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Technical Note

May 1993

By H. Thomson

Sponsored By Naval Facilities
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DIVER-OPERATED BURIED PIPE AND CHAIN LOCATOR

ABSTRACT A prototype system has been developed for use by the Navy Underwater Construction Teams (UCTs) in locating submerged ferrous objects (such as pipelines and mooring chain). The system consists of a commercially available magnetometer modified to meet the UCT mission requirements. The magnetometer, a fluxgate sensor built for terrestrial use, is manufactured by Forster Instruments, Incorporated. The sensor was modified to be used underwater by divers, or dipped (slow towed) from a small inflatable boat. This report documents the development of this prototype tool, called the Diver-Operated Buried Pipe and Chain Locator.

CIVIL ENGINEERING LABORATORY PORT HUENEME CALIFORNIA 93043-4328

METRIC CONVERSION FACTORS

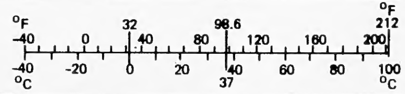
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2,000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1,000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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13. ABSTRACT *(Maximum 200 words)*

A prototype system has been developed for use by the Navy Underwater Construction Teams (UCTs) in locating submerged ferrous objects (such as pipelines and mooring chain). The system consists of a commercially available magnetometer modified to meet the UCT mission requirements. The magnetometer, a fluxgate sensor built for terrestrial use, is manufactured by Forster Instruments, Incorporated. The sensor was modified to be used underwater by divers, or dipped (slow towed) from a small inflatable boat. This report documents the development of this prototype tool, called the Diver-Operated Buried Pipe and Chain Locator.

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CONTENTS

INTRODUCTION

Under the sponsorship of the Naval Facilities Engineering Command (NAVFAC), the Naval Civil Engineering Laboratory (NCEL) has developed a metal detecting system. This system was developed for use by the Underwater Construction Teams (UCTs) to locate buried or submerged metallic pipe, chain, anchors, and miscellaneous ferrous objects. The tool is a marinized Forster Ferex magnetometer (Model 4.021) and is designed for use in either a dipping mode (from an inflatable boat) or a self-contained diver-operated mode.

Attributes of the system include the following:

1. Visual and audio output.

2. Adjustable sensitivity.

3. Adjustable standoff device between the magnetic sensor and the operator.

4. Rechargeable battery-powered system (each set lasts up to 6 hours).

5. Minimal maintenance at the UCT level (the unit is sealed and will not be broken down for repairs or overhaul except by the Depot maintenance activity Ocean Construction Equipment Inventory (OCEI) or manufacturer).

This report documents the development of the Diver-Operated Buried Pipe and Chain Locator (BP&CL), and provides documentation to support the production milestone decision.

BACKGROUND

An efficient, safe, and reliable metal detecting system for UCT use is required to provide underwater detection and tracking of the following items:

1. Chain (1-1/2 inches or larger) buried up to 6 feet.

2. Pipelines buried up to 2-1/2 feet.

3. Anchors (6,000 pounds) buried up to 10 feet.

4. Armored cable (SD List 5) buried up to 3 feet.

In the past, several types of diver-operated systems have been investigated and developed for use by Naval Underwater Demolition Team (UDT) and Explosive Ordnance Disposal (EOD) divers. These include the MK-14 magnetometer, a cesium vapor magnetometer, and the MK-10 gradiometer. However, these developments were tailored to the special requirements of ordnance work (i.e., low magnetic signatures and detection of nonferrous materials). In addition, these systems typically require specialized training and diving equipment that is not readily available to the UCTs.

To provide a suitable system for UCT use, an investigation of specific UCT requirements and an evaluation of both military and commercially available systems were performed. Appendix A lists the Test and Evaluation Master Plan (TEMP) thresholds for the BP&CL.

To identify candidate metal detecting systems and technologies suitable for UCT use, a literature survey of metal detecting systems was performed by NCEL. This survey, documented in Reference 1, encompassed both active and passive military and commercially available systems and identified several promising candidate systems that appeared to be suitable for UCT use. These systems were:

- Navy MK-10
- Garrett XL500
- Fisher Pulse 10
- Fisher Pulse 8
- White's PI-1000
- Forster Ferex 4.021

Figure 1 shows the family of metal detecting systems.

The MK-10 is a portable diver-held fluxgate magnetometer designed as an ordnance locator. It has been in service since the early 1960s. However, the Navy EOD community has experienced extreme difficulties in keeping sufficient units operating (Ref 2) and is in the process of phasing this system out.

The Garrett, Fisher, and White's units are commercially available pulse-induced systems. With the exception of the Fisher Pulse 10, these systems were developed primarily for the treasure or sport diver. The Pulse 10 is a boat-towed system.

The Forster Ferex 4.021 is a magnetometer designed for terrestrial use. UCT-ONE has used this system with some limited success to locate a 12,000-pound anchor at the Naval Weapons Station, Earle, New Jersey. It was reported (Ref 3) that one of three buried anchors was located using this system. However, only the probe can be submerged. The power and control modules are not submersible.

To determine the suitability of these systems for UCT use, tests and evaluations of these systems were performed at NCEL. The results of this evaluation are provided in the next section of this report, Advanced Development Model (ADM) System. Based on the results of the ADM testing, the Forster Ferex magnetometer was modified to provide enhanced performance for UCT use. This development is documented in the Engineering Development Model (EDM) System section of this report.

