Using ZoomingADC to Adapt the ADC to the Sensor, and not the Other Way Around !

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Abstract

There is a wide variety of sensing elements available on the market to accommodate different types of measurements. One thing most of these sensors have in common is that their output signal is less than optimal, and low-cost versions of the sensors introduce quite a large spread of gain and offset variation into the production of a sensing device. A conventional way to overcome this spread is to add amplification ICs and to laser trim the amplification settings before connecting the sensing element to the ADC, or to buy higher cost, more sensitive and better-controlled sensor elements. Another way to overcome the gain and offset variation is to use Semtech's ZoomingADC data acquisition device, which combines the advantages of over-sampled ADCs with an embedded amplification stage to measure low cost sensor elements with the highest resolution.

Introduction

Sensors deliver a voltage signal that can be much smaller than their supply voltage, and this signal often has a significant offset. Acquiring such a signal with a regular Analog-to-Digital Converter (ADC) means either a dramatic waste of resolution or a need for several external components that have to be adapted to the sensor, often through complex and costly calibration algorithms.

The ZoomingADC is a revolutionary product for these applications as it makes acquiring such signals possible without resolution losses and without any external amplifier or offset compensation. Semtech offers the ZoomingADC capability in its XE8801A and XE8805A SoCs that combine the ADC functionality with a microcontroller (MCU) and a preamplifier to support the complete data acquisition process of a sensing application.

Fundamental limitation of the ADC process

Most common sensors, such as temperature sensors or pressure transducers have relatively static signals. This is also the case for more exotic chemical and humidity sensors. In such situations, the measured signal is stable and the main challenge for the ADC is accuracy. This is best handled by over sampled ADCs such as sigma-delta and incremental converters.

The first limitation of an ADC is the quantization error. This is a fundamental limitation of the analog-to-digital conversion process. The normal way to reduce this error is to increase the resolution of the ADC at the price of a longer acquisition time, a higher current consumption, and, most often, a more expensive bill of materials. With a full understanding of the data acquisition process, it is possible to find another solution to that limitation. With ZoomingADC, the full resolution of the ADC can be applied to only part of the signal that is of interest to the sensing application, resulting in a significant increase in the resolution of the measured parameter.

Take, as an example, a chemical sensor with a 5 V or less supply voltage and with an output varying from 1.15 to 1.25 V. Reading it directly with a 10-bit ADC will give a step of 5 mV, or a resolution of 20 points on its output. Amplifying its output by a factor of four will mean an output of 4.6V to 5V, boosting the resolution to 80 points. But with the ZoomingADC focused on just part of that output voltage, the resolution can be increased to 1024 points using just a 10-bit ADC.

Block diagram

The ZoomingADC is the combination of a high-resolution ADC with several programmable gain and offset pre-amplifiers. The gain and offset settings can be made in very fine steps (10%) over a very large range (gain from 0.5 to 1000, offset can be set bigger than the signal input full scale).

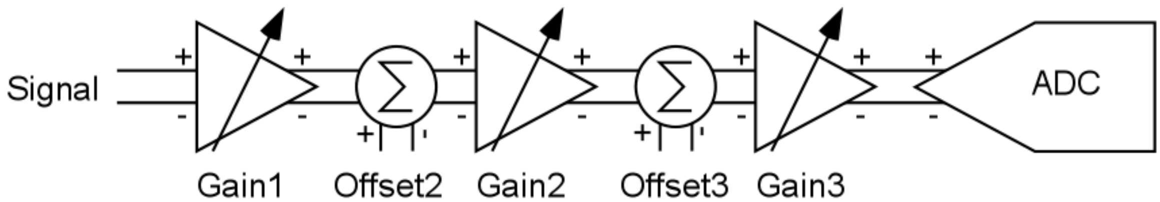


Figure 1: *ZoomingADC*

This very precise setting capability, together with the tight integration of the pre-amplifiers and the ADC, is the key for the extreme signal magnification capability of the ZoomingADC. The ZoomingADC can measure a signal that is 22 bits smaller than its power supply. With such a front end, a design can get signals as small as 1 µV when operating with a 2.4 V voltage supply.

