Additional Mine Classification Capabilities for the INSS
Final Group Report under Grant No. N00014-99-1-0171

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14. ABSTRACT
As a diver scans a shallow water or very shallow water (SW/VSW) area with an INSS high frequency sonar, many objects may be detected or imaged in the scene. The objective of this project is to develop algorithms that capture the broadband echo responses from these objects detected by the INSS and extract special echo features to assist in target discrimination from the background. The algorithms are based upon geometric acoustics, broadband array and signal processing techniques, and the physics of elastic waves on thin shells. Initially, three algorithms were investigated for acoustic robustness. These were, Shell Thickness Resonance (STR) Frequency Notch to estimate the targets shell thickness, Local Target to Bottom Multi-path Echo to discriminate cylindrical and spherical objects, and Multi-channel Phase Comparison (MPC) to estimate the target's height. The third algorithm, MPC, was the most acoustically robust, but required a modification to the INSS array geometry. The first algorithm, STR, was sufficiently robust to be implemented within an INSS unit and tested with Navy and ARL:UT divers. The implementation required reductions in the algorithm's capabilities to fit within the INSS hardware and software architecture. Three sets of diver test were conducted in Lake Travis Texas and Coronado California. The final recommendation was to not modify the current operational systems but to consider the STR and MPC algorithms as part of the target sensing and discrimination suites in future implementations of broadband sonar systems.

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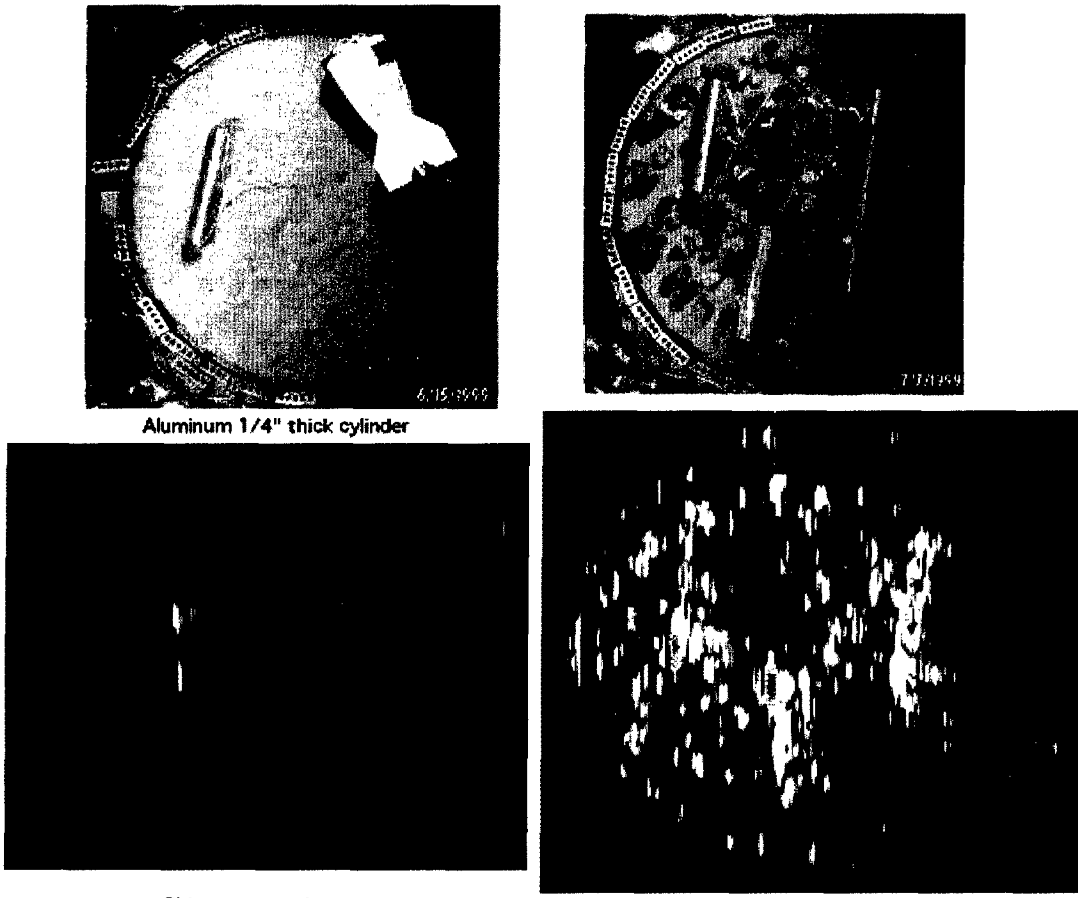
Additional Mine Classification Capabilities for the INSS
Executive Summary

Overview: This task was part of a set of P3I efforts to increase the capability of the diver handheld sonar, INSS. This task was an investigation and implementation of a few target discrimination techniques, which had been demonstrated in laboratory tests. The goals were to assess the robustness of each technique in operational environments and when implemented within the constraints of the sonar system's hardware and software. Each technique investigated in this project detects particular high-frequency broadband elastic and/or specular echo response feature, extract specific echo feature parameters, and provide additional target discrimination clues to the operator. Three echo features were initially selected for development:

- *Shell Thickness Resonance (STR) Frequency Notch*: This technique measures a frequency dependent target response. It first makes a thin-shelled object discrimination and then estimates the shell thickness. [1,2,3,5].
- *Local Target to Bottom Multi-path Echo:* This technique measures the relative time delays of multiple echo returns fom the target and local multi-paths between the target and the bottom. From this set of echoes, it makes a circular object (e.g. cylinder) discrimination and then estimates its radius.
- *Multi-channel Phase Comparison (MCP) (a.k.a. vertical mono-pulse processing [4]):* This technique measures the instantaneous vertical phase front of the return echo and first identifies phase discontinuities to discriminate object or object parts above the bottom. This can provide an object height estimate, which can often be the most distinguishing feature of a mine-like object when discriminating against high bottom backscatter.

Laboratory Algorithm Evaluations: The first set of evaluations used a surrogate single beam data collection sonar system was assembled to collect data to develop and evaluate algorithms based on these target characteristics. The surrogate sonar had an array configuration that was similar to the handheld sonar. The data were recorded and processed offline in these tests. Algorithms were evaluated for their acoustic robustness and INSS implementation compatibility. Algorithms showing the greatest robustness and feasibility were then selected for INSS test implementation.

An initial acoustic database was collected for these evaluations in a controlled indoor tank environment for algorithm development. Targets were placed on a circular underwater 8 ft diameter rotating platter. The targets and environment were insonified, and images were collected over a complete 360° of aspect angles (Fig. 1), which allowed the evaluation of the algorithm's aspect dependencies. The frequency band of operation was chosen to match that of the INSS and covered nearly one full octave of bandwidth. Targets tested included reference objects with simple geometry (e.g. cylinders or spheres), natural objects (e.g. rocks of different shapes and sizes), different bottom surfaces (e.g. smooth sand and rocky), and several mine-like shapes (moored targets, cones, complex shapes).



Aluminum 1/4" thick cylinder

Objects on sand

Objects on rocks

Figure 1: Data collected at the ARL:UT laboratory platter: These images illustrate the typical of the data collected by the surrogate sonar for developing and evaluating the algorithms. First pair shows an easily distinguished echo on a clean sand bottom, while the second image set shows similar objects on a bright rocky bottom. The rocky bottom hides the targets, but they are discriminated with the STR algorithm.

Three techniques were evaluated. Of these, only the "*Local Target to Bottom Multi-path Echo*" algorithm was insufficiently robust to continue into the next phases of testing. Both the "*Shell Thickness Resonance (STR) Frequency Notch*" and "*Multi-channel Phase Comparison (MCP)*" algorithms demonstrated sufficient acoustic robustness to be considered for further evaluations.

The STR algorithm exploits distinct high ka features in the spectrum of the back scattered echo to estimate the material properties and shell thickness. FFT's are used to to estimate the spectral shape. The fidelity of the esitmates improved with increasing FFT lengths. Algorithms based on shorter length FFT's lose some fidelity and can only estimate the shell thickness for assumed material type. These are primarily "thin-shell detectors."

The MCP algorithm was the most acoustically robust of the three techniques. It estimates the vertical angle of the phase front back scattered echo. Height changes of the bottom or object cause rapid changes in the phase front angle. Jumps in this angle can be used to enhance object detection, particularly in highly reverberatant environments. And, with a few realistic assumptions, the angle can be used to estimate the height of the object. The algorithms that compute height estimates are relatively simple and robust. (Versions of these algorithm are being used in the most recent class of Navy obstacle avoidance sonars.)

Both the STR and MCP were selected to continue the evaluations based upon their acoustic robustness results in the laboratory tests with the surrogate array and offline processing.

Algorithm INSS Implementation: Two selected techniques were for the next set of evaluations. These would be implemented on an INSS operational or ADM system to determine their ability to operate within the system constraints with minimal modifications to the operational hardware, software, and user interface. Early on in the evaluations, in discussions at the review meeting with the EOD and ONR program offices, it was decided to not pursue the MCP 3D technique. This technique would require an additional array element and signal electronics channel, which was outside the scope of the overall INSS P3I program. Future implementations should consider it since it is a very robust technique.

The remaining technique, STR algorithm, was implemented on an INSS ADM system. To install the STR algorithm into the INSS unit, the algorithm was compressed to match the INSS front-end architecture and adjusted to operate in real-time. The constraints of the processing hardware required that the fidelity of the algorithms be reduced. For example, FFT lengths were shortened to reduce the processing load. This increased the frequency bin sizes and reduced the algorithms ability to detect and measure spectral notches, which reduced the accuracy of the thin shell discrimination and thickness estimates. The STR algorithm was successfully implemented into an INSS ADM system in a real time configuration and tested in the laboratory test facilities where the original surrogate sonar data was collected. After successful completion of these tests, the STR-enabled INSS prototype unit moved to a series of diver tests.

Developing an INSS display and user interface for the implemented algorithms was an additional task in this project. The goal was to provide the diver with the appropriate visual cuing on the display that would indicate the discrimination algorithm had classified a target without impacting the basic INSS functionality. A number of prototype displays were developed on a desktop computer using the laboratory data and discrimination algorithm's classifications. These prototype displays were presented to Navy divers who provided a number of concise, specific, and clear comments that were incorporated into the display implementations on the INSS ADM unit. In the final implementation, one of the diver selectable modes initiates the target discrimination processing. When the discrimination feature is detected, a small color-coded mark is placed on the target on the image. The divers would typically rescan the target to determine the consistency of the mark and then store the resultant image.

Diver Tests: A series of diver tests were conducted to test the STR algorithm's characteristics and robustness in multiple environments (Fig 2). In the first set of diver tests, ARL:UT and Navy divers tested the STR-enabled INSS prototype unit in a controlled environment (Fig 3). The divers tested the unit at the ARL:UT outdoor redwood tank facility against reference targets, mine-like shapes, and natural targets (boulders and a limited rocky field) resting on a smooth bottom. In these tests, 4 out of the 5 divers found the STR algorithm and display beneficial for mine-like (thinned shelled) objects versus non-mine objects (rocks) discrimination. They noted that a slow panning speed enhanced performance and that there was an apparent sensitivity to D/E angle relative to the target. Navy diver feedback was favorable and provided a guide to the first major revision.

a) b) c)

Figure 2: Navy diver scanning a target at the ARL outdoor tank facility. b) Navy diver receiving dive instruction at the Naval Amphibious Base. c) STR enabled HRLMD unit

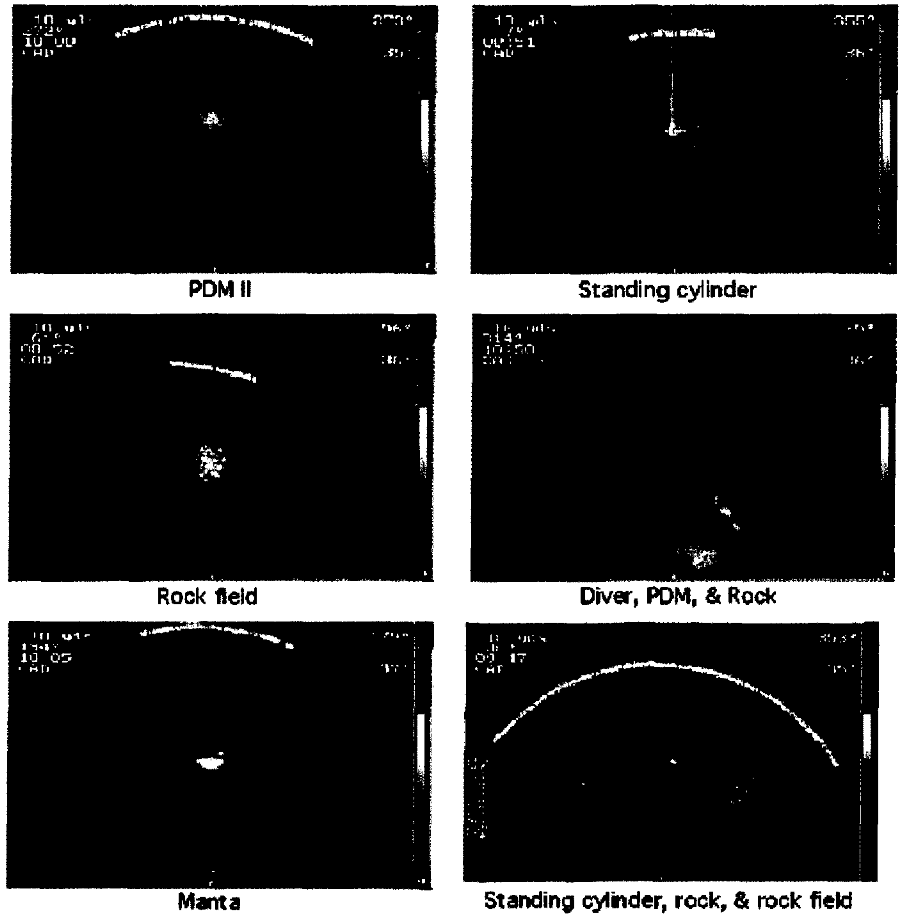
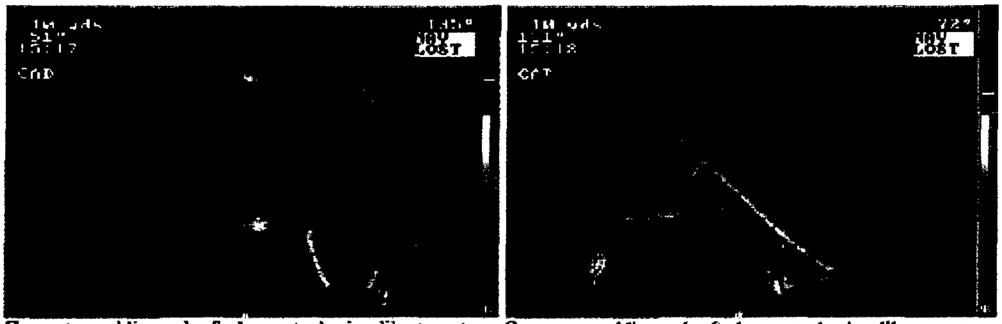


Figure 3: Data collected at the ARL:UT outdoor tank facility: These images illustrate the results typical of the diver tests in the large cylindrical redwood tank with thinned shelled objects marked by the STR algorithm. Very few false calls were made on the tank floor, although the outside walls were often marked by the algorithm. The 4^{th} image illustrates the results of improper grazing angle.

In the second set of diver tests, ARL:UT divers tested the algorithm in a real-world environment (Fig. 4). The divers tested the revised STR-enabled INSS prototype unit at the ARL:UT Test Station (LTTS). This is a highly reverberant environment (i.e. rocky bottom). Mine-like targets, as well as ideal targets, were resting on a rocky bottom and tested out to a range of 40yds. The algorithm performed well in this environment. The MK56 mine was consistently marked by the STR algorithm while a bright, (high TS) solid concrete, non-minelike target was not marked. There were very few false alarms on the limestone and mud bottom with sporadic false alarms on the rock cliff.



Concrete wedding cake & large steel mine-like target   Concrete wedding cake & large steel mine-like target

Figure 4: Data collected at the ARL:UT Lake Travis Test Facility: These images illustrate the results typical of the diver tests on the rocky lake bottom at Lake Travis. Note that the (thinned shelled) mine-like steel cylinder is properly marked, while the bright, yet solid, concrete "wedding cake" is appropriately not marked by the STR algorithm.

For the third and final diver tests, an STR enabled INSS unit was evaluated at the Naval Amphibious Base (Coronado, CA) during the spring of 2002 by Navy divers familiar with VSM-MCM and NSW missions (Fig. 5). Seven objects; mines, mine-like targets, STR test targets, and a rock; were deployed for the test. Each diver made two dives, a shakedown and evaluation, with the unit. Each completed 2 or 3 scans and saved the images to cover the object test field. After each dive, the images were uploaded and comments were logged for evaluation. The eel grass, which was often brighter than the targets, made it a very difficult environment for the STR algorithm to discriminate the objects. The STR algorithm consistently marked the STR test targets but not the other mine-like targets (PDM II, Rockan, and buried Manta). The sensitivity of the vertical D/E angle relative to the targets appeared more critical in this test. The divers noted the vertical beam sensitivity, but felt that the STR concept was a "good feasible application" and could help scout swimmers to avoid minefields.

