



LEVEL 4 ASSESSMENT SPECIFICATION

Student name:	Iwan Bevan	Student ID number:	58125
Programme:	HNC Instrumentation Engineering		
Module:	Instrumentation, Automation and Control		
Module code:	PCEE4009	Contribution to Overall Module Assessment (%):	50%
Lecturer:	Nigel Richards	Internal Verifier:	Jason Pointer
Assignment Title:	Temperature Measurement System and Signal Transmission	Word count (or equivalent):	2000
Submission deadline:	14/01/23	Return date of provisional marks & written feedback:	06/02/23
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. Penalties for late submission: Up to one week late, maximum mark of 40%. Over one week late, 0%. Only the Extenuating Circumstances Panel may approve a change to submission dates.		
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.

TASK DESCRIPTION

Introduction

You are working as an Instrumentation Engineer for Solero Measurement Systems Ltd. Your line manager needs a report on how to select the most appropriate sensor with a view of incorporating them into some of the company's measurement systems.

Task 1 –Sensor Functionality

The company would like you to write a report discussing the construction and key features (process variables, performance, benefit, limitations) of 2 different but common pressure sensors with respect to measuring and control system applications

Pressure is a measure of force over area

$$P = \frac{F}{A}$$

From knowing the force and the area over which it is applied the pressure can be calculated. Two common sensors for measuring pressure are strain gauges and capacitive pressure sensors.

Strain Gauge

The strain gauge comprises of a thin electrical wire. Compressive or tensile forces will stretch the wires, decreasing the cross-sectional area. Consequently, the electrical resistance increases with smaller cross-sectional area. For the material of the strain gauge will be a relationship between strain and resistance. From the strain, the pressure exerted on the gauge can be inferred.

Metal strain gauges have a Gauge Factor (GF)

$$GF = \frac{\Delta R / R}{\text{Strain}}$$

where $\Delta R / R$ is the change in resistance over the nominal resistance of the wire.

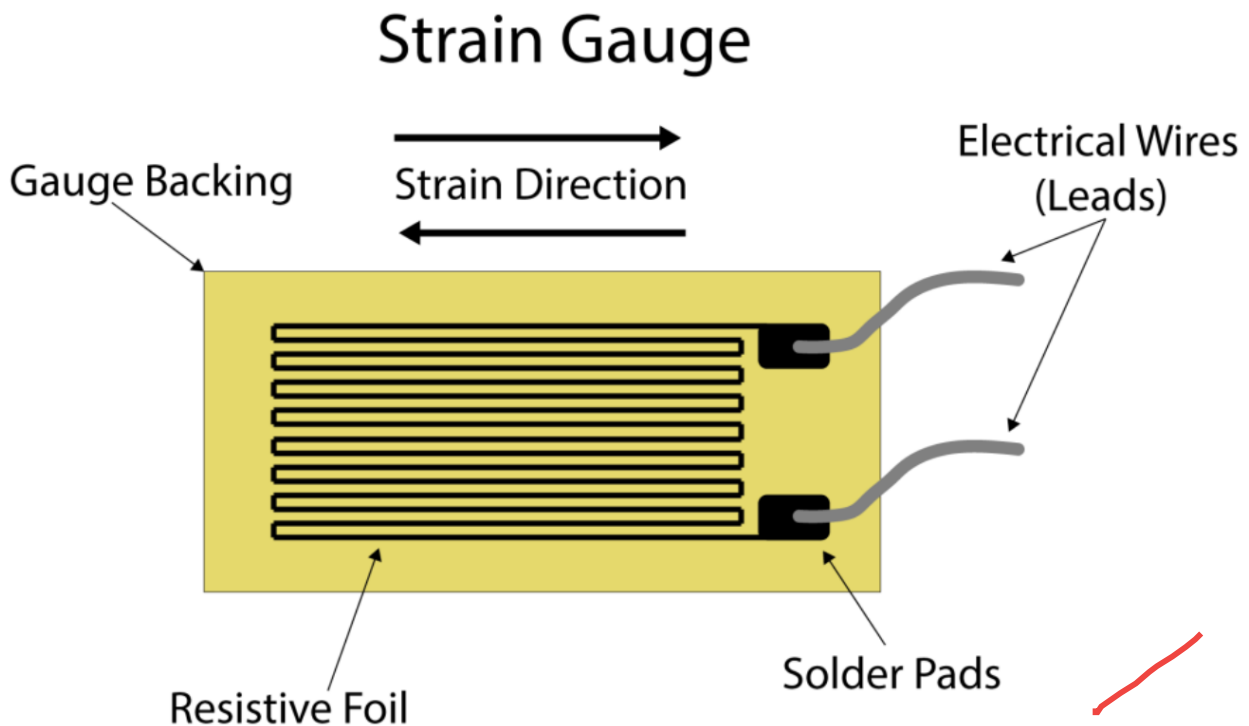
Strain is $\Delta L / L$, change in length over original length.

