

LEVEL 4 ASSESSMENT SPECIFICATION

Student name:	Beau Lawrence	Student ID number:	
Programme:	HNC Instrumentation Engineering		
Module:	Instrumentation, Automation and Control		
Module code:	PCEE4011	Contribution to Overall Module Assessment (%):	50%
Lecturer:	Jason Pointer	Internal Verifier:	Nigel Richards
Assignment Title:	Temperature Measurement System and Signal Transmission	Word count (or equivalent):	2000
Submission deadline:	23/01/25	Return date of provisional marks & written feedback:	06/02/25
Submission method:	All written assessments, where practical and possible, must be submitted via Turnitin unless otherwise instructed by the Lecturer. (Please DO NOT put this assessment specification into Turnitin or it will match many similarities with other students' submissions.) Alternative submission method (if applicable): Late submission of the assessment will result in a late penalty mark: Work which is submitted up to 1 week late will be capped at 40% for the first attempt and will be awarded a mark of 0% for re-assessment. Late submission penalties may be lifted only if there is an approved extenuating circumstances claim. Work submitted more than 1 week late will be considered as a non-submission and will not be marked. The work may be considered as a submission for reassessment if offered by an Examining Board or if there is an approved extenuating circumstances claim.		
Academic honesty / referencing:	Academic honesty is required. In the main body of your submission you must give credit to authors on whose research and ideas your work is based. Append to your submission a reference list that indicates the books, articles, etc. that you have used, cited or quoted in order to complete this assessment.		

Module Learning Outcomes (from module syllabus)

1. Explain the principles of operation for a range of industrial measuring systems and demonstrate an understanding of the requirement for interfacing sensors with conditioning, indication and analogue/digital signal transmission circuits.
2. Select an appropriate sensor for specific operation and demonstrate an understanding of their benefits and limitations with respect to measuring and control system applications.

STUDENT FEEDBACK FORM

This section details the *extent* to which the assessment criteria are demonstrated by you, which in turn determines your mark. The marks available for each category of skill are shown. Lecturers will use the space provided to comment on the achievement of the task(s), including those areas in which you have performed well and areas that would benefit from development/improvement.

Generic Assessment Criteria	Marks available	Marks awarded
1. Engagement with Literature Skills	15	7.8
Engagement with an appropriate range of literature, including sources retrieved independently. Referencing may show minor inaccuracies or inconsistencies.		
2. Knowledge and Understanding Skills	40	28.1
Task 1 - 77%. Task 2 - 72%. Task 3 - 68%. Task 4 - 64%. Excellent knowledge and understanding of the basic underlying concepts and principles for each task.		
3. Cognitive and Intellectual Skills	10	5
Good evaluation of the underlying concepts and principles for tasks 2 and 3.		
4. Practical Application Skills	25	19.25
Task 1 - 82%. Task 2 - 72%. An excellent application of practical work for tasks 2 and 3, very good use of the test equipment and Multisim to obtain the required test results.		
5. Transferable Skills for Life and Professional Practice	10	6.6
Work is accurate, coherent, fluent, well-structured and organised.		

Assessment Mark (Assessment marks are subject to ratification at the Exam Board. These comments and marks are to give feedback on module work and are for guidance only until they are confirmed.)

Late Submission Penalties (tick if appropriate)

Up to 1 week late (40% Max)

Over 1 week late (0%)

67%

HNC Instrumentation Engineering

Instrumentation , Automation and Control



Student name – Beau Lawrence

Student ID - 175221

Task 1 – Temperature Sensors Research

Temperature Sensors like the Platinum RTDs and NTC thermistors are important in various industries such as in engineering and commercial applications. This report will discuss and compare these two sensors, focusing on the process variable, the performance, environment suitability, constraints, availability and overall cost.

Platinum RTD Construction

A Platinum RTD will consist of a thin wire/ or film from platinum. The resistance of platinum will increase linearly with the temperature, enabling for an accurate temperature measurement. A type of RTD that is commonly used is the Pt100, which has a resistance of 100 ohms at 0 degrees. Platinum RTDs are commonly constructed by winding the platinum into a coil, forming into a film on a ceramic substrate. This structure ensures durability and stability for highly precision applications. Platinum has excellent corrosion resistance, long term stability and means a wide range of temperature (-200...+850 degrees). ✓

NTC Thermistor Construction

NTC (Negative Temperature Coefficient) thermistors are thermally sensitive semi-conductor resistors, which show a decrease in resistance when there is an increase in the temperature. In the NTC thermistor there will be a polycrystalline semiconductor ceramic material with a spinal structure mostly made of metal oxides such as manganese, nickel, iron, copper etc. As the metal temperature increases, the frequency of the metal atoms vibration will also increase, which in turn stop free electron transfer. Thus, the metal's resistance will overall be increased. They are less expensive than RTDs, as their construction is more simple, relying on ceramic materials instead of precious metals as used in the RTD. ✓

