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INTERFACING METHODS OF THE THERMOCOUPLES IN APPLICATIONS WITH THE MICROCONTROLLER

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Articolul tratează modalitățile de interfațare a senzorilor de temperatură la porturile de intrare/ieşire ale unui microcontroler flash din familia PIC- Microchip, unde sunt prezentate şi analizate câteva din metodele hardware de compensare a joncțiunii terminalelor reci, corecțiile de măsură, condiționarea traseului (amplificarea la nivelul minim perceptibil) a semnalului util compensat în vederea aplicării acestuia la intrarea convertorului analog/digital din interiorul microcontrolerului.

Desigur, scopul aplicației, gama temperaturii măsurate, desemnează alegerea celei mai potrivite metode de compensare şi aplicare a corecției precum şi tipul optim de termocuplu sau alt tip de senzor care trebuie utilizat pentru obținerea unei bune precizii a rezultatului măsurătorii.

În opinia autorilor reprezintă contribuție originală, determinarea şi analiza principalelor tipuri de ecuații matematice, care au loc la nivelul convertorului analog digital intern microcontrolerului pentru stabilirea rezoluției optime de conversie şi a metodelor de interfațare.

This article deals with the interfacing modalities of the temperature sensor at the IN/OUT ports of a flash microcontroller from the PIC Microchip family but also, there are being presented and analysed some of the compensation hardware methods of the cold terminal junction, the measurement corrections, the dependence of the route (amplifier to the minimal perceptible level) of the useful compensated signal with a view to its application to the input Analog-Digital converter enclosed in microcontroller.

By all means, the purpose of the application, the range of the measured temperature (the temperature variation) determine the choice of the most appropriated compensation methods as well as the optimal type of thermocouple or another sensor type which must be used in order to obtain a good precision of the measuring results.

In the author's opinion represent an original contribution, the determination and analysis the main types of the mathematical equations at the level of the AD converter enclosed in the microcontroller in order, to release the optimal resolution conversion and the interfacing methods.

Keywords: Electromotive force (EMF), Seebeck coefficient, Resistive Temperature Detector (RTD)

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1. Introduction

It is a well known that each thermocouple having two terminals can change to a group of three thermocouples by simply connecting its terminals with cables conductors made of a different material than the one from which the thermocouple is built. Consequently, the user has to use special cables made of pairs of adding conductors of the same materials as the thermocouple if the signal is transmitted to a long distance or use signal converters close by the thermocouples.

A method to avoid this inconvenience can consist in using the signal converters in the neighbourhood of the thermocouple but, the existing types of thermocouples indicate an extremely large variation of the electromotive force (Seeback effect) corresponding to a 1˚C/variation of temperature and that requires converters specialised for each type of thermocouples which seems to be an unrightful solution if the interchanging is taken into account .

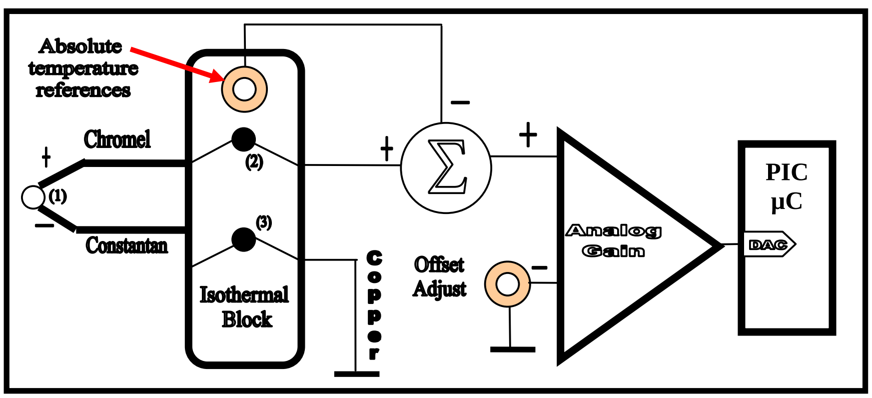

Fig. 1 The interfacing of the thermocouples with the microcontroller using an operational amplifier [1]

The thermocouple signal path starts with the thermocouple which is connected to the copper traces of the PCB on the isothermal block. The signal path continues then on to a different circuit that subtracts the temperature of the isothermal block from the thermocouple's temperature.

