Transport Refrigeration Unit Control using CAN Communication

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Abstract – *Transport Refrigeration units are used for maintaining the quality of food products and transporting them from one place to another. It can be observed that one of the most important parameters in TRU is temperature. There are multiple temperature sensors located physically at different places within the refrigeration systems and the containers to record the temperatures. Therefore, the harness required to connect these temperature sensors with the controller is high. A small temperature sensor module which produces CAN signals that can directly be connected to the receiver interface is proposed in this work. This will make the system compact as the amount of harness required is reduced and it also reduces the overall cost. The prototype was built considering PT(Platinum) temperature sensor. A signal conditioning circuit is designed to improve the resolution, accuracy and sensitivity. Simulation of signal conditioning circuit is performed in PSIM and the results were verified. Error analysis was performed using LTSPICE considering the tolerance values using Monte-Carlo method. The error offered by the circuit was found to be varying between 0.808℃ to 0.5739 ℃ for -50 to 150 ℃ respectively. It was also observed that the sensitivity is improved 11 times with the help of a signal conditioning circuit. The hardware module is built using ATMEGA 328P microcontroller and MCP 2515 CAN controller. The microcontroller is programmed using Embedded C language. Testing is carried out between the melting point of ice (0 ℃) to boiling point of water (100 ℃).*

Key Words: **Transport Refrigeration unit, CAN Communication, Temperature Monitoring, Temperature Sensors, Signal Conditioning.**

1.INTRODUCTION

In the 1830's the consumer demand for fresh food was growing. This led to the invention of refrigeration system by American inventor Jacob Perkins in the year 1834 [1]. Since then, there have been significant developments in modern refrigeration systems. Although, refrigeration system was primarily built for storing food products in the initial days, it also proved vital in pharmaceutical industry as the medicines had to be maintained at a specific temperature. One of the major concerns with the Refrigeration systems was its inability to transport food and medical products from one place to another. This paved the way for developing Transport Refrigeration Unit (TRU) in the year 1940 [2]-[4].

Ever since its emergence, the pattern of food consumption has totally changed. There are multiple temperature sensors mounted in the TRU at different places for temperature measurement. In addition, there are different types of temperature sensors available in the market today. However, selection of the right temperature sensor largely depends on the nature of application. Modern semiconductor temperature sensors (IC Based) offer high linearity and accuracy over an operating range of -55° C to -150° C. Thermistors have the best sensitivity among the sensors available but are the most non-linear. However, they are popularly used in portable applications such as battery management systems. Thermocouple have the widest operating range but would require cold junction compensation. Resistance Temperature Devices (RTD) are accurate with an operating range of -200° C to 850° C and are used in refrigeration applications [5].

As there are multiple temperature sensors present in a TRU and containers, communicating and prioritising individual sensor unit with the Electronic Control Unit (ECU) is one of the major challenges. However, the evolution of Controller Area Network (CAN) by Bosch in the 1980's redefined the communication protocol in automobile industry [6]. CAN is a serial half duplex asynchronous communication-based protocol. It uses differential communication with CAN H and CAN L outputs to minimize the effect of external noise signal during communication. In the past, automotive manufacturers connected electronic devices using wires [7]-[8]. As the number of electronic components increased in the vehicles, it resulted in bulky wire harnesses that were heavy and expensive [9] – [10]. It accounted for multiple ECU's in the system. From the development of CAN protocol the number of ECU's came down to one and there are multiple CAN interfaces to communicate with the ECU.

1.1 Block Diagram of the transmitter

The block diagram of the transmitter unit is shown in Fig 1. The temperature sensor chosen is PT 100 / PT 1000 whose output is in resistance. The resistance is converted to proportional output voltage through a signal conditioning circuit. In addition, the signal conditioning circuit has been designed considering the scope for resolution improvement and better system performance. The output of the signal conditioning circuit is analog signal and hence needs to be converted to an equivalent digital value. It is done with the help of internal ADC of ATMEGA 328P microcontroller.

