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

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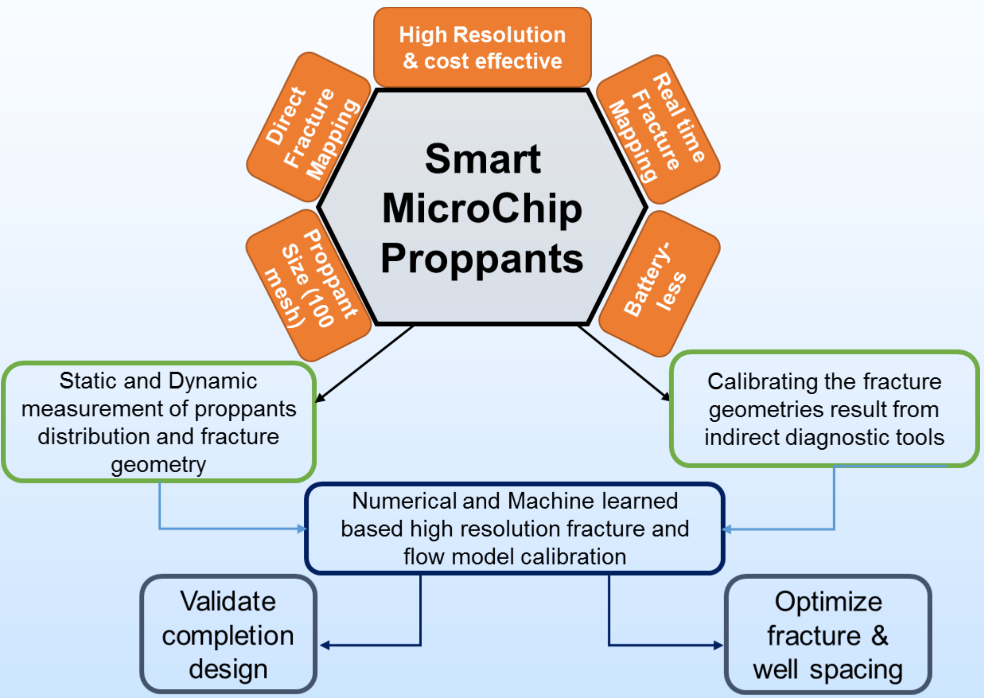
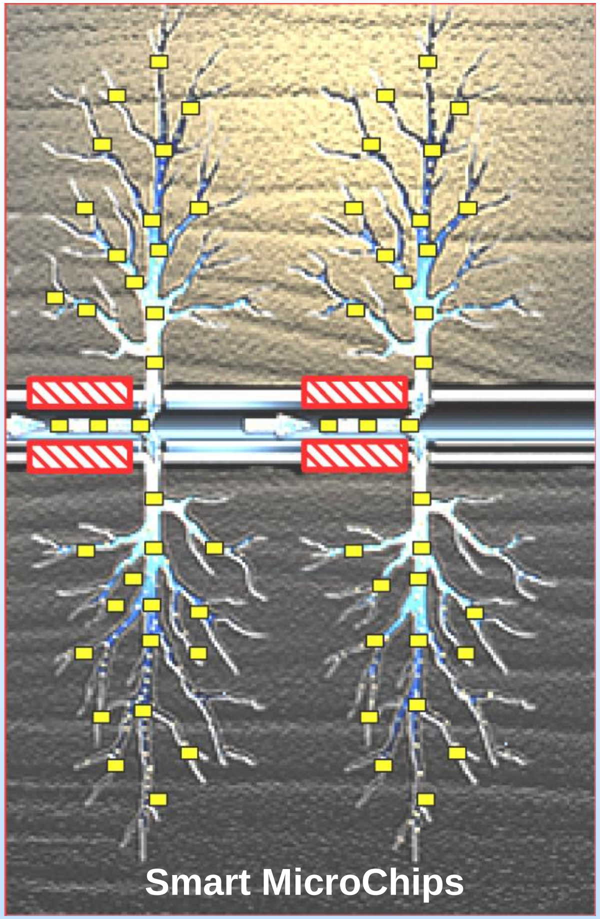
2020 Integrated Review Webinar

Program Overview

– Funding
  • (DOE:$2.49M and Cost Share:$1M)
– Overall Project Performance Dates:
  • October 2019-September 2023
– Project Participants
  • University of Kansas(Lead institution), UCLA, MicroSilicon Inc., NSI Fracturing Inc., Confractus Inc, NITEC and EOG Resources
– 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.