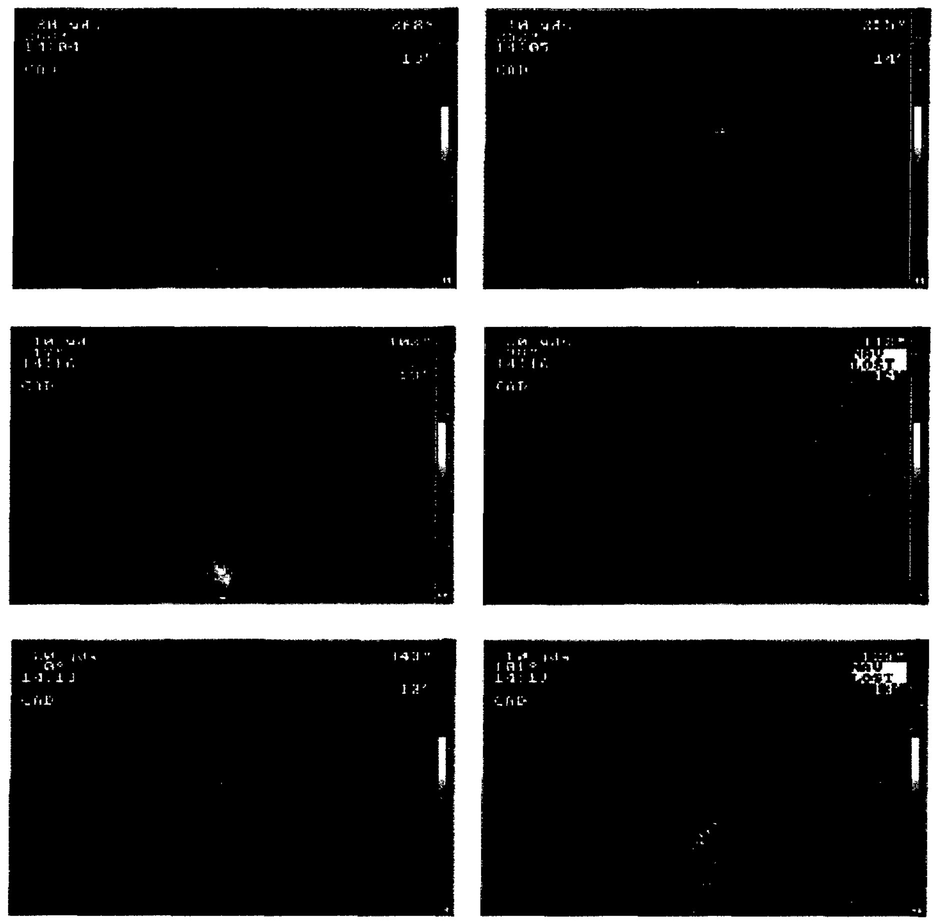


Figure5: Data collected in the Coronodo Tests: These images illustrate the results typical of the diver test near the pier at the Naval Amphibious Base in Coronado, CA. The shallow water and eel grass made this a challenging environment.

Final Recommendation: Two sets of recommendations were derived from the diver tests and the overall program. In the short-term, the STR algorithm should not be implemented within the INSS. The system constraints imposed upon the algorithm due to processing load (e.g. shortened analysis FFT lengths) and physical constraints (e.g. the fixed vertical D/E angle) resulted in an algorithm that was promising but not yet sufficiently robust to support an operational implementation. In the long term, it is recommended that an STR implementation is considered in a future upgrade of the INSS or for a similar AUV implementation. An STR algorithm enabled sonar system should be designed with some specific characteristics that do not constrain its capabilities. In addition, the MPC height discrimination algorithm that was tested in the laboratory in this project, should be considered for future INSS and AUV implementations. It is a robust algorithm that can provide a significant discrimination (height) clue in mine and object detection.

The remainder and bulk of this document consists of a detailed final presentation report that summarizes the complete project located in the appendix entitled "Additional Mine Classification Capabilities for the INSS". It is composed of the following sections:

I. Objective and Project Outline
II. Algorithms Investigated in Initial Data Collection
- Shell Thickness Resonance (STR) Frequency Notch
- Local Target to Bottom Multi-path Echo (triple flash)
- Multi-channel Phase Comparison (MCP) (a.k.a. vertical mono-pulse)

III.STR Algorithm INSS Implementation
- Algorithm Integration
- Display STR Marker Integration

IV.INSS CAD Operational Procedure
V. Navy Diver Tests at ARL Tank
VI. ARL Diver Tests
VII. Navy Diver Evaluation at Naval Amphibious Base, Coronodo CA
VIII. Summary and Conclusions

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APPENDIX

"ADDITIONAL MINE CLASSIFICATION CAPABILITIES FOR THE INSS"

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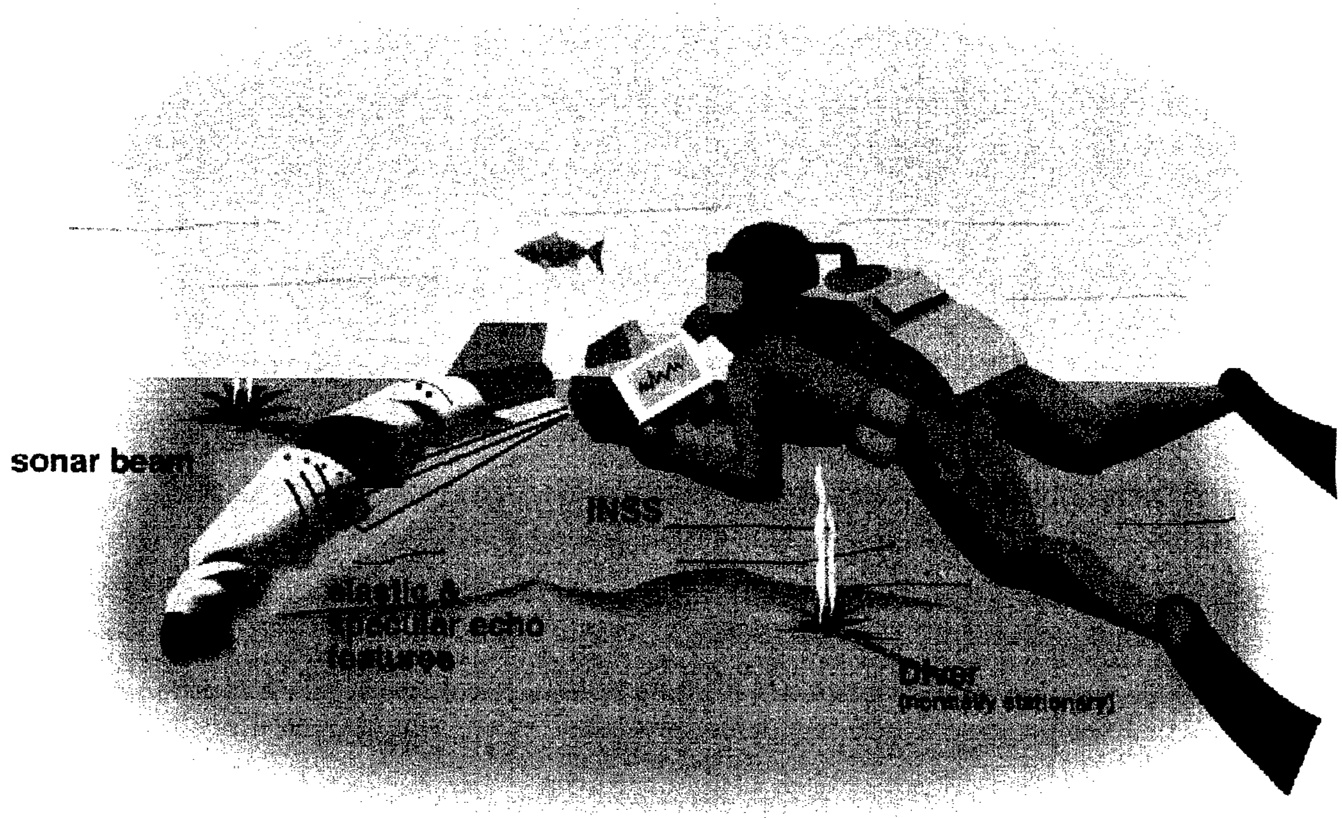
ADDITIONAL MINE CLASSIFICATION CAPABILITIES FOR THE INSS



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ADDITIONAL MINE CLASSIFICATION CAPABILITIES FOR THE INSS

OBJECTIVE AND OUTLINE

Objective:

To develop and test algorithms for the INSS that extract special echo broadband features to aid a diver's classification/discrimination capabilities of man-made/mine-like targets.

Discussion Outline:

* Initial Investigated Algorithms (Theory, Motivation, Results)
  - Local Target to Bottom Multipath Echos
  - Multi-channel Phase Comparison
  - Shell Thickness Resonance (STR) Frequency Notch
* STR CAD INSS implementation
  - Algorithm overview
  - Processing path and lookup table
  - INSS diver display
* Using a CAD enabled INSS unit.
* Diver Results
  - ARL large outdoor tank
  - Lake Travis Test Station (ARL:LTTS)
  - Naval Amphibious Base, Coronado CA
* Conclusions and future work

ADDITIONAL MINE CLASSIFICATION CAPABILITIES FOR THE INSS

ALGORITHMS INVESTIGATED IN INITIAL DATA COLLECTION

- **Triple-flash detector**

  Provides a circular object with a radius discriminant based upon target/bottom acoustic interaction.

- **Multi-channel phase comparison**

  Provides an object height discriminant base upon the vertical phase front of the echo return.

- **Shell-Thickness-Resonance (STR) Frequency Notch Detector**

  Provides a shell thickness discriminant based upon the frequency dependent thickness resonance of the shell.