The microcontroller is interfaced with MCP 2515 CAN controller. The communication between MCP 2515 and ATMEGA 328P is through Serial peripheral interface (SPI). The inbuilt TJA1050 Transceiver is responsible for facilitating the communication between the CAN controller and ATMEGA 328P.

The CAN controller will produce two output signals i.e. CAN High and CAN low. These are also referred to as differential signals. The output of the CAN controller at the transmitter unit is given to the CAN controller at the receiver unit through cables. The microcontroller is programmed using Embedded C language and the program is loaded in the microcontroller through ATMEGA 16U2 processor.

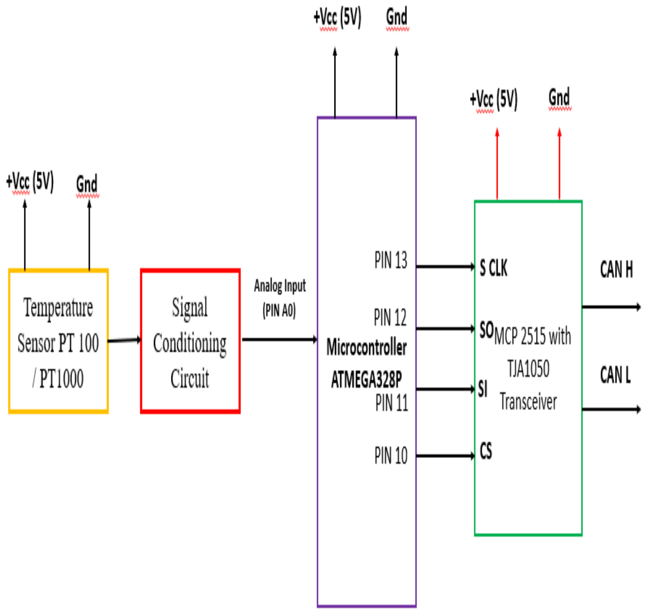


Fig 1: Block Diagram of Transmitter

1.2 Block Diagram of the Receiver

The block diagram of the receiver is shown in Fig 2. It is to be noted that the receiver unit is developed for prototype purpose. The receiver unit again contains MCP 2515 CAN controller module. The CAN signals are now interfaced with microcontroller through SPI interface.

The microcontroller at the receiving end will be responsible for determining the temperature sensor with unique CAN_ID. The microcontroller chosen at the receiver is ATMEGA 328P. The results obtained will be displayed with a 16x2 LCD display or by serial monitor screen. The communication between microcontroller and LCD display is through I2C.

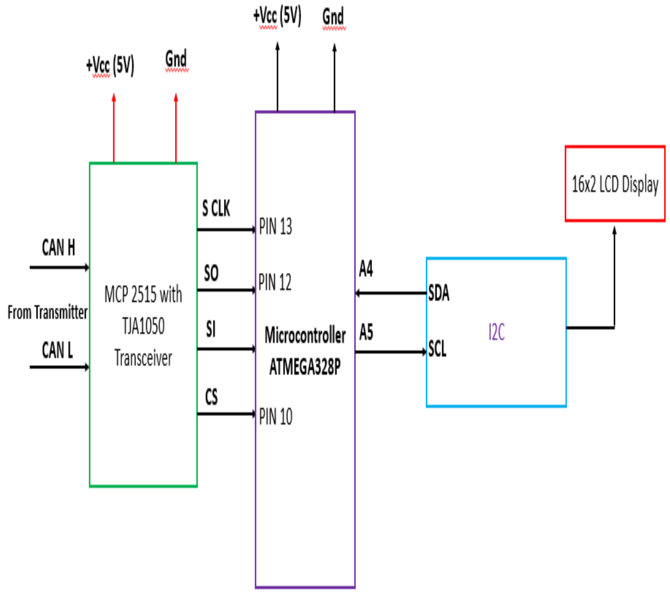


Fig 2: Block Diagram of Receiver

2. SIGNAL CONDITIONING CIRCUIT

The circuit diagram of the proposed signal conditioning circuit is shown in Fig 3. The PT 100/ PT 1000 temperature sensor is connected to the lower voltage divider circuit. The upper voltage divider acts as a constant voltage source producing an output voltage of 0.3716V. The resistors are designed based on the amount of voltage required at the midpoint of the two voltage dividers. As the temperature of PT 100 / PT 1000 sensors changes, the output of the sensor (resistance) will vary linearly proportional to the temperature. The lower voltage divider will convert the resistance values into proportional voltage. Two voltage followers are used for higher input impedance and isolation between input and output signals.

