

# Experimental Investigation of Techniques for the Detection of Near Surface Targets in Cluttered Media

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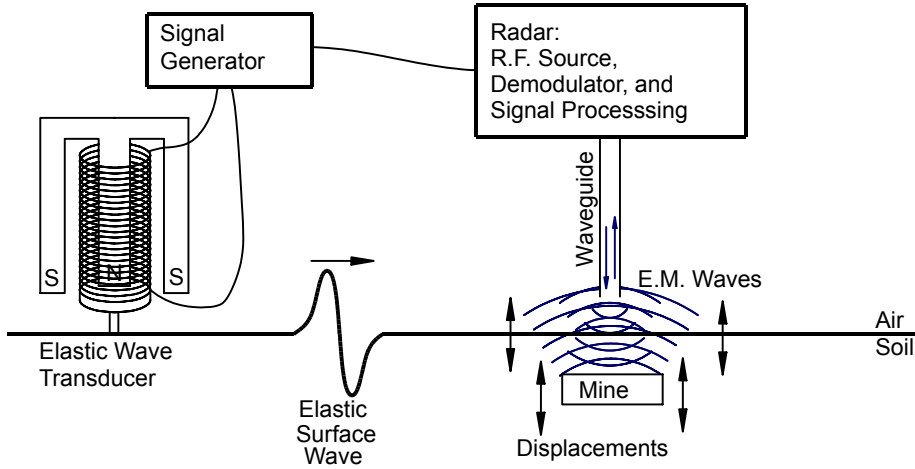
404-894-3048

## Outline

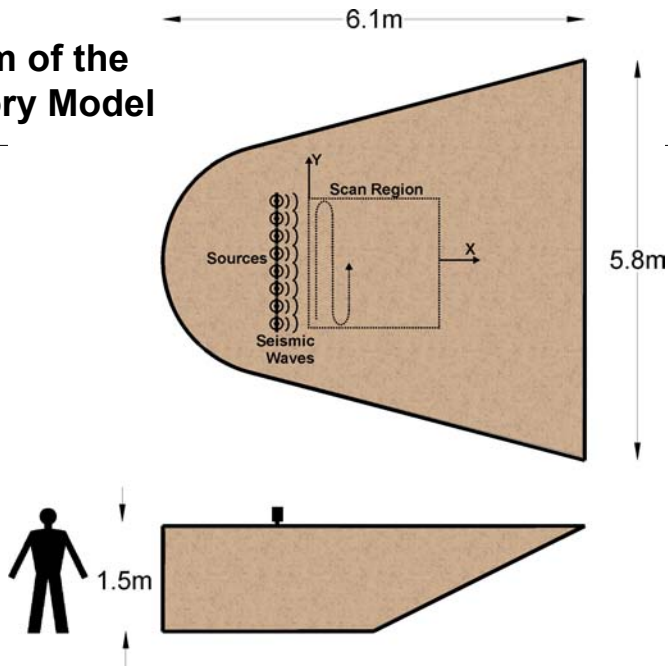


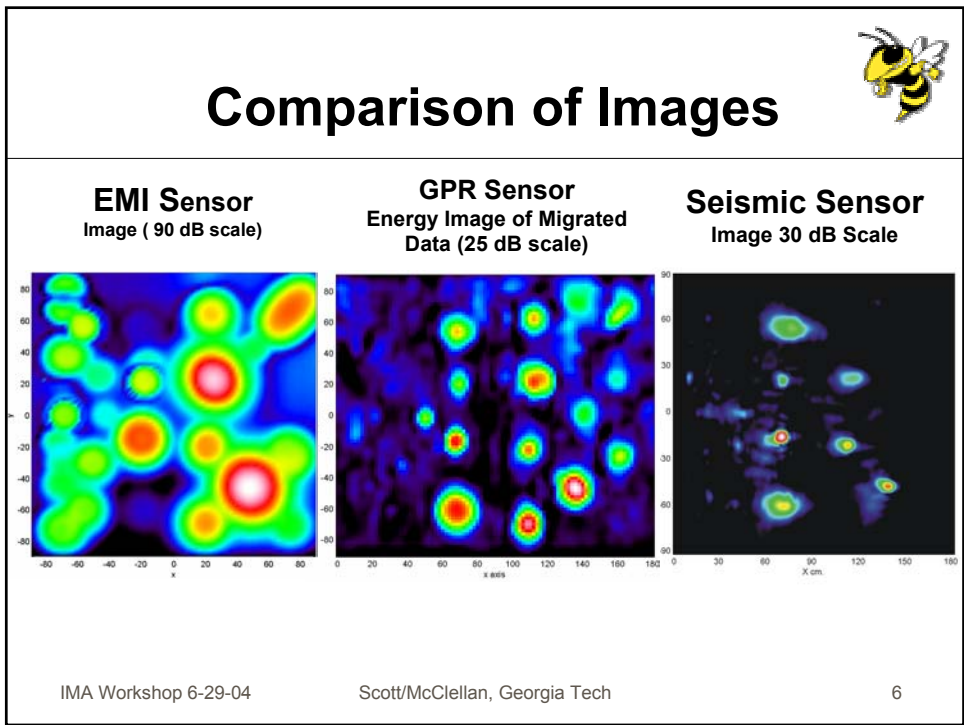
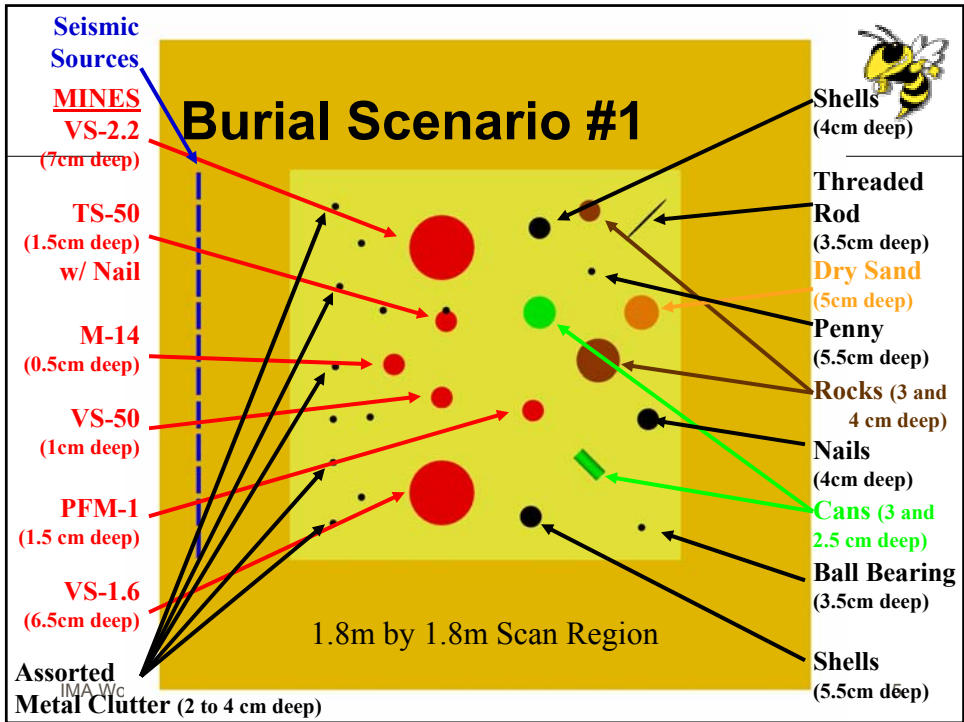
- **Seismic Experiments**
  - Focusing
  - Remote Imaging
- Multi-static Radar

