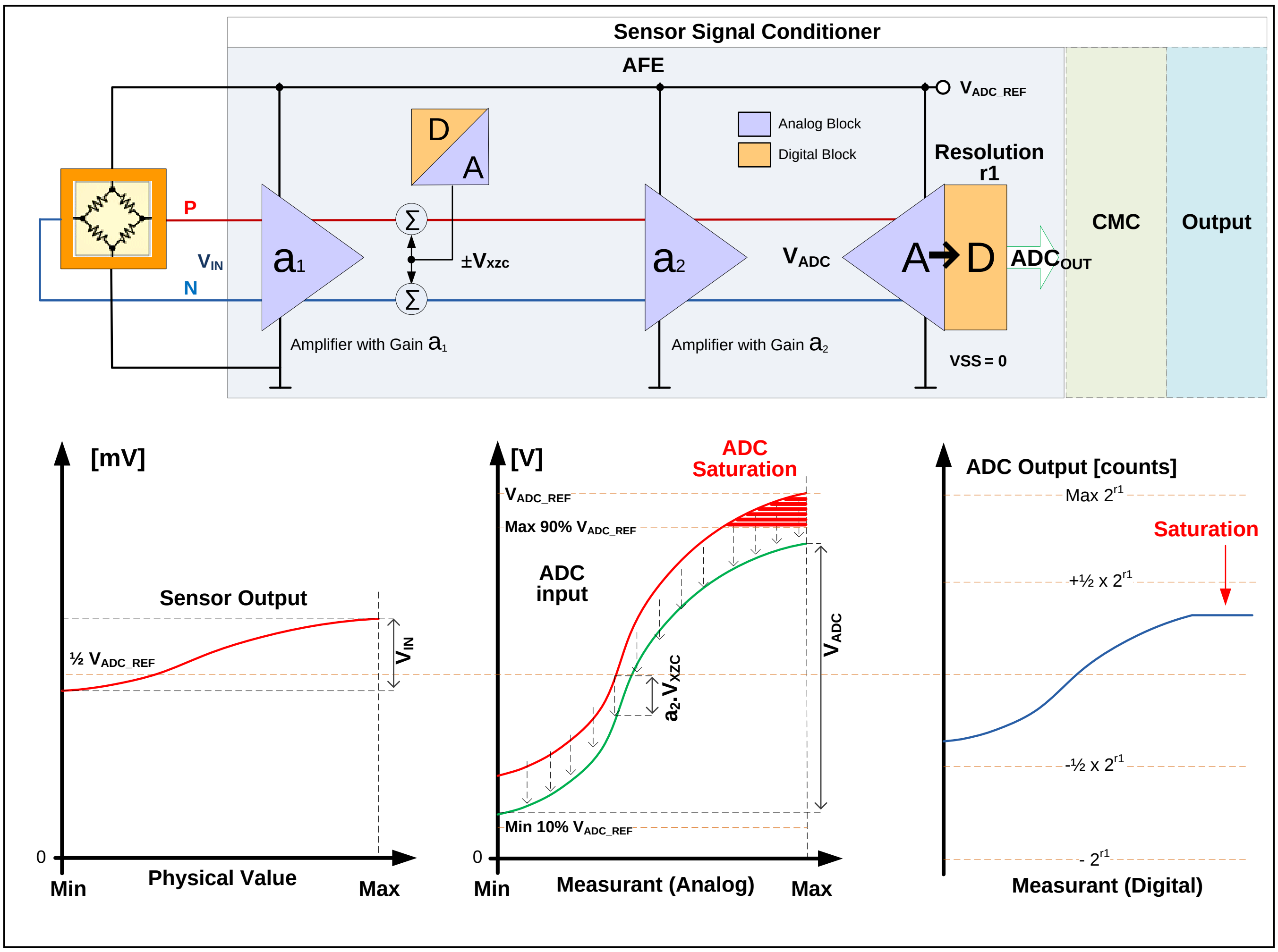
There are different techniques for sensor offset compensation at the analog front end (AFE) stage of an SSC as described in this section.

2.1 Analog Offset Compensation

For comparison, Figure 2.1 shows an analog offset compensation performed by adding a voltage to the signal path (r = ADC resolution). This is a very effective, but costly, method that demands higher gaining and piece-wise calibration of the SSC.

The analog compensation is used for large sensor offset values (up to a maximum of approximately 300% of span, depending on the gain adjustment), which would overdrive the analog signal path if the gain is uncompensated.

