All-digital Sensor System for Distributed Downhole Pressure Monitoring in Unconventional Fields

DE-FE0031781

Hai Xiao

Clemson University

U.S. Department of Energy

National Energy Technology Laboratory

Oil & Natural Gas

2020 Integrated Review Webinar

Program Overview

- DE-FOA-0001990
  - Area of Interest 1A - Improving Ultimate Recovery from Unconventional Oil and Gas Resources
- Total project budget: $1,750,000
  - DOE: $1,500,000
  - Costshare $250,000
- 3 Year: Oct. 1, 2019 – Sept. 30, 2020
- Interdisciplinary team
  - Clemson University (Lead)
  - University of Oklahoma (Subcontractor)
  - Quest Drilling Facilities LLC (Subcontractor)

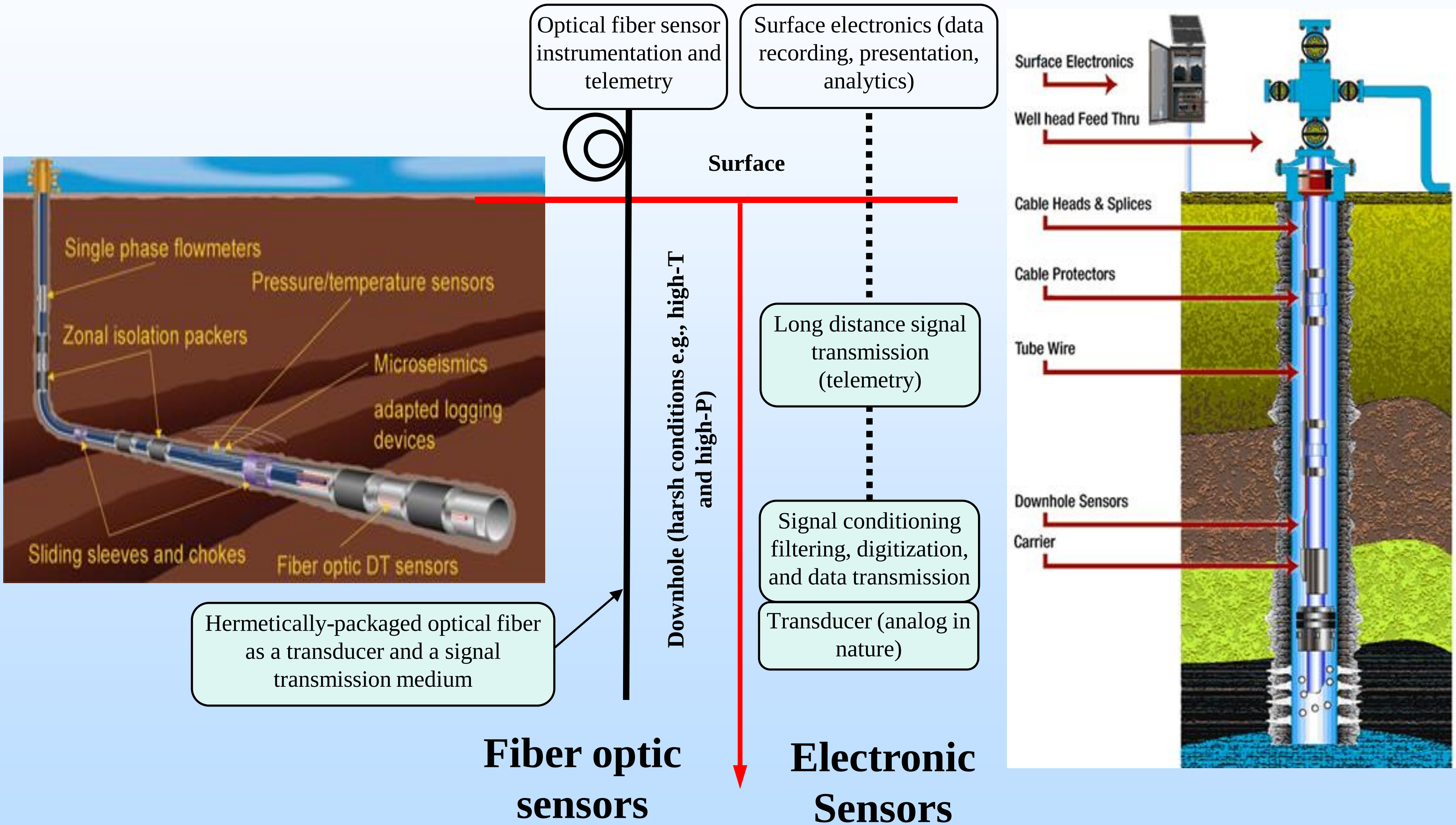
Project Objectives

- Objective: To develop and validate a low-cost all-digital sensing technology for distributed downhole pressure monitoring in Unconventional Oil and Gas (UOG) fields.
- Pressure information is critical to
  - Guide hydraulic fracturing operations
  - Monitor potential leakage occurrence
- Existing sensing technologies are too costly for UOG

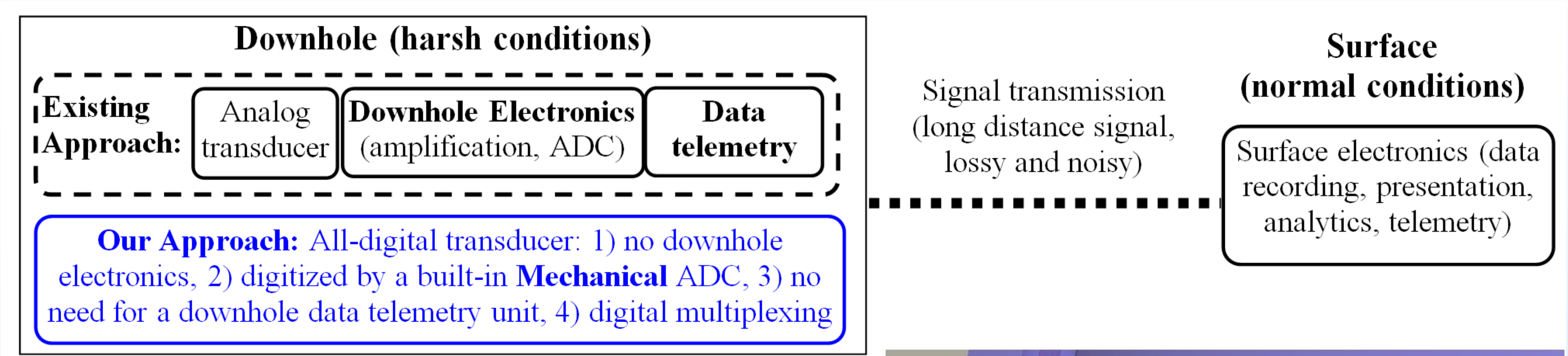
Technical Challenges

- Downhole sensors
  - Harsh environment (high-T, high-P, vibrations, etc.)
  - High pressure resolution (0.2%)
  - Large range (10,000 psi)
  - Restricted dimensions (less than 2-inch in diameter)
  - Long-term stability
- Data transmission
  - Long distance (km)
  - Sensor multiplexing to save cost