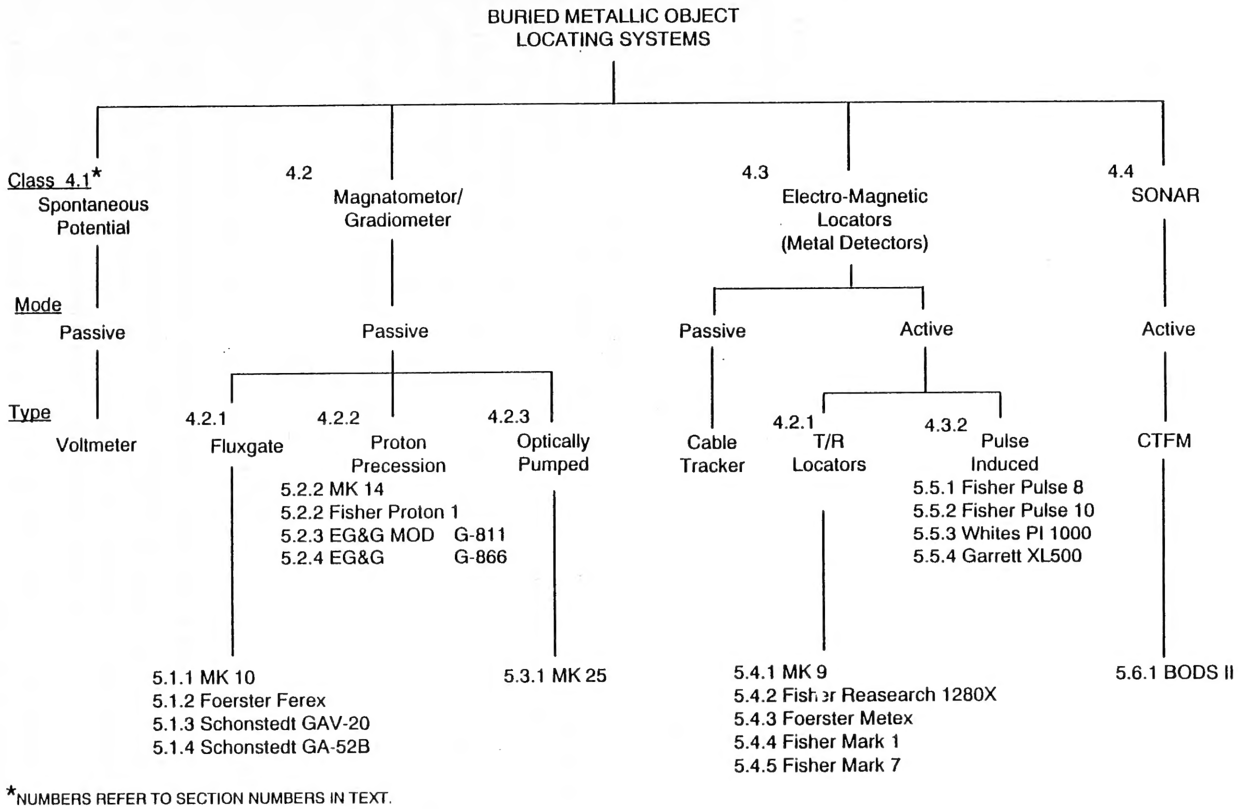


Figure 1
Metal locating systems - available units.

ADVANCED DEVELOPMENT MODEL (ADM) SYSTEM

To evaluate the most promising candidates identified in the state-of-the-art survey (Ref 1), the following units were purchased for test and evaluation:

1. Garrett XL500

2. Fisher Pulse 10

3. Fisher Pulse 8

4. White's PI-1000

5. Forster Ferex 4.021

The Navy MK-10 system was not available for evaluation. A request to the Navy EOD community for loan of an MK-10 indicated that there were relatively few of these units operating.

The following is a description of the systems purchased for evaluation.

Equipment Description

Pulse-Induced Systems (Garrett XL500, Fisher Pulse 8, and White's PI-1000). Pulse-induced systems operate by intermittently pulsing an electric current into a coil, creating a high-energy magnetic field. When a transmitted pulse encounters a metallic object, eddy currents begin to flow in the metal, which in turn generates a second magnetic field. This field is sensed by the coil, amplified, and then either displayed by a meter or heard in an earphone.

Figure 2 shows the Garrett XL500. It is supplied with either a 10-inch or a 13-inch coil. The electronics package is detachable so that it can be worn on a belt. Control features include the following:

1. Detection Depth Setting - A three-position rotary switch for maximum, normal, or minimum output.

2. Audio volume.

3. Trash Eliminator - A rotary switch for adjusting the discrimination level.

The Garrett has both audio and visual output. Headphones are provided for the audio output. A meter located on the electronics package provides visual indication of the signal strength.

Figure 3 shows the Fisher Pulse 8. It comes with a 10-inch-diameter coil. Detection is indicated to the diver by both a meter and tone (via an earphone). The electronics package can be removed from its holder for servicing or replacement. Control features include the following:

1. Detection Depth Setting - A three-position rotary switch for selecting high, medium, or low output.

Manufacturer:
Garrett Metal Detectors, Tx.

Model:
XL500

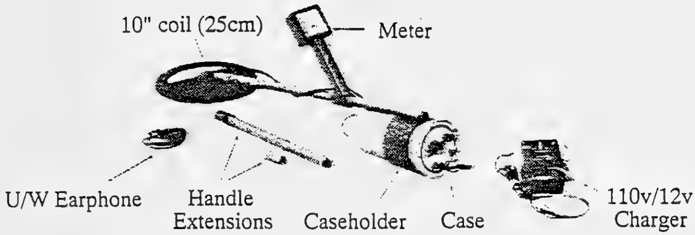
Class:
Metal Detector

Sizes:
8 inch coil standard
13 inch coil optional

Power Supply:
Rechargeable Batteries

Description:
Totally Submersible, Diver Held

Figure 2
Garrett XL500.



Manufacturer:
J. W. Fisher Manufacturing Co, Ma.

