

LEVEL 4 ASSESSMENT SPECIFICATION

Student name:	Harry Myers	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	9.75
Engagement with a wide range of literature, including sources retrieved independently. Generally sound referencing, with very few inaccuracies or inconsistencies.		
2. Knowledge and Understanding Skills	40	28
Task 1 - 75%. Task 2 - 60%. Task 3 - 68%. Task 4 - 77%. 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	19.75
Task 1 - 82%. Task 2 - 76%. 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	6.8
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%)

69%

PCEE4011 – Instrumentation, Automation and Control

Assignment 1 – Temperature Measurement System and Signal Transmission

Submission Deadline 23/01/25

Harry Myers

LECTURER NAME: JASON POINTER

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Task 1 – Temperature Sensors Research

The two types of temperature sensor being researched are platinum RTDs and NTC thermistors.

Platinum RTD

RTDs (resistance temperature detectors) come in different metals, such as copper, nickel or gold. Platinum is the most expensive option, but with it comes reliability.

Construction

A diagram of the construction of a platinum RTD is shown below in figure 1.

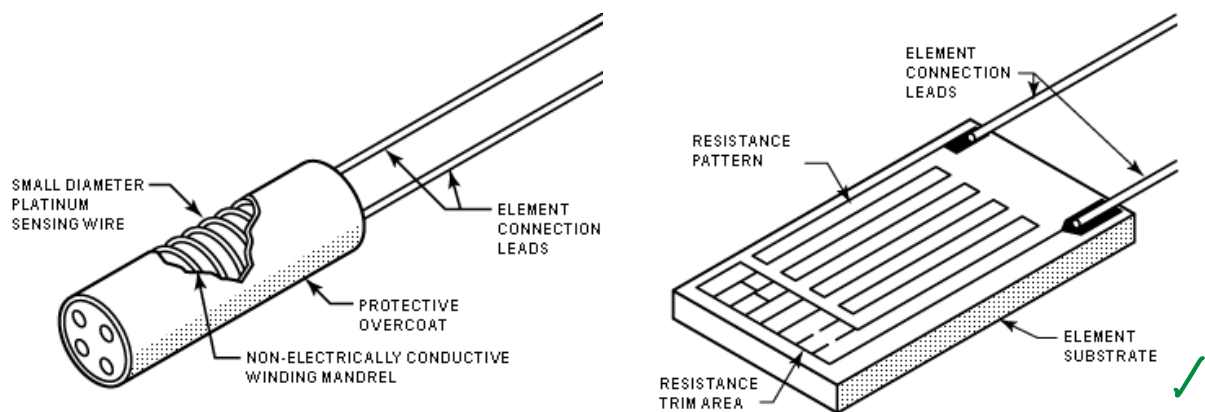


Figure 1 - Platinum RTD Construction (RDF Corporation, 2025) Left hand image is a wire type, right hand image is film type.

As seen in figure 1 - the key components of a platinum RTD are:

Platinum wire/film: Platinum is used as its resistive properties are stable and predictable, which is ideal for converting into a temperature measurement. Thinner and thicker wires/films can be used to provide different temperature/resistance coefficients, for example a PT100 uses relatively thin wire compared to a PT1000, which measure 100Ω and 1000Ω respectively at zero degrees Celsius (known as ice point). ✓

Insulative base: The platinum is either wound around (wire type), or deposited into (film type) an electrically insulative base (usually ceramic or mica). Electrically insulative materials are used to ensure there is no electrical interference with the platinum which could skew the readings, whilst also providing support for the wire or film. ✓

Lead wires: These are used for connecting the RTD to the temperature instrument/controller. Different configurations of wires can be found, these being 2-wire, 3-wire and 4-wire types. All configurations are connected as the variable resistor in a Wheatstone bridge to the instrument/controller for resistance measurement. The 2-wire configuration is more suited, and

cheaper to use if only a short run of cable is needed, as the resistance in the cable increases with the length of cable. The inherent internal resistance can be measured using a third, and this can be subtracted in the instrument/controller to give a truer reading. The 4-wire configuration is the most expensive and can be used to completely isolate the resistive element from the resistance of the wires. A three-wire configuration is shown below in figure 2, with L1, L2, and L3 being the lead wires, and R1, R2, R3 and R_T being the Wheatstone bridge circuit. This setup relies on the leads being identical, therefore having the same internal resistance.

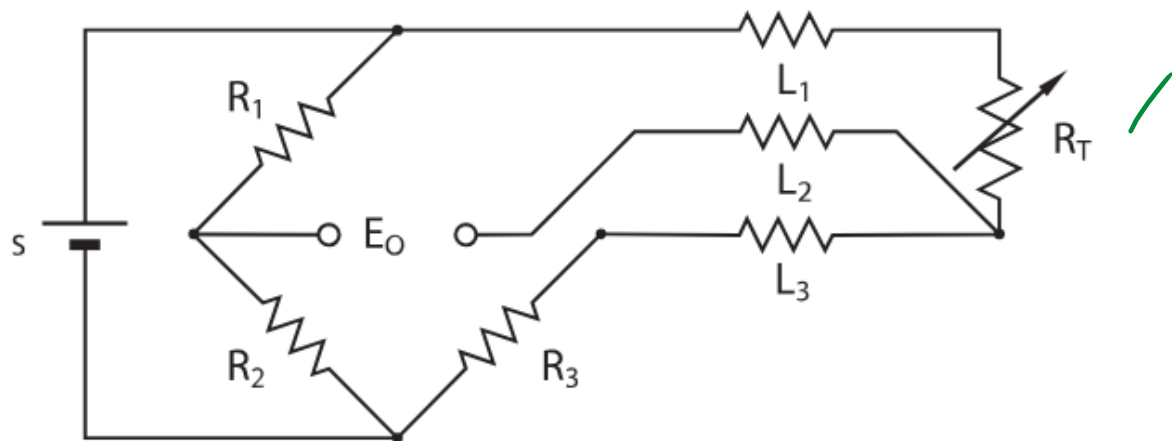


Figure 2 - 3-Wire RTD Connected Via Wheatstone Bridge (Minco, 2025)

Protective sheath: This protects the RTD from physical damage, and is usually constructed of a durable, rigid, non-corrosive material to ensure it lasts the lifetime of the RTD.

Key Features

High Accuracy: The International Electrotechnical Commission (IEC) has created standards for RTDs, which are categorised into class A and class B in terms of their accuracy. Table 1 shows this classification table, specifically for PT100s.

Device performance: Table 2, shown below, is taken from the Instrument Engineers' Handbook and compares the performance of RTDs against other temperature sensors. This will be referred to again in the thermistor section of task 1.

<i>Evaluation Criteria</i>	<i>Platinum RTD 100 Ω Wire Wound and Thin Film</i>	<i>Platinum RTD 1000 Ω Thin Film</i>	<i>Nickel RTD 1000 Ω Wire Wound</i>	<i>Balco RTD 2000 Ω Wire Wound</i>	<i>Thermistor</i>	<i>Thermocouple</i>	<i>Semi-conductor Devices</i>
Cost-OEM Quantity	High	Low*	Medium	Medium	Low*	Low*	Low*
Temperature Range	Wide -400°F to +1200°F (-240°C to +649°C)*	Wide -320°F to +1000°F (-196°C to +538°C)*	Medium -350°F to +600°F (-212°C to +316°C)	Short -100°F to +400°F (-73°C to +204°C)	Short to Medium -100°F to +500°F (-73°C to +260°C)	Very Wide -450°F to +4200°F (-268°C to +2316°C)**	Short -57°F to +257°F (-49°C to +125°C)
Interchangeability	Excellent*	Excellent*	Fair	Fair	Poor to Fair	Good*	Fair
Long-Term Stability	Good*	Good*	Fair	Fair	Poor	Poor to Fair	Good to Fair
Accuracy	High*	High*	Medium	Low	Medium	Medium	Medium
Repeatability	Excellent**	Excellent**	Good*	Fair	Fair to Good	Poor to Fair	Good*
Sensitivity (Output)	Medium	High*	High*	Very High**	Very High**	Low	High*
Response	Medium	Medium to Fast*	Medium	Medium	Medium to Fast*	Medium to Fast*	Medium to Fast*
Linearity	Good*	Good*	Fair	Fair	Poor	Fair	Good*
Self-Heating	Very Low to Low*	Medium	Medium	Medium	High	N/A	Very Low to Low*
Point (End) Sensitive	Fair	Good*	Poor	Poor	Good*	Excellent**	Good*
Lead Effect	Medium	Low*	Low*	Low*	Very Low**	High	Low*
Physical Size/Packaging	Medium to Small	Small to Large*	Large	Large	Small to Medium	Small to Large*	Small to Medium