Key features

Platinum RTDs are known for their wide temperature ranging, spanning from (-200...+850 degrees), as shown in the graph below, which makes them suitable

for industrial, high temperature applications. They offer high amounts of accuracy “+/- 0.3°C at 0°C, which is quite good, in comparison to types of thermocouples” (Jones.2012). The relationship between resistance and temperature between resistance and temperature is nearly linear, which simplifies calibration and enhances measurement precision. RTDs are highly stable over time with minimal drift in their performance, even under long periods of use.

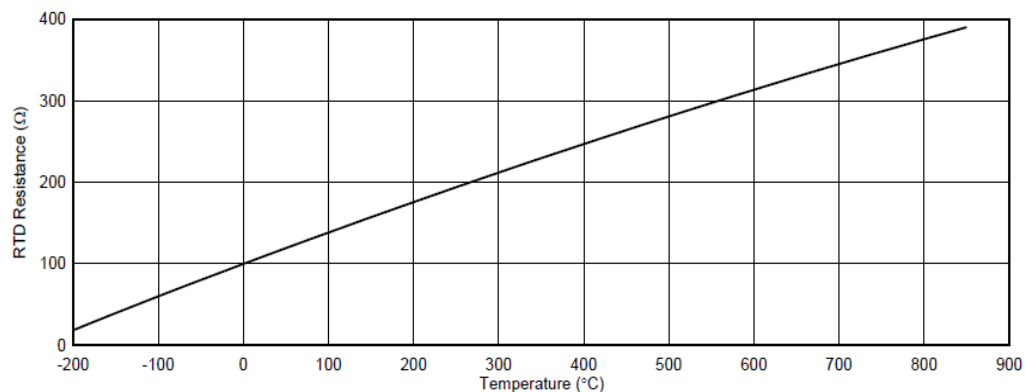


Figure 1. PT100 RTD Resistance From -200°C to 850°C

The graph above shows the RTD resistance is fairly linear, while the graph below shows the resulting non-linearity if an end point is made to the curve in figure 1.

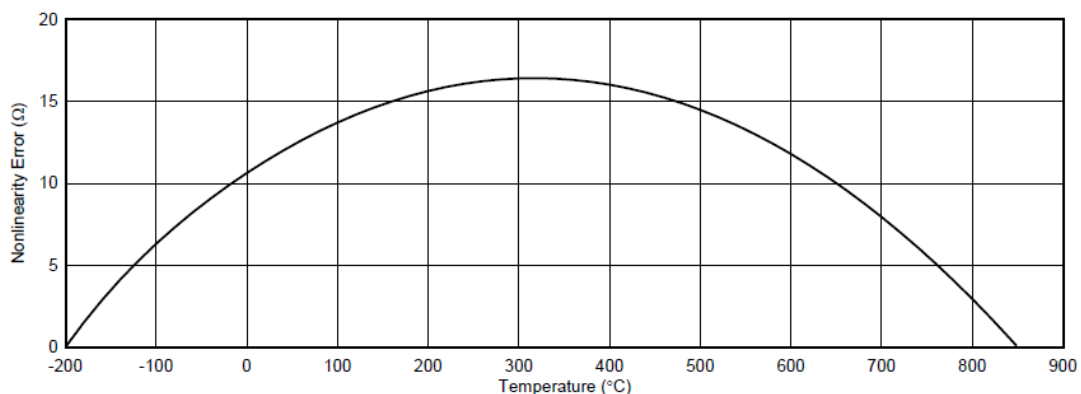


Figure 2. PT100 RTD Non-Linearity From -200°C to 850°C

NTC thermistors commonly operate in a smaller temperature range from -40 to +150. They are mostly acceptable for consumer electronics and moderate temperature applications. The NTC thermistor are highly sensitive to temperature changes that occur within this temperature range, often offering accuracy within +/-0.1 degrees. The resistance- temperature relationship is non- linear, which will require compensation for accurate measurements. NTC thermistors will still have

a quick response time, due to their smaller size and low thermal mass, allowing for them to detect rapid temperature changes quicker in comparison to the RTDs. ✓

Performance of the NTC Thermistor and RTD - Accuracy, Response Time, and Stability

