Detection of Buried Land Mines with High-Frequency Seismic Waves

Waymond R. Scott, Jr.[a], Christoph Schroeder[a], Seung-Ho Lee [a], Peter H. Rogers[b], James S. Martin[b], Gregg D. Larson[b], and George S. McCall II[c]

[a]School of Electrical and Computer Engineering
[b]School of Mechanical Engineering
[c]Georgia Tech Research Institute
Georgia Institute of Technology
Atlanta, GA 30332
waymond.scott@ece.gatech.edu
404-894-3048

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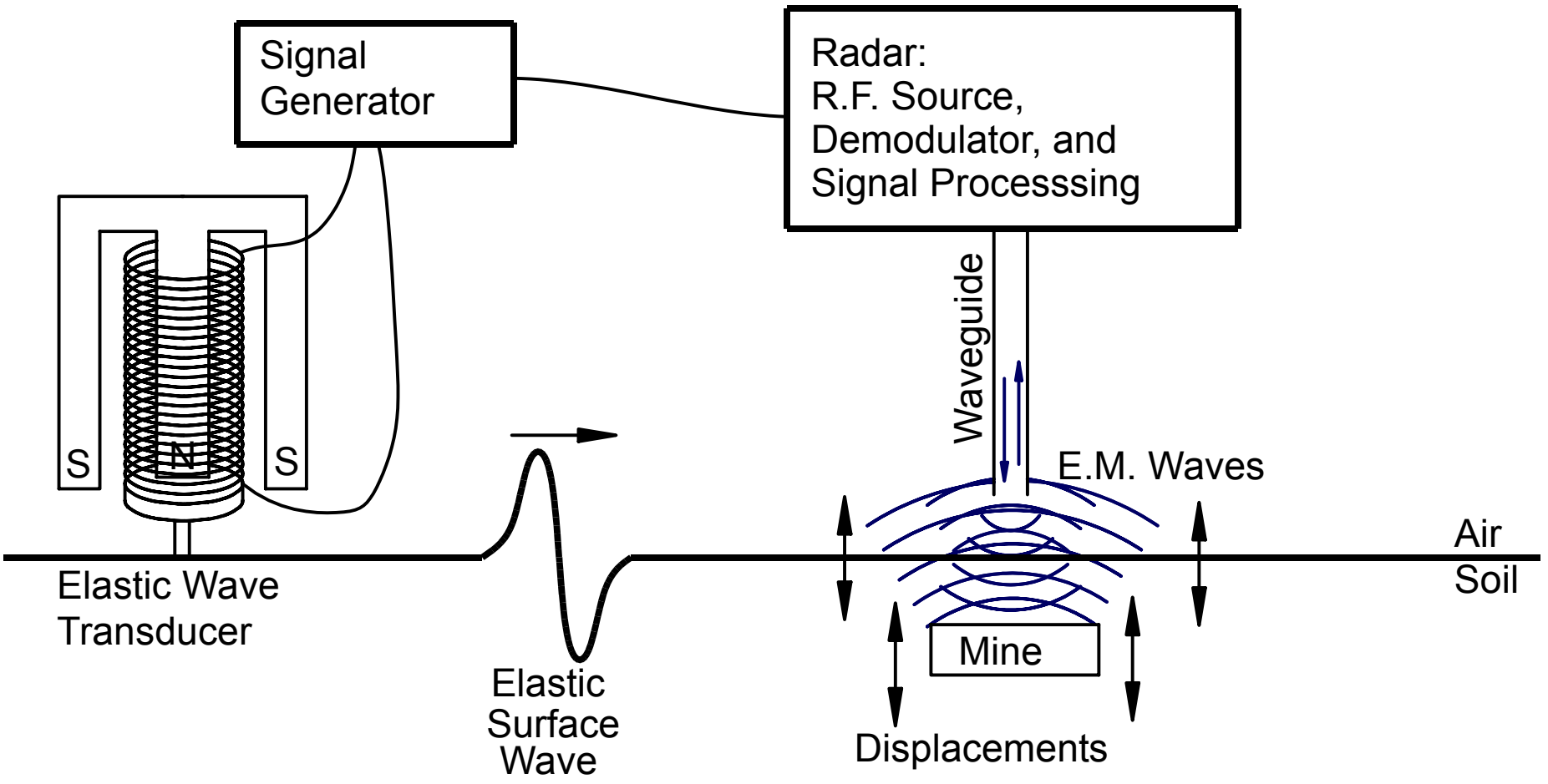
Outline

- Introduction
- Theoretical Model
  - Interaction of Elastic Waves with a Buried Land Mine
  - Resonant Behavior of a Buried Land Mine
- Experimental Model
  - Laboratory Model
  - Field Model
- Elastic Wave Sources and Sensors
  - Focused Antenna Array
- Conclusions

Elastic/Electromagnetic Sensor



Configuration of the Sensor Currently being Studied

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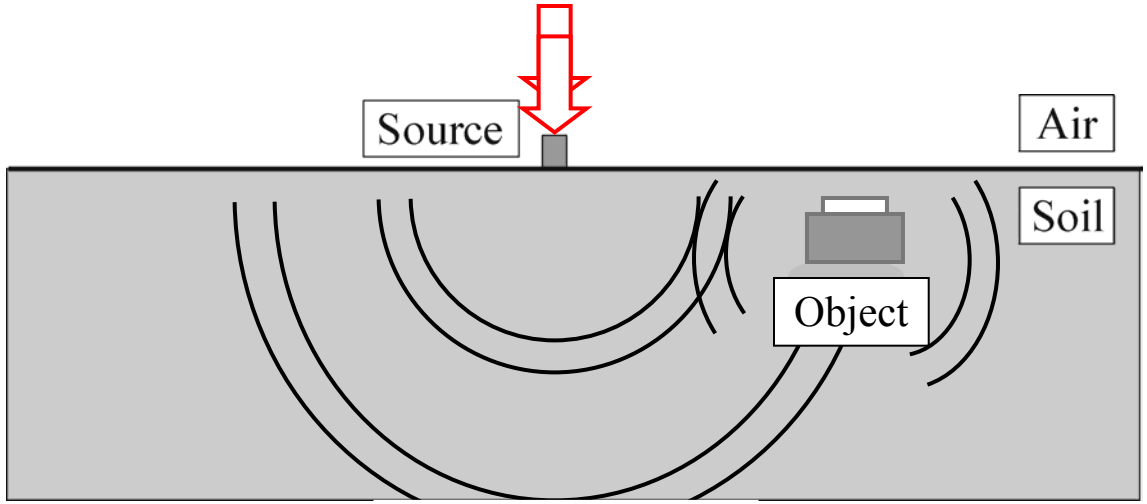
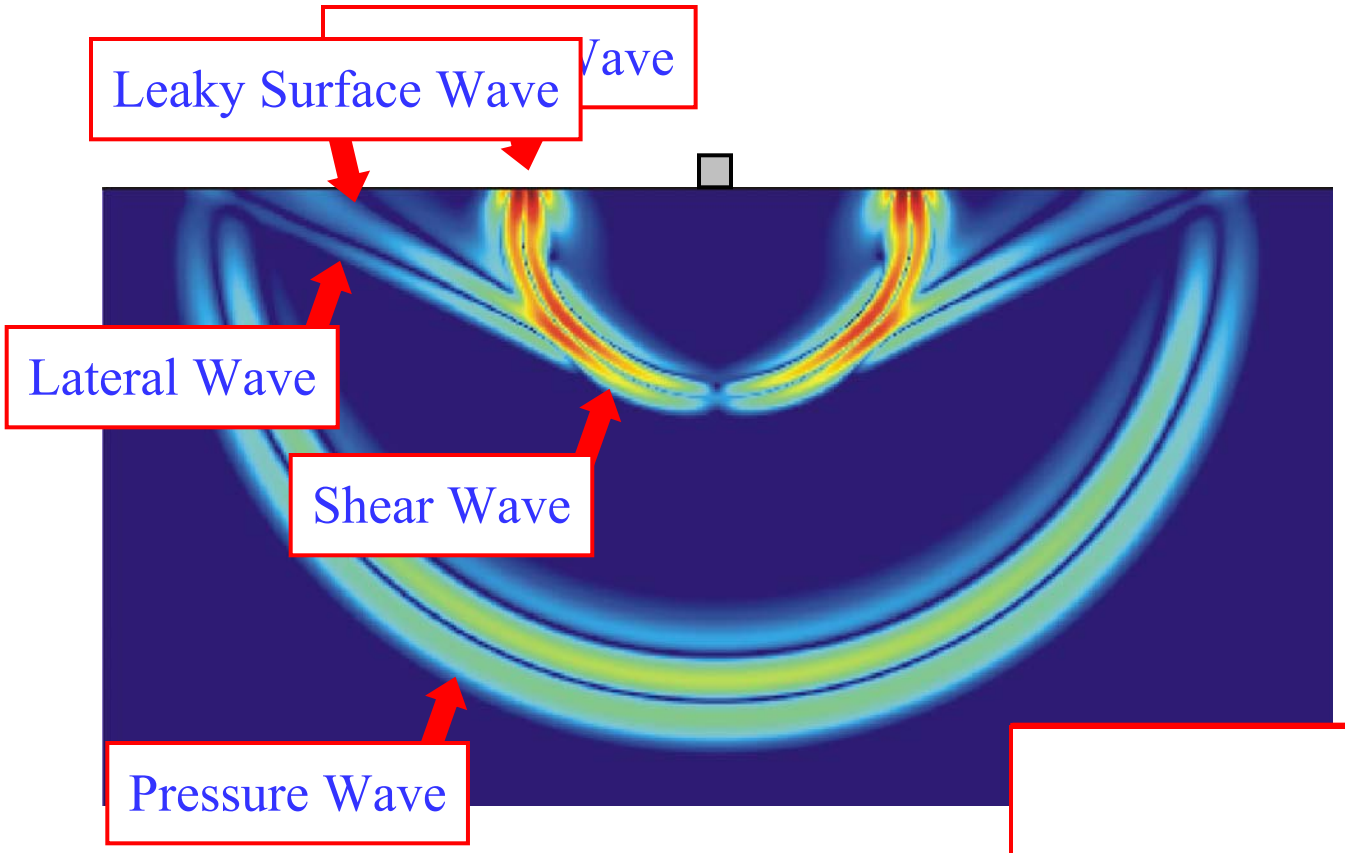
Elastic Waves in the Ground

- To investigate the elastic wave motion in the soil, a numerical model has been developed.
- Scenario:
  - A source on the surface launches elastic waves.
  - The waves propagate along the surface and in the medium.
  - The waves are scattered by an object buried in the ground.