Johnson (2000) states metal gauges have a GF of close 2 but that some special alloys and carbon gauges have a GF of close to 10. Further, a high GF is desirable because it indicates a larger change in resistance for a given strain and is easier to measure.

The nominal strain gauge resistance is usually between 60Ω and $1,000\Omega$. The most common being 120Ω . Johnson (2000) comments that a good strain gauge has a resolution of $2\mu\text{m/m}$. Such a resolution would yield a change in resistance of $4.8 \times 10^{-4}\Omega$. Therefore, the measured change in resistance is very small. Subsequent signal conditioning would be necessary to make signal interpretation easier.

Strain gauges can be in either wire or foil form and act unidirectionally. The illustration below is of a typical strain gauge. As can be seen, the strain can only be effectively measured in the longitudinal direction. A strong strain acting transversely would unravel the gauge.

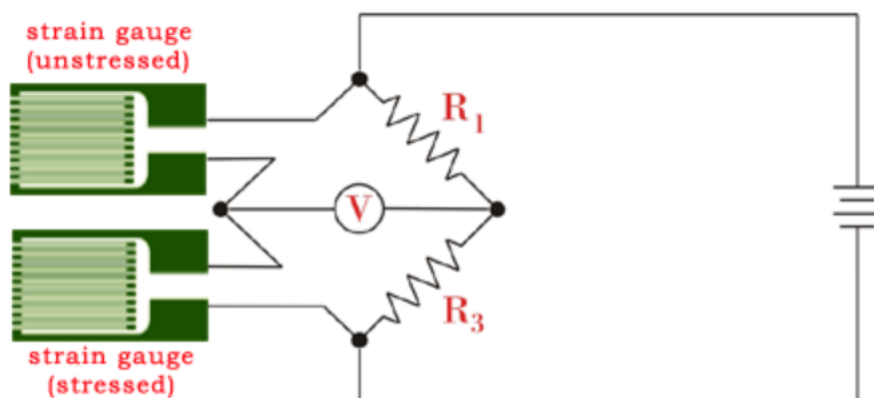
The wires are sandwiched between flexible backing plates. Bolton (2004) suggests the strain gauge could be placed on a surface like affixing a postage stamp. The gauge can be placed on the inside wall of a pipe or at the bottom of a vessel to measure the fluid pressure.



(Nachazel, 2020)

The strain gauge is placed in a Wheatstone Bridge. A change in resistance would change the voltage observed across different legs of the bridge.

Besides signal conditioning, another problem is the effect temperature has on a change in resistance. To overcome this, the Wheatstone Bridge could incorporate two identical strain gauges, both exposed to the same temperature but only one of them experiencing the process variable pressure. The difference between the two can be attributed solely to pressure.



Quarter-bridge strain gauge circuit
with temperature compensation

(Electrical4U, 2020)

Capacitive Pressure Sensor

A capacitor holds charge between two conductive plates separated by a dielectric material. Measured in Farads, it is the amount of charge held per volt.

The capacitance of a parallel plate capacitor is $C = \frac{\epsilon_0 \cdot \epsilon_r \cdot A}{D}$

where ϵ_0 is a constant called the relative permeability of free space,
 ϵ_r is the relative permeability,
 A is the area of the plate, and
 D = distance between the two plates.

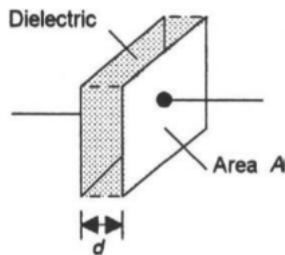


Figure 2.4 *Parallel plate capacitor*

(Bolton, 2004)

The parameters that could change to vary the capacitance are the area of the plates, the distance between the plates or the dielectric between the plates. A capacitive pressure sensor varies as a result of one plate moving nearer or further away from the other plate.

The capacitive pressure sensor can measure gauge pressure, as can be seen in the image below left, or by measuring a differential pressure, as can be seen by the image below right. In both of the images, fluid exerts pressure on a moveable metal plate. It will either move nearer to the other plate by deflection, like a diaphragm. As the moveable plate gets nearer to the other the capacitance increases.