Accuracy and Linearity

Platinum RTDs are known for their high accuracy and Linear behaviour. Close linear relationship between resistance and temperature will enable it for precise measurements over a specific temperature range, making them suitable for high accuracy applications like process control, calibration standards etc. In comparison, NTC thermistors have a non- linear resistance temperature relationship. They can still have high accuracy within a certain temperature range, but due to them being non-linear they will need additional compensation for accurate readings across larger ranges. ✓

Response time

NTC thermistors offer a faster response time in comparison to RTDs, due to their smaller size and low thermal mass it enables them to detect temperature changes faster, which makes them suitable for where rapid temperature fluctuations require monitoring. RTDs have slower response time because of their larger mass of their sensing element, can be a problem in faster pace applications. ✓

Stability

RTDs are known for their high stability over time, and the use of platinum in the RTD helps as it's a highly stable material, which ensures a minimal drift in the sensor's performance even after long periods of use, making RTDs highly reliable for long term temperature monitoring in industrial applications. "NTC thermistors, in comparison, have a lower stability and can experience drift or degradation, especially in harsh environments which can cause this. Thus, making them less ideal for long term applications." (Jones,2012) ✓

Environmental suitability and Durability

Platinum RTDs are highly durable and are able to work efficiently in extreme environments. These RTDs are resistant to high temperatures, vibration, and mechanical stress, which makes them suitable for industrial settings where these environmental factors occur. RTDs can be used in corrosive or hazardous environments, however only with suitable protection, ensuring their longevity and reliability under these conditions. ✓

NTC thermistors are more sensitive to environmental factors like mechanical shock, vibration, and humidity, they are still suitable for applications in controlled environments. For example, they are commonly used in consumer electronics, HVAC systems, and automotive temperature monitoring, where the temperature range is moderate, and exposure to harsh conditions is minimal. However, NTC thermistors are less durable and may be prone to damage in rugged environments. ✓

Cost

The Cost is a main drawback of Platinum RTDs. Platinum is a precious metal and the manufacturing process for RTDs is more complicated in comparison to thermistors. RTDs are usually more expensive than NTC thermistors. The higher cost can be a limiting factor in applications that need large numbers of temperature sensors. However, they have higher accuracy and stability which may justify the additional cost in certain high-precision applications. ✓

“NTC thermistors are more affordable compared to the Platinum RTD due to the use of inexpensive ceramic materials in their construction. This makes them suitable for applications where a large number of temperature sensors are needed, such as in battery management systems, and mass-produced devices.”(Han,2024) Their low cost makes them a more suitable option when cost efficiency is a priority, although their performance limitations may affect their suitability for high-precision applications. ✓

Conclusion

To conclude, the Platinum RTD and NTC thermistor both have distinct strengths and weaknesses. The RTD will offer a high amount of accuracy, a wide temperature range and stability, which makes them suitable for high precision and industrial applications. One limiting factor is the overall cost and slower response time. However, NTC thermistors are more cost effective, offer faster response times and are more ideal for moderate temperature applications. By evaluating these factors like accuracy, temperature range, environmental conditions etc, this report shows which sensor is more suitable in those specific requirements. ✓



