Investigating Ultrasonic Diffraction Grating Spectroscopy and Reflection Techniques for Characterization Slurry Properties

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Environmental Management Science Program
High Level Waste Workshop
Savannah River National Laboratory
January 19-20, 2005

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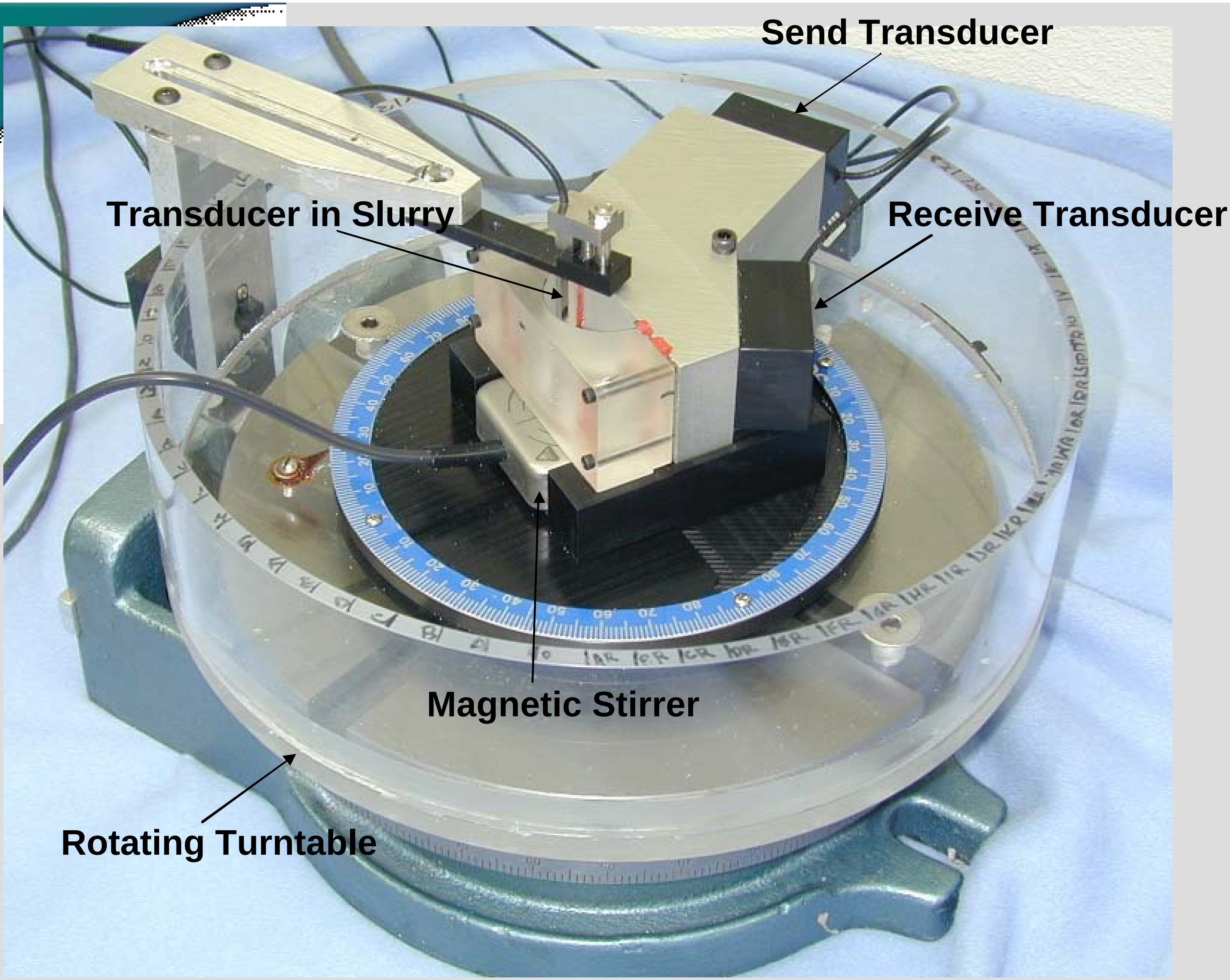
Research Objectives

- Develop ultrasonic diffraction grating spectroscopy for the measurement of particle size.
    1. Perform experiments with increased sensitivity for particle size measurement.
    2. Computer modeling for the passage of ultrasound through an ultrasonic grating.
- Utilize the reflection of ultrasonic shear waves for the measurement of viscosity.



