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A Multi-Channel, High-Precision Sensor Interface for Low-Power Applications – ZMD21013

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Abstract: Today's markets are eager for high precision combined with minimum power consumption in almost every technical application area. Detection, processing and analysis of environmental changes have also come to the fore. To address these additional requirements, well-designed sensors and sensor-interface systems are becoming essential for future technologies. To push forward to mobile sensor applications, designers must achieve both lower power consumption and better data accuracy.

To support this demand, ZMD has developed the ZMD21013, a high-precision, low-power resistive sensor interface integrated circuit, which can enable implementing a large variety of sensors in mobile, battery-based applications. The IC provides programmable amplification and analog-to-digital (A/D) conversion of the applied sensor signal with optional temperature and auto-zero measurements. The ZMD21013 is optimized for low voltage and low power resistive sensor bridge applications, such as battery-operated consumer or industrial products. *Copyright © 2008 IFSA.*

Keywords: Sensor interface, IC, Charged-balanced, ADC, Low-power

1. Introduction

The growing demand for gathering diverse information about the analog environment has led to a rapidly increasing use of diverse sensor technologies. Mobility and flexibility are also key criteria for today's applications. As a result, low-power sensor interface ICs are required to enable mobile environmental data gathering. With many years of experience in semiconductor design and manufacture, ZMD has developed the ZMD21013 to meet these market demands (Fig. 1).

The ZMD21013 is a high-precision resistive sensor interface circuit qualified for operating temperatures from -25°C to +85°C. As the cornerstone of ZMD's MUSic™ family, the IC is optimized for multi-channel, low-power, microcontroller-based mobile applications. The ZMD21013 can support a large variety of consumer and industrial applications (e.g., altimeters, barometers, pressure monitoring, compass functions, flow meters, velocity instruments, density meters, etc.). It can also provide additional temperature measurements for these applications.

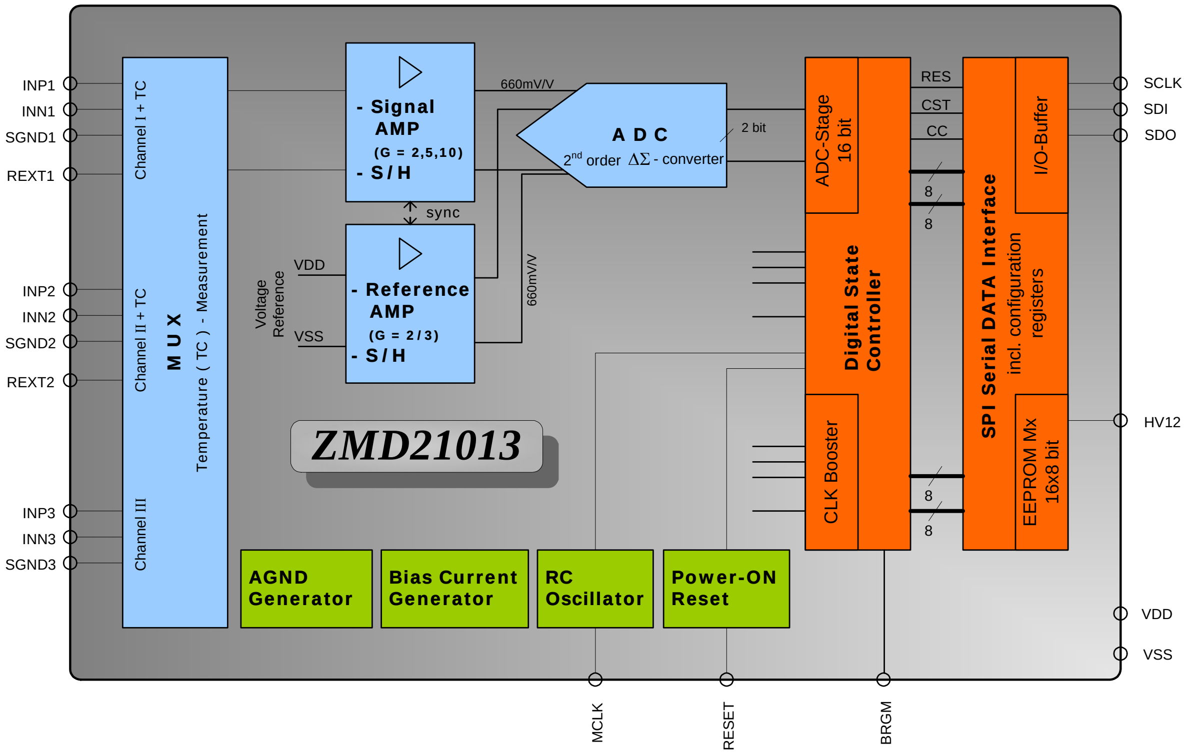

Fig. 1. Functional Block Diagram of the ZMD21013 Low-Power Sensor Interface IC.

