D1.2 OptiDrill Sensor Specification

Deliverable No	D1.2
Work package No. and Title	WP1 Task 1.2 Preparation of sensor & data acquisition system design specification
Version - Status	V1.0 – Final Draft
Date of Issue	30/06/2021
Dissemination Level	PUBLIC
Filename	OptiDrill Sensor Specification D1.4 v01

This project has received funding from the European Union's Horizon 2020 research and innovation action under grant agreement No 101006964

DOCUMENT INFO

Authors

Author	Organization	e-mail
IA / MQ / PO / KM*	PVI / Geolorn*	ianarnold@pvi.co.uk

Document History

Date	Version	Editor	Change	Status
1/7/21	0.1	IA (PVI)	Document creation	Final draft
05/10/24	0.2	Pufinji Obene	Revisions addition	Final
05/10/24	0.2	Shahin Jamali	Final Review	Final

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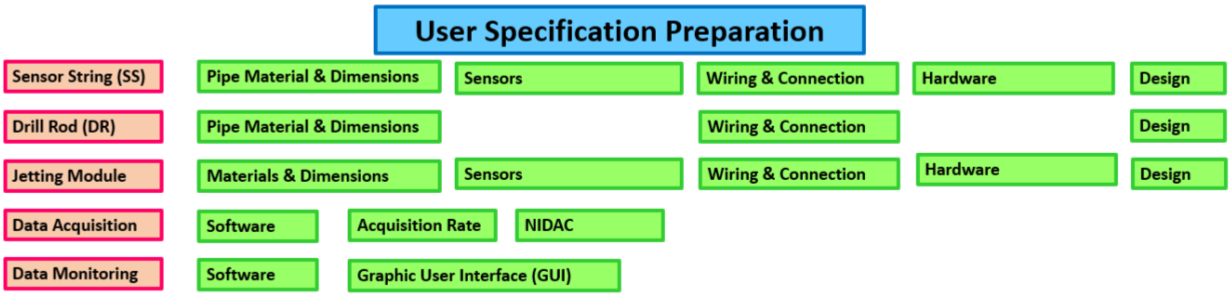
EXECUTIVE SUMMARY

Deliverable 1.4 (Task 1.2) Preparation of Sensor & Data Acquisition System Specification

In April 2019, at the start of the OptiDrill project, the PVI team, led by Dr. Pufinji Obene, were tasked with preparing the specification for the sensor and data acquisition system that they would be developing for the OptiDrill project.

In this task we will prepare sensor specification for lithology & jetting performance prediction and data acquisition system specification. This specification will be used in WP2 for OPTIDRILL measurement and monitoring system development and in WP3 for OPTIDRILL novel BHA sensor housing development to include sensor string casing package requirements, power cables selection, sensor materials for sensor string and jetting module, and micro-processing specifications based on data acquisition resolution as defined by user expectation in **task 1.1**.



The task (1.2) of developing the specification starts with a general review of the aims and objectives of the OptiDrill project. We engaged with project partners to clarify the goals that we would be working towards, both within each work package and for the project as a whole.

Based on our experience in sensor development and manufacturing, and after discussions with project partners to utilise their expertise, PVI have created and submitted the Deliverable Task 1.2 **Preparation of sensor & data acquisition system design specification.**

The 1.4 Deliverable (Task 1.2 of WP1) was due to be delivered in Month 5 (May 2021). The on-line M6 meeting will give the project partners an opportunity to present their specifications and discuss the proposed approaches. PVI has continued to work closely with our project partners to maintain a focus on the project goals and ensure that we continue to work along the lines set out in the Specification. Where necessary, PVI has reported, discussed, and agreed any significant deviation from the original specification (D1.4 (Task 1.2) for PVI).

The **D1.1 user requirements specification** (Task1.1) has been the basis for PVI's delivery of Task 1.2. This document draws from the User Specification and should be read alongside it.

1. INTRODUCTION

1.1 General Overview of OptiDrill Project

(Adapted from Executive Summary from User Requirement Report – Deliverable 1.1)

Data driven approaches to drilling are becoming commonplace. It is reasonable to assume that given all the wells that have been drilled around the world, there will be some identifiable trends and patterns, that if collated and analysed will assist future projects to plan and execute more efficient operations.

