Intelligent Sensor Interface using Microcontroller and PGA

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Abstract

Interfacing various sensors to process control equipment is a challenging task. One may design specific interface circuit for typical applications. The present paper addresses performance of signal conditioning circuit used for J- type thermocouple as example. The low cost, fast simulation technique for the linearity and accuracy of the circuit performance is reported by using the PSpice test tools. The results are explored with browsing output data facility and run probe analysis.

The paper also describes a microcontroller based intelligent sensor interface, which allow connection of different types of thermocouples to a data acquisition and (or) control system and use them for various temperature ranges. The interface is divided into two parts; a microcontroller based unit and a sensor specific plug-in module. The user has to adjust the DIPswitches present on the module to indicate the type of thermocouple and range of temperature. The base unit consists of microcontroller (for monitoring and control) and other circuits. The microcontroller software identifies the connected thermocouple type, temperature range and sets amplifier gains of PGA that provides a fixed range of voltage 0-5V. The base unit converts this voltage into fixed 4-20 mA current and parallel 12 bit digital data. The microcontroller sends this digital data to a host PC using RS 232C interface for further processing. These are among the major tasks of an intelligent sensor interface.
KEYWORDS: Intelligent sensor interface, Signal-conditioning module, Programmable gain amplifier (PGA)

1 Introduction

The evolution of process control has seen the infusion of electronics technology into almost every facet because of low cost, reliability, miniaturization, and ease of interface. Using the signal conditioning circuits the direct transudation of any physical signal is converted into the required output signal. The specific type of signal conditioning depends, of course on the type of sensor employed as well as the nature of the specified output signal characteristic [1]. The electronic industry is getting progressively more efficient at developing new products in wide ranges and variety of sensor applications to customers. We also see more products coming into the market with increasingly shorter product lives and sometimes they may be fatal at times [2]. Hence, low cost circuit design, with an accurate, linear and faster testing technique is addressed.

In the industrial processes temperature is a main factor. A variety of temperature sensors are commercially available however signal conditioning plays an important role in design and development of accurate circuit performance and optimum reliability. Here, the product has to be practically designed first and then tested for its intended results, but if any degradation in the output signal is found then the circuit parameters and values have to be replaced and the circuit is re-tested for improved performance and low drift in specified parameters over the operating range. To complete one such process involves large amount of time, higher cost and accurate component values. This critical problem of product design and testing is simplified by the use of PSpice simulations. This allows user to design, test, and perform various analysis to optimize the accuracy, circuit performance and its reliability before any product is actually made and transferred to the customer for their use [3]. The performance of signal conditioning circuit-using PSpice for J-type thermocouple is discussed in this paper.

There is also a need to have an intelligent sensor interface which allows connection of various types of sensors on one side and various types of outputs on the other side. The present paper describes such interface and its use for various types of thermocouples and for various temperature ranges of measurement. Following section describes first the simulation of signal conditioning circuit for J-type of thermocouple.

2 Simulation Concepts

Electronic Simulation of circuit function is now a common practice in the design both of individual circuits and complete systems. The more of the circuit a designer can simulate, the faster the circuit can get into production and hence, to market. PSpice (PC Version, Simulation Program with Integrated Circuit Emphasis) has become a common tool for analogue simulations and widely used, even for some mixed mode circuit designs [4].

PSpice allow the designer to construct entirely new circuits without fabricating the actual circuit using hard wires, components and PCBs. The circuit performance and its reliability in any circuit to minimize failure can be tested. To meet the required standards of a circuit and hence quality instrument, the circuit analysis is performed. In case of any failure or problems observed, one can easily redesign it by modifying the very same circuit in few minutes using highly sophisticated simulation tools. With adequate number of design and redesign iterations on a computer platform it consumes only a small amount of time and no material. The design can be made robust. The simulated circuit can then be subjected to different analysis *i.e.* actual tests. The performance and reliability of circuit and instrument definitely shows results of up most levels. Thus it is the faster and low cost and less cumbersome process.

Dr. Lawrence W. Negal at University of California, Berkeley, originally developed PSpice; it is a general- purpose circuit simulator program that simulates electronic circuits. It performs various types of analysis of electronic circuits. PSpice contains models for common circuit elements, active as well as passive, and it is capable of simulating most electronic circuits. It is a versatile program and is widely used both in industries and universities [5].