Figure 2.1 Analog Offset Compensation

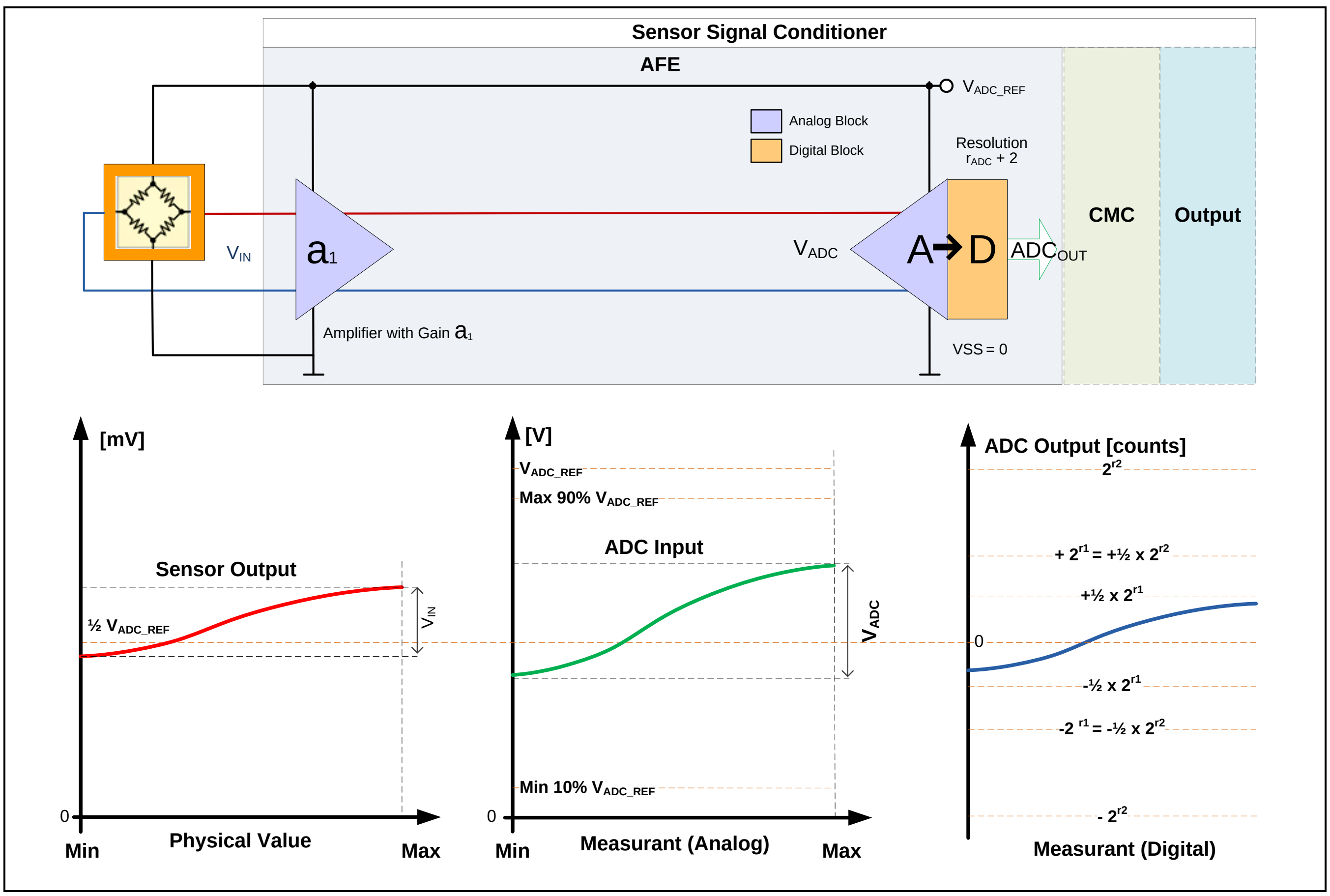


2.2 Range Zooming

Range zooming is an alternative to the analog compensation method described in section 2.1. Range zooming achieves the same or better ADC output signal resolution without requiring complex analog hardware. This is realized by using a higher ADC resolution, lower gain, and a selected segment (zooming) of the ADC output. The Evaluation Kit Software allows selecting a segment of the input signal.

This selected segment should contain the input signal range within certain limits and have a span that will not cause a math saturation of the calibration microcontroller (CMC). Therefore it is usually mapped to the output resolution. Selection of the segment depends on where the signal is situated in the selected ADC range and should be determined on an experimental basis. Figure 2.2 illustrates the method.

Figure 2.2 Range Zooming



The lower span of the ADC input signal is compensated with a higher ADC resolution r_2, which should give the same or better digital results and measurement accuracy. For the subsequent example, a gain that is two times lower is compensated with 1 bit more resolution, which gives the same output signal resolution in ADC counts. An advantage of the range zooming is that for inner segments of the signal, the whole segment range can be used without risking saturation of the ADC. For comparison with the analog offset compensation method, the ADC range used is within 10% to 90% of its range.

