Handheld Time-domain Electromagnetic Identification (TEMID) Sensor System

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Executive Summary

- **Purpose: Develop a prototype handheld sensor system to reduce the false alarm rate associated with detection of medium and high metal content landmines.**
- Technical Approach: **The sensor concept incorporates advanced signal processing and a conventional time-domain electromagnetic induction metal detector.**
- Project Accomplishments:
  - **Developed state-of-the-art electromagnetic induction sensor**
  - **Conducted proof-of-concept laboratory tests**
  - **Conducted field tests using inert mines in a variety of soil types**
  - **Developed signal processing methodology for target discrimination**
- Project Conclusion: **Sensor system can differentiate mines from non-mine targets**

Presentation Outline

- TEMID Project Objectives
- Time-domain Method
- Simulation Summary
- TEMID System Description
- Instrumentation Summary
- Signal Processing Summary
- Lab Test Data Summary
- Ft Belvoir Mine Lane Test Summary
- Ft AP Hill Field Test Summary
- Project Summary

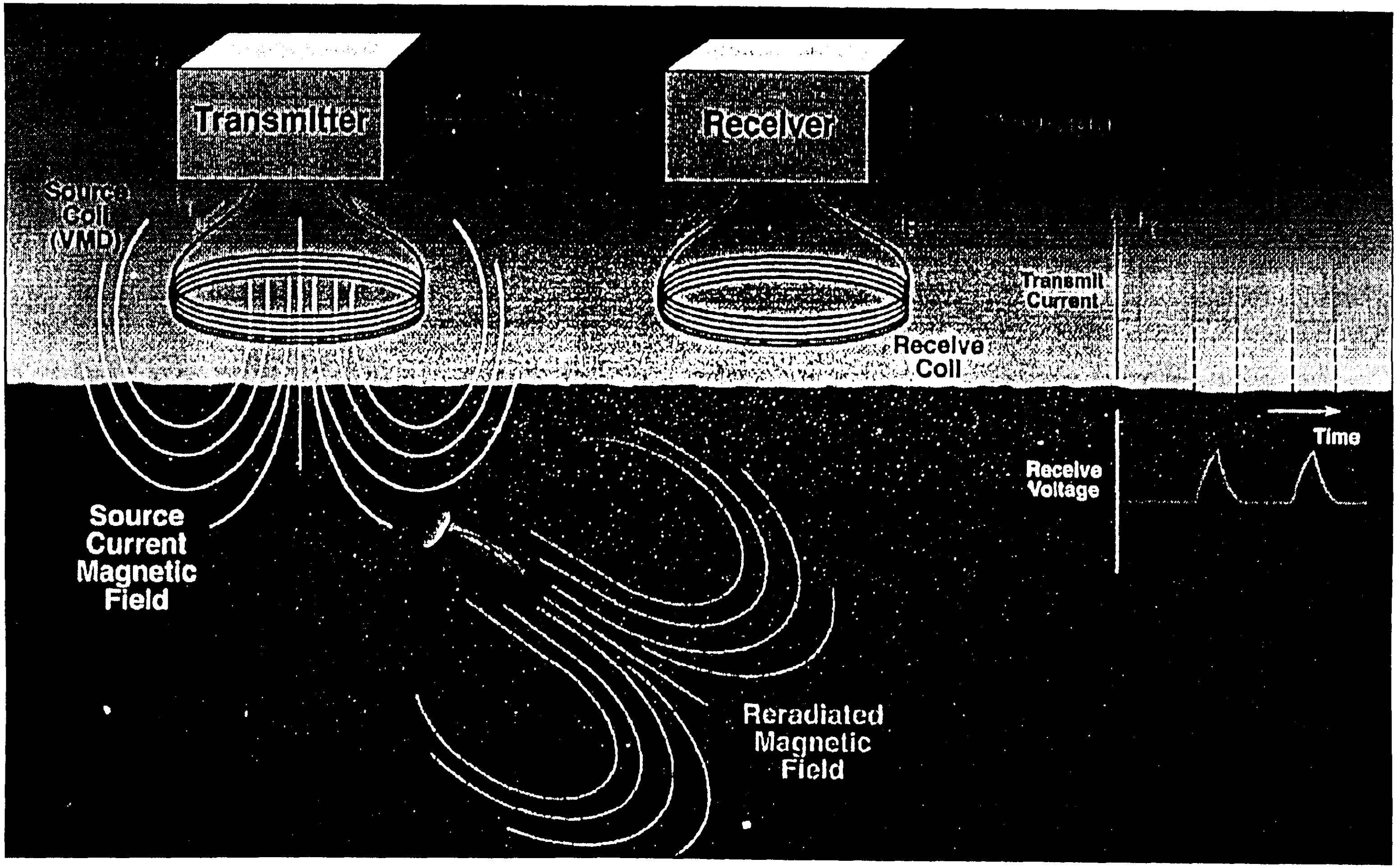
TEMID Project Objectives

- Research, development, fabrication and test of a prototype handheld Time-domain Electromagnetic Identification (TEMID) sensor using Commercial Off-The-Shelf (COTS) technology.

- The overall objective is to improve the false alarm rate associated with the detection and identification of high and medium metal content mines, i.e., discriminate mines from the myriad of metallic clutter, such as nails, wire, and bullet shells.

- The TEMID sensor concept incorporates advanced signal processing to the basic time-domain handheld magnetic induction metal detector to improve its ability to discriminate specific types of mines and clutter.

Electromagnetic Induction Detector
Time-Domain Method



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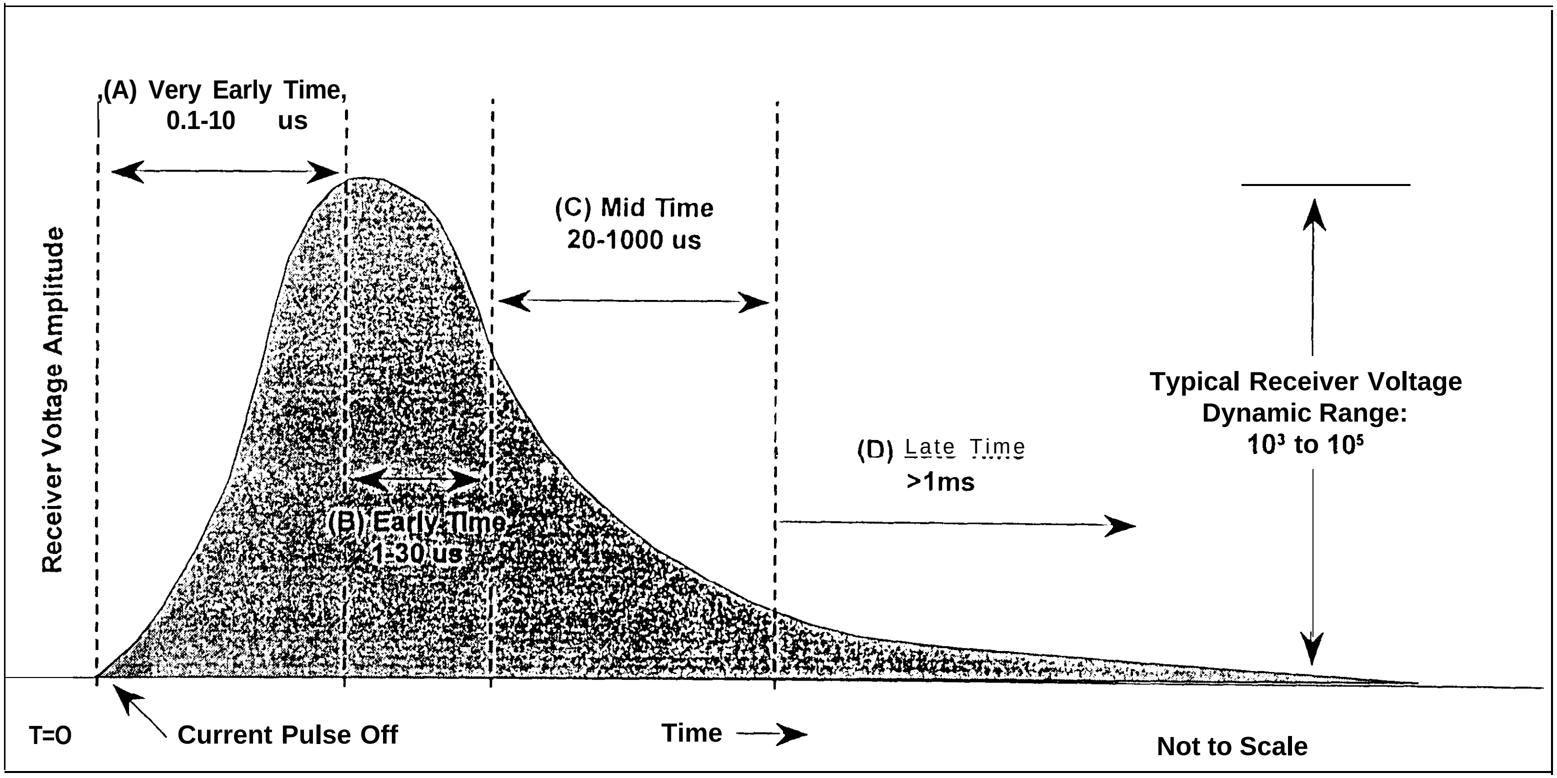
Typical Time Domain Electromagnetic System Signal Time History for Large Steel Mine-Like Target



A. Very Early Time:	**Currents form in target conductor to preserve the original magnetic field before turn-off. Transmitter turn-off transients lie in this region**
B. Early Time:	**Resistive losses cause current to attenuate and time rate of change induce other currents.**
C. Mid Time:	**Currents are diffusing through target.**
D. Late Time:	**Spatial distribution of currents in target no longer change, all currents decay at rate determined by target size, conductivity & permeability**

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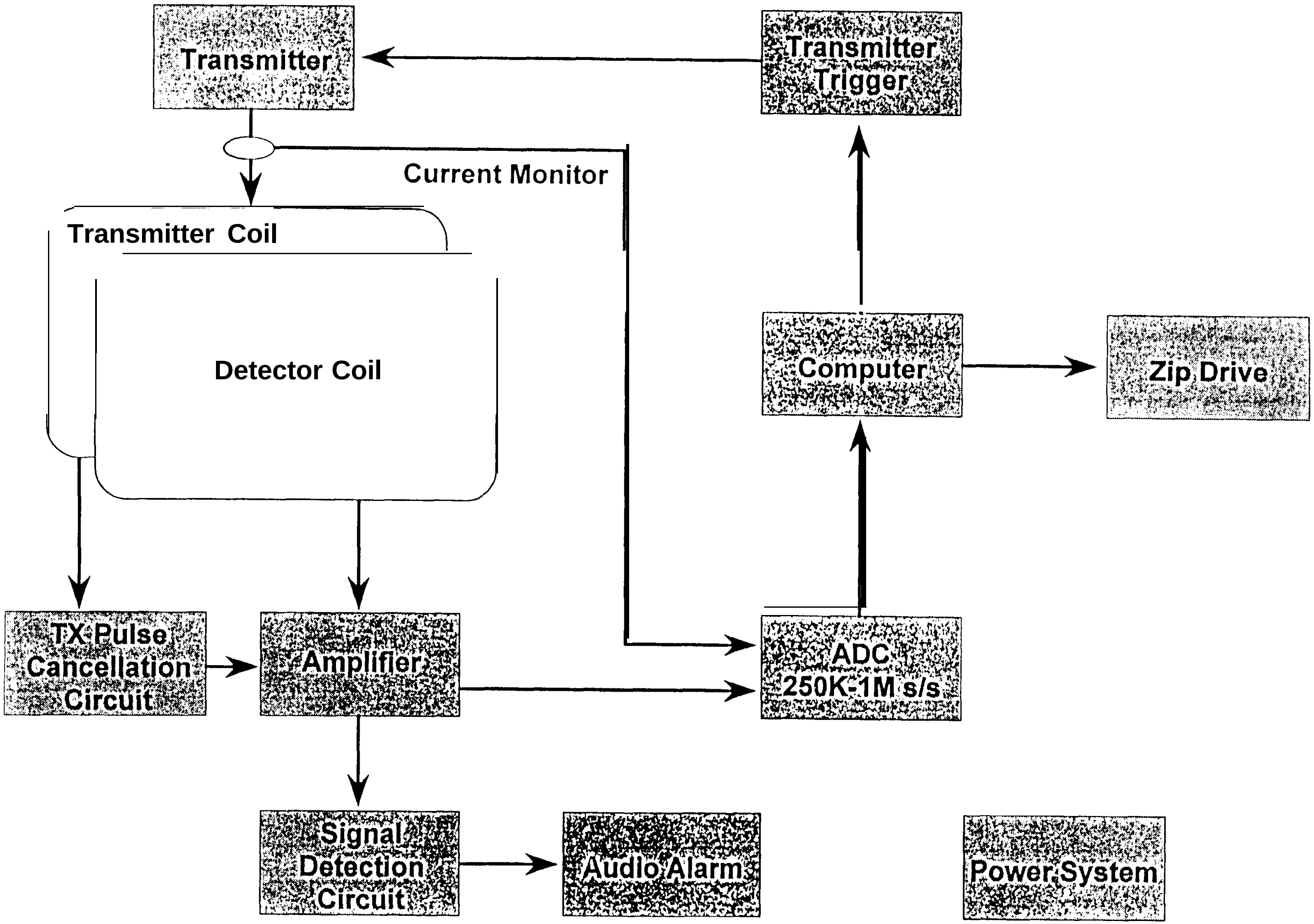
Simulation Summary

