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THERMOD- Signal Conditioning Module with Cold Junction Compensation in Thermocouple

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Abstract— Thermocouple sensors are used to measure temperatures in systems widely. However, thermocouples suffer from cold junction compensation errors as well an output voltage in the range of mV. This paper serves to provide the means for active Cold Junction Compensation (CJC) as well as the subsequent scaling and amplification of the corrected voltage. A system is designed to acquire temperature data which consists of a temperature sensor, signal conditioning circuit, an Analog to Digital Convertor (ADC), as well as software that manages the configuration of the system. This paper discusses a circuitry for the measurement of temperature incorporating CJC with necessary software and hardware results. The CJC potential is computed from its ambient temperature using a temperature sensor (LM35) interfaced with Arduino UNO board and displayed in a Liquid Crystal Display (LCD) screen. The primary advantage of the active compensation circuit is the replacement of the cumbersome ice bath method. Further the circuit is capable of incorporating different kinds of thermocouples.

Index Terms— Thermocouple, Cold Junction Compensation, Temperature sensor, Proteus

1 Introduction

THERMOCOUPLES are a popular type of temperature measurement device. A relatively low price, ruggedness, wide temperature range, repeatability, fast response, no excitation, long-term stability, and proficiency with contact measurements make thermocouples very common in a wide range of applications especially in process industries. The low cost and versatility of a thermocouple make up for the difficulty in precision. The use of thermocouples often simplifies application circuitry because they don't need excitation. That is, these devices generate voltage without any supplementary active circuitry. Thermocouples do, however, require a stable voltage reference and some kind of ice-point or cold-junction compensation. The purpose of CJC is to compensate for the recorded temperature of cold junction for which a common method is forcing the junction from the thermocouple metal to copper metal to a known temperature (such as 0 °C) by submersing the junction in an ice bath, and then connecting to the copper wire from each junction to a voltage measurement device.

2 Thermocouple Measurement Principles

2.1 Traditional Measurment Techniques

In a classical design, one end of a thermocouple is kept in an ice bath to establish a known temperature. For most applications, providing a true ice point reference is not viable. Instead, the temperature of junctions kept in the ice bath are continuously monitored and used as a point of reference to calculate the temperature at hot junction at the other end of the thermocouple. These endpoints are termed as junctions because they connect to a terminal block which transitions from the thermocouple alloys into the traces used on the Printed Circuit Board (PCB), which is usually copper. This transition back to copper leads to cold junctions. Because of the law of intermediate metals, these junctions can be treated as a single reference junction, provided that they are isothermal. When the temperature of the cold junction is known, the absolute temperature at hot junction can be calculated. Measuring the temperature at cold junctions and thereby using that temperature to calculate a second temperature at the hot junction is known as cold-junction compensation. In many applications, the temperatures of cold junctions are measured using a diode, thermistor, or RTD. The essential conditions for measurement are:

1. The cold junctions must remain isothermal. This condition can be attained by keeping junctions in very close proximity to each other and away from any sources of heat that may exist on a PCB. Many times, isothermal blocks are used to keep the junctions at the same temperature. A large mass of metal offers a very good form of isothermal stabilization. For other applications, maximizing the copper fill around the junctions may be sufficient. By creating an island of metal fill on both the top and bottom layers, joined with periodically placed through a simple isothermal block can be created. Ensure that this isothermal block is not affected by parasitic heat sources from other areas in the circuit, such as power conditioning circuitry.

