A Novel "Smart Microchip Proppants" Technology for Precision Diagnostics of Hydraulic Fracture Networks

Project Number: DE-FE0031784

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National Energy Technology Laboratory
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Presentation Outline

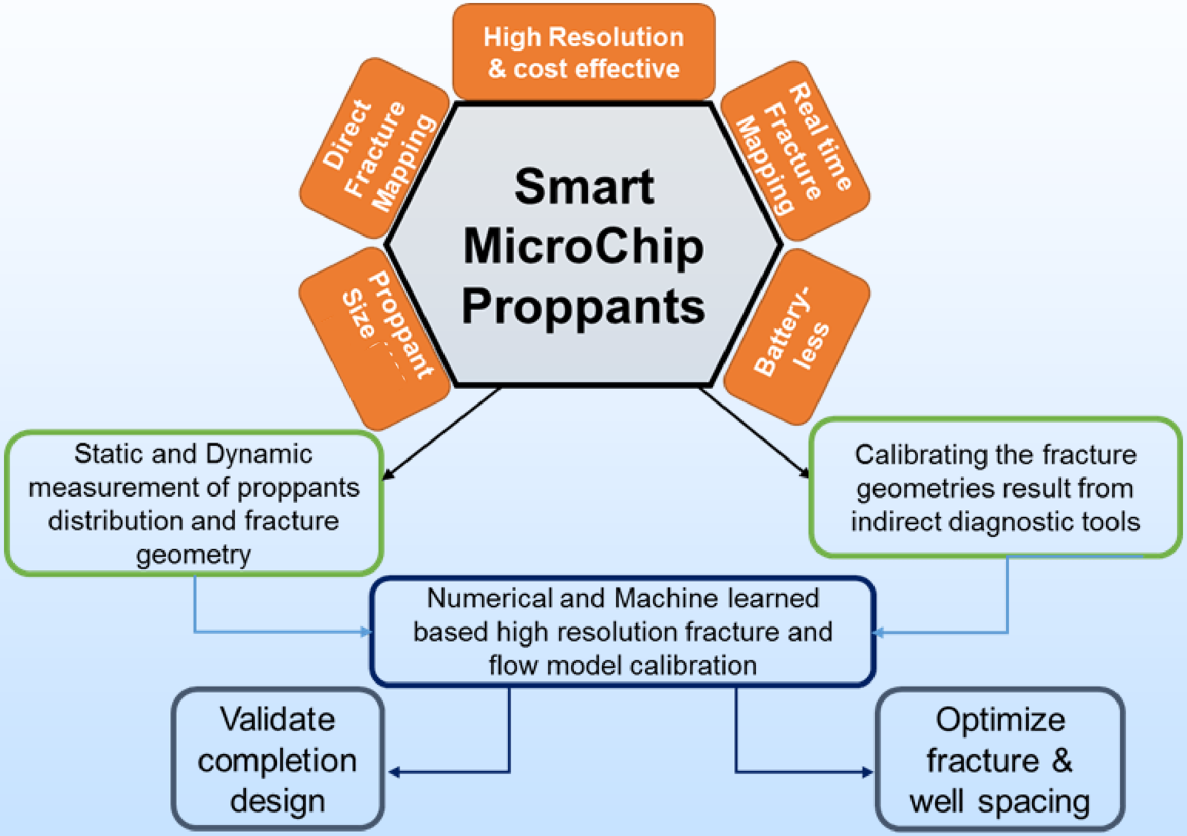
- Technology Background
- Benefit to the Program
- Technical Approach/Project Scope
- Accomplishments to Date
  - Smart Microchip Sensors development and testing
  - Building downhole tool to power the chips
  - Novel iGeoSensing Fracture Diagnostic tool
- Plans for future testing/development/ commercialization
- Organization Chart
- Gantt Chart

Program Overview

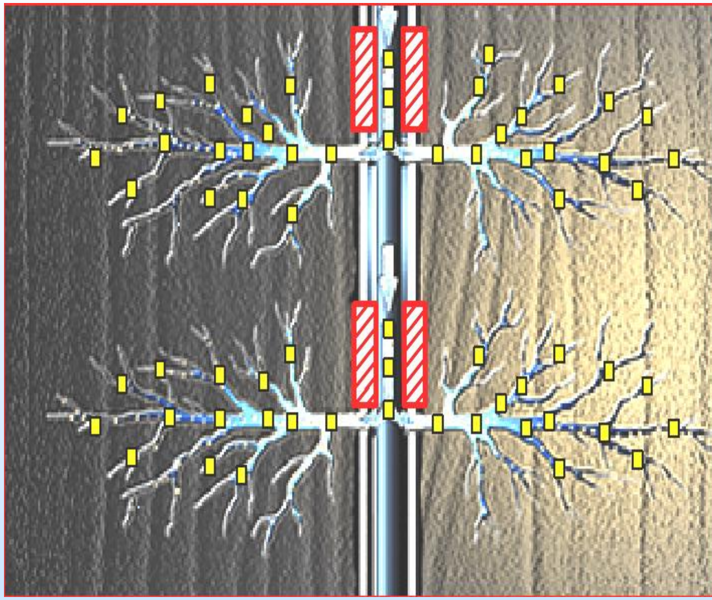
- Funding
  - (DOE:$2.49M and Cost Share:$1M)
- Overall Project Performance Dates:
  - October 2019-August 2024
- Project Participants
  - University of Kansas(Lead institution), UCLA, MicroSilicon Inc., and EOG Resources (Cost share)

  (Consultants: NSI Fracturing Inc and Confractus Inc)
- Overall Project Objectives
  - to develop and field test fine size and wirelessly powered smart MicroChip Proppants
  - to develop a closed-loop fracture diagnostic and modeling workflow using the collected data from Smart MicroChip Sensor to better characterize propped fracture geometry in real time.

Technology Background



Smart MicroChips



Pilot Location:
Permian Basin
EOG Resources

Technology Background

- The proposed technology responds to the currently limited understanding of the near wellbore fracture properties.
- Smart MicroChips injected along with proppant to map the geometry of a fracture network.
- A downhole tool injects electromagnetic energy into the rock
- The sensor harvests the energy to activate an on-chip radio that communicates back to the down-hole tool.
- MicroChips change the frequency of the received signal and respond back in a different band.
- All chips communicate back at the same frequency and the amplitude/phase of the incoming signal is stored in memory.

Technology Background

- For this generation device, the tool is then returned to the surface and the signal passed to a surface laptop where software combines that with recorded tool depth position to convert the data into a map of chip positions with a resolution of better than 1 ft.
- Physics informed, Al-based iGeoSensing platform on cloud enables real-time processing of the computed signals to generate multiple realizations of HF geometries and generate the corresponding flow responses.

Benefit to the Program

Technology Impact:

- Reduce unconventional resources development cost by optimizing well spacing while minimizing the development related environmental footprint.
- Maintain the US leadership in unconventional energy development

Vision

Metric	State of the Art	Proposed
Resolution	50 ft	<1ft
Data streaming	Only during the hydraulic fracturing (HF)	Real time, during , after the HF job and during the production
Manufacturing cost	$10-100 per proppant	Few cents

MEMS (micro electro mechanical systems)

Technical Approach/Project Scope

Design and work plan

- Experimental components:
  - ✓ build and calibrate novel Smart MicroChip Sensor in the lab environment
  - ✓ construct synthetic cores with different levels of fracture complexity for testing Microchips.
  - ✓ build a downhole logging tool to power the Smart MicroChip Sensors and assimilate their data
  - ✓ perform basic and comprehensive rock mechanical tests
  - ✓ conduct two fluid sensitivity testing-pH& Potassium Chloride (KCl) tests
  - ✓ Field Laboratory testing

Technical Approach/Project Scope

Design and work plan:

- Computational components:
  - ✓ iGeoSensing platform development
  - interpret and map the received data from the "Virtual" Smart MicroChip Sensor by developing a new algorithms to process amplitude and phase date collected at discrete tool positions
  - real-time fracture mapping
  - real time proppant transport modeling
  - real time flow back and production history matching by coupling numerical and machine-learned models.