# Seismic Sensor



# Diagram of the Laboratory Model

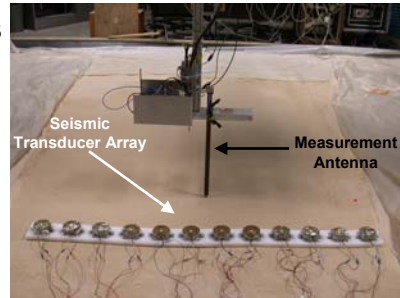




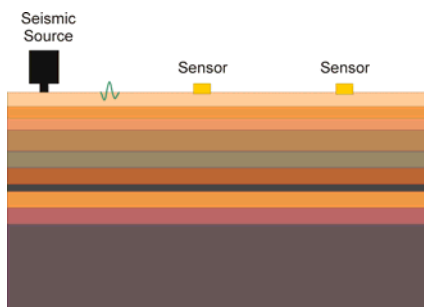


## Experimental Facility

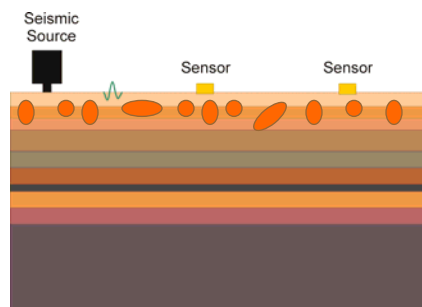
- Sand tank filled with 60 tons damp sand
  - Similar to many soil types
  - Easy to bury objects
- Transducer array excites elastic waves
- Antenna measures displacement in ground
- Data recorded on computer



## Introduce Rocks for Lateral Inhomogeneities



*Sand is Vertically Stratified*



*Add Rocks to Create Scatterers*



# Experimental Facility



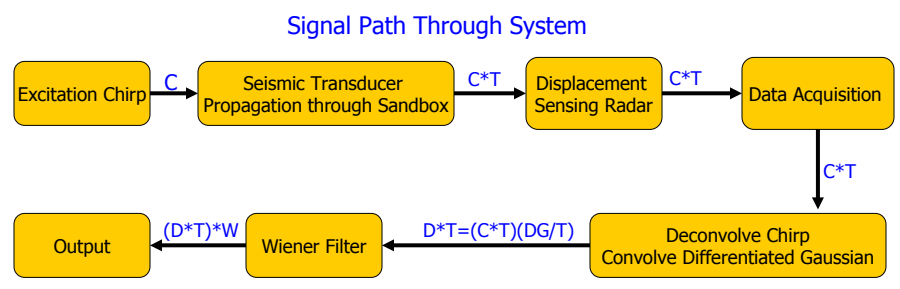
Rocks Randomly Dispersed Throughout Sand Tank