ADDITIONAL MINE CLASSIFICATION CAPABILITIES FOR THE INSS

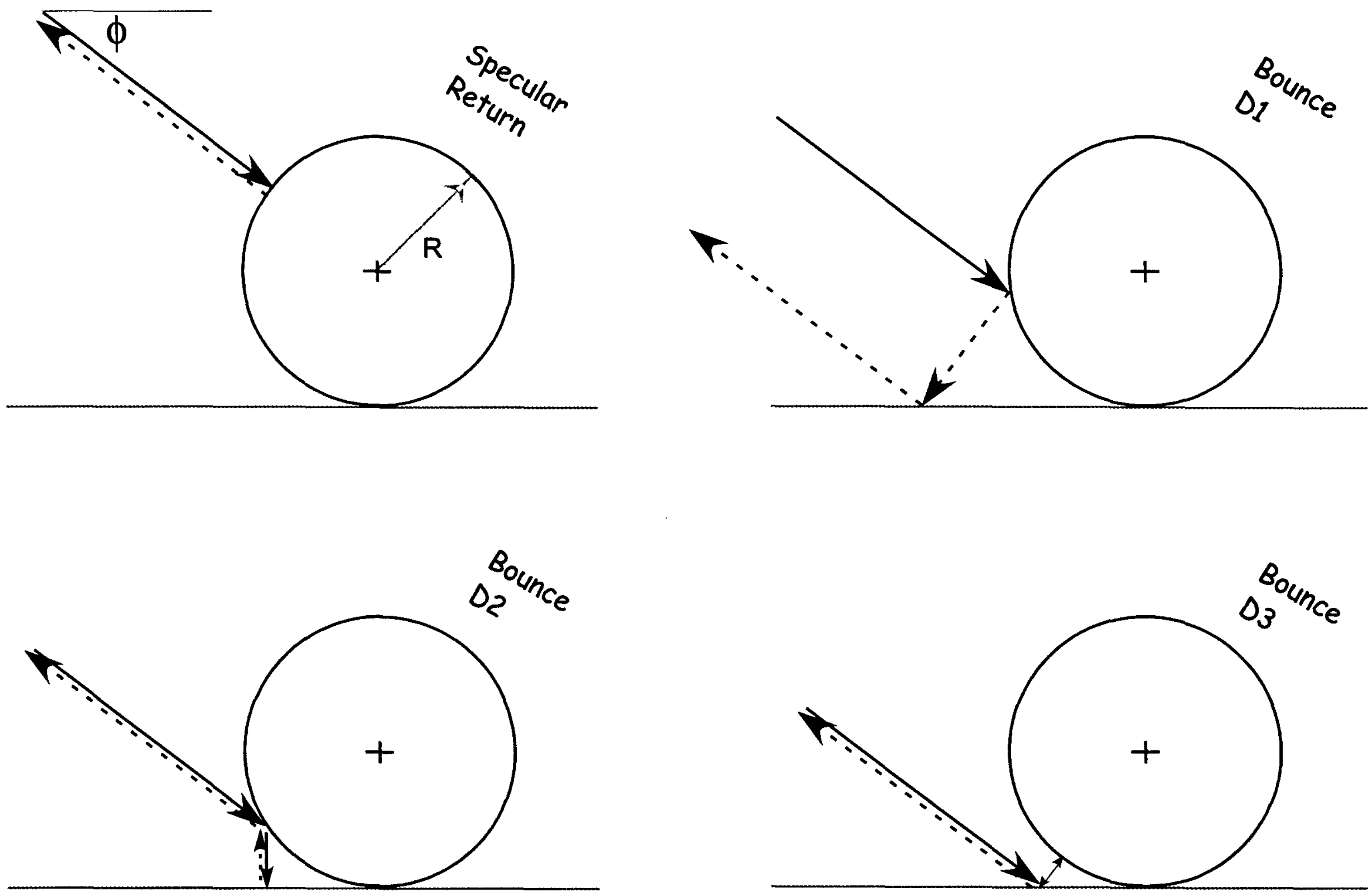
ALGORITHMS INVESTIGATED IN INITIAL DATA COLLECTION

Triple Flash Detector

i.e. Local target to bottom multi-path echo

ADDITIONAL MINE CLASSIFICATION CAPABILITIES FOR THE INSS

TRIPLE FLASH DETECTOR -- LOCAL TARGET TO BOTTOM MULTI-PATH ECHO

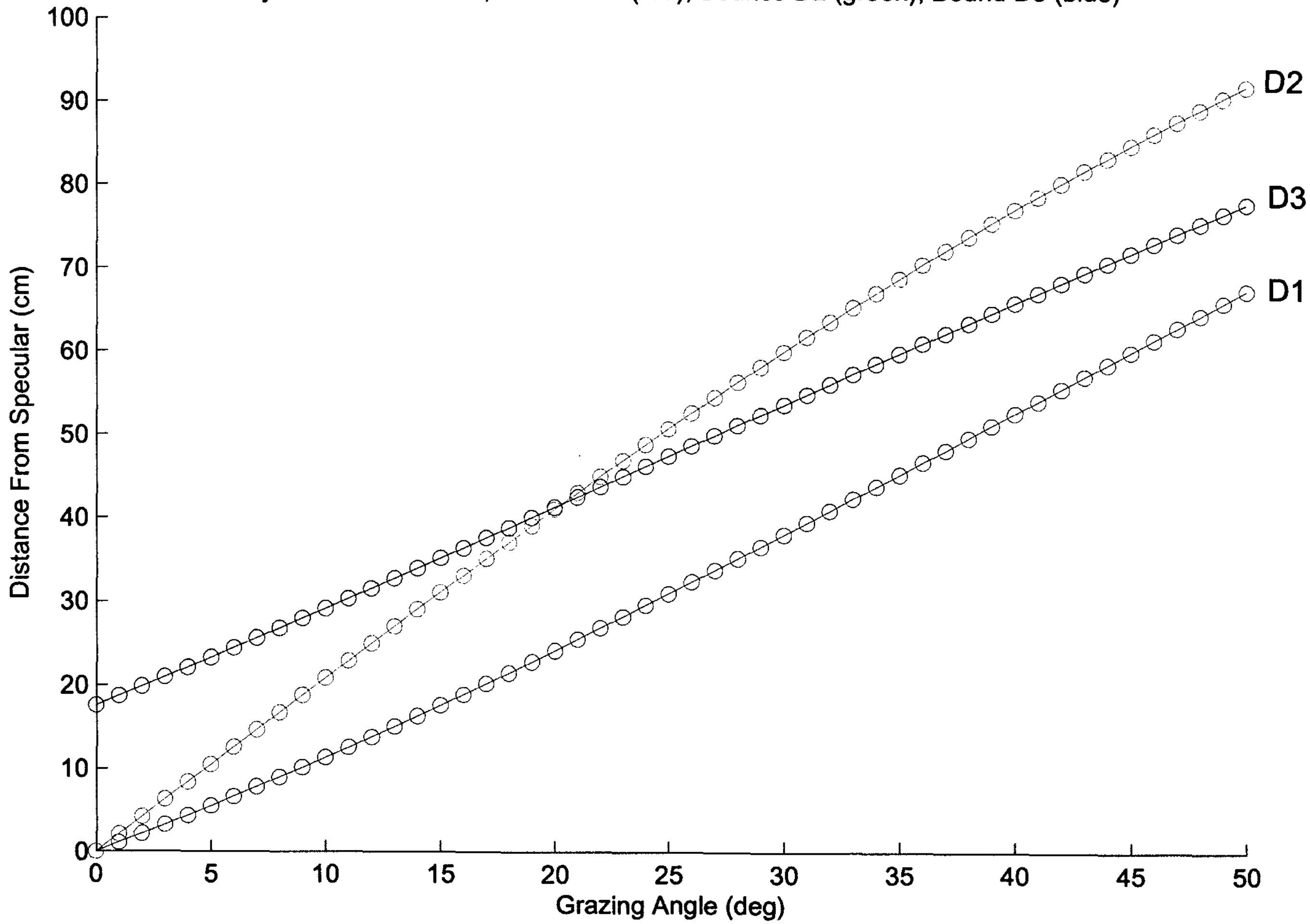


ADDITIONAL MINE CLASSIFICATION CAPABILITIES FOR THE INSS

TRIPLE FLASH DETECTOR -- LOCAL TARGET TO BOTTOM MULTI-PATH ECHO

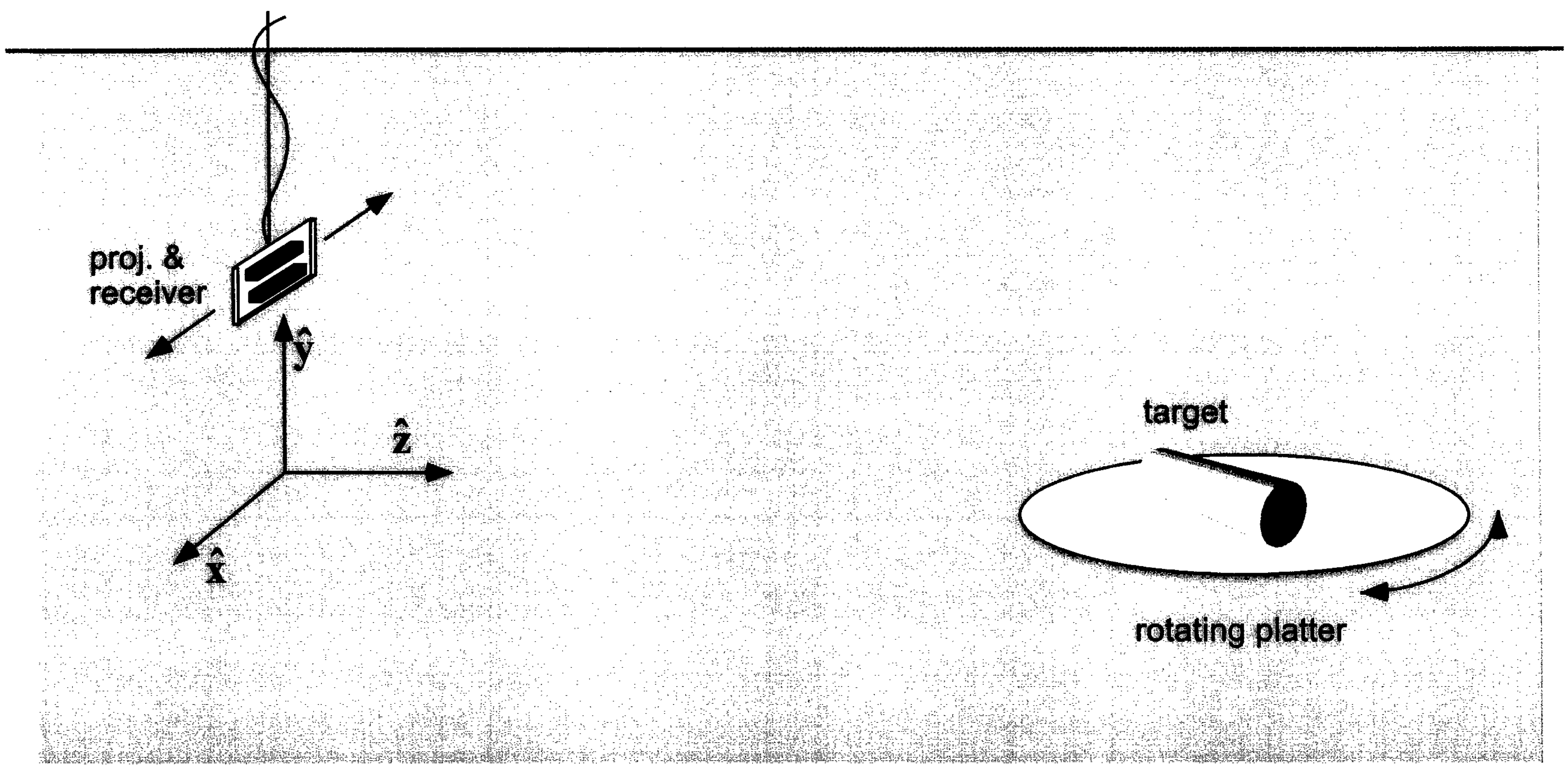
Triple Flash Detector Distance for Fixed Radius & Varying Grazing Angles

Object Radius = 30cm, Bounce D1 (red), Bounce D2 (green), Bound D3 (blue)



ADDITIONAL MINE CLASSIFICATION CAPABILITIES FOR THE INSS

EXPERIMENTAL TANK SETUP



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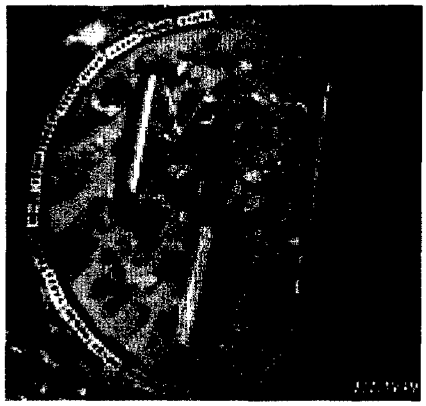
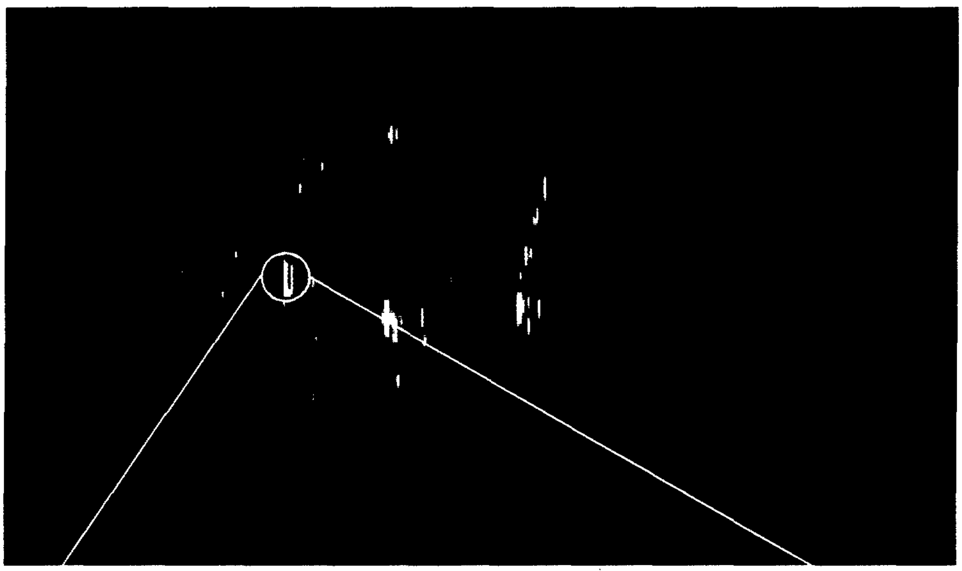
ADDITIONAL MINE CLASSIFICATION CAPABILITIES FOR THE INSS

TRIPLE FLASH DETECTOR -- LOCAL TARGET TO BOTTOM MULTI-PATH ECHO



Cylinders on rocky bottom



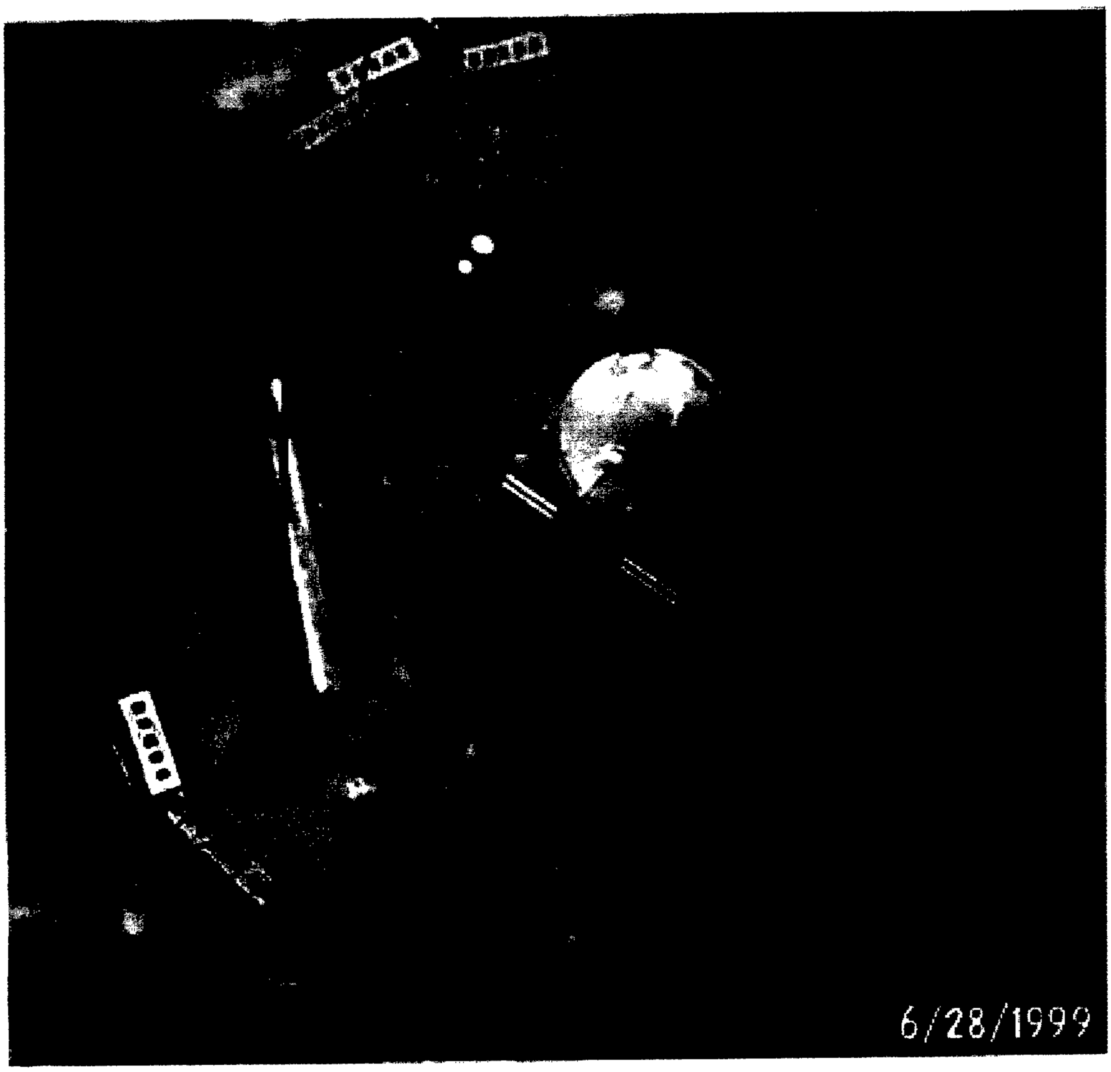
Experimental acoustic image

Close up of triple flash

Multi-channel Phase Comparison

i.e. Object height discriminator

Rocky Bottom With Floating Sphere



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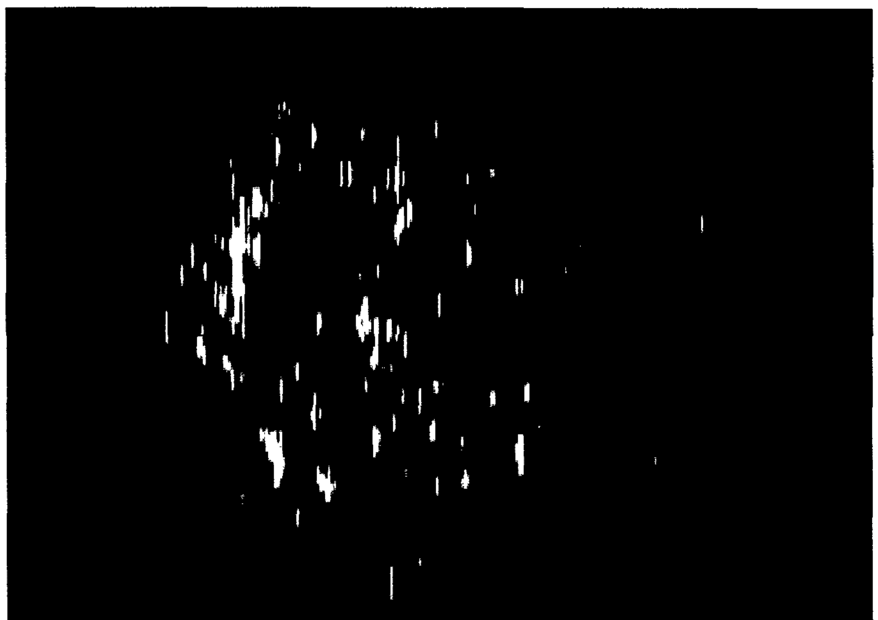
Phase Discriminant