Existing Technologies

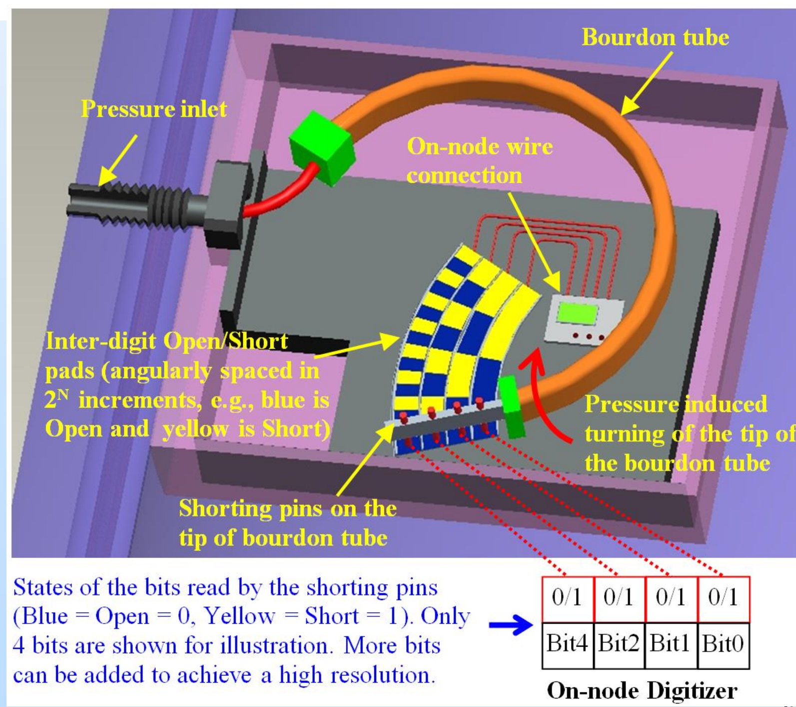


All-digital Sensor Concept



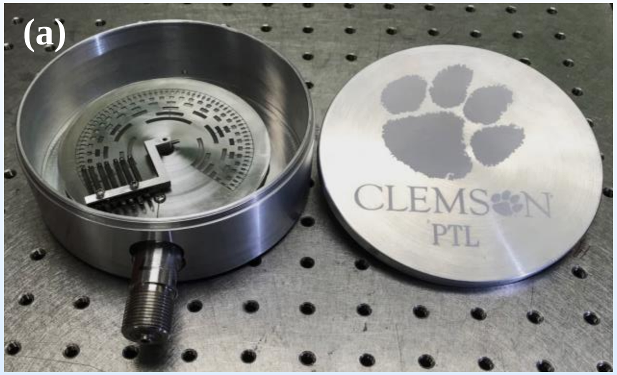
Advantages of all-digital sensors

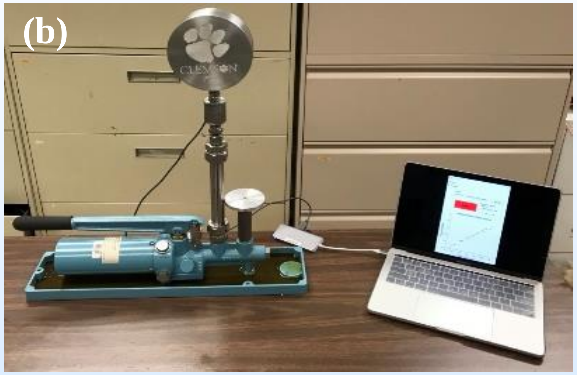
- High-temperature and high-pressure capability
- Low-cost implementation
- Multiplex for distributed sensing
- Reliable digital signal transmission over a long distance
- The all-digital platform can be modified to measure other downhole parameters such as temperature and acoustic

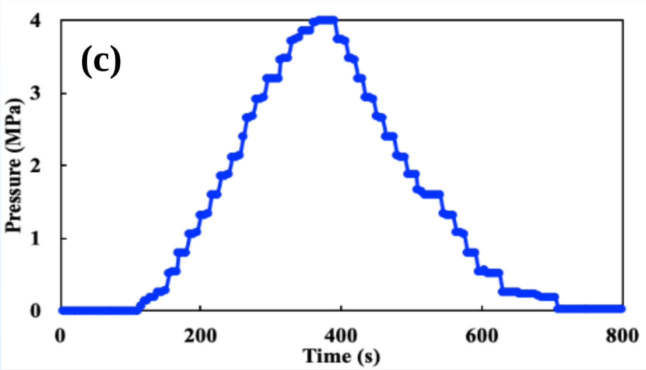


Proof of Concept

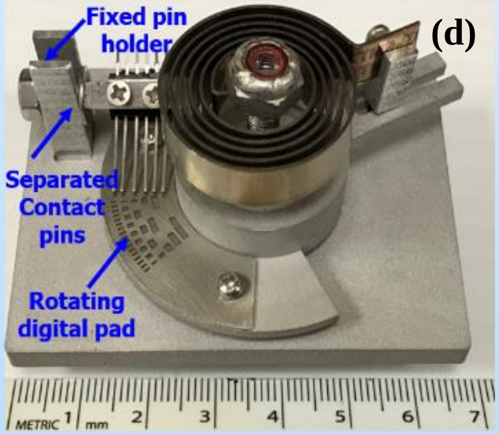
– All-digital pressure sensors using Bourdon tube