Progress and Current Status of Project

- **Summary of achievements:**

❖ Successful laboratory testing of Smart MicroChip proppants functionality and transport: (SOPO Tasks 5.8,6.1,6.3 and 6.4)

- successful energy harvesting of Smart Microchips and communication with the downhole tool in lab environment verification(SOPO Task 6.1)
- Smart Microchips functionality verification (SOPO Task 6.1)
- Coherent power combining verification (SOPO Task 6.1)
- Smart proppants transport and imaging capability testing (SOPO Task 5.8 and 6.3)
- MicroChips functionality verification at the high temperature of 250 °C (482 °F). (SOPO Task 6.4)

  ✓ This significant accomplishment opens doors to take this novel technology to the next level to be applicable in very high-temperature fields including geothermal operations.

Progress and Current Status of Project

- **Summary of achievements:**
  - MicroChips functionality verification at the high pressure of 3490 psi (24.06 Mpa) (SOPO Task 6.4)
    - ✓ with no epoxy protection embedded in the cement under compressive forces.
    - ✓ The final MicroChip proppants for field trial will have epoxy-type protection for up to 10,000 psi.
  - Characterizing received power vs distance
  - Flexible options to tolerate misalignment between tool and chip antenna

    For applications with chip in cemented annulus, design was robust to ~60 degrees misalignment but chips in fracture will have ~90 degree "misalignment"

    - ✓ Design of new PCB layout resolves this misalignment problem
    - ✓ Ongoing chip miniaturation

Progress and Current Status of Project

- **Summary of achievements:**

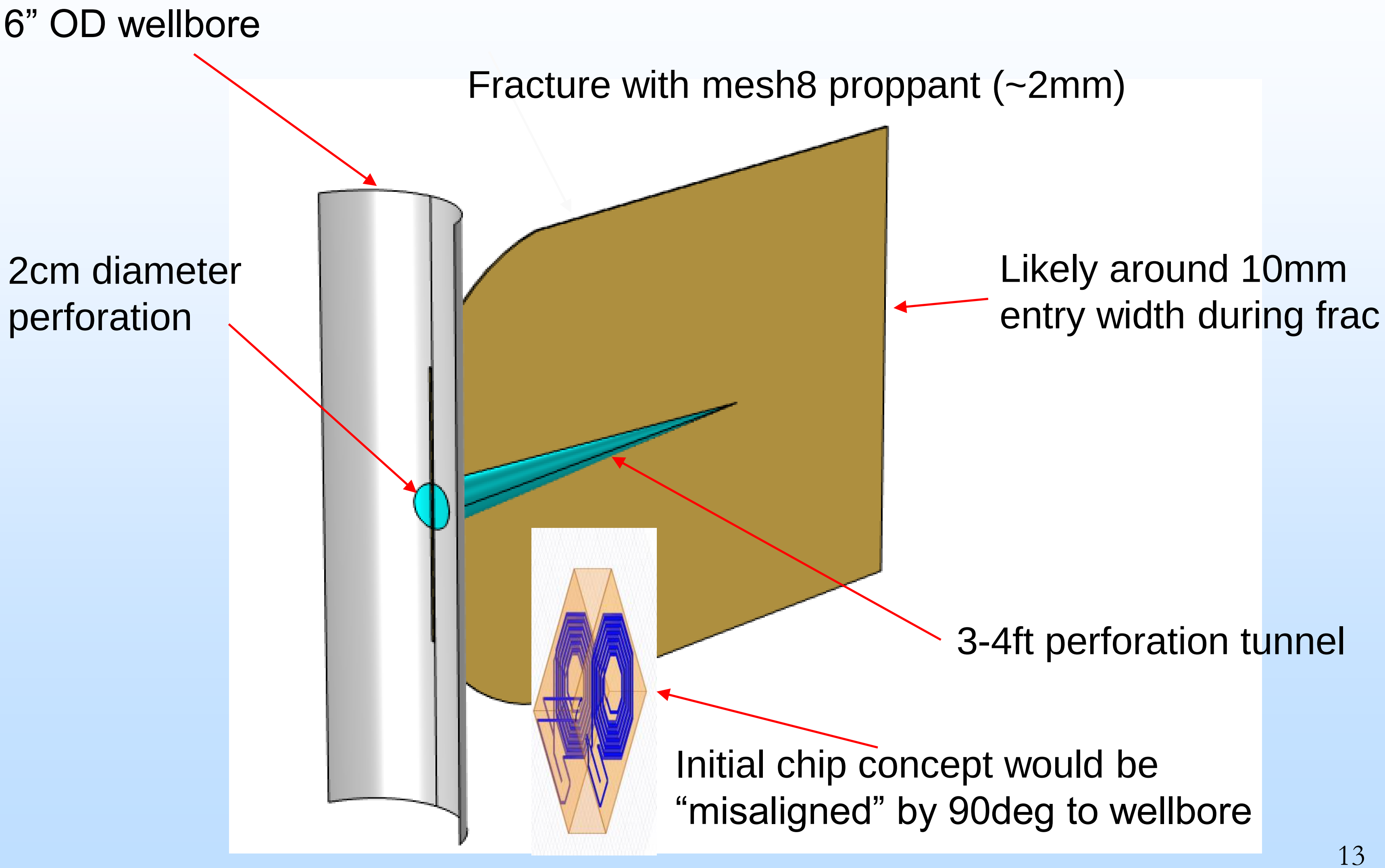
❖ Successful initial testing of the downhole tool in the lab environment:(SOPO Task 6.6)
  - Successfully power even the smallest Microchips
  - Continuous optimization to extend the range with those MicroChips.

❖ Downhole tool PCB electronics complete and software can record and download signals from the chips

❖ Final mechanical components waiting on completion confirmation from EOG (meeting in UCLA on April 10th)

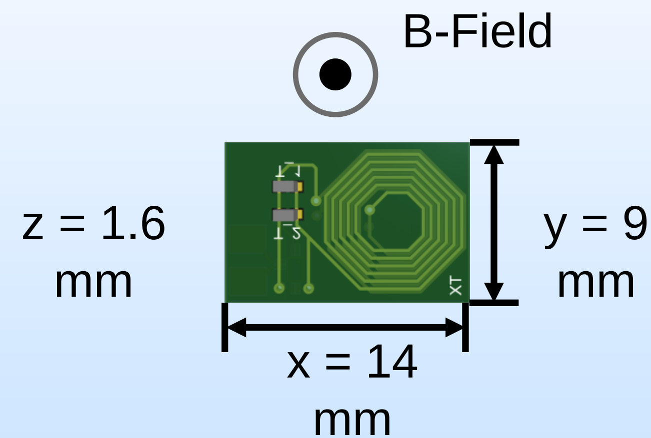
❖ iGeoSensing web-based platform development (SOPO Tasks 8 and 8.1)
  - Significant progress on developing a Smart, physics-informed iGeoSensing software application that enables real-time processing of MicroChips signals and any other fracture diagnostic tools under static, dynamic, and flow conditions.
  - Core algorithms implemented for the unsupervised module: dimensionality reduction, density-based clustering & surface reconstruction
  - Core algorithms implemented for the supervised module : Point Cloud transformation, Point Net, MLP
  - Core algorithms for the backend: image processing, sampling/combinatorics (discrete objects) techniques & Fracture Design Scripting
  - The backend is connected to the unsupervised & supervised