Technology Background





Pilot Location:
Permian Basin, Yeso Field, Paddock Reservoir, NM
Cored interval 2594-2600 (6ft)

Technology Background

- The proposed technology responds to the current limited understanding of the near wellbore fracture properties understanding.
- Smart MicroChip proppants map the geometry of a fracture network with a resolution of less than 1 ft.
- A downhole tool will be built to inject electromagnetic energy through the perforations.
- The sensor harvests energy from these electromagnetic waves activates an on-chip radio to communicate back with the down-hole tool.
- MicroChips change the frequency of the received signal and respond back in a different band.

Technology Background

- This frequency-shift technology enables the down-hole tool to separate the strong reflection caused by the reservoir from the signals generated by the MicroChips.
- Based on the preliminary studies, the custom down-hole tool will communicate with the MicroChips in the frequency range from 3MHz to 100MHz.
- The exact choice of frequency depends on the resistivity of the reservoir.
- In a highly resistive reservoir (resistivity of 1000 ohm.m or larger), higher frequencies (above 50MHz) can be used to enhance the resolution of the images.
- In addition to powering the sensors, a separate transmitters may be needed to create a background magnetic field that will act as a beacon for the Microchips to geolocate.

Technology Background

Technology Impact:

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

Targets

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

Technology Background

Technical Challenges:

- to miniaturize the smart microchip proppants to 100 mesh.
  - risk mitigation strategy:
    - ✓ use 180 nm CMOS technology to build the smart proppants. If we can't fit the entire electronic components in 100 mesh using 180 nm CMOS process, we will use smaller CMOS nodes such as 22 nm or 16 nm to reduce the size of the active components (transistors) by a factor of larger than 10.
- Antenna size (or on-chip inductor) used to harvest electromagnetic energy.
  - risk mitigation strategy:
    - ✓ ultrathin and flexible antennas such as nanowires. In this case, the core of the active circuitry will be integrated and fit within 100 mesh

Technical Approach/Project Scope

Experimental 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 Sensor and assimilate their data
  - ✓ perform basic and comprehensive rock mechanical tests
  - ✓ conduct two fluid sensitivity testing-pH& Potassium Chloride (KCl) tests
  - ✓ determine the reduction of particle size due to mechanical attrition and reaction of shale particles with the reacting fluids
  - ✓ Field Laboratory testing

Technical Approach/Project Scope

Experimental design and work plan:

- computational components:
  - ✓ interpret and map the received data from the "Virtual" Smart MicroChip Sensor by developing a new stochastic algorithm to process discrete points
  - real-time fracture mapping
  - proppant transport modeling
  - flow back and production history matching by coupling numerical and machine-learned models.