Model:
Pulse 8

Class:
Metal Detector

Size:
10 inch dia. coil

Power Supply:
Rechargeable Batteries

Description:
Totally Submersible, Diver held

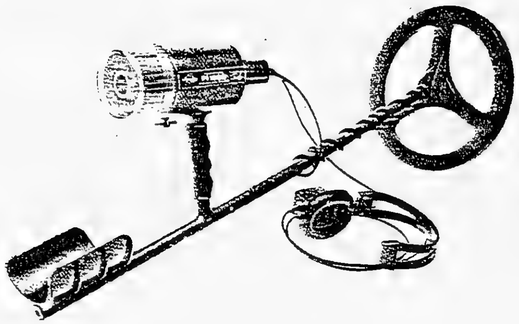
Figure 3
Fisher Pulse 8.

2. Zero Adjustment - A rotary switch for adjusting the discrimination level.

3. Battery check.

Figure 4 shows the White's PI-1000. It comes with a 10-inch-diameter coil. Detection is indicated to the diver by an audible clicking and by light-emitting diode (LED) display. It can be powered by six "AA" alkaline or rechargeable batteries. Controls feature a rotary switch for on/off operation, battery check, and tuning/zeroing.

Magnetometer (Forster Ferex 4.021). A fluxgate magnetometer is made up of a coil of wire wound around a highly permeable core. The core is driven in and out of saturation by a low-frequency electrical signal. This saturation, which is affected by changes in the total ambient magnetic field, is sensed by a separate winding and amplified to provide a signal to the operator.



Manufacturer:
White's Or.

Model:
PI 1000

Class:
Pulse Induced

Sizes:
10 inches dia. coil

Power Supply:
Batteries

Description:
Totally Submersible,
Diver Held

Figure 4
White's PI-1000.

The Forster Ferex 4.021 consists of two fluxgate magnetometers mounted in the opposite ends of a probing bar. This unit is available in both land and underwater versions. The underwater version, shown in Figure 5, is designed for use in bore-hole applications. The system consists of a 24-inch-long submersible probe, extension cable, power supply, and a control/signal strength indicator unit. The power and control units are not waterproof. Control features include the following:

1. Sensitivity Dial - The sensitivity of the unit is adjustable between 3 gammas and 10,000 gammas.

2. Operating Mode Switch - The operating mode switch provides selection of one of the following:

    a. Normal searching.

    b. Normal searching with some small ferrous metals damped out.

    c. Special searching for searching next to large ferrous metal objects such as pipes.

    d. Compass to find north, south, east, and west.

3. Sensitivity Test Switch - A momentary contact switch for checking proper operation.

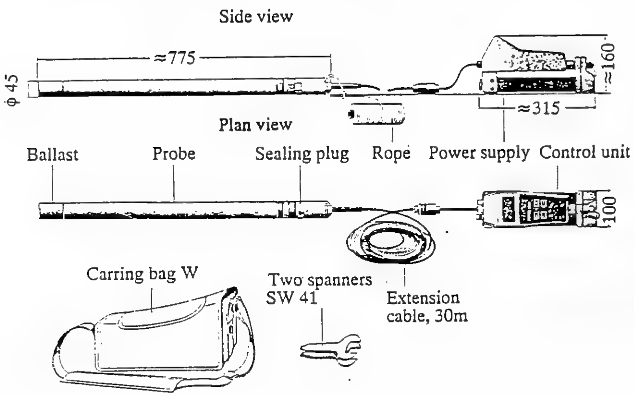
4. Battery Check - Located at the first position of the sensitivity dial.

5. Volume Control - Two momentary contact switches (up and down) for adjusting the audio output of the probe.

Laboratory Tests

The objective of the laboratory tests was to provide initial performance data on the candidate metal detecting systems. Three sets of laboratory tests were performed: (1) comparison of physical characteristics, (2) sphere of detection tests, and (3) electronic characteristics analysis. The results of these tests are summarized below.

Comparison of Physical Characteristics. The physical characteristics of each unit were examined for general construction, human factors engineering, and maintenance. Table 1 lists test results of the items measured or evaluated. Appendix B contains a discussion of qualitative results.



Manufacturer:
Institute Dr. Forster, West Germany

Model:
Ferex 4.021

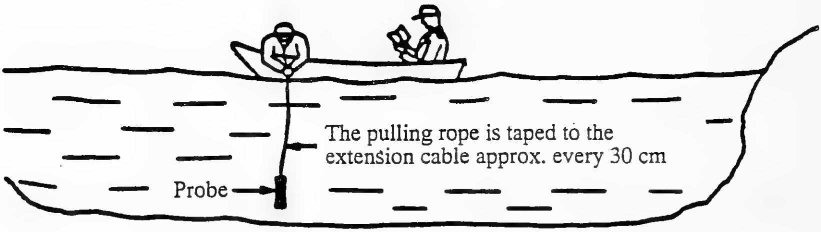
Class:
Magnetometer

Size:
24" long probe

Power Supply:
Self contained rechargeable batteries

Description:
Submersible Probe
Hand-Held/Boat-Towed

(a)



(b) Using the Ferex from a boat.

Figure 5
Forster Ferex 4.021.

Table 1. Comparison of Physical Characteristics

Characteristic	Fisher Pulse 8	Garrett XL500	White's PI-1000	Forster Ferex 4.021
Weight in Air	8 lb	7.5 lb	4.25 lb	11 lb[a]
Weight in Seawater	1 lb neg	1 lb pos	1 lb pos	3.5 lb[b]
Visual Output	Fair	Poor	Poor	Good
Audio Output	Good	Fair	Fair	Fair
General Handling	Poor	Fair	Good	N/A
Ruggedness	Poor	Fair	Fair	Good
Maintenance	Fair	Good	Good	Good
Repair	Fair	Fair	Fair	Fair

[a]Includes only the sensing probe, electronics module, and power supply.
[b]Includes only the probe with 2 pounds ballast weight.