- Used Vector Fields “Opera 3-D” to model plates of different conductivities and permeabilities
- FEM simulation software
- Program calculated current distribution in model as a function of time.
- Simulation was beneficial for visualizing target responses
- Applied step-up function magnetic field change to models
  - Step-down magnetic field not available in time for project
  - Step-up magnetic field complicated simulation result interpretation
    - » Encountered round-off errors
- Experimented with different time steps
  - Found that a time step of 1 us was good compromise between processing speed and simulation results
- Simulation software had difficulty with shell models
- Simulation software helped to design transmitter and receiver coil design- confirmed experimental results

System Block Diagram of Hand-Held Time-Domain Electromagnetic Identification Sensor: TEMID Sensor



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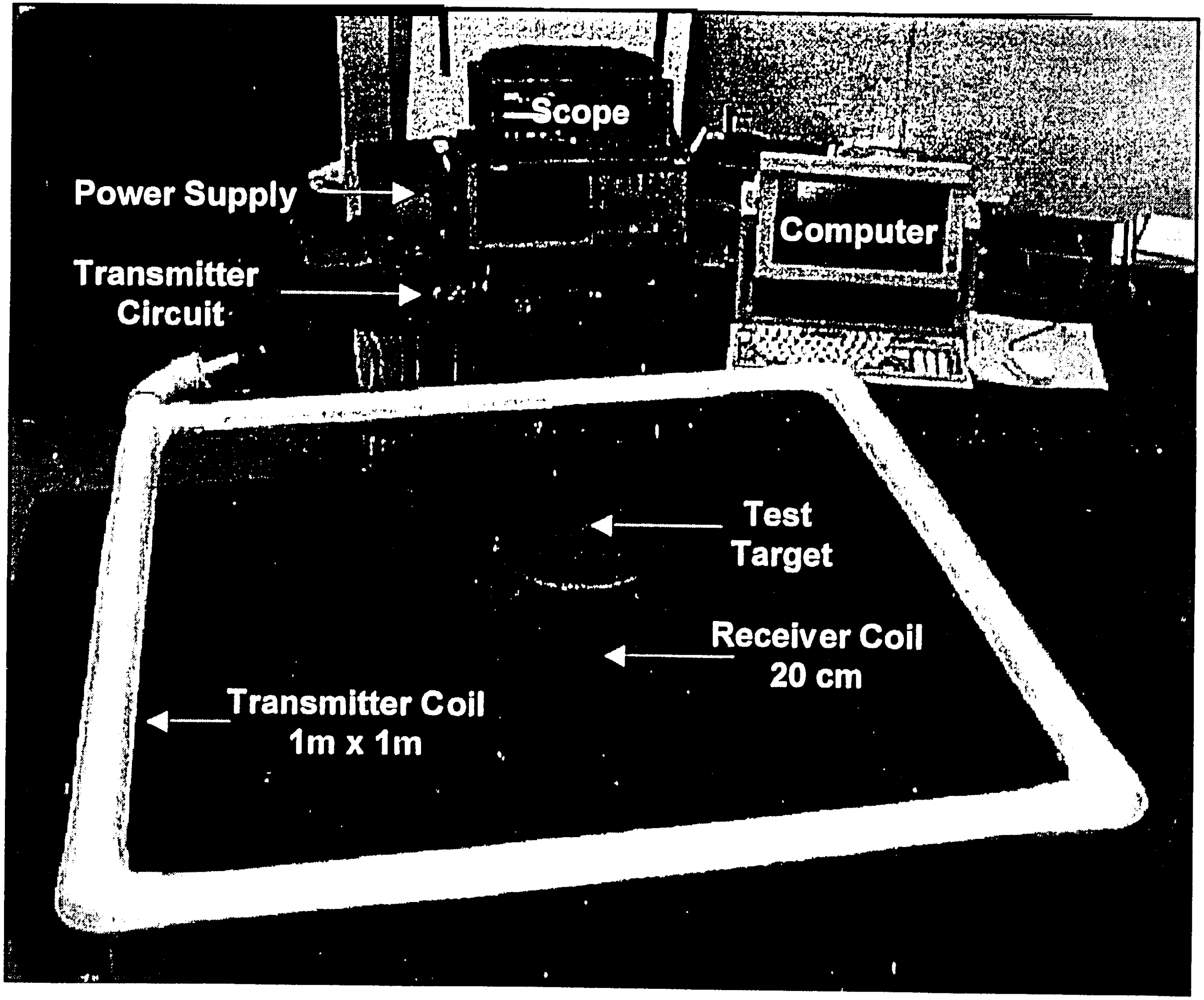
Laboratory Time Constant Apparatus



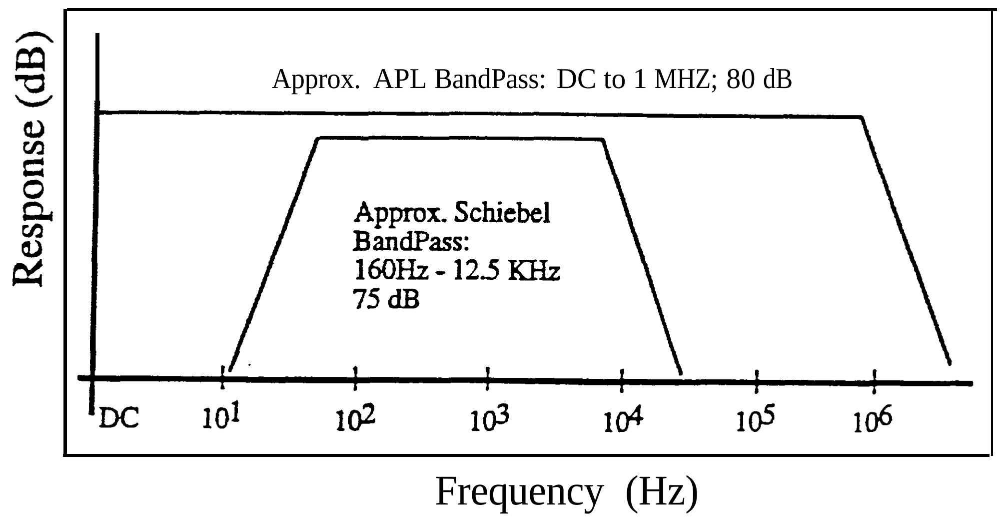
Instrumentation Summary

- **Developed an inexpensive transmitter and receiver system**
- **Tested several transmitter and receiver coil designs**
- **Developed a unique transmitter coil design that enhances fast turn-off times**
- **Developed a receiver coil design that nulls soil background response and minimizes transmitter transient response**
- **Receiver design allows two concentric receiver coils to 'coexist' in the same circuit. Implications for receiver array designs.**
- **Coil Design**
  - **Transmitter: 25" x 45": 8 loops**
  - **Receivers: 16" x 16" and 4" x 4": 2 each: 7 loops**
- **Electronic System**
  - **Gain: 10,000**
  - **Frequency Response: 500KHz**
  - **Dynamic Range: 12 bits**
  - **Data Collection Time: 1-10 seconds (SNR dependent)**

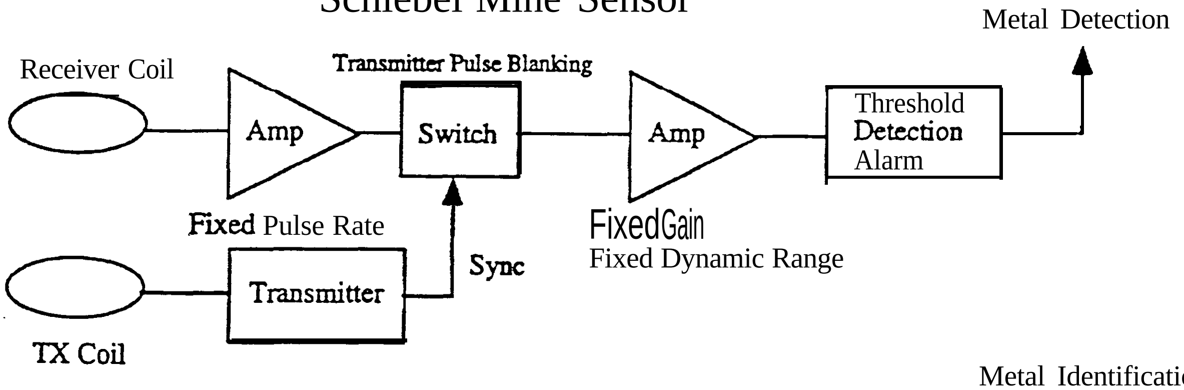
Instrumentation Summary **(con't)**

- **Studied and compared Schiebel and APL Sensors**
- **Important Sensor System Features:**
  - **Can operate sensor system in high electrical noise environments**
  - **Bipolar transmitter current pulse: Zero net magnetic field**
  - **Measure target responses IO-20 us after transmitter turn-off**
  - **Fast recovery receiver amplifier (less than IOOns)**
  - **For this study, measurement results not critically dependent on transmitter and receiver construction details**
- **Future Design Ideas**
  - **Time variable gain amplifier to increase dynamic range**
  - **Custom-designed, hig h-speed,1 6-bit ADC**
  - **Energy efficient transmitter design**
  - **Automatic transmitter power and receiver gain control**
  - **Improved transmitter and receiver coil design: better transient response characteristics and background nulling**
  - **Modify transmitter and receiver for small targets**
  - **Develop a receiver array for spatial measurements of magnetic induction**