After digitizing this signal, the microcontroller uses the digital word from the temperature sensing circuit for further processing. The temperature of the thermocouple's cold heads, in the point where the temperature information is taken from, would need to maintain a constant of 0˚C inside of an isothermal block, to be measured with a standard ambient temperature sensor mounted close by the cold junction of the thermocouple and then make the correction of the measurement by diminishing this value (something which is very expensive and difficult to put into practice within an installation).

The reason for which determining the best thermocouple for the interfacing with the microcontroller is given by the requirements of the adjustable processing. Still, an unpleasant aspect of thermocouple's use is the temperature compensation of the cold jonction.

Certainly, the error resulted in the lack of this correction for a measured temperature of 1000C is extremely low so that in practice, the correction may not be done. It is not the same for a less than 200C temperature in which case the error may get to 10%.

Yet, the most difficult problem regarding the interfacing of the thermocouples with the microcontroller remains the measuring, the processing and the transmitting of the right temperature, a linearity of the analogic signal evolution due to the temperature and providing the necessary satisfactory voltage level for the correct functioning of the analog/digital converter from the inside of the microcontroller-(see Fig. 1).

The methods to be presented need a voltage reference, a constant current generator to diminish the error of the measurement due to the current variation with the temperature through a sensor and a circuit of amplifying the potential taken from the sensor.

This leads to a complication in the case of the technology meant to measure the tension of the cold terminals mounted with a metallic block (isothermal block) so that both terminals have the same temperature.

Many other problems still remain, problems related to the conceiving of a programme specialised in microcontrollers, perfecting the hysterizes problems using software if comprising in the adjustable loops of the thermostats having as execution elements electromagnetic relays and displaying the results of the measurement using digital display devices, proper to realise the interface with microcontroller devices.

2. Hardware methods for the compensation and correction of the signal using thermocouples in the application with a microcontroller

There are compensation techniques that can be used to determine the reference temperature of different types of sensors enclosed in the isothermal block; from this point of view we can classify the compensation methods in:

- **Using a second thermocouple on the isothermal block in order to get the required reference voltage of the analog/digital converter.**

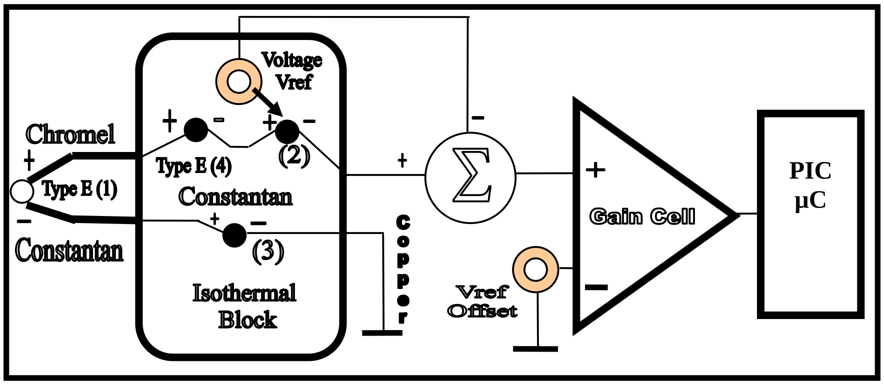

Fig. 2 - The compensation of the cold heads using a second thermocouple inside the isothermal block [1]

For this circuit configuration, two additional thermocouples are built, both of them being of chromel and copper. These two thermocouples are opposing each other in the circuit. If both of these newly constructed thermocouples are at the same temperature, they will cancel each other's temperature induced errors. The two remaining Type E thermocouples generate the appropriate EMF voltage that identifies the temperature at the sight of the first thermocouple.

This design technique is ideal for instances where the temperature of the isothermal block has large variations or the first derivative of voltage versus temperature of the selected thermocouple has a sharp slope (see Fig. 2). Thermocouples that fit into this category with a temperature range from 0°C to 70°C are Type T and Type E.