ZoomingADC

The ZoomingADC operates the same way as the zoom on a camera lens: choose which part of the picture to be amplified, adjust the magnification until it fills the screen, and then shoot. In this way the full resolution of the picture frame is dedicated to the desired part of the picture. With the ZoomingADC, the part of the signal that is carrying the information is selected, then amplified and converted to digital with the full resolution of the ADC.

By sharing the gain and offset compensation over three stages, the ZoomingADC makes it possible to compensate for large offsets on small signals without saturation or resolution losses.

An extra feature of the ZoomingADC is the capability to capture single and differential signals. The ZoomingADC is based on a differential signal path, and accommodates single-ended signals with the addition of a controlled offset.

Example with a Wheatstone bridge pressure sensor

Pressure sensors vary in sensitivity from each other requiring external calibration when a final sensing system is assembled.

The Wheatstone bridge is made of four pressure-sensitive resistors. Two of these resistors increase their resistivity when pressure is applied two decrease their resistivity when pressure is applied. The resistors are connected as a bridge, such that when bias voltage (Vb) is applied on one pair of connections, a small differential voltage (Vin) proportional to the applied pressure is measured on the other pair of connections.

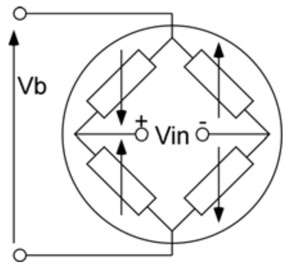


Figure 2: *Sensor's equivalent schematics*

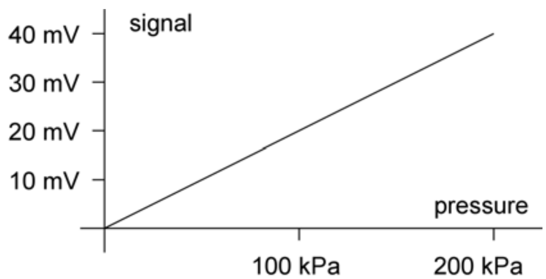


Figure 3: *Sensor's typical Vin signal*

For a Freescale MPX2010, for example, sensor sensitivity is given at 0.2 mV/kPa for a sensor voltage supply of 10 V. This is a compensated sensor, therefore it has a small offset and does not need temperature compensation. A sensor's sensitivity is proportional to its supply voltage and 1 kPa is 10 mbar. Using the sensor on a 3 V battery will result in a sensitivity of 60 μV/kPa or 6 μV/mbar. For a barometer application, the sensor will need to be able to measure pressures between 500 and 1300 mbar.

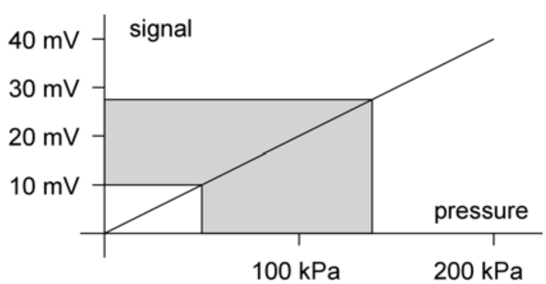


Figure 4: *Interesting part of sensor's signal*

The gain of the zoom must be set as big as possible without saturating the interesting part of the sensor's signal. Therefore, gain must be equal to power supply voltage divided by maximum input swing. In this application, the ZoomingADC's input top limit is 800 mbar or 4.8 mV. According to the 3 V power supply voltage, a gain of 625 could cover the full input range of the ADC that is +/- 1.5 V of the differential signal under this bias condition. A gain of 500 will make covering sensors with gain variations possible.

The offset of the zoom must be set so that the full scale of the signal is in the middle of the ADC input range. As this sensor has a zero output for 0 mbar, one will compensate an offset at mid-scale (900 mbar or 5.4 mV). This offset is compensated before the final gain, otherwise the signal would be saturated. This will be done by setting the offset of the third amplifier to 0.9 (multiplied by the 3 V reference, and divided by the 500 pre-amplification gain, this will cancel 5.4 mV of input offset).