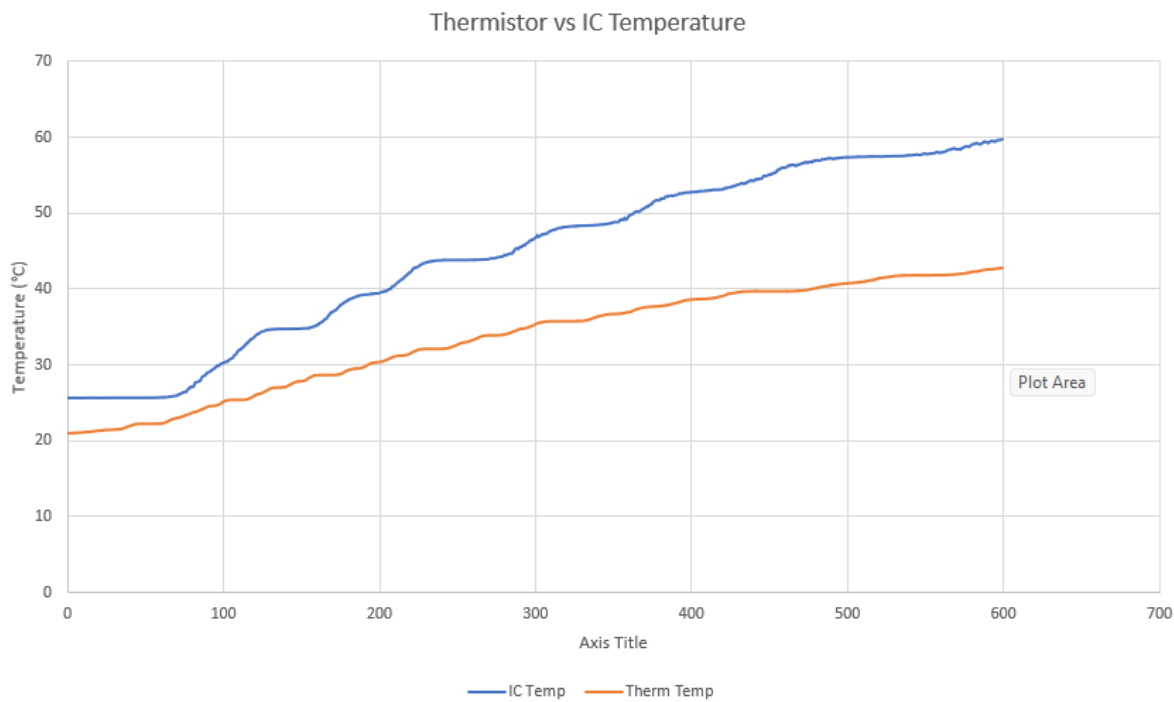
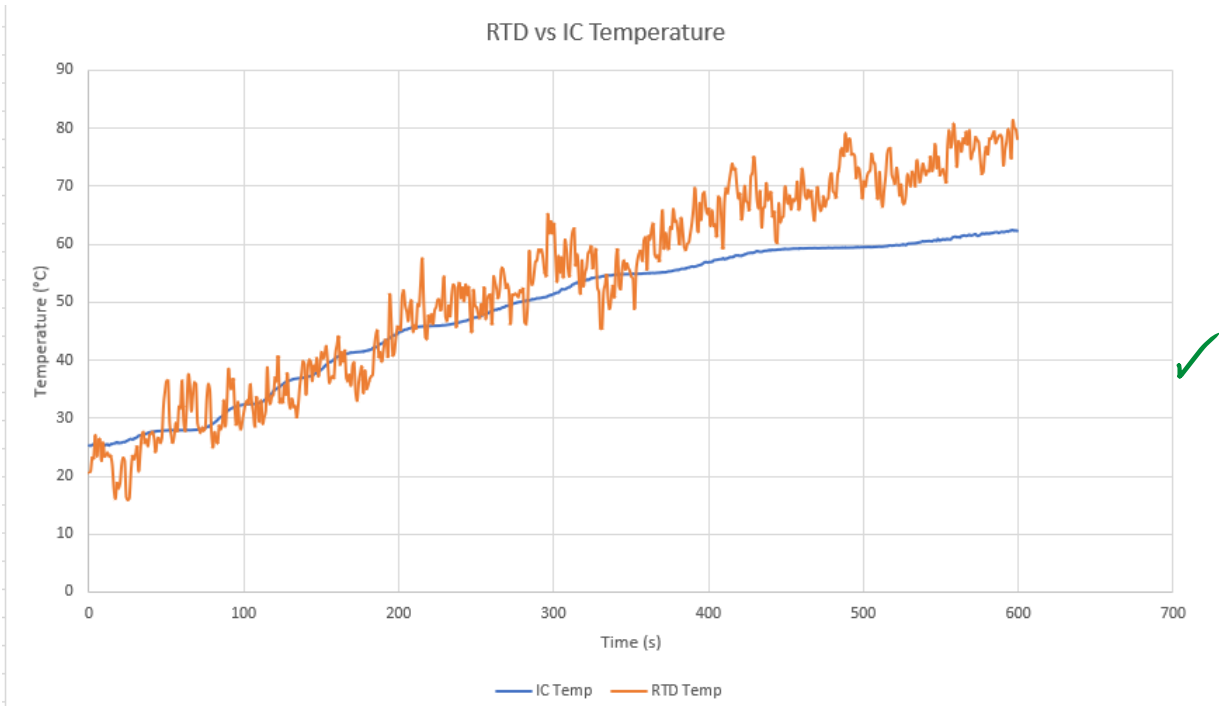
PT100 platinum RTD