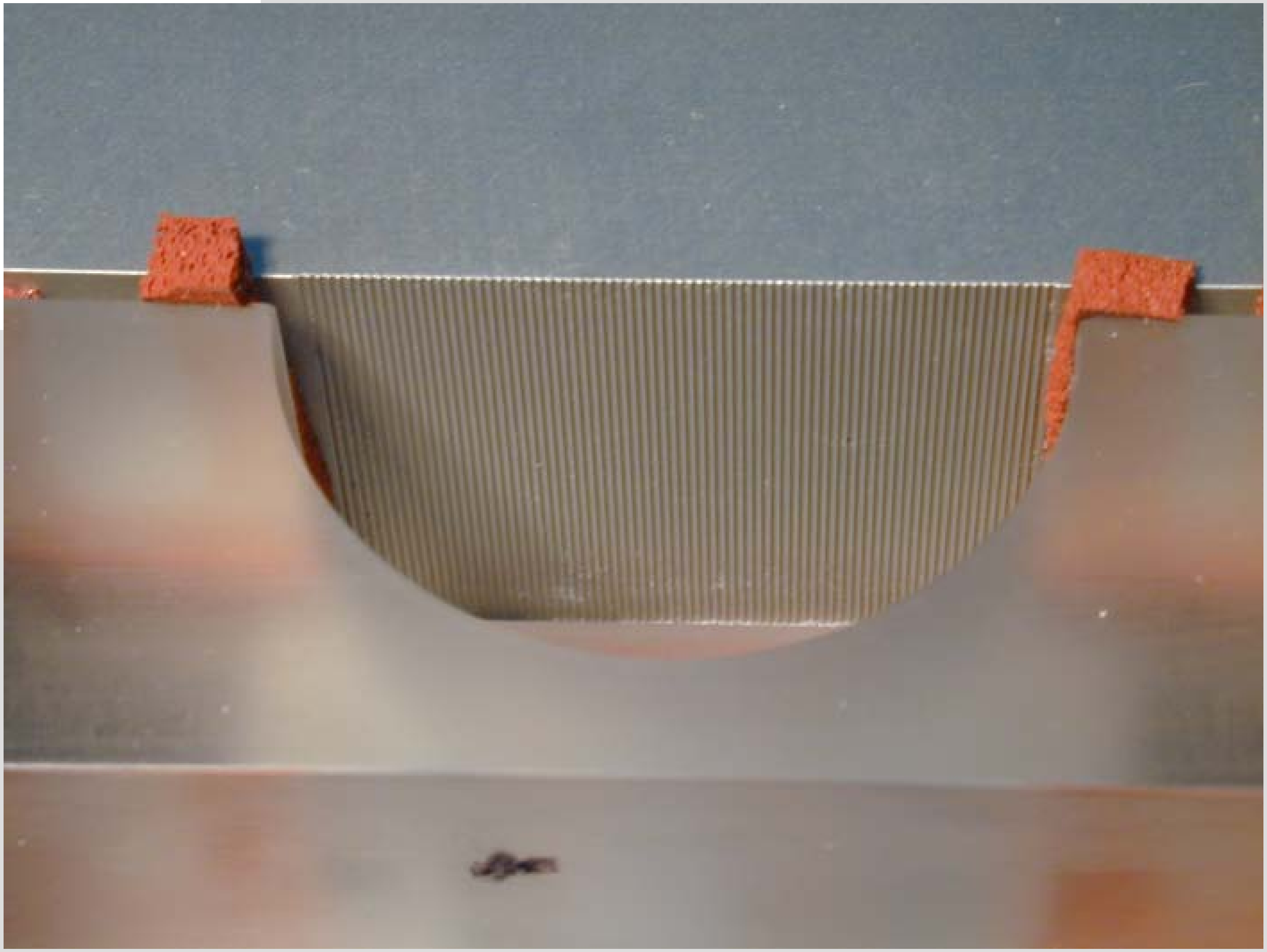
Send Transducer

Transducer in Slurry

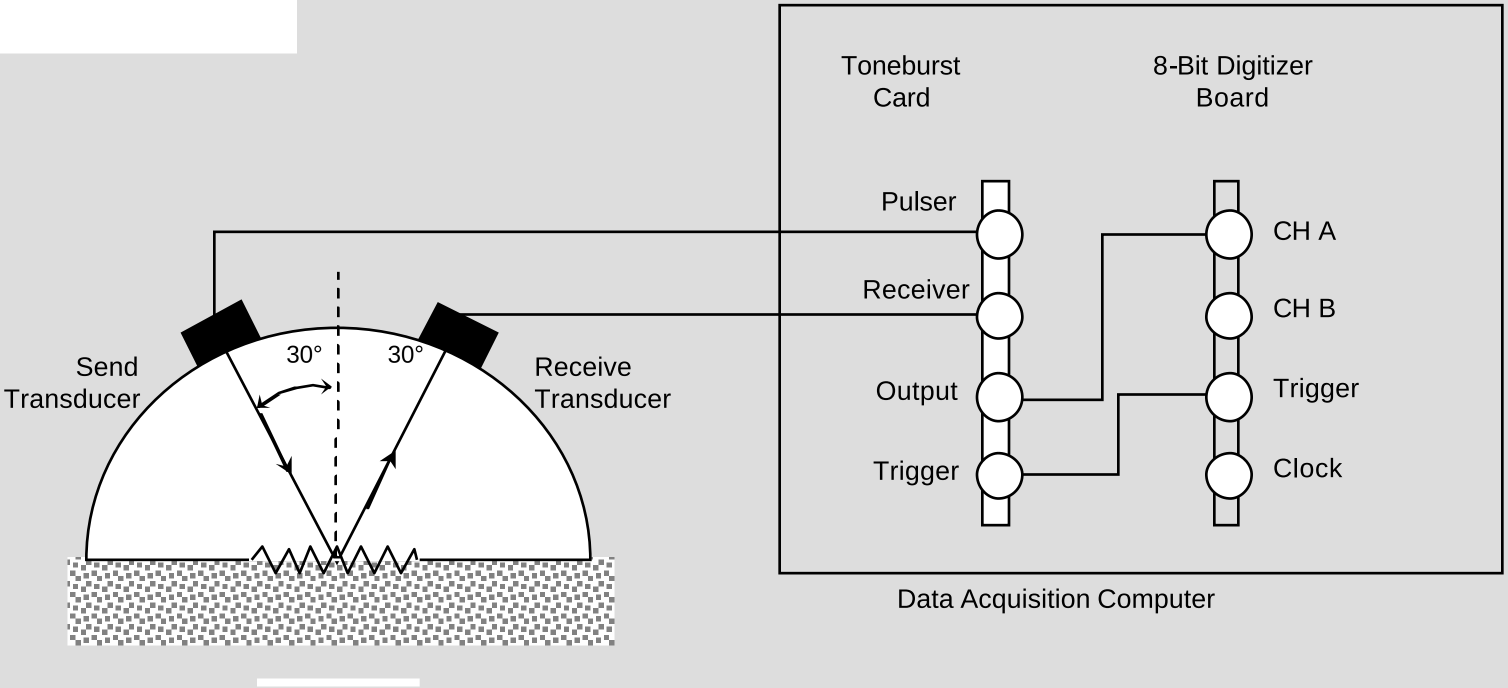
Receive Transducer

Magnetic Stirrer

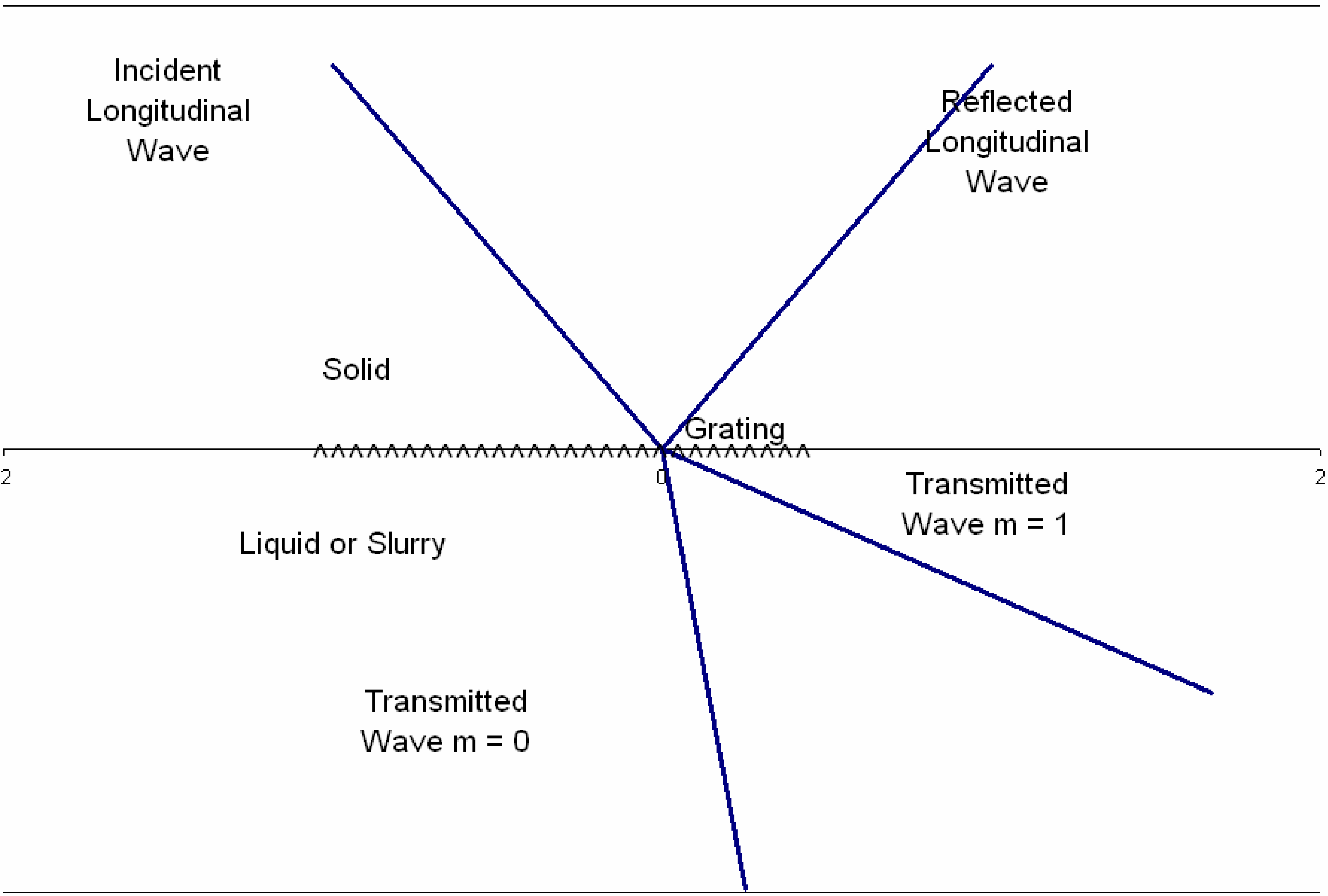
Rotating Turntable



Experimental Setup for UDGS


Toneburst
Card
8-Bit Digitizer
Board
Pulser
Receiver
Output
Trigger
CH A
CH B
Trigger
Clock
Send
Transducer
Receive
Transducer
30°
30°
Data Acquisition Computer

Observation of Peak


Incident
Longitudinal
Wave
Reflected
Longitudinal
Wave
Solid
Grating
-2
0
2
Transmitted
Wave m = 1
Liquid or Slurry
Transmitted
Wave m = 0

Critical Frequency

- As the frequency of ultrasound decreases, the angle of the m = 1 transmitted wave in the liquid increases. At a frequency, called the critical frequency, the angle reaches 90º.
- At the critical frequency

Traveling wave → evanescent wave

- At a frequency < critical frequency, m = 1 transmitted wave disappears.
- Conservation of energy: Energy is redistributed to all other waves.

↓

- Peak in data in receive transducer at critical frequency.

Need for Theoretical Modeling

- Currently the ultrasonic diffraction gratings are machined using a symmetric triangular groove, with 110° or 120° included angle.
  - Q: Would a smaller angle be better?
  - Q: Should the groove be tilted at an angle?
  - Q: Should the groove be deeper?
  - Q: What material is best for the grating?
  - Q: *How can more energy be directed to the m = 1 transmitted wave and less to m = 0?*

- In *optical* spectroscopes, the wavelength is obtained using m = 1(or order not equal to zero) and blazed gratings are used to obtain more energy in the m = 1 order. Wood’s gratings were seen to light up, or “blaze” when viewed at the correct angle. One goal of the computer modeling is to find the conditions for a “blazed grating” for ultrasonics.
- This research is being performed by Dr. Salahuddin Ahmed.