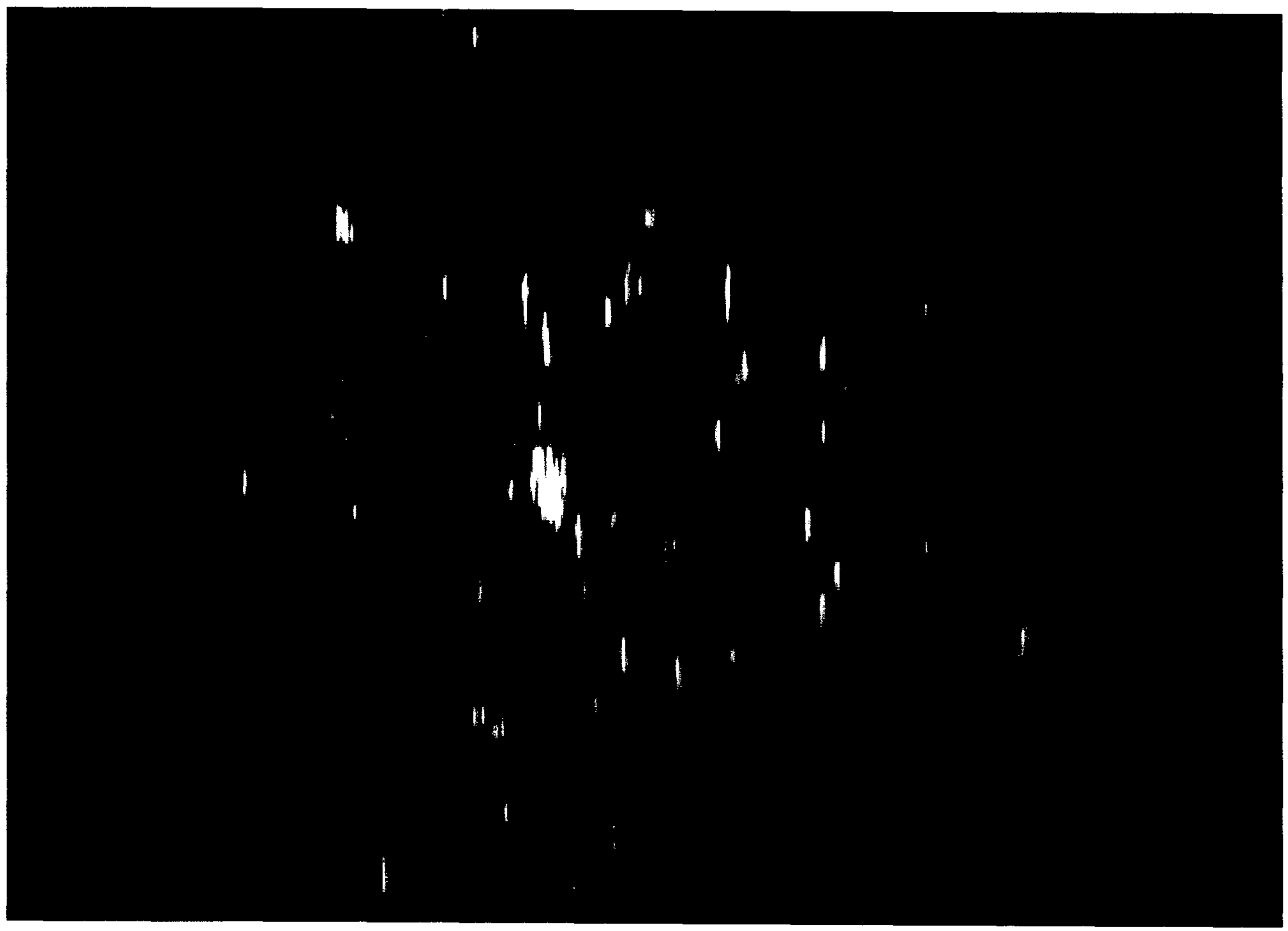
Intensity Image



Phase Height Discriminant

Floating sphere On rocky bottom

Rocky Bottom With Floating Sphere: Intensity Weighted Phase Image

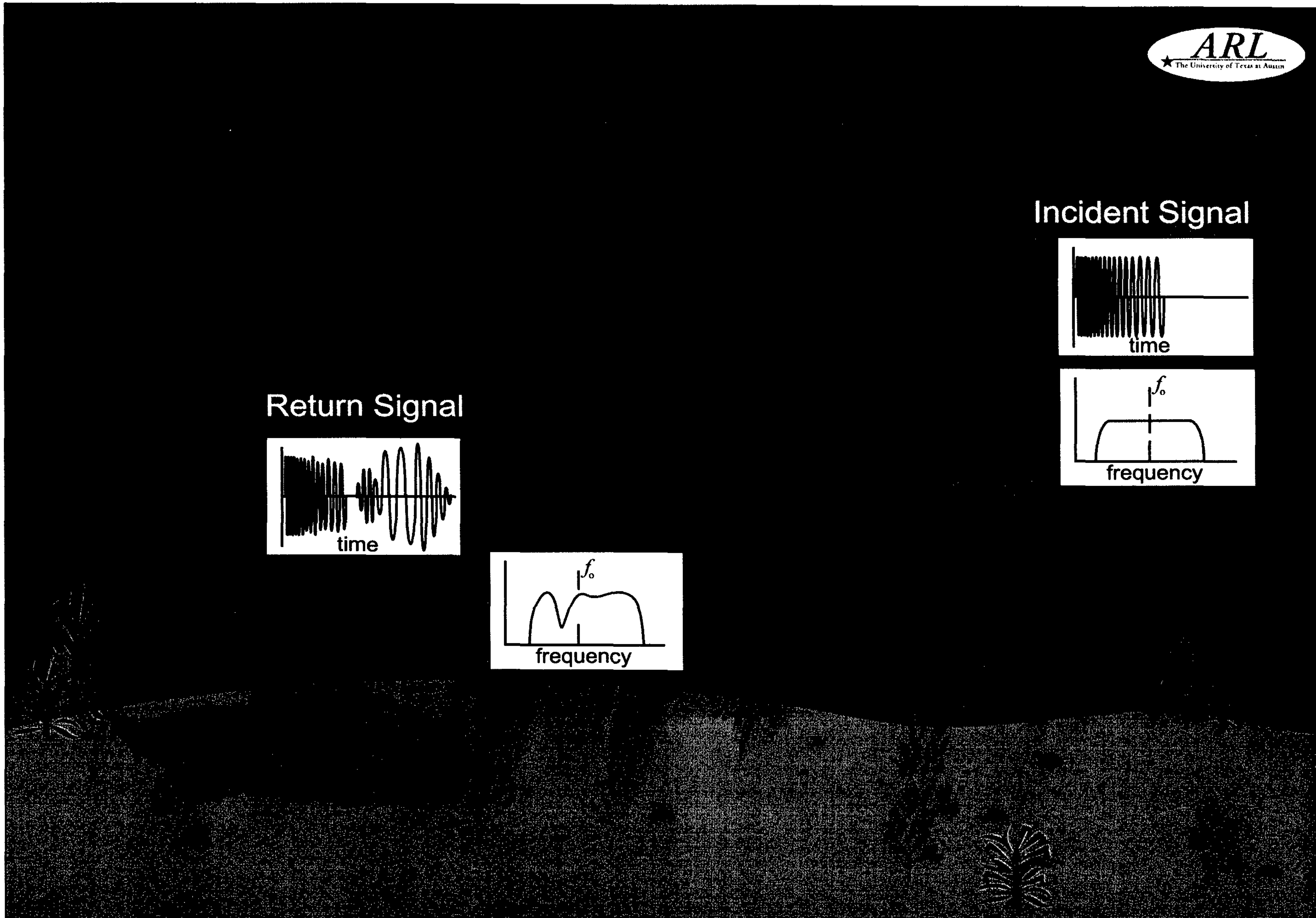


ADDITIONAL MINE CLASSIFICATION CAPABILITIES FOR THE INSS

ALGORITHMS INVESTIGATED IN INITIAL DATA COLLECTION

Shell Thickness Resonance (STR)

i.e. Object shell thickness discriminator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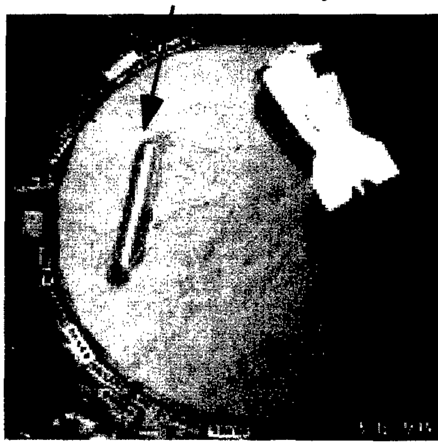
Incident Signal
time
f_o
frequency
Return Signal
time
f_o
frequency

ADDITIONAL MINE CLASSIFICATION CAPABILITIES FOR THE INSS

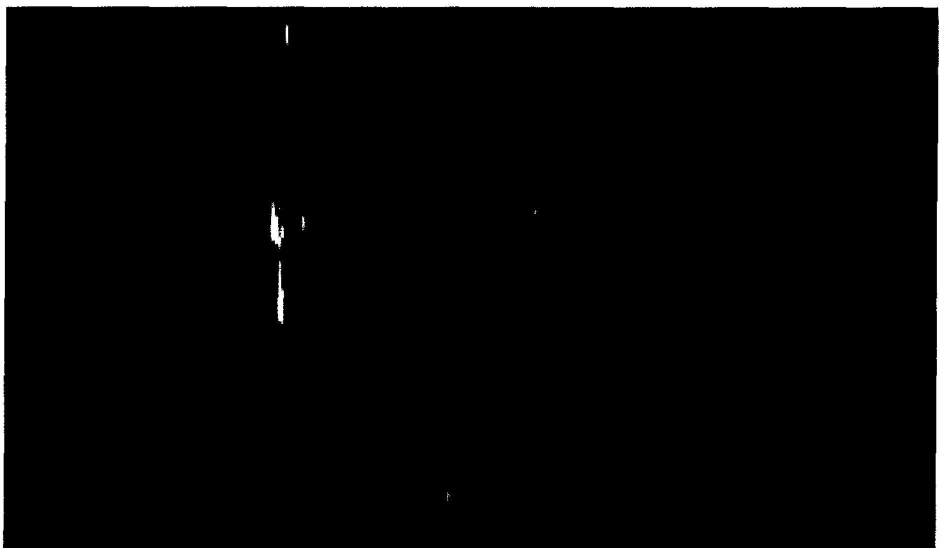
Shell Thickness Resonance Notch Example

Aluminum 1/4" thick cylinder

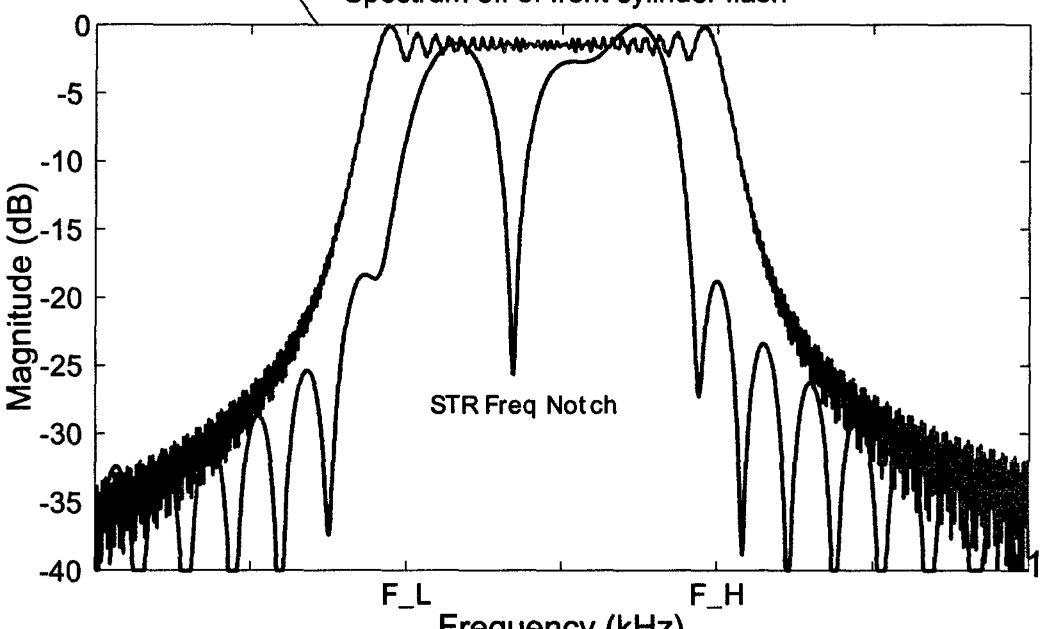


Aluminum 1/16" thick object

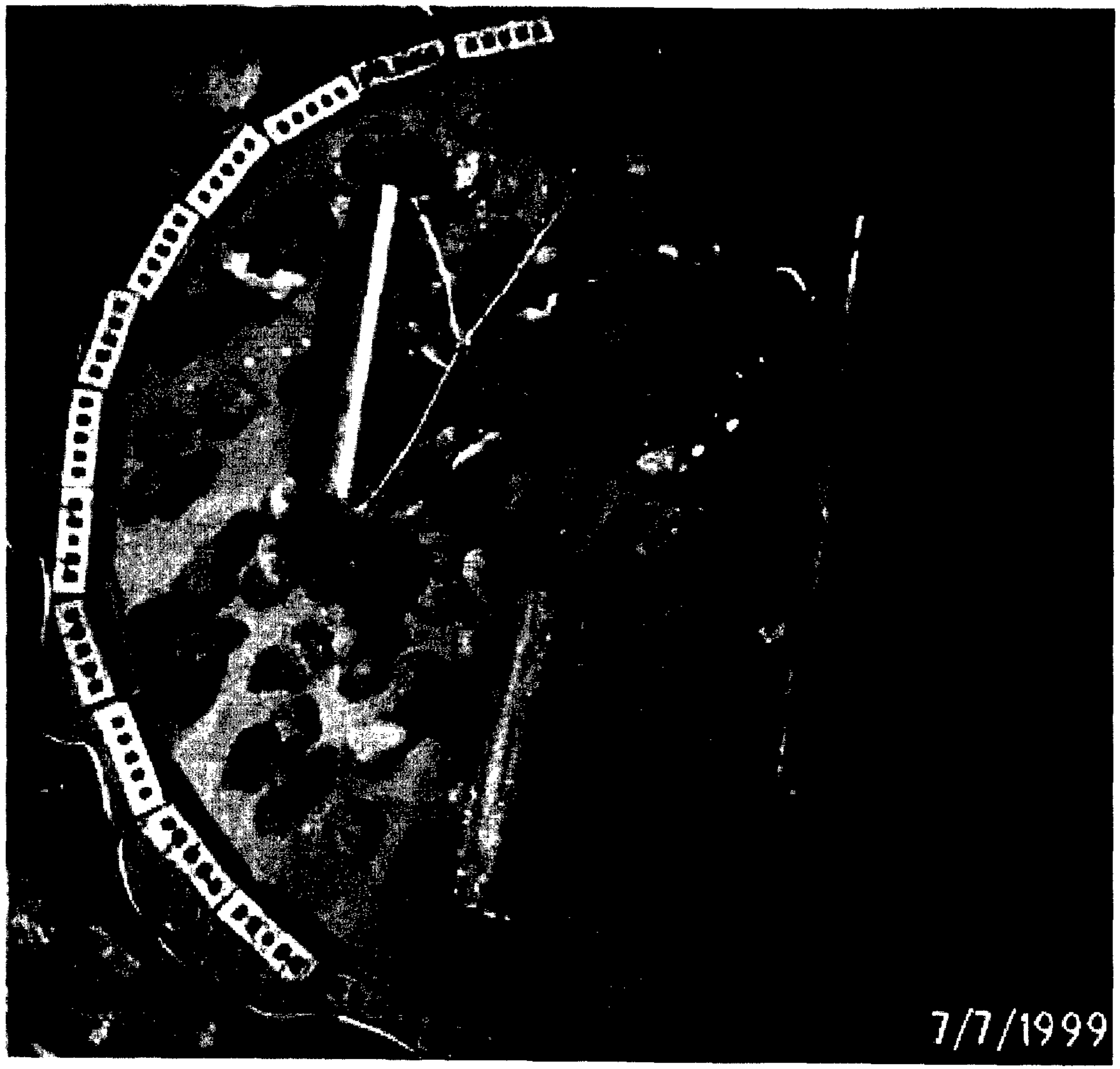
Acoustic Intensity Image of Cylinder



Spectrum off of front cylinder flash

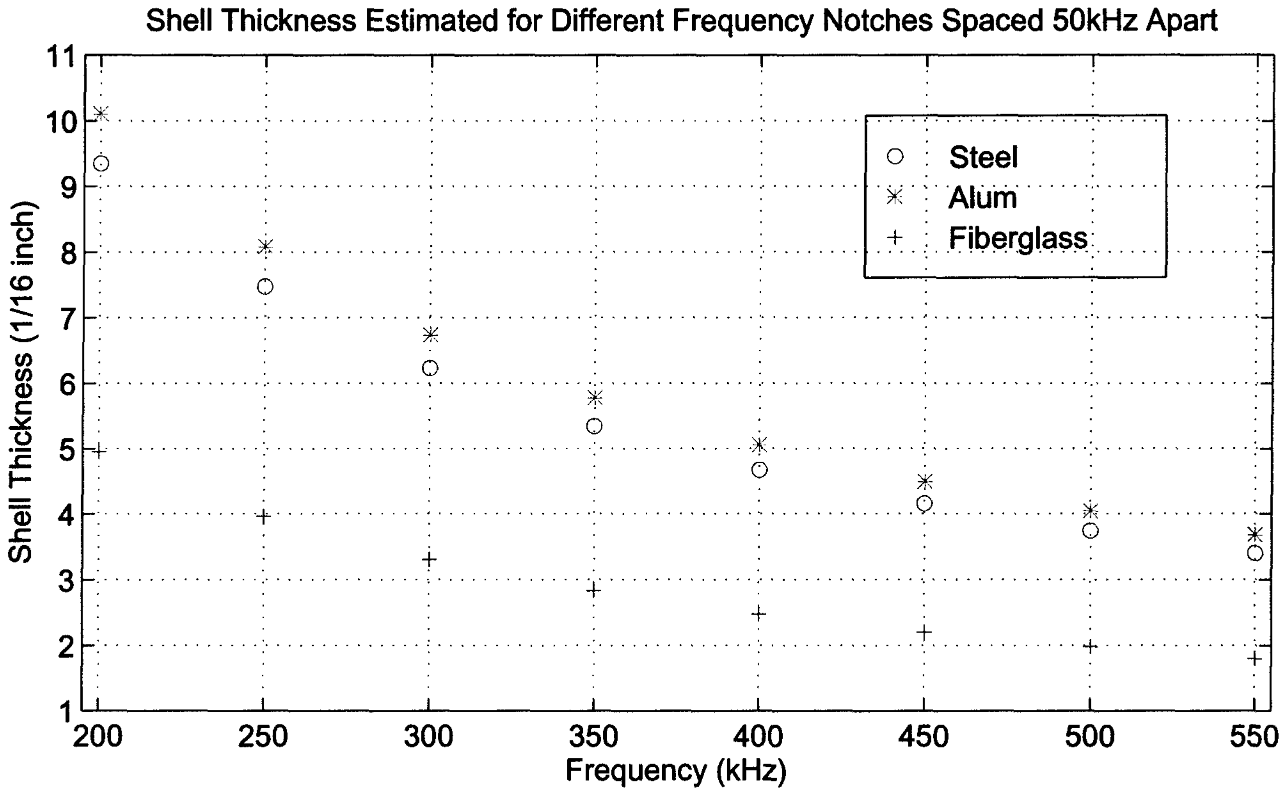


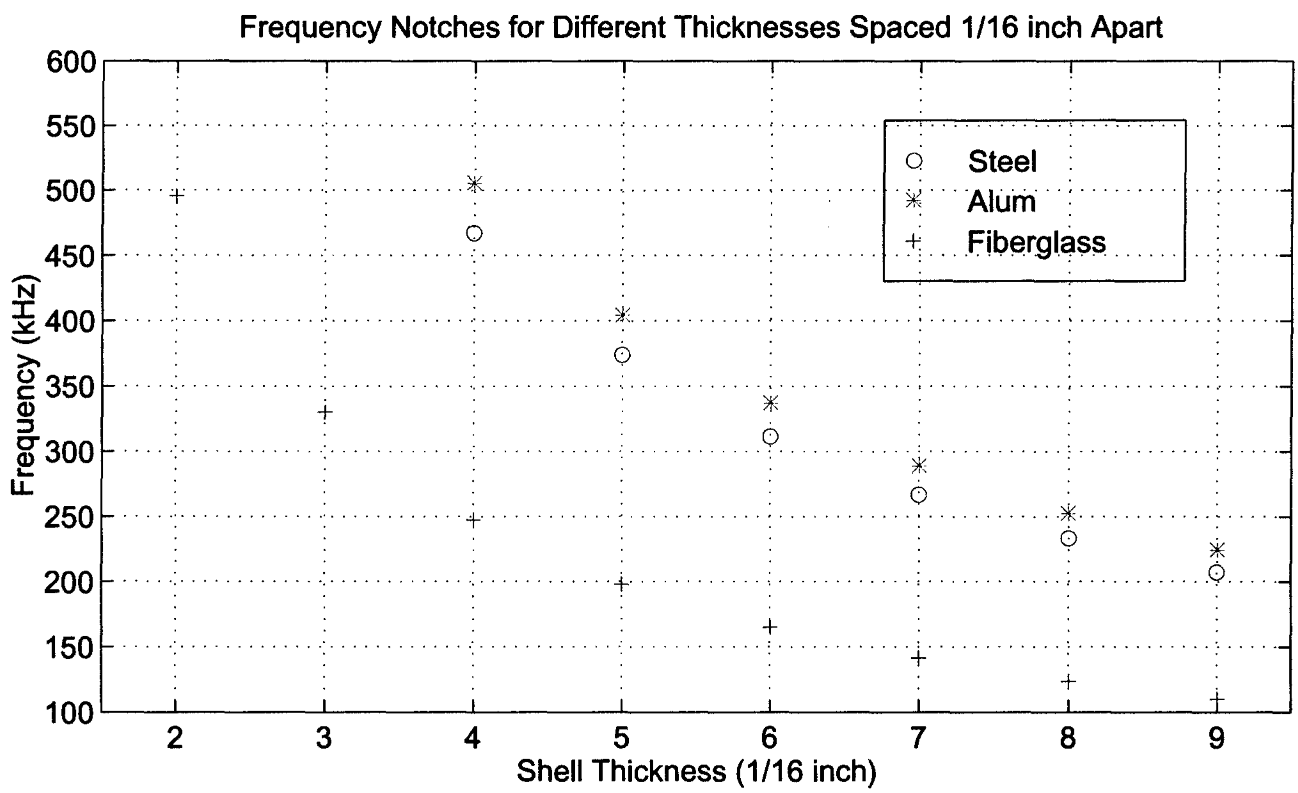
Cylinders on Rocks



Cylinder on Rocks With Initial STR Frequency Notch Detection Algorithm

Thickness Resonance Theory For Different Shell Materials





ADDITIONAL MINE CLASSIFICATION CAPABILITIES FOR THE INSS

ALGORITHMS INVESTIGATED IN INITIAL DATA COLLECTION CONCLUSIONS

- **Triple-flash detector**
  - Reliably estimating mult-path time arrival differences on rocky bottoms proved to be difficult.
  - Did not proceed with INSS implementation.
- **Multi-channel phase comparison**
  - Algorithm proved to be a reliable method to discriminate objects protruding from the ground; however, requires INSS **hardware change**.
  - Did not proceed with INSS implemenation.
- **Shell-Thickness-Resonance (STR) Frequency Notch Detector**
  - Initial experimental tests have shown correlation between the detection of frequency notches and shells of man-made objects.
  - Proceeded with INSS prototype installation, testing, and evaluation.