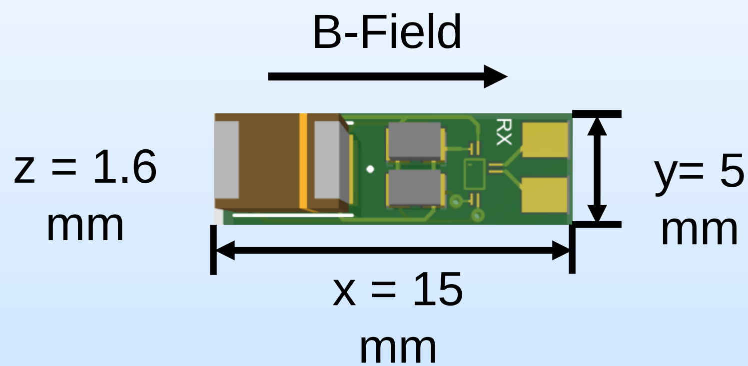
Progress and Current Status of Project

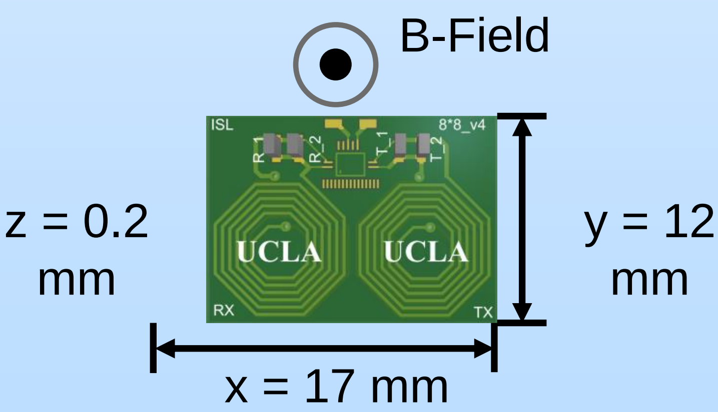


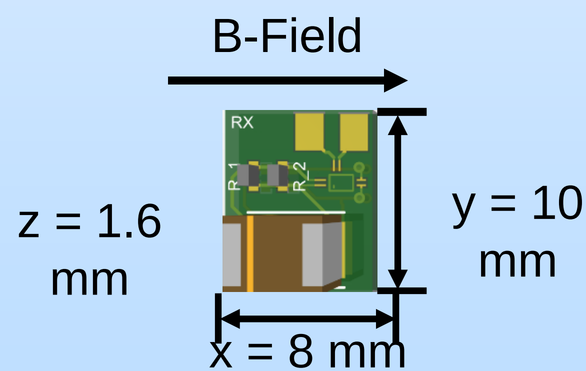
Progress and Current Status of Project

Several smart proppants with different geometries and properties have been implemented that can be activated with B-fields in different direction as required by application

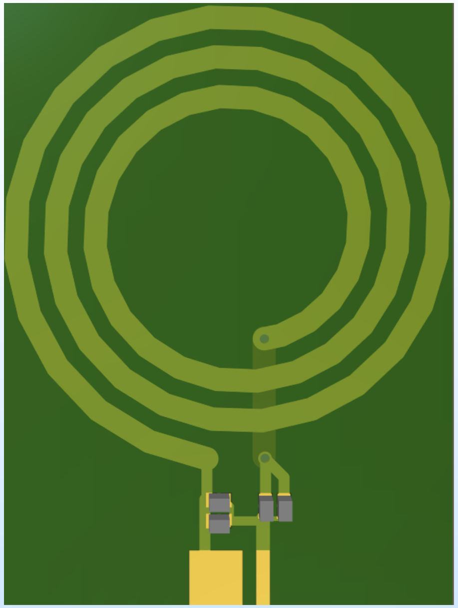


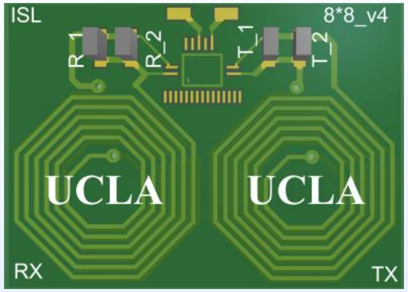


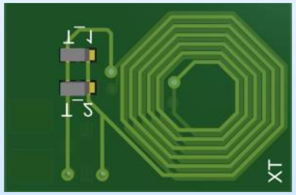




Progress and Current Status of Project

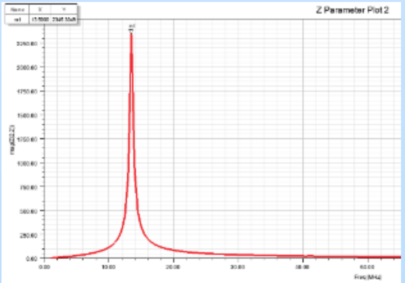


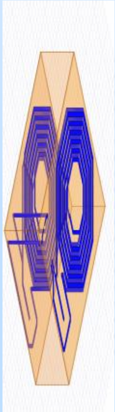




- 6-7 cm using 8 mm on-PCB coils and matched TX coil with 1W
- Downhole tool has 100W so significant powering distance can be anticipated.
- Except misalignment…

TX coil resonated at ~13.56 MHz





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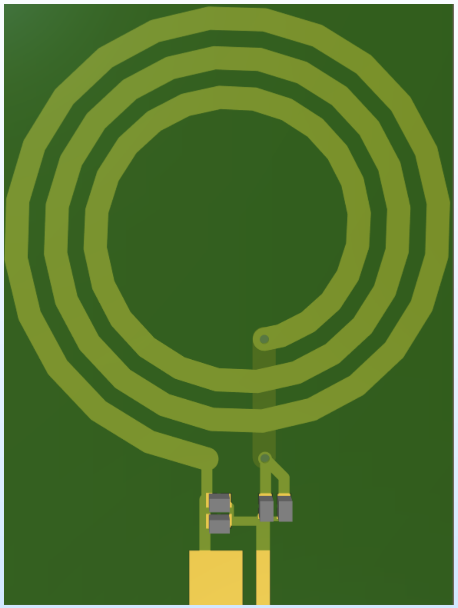
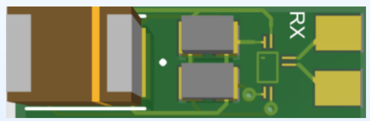


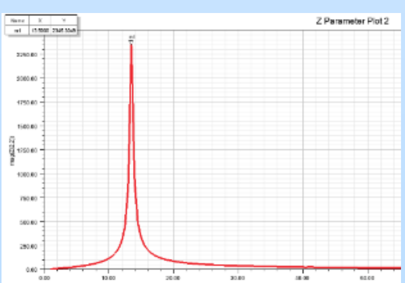


- 2-3 cm with SMD inductor and mismatched TX
- Downhole tool has 100W so significant powering distance can be anticipated.

