Presented at the COMSOL Conference 2009 Boston

Designing a Current Injection Tool for Logging While Drilling

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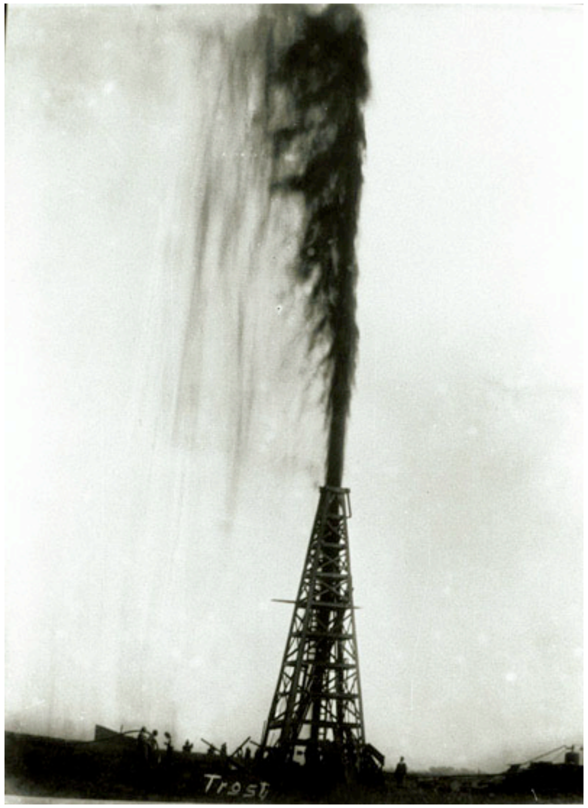
Motivation



Spindletop discovery well in Beaumont Texas, 1901. Photo courtesy of Texas Energy Museum.

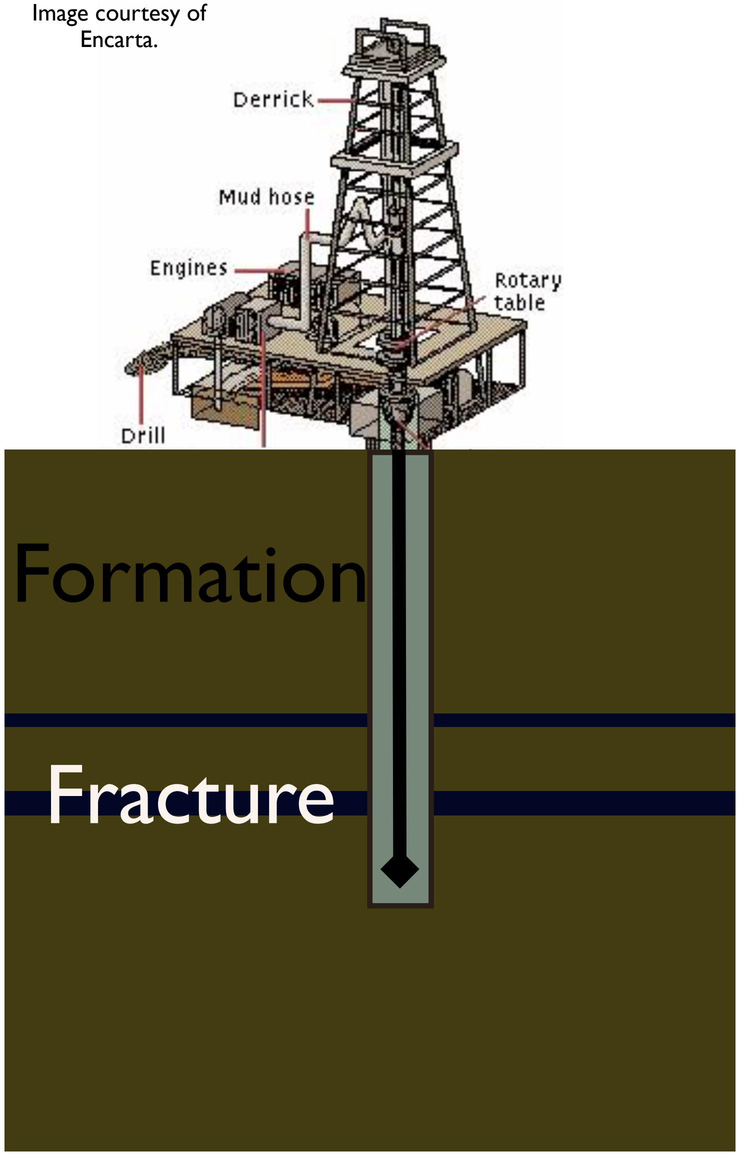
- Worldwide 84 million barrels of oil are consumed each day.
- Besides energy, oil is needed for
  - Plastics.
  - Textiles.
  - Pharmaceuticals.
  - Inks, dyes & paints.
  - Fertilizers
- Finding oil is becoming more difficult.
- More sophisticated techniques are needed to identify deposits.

Review of Oil Field Terminology

- ***Formation*** **-** generic term used to describe a layer of rock.
- ***Borehole*** **-** the hole created during the drilling process.
- ***Mandrel*** - the pipe used to drill the hole.
  - Drill bit, sensors, and communication devices are mounted to the mandrel.
- ***Logging*** - measuring the properties of the formations at various depths.
- ***Logging while drilling (LWD)*** - Logging at the same time as drilling the hole.
- ***Fracture*** **-** a crack in the formation where oil or gas may be found.