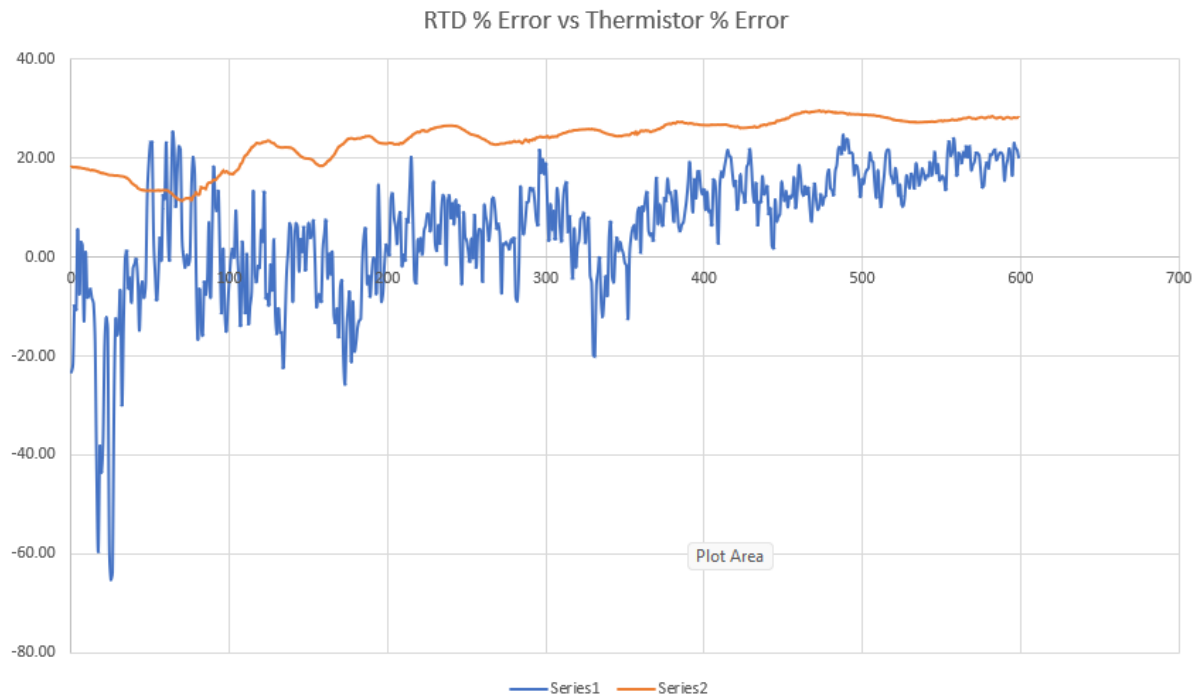
Very well written have consider all aspects of the devices.



NTC thermistor

Task 2 – Testing the Sensors





In this task ¹ will be comparing the performance of an RTD to a Thermistor temperature sensor and how well it performs when put up against an IC temperature sensor. The graphs above demonstrate the accuracy, sensitivity, errors and response.

Accuracy and Error of the RTD

As demonstrated above in the first graph, the RTD in comparison to the IC temperature shows that the accuracy is high as many commercial “RTDs have an accuracy range of $\pm 0.1^{\circ}\text{C}$ to $\pm 0.5^{\circ}\text{C}$.” (Jones,2012) This is because of their near linear, predictable resistance-to-temperature relationship. There is not much error in this graph, as if RTDs have been calibrated and operate in its temperature range from -200°C to 850°C they should operate very accurately.

Accuracy and error in the Thermistor

The second graph shows the accuracy level in comparison to the RTD sensor. Thermistors typically have a smaller temperature range from around -50°C to 150°C . Only in that range they can achieve accuracy comparable to the RTD. The thermistor is non linear, making it more prominent to error. And if the thermistor is not calibrated correctly, error can become significant.

Sensitivity of an RTD

Compared to thermistors, the RTD is less sensitive at lower temperatures, as their resistance change per degree of temperature is more gradual/ linear. Linearity will have an advantage of accuracy. The RTD is not as sensitive as the thermistor, the consistent response makes make them better for precise measurement.

Sensitivity of Thermistors

The thermistor is highly sensitive in comparison to the RTD, especially in temperature changes in the range where they are designed to operate. Their resistance changes significantly with small temperature changes, making them suitable for measurements requiring precision and high sensitivity.

Errors of both Thermistor and RTD

The RTD graph demonstrates the minimal error used in their specific range. The thermistor has larger errors, especially outside of their optimal operating range due to their non linear resistance temperature relationship.

Response time of both Thermistor and RTD

The RTD has a slower response time compared to the Thermistor. RTDs typically take longer to stabilise to a new temperature. Thermistors have quicker response time due to their smaller size and lower mass. This makes them more ideal for fast temperature changes. Thermistors are quick to adjust to temperature shifts, making them respond quicker.

Considering all these factors I would recommend the RTD as the new temperature device for the company.

Task 3 – Temperature Circuit Design

In this Task, I designed a measuring circuit that converts the resistance of the sensor to a comparative volage value. The instrument used to measure will have an input range of 0 to 100 degrees and an output range of 0 to 100 volts. I built a signal processing circuit containing a Wheatstone bridge and instrumentation amplifier that met the system specifications. The Wheatstone bridge and circuit was built on the software called 'Mutlism'.