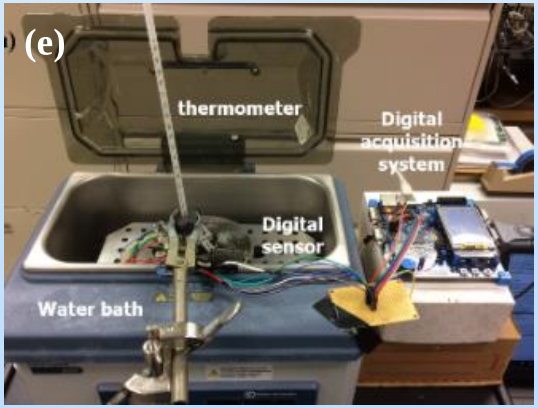


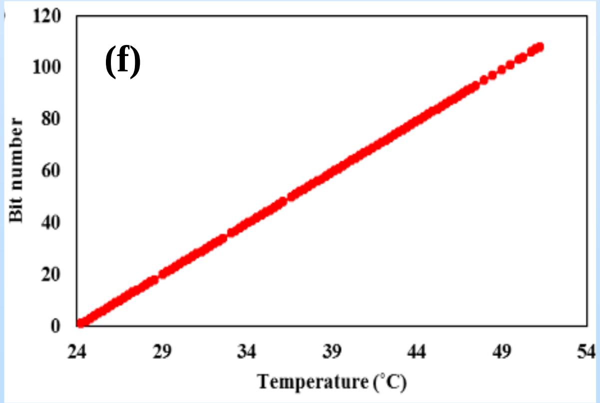




– All-digital temperature sensors using bimetallic coil

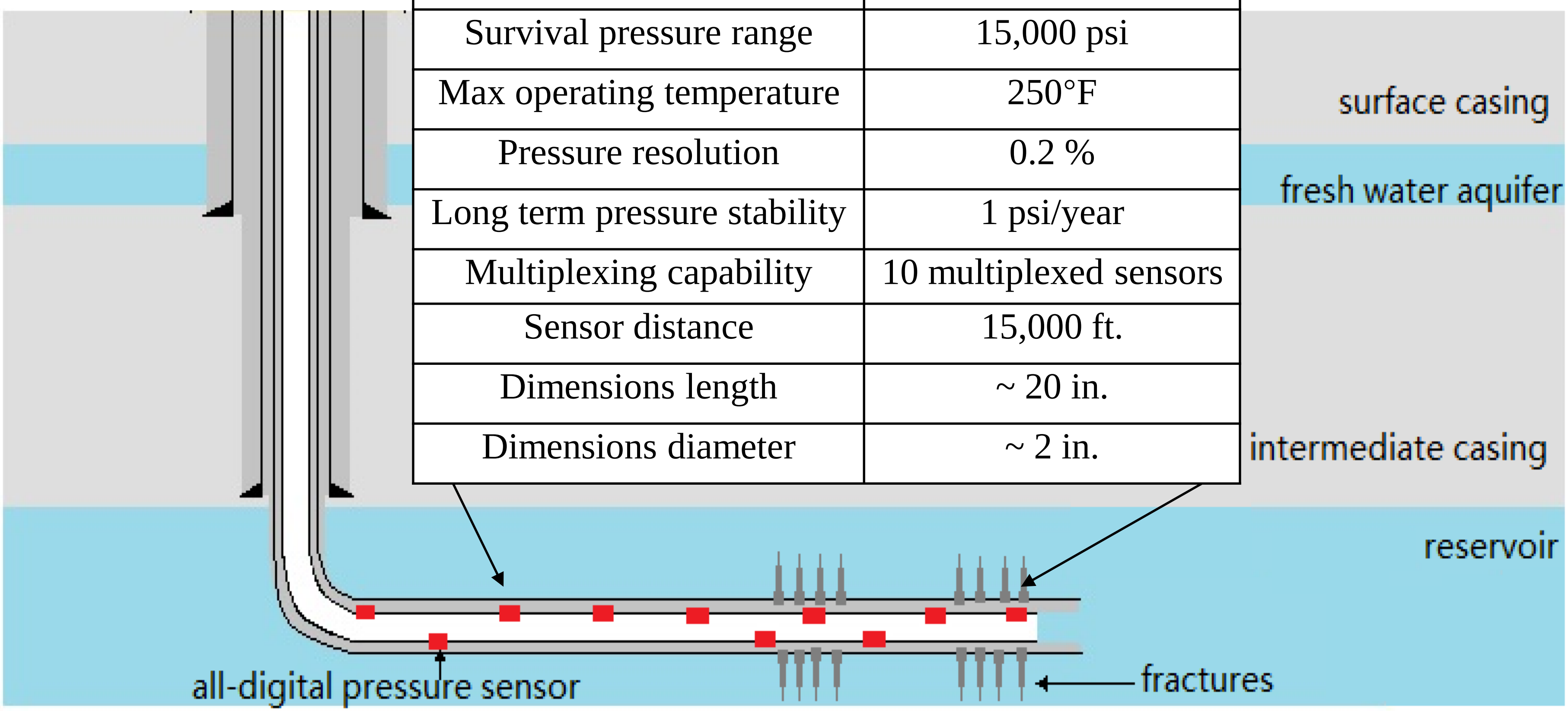






Sensor Specifications

Working pressure range	10,000 psi
Survival pressure range	15,000 psi
Max operating temperature	250°F
Pressure resolution	0.2 %
Long term pressure stability	1 psi/year
Multiplexing capability	10 multiplexed sensors
Sensor distance	15,000 ft.
Dimensions length	~ 20 in.
Dimensions diameter	~ 2 in.



Technical Approach

- **Sensors:** Design, engineer, fabricate, package and test/validate the all-digital pressure sensors.
- **Instrumentation:** Develop and test sensor multiplexing and data transmission methods for distributed pressure sensing.
- **Pilot test:** validate the prototype sensors and instrumentation in research wellbores.
- **Field test:** validate the all-digital pressure monitoring system in a production well.

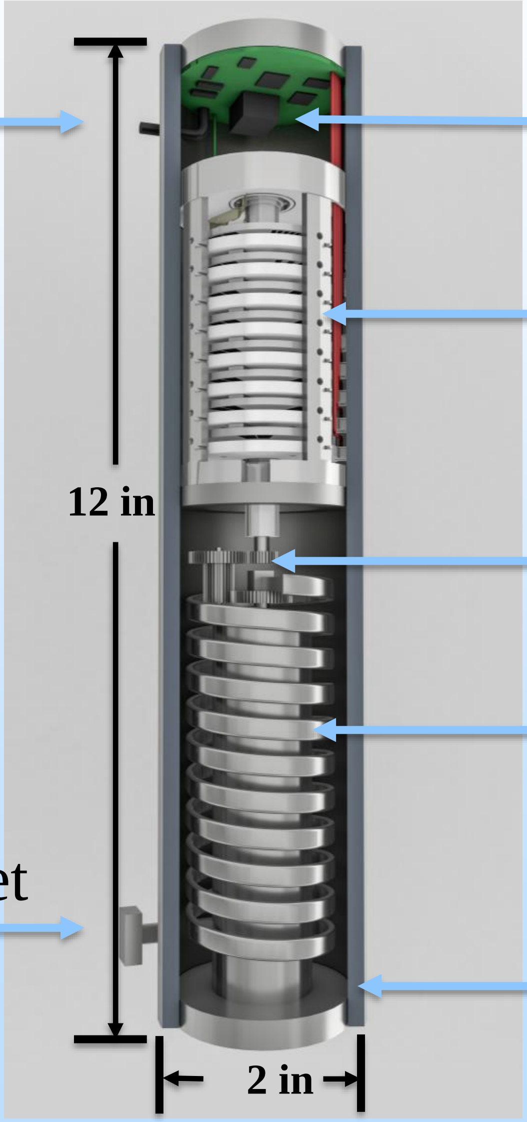
Project Scope

- **Budget Period 1:** Design, fabricate, package and validate of the all-digital pressure **sensors**.
- **Budget Period 2:** Develop and test sensor multiplexing technology, fabricate and validate the prototype sensors and **instrumentation** through pilot tests.
- **Budget Period 3:** Conduct a **field test** in a production well to demonstrate and confirm the performance of the new pressure monitoring technology.