Measurement of Velocity

- Grating spacing
- Velocity of sound in grating material
- Incident angle of ultrasound striking grating
- Velocity of sound in liquid or slurry

Critical frequency ⟷ Velocity of sound in liquid or slurry

Measurement of Particle Size

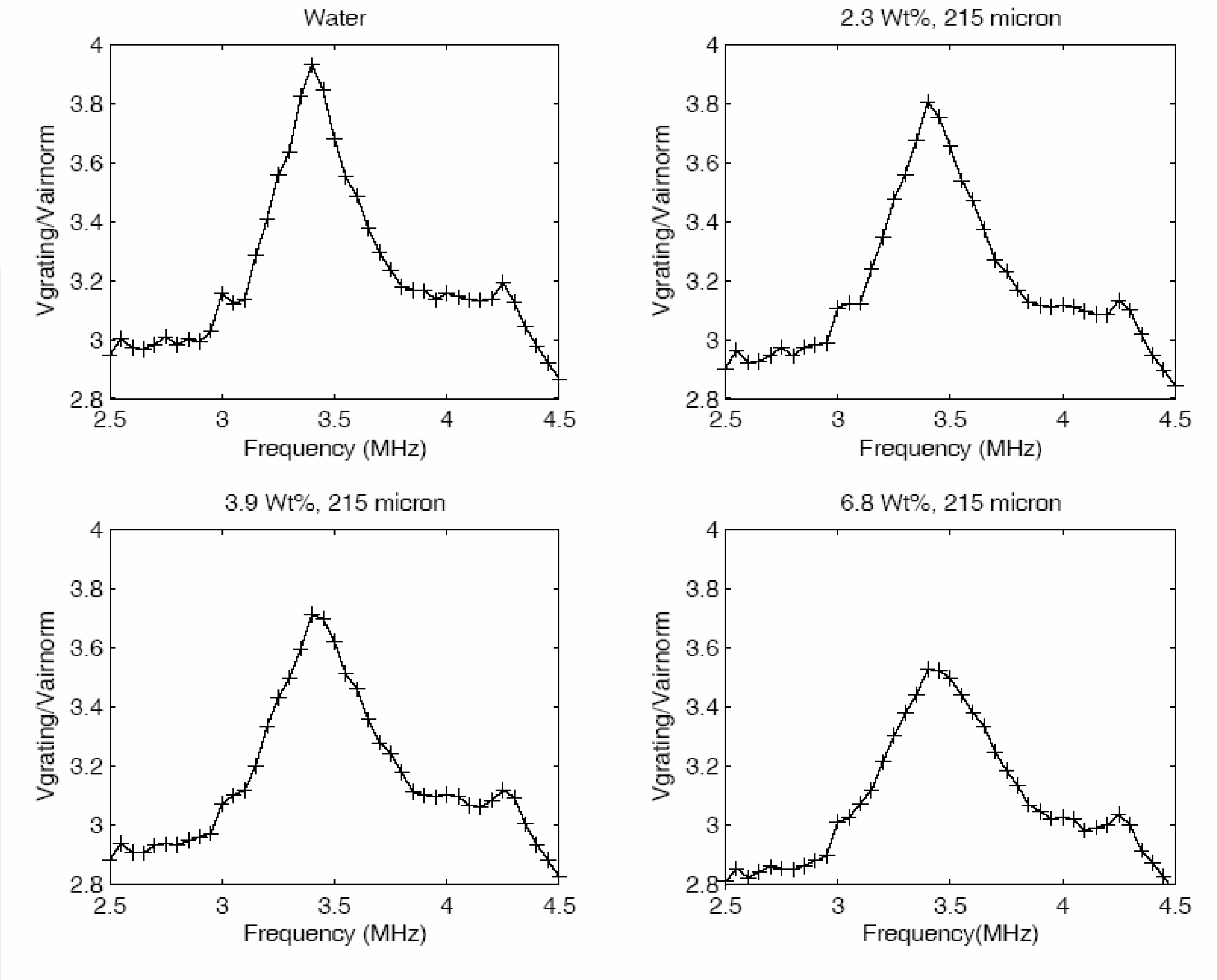
- When the critical frequency is reached, an evanescent wave is produced. This is a traveling wave parallel to the grating surface (complex exponential) whose amplitude decays exponentially (real exponential) in the direction perpendicular to the grating surface.
- Essentially, the evanescent wave is similar to a surface wave traveling along the grating surface.
- Energy is lost through interaction with the particles. Therefore, the signal in the receive transducer is smaller. This effect depends upon particle size.

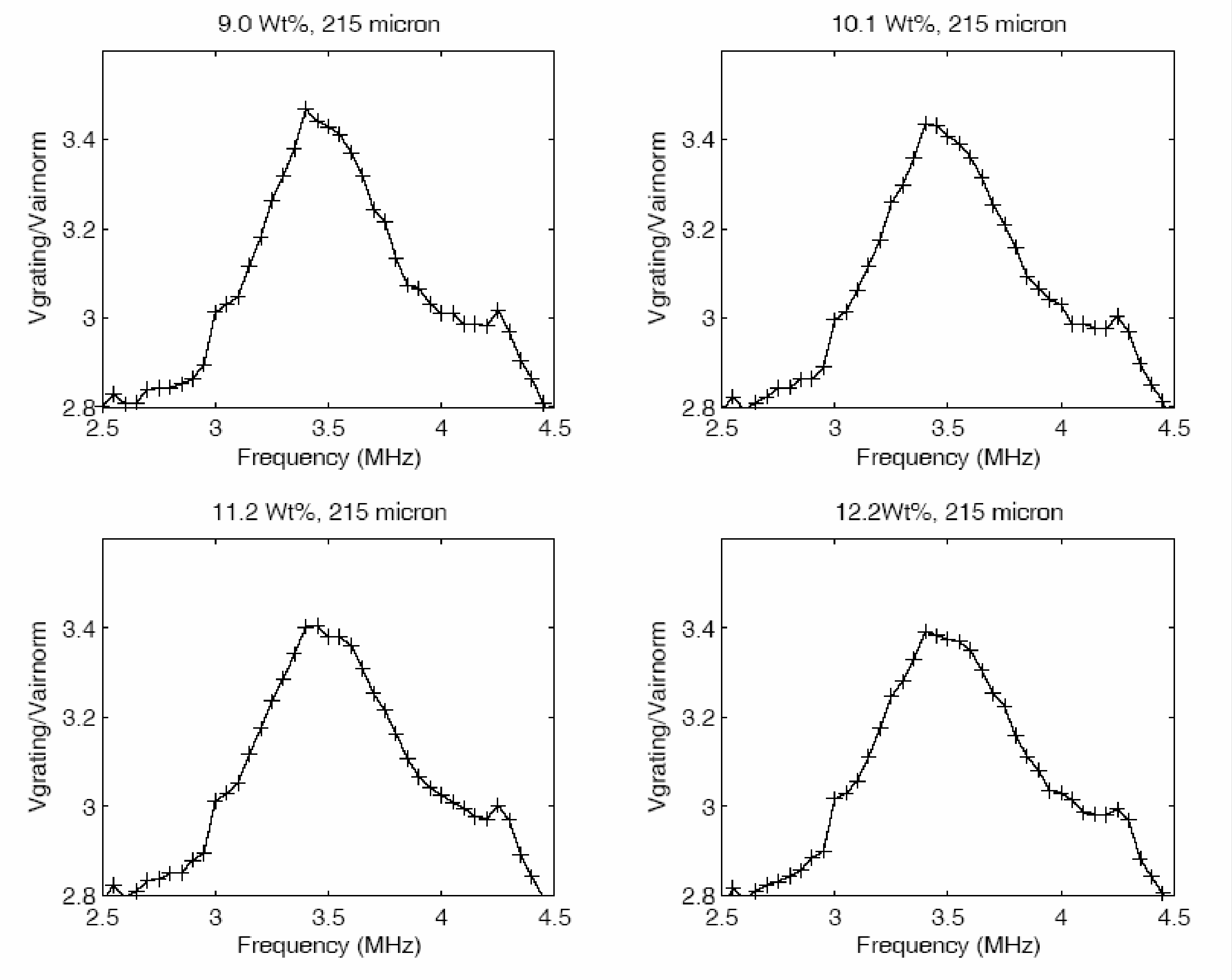
Recent Data with Polystyrene Spheres

- Grating spacing = 483 microns >>>Critical frequency = 3.4 MHz.
- Aluminum grating to maximize ultrasonic wave in slurry.
- Polystyrene sphere diameters of 215, 275, 363, and 463 microns.
- Weight percentages of spheres in water range from 1 to 12%.
- Amplitude of signal in receiver obtained as frequency changes in steps of 0.05 MHz.
- Peak height above background defined as:

