intersema
AN401

Analog Sensor Interfacing

1 Purpose

This document is intended to give hints on how to bias the Intersema pressure sensors operating as a passive Wheatsone Bridge. It also gives examples for sensor interface circuits allowing to compensate the temperature and process dependent variations of the sensor properties.

2 Introduction

The piezoresistive silicon pressure sensors are configured as Wheatstone bridges made of diffused resistors. Like for all Wheatstone Bridges the output of the sensors is ratiometric to the bridge bias voltage at any given temperature. Intersema usually specifies the sensor properties for a given bridge bias voltage of 5V. Current Biasing is also possible but results in different temperature coefficients. In any case it must be made sure that Vs is the most positive potential on the sensor in order to avoid leakage from forward biased junctions.

The sensor properties specified by Intersema are as follows:

- Span — Swing in differential voltage VOp -VOm at T=25C, Vbias=5V for a pressure change from 0mbar to the specified FSR
- Offset — Differential output voltage VOp -VOm at T=25°C, Vbias=5V at p=0mbar
- TCSpan — Temperature Coefficient in ppm/K of the Span
- TCOffset — Temperature Coefficient of the Offset in uV/K
- Rbridge — Resistance between VS and GND (Vs positive!!) for Ooutput+ and Output- floating
- TCRbridge — Temperature coefficient of bridge resistance in ppm/K

All of these properties are subject to process tolerances and thus vary from sensor to sensor. Depending on the accuracy requirements of the application some or all of these properties must be individually calibrated for each sensor.

3 Calibration/Compensation

Basically all applications require the calibration/compensation of the Offset as this may be a significant voltage compared to the Span. Most applications also require a calibration of the individual Span for a given sensor. Only if the pressure range of interest is very small, acceptable accuracy may be achievable using typical values for the Span. Depending on the temperature range of the application it may or may not be necessary to compensate for the temperature variations of the Offset.
The TC of the Span (TCS) is the most constant of all the above mentioned sensor properties. So accuracy might be sufficient for many applications to use typical values for the TCS. Please note that even though the TCS has little variations from die to die you still need to compensate for its typical value as the Span has a strong (but rather constant) temperature dependency.

4 Temperature measurement

In order to compensate for the temperature dependency of Span and Offset, the temperature must be known. Even though different temperature sensors could be used, it is preferable to use the temperature dependency of the bridge resistance to measure the temperature. This way the actual sensor temperature is measured, so the setup is less sensitive to self heating effects or effects due to thermal capacity.
In order to use the bridge resistance as thermometer it has to be calibrated in terms of absolute resistance and TCR (see above).

5 Concepts for compensation

5.1 High accuracy solutions

For high end applications requiring optimum accuracy over wide temperature and pressure ranges all four properties (Offset, Span, TCS and TCR) have to be individually calibrated and compensated for. The temperature measurement should be based on the bridge resistance.

For highest flexibility it is preferable to do the compensation by software. This offers the possibility to easily apply higher order compensations and digital nonvolatile storage of calibration coefficients (no analog trimming required). Such an approach could use software switched bridge biasing (voltage bias for pressure measurement, current bias or voltage dividers with external resistors for temperature measurement).

An instrumentation amplifier with fixed gain and offset with enough headroom to accommodate all possible sensor signals would feed the signal to a high resolution ADC. Linear calibration can be done at 2 temperatures and 2 pressures. Calibration coefficients can be calculated and stored in nonvolatile memory. Intersema uses such a concept with its high precision, low power barometer modules (e.g. MS5534, MS5535).

5.2 Middle end applications

Most applications require a digital representation of the pressure value. So they include an ADC anyway (e.g. the ADC port of the microcontroller). Application of the above mentioned high end concept does however require significant analog interface circuitry between sensor and ADC as well as high resolution ADCs (15 … 16 Bit) which may be beyond the scope of some applications. In order to get away with less resolution for the ADC it is preferable to compensate for the (typical) temperature dependency of the Span and possibly the Offset at 25°C. Higher order compensations could be applied by software (eventually using an external temperature sensor) if necessary (see paragraph 3).

A schematic for a possible interface circuit is shown in Fig.1 The circuit is ratiometric to the supply voltage (VDD-VSS) so the same potentials should be used as reference for the ADC. Compensation for the typical TCS is achieved by biasing the bridge out of a given impedance (R8,R9) with low TCR. This concept of biasing inbetween pure current and pure voltage biasing makes use of the positive TCR of the bridge (around 3000ppm/K) generating a bridge supply voltage increasing over temperature in order to compensate for the negative TCS (around –2000ppm/K).