✓ Misalignment issues solved

- We anticipate chip to orient itself to fracture plane as it is being pumped in and/or as the fracture pressure is released.
- Chips are designed to tolerate 10,000psi

TX coil resonated at ~13.56 MHz

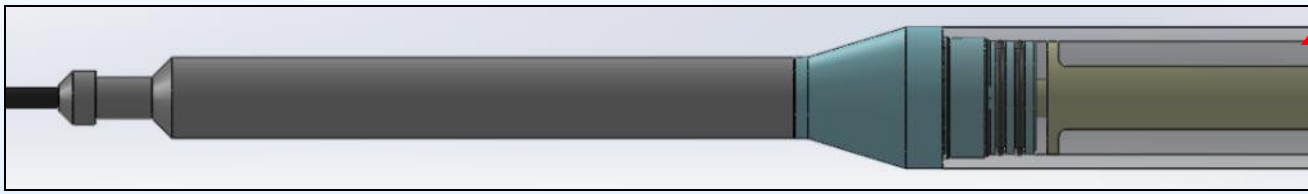


Progress and Current Status of Project

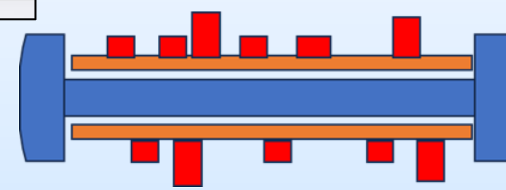
Head Assembly

Use commercial parts where available

Pressure housing

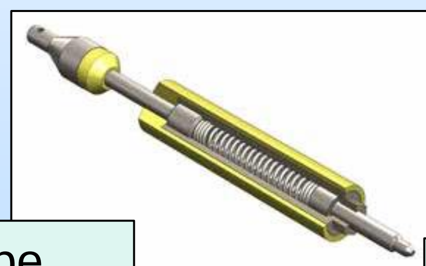


Chassis



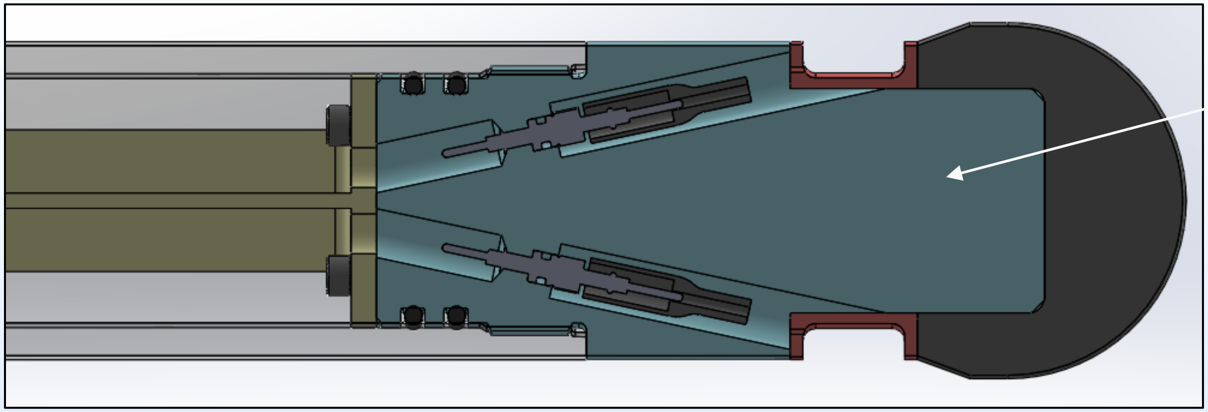
Transmitter and receiver systems will be either side of tool

