Sensor Technologies for Remote Environmental Aquatic Monitoring -STREAM

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STREAM

Agenda

Introduction to the STREAM Project – WCPC side

Commercial Sondes

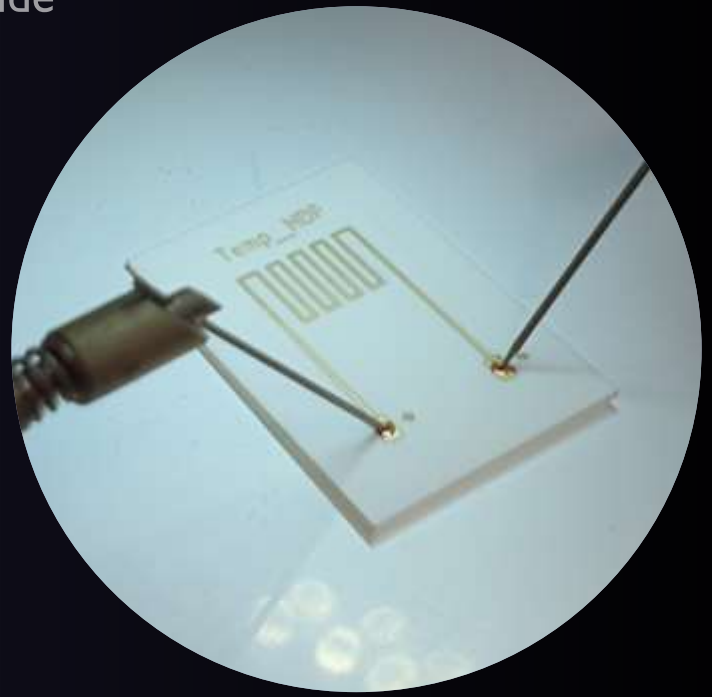
Weather Monitoring Radar

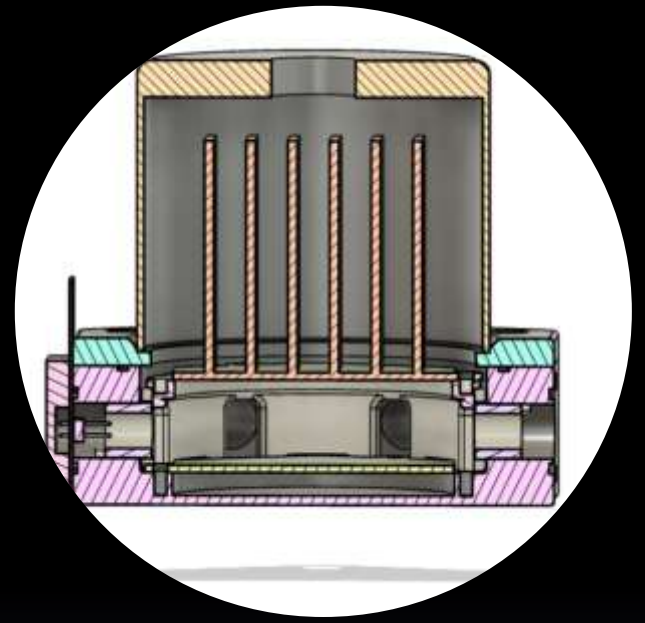
Printed Sensors

- Substrates
- Temperature
- Conductivity
- pH
- Dissolved Oxygen

Deployment

- Enclosure Design
- Electronics
- Communications





STREAM

Introduction

The STREAM project aims to develop sensors capable of providing real-time environmental data and disseminating this data via web portals and mobile applications to organisations responsible for protecting and improving Welsh and Irish waters.

When assessing water quality, different chemical, physical, and biological properties can be tested to evaluate the status of a waterbody. These include temperature, dissolved oxygen, salinity, pH, turbidity, chlorophyll and nutrients.

The data collected from the project is publicly available through the STREAM portal - https://grafana.marinestream.eu/.

Prifysgol Abertawe
Swansea University

SETU Ollscoil Teicneolaíochta an Oirdheiscirt South East Technological University

MTU Ollscoil Teicneolaíochta na Mumhan Munster Technological University

Overview

PROJECT AIMS - WCPC

- To develop low-cost sensor systems consisting of printed physical and chemical sensor technologies for Estuarine Monitoring.
- Ensure the data collected from sensors is accurate and has sufficient resolution to provide value.
- Transmit the data to the public facing project server to allow dissemination of the information to concerned parties.

PROJECT CHALLENGES

- Identification of compatible material sets
- Construction/sealing/leak prevention
- Sensor degradation/lifetime
- Bio-fouling
- Mechanical damage to sensors or installation
- Deployment

https://www.marinestream.eu/ https://grafana.marinestream.eu/

Commercial Sensor Deployments

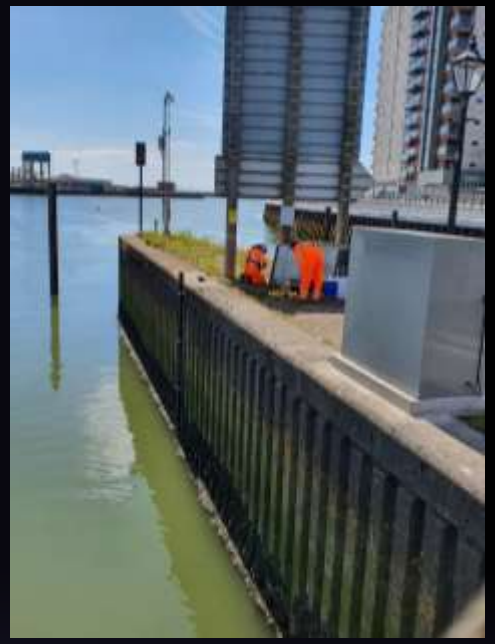
Two RS Hydro Sondes deployed in South Wales

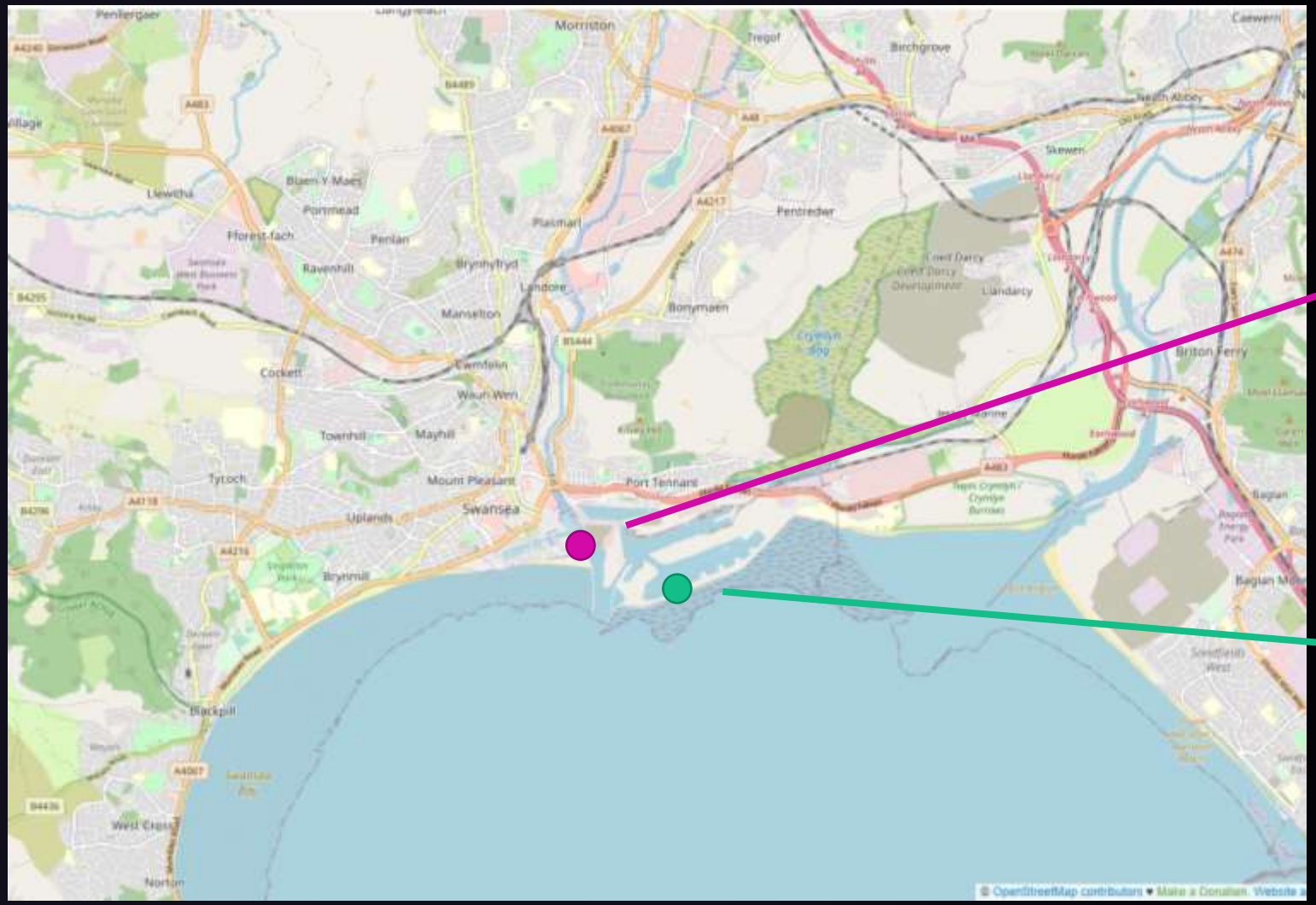
Overview

Two commercially available Proteus systems provided by RS Hydro are installed in Swansea as part of the STREAM project

Tendered Value: ≈£48,500 plus installation

- Temperature
- Conductivity
- pH
- Dissolved Oxygen
- Turbidity
- Total Organic Carbons
- Chlorophyl A
- Chromophoric Dissolved Organic Matter





TAWE BARRAGE

360 AQUACULTURE

Sonde Installation

- A 110mm ABS tube, known as a stilling tube, is used to contain and protect the sensor.
- The depth of the sensor is set by a stainless steel cable connected to the top of the tube. As the tide changes relative to the fixed height of the top of the tube the sonde effectively measures different depths of water.
- Water moving past the end of the pipe, and changes in the tide will lead to changes of the water in the pipe.
- Stainless steel Unistrut is used throughout and all anchors appear to be stainless steel too
- Measurements are taken every 15 minutes and the data is transmitted to a server every 2 hours.

Weather Monitoring Radar

SIMRAD

Weather Monitoring

As part of the STREAM project a weather monitoring radar has been installed in Swansea which captures the Swansea Bay area.

This will enable recorded sensor data to be related to local weather events, in particular heavy rainfall.

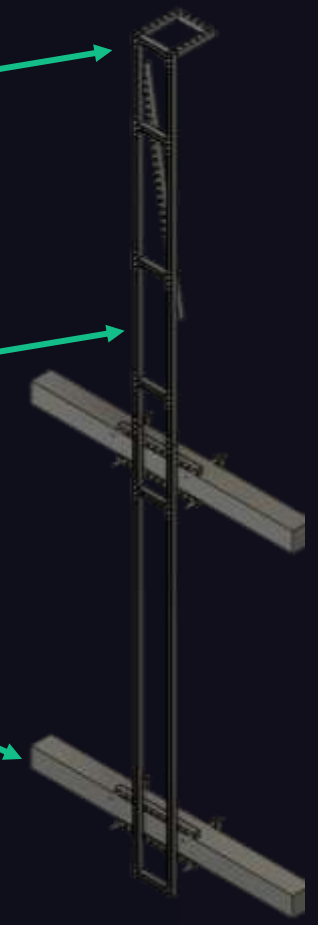
As more water quality sensors are deployed, this could enable identification of points where agricultural/industrial run off is contaminating/influencing the water system.

