Signal Conditioning for MEAS Pressure Sensors

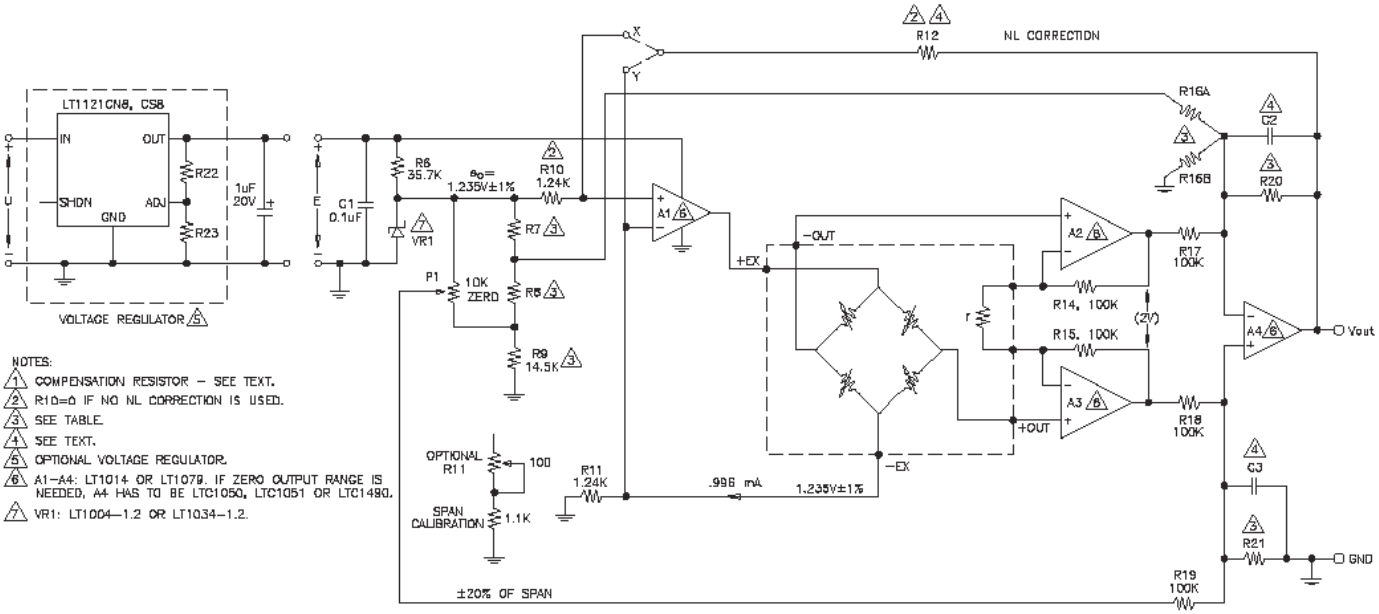
INTRODUCTION

Piezo resistive pressure sensors provide an analog output signal that is proportional to input pressure. The typical full scale span for this type of integrated sensor is 100 mV which is sufficient for many applications. Various applications do exist however, that require higher level (e.g. 5 volt) output span and thus bring about the need for gain stages and other signal conditioning circuitry.

A basic signal conditioning circuit should provide zero balance adjustment, calibration of pressure sensitivity, temperature compensation of zero and span, signal amplification and voltage regulation. In addition to these basic functions, an active nonlinearity correction and frequency response shaping may be required to enhance sensor performance.

This application note describes an amplification circuit for temperature-compensated pressure sensors, shown in Figure 1. It provides noninteracting zero and span calibration with a single power supply for three wire voltage output and two-wire current output configurations. This circuit is appropriate for all compensated Measurement Specialties pressure sensors which utilize constant current excitation (most HIT, TO-8, and ISO products). Several output signal options are shown including live zero (1V) which allows differentiation between transducer failure and zero pressure signal.

The circuit consists of the following functional blocks: sensor assembly, reference voltage source, current source, differential normalizing amplifier, output amplifier, nonlinearity correction loop, frequency response shaping network and optional voltage regulator.