2. The isothermal temperature of cold junctions must be accurately measured. The closer a temperature sensor can be positioned to the isothermal block, the better. Air currents can also lessen the accuracy of the CJC measurement. To achieve best performance, it is recommended to ensure that the cold junction be placed within an enclosure and thereby air currents can be kept to a minimum near the cold junction. In cases where air currents are unavoidable, an alternative may be

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to use some form of shielding or other mechanical method to cover the cold junction measurement unit and connector block to protect the cold junction from air currents. Furthermore orientation of the PCB can affect the accuracy of the cold-junction compensation. If there are heat-generating elements physically below the cold junction, for example, inaccuracies can become significant when heat from those elements rises.[1]

2.2 Active Cold Junction Compensated Measurment Techniques

Here a temperature sensor is made use of to determine the surrounding temperature. It generates a voltage corresponding to the sensed temperature. This voltage is scaled corresponding to the thermocouple being used. This serves as one of the inputs for an instrumentation amplifier[5]. The other of which is the sensed thermocouple voltage. The difference is amplified and finally scaled to obtain the compensated conditioned output. The versatility of this arrangement is clearly understood from the process flow as given in Fig.1.

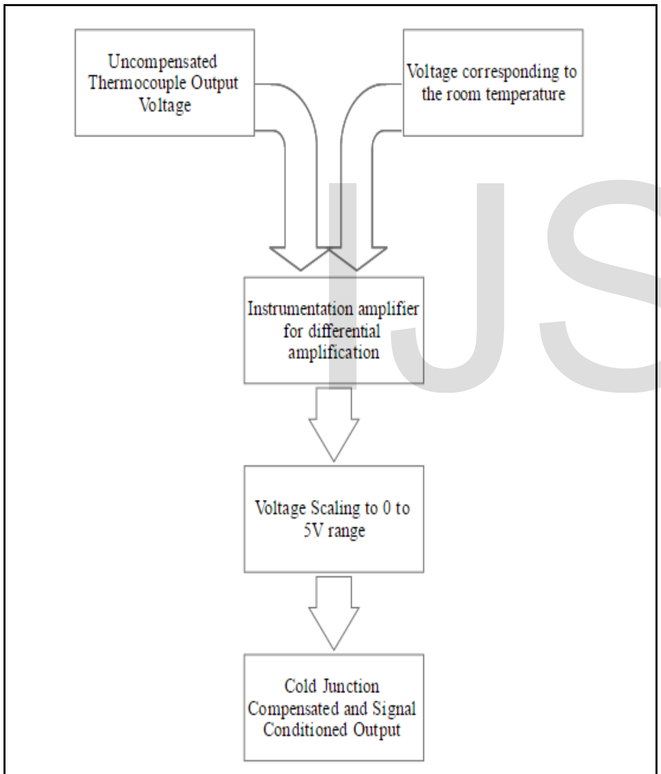

Fig. 1. Process Flow Diagram

3 Active Compensation Circuits

Here compensation involving two sensors are discussed, that of LM335 and LM35. The former offers output in the range of volt corresponding to the Kelvin Scale. The latter offers output voltage in the scale of mV corresponding to the Celsius Scale. The aim of both is the same, to generate a voltage corresponding to the error voltage allowing us to remove that from the voltage equivalent to the measured temperature.

3.1 Generation of Signals for Cold Junction Compensation using LM335

A single-supply circuit is shown in Figure 1. R3 and R4 divide down the 10 mV/K output of the LM335 to match the Seebeck coefficient of the thermocouple. The 1M110ZS5 and its associated voltage divider provide a voltage to buck out the 0 °C output of the LM335. To calibrate, alter R1 so that V1 less than (5°C×T), where less than 5°C is the Seebeck coefficient and T is the ambient temperature in degrees Kelvin. Then, adjust R2 so that V1,V2 is equivalent to the thermocouple output voltage at the identified ambient temperature. To achieve maximum performance from this circuit the resistors must be sensibly chosen. R3 through R6 should be precision wire wounds, precision metal film types with a 1 percent tolerance and a temperature coefficient of ±5 ppm/°C or better.

Furthermore having a low TCR(Temperature Coefficient of Resistance), these resistors exhibit low thermal emf when the leads are at diverse temperatures, ranging from 3 µV/°C for the TRW MAR (series of resistors by TRW limited) and to only 0.3 µV/°C for the Vishay types. This is especially important when using S or R type thermocouples that output only 6 µV/°C. R7 should have a temperature coefficient of ± 25 ppm/°C or better and a 1 percent tolerance. Note that the potentiometers are placed where their absolute resistance is not important so that their TCR is not critical.