Weather Radar Installation

Plate for radar pedestal

41mm slotted channel Unistrut (Galvanised Steel)

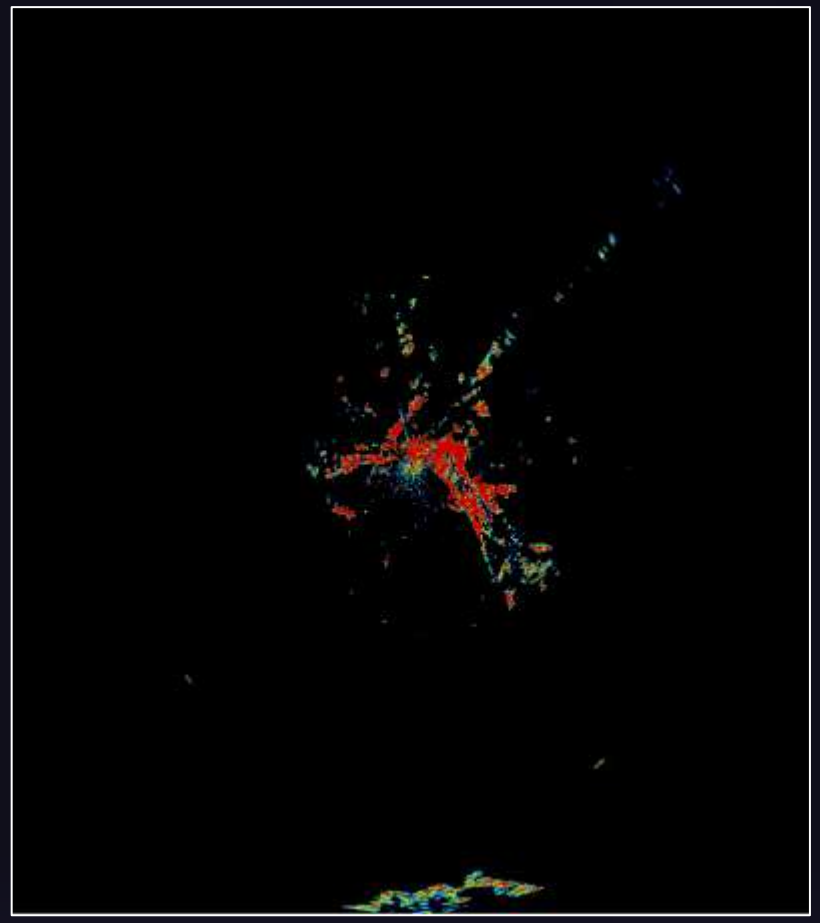
Secured to building framework with 8 pieces of M12 A4 Stainless Steel threaded rod



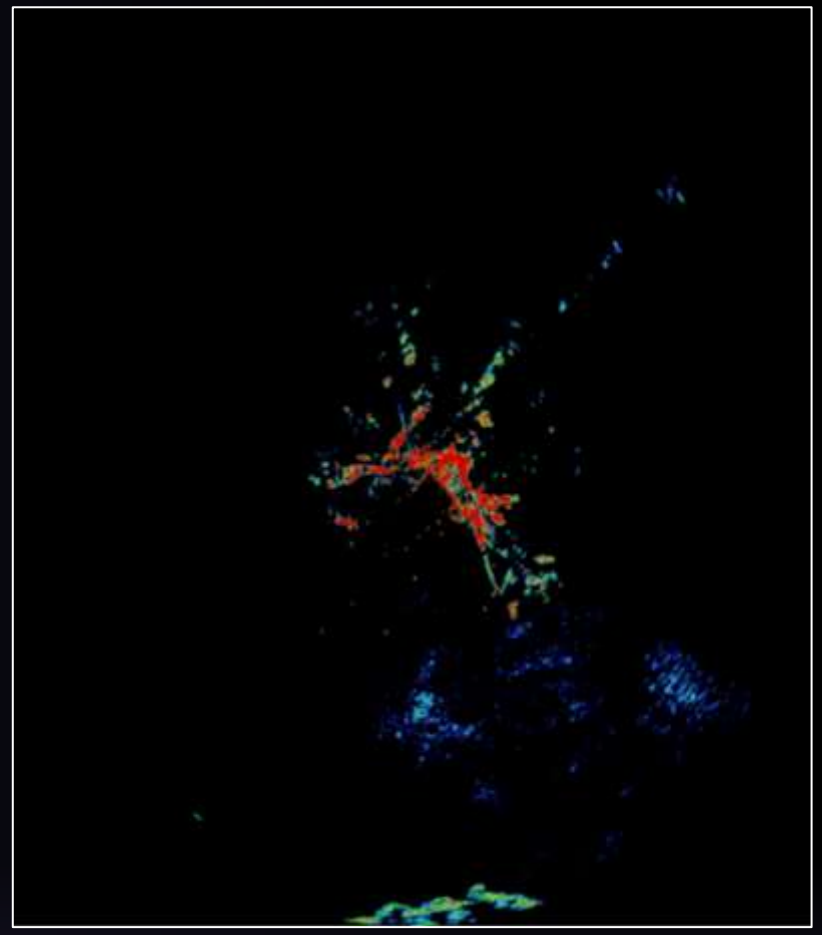
5.8 metres

Weather Radar Data

CLEAR DAY

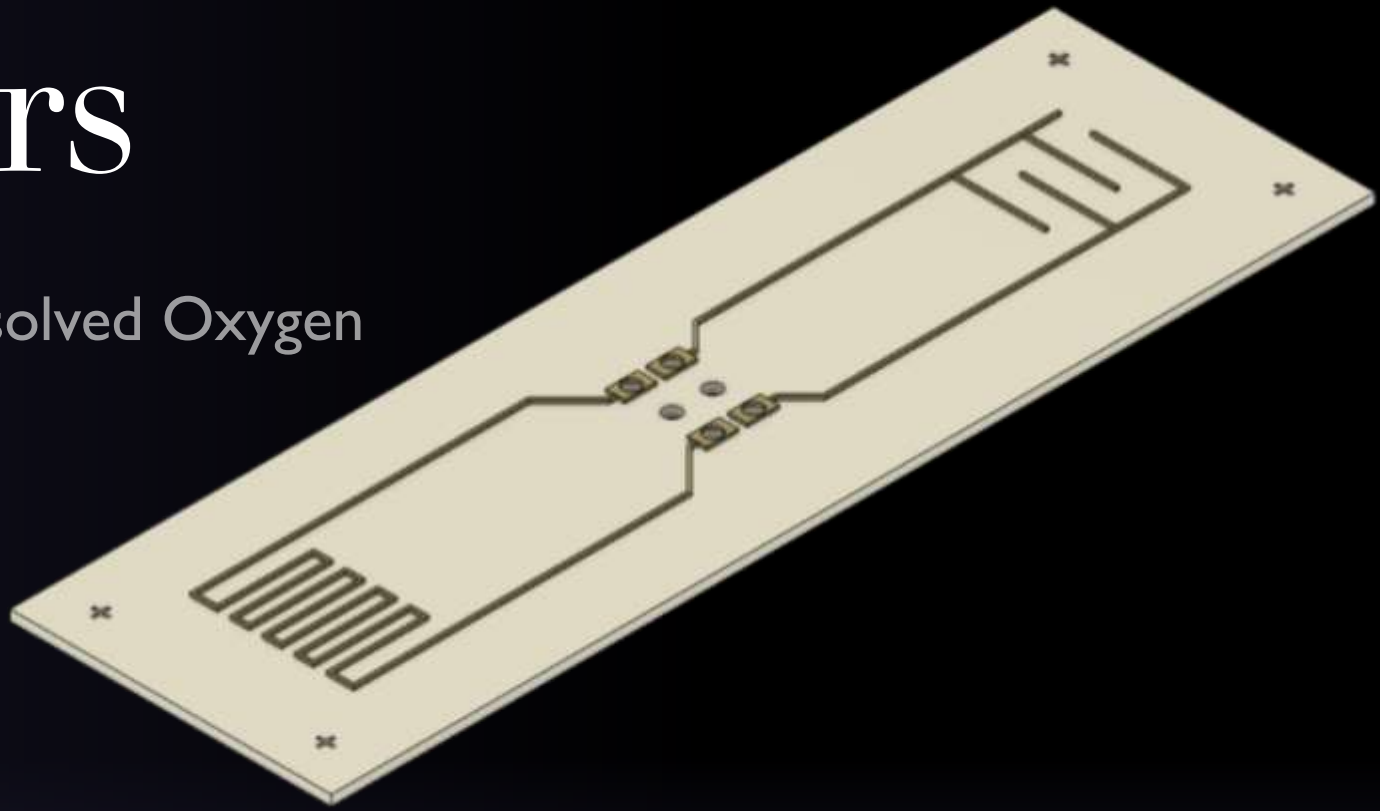


RAIN CLOUDS



Printed Sensors

Temperature, Conductivity, pH, and Dissolved Oxygen



Biofouling Testing

- Several substrates were initially considered (including SU320 PET, 339 Melinex PET, Powercoat HD, glass, polycarbonate and ceramic) and subjected to biofouling testing.
- Samples were placed in the raceway at CSAR and visually monitored – Water was changed weekly
- None of the substrates performed well.
  - The PowerCoat HD (coated paper) failed completely.

DAY 0

DAY 27

DAY 55

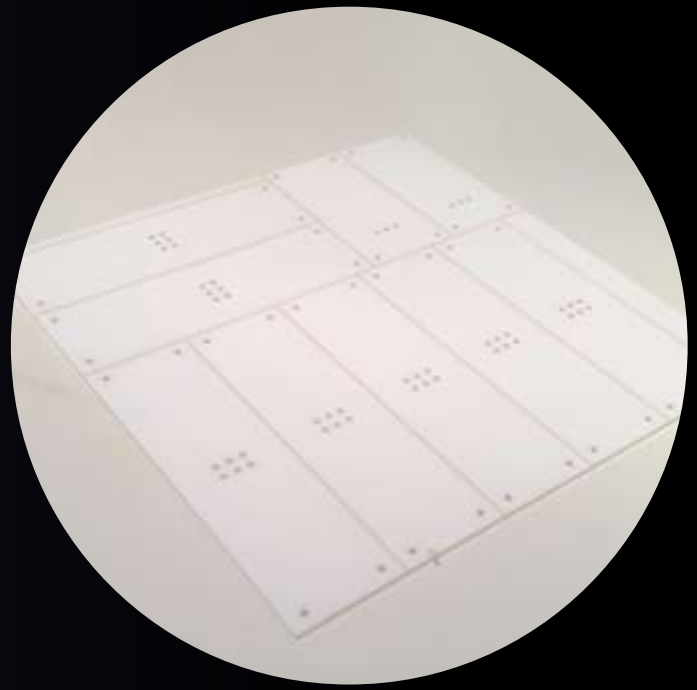
Biofouling Results

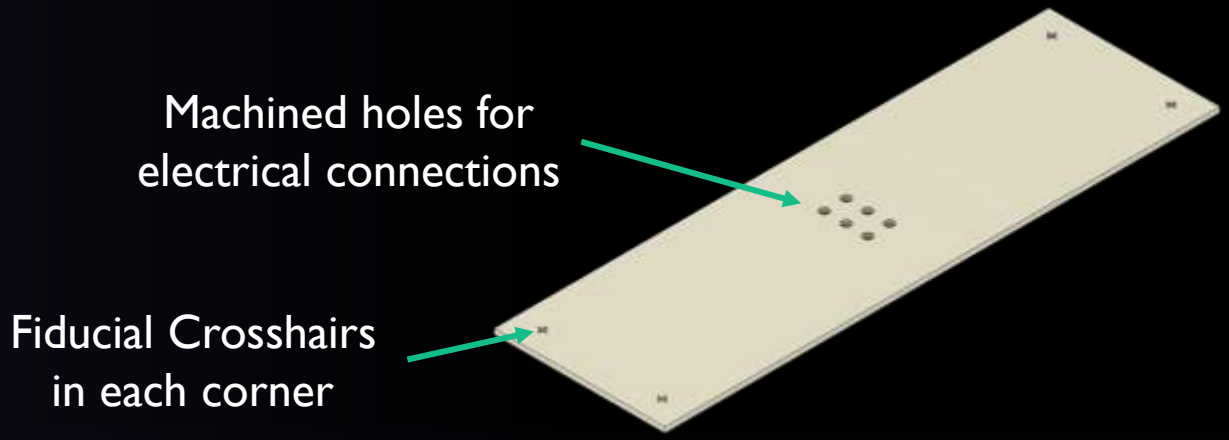
Substrate Selection

- 96% Alumina has been selected as the substrate for the printed sensors
  - Allows the use of robust furnace fired inks.
  - Low contamination of the surrounding water
  - Smooth substrate can form a seal against an O-ring
  - Mechanically robust and could withstand cleaning

Substrate

- The alumina is purchased as sheets with overall dimensions of 108 x 108mm and a thickness of 0.635mm.
- These sheets are then laser machined to produce a panel of substrate dies which can be singlulated each with holes for electrical connections and fiducials for alignment in both the aerosol jet system and screen printers.
- The machined holes for the electrical connections consist of two rows of three holes allowing for both two and three electrode sensor designs.





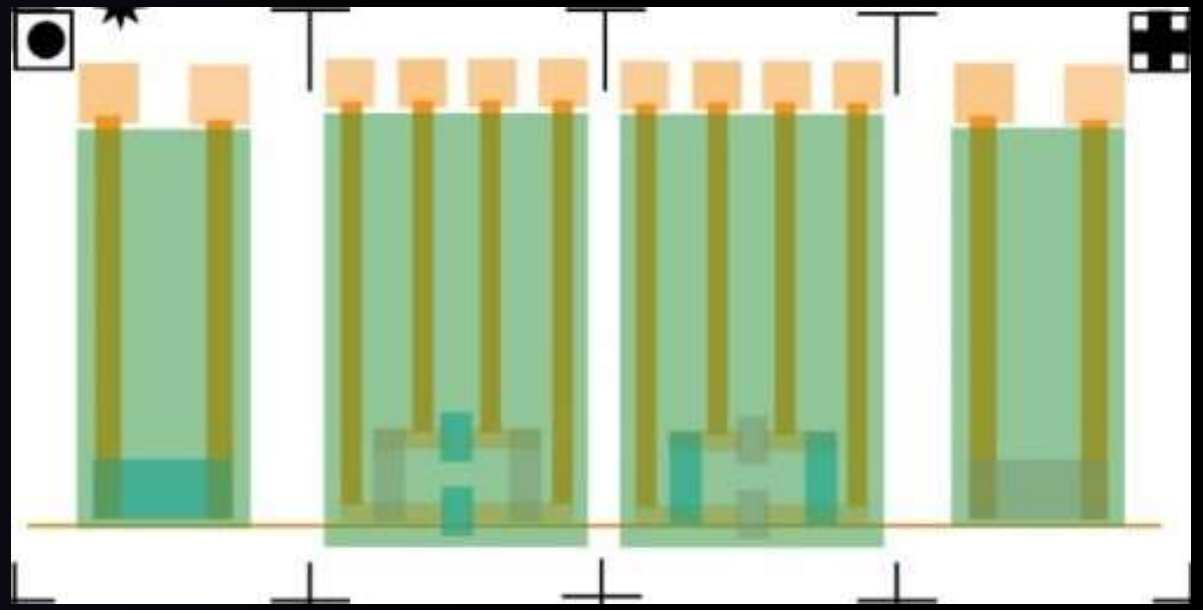
Temperature Sensors

Temperature can be measured from the electrical resistance of a conducting material - typically a metal but can be carbon or some polymers.