Progress and Current Status of Project

Wire outlet

Pressure inlet



Data telemetry module

Digitizer - convert rotation angle to digital outputs

Gear set - amplify the angle

Helical coil Bourdon tube - convert pressure to rotation angle

Hermetic package

Pressure Transducer

1. C-type (single coil) Bourdon tube

- Too large in cross section dimensions
- Low sensitivity
- Good reliability

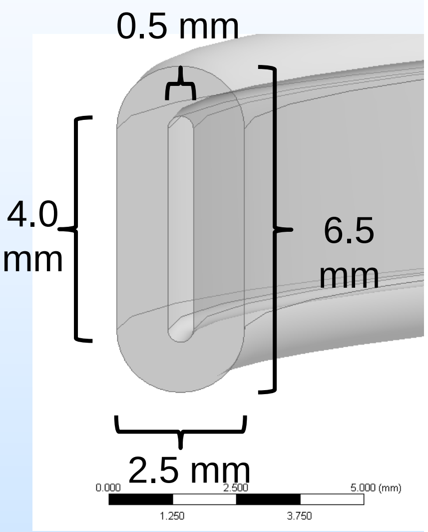
2. Metal bellows tube

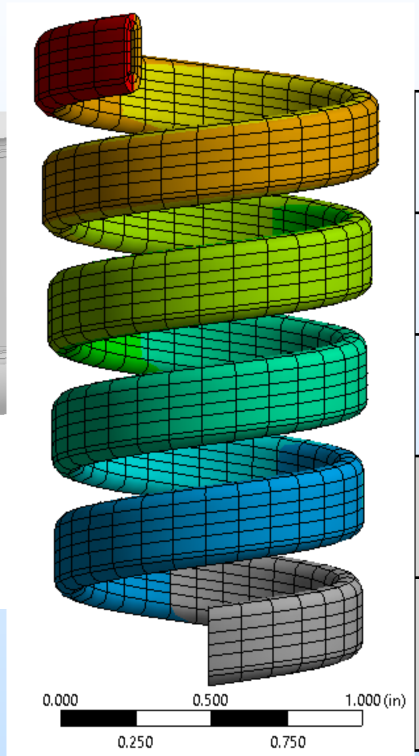
- Difficult to fabricate
- Poor reliability

3. Helical coil Bourdon tube

- High sensitivity
- Easy fabrication
- Good reliability

Coil Design by Simulations





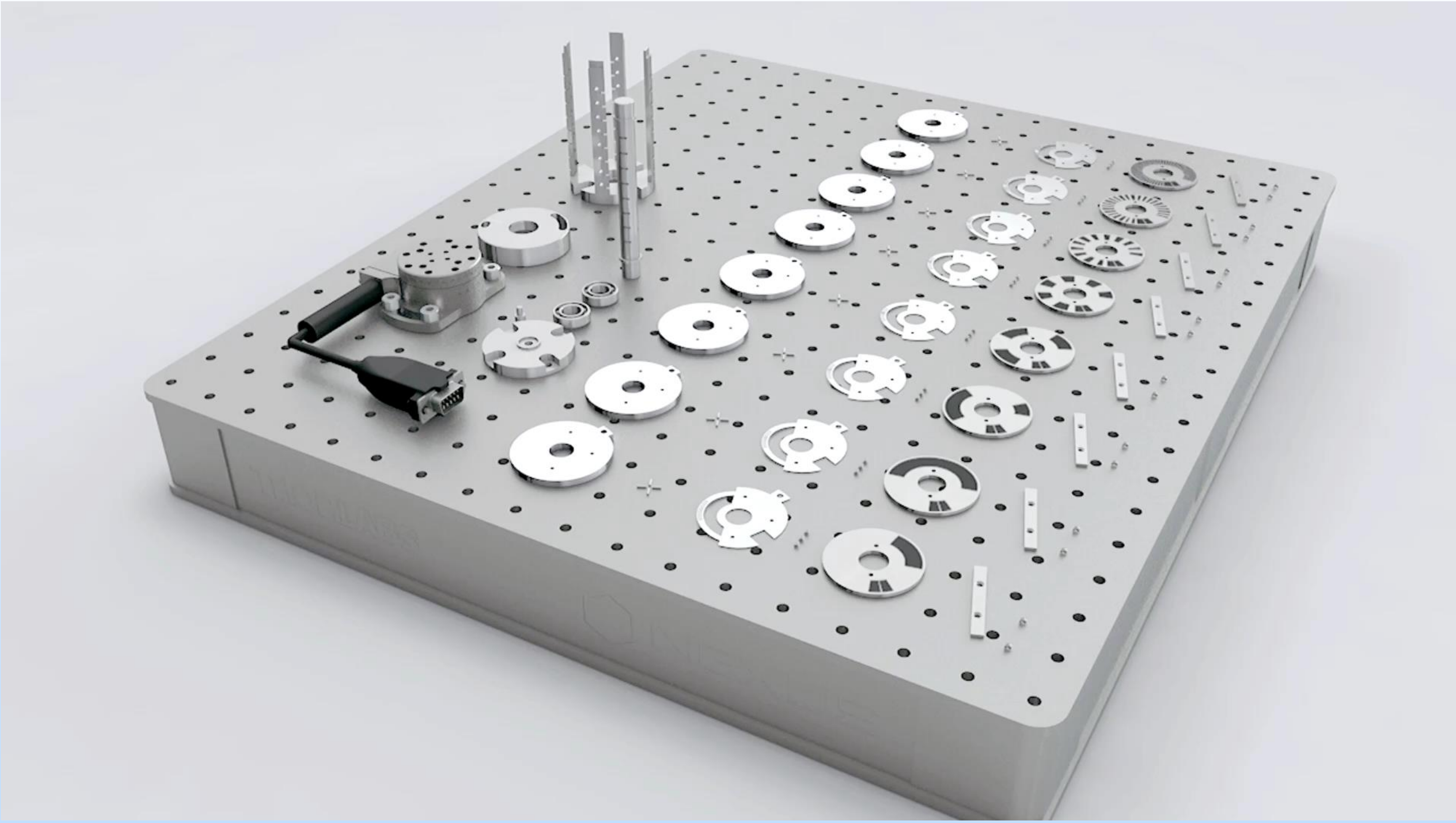
1 in. Dia. 5 coils

Coil Simulation Summary

Coil Diameter (in)	**2**	**1**		
Number of Coils	5	5	10	20
AVG Stress (psi)	64,158	47,603	47,651	47,674
Rotation Angle (°)	**109**	**32**	**64**	**129**
Radial Deformation (in)	3.91	1.28	1.56	2.12