However, the trim pots should be of a stable cermet type. While multi-turn pots are usually considered to have the best resolution, many modern single-turn pots are just as easy to set to within ±0.1 percent of the desired value as the multi-turn pots. Also single-turn pots usually have superior stability of setting, versus shock or vibration. Thus, good single-turn cermet pots (such as Allen Bradley type E, Weston series 840, or CTS series 360) are good candidates for high-resolution trim applications, competing with the more obvious (but slightly more expensive) multi-turn trim pots such as Allen Bradley type RT or MT, Weston type 850, or similar. With a room temperature adjustment, drift error will be only ± 0.5°C at 70°C and ±0.25°C at 0°C. Thermocouple nonlinearity results in additional compensation error. The chromel/alumel (type K) thermocouple is the most linear.

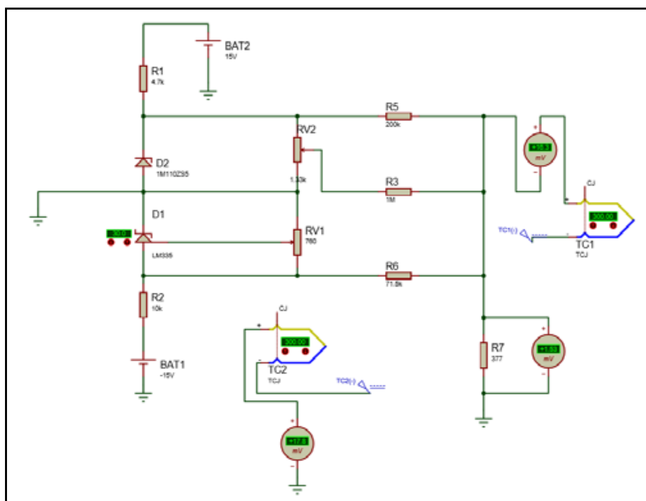

Fig. 2. LM335 Compensation Circuit in Proteus

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With this type, a compensation accuracy of ±0.75°C can be obtained over a 0°C-70°C range. Performance with an iron-constantan thermocouple is almost as good. To keep the error minimal for the less linear S and T type thermocouples, the ambient temperature must be maintained within a more limited range, such as 15°C to 50°C. Of course, more accurate compensation over a narrower temperature range can be obtained with any thermocouple type by the proper adjustment of voltage and offset. [2]

From the circuit analysis, it is observed that the voltage provided at the output varies with and without CJC design. Initially set the temperature to be 300°C for which we obtain a corresponding output voltage of 17.8 mV for the thermocouple which hasn't been compensated. Upon the design and the attachment of the compensation circuit to the thermocouple we have an output voltage of 16.3 mV at the output. This is obtained by the compensation circuit generating a drop of 1.53 mV when the LM335 is set at a room temperature of 30°C. The voltage generated by the LM335 is stabilized by means of the zener diode 1M110ZS5 [6].

3.2 Generation of signals for Cold Junction Compensation using LM35

The LM35 series are precision integrated-circuit temperature devices with an output voltage linearly-proportional to the Centigrade temperature. The LM35 device has an advantage over linear temperature sensors calibrated in Kelvin, as the user is not obliged to subtract a large constant voltage from the output to obtain convenient centigrade scaling. The LM35 device does not require any peripheral calibration or trimming to deliver typical accuracies of ± 0.25°C at room temperature and ± 0.75 °C over a full 55 °C to 150 °C temperature range [3].

Some of its properties include:

- Calibrated Directly in Celsius (Centigrade)
- Linear +10 mV/ °C Scale Factor
- 0.5 °C Ensured Accuracy (at 25°C)
- Rated for the full 55°C to 150°C Range
- Operates from 4 V to 30 V
- Low Self-Heating, 0.08 °C in Still Air
- Low-Impedance Output, 0.1Ω for 1 mA Load
  Non-Linearity Only ±0.25 °C typically

4 Passive Compensation Circuits

Both the previously discussed circuits are capable of actively varying the error voltage corresponding to the room temperature. Making use of simple attenuator circuit involving op amps we can further simplify the previously discussed circuits. The following are the values of voltages in and around the room temperature of 30°C for a J type thermocouple.