Early tests focused on using carbon and PEDOT:PSS materials with silver conductive electrodes in the configurations shown on polymer substrates.

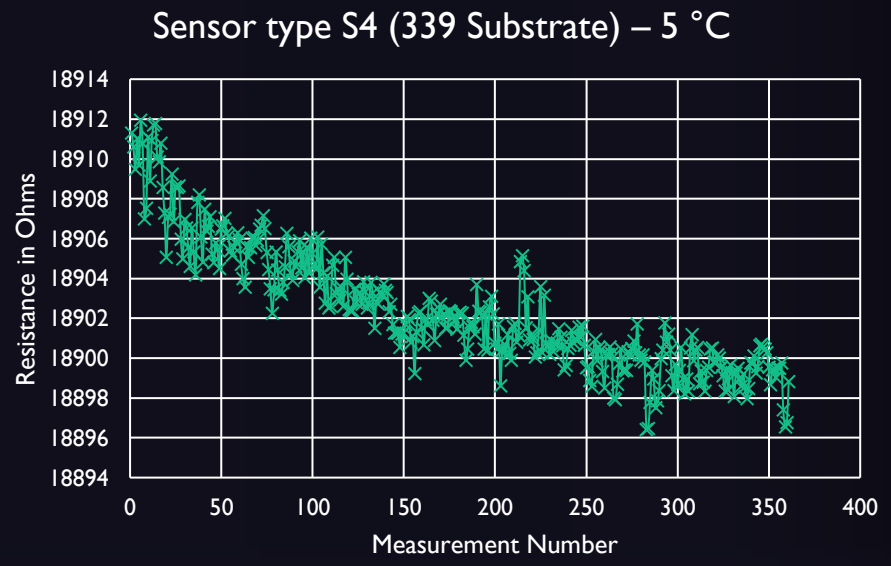
These sensors showed poor and unstable responses believed to linked to several factors:

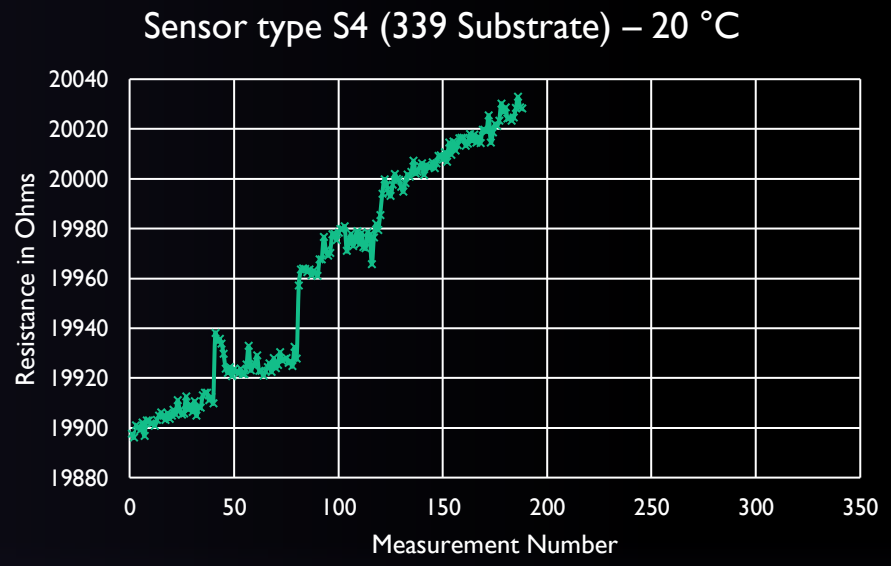
- Water uptake
- Multiple material architecture
- Combination of PTC and NTC components



Temperature Sensors – Stability Testing

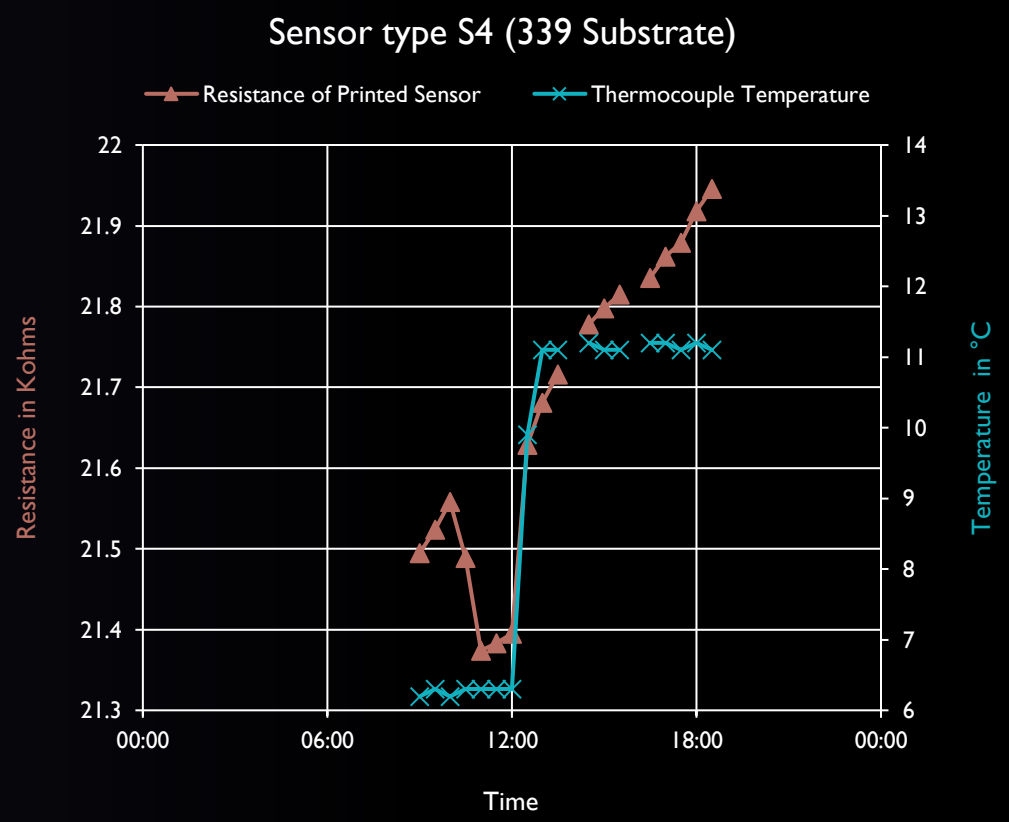
- Sensors were placed in a sealed pot of deionized water that was already at the set temperature and left for 1 hour to stabilise before starting the measurement.
- Measurements were taken at 30 second intervals and logged using a Keithley 2100 Multimeter.





Temperature Sensors – Dynamic Testing

- A sealed pot of deionized water was placed in the environmental chamber set at 5 °C and left overnight.
- A sensor was then added to the pot at 8:45 and the resistance measured every 30 minutes from 9:00 using a Keithley 2100 Multimeter.
- At 12:00 the environmental chamber was set to 10 °C
- The temperature inside the pot was measured using a reference thermocouple



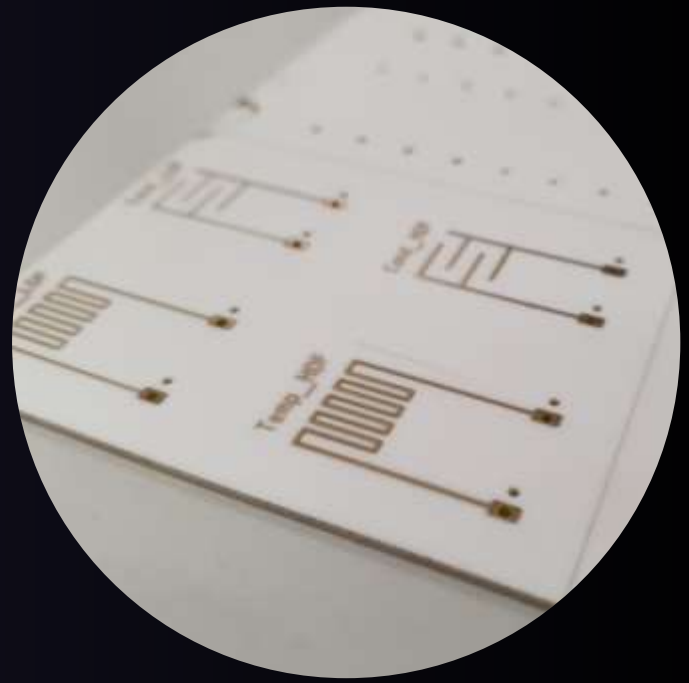
Temperature Sensors

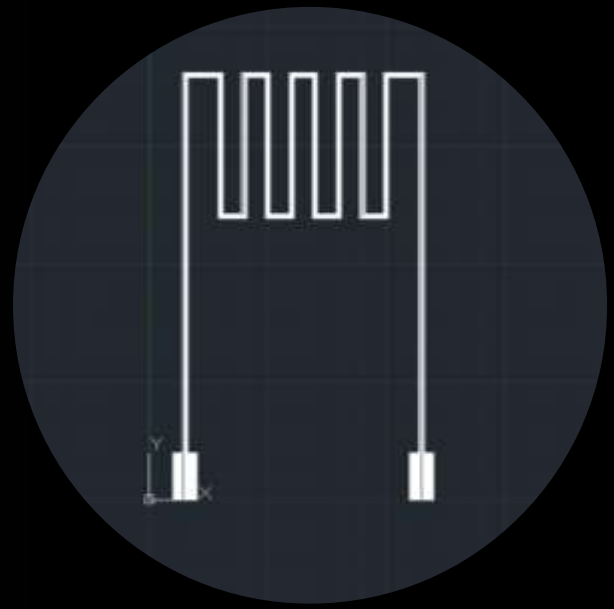
- Whilst the exact cause of the drift was not identified, published literature suggests:
  - Multi-material set sensors may show non-linear results with both drift and hysteresis as a result of different temperature coefficients of resistance.
  - Although silver has a positive temperature coefficient, carbon typically has a negative temperature – most binders are organic/carbon-based which may explain the difference in behaviour when compared with pure metals.

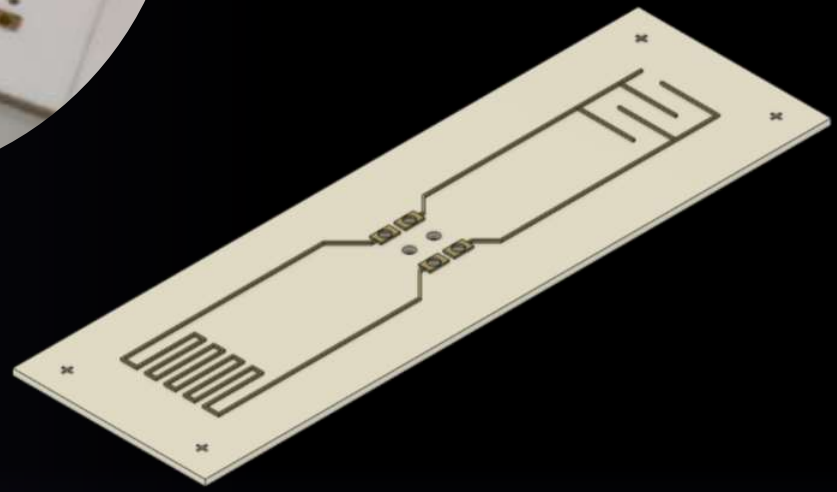
- Based on the results seen, available literature and previous work, we decided to switch to a simpler architecture with a single material ink – Gold with low binder content.

Temperature Sensors

- Aerosol Jet Printed – Ultrasonic atomiser
- Nanoparticle Gold Ink – Solvent Based
- Low Binder Content
- Low Overspray







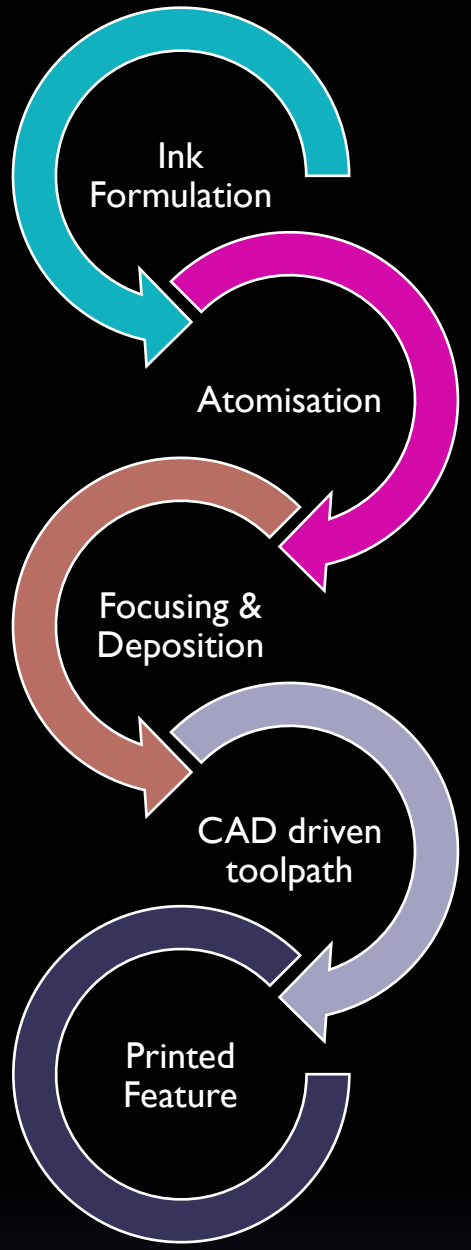
Aerosol Jet Deposition

1. A functional material is dispersed into a solution with a binder forming an ink.

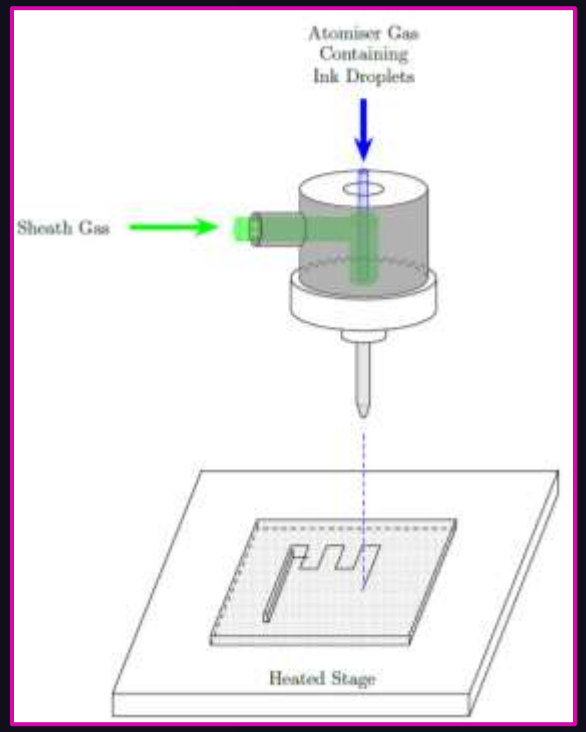
2. This solution/suspension containing a functional material is atomised into a fine mist of droplets which become suspended in a carrier gas.