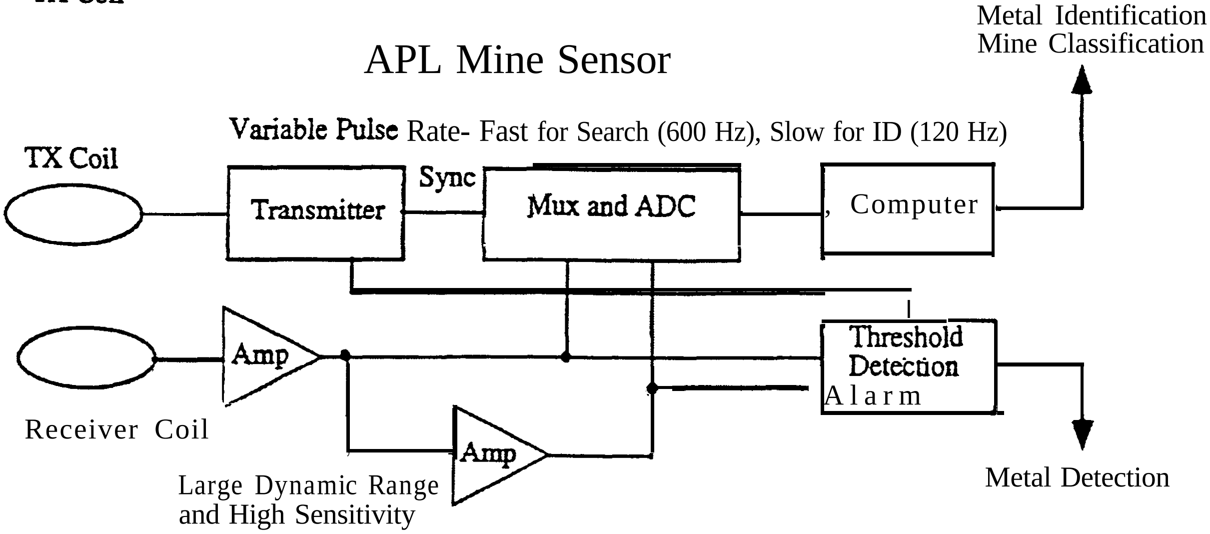
Simplified Comparison Between Schiebel and APL Mine Sensor Systems



Schiebel Mine Sensor



APL Mine Sensor



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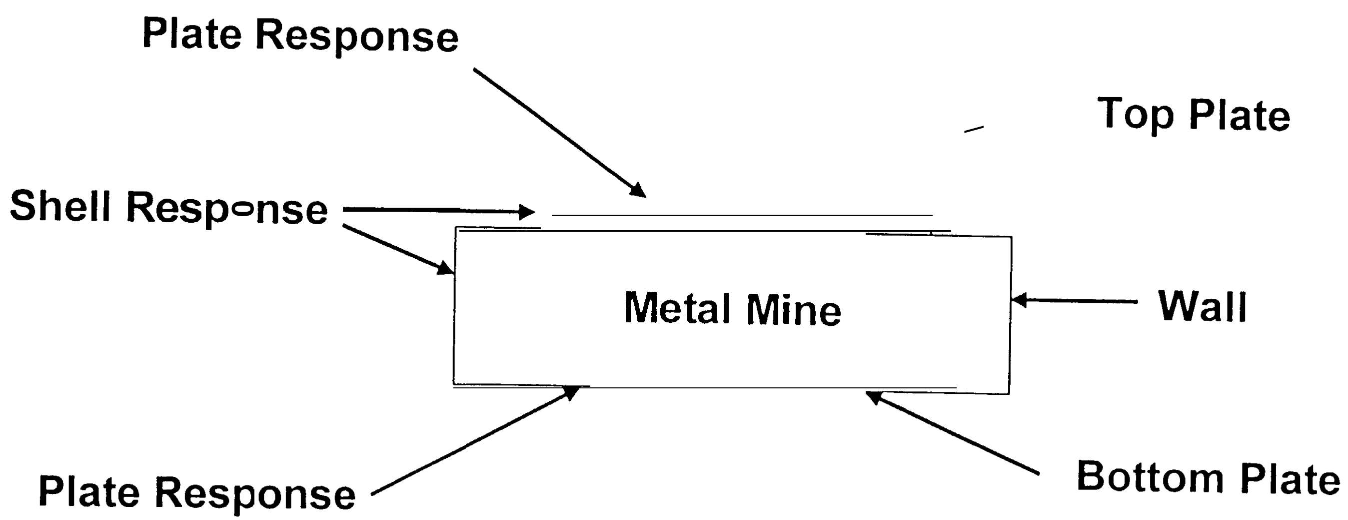
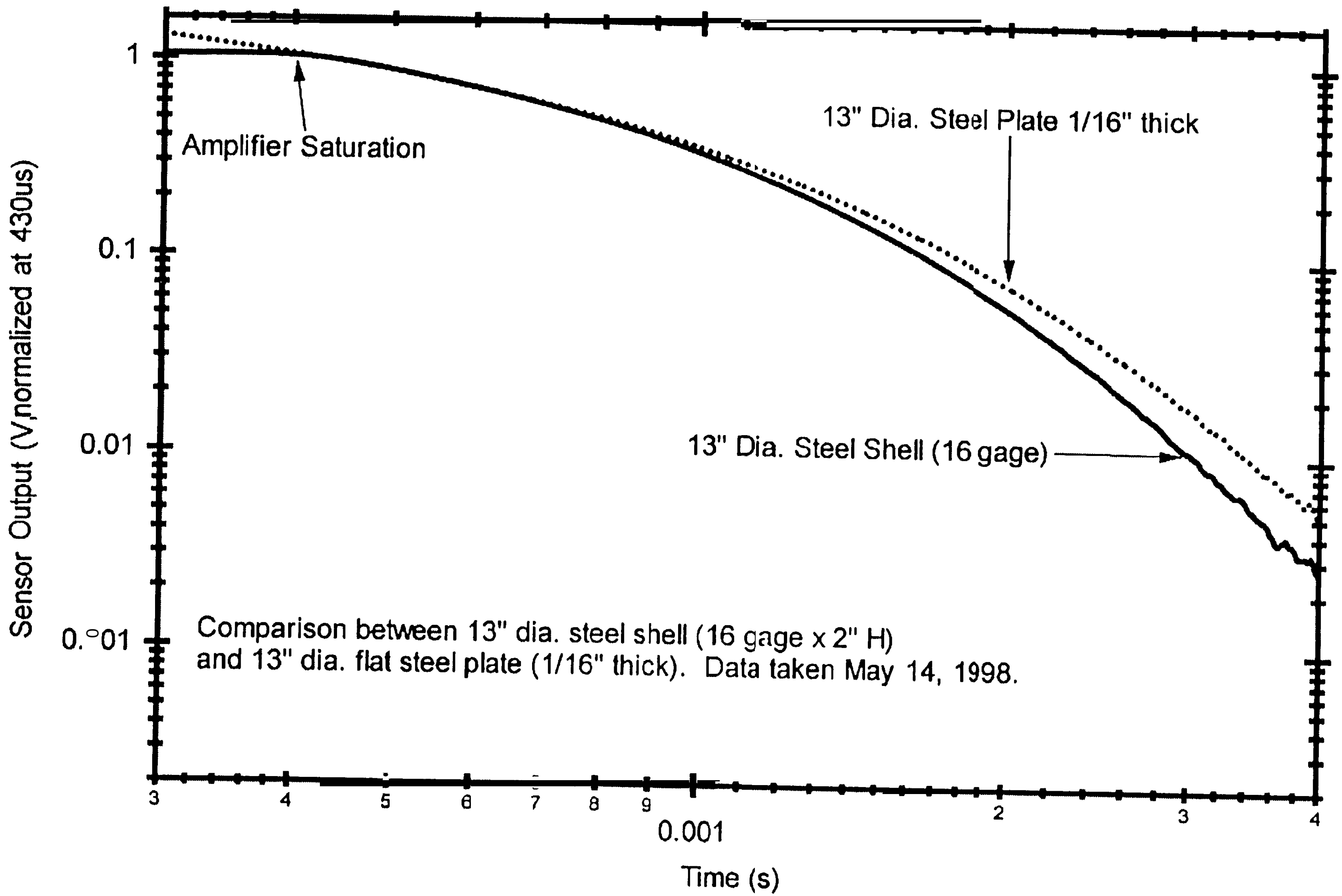
Laboratory Test Data Summary

- Documented differences between plates and shells (rings) representing different parts of a typical mine
- Documented differences between different metals: steel, brass, aluminum and copper
- During 'Early Time' decay response is a function of skin depth and hence material only. Currents are confined to outer layers of target.
- During 'Mid Time' and 'Late Time' eddy currents distribute themselves according to target geometry.
- For 'Early Time' and 'Mid Time' regions, the decay response is a weak function of target angle for angles up to about 20 degrees (for mines and mine-like targets in study).
- For 'Late Time' region, the decay response is a relatively stronger function of target angle. Exact relationship not established.
-