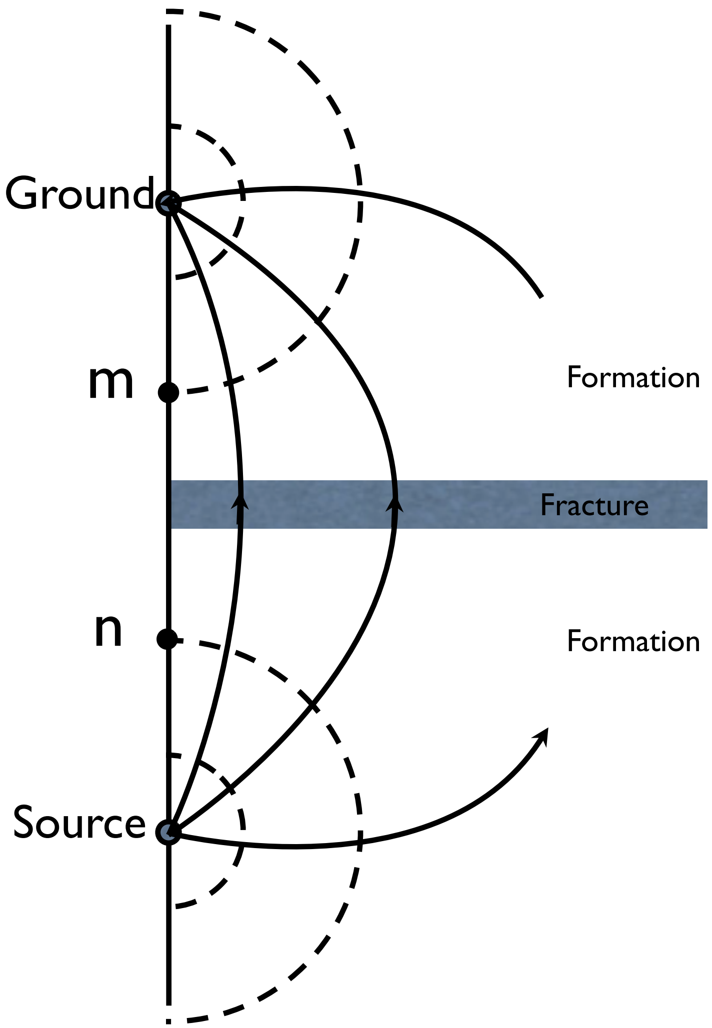
Many oil & gas deposits are associated with thin (mm) fractures

Image courtesy of Encarta.



- It is difficult to locate thin layers from the surface.
- Logging can be done after drilling, but…
  - It is time consuming.
  - Don't know when to stop drilling.
- Logging while drilling (LWD).
  - Place sensor behind drill bit.
- Sensor must be able to resolve thin fractures.

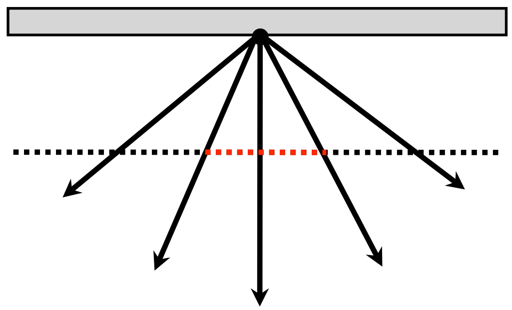
Injecting current into the formation to find fractures



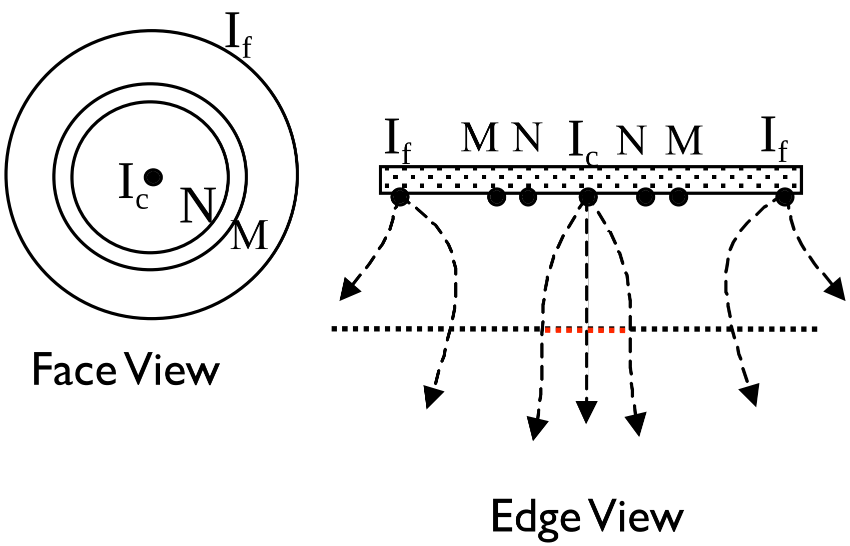
- Idea was developed in the 1930's by Schlumberger.
- Refinements made in 1950's.
  - Microlaterolog (MLL).
  - Short Guard (SG).
- Fracture is filled with oil or drilling mud.
  - Has a different resistivity than formation.
  - When fracture is between Source and Ground, Vmn changes.
- Calculating resistivity allows for identification of producing region.

$$\rho = G\frac{\Delta V}{I}$$

Microlaterolog (MLL)