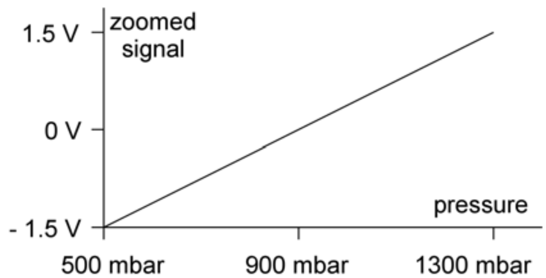


Figure 5: *Zoomed sensor's signal*

The zoomed sensor's signal is then fed into the differential input of the ADC so it can now work with its complete resolution on the interesting part of the signal.

Using this 500 gain, resolution of the 16-bit 3 V referenced ADC referred to the input signal is:

$$\frac{3\ \text{V}}{2^{16} \cdot 500} = 0.09\ \text{uV}$$

This is lower than the noise level of the sensor, therefore the resolution of the ADC is not a limitation of this system anymore.

Setting the zoom

Setting the zoom is as easy as inputting the desired gain and offset. Semtech's XE8000 ZoomingADC-based acquisition devices also feature an MCU and a multiple-time programmable memory (MTP), so setting the zoom is just a matter of inserting a few lines of code.

Taking the above example as reference, the necessary C-code is shown in listing 1.

Listing 1: Setting the ZoomingADC

```
// set parameters
// gain    = 10
#define Gain1 0x01
// gain2   = 10
#define Gain2 0x03
// gain3   =  5
#define Gain3 0x3C
// offset2 =  0
#define Offset2 0x00
//offset3 =  0.9
#define Offset3 0x0C

// build the data structure
ADConfig3.AsField.Pga1Gain = Gain1;
ADConfig2.AsField.Pga2Gain = Gain2;
ADConfig3.AsField.Pga3Gain = Gain3;
ADConfig2.AsField.Pga2Off = Offset2;
ADConfig4.AsField.Pga3Off = Offset3;

// write data in ZoomingADC register
W_RegAcCfg(&ADCongig0, &ADCongig1, &ADCongig3, &ADCongig4, &ADCongig5);
```

This code has been written for the XE8000 ANSI C-compiler. Information about Semtech development tools for the XE8000 series can be found on the Semtech web site at www.semtech.com.

Signal Values in the ZoomingADC

The following table shows the value of the signal inside the zoom and the ADC of the ZoomingADC.

	min	typ	max	unit
pressure	500	900	1300	mbar
Input	3.0	5.4	7.8	mV
S1*	30	54	78	mV
S2*	300	540	780	mV
ADC in	-1.2	0.0	1.2	V
ADC out	E600	0000	6600	16-bits code

*S1 is the output of first amplifier; S2 is the output of the second amplifier.

Table 1: *Signal in the ZoomingADC*

As can be seen from the above table, there is some margin left for sensors that have non-ideal parameters. These will be compensated for after the ADC acquisition in the MCU.

Design example with Microsens MSGS3000 air quality sensor

Low-power air quality sensing is a challenge. Most chemical sensors are not precise and require power hungry heating elements to work. The MSGS3000 sensor developed by Microsens is an example of a part that is ideal for these applications because it has excellent reliability and its heating uses relatively little power because the sensing part is very small.

In this application, an XE8000 with ZoomingADC is used to acquire data from several MSGS3000 sensors. The XE8000 MCU is used to bias the heating element of the sensors with the correct waveform to read each sensor's value, and to send the corresponding data to a PC via an RS-232 link.

Main performance

- Alarm applications:
  - Detection of CO: 0 – 400 ppm
  - Detection of CH_4: 0 – 20% LEL
- Air quality monitoring applications:
  - Measurement of CO: 0 – 100 ppm
  - Measurement of NO_x: 0 – 5 ppm
  - Measurement of VOC: 0 – 100 ppm
  - Measurement of O_3: 0 – 500 ppb
- Pre-calibrated data
- High resolution and linear sensing
- Standard serial RS-232 output
- 8 programmable digital IO
- 2 programmable external interrupts
- In-site programmable
- Single 5 V supply, max 55 mA
- Low power "mW operation" possible
- Miniature: 25 cm^3

Typical applications

Typical applications include:
- laboratory test systems
- indoor air monitoring systems

- environment monitoring
- security
- industrial process control

The low-power capabilities of these sensors make them suitable for remote sensing and stand-alone RF applications. Sensor integration makes this system very low cost compared to previous technologies and miniatures. And the miniaturization of the module makes it portable.