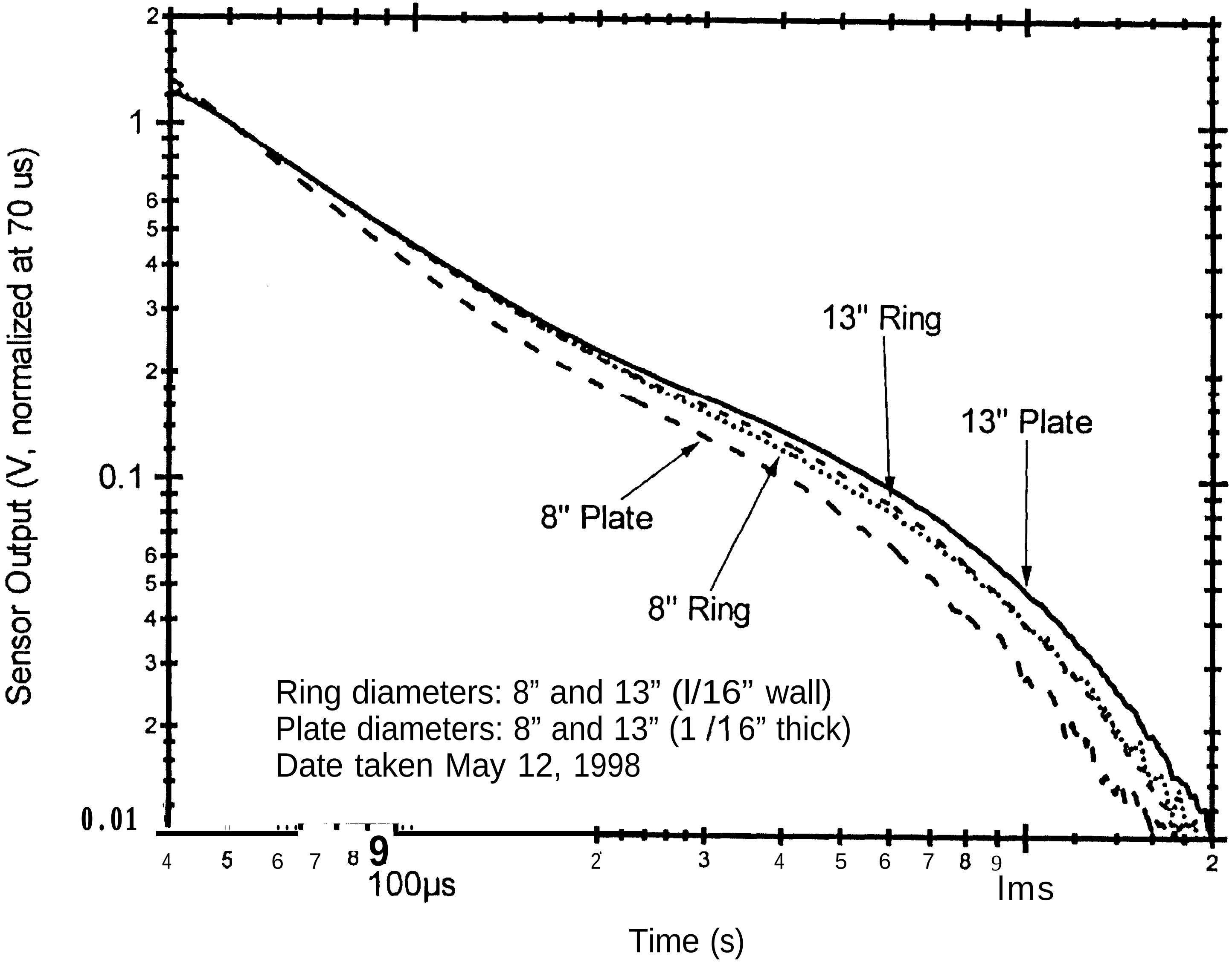
Typical Mine Physical Features



Comparison Between Shells and Plates



Ring and Plate Response vs. Diameter



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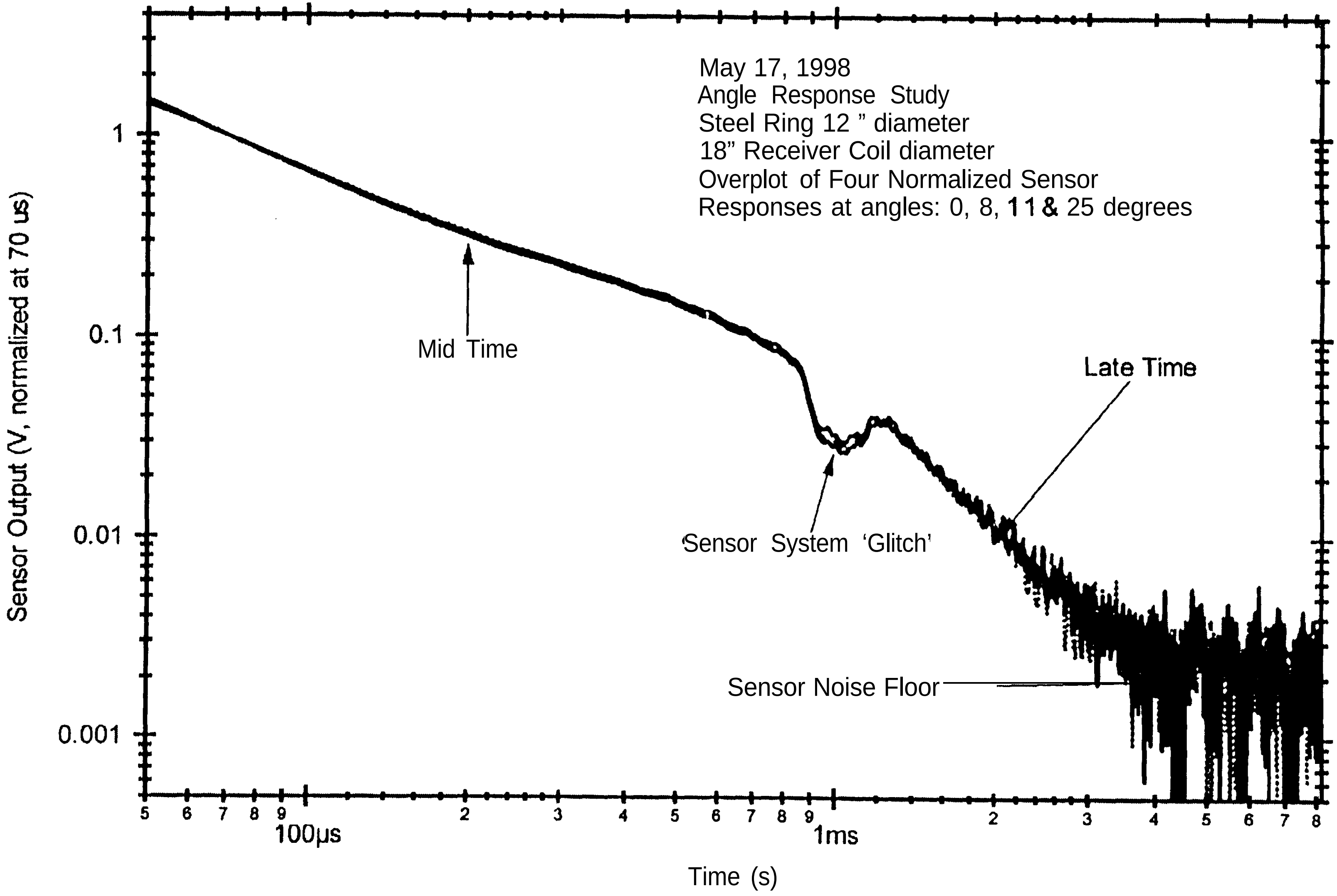
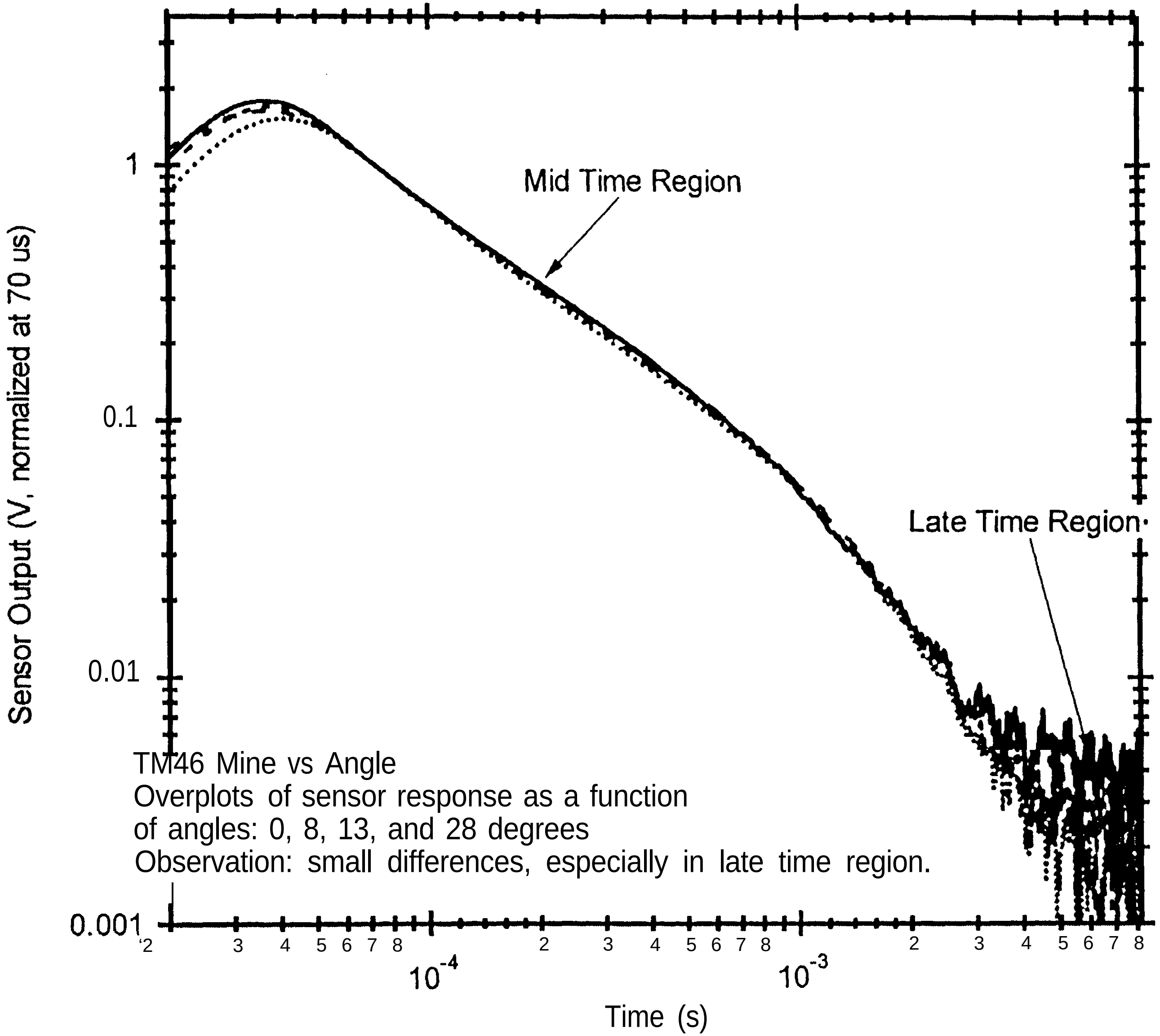
Steel Ring vs. Angle



TM46 Mine vs. Angle



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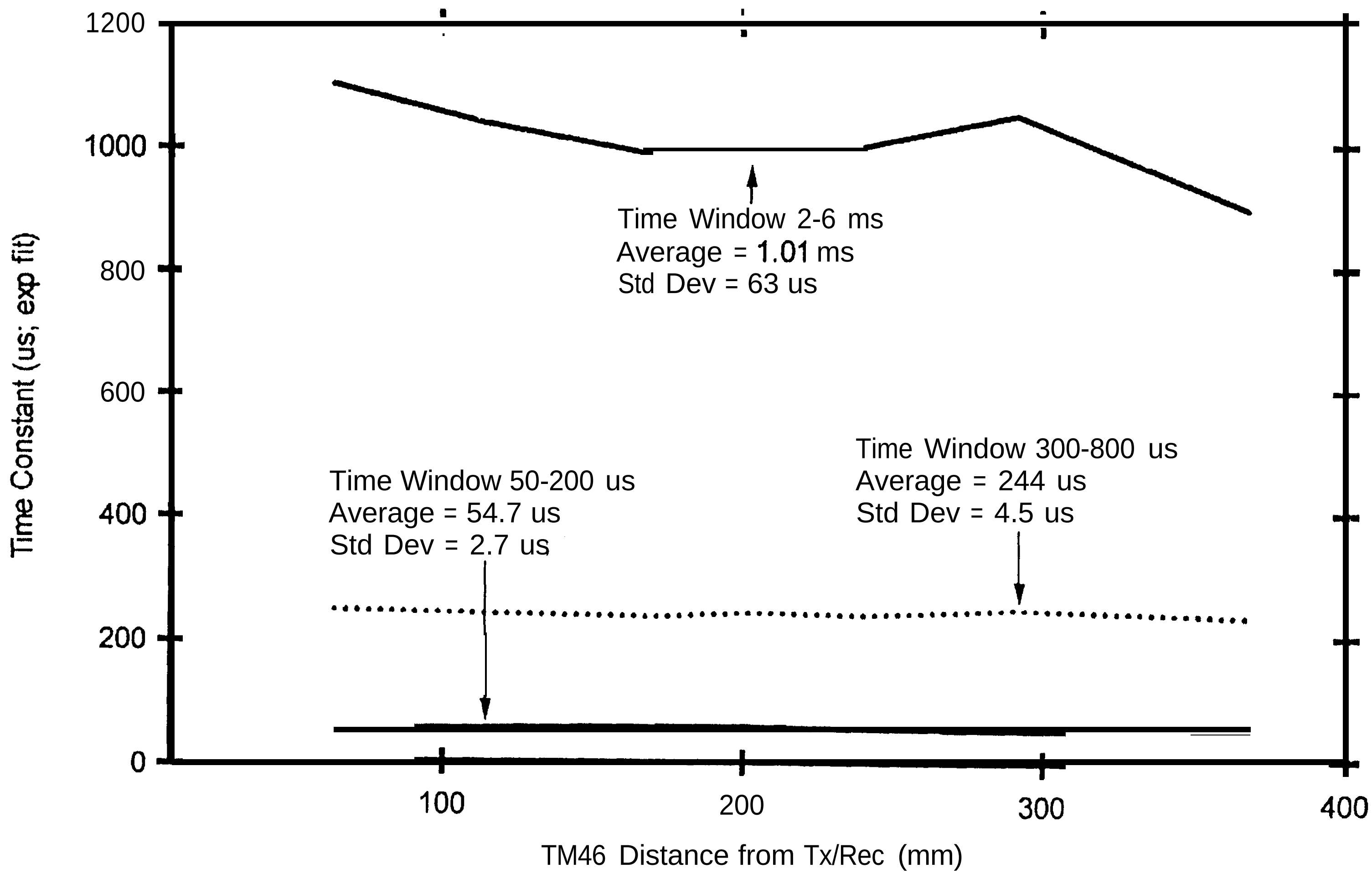
Time Constants vs. Depth for TM46 at Mine

Exp Fit of Data Over Listed Time WIndow



Signal Processing Summary

- **Hardware/Firmware Signal Processing Summary**
  - **Hardware trigger data collection at 60 Hz rate = 1 data scan**
  - **Data sampled at 2 us intervals**
  - **4000 to 8000 data points collected during 1 scan**
  - **Between 10 - 1000 data scans are averaged to create final sensor signal**
- **Direct use of sensor signal**
  - **Do not require application of sensor transfer function**
  - **Do not need to integrate signal to get magnetic induction signal**
  - **Some improvement in SNR if signal is integrated; however, not needed or used in this study**
- **Multiple analysis methods for target discrimination**
- **Simple conceptual analysis method: Decay Time Response**
  - **Curve-fit data using exponential model over different time windows**
  - **Multiple exponential decay times characterize target response**
  - **Selection of time for amplitude normalization not critical**