Excavated Scan Region Showing Buried Rock Layout



# Experimental Method





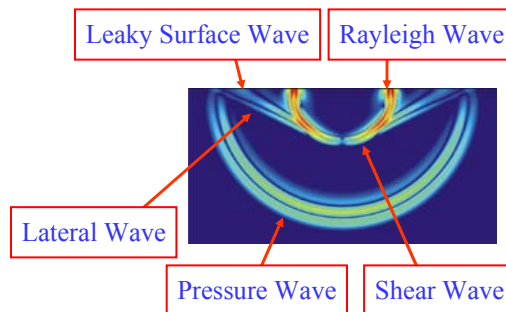
## Wiener Filter: Application

- Motivation
  - Increase bandwidth of excitation signals
  - Make signal more compact in time
- Time Reverse Focusing
  - Excitation signal passes through system elements twice [Seismic transducer, Sand]
  - Wiener filter compensates for these effects, returning frequency content to desired content
- Time Reverse Imaging
  - Original excitation signal becomes very spread out in time, loses high frequency content
  - Difficult to separate: forward traveling waves, reflected waves
  - Wiener filter creates compact excitation pulse: allows for separation of forward and reflected waves



## Complex Wave Propagation

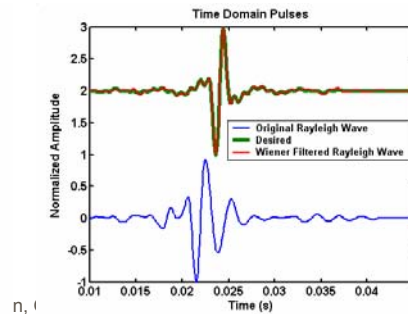
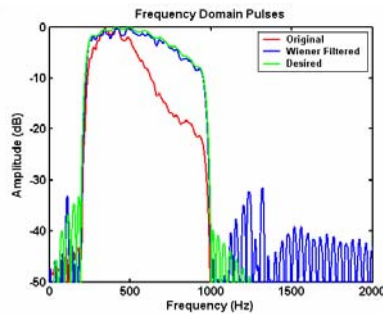
- Wave Propagation is complex
  - 5 wave types for homogeneous half space
  - More wave types for layered half space
  - Clutter
  - Isotropic vs. Anisotropic
  - Linear vs. Nonlinear





# Wiener Filter: Implementation

- Given Signals
  - Input
  - Desired output: bandlimited differentiated Gaussian pulse
- Filter Implementation
  - LMS Filter
  - Compute coefficients using Steiglitz-McBride method



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# Outline

- Seismic Experiments
  - Focusing
  - Remote Imaging
- Multi-static Radar



# Focusing

- The seismic system only works in areas where there is sufficient incident seismic energy.
  - The incident seismic energy can be blocked/redirected by inhomogeneities in the ground.

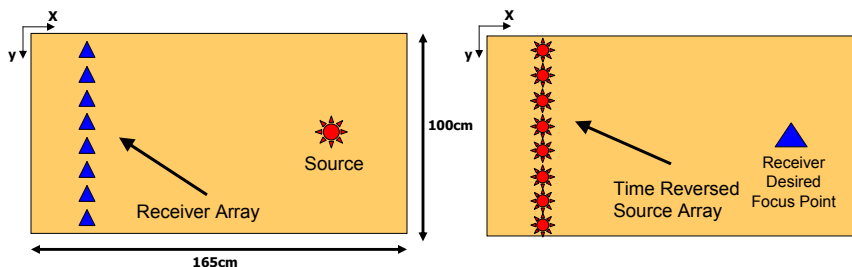
or

- Only a small region may need investigating with the seismic system.
- Reverse-Time processes can focus energy in a specified region



# Geometry

- Excitation sent out from source
- Signal is recorded at an array of sensors
- Signal is reversed in time
- Reversed Signal is used to excite sources at array locations
- Propagating waves should focus at location of original source

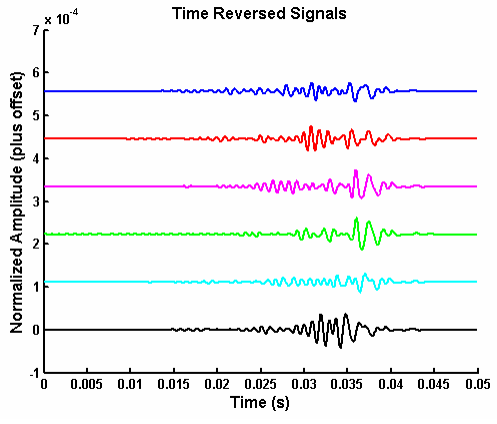
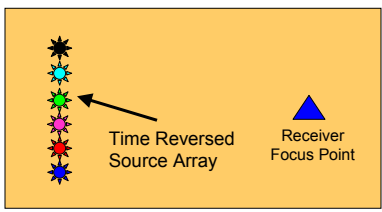


Forward Problem

Time Reverse Problem



# Time-Reverse Signals

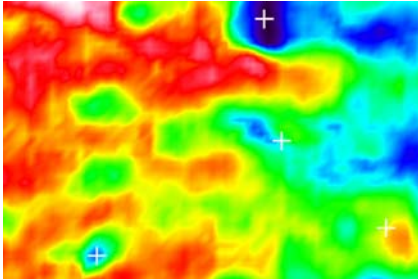


# Experimental Results

Identical Excitations  
40dB Scale



# Time-Reversal Focus Locations



Maximum Displacement for Identical Excitation  
Locations chosen for focusing are indicated  
20dB Scale



Layout of rocks in experimental setup  
Locations chosen for focusing are indicated