STR Algorithm INSS Implementation

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INSS Integration of STR Frequency Notch Algorithm

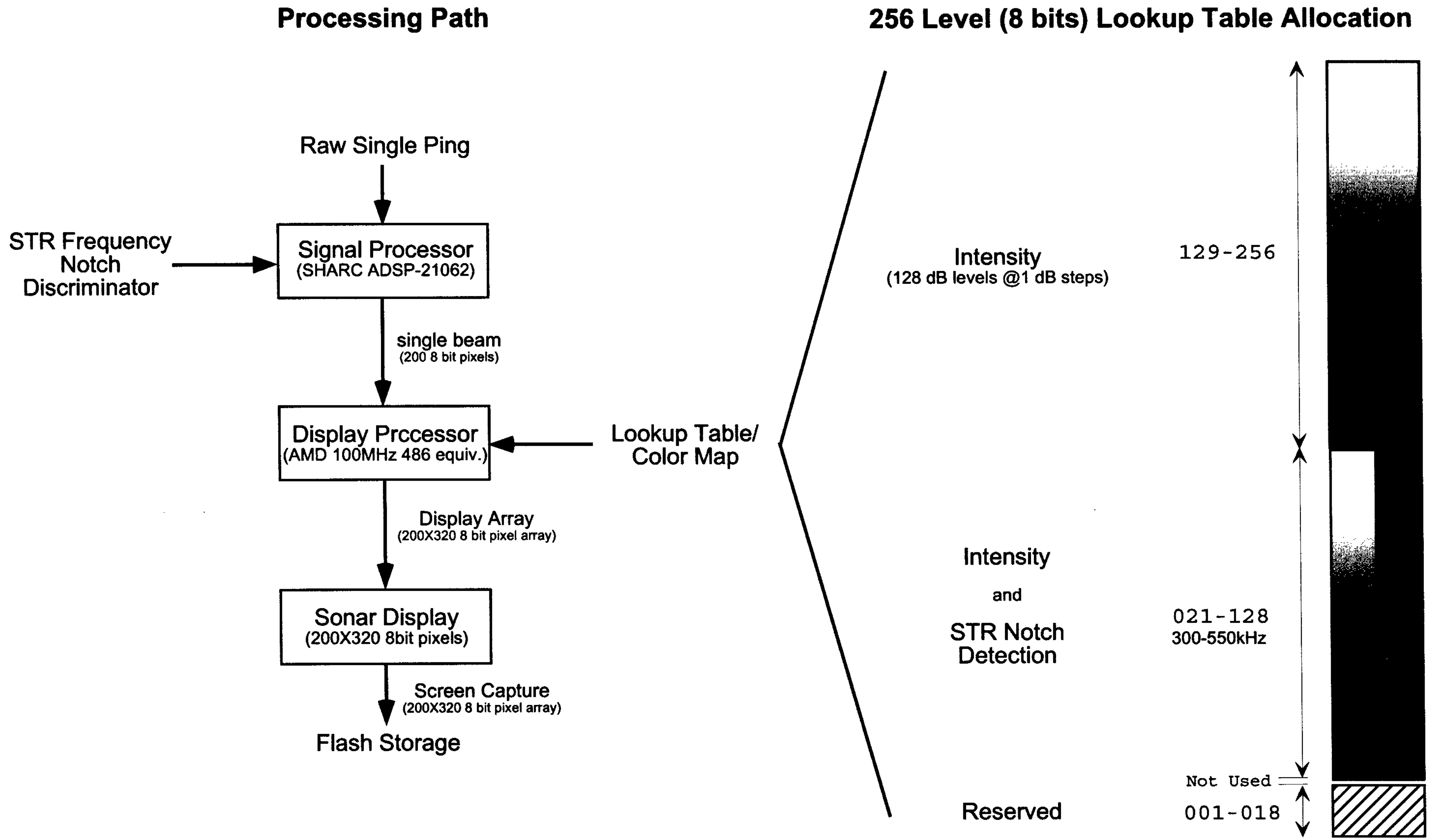
INSS Algorithm Integration

- -- Initial frequency notch algorithm was sized to match the INSS architecture.
- -- All processing implemented on the front end SHARC ADSP21062.
- -- Algorithm blocked to match architecture due to limited processing resources
- -- Algorithm operates in *REAL TIME*

INSS Display Integration

- -- Completely fits within INSS display format storage.
- -- Processing is performed on the 486 equiv. display processor.
- -- Detected "notch" targets are identified in real time during a scan on the current beam with blinking markers.

ADDITIONAL MINE CLASSIFICATION CAPABILITIES FOR THE INSS



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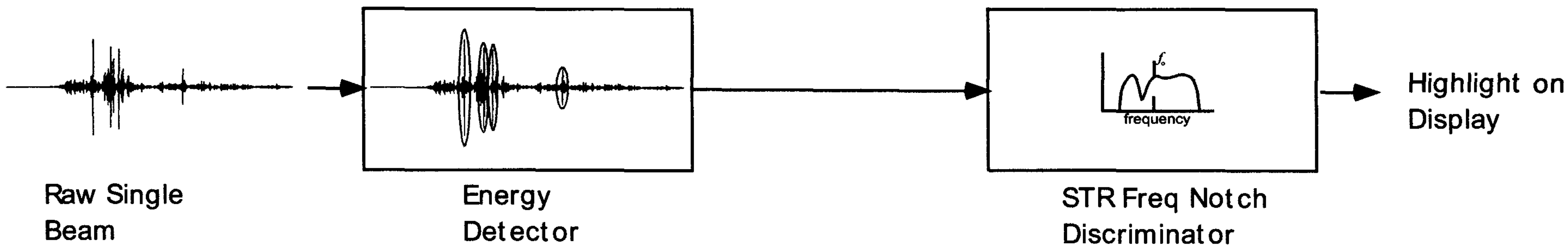
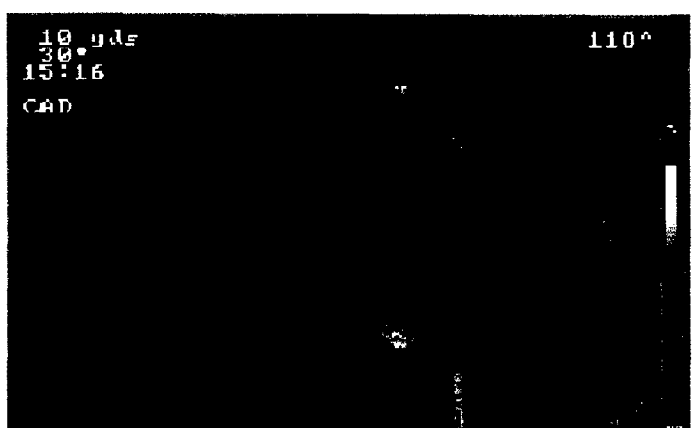
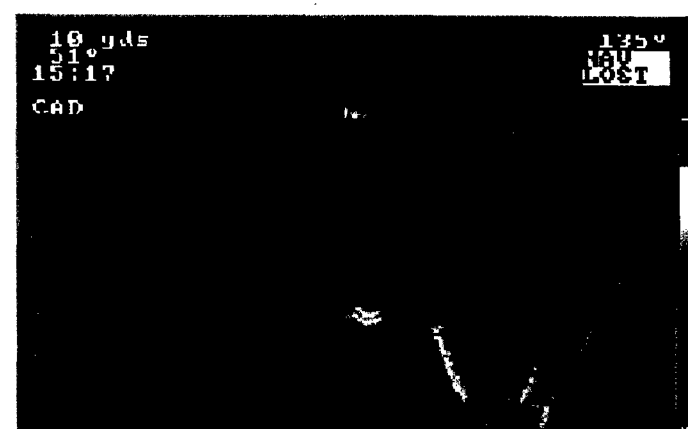
STR Frequency Notch Discriminator Processing





Scene With Energy Detector



Similar Scene With CAD STR Notch Discrimator

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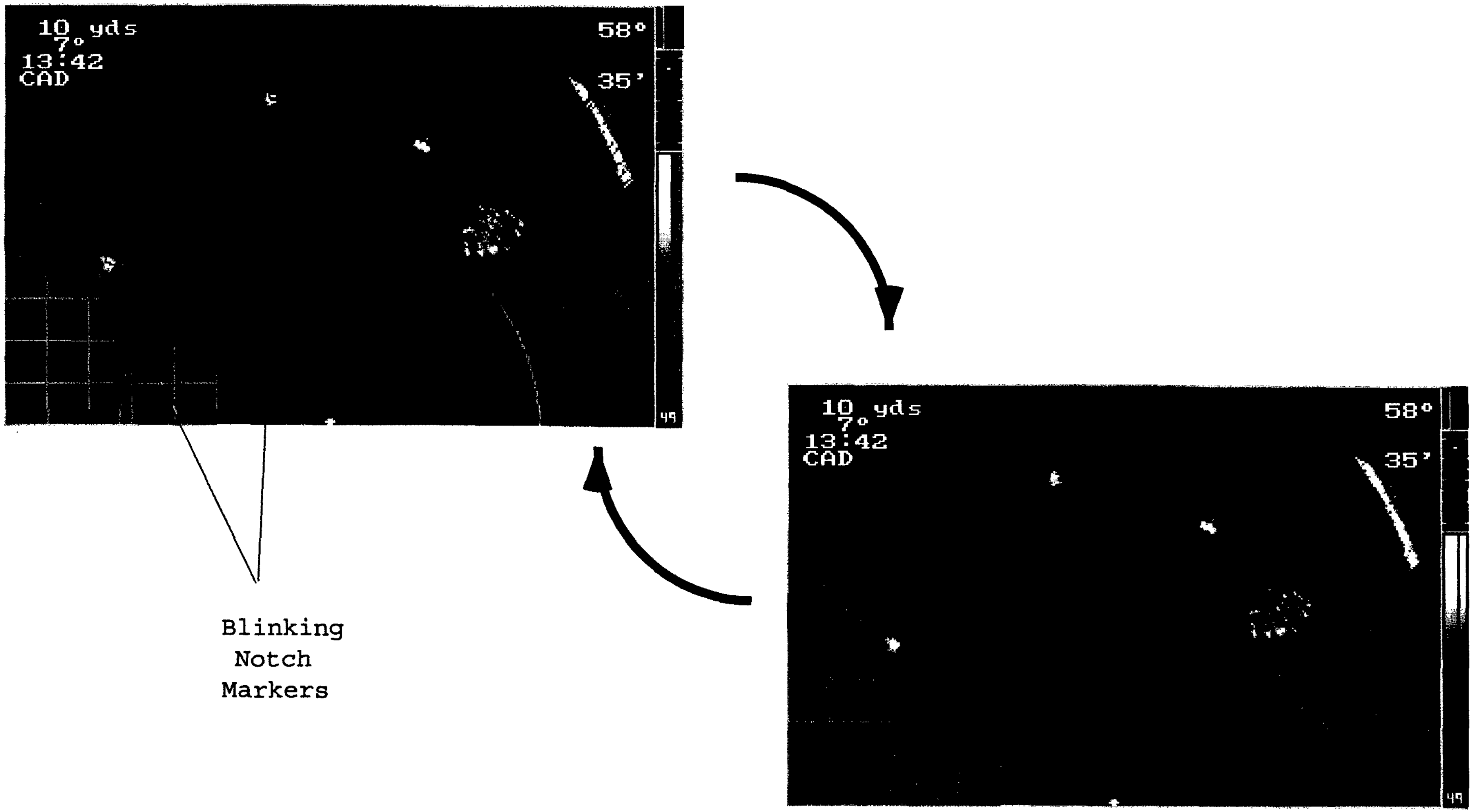
Current Display Setup

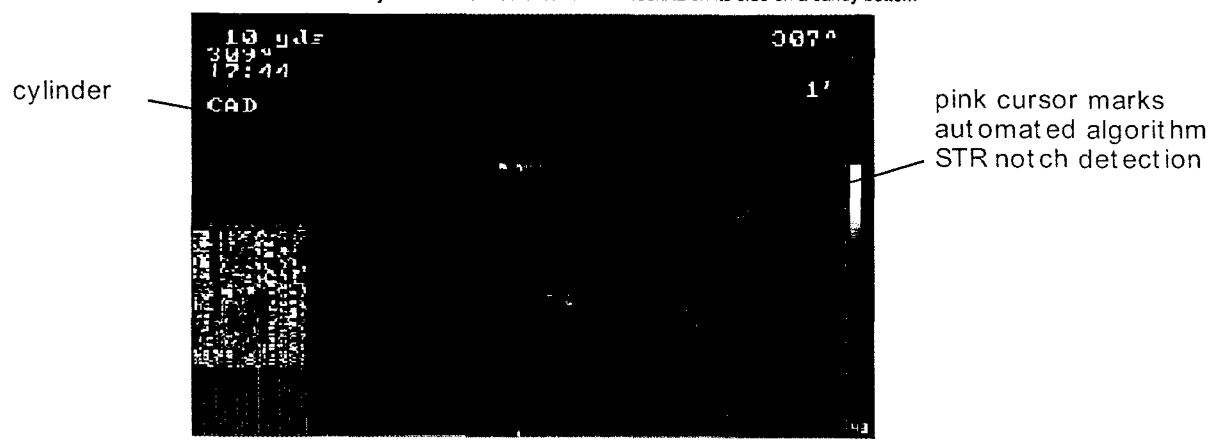


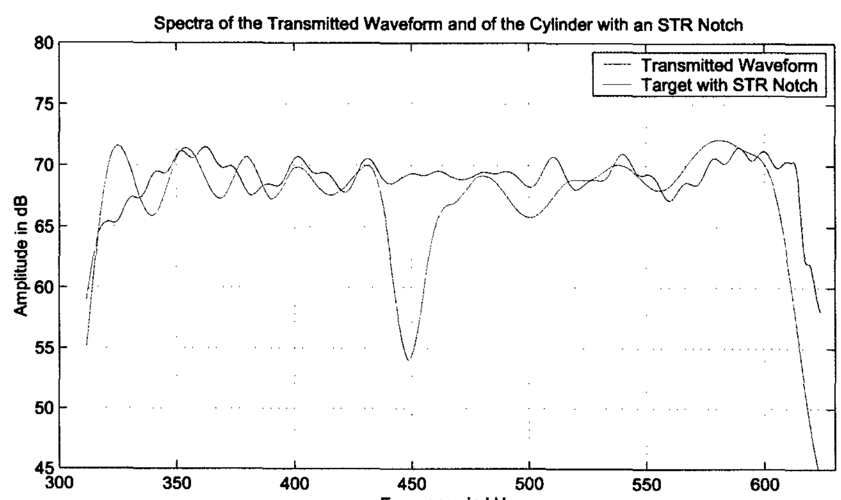
ADDITIONAL MINE CLASSIFICATION CAPABILITIES FOR THE INSS

INSS ALGORITHM IMPLEMENTATION -- STR FREQUENCY NOTCH AS SEEN ON THE INSS

Automated STR Algorithm installed on a HRLMD unit

Screenshot of an Aluminum Cylinder with a theoretical STR of 460kHz on its side on a sandy bottom





INSS CAD operational procedure

How to use a CAD enabled INSS unit

INSS PIP (Computer Aided Discriminator)

Using a CAD enabled INSS unit

Operational Steps

1) Turn on CAD option(currently performed by engineer on surface)

2) Kneel down and/or place yourself in a stable position for scanning with the unit facing the center of the scan center.

3) Pull trigger and adjust unit until level or slightly pitched forward.

4) Pull trigger again to start scan and slowly rotate the unit to the left and to the right to complete the scan.

5) Pull trigger to stop scanning.

6) Save image if necessary.

INSS PIP (Computer Aided Discriminator)

Using a CAD enabled INSS unit

Best performance is achieved by ...

* Carefully panning across targets (pan slightly slower than the typical scan rate)
* Panning back over target in question (Look for markers consistently reappearing over targets)
* Vertical beam sensitivity (i.e. Make sure unit tilt indicator shows unit is level or slightly pitched forward).
* Any combination of the above (i.e. Panning back over targets while slightly varying unit pitch).

