

## LEVEL 4 ASSESSMENT SPECIFICATION

|                                        |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |                                                                 |                       |
|----------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------|-----------------------|
| <b>Student name:</b>                   | <b>Scott Dowler</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | <b>Student ID number:</b>                                       |                       |
| <b>Programme:</b>                      | <b>HNC Instrumentation Engineering</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |                                                                 |                       |
| <b>Module:</b>                         | <b>Instrumentation, Automation and Control</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |                                                                 |                       |
| <b>Module code:</b>                    | <b>PCEE4011</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | <b>Contribution to Overall Module Assessment (%):</b>           | <b>50%</b>            |
| <b>Lecturer:</b>                       | <b>Jason Pointer</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       | <b>Internal Verifier:</b>                                       | <b>Nigel Richards</b> |
| <b>Assignment Title:</b>               | <b>Temperature Measurement System and Signal Transmission</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | <b>Word count (or equivalent):</b>                              | <b>2000</b>           |
| <b>Submission deadline:</b>            | <b>23/01/25</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | <b>Return date of provisional marks &amp; written feedback:</b> | <b>06/02/25</b>       |
| <b>Submission method:</b>              | <p>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.)</p> <p><b>Alternative submission method (if applicable):</b></p> <p><b>Late submission of the assessment will result in a late penalty mark:</b></p> <p>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.</p> <p>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.</p> |                                                                 |                       |
| <b>Academic honesty / referencing:</b> | <p>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.</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |                                                                 |                       |

### 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 |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------|---------------|
| <b>1. Engagement with Literature Skills</b>                                                                                                                                           | 15              | 10.05         |
| Engagement with a wide range of literature, including sources retrieved independently. Generally sound referencing, with very few inaccuracies or inconsistencies.                    |                 |               |
| <b>2. Knowledge and Understanding Skills</b>                                                                                                                                          | 40              | 29.8          |
| Task 1 - 75%.<br>Task 2 - 75%.<br>Task 3 - 71%.<br>Task 4 - 77%.<br>Excellent knowledge and understanding of the basic underlying concepts and principles for each task.              |                 |               |
| <b>3. Cognitive and Intellectual Skills</b>                                                                                                                                           | 10              | 6.6           |
| Sound evaluation of the underlying concepts and principles for task 2 and 3.                                                                                                          |                 |               |
| <b>4. Practical Application Skills</b>                                                                                                                                                | 25              | 19.5          |
| Task 1 - 82%.<br>Task 2 - 74%.<br>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. |                 |               |
| <b>5. Transferable Skills for Life and Professional Practice</b>                                                                                                                      | 10              | 7             |
| Work is coherent, very fluent and is presented professionally. Excellent layout making the assignment easy to read.                                                                   |                 |               |

**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%)

**73%**

# HNC Instrumentation Electronics

PCEE4011 – Instrumentation, Automation and Control

## Assignment 1 – Temperature Measurement System and Signal Transmission

Submission Date – 23<sup>rd</sup> January 2025

Scott Dowler

Lecturer: Jason Pointer

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## Task 1 – Temperature Sensor Research

### Platinum RTD

A platinum RTD (Resistance Temperature Detector) is a device that measures absolute temperature and is made up from a fine wire or thin film which is encapsulated in a ceramic or glass substrate. An RTD operates on the principle that the internal resistance to the flow of electricity increases as the temperature increases. A small electrical current is passed through the RTD, and a resistance element is used to measure the resistance of the current through the sensor in Ohms. This resistance value can then be converted into a temperature value based on the element's characteristics (Peak Sensors - Temperature Measurement & Control, 2024) ✓

*“The resistance of a conductor varies according to its temperature, and this forms the basic principle of resistance thermometry. By the choice of a conductor material whose resistance bears a constant relationship to temperature, a reliable resistance thermometer can be built”* (LAB FACILITY LTD, 1986). ✓

Due to the stability and chemical inertness of platinum, it makes an excellent choice for an RTD within harsh industrial applications as it exhibits a repeatable, linear, and positive temperature coefficient characteristic. Platinum has a large temperature range, with the ability to measure between -196°C up to 800°C (ATC Semitec, 2024). RTDs are widely available, however those that are designed for specialist environments, different material types, or in non-standard sizes may require custom manufacturing. ✓