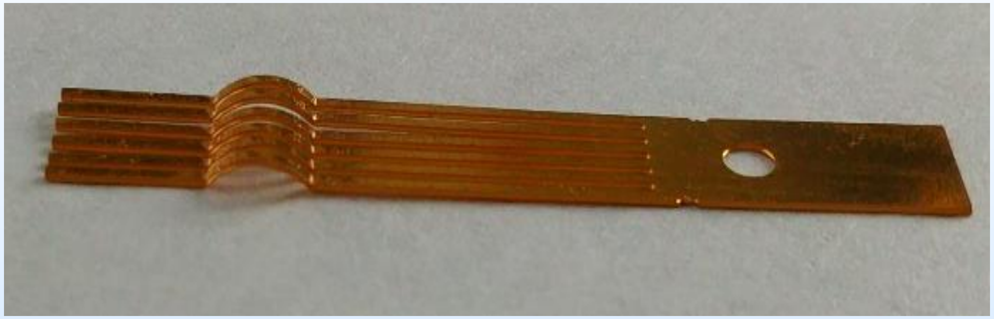
- **Rotation angle increases with increasing number of coils**
- **Radial deformation increases with increasing number of coils**
- **Radial deformation increases with increasing coil diameter**

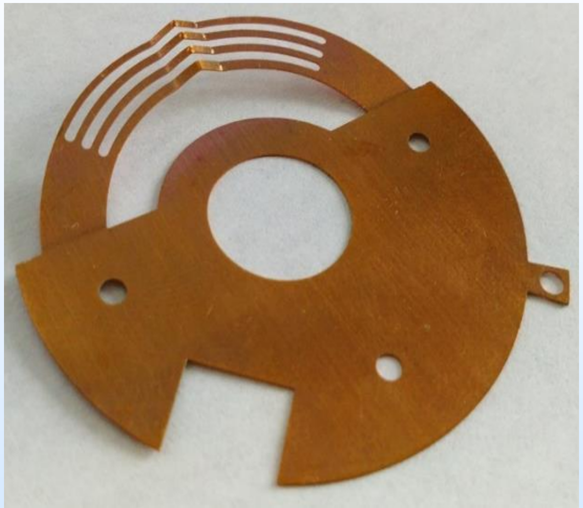
All-digital Sensor Design and Assembly



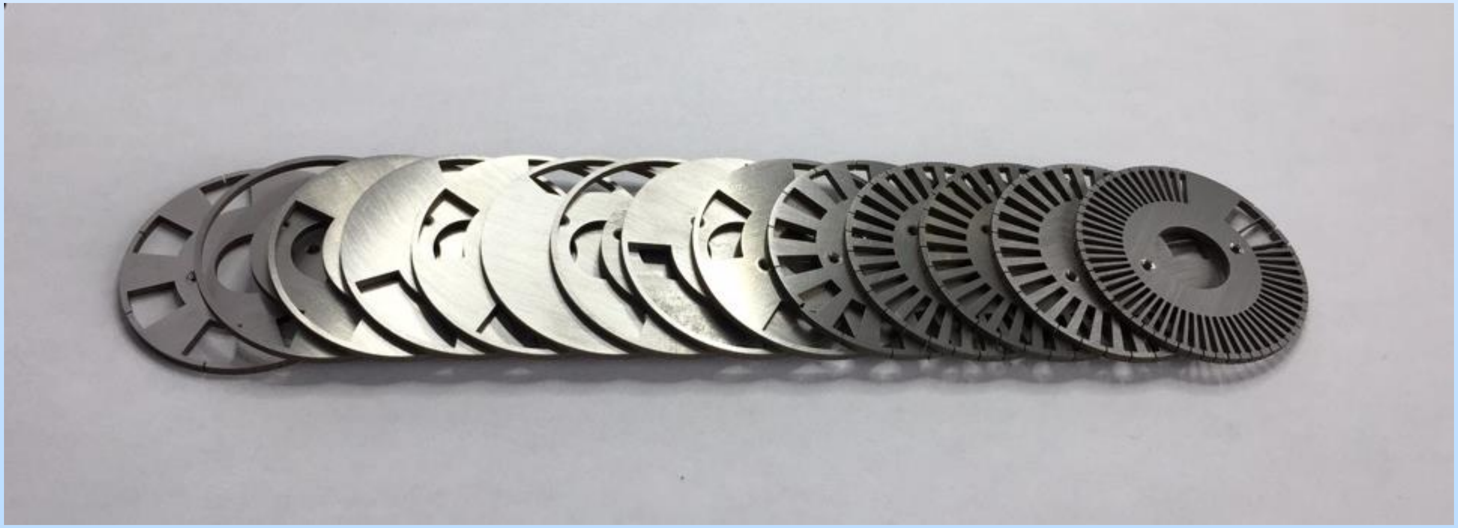
Parts Fabrication