3. The generated mist is transferred to a deposition head where it is focused into a collimated stream by a sheath gas flow and ejected through a converging nozzle towards a substrate below.

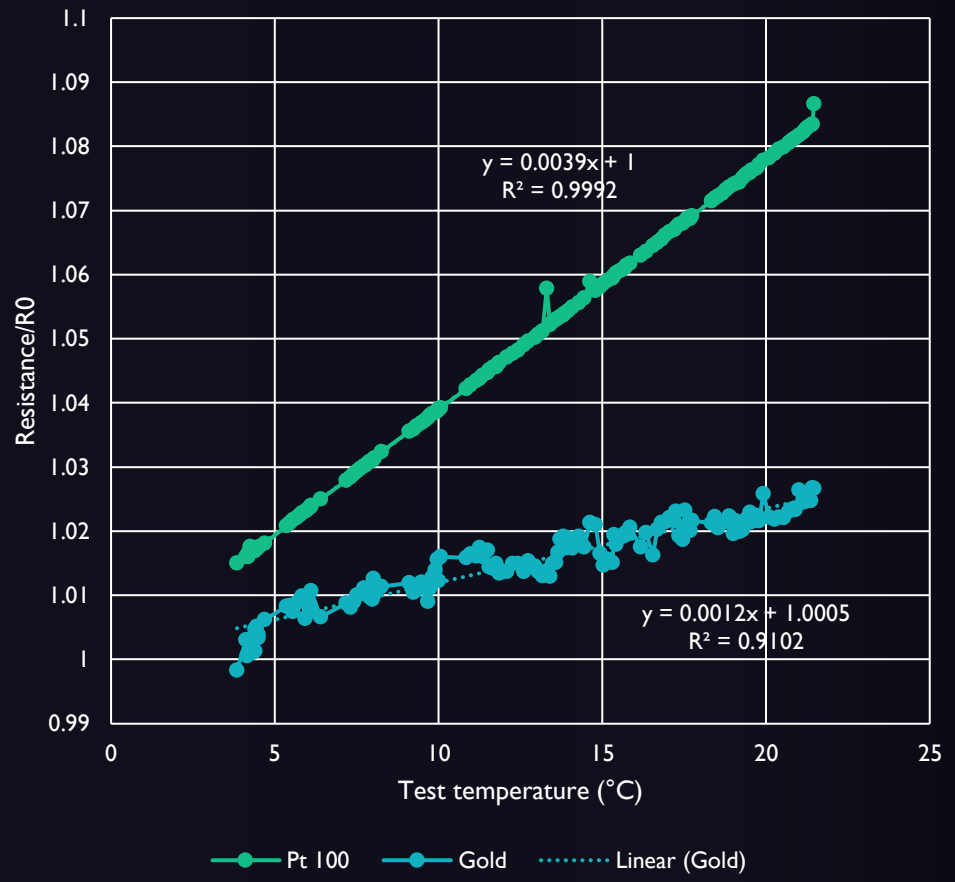
4. The substrate is positioned on a motion controlled heated stage which moves according to a design file producing the desired pattern.



Aerosol Jet Deposition



Temperature Sensors



The printed gold temperature sensor shows an increase in absolute resistance with temperature (Ohms/°C).

When normalised against it's "base" resistance (R0), it appears to be ~3 times less sensitive than the PT100 what would be expected from a pure gold layer.

Temperature coefficients of resistance:

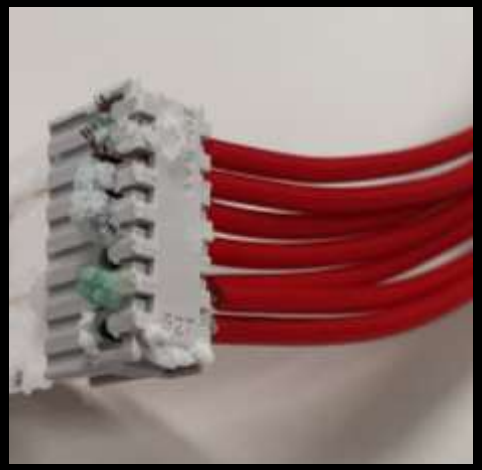
Platinum: 3.92 x 10-3
Gold: 3.4 x 10-3
Printed Gold: 1.2 x 10-3

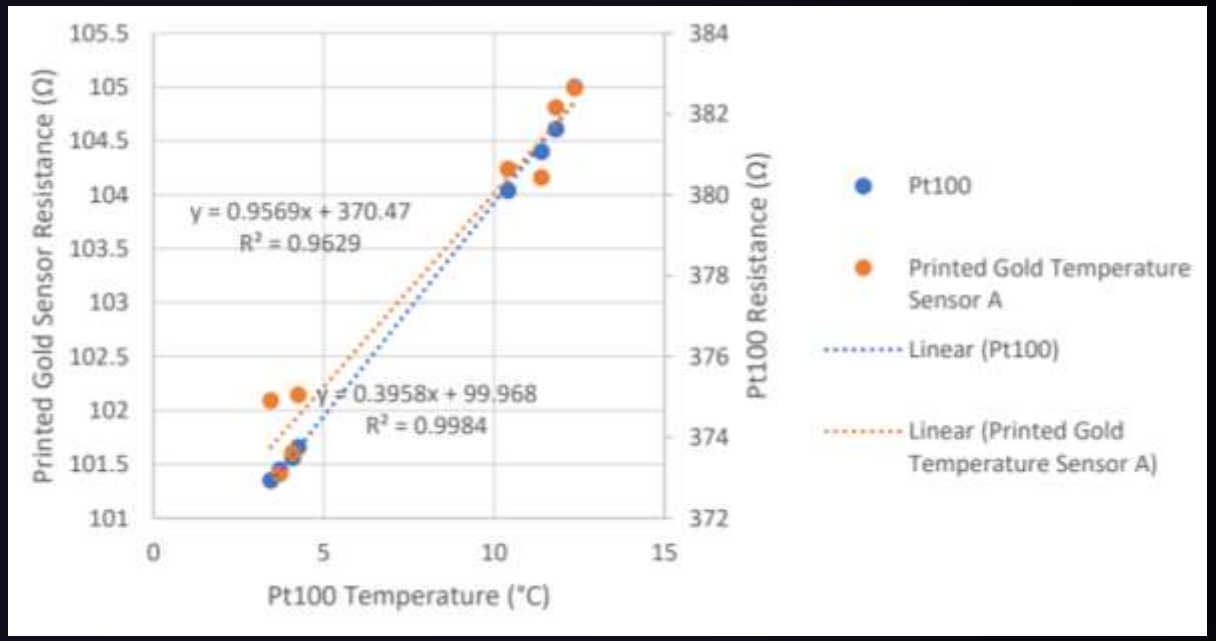
Some noise in the results as a result of long test leads and the board edge connection method.

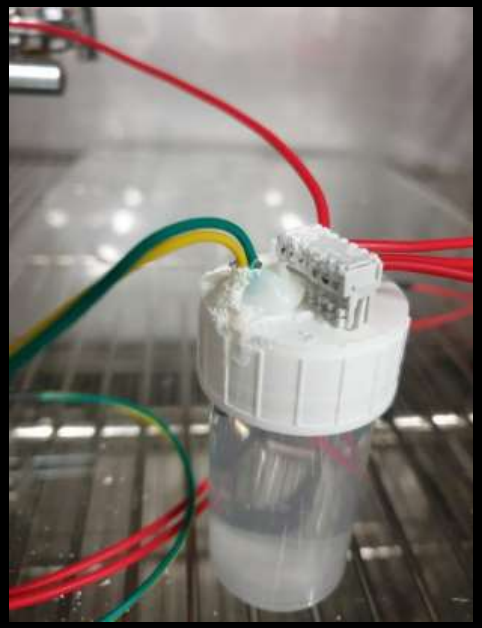
Temperature Sensors

The printed gold sensors showed no significant difference in behaviour when the test was repeated once in salt water (Deionised water + Sodium Chloride).

Further tests showed inconsistencies which is believed to have been down to salt wicking over the sensor to the electrical connection resulting in partial shorting.

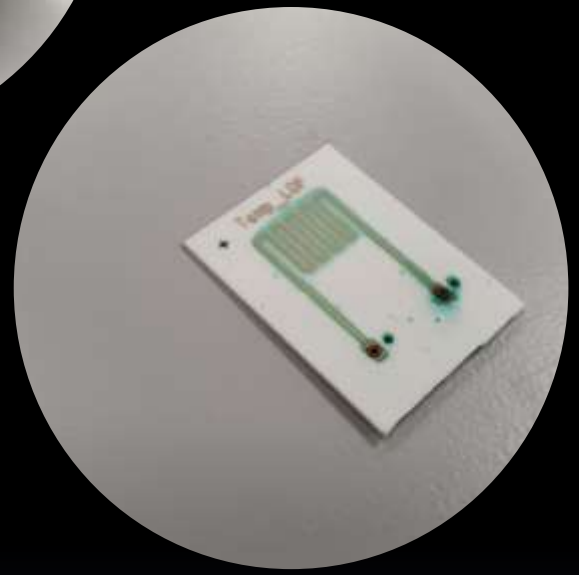






Sea Water – Effect on Gold Ink

- Water sample from 360 Aquaculture collected on 19th July 2022
- Temperature sensor placed in water sample on 20/07/2022 with resistance to be measured every 2-3 days for two weeks.
- Initial resistance before submersion was 118.8Ω
- Lab temperature is constant

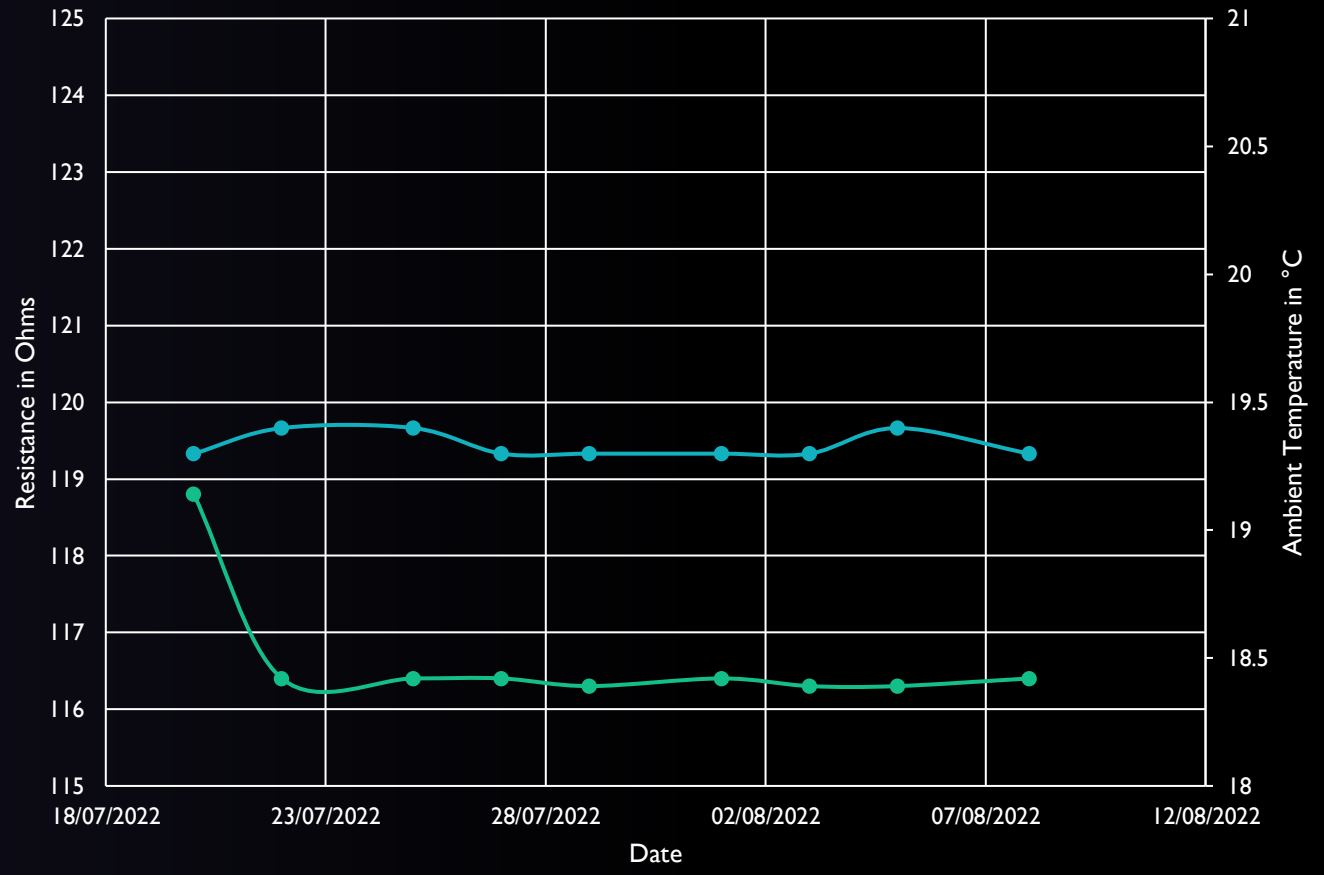


Observations

- Copper rivets had tarnished by first measurement and there is some green/blue discolouration around them as a result.