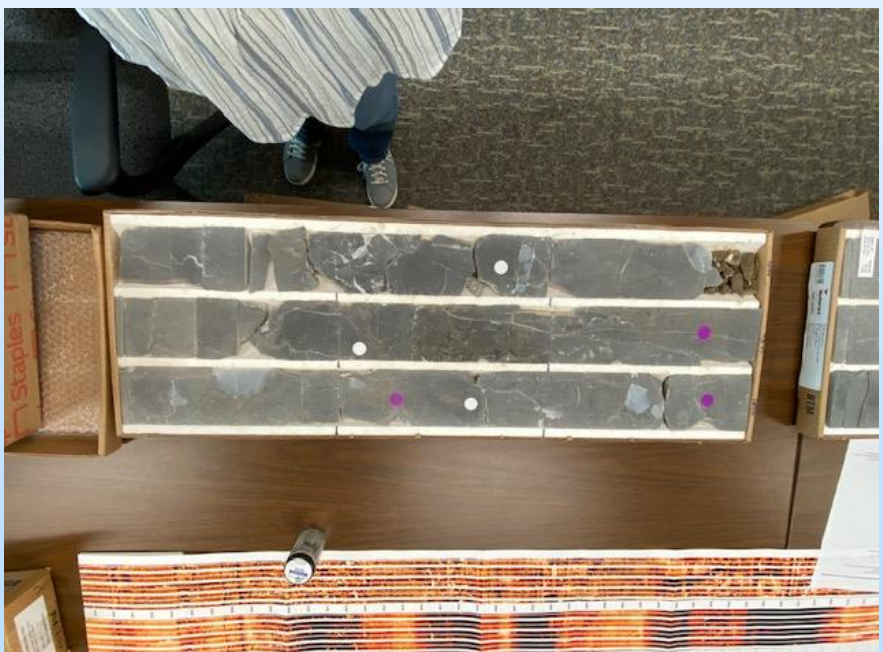
Technical Approach/Project Scope

Project schedule –key milestones

Task/ Subtask	Milestone Title/ Description	Planned Completion Date
1.2	Project Kickoff Meeting Held	10/28/2019
4	Field Laboratory (Science Well) Site Selection	Q5
5	Detailed Rock/Fluid experiments and Rock Mechanics testing	Q11
6.1 and 6.5	Build and calibrate novel Smart MicroChip Sensor	Q12
6.2 and 6.3	3D printed Synthetic core design to test imaging capability of Smart MicroChip Sensor	Q7
6.4	Test the Smart MicroChip Sensor in a high pressure and temperature lab environment.	Q11
6.6	Build a downhole logging tool to power the Smart MicroChip Sensor and assimilate their data.	Q14
6.7	Report the results of injecting the Smart MicroChip Sensor into the formation (small-scale frac job) and validate the survival of the chips.	Q16
6.8	Interpret and map the received data from the Smart MicroChip Sensor	Q16
8.1 and 8.2	Development of state-of-the-art predictive fracture and flow models	Q16

Progress and Current Status of Project

- **Field Laboratory (Science Well) Site Selection**
  - ✓ We worked with EOG resources to identify multiple locations for the field pilot testing.
  - ✓ Permian Basin, Yeso Field, Paddock Reservoir, NM is selected for field trial
  - ✓ 6ft of core and logs were obtained from the pilot well (Boyd XState)



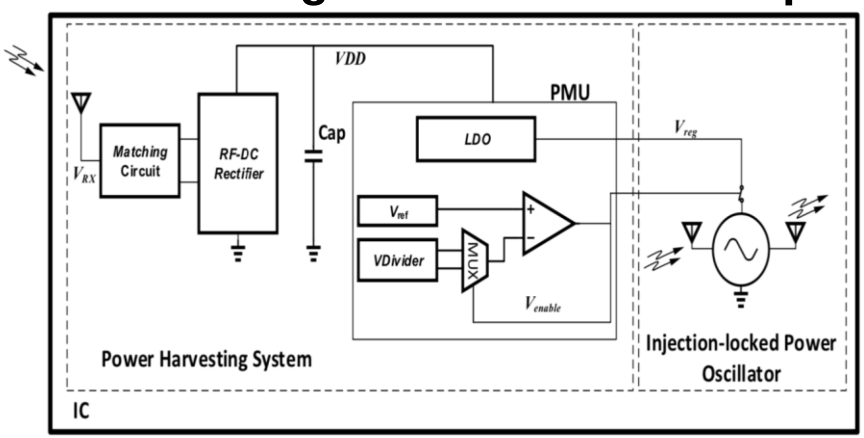
Progress and Current Status of Project

- **Build and calibrate novel Smart MicroChip Sensor**
  - ✓ demonstrated successful Coherent Radiation from a Swarm of Chips operating in GHz range
  - ✓ designed a 40MHz wirelessly powered tag to increase the depth of penetration
  - ✓ measuring the electromagnetic properties of the EOG's pilot well cores