However, being wholly dependent upon such data, may result in less advances than first expected. There was a recently published Society for Petroleum Engineers article (1st March 2021) entitled; Robust Data-Driven Machine-Learning Models for Subsurface Applications: Are We There Yet? The article raises and highlights many issues that need to be considered when relying on ML models for subsurface applications and there needs to be an appropriate mindset that benefits from the extraction from data, to make better decisions. Information without knowledge has limitations, which is what underpins the ethos of the OptiDrill project. Gathering together drilling (training) data, both digital and analogue, and develop ML algorithms to analyse and present the data in order to assist the drilling team, make better and more informed decisions, with a view achieve better value from drill programmes.

OptiDrill will also contribute to future project planning with better collated data sets and an understanding where efforts to reduce NPT should be focused. Importantly, the drill string data sensor system being developed within the OptiDrill project, should additionally provide robust, real-time data, that complements the machine learning models analysis based on historical data sets gathered together for each well drilled and made available across a platform to assist other sub-surface industry sectors, both industrial and research based.

With a particular emphasis on deep geothermal resources, it is envisioned that the OptiDrill Drilling Advisory system, will greatly help the transition away from fossil energy sources, as it will facilitate Geological Carbon Capture & Storage, green hydrogen storage and many other green house gas emission mitigating strategies.

2. Review of Assumed Physical Conditions for Geothermal Drilling

2.1 Down the Hole (DTH) Physical Conditions

In order to be functional in the Geothermal Drilling Environmental. The materials and components chosen for the OptiDrill sensor system should be:

- Chemical Resistant – **CO_2, H_2S**, NH_3, Sulphate, Chloride ions
- Abrasion Resistant – it is expected that elements of the system will be exposed to abrasion and so these should be capable of withstanding this.
- Moisture Resistant – Geothermal drilling uses drilling fluids to remove material from the drill hole, therefore, where necessary, the materials and components utilised should be protected from moisture.
- **Heat Resistant** – the materials and components selected should tolerate temperatures in the range of 23-180°C.
- Pressure Resistant – It is anticipated that the sensor system will be exposed to DTH pressures of up to 60Mpa (8700 psi).
- Impact Resistant – the sensor system will experience reflected impact energy in the range 10-20 kN.

The early design of the sensor string means that individual components are housed in such a way, that they are protected from many elements of the drilling environment. Heat resistance is probably the greatest issue facing the sensor system components.

2.2 Drilling depths

The OptiDrill project anticipates a range of target drilling depths from 500m to 2.5km.

3. Clarification of Drill Pipe / String Dimensions and Configuration

3.1 Drill pipe dimensions and configuration / components

3.1.1 **Dimensions:**

The sensor string which contains sensors required in the OptiDrill system will be matched to the application and the drill pipe being used at that drill site.

3.1.2 **Prototypes: OptiDrill prototype designs will be based on the following pipes dimensions:**

- Outer Ø of drill string to be used in OptiDrill project **89mm**
- Inner Ø of drill string to be used in OptiDrill project **25.4mm** at **(internal)** upset
- Inner Ø of **mid drill pipe** to be used in OptiDrill project **71.4mm**
- **Wall thickness in mid pipe 8.8mm**
- Steel Grade: **S135 / N80**

3.2 Modes of drilling:

As per 1.3.4 of the proposal, the focus of the OptiDrill Project will be **rotary drilling as the main drilling mechanism**, and **high-pressure jetting** as main well stimulation and completion technology (figure1); although it is anticipated that OptiDrill will contribute to the optimization of multiple drilling technologies such as DTH hammers and percussive drilling technique.