The difference between the two analog voltages is applied as an input to the difference amplifier. The gain of the amplifier is decided by the ratio of feedback and the input resistor of the Op Amp. The gain chosen for the proposed circuit is 11 in order to increase the number of divisions that the microcontroller will sense. Length of PT sensor along with its leads are longer and hence might act as antenna and might pick up noise and mix with the temperature voltage. Hence 100uF capacitor is connected in parallel across PT sensor. It acts as a filter and removes noise levels. The output of the signal conditioning circuit will be applied as the input to the internal ADC of ATMEGA 328P microcontroller.

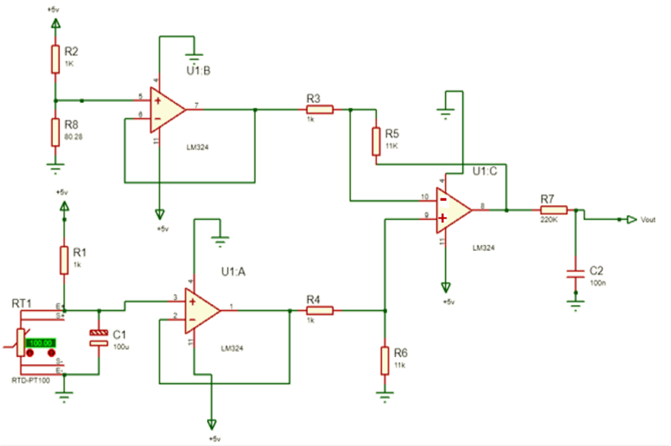


Fig 3: Signal Conditioning Circuit

3. DESIGN

The proposed module is designed to meet the following specifications shown in Table 1.

Table -1: Specifications

Parameters	**Values**
Supply	5 V
RTD range of temperature	-50°C to 150°C
RTD range of resistance	80.3Ω to 157.33 Ω
Output range of voltage	0V to 3.3891 V
Analog to digital conversion	10-bit ADC
Resolution of ADC	4.88mV/ Step
Accuracy	±2 LSB
Sensitivity	9.76mV
Sampling Speed	15kSPS

The value of R1 and R2 is chosen to be 1kΩ for three reasons:

- Value of R must be low to avoid problem of low signal to noise ratio.
- The bias current required for LM 324 is very low (45nA).
- If the value of R is very high then it might cause more voltage drops and results in self heating.

The value of R8 is chosen to be 80.28 Ω because the voltage required from the voltage divider is 0.3716V.

When temperature of PT100 is -50 °C
Vcc = 5V (Fixed), R1 = 1k Ω, RPT100 at -50°C = 80.31Ω

$$\text{Vout} = \frac{\text{Vcc}\times\text{Rpt100}}{\text{Rpt100}+\text{R1}} \tag{1}$$

Substituting from equation 1 we get,

$$\text{Vout} = \frac{5\times 80.31}{80.31+1000} = 0.3716\text{V}$$

When temperature of PT100 is 150 °C

Vcc = 5V (Fixed), R_1 = 1k Ω, R_{PT100} at 150 = 157.33 Ω
Substituting the values in equation 1 we get,

$$\text{Vout} = \frac{5\times 157.33}{157.33+1000} = 0.6797\text{V}$$

The range of voltage from the PT 100 voltage divider is 0.3716V to 0.6797V.