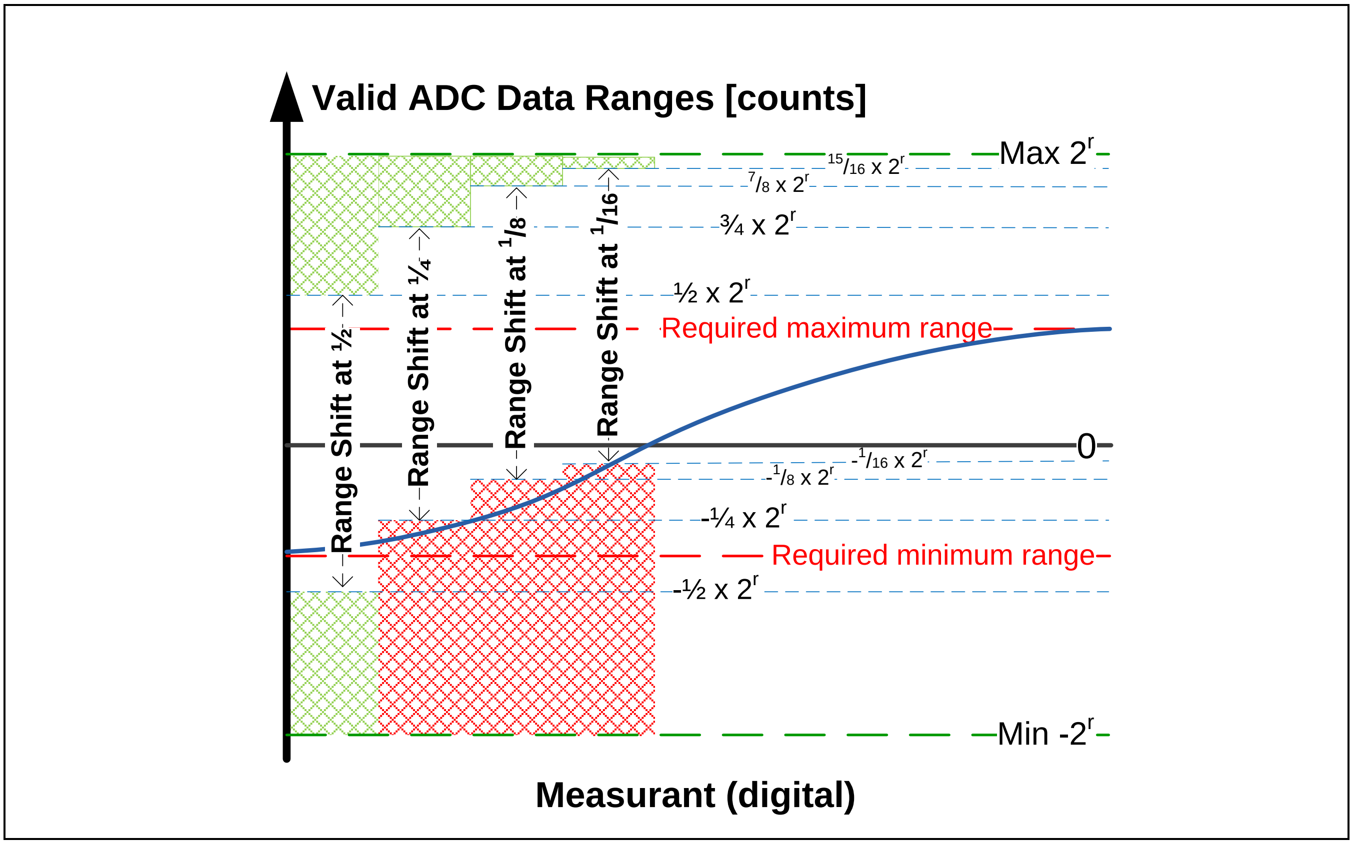
2.3 Range Shift

In both cases discussed in preceding sections, an additional ADC range shift is selected in the ZSC31150 / ZSSC3138 configuration registers to match the sensor signal symmetry. The selected "Range Shift" value of the digital output corresponds to the analog input's common mode voltage (CMV) (the analog ground = ½ V_{ADC_REF}).

The Range Shift selection depends on the sensor signal span, offset, temperature dependency, and tolerances. All these factors should be calculated to determine the most appropriate setting to get the maximum use of the analog signal path.

The example in Figure 2.3 shows a symmetric sensor signal around the common mode voltage (CMV) and the possible Range Shift values that can be used with the ZSC31150 / ZSSC3138 (½, ¼, $^1/_8$, and $^1/_{16}$). The input signal should not saturate the ADC; thus for this example, a Range Shift setting of ½ fits the requirements.