**Best Rating
*Good Rating

Table 2 - Temperature Sensor Comparison Table (Liptak, 2003)

It can be seen in table 2 that platinum RTDs ranked highly across most performance markers. They are highly accurate pieces of equipment, producing stable and reliable results for long periods of time. Where they are lacking is more specific to two-wire platinum RTDs, where they are susceptible to internal resistances being introduced. This problem is solved by the use of three and four wire RTDs.

Availability: Platinum RTDs are widely available from a range of suppliers, including Omega, ATC Semitec and Endress & Hauser. A link to a datasheet for a PT100 is included below, taken from the RS website.

Class B PT100 from RS: [A700000008838945.pdf](https://www.rs-online.com/media/pdf/A700000008838945.pdf)

Constraints and cost: These terms have been grouped together as they are interlinked in regard to platinum RTDs. The cost could be considered a constraint as they are generally more costly than

other temperature sensors due to their high quality construction and the use of platinum. Although they are well constructed, they can often contain a glass protective sheathing, which could easily break if handled poorly.

NTC Thermistors

NTC is an abbreviation of 'negative temperature coefficient'. This refers to the resistive properties of the thermistor, which are; as temperature increases, the resistance of the thermistor decreases. PTC (positive temperature coefficient) thermistors are also available and are generally used as fuses. Like platinum RTDs, NTC thermistors are also connected via Wheatstone bridge circuits to calculate their resistance.

Construction

"NTC thermistors, or NTCs for short, are semiconductors made from specific mixtures of pure oxides of nickel, manganese, copper, cobalt, tin, uranium, zinc, iron, magnesium, titanium, and other metals sintered at temperatures above 1800°F (982°C)." (Liptak, 2003). Their thermal and resistive properties will change depending on their makeup and sintering environment. The high temperature sintering process causes the raw materials to blend into a solid, ceramic structure, which is then pressed together and encapsulated in materials such as glass or plastic. Solid, non-permeable materials are chosen for encapsulation to serve as protection for the internal wires, for easier handling, and to ensure current/heat flow across the sensor is uniform. Figure 3 shows the many different physical forms they can come in.

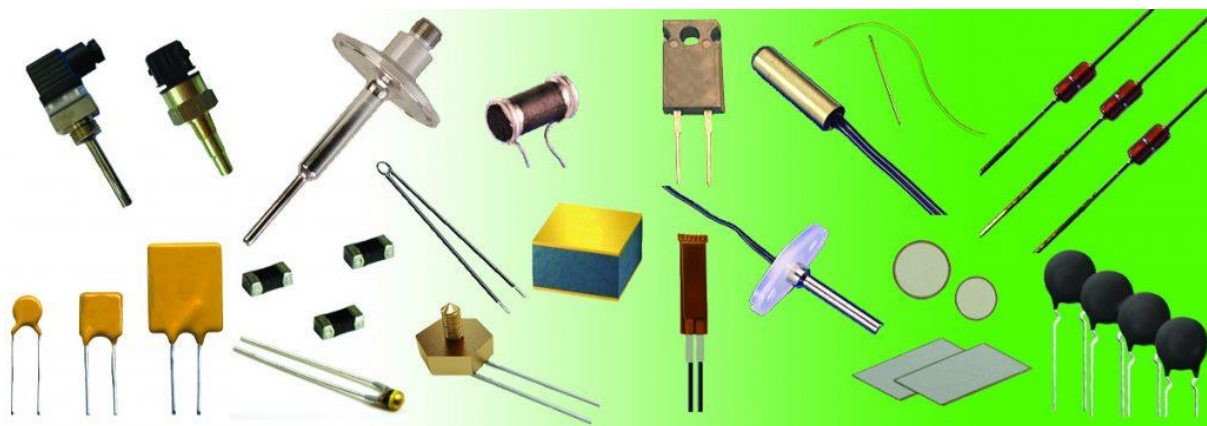


Figure 3 - Types of Thermistors (Wavelength Electronics, 2018)

Thermistors are hooked up to an ammeter via a probe and cable, and part of a circuit which requires a steady voltage to be supplied. From this, a current reading can be taken, and because the voltage is known, a resistance value is derived from it using Ohms law – " $V = I \times R$ ", where V is voltage, I is

current and R is resistance. The type of probe used for measurement will impact the response time of the device, as illustrated below in figure 4. ✓

LN0255 Immersion Probe For liquid and semi-solids. Stainless steel. For foods, chemical, pharmaceutical and laboratory work. 0.1°C interchangeability, 6" long stem, .125" diameter for 12" length option, order, **LN0255-12**. 1.0 Second response time*.

LN0255 Immersion Probe With .05°C interchangeability, .250" diameter.

LN0250 Flexible Immersion Probe Vinyl sheath and .135" diameter epoxy tip. Small and flexible. 3.6 Second response time*.

LN0252 Button Surface Probe Solid .375" diameter button can be attached with pressure sensitive adhesive tape or epoxy. Stainless steel contact surface. 1.1 Second response time*.

LN0253 Screw-In Immersion Probe For measurements in pipes, vessels or reactors. 3.6 Second response time*. Stainless steel shank with 1/8" NPT fitting, 6" standard stem length, 12" option, order **LN0253-12**.

*Response time is based on 63% in water moving at 3 feet per second.

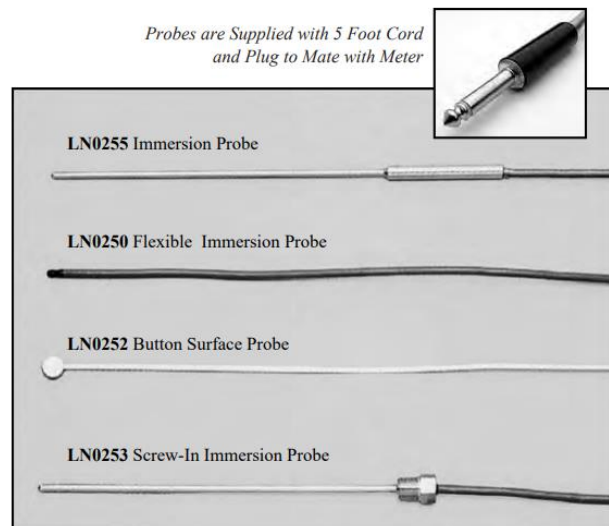


Figure 4 - Thermistor Probe Types (Liptak, 2003)

Figure 5, shown below, depicts a typical negative temperature coefficient curve of an NTC thermistor which, unlike a platinum RTD, is non-linear. ✓

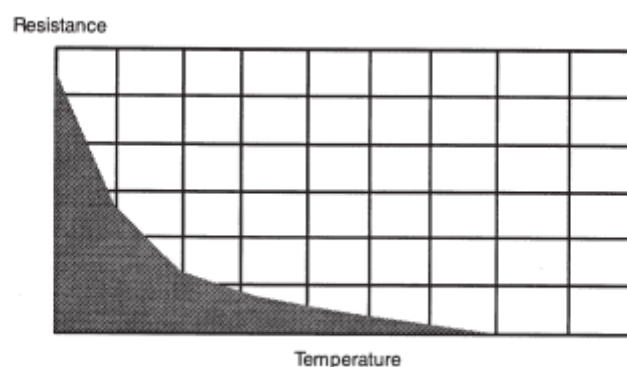


Figure 5 - Relationship Between Temperature and Resistance in an NTC Thermistor - (Lab Facility, 2006)

Key features

Process Variable: NTC thermistors are similar to platinum RTDs in that they both are used to measure resistance in respect to a change in temperature, although thermistors are far more sensitive.