The IC's analog sampling architecture achieves a significant reduction of average power consumption due to switched measuring. The applied sensor is only switched on during the sampling time, which leads to a typical average power consumption of 25µW to 30µW. Combined with additional features, low power consumption makes the ZMD21013 the interface device of choice for low-power, sensor-based applications.

By default, the sensor bridges operate in a voltage-driven mode. The ZMD21013's A/D conversion resolution, duration, input range, sensitivity, and measurement mode are programmable. The IC supports an Auto-Zero Mode that allows monitoring of temperature, long-term stability drifts, and offsets. The actual compensation for these must be handled by a connected microcontroller.

The ZMD21013 includes an on-chip clock generator and a 16x8-bit EEPROM to store non-volatile configuration data. An SPI-standard digital interface provides flexible adaptability to the respective external digital system components (e.g., a microcontroller).

2. System Overview

The ZMD21013's high precision combined with ultra-low average power consumption is achieved via a switched measurement procedure. The bridge and the analog processing section of the IC up to the analog-to-digital converter (ADC) are only powered while reading the most significant bits (MSB) portion of the sensor bridge measurement.

Up to three resistive bridge sensors and two additional highly stable TC resistors for temperature measurement can be supported by the ZMD21013 (Fig.2). It is well-suited for mass market applications, such as a three-dimensional compass or a conventional two-dimensional compass with an additional reading (e.g., an altitude (pressure) meter, variometer, accelerometer, density scale, or other type of scale) with additional optional temperature measurements. In general, this single IC can support any system in which the function $f(s_1, s_2, s_3, T_1, T_2)$ is implemented. Here, s_1 to s_3 are readouts of arbitrary sensors and T_1 and T_2 are two optional temperature measurements.

Each of up to three connected sensors is powered separately. The respective sensor of interest is selected with the multiplexer (MUX). The IC's MUX can be programmed via the ZMD21013's SPI-standard digital interface. The 1st and 2nd input channels of the IC support the additional temperature measurements, which are derived by analysis of the temperature coefficient (TC) of an internal or externally-connected resistor. The latter option is for very high sensitivity requirements of the TC measurement. In this case, a highly stable TC resistor must be connected between the bridge's foot point and the "REXT" input pin of the ZMD21013.

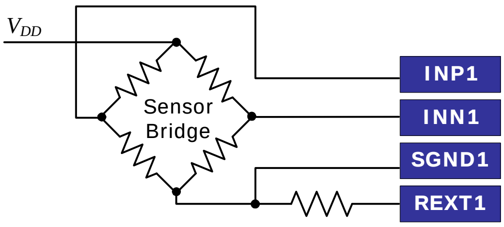

Fig. 2. Configuration Example for a Sensor Bridge with an External TC Resistor.

When the equivalent sensor readout allows the sample-and-hold (S/H) block of the IC to settle and the MSB has been converted, the analog front end and also the sensor bridge are switched off. These system components do not consume any further power.

Next, the ADC ratiometrically digitizes the remaining least significant bits (LSB) signal portion. The reference amplifier provides the virtual ground voltage for the ratiometric A/D conversion. This virtual ground voltage is obtained via processing the applied supply voltages, V_{DD} and Vss. The respective digital measurements are output via the Serial Peripheral Interface (SPI).

Different levels of reset are supported – from basic SPI register reset to complete hardware reset via a separate pin. The clock signal can be supplied by the microcontroller or the ZMD21013's internal RC oscillator.

3. The Charge-Balanced ADC

In general, the input signal is fed via a differential stage into an integrator for charge-balanced A/D conversion. The respective output signal of the integrator is interpreted by a comparator as logic one or zero. Based on this, a positive or negative feedback voltage is provided which resets (via the differential stage) the integrator to zero (control loop). The applied digital filter converts the serial bit stream into digital, i.e., discrete values. One of the main advantages of this kind of ADC (as well as for the whole class of sigma-delta topologies) is the so-called noise shaping. The effective accumulated noise (within the input signal to the ADC) is diminished during the integration. In other words, an over-sampling of the input signal is applied and decreases the noise's standard deviation and increases the signal-to-noise ratio (SNR), respectively. This effect is especially effective for low frequency measurement signals like the short-time, nearly-DC inputs of a resistive sensor bridge. This topology enables high precision due to an SNR increase. Fig. 3 illustrates the noise shaping or reduction for such a topology using an example of a 50mV noise-affected input signal.