# Experimental Results

Time-Delayed Excitations  
40dB Scale



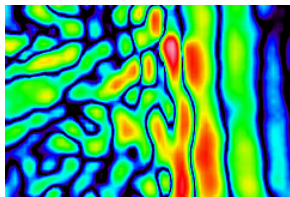
# Experimental Results

Time-Reversed Excitations  
40dB Scale

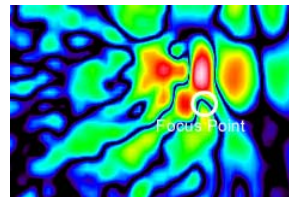


# 3 Focus Methods

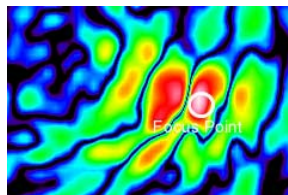
Snapshot at Focus  
40dB Scale



Identical Excitation



Time-Delayed Excitation

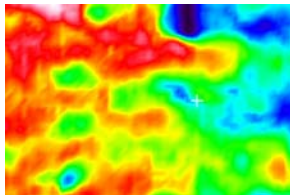


Time-Reversed Excitation

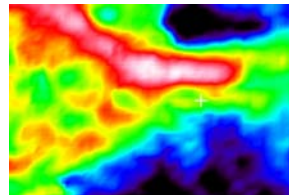
# 3 Focus Methods

## Maximum Displacement

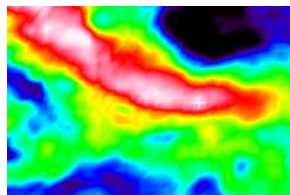
20dB Scale



Identical Excitation



Time-Delayed Excitation

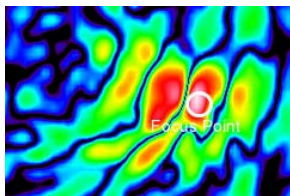


Time-Reversed Excitation

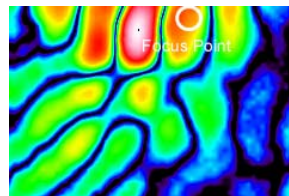
# Time-Reversal

## Snapshot at Focus

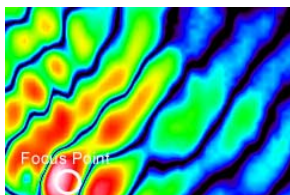
40dB Scale



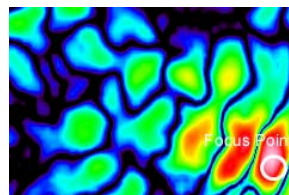
Focus: (80,0)



Focus: (75,35)

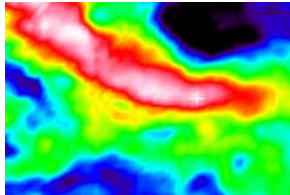


Focus: (27,-33)

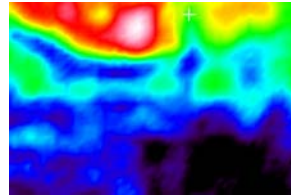


Focus: (110,-25)

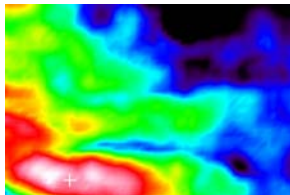
# Time-Reversal Maximum Displacement 20dB Scale



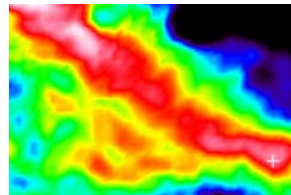
Focus: (80,0)



Focus: (75,35)



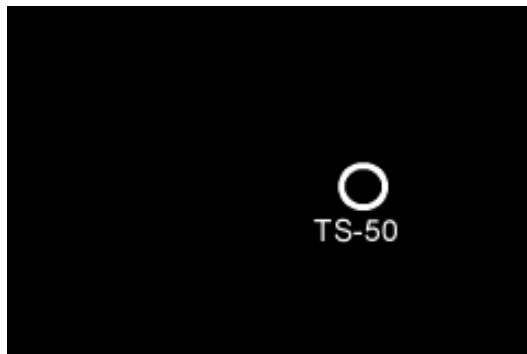
Focus: (27,-33)



Focus: (110,-25)