Figure 2.3 ADC Range Shift



Chapter 4 describes the calibration process and calculation of coefficients using the ZSC31150 Evaluation Kit as an example. Refer to the *ZSC31150 Data Sheet* or *ZSSC3138 Data Sheet* for further information regarding ordering the product's Evaluation Kit and accessing available additional documents. Contact IDT at www.IDT.com/go/support for configuration files for range zooming.

3 Range Zooming Procedure

The result of the AD conversion ADC_{OUT} (i.e., the Z_{CORR} used in the formulas below), which is the input value for further signal conditioning by the CMC, depends on the resolution selection $\mathbf{r_{ADC}}$ ranging from 13 to 16 bit resolution. Measurement data acquired with resolutions of 15 and 16 bits must be mapped to the 13 or 14 bit resolution range for further calculations:

- CMV, SSC+, and SSC- measurements are always shifted to 13 bits (see the *ZSC31150 Functional Description* or *ZSSC313x Functional Description* for further information on these measurements).
- Temperature measurement data are divided by 4.
- Sensor data should have a 14-bit or slightly higher delta span within the +/- 215 range (see Table 3.1), corrected by subtraction of the offset selected in configuration register CFGAPP:POFFS (segment selection). See the *ZSC31150 Functional Description* or *ZSSC313x Functional Description* for further information about programming registers.

AD conversion result segmentation calculation (only if r_{ADC} = 15 or 16 bit)

$$Z_{CORR\_OUT} = Z_{CORR\_IN} - POFFS \cdot 2^{13}$$

with segment selection by POFFS $\in$ [0; 7]

$$Z_{CORR\_T} = \frac{Z_{CORR\_TIN}}{4}$$

r_{ADC}	Resolution of AD conversion
Z_{CORR_IN}	Raw main channel A/D result for measured value (auto-zero compensated; $D8_{HEX}$ and $D9_{HEX}$ commands)
Z_{CORR_OUT}	Raw main channel A/D result for measured value (auto-zero compensated) mapped in range per Table 3.1
Z_{CORR_TIN}	Raw temperature input A/D result for measured value (auto-zero compensated)
Z_{CORR_T}	Raw temperature A/D result for measured value (auto-zero compensated) mapped in range [-2^{14}; 2^{14})

Table 3.1 Valid Data Ranges in Counts for 15-bit and 16-bit ADC Resolution

ADC Resolution	Range Shift	1/2		3/4		7/8		15/16	
	Data	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**
16 bits	Z_{CORR_IN} ($D8_{HEX}$ and $D9_{HEX}$ commands)	-32768	32767	-16384	49151	-8192	57343	-4096	61439
15 bits		-16384	16383	-8192	24575	-4096	28671	-2048	30719
16 bits	Z_{CORR_OUT}	-32768	32767	-16384	32767	-8192	32767	-4096	32767
15 bits		-16384	16383	-8192	24575	-4096	28671	-2048	30719

The ZSC31150's user-accessible configuration registers can be programmed as needed to meet the application performance requirements given in Table 3.2, which are needed when using range zooming. For the complete list of the ZSC31150 commands, refer to the *ZSC31150 Functional Description*.

Table 3.2 Application Performance Parameters for Range Zooming with the ZSC31150

Parameter	Min	Max	Unit
Signal Reference	Sensor Supply	Supply Voltage	V
Signal Symmetry	1/2	15/16	Supply Voltage
Resolution	13	16	Bits
AFE Gain	2.8	420	
Segmentation	1	8	ZSC31150 Evaluation Kit Software segmentation index

4 Calibration using the Range Zooming Function

The task of configuration is to setup the AFE according to the sensor signal requirements and correctly select the segment so that the data comply with the requirements given in section 3.