Rope Socket Mechanical Connection to Cable

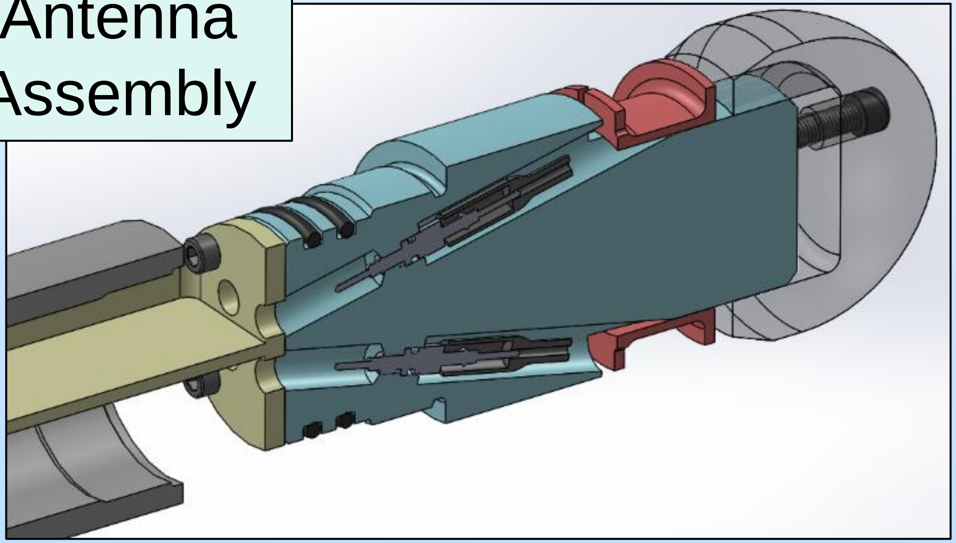


Spring Loaded Electrical Contact

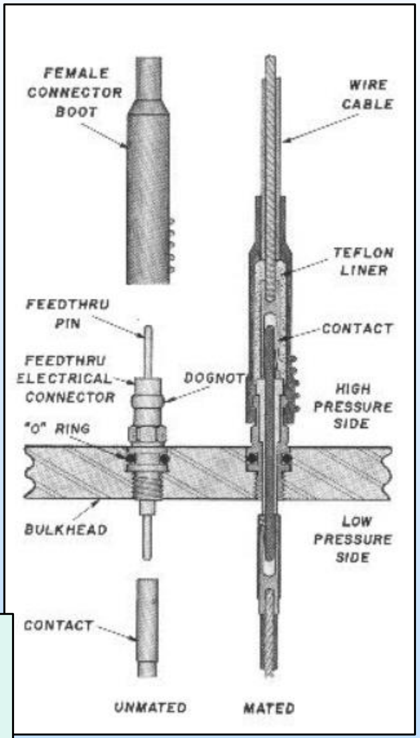
Progress and Current Status of Project



Flexibility to change antenna design



Antenna Assembly

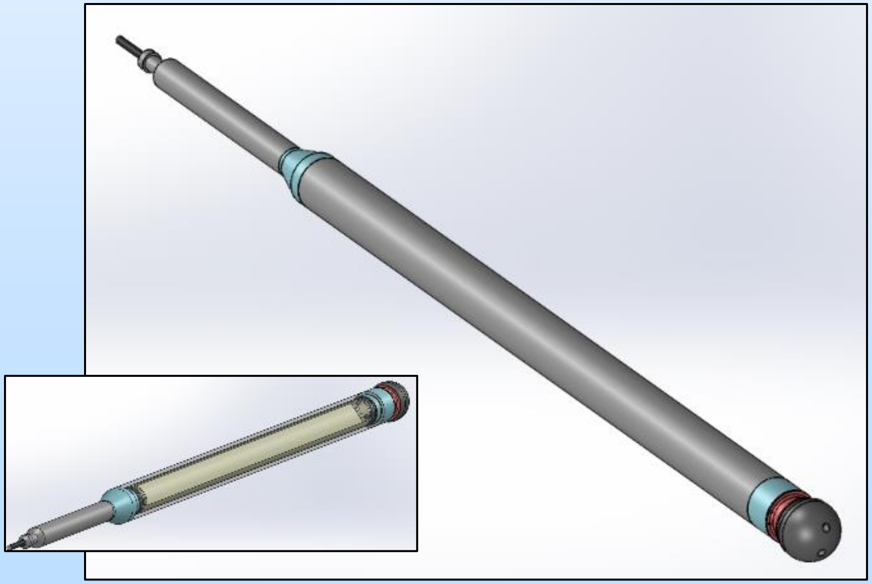


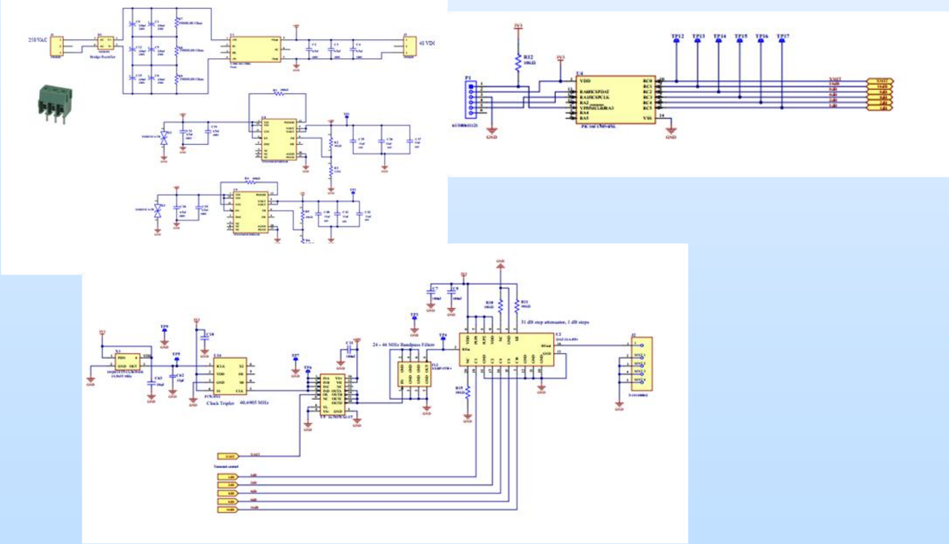
Kemlon Single Pin High Pressure Feedthrough

Progress and Current Status of Project

- **Build a downhole logging tool to power the Smart MicroChip Sensor (**SOPO Task 6.6)
  - Electronics complete as is first generation of software for controlling tool, recording data and downloading data at surface

Frac Tag Locator - Mechanical Packaging





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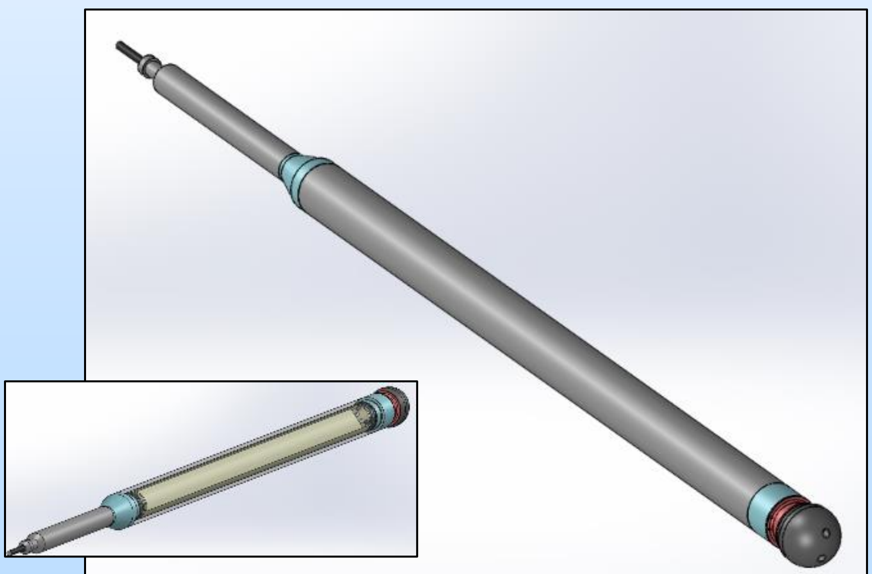