Sea Water – Effect on Gold Ink

Date	Resistance in Ohms	Ambient Temperature
20/07/2022	118.8	19.3
22/07/2022	116.4	19.4
25/07/2022	116.4	19.4
27/07/2022	116.4	19.3
29/07/2022	116.3	19.3
01/08/2022	116.4	19.3
03/08/2022	116.3	19.3
05/08/2022	116.3	19.4
08/08/2022	116.4	19.3



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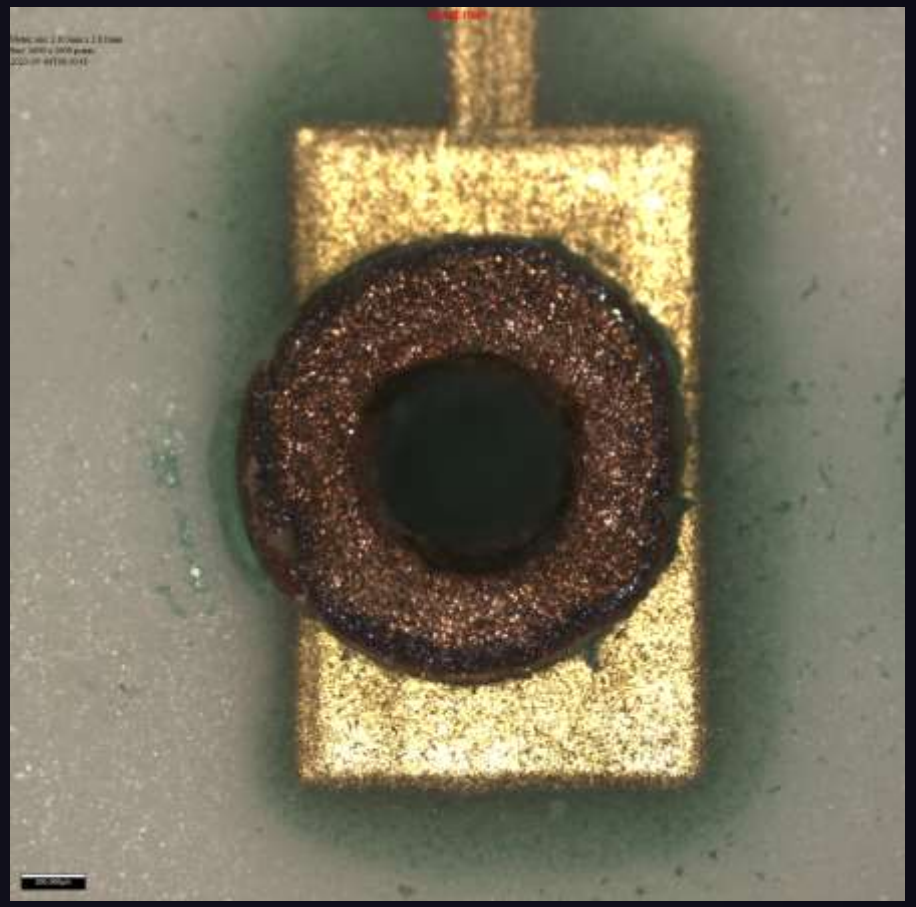
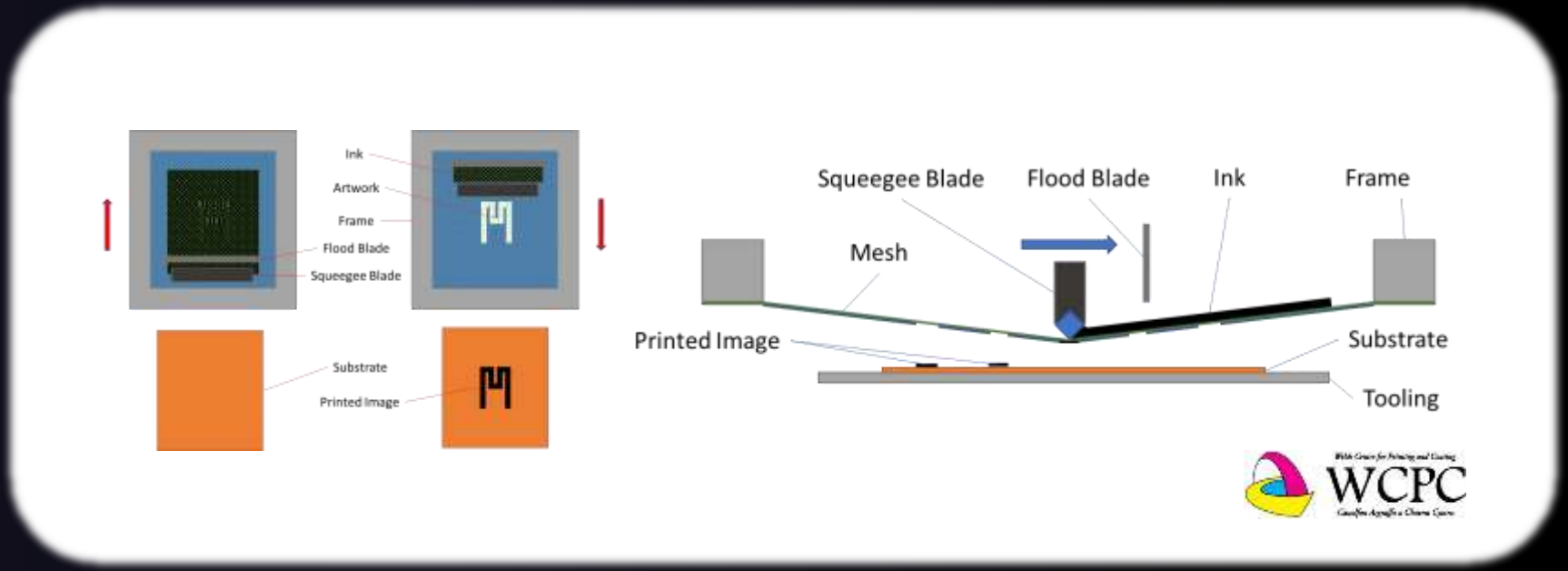


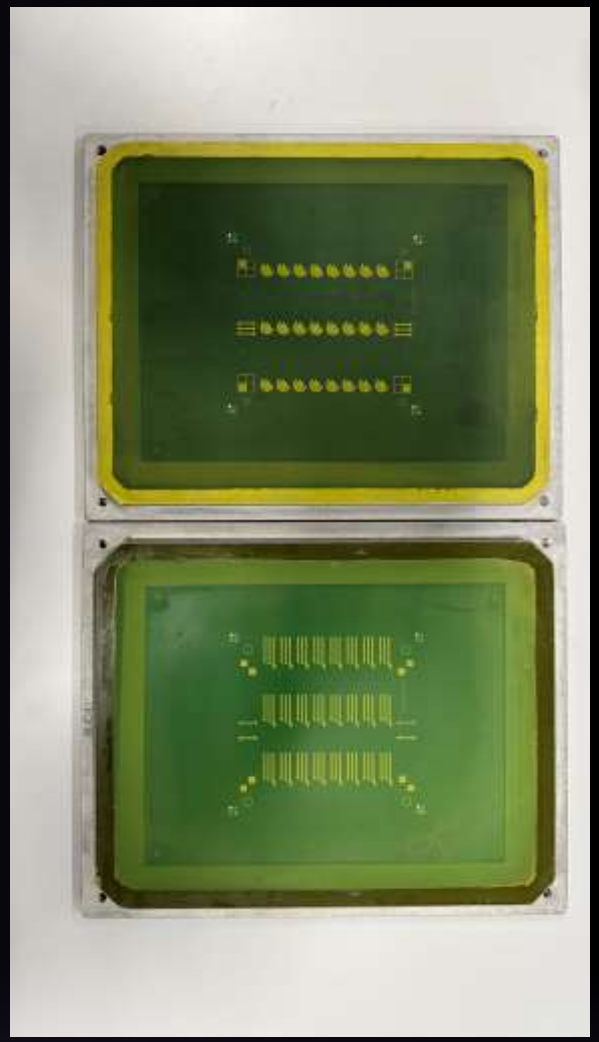
Rivet after 9 Months

Fresh Rivet

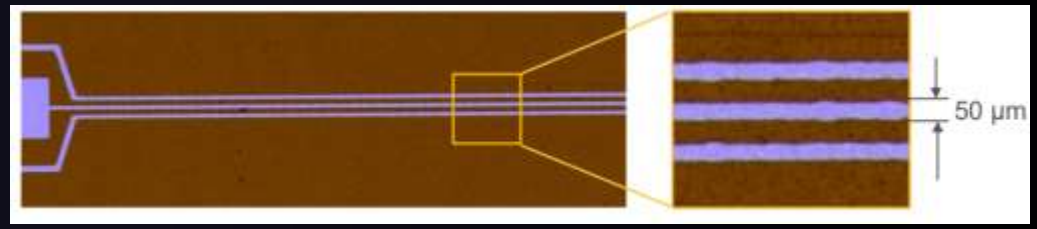
Screen Printing

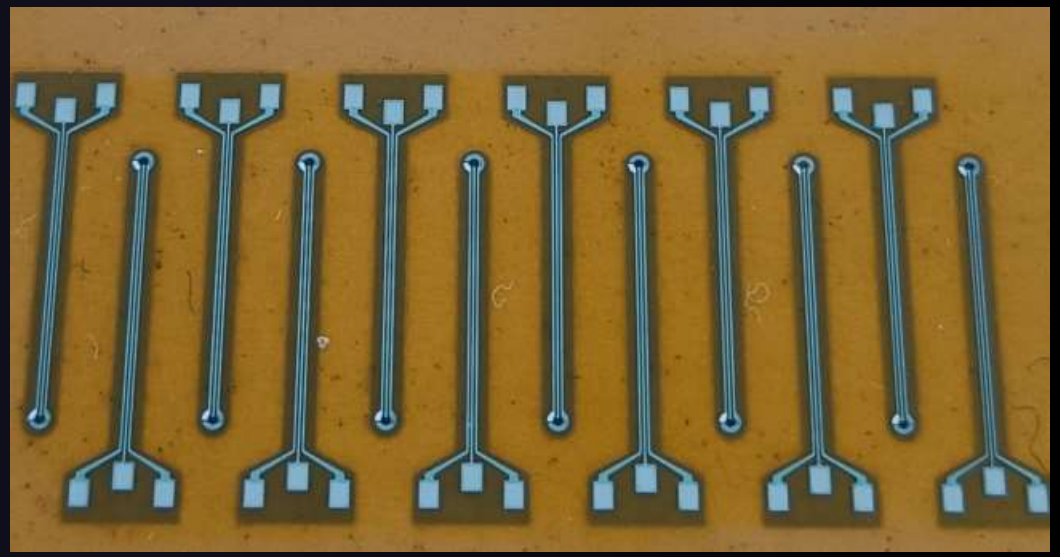


Screen Printing



Miniaturised sensors in Industry

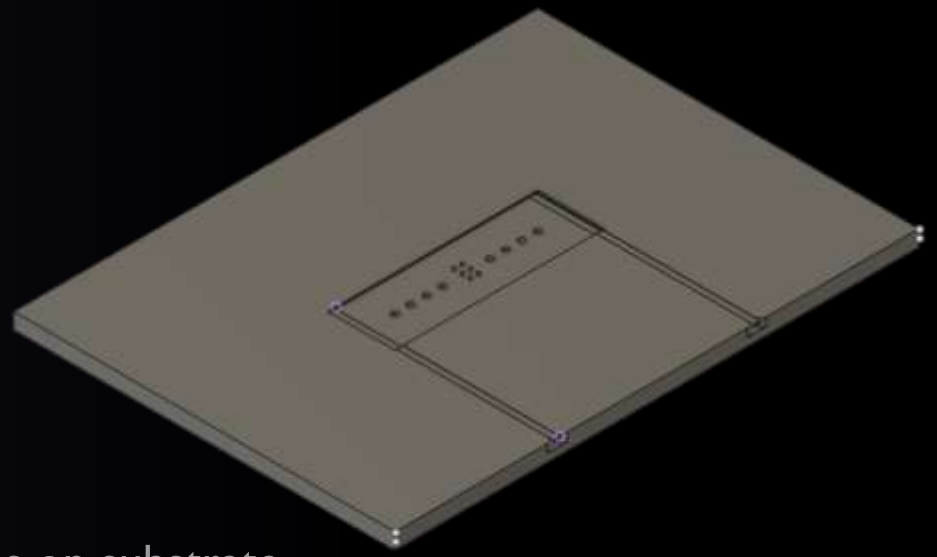




*Applied Materials

Screen Printing Tooling Design

- Dedicated tooling to enable accurate multi-layer printing
- Enable the use of smaller substrates on screen printer
- Reduced cycle time by removing the need for adjustment
- Reduce the risks of damaging delicate screens
- Alignment of tooling and screen via fiducials
- Alignment between tooling and substrate via pins on machined holes on substrate