Platinum RTDs are highly accurate with long term stability, often incorporating a third or fourth wire to remove the lead wire resistance. The industry standard for platinum RTDs in accordance with IEC-751 is +/- 0.12% (of resistance) at 0°C, which is 0.3°C which when compared to a J or K type thermocouple with a tolerance of +/-2.2°C is very good (Thermometrics - Precision Temperature Sensors, 2012). ✓

There are two types of RTDs based on their construction, wire-wound or thin film. Thin film RTDs are constructed by placing a thin layer of the chosen metal onto a ceramic substrate. The metal film provides a specified resistance value and is laser cut or etched into a circuit pattern. Next, a glass or ceramic coating for protection is applied with lead wires being attached. Thin films RTDs are reliable, cheaper to produce and compared to wire-wound RTDs more resistant to vibrations. Wire-wound RTDs are constructed using a small, thin coil of the chosen metal. This coil is packed into a ceramic or glass tube or can be wound around the outside. Wire-wound RTDs are more ✓

accurate. Those with glass cores are particularly suited for immersion in liquids, while those with ceramic cores are used for measuring high temperatures (ABB INSTRUMENTATION, 2008).

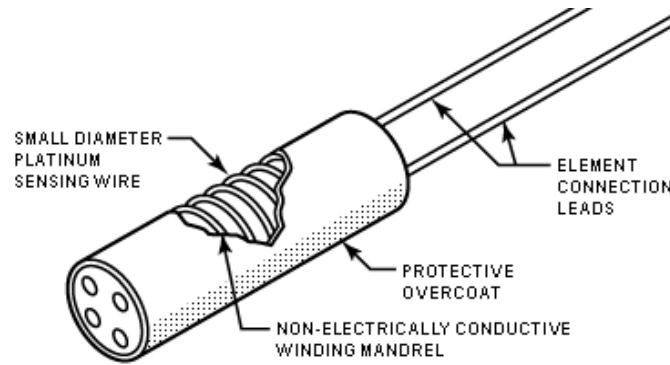


Figure 1 - Wire-Wound RTD (RdF , 2024)

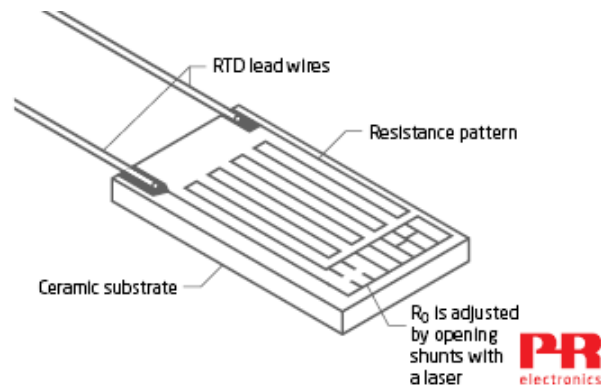


Figure 2 - Thin-Film RTD (PR Electronics, 2024)

## NTC Thermistor

A NTC (Negative Temperature Coefficient) Thermistor is a thermally sensitive semiconductor which decreases in resistance as temperature increases. Typically, thermistors are configured to show substantial changes in resistance in proportion to small temperature changes. *“A typical 2000 ohm (at 25°C) thermistor when externally heated as in a temperature measuring application, will exhibit a resistance change of 78 ohms per degree centigrade alteration of external temperature”* (LAB FACILITY LTD, 1986). Thermistors have a non-linear characteristic, meaning their resistance characteristic changes the greater the change in temperature. Although it is possible to get thermistors that have a linear characteristic over a limited range. The thermistors usual temperature operating range is between -55°C to 200°C, however depending on the application they can be used outside of this range usually up to 300°C (LAB FACILITY LTD, 1986).