Temperature (°C)	PT 100 (Ω)	Bridge Output Voltage (mV)	Ampifier Output Voltage (V)
0	100	0.00	0.00
10	103.85	55.32	0.96
20	107.7	109.90	1.90
30	111.55	163.76	2.83
40	115.4	216.92	3.75
50	119.25	269.37	4.66
60	123.1	321.15	5.55
70	126.95	372.26	6.44
80	130.8	422.71	7.31
90	134.65	472.52	8.17
100	138.5	521.70	9.02

Calculated voltage

Temperature (°C)	PT 100 (Ω)	Bridge Output Voltage (mV)	Ampifier Output Voltage (V)
0	100	0.000	0.002
10	103.85	0.055	0.959
20	107.7	0.109	1.903
30	111.55	0.164	2.834
40	115.4	0.217	3.754
50	119.25	0.269	4.661
60	123.1	0.322	5.550
70	126.95	0.372	6.440
80	130.8	0.423	7.310
90	134.65	0.472	8.170
100	138.5	0.522	9.020

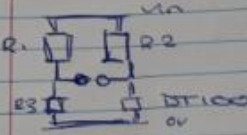
Measured results

Wheatstone Bridge		Instrumental Amplifier	
R1 =	470 Ω	R =	22 k Ω
R2 =	470 Ω	Rgain =	2.7 k Ω
R3 =	100 Ω	Vs =	10 V

Wheatstone bridge.

Calculation:

$R_1 = 470\Omega$ $R_2 = 470\Omega$ $R_3 = 100\Omega$



$$V_{out} = V_{in} \left(\frac{R_3}{R_1 + R_3} - \frac{PT100}{R_2 + PT100} \right)$$

PT100

$$R_T = R_0 (1 + \alpha \Delta T)$$

$$\alpha = 0.385$$

at 10°C $R_0 = 100\Omega$

$$R_T = 100 + 10 \times 0.385$$

$$= 103.85\Omega$$

Instrumental Amp:

$$A_V = \frac{V_{out}}{V_{in}} \quad A_V = \left(1 + \frac{2R}{R_{gain}} \right)$$