Signal Processing Summary (cont'd)

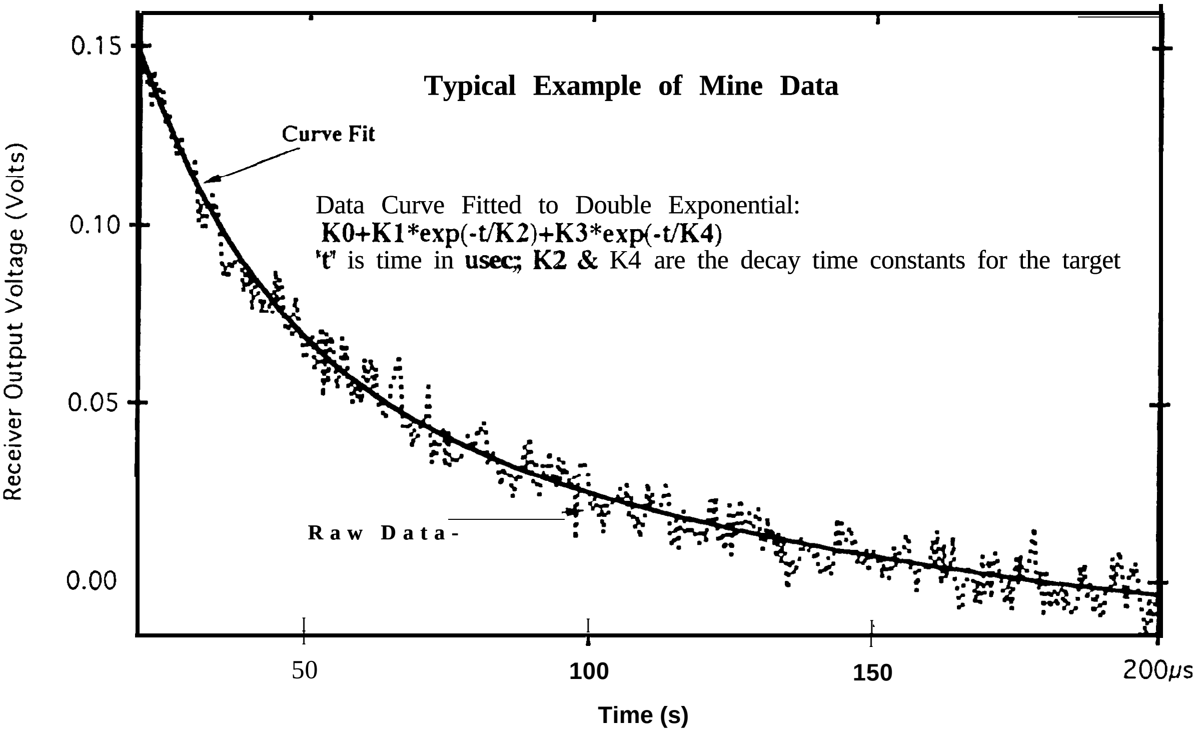
- **Double exponential line fits can be made on each series**
  - **more closely matched data than single exponential**
  - **The two coefficients produced from each fit can be used to classify at the mine/no mine AND type of mine level**

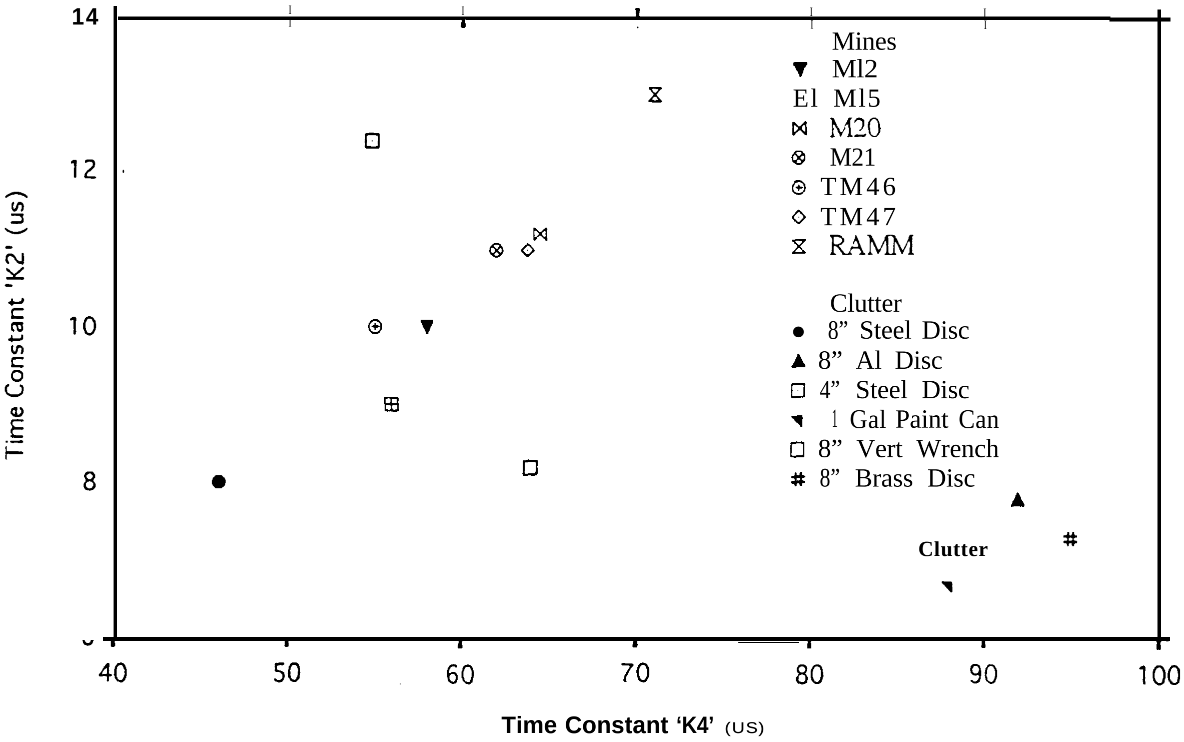
- **Multiple time series from each target can be parameterized and used as training data for an adaptive neuro fuzzy classifier**
  - **Classifier is trained on targets in each type of background soil**
  - **"unknown" series from that soil are input to test trained classifier**
  - **Initial results show that classifier can identify type of mine and clutter**

- **Both methods can separate mine versus no mine and classify to the mine level**

FT AP Hill **Test** Data
April 8, 1998

Preliminary Comparison of Curve Fit Time Constants for Various Mines and Clutter





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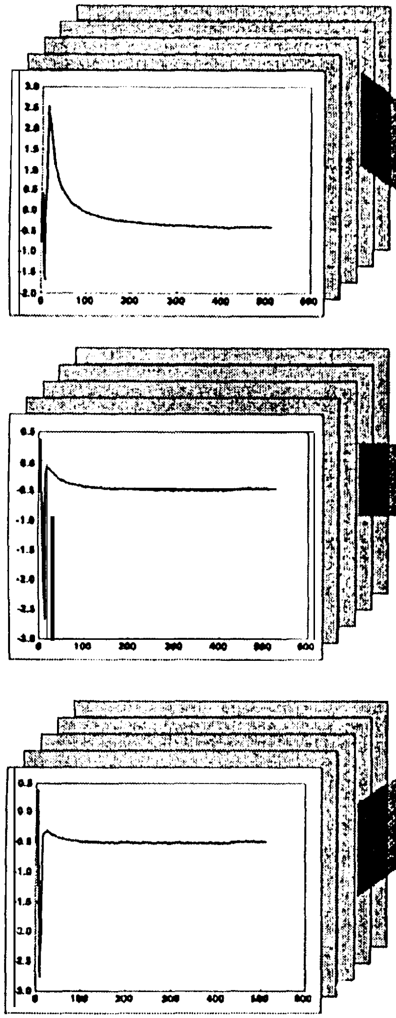
Training Adaptive Neuro System

Training Data

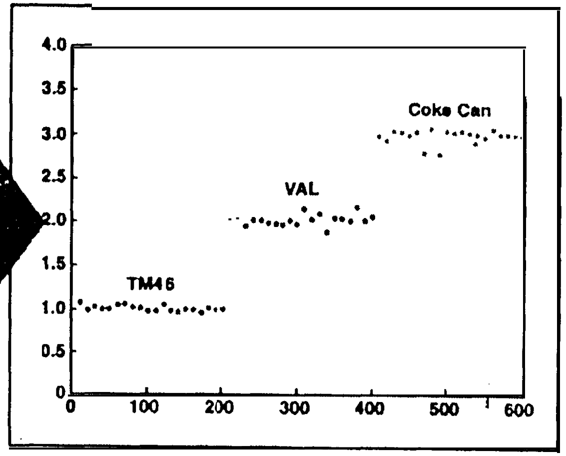


Parameterize

-0.9572	-1.9101	0.9126	-0.0016	1.0000
-0.9654	-1.9200	0.9219	-0.0013	1.0000
-0.9597	-1.9125	0.9148	-0.0015	1.0000
-0.9619	-1.9150	0.9172	-0.0014	1.0000
-0.9627	-1.9167	0.9188	-0.0013	1.0000
-0.8781	-1.8253	0.8323	-0.0045	2.0000
-0.8889	-1.8509	0.8568	-0.0035	2.0000
-0.9009	-1.8524	0.8575	-0.0033	2.0000
-0.8850	-1.8330	0.8382	-0.0030	2.0000
-0.8904	-1.8475	0.8540	-0.0043	2.0000
-0.8089	-1.8042	0.8237	-0.0115	3.0000
-0.8438	-1.7772	0.7954	-0.0103	3.0000
-0.8437	-1.7691	0.7888	-0.0111	3.0000
-0.8040	-1.7670	0.7949	-0.0164	3.0000
-0.8115	-1.7421	0.7714	-0.0183	3.0000