High Sensitivity (in mid-range): As previously stated, thermistors have a non-linear (or exponential) response in resistance when exposed to changes in temperature. This property means they can detect miniscule changes in temperature. This high sensitivity is only prevalent in the most curved part of the response graph shown in figure 5. This means that as temperatures get more towards the high-end or low-end of their span, sensitivity and accuracy decreases.

High Durability: Due to their solid construction, they are robust and able to withstand moderate impact and harsh environments.

Evaluation Criteria	Platinum RTD 100 Ω Wire Wound and Thin Film	Platinum RTD 1000 Ω Thin Film	Nickel RTD 1000 Ω Wire Wound	Balco RTD 2000 Ω Wire Wound	Thermistor	Thermocouple	Semi-conductor Devices
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Temperature Range	Wide -400°F to +1200°F (-240°C to +649°C)*	Wide -320°F to +1000°F (-196°C to +538°C)*	Medium -350°F to +600°F (-212°C to +316°C)	Short -100°F to +400°F (-73°C to +204°C)	Short to Medium -100°F to +500°F (-73°C to +260°C)	Very Wide -450°F to +4200°F (-268°C to +2316°C)**	Short -57°F to +257°F (-49°C to +125°C)
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Repeatability	Excellent**	Excellent**	Good*	Fair	Fair to Good	Poor to Fair	Good*
Sensitivity (Output)	Medium	High*	High*	Very High**	Very High**	Low	High*
Response	Medium	Medium to Fast*	Medium	Medium	Medium to Fast*	Medium to Fast*	Medium to Fast*
Linearity	Good*	Good*	Fair	Fair	Poor	Fair	Good*
Self-Heating	Very Low to Low*	Medium	Medium	Medium	High	N/A	Very Low to Low*
Point (End) Sensitive	Fair	Good*	Poor	Poor	Good*	Excellent**	Good*
Lead Effect	Medium	Low*	Low*	Low*	Very Low**	High	Low*
Physical Size/Packaging	Medium to Small	Small to Large*	Large	Large	Small to Medium	Small to Large*	Small to Medium

**Best Rating

*Good Rating

Table 3 (Repeated) - Temperature Sensor Comparison Table (Liptak, 2003)

Device Performance: As seen in table 2, repeated above, their temperature range (333°C) is much smaller compared to a platinum RTD (889°C). Their sensitivity is much higher than a platinum RTD but they are also much more susceptible to self-heating errors. NTC thermistors score poorly

compared to platinum RTDs in accuracy but are slightly better in response time, which can be helped further by choosing a probe with a faster response time. ✓

Availability & Cost: Thermistors are widely available from many different suppliers and are much cheaper than platinum RTDs. A datasheet is provided below for a thermistor found on the RS website. ✓

<https://docs.rs-online.com/2f27/0900766b81582e16.pdf>

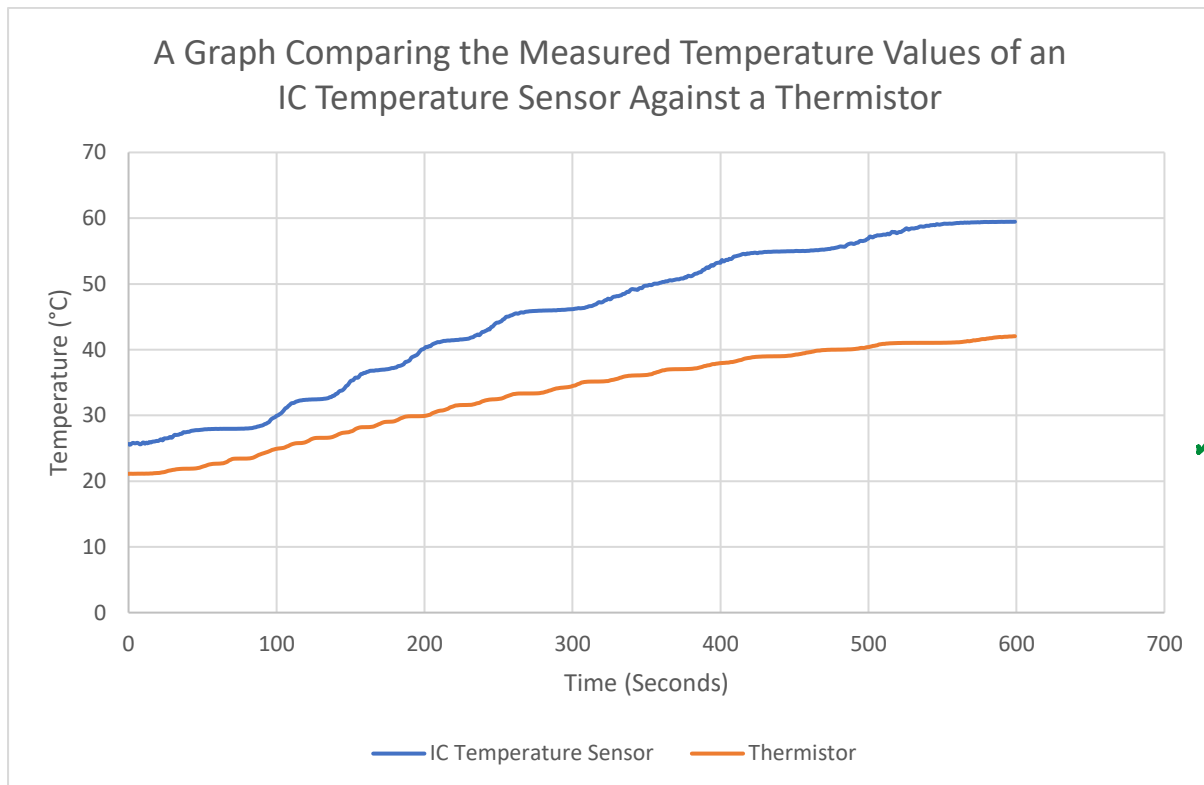
Constraints: Many of the constraints have been mentioned already but will be summarised here:

- Poor sensitivity and accuracy in more extreme temperatures
- Much lower range than platinum RTDs.
- Subject to self-heating effect, whereby their internal temperature increases during operation and causes inaccurate results. This can also cause overheating and failure.
- Their non-linear response makes it harder to calculate their resistance. ✓

Well done.