Depending on the chosen materials, the sensitivity of a NTC thermistor is typically from -3% to -6% / °C. The accuracy of thermistors can range depending on the manufacturer and application but between 0.005° and 1°C is usual (EE Power, 2024). NTC thermistors are suitable for moderate environments but can be sensitive to extreme temperatures, they are also prone to self-heating if

there is an excessive current flow. Thermistors are relatively inexpensive compared to RTDs and are readily available in a variety of resistance values and tolerances making them suitable for cost-sensitive applications. ✓

NTC thermistors are made from metal oxides such as manganese, nickel, cobalt, and copper which are added to binders in a wet process technique called ball milling. The composition of the metal oxides and binding agents determines the temperature-resistance characteristics of the resultant ceramic component. The wet mix is sintered into bead, disk, or chip form before being fired into a ceramic component. To protect the thermistor from humidity, chemicals, and corrosion, the thermistor is often coated in epoxy resin, silicon, or urethane. Lead wires are attached either by soldering or pressure contact. A glass sleeve encapsulates the thermistor and is heated until it seals around the thermistor chip and lead wires (Littelfuse, 2022). ✓

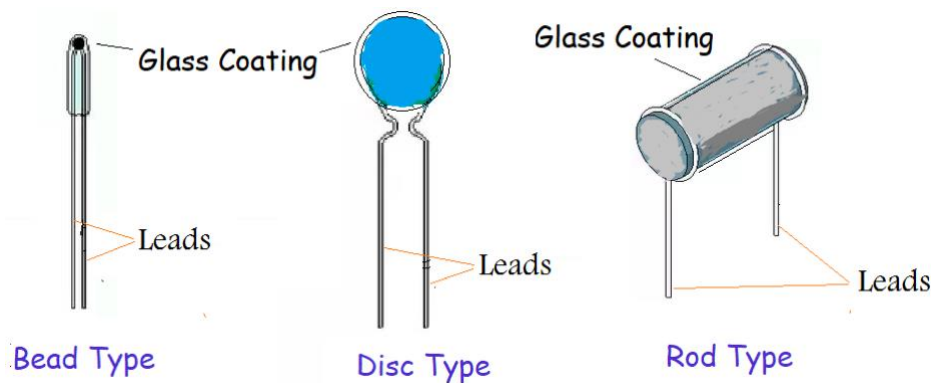


Figure 3 - Thermistor Types (M, 2023)