at 100°C $V_{out} = 10\text{V}$

$$V_{in} = 521.7\text{mV} = 0.5217\text{V}$$

$$A_V = \frac{10}{0.5217} = 18.97$$

$$A_V = 1 + \frac{2R}{R_{gain}} \rightarrow 2R = R_{gain} \times (A_V - 1)$$

$$R = \frac{R_{gain} \times (A_V - 1)}{2}$$

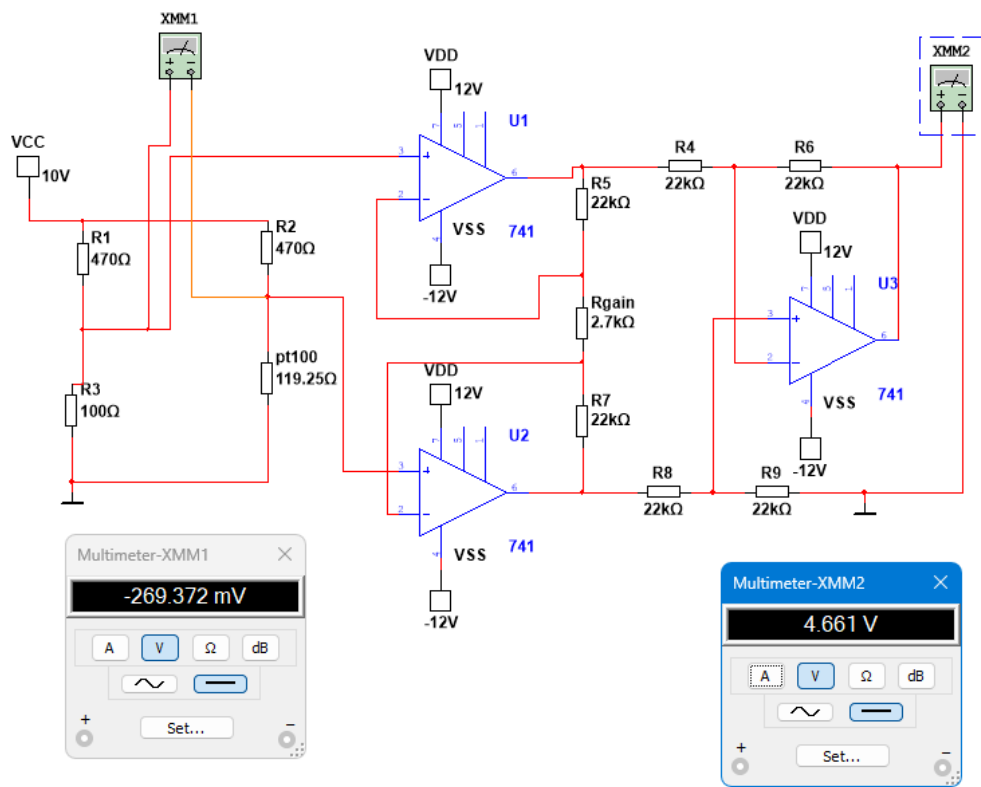
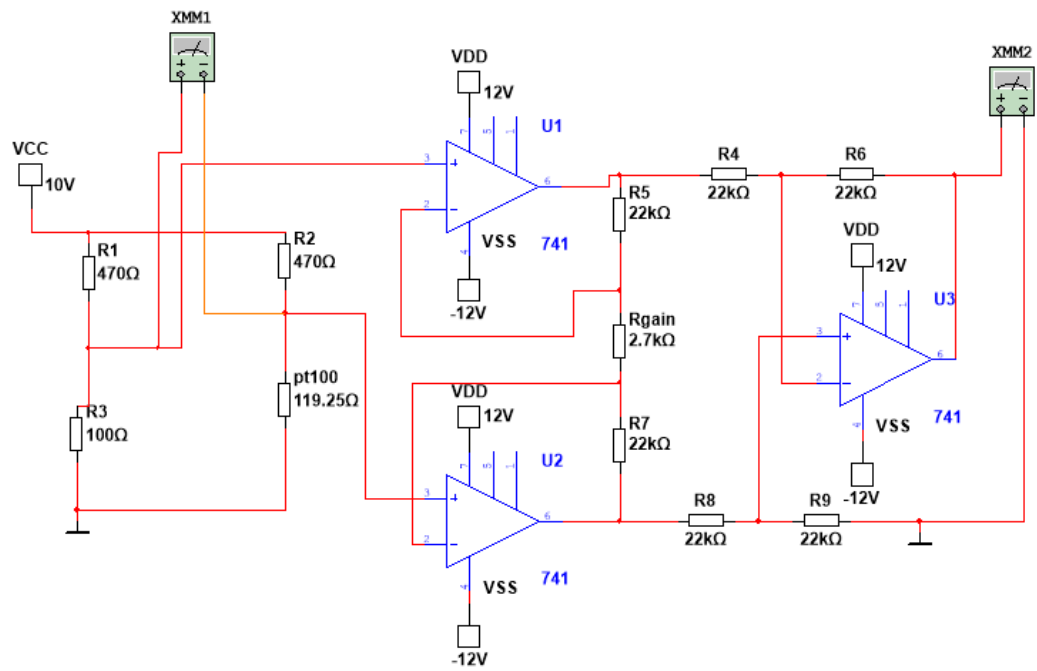
Let $R_{gain} = 2.7\text{k}\Omega$

$$R = \frac{2.7 \times (18.97 - 1)}{2} = 24.264\text{k}\Omega$$

nearest value is 22k

22k Ω

Next time try to type this up on the computer.



Evaluation

It is clear to see that from the calculations, that the values were extremely close to the measured results. From the results above it demonstrates that when the temperature increases to 50 degrees, there is also a change in resistance. ✓

Although the results of both have close values, there is a slight difference. The CMRR of the operational amplifier can have impact the circuit performance. ✓

In a Wheatstone bridge circuit, the common mode rejection ratio of the operational amplifier is important in determining how well the circuit can reject noise or interference that appears equally on both inputs of the op-amp. ✓

“The Common Mode Rejection Ratio of an operational amplifier measures how well it can reject unwanted signals that are common to both inputs like noise. A high CMRR means that the op amp will amplify only the difference between the inputs – the desired signal, while ignoring common mode noise.” (Taylor, 2011) ✓
This will ultimately improve the accuracy and decrease noise interference in these circuits. A low CMRR can result in distorted outputs due to amplified noise.

Example – Accuracy in circuits

The operational amplifier can have an impact on the accuracy of the results inside of the circuit. A low CMRR again could distort the output, which makes the results inaccurate and causes unreliable resistance measurements. A high CMRR is crucial in a Wheatstone bridge circuit to ensure that the operational amplifier only amplifies the wanted signal (caused by the change in resistance) and rejects unwanted noise. ✓

Task 4 – Signal Transmission

Foundation field bus

Foundation Field bus is an all-digital, serial, two way communication system that works as a base level network in plant or automation.