Task 2 – Testing the Sensors

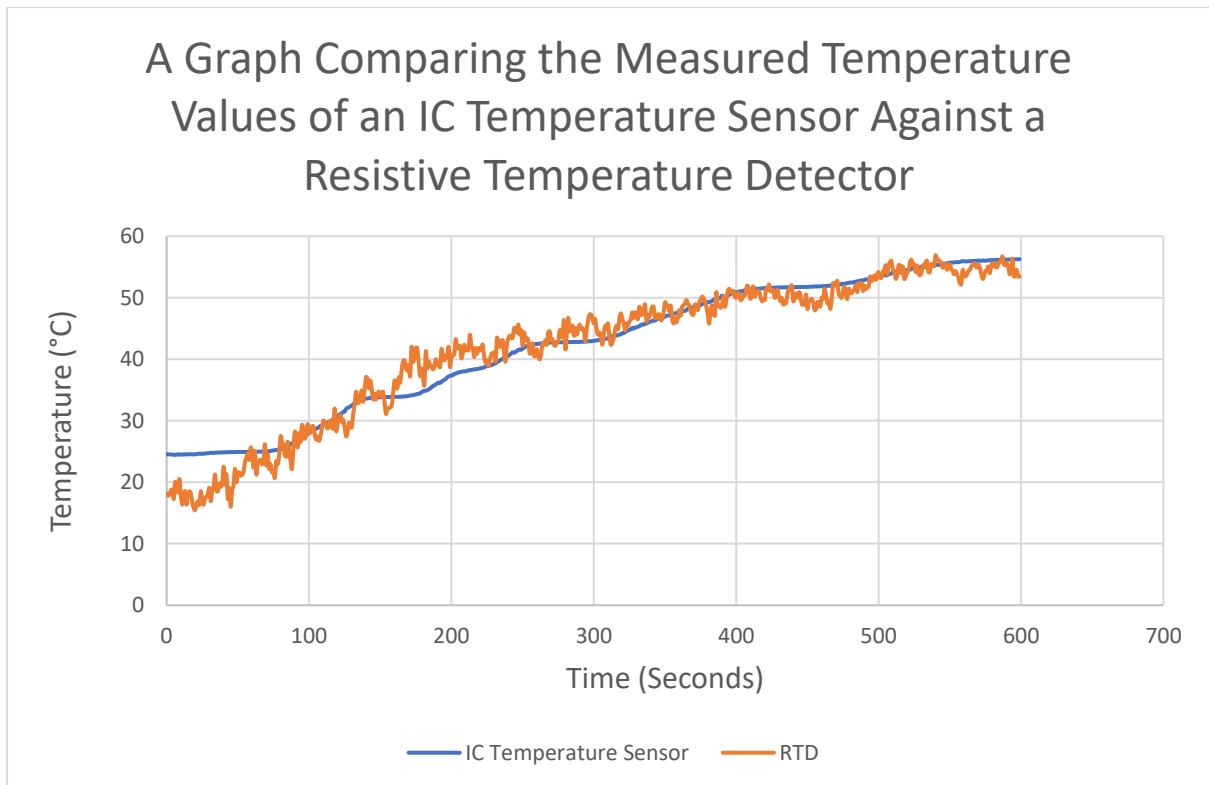
Data for task 2 was obtained using an instrumentation board and a Picoscope. Temperature was slowly increased over a 10-minute period, with 1 sample being taken every second. Graph 1 shows the results acquired from comparing a thermistor against an IC temperature sensor (the true value).



Graph 1 - IC Temperature Sensor vs. Thermistor

It is clear from this data that due to the thermistor's non-linear response to changes in temperature, it drifts further away from the true value as temperature increases. The thermistor being used here is not displaying a high level of sensitivity as its temperature plot is relatively smooth and therefore not detecting the minute changes in temperature.

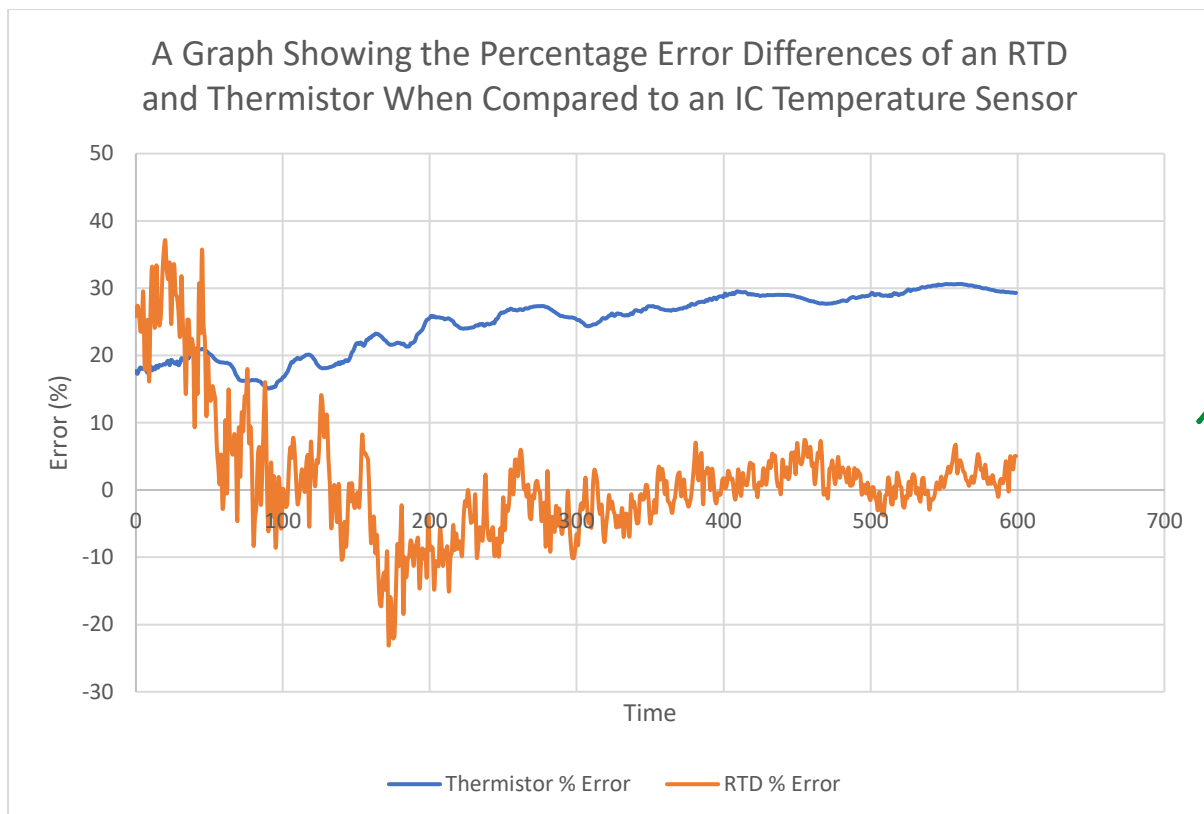
Graph 2 shows the same experiment but this time using an RTD instead of a thermistor.



Graph 2 - RTD vs IC Temperature Sensor

It can be seen from graph 2 that due to its more linear response, the RTD follows the true temperature value quite consistently when compared to the thermistor. There is a slight inaccuracy at the start of the experiment, but after about a minute, the RTD begins following the IC temperature sensor. It is far more sensitive than the thermistor, detecting miniscule changes in temperature, hence its seemingly erratic response, but this could be smoothed out by increasing the time between samples. ✓

Graph 3 compares the percentage error of both temperature devices.



Graph 3 - Percentage Errors, Thermistor vs RTD

This graph clearly shows that, apart from at the lower end of the temperature range, the RTD is far more accurate in this scenario than the thermistor. Its accuracy seemingly improves with rises in temperature while the thermistor's worsens.

From these results it would be recommended to choose the RTD over the thermistor because of its far greater degree of accuracy. ✓

There other factors that should be included.

Task 3 – Temperature Circuit Design

As the results for the platinum RTD proved better than the thermistor in task 2, it will be used to design a measuring circuit to convert its resistance to a voltage.