Conductivity Sensor

Screen Printed Sensor

Silver Ink / Carbon Ink

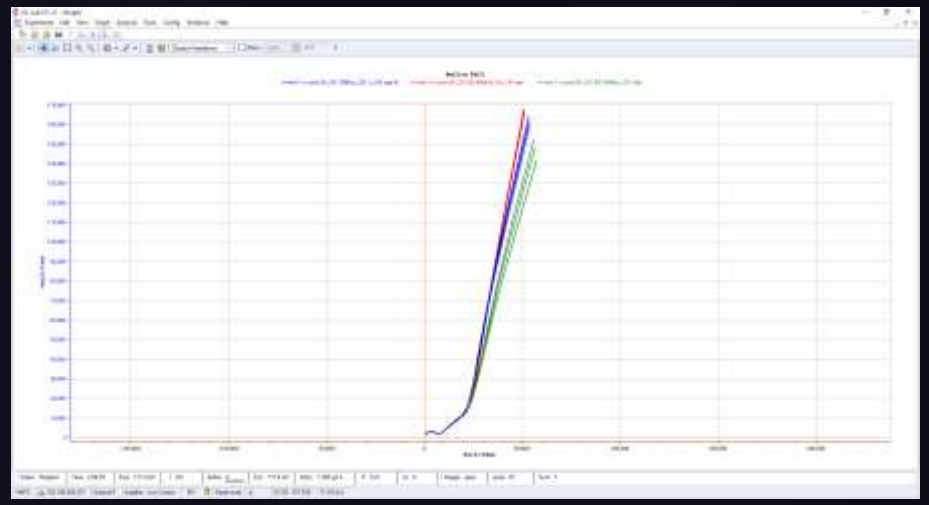
20 mm x 27 mm (not including legs)

1.2 mm Track

1.6 mm Gap

Cell Constant : 0.7

Conductivity Sensor – Material Evaluation

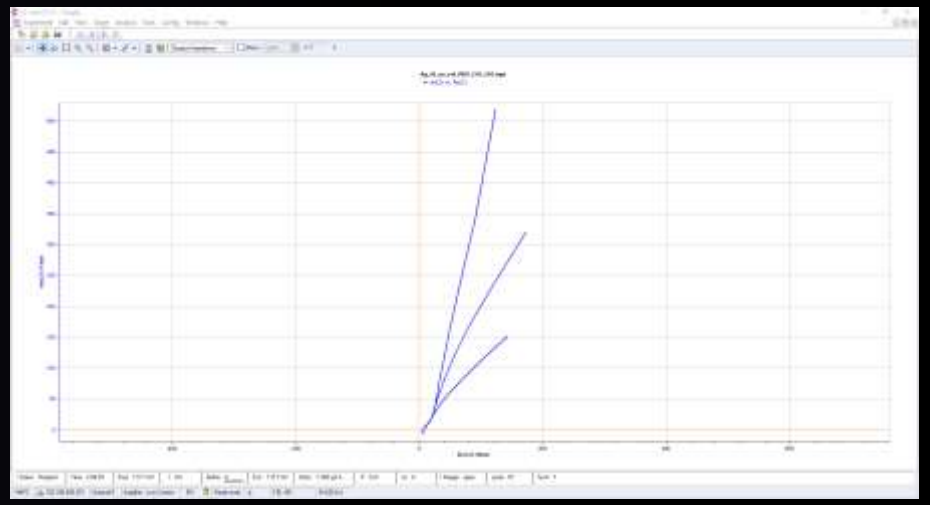


EIS

1Hz - 500kHz

Nyquist plot

Drifting issue on Carbon sensor



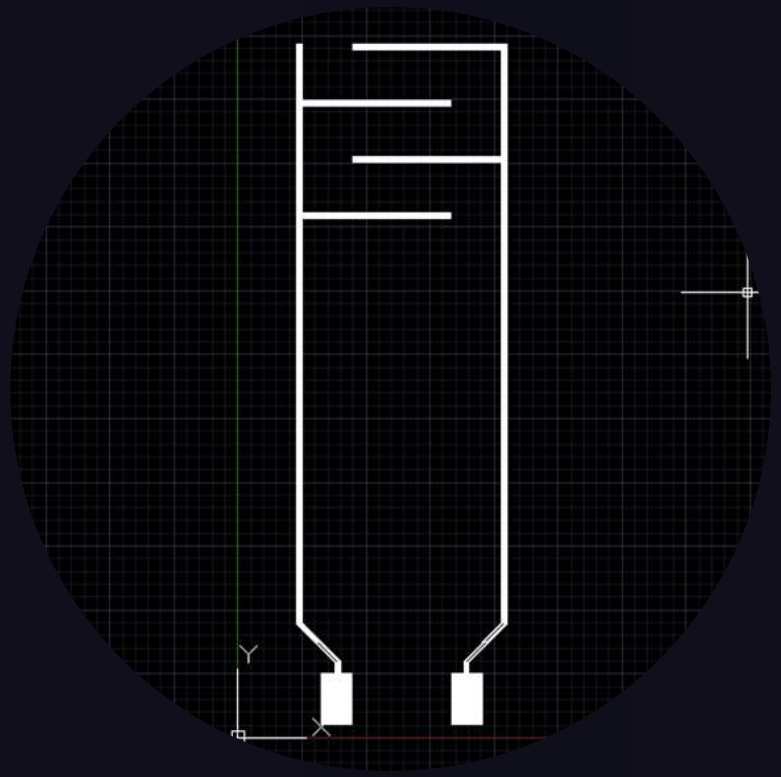
EIS

1Hz - 500kHz

Nyquist plot

Oxidation issue on Silver sensor

Conductivity Sensor - Current Design



Aerosol Jet Printed

Nano Gold Ink

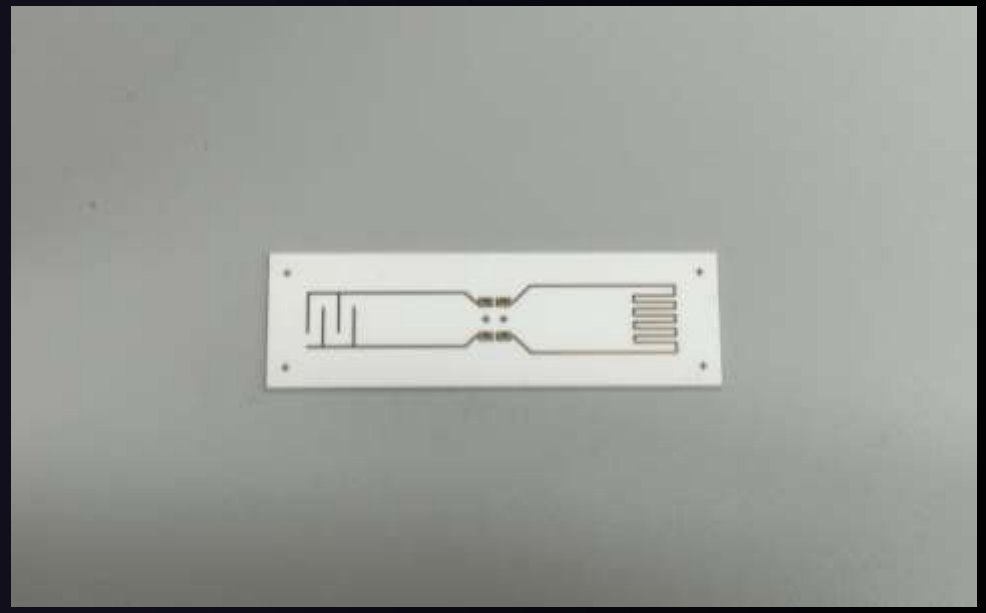
8.2mm x 7 mm (not including legs)

0.2mm Track

2.0mm Gap

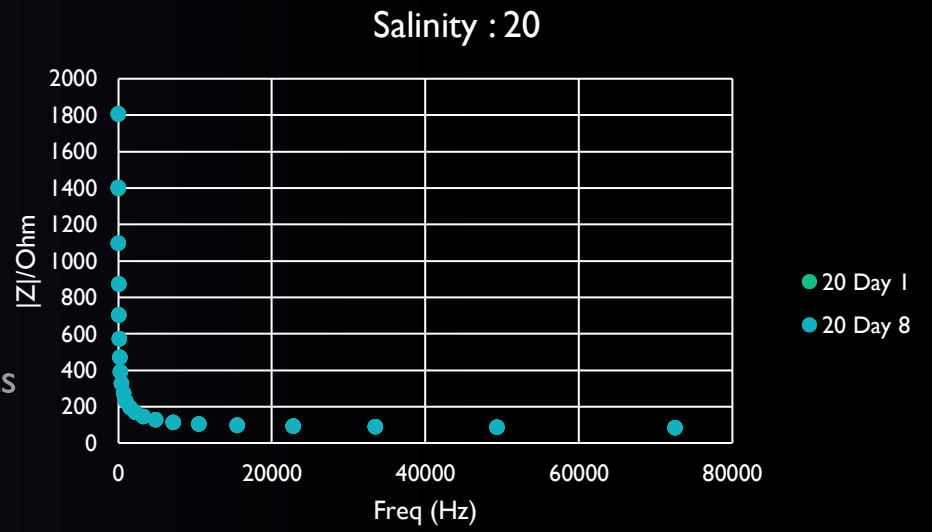
Cell Constant : 3

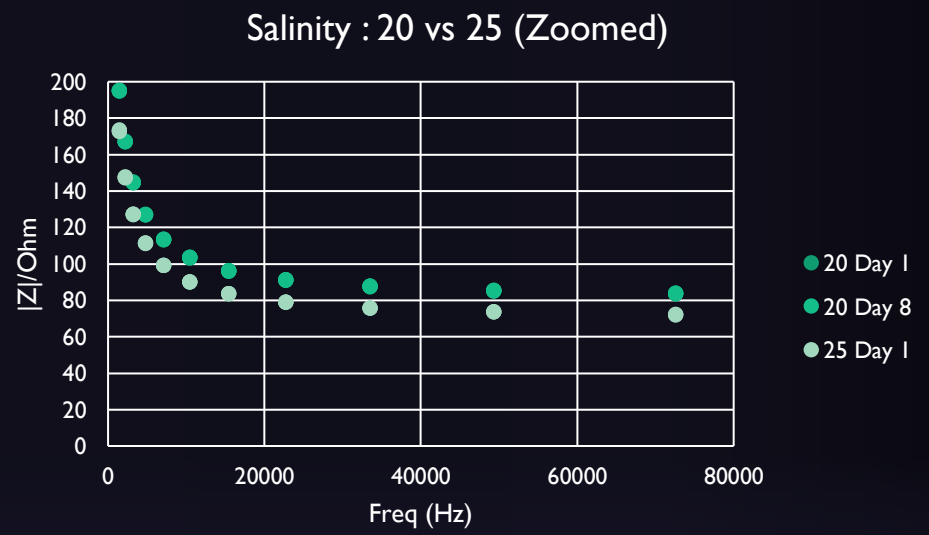
Temperature and Conductivity Sensor

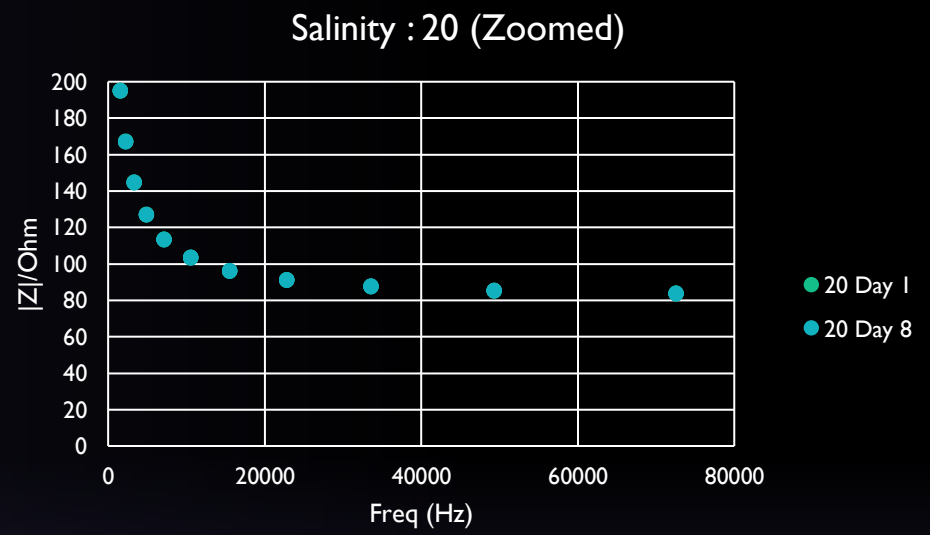


Conductivity Sensor - Current Results

- Further Testing on Machined Substrates
- Long term evaluation of sensors connections in seawater
- Evaluation of effect on connections under AC measurements