4.1 Data Ranges (16 Bit)

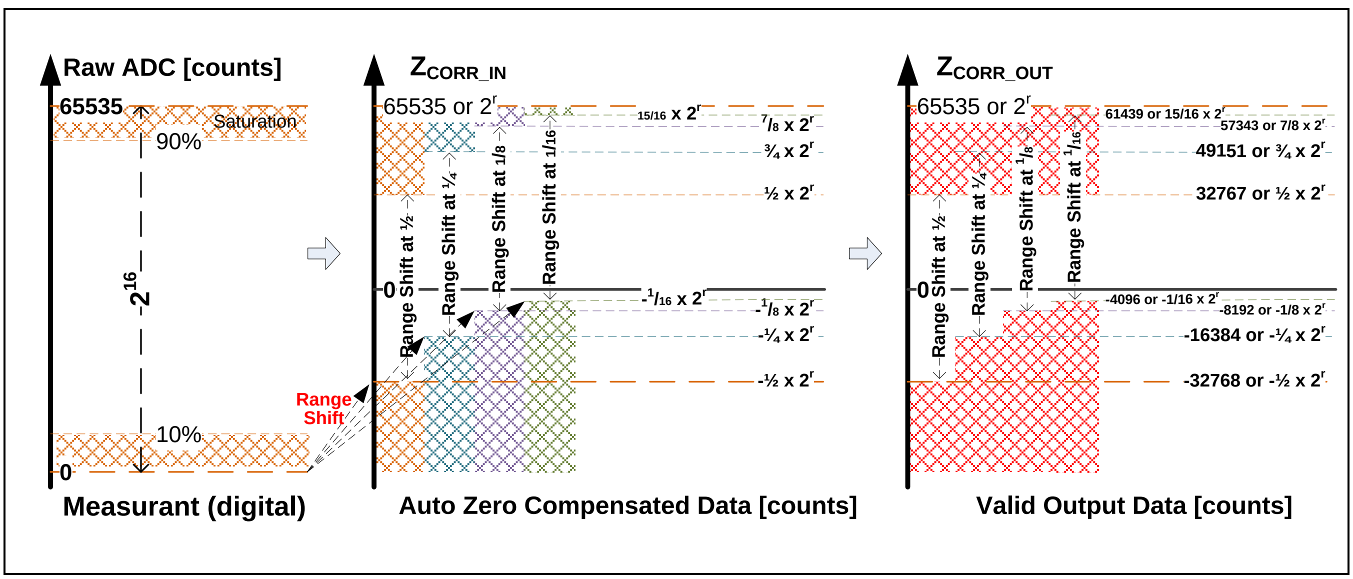
Depending on the Range Shift selected, the result of the ADC can range as wide as -32768 to 61439 counts (see Table 3.1) when using 16-bit resolution. However if the output data value (Z_{CORR_OUT}) is greater than 32767 counts (2^{15}), this will result in a negative read-out value and the wrong analog output voltage during normal operation (NOM). The solution in this case would be to use a greater segmentation index or lower the gain.

Another limitation occurs if the raw ADC data (acquired by $D0_{HEX}$ and $D1_{HEX}$ commands) is outside of the recommended 10% to 90% ADC limits. Outside these limits, the ADC might be saturating or outputting a non-linear response as illustrated in Figure 4.1.

The delta range of the input signal (the difference in counts between the minimum and maximum acquired data corresponding to the sensor minimum and maximum output voltage) must have 14-bit (16384 ADC counts) or slightly higher resolution. This is needed in order to avoid math overflow and proper calibration coefficients calculation by the CMC.

The process of auto-zero compensation removes any residual offset of the AFE. The output data results from subtraction between the raw data and the measured auto-zero value. For a detailed explanation and formulas regarding this signal conditioning, refer to the data sheet for the product.

Figure 4.1 ADC Ranges



4.2 Calibration Procedure

During the calibration procedure, the appropriate calibration coefficients are determined in order to match the user requirements. Calibration can be done using the Evaluation Kit Software. The signal conditioning is performed by polynomial equations. Based on the coefficients for this equation, the CMC calculates the linearization and temperature compensation of the sensor signal.

The calibration coefficients result from solving the calibration formula for a specified set of calibration points as illustrated in Figure 4.2. An equation solver is provided by a .DLL file to support this step of the procedure. The .DLL file is included in the Evaluation Kit and is also available upon request.

Based on user requirements defining the quality of signal linearization and temperature compensation, an appropriate calibration approach should be defined in order to select the calibration points.

A given calibration point (Zp) corresponds to a defined sensor input signal, its user-required output signal (Z), and a temperature value (T). One raw measurement value must be logged for each required calibration point. From the raw measurement values, the coefficients are calculated by the equation system based on the calibration formula. A practical procedure is organized into the basic steps listed in Table 4.1.