INSS PIP (Computer Aided Discriminator)

Vertical Beam Placement and Tilt Indicator

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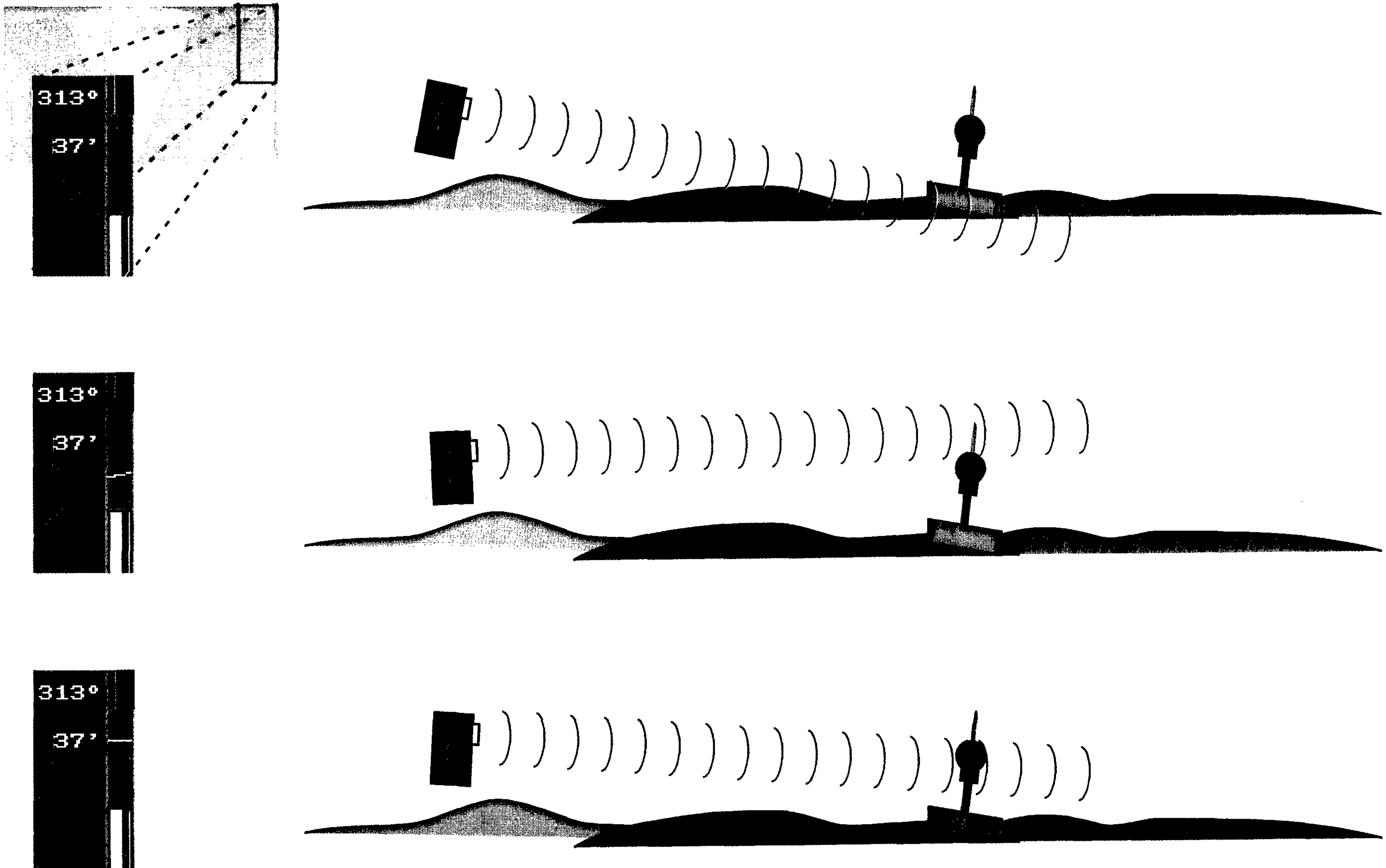

INSS PIP (Computer Aided Discriminator)

Minimum Scan Rates vs Range Scales

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Range Scale	Minimum Scan Times
3 yds	6.0 s
7 yds	7.0 s
10 yds	9.0 s
20 yds	12.0 s
40 yds	20.0 s

STR algorithm results for the INSS

Navy diver tests @ ARL tank

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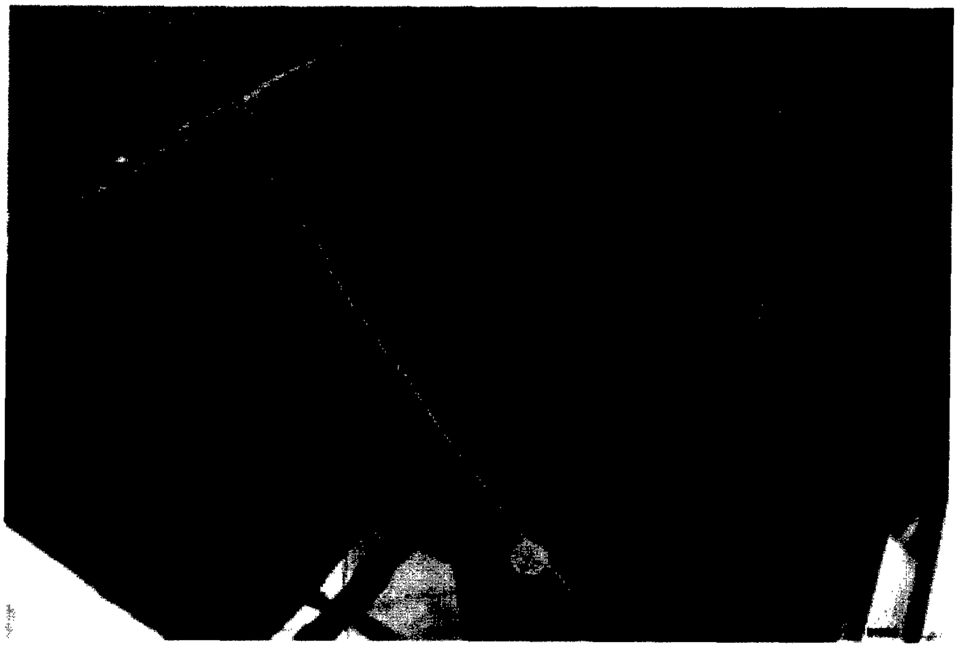
ADDITIONAL MINE CLASSIFICATION CAPABILITIES FOR THE INSS

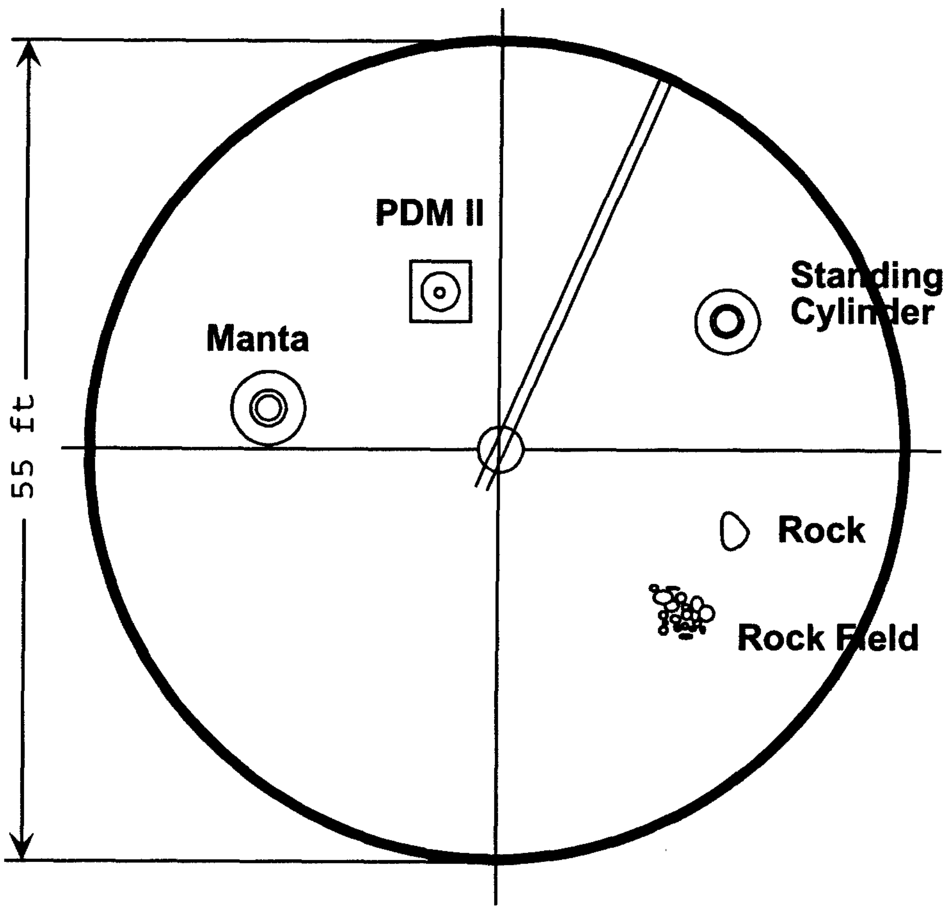
Setup of Diver Tests (Oct. 5, 2000)

Setup

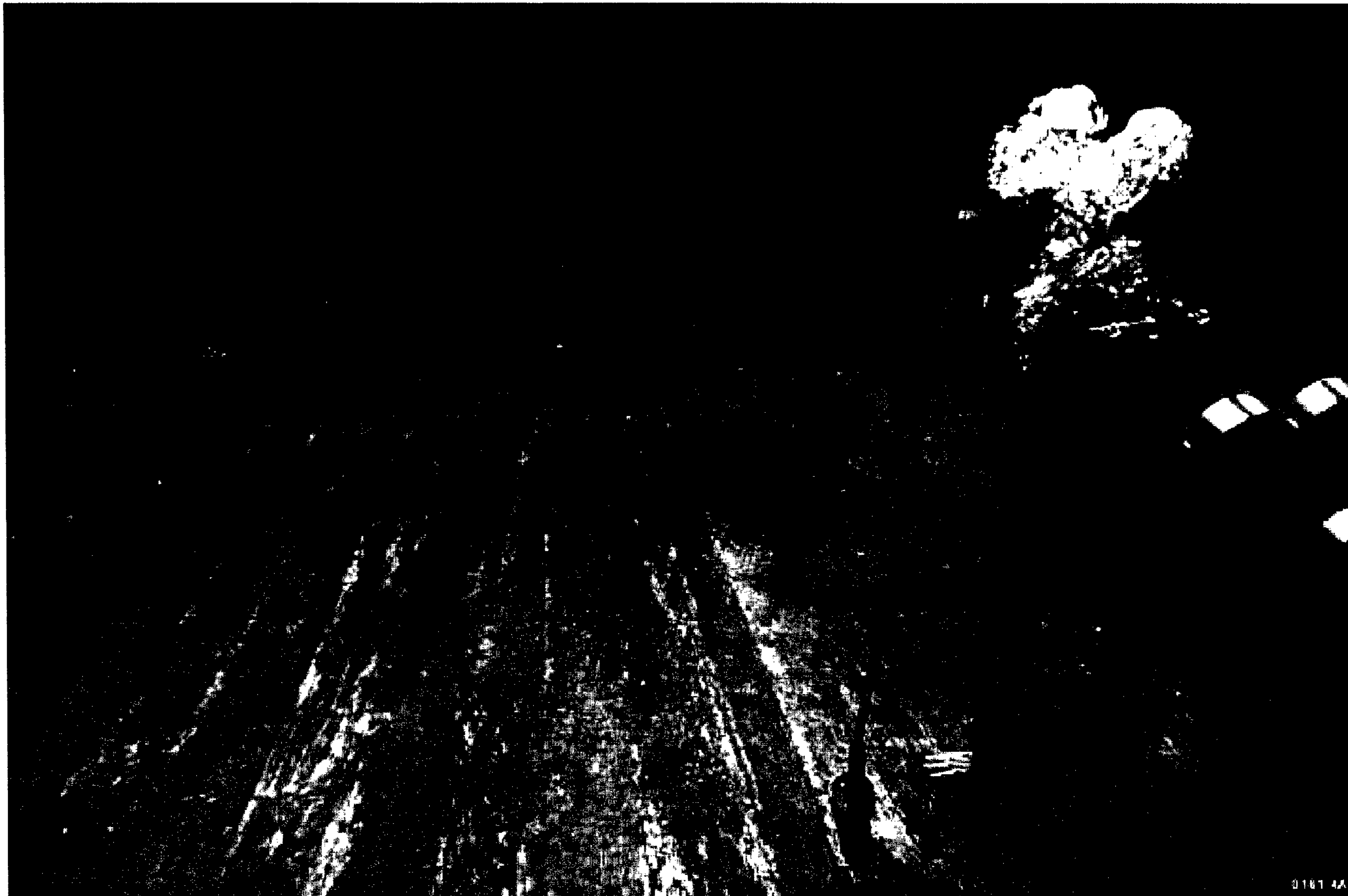
* Tested current STR frequency notch discriminator on prototype INSS.
* Target field consisted of 2 natural and 3 man-made targets located in a 55 ft diameter by 40 ft deep wooden tank
  - Manta Simulator
  - PDM II
  - 2 ft steel cylinder
  - Large rock
  - Small rock field
* 5 Divers evaluated STR notch algorithm and INSS display