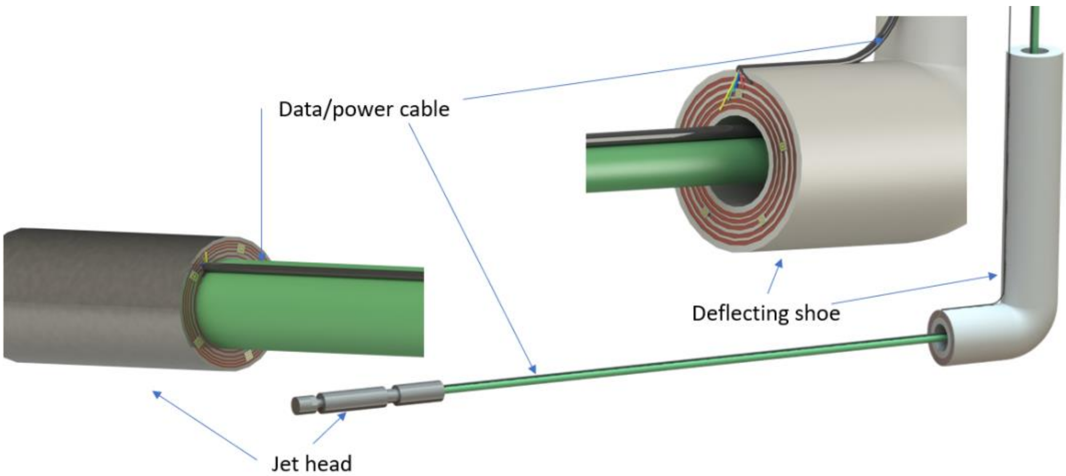


Figure 1 - Jetting Bottom Hole Assembly (BHA) with proposed data cabling

3.3 Proposed sensors for OptiDrill

In addition to the two sensors specified in the project proposal (Acoustic emission/vibration and accelerometer), PVI aims to include temperature, pressure, and strain sensors to characterize the drilling environment.

- **Acoustic emission sensors**: To sample the acoustic signature during drilling process, OptiDrill sensor strings will contain multiple PZT acoustic capacitive sensors. The sensor that informs the 'learning' system will have a wider frequency range until we determine the exact frequencies that we are listening for to achieve our objective of characterising the sound made by drilling various rock type formations.

- **Accelerometer:** To detect movement / impacts during drilling. Each sensor string will contain PZT manufactured tri-axial accelerometers.
- **Temperature:** To collect data on temperatures in the drilling environment.
- **Strain Gauge:** To gather data on the strains experienced on the drill string during drilling operations.
- **Pressure:** To ascertain the pressure around the various drilling components.

Location and configuration of sensors: The position of the sensors on the drill string for optimal data collection will vary with the type of sensor and the drilling method.