The error calculation for this compensation scheme is:

$$V_{TEMP} = +EMF_3+EMF_1-EMF_4-EMF_2$$

Where,

- *EMF1* is the voltage drop across the Type E thermocouple at the test measurement site.
- *EMF2* is the voltage drop across a Copper/Constantan thermocouple, where the copper metal is actually a PCB trace.
- *EMF3* is the voltage drop across a Copper/Constantan thermocouple, where the copper metal is actually a PCB trace.
- *EMF4* is the voltage drop across a Type E thermocouple on the Isothermal Block.

- *V TEMP* is the equivalent EMF voltage of a Type E thermocouple (1) to 0°C. The temperature reference of the circuit is configured to track the change in the Seebeck Coefficient accurately.

The dominating errors of this circuit will occur as a consequence of less than ideal performance of the Type E thermocouples, variations in the purity of the various metals and an inconsistency in the temperature across the isothermal block [3]

- **Using a standard PN junction on the isothermal block**

A standard PN junction can be used to sense the absolute temperature inside the isothermal block and this is done through negative voltage coefficient with the temperature which is characteristic to -2,2mV/C semiconducting PN junctions.

PN junctions are useful temperature sensing devices where, high precision is not a requirement. Given a constant current excitation, standard PN junctions, such as the IN4148, have a voltage change in temperature of approximately -2.2mV/°C. These types of PN junctions will provide fairly linear voltage versus temperature performance. However, they may have variations in the absolute voltage drop across the PN junction as well as temperature drift.

This type of linearity is not well suited for thermocouples with wide variations in their Seebeck Coefficients over the temperature range of the isothermal block (referring to Fig. 2). If there are wide variations of the isothermal block temperature, Type K, J, R and S thermocouples may be best suited for the application. [2]

If the application requires more precision in terms of linearity then a PN junction, (for example - the MTS102, MTS103 or MTS105 from Motorola) can be substituted. A circuit that uses a PN junction as an absolute temperature sensor is shown in Fig. 3.

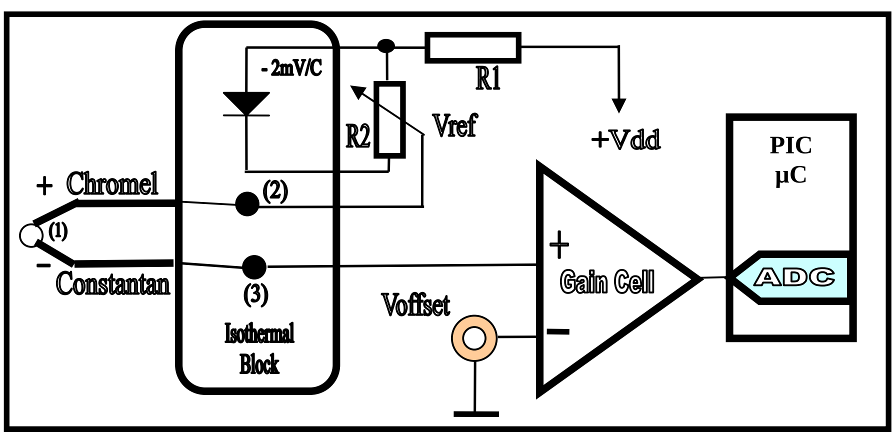

Fig. 3 - The compensation of the cold heads using a PN junction inside the isothermal block [1]

A voltage reference is used in series with a resistor to excite the PN junction. The PN junction changes the temperature and has a negative coefficient; however, the magnitude of this change is much higher than the change of the collective thermocouple junctions on the isothermal block.

This problem is solved by comparing two series resistors with the PN junction. This way, the change of - 2.2mV/°C of the PN junction is attenuated (reduced) to (by) the Seebeck Coefficient of the thermocouple on the isothermal block.

- **Using a thermistor as a temperature sensor with a negative NTC coefficient of temperature; this is avoided due to the unlinearity of the thermistor.**

Thermistors are resistive devices that have a Negative Temperature Coefficient (NTC). These inexpensive sensors are ideal to moderate the precision of the thermocouple sensing circuits when some or all of the non-linearity of the thermistor is removed from the equation.

The NTC thermistor’s non-linearity can be calibrated out with firmware or hardware techniques. However, the firmware techniques are more accurate; the hardware techniques are usually more than adequate. Fig. 4 shows a thermistor in series with an equivalent resistor and voltage excitation.