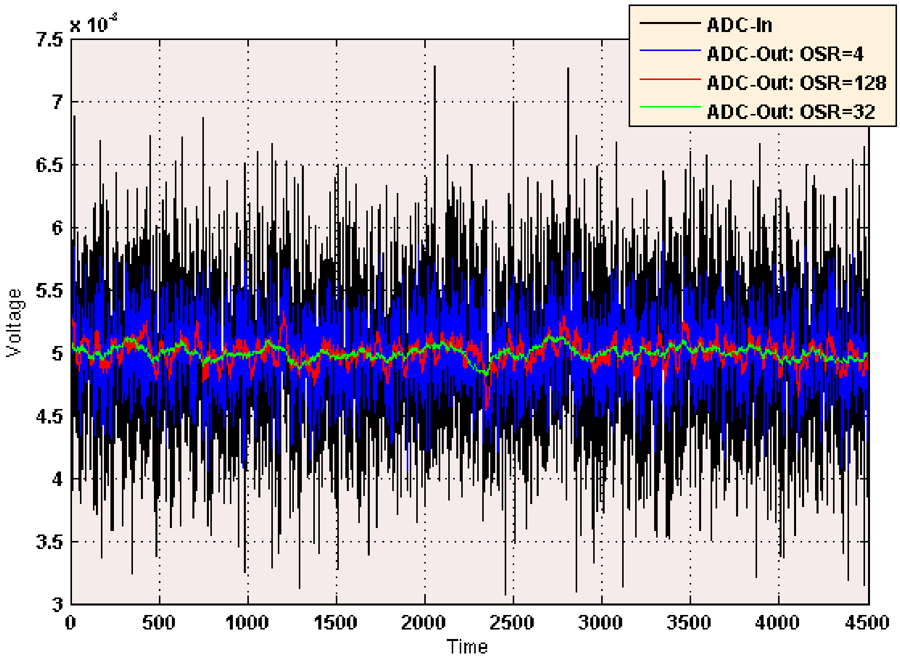

Fig. 3. Example of the Time Series of a Noise-Affected Input Signal and the Respective ADC Output (Analog Equivalent) for Different OSRs.

In the ZMD21013, the ADC is a two-stage, charge-balanced topology operating at 32 kHz and supporting resolutions from 10-bit to 16-bit. The ADC is divided into two stages: MSB and LSB. The split between the MSB and the LSB segments is uneven such that the MSB conversion prevails, e.g. 10-bit resolution for MSB and 7-bit resolution for the LSB. This two-stage A/D conversion topology yields faster overall conversion time. Compared to an otherwise comparable ADC, the two-stage, charge-balanced topology is at least ten times faster yet consumes less power and achieves the same precision. Moreover, the topology accommodates the potential production process and thus circuit element deviations for the analog components. There, the circuitry precision requirements are more relaxed. Therefore, it is possible to specify and guarantee a high degree of quality for engineers using the ZMD21013. The ADC's over-sampling ratio (OSR) can be set to fixed values in the range of 2 to 128.

A counter detects the time increments needed for the equivalent capacitance to discharge. The result is the digitized sensor signal within the state controller block.

4. The SPI Interface

The Serial Peripheral Interface (SPI) used for communication between the ZMD21013 and an external microcontroller is organized by bytes. The SPI is a three-wire version with serial clock (SCLK), serial data in (SDI) and serial data out (SDO) pins. It contains a 16x8bit EEPROM, two configuration registers and an address decoder for internal communication purposes as well as 2x8bit registers for the A/D conversion results memory (Fig. 4).

The EEPROM is directly accessible for writing customized settings. The serial clock signal (SCLK) initiates and synchronizes the IC's data transfer with each bit:

- At every rising edge of SCLK for transmission from the ZMD21013 to the microcontroller
- At every falling edge of SCLK for reception by the ZMD21013 of data from the microcontroller.

When the "trigger" bit B00 = 1 is written in configuration register 1, the signal conversion is initiated. Then, SDO goes high. The high to low transition of SDO will indicate the end of a conversion and the availability of the respective measurement result in the 2x8bit A/D result registers.