Contact pins

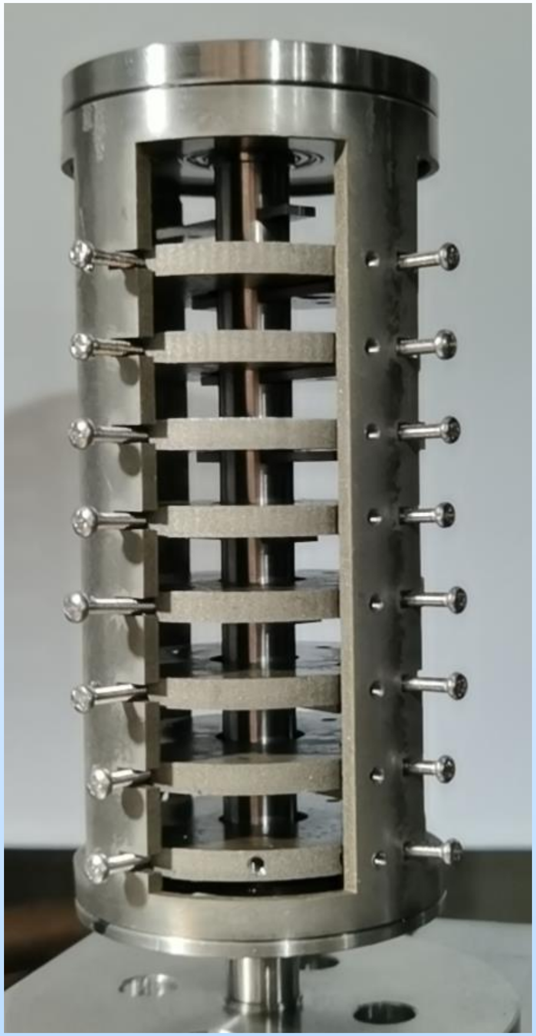




Digital encoding pads

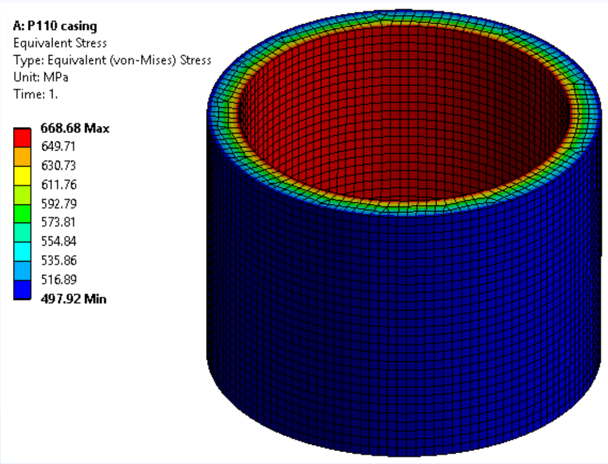


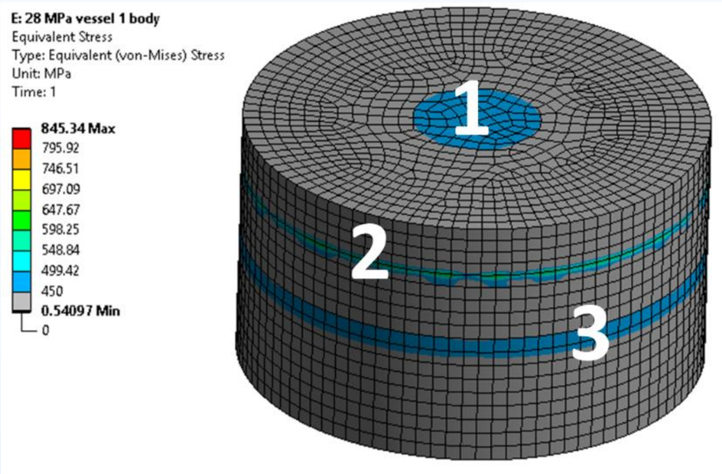
Partially Assembled Decoder



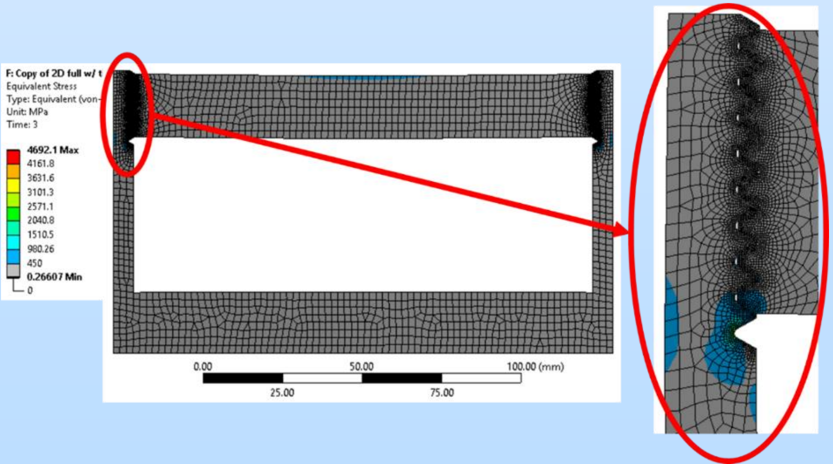
Hermetic Package Design

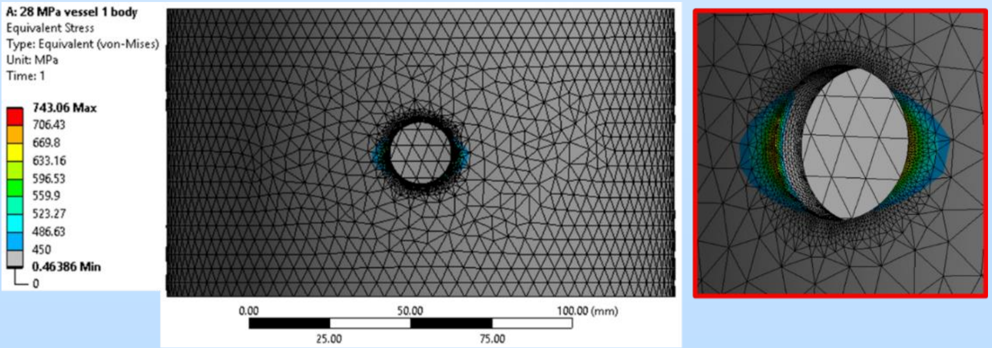
- **Minimum thickness (Wall: 3/16-inch, Lid: 11/16-inch)**