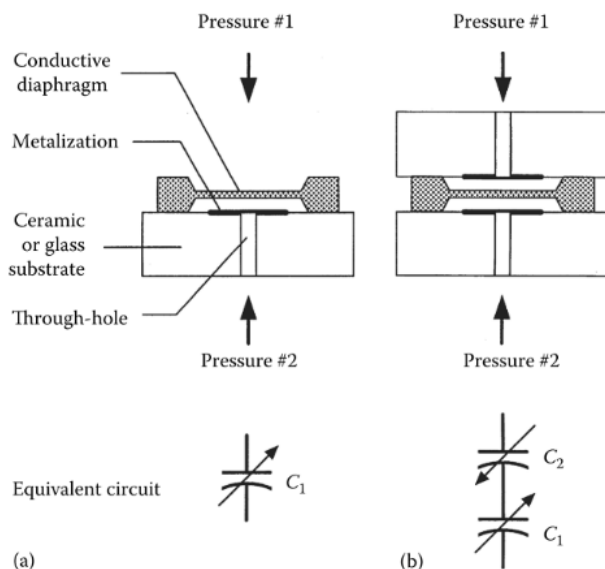


FIGURE 39.2 Operating principle of capacitive pressure sensors, (a) single capacitor design and (b) differential capacitor design.

(Webster, 2014)

Webster (2014) commends capacitive pressure sensors for being highly accurate: better than 0.1%. They can be designed to measure pressures up to 10MPa and as low as 10^{-3} Pa.

The image below shows a design for a differential capacitive sensing element.

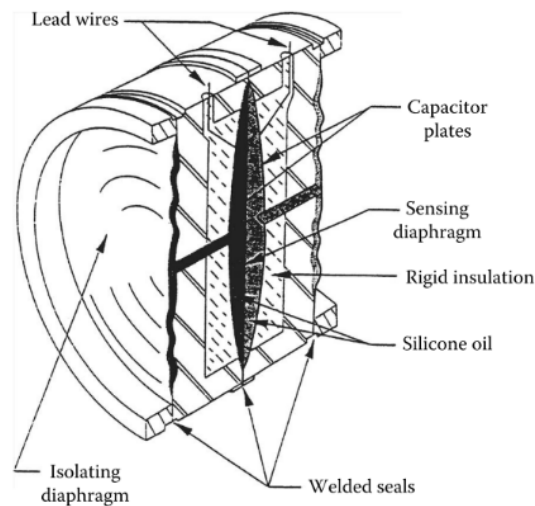


FIGURE 39.3 Differential capacitive sensing cell that is equipped with isolating diaphragms and silicone oil transfer fluid suitable for measuring pressure in corrosive media. (Courtesy of Rosemount, Inc., Eden Prairie, MN.)

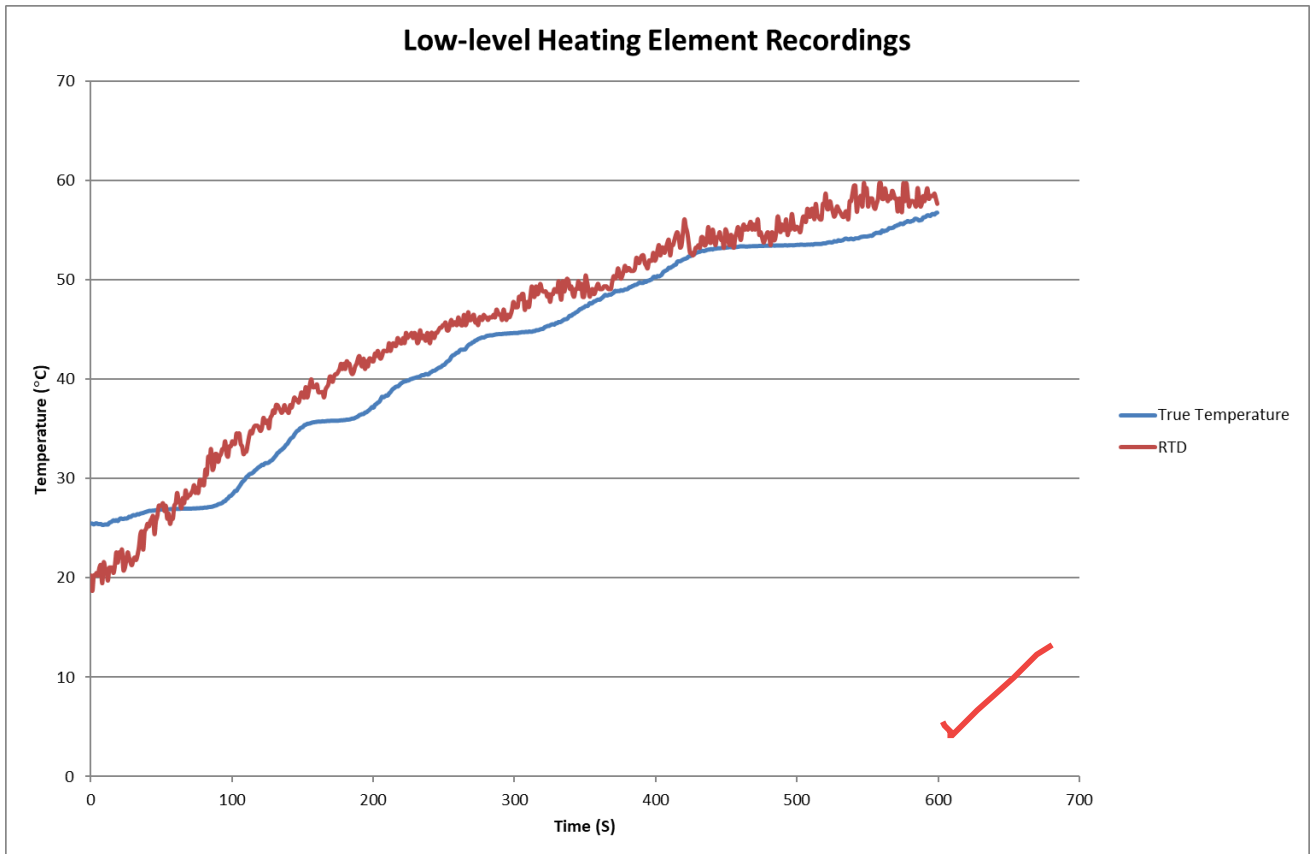
(Webster, 2014)