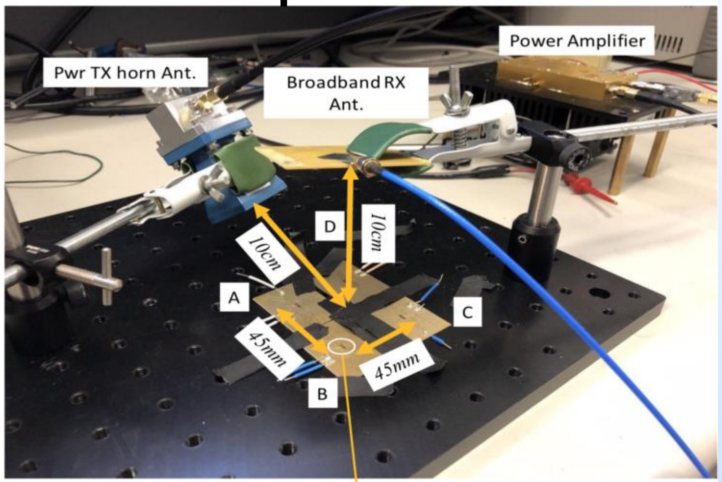
Progress and Current Status of Project

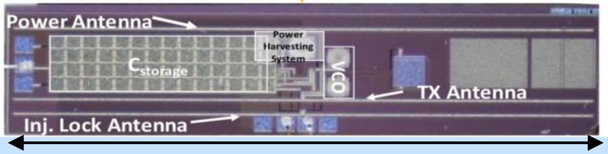
- **Build and calibrate novel Smart MicroChip Sensor**
  - ✓ **Coherent Radiation from a Swarm of Chips**

Block diagram of the initial chip



Benchtop Measurement





0.7mm

3.9mm

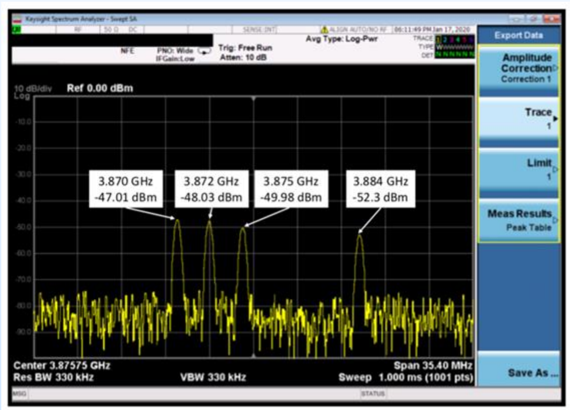
Chip Micrograp

- A new technique is developed to synchronize a swarm of sensor nodes at the RF domain and produce coherent radiation from the sensor nodes to increase the amplitude of the reflected signal.
- A network is formed by an array of microchips that are wirelessly powered, and upon activation, radiate back an RF signal.

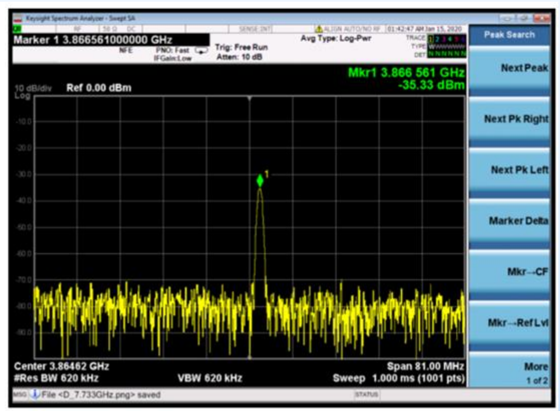
Progress and Current Status of Project

- **Build and calibrate novel Smart MicroChip Sensor**
  - ✓ **Experimental Results on Coherent Radiation**

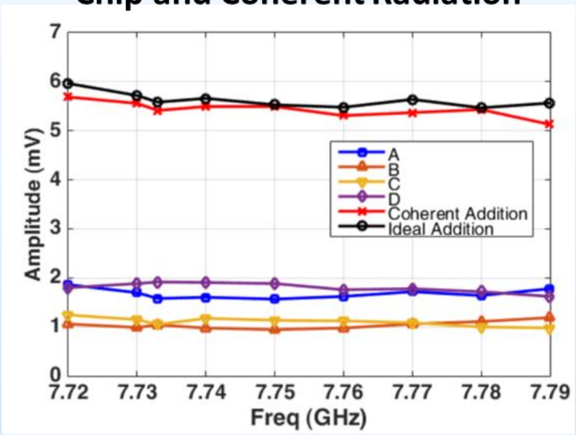
Four Chips Radiate Incoherently



Coherent Radiation Boosts the Signal Radiated by Microchips



Comparison between Individual Chip and Coherent Radiation



- When all chips are synchronized and radiated coherently, the signal radiated by the swarm of chips become strong. In theory, N chips increase the radiated signal by N^2.
- More details provided in this reference:

H. Rahmani, Y. Sun, M. Kherwa, S. Pal and A. Babakhani, "Coherent Radiation From a Swarm of Wirelessly Powered and Synchronized Sensor Nodes," in *IEEE Sensors Journal*, vol. 20, no. 19, pp. 11608-11616, 1 Oct.1, 2020, doi: 10.1109/JSEN.2020.2996571.