- **Simulations of thread and hole**

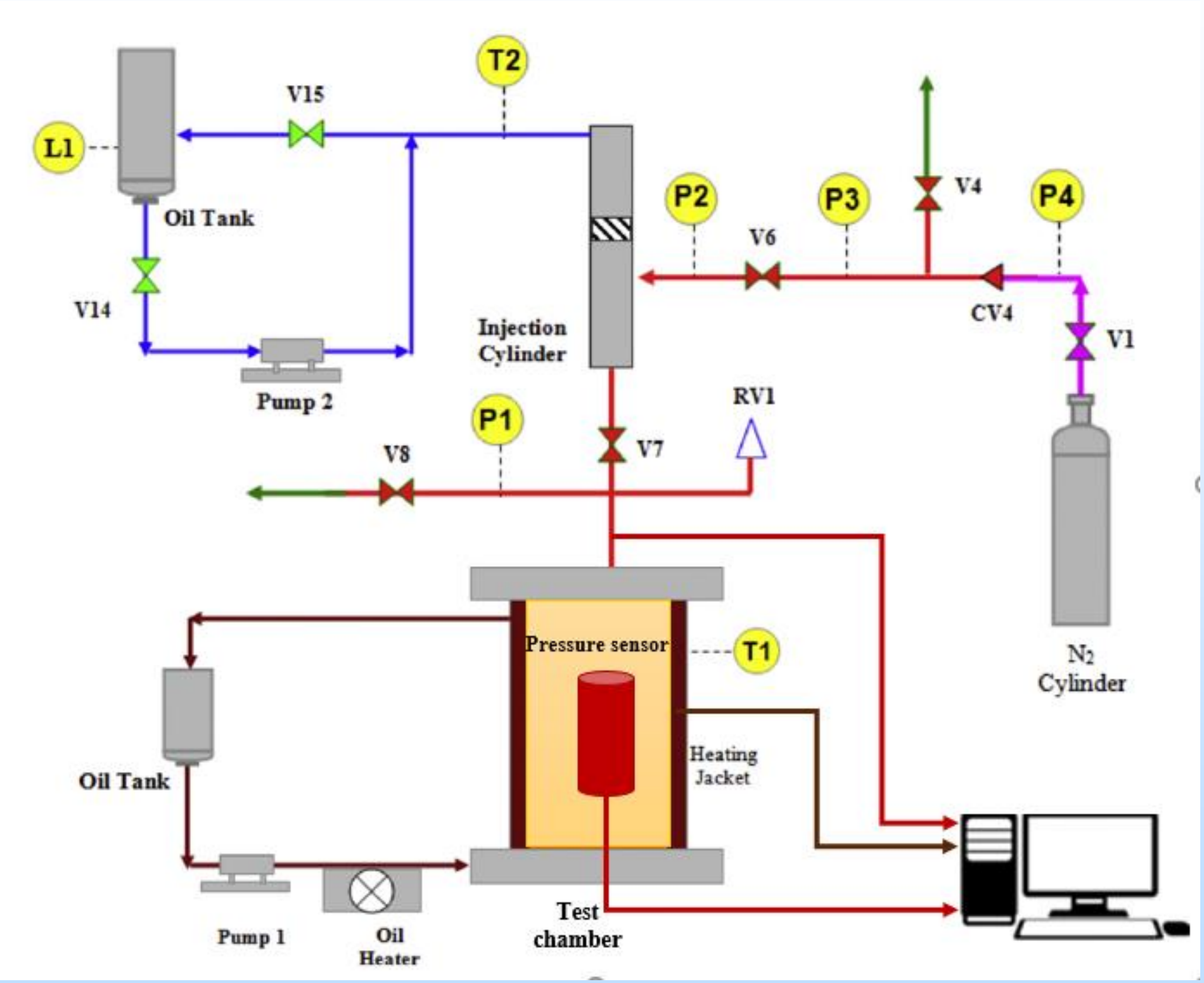




Plans

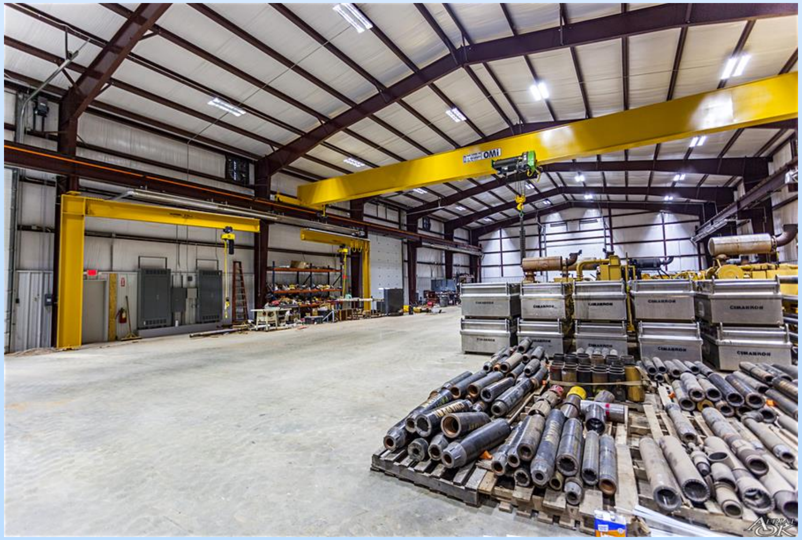
- Sensor prototypes and in-lab test under simulated conditions (250ºC, 10,000psi). – **BP1**
- Instrumentation for sensor multiplexing and long-distance data transmission. – **BP1 and BP2**
- Preparation of sensors and instrumentation for the field tests. – **BP2 and BP3**
  - Tested in the research wellbore at the depth of 3,000 ft.
  - Test in a production well

Sensor P&T Laboratory Test



Testing in a research wellbore

Quest Drilling Test Facility, Payne, Oklahoma



Summary

- Requested a no-cost extension of 6 months for BP1, closedown of labs due to Covid-19.

- Has followed the schedule and completed the key milestones as planned.

- Excellent collaborations - the team has been effectively working together.

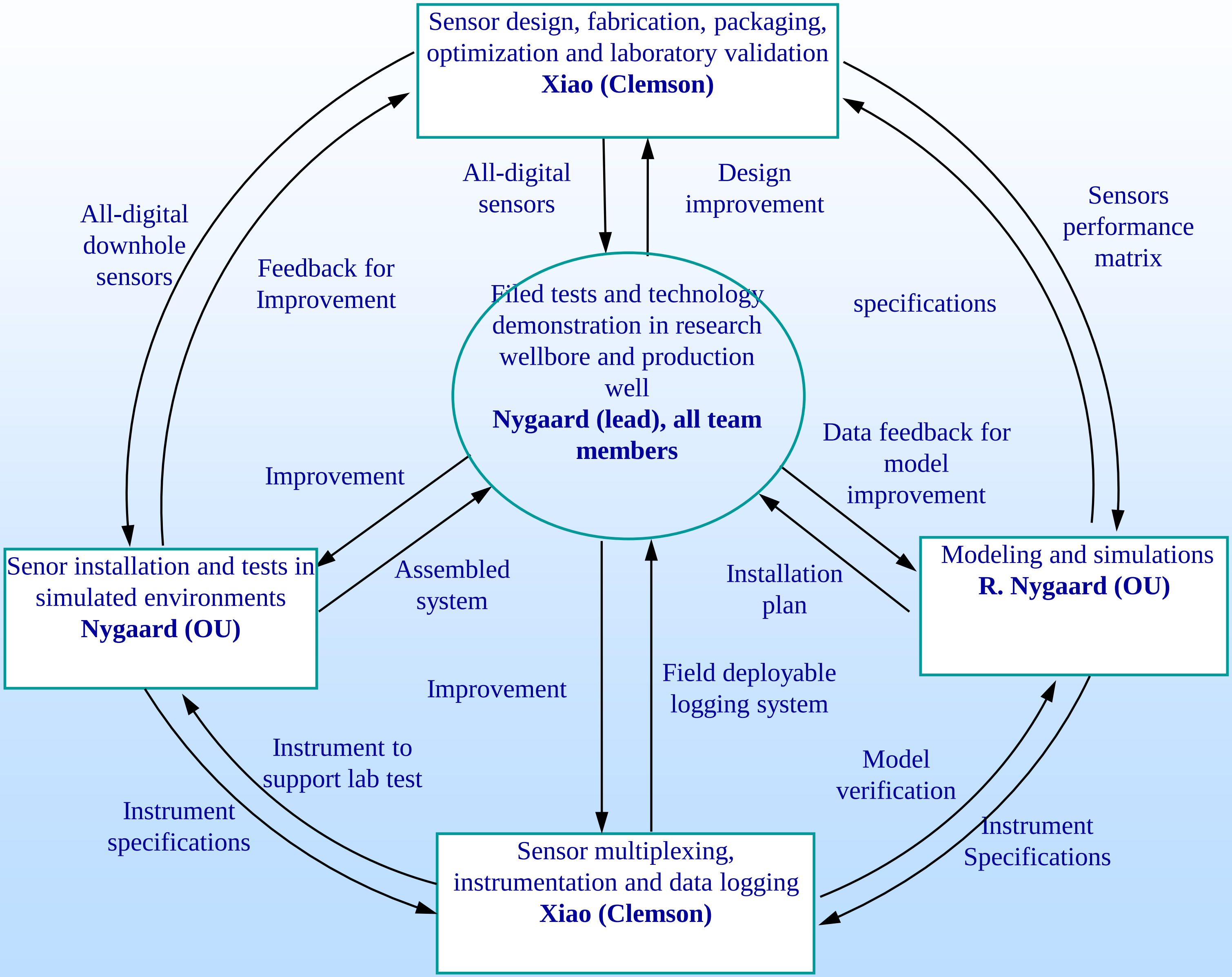
Thank You!