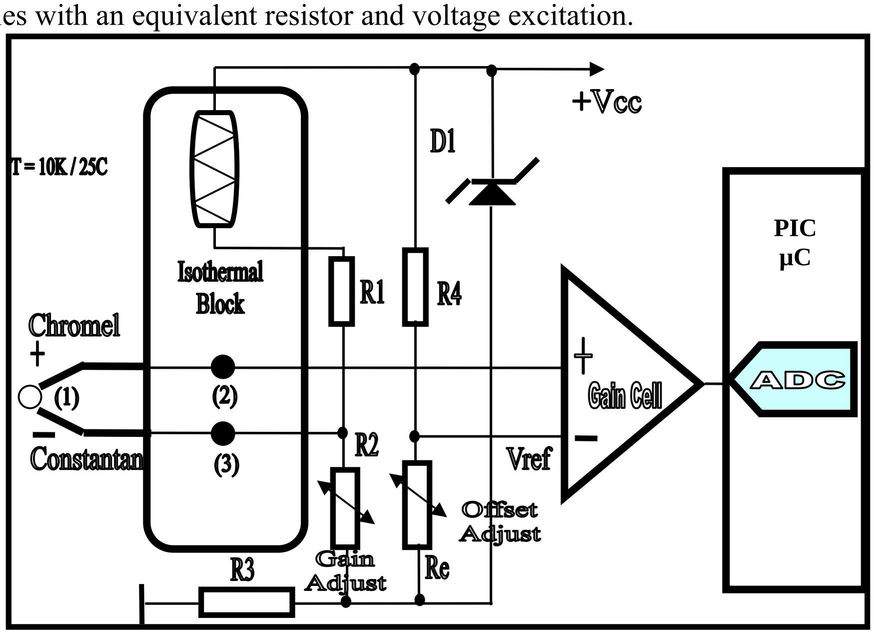

Fig. 4 - The compensation of the cold heads using a NTC thermistor inside the isothermal block [1]

In this circuit, the change in voltage with the temperature is ~ -25mV/°C.

This temperature coefficient is to high. A resistor divider R1 and R2 can easily provide the required temperature coefficient dependent on the thermocouple's type. This type of voltage excitation does have fairly linear operation over a limited temperature range (0°C to 50°C). Taking advantage of this linear region reduces firmware calibration overhead significantly. Alternatively, the NTC thermistor can be excited with a current source. Low level current sources, such as 20mA are usually recommended which minimizes self heating problems.

A thermistor that is operated on with a current firmware excitation has a fairly non-linear output, and with this type of circuit, firmware calibration would be needed. Although the firmware calibration is somewhat cumbersome, this type of excitation scheme can be more accurate.

- **Using an integrated silicon sensor to generate the reference temperature needed by the AD converter enclosed in the microcontroller**

It conditions the temperature response internally and provides an usable such as 0 to 5V output, digital 8 or 12 bit word, or temperature – to – frequency output. The output of this type of device is used by the microcontroller to correct or remove the isothermal block errors (see Fig. 5).

Once the reference temperature of the isothermal block is known, the temperature at the head of the thermocouple can be determinated. This is done by taking the EMF voltage, subtracting isothermal block errors and determining the temperature using the linearization equations.

The EMF voltage must be digitized in order to easily perform these operations. Prior to the analog/digital conversion process, the low level voltage at the output or the thermocouple must be gained from the operational amplifier devices.

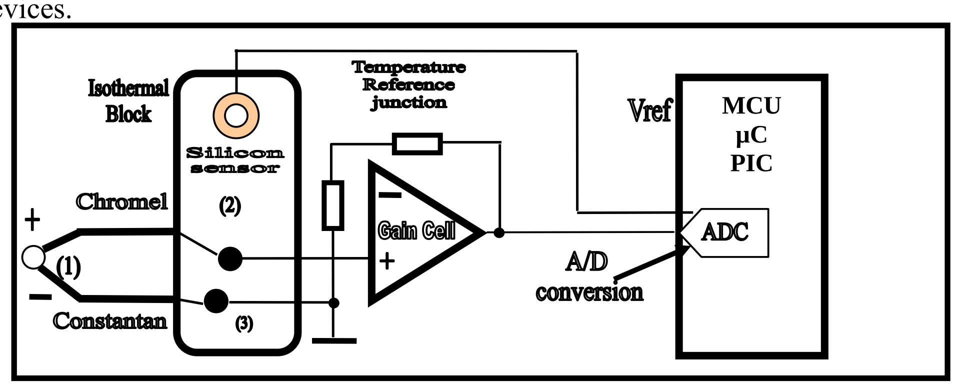

Fig.5-The compensation of the cold heads using a silicon sensor inside the isothermal block[1]