Train Adaptive Neuro Fuzzy System

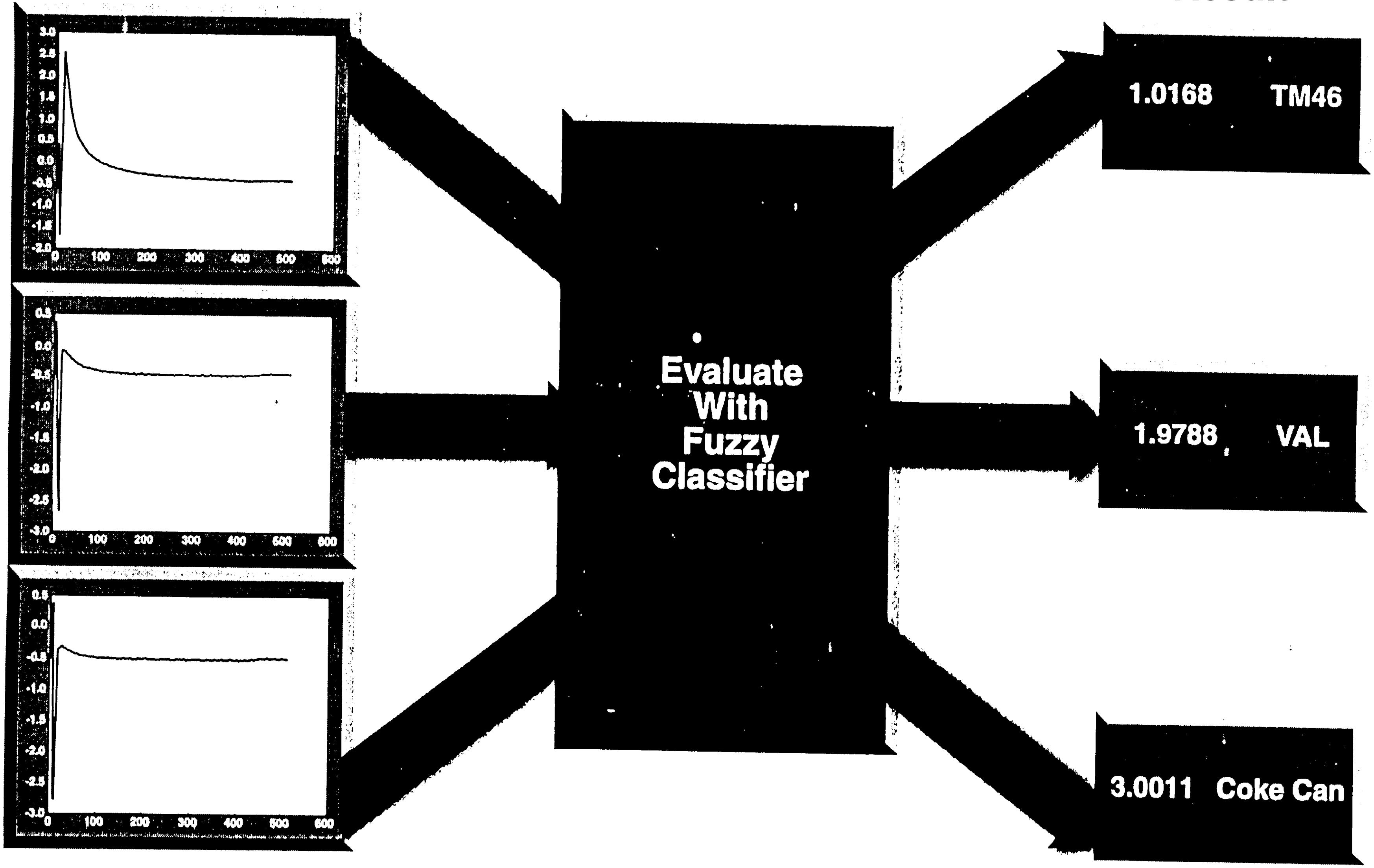
Training Results



Evaluating Unknown Time Constants With Trained Adaptive Neuro Fuzzy System

Unknowns

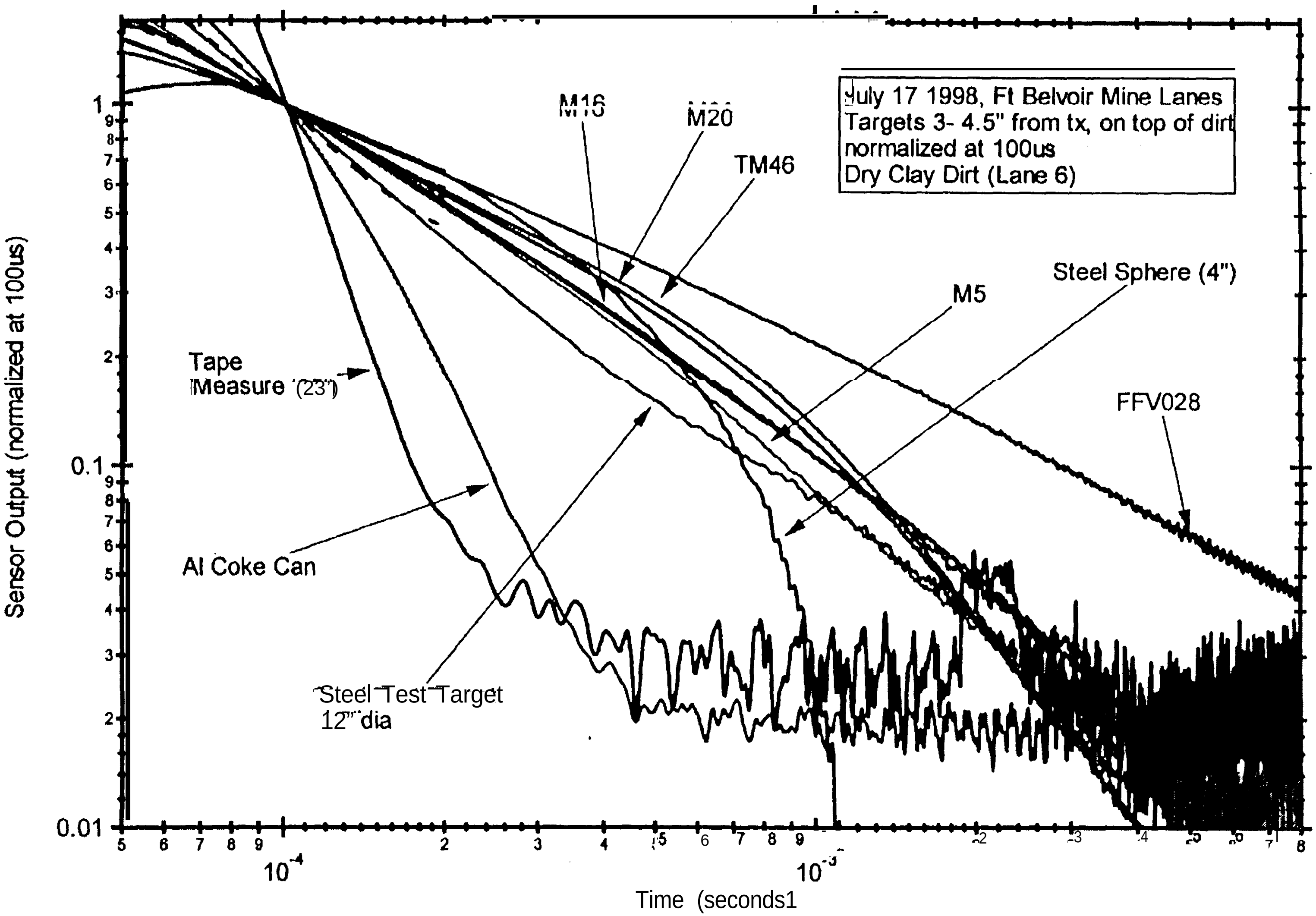
Result



Ft Belvoir Test Summary

- **Test Objectives:**
  - **Pretest system before final field testing at Ft AP Hill**
  - **Collect target data in different soil types**
  - **Collect data at different sensor heights above target**
  - **Test effects of soil on sensor/target response**
  - **Test effectiveness of nulling techniques**
- **July 15, 16 & 17 1998**
- **Indoor Mine Test Lanes**
- **Dry clay soil and magnetic sand**
- **Transmitter Coil: 25” x 25”: 7 loops**
- **Receiver Coil: 17.5” x 17.5”: 4 loops**
- **Null Coil: 4” diameter: 6 loops**
- **Targets: FFV028, Ml6,M20, M5, TM46, Small Steel Ball, AL drink can, Steel Tape Measure, Steel Test Target**
- **Data Collection System: FieldWorks portable computer & MicroStar ADC**

Ft. Belvoir Summary



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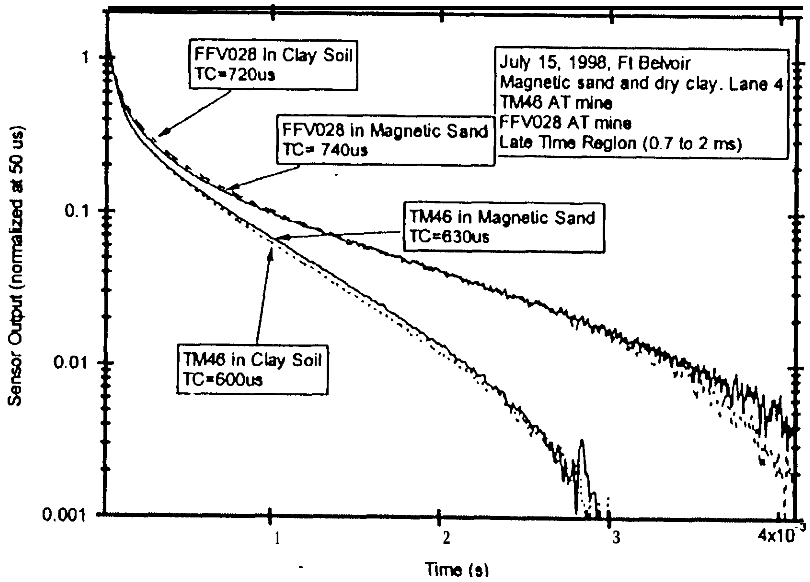
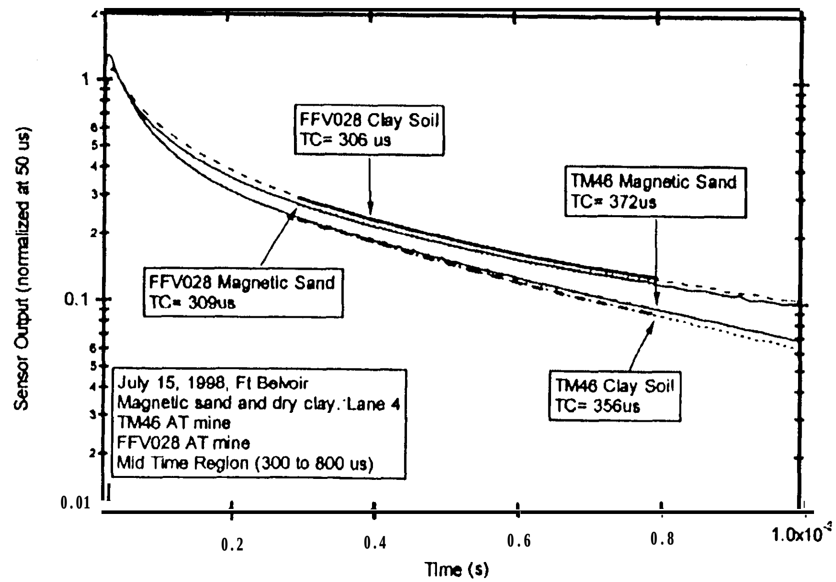
Clay vs. Mag Sand