Based on the minor changes in voltage in and around room temperature we have can design a circuit capable of generating 1.55425 mV from an input of -5V .This voltage is to be fed into one arm of the instrumentation amplifier the other arm of which is used to input the thermocouple measured voltage. The result of which is the produce an amplified value of the cold junction compensated voltage.

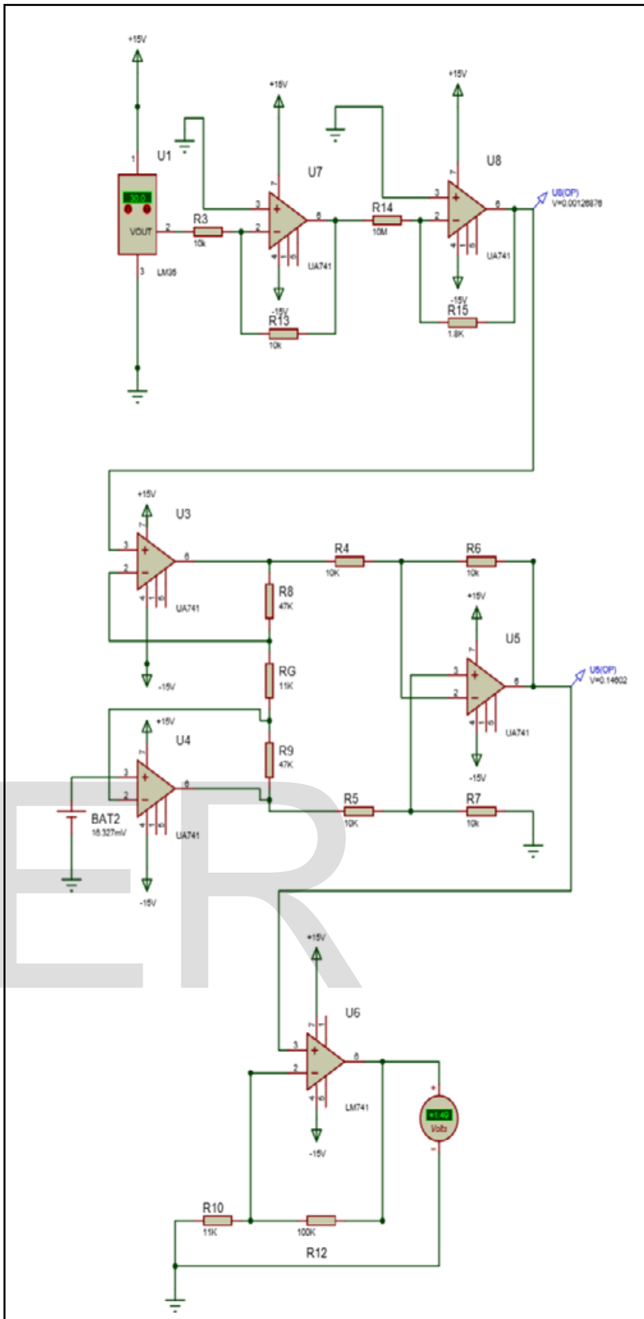

Fig. 3. LM35 Compensation and Signal Conditioning Circuit

5 Signal Conditioning Circuits

The compensated voltage needs to be subsequently amplified and scaled to meet our requirements.