Redwood Tank Target Field



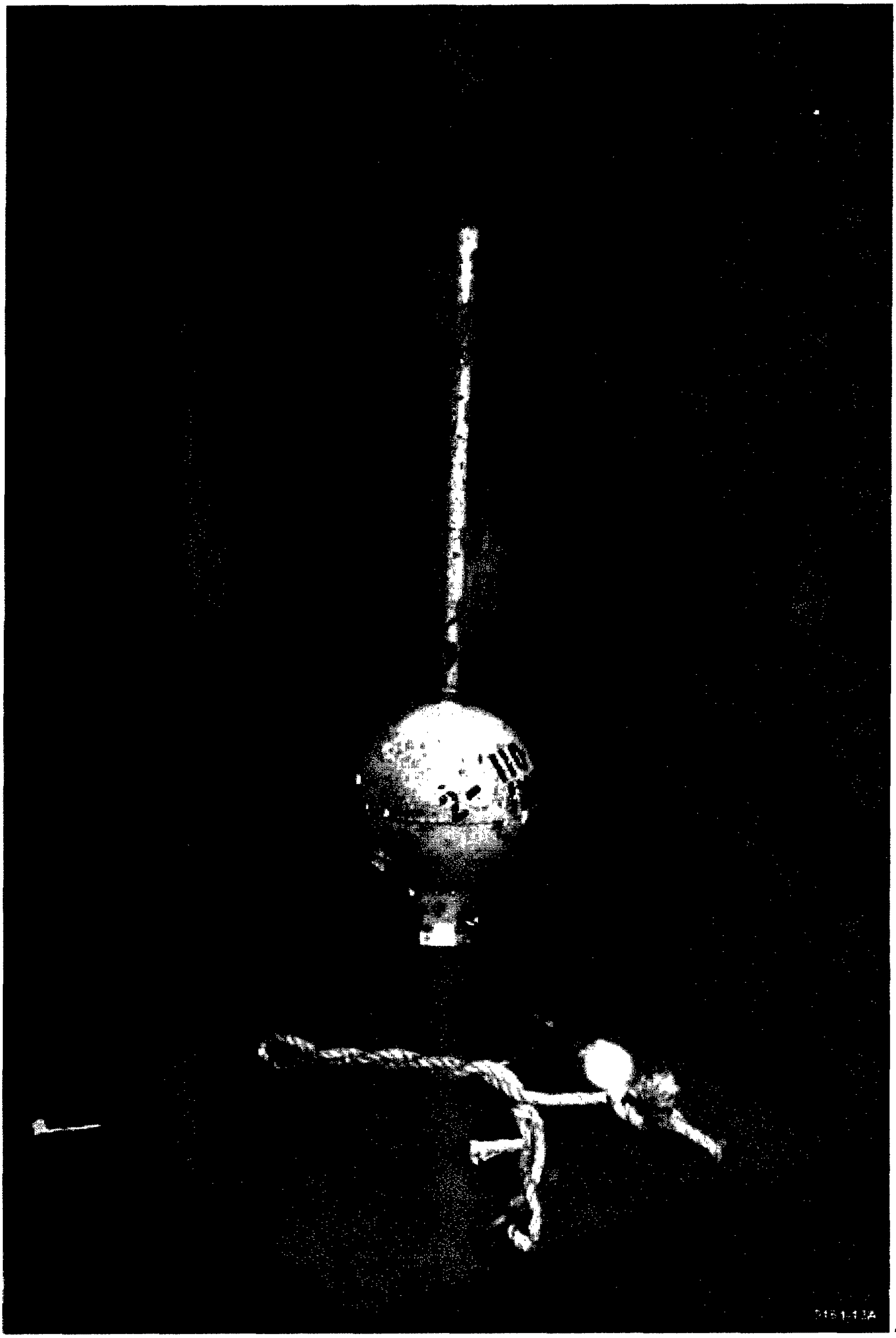


DIVER IMAGING TARGET WITH STR FREQUENCY NOTCH DETECTOR

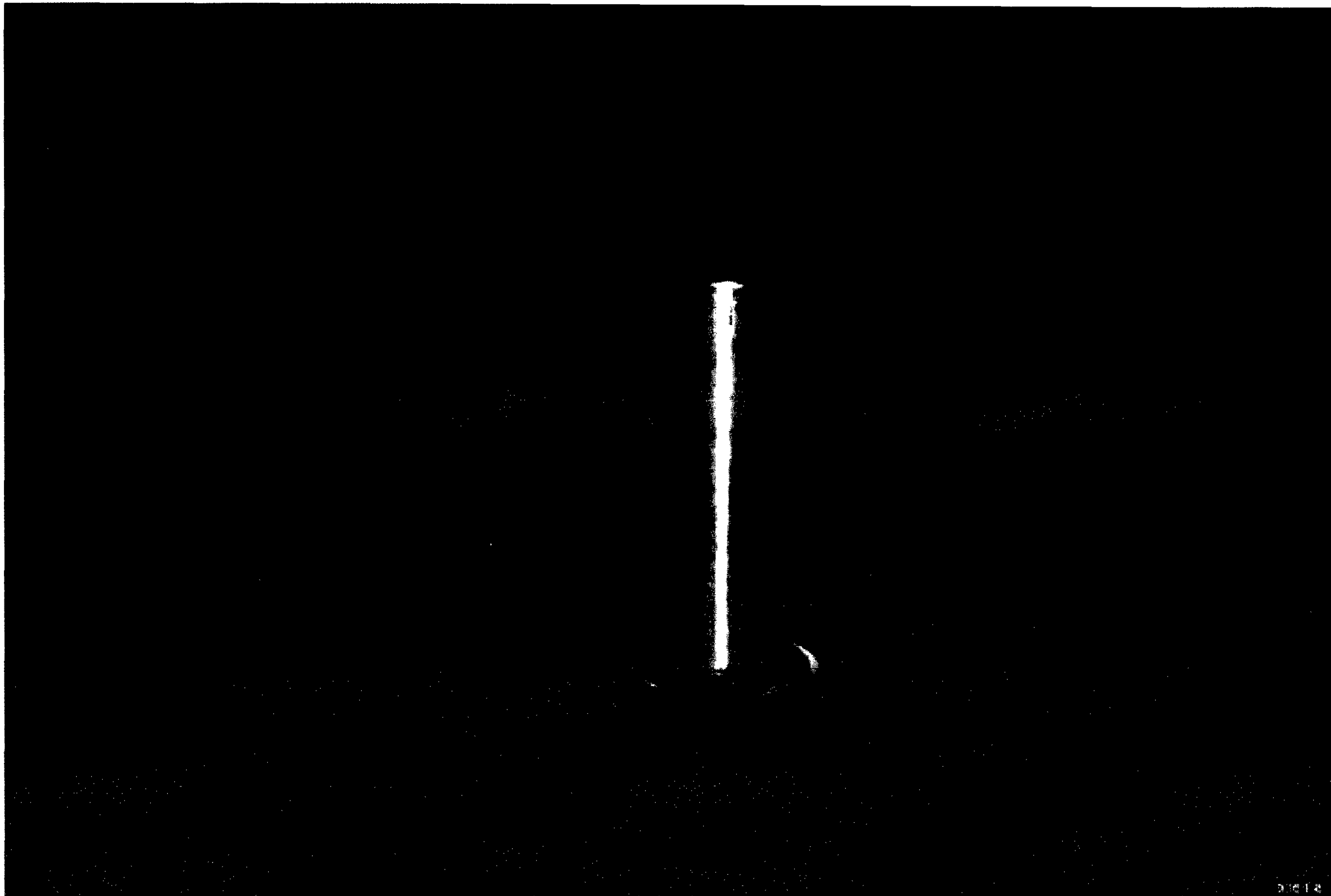


MANTA SIMULATOR

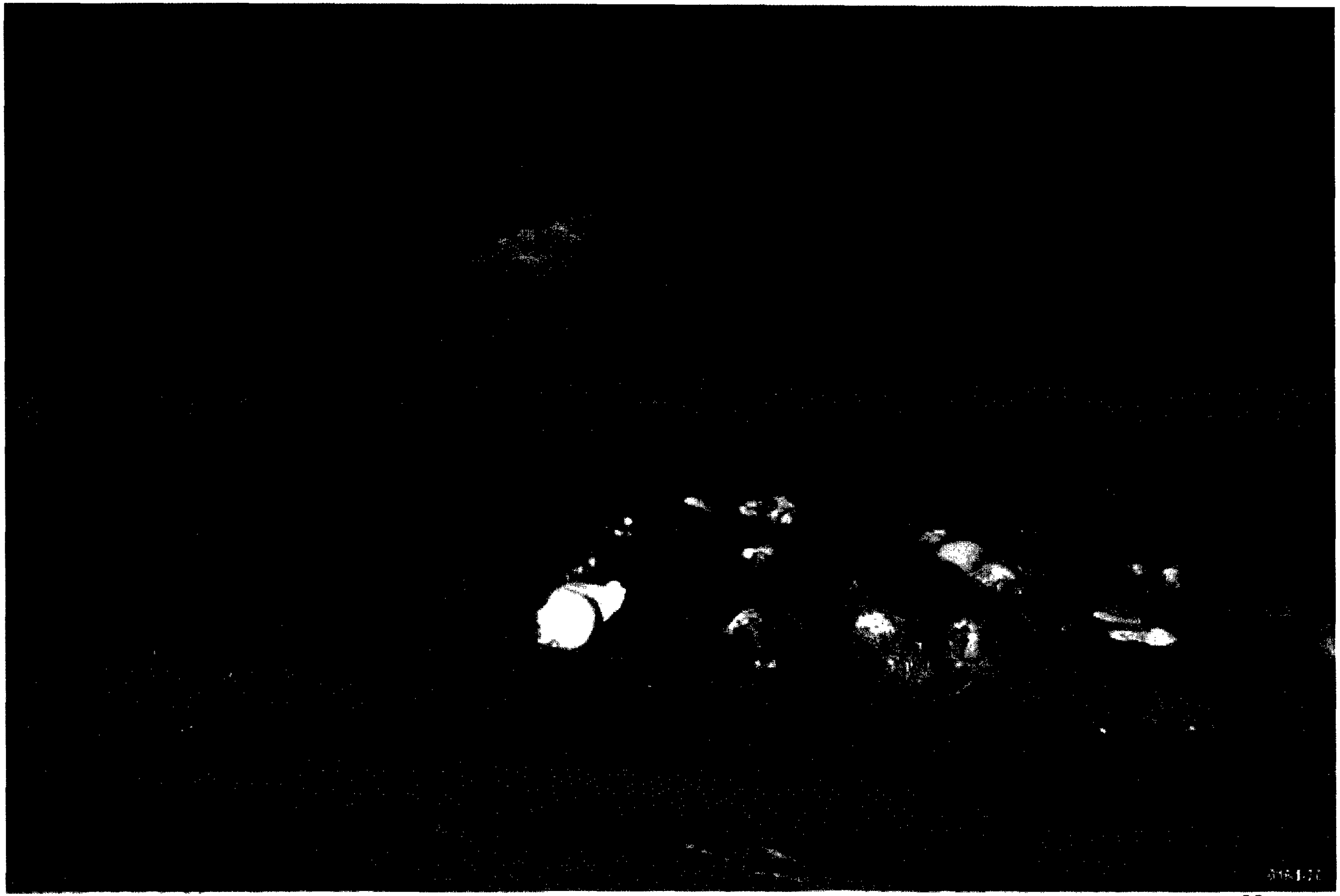
PDM II



STANDING CYLINDER



ROCK AND ROCK FIELD



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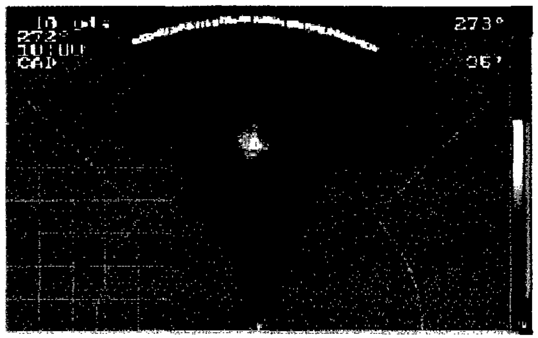
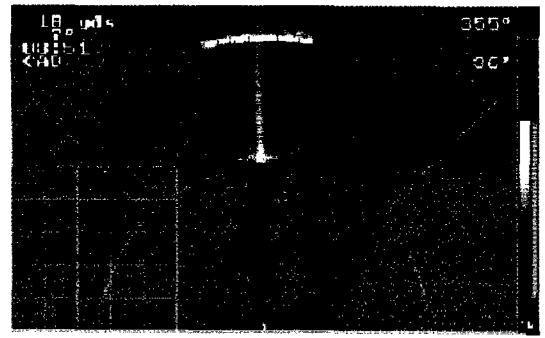
ADDITIONAL MINE CLASSIFICATION CAPABILITIES FOR THE INSS

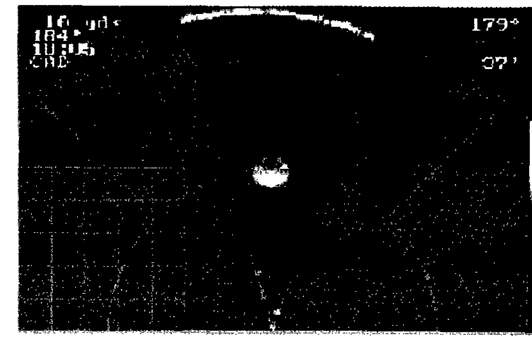
NAVY DIVER SCREEN SHOTS -- OCT. 2000



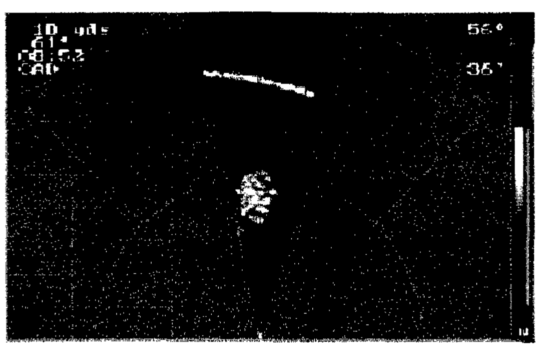
A) PDM II



B) Standing cylinder

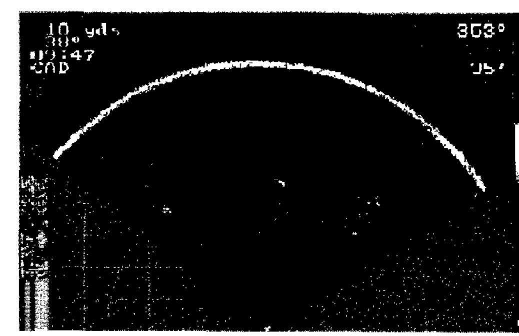


C) Manta



D) Rock field

E) Diver, PDM, Rock. (Effect of improper grazing angle shown)



F) Standing cylinder, rock, & rock field

Navy diver screen shots taken in ARL large redwood tank facility. Pink markers show STR notches found by INSS CAD algorithm. Mine-like targets (PDM II, cylinders, Manta) are clearly tagged with STR markers. False alarms are prevalent on the circular tank wall.

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Results of ARL Redwood Tank Navy Dive Tests (Oct. 5, 2000)

Initial results of STR frequency notch discriminator in a controlled environment

- 4 of 5 divers found algorithm beneficial in drawing attention to targets of importance
- Positive detects off of PDM, Manta, and cylinder were common for 4 of 5 divers
- False detects occurred on tank wall for all divers and less frequently on the rock and rock field

Diver Feedback and Comments

Performance issues

- Target discrimination enhanced by:
  - slowly panning across targets (e.g., scan rate appropriate for the 40 ydr range scale)
  - panning back over a target in question
- Sensitivity towards vertical beam placement relative to target

Display

- Blinking target markers were useful and non-distracting. Marker color choice fine.
- All divers recommend blinking colorbar be removed

Misc.

- Recommended operational range increased to 40 yds

STR algorithm results for the INSS

ARL diver tests

ADDITIONAL MINE CLASSIFICATION CAPABILITIES FOR THE INSS

ARL DIVER SCREEN SHOTS -- 2001-2002

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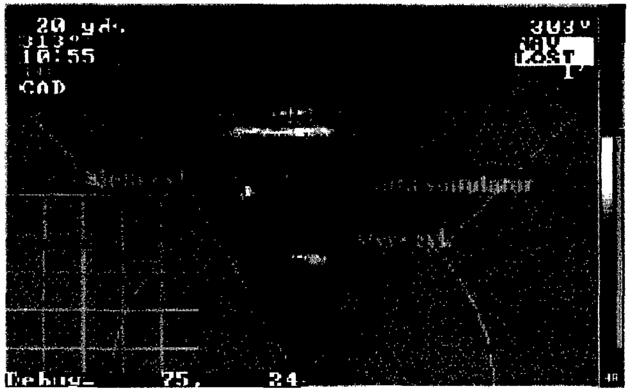
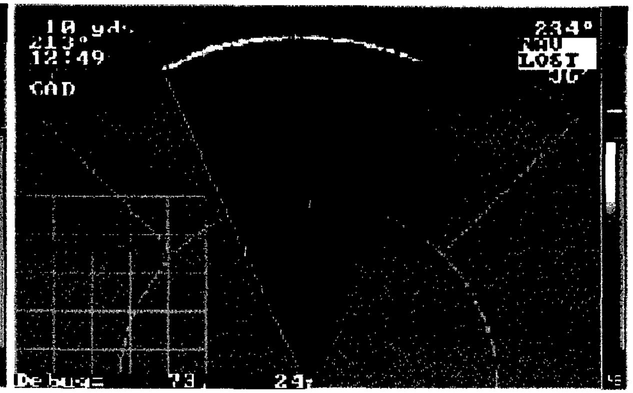


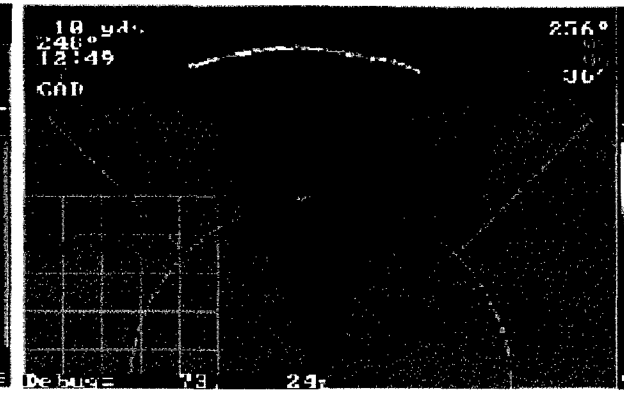
ARL indoor test tank

A) cylinders, manta sim



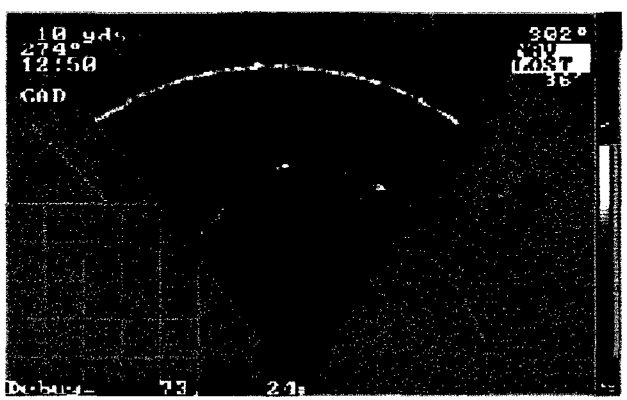
ARL large redwood tank facility

B) manta simulator



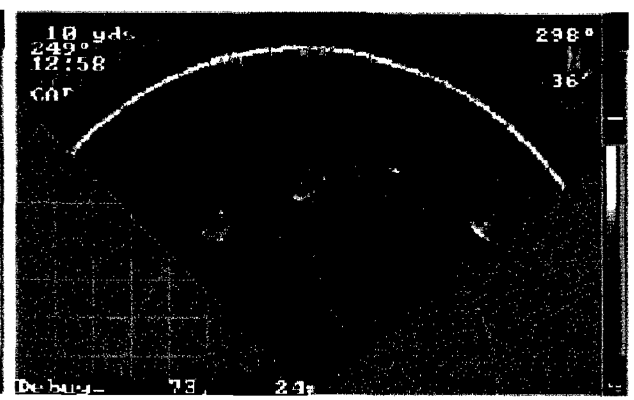
ARL large redwood tank facility

C) rockan simulator



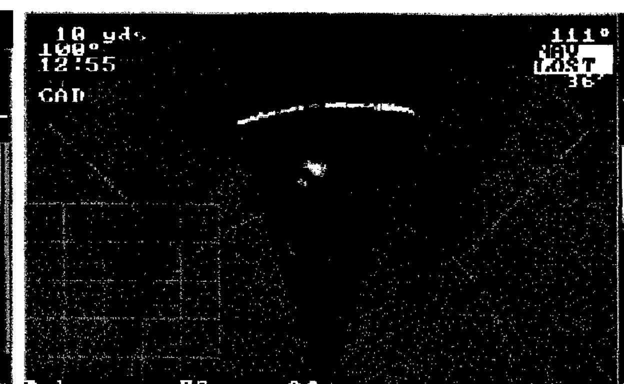
ARL large redwood tank facility

D) rockan simulator, cylinders



ARL large redwood tank facility

E) manta & rockan simulators, cylinders

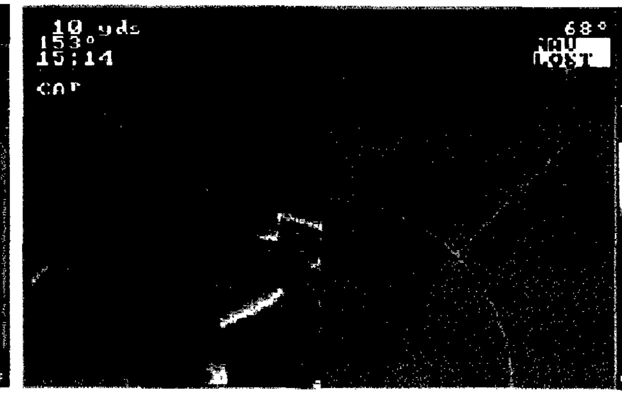


ARL large redwood tank facility

F) cylinder, diver & airtank

ADDITIONAL MINE CLASSIFICATION CAPABILITIES FOR THE INSS

ARL DIVER SCREEN SHOTS -- LTTS



ARL Diver Test Observations:

* Tests performed at Lake Travis Test Station @ 50ft depth
* mk56 mine casing consistently marked by the CAD
* concrete wedding cake target remained undetected even though it very bright (which is as it should be since it is not a thin shelled target)
* Sporadic false alarms existed along cliff wall
* No false alarms occurred on the bottom (areas of limestone and mud)

STR algorithm results for the INSS

Navy diver evaluation @ Naval Amphibious Base, Coronado CA

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INSS PIPS (Computer Aided Classifier, Very High Res & Buried Target Sonar)

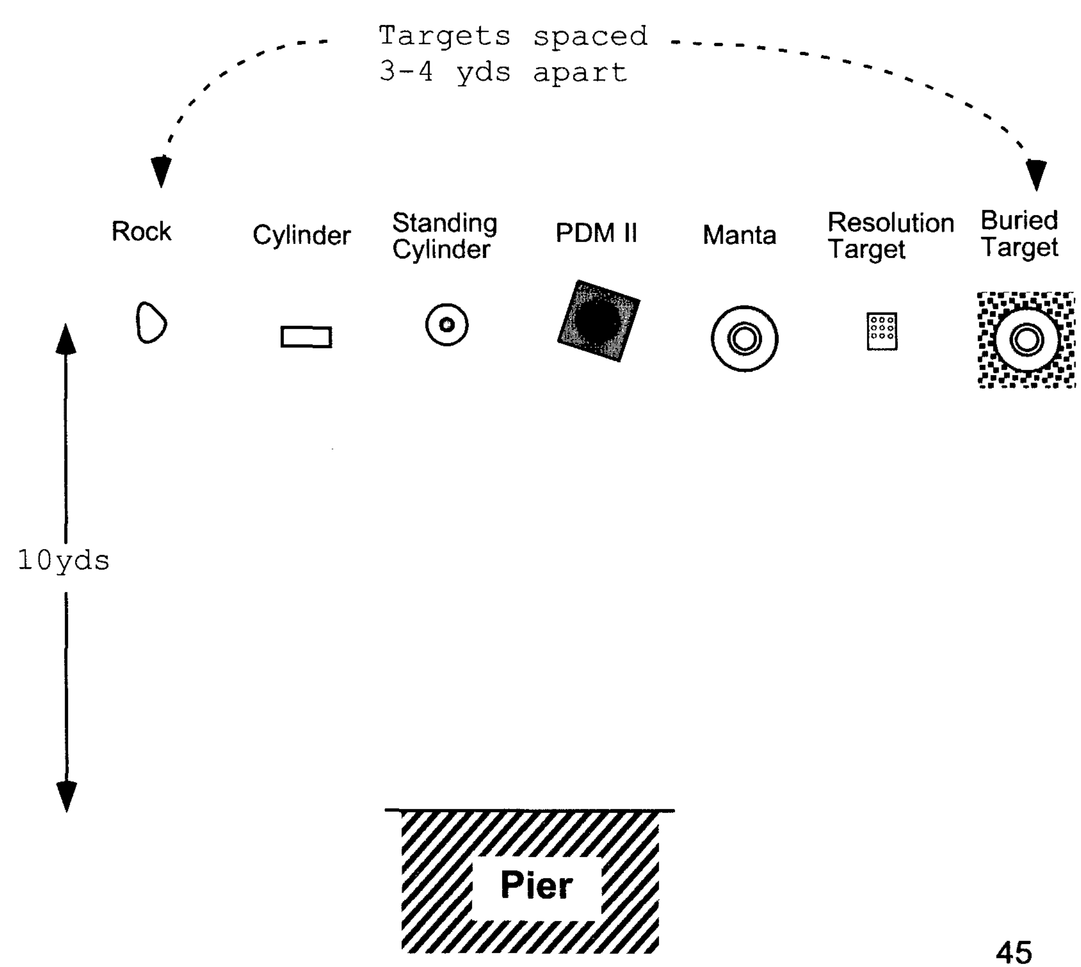
Dive Test Setup

Mine Types

* Rock (1 to 2 ft of any type)
* 3ft aluminum cylinder (ARL supplied)
* 3ft vertical aluminum cylinder with base. (ARL supplied)
* PDM Type II (filled with water or explosive simulator).
* Manta
* Resolution target (ARL supplied)
* Buried Manta or PDM (completely covered)

Mine placement

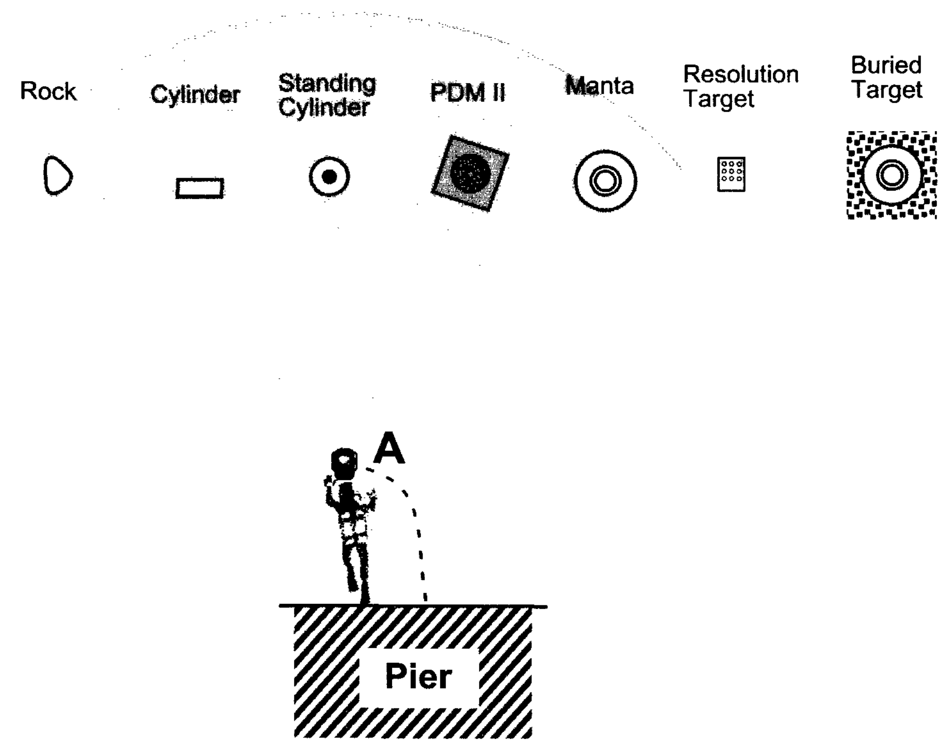
* Targets set ~10 yds from pier edge.
* Targets separated by 3-4yds.



INSS PIP (Computer Aided Classifier)

Dive 0: Shakedown

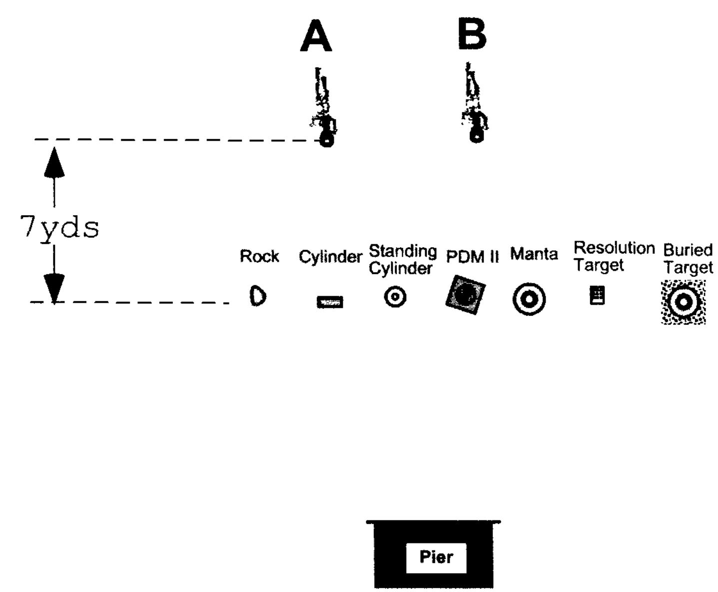
- ☐ Engineer: initializes HRLMD unit. (calibrate sensors, set unit to CAD mode, Range scale to 10yds, Set Colormap to 48)
- ☐ Diver: Verify Range Scale 10yds. Verify Colormap to 48.
- ☐ Diver: Move to **A**
- ☐ Diver: Complete 3 sector scans of targets. Save all 3 images.
- ☐ Diver: Return to pier.
- ☐ Engineer: Evaluate scanned images and log comments from diver.



INSS PIP (Computer Aided Classifier)

Dive 1: 7-10 yd Evaluation

- [ ] Diver: Verify Range Scale = 10 yds,
  Verify colormap = 48.
- [ ] Diver: Move to **A**
- [ ] Diver: Complete 2 or 3 scans of the rock and cylinders. Save each image.
- [ ] Diver: Move to **B**
- [ ] Diver: Complete 2 or 3 scans of the Manta and PDM II. Save each image.
- [ ] Diver: Return to pier
- [ ] Engineer: Evaluate scanned images
  and log comments from diver.



ADDITIONAL MINE CLASSIFICATION CAPABILITIES FOR THE INSS

NAVY DIVER PIP EVAL -- CORONADO 2002

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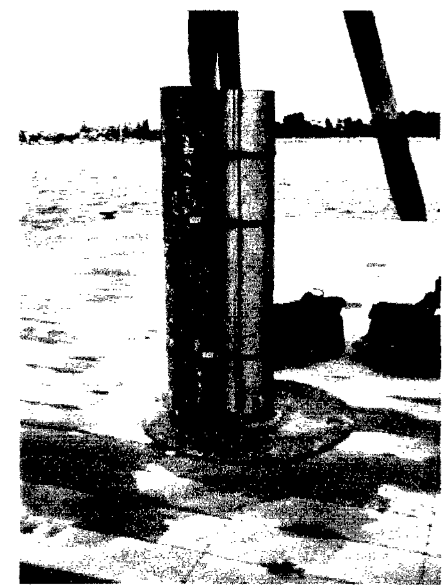
CAD enabled HRLMD

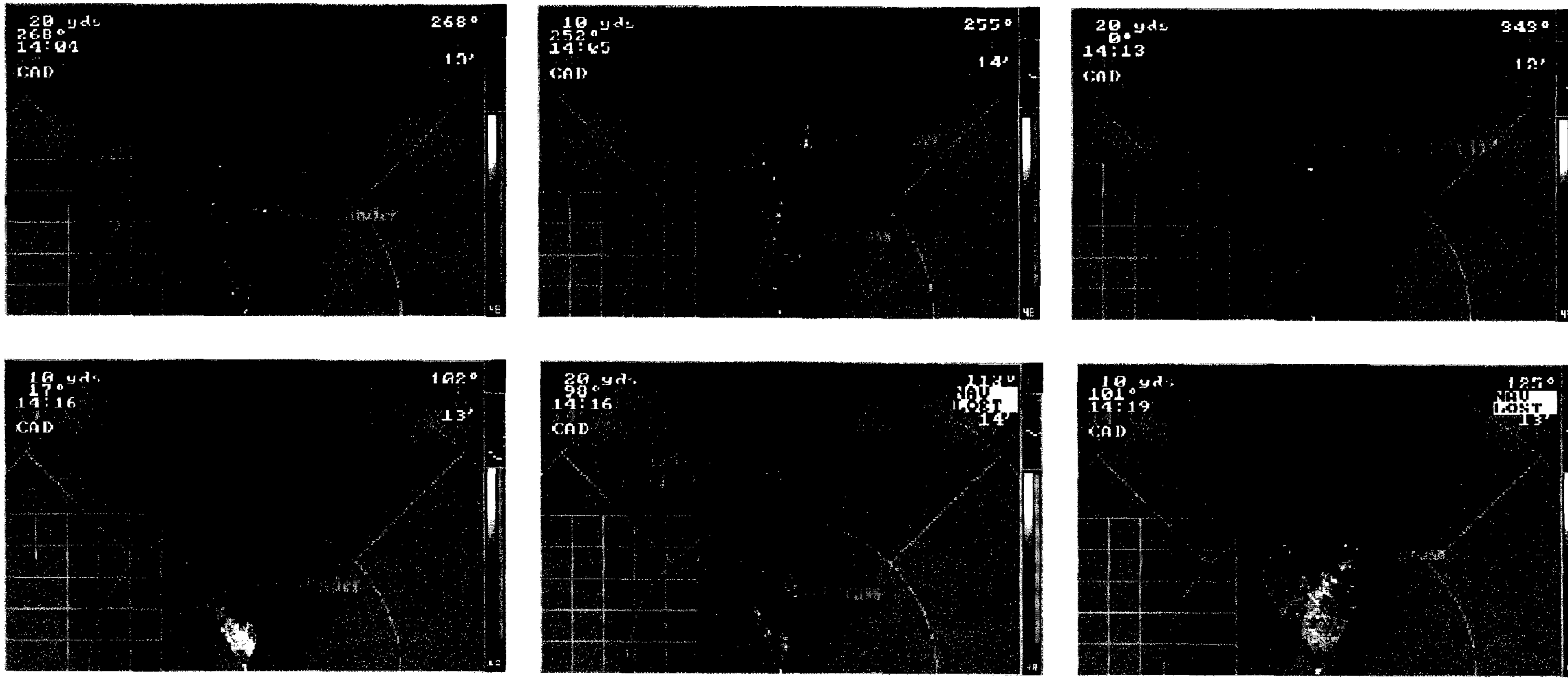
Divers receiving operational instructions on using the PIP enhanced INSS unit



Vertical and horizontal cylinders (separated during testing)

ADDITIONAL MINE CLASSIFICATION CAPABILITIES FOR THE INSS

NAVY DIVER SCREEN SHOTS -- CORONADO 2002



Navy Diver Test Observations:

* Vertical and horizontal aluminum cylinders were consistently marked.
* Other mine-like targets (PDM II, rockan, buried manta) were not detected.
* Difficult operating environment!!
  i.e. > 3ft tall eel grass populated test area, bottom composed of very soft & deep mud
* Eel grass caused most of the false alarms and was often brighter than many targets.

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ADDITIONAL MINE CLASSIFICATION CAPABILITIES FOR THE INSS
NAVY DIVER EVALUATION -- CORONADO 2002

- **Two Navy divers familiar with VSW-MCM and NSW missions participated in the test**
- **Diver comments**
  - "Good feasible application" as an aid for the VSW-MCM mission
  - May be "used [in] scout swimmer missions to avoid minefields" as for NSW missions
  - Thin-shelled cylinders were *easily* marked (especially the vertical cylinder)
  - Eel grass caused frequent false detects
- **Recommended changes**
  - Fix blinking cursors relative to the ground. (i.e. As a diver approached a lit target while continuously scanning it, the older cursors did not adjust to the diver movement)
  - Less sensitivity towards vertical beam placement.
  - Ergonomic changes in the HRLMD body (adjustable screen angle?)

ADDITIONAL MINE CLASSIFICATION CAPABILITIES FOR THE INSS

SUMMARY & CONCLUSIONS

- **Initial Algorithm Investigation**
  - **Triple-flash detector (circular object size discriminant):**
    * On smooth (i.e. sandy) surfaces, measuring the mult-path arrival times can be used as a reliable size discriminant for circular objects.
    * On uneven (i.e. rocky) surfaces, this type of size discriminant was inaccurate.
  - **Multi-channel phase comparison (object height discriminant):**
    * On both smooth and uneven surfaces, the algorithm proved to be a very robust method to discriminate objects protruding from the ground. Beneficial for moored mines (e.g. PDM II).
    * The two extra channels needed would require INSS hardware change.
  - **Shell-Thickness-Resonance Freq. Notch Detector (object shell thickness discriminant):**
    * Experimental tests showed a strong correlation between the detection of frequency notches and thin shelled objects. Measuring the notch frequency was a reliable means of estimating the shell thickness (if the shell type is known).

- **STR Freq. Notch Detector INSS implementation**
  - Algorithm modified to operate in real-time in existing hardware and fit current storage formats
  - New STR colormap and blinking cursors added for CAD mode.

- **Results**
  - STR notch detector can be an effective means of aiding an INSS operator in discriminating certain man-made thin shelled targets. Operational range up to 20 yds.
  - Performance influenced by scan rate and vertical beam placement.
  - Increased processor capabilities may allow for a more robust algorithm implementation.
  - Certain bottom types (i.e. Eel grass) caused an unacceptable number of false alarms

ADDITIONAL MINE CLASSIFICATION CAPABILITIES FOR THE INSS

POTENTIAL FUTURE WORK

- **Short Term**
  - Modify display markers to account for diver movements.
  - Processor and storage upgrade path to allow for full-blown STR algorithm and in field data collection.
  - Investigate STR algorithm with more varied bottom types and mines
- **Long Term**
  - Add multi-channel height discriminator capabilities to INSS
  - Investigate both STR shell thickness and multi-channel height discriminators feasibility towards other mine-hunting/mine-avoidance platforms (small AUV's).
  - Investigate other elastic effects for their application towards automated mine-discrimination.

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