Block diagram

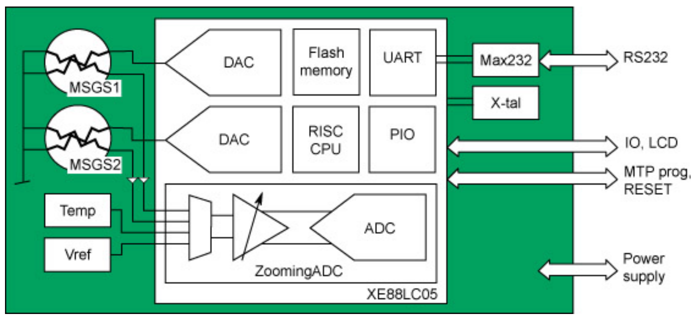


Figure 6: *MGSM3000 schematics*

The MGSM3000 is made of two MSGS3000 gas sensors, one KTY13-5 temperature sensor, one XE8805MI028 sensing MCU, one MAX232 level shifter, one Xtal and one voltage reference.

Both the MSGS3000 and the XE8805 are described below. The system is mounted on a small PCB, with very easy insertion in a bigger modular system.

All of the sensor management is inside the module. Usage of the serial data is highly simplified, so that any RS-232 equipped PC with a monitor program can read the data. One can even program the MCU for direct action via its parallel I/O port.

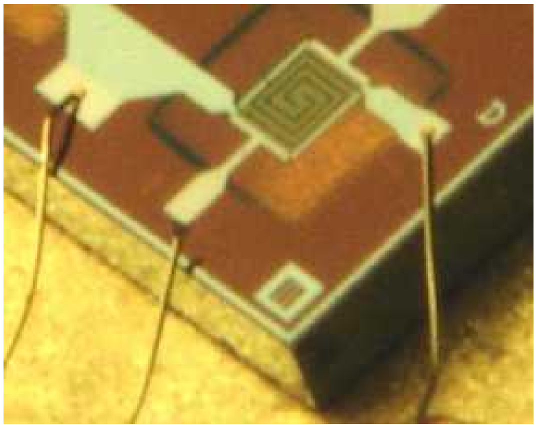
Gas sensing versus air quality monitoring

Gas sensing for alarm systems is based on a few identified gases, and only potentially dangerous conditions have to be detected, whereas air quality monitoring requires much finer detection of a broader range of chemical types.

Looking at the performance tables shows the big differences between alarm applications and air quality monitoring applications. Doing both with the same system requires a sensor with a very large dynamic range and an acquisition device that matches that range. This can be achieved with the state-of-the-art integrated micro-machined sensors of Microsens and the ZoomingADC that is available in Semtech SX8000 series.

MSGS3000 gas sensor

The MSGS3000 gas sensor is made of two resistors built on a thin micro-machined silicon bridge. One resistor, named heater, is used to heat the second resistor, named sensing element, between 50°C and 500°C, depending on the measurement application.



The sensing element resistivity depends on temperature and gas concentration. Reactivity of the sensing element also depends on temperature. Therefore, an acquisition cycle uses multiple temperatures from two sensors to get accurate gas discrimination and gas concentration data.

Sensing element resistivity varies over orders of magnitudes under heating and chemical detection. Impedances between 15 kΩ and 10 MΩ have to be measured.

Extensions capabilities

Thanks to the integration of the ZoomingADC with an MCU in the SX8000 family of SoCs, the MCU can be used for extending the capabilities of the acquisition system. Major uses of the MCU are calibration (automatic or on demand), signal processing, communication, and power supply management.

The sensor parameters can be stored in the MTP (multiple time programmable) memory of the SoC. Other users may prefer to use a small external serial EEPROM (I2C or SPI) for easier access during calibration, or for saving many intermediate measurements.

References

1) SX8724 datasheet, XE8801A datasheet: www.semtech.com

3) MPX2010 datasheet: www.freescale.com

4) MGSM3000 datasheet: www.silsens.ch

About the author

Michel Chevroulet is product group manager for Semtech’s sensing products. Previously, he was a design engineer for the Swiss Centre for Electronics and Microtechnology (CSEM) and a product line manager for XEMICS, which was acquired by Semtech in 2005. Michel has a master degree in physical electronics from the University of Neuchâtel, Switzerland. He can be reached at mchevroulet@semtech.com.