5.1 Instrumentation Amplifer

The output of the thermocouple is of very low amplitude (often in the range of mV). There is thus a need to amplify the output but there we should ensure that noise does not cause large errors. Thermocouples in particular are susceptible

TABLE 1
TEMPERATURE(°C) VS VOLTAGE (MV)

S.NO	TEMPERATURE (°C)	VOLTAGE (MV)
1.	26	1.329
2.	27	1.389
3.	28	1.433
4.	29	1.485
5.	30	1.537
6.	31	1.589
7.	32	1.641
8.	33	1.693
9.	34	1.745

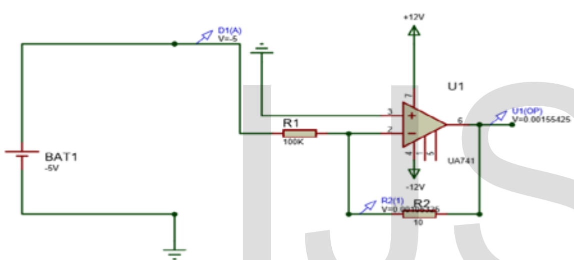

Fig. 4. Attenuator Compensation Circuit in Proteus

to noise generated in the output signal as a result of external disturbances. Thus here an instrumentation amplifier is made use of in place of a differential amplifier due to its high CMRR ratio[4].

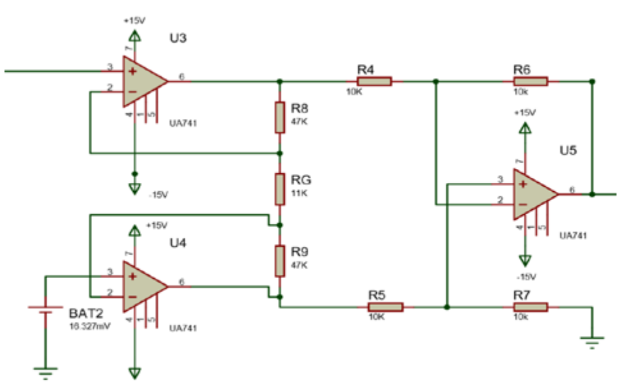

Fig. 5. Instrumentation Amplifer Circuit Executed in Proteus

In this work, two inputs are fed into the instrumentation amplifier. One would be the output of the thermocouple without CJC while the other would be the output of the compensation circuit. This will allow us to eliminate the cold junction effect and directly amplify the signal as the input voltage will now be the difference of both the inputs. As per the circuit a gain of 10 has been assigned to the circuit. For example for an input of 13.5 mV we have an output voltage of 135 mV thus giving us an amplified output signal.

5.2 Scaling Circuit

The standard values in terms of current are 4-20 mA range and in terms of voltage this converts to a 0-5 V range.

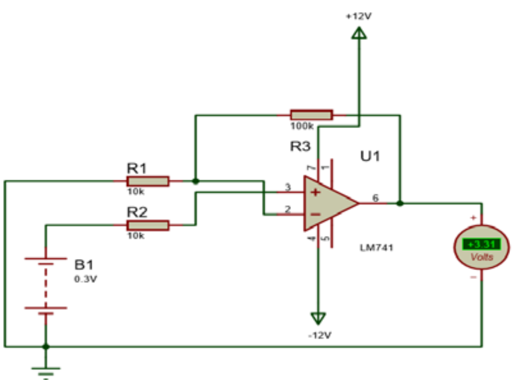

Fig. 6. Scaling Circuit in Proteus

6 SYSTEM PROTOTYPE UNIT

In this work an Arduino Uno powered by an ATmega328 microcontroller is utilized. Further the display is registered on an LM016L Liquid Crystal Display (LCD).

6.1 Arduino Uno with Atmega328

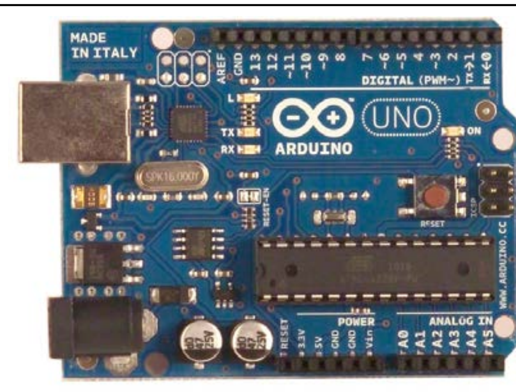

Fig. 7. Arduino Uno Board[7]

6.2 LM016L

The most commonly used LCDs are of 1,2 and 4 line. These make use of 1 controller and support at most of 80 characters, whereas 2 HD44780 controllers are made use of when more support is required. LCDs with 1 and 2 controllers have 14 and 16 pins respectively.