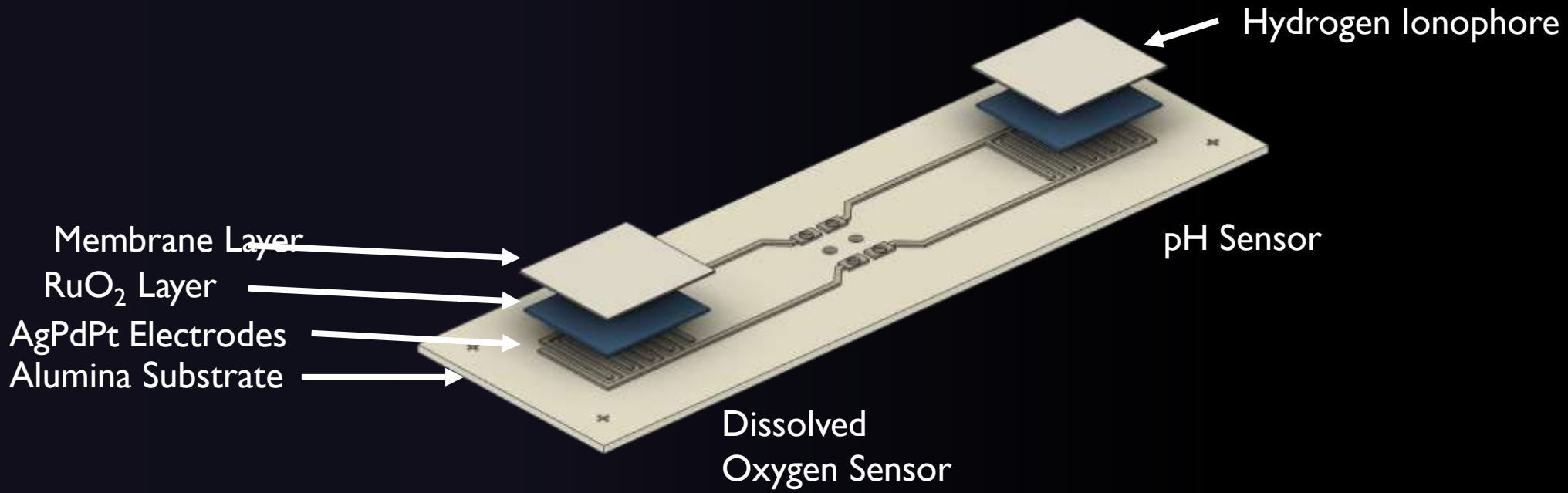




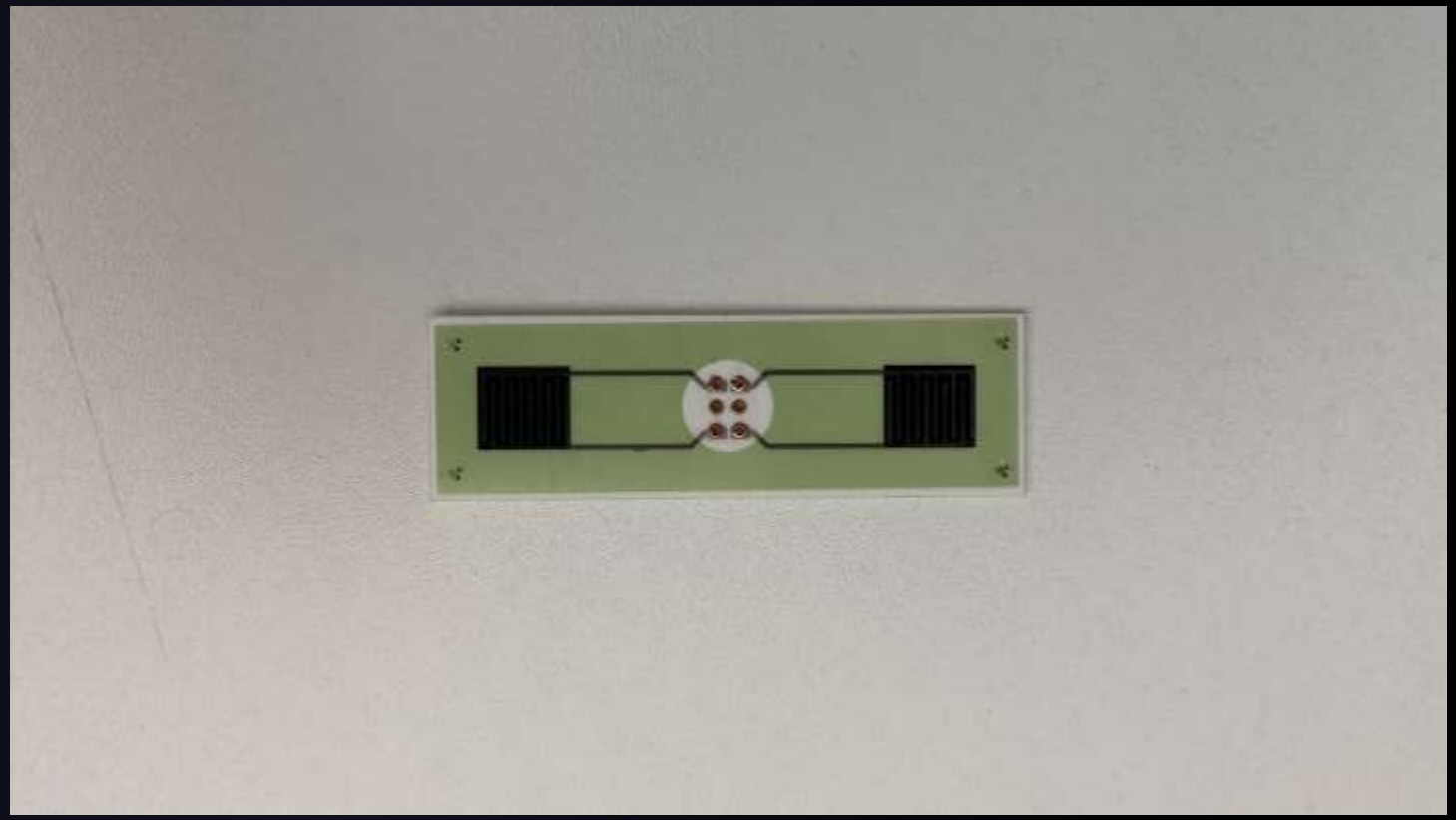


Tooling for testing

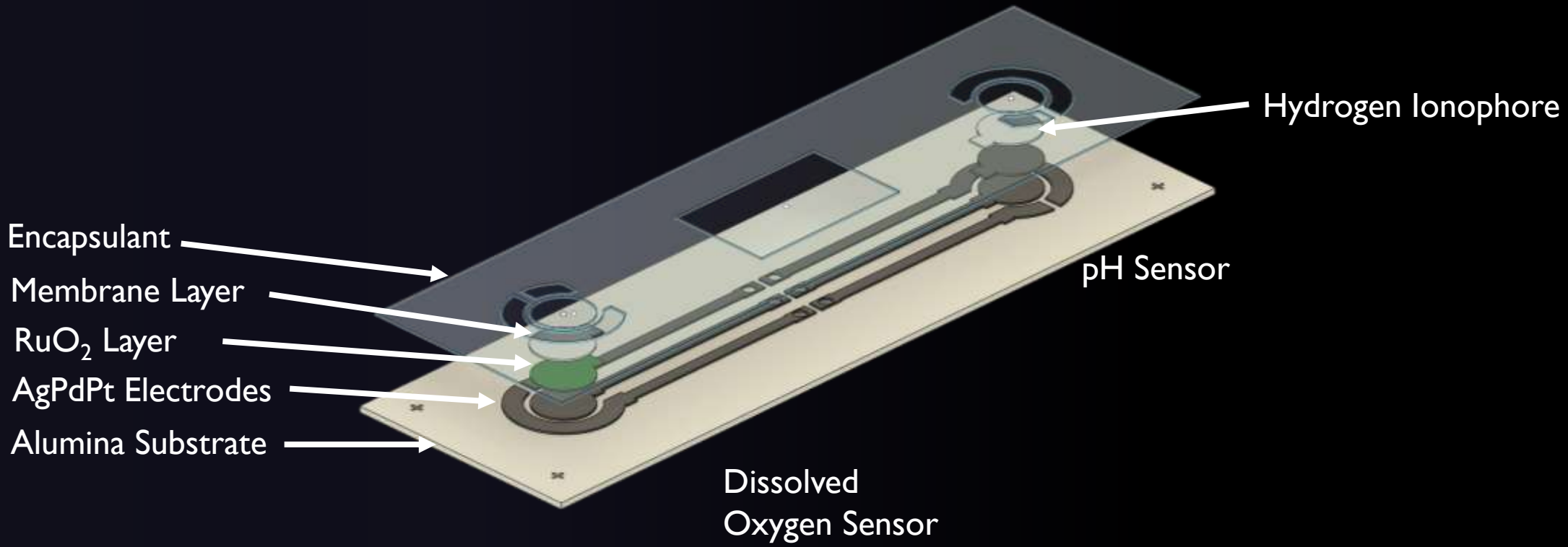
pH and Do Sensor Architecture 1 - IDT



pH and DO Sensor Architecture 1 - IDT



pH and Do Sensor Architecture 2 - Biosensor

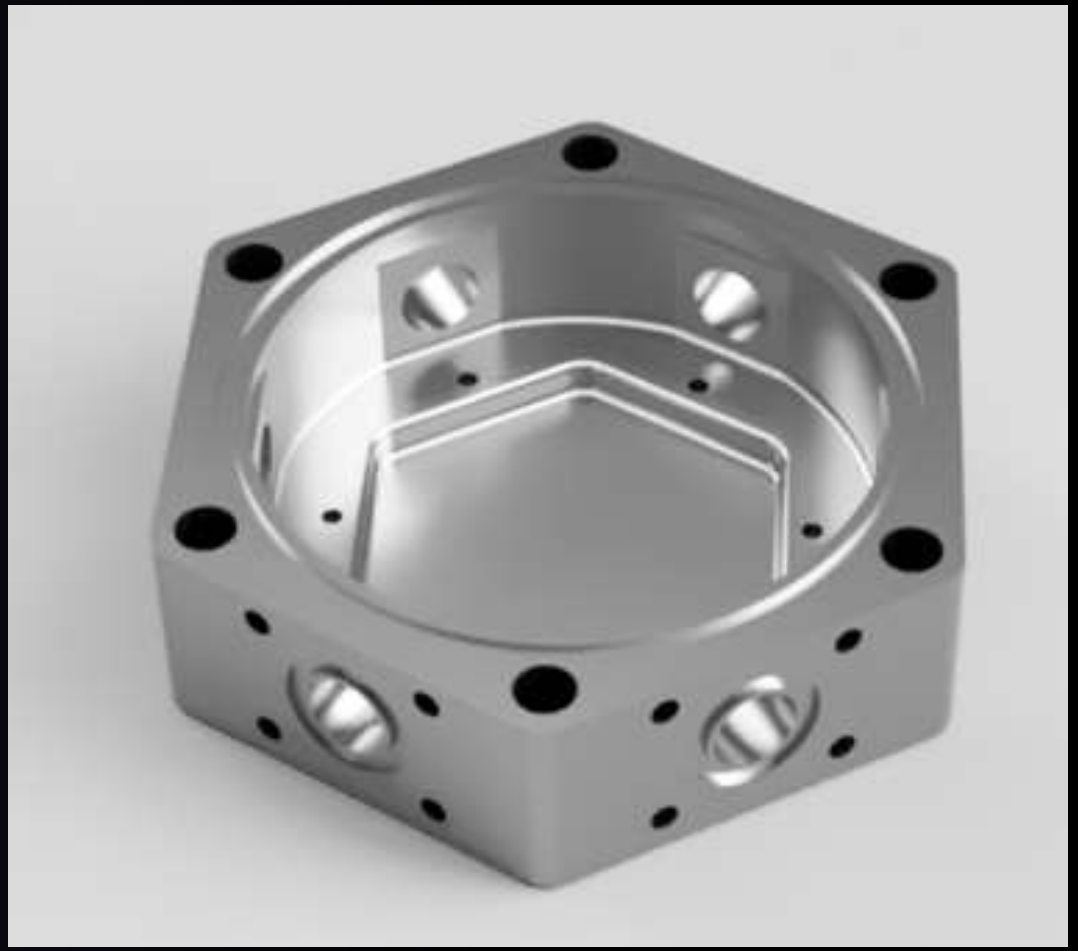


Enclosure Design & Deployment

Materials, Waterproofing, Sealing

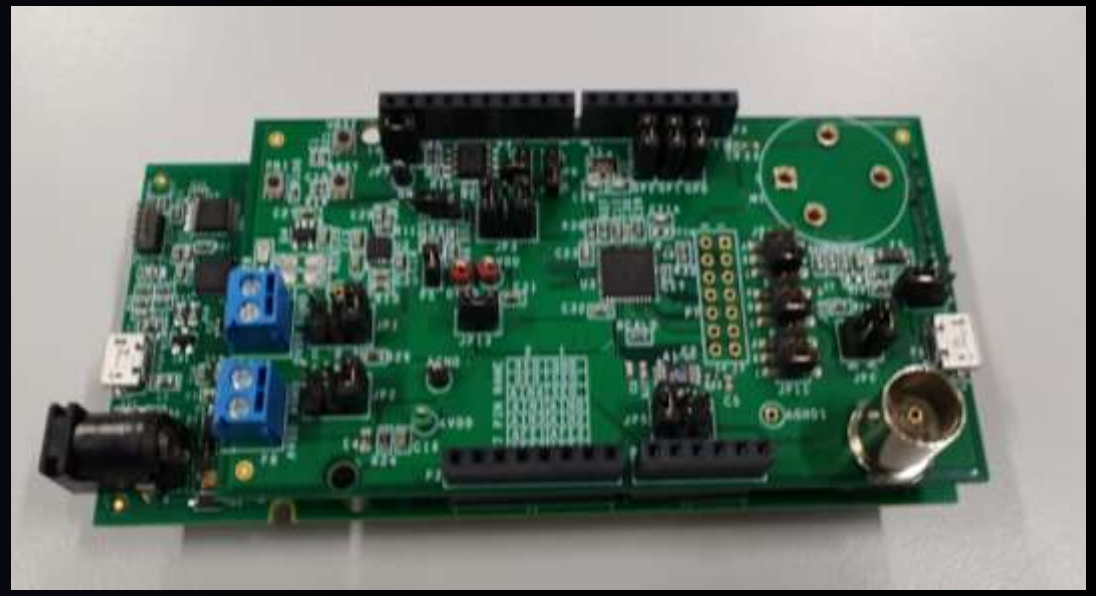
Main Body Requirements

- Hold up to 6 ceramic dual sensors, allowing concurrent deployment of previous sensors during testing for calibration.
- Large enough to contain all required measurement electronics.
- Stainless Steel
- Waterproof
- Robust