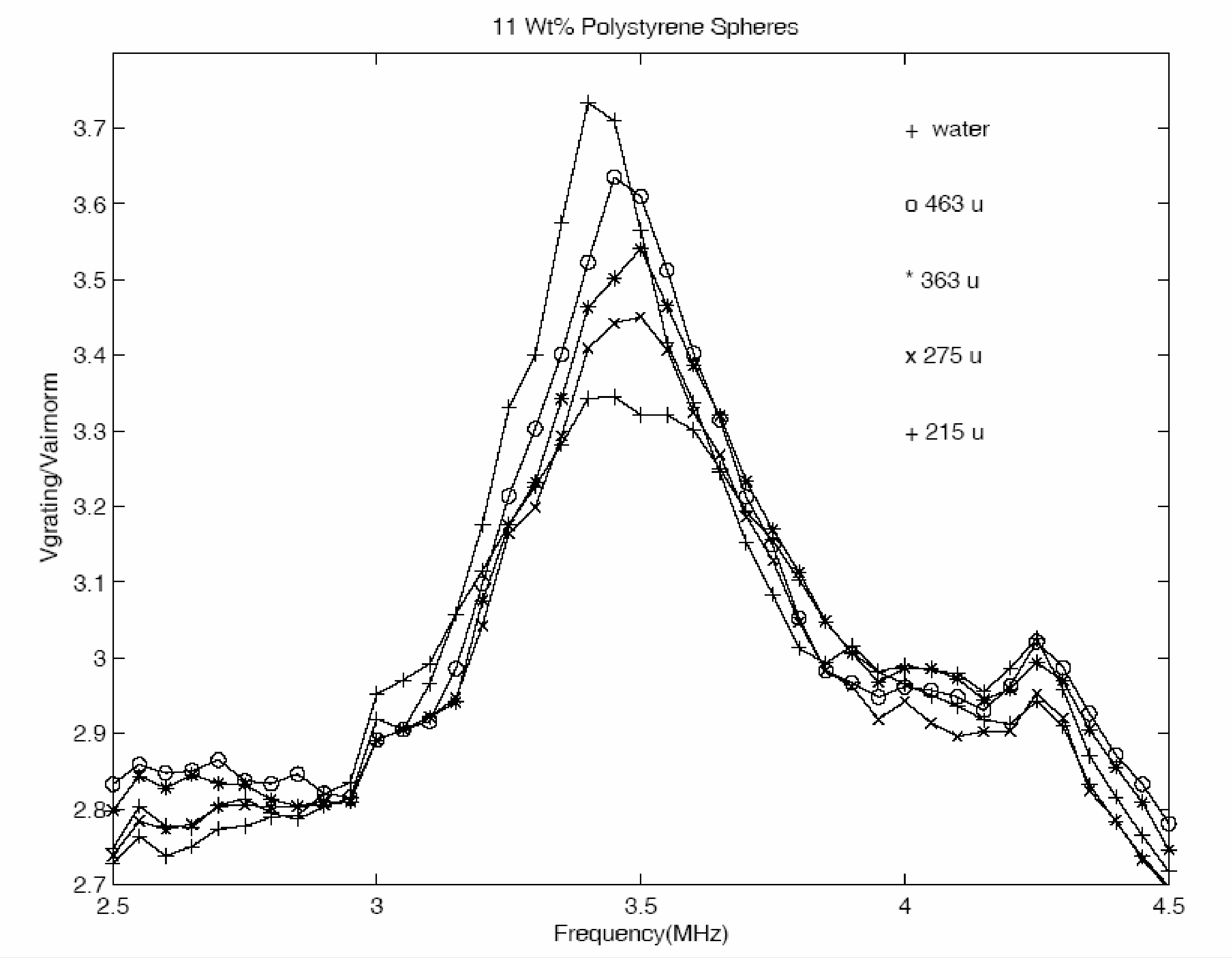
  PKABG = Maximum amplitude of peak - Amplitude at 2.9 MHz

Data for 215 micron spheres

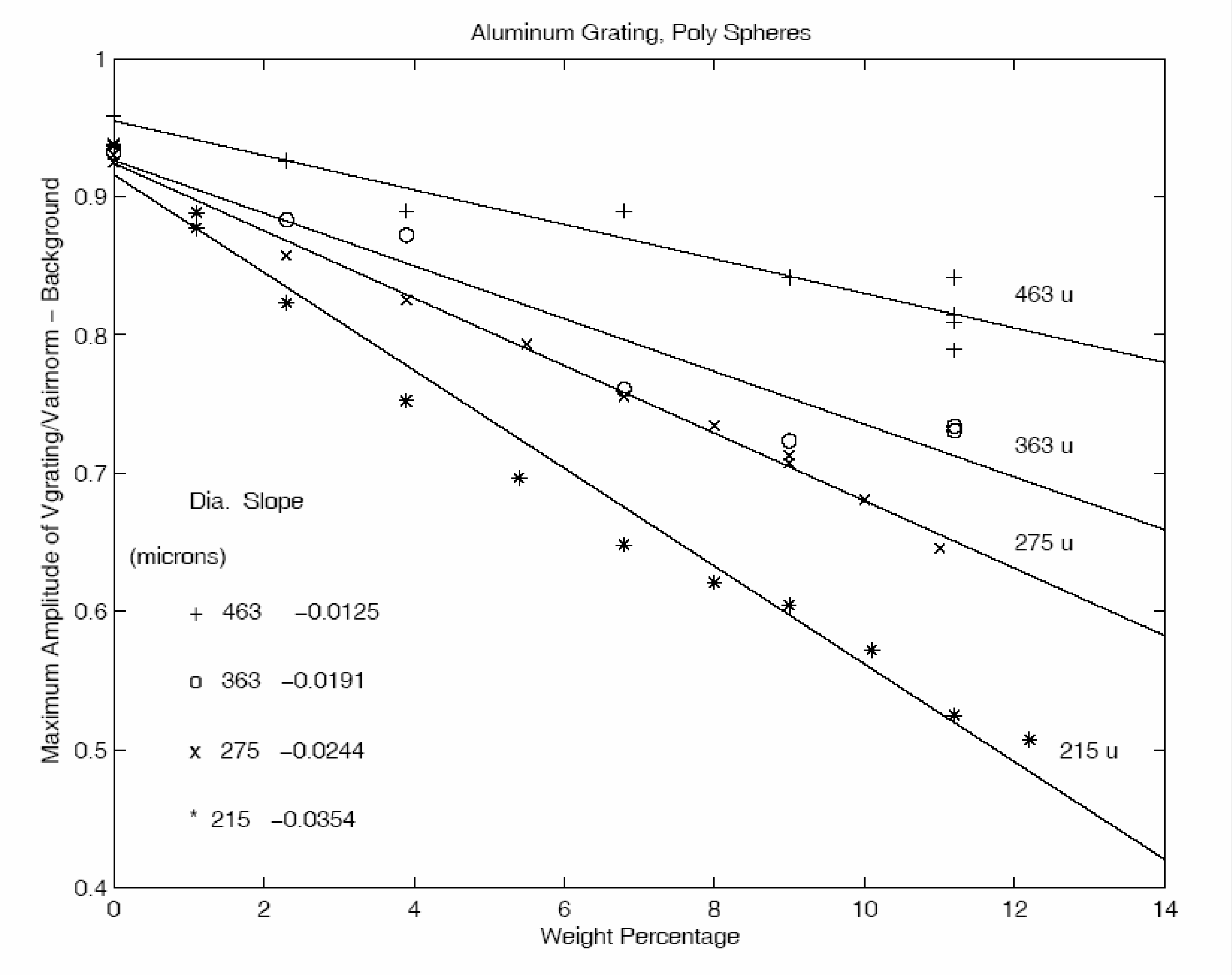



9.0 Wt%, 215 micron
10.1 Wt%, 215 micron
11.2 Wt%, 215 micron
12.2Wt%, 215 micron
Vgrating/Vairnorm
Frequency (MHz)
2.8
3
3.2
3.4
2.5
3
3.5
4
4.5

Comparison of Peak Heights for Different Diameter Spheres



Data for Peak Height above Background versus Weight Percentage



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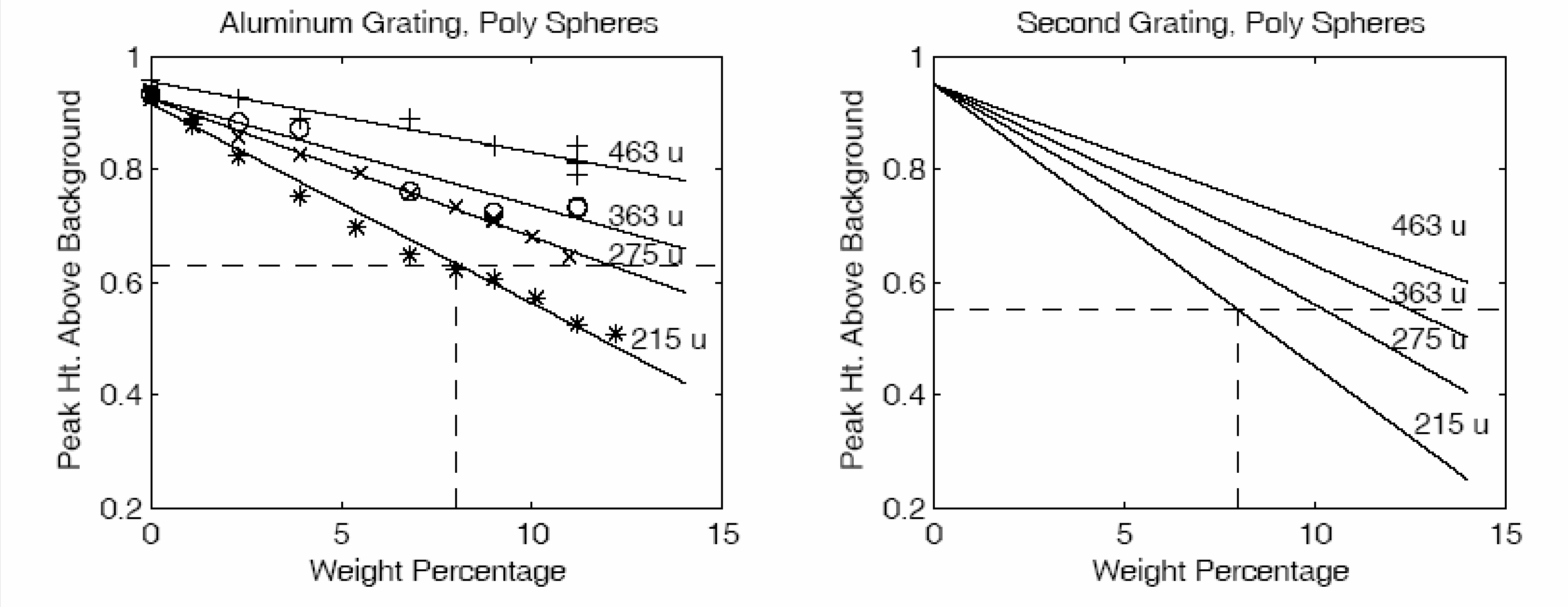
Obtaining the Particle Size AND Weight Percentage

- Use different orders for one grating: m = 1 and m = 2.
- Use two gratings for m =1 with different frequencies.