Elastic Waves in the Ground

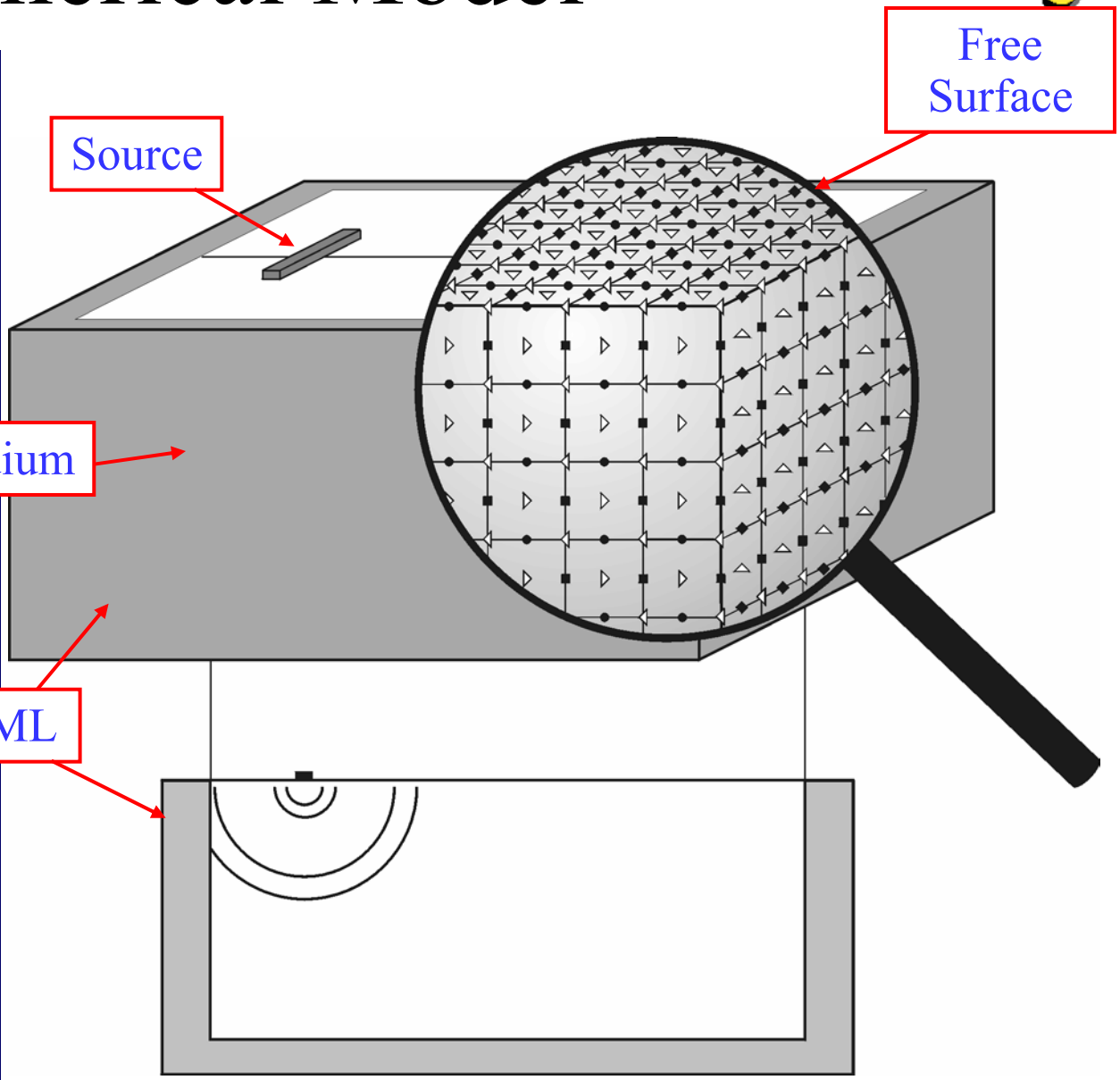


- Pressure Wave
- Shear Wave
- Rayleigh Surface Wave
- Lateral Wave
- Leaky Surface Wave

Waves in the far field:

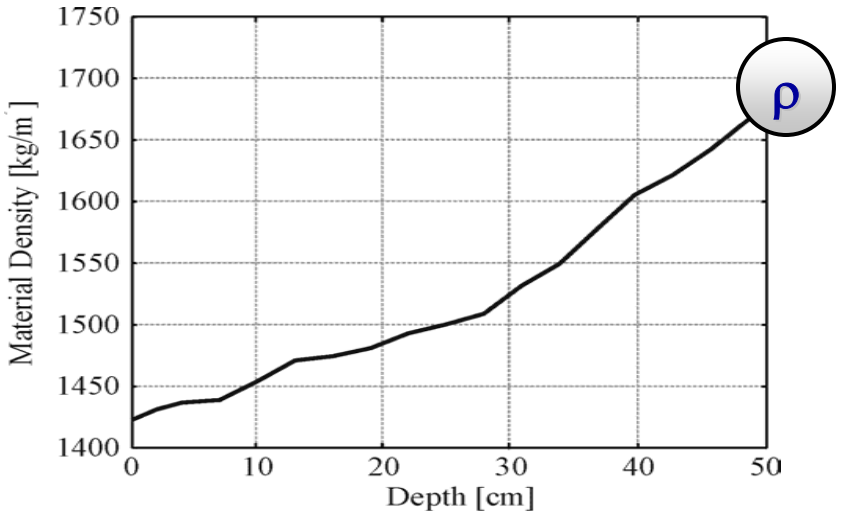
Numerical Model

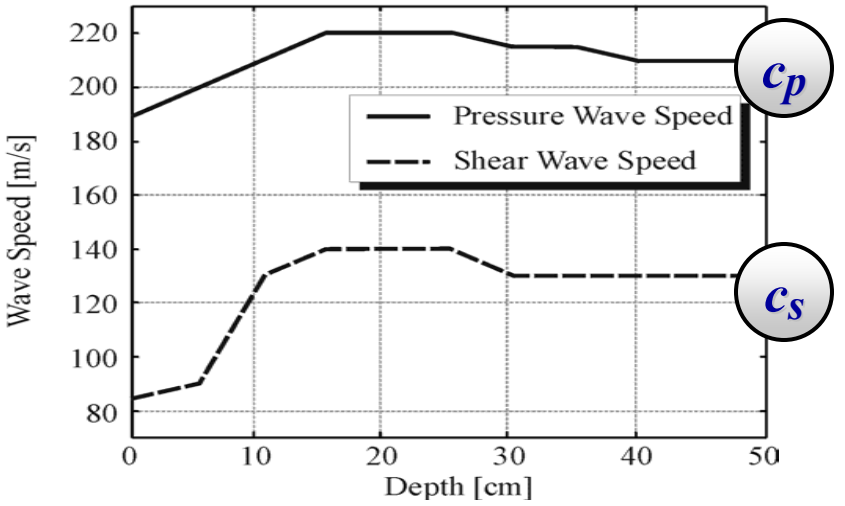
- 3-D model: semi-infinite half-space.
- Medium is assumed to be linear, isotropic, lossless.
- The transducer (source) is modeled by exciting the normal particle velocity on the surface.
- The air-ground interface is modeled by a free-surface boundary condition.
- The solution space is surrounded by a Perfectly-Matched-Layer (PML) absorbing boundary.
- A discrete numerical grid is introduced.



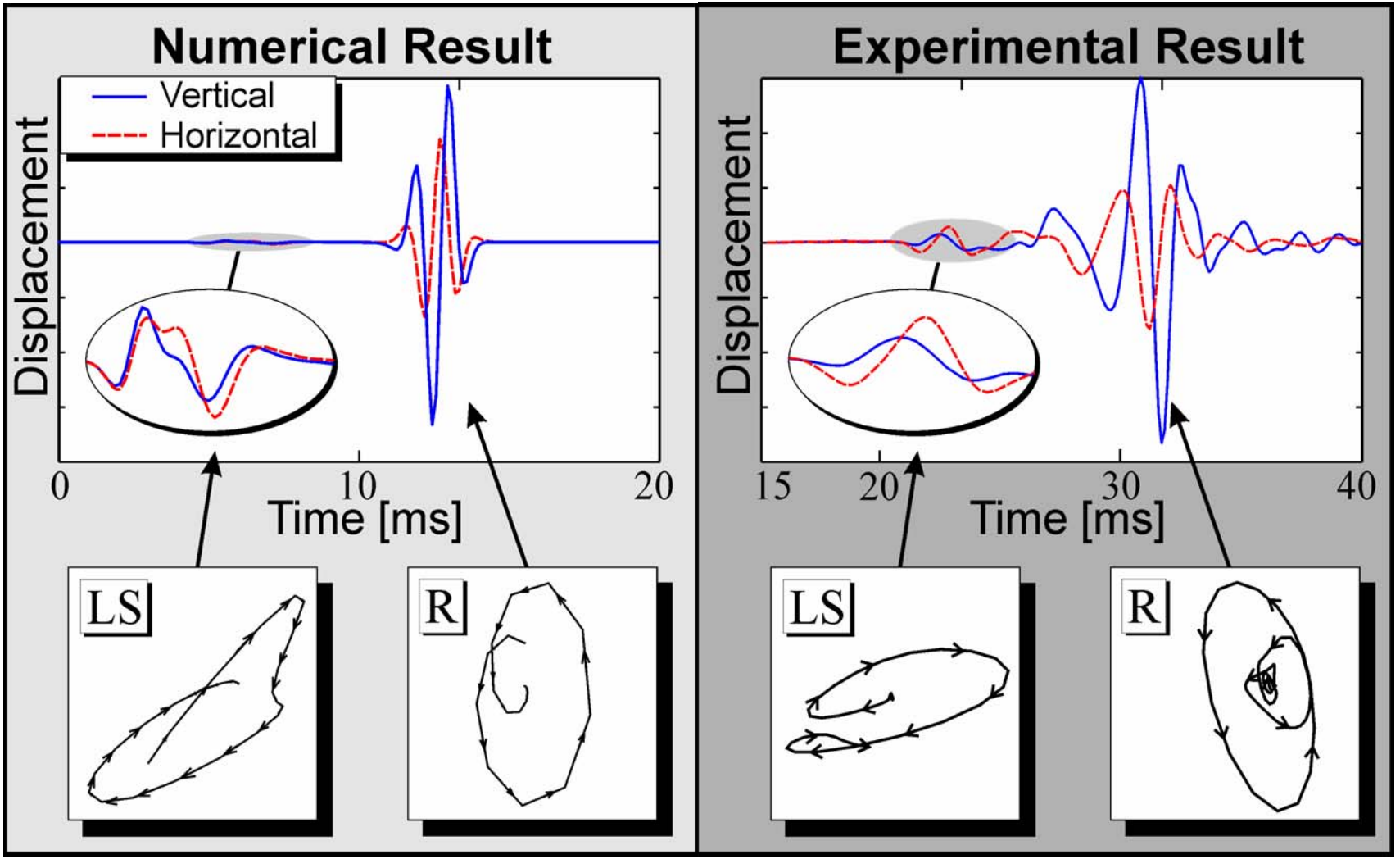
Material Properties

- In experiments, mines have been buried in sand.
- The material properties of sand can be described by three independent quantities: ρ, c_p, c_s.
- The soil properties of sand have been measured as a function of depth:
  - Due to changes in the water content, the material density changes with depth.
  - Both shear and pressure wave speed vary with depth.
  - "Slow" layer close to the surface. Pressure and shear wave speed increase rapidly beyond the surface layer.