Measurement electronics

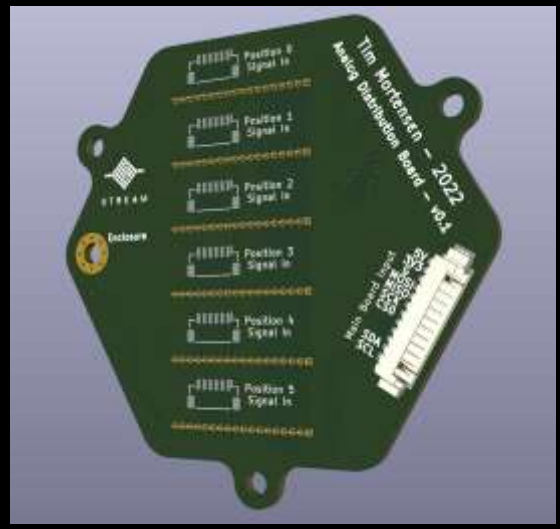
- Wide range of sensor types with various measurement requirements
  - Conductivity/Interdigited Sensor Design - Impedance
  - Bio-sensor Design – Amperometry
  - Temperature Sensor – Precision Resistiance



- Analog Devices have created an Analogue Front End (AFE) chip to make such measurements easier – AD5941
- The development kit allows testing a single channel, custom electronics are required for our device based around this AFE device.

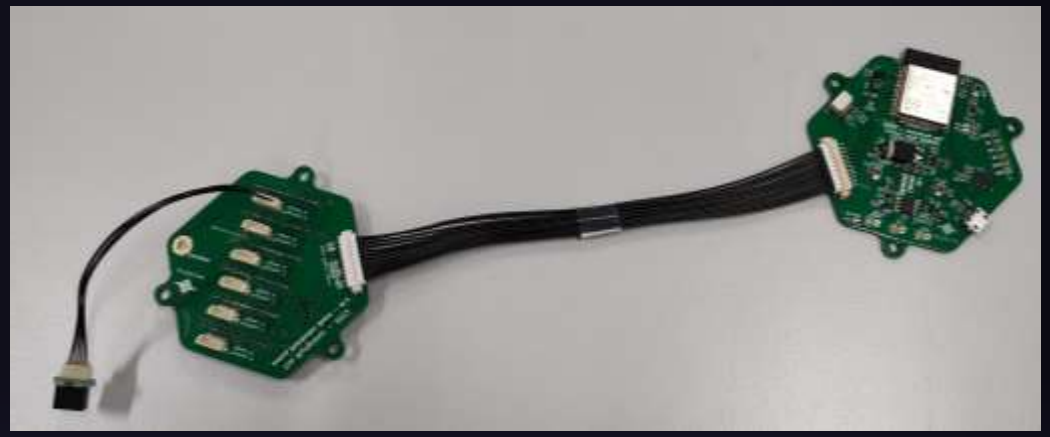
Modular Electronics Board

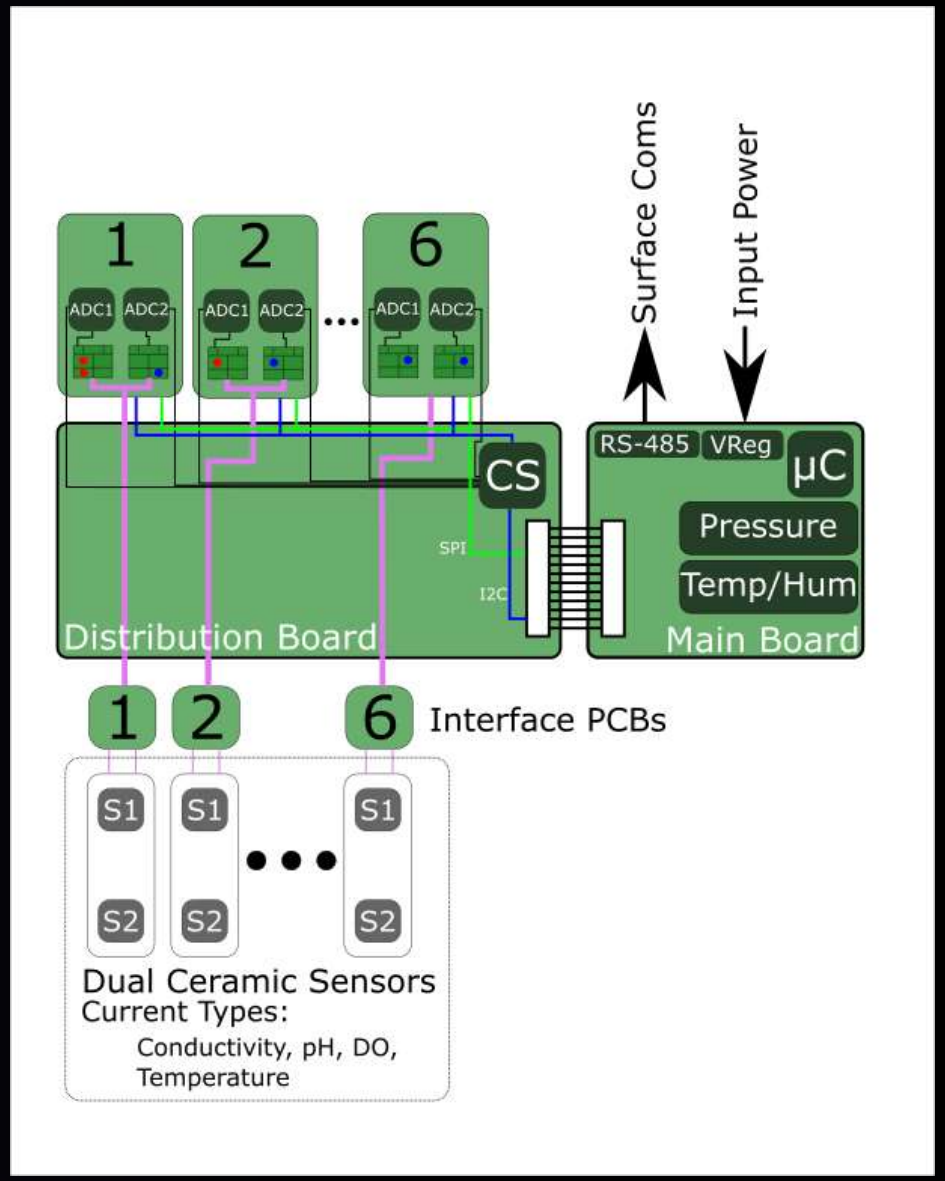
- Connect up 6 daughter boards allows each ceramic to use different measurement electronics
- Allows for new sensor types and upgrades without replacing entire electronics
- Gives an option for troubleshooting



Electronics Overview

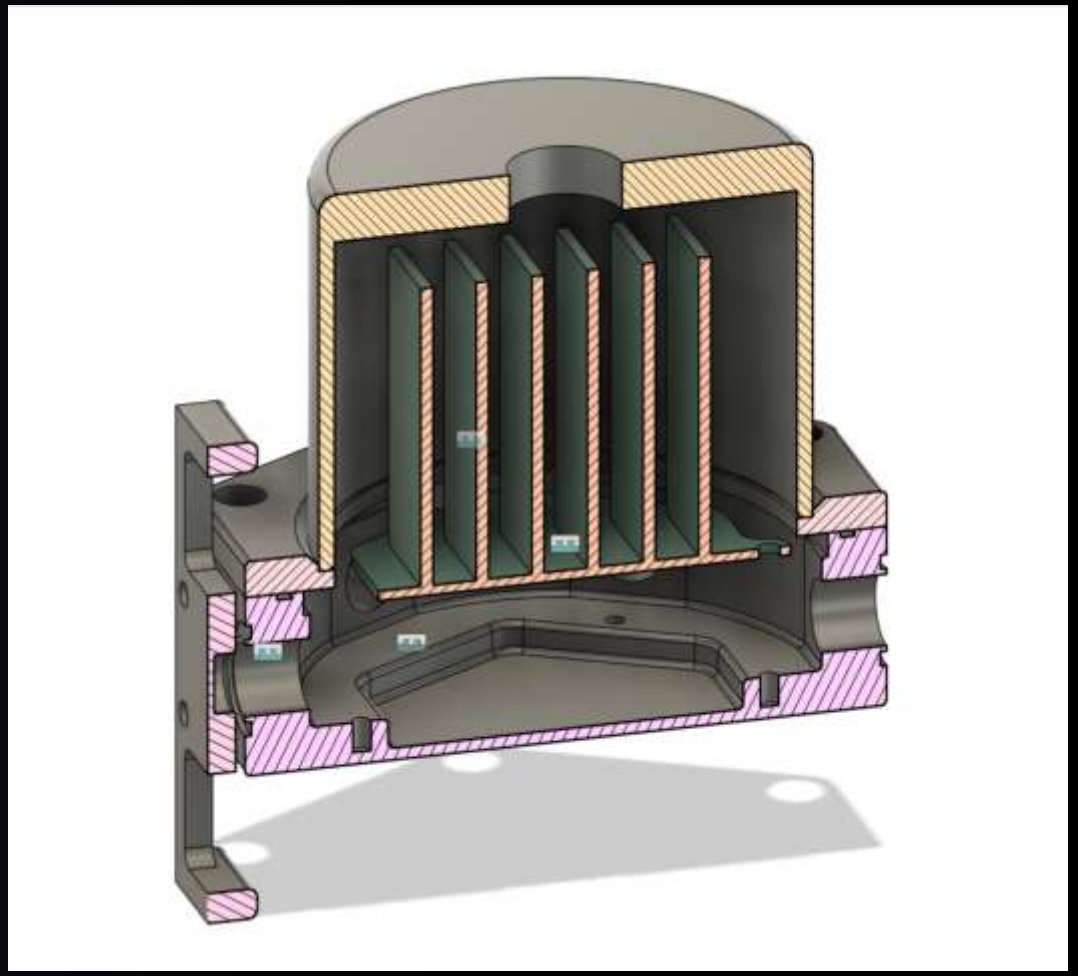
- Microcontroller board handles communications with surface via RS485 (>50m Range)
- Measurement electronics connects to analogue distribution board
- Ceramic Interface boards connect to distribution board
- Microcontroller contains conventional sensors for debugging/testing





Enclosure Design

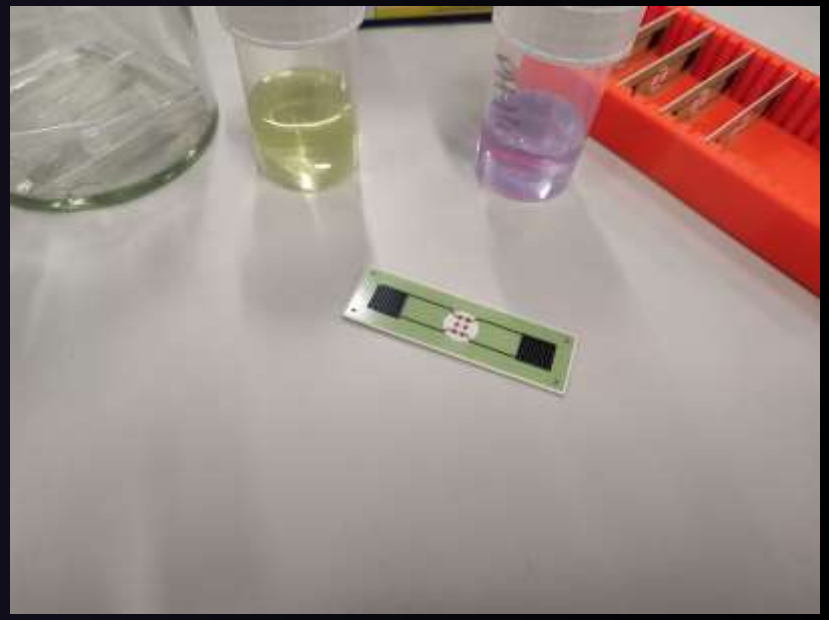
- Main body has 6 attachment ports and protective mounting plate to reduce chance of damaging the fragile ceramics.
- Dome gives room for modular electronics and incoming connection to the surface .
- Stainless steel hardware to minimise corrosion and susceptibility for damage.
- Mounting points for the electronics to prevent accidental shorts or disconnects



Sensor Connection

- Probing the sensors during testing is challenging.
- Complete sensors feature copper rivets and 0.1” male header pins attached with conductive epoxy
- Internal side of the connection is waterproof due to the o-ring of the enclosure
- External side is encapsulated with Loctite 4460 a chemical and water resistant encapsulant.

Sensor Testing



Thank You

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https://www.marinestream.eu/