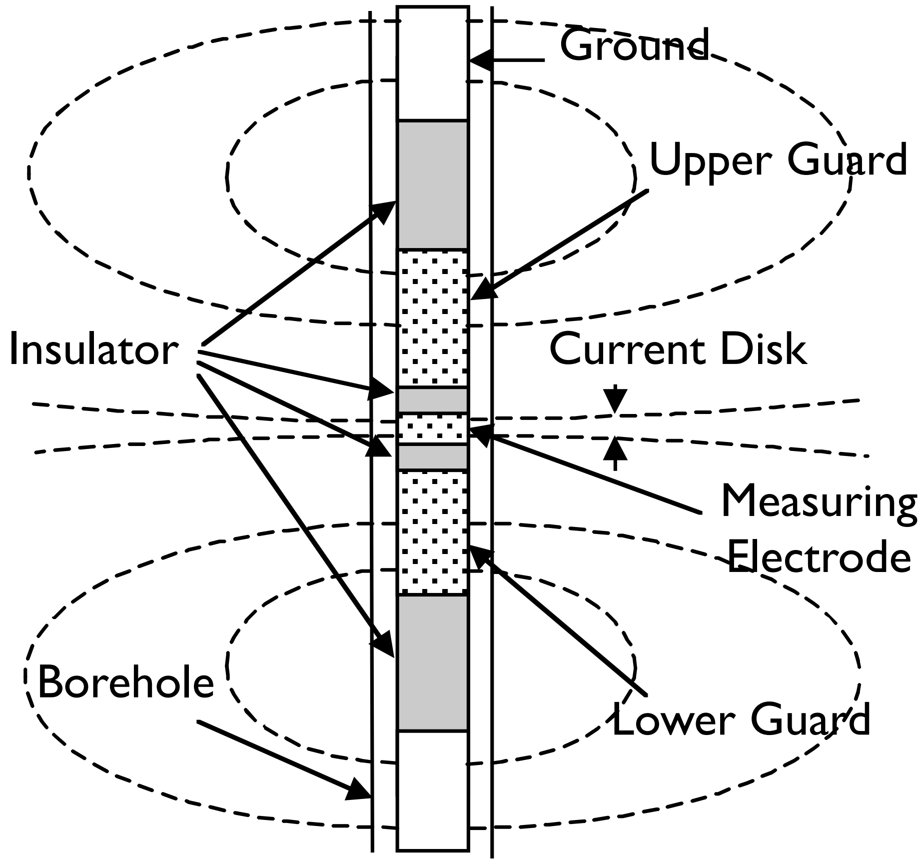
- Point current sources are sensitive to variations in the sensor-borehole distance.
  - Limits resolution of device.
  - Limits ability to measure resistivity.



- MLL focuses current.
  - Current from focusing ring forces current from central electrode into a “pencil of current.

Short Guard

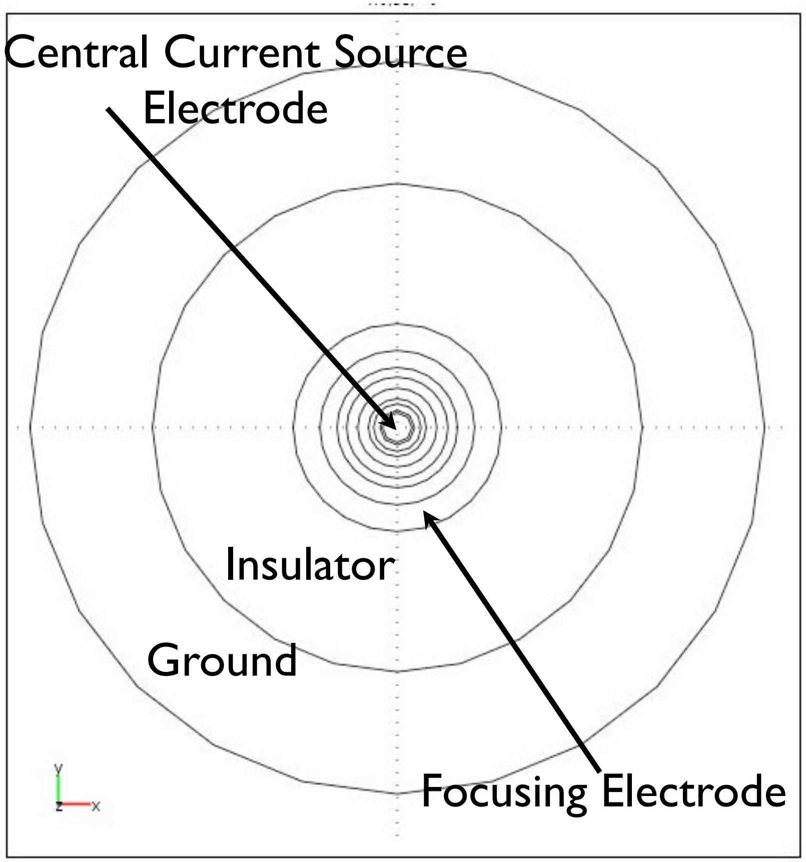
- SG is similar to MLL in that it uses current to focus the "measuring" current.
  - Constant current source from measuring electrodes and guard electrodes.
  - Measuring voltage of measuring electrode gives resistivity.
- Current forms a disk rather than a pencil.
- Azimuthal symmetry.
  - Measures average resistivity around borehole.