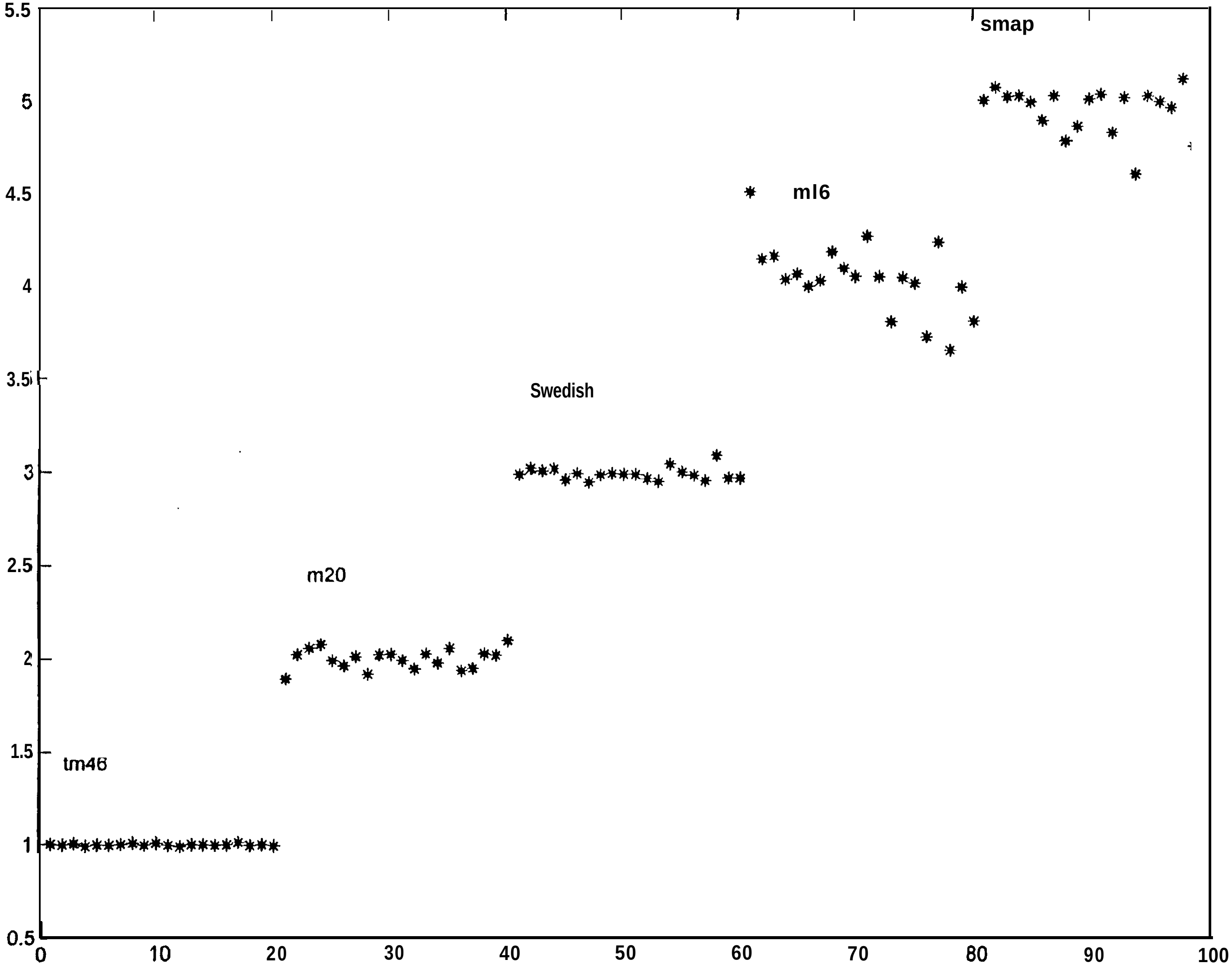




Ft Belvoir Test Result Summary

- Sensor system and data acquisition software worked well
- For targets studied, "Easy" to visually discriminate between mines and clutter targets
- For shallow buried mines, very small changes in time decay response
- Variation in decay time constant was about 5-10% for different soil types (dry clay & magnetic sand), covered vs uncovered, and target distance from sensor
- Lessons Learned:
  - Increase data collection time from 4 ms to 8 ms
  - Boost transmitter power to look at 'Late Time' signals
  - Cumbersome background subtraction method- designed new receiver coil for automatic bac kground subtraction
  - No real need to cover targets with soil
  - Target to sensor distance of I-5 inches OK for consistent results
  - Focused attention on 'Mid Time' region and transition to 'Late Time' region (100 us to 3 ms) of decay response
  - Small amount of drift in electronics- minor change in new version should fix problem: problem does not effect time constant calculation only data processing steps and graphic visualization

Clay Soil Training Results
Ft. Belvoir - July 1998



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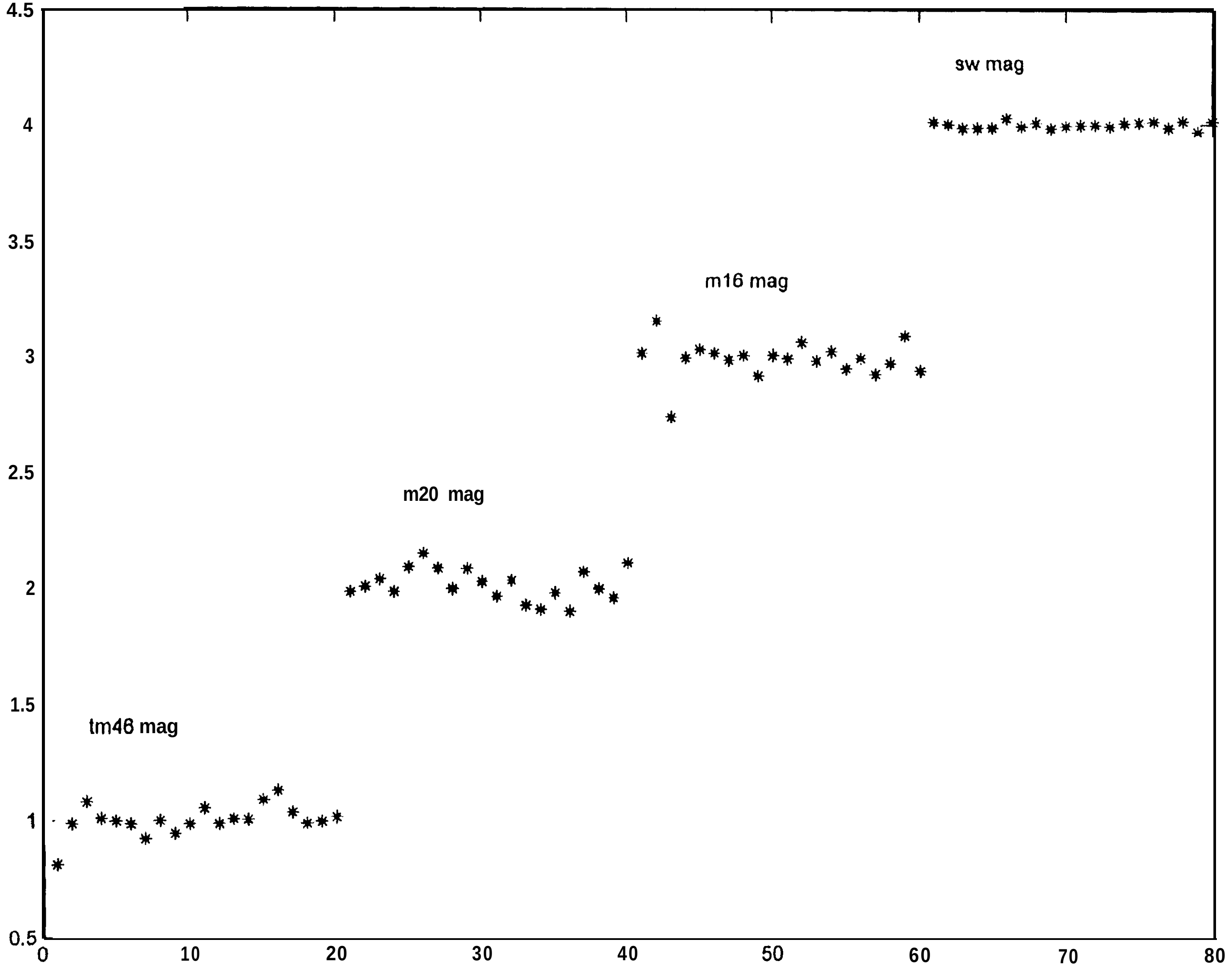
Magnetic Soil Training Results
Ft. Belvoir - July 1998



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Classification With Adaptive Neuro Fuzzy System

25 Block Averages Collected

24 Used Used Train System (Results Seen In Following Two Charts)

1 Used as Unknown Not Used in Training

July 1998 Ft. Belvoir

Unknown Results

Clay		
1	TM46	0.9966
2	M20	2.0137
3	FFV028	3.0800
4	MI6	4.1388
5	Small AP	4.9779

Magnetic		
1	TM46	1.0124
2	M20	1.9578
3	MI6	2.8801
4	FFV028	3.9778

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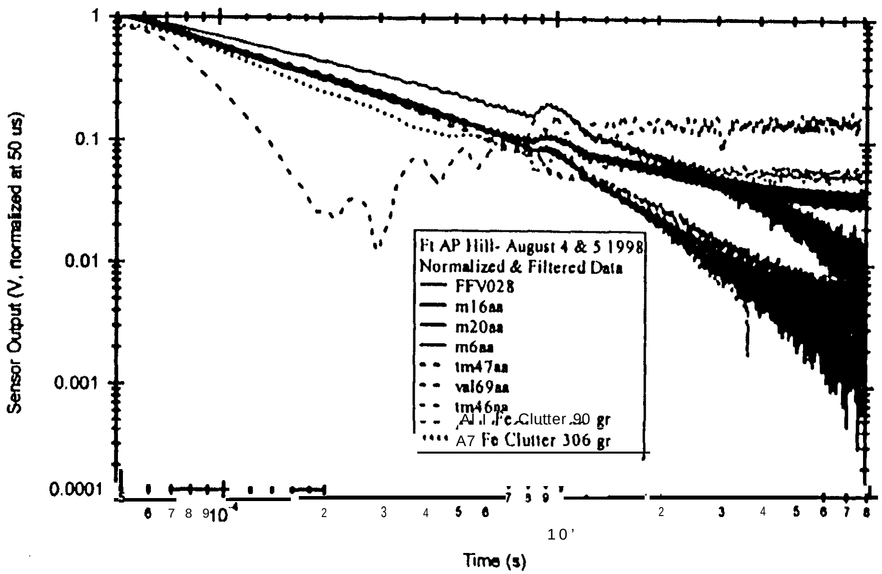
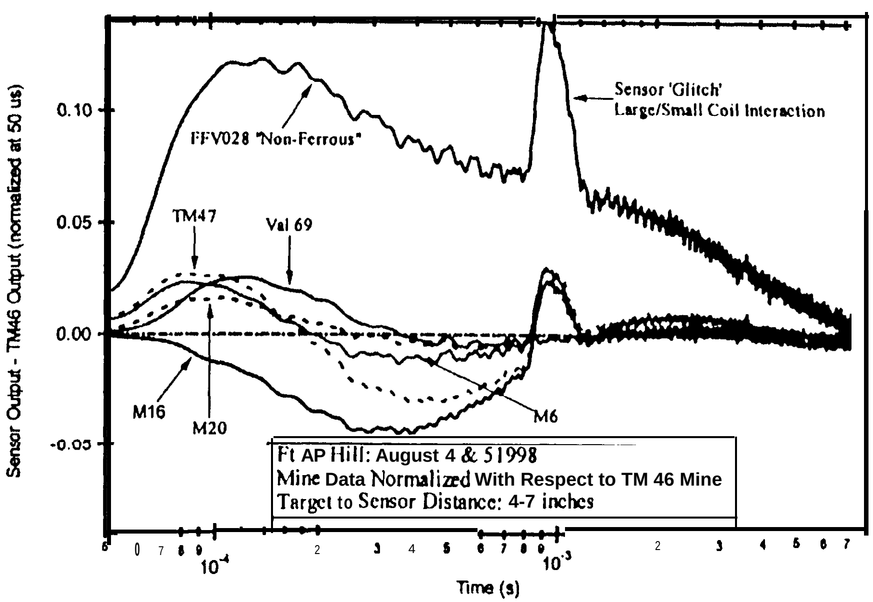
Ft AP Hill Test Summary

- **Test Objectives**
  - **Final demonstration of prototype TEMID sensor system**
  - **Collect data from multiple mine, mine-like and clutter targets**
- **August 4 & 5, 1998**
- **Ft AP Hill 71A range, JUXOCO and ‘special test area’**
- **Data Acquisition System the same as Ft Belvior test except for improved transmitter and receiver design**
- **Soil Types:**
  - **JUXOCO range- hard, dry clay**
  - **‘Special test area’- sandy soil in treed area 50’ south of range house**
- **Target to sensor distance: 2-7 inches**
- **Mine Targets: FFV028, M16, M20, M21, M6, M16, Val69, TM47, TM46**
- **Clutter Targets: All fe clutter (90 gr), A7 fe clutter (306 gr), Ml6 cartridge, Ml6 cartridge clip, 50 cal cartridge, coffee can, Al drink can, l/4” lag screw, small tools**