The diaphragms are made of special metal alloys that can handle corrosive materials. An oil chosen is chosen for a predictable dielectric constant between the plates. It serves to provide adequate damping to reduce vibration shocks and vibration effects. Webster (2014) finalises his comments by observing that with modern sophisticated electronics stray capacitances of as little as 10^{-18}F can be minimised by resolving diaphragm deflections as small as a fraction of a nanometer.

The capacitive pressure sensor is therefore rugged, robust and reliable. It can be designed to accommodate enormous pressures and miniscule pressures. It can eliminate noise thanks to the dielectric oil and today's electronics. As it can be built to withstand corrosive substances it can be utilised in a number of industrial environments and measure the pressures exerted by a number of process fluids.

Task 2 – Sensor Testing

The company have shortlisted 2 Temperature sensors (Thermistor & RTD-both supplied) for incorporating into a system but want to investigate the accuracy and performance of each by using a resistor device as a low-level heating element operating over a **five-minute** period. The measurements will be compared with the results of an IC temperature sensor which is currently being used by the company. Using graphs as required analyse and compare of the results, referring to accuracy, sensitivity, errors and response to recommend the most suitable sensor.



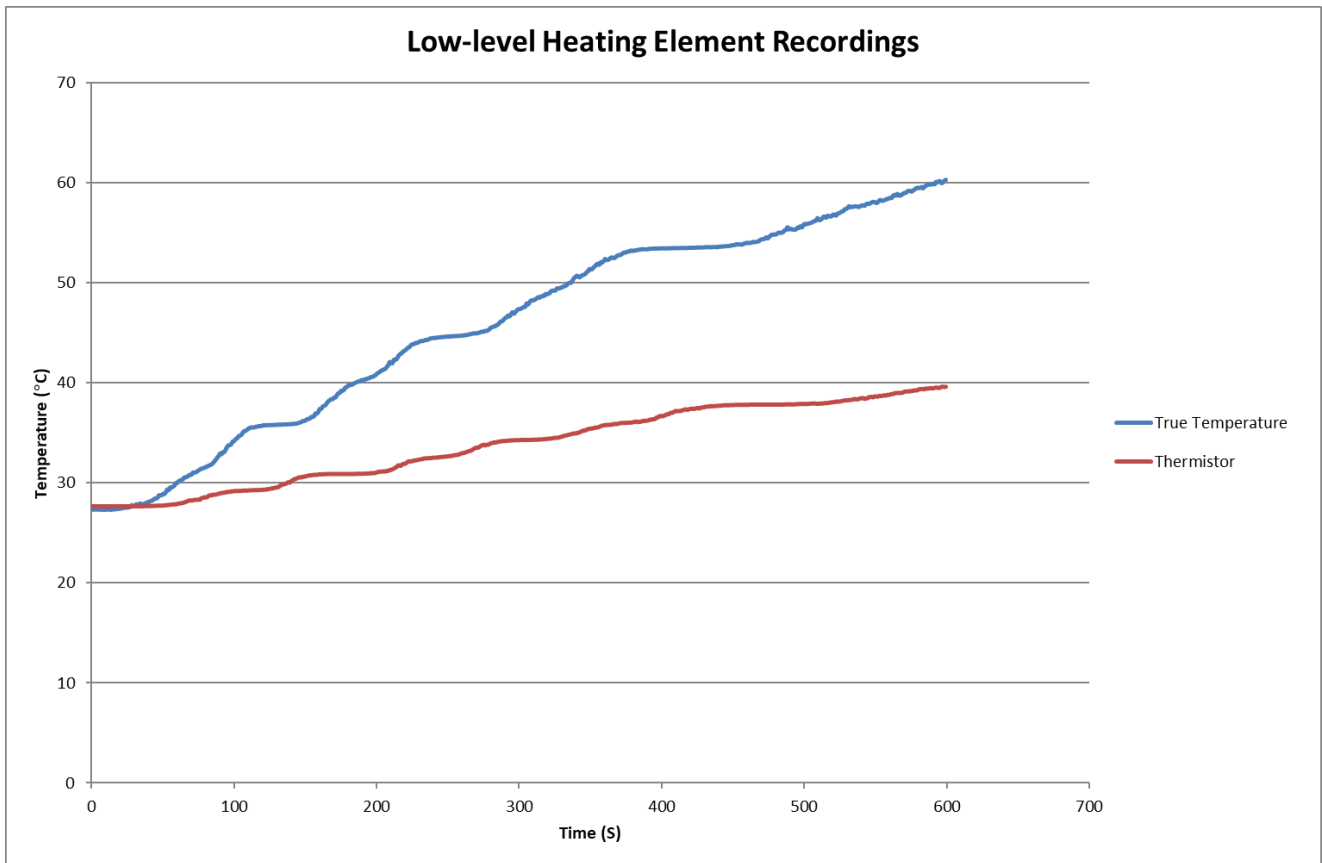
Initially, the RTD inaccurately records a lower temperature. At approximately 50 seconds the RTD does accurately record the temperature when it is around 27°C. Thereafter, the RTD overestimates the temperature.