Progress and Current Status of Project

- **Build and calibrate novel Smart MicroChip Sensor**
  - ✓ **Status of 40MHz Wirelessly-Powered Chips**
    - We are designing a new RFID chip that harvests energy around 40MHz and radiate back at 13MHz.
    - This unique frequency separations allows the downhole tool to send a large power at 40MHz while listening to a weak signal radiated from the chips at 13MHz.
    - The design of this chip is finalized and being sent for fabrication.
    - We already tested RFID chips that successfully harvest energy at 40MHz but they don’t yet have a 13MHz transmitter to radiate back. The 13MHz transmitter will be included in the next version of the chip.
    - Picture of a proof-of-concept RFID operating at 40MHz is shown below. The current dimensions of the PCB is 3mm by 17mm. We are reducing the dimensions to around 3mm x 3mm.

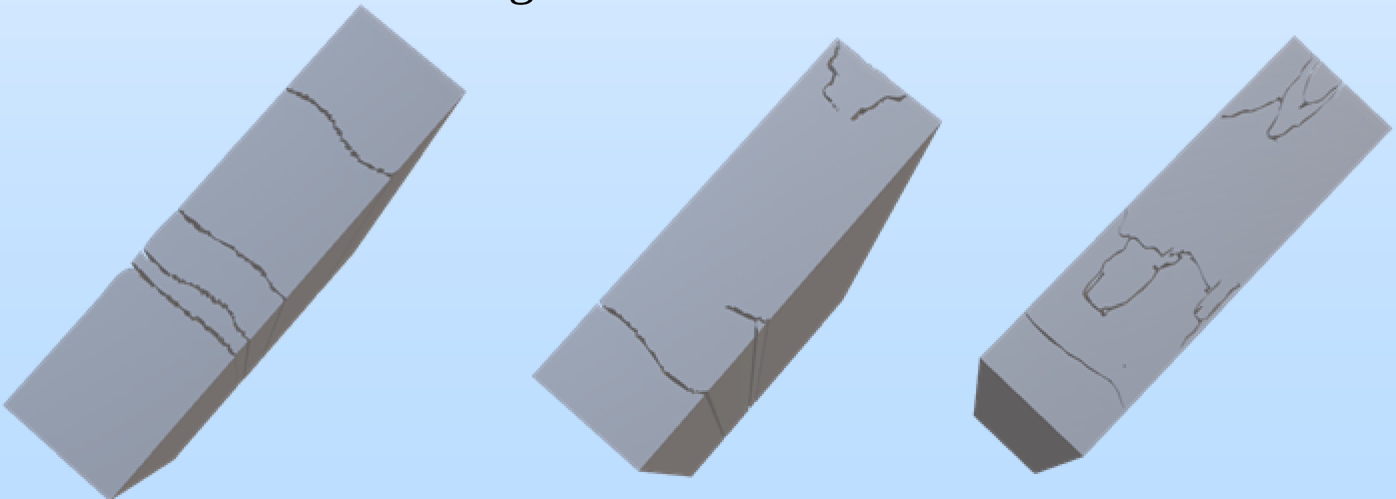
Progress and Current Status of Project

- **Build a downhole logging tool to power the Smart MicroChip Sensor**
  - Identify main components required to power chips deployed into a reservoir and receive signal from them
  - we have begun a COMSOL design with incoming transmission line
  - a Python numerical code is developed to rapidly solve Maxwell’s equations of the EM fields. This will enable the project team to essentially convert from the hundreds of voltages leaving the tool to the millivolts that will be picked up by the chips.