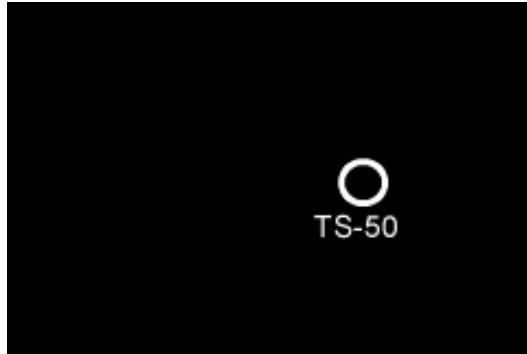
# Experimental Results

Identical Excitations: TS-50 @ (80,0)  
40dB Scale



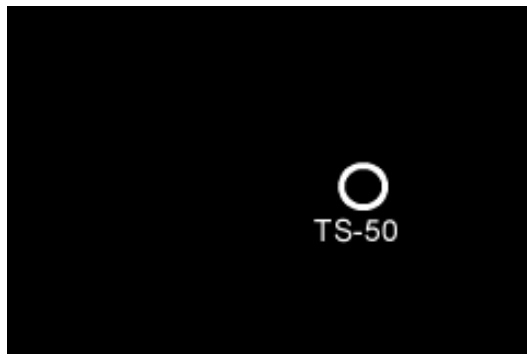
# Experimental Results

Time-Delayed Excitations: TS-50 @ (80,0)  
40dB Scale



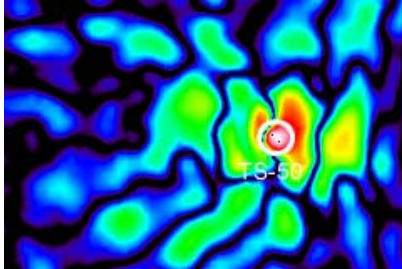
# Experimental Results

Time-Reversed Excitations: TS-50 @ (80,0)  
40dB Scale

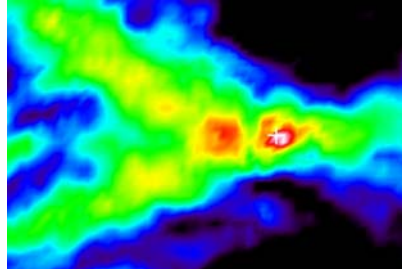


# Experimental Results

Time-Reversed Excitations: TS-50 @ (80,0)



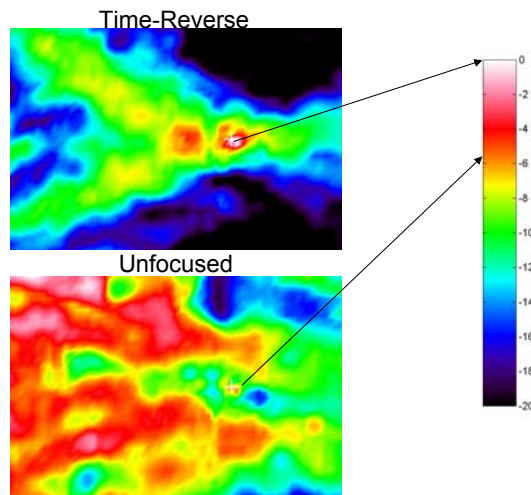
Snapshot at Focus  
40dB Scale



Maximum Displacement  
20 dB Scale

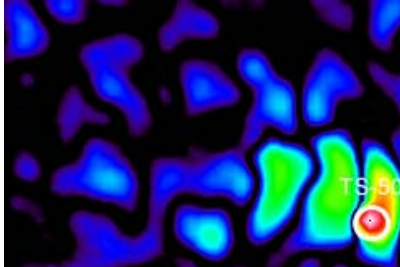
# Maximum Displacement:

TS-50 @ (80,0)

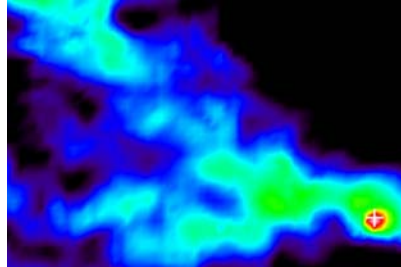


# Experimental Results

Time-Reversed Excitations: TS-50 @ (110,-25)



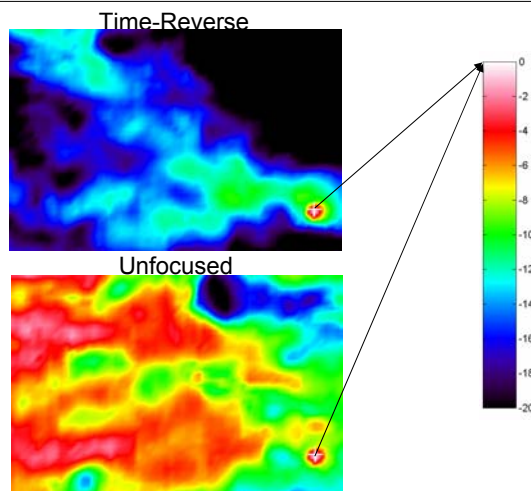
Snapshot at Focus



Maximum Displacement

# Maximum Displacement:

TS-50 @ (110,-25)

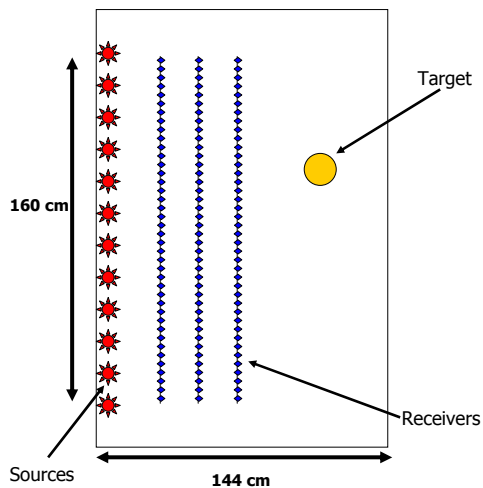


# Outline



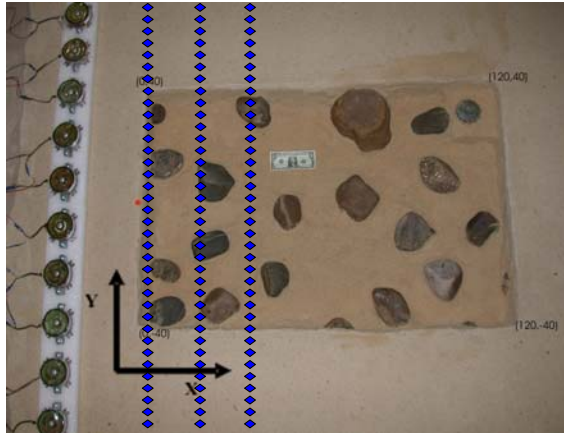
- **Seismic Experiments**
  - Focusing
  - **Remote Imaging**
- Multi-static Radar