Modified SG and MLL

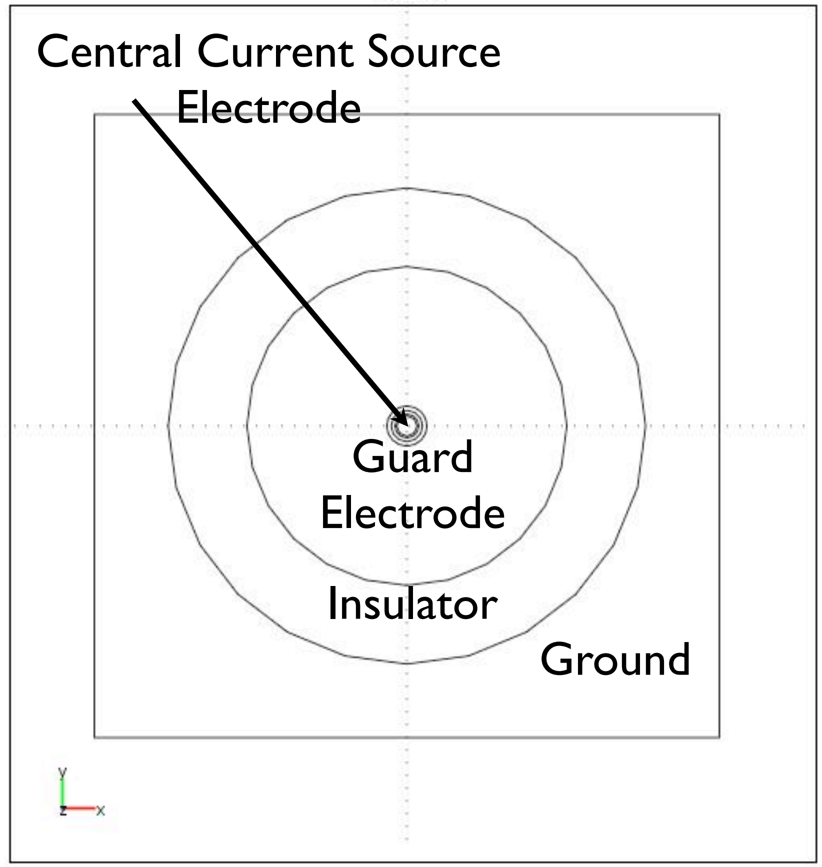
- We developed modified microlaterolog (MMLL) and modified short guard (MSG) to better suit our needs.

MMLL



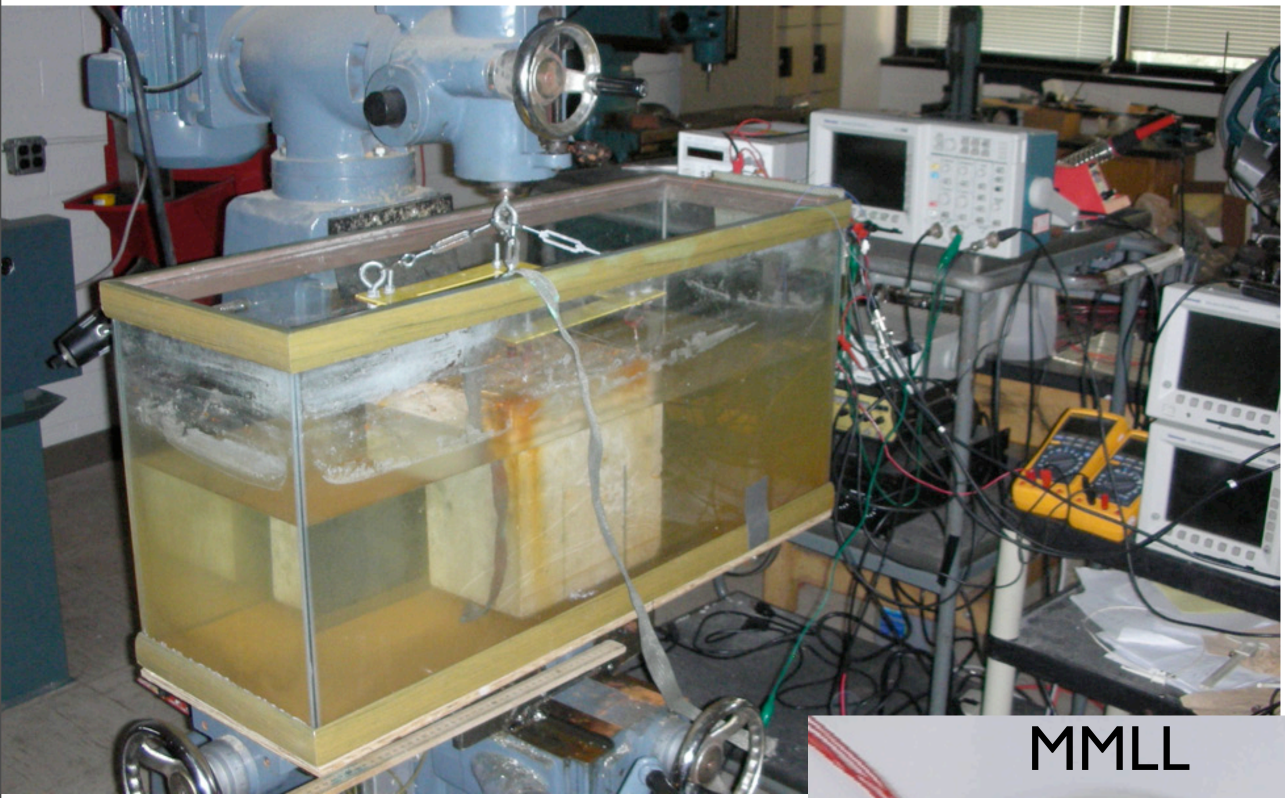
- Central current source is a disk.
- Central and focusing current densities are equal