Questions?

Appendix

– These slides will not be discussed during the presentation, but are mandatory.

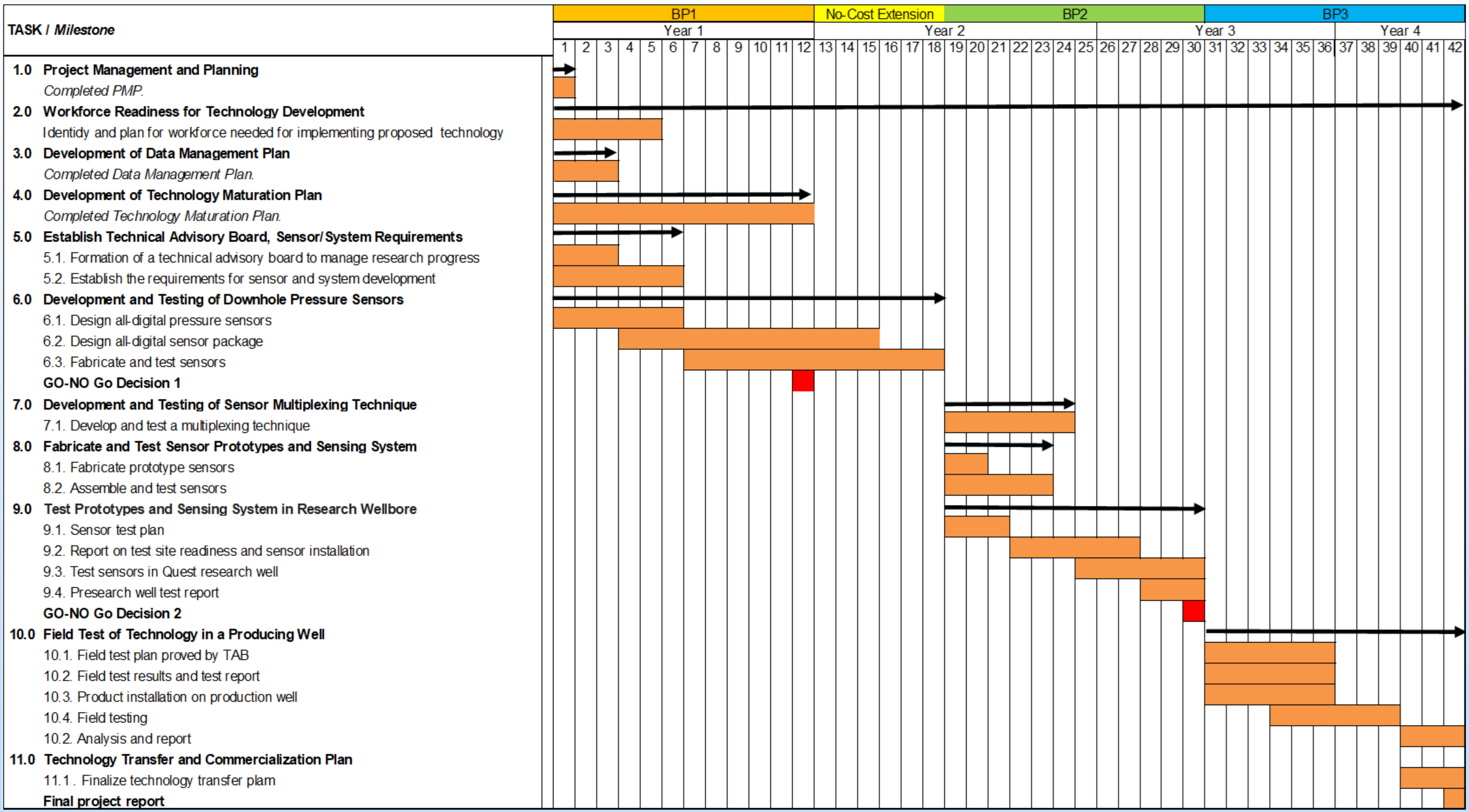
Organization Chart



The Team

- Hai Xiao (PI)
  - Professor, Electrical & Computer Engineering, Clemson University
  - Sensors and instrumentation
- Runar Nygaard (Co-PI)
  - Professor, Petroleum Engineering, University of Oklahoma
  - Drilling, simulation, testing and data analysis
- Brian McCutchen (Co-PI)
  - Operation Manager / Owner, Quest Test Facility LLC
  - Drilling and sensor deployment

Gantt Chart



TASK / Milestone
BP1
No-Cost Extension
BP2
BP3
Year 1
Year 2
Year 3
Year 4
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42
1.0 Project Management and Planning
Completed PMP.
2.0 Workforce Readiness for Technology Development
Identidy and plan for workforce needed for implementing proposed technology
3.0 Development of Data Management Plan
Completed Data Management Plan.
4.0 Development of Technology Maturation Plan
Completed Technology Maturation Plan.
5.0 Establish Technical Advisory Board, Sensor/System Requirements
5.1. Formation of a technical advisory board to manage research progress
5.2. Establish the requirements for sensor and system development
6.0 Development and Testing of Downhole Pressure Sensors
6.1. Design all-digital pressure sensors
6.2. Design all-digital sensor package
6.3. Fabricate and test sensors
GO-NO Go Decision 1
7.0 Development and Testing of Sensor Multiplexing Technique
7.1. Develop and test a multiplexing technique
8.0 Fabricate and Test Sensor Prototypes and Sensing System
8.1. Fabricate prototype sensors
8.2. Assemble and test sensors
9.0 Test Prototypes and Sensing System in Research Wellbore
9.1. Sensor test plan
9.2. Report on test site readiness and sensor installation
9.3. Test sensors in Quest research well
9.4. Presearch well test report
GO-NO Go Decision 2
10.0 Field Test of Technology in a Producing Well
10.1. Field test plan proved by TAB
10.2. Field test results and test report
10.3. Product installation on production well
10.4. Field testing
10.2. Analysis and report
11.0 Technology Transfer and Commercialization Plan
11.1 . Finalize technology transfer plam
Final project report