Detection Threshold. The objective of this test was to obtain baseline detection threshold data on each unit in air. Figure 6 shows the test setup for the pulse-induced systems. As a standard, twin 72 SCUBA tanks were used as the detection target by moving them toward the detector from various angles. Upon initial detection of the tanks, the angle and distance of detection were noted. Figure 7 shows the test setup for the Forster Ferex magnetometer. Since proper operation requires that the probe be oriented with its major axis perpendicular to the earth's surface, these tests were conducted by lowering the probe toward the tanks until a half-scale reading was obtained.

Appendix C contains detection thresholds of the pulse-induced systems plotted for coil angles of 0 degrees, 45 degrees, and 90 degrees at the various power settings of each unit. Appendix D shows detection thresholds of the Forster Ferex plotted for sensitivities of 100 and 300 gammas. The results of these tests showed the following maximum ranges for each of the units in air:

1. Forster Ferex - 7.0 feet (sensitivity switch set at 100 gammas)
2. Fisher Pulse 8 - 5.7 feet
3. Garrett XL500 (with 13-inch coil) - 5.1 feet
4. Garrett XL500 (with 7-inch coil) - 2.7 feet
5. White's PI-1000 - 3.3 feet

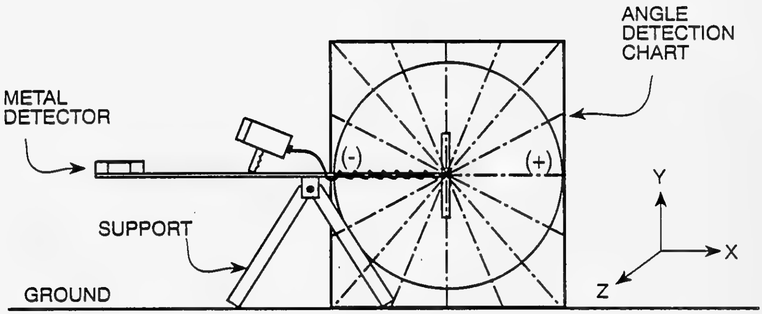


Figure 6
Setup for testing the range of pulse-induced systems.

From the results of these tests, it is clear (in air at least) that larger detection distances can be expected with the Forster Ferex unit.

Electronic Characteristics Analysis. The electronic characteristics of the pulse-induced systems were analyzed in order to obtain a baseline comparison of common features. Several of the characteristics examined include pulse width, response time, energy per pulse, and battery life. Figure 8 shows a general block diagram for pulse-induced metal detecting systems. Table 2 summarizes the test results. In comparing these results with the results of the detection threshold tests, the units with the larger signal output have the greater detection range. They also have the shortest battery life. Also, the response time of the different units should be noted. In comparison to the other units, the Fisher Pulse 8 has a very long response time. The long response time is undesirable since the unit can easily miss a target unless the coil is moved very slowly.

Ocean Tests

In January and February 1986, ocean tests of the four candidate metal detection systems were conducted offshore of the West Jetty at the Naval Construction Battalion Center, Port Hueneme, California. These tests were conducted to determine the detection capability of each unit for buried chain (1-1/2 inch) and buried armored cable (3-1/2-inch diameter). No tests were planned at this time for detection of an anchor (6,000 pounds) buried to 10 feet and armored pipeline (5-inch diameter) buried to 2-1/2 feet.

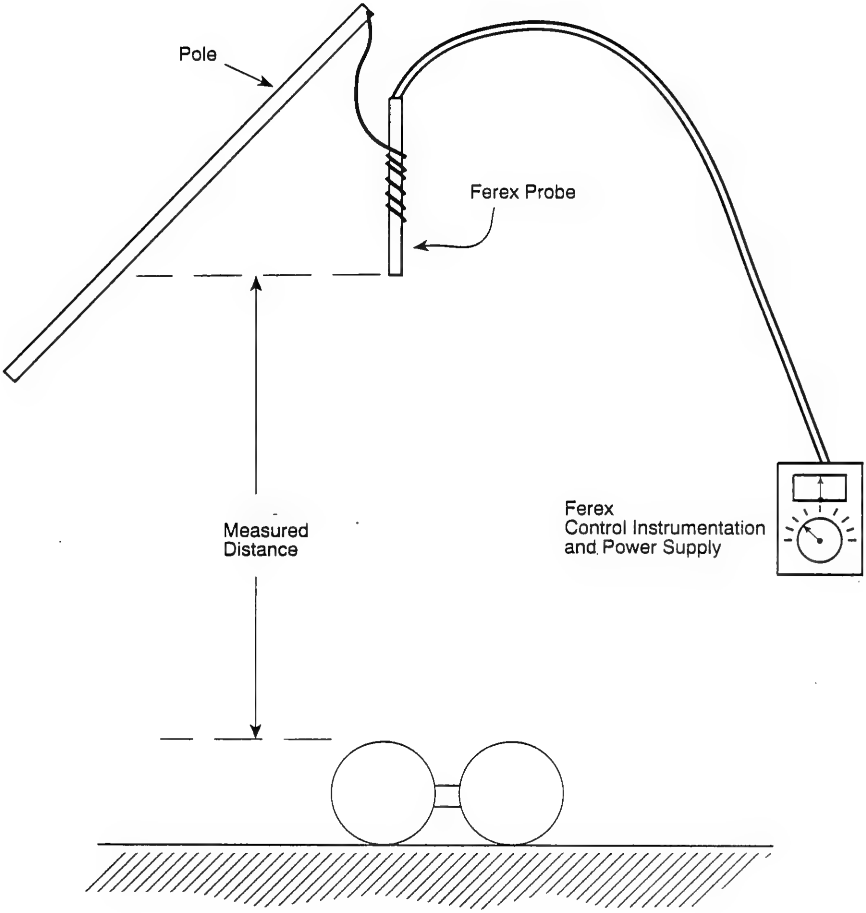


Figure 7
Setup for testing the range of the Forster Ferex.