Polarization of Surface Waves Observed in the Models



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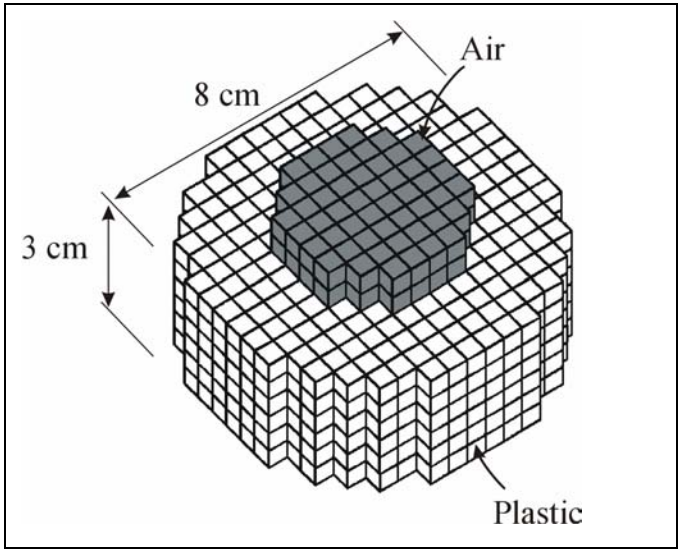
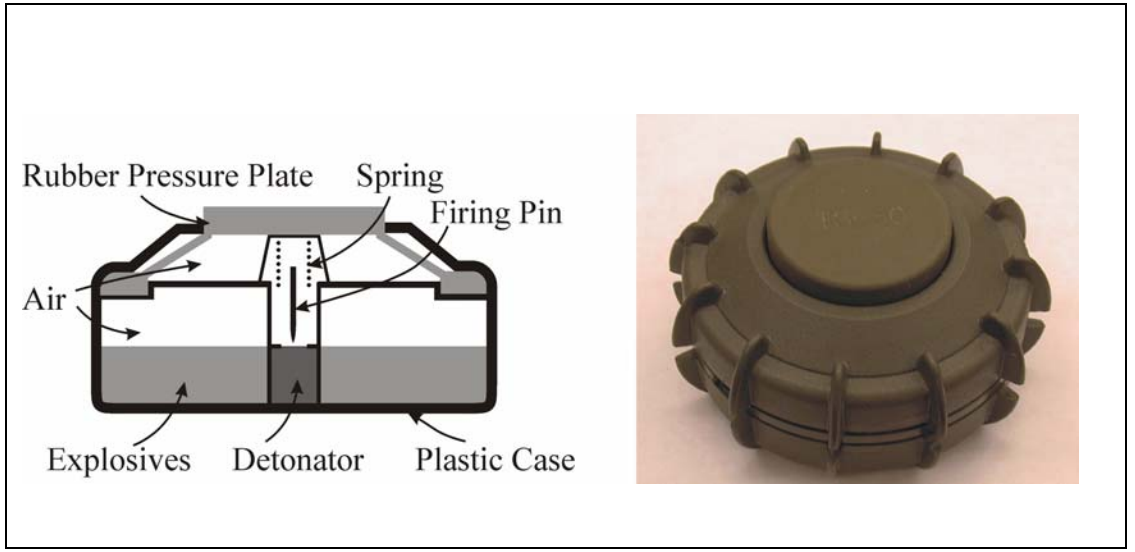
Antipersonnel Mine





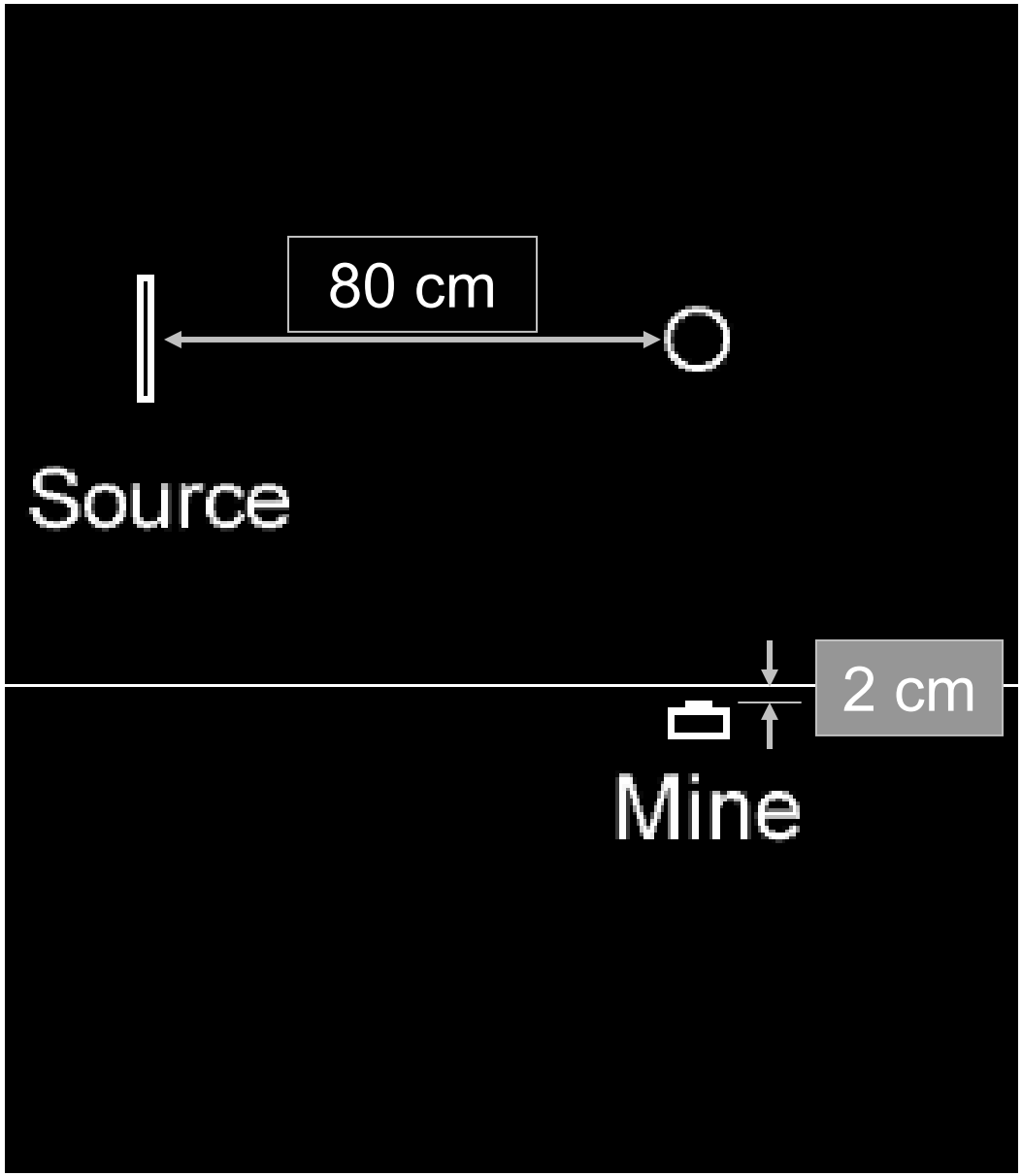
Model

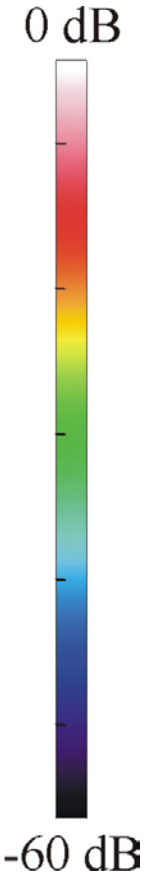
- Mine is discretized with voxels;
- Main chamber consists of plastic explosives;
- Small air-filled chamber on the top of the main chamber.

TS-50 Mine

- Plastic explosives
- Trigger mechanism (springs, firing pin)
- Plastic case
- Rubber pressure plate
- Air-chambers

Mine-Wave Interaction





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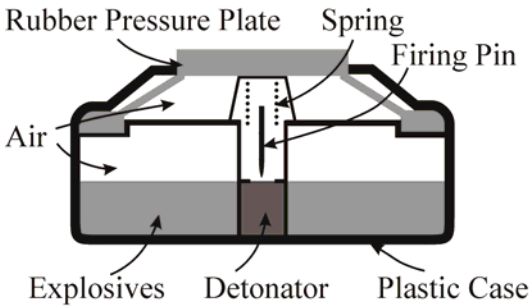
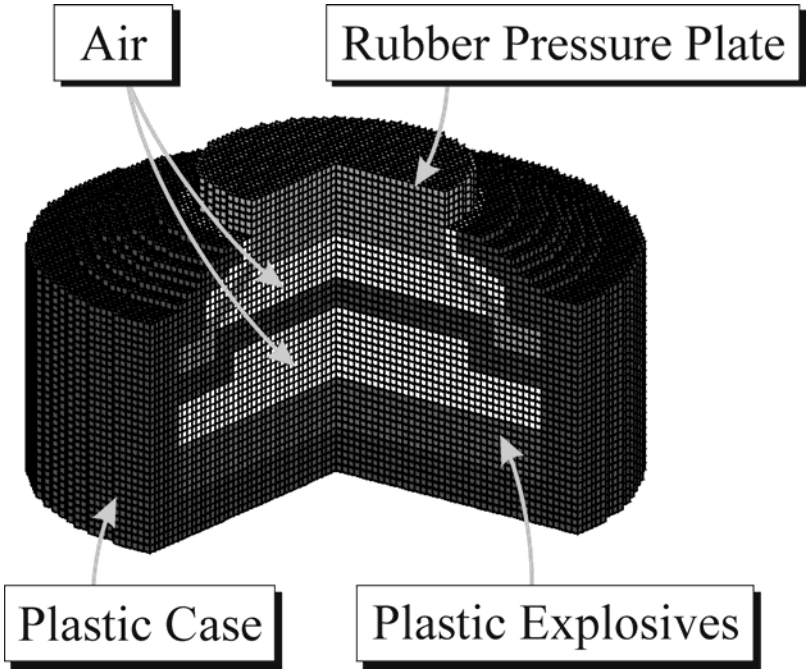
Detailed Mine Model

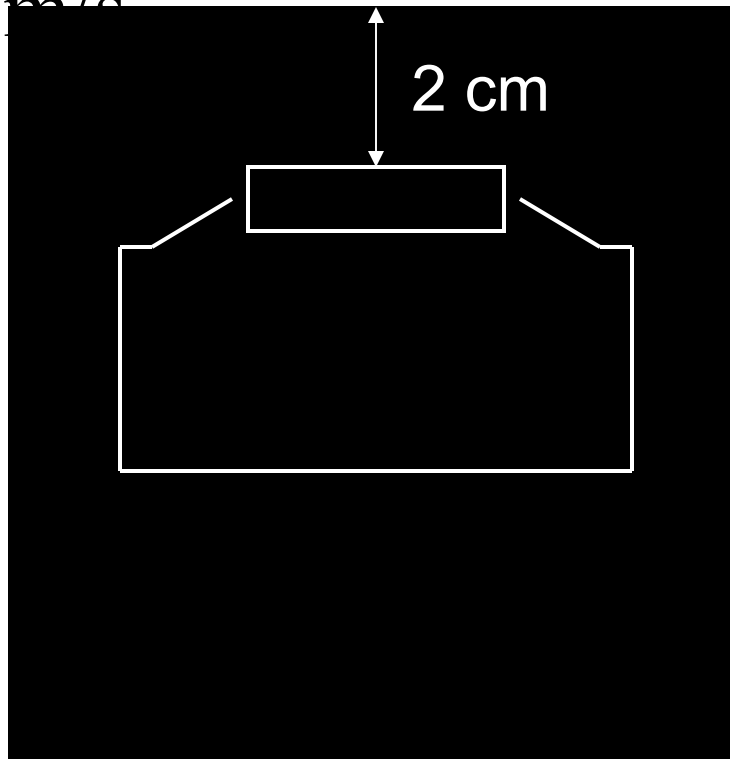
- The mine model used thus far is very simple.
- To study the resonance at the mine location, a mine model is created which includes more details of the mine:
  - Case
  - Explosives
  - Rubber Plate
  - Air Chambers