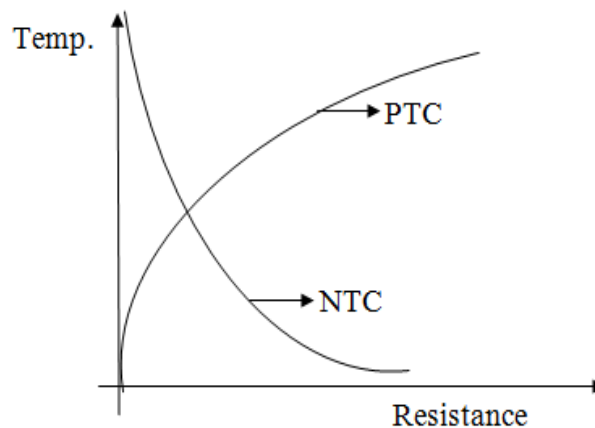
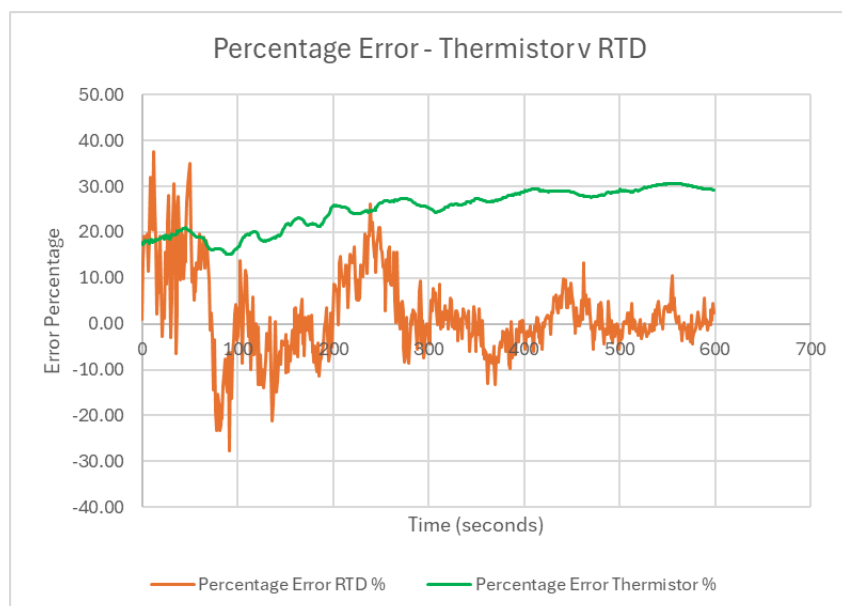
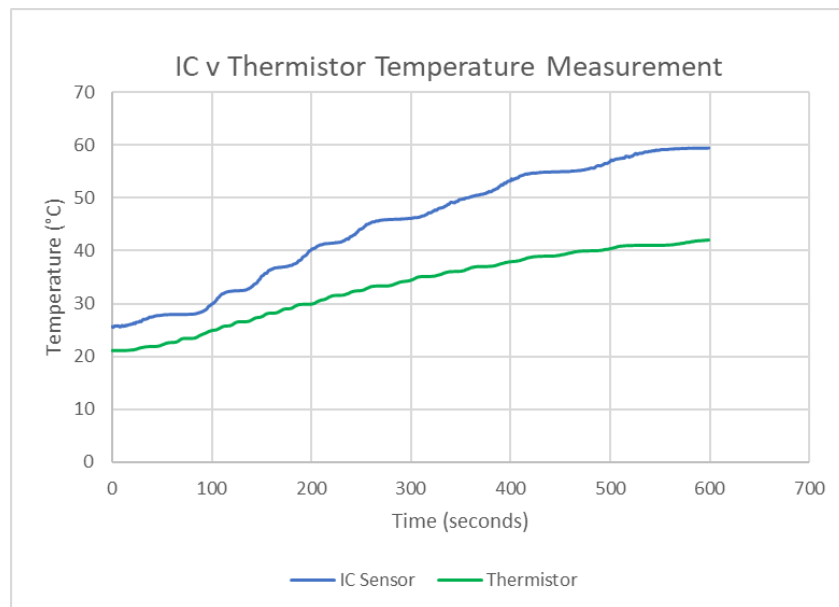
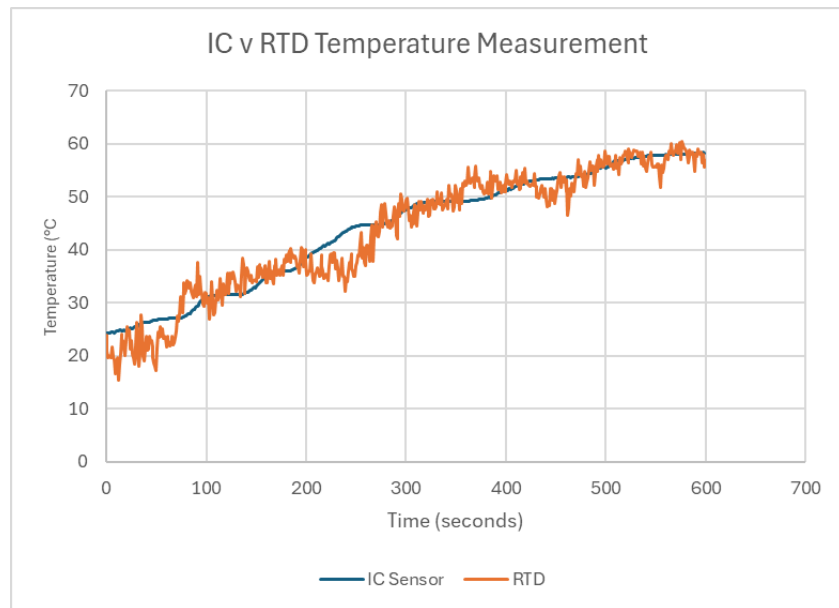


Figure 4 - PTC / NTC Thermistor Temp-Resistance Graph (Jack, 2016)

Both platinum RTDs and NTC thermistors have their own place within temperature measurement, but their selection is dependent on the requirements of the application. RTDs are preferable where high accuracy, stability, and linearity are required but with a trade-off of higher cost. NTC thermistors are suitable for lower cost applications and for rapid response. Ultimately, the decision comes down to the level of precision required, cost, and environmental factors. ✓

✓ very well written.

## Task 2 – Testing the Sensors



The graphs above show a comparison between temperature measurements taken from an IC sensor, an RTD, and a Thermistor over a ten-minute period.