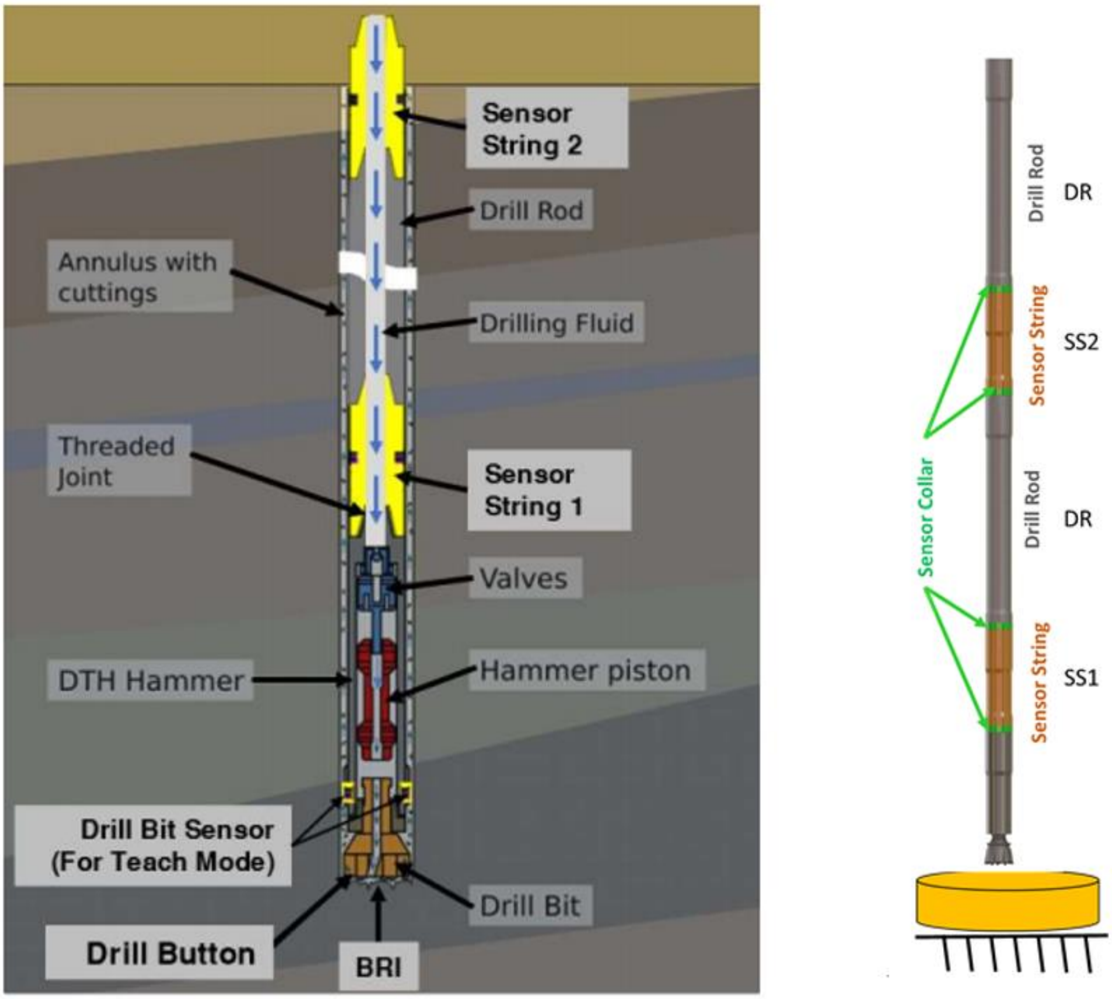


Figure 2 'Traditional' percussive drill string configuration (L) and sensor string / collar locations (R)

4. Specification for wiring and inter-pipe connectivity

4.1 Requirements for wiring the sensors into the drill string

Based on the power/data requirements, OptiDrill will utilize a shielded cable + robust physical connections approach.

4.2 Requirements for pipe-to-pipe connections

To integrate the pipe housing the sensors into standard pipe drill string it will have threads that comply to relevant standards for the industry. If this is not possible, then adapter sections will be produced and used. The bore of all pipes must be sufficient to allow delivery of drilling mud during operations. The actual dimensions of each sensor string unit will depend upon the pipe in use at each drilling site. **The dimensions of the pipes that will be used for prototyping are shown in section 3.2.2.**

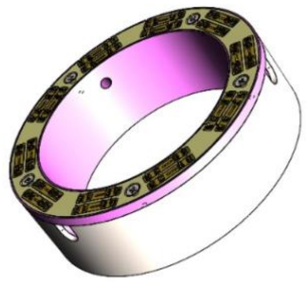


Figure 3 - OptiDrill Sensor Collar Assembly

The OptiDrill system will utilise an innovative collar assembly to house the sensors and provide connectivity between drill pipes (figure 3).

The tough plastic collars are secured to the drill pipe pin and box ends. Selected collars will contain sensors, the majority will be connectors only allowing data and power to be passed from drill pipe to drill pipe and on for up-hole data collection.