Between 30°C and 55°C the discrepancy is up to 5°C over the true temperature. Though it is inaccurate it is precise because the margin is consistent. At various points the RTD does near the true temperature but is still marginally above it.

After 100 seconds and at approximately 33°C the RTD displays good linearity with no drift. The repeatability is very good since there are no outlying recordings.

Its resolution is very good to 2 decimal places. The curve is not smooth but has jagged movements.

Until approximately 30°C there is a retardation lag of the RTD. However, there is a dynamic error in response to temperature changes after that 30°C.



The curve of the thermistor is much smoother than that of the RTD. The thermistor demonstrates good linearity.

At temperatures around 28°C the thermistor is very accurate but soon diverges away from the true temperature. As time progresses, the thermistor underestimates the true temperature further and further. It therefore is both inaccurate and imprecise.

The ambient temperature is recorded at the beginning of the experiment. The thermistor records this accurately and then displays zonal drift. This would suggest it has a dynamic response that has a time delay. The heating element raises the temperature too rapidly for the thermistor to respond accurately. There is a time delay of approximately 200 seconds before the thermistor recognises a temperature of 35°C.

Due to its slow response time it would have a very poor static characteristic of repeatability. The thermistor has a good resolution of 2 decimal places.

In view of these graphs the RTD would be the better of the two for recording the temperature. It is precise though slightly inaccurate. Its dynamic error is consistent, which is a tolerance that could be accepted.

The zonal drift of the thermistor exacerbates with temperature. It would therefore be unreliable.

Task 3 – Sensor Design

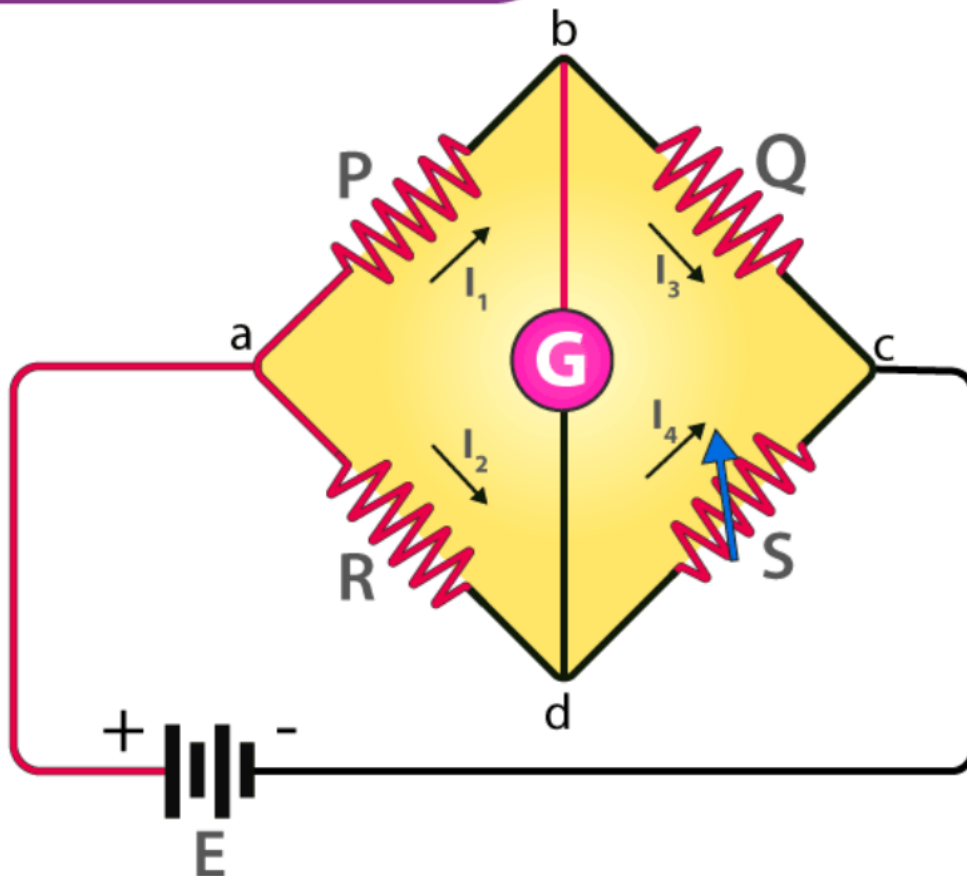
If your chosen temperature sensor was to be incorporated in to the system it will need some form of signal processing. Explain the need for signal conditioning and processing in order to fully utilise the sensor in a practical application. Justify a suitable measuring circuit that will convert the resistance of the sensor to a comparative **current** value. (Input range: User defined Output range: **4 to 20 mA**)