Progress and Current Status of Project

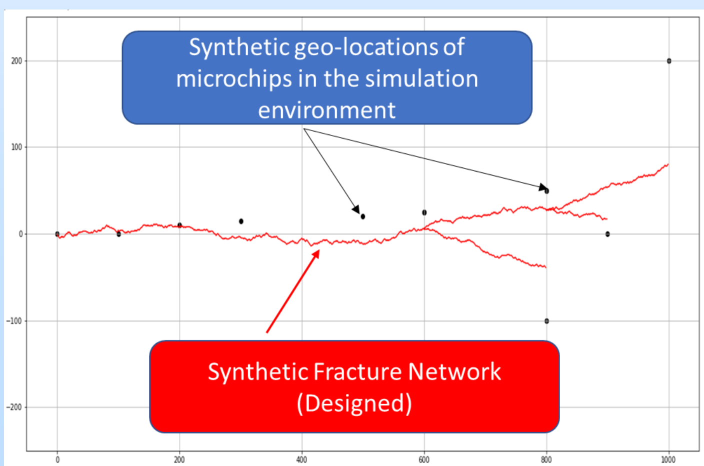
- **Construct synthetic cores with different levels of fracture complexity for testing Microchips**

  - detached irrelevant details from the main fracture network bodies from hydraulically fractured core samples' images
  - reconstructed the skeleton of fracture networks (i.e. "base" fracture networks) from hydraulically fractured core samples' images
  - modified the fracture aperture to generate different fracture networks using base fracture networks
  - add dimensions to all generated fracture networks in both 2D and 3D spaces.

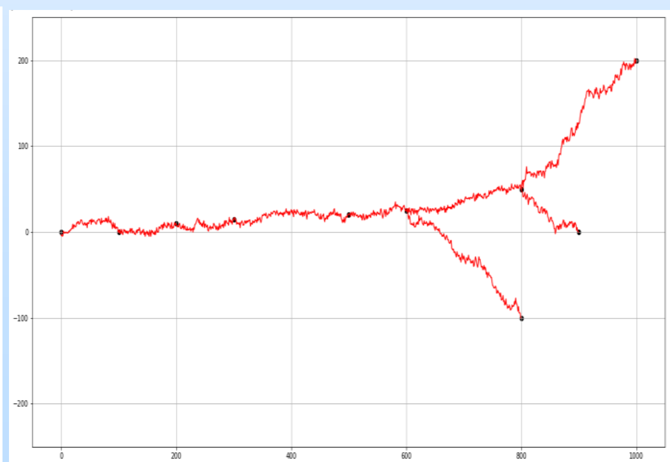


Progress and Current Status of Project

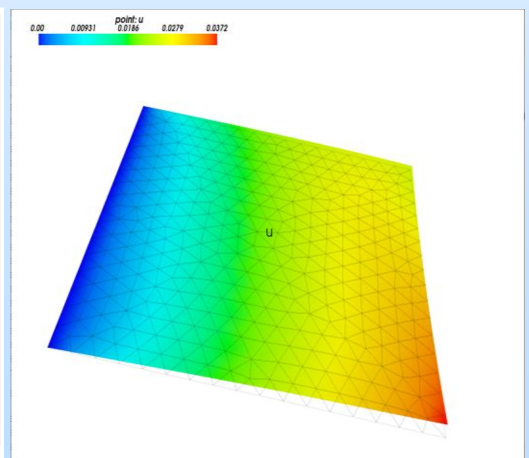
- **Interpret and map the received data from the “Virtual” Smart MicroChip Sensor**
- a new stochastic algorithm to process discrete points, which are geo-locations of microchips in the simulation environment and generates multiple realizations of fracture geometry
  - ✓ implemented a random walk algorithm in 1D, 2D.
  - ✓ developed an “Enhanced” random walk algorithm to satisfy the fracture mapping task.
  - ✓ working on coupling the new “Enhanced” random walk algorithm and fracture mechanics