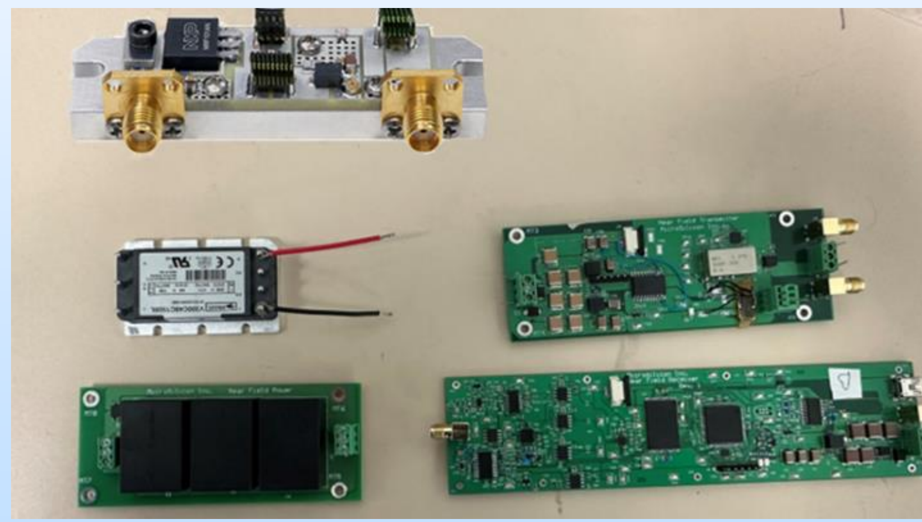

Progress and Current Status of Project

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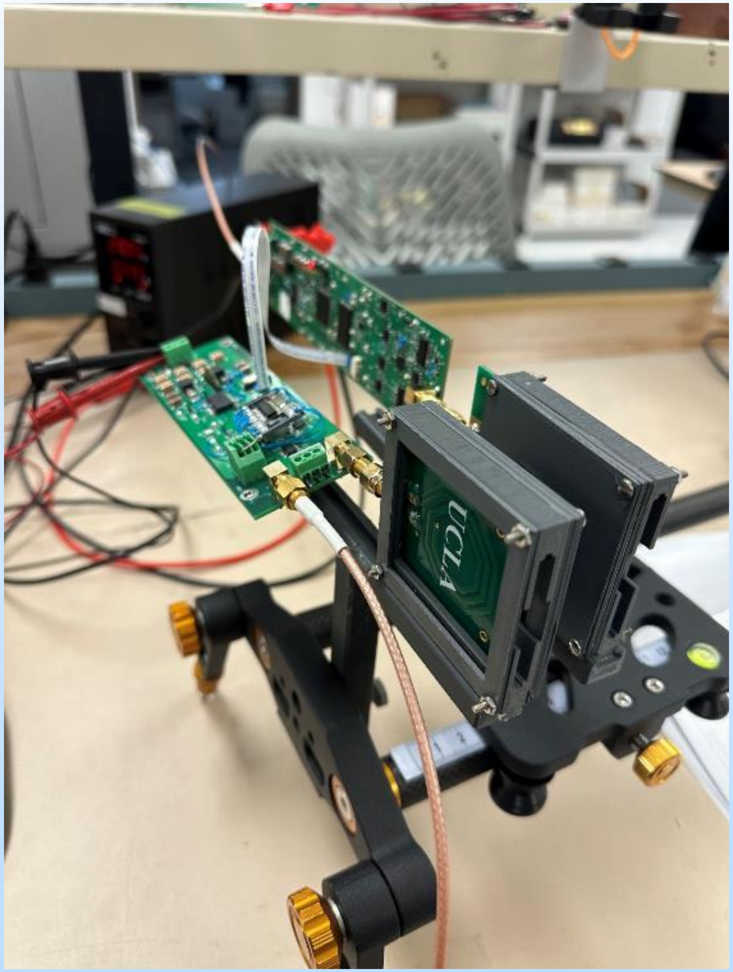
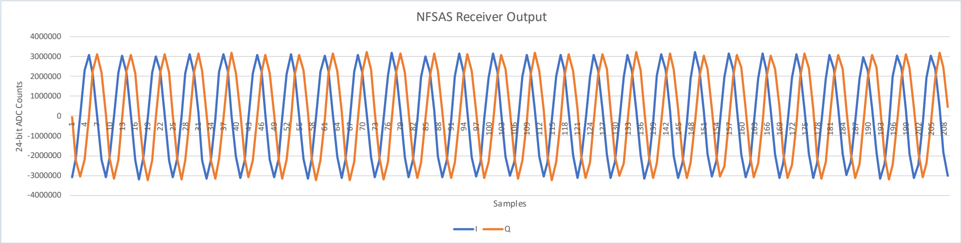


Circuitry fully compatible with the UCLA TX, RX and microchip topologies



FFT of this signal is stored as the data point for that tool position.
Surface software converts it into a distance and orientation from the tool.

Progress and Current Status of Project

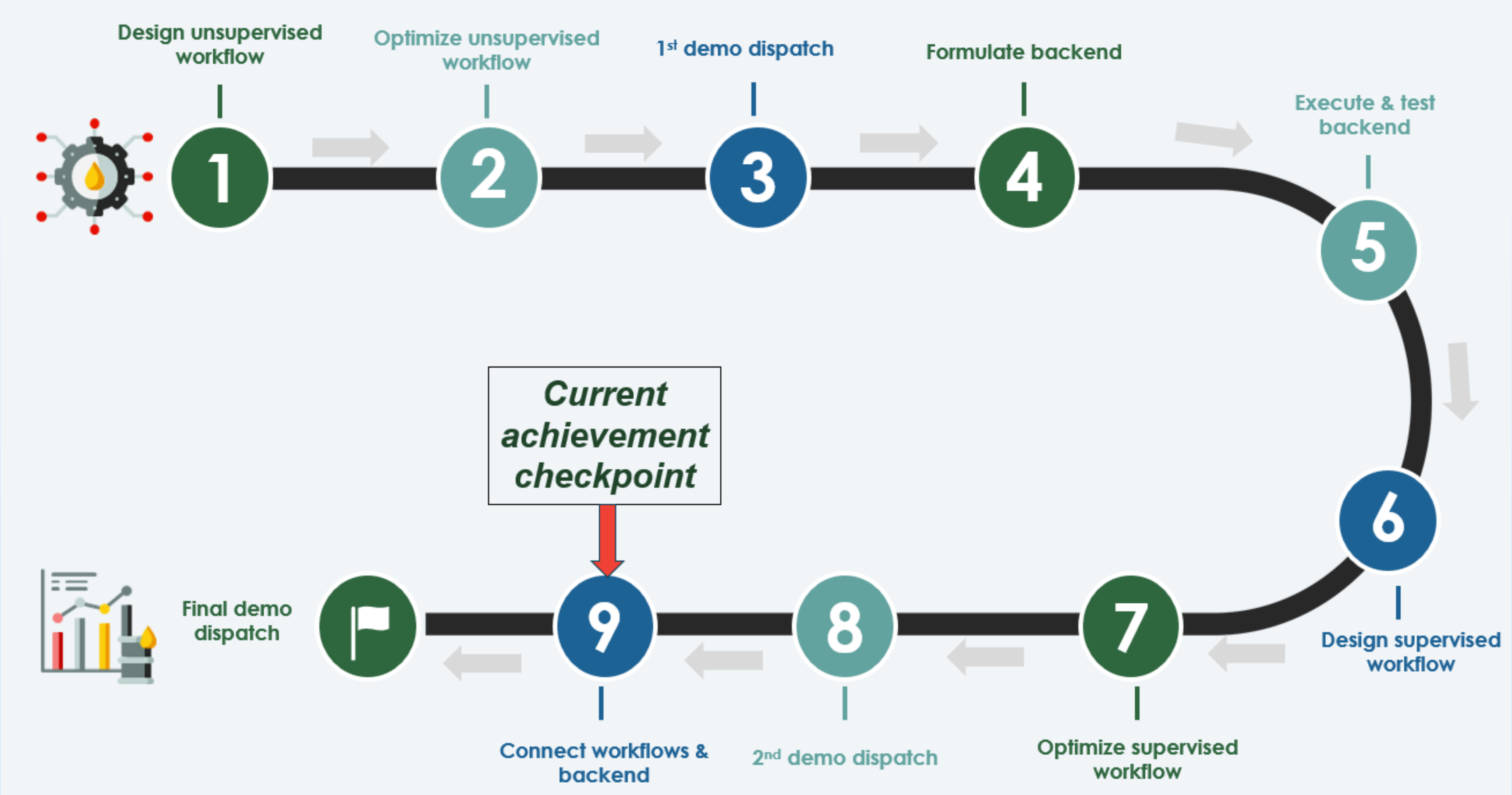
iGeoSensing Fracture Diagnostic Software Package Development (SOPO Task 8)

- ***Software:*** the iGeo Sensing platform to process the geolocation data from the SMPs (synthetic environment) in discrete-point data files:
  - ✓ Developed an unsupervised learning module to initiate possible fracture geometries
  - ✓ Estimate fracture aperture profiles along fracture height and half-length
  - ✓ Developed a supervised learning module to utilize *Recurrent Deep Learning,* fracture aperture profiles, flow-back/ production data for history matching, and correct the possible fracture geometries from the unsupervised module
  - ✓ Developed a backend engine to connect the unsupervised & supervised modules and integrate with commercial flow simulators (e.g., CMG/Res-Frac)
  - ✓ Built a “fracture geometry library” from the backend engine to assist in training & validation for the *Recurrent Deep Learning* inside the supervised module
  - ✓ Combined the unsupervised, supervised & back-end to dispatch the 2nd demo for a synthetic fracture network case study

Progress and Current Status of Project

iGeoSensing Fracture Diagnostic Software Package Development (SOPO Task 8)