To test and analyze the circuit performances first set the circuit for initial conditions such as zero and span adjustments. Spice simulations and testing process is as follows.

- Drawing the circuit
- Selecting the type of analysis

- Simulation of the circuit
- Displaying the results of the simulation

The Design Center software package has three major interactive programs: *Schematics*, *Spice*, and *Probe*. Schematics are a powerful program that let's you build circuits by drawing in a window on the screen. Spice analyzes the circuits created by schematics and generates voltage and current solutions. Probe is a graphics post-processor that allows you to display plots of parameters such as voltage, current, impedance, and power [6].

3 Signal Conditioning Circuits

Sophisticated instrumentation systems rely heavily on the application of a wide range of electronic circuits. Signal processing circuits constitute the essential link between the sensors and the final output equipment such as readout systems, computers and other devices. The signals obtained from sensors/transducers may be in analog or digital domain; very few instrumentation systems are fully digital by nature. Signal processing and conditioning is carried out in order to bring out the output signal to the desired description and standardized levels. In most cases, it is essential to see that the signal processing circuitry chosen preserves the desired functional relationship between the input and output signals and does not in any way impair the basic accuracy with which the measurement is carried out. The signal conditioner can vary in complexity with or without detectors, and filters. Alternatively, they are termed as signal modifiers or signal processors. The output signal may be an analog or digital quantity [1].

Measurement systems handle various types of signals produced by the sensors. These signals are required to be conditioned for user-friendly access. Following section describes the signal conditioning circuit used for widely used temperature sensor viz. J-type thermocouple.

3.1 Signal Conditioning Circuit for Thermocouple

The J-type thermocouple is used frequently in industry because it is economical and has high output in millivolts over its temperature range. Due to relatively low voltage output associated with most thermocouples, amplification circuit is used to increase sensitivity. The resulting output of this circuit is used to drive or activate a readout device [7]. This circuit, as shown in figure 1, converts the change in thermocouple voltage in mV into the corresponding change in output voltage in volts.

In this card, a +12 V supply is used to apply excitation voltage Resistors R4, R5, R6 and capacitors C3, C4 forms a low pass filter. An Op-amp is used in non-inverting mode. Trimpots PT2 and PT1 are used for zero and span adjustments. For testing the circuit using PSpice test tools the DC input voltage was swept in the range 0 to 6mV in step of 0.1mV. While testing the card practically, initially the inputs of card were shorted to the ground and PT2 is adjusted to get a voltage in mV, which corresponds to room temperature. For testing this card, using potential divider an input voltage in mV was applied to the card and output voltage was noted.

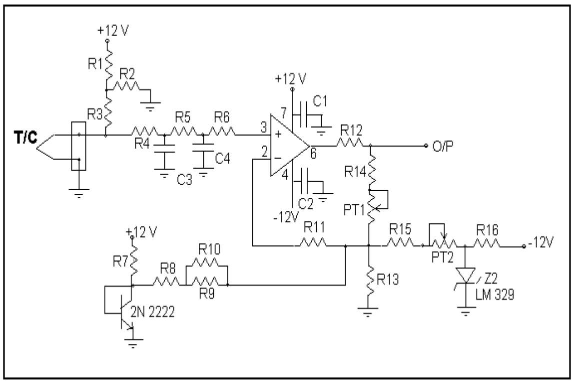

Figure 1: Signal Conditioning Circuit for J-Thermocouple

4 Microcontroller based Intelligent Sensor Interface

The interface, as shown in figure 2, is divided into two parts a microcontroller based intelligent interface (base unit) and a signal-conditioning module. The module consists of the signal conditioning circuit, DIPswitches to indicate the type of thermocouple and the temperature range. Before using it the user must select the position of DIPswitches and then plug it in the base unit. The microcontroller uses its ports as shown in figure 3 to

1. Identify the type of plugged signal conditioning module whether for thermocouple or any other sensor,
2. Read the code assigned for type of thermocouple whether J or any other,
3. Read the code assigned for temperature range of measurement whether 0-100^{0}C or any other.

Digitally programmable gain amplifiers can be realized with an operational amplifier (OA), a switched resistor network, and a switch driving circuit, actuated by a digital word [8].