MSG



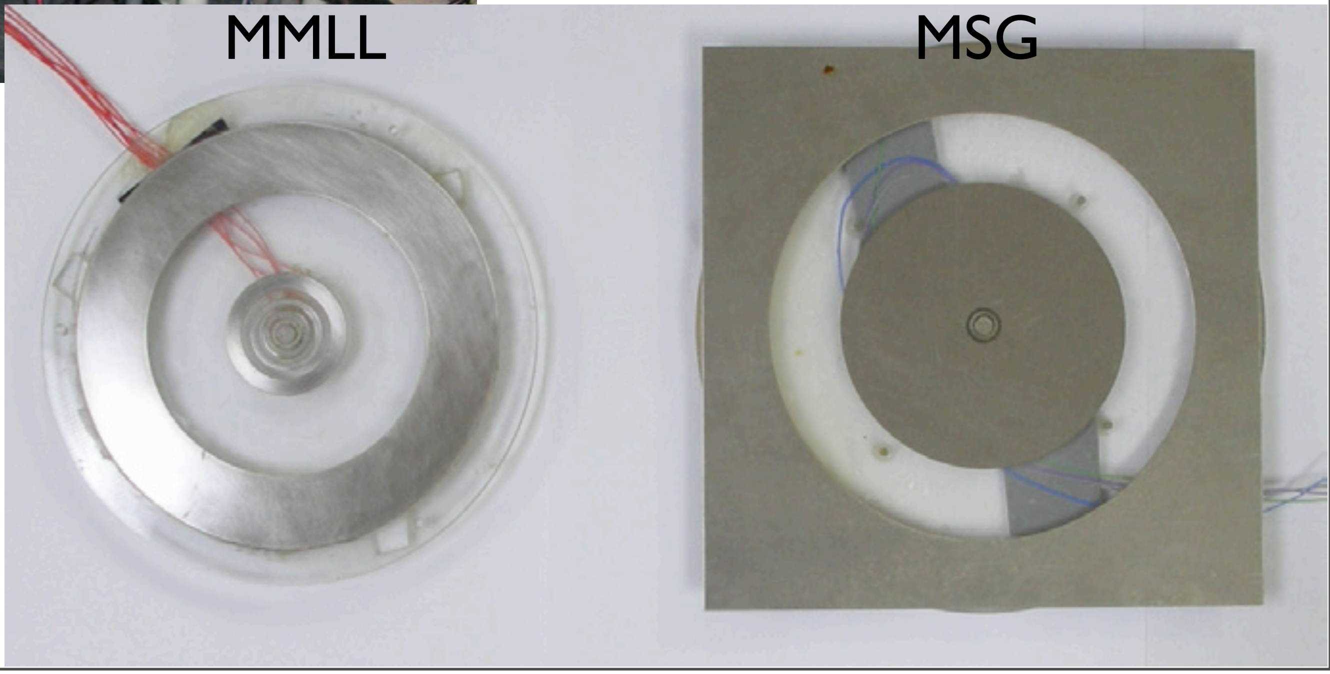
- Central current source is a disk.
- MSG is not axially symmetric.

Lab Model



- Prototypes tested in aquarium tank filled with water.
- Formation is a ceramic block with slots cut into it.

- Prototypes are conducting layers on insulating backing.

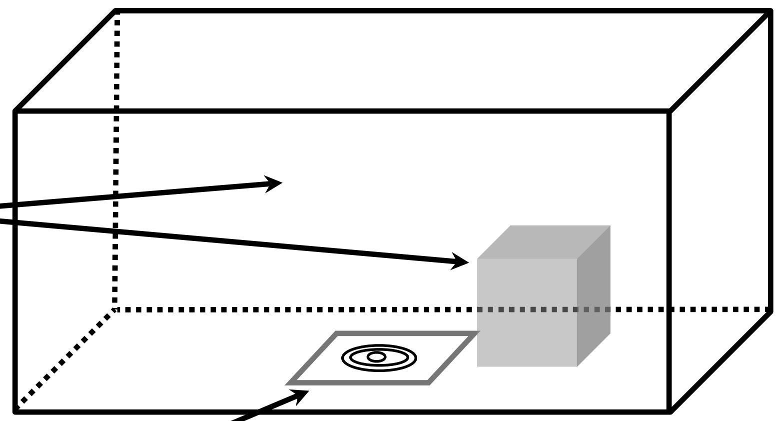


Why Use Comsol Multiphysics?

- Computer models are cost-effective for determining if a device will function as predicted by theory.
  - We can use the model to identify problems before the device is actually built.
- Models are an efficient way of testing a device under various operating conditions.
  - We are interested in how well this device works for various formation and mud conductivities.
- Prototypes take weeks (sometimes months) to build, and they are expensive.
  - *COMSOL models allow us to evaluate many designs and quickly decide which is most effective.*

Comsol Model

- 0.9 m x 0.3 m x 0.4 m tank walls are *insulators*.
- One subdomain with conductivity defined by an equation.
  - Allows block to be moved parametrically.
- Device is array of surfaces on bottom of tank, with BC's:
  - Ground.
  - Electric Insulator.
  - Floating Potential.