Instrumentation Amplifier Calculations:

$A_V = \text{Voltage Gain}$

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

$$A_V = \frac{V_{out}}{V_{in}} \quad \text{at } 100^\circ\text{C:} \quad V_{out} = 10V$$

$$V_{in} = 630.66mV = 0.63066V$$

$$A_V = \frac{10}{0.63066} = 15.86$$

Rearrange:

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

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

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

Let $R_{gain} = 1.5k\Omega$:

$$R = \frac{1.5(15.86 - 1)}{2} = 11.145k\Omega$$

Nearest true available resistor value is $12k\Omega$, so let $R = 12k\Omega$

Calculated Values for Wheatstone Bridge and Instrumentation Amplifier Circuit

Wheatstone
Bridge

R1 = 330 Ω
R2 = 330 Ω
R3 = 100 Ω

Instrumentation
Amplifier

R = 12 k Ω
Rgain = 1.5 k Ω
Vs = 10 V

Temperature (°C)	PT 100 (Ω)	Bridge Output Voltage (mV)	Amplifier Output Voltage (V)
0	100	0.00	0.00
10	103.85	68.10	1.16
20	107.7	135.01	2.30
30	111.55	200.75	3.41
40	115.4	265.35	4.51
50	119.25	328.84	5.59
60	123.1	391.26	6.65
70	126.95	452.62	7.69
80	130.8	512.96	8.72
90	134.65	572.30	9.73
100	138.5	630.66	10.72

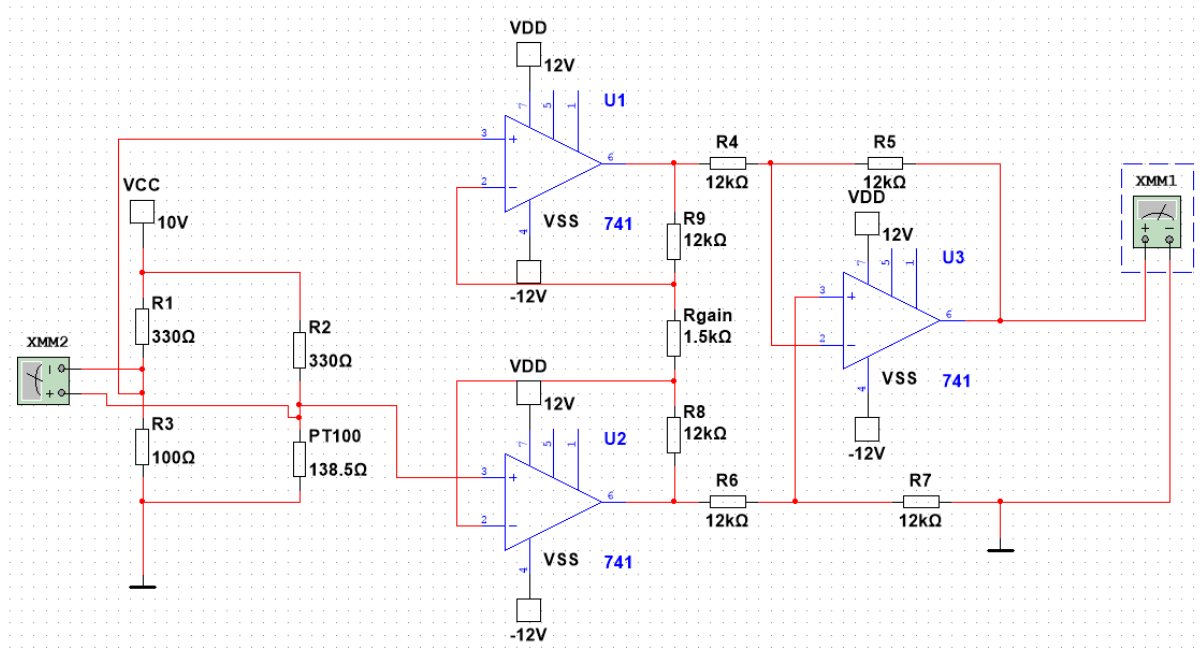
Table 4 - Calculated Values

From the specifications, a 0 – 10V output range is required. It can be seen on the calculations that the output voltage slightly exceeds 10V, this is due to choosing the nearest available resistor value as a 11.145k Ω resistor is not commercially available.

From these values, a circuit was built in Multisim and simulated to check if the calculated values were correct.

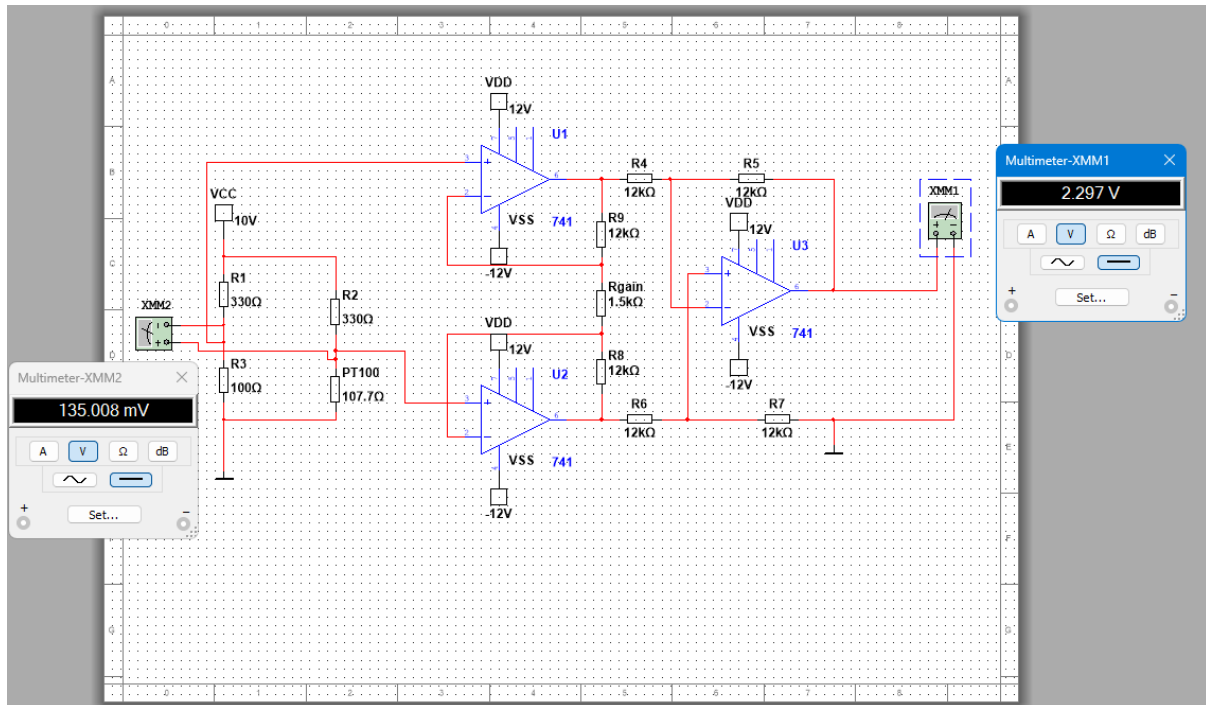
Circuit Simulation

Multisim figure 1 shows the circuit built in Multisim, of a Wheatstone bridge incorporating a PT100, wired into an instrumentation amplifier. As can be seen in the figure, the values used correspond to the table of calculations in *Table 4 - Calculated Values*.



Multisim Figure 1

Multisim figure 2 shows the readings from the simulated multimeters for both the Wheatstone bridge output voltage (left) and the amplifier output voltage (right).



Multisim Figure 2 – Measured Values

The values measured in the simulation were checked against all calculated values and all almost identical. This proves the circuit is designed up to specification and works correctly, enabling miniscule voltages measured in the Wheatstone Bridge to be amplified to great, more measurable readings. Slight variations in measured values and calculated values can be due to common mode rejection ratio (CMRR), which is simulated in Multisim. As seen in the Multisim figures, instrumentation amplifiers have 2 inputs. The CMRR refers to the amplifier's ability to reject unwanted noise from common signals on both inputs and only amplify the desired signal. ✓

Task 4 – Signal Transmission

Overview of Fieldbuses

A fieldbus refers to a bi-directional digital communication network involving controllers/monitors and field devices. They are used in industrial automation processes to create integrated control systems whereby the instruments themselves are just as much a part of the system as the controllers (Powell, 2015). It is this bi-directional communication which allows the feedback and control between devices, without the need for a separate controller to be connected to each field device. It removes the need for excessive wiring as multiple field devices can be connected to one point and be governed by a central controller. It replaces the traditional 4-20mA system with a digital system, of which their differences are outlined below in figure 6.