Figure 4.2 Selection of Calibration Points

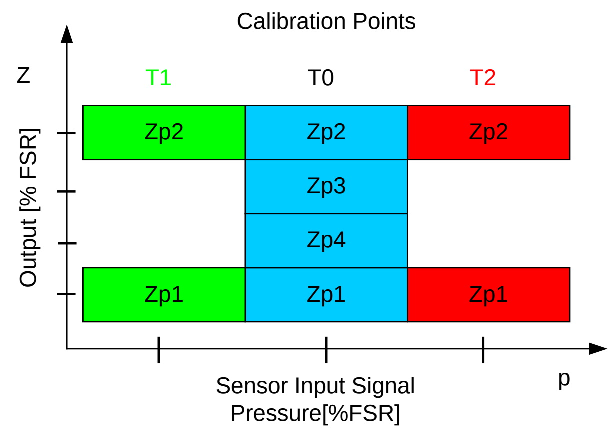
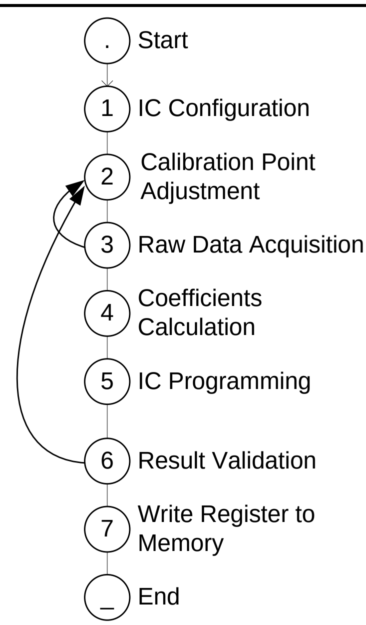


Table 4.1 ZSC31150 Calibration Procedure Main Steps

1. Determine the basic configuration and program in RAM registers.
2. Adjust the sensor signal and temperature (if required) to match the calibration point
3. Acquire raw measurement data
4. Calculate coefficients (based on the calibration formula supported by the .DLL file).
5. Program the calculated coefficients into EEPROM or/and RAM.
6. Activate the Normal Operation Mode and validate the calibrated output signal measurement result.
7. Program the calculated coefficients into the non-volatile memory.



A summary showing the interactions of the basic steps is given in Table 4.2. Before starting with the calibration procedure, a base configuration must be programmed in the RAM registers to setup all the registers. The base configuration of the ZSC31150 is non-calibrated.

The hardware setup of the AFE is taken into account during the calibration, so any later changes of the AFE configuration (e.g., gain, ADC resolution, range shifts) will require new calibration coefficients.

Table 4.2 gives an overview of possible calibration options. The necessary calibration points and the required coefficients are listed and marked with a "✓." The higher the required grade of signal linearization or temperature compensation, the more calibration points and coefficients (c_x) are necessary to calculate the ZSC31150 coefficients.

Table 4.2 ZSSC3xxx Calibration Alternatives and Coefficients

Sensor Signal Linearization Grade	Temperature Compensation Grade	Calibration Temperature	Calibration Points				Coefficients							
			Zp1	*Zp2*	*Zp3*	*Zp4*	c0	c1	c2	c3	c4	c5	c6	c7
Linear	**None**	**T0**	✓	✓			✓	✓						
2nd Order	**None**	**T0**	✓	✓	✓		✓	✓	✓					
3rd Order	**None**	**T0**	✓	✓	✓	✓	✓	✓	✓	✓				
Linear	**1st Order**	**T0**	✓	✓			✓	✓			✓	✓	✓	
		T1	✓	✓										
2nd Order	**1st Order**	**T0**	✓	✓	✓		✓	✓	✓		✓		✓	
		T1	✓	✓										
3rd Order	**1st Order**	**T0**	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	
		T1	✓	✓										
Linear	**2nd Order**	**T0**	✓	✓			✓	✓			✓	✓	✓	✓
		T1	✓	✓										
		T2	✓	✓										
2nd Order	**2nd Order**	**T0**	✓	✓	✓		✓	✓	✓		✓	✓	✓	✓
		T1	✓	✓										
		T2	✓	✓										
3rd Order	**2nd Order**	**T0**	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
		T1	✓	✓										
		T2	✓	✓										

During the calibration process, the coefficients are calculated and programmed into the RAM and/or EEPROM in their respective registers.