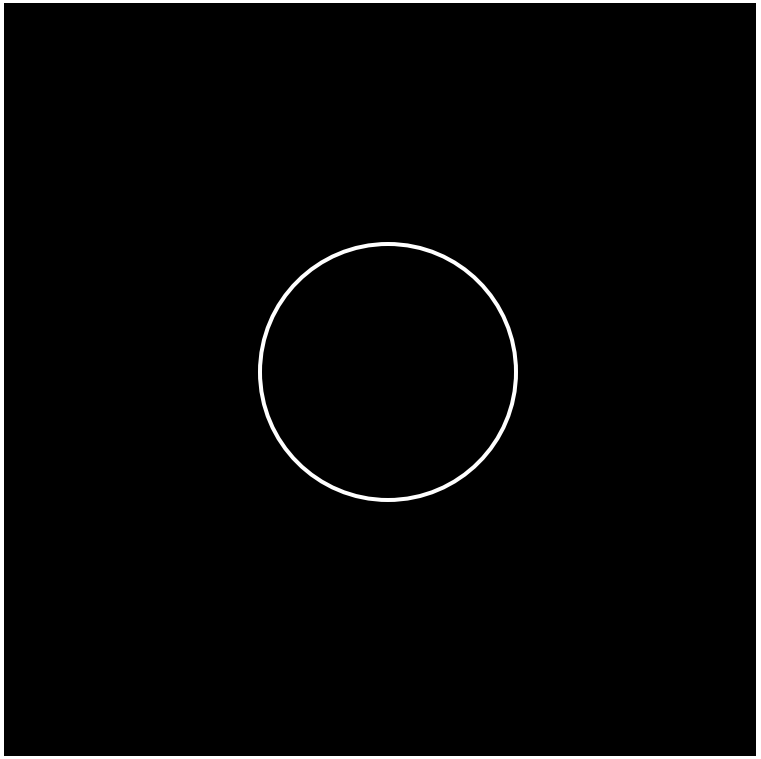




Detailed Mine Model

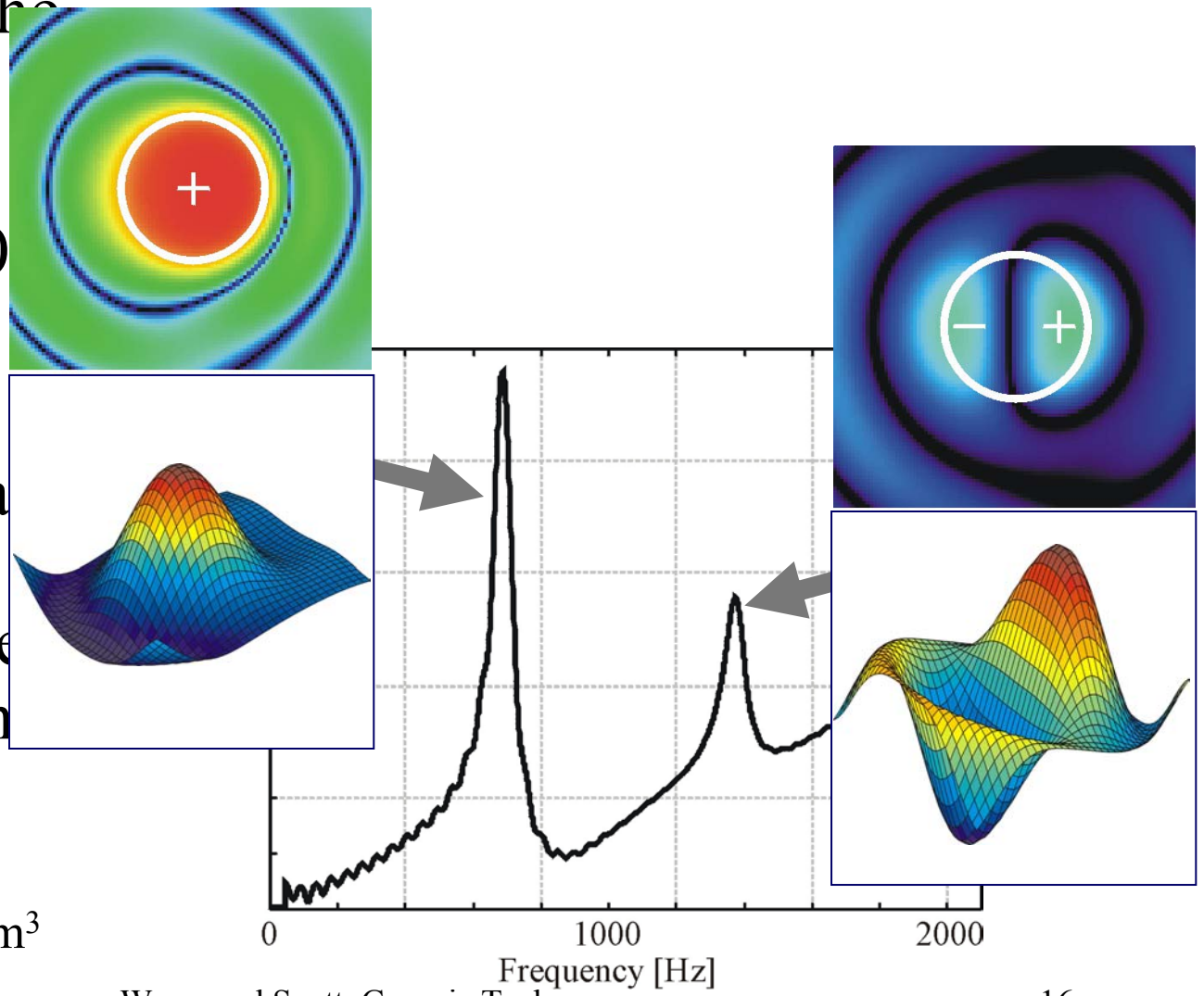
- Mine buried 2 cm beneath the surface.
- ρ = 1400 kg/m^3, c_p = 250 m/s, c_s = 40 m/s





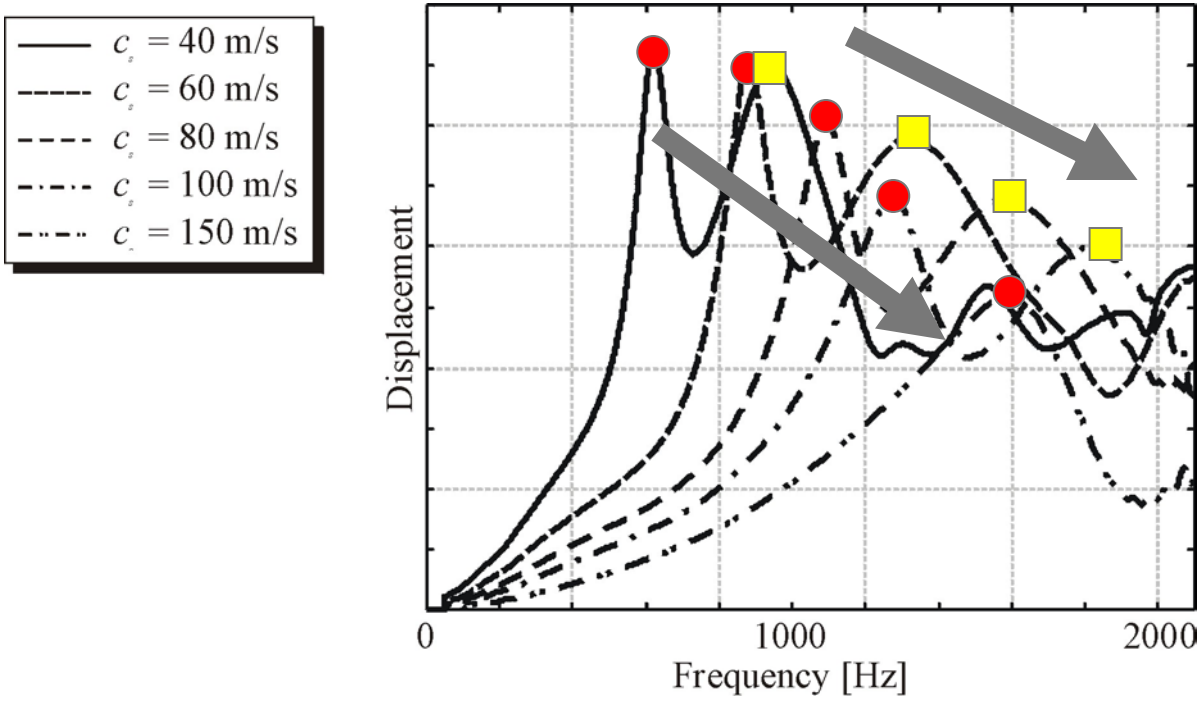
Resonance

- Mine buried 1 cm beneath the surface
- Shear wave speed $c_s = 40$ m/s
- The pressure wave speed and the material density are kept constant in the following:
  - $c_p = 250$ m/s
  - $\rho = 1400$ kg/m^3



Resonance

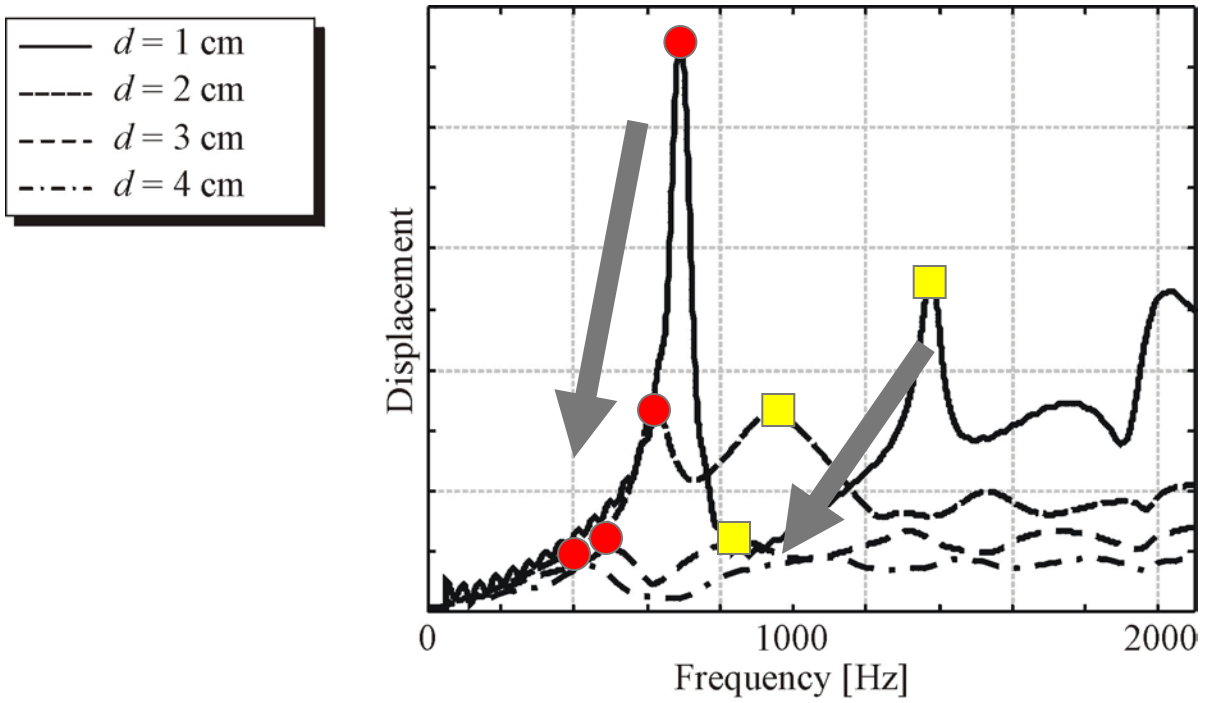
- Resonance as a function of the shear wave speed:
- Mine buried at 2 cm