From the previous task, the RTD was found to be the best temperature sensor between itself and the thermistor.

Signal conditioning and processing involves 5 key stages: conversion, protection, amplification, elimination and manipulation.

A change in temperature will generate a change in resistance in the RTD. When the RTD is placed in a Wheatstone Bridge a voltage change will be detected across the ~~legs~~ of the bridge.

WHEATSTONE BRIDGE



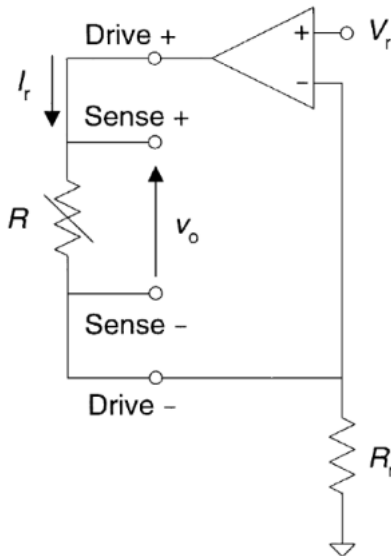
(BYJU'S, 2023)

values?

If the RTD (given by resistor S in the image above) is at ambient temperature along with the other three resistors in the bridge, there will be no potential difference across points b and d, measured by G. As the RTD records a temperature change the resistance and will change and there will be a voltage drop across. Hence, a potential difference will develop between points b and d.

From the graph in Task 2 it can be seen that the plot of the RTD temperature is nearly linear but not quite. A conversion formula could be used to linearise the plot. This would be the manipulation.

(Pallas-Areny, 2001)



Pallas-Areny (2001) considers that the set-up left is often employed for RTDs. It is an inverting operational-amplifier.

In the image left, resistor R could directly represent the RTD or the Wheatstone Bridge measured voltage. ✓

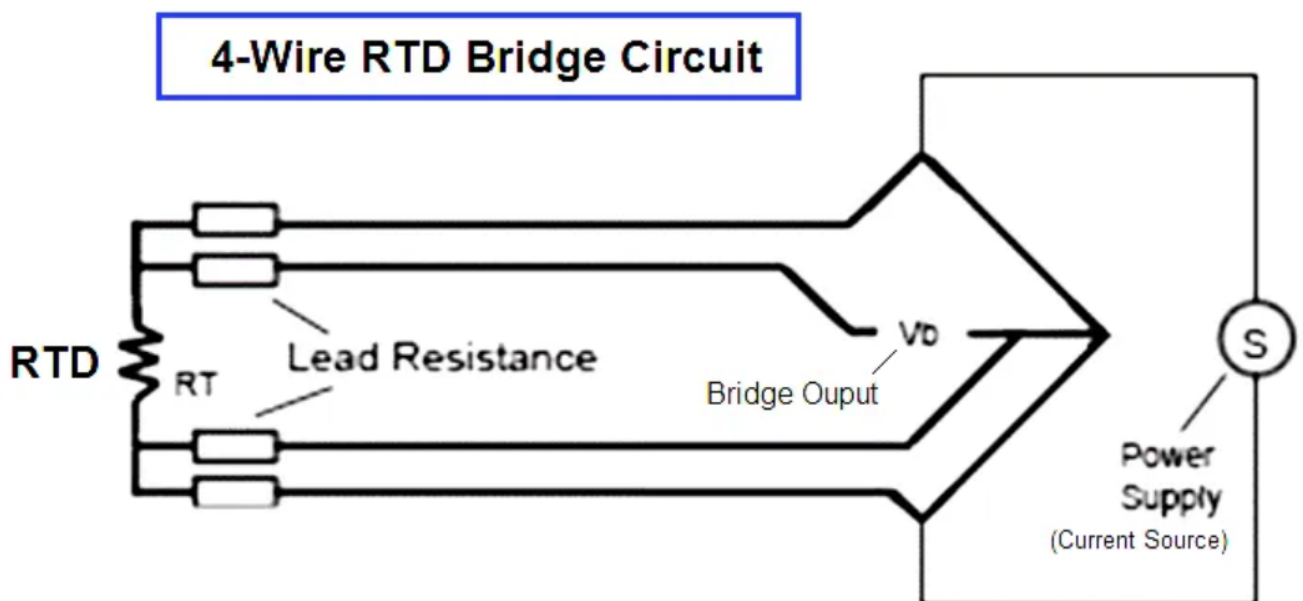
A change in voltage across the RTD will cause a difference in voltages between the non-inverting and inverting inputs of the op-amp. To balance the op-amp inputs the output voltage will have to be raised. This would be amplification of the signal and conversion from voltage to current.