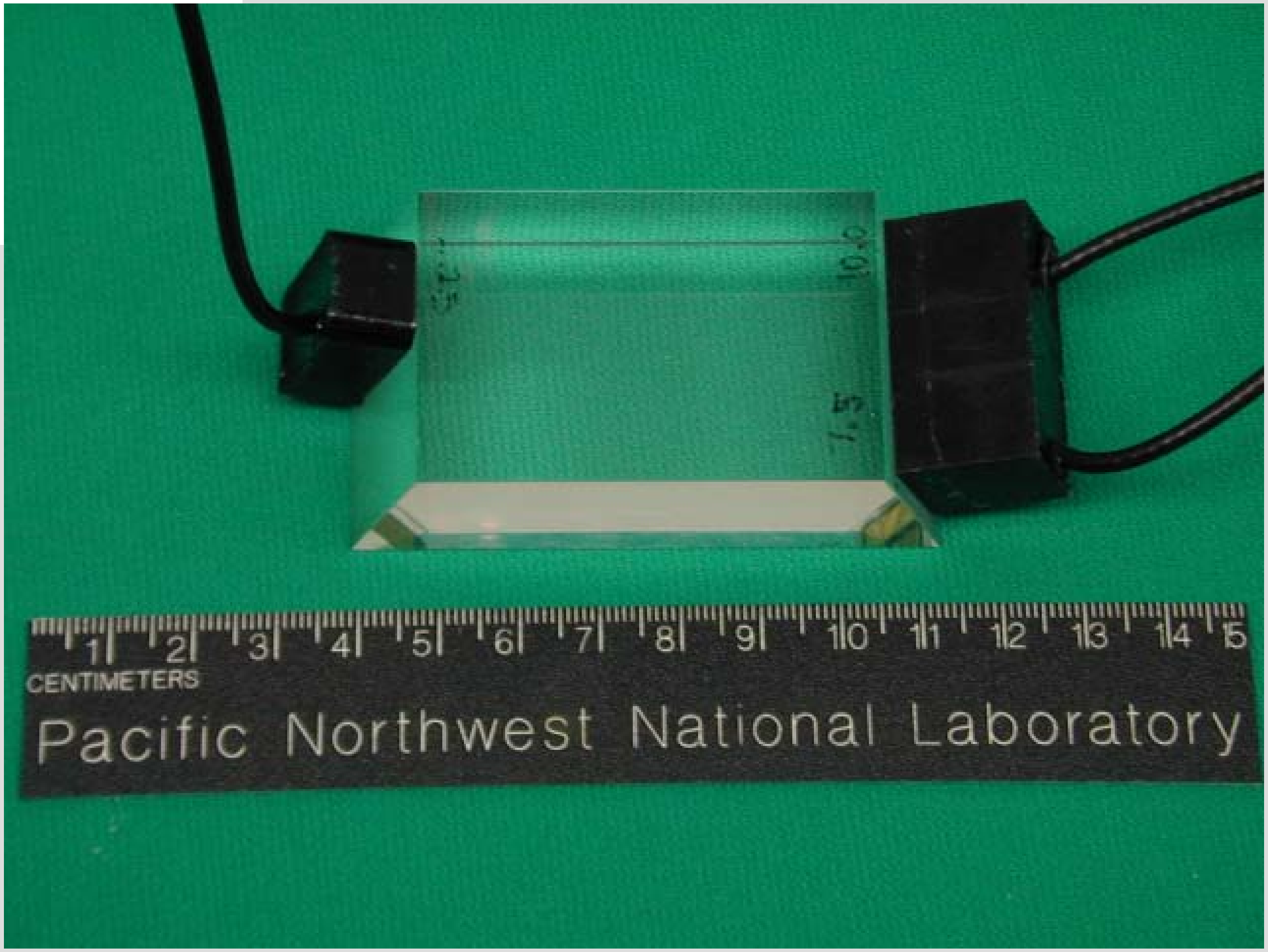
Conclusions

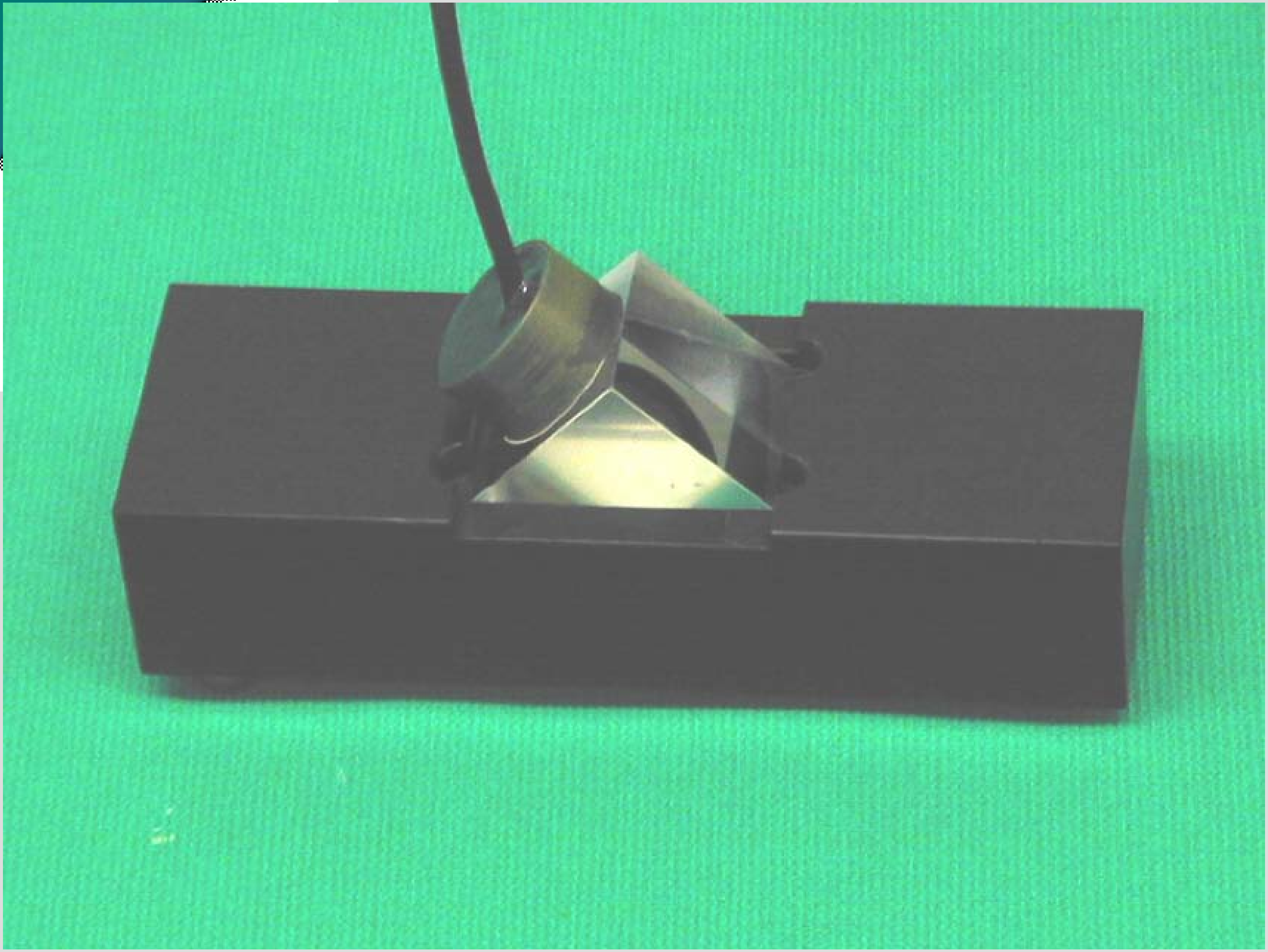
- Experimental data show the effects of particle size.
- Good discrimination between particle size.
- Ability to determine particle size and weight percentage experimentally.