### **Accuracy**

Graph 1 (IC Sensor v RTD) shows the RTD closely following the reading of the IC sensor showing a high accuracy. Graph 2 (IC Sensor v Thermistor) shows a deviation between the two devices. Initially, the Thermistor has a similar value to the IC sensor but as the temperature increases the deviation also increases showing that the accuracy of the Thermistor is not as high as the RTD. This is further supported by Graph 3 (Percentage Error) which shows that while the RTD is more erratic the percentage error is much lower on average. ✓

### **Sensitivity**

The sensitivity refers to how well a sensor reacts to changes in the temperature. Graph 1 is very erratic but shows that the RTD has a very high sensitivity. The RTD would be better off used to take a sample every five seconds instead of every second which would provide a smooth result. Graph 2 shows less fluctuations and a smooth graph which indicates that the sensitivity of the Thermistor is not as high as the RTD. ✓

### **Errors**

Graph 3 shows a consistently high error percentage of 20-30% for the Thermistor. The RTD shows a few high percentage error fluctuations and initially has a higher percentage error but stays much closer to the readings of the IC sensor. ✓

### **Response Time**

Graph 1 shows that the RTD response quickly to the changes in temperature as its values remain close to that of the IC sensor whereas the thermistor appears to have a slower response time shown in Graph 2 by the fact that it takes much longer to increase in temperature. ✓

In conclusion, the RTD would be a better choice for temperature measurement showing much better accuracy and response time to the true value than the Thermistor. Also, the thermistor shows significant percentage errors which would make it less suitable for precision measurement. However, the RTDs sensitivity while good, is potentially too good and would be improved by a slower sampling rate of either every five seconds or some form of damping. ✓

### Task 3 - Temperature Circuit Design

| Calculation of Voltage |     |   |                           |     |    |
|------------------------|-----|---|---------------------------|-----|----|
| Wheatstone Bridge      |     |   | Instrumentation Amplifier |     |    |
| R1 =                   | 220 | Ω | R =                       | 12  | kΩ |
| R2 =                   | 220 | Ω | R <sub>gain</sub> =       | 1.8 | kΩ |
| R3 =                   | 100 | Ω | V <sub>s</sub> =          | 10  | V  |

| Temperature (°C) | PT 100 (Ω) | Output Voltage (mV) | Amplifier Output Voltage (V) |
|------------------|------------|---------------------|------------------------------|
| 0                | 100        | 0.00                | 0.000                        |
| 10               | 103.85     | 81.73               | 1.171                        |
| 20               | 107.7      | 161.54              | 2.315                        |
| 30               | 111.55     | 239.50              | 3.433                        |
| 40               | 115.4      | 315.67              | 4.525                        |
| 50               | 119.25     | 390.11              | 5.592                        |
| 60               | 123.1      | 462.88              | 6.635                        |
| 70               | 126.95     | 534.03              | 7.654                        |
| 80               | 130.8      | 603.62              | 8.652                        |
| 90               | 134.65     | 671.70              | 9.628                        |
| 100              | 138.5      | 738.32              | 10.583                       |

Calculated Results

#### PT100

$$R_T = R_0 + \alpha t$$

$$\alpha = 0.385$$

$$\text{At } 10^\circ\text{C}, R_0 = 100\Omega$$

$$R_T = 100 + 10 \times 0.385 = 103.85\Omega$$

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

| PT100  | Wheatstone Bridge | Instrumentation Amplifier |
|--------|-------------------|---------------------------|
| 100    | -1.76fV           | 2.164mV                   |
| 103.85 | 81.731mV          | 1.173V                    |
| 107.7  | 161.542mV         | 2.317V                    |
| 111.55 | 239.5mV           | 3.435V                    |
| 115.4  | 315.667mV         | 4.526V                    |
| 119.25 | 390.106mV         | 5.593V                    |
| 123.1  | 462.875mV         | 6.636V                    |
| 126.95 | 534.028mV         | 7.656V                    |
| 130.8  | 603.619mV         | 8.653V                    |
| 134.65 | 671.7mV           | 9.629V                    |
| 138.5  | 738.318mV         | 10.583V                   |