In order to increase the resolution of the output voltage, it is necessary to choose a suitable value of gain. The gain of the Amplifier is chosen considering the minimum and maximum voltages,

At lowest possible temperature -50 °C,

$$Vout = \frac{R_B}{R_A} \times (0.3716 - 0.3716) = 0V$$

At highest possible temperature 150 °C,

$$Vout = \frac{R_B}{R_A} \times (0.6797 - 0.3716) = 0.3081V$$

$$Vout = \text{Gain x Maximum Possible Voltage} \tag{2}$$

The best performance of Op Amp LM 324 is achieved below 3.5 volts. Hence the gain i.e. The ratio of RB and RA is selected as 11.

Therefore, we have

R_B = 11k Ω and R_A = 1k Ω.

The maximum input voltage that will be applied is 0.3081 x 11 = 3.3891 V that is well within the operating voltage (5V) of microcontroller to sense.

4. SIMULATIONS AND RESULTS

The simulation of the signal conditioning circuit is initially carried out in an ideal environment such as PSIM. Later, the error analysis is performed using LTSPICE to verify the performance of the circuit. The error offered by the sensor and the overall circuit is found out using Monte-Carlo analysis.

4.1 Simulation Circuit

The Fig 4 shows the simulation of signal conditioning circuit in PSIM. There are two voltage divider circuits employed in the design. The upper voltage divider circuit acts as a constant voltage source providing an output voltage of 0.3716V, whereas the lower voltage divider converts the resistance of PT temperature sensor into proportional voltage value. Voltage follower is used to provide high input impedance and provides isolation between the amplifier stage and the source. The difference between two voltages are amplified using a difference amplifier with a gain of 11.

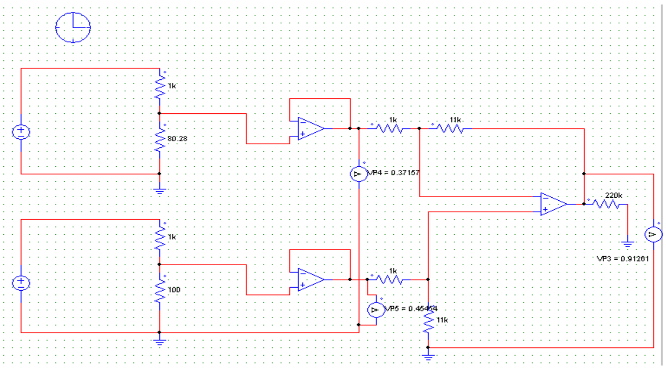
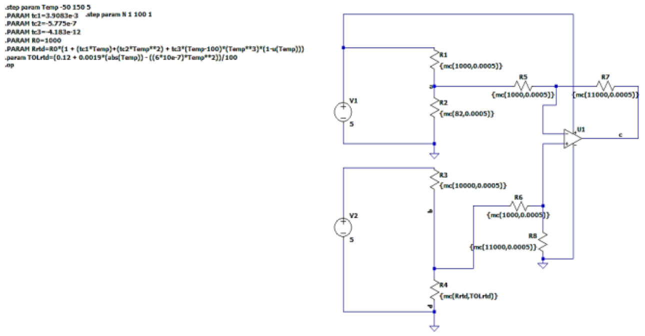


Fig 4: Signal Conditioning Circuit in PSIM

The Fig 5 shows the simulation of signal conditioning circuit in practical conditions using LTPSICE. One of the major issues with the temperature sensor is the error associated with it under industrial conditions. It is therefore necessary to determine the error obtained from the temperature sensor and the signal conditioning circuit. The tolerance of each of the components in signal conditioning circuit is taken into consideration and the error analysis is performed using Monte-Carlo method.



```
.step param Temp -50 150 5
.PARAM tc1=3.9083e-3   .step param N 1 100 1
.PARAM tc2=-5.775e-7
.PARAM tc3=-4.183e-12
.PARAM R0=1000
.PARAM Rrtd=R0*(1 + (tc1*Temp)+(tc2*Temp**2) + tc3*(Temp-100)*(Temp**3)*(1-u(Temp)))
.param TOLrtd=(0.12 + 0.0019*(abs(Temp)) - ((6*10e-7)*Temp**2))/100
.op
```

Fig 5: Signal Conditioning Circuit in LTSPICE

4.2 Simulation Results

The overall output voltage after amplification will be discussed in this section. From the simulation waveform shown in Fig 6, it is observed that the output voltage varies between -6mV to 10.5mV at -50 °C. However, according to the calculations the output voltage at -50 °C must start from 0V. Similarly, the output voltage variation at 150 °C as shown in Fig 7 was found to be between 3.37V to 3.40V. Whereas, the expected value was supposed to be 3.3891 V. The deviation in the output voltage is mainly due the sum of error offered by the two voltage dividers, Temperature sensor and Op Amp.