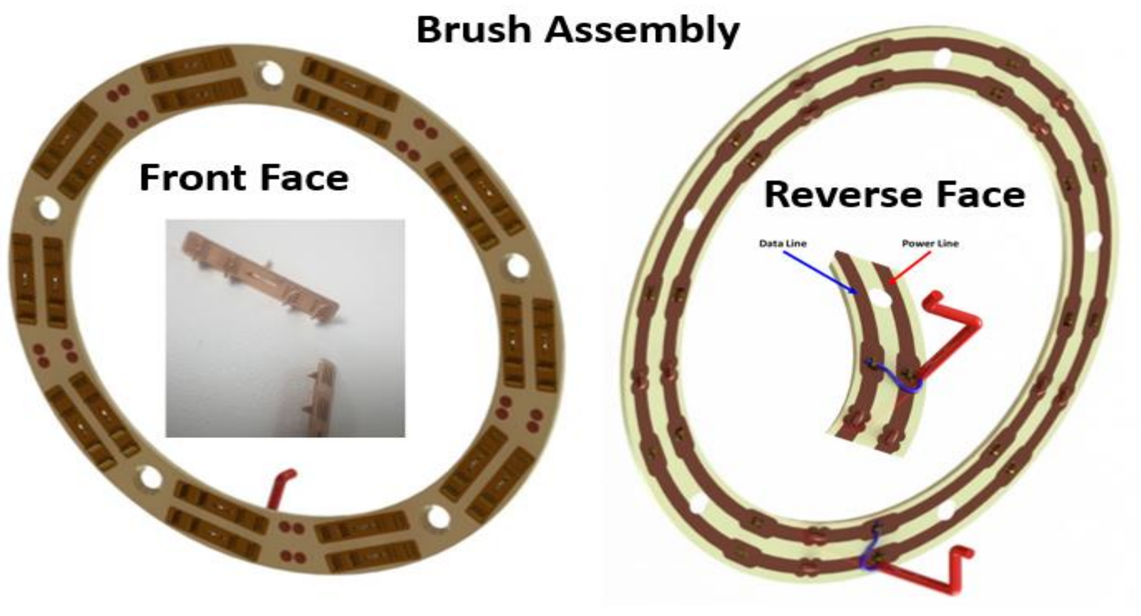


Figure 4 - Brushed connection between pipes

OptiDrill system will employ a unique brush connection technology to provide robust connectivity between drill pipes (figure 4).The FR4 plastic collars will have two concentric rings of brushed phosphor bronze alloy connectors that will interface when brought together as the pipe sections are made up.

5. Specification for MWD (Measuring While Drilling) Sensors

The **User Requirements** document outlines the data required for the OptiDrill system in the Well Planning Stage table 1 (P8) and the accompanying Stakeholder Data Requirements Table (P9). These include measurement of temperatures and other data that will assist the identification of the rock type being drilled. In section 3.3, it was explained that the original proposal included two sensor types. Still, in addition, PVI aims to incorporate an additional three sensor types – temperature, strain, and pressure into the system.

5.1 Sensor specification – Acoustic emission Sensor

The AE sensor (s) will detect sound and vibration across a specific frequency range and have a suitable sensitivity for the application. These sensors must function in the drilling conditions described in section 2.1

The size of the finished sensor will be small enough to be integrated into the sensor string while being of a suitable size to collect the acoustic emission waves and vibrations in the frequency range being measured.

Parameter	Value Range
Temperature (°C)	23-180
Pressure (MPa)	0.1-60
Impacts (kN)	10-20
Frequency range measured	Varies depending on the used drilling method

Table 1 -Acoustic Sensor - Material Specification

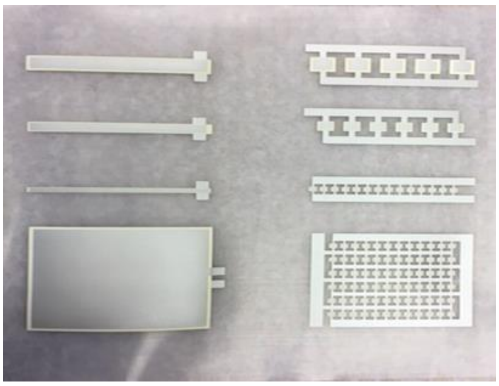


Figure 5 - Acoustic sensor prototype designs

Fabrication Materials for Prototyping

- Substrate: Flexible PI film (Kapton® 200MT) from DuPont.
- Electrode: Printable Cu Ni Au ink
- Sensor Type: Screen printable PVI Piezo-Resistive Paste.
- Other: PVI formulated dielectric Paste.

5.2 Sensor specification – Accelerometer

The sensor must detect acceleration in a range (G's or m/s^2) that will be experienced by the BHA equipment during drilling and have a suitable sensitivity for the application. It must function in the DTH conditions described in section 2.1. The size of the sensor should be small enough to be integrated into the sensor string.