6.3 PCB board layout

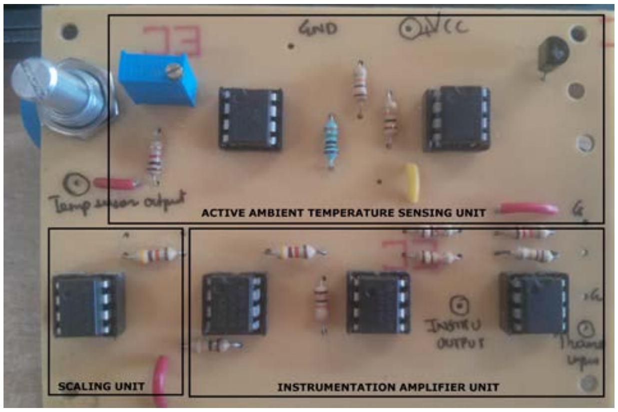

Fig. 8. PCB Circuit for CJC compensation and signal conditioning

TABLE 2
LCD PIN CONFIGURATION

PIN	SYMBOL	I/O	DESCRIPTIONS
1	VSS	--	GROUND
2	VCC	--	+5V POWER SUPPLY
3	VEE	--	POWER SUPPLY TO CONTROL CONTRAST
4	RS	I	RS=0,TO SELECT COMMAND REGISTER RS=1, TO SELECT DATA REGISTER
5	R/W	I	R/W=0 FOR WRITE R/W = 1 FOR READ
6	E	I/O	ENABLE
7	DB0	I/O	THE 8 BIT DATA BUS
8	DB1	I/O	THE 8 BIT DATA BUS
9	DB2	I/O	THE 8 BIT DATA BUS
10	DB3	I/O	THE 8 BIT DATA BUS
11	DB4	I/O	THE 8 BIT DATA BUS
12	DB5	I/O	THE 8 BIT DATA BUS
13	DB6	I/O	THE 8 BIT DATA BUS
14	DB7	I/O	THE 8 BIT DATA BUS

7 RESULTS

The measurements were carried out at room temperature, in particular at 30°C. Thus here we have the compensation voltage to be 1.203mV and 1.537 mV for K type and J type thermocouples respectively. The experimental values have been obtained as 1.20292 mV and 1.53809 mV for the K type and the J type thermocouples respectively.

TABLE 3
K TYPE THERMOCOUPLE RESULTS

TEMPERATURE (°C)	OUTPUT VOLTAGE(MV)	CJC AND SIGNAL CONDITIONED OUTPUT VOLTAGE (V)	
		THEORETICAL	EXPERIMENTAL
100	4.096	0.2893	0.3221
200	8.138	0.6935	0.7114
300	12.209	1.1006	1.1034
400	18.091	1.6888	1.6699
500	20.644	1.9441	1.9158

TABLE 4
J TYPE THERMOCOUPLE RESULTS

TEMPERATURE (°C)	OUTPUT VOLTAGE(MV)	CJC AND SIGNAL CONDITIONED OUTPUT VOLTAGE (V)	
		THEORETICAL	EXPERIMENTAL
100	5.269	0.3732	0.4028
200	10.779	0.9242	0.9334
300	16.327	1.4790	1.4677
400	21.848	2.0311	1.9994
500	27.393	2.5856	2.5334

8 CONCLUSION

This paper summarizes an analog signal conditioning circuit for CJC of a thermocouple. Simulations have been performed in Proteus software and circuitry has been developed in real time for active CJC. The implemented circuit design is capable of incorporating different kinds of thermocouples at different gains. Experiments are being conducted to test the effectiveness of the circuit developed. It holds great promise in automation as well as connected industrial systems.

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