OUTPUT RANGE	R7	R8	R9	R16A	R16B	R20	R21	R22	R23	E_{MIN}	U_{MIN}
1 TO 5V	——	——	4.75K	——	100K	200K	200K	18K	13K	8.9V	10V
1 TO 6V	——	——	4.75K	——	100K	250K	250K	18K	13K	8.9V	10V
0 TO 5V	4.99K	4.99K	3.01K	100K	——	250K	250K	18K	13K	8.9V	10V
0 TO 10V	4.99K	4.99K	3.01K	100K	——	500K	500K	22K	12K	10.1V	11V

Figure 1 - Transducer Circuit - Voltage Output

SENSOR ASSEMBLY

The sensor assembly consists of a compensated silicon pressure sensor and gain-set resistor r. The gain-set resistor normalizes the span of the recommended external amplifier, thus creating a low-cost, interchangeable, high level transducer. Please refer to the product data sheet to determine whether a particular model is uncompensated, has temperature compensation on board, or has temperature compensation plus a gain-set resistor on board. For a detailed discussion of passive temperature compensation, please refer to Application Note TN-002, "Temperature Compensation-IC Pressure Sensors." For a discussion on interchangeability, see TN-003 "Gain Programming Using an MEAS Pressure Sensor."

CONSTANT CURRENT SOURCE

The simplest sensor temperature compensation requires constant current excitation which is built around amplifier A1 as shown in Figure 1. The sensor is connected to the feedback loop of the amplifier. The current in this loop is controlled by the reference voltage e_0 (neglecting the nonlinearity correction loop) and by resistor R11:

$$I = e_0 / R_{11} \qquad [1]$$

The compliance voltage of this current source is limited by the supply voltage, the output stage saturation of amplifier A1 and the voltage across resistor R11. The required compliance voltage may be derived based on 6.0 k Ohm worst case bridge resistance at 25°C and TCR = +0.22%/°C for the compensated sensor. The reference voltage generator is based on the temperature compensated band gap reference diode VR 1, whose voltage is used to provide a reference for the constant current source. It also provides a reference for the live zero level in the case of 1 to 5V and 1 to 6V output signal levels and a zeroing voltage across potentiometer P1.

DIFFERENTIAL NORMALIZING AMPLIFIER

The zero and span temperature compensation for the sensor is calculated based on a no output load condition. Since the bridge resistance changes with temperature, an amplifier input resistance that is too low will introduce an additional temperature error. The differential normalizing amplifier configuration was selected because of its high input resistance and excellent common mode rejection which is virtually independent of circuit component tolerance.

The maximum output voltage of this stage is limited by the input common mode voltage. The output of amplifier A2 is on a common mode voltage level with zero differential input voltage and it can decrease only to the signal common ground level. The worst case common mode voltage at 1.0 mA excitation current will be about 2.3V in the configuration shown, limiting maximum differential output voltage to about 4.6V. For the circuit shown, a 2.0V span was selected. Gain adjustment covers the input signal range from 33 to 115 mV span at 1.0 mA excitation which corresponds to 50 to 170 mV span at 1.5 mA. Gain K1 is given by:

$$K_1 = 1 + (R_{14} + R_{15})/(R_{13} + P_2) \qquad [2]$$

Denoting minimum required gain by G1, maximum required gain by G 2 and the available worst case (minimum) potentiometer P 2 resistance Rp, the value of symmetrically distributed resistors R 14 = R 15 as well as gain adjustment stop R 13 may be calculated as follows:

$$R_{13} = P\ (G_1 - 1)/(G_2 - G_1) \qquad [3]$$

$$R_{14} = P\ (G_1 - 1)(G_2 - 1)/2(G_2 - G_1) \qquad [4]$$

Common mode rejection (CMR) is relatively important for this stage. Bridge resistance changes with temperature from 0.22%/°C for compensated sensors to 0.27%/°C for uncompensated sensors, Thus, bridge voltage will change with temperature in the constant current excitation mode. For the worst case condition, including 100°C temperature span, the common mode voltage would change by about 0.66V for compensated sensors. Assuming 90 dB worst case differential CMR for this stage (using LT1014), this change would introduce a 0.042%/100°C zero error based on a 50 mV sensor span.

TRANSDUCER CIRCUIT

The differential offset temperature drift of amplifiers A2- A3 creates an attendant change in the zero temperature error of the transducer. For example, the LT1014amplifier has a worst case differential offset drift of 5 µV/°C which translates into a 1%/100°C zero error, assuming a minimum span of 50 mV.

SECOND STAGE AMPLIFIER

The fixed gain output amplifier has two differential inputs. The first input (R17, R18) processes the output from the normalizing amplifier. The other input (R16, R19) is used to generate a zero bias level for the output options with live zero and provides fine zeroing adjustment of ±20% of the sensor span. Since zeroing is done in the first stage, the change of zero does not affect span.