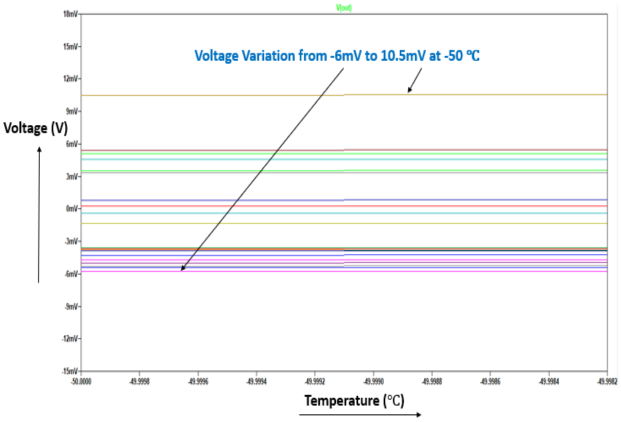


Fig 6: Overall Output voltage after the Amplification at -50°C

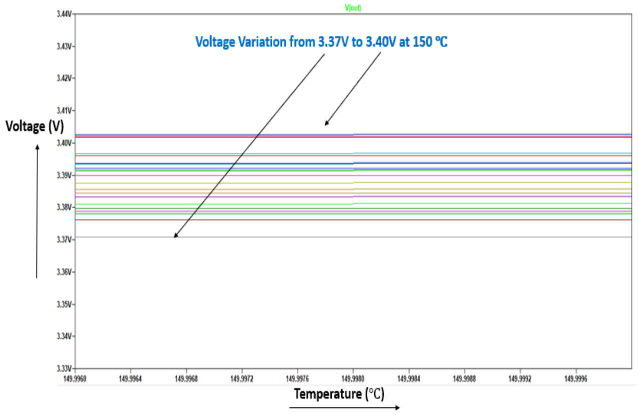


Fig 7: Overall Output voltage after the Amplification at 150°C

The linear variation of the temperature sensor is verified using LTSPICE shown in Fig 8.

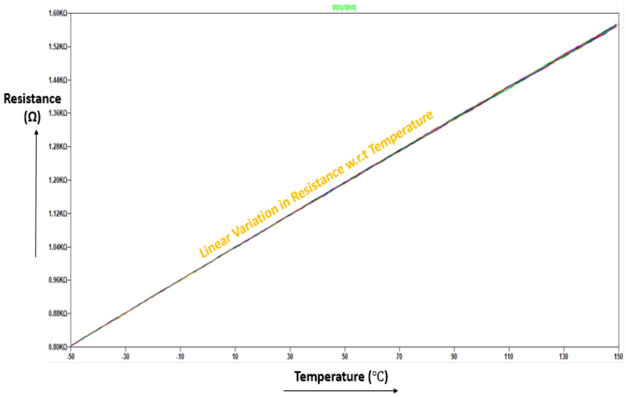


Fig 8: Resistance vs Temperature from -50°C to 150 °C

The Output voltage vs Temperature variation from -50°C to 150°C is shown in Fig 9. It is observed that the output voltage varies linearly with respect to temperature between -50°C to 150°C.