Going through the math it can be found that the series resistances (R8+R9) have to be around 6.8K in order to compensate for the typical TCS. How to divide the total resistance between R8 and R9 depends on the input common mode requirements of the OPAmps used.
Please note that although the TCS of the sensor has little process variations (see above) the sensitivity of the sensor in this setup also depends on the bridge resistance and the TCR. So the observed variations in both the absolute Span and its TC will be higher than for a voltage biased sensor. The voltages at Vs or GND depend on the temperature of the sensor and can thus be measured by the ADC and used serve to compensate remaining TCs of Span and Offset by software (details not shown here).

Please note that the shown compensation of typical TCS leads to a reduction of bridge bias (and signal) by about 66% compare to voltage biasing the bridge between VDD VSS. Corresponding losses in SNR are the consequence.
It is theoretically possible to trim the TCS by making R8 or R9 trimmable. This kind of analog trimming is however tedious as it would requires several temperature cycles. Software compensation of the remaining TCS is preferable if at all necessary.

OP1 and OP2 form a 2 amplifier instrumentation Amp. The differential gain can be adjusted by changing R3. This can be made trimmable if analog Span adjustment is required. The voltage divider R6/R7 sets the quiescent voltage at N6 (i.e. for V1=V2). This divider could theoretically be used to trim bridge Offset voltages. Unfortunately there are 2 problems with such a concept:

1. The output impedance of the divider must have a given value in order not to deteriorate CMRR of the instrumentation amplifier so using a simple trimpot is not possible.

2. The quiescent voltage can only be adjusted between VDD and VSS. For sensor with a unipolar pressure range (e.g. all absolute sensors) and a positive Offset it may however be desirable to have a quiescent voltage outside the range VDD to VSS in order to make best use of the ADCs dynamic range. This is not possible if using N6 as output.

If the loss in dynamic range as described under 2) can be accepted it is best to set gain and quiescent voltage fixed (no trimming) such that the signal remains inside the dynamic range of the ADC under all operating conditions and for all sensors of the population. Trimming of Offset (and eventually Span) can then be done by software by performing a measurement at a single pressure (2 pressures if Span is to be calibrated as well).

If the loss in dynamic range as described under 2) is not acceptable, a circuit like OP3 can be added. Now N7 should be used as ADC input. By properly adjusting R10 the quiescent voltage can be trimmed between –50% and 150% of the supplies (of course N7 will be clamped to the rails in case the differential bridge output really went to 0V).This allows to make optimum use of the ADCs dynamic range in most applications. An analog adjustment of R10 is however required.

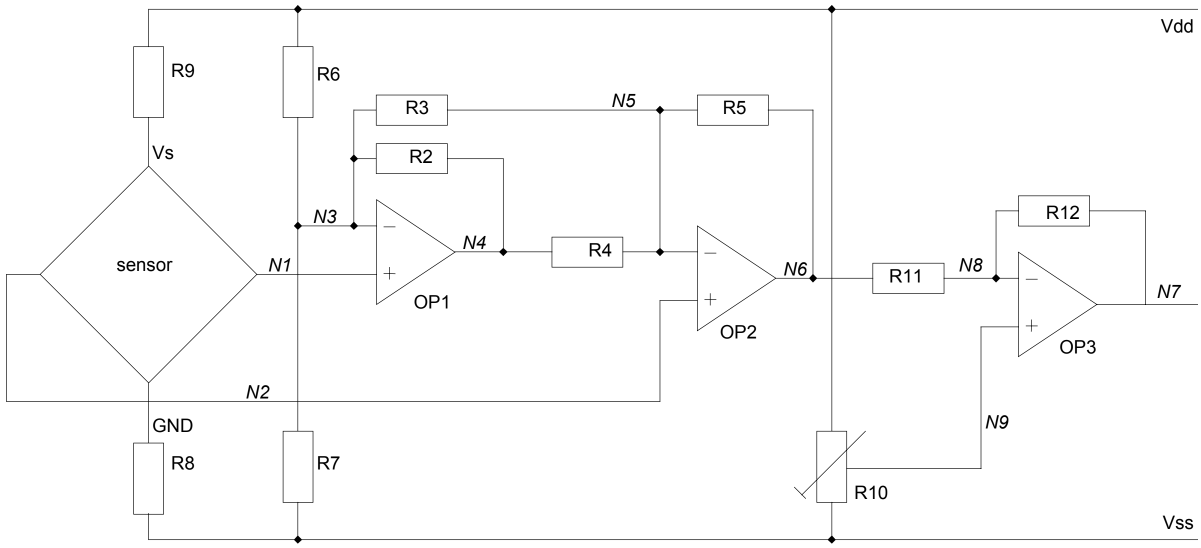

Fig.1 Schematic of simple sensor interface circuit

5.2.1 Design Equations

The common mode gain from N1,N2 to N6 is given by:

$$\mathrm{Acm} = 1 - \frac{\mathrm{R2\,R5}}{\mathrm{R4}} \frac{\mathrm{R6+R7}}{\mathrm{R6R7}} \qquad \text{(Eq. 1)}$$