Resonance

- Resonance as a function of burial depth:
- Shear wave speed

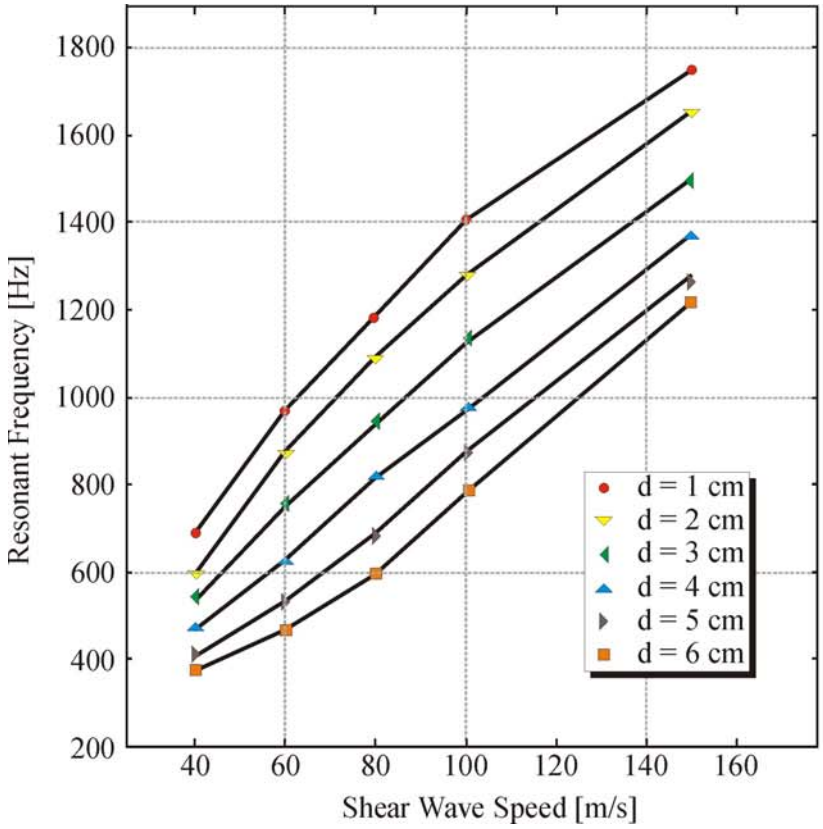
  $c_s = 40$ m/s



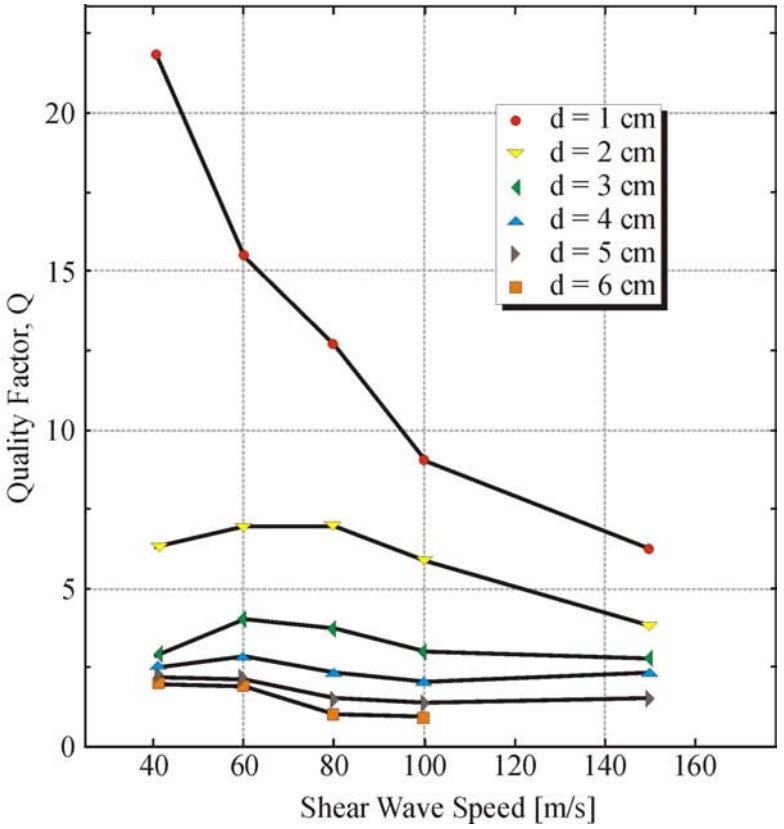
Resonance

- First resonance:

Resonant Frequency

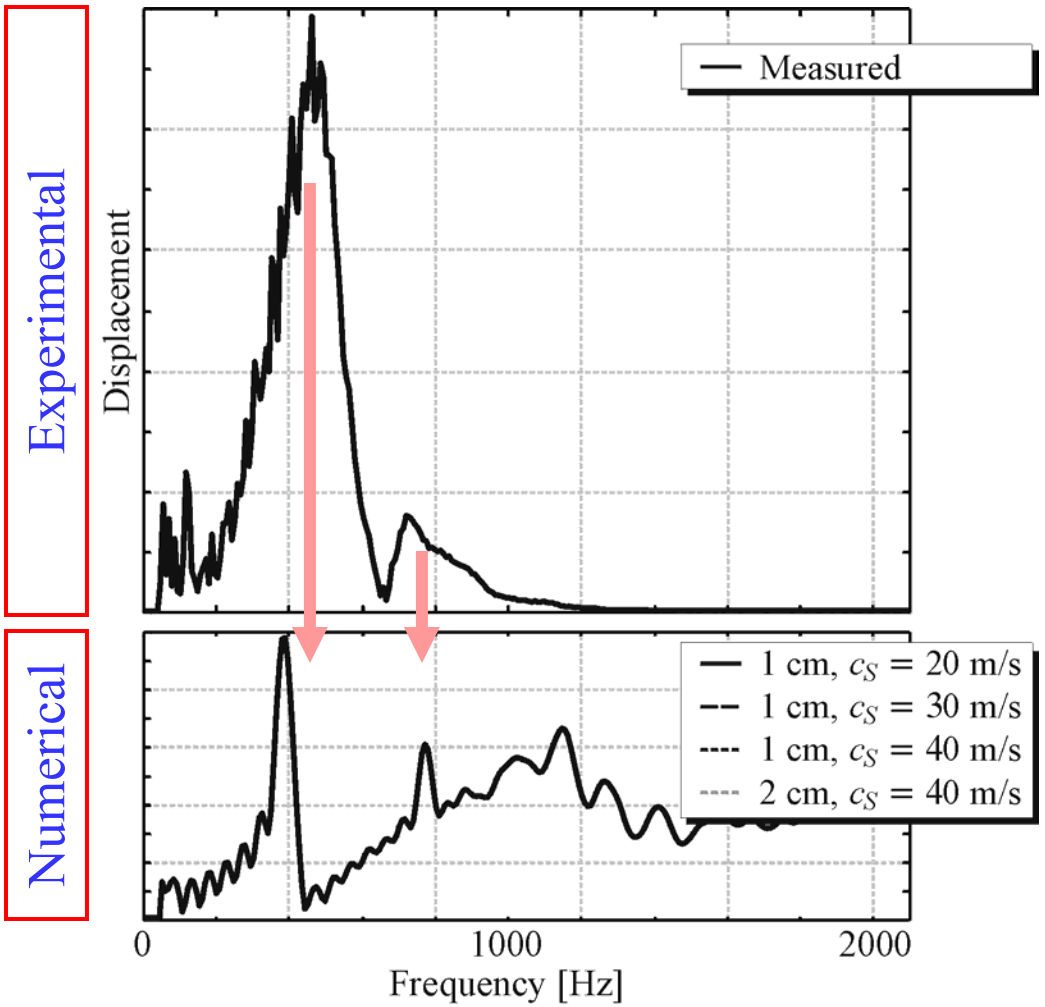


Quality Factor



Experiment

- TS-50 AP mine at 1 cm



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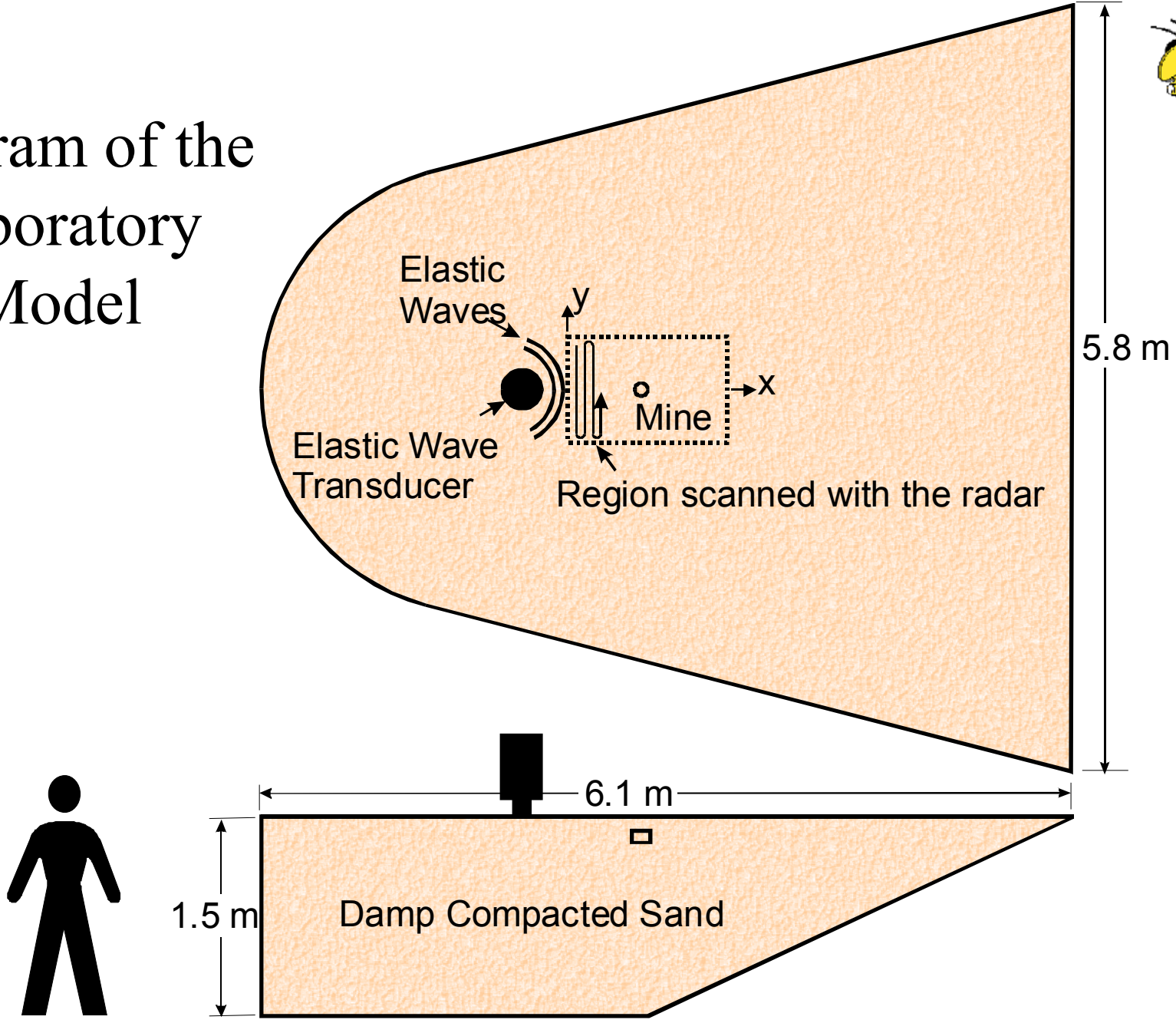
Experimental Results

- Both anti-tank and anti-personnel mines have been investigated.
  - Anti-Tank Mines
    - Two Inert Mines: VS-1.6 and VS-2.2.
    - Acrylic Plastic: 30 cm by 30 cm by 7.5 cm.
    - Simulated Mine: SIM-30; depths to 30 cm.
  - Anti-Personnel Mines
    - Four Inert Mines: PFM-1, M-14, TS-50, and VS-50.
    - Two Simulated Mines: EM-3 and SIM-9.
  - Clutter Items
    - Rocks, Sticks, Cans, Surface Cover (Pine Straw).
- Resonance
  - All of the inert AP and AT mines studied exhibit a resonant response which enhances the response of the mine and can be used to help distinguish it from clutter.
  - Other types of mines are expected to exhibit this type of resonance.