How Fieldbus works

Instead of facilitating communication only through serial communications, Fieldbus enables many other field devices to connect to a single connection point. The single point will have a connection to the controller to ease the spread of information throughout a system. Usually, “the information that gets transferred

in a Fieldbus happens via small packets that are transmitted in a sequential method and multiplexed over a period of time.” (Aneri,2023)

This communication layout will eliminate point-to-point links between field bus devices and controllers, ensuring that less connection lines are needed compared to parallel transfers. Rather than only enabling two devices to communicate with each connection, making a single connection through which all information is communicated enables numerous devices to connect via just a single controller.

Applications

It is suitable for applications using basic and high levels of regulatory control, and for the discrete control linking with those functions. Two related implementations of fieldbus have been introduced to meet the requirements in the process automation environment. The two implementations will use different media and communication speeds.

H1 will operate at 31.25kbps and connects to field devices. This will provide communication and power over standard twisted pair wiring. H1 is the most used implementation.

HSE, which stands for high speed Ethernet will operate at 100Mbit/second and will connect to input / output sub system, linking devices, field devices etc using Ethernet cabling.

Fieldbus is used in industries like the chemical processing, oil and gas and power generation, where it requires continuous monitoring and control. Fieldbus based systems are used to control and monitor variables in a system like pressure, flow and level, where real time communication between the devices is important for high levels of accuracy.

Examples of Fieldbus Foundation applications:

- Process automation – In Chemical plants, these Fieldbus systems will connect devices like flow meters, pressure sensors and control valves, allowing for decentralised control and data exchange.
- Oil and gas – Fieldbus communication allows real- time monitoring of devices and equipment like pumps and compressors out in the field in remote locations, ensuring predictive maintenance and operational efficiency.

Profibus (Process Field bus)

Profibus is a highly common communication protocol in industrial automation. It's a standardised method for devices in industrial settings to share and also communicate data efficiently. Sensors, actuators, controllers and other automated equipment can use to interact seamlessly. This protocol is made important in connecting various components of an individual system, allowing them to exchange information easily and accurately. Profibus is valued when it comes down to industrial environments where multiple devices and equipment is required to operate together cohesively. There are different versions of Profibus for different applications. For example:

- Profibus DP, facilitates rapid data exchange between equipment like programmable logic controllers (PLCs) and field devices.
- Profibus DA, Process Automation is created for use in process industries such as chemical/ petrochemical plants, where accurate control and monitoring are crucial.

Profibus will be used to aid operational efficiency by streamlining between devices, which enables real time monitoring, and control of process in the industrial environment. Its versatility has made it extremely suitable for modern industrial automation system, contributing significantly to increased productivity and reliability in many industrial sectors. Down below are some examples of where it is used in industry:

Power generation

Profibus is used in power plants, enabling the connection of different components like turbines and monitoring systems. It will help in collecting to transmitting data for the monitoring of operational parameters, allowing for easy functioning and enabling timely maintenance when needed.

Automotive industry

Profibus is commonly used in manufacturing, like controlling assembly line robotics, monitoring control sensors and managing inventory systems, which aids production processes.

Water treatment

Profibus is used in water treatment plants to control pumps, valves, sensors etc which are used for the purifying the water in the system. It ensures efficient operation, accuracy of monitoring and precise adjustments in the water treatment.

In these various applications, Profibus technology allows for efficient control, coordination and communication in different devices and systems, which aids the performance, helping with productivity and reliability in industrial systems

HART Protocol

Highway Addressable Remote Transducer (HART) is a communication protocol created for industrial process measurement and control applications. It is known as a 'hybrid' protocol due to it combining analogue and digital communication. This type of protocol is able to communicate a single variable using a 4 to 20 mA analogue signal, while also being able to communicate added information on a digital signal. "Digital information will be carried by a low level modulation superimposed on the standard 4 to 20 mA current loop."

With the analogue signal, information is sent through one way, either through the device to the host(inputs) or from the host to a device (outputs). However, using the HART digital communication signal, digital information is able to travel in both directions.

This opens the way for an "instrument that usually only receives control signal information from a host. For example, with a valve controller, to send information to the host regarding what is happening at that valve.

Applications

Upgrading Analogue systems

In oil refineries or industrial plants , HART is used to upgrade 4 to 20mA instruments to smart devices, allowing digital information without needing a full overhaul of the infrastructure.

Device Diagnostics

HART is typically used in power generation and utilities allow remote diagnostics of equipment like pressure transmitters, providing more detailed information for when maintenance is carried out.



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