# Time-Reverse Imaging Data Acquisition



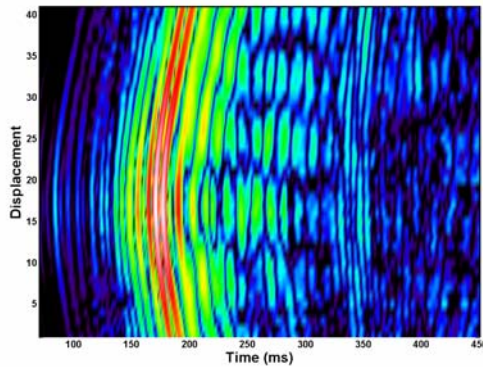
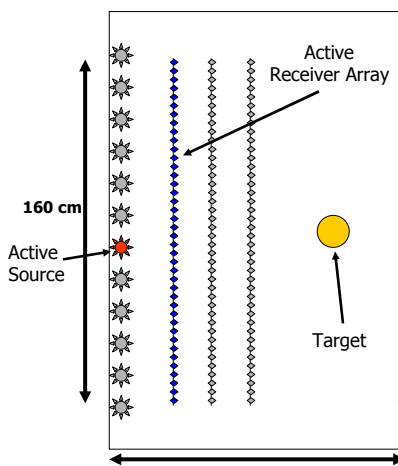
- Sources
  - 15 cm spacing
  - Independently controlled
- Receivers
  - 120 receivers [40 x 3]
  - 2 cm spacing in array
  - 15 cm between arrays
- Measurements
  - 12 sources x 120 receivers
  - 1440 independent measurements

# Time-Reverse Imaging Data Acquisition



Photograph of layout for time-reverse imaging  
Region of interest is excavated. Dollar bill is for scale

# Time-Reverse Imaging Data Acquisition



Displacement on active receiver array  
for a single active source  
50 dB scale

# Outline

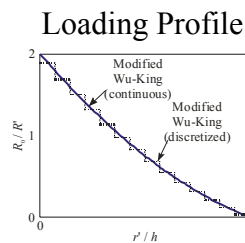
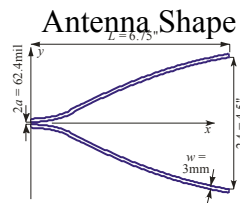


- Seismic Experiments
  - Focusing
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# GPR Sensor

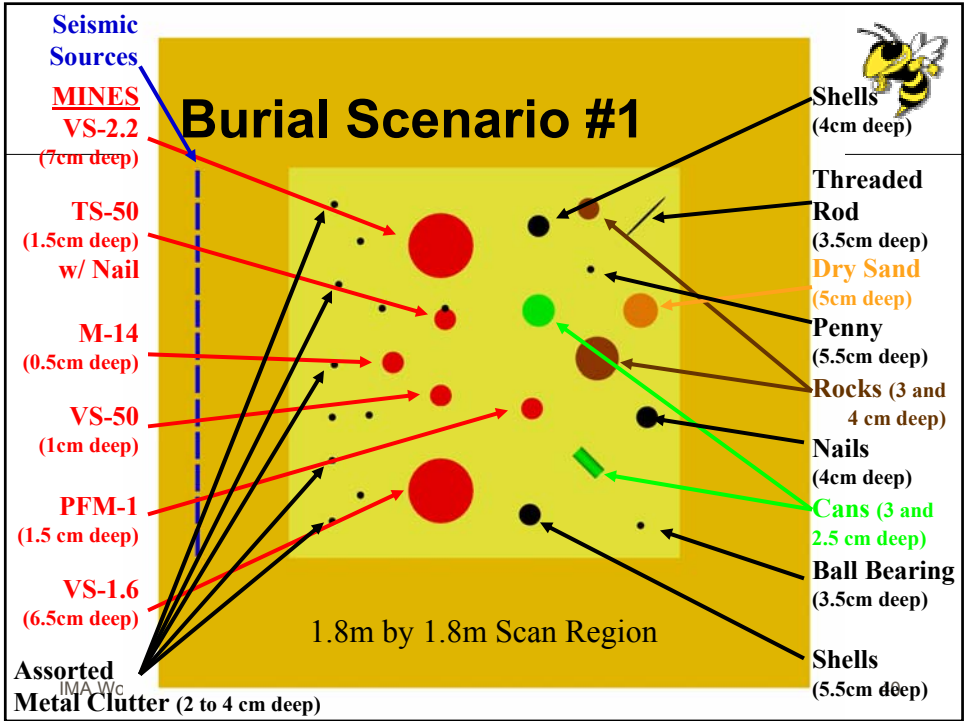
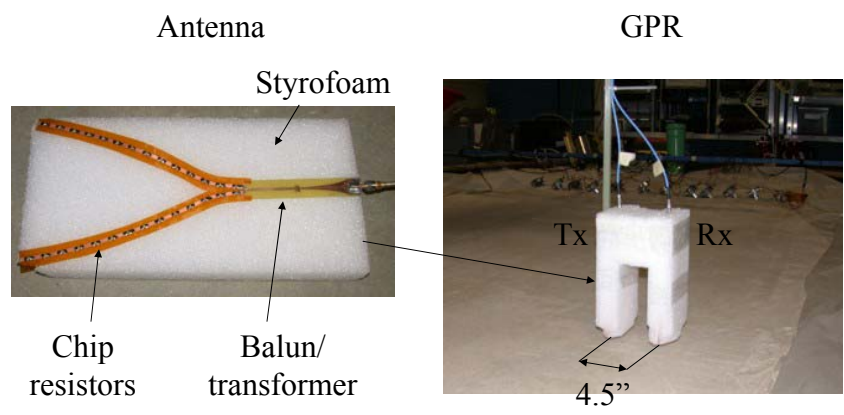