- Conductivity of formation is 0.25 $(\text{Ohm-m})^{-1}$.
- Conductivity of the water is 1 $(\text{Ohm-m})^{-1}$.

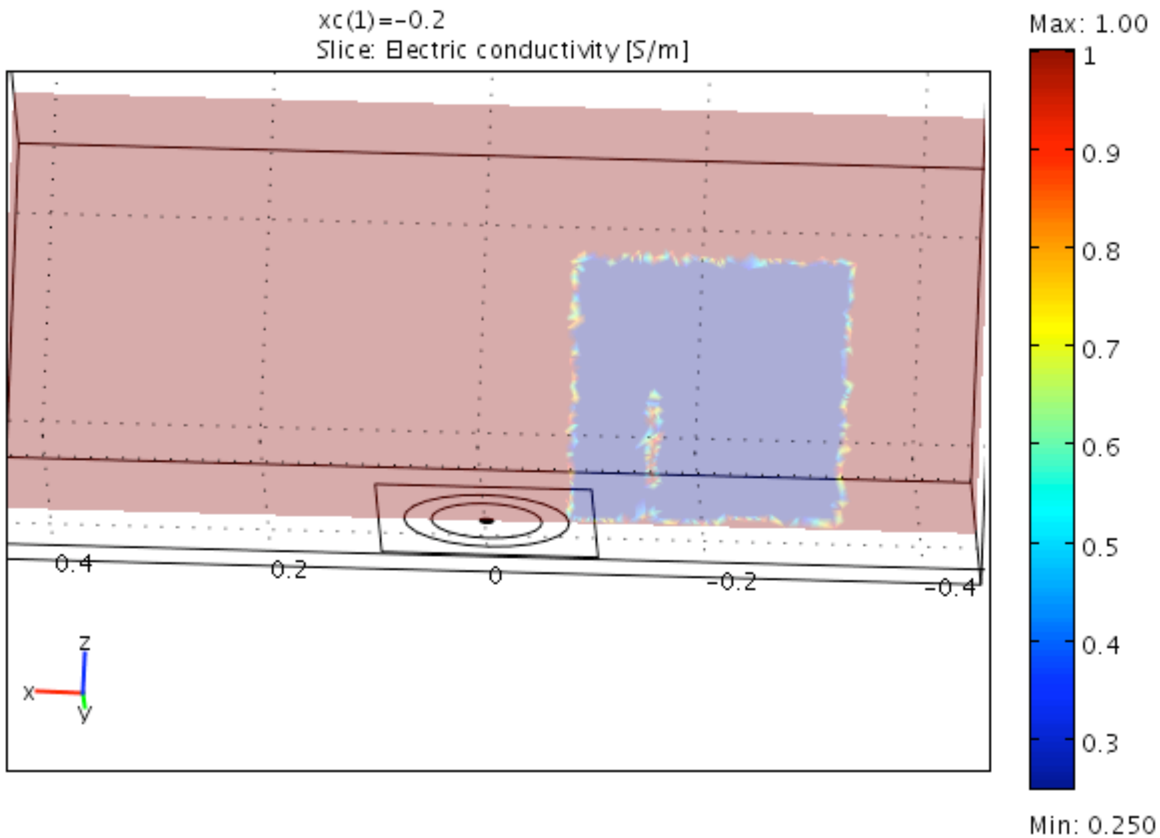
Moving Block

- Block is defined as part of the subdomain conductivity so it can be moved parametrically.

$$\sigma_w + (\sigma_r - \sigma_w) \cdot \left(x > \left(x_c - \frac{x_b}{2} \right) \right) \cdot \left(x < \left(x_c + \frac{x_b}{2} \right) \right) \ldots_{y,z}$$

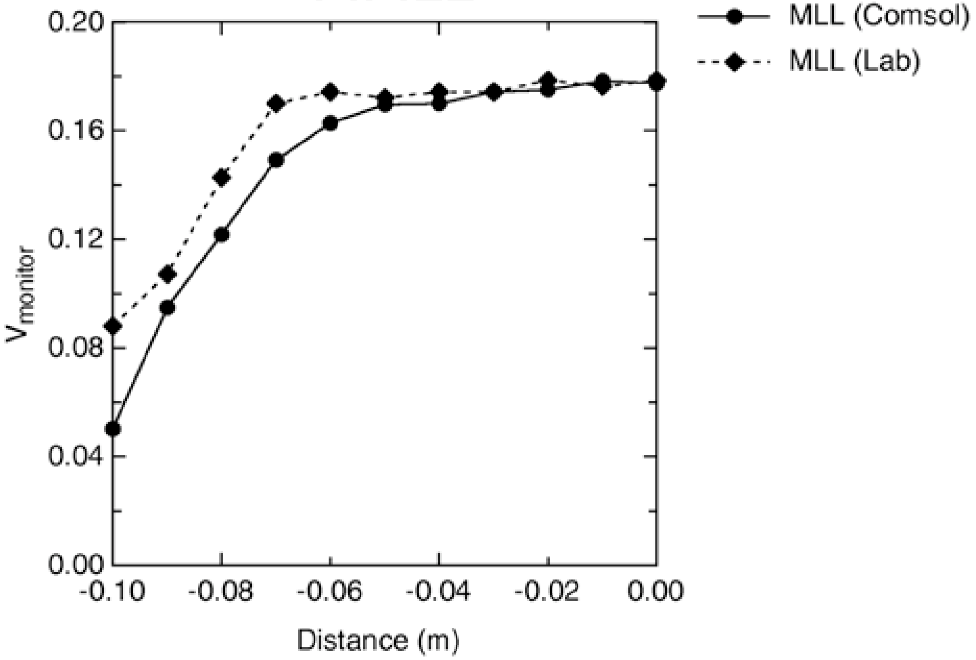
$$-(\sigma_r - \sigma_w) \cdot \left(x > \left(x_c + x_{slc} - \frac{x_{sl}}{2} \right) \right) \cdot$$

$$\left(x < \left(x_c + x_{slc} + \frac{x_{sl}}{2} \right) \right) \ldots_{y,z}$$