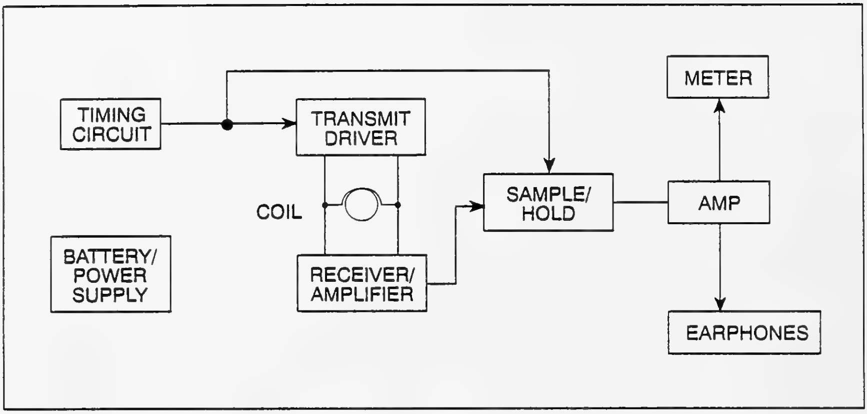


Figure 8
Pulse-induction metal detector block diagram.

Table 2. Electronic Characteristics Analysis

Characteristic	Garrett XL500	White's PI-1000	Fisher Pulse 8
Output Pulse Width	160 microseconds	30 microseconds	400 microseconds
Output Pulse Repetition Rate	9.5 milliseconds	300 milliseconds	11.5 milliseconds
Energy Per Pulse	4.6 millijoules	25 millijoules	13.8 millijoules
Power Supply Voltage	9.6 volts DC	9.0 volts DC	8.2 volts DC
Power Supply Current	110 to 125 milliamps	65 to 80 milliamps	310 to 325 milliamps
Response Time	approximately 100 milliseconds	approximately 500 milliseconds	approximately 200 milliseconds
Receiver Sensitivity	unable to measure	unable to measure	unable to measure
Battery Life	9 hours on fully charged batteries	12 to 15 hours on six nonrechargeable "AA" batteries	4 hours on fully charged batteries

In preparation for these tests, an underwater search range consisting of 1-1/2-inch chain, 3-1/2-inch armored cable, and twin 90 steel tanks was prepared in about 35 feet of water. These targets were buried in sand approximately 30 feet apart from each other with floats attached for identification. The targets were buried by fluidizing the soil around the target with a jetting nozzle. Burial depths were estimated by measuring between the surface of the sand and reference marks on the float line.

The test procedure consisted of swimming the range with the metal detecting device and searching each target location. At sites where a target was located, the maximum detection distance was estimated by raising the sensor above the target until its detection threshold was reached. The detection depth was estimated by adding the distance between the sensor and the seafloor to the burial depth of the target (estimated from the tape marks on the float line).

In addition to these tests, the Forster Ferex was used in the dipping mode to assess this operating scenario. During these tests, the Ferex was used from an inflatable boat with the probe submerged to within about 10 feet of the bottom. The distance off the seafloor was estimated by periodically lowering the probe until slack appeared in the cable.

Results of the detection tests are shown in Table 3. Detection thresholds from the TEMP are also listed for comparison. These tests show the following:

1. The detection ranges of commercially available pulse-induced systems cannot meet the detection thresholds of the TEMP. In addition, several serious deficiencies were noted for each system. These are as follows:

a. Garrett XL500 - Although this unit out-performed the other pulse-induced systems, it did not have the ruggedness required for UCT operations. During these tests the arm rest bracket broke off. In addition, the meter display was small and difficult to view. The headphones were awkward to wear and had a tendency to slip off the head. The sound was also muffled significantly when the headphones were worn over a diving hood.

b. Fisher Pulse 8 - This unit was difficult to zero (adjust to background interference) because of the 2-second response time of the electronics. Proper adjustment of the zero is important for optimum performance. If the zero is overadjusted, then the unit becomes too sensitive and is susceptible to the detection of small, insignficant items. If the zero is underadjusted, then the sensitivity of the unit is decreased, thereby decreasing the detection distance. Once properly adjusted, the slow response time requires that the unit be moved very slowly to avoid missing a target. In addition to the zeroing problem, the unit was awkward to handle because the front end "planes" from side to side. This is because the front-end housing of the sensing coil is shaped in a solid disk and therefore presents resistance to forward motion. This motion further compounds the problem related to the slow response time of the electronics.

c. White's PI-1000 - This unit could not be zeroed during these tests. Subsequent inspection of this unit indicated that the detent mechanism on the main switch was either broken or worn at the position for tuning/zeroing the unit. No further tests were conducted with this unit since it generally lacks the integrity and ruggedness required for UCT use.