- Data taken in frequency domain with network analyzer: 500 MHz to 8 GHz
- Antennas
  - Characteristics of Resistive Vee Dipole:
    - Radiates short, directive pulse
    - Low radar cross section
    - Low internal clutter
    - Light and array-able
    - Easy to manufacture
  - Shape & profile have been optimized.



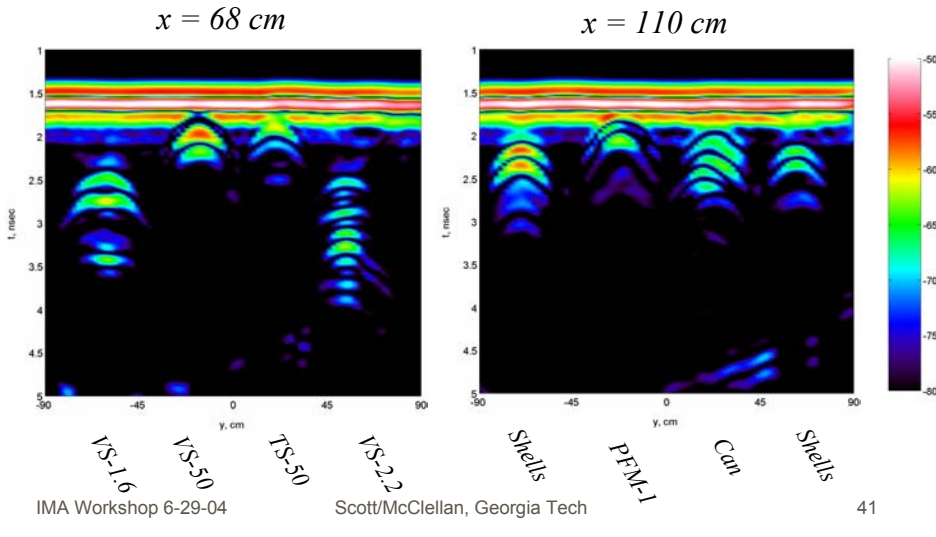


# GPR Sensor

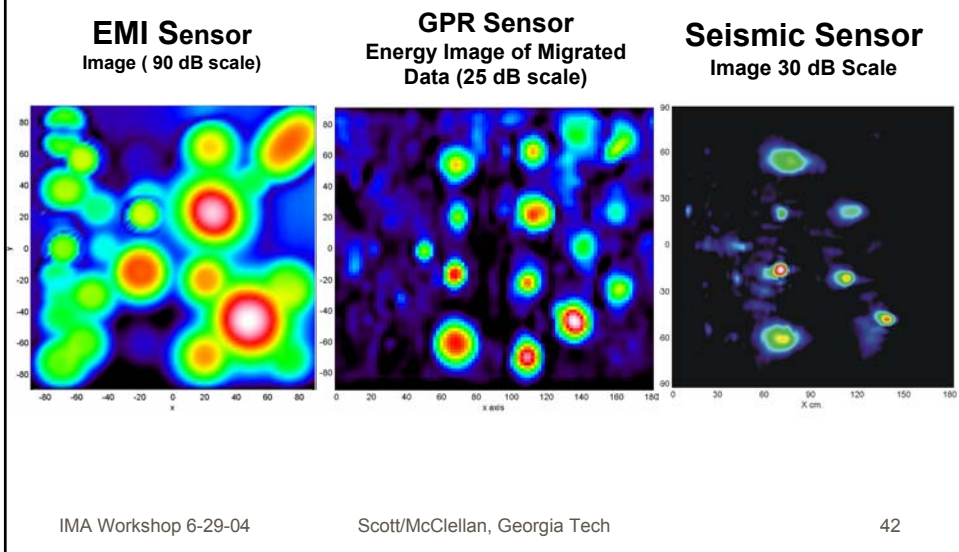


Assorted  
IMA VVC  
Metal Clutter (2 to 4 cm deep)

# GPR Sensor Raw Data-Air Data



# Comparison of Images





# Antenna & Array Assembly

Port-2 Out, Tx-2, Port-1 Out, Tx-1, Port-1 In, Rx-1, Port-2 In, Rx-2, switch, Rx-3, Rx-4