S.NO	Description	4-20mA System	Fieldbus System
1	Number of field devices per wire	1	Max. 32
2	Signal/data	1	Up to thousands
3	Power supply over the wires	Yes	Yes
4	Signal degradation	Yes	Managed with terminators
5	Failure analysis	By human intervention	Reported at HMI
6	Max. run length	2000 m with proper cables and power supply	1900 m, extendable to 5700 m with repeaters
7	Field device interchangeability	Yes	Yes
8	Intrinsic safety	Yes, more barriers needed	Yes, less barriers needed
9	Control in the field	No	Yes
10	Device failure notification	Very limited	Extensive
11	Networking of field devices	No	Yes

Figure 6 - Differences Between Fieldbus and 4-20mA System (Instrumentation Tools, 2025)

Fieldbus systems can be broken down into levels of increasing scale as follows:

Sensor Bus Networks – These contain low-level devices such as switches and ultrasonic sensors, all of which are connected to a single network cable. The output signals relayed by these devices are sent via a single cable which can be setup as alarms/indicators or to equipment such as automatic valves/actuators.

Device Bus Network – This level contains a larger number of sensors and actuators and connects to more sophisticated control elements such as VSDs (variable speed drives).

Control Bus Network – This level refers to high level devices such as PLCs, all connected together and linked to interfaces such as HMIs (human-machine interfaces) to allow configuration of the devices in the network from all levels. ✓

Enterprise Bus Network - This involves the large-scale data transfer between different systems and is the most expansive level of Fieldbus.

The topology of different Fieldbus networks is also important to understand, topology referring to the arrangement of the elements in the network (Instrumentation Tools, 2025). There are six topologies which will be explored below and are shown in figure 7. ✓

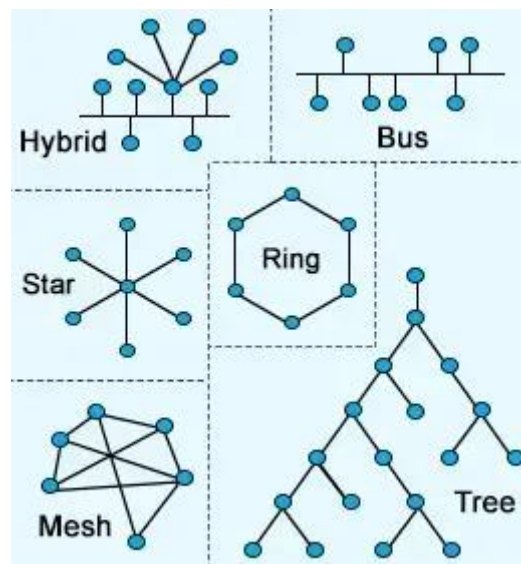


Figure 7 - Network Topologies of Fieldbus Systems (Instrumentation Tools, 2025)

Bus topology – There are two versions of bus topology; linear and distributed. Linear bus topology is shown in figure 7 and refers to when devices are connected to a common channel and the system has 2 end points. When there are multiple channels with more than 2 end points, this is known as distributed bus topology. ✓

Ring topology: In this version of networking, each device is connected to each other so signals must pass through each device to reach their destination. If one ring is used the signal flow is uni-directional, but two rings can be used whereby each ring is independent of the other to create bi-directional signal flow. Dual rings can be used as a backup in case one ring fails. It is preferable to use dual rings over single rings as a network connected in series only has to have one component fail for the whole system to fail. ✓

Mesh topology: Mesh topologies are robust networks which involve more wiring. Each device is connected to each other, so if a communication link fails, one of the others connected to it can be used in its place whilst the first is repaired. It also means more data can be transferred at one time as one device can send data to multiple devices as they are all interlinked. ✓

Star topology: This is when each device is singularly connected to a central device, therefore the entire system is reliant on this central device. This central device acts as a signal booster, so can receive signals and output these signals further afield. Star topology networks can be interlinked to further increase this effect. ✓

Tree topology: In this system a hierarchy is established whereby each device is linked to one or two devices as shown in figure 7. This type is easy to be added to in the future as a new branch can be added to whatever device is at the “bottom” of the tree. It is reliant on a common channel, which could cause the whole system to fail if it fails. ✓

Hybrid topology: This simply means a combination of any of the above topologies. They can be used to harness the advantages of each system to create a more robust system.

The type of Fieldbus used refers to a set of protocols defined by its system. The 3 being researched in this assignment are Foundation Fieldbus, HART Protocol and Profibus. ✓

Foundation Fieldbus

Foundation Fieldbus is a digital bi-directional communication system designed for use in automation (Emerson, 2002). The system is controlled by a ‘host’ which is user operated such as a software package on a site desktop. ✓

Key Features of Foundation Fieldbus (FF)

- H1 connector – this is shielded two-wire cable which contains the supply voltage wire and the comms wire, which transmits data at 31.25kbit/s. Alternatively HSE connections can be used (High-speed ethernet) which work at 100Mbit/s but does not provide a supply voltage. H1 is most commonly used.
- Multidrop wiring allows up to 32 devices to be connected via single H1 connector cable, this is known as a segment.
- Able to transmit multiple variables from one field device i.e. temperature and pH from a pH probe/controller. This can be helpful in reducing the total amount of devices in the field as single multivariable devices can be used and linked up via 1 cable. ✓

- Bi-directional communication allows for closed loop feedback systems.
- Foundation Fieldbus H1 is intrinsically safe and can also be used in potentially explosive areas, making it ideal for industrial processes.
- 'Publisher and subscriber' system. The publisher refers to when a field device is sending data to the Foundation Fieldbus and vice versa. Publishers send data and subscribers receive data (Siemens, 2012). The synchronisation of this system is determined by the 'Schedule'.

Figure 8 shows a basic layout for a Foundation Fieldbus network. As demonstrated by the image, field devices are each connected to a junction box, and from here are connected via a single cable to the I/O channel/PLC.

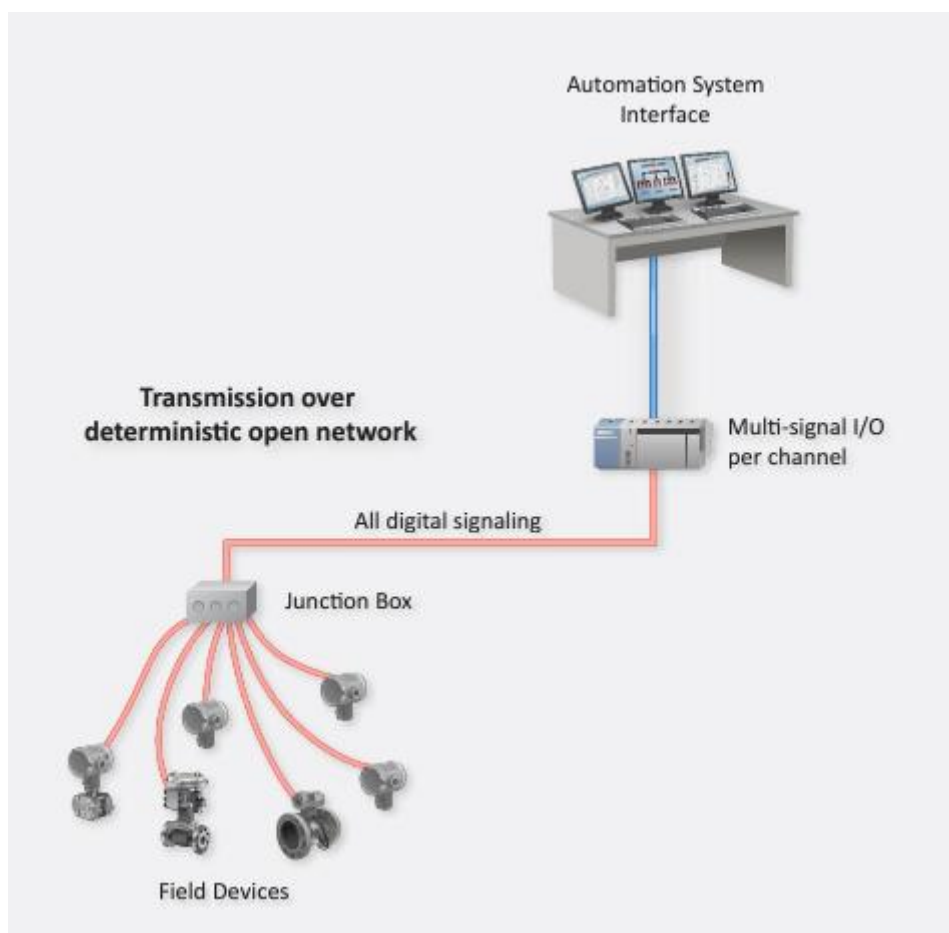


Figure 8 - Foundation Fieldbus Layout (FieldComm Group, 2017)