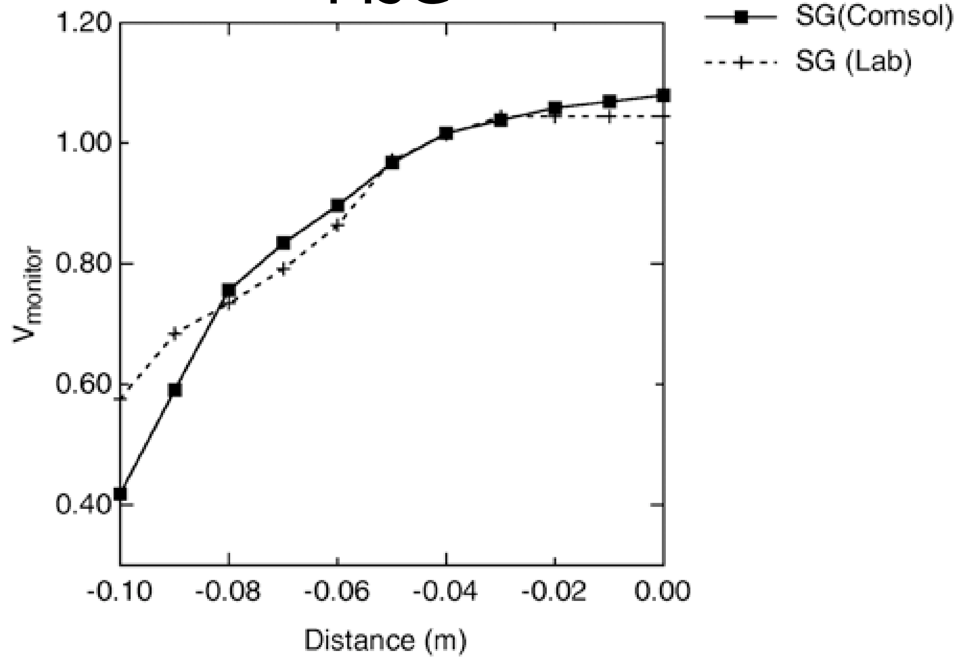


Comparing Lab to Comsol

MMLL

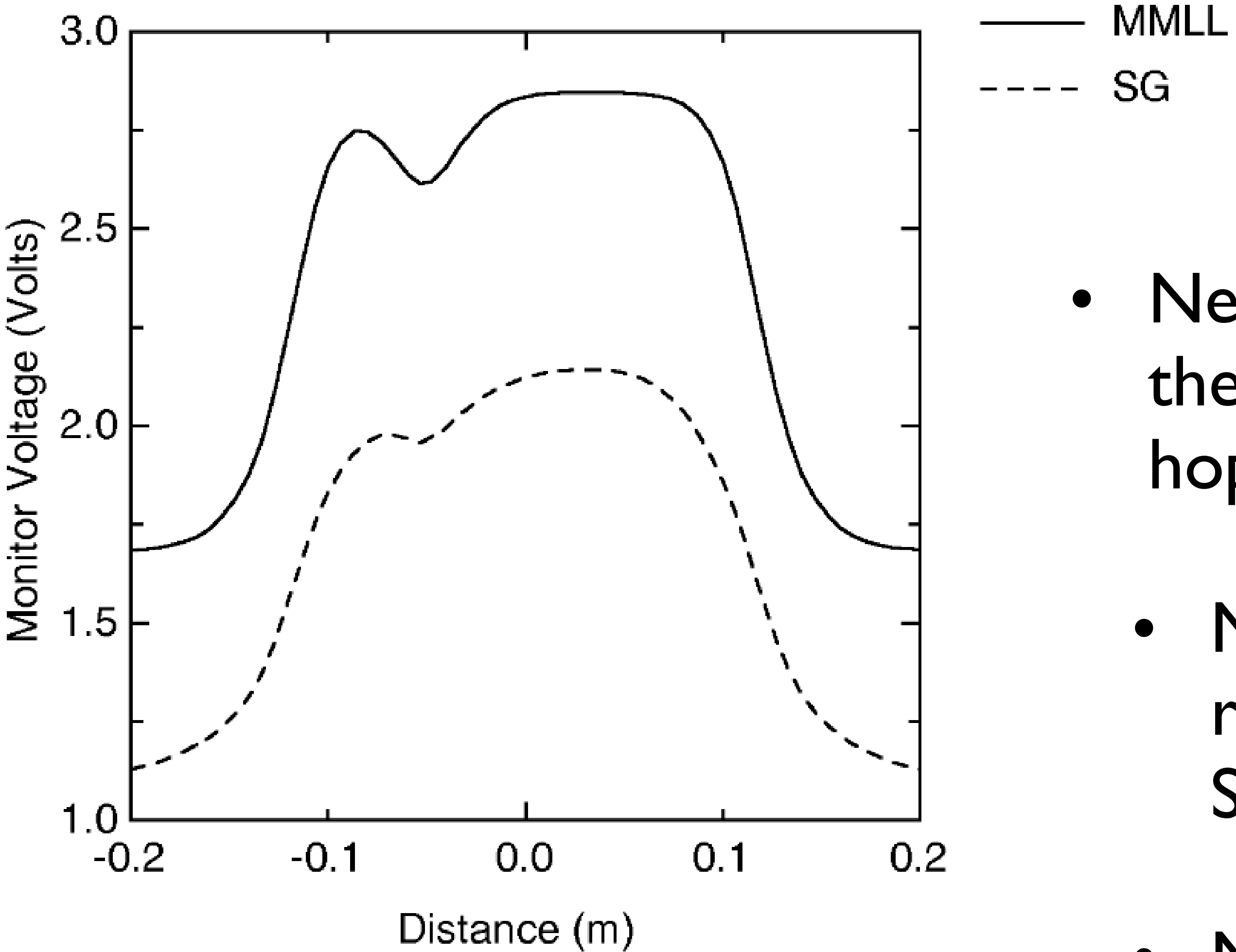


MSG



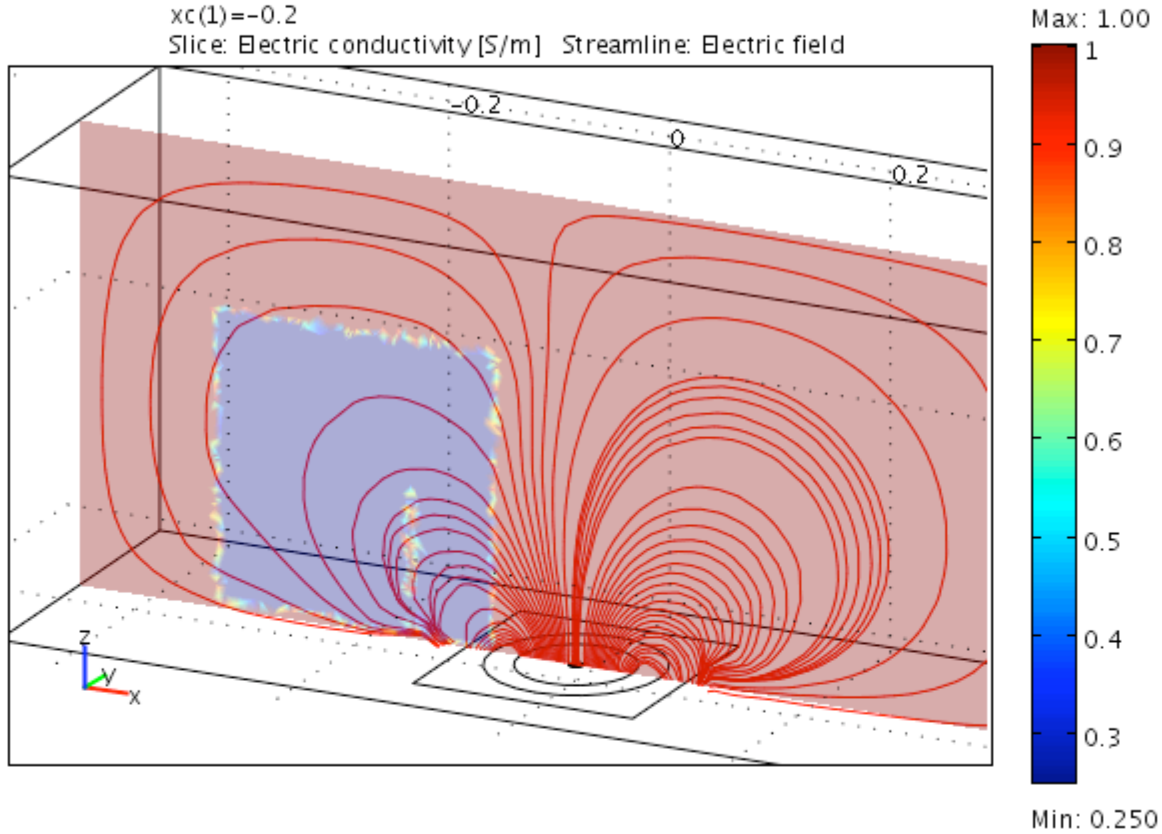
- Lab and Comsol models compare favorably.
  - Now that we are convinced that the COMSOL model gives a realistic result, we can further evaluate the two models.

Results of Comsol Models



- Neither device provides the resolution we had hoped for.
  - MMLL has better resolution (6 cm) than SG (9 cm).
  - MSG gives better contrast measurement (1.90) than MMLL (1.68).

Why is resolution so poor?



- Electric field (i.e. current lines) show that the potential at the measurement electrode begins to change when the edge of the formation (or fracture) encounters the edge of the guard electrode (focusing electrode).

What's Next?

- The resolution is not as good as we need it to be.
  - We are considering alternate designs.
  - We are looking at changing how the device is operated by tweaking the boundary conditions.
- We would like the contrast to be better.
  - The device is more useful if it can give an accurate measure of the formation resistivity.
- How well does the "2D" model approximate the actual device, which will be wrapped around a cylindrical mandrel?
  - We are working on a 3D model that will be geometrically more similar to the device.

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