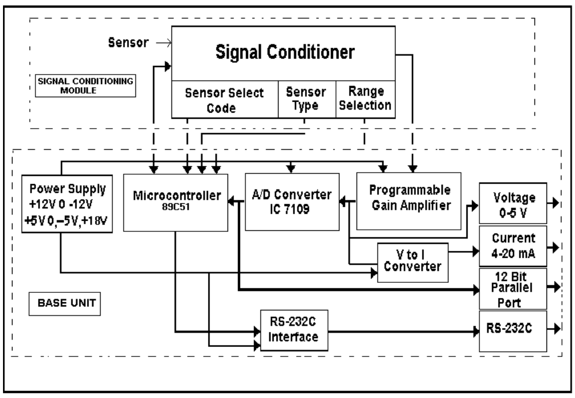

Figure 2: Block Diagram of Universal Intelligent Sensor Interface

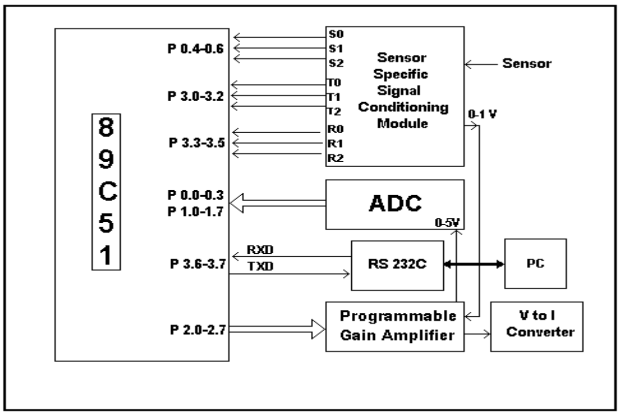

Figure 3: Port Configuration of Microcontroller

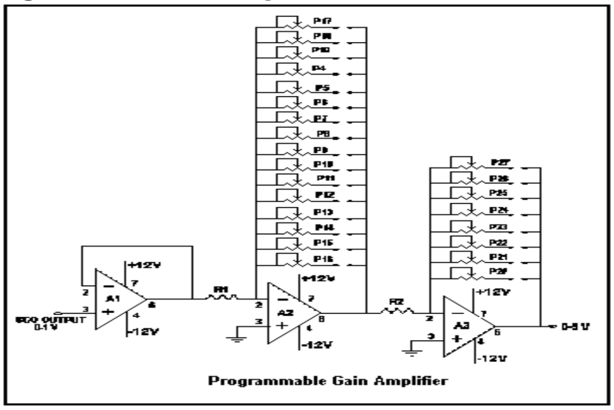

Figure 4: Programmable Gain Amplifier

The output of signal conditioner is applied to the programmable gain amplifier as shown in figure 4 The A1 amplifier is used as a buffer. The output of buffer is applied to the inverting amplifier A2 whose gain, as shown in table 4.1, is set by the microcontroller according to the type of the thermocouple. The output of A2 is given, as an input to the next A3 inverting amplifier, whose gain, as shown in table 4.2, is set according to the temperature range of measurement. For both A2 & A3 connecting one of the feed back resistances change the amplifier gain. This connection is possible by making the FET (Field Effect Transistor) switch of ADG 201 switch 'ON' by using microcontroller. The trim pots in series with a switch are adjusted according to the type and range.

The microcontroller software is stored in internal EEPROM (Electrically Erasable Programmable Memory) and it reads the position of DIPswitches, and sets the gain of programmable gain amplifier to provide a fixed range of output voltage 0-5V. This voltage is converted into current 4-20 mA by V to I converter and into digital form by a 12bit Analog to digital converter.

The microcontroller software continuously acquires the output of ADC using parallel ports and then sends it to a PC for further processing The output analog voltage, current, a raw 12 bit digital data, RS 232C serial port are provided by the base unit.