As previously stated, Foundation Fieldbus was designed to be used in industrial automation processes. It does so very well and can reduce installation costs by a large margin compared to an analogue system due to the decrease in wiring costs. Its H1 segments can travel up to 1900m (FieldComm Group, 2017) which is especially useful on larger sites. Foundation Fieldbus can be used in any industrial application with a large number of field devices to create a unified and controllable automated system, for example water treatment works and oil and gas refineries.

HART Protocol

HART, or highway addressable remote transducer, is a protocol used in industrial process measurement (Emerson, 2002) to transmit analogue and digital data at the same time using a single pair of wires. HART is not technically a fieldbus as it is not fully digital, but it shares some similarities.

In regard to a field device, analogue data refers to a process variable, such as temperature, whilst the digital HART data refers to things like alarm limits and tagnames for devices. Figure 9 shows a visual representation of how this data is sent.

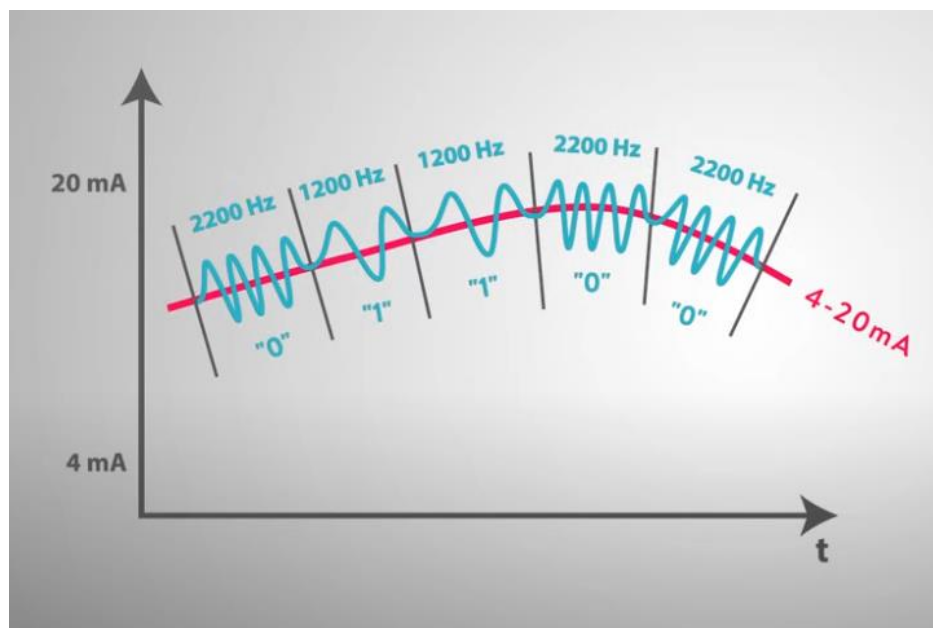


Figure 9 - HART Protocol Signal Transmission (RealPars, 2018)

The blue line on the graph represents what is known as a Bell 202 signal, which in short is a digital representation of a sine wave with frequencies alternating between 1200Hz (represents a 1) – 2200Hz (represents a 0). The red line is a standard 4-20mA analogue signal.

Key Features of HART Protocol

- HART enabled systems can easily replace existing non – HART systems as the field devices still only need a single pair of wires, so no wiring modifications need to be made where this is the case. The relevant PLC I/O card must also be replaced with a HART enabled card if it is not already.
- Bi-directional communication system like Foundation Fieldbus.
- HART networks can carry up to 63 field devices in the same multidrop wiring method as Foundation Fieldbus, although multiple devices can cause lagging in the system so it is preferable to use a minimum amount. Their data can all be accessed remotely removing the need to physically go to each device individually for things such as calibration.

- HART network systems can be wired up to a distance of 10,000ft (Jagan & Rao, 2019).
- Each field device can send/receive up to 50 different parameters e.g. limits, diagnostic alerts and alarm settings.
- Transmits data between 1200 and 3600b/s.
- Hardware devices known as HART communicators also allow for access to a field device's data via a parallel connection on the device's loop wires, be it at the device itself or at a junction box. This can be used in lieu of a PLC and is useful when the field device is in a difficult to reach area, so a connection can be made at the junction box rather than trying to get access to the device to configure it. An image, taken from the Fluke website, is shown below of a Fluke HART Communicator (figure 10).

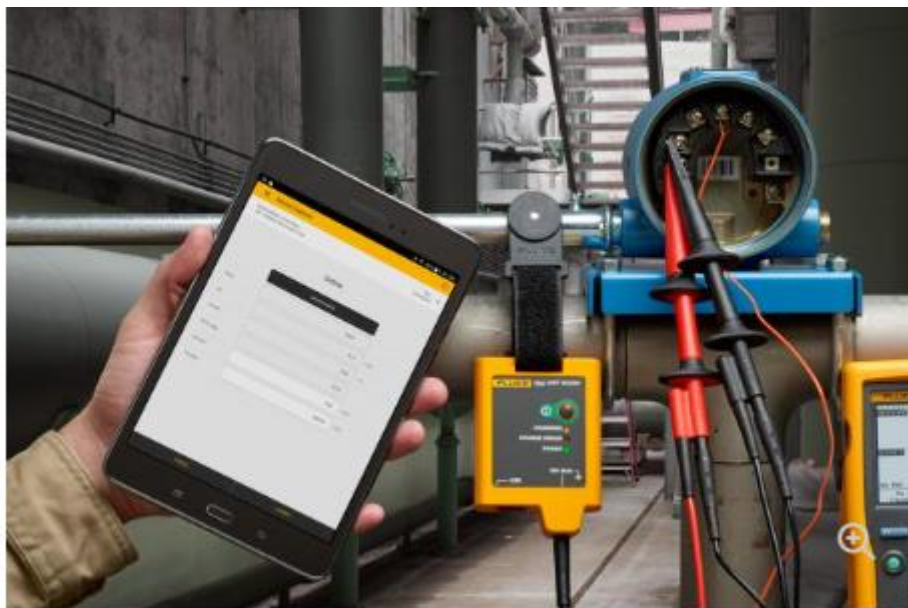


Figure 10 - Fluke HART Communicator (Fluke, 2025)

- HART networks feature a 'master' node, which controls when data is requested from the field device in the network loop. Multiple master nodes can be connected to one loop, meaning data can be accessed and configured from more than one location.

The HART protocol is similar to Foundation Fieldbus in the fact that it is bi-directional in its data transfer which allows remote control of a network of field devices. It differs in so much as it is less useful for automation, as it is relatively slow once you connect multiple devices, and more useful for monitoring and control. It is also useful in that it can be used with multivariable instruments such as flow meters, as it can receive multiple signals in one request from the master node. HART systems are widely used across many industries, with many sensors and field devices already HART enabled as standard, therefore making it an easy-to-integrate system into any industry involving a multitude of 4-20mA field devices.