Experimental Results

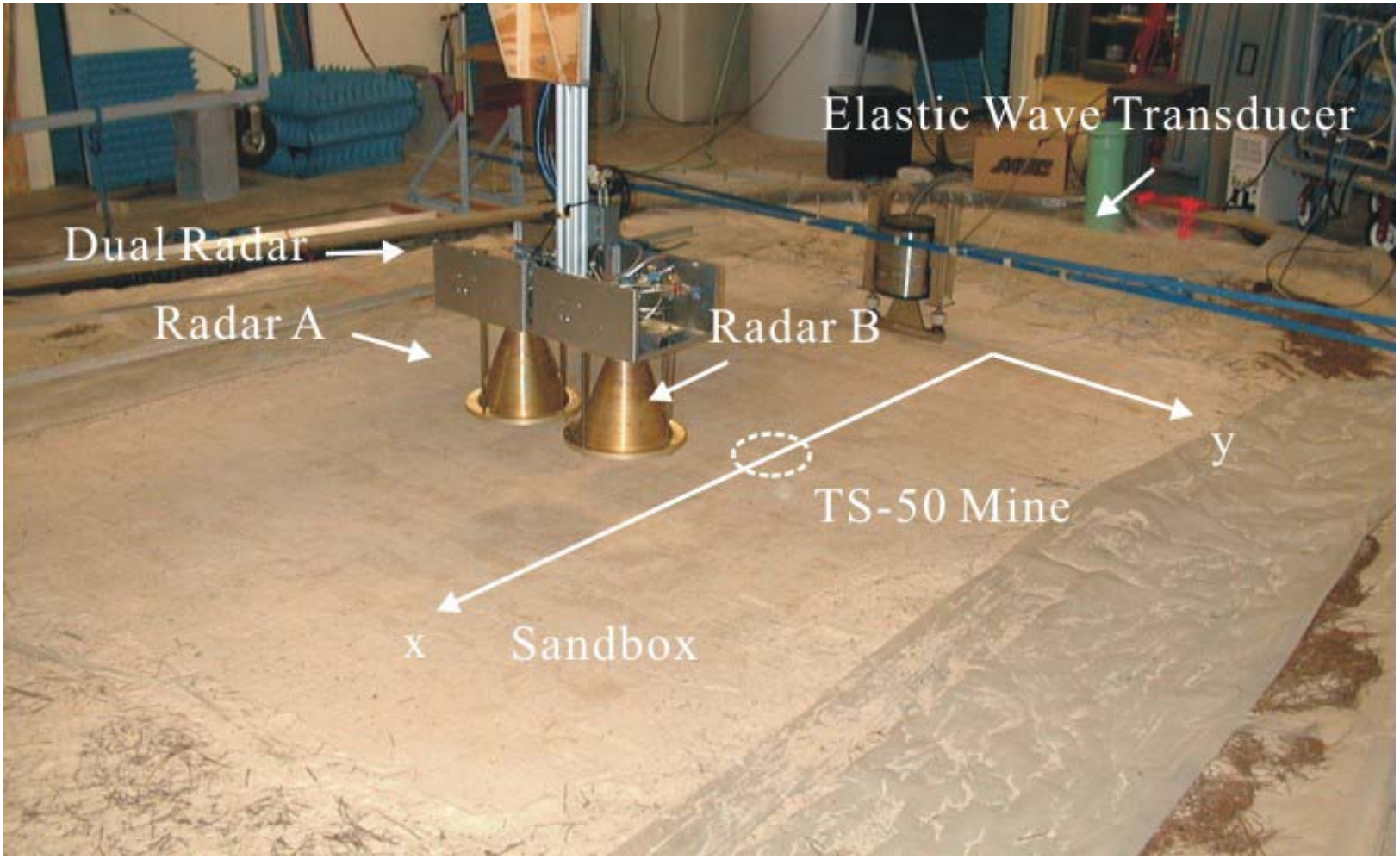
- Results presented today.
  - Laboratory Experiment: Sandbox
    - Single TS-50 mine
    - Single AT mine surrounded by AP mines and clutter.
  - Field Experiment: Georgia Red Clay: CCRF
    - Single TS-50 mine.

Diagram of the Laboratory Model



Laboratory Experiment

TS-50 Mine 1cm Deep



TS-50 Mine: 1 cm deep

Raw Measured Data: Focused Antenna 20 cm High;
Radar A with Radar B operating

Signal Processing

- Filter out forward traveling waves, leaving only the reflected waves.
  - Enhance the signature of the mine.
  - Resonance.
- Image.
  - Energy in the reflected wave at times near the time of arrival of the incident wave.

TS-50 Mine: 1 cm deep

Image: Dual Focused Antenna 20 cm High

15 cm of Pine Straw

30 dB Scale

Antenna A

Antenna B

Experimental Results

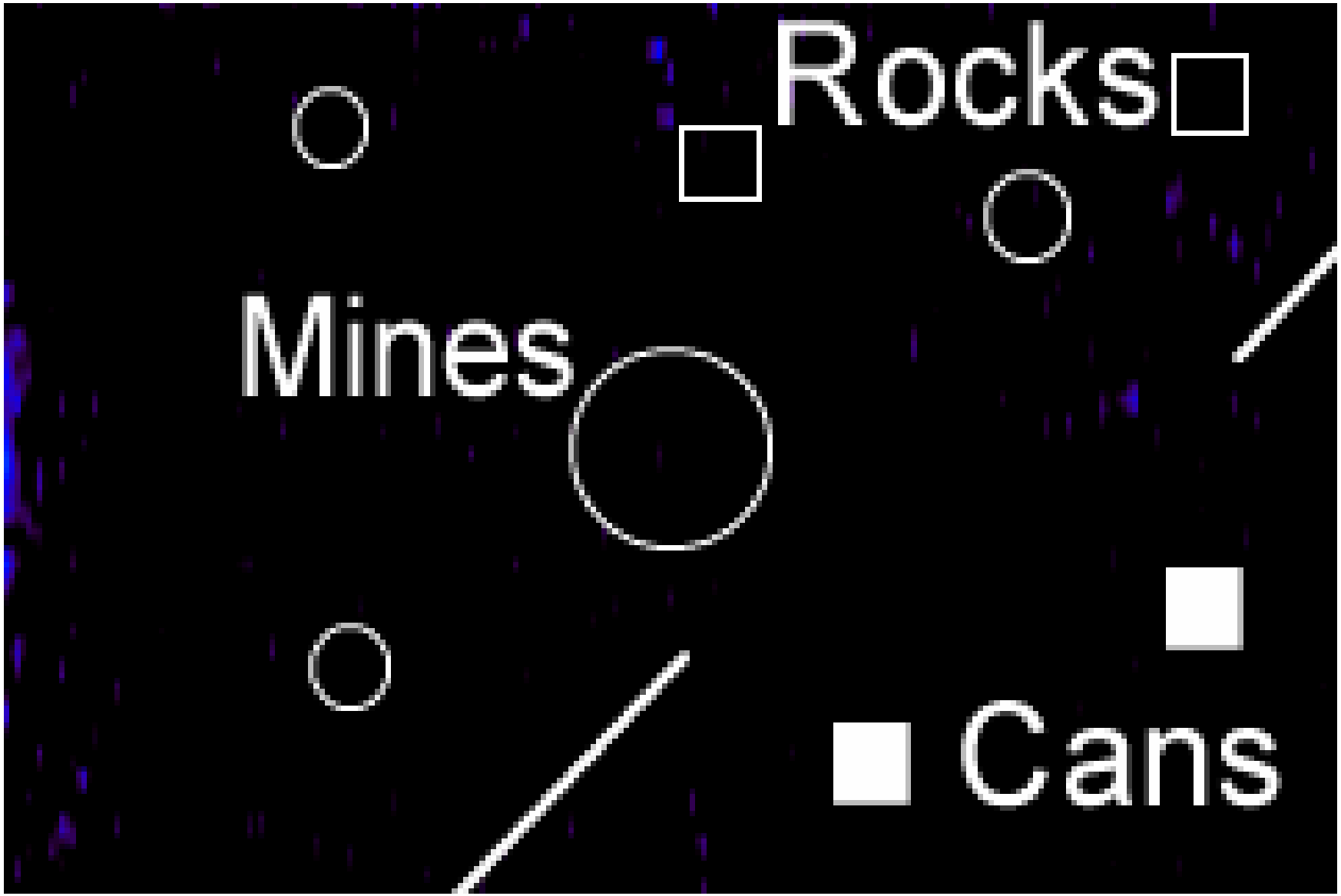
- Single AT (VS1.6) Mine surrounded by Multiple AP mines and clutter.
  - VS1.6 buried 4 cm deep.
  - VS-50 buried 1 cm deep.
  - TS-50 buried 1 cm deep.
  - PFM-1 buried 1 cm deep.
  - Two rocks buried approximately 2 cm deep.
  - Two metal cans buried 2-3 cm deep.
  - Metal rod buried 2 cm deep.
  - Wood stick buried 2 cm deep.

Minefield Covered with 15 cm of Pine Straw

Photograph of the Uncovered Mines and Rocks.