Multisim Simulated Results

#### Instrumentation Amplifier

$$A_v = \left( 1 + \frac{2R}{R_{Gain}} \right)$$

$$A_v = \frac{V_{out}}{V_{in}}$$

$$\text{At } 100^\circ\text{C}, V_{out} = 10V$$

$$V_{in} = 738.32\text{mV} = 0.73832V$$

$$A_v = \frac{10}{0.73832} = 13.54$$

$$A_v - 1 = \frac{2R}{R_{Gain}}$$

$$2R = R_{Gain} \times (A_v - 1)$$

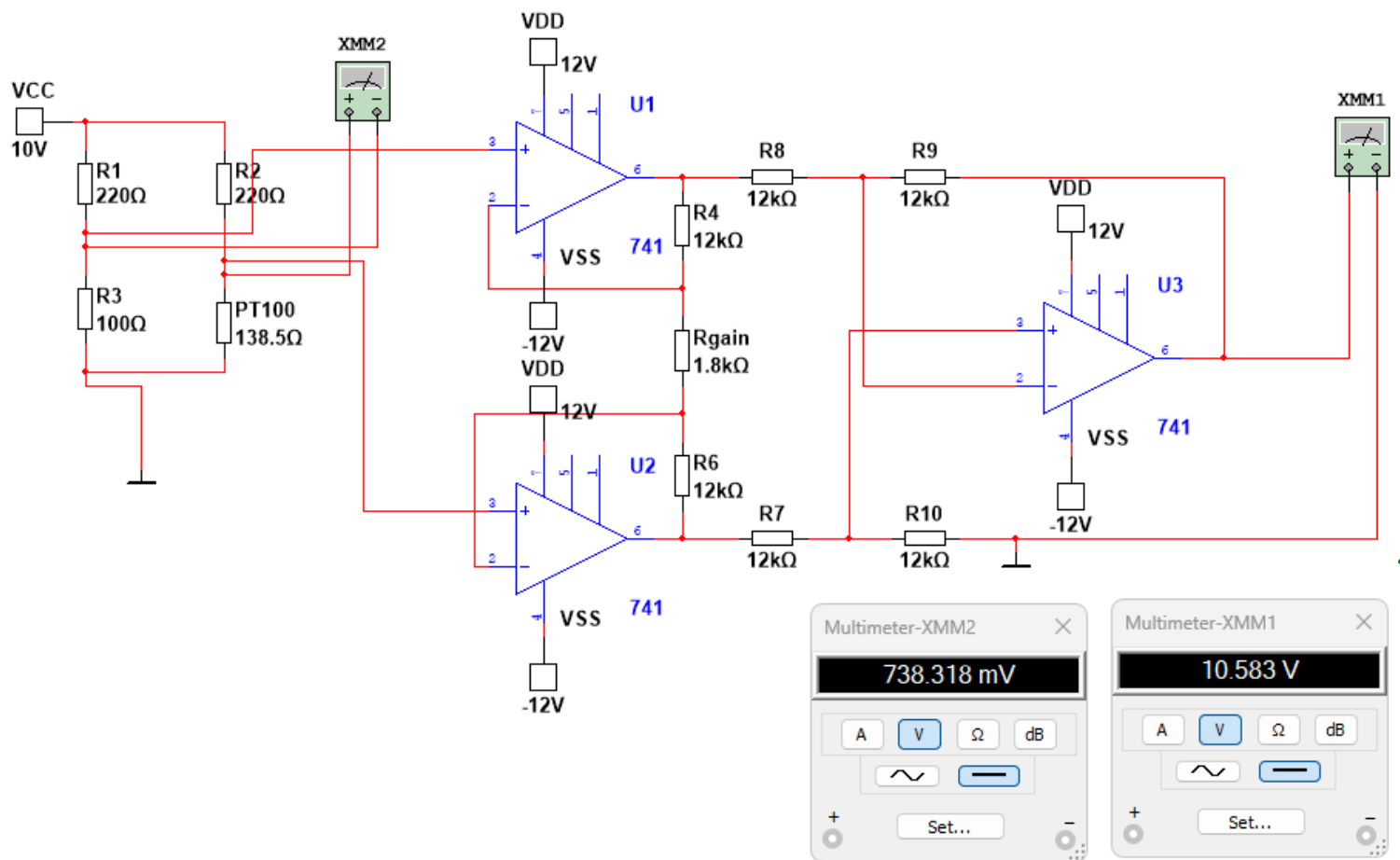
$$R = \frac{R_{Gain} \times (A_v - 1)}{2}$$

$$\text{Let } R_{Gain} = 1800\Omega = 1.8\text{k}\Omega$$

$$R = \frac{1800 \times (13.54 - 1)}{2} = 11,286\Omega$$

Nearest value resistor is 12kΩ

Very well done,  
good design work.