Table 3. Metal Detecting Systems Testing Summary

Item	SCUBA Tank (Twin 72) Laboratory Tests	Ocean Tests				
		SCUBA Tanks (Twin 72)	Chain (1-1/2 Inch)	Armored Cable (3-1/2-Inch Diam)	Anchor (6,000 Pounds)	Armored Pipeline (5-Inch-Diam)
TEMP Threshold	None	None	6 ft	3 ft	10 ft	2-1/2 ft
Garrett XL500	5.1 ft	4.0 ft	<4 ft	1.5 ft	Not Tested	Not Tested
Fisher Pulse 8	5.7 ft	Not Found	Not Found	Not Found	Not Tested	Not Tested
White's PI-1000	3.3 ft	<3 ft	<4 ft	Not Detected	Not Tested	Not Tested
Forster Ferex	Not Tested	Not Tested	5 ft	3 ft	Not Tested	Not Tested

2. The Forster Ferex unit has the greatest detection range among the systems tested. As shown in Table 3, the Ferex unit met the TEMP threshold for detection of armored cable and was within 1 foot of meeting the TEMP threshold for detection of chain. These tests were conducted with the unit set at a sensitivity of 300 gamma. While the unit does have a greater sensitivity (and presumably a greater detection distance), it was difficult to use at a higher sensitivity for the following reasons:

a. The diver's gear became a significant magnetic target. To reduce this effect will require either nonmagnetic equipment for the diver or a standoff device (about 5 to 7 feet) between the probe and the diver.

b. Periodic adjustment (zeroing) is required and the diver does not have direct access to the control instrumentation with the present configuration of the unit. Since the control instrumentation is not waterproof, all tuning adjustments (such as selecting the operating mode (mode 1, 2, or 3) and the sensitivity, as well as periodic compensation for background noise) must be done at the surface by a remote operator rather than at the dive site by the diver. This operating scenario can easily result in confusion (particularily at the higher sensitivity levels) unless the diver and top-side operator know exactly what the other person is doing.

c. Use of an earphone as the sole means to provide detection signals to the diver is inadequate. Although the diver earphone provides a good general indication of target strength, it does not adequately provide specific location information. This is because the tone level does not change significantly when the unit is moving over a target (unless the probe is moved very slowly over the exact magnetic center). By comparison, the meter located on the control instrumentation swings from one extreme to the other (i.e., positive to negative) when the sensor is moved over a target. This provides clear indication of the target location.

Results of the dipping test indicated that the Ferex used in this mode of operation provides a system for general location of targets. This feature is clearly beneficial since it can minimize diver time in the water. For use in this mode, the Ferex must be used at high sensitivity levels since it is towed with the probe approximately 10 feet off the bottom. This requires that a maximum distance be maintained between the probe and the boat since the boat can be a significant magnetic target at high sensitivity levels. It was also noted that there is a tendency for excess cable in the boat to become tangled and knotted. Snarling and entanglement of cable in a small boat is a nuisance and a safety hazard, and can also result in damage to the electrical conductors in the cable.

As shown in Table 3, the TEMP thresholds for detection of an anchor (6,000 pounds) buried to 10 feet and armored pipeline (5-inch diameter) buried to 2-1/2 feet were not tested with these systems. Based on the results of the laboratory and ocean tests, it appeared unlikely that the pulse-induced systems in their current off-the-shelf form would meet these requirements. However, the Forster Ferex appeared to have the capability for detecting these items. Table 4 shows the magnetic signature of SD cable (list 5), armored pipe (5-inch diameter), and a 6,000-pound anchor at 5 feet, 4-1/2 feet, and 12 feet, respectively (Ref 1). Based on this information and the results of the ocean tests, it appeared highly likely that the Forster Ferex could meet these TEMP thresholds.

Table 4. Magnetic Signatures of SD Cable, 5-Inch Pipe, and 6,000-Pound Anchors

Object	Burial Depth (ft)	Sensor Distance (ft)	Magnetic Signature (γ)
SD List 5	3	5	291
5-Inch Pipe	2-1/2	4-1/2	257
6,000-Pound Anchor	10	4-1/2	3,055

Conclusions and Recommendations from the ADM Tests

1. Commercially available pulse-induced systems cannot satisfy the performance requirements of the TEMP. Increasing the detection thresholds may be possible by modifying these systems to incorporate a more powerful system with a larger sensing coil.

2. The Forster Ferex magnetometer had the greatest detection distance among the units tested. Modification of this unit holds the most promise for providing a metal detecting system suitable for UCT use.

Based on these results, the following recommendations were made for the Engineering Development Model system:

1. The Forster Ferex magnetometer should be modified for use in both dipping mode (from an inflatable) and self-contained diver-operated mode. This system should also be designed for quick and easy conversion between these two operating modes.

2. The dipping mode should incorporate a spring wound reel for paying-out and handling the cable between the probe and the electronics module.

3. The self-contained diver-operated mode should incorporate ready access to all control adjustments and a standoff mechanism between the sensors and the diver. No electronic modifications are anticipated.

ENGINEERING DEVELOPMENT MODEL (EDM) SYSTEM

From May through August 1987, laboratory and ocean tests of the engineering development model BP&CL were conducted to verify reliability and performance thresholds (as specified in the Test and Evaluation Master Plan, TEMP) and identify any safety or human factors deficiencies.

System Description

The EDM system consisted of a commercially available Forster Ferex (Model 4.021) system modified for use by the UCTs. Modifications to the magnetometer consisted of new waterproof housings and accessories for use in two different operational modes: (1) as a dipping mode from an inflatable boat, and (2) as a self-contained, hand-held diver tool. Figure 9 illustrates the two operational modes.

The stock Forster Ferex 4.021 magnetometer is designed to sense anomalies in the earth's magnetic field resulting from the presence of a ferrous object. To sense the anomaly, the magnetometer uses two fluxgate sensors located a fixed distance from each other inside a cylindrical probe. The output from the fluxgate sensors are processed and converted to provide the operator with both audible and visual signals. As the magnetic field disturbance increases, the intensity of the signal output increases. The visual output is a meter with an indicator needle that shows increasing signal strength by moving off-center to the right or left depending on the polarity of the section that the probe is approaching. As the probe is passed over the object, the needle swings across the meter to indicate signal strength in the opposite polarity. The earphone indicates increasing signal strength by increasing the frequency of the audio output.