Parameter	Value Range
Temperature (°C)	23-180
Pressure (MPa)	0.1-60
Acceleration Range Measured (G)	20-40
Impact range (kN)	10-20

Table 2 -Accelerometer Sensor - Material Specifications

5.3 Sensor specification – Temperature Sensor

The temperature sensor (s) must detect temperatures in a suitable range (23-180°C). These sensors must function in the DTH conditions described in section 2.1 The size of the completed temperature sensor will be small enough to be integrated into the sensor string.

Parameter	Value Range
Temperature Experienced / Measured (°C)	23-180
Pressure (MPa)	0.1-60
Impact Range (kN)	10-20

Table 3 -Temperature Sensor - Material Specification

Prototype Materials Nickel RTD (resistance temperature detector):

- Substrate: Flexible PI film (Kapton® 200MT) from Dupont.
- Sensor Type: ESJET deposited Super Shield ™ Water Based Nickel Conductive Coating.

Prototype Design

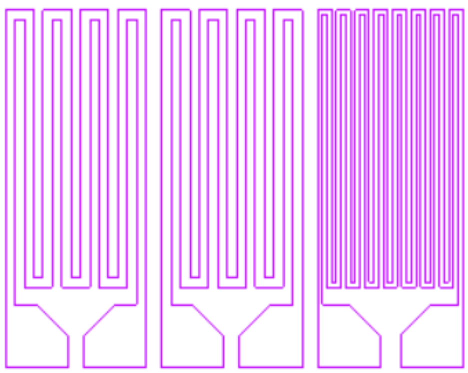


Figure 6 – Serpentine Temp Sensor Designs (RTD) approx. each 10mm x 40mm

5.4 Sensor specification – Strain Gauge / Sensor

The OptiDrill project will build suitable Strain Gauge/sensor (s) to measure mechanical stresses imposed on the drill string in multiple axes accurately during the drilling process. These sensors must function in the DTH conditions described in section 2.1. The target size of the final design of the strain gauges / sensors should be small enough to be integrated onto the sensor string.

Parameter	Value Range
Temperature (°C)	23-180
Pressure (MPa)	0.1-60
Impact Range (kN)	10-20

Table 4 -Strain Gauge - Material Specification

Fabrication Materials for Prototyping

- Substrate: Flexible PI film (Kapton® 200MT) from DuPont.
- Electrode: Screen Printable PVI formulated Nano-Ag Paste.
- Sensor Type: Screen printable PVI Piezo-Resistive Paste.
- Other: PVI formulated dielectric Paste.