The gain K2 of the second stage is set by:

$$K_2 = R_{20}/R_{17} = R_{21}/R_{18} \qquad [5]$$

Common mode rejection of this stage is more important than in the first stage. The common mode voltage change is still 0.66V/100°C worst case at the input (R 17/R 18 resistors). With ±1% tolerance of feedback resistors, about 28 dB CMR may be expected (worst case). That translates to a 1.3%/ 100°C worst case zero drift at the output due to common mode voltage change. With better matching of the feedback resistors, this error decreases and the typical error is about two to four times better than the maximum one.

The temperature drift of the offset voltage is not critical here. Assuming 5 µV/°C drift over the 100°C temperature range, the output zero change is only 0.025%/100°C based on 2V input span.

NONLINEARITY CORRECTION

The optional nonlinearity correction loop is established by resistor R 12. This loop feeds back the output voltage in order to control the bridge voltage, thus creating a second order pressure related component in the output signal. This feedback is used to compensate for the sensor's pressure nonlinearity.

For sensors with positive nonlinearity (Figure 2), the feedback is connected to the noninverting input X of amplifier A1. For negative nonlinearity, the feedback is connected to the inverting input Y.

The value of the feedback resistor R 12 may be calculated using the following formula:

$$R_{12} = 4R\ (10)^A / S(NL)^B \qquad \textbf{[6]}$$

Where: A = 1.9074

B = 0.97242

R - value of resistor R 10 or R 11, whichever is connected to resistor R 12 for given feedback configuration.

S - output signal span (V 2-V 0) driving resistor R 12:

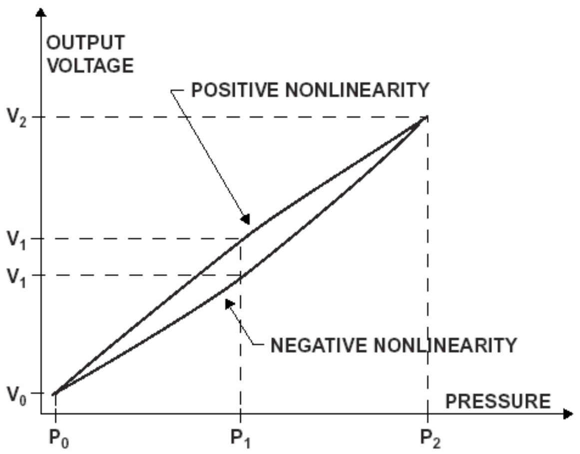
4V for 1 to 5V output

5V for 1 to 6V and 0 to 5V outputs

10V for 0 to 10V output.

NL - absolute value of terminal based nonlinearity expressed in % of span (Figure 2):

$$NL = \frac{100[V_1 - (V_2 - V_0)(P_1 - P_0) / (P_2 - P_0) - V_0]}{(V_2 - V_0)}$$



SENSOR TRANSFER FUNCTION

Figure 2- Sensor Transfer Function

FREQUENCY RESPONSE

Frequency response may be shaped by capacitors C2 and C3. The corner frequency for 3 dB drop of sensitivity is given by:

$$f = {}^1/_2 p C_2 R_{21} \quad \textbf{[7]}$$

with the assumption that C 2 = C 3 and R 21 = R 20. Shaping the frequency response is commonly used to filter out unwanted high frequency noise.

VOLTAGE REGULATOR

The optional voltage regulator (LT1121) provides protection against reverse polarity connection. The device includes current limiting, thermal limiting and shutdown. It extends the operating voltage range and provides for additional voltage regulation making the output independent of the amplifiers power supply rejection ratio.

The output voltage is set by resistors R 22 and R 23 according to the formula:

$$V_{out} = 3.75V\ (1 + R_{22}/R_{23})$$

RATIOMETRIC APPLICATIONS

For ratiometric applications, the optional voltage regulator should not be used, and reference diode VR1 should be replaced by a resistor. The value of this resistor should not deliver a higher voltage than 1.26V across it at maximum operating power supply voltage in order to avoid saturation of the amplifiers.

Typical performance when using the LT1014 amplifier, is shown in Table 1.