Standard control features of the Forster Ferex 4.021 magnetometer include the following:

1. Mode Selector Switch - Any one of four different search functions can be selected with this switch. Mode 1 is for normal searching of all ferrous metals. Mode 2 is also for normal searching but eliminates disturbances from small ferrous objects. Mode 3 is used when searching next to a large ferrous object (such as a pipeline). Mode 4 allows the tool to be used as a magnetic compass.

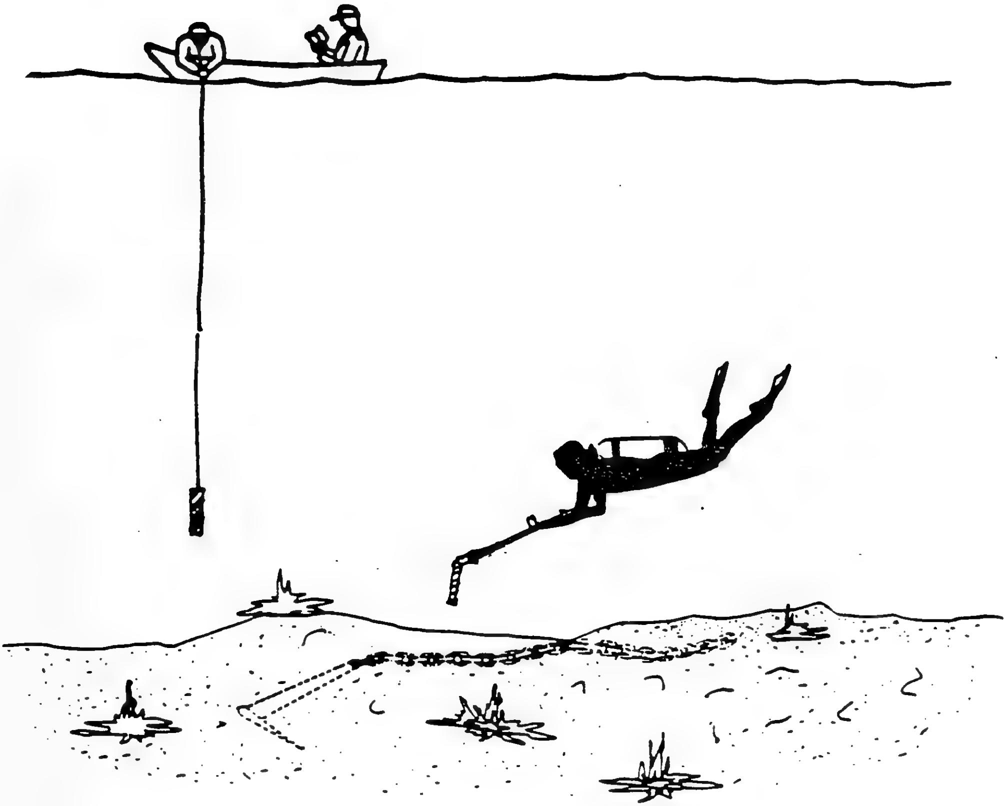


Figure 9
Two operational modes for the buried pipe and chain locator.

2. Compensation Switch - The compensation switch is used to "zero" the instrument in operating modes 1 and 2. This feature compensates for magnetic noise at a search site by resetting the output to read zero.

3. Test Switch - The test switch is used to check for proper operation of the system.

4. Sensitivity Selector Switch - The sensitivity switch is used to select one of eight sensitivity levels between 0.3 to 1,000 gammas.

5. Volume Switch - The volume control switch regulates the output level of the audible signal.

Modifications to the existing system consisted of reconfiguring the tool for use in both the dipped mode (from an inflatable boat) and a diver-held mode. The modifications included new, waterproof housings for the control electronics and batteries, a telescoping standoff device (to maintain distance between the diver's gear and the sensing probe), and a cable reel for using the probe in the dipped mode. Figure 10 shows the EDM BP&CL.

Reliability Tests

Reliability is expressed as the probability that the BP&CL will perform its functions without failure within performance characteristics for a 4-hour mission. The threshold reliability specified for this tool by the TEMP is 90 percent.

The mean time between failure (MTBF) is an estimate of the true system reliability based on the mission time and threshold reliability. To assure that the test duration will verify the system reliability, a confidence level multiplier is applied to the MTBF estimate. Table 5 summarizes the required test durations for confidence levels of 60, 80, and 90 percent. The number of failures recorded within the test period determines the confidence level achieved at 90 percent reliability. Based on this information, a 98-hour test period with no failures is required to demonstrate a 90 percent reliability with 90 percent confidence for a MTBF of 42 hours.

Table 5. Reliability Test Time Required

MTBF (hours)	Confidence Level (%)	Test Time (hours)		
		0 Failures	1 Failure	2 Failures
42.4	60	38	85	130
42.4	80	70	130	180
42.4	90	97	160	220