Prototype Design

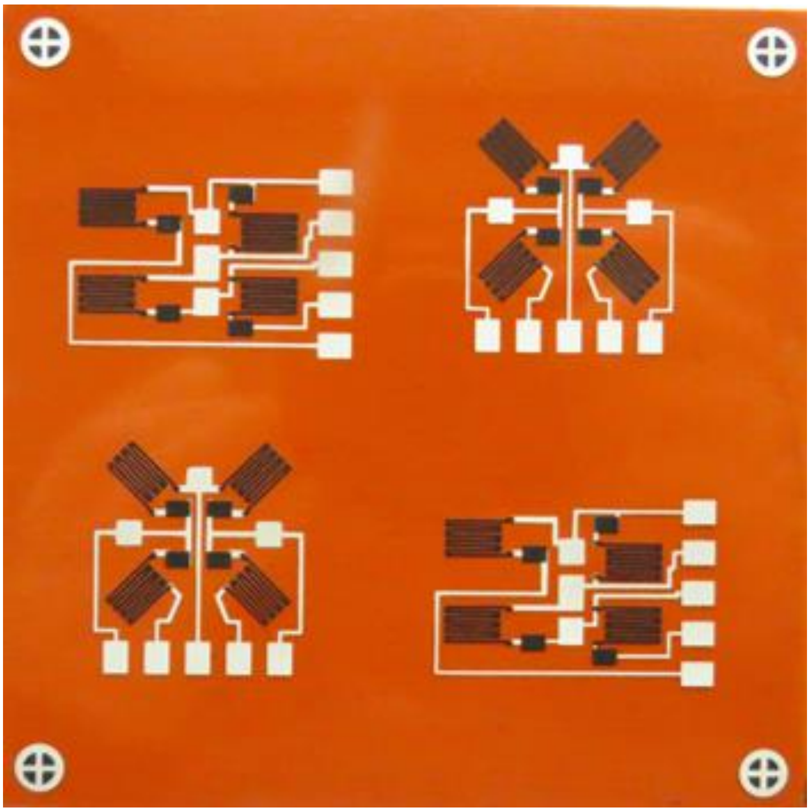


Figure 7 - Prototype Strain Gauge Full Bridge Design – to measure bending and shear (-/+)

with temperature compensation on 100x100mm substrate.

5.5 Sensor specification – Pressure Sensor

The OptiDrill project will build pressure sensor (s) to accurately measure pressures around the drill string. These sensors must function in the DTH conditions described in section 2.1
The final size of the pressure sensors must be small enough to be integrated onto the sensor string.

Parameter	Value Range
Temperature (°C)	23-180
Pressure (MPa) Experienced / Measured	0.1-60
Impacts (KN)	10-20

Table 5 -Pressure Sensor - Material Specification

Fabrication Materials for Prototyping

- Substrate: Flexible PI film (Kapton® 200MT) from DuPont.
- Electrode: Screen Printable PVI formulated Nano-Ag Paste.
- Sensor Type: Screen printable PVI Piezo-Resistive Paste.
- Other: PVI formulated dielectric Paste.

Prototype Design

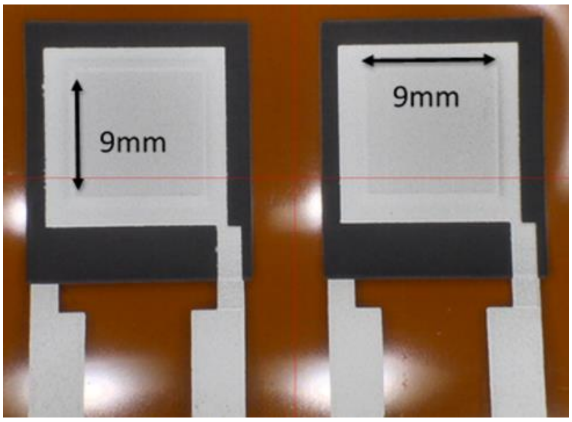


Figure 8 - Prototype windowed piezo-resistive pressure sensor

6. Data Acquisition Specification (through to above ground PC)

6.1 Data Acquisition Specifications

6.1.1 Software:

- A range of sampling rates will be used for the sensors depending upon the location and application of each sensor type. The target is **8-bit** data resolution (256 data points between impacts for system identification module), 6-**bit** resolution between impacts for uphole data (64 data points between impacts)
- Output data will be produced in a format suited to the requirements of PVI and the learning system being developed and implemented in other OptiDrill workstreams.

7. Sensor Data Conditioning and Electronics / Electrical Specification

7.1 Sensor system hardware

7.1.1 Hardware

- To acquire and communicate sensor data, a range of hardware devices will be required in addition to the sensors: microprocessors, multiplexers and demultiplexers, signal conditioners, and amplifiers.
- Electrical design / requirements (powering the sensors and relaying data to the surface).

7.1.2 Power Requirements:

The power requirements for the sensor system will be budgeted against available power.

Parameter	Value Range
Output Voltage (V)	5-40
Power Rating (W)	10
Current Rating (A)	2

Table 6 - Power Budget

8. Realtime Monitoring and Control Specification and User Interface

8.1.1 Sensor system software – Surface-based Data processing and operator GUI.

8.1.2 Comms protocol Data Transfer Speed and connection method PC serial, USB, TCP.

8.1.3 Drill Monitoring Requirements: Master-Slave protocol for data transmission.

The monitoring system will be implemented in a configuration with the following hardware:

1) PC with analysis algorithms implemented in MATLAB™.
2) PC with a graphical user interface.
3) Programmable Logic Controller used as a core system for two-way communication between PCs, sensors, and controlled hardware.