Single AT Mine Surrounded by AP Mines and Clutter

Raw Measured Data: Focused Antenna 20 cm High; 15 cm of Pine Straw

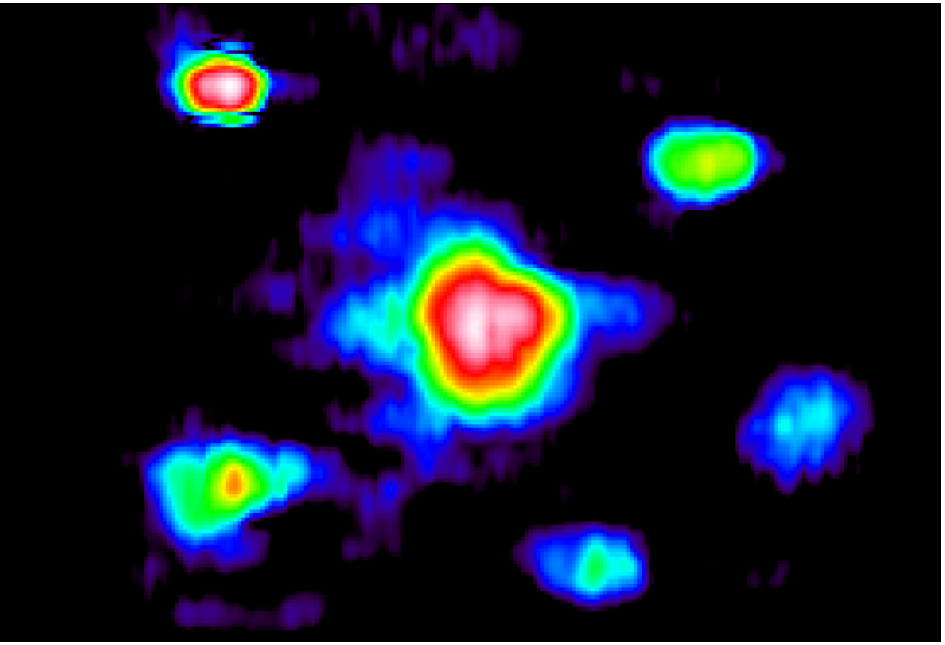


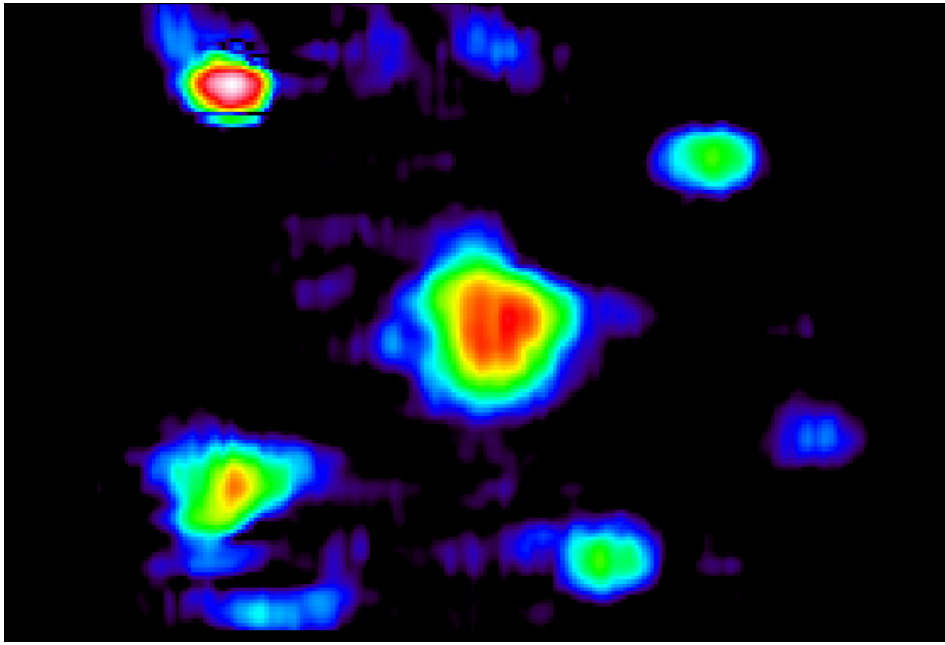
Single AT Mine Surrounded by AP Mines and Clutter

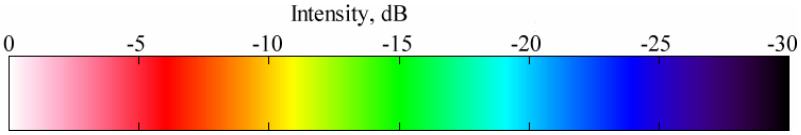
Raw Measured Data: Focused Antenna 20 cm High; 15 cm of Pine Straw
30 dB Scale

Surface Clean

Surface Covered with
15 cm of Pine Straw

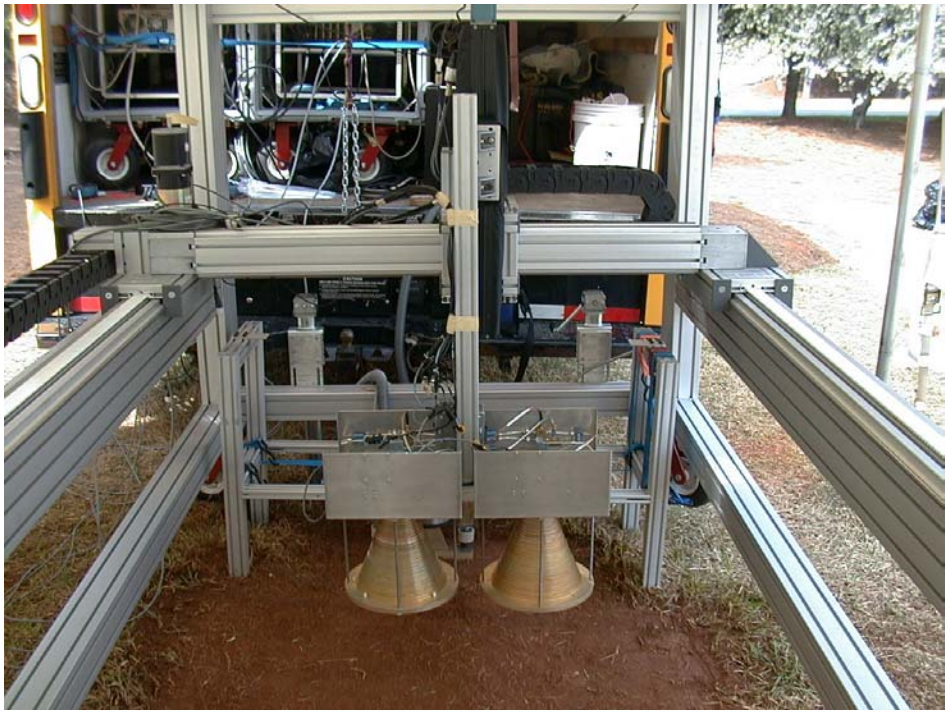






Field Experiment

Georgia Red Clay: CCRF



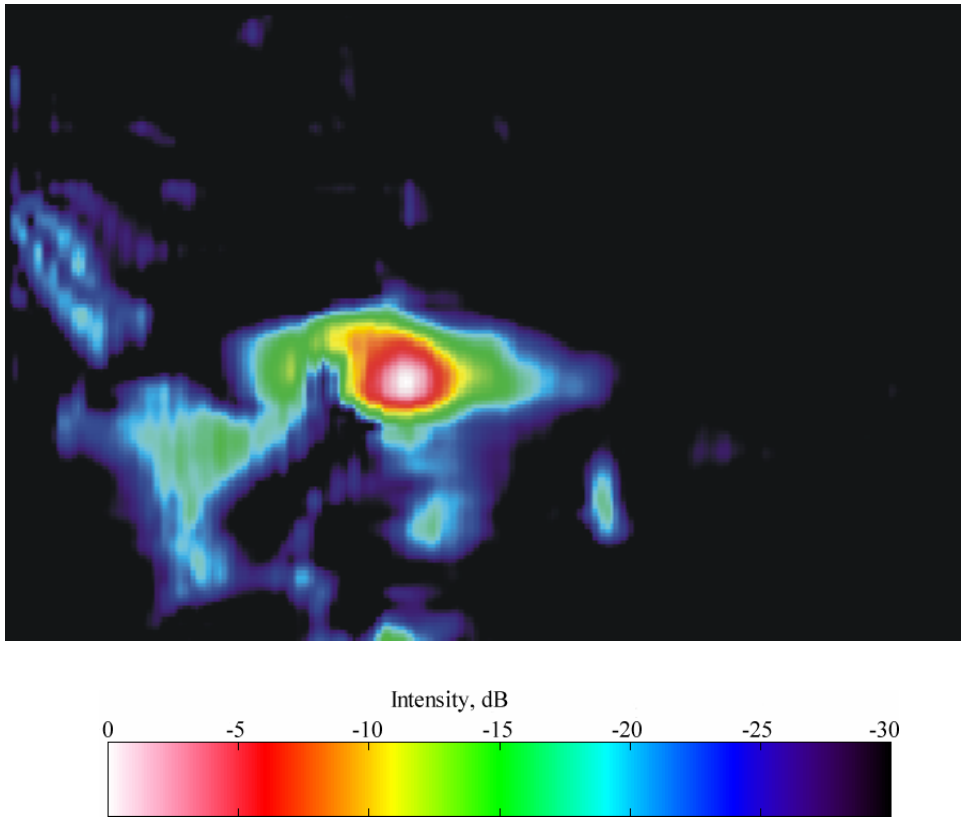
Field Experiment; CCRF

TS-50 Mine 0.5 cm deep

Field Experiment; CCRF

TS-50 Mine 0.5 cm deep

Focused Antenna 20 cm High; 30 dB Scale



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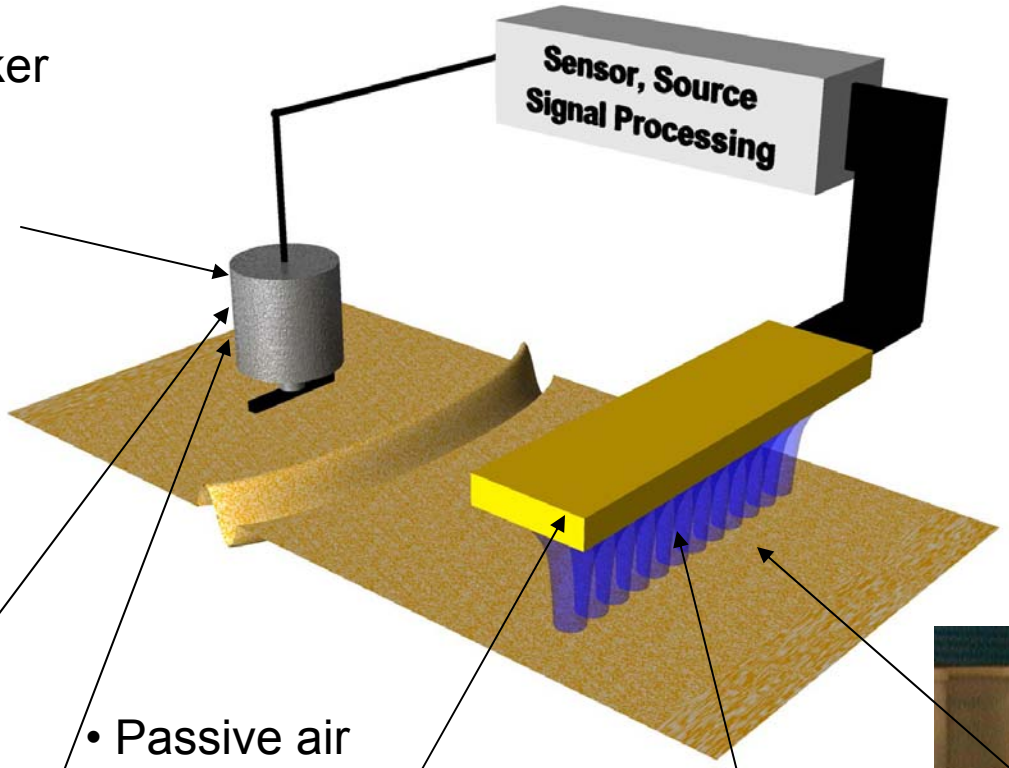
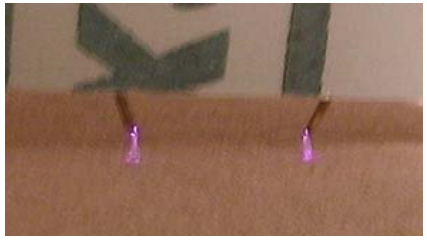
Elastic Wave Sources and Sensors Development