- ***Software:*** the iGeoSensing platform



Progress and Current Status of Project

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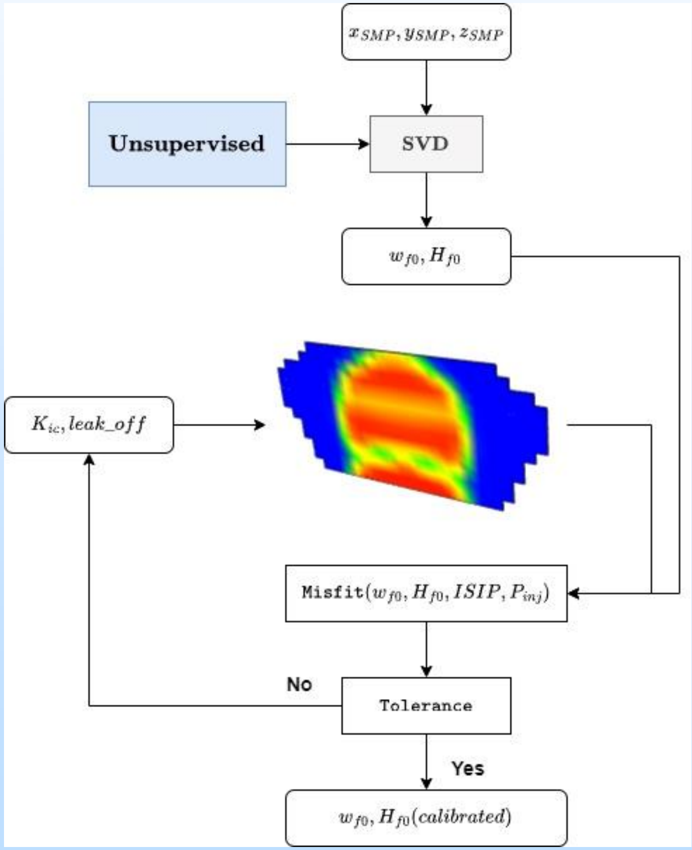

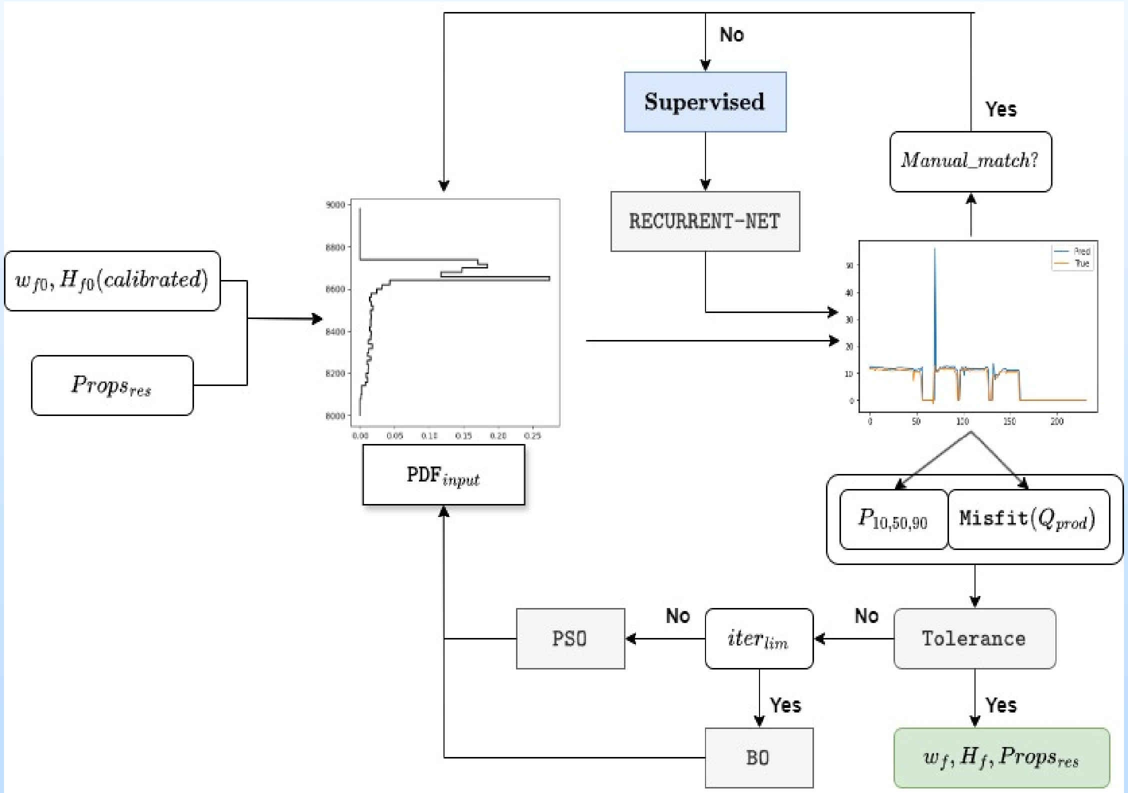

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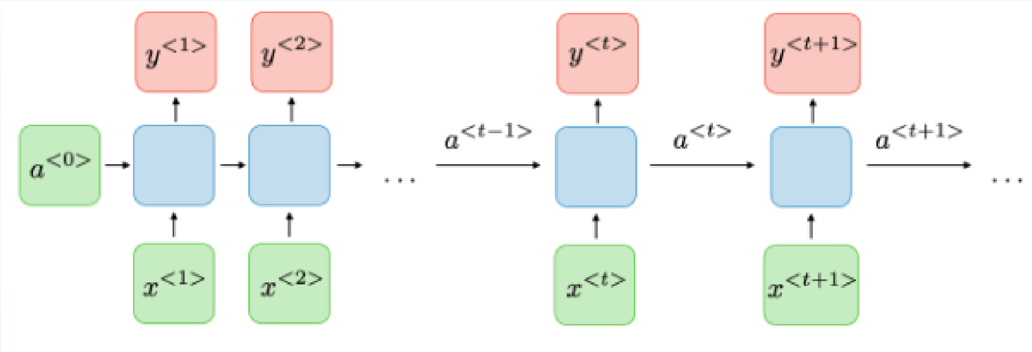
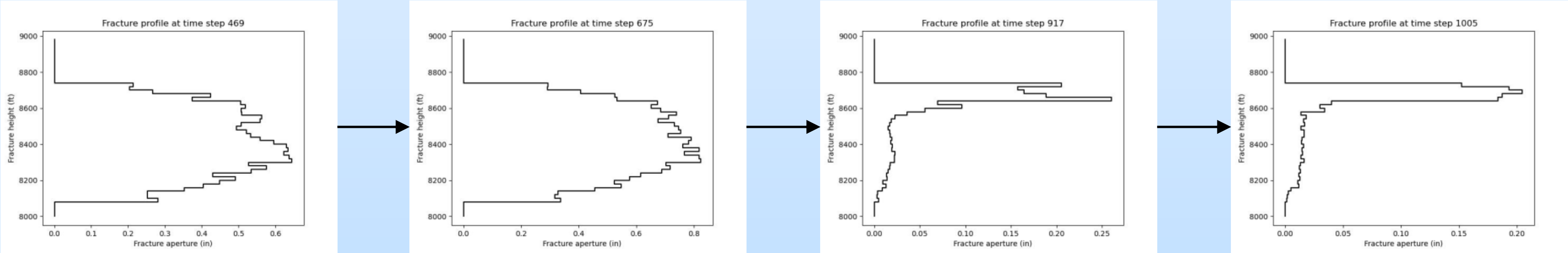




$x^{<1>}$ $x^{<2>}$ … $x^{<t>}$ $x^{<t+1>}$

The Recurrent Deep Learning conducts history matching & proxy development via changes in fracture profiles

Plans for future applications

❖ Transfer learning from the current MicroChips project, customize and further equip the Smart Microchips with chemical sensing capabilities, and upgrade the iGeoSensing package for Pipeline integrity and real-time sensing data processing and monitoring of CCUS and Hydrogen transport and storage.