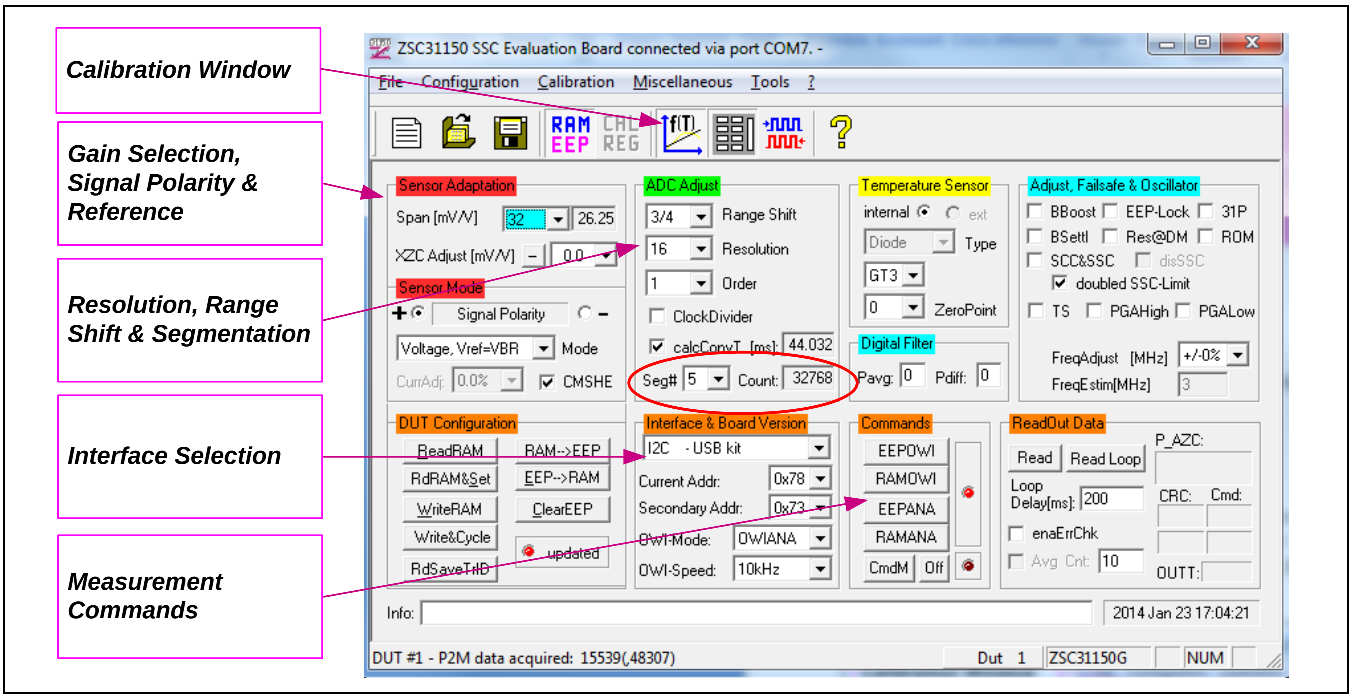
4.3 ZSC31150 Calibration Example

For the example below, a linear (2-point calibration) will be performed for a ceramic-cell sensor with a large offset and small signal span (with a 5V power supply):

- Signal Span: 20mV
- Offset: 100mV

The differential input signal will range from 100mV to 120mV plus temperature variations and tolerances that should also be taken into account. The AFE gain can be calculated roughly as (90%-10%) x VDD / 120mV = 33.3, corresponding to nearest lower gain setting 26.25 (or 32mV/V span) in the ZSC31150 Evaluation Software.

Figure 4.3 ZSC31150 Evaluation Software



AFE Initial Configuration

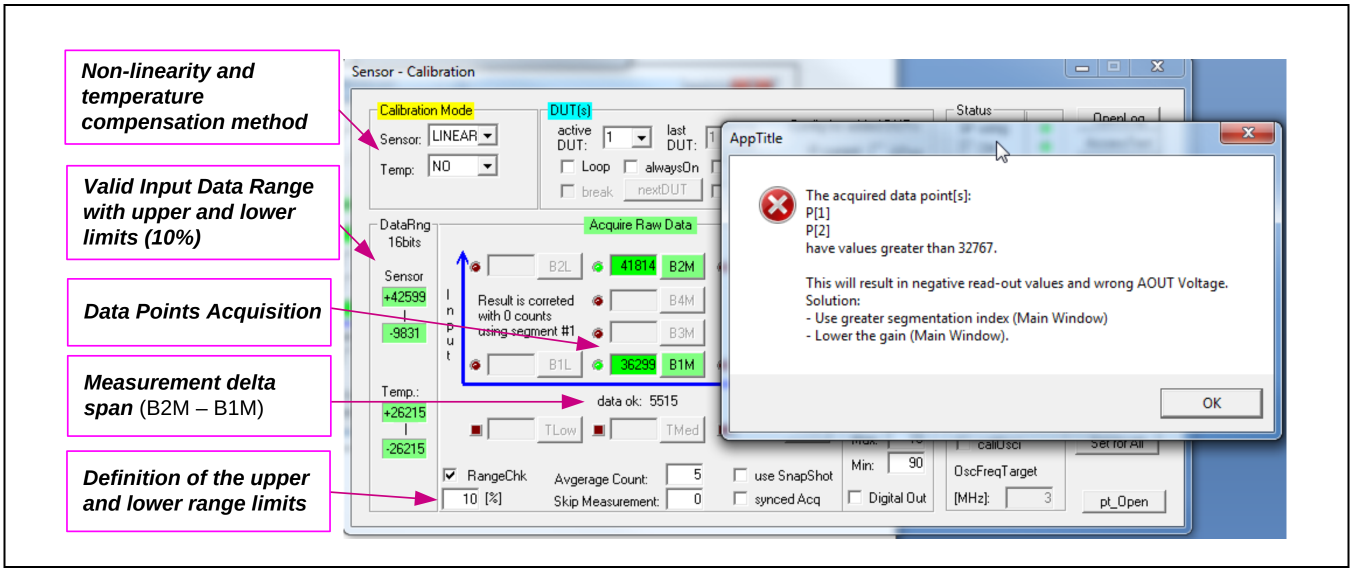
1. Select the proper gain and signal polarity based on the sensor parameters (26.25 for the example).
2. Select the proper “Range Shift” value based on the sensor output signal symmetry (3/4).
3. In the Seg# field, select segment #1 as a starting point (no data correction) and 16-bit resolution.
4. Select one of the USB kit interfaces from the drop down menu.