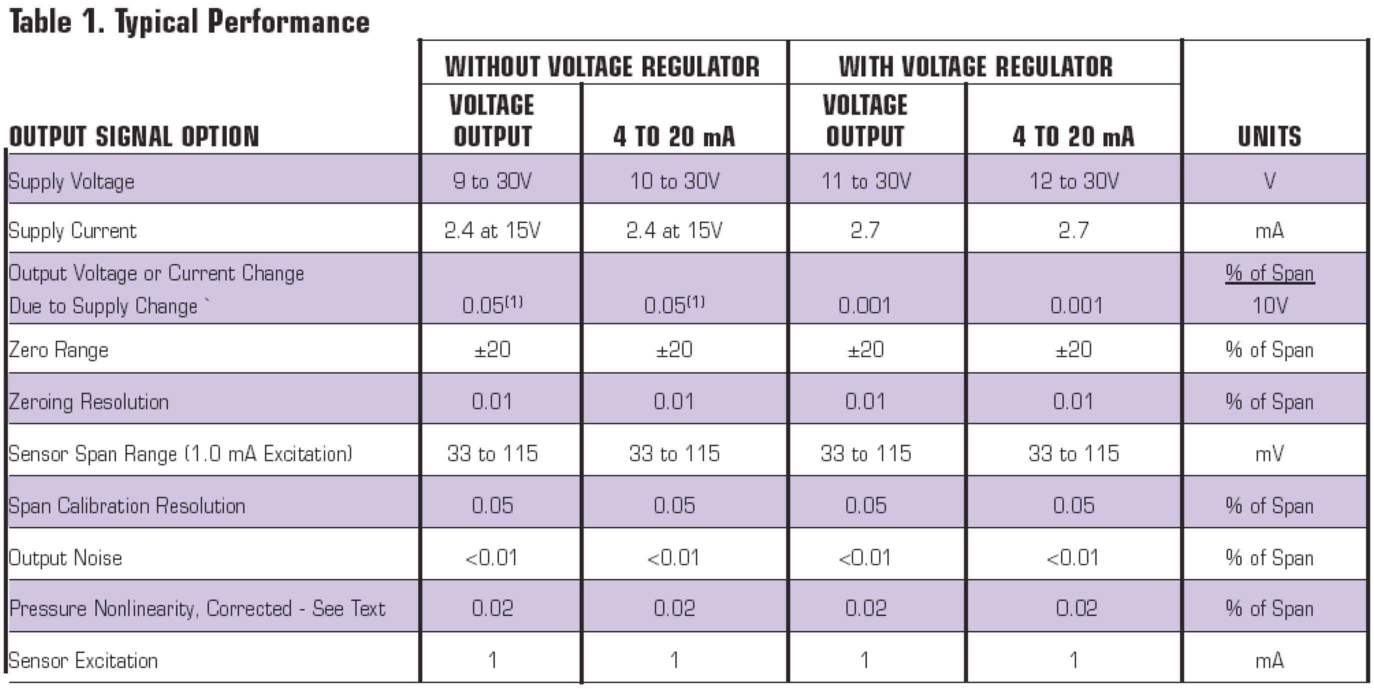


Table 1. Typical Performance

OUTPUT SIGNAL OPTION	WITHOUT VOLTAGE REGULATOR		WITH VOLTAGE REGULATOR		UNITS
	VOLTAGE OUTPUT	4 TO 20 mA	VOLTAGE OUTPUT	4 TO 20 mA	
Supply Voltage	9 to 30V	10 to 30V	11 to 30V	12 to 30V	V
Supply Current	2.4 at 15V	2.4 at 15V	2.7	2.7	mA
Output Voltage or Current Change Due to Supply Change `	0.05(1)	0.05(1)	0.001	0.001	% of Span 10V
Zero Range	±20	±20	±20	±20	% of Span
Zeroing Resolution	0.01	0.01	0.01	0.01	% of Span
Sensor Span Range (1.0 mA Excitation)	33 to 115	33 to 115	33 to 115	33 to 115	mV
Span Calibration Resolution	0.05	0.05	0.05	0.05	% of Span
Output Noise	<0.01	<0.01	<0.01	<0.01	% of Span
Pressure Nonlinearity, Corrected - See Text	0.02	0.02	0.02	0.02	% of Span
Sensor Excitation	1	1	1	1	mA

Note:

1 Function of Power Supply Rejection rate for the amplifier

ADDITIONAL INFORMATION

A detailed discussion on sensor compensation techniques (calculating the temperature compensation resistors and the gain-set resistor) can be found in Application Notes TN-002 and TN-003. For other output options, including 4-20mA, please refer to Application Notes APP103 to APP105.

ORDERING INFORMATION

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