Comparing the results of the calculated values to the measured values, it can be seen that the calculated and measured results are very close. There are several reasons why there could be slight differences between the two sets of results. Firstly, the value of the resistor. The calculated resistor value came to 11.286kΩ but we were not able to use exact value and used the closest resistor value – 12kΩ. The slight difference in specification, 10.583V at 100°C instead of 10V can be explained by this difference in resistor but as a prototype this tolerance is acceptable. ✓

The Multisim results may have also had slight differences due to losses in the instrumentation amplifier known as Common Mode Rejection Ratio (CMRR). CMRR is a measure of the ability of an Op-Amp to suppress a common mode signal to both inputs. If both inputs fluctuate the same, there will be no change on the output. Ideally an Op-Amp will cancel out any noise or electromagnetic interference (EMI) which appear on both inputs but depending on the CMRR of the amplifier it is possible for noise or EMI to be amplified and affect your output value. ✓

## Task 4 – Signal Transmission

### Fieldbus Foundation

Foundation Fieldbus (FF) is a two-wire, digital, serial communication protocol that allows multiple (up to 32) field devices to have two-way communication through a single network connection point instead of individual controllers. This is known as a decentralised architecture. This single point then connects to a controller where information is spread through the system. The multi-drop capability of Foundation Fieldbus eliminates the need for as many point-to-point connections between the field device and controller which reduces the amount of wiring, the complexity, and installation time and costs. The other advantages of Foundation Fieldbus include advanced diagnostics, enhanced field level control, simpler integration, more supplier flexibility due to inoperability, and the digital communications increase the data integrity and reliability (Mackay, et al., 2007).

There are four networks to Foundation Fieldbus, the sensor bus, device bus, control bus, and the enterprise bus. The sensor bus is made up from the from field devices which are connected through one network cable to a controller. The device bus is similar to the sensor bus but on a larger scale facilitating the control of individual components across the network. The control bus network connects programmable logic controllers (PLCs) to smart instruments and human interface panels (HIPs). This allows for configuration and control of each instrument connected to the network. The enterprise bus network is the most complex and connects all of the departments and computers together (Bryan & Bryan, 1997).

Foundation Fieldbus is used for a variety of applications within industry. It can be used for turbine control and boiler automation within power plants and for refinery automation within oil and gas. Among many other applications, it is also used for batch processing and manufacture within the chemical industry.

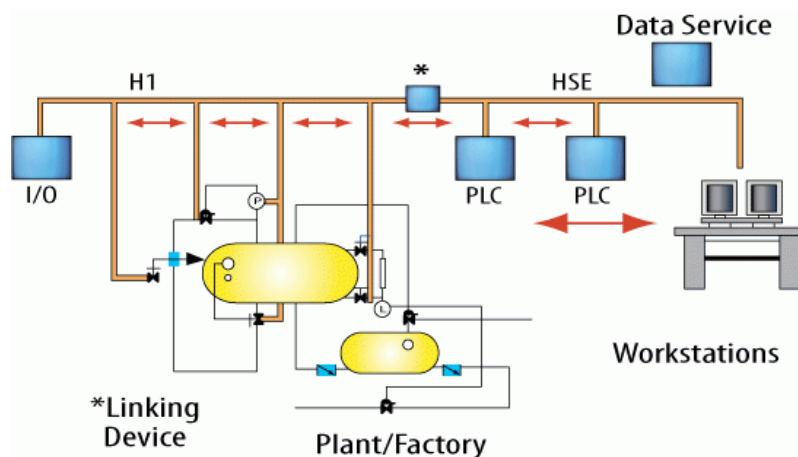


Figure 5 - Foundation Fieldbus Architecture (FieldComm Group, 2024)

## Hart Protocol

The Highway Addressable Remote Transducer (HART) protocol is a typical hybrid communication standard designed for industrial process measurement and control applications. It is considered a hybrid protocol because it superimposes a digital signal onto a conventional 4-20mA analogue signal through low level modulation. The digital signal does not affect the analogue signal as it is removed through standard filtering. Being able to carry this digital signal is one of the benefits of HART as it allows for two-way communication for an instrument that traditionally only receives information. For example, a valve controller would receive a signal to move the valve to a set point, digital communication allows for the valve controller to send feedback information about the true position of the valve. (Mackay, et al., 2007). Some other key features of HART are that it allows for remote device configuration and diagnostics and uses frequency shift keying (FSK) for data transmission (Texas Instruments, 2023). ✓