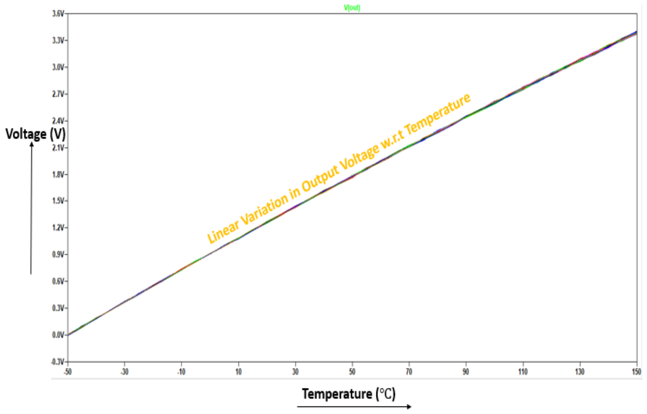


Fig 9: Output voltage vs Temperature for -50°C to 150°C

5. HARDWARE IMPLEMENTATION

The Fig 10 shows the Hardware setup using PT100 Temperature sensor. The prototype was tested considering the extreme temperature points of the temperature sensor and the system was found to produce desired results with high resolution and accuracy up to 0.28 degree Celsius.

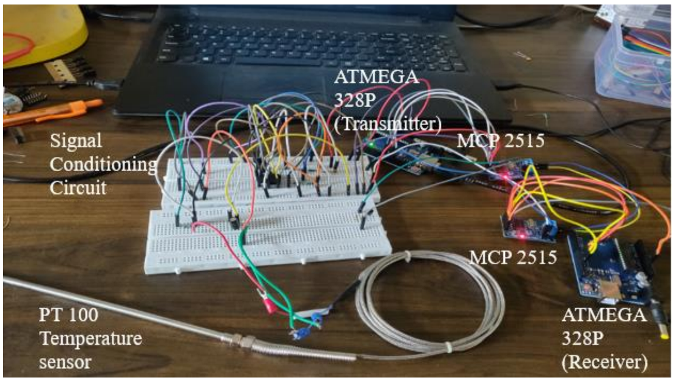


Fig 10: Hardware setup using PT 100 Temperature Sensor

The Fig 11 shows the signal conditioning circuit. The amplification of the voltage signal is achieved using LM-324. The figure also highlights 3 wire PT 100 configuration used in the setup.

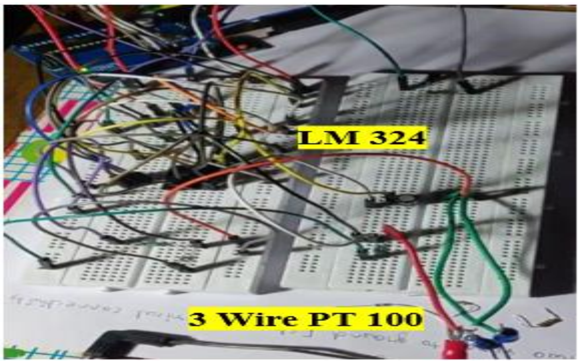


Fig 11: Signal Conditioning Circuit

6. CONCLUSIONS

Temperature sensor module that produces CAN signals is developed in this project. Detailed literature review was performed and it was found that RTD's are the most linear temperature sensor and are perfectly suitable for refrigeration applications. Therefore, the prototype was built considering PT temperature sensor. A signal conditioning circuit is designed to improve the resolution, accuracy and sensitivity. The simulation of signal conditioning circuit is performed in PSIM and the results were verified. Error analysis was performed using LTSPICE considering the tolerance values using Monte-Carlo method. The error offered by the circuit was found to vary between 0.808°C to 0.5739 °C between -50 to 150 °C respectively. It was also observed that the sensitivity is improved 11 times with the help of a signal conditioning circuit.

The module was built using ATMEGA 328P microcontroller and MCP 2515 CAN controller. The microcontroller is programmed using Embedded C language. The data is stored in structures and is sent once the CAN transceiver is ready to accept the signal from the Microcontroller. Each temperature sensor is uniquely identified with the help of a CAN_ID that is stored in database of the controller. Testing is carried out between the boiling point of water (100 °C) to melting point of ice (0 °C). Theoretical and Practical results were compared and the results were very close to each other. However, the small deviations are mainly due to the error found out in simulation analysis.

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