Random walk with fixed parameters



Enhanced random walk



Automatic meshing

Plans for future testing/development/ commercialization

- In this project, once the Smart MicroChips proppant tested in the lab, we go for the field trial.
- The developed smart Microchips are expected to interface with existing indirect hydraulic fracturing diagnostics to improve understanding of hydraulic fracture geometry.
- It helps the operators to maximize the return from their unconventional reservoir operation.
- It also helps to reduce the environmental footprints and will help in better designing the EOR system for unconventional reservoirs.
- Additionally, regulation agencies can benefit from using this technology to monitor and consequently minimize HF operation issues.
- A low-cost approach and partnership with EOG will aid in transitioning technology to commercial deployment if successful.
- The technology can be further tested in other DOE-sponsored Science wells as well as oil and gas operators' core assets.
- This technology can be further developed to measure pressure and detect phases

Summary Slide

- the Pilot location has been identified.
- 6 ft of the core are obtained and are being used for laboratory testing
- Demonstrated successful Coherent Radiation from a Swarm of Chips operating in GHz range
- Designed a 40MHz wirelessly powered tag to increase the depth of penetration
- Design of synthetic core with different levels of fracture complexities are completed and are ready for 3D printing
- A new stochastic algorithm to process discrete points, which are geo-locations of microchips in the simulation environment is developed.
- The new "Enhanced" random walk algorithm will be coupled with the and fracture mechanics
- We continue working on Smart Microchips and downhole tool development.
- A series of fluid and geomechanical testing will be conducted.

Organization Chart

Gantt Chart

Task Title	Start Date	End Date
Task 1: Project Management and Planning	10/1/2019	9/30/2022
Task 2.0: Workforce Readiness for Technology Deployment	10/1/2019	9/30/2022
Task 3.0: Data Management Plan	10/1/2019	9/30/2022
Go/No-Go Evaluation	10/1/2019	4/30/2022
Task 4: Field Laboratory (Science Well) Site Selection and Data Acquisitions Plan	10/1/2019	8/30/2022
Subtask 4.3.1: Pilot well data collection	10/2/2019	8/30/2022
Subtask 4.3.2: Near wellbore hydraulic fracture diagnostic tests data collection	9/1/2021	8/30/2022
Subtask 4.3.3: Far-field hydraulic fracture diagnostic data collection	2/1/2022	5/30/2022
Subtask 5.1 to 5.4 Detailed Micro Scale Rock/Fluid experiments	6/1/2020	9/30/2020
Subtask 5.5 Preliminary & basic core work	2/1/2020	4/30/2020
Subtask 5.6 Rock Mechanics Testing	4/1/2020	12/30/2020
Subtask 5.7 Additional project testing (Fluid sensitivity and Un-propped crack tests)	12/1/2020	5/30/2021
Subtask 5.8 Smart Proppant Transport tests in Lab	6/1/2021	9/1/2021
Subtask 6.1: Build and calibrate novel smart MicroChip proppant sensors	11/1/2019	9/30/2021
Subtask 6.2. Constructing multiple synthetic fracture network models and building synthetic cores using 3D printing technology	1/1/2020	10/30/2020
Subtask 6.3: Test the imaging capability of MicroChip proppants with 3D printed synthetic cores	10/1/2020	2/28/2021
Subtask 6.4: Test the MicroChip proppants in a high pressure and temperature lab environment.	4/30/2021	9/30/2021
Subtask 6.5: Develop downhole beacon technology	11/1/2019	4/30/2021
Subtask 6.6: Build downhole logging tool to power the Microchips and assimilate their data.	10/1/2019	2/1/2022
Subtask 6.7: Inject the MicroChip proppants into the formation (small-scale frac job) and validate survival of the chips.	9/1/2021	8/30/2022
Subtask 6.8: Interpret and map the received data from the MicroChips	9/1/2021	8/30/2022
Task 7.0: Integration of near wellbore (microchip) and the other diagnostic tools through machine learning techniques	9/1/2021	8/30/2022
Task 8.0: Development of state-of-the-art integrated machine earning, analytical and numerical predictive fracture and flow models	6/1/2021	8/30/2022
Subtask 8.1: Construct a high-resolution base geological, petrophysical and geomechanical models	10/1/2021	8/30/2022
Subtask 8.2: Develop extremely fine resolution fracture and flow simulation and machine learning model	2/1/2020	8/30/2022
Subtask 8.3: Develop new diagnostic plots and enhance analytical solutions/ type curves	9/1/2021	8/30/2022
Report and presentation	10/1/2019	9/30/2022