- Electrodynamic Shaker

- Air acoustic source

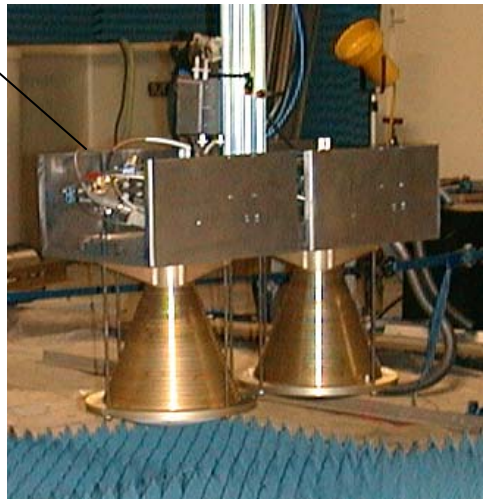
- Electrical arc source



- Passive air acoustic sensor

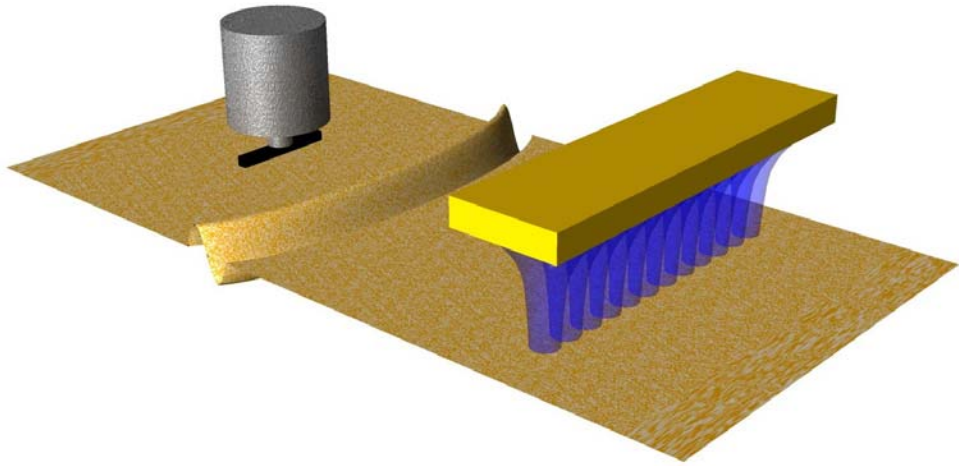
- Ultrasonic sensor

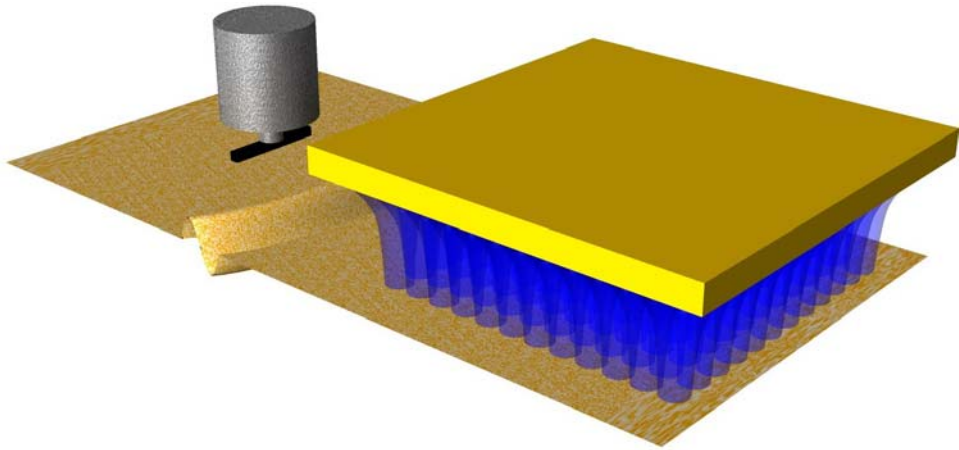
- Radar Sensor



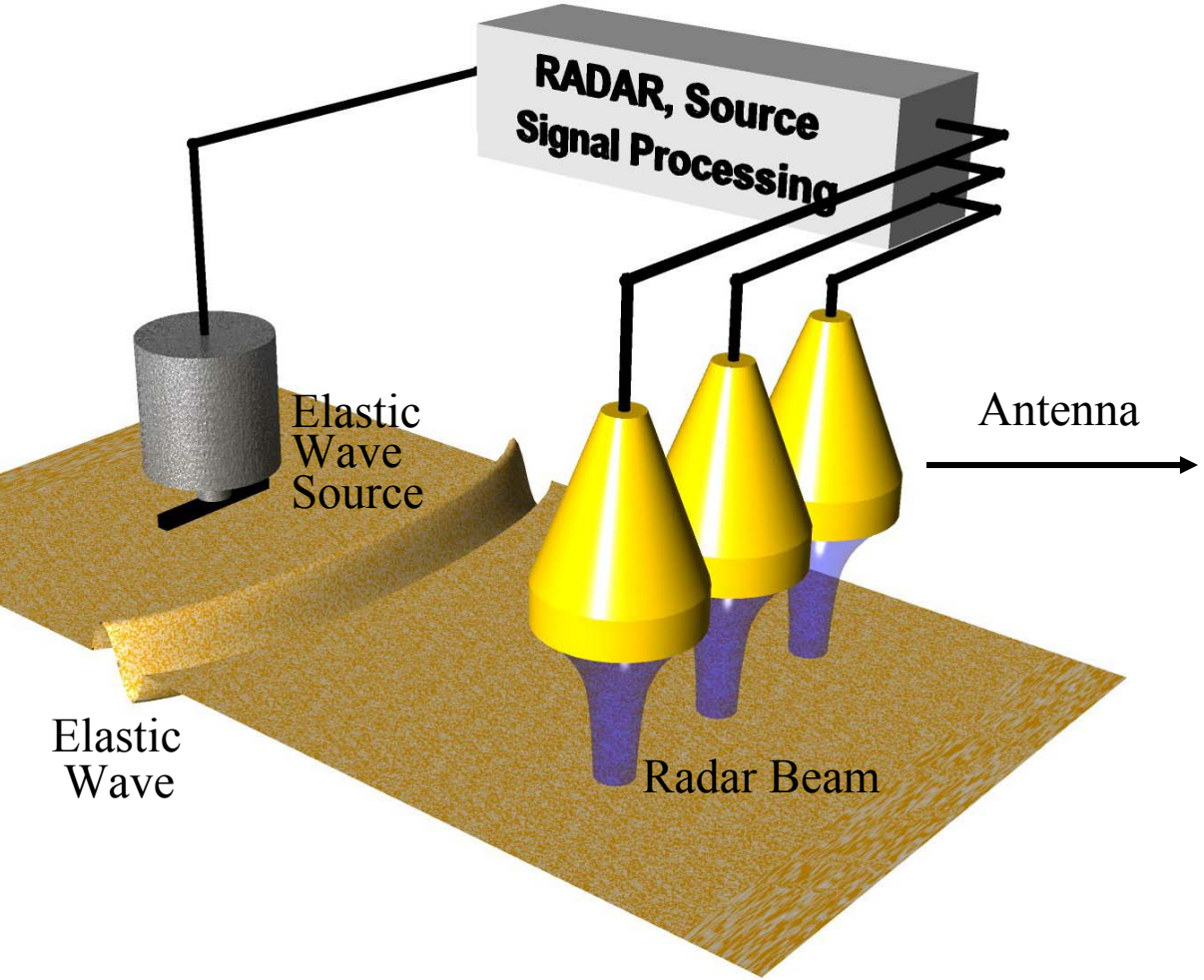
Array of Stand off Sensors

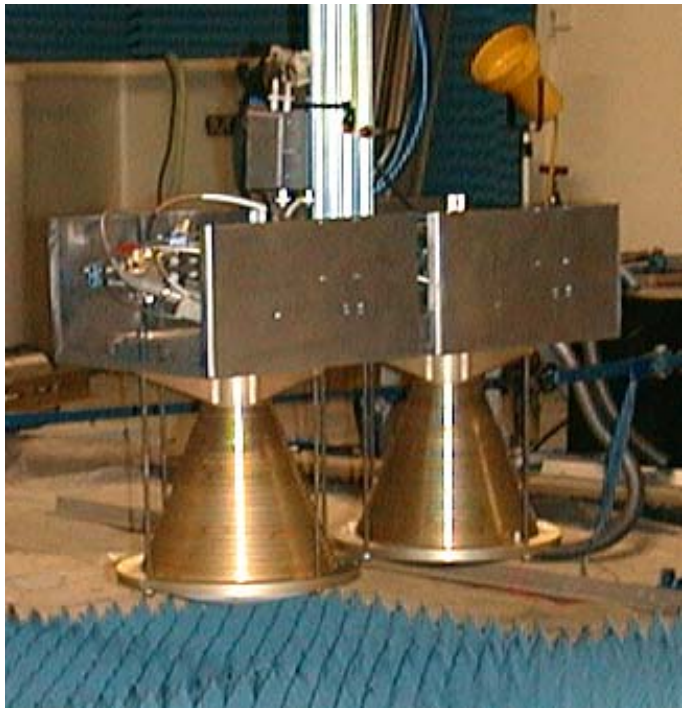
- Requirements
  - Standoff
  - Spatial resolution
  - Sensitivity
  - Speed
    - Linear N element array: N times faster
    - Planar N by N array: N^2 times faster
  - Surface roughness
  - See though surface vegetation/clutter
  - Cost





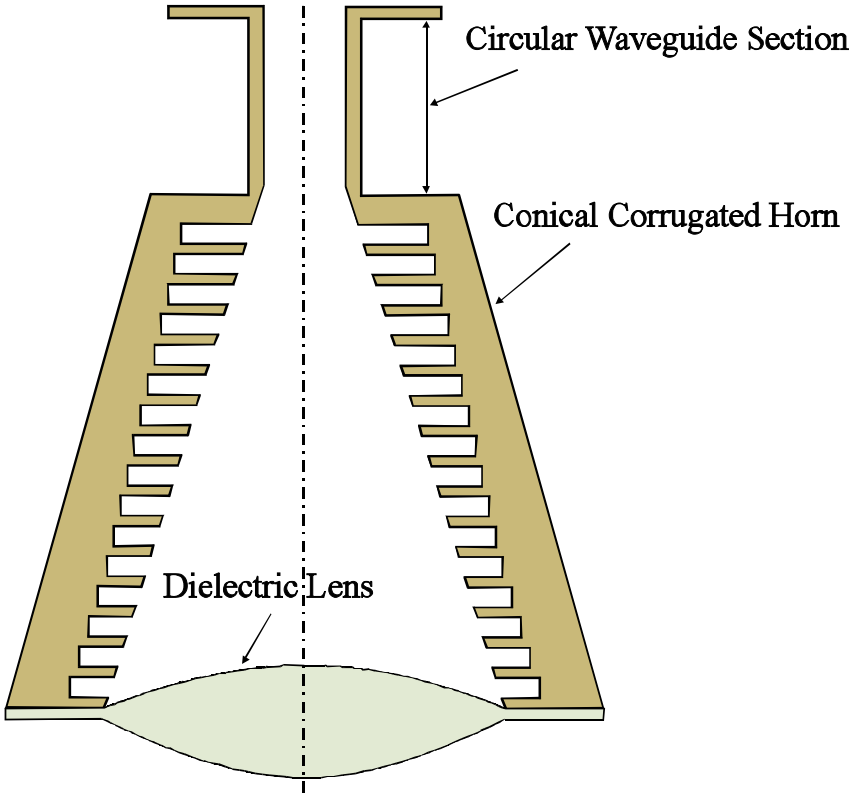
Current Radar Sensor





Lens-Focused
Corrugated Horns

Focused Antenna



Lens-Focused Corrugated Horn

Conclusions

- The technique shows great promising.
  - System detects both simulated AP and AT mines.
  - System discriminates between mine and some common types of clutter.
  - Focused antenna and array perform well.
  - System seems to be robust in varying soil conditions.
- Ongoing investigations.
  - Focused antenna array.
  - Alternative sensor arrays.
  - Signal processing techniques.
  - Mechanical properties of soils (wave speeds vs depth, nonlinearities, etc.).
  - Range of soil types.