In the image to the left, the current through resistor R_f could be measured as the current conversion. The voltage through this resistor would be a function of the op-amp output trying to balance the voltage between the inverting and non-inverting inputs.

A change in R would change the voltage at the inverting op-amp input, forcing the op-amp output to change to rebalance the inputs. The current goes directly to ground.

By Ohm's Law, $V=IR$, if the resistor is fixed but the voltage varies as a result of the op-amp output, then so too must the current. The current measured through the R_f would be the current conversion. ✓

A problem with the Wheatstone Bridge is that the wires have resistance themselves. This would affect the true resistance change across the RTD. A solution to this would be a 4-wire Wheatstone Bridge.

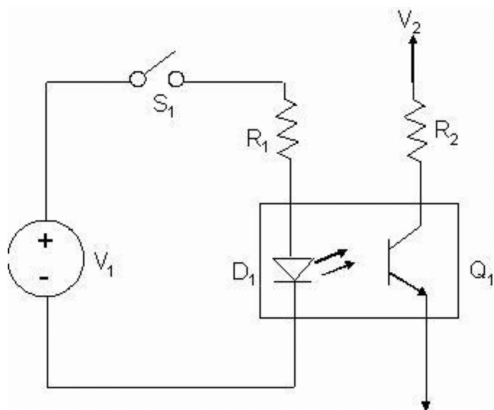


(Inst Tools, 2023)

The use of the 4-wires, as shown above, eliminates the effect of conductor resistance by raising the conductive capacity.

Converting to a 4 – 20mA signal would have the benefit of having a live zero. It could be calibrated to read 4mA at the lowest temperature that the RTD would be expected to record. In Task 2, this could be 25°C. The 20mA could be assigned to the highest temperature that the RTD can expect to record. In Task 2, this could be 60°C.

Another key component of signal conditioning and processing is protection. This would be protecting the signal loop from the sensor.



(Uddin, 2010)

There are several tools available. An opto-isolator protects the PLC from voltage and current surges in the op-amp circuit.

A voltage through a photodiode would cause it to emit infrared light, which would in turn open a phototransistor and allow current to flow through the secondary circuit.

The photodiode and phototransistor could be sealed in an intrinsically safe box, thus eliminating the risk of spark and explosion in a potentially explosive environment.

Another tool could be the use of fuses. These are sacrificial by burning out if the current exceeds the fuse's tolerance and thereby breaking the continuity of the circuit. Such a break would protect components in the rest of the circuit.

Also available is the use of relays. These protect the rest of the circuit from voltage and current surges. As with opto-isolators, relays can be used to control secondary circuits that are set-up on voltages and currents different from the primary circuit. For example, the circuit of the op-amp could operate at a few millivolts and milliamperes but the secondary PLC circuit would operate at 5V and 1A.

Frequency Modulation (FM) can be used to convert analogue signal to digital signal. A message signal is sent over a carrier signal. Their amplitudes and frequencies mingle and can be deconstructed at the receiver. For bands of frequency a bit of information can be assigned. From these bits a digital signal can be generated.

Task 4 – Signal Transmission

Finally, the company would like you to produce a short report explaining the key principles and benefits of the HART Protocol as part of a signal transmission system.

The Highway Addressable Remote Transducer (HART) protocol is a system for communicating between process variable's sensor and a master node in a network of process control.

A process variable's sensor could be a number of different variables: the level in a vessel, the temperature in a chamber, pressure, flow, or opacity, amongst many others. One sensor could record more than one variable; for example, a flow meter could measure pressure, temperature and viscosity.

Each sensor is connected to a master node. A master node could be a PLC or the plant's Distributed Control System (DCS) that monitors functioning of the plant. A master node could also be a handheld communicating tool. More than one node can be connected to sensor's transmitter at one time.