For HART communications, a zero is represented by a 2200Hz frequency and a one by a 1200Hz frequency. *“The arrangement is that a master, such as a display terminal, sends a message with a request for data to a device, the device interprets the request and replies with the data”* (Bolton, 2004). ✓

HART is used in many of the same ways as Foundation Fieldbus for industrial automation and control. It would typically be used for device diagnostics and live process information while performing maintenance or for configuring instruments such as pressure and flow transmitters or level and temperature sensing devices. ✓

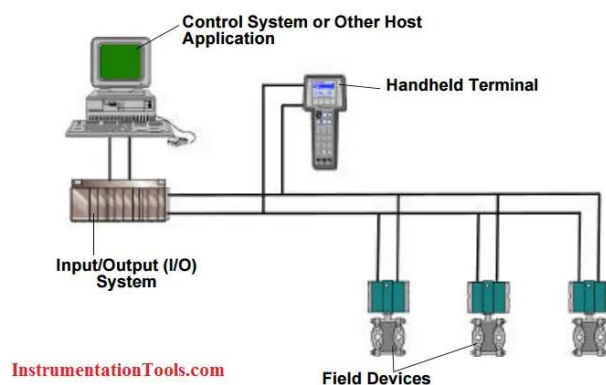


Figure 6 - HART Protocol Architecture (Instrumentation Tools, 2017)

## Profibus

Profibus (Process Field Bus) is another industrial communication protocol largely found in process control material handling and assembly for communicating between field devices and control systems. There are two main variants of Profibus, Decentralised Peripherals (DP) and Process Automation (PA). DP is used for fast cyclic data exchange while PA is used for continuous process control (Endress+Hauser, 2024).

Profibus is capable of high-speed data-transmission up to 12Mbps and supports centralised and decentralised automation. It also provides robust fault detection and error handling and is compatible with a large variety of field devices, controllers, and manufacturers.

Profibus is used within a number of industrial applications including manufacturing automation where it allows communication between field devices and PLCs. Chemical plants commonly use Profibus for sensor communication to measure temperature, pressure, level, and flow rate which allows for precise control over the production line.

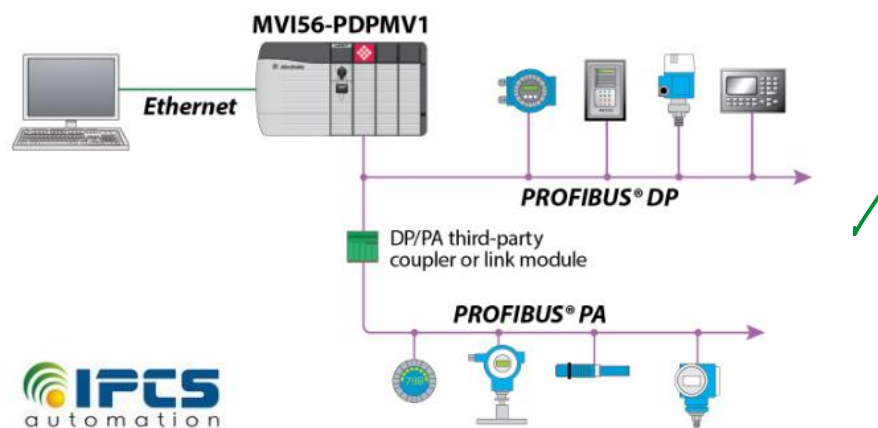


Figure 7 - Profibus Architecture (IPCS Global, 2019)

Foundation Fieldbus, HART, and Profibus all serve their own purpose within industrial automation. Foundation Fieldbus is particularly strong in real time automation with the benefit of simple wiring and is suited well for precise control and diagnostics. HART remains useful due to its hybrid nature being able to move between digital and analogue, and its ability to integrate with legacy equipment. Profibus is ideal for industries that rely on fast data exchange due to its high speed, digital communication.

Each protocol offers advantages dependant on the system requirements, environment and operational needs which should be evaluated when choosing a communication protocol.

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