Table 4.1

Temp. Range	Range Select Code R2 R1 R0	Trim Pot No.	Adjusted Gain
0 - 100^{0}c	0 0 0	P 27	1
0 - 150^{0}c	0 0 1	P 26	0.667
0 - 300^{0}c	0 1 0	P 25	0.334
0 - 600^{0}c	0 1 1	P 24	0.166
0 - 900^{0}c	1 0 0	P 23	0.122
0 -1200^{0}c	1 0 1	P 22	0.084
0 -1500^{0}c	1 1 0	P 21	0.067
0 -1800^{0}c	1 1 1	P 20	0.0556

Table 4.2

Sensor Type	Type Select Code (P3.2P3.1P3.0) T2 T1 T0	Trim pot No.	Adjusted Gain
J	0 0 0	P 17	5
K	0 0 1	P 18	6.432
R	0 1 0	P 19	40.71
S	0 1 1	P 4	40.84
B	1 0 0	P 5	798.2
E	1 0 1	P 6	4.17
N	1 1 0	P 7	9.5
T	1 1 1	P 8	6.158

The base unit is fitted on the inner side of rear panel of the instrument in such a way that the module can be plugged from the front side and different outputs can be made available on the backside. The instrument case has been designed as an economical packaging solution for bench-top equipment.

5 Results and Discussions

The PSpice simulation of signal conditioning circuit for J type thermocouple was carried out successfully. The performance dependence characteristic on input voltage in mVs is shown in Figure 5.

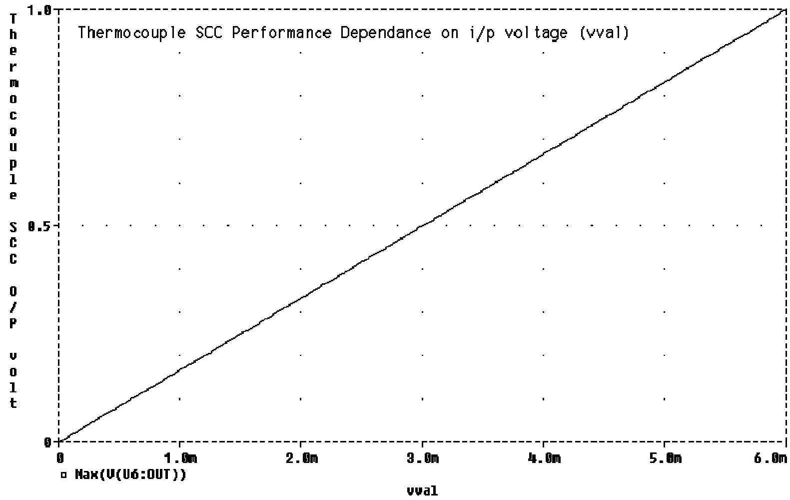

Figure 5: Thermocouple SCC Performance Dependence on I/P Voltage (Vval)

As shown in figure 6 the output voltage varies from 0 -1V with respect to changes in input voltage in mV from 0-6mV for a temperature range 0-100^{0}C. It shows that as input voltage increases the output voltage also increases and this change is linear.

It was also found that after setting the position of DIP switches on signal conditioning module and plugging it in the base unit, the output of PGA (Programmable Gain Amplifier) shows variation of voltage from 0-5V for selected type of thermocouple and temperature range. This paper reports that the results obtained after applying inputs to SCC (Signal Conditioning Circuit) using PSpice test tools and the results obtained after applying inputs practically are same.

Since Spice is the industry standard for electronic circuits simulations, it is used extensively for the design of other sensor signal conditioning circuits such as pressure, flow, displacement, force, vibration, etc. in sensor design and applications as the new product.

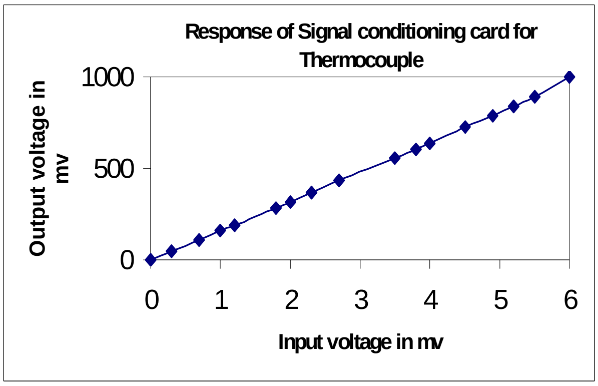

Figure 6: Response of Signal Conditioning Card for J-Thermocouple

Also these simulation studies uniformly may be applied for testing the circuit performance and reliability under changing physical conditions under which they are operating before actual circuit or product is made [9,10]. Hence it avoids the complex, cumbersome, cyclic testing procedures for a newly developed product.

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