Path Forward

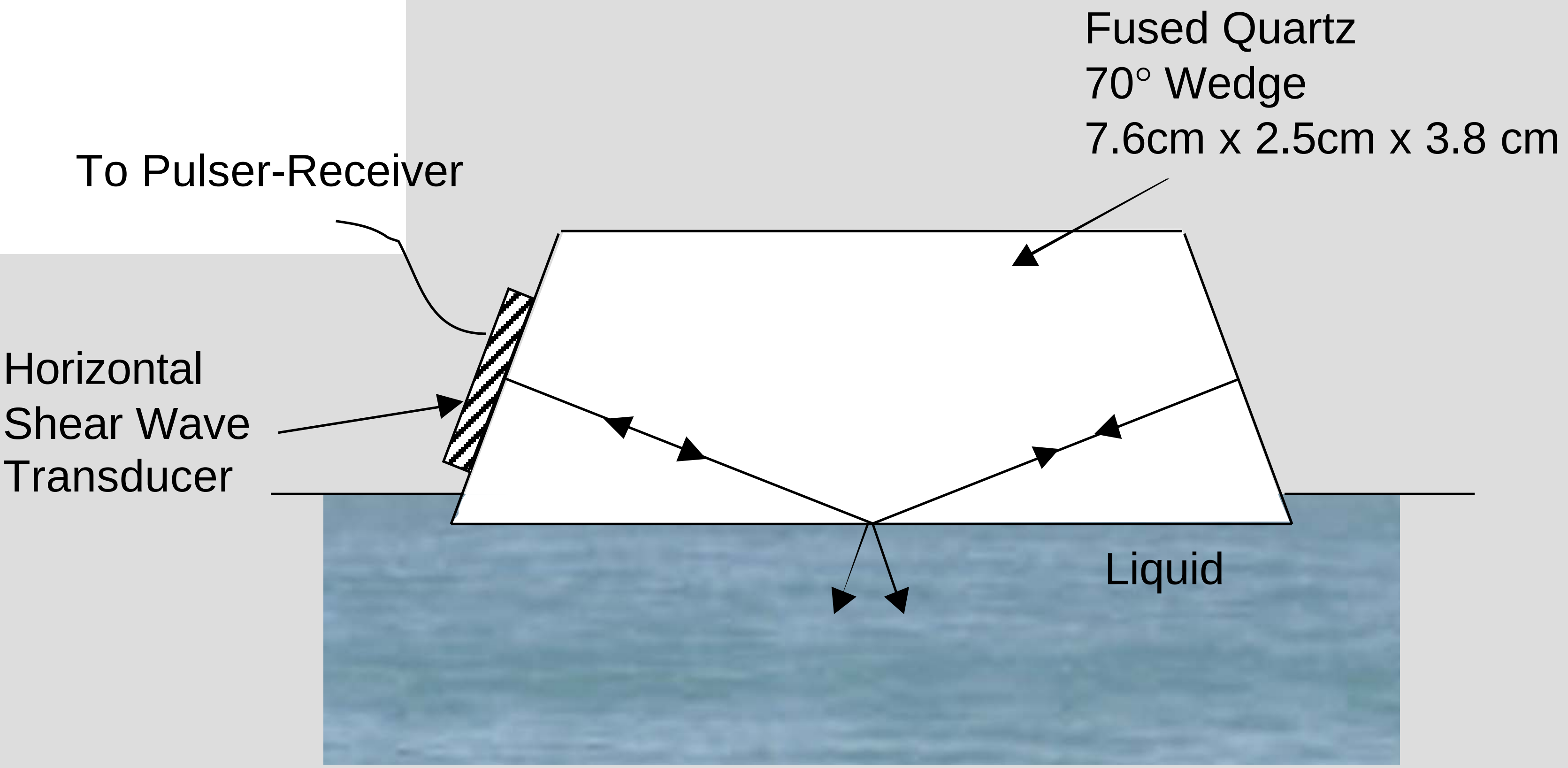
- Perform computer modeling so that the most effective grating and transducer frequency can be determined.
- Carry out experiments and compare with theory.
- Consider interaction mechanism of ultrasonic wave with particles.
- Compare experimental data with theoretical calculations using interaction mechanism.
- Extend range of particle size.

Viscosity and Reflection of Shear Waves

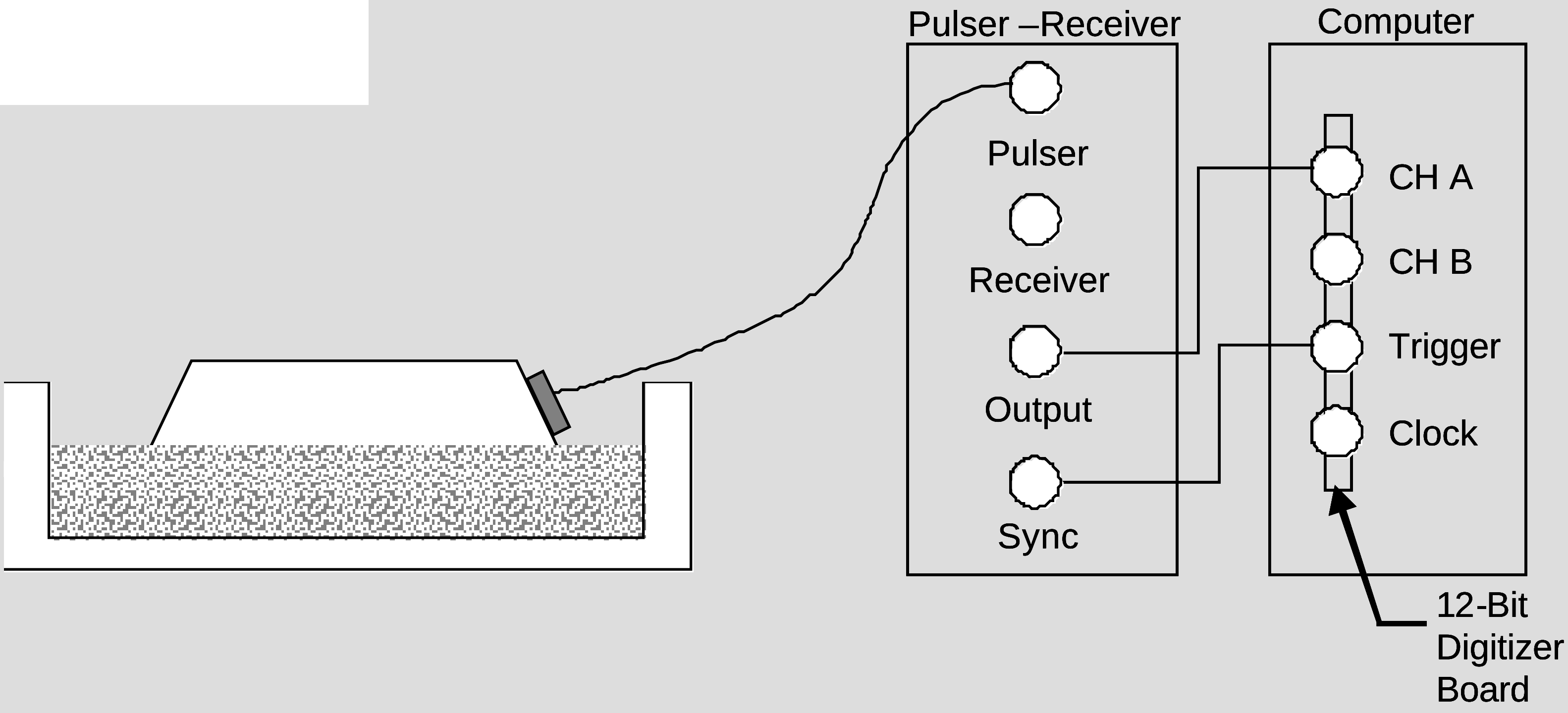

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
CENTIMETERS
Pacific Northwest National Laboratory
12.5
10.0
7.5