Heat-sealable plastic sheet

Absorber

48cm, 12, 12, 12, 12

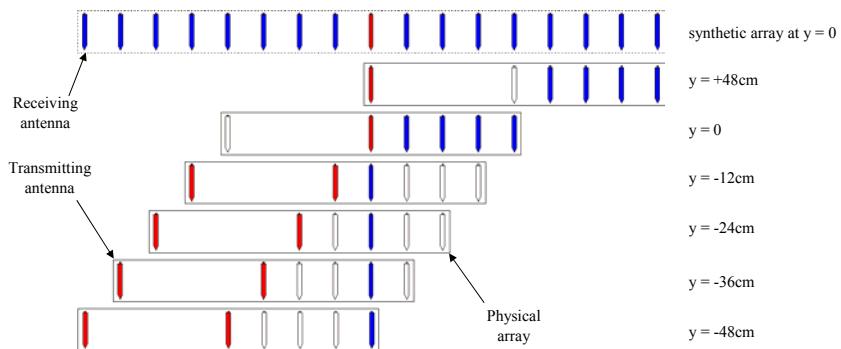
Resistively-Loaded Vee, Double-Y balun, Styrofoam, FR-4 Support Panel

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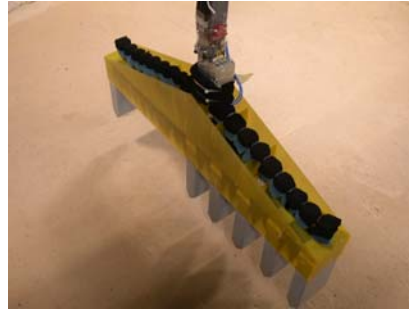
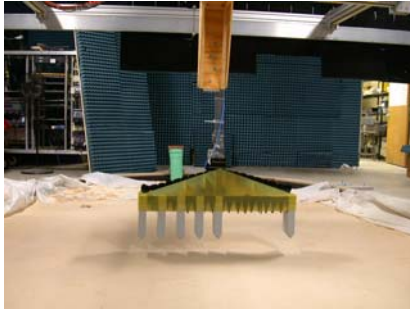


# GPR Array

We can obtain 192cm-wide synthetic array aperture by using reciprocity and synthesizing the scans at 6 positions



# 10cm Diameter Metal Sphere at $y=0$ , Buried 25cm Deep

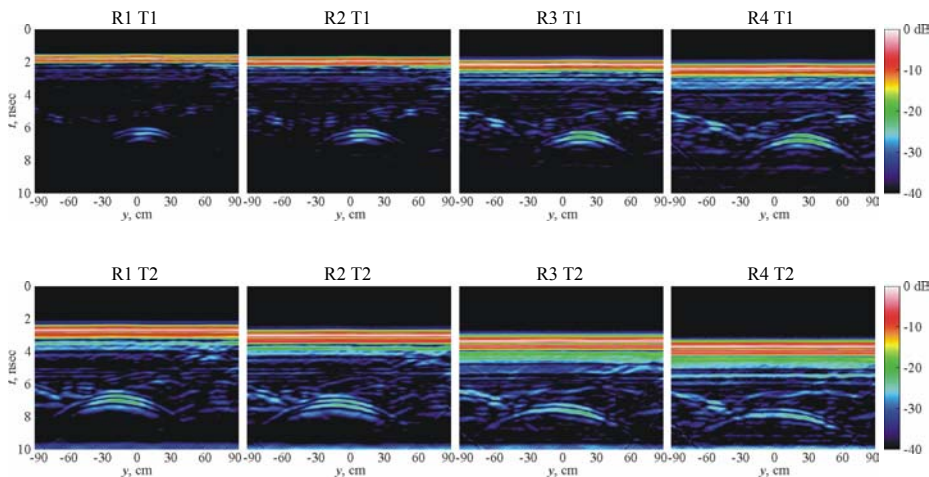


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# 10cm Diameter Metal Sphere at $y=0$ , Buried 25cm Deep



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# 10cm Diameter Metal Sphere at $y=0$ , Buried 25cm Deep with Surface Clutter

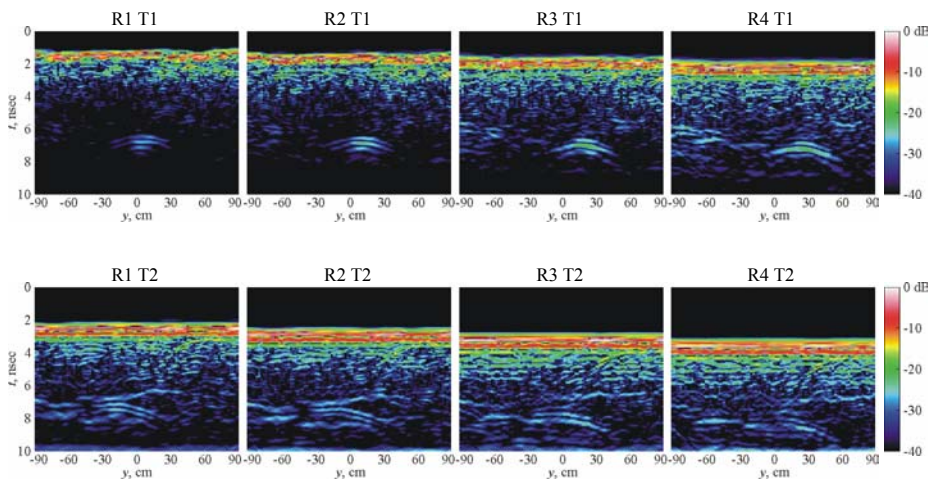


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# 10cm Diameter Metal Sphere at $y=0$ , Buried 25cm Deep with Surface Clutter



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