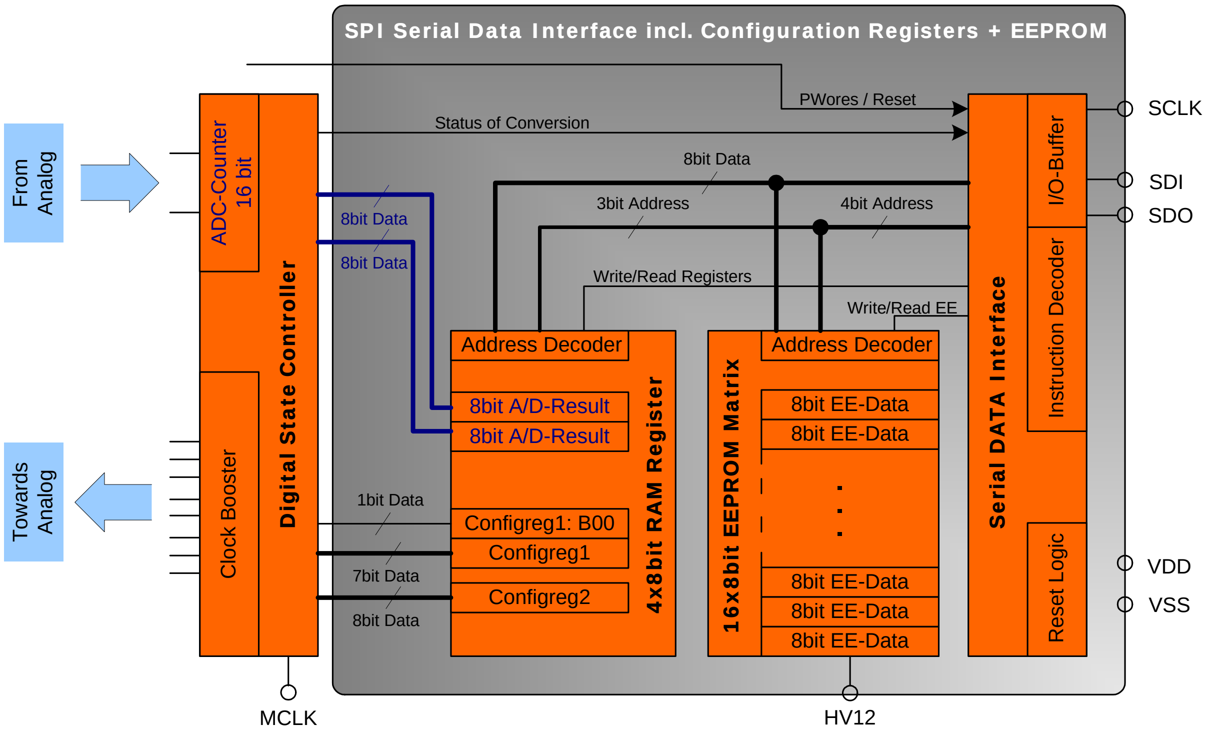

Fig. 4. SPI Block Diagram.

4.1. Operating and Measurement Modes

The ZMD21013 operates in one of the following modes:

- Idle Mode: Neither the A/D conversion nor the SPI communication is active (SCLK must not be utilized; MCLK can be inactive). The IC consumes almost no power.
- Active Mode: The A/D conversion is running. The respective selected input signal (sensor bridge, TC resistor, or auto-zero) is digitized. A clock signal (either MCLK or internal RC-oscillator clock) is required. SPI communication should be inactive.
- Communication Mode: The analog stages (shaded blue in Fig. 4) are inactive. No input signal A/D conversion is running. Communication between the external microcontroller and the SPI is active. The

interface clock signal SCLK is required.

For sensor signal readout (during Active Mode), the respective sensor bridge operates as voltage-driven. The ZMD21013 provides four measurement modes for connected sensor's signal readout, determination of temperature, and generation of compensation value. The definition of the selected channel and the respective measurement mode are controlled by programming the configuration registers via the SPI-standard interface. The bridge foot point and VSS are connected via a very low resistance switch in the normal sensor signal measurement modes (Mode A: 60 mV/V full-scale input span; Mode B: 120 mV/V full-scale input span). Switched on, the switch resistance must be much less than the bridge resistance to circumvent potential influences (like drifts or TC changes) on the sensor supply voltage. The measurement modes can be summarized as follows:

- Mode A is the usual sensor measurement mode for any application with the requirement of maximum precision (3μV/LSB). The differential output voltage of the respective sensor bridge (according to the MUX selection: channel I, II or III) is processed by the IC. The signal is amplified by 20 dB (a factor of 10). The full-scale input voltage range is 60 mV/V. The effective sensitivity (ca. 3 μV/LSB) is twice as high as in Mode B.
- Mode B is the sensor measurement mode for any application with relaxed precision requirements (6μV/LSB) but wider measurement range. The differential output voltage of the respective sensor bridge (according to the MUX selection: channel I, II or III) is processed by the IC. The signal is amplified by 14 dB (a factor of 5). The full-scale input voltage range is 120 mV/V. In exchange for a wider full-scale range, the sensitivity (ca. 6 μV/LSB) is less than in Mode A.
- TC: For the temperature coefficient (TC) measurement mode, the sensor bridge's low end must be connected to the IC via a series resistor. One can select between three internal resistors (500 Ω, 3.4 kΩ, or 14 kΩ) or an additional external resistor. The respective resistance must be equivalent to the overall bridge resistance. The signal obtained is related to the reference voltage $V_{DD}/2$. A temperature equivalent signal is acquired and provided at the IC's digital output. The signal is amplified by 6dB (a factor of 2). This mode can only be applied for channel I or II.
- Auto-Zero: The fourth option for measurements is the Auto-Zero Mode for the generation of calibration and compensation values. This mode is always used in combination with one of the above modes in order to generate correction values for systematic interface errors. The sensor bridge's differential input of the respective sensor bridge (according to the MUX selection: channel I, II or III) is shorted. A measurement value is generated which characterizes the IC's (analog part) systematic offset within each measurement. This auto-zero value should be used for the offset correction of subsequent sensor measurements by the connected external microcontroller. During the auto-zeroing, the IC's setup should be the same as for the respective intended measurement mode, i.e. Mode A, Mode B or TC.

5. Overall System's Power Consumption

In order to reduce the overall power consumption, the ZMD21013 was designed with consideration for all relevant system components including sensor elements and a connected microcontroller.

The bridge is powered only for A/D conversion of the MSB part of the signal. The subsequent LSB A/D conversion is based on the remaining signal portion (electrical charge / voltage) after the MSB A/D conversion. As a result, the supply voltage V_{DD} for the bridge can already be switched off during LSB A/D conversion. There are several ADC precision settings resulting in a large variety of precision versus measurement duration and power consumption relationships. For example, for a single measurement per second using $V_{DD} = 3$ V with 10-bit resolution and 125 μs measurement duration, two samples would be accumulated and 2 μA/s current would be consumed (for the IC only). In comparison, with 16-bit resolution and 8000 μs measurement duration, 128 samples would be accumulated and 8 μA/s current would be consumed. The idle current of the sensor interface IC is

500nA/s at maximum – typical values are in the range of about 100 nA/s. The average typical power consumption of the IC is about 25 µW for a 16-bit high precision measurement.

6. Conclusion

The ZMD21013 supports a large variety of high precision (high resolution) and low power sensor applications. The sensor interface can enable systems with up to three separate sensor elements. Additionally, temperature measurements for application as well as correction purposes can be conducted.

The switched measuring concept of the IC yields typical average power consumption as low as 25 µW for a 16-bit precision value (@V_{DD} = 3 V). Moreover, the IC's charge-balanced ADC is especially designed for robustness and noise reduction due to over-sampling.

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Guide for Contributors

Aims and Scope

Sensors & Transducers Journal (ISSN 1726-5479) provides an advanced forum for the science and technology of physical, chemical sensors and biosensors. It publishes state-of-the-art reviews, regular research and application specific papers, short notes, letters to Editor and sensors related books reviews as well as academic, practical and commercial information of interest to its readership. Because it is an open access, peer review international journal, papers rapidly published in *Sensors & Transducers Journal* will receive a very high publicity. The journal is published monthly as twelve issues per annual by International Frequency Association (IFSA). In additional, some special sponsored and conference issues published annually.

Topics Covered

Contributions are invited on all aspects of research, development and application of the science and technology of sensors, transducers and sensor instrumentations. Topics include, but are not restricted to:

- Physical, chemical and biosensors;
- Digital, frequency, period, duty-cycle, time interval, PWM, pulse number output sensors and transducers;
- Theory, principles, effects, design, standardization and modeling;
- Smart sensors and systems;
- Sensor instrumentation;
- Virtual instruments;
- Sensors interfaces, buses and networks;
- Signal processing;
- Frequency (period, duty-cycle)-to-digital converters, ADC;
- Technologies and materials;
- Nanosensors;
- Microsystems;
- Applications.

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