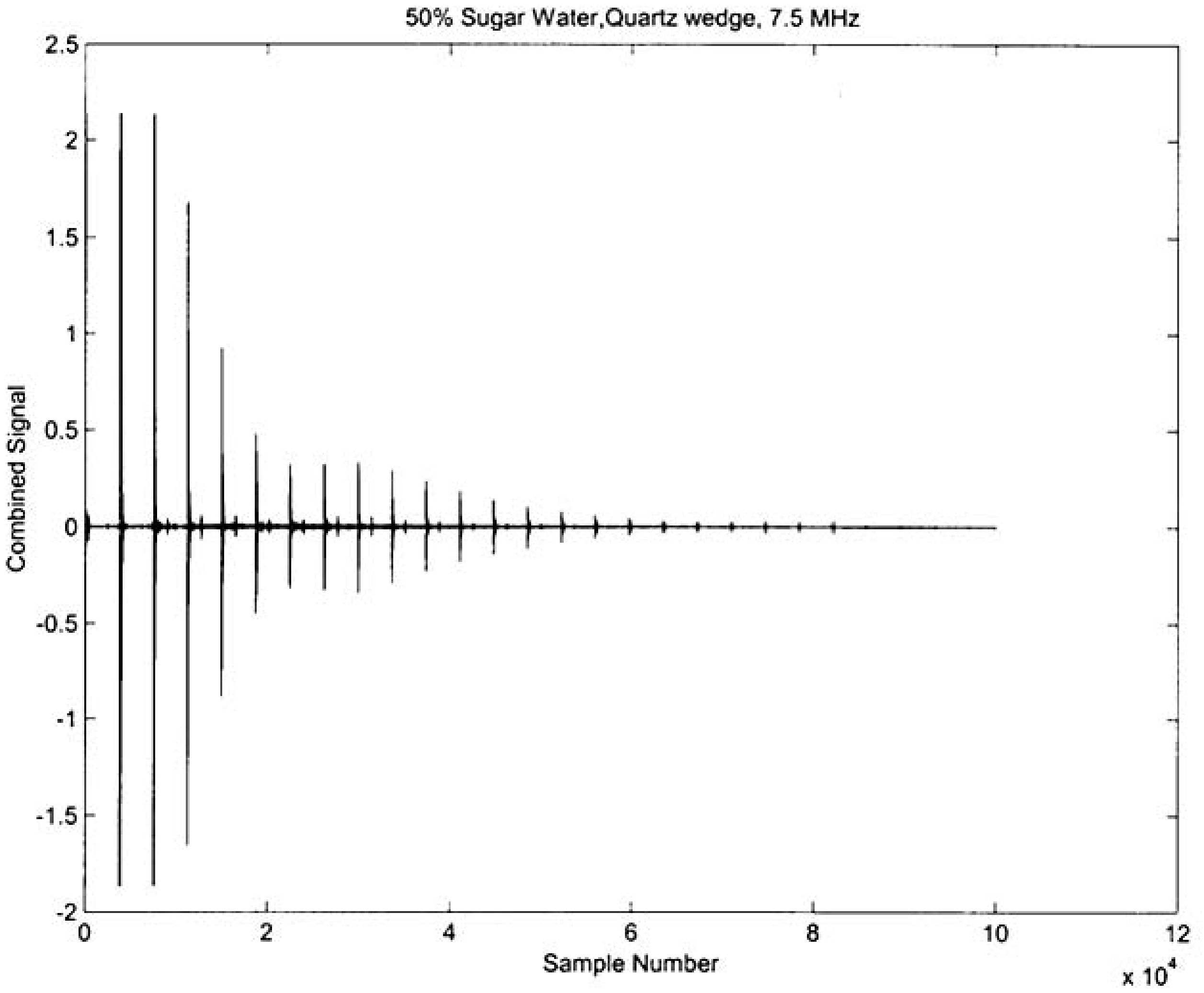
Fused Quartz Wedge


Fused Quartz
70° Wedge
7.6cm x 2.5cm x 3.8 cm
To Pulser-Receiver
Horizontal
Shear Wave
Transducer
Liquid

Experimental Setup


Pulser –Receiver
Computer
Pulser
Receiver
Output
Sync
CH A
CH B
Trigger
Clock
12-Bit Digitizer Board

Multiple Echoes



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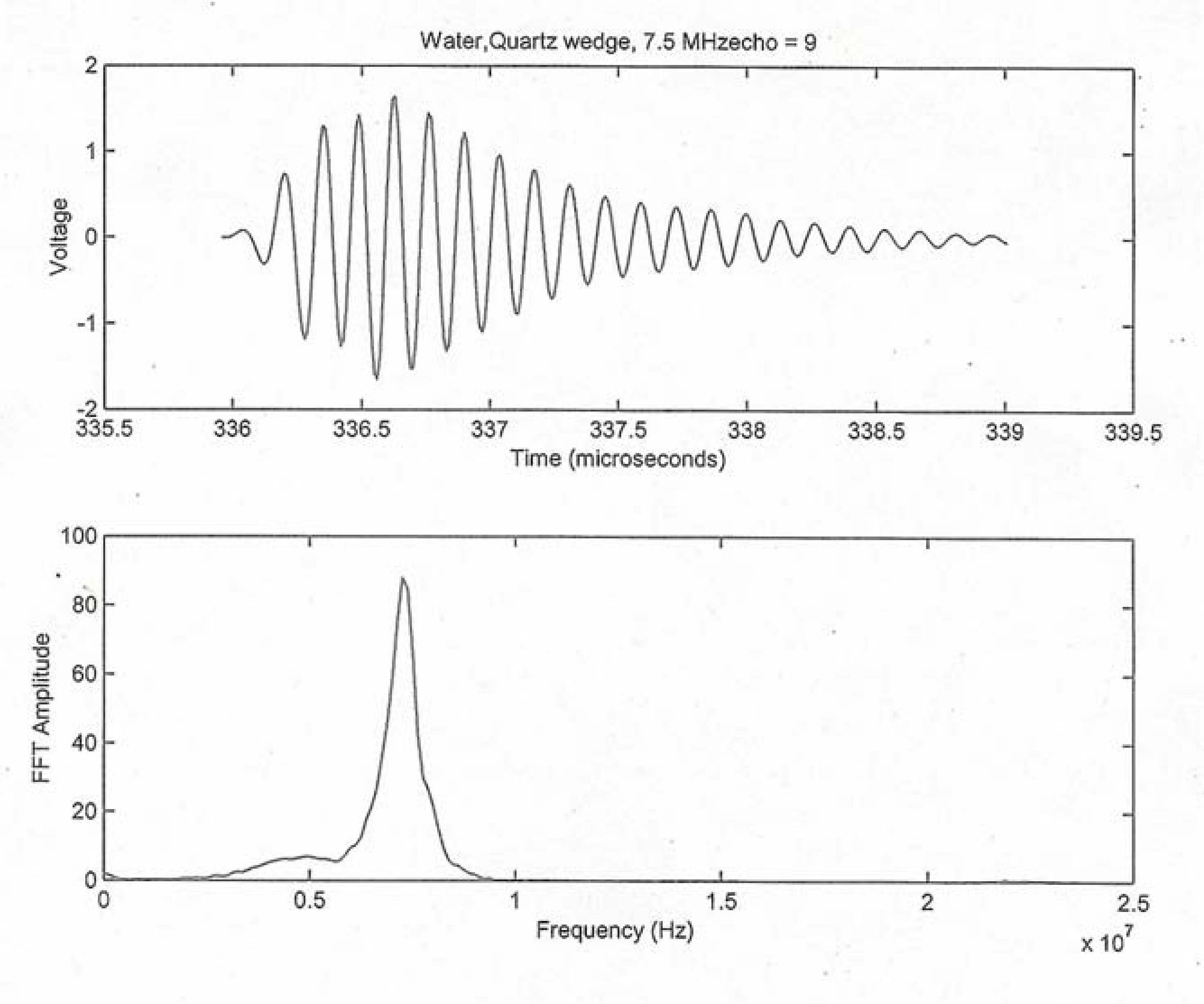
Signal and FFT