3. The main types of mathematical equations solved by analog/digital converter (ADC) enclosed in microcontroller devices

The analog/digital conversion process is directly made in the microcontroller's memory. A direct interfacing with the analog/digital converter (ADC) enclosed in the microcontroller is performed by correctly choosing the initial resistance of the sensor and the current's polarization so that the generated tension at the measured temperature could be taken over with a maximum resolution by the microcontroller- (see Fig. 6)**.**

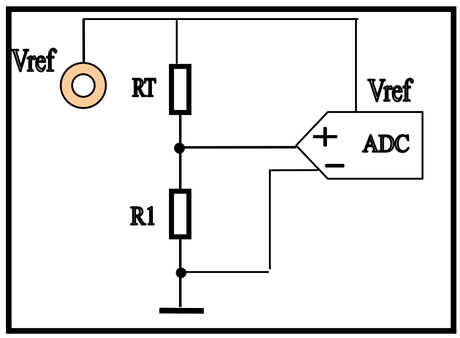

Fig. 6- Interfațarea directă cu convertorul AD sau convertorul tensiune-timp din interiorul microcontrolerului

The mathematical equation for V_T voltage for the converter is:

$$V_T = \left(\frac{R_1}{R_1 + R_T}\right) \times V_{REF} \qquad (1)$$

The mathematical equation to calculate the resolution needed by the converter enclosed in the microcontroller is:

$$ADC = \left(\frac{V_T}{V_{REF}}\right) \times 2^N \qquad (2)$$

By replacing the 4.5 relation, in the 4.6 relation the result is:

$$ADC = \left(\frac{R_1}{R_1 + R_T}\right) \times 2^N \qquad (3)$$

From the 3rd equation the resulted rezistance value of the sensor must be chosen according to the maximum resolution of the AD converter from inside the microcontroller

$$R_T = \frac{(2^N - ADC)}{ADC} \times R_1 \qquad (4)$$

The microcontroller solves the following equation to find the measured temperature

$$T_{^\circ C} = \left[b_0 + b_1 \times \ln R_T + b_2 \times (\ln R_T)^2 - 273{,}5\right] \qquad (5)$$

There are cases in which the scalar leads to a dramatic lowering of the resolution's temperature from 10bits to 6.7 bits. If the application needs no comparison with the reference temperature with integral value, the reducing of the resolution, which is due to the scalar, does not create problems.

4. Conclusions

- The most difficult problem which may occur at the interfacing of the thermocouples with the microcontroller regards the correct measuring of the reference tension needed by the analog/digital converter enclosed in the microcontroller and implicitly, providing a correct level of tension to the analogic signal generated in the field of the measured temperature in order to be taken over by the microcontroller.
- For example, a S or R thermocouple functioning at 1500ºC requires the measuring of a tension of 1500·5μV=7,5mV. I n order to get the maximum resolution of 1500ºC/1024=1,46 of the internal analog/digital converter the signal must be amplified with 7,5mV·588 = 4,4Vcc.
- Thermocouples have their advantages when used in tough application problems. They are rugged and impervious to hostile environments.The voltage output of this temperature sensing element is relatively low when compared to the devices that can convert voltage signals to a digital representation.
- Consequently, analog gain stages are required in the circuit, using a performant operational amplifier. The offset voltage must be 20 times lower than the value given by the thermocouple and stable as the ambient temperature. This can be possible by lowering the individual amplification of the amplifiers in the chain having positive effects on the global histerizes.
- The analogic signal performed on the converter is transformed in logical information having the shape of a word of data of 4, 8 or 12 according to the type of each of them and this value is kept in the microcontroller's memory.
- The reaction speed, the response time, the dynamical characteristics and the problems connected with the histerizes cycles depend on the type of the temperature sensor which is being used and on the performances of the correction and amplification circuits enclosed in the transmission loop of the signal.

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