Note: the sensor can be simulated by using a precise low-noise voltage generator connected to the VINP and VINP pins of the ZSC31150. Shielded or twisted pair cables should be used to avoid noise on the signal.

Raw Data Acquisition

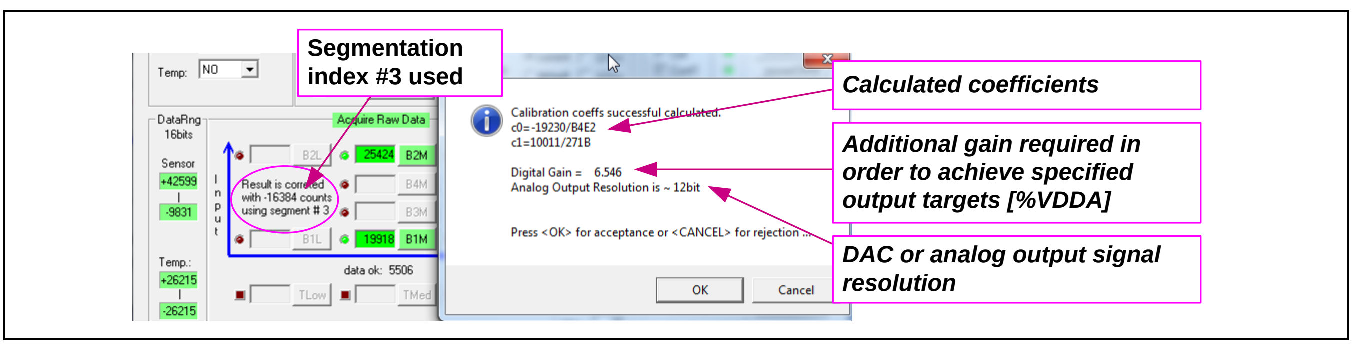
Open the calibration window to start the calibration procedure. The simplest example is a linear calibration based on measurement of two points (sensor minimum and sensor maximum) without temperature compensation of the sensor response. As defined in section 3, the goal is to select data in the -32768 to +32767 range with an approximately14-bit delta span.

Figure 4.4 Calibration Window



1. Acquire measurement data.
2. Adjust the Seg# field to get values into the valid ranges (in this case, select segment #3).
   Note: When using segmentation, the ADC might go into saturation even when the acquired data is within the limits. In this case, a warning will be displayed. Actual uncompensated data can be acquired with the $D0_{HEX}$ and $D1_{HEX}$ commands or via the *Calibration > Get_Raw_Values* window.
3. Re-measure the points.
4. Calculate coefficients and write to EEPROM.

Figure 4.5 Coefficients Calculation



Note: Before coefficient calculation, the output signal should be specified as analog or digital in order to fit the normalized conditioning result to the DAC or serial interface ranges.

5 Output

The main channel output signal is transmitted via the serial interface with resolution of 15 bits or by the analog output as a voltage in the addressable output range of 5% to 95% of the supply voltage. Temperature data is measured only for sensor temperature compensation.

The I^2C™* and OWI interfaces are intended for programming or testing of different configurations. Both interfaces provide access to all data that are transmitted as output.

6 Glossary

Term	Description
ADC	Analog / Digital Converter
AFE	Analog Front-end
CMC	Calibration Microcontroller
CMV	Common Mode Voltage
DAC	Digital to Analog Converter
IC	Integrated Circuit
NOM	Normal Operation Mode

7 Related Documents

Document
ZSC31150 Data Sheet
ZSC31150 Functional Description
ZSC31150 Evaluation Kit Description
ZSSC3138 Data Sheet
ZSSC313x Functional Description
ZSSC313x Evaluation Kit Description

Visit the product page (www.IDT.com/ZSC31150 or www.IDT.com/ZSSC3138) or contact your nearest sales office for the latest version of these documents.

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8 Document Revision History

Revision	Date	Description
1.00	March 10, 2014	First release of document
	April 26, 2016	Changed to IDT branding.

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