Summary AP Hill





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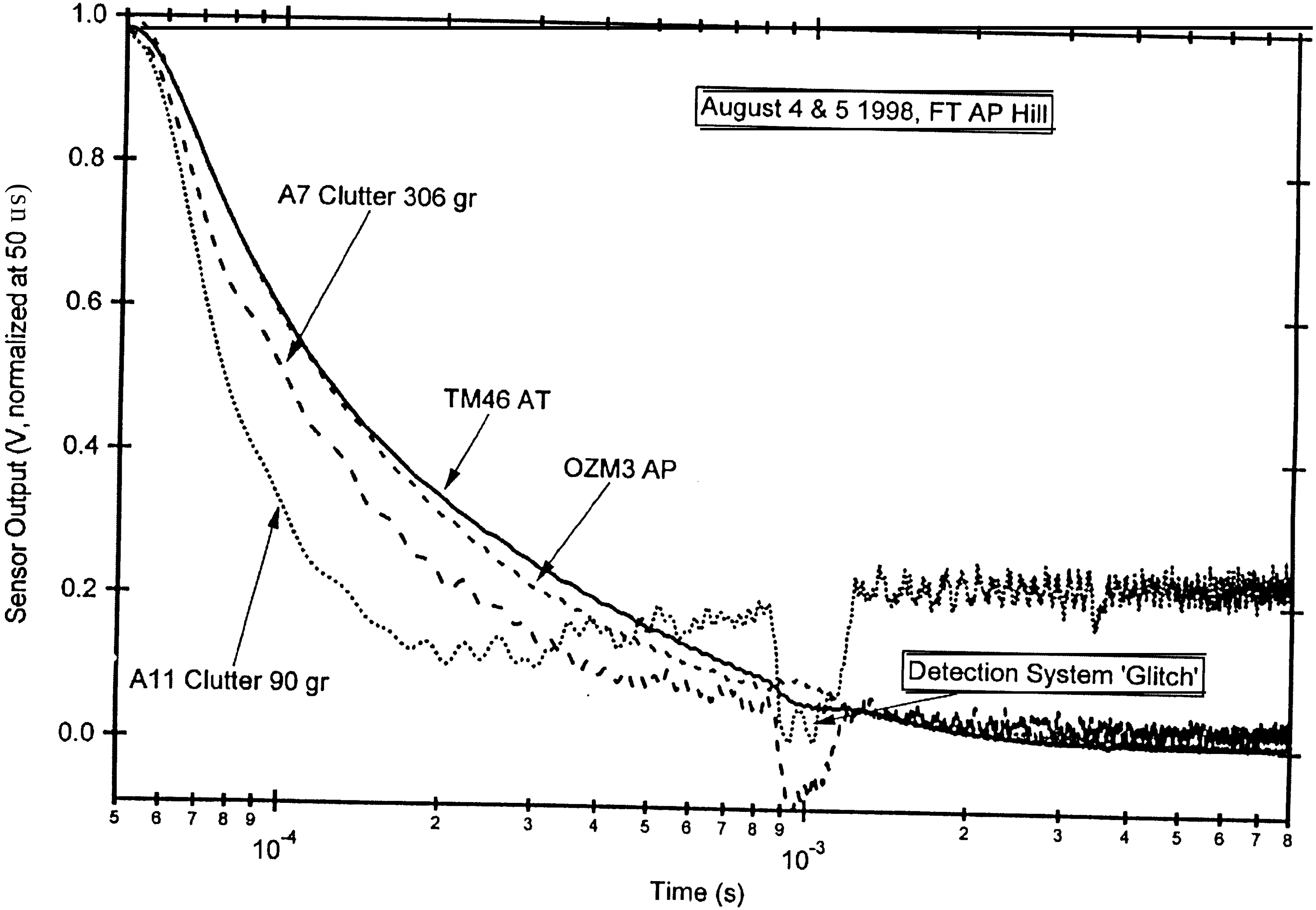
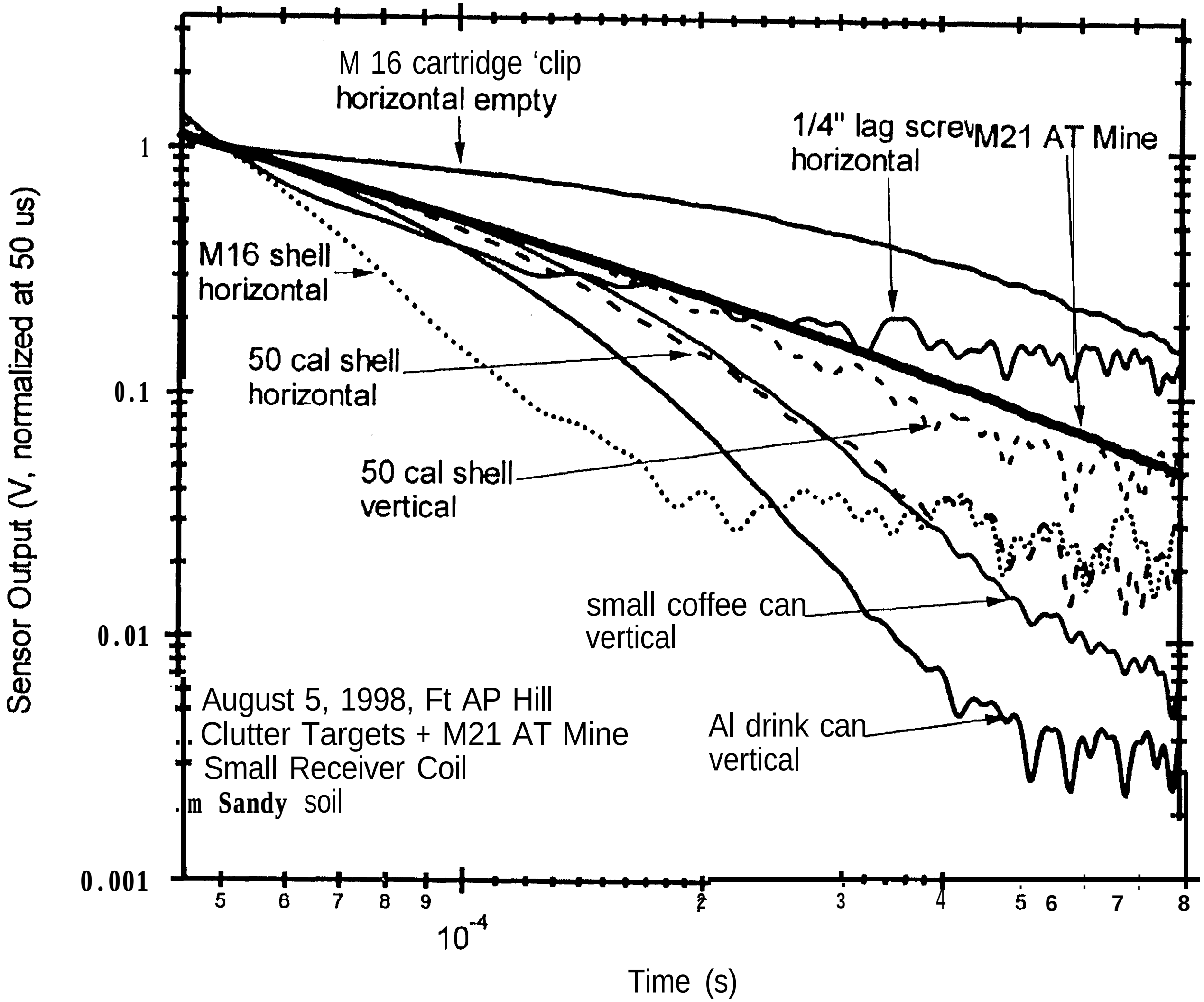
Aug 4 Clutter vs. TM46

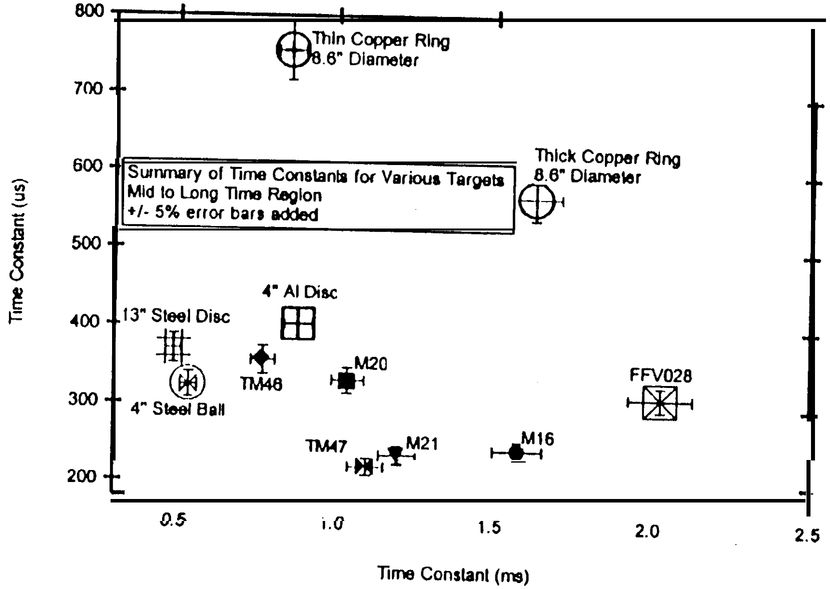


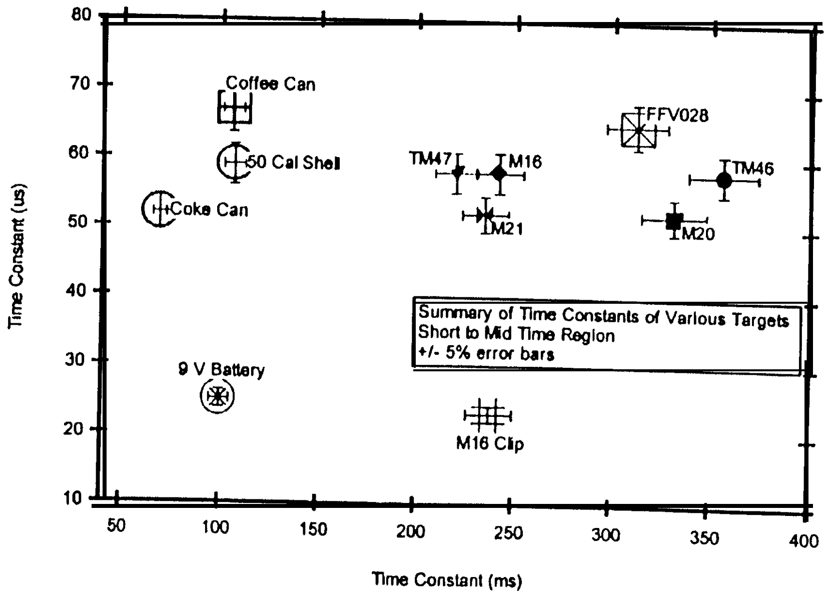
Battle Field Clutter vs. M21 Mine

lag screw



Summary Time Constant Plots





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Ft AP Hill Test Data Summary

- For AT and AP mines in test study, 'easy' to discriminate between mines and clutter: Mine vs No Mine
- Under these 'ideal' test conditions, we can discriminate between different mines, even mines that appear very similar, e.g., TM46 and TM47 or M20 and M21
- Classify mine types and clutter using time constant plots
  - Selected three time windows: 70 - 200 us; 300 - 700 us; and 800 us - 3 ms
  - Exponential curve fit data in selected time windows
  - Normalization of data not required for curve fitting
  - Normalization of data good for graphic comparison of data
  - Mine and clutter time constants substantially different

Project Summary

- Investigated Medium/High Metal Content Mines and Mine-like Targets
- Developed instrumentation to measure target time-domain decay responses over time range of 20 us to 16 ms
- Developed Two Classification Methods for Discriminating Mines from Non-Mines
- Major Target Signal Characteristics
  - 'Good' starting time around 50-100 us
  - 'Good' stopping time around 10-20 ms
- Exponential curve fitting method works well for Mine vs No Mine Discrimination
  - Related to mine physics
  - Three or more time windows for curve fitting
  - No need to normalize data
- Adaptive neuro-fuzzy classifier results very encouraging
  - Classify to the type of mine level in clay and magnetic soil

Project Summary (cont'd)

- All program responsibilities met
  - technical meetings
  - status reviews (multiple)
  - Final report delayed due to low metal content detection task that was added to contract

- Based on analyses performed on this contract, time domain technology appears very promising for insertion into vehicle and hand held systems