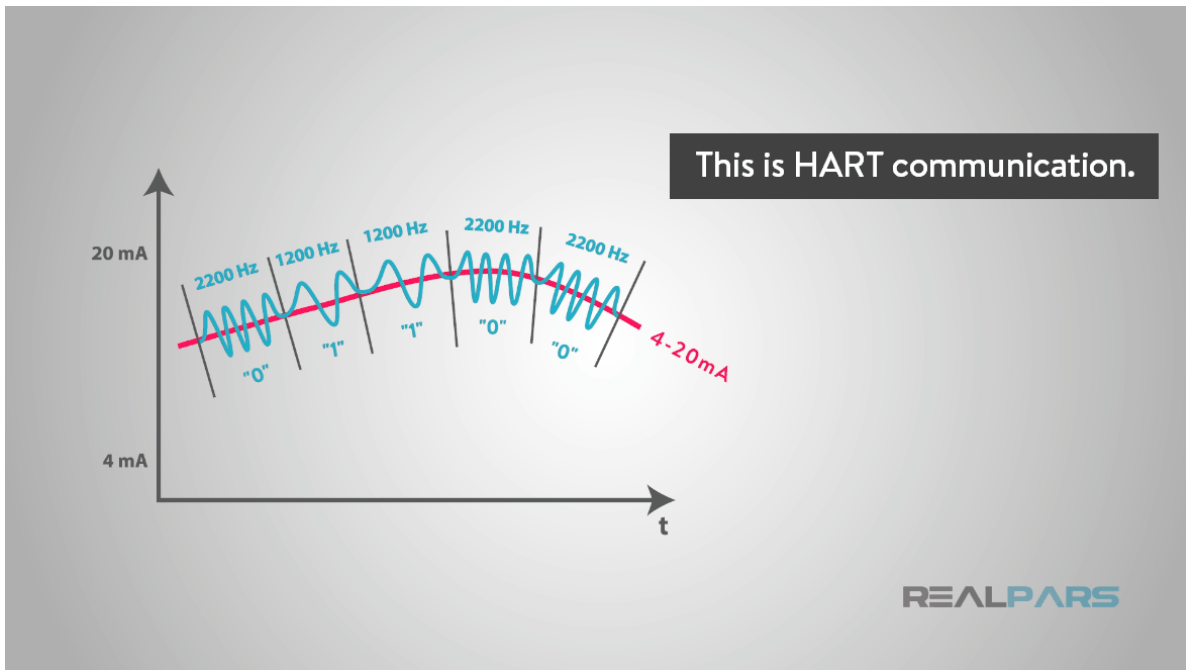
The HART protocol is a slow communication. Therefore, more than one transmitter is not on the same loop of the network but instead each transmitter communicates directly with a master node and hence the connection to the master node of each sensor, instead of being connected to other sensors in a slow HART loop. The master node communicates with the rest of the DCS network.

Not one vendor or manufacturer has a monopoly on the HART protocol. It is developed by the HART Communication Foundation, which is non-vendor specific. Therefore, hardware and software from different manufacturers should be conversant with each other if they are both HART enabled.

The protocol has the capability to transmit a digital signal and analogue signal simultaneously. The process variable will be the analogue signal transmitted in the 4-20mA range.

4mA would represent the lower range value. It is a live-zero to show that if the current was 0mA then there is a loss of signal and not necessarily that the process variable is at the lower range value. 20mA would represent the process variable's upper range value.

On top of the analogue signal is a frequency change of 1,200Hz to represent a 1 or 2,200Hz to represent a zero. These frequency changes represent the digital signal over which information about the transmitter could be conveyed.



Current and digital signal on the HART protocol (REALPARS, 2022)

Besides the process variable signal the additional digital signal could carry information on the tag number of the transmitter and the upper and lower range values.

The signal duality is advantageous by requiring only a pair of wires to carry two separate analogue and digital signals.

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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		
Regular and consistent referencing. Good range of research	20	12
2. Knowledge and Understanding Skills		
Exhibits very good understanding. Logical approach	35	28
3. Cognitive and Intellectual Skills		
Very good interpretation of qualitative and quantitative data. Excellent evaluation of underlying principles	10	8
4. Practical Application Skills		
Some good consideration of the context of the application - could have had more workplace reference, Sound problem solving,	25	14
5. Transferable Skills for Life and Professional Practice		
Work is coherent, accurate, well structured and organised. Hard answers not overtly clear but within text	10	6

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%)

68 %

Moodle Feedback - Iwan Bevan – Assignment 1

Practical application addressed at general level in context with the question asked although reference to your industry/work-related activities or processes would have helped show your understanding of the theory.

Resistor values in the wheatstone bridge would need to be equal given the same ambient temp for zero potential at the centre.

Regular and pertinent referencing

HART benefits present but not clearly articulated.