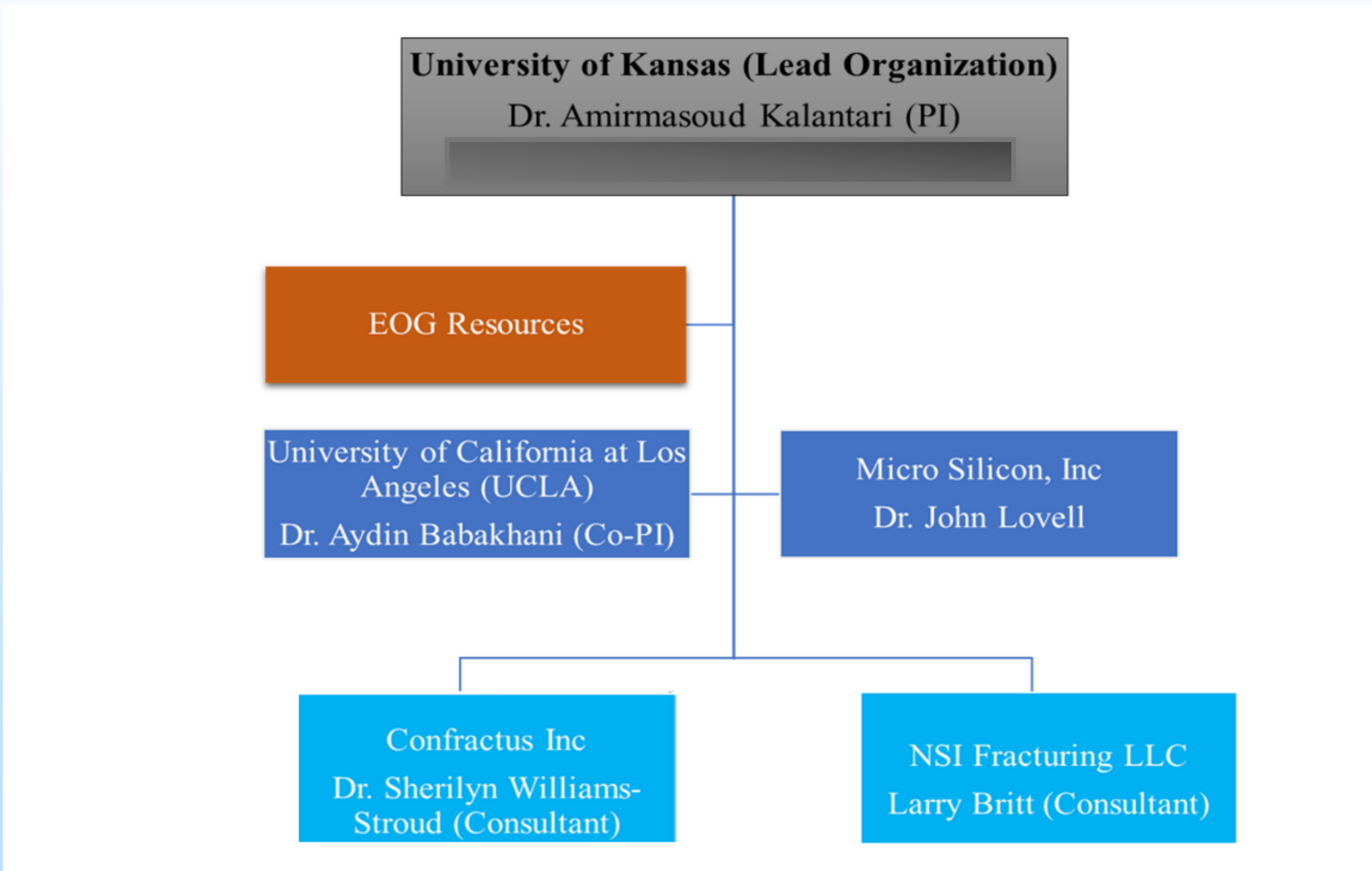
Potential Areas of Interest :

- ***Methane Mitigation Technologies***:
  - ✓ advance methane sensor technologies and development of pipeline data management and AI-empowered computational tools
- ***Natural Gas Decarbonization and Hydrogen Technologies***:
  - ✓ enabling safe and efficient transportation within the U.S. natural gas pipeline system
- **Chemical Sensing System and Carbon Management Technologies**:
  - *Hydrogen with Carbon Management*: Smart Sensors, Controls, and Novel Concepts, low-cost and reliable multi-sensing wired and wireless technologies, focusing on hydrogen and CCS activities.
  - Advanced sensors and monitoring systems that create data, and processing data streams that enable intelligent monitoring systems and AI-based technologies.

Outreach and Workforce Development Efforts or Achievements (If Applicable)

- Outcome of this research has been presented in multiple SPE, IEEE conferences.
- Workforce Development –
  - ✓ Training 6 Ph.D. students and research associate

Organization Chart



Gantt Chart

Budget Period 1 (Including NCE): Q5, Q6, Q7, Q8 | Budget Period 2 (Including NCE): Q11, Q12, Q13, Q14 | Budget Period 3 (Including NCE): Q17, Q18, Q 19, Q20

Task Title	Start Date	End Date
Task 1: Project Management and Planning	Q1	Q16
Task 2.0: Workforce Readiness for Technology Deployment	Q1	Q16
Task 3.0: Data Management Plan	Q1	Q16
Decision Point		
Task 4.1: Field Laboratory (Science Well) Site Selection and Static data collection	Q1	Q5
Task 4.2: Field Laboratory –Dynamic Data collection	Q14	Q16
Task5 Preliminary & basic core work	Q5	Q7
Task 5 Detailed Rock Mechanics Testing	Q5	Q8
Subtask 5 Additional project testing (Fluid sensitivity and Un-propped crack tests)	Q9	Q11
Subtask 5.8 Smart Proppant Transport tests in Lab	Q13	Q14
Subtask 6.1: Build and calibrate novel smart MicroChip proppant sensors	Q1	Q14
Subtask 6.2. Constructing multiple synthetic fracture network models and building synthetic cores using 3D printing technology	Q2	Q8
Subtask 6.3: Test the imaging capability of MicroChip proppants with 3D printed synthetic cores	Q7	Q13
Subtask 6.4: Test the MicroChip proppants in a high pressure and temperature lab environment.	Q10	Q14
Subtask 6.6: Build downhole logging tool to power the Microchips and assimilate their data.	Q1	Q16
Subtask 6.7: Inject the MicroChip proppants into the formation (small-scale frac job) and validate survival of the chips.	Q13	Q18
Subtask 6.8: Interpret and map the received data from the MicroChips - iGeoSensing Package	Q13	Q18
Task 7.0: Integration of near wellbore (microchip) and the other diagnostic tools through machine learning techniques	Q13	Q18
Task 8.0: Development of state-of-the-art integrated machine earning, analytical and numerical predictive fracture and flow models	Q12	Q18
Subtask 8.2: Develop extremely fine resolution fracture and flow simulation and machine learning model	Q12	Q18
Subtask 8.3: Develop new diagnostic plots and enhance analytical solutions/ type curves	Q12	Q18
Report and presentation	Q1	Q18

Field Trial: July-August 2024