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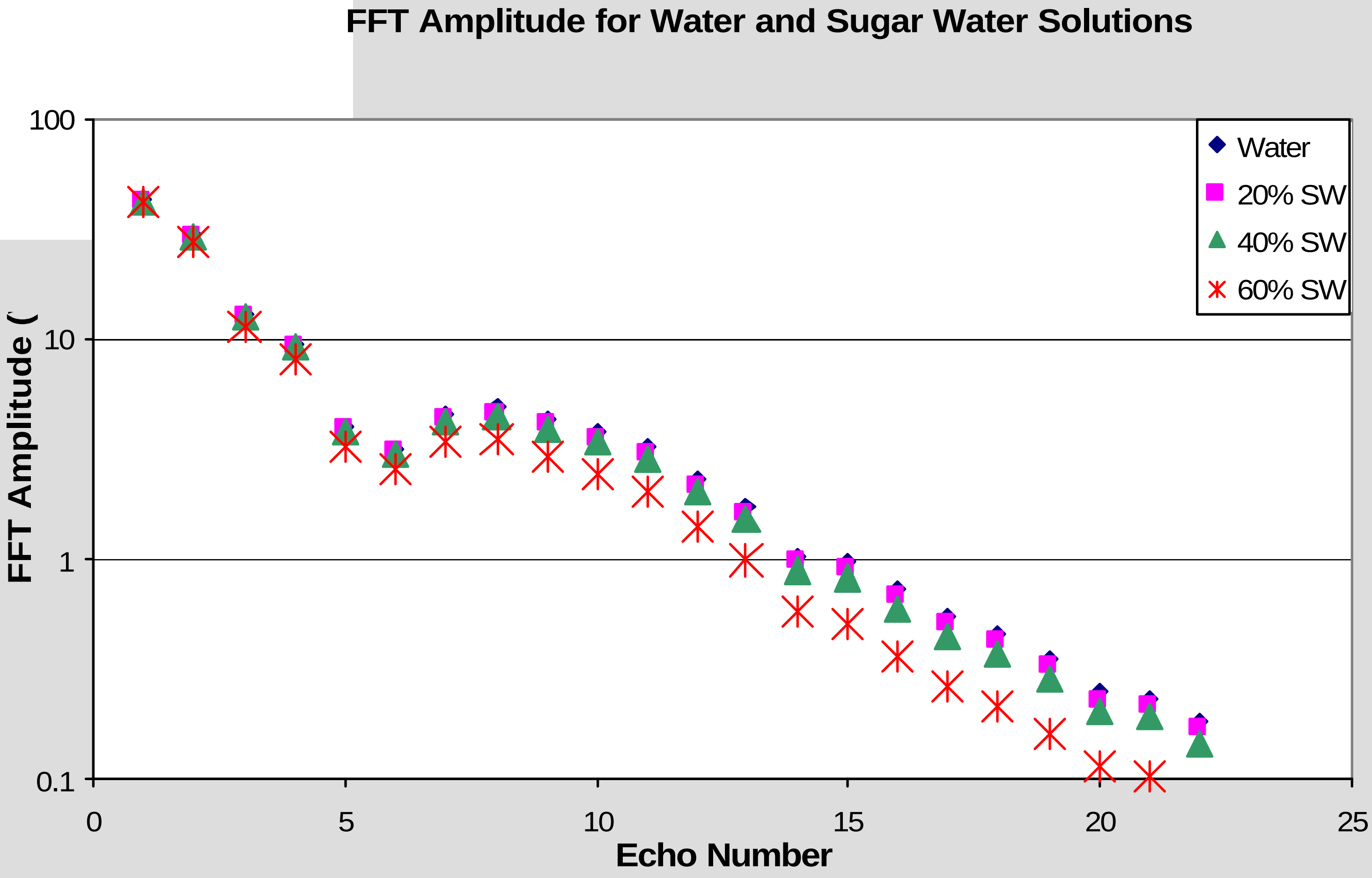
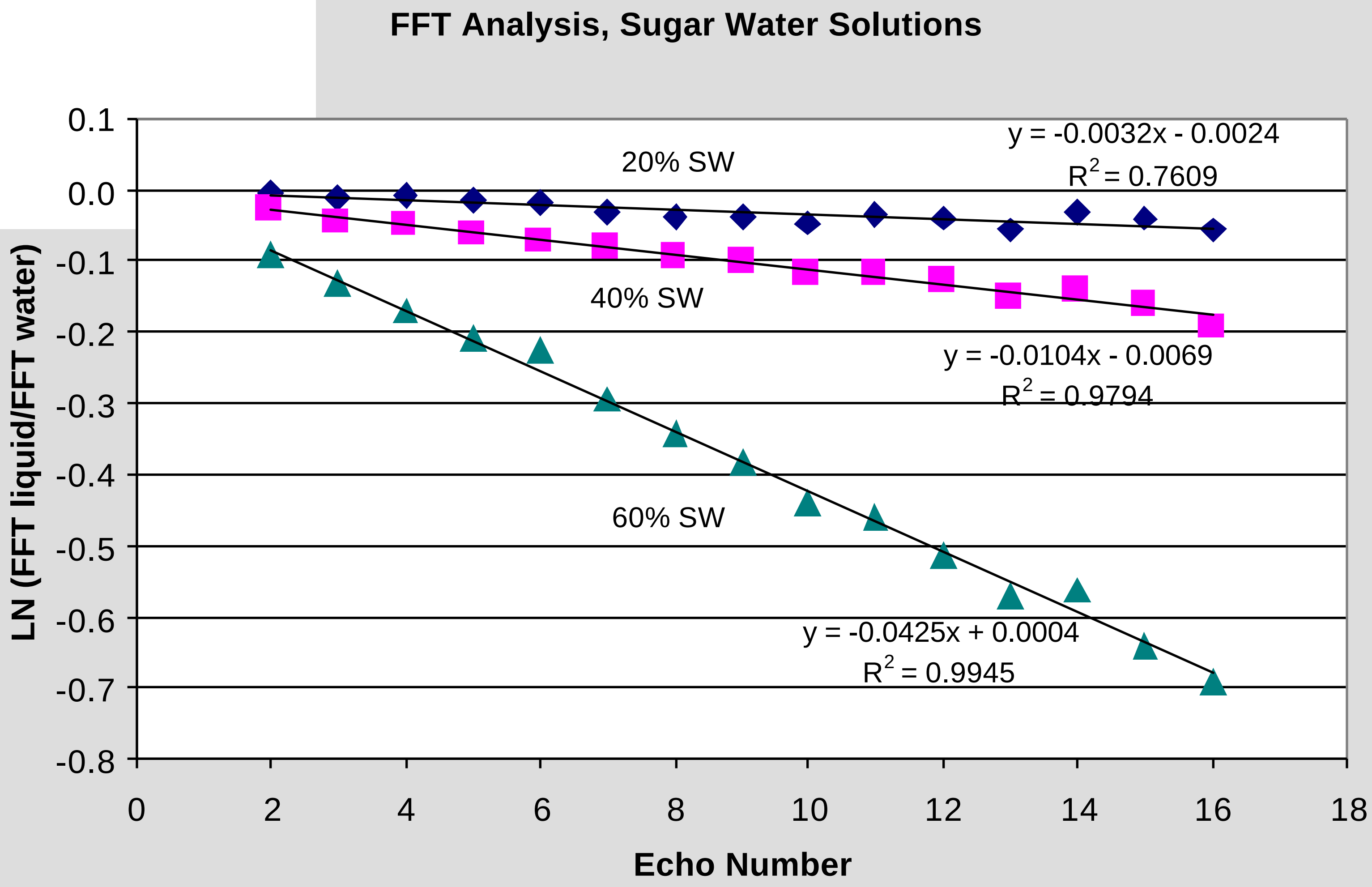
Comparison of Amplitudes



Measurement of the Slope



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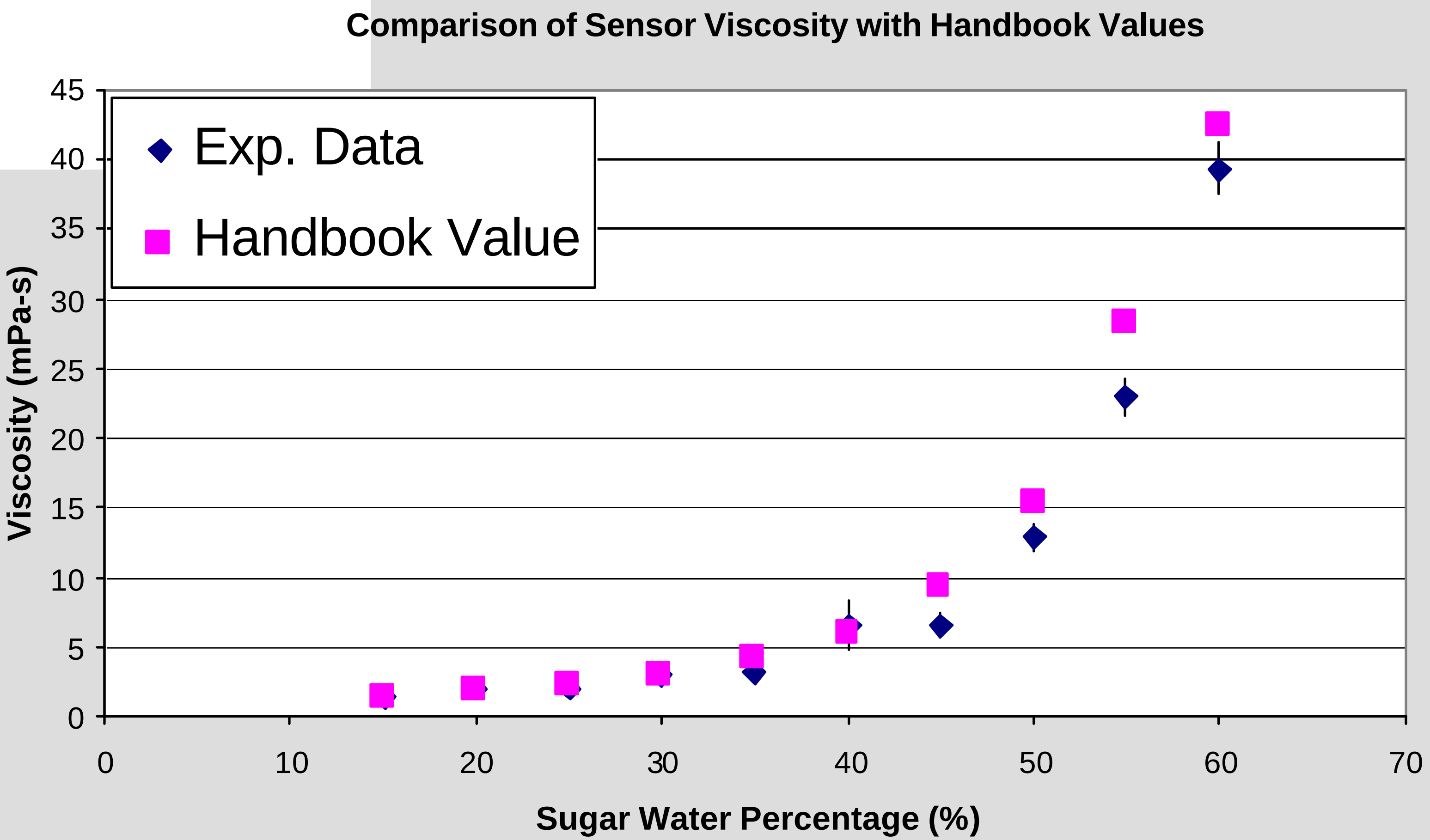
Comparison with Handbook Values



Conclusions and Path Forward

- Use of shear-horizontal waves with a quartz wedge provides a sensitive measurement of viscosity.
- Carry out measurements using 45° fused silica wedge.
- Extend theoretical analysis to include change of phase of upon reflection in order to study oils and very viscous fluids.
- Design a thin stainless steel element for the measurement of viscosity using multiple reflections.