In order to ensure good CMRR it is thus required to have:

$$\frac{\mathrm{R5}}{\mathrm{R4}} = \frac{\mathrm{R6R7}}{\mathrm{R6+R7}} \frac{1}{\mathrm{R2}} \qquad \text{(Eq. 2)}$$

The differential gain (from V1-V2) to N6 (Eq. 2 given) is:

$$\mathrm{Adiff6} = 1 + \frac{\mathrm{R5}}{\mathrm{R4}} + \frac{\mathrm{R5}}{\mathrm{R3}}\left(1 + \frac{\mathrm{R2}}{\mathrm{R4}}\right) \qquad \text{(Eq. 3)}$$

The Quisecent Voltage at N6 (for V1==V2) (Eq. 2 given) is:

$$\mathrm{VQ6} = \frac{\mathrm{R7}}{\mathrm{R6+R7}} \mathrm{VDD} \qquad \text{(Eq. 4)}$$

From equations 2,3 and 4 it can be seen, that R3 can be used to adjust the differential gain without affecting the CMRR nor the quiescent voltage at N6.

The differential gain (from V1-V2) to N7 (Eq. 2 given) is:

$$\mathrm{Adiff7} = -\frac{\mathrm{R12}}{\mathrm{R11}}\mathrm{Adiff6} \qquad \text{(Eq. 5)}$$

The Quiescent Voltage at N7 (for V1==V2) (Eq. 2 given) is:

$$\mathrm{VQ7} = (1+\frac{\mathrm{R12}}{\mathrm{R11}})\mathrm{V9} - \frac{\mathrm{R12}}{\mathrm{R11}}\mathrm{VQ6} \qquad \text{(Eq. 6)}$$

From equation 6 it can be seen that the voltage divider R10 can be used to independently adjust VQ7.
For R6=R7 and R12=R11 VQ7 can like this be adjusted between –0.5 VDD and 1.5 VDD.

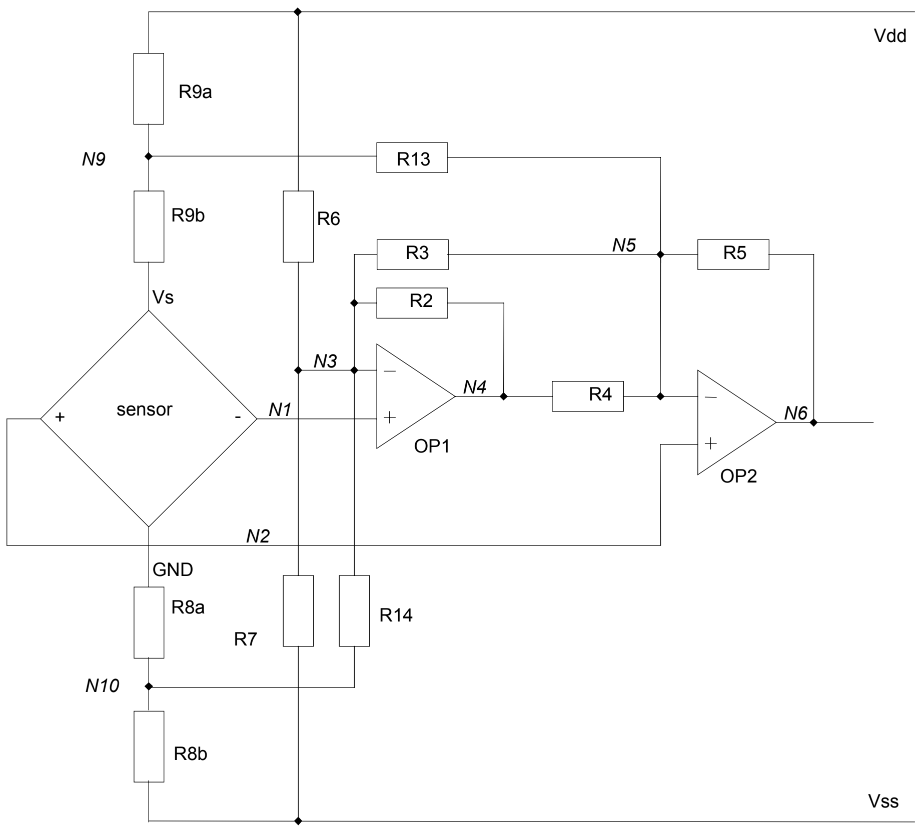

Fig. 2

REVISION HISTORY

Date	Revision	Type of changes
August 26, 2002	V1.0	Initial release
January 31th, 2003	V2.0	Figure 2 added

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