Profibus

Process field bus, shortened to Profibus, offers greater simplicity over Foundation Fieldbus and HART protocol as it can be used to network an entire plant without the need for other systems to be in place. This cuts down on the amount of knowledge staff are required to have and makes installation/fault finding/maintenance easier (Powell & Vandelinde, 2015). The overarching standard in Profibus is known as Profibus DP, there are 3 other standards which are integral to the operation of a Profibus network and are listed below in figure 11. For the purpose of this assignment only Profibus DP and PA will be explored in more detail. In short, Profisafe is a protocol used to increase accuracy of data transmission, ensuring it is correct. Profidrive is used in situations where high speed drives are in use and allows the synchronisation of multiple drives.

PROFIBUS DP	DP: Decentralized Peripheral
PROFIBUS PA	PA: Process Automation
PROFIsafe	PROFIBUS for safety applications
PROFIdrive	PROFIBUS for drive applications

Figure 11 - Profibus Protocols (Powell & Vandelinde, 2015)

Profibus DP

Profibus decentralised peripheral, shortened to DP, refers to the physical element of the Profibus network. Generally, RS-485 cable (standard cable for data transmission) is used, although fibre optic can be used, to transmit data at high speeds from an I/O module to a PLC. Traditionally, the I/O module for the PLC would be next to the PLC in the same rack, but with Profibus it can be moved if the field devices are a great distance away. The field devices can then be connected to the I/O module, and their data can be transmitted along a single RS-485 cable to the PLC, saving time and money in wiring individual components. A visual representation of this is shown in figure 12 below.

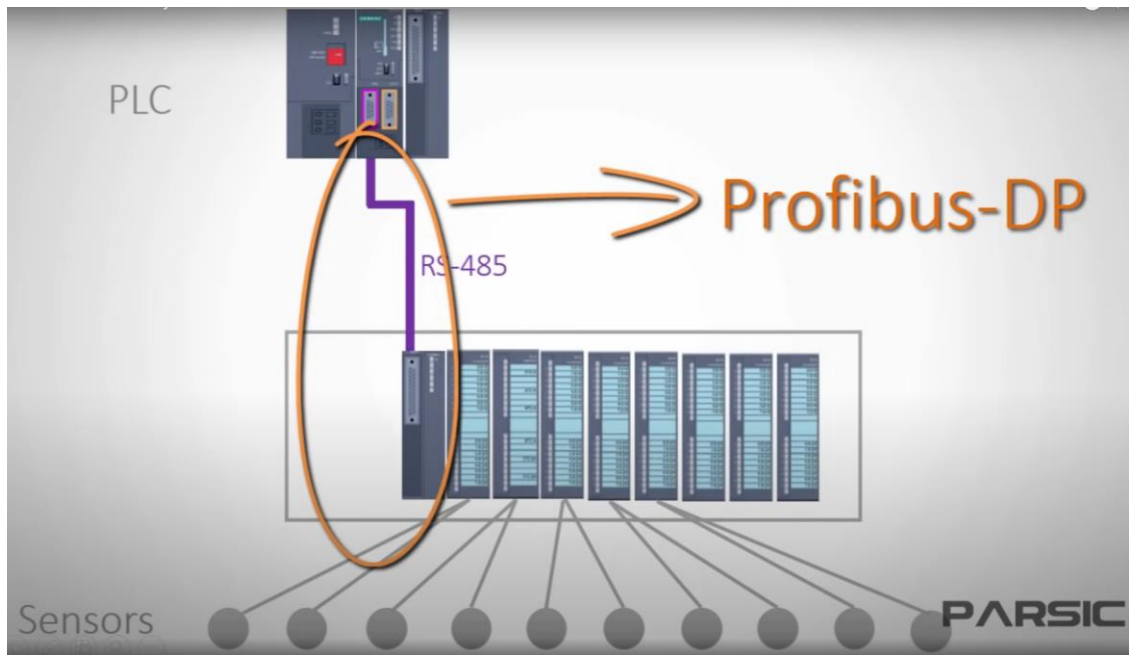


Figure 12 - Profibus DP Network Layout (RealPars, 2015)

This explains why it is known as decentralised peripherals (also termed remote I/O), because the I/O channel has been moved away from the PLC rack.

Key Features of Profibus DP

- Digital data transmission – this is ideal for use in areas where wires could be subject to electrical noise from plant/machinery as it is more robust than analogue signals when it comes to noise interference.
- Decentralised I/O modules connected to PLC via RS-485 cable greatly reduce amount of wiring required. The range of Profibus DP is up to 1200m of wiring (Jagan & Rao, 2019).
- All data being transmitted by a single RS-485 cable. This improves efficiency but means if the cable fails, all communications to the field devices will be lost. It is therefore best practice to wire in key devices direct to the PLC, and all other devices via Profibus. Another method of backup is using two RS-485 cables, with one cable being used as the main data transfer cable, and the other one as backup.
- Transmits data between 9.6kb/s and 12Mb/s. ✓

Profibus PA

Profibus process automation (PA) is a protocol used in Profibus networks to further reduce the amount of wiring required. Profibus PA transmits data at 31.25kbit/s.

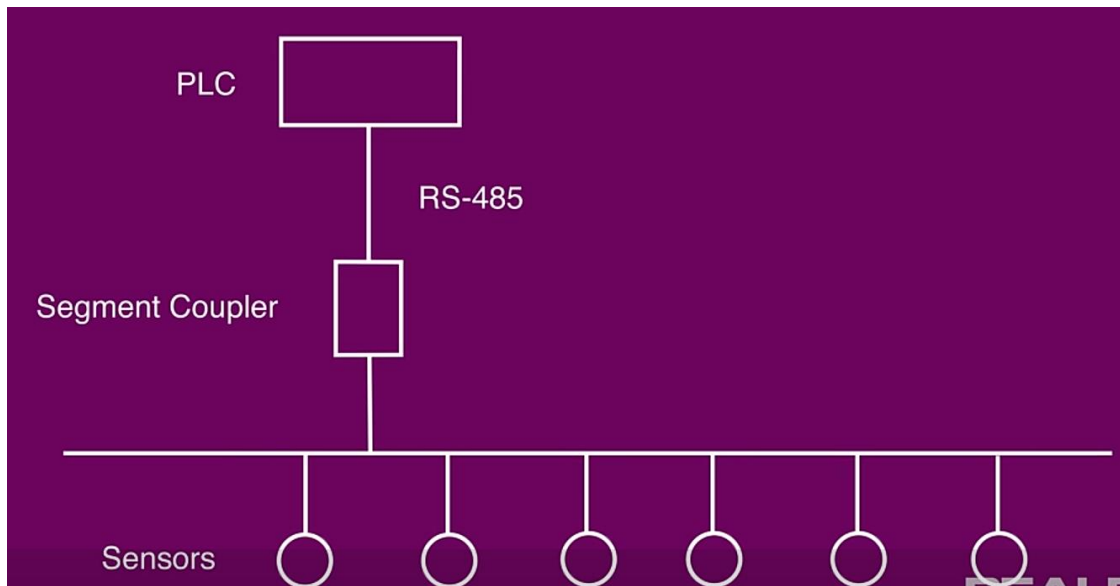


Figure 13 - Profibus PA Network Layout (RealPars, 2018)

An important aspect of Profibus PA is a feature known as bus power. This utilises a single wire (known as the Profibus PA bus), rather than a pair, which can be used for both power to the field device, and communication from the device to the PLC. A segment coupler is used as a converter (Profibus PA input and Profibus DP output) as PLCs don't generally come with Profibus PA ports as standard. ✓

In many scenarios, Profibus is the most suited out of the three systems discussed for process automation and control as it is simple, efficient, widely available and relatively fast in its data transfer. Foundation Fieldbus may be a better choice if higher speed data transfer is needed using the FF HSE protocol. It also facilitates inter-device communication so may be favoured if more complex tasks are required. HART protocol is the slowest of the 3, but also the simplest and cheapest way of converting an already wired in 4-20mA circuit to a network incorporating digital signalling. ✓

Very well done.

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