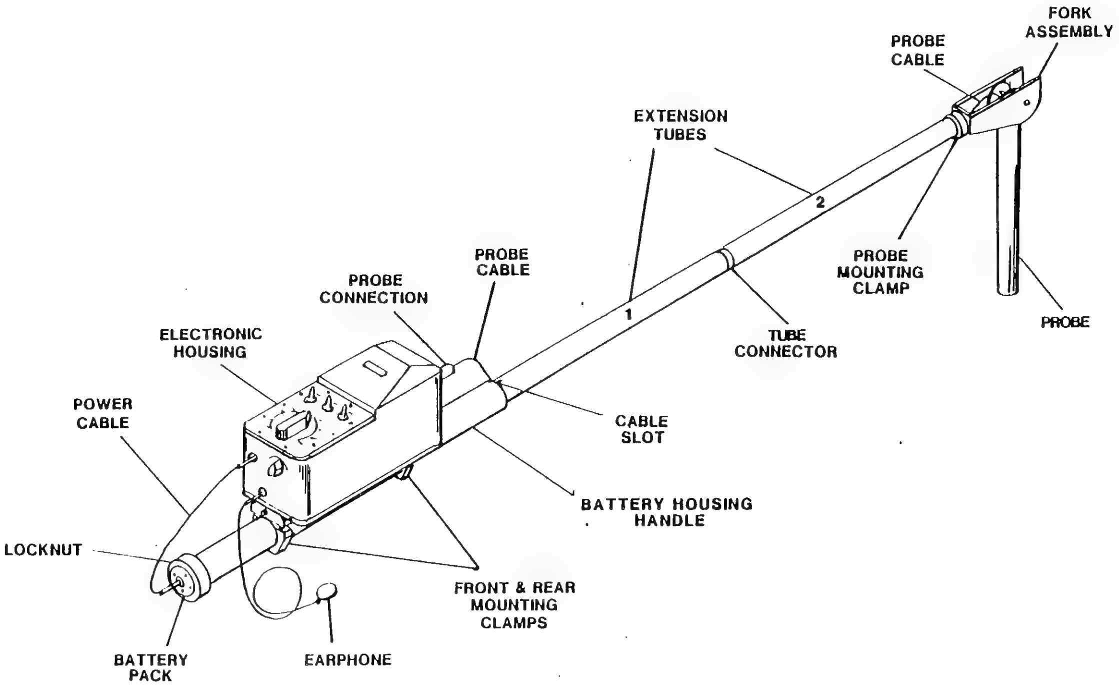


Figure 10
Components and asembly of the engineering development model BP&LL.

Table 6 shows the results of the reliability tests. No failures in over 107 hours of operation were observed, demonstrating a reliability greater than 90 percent with 90 percent confidence for a MTBF of 42 hours. The test was interrupted only once a day for replacement of batteries.

Two items requiring minor modification were identified during these tests: the sensitivity switch and the low battery indicator system. The sensitivity switch is a "break before make" type that sometimes turns the output volume off when changing sensitivity levels. Since this does not affect completion of the mission (the operator simply readjusts the volume), this item was not categorized as a failure. However, a more suitable switch will be used on the preproduction models.

The low battery indicator system monitors the battery voltage and provides early warning to the operator when the battery is getting low. During the initial part of these tests, the indicator system was only providing about 2 to 3 minutes warning before the system would quit working.

Table 6. Reliability Summary

Incident	Test Hours Completed	Description
1	11.2	Volume level sometimes affected by changing sensitivity levels.
2	20.6	Battery voltage low. Low battery indicator not yet lit. Battery test functioning and shows a low battery condition.
3	20.6	New batteries installed.
4	64.5	Battery voltage low. Low battery indicator not yet lit.
5	64.5	New batteries installed. Battery life was 43.9 hours. Note: No audio output was generated during this period of battery use.
6	105.1	Battery voltage low.
7	107.5	New batteries installed. Battery life was 43.0 hours. Note: No audio output was generated during this period of battery use.
8	107.5	Reliability testing completed.

This problem was corrected during the testing by changing a resistor value in the low battery circuit. About 30 minutes of operation is available after the low battery indicator light comes on.

Operational Effectiveness

To determine the operational effectiveness of the BP&CL, both laboratory and ocean tests were conducted. The objective of the laboratory tests was to establish detection thresholds for the BP&CL. The effects of sand on the detection distance of buried objects were also investigated. The ocean tests were performed to verify performance under operational conditions and to identify any safety or human factor deficiencies.

Laboratory Tests. The objective of the laboratory tests was to verify the detection thresholds specified in the TEMP. Table 7 lists the TEMP detection thresholds for SD List 5 cable, armored Simplex Pipe, 1.5-inch chain, and a 6,000-pound anchor.

Table 7. Vertical Detection Distances

Target	TEMP Detection Threshold (ft)	Detection Threshold (ft) Sensitivity Level (gamma)						
		1	3	10	30	100	300	1000
Pipe (5-inch) Simplex with Armor	2.5	-	-	-	4.0	2.9	1.7	-
Chain (1-1/2-inch)	6.0	6.1	6.0	5.1	3.9	2.4	-	-
Anchor (6,000 Pounds)	10.0	-	10.0	9.4	5.9	3.6	-	-
Cable (SD List 5)	3.0	-	6.0	5.0	3.5	3.0	2.1	1.0

In theory, the sand or water covering a buried ferromagnetic object should not greatly affect the detection distance (provided this covering has a relatively undetectable magnetic signature of its own). To verify this, the detection thresholds for an SD List 5 cable section (about 7 feet long) and 3/4-inch chain were measured while they were buried in sand and lying on the beach surface.

The results of this test confirmed that the individual detection distances of the SD List 5 cable and the 3/4-inch chain were the same whether the objects were buried or lying on the sand. The detection threshold for both the buried and unburied cable was 36 inches with the tool set for a sensitivity of 100 gammas. The detection threshold for both the buried and unburied chain was 20 inches with the tool set for a sensitivity of 100 gammas.

Based on the above results, the detection thresholds for the buried objects listed in the TEMP were determined in the laboratory by measuring the vertical distance between the probe and the object with the object lying on a bed of sand. These tests were performed by lowering the probe directly over the target for each sensitivity level until a half-scale deflection of the meter was observed. The vertical distance between the probe and the target was then recorded for each sensitivity setting.

The results of these tests and TEMP threshold values are shown in Table 7. These results show that the BP&CL met or exceeded all of the detection distance thresholds specified in the TEMP.

During these tests, it was observed that a slight swinging of the probe produced detection ranges that were greater than those possible with the probe hanging still over the target. With the probe hanging still over the target, increasing signal strength is indicated by an increase in the deflection of the indicator needle. As the probe is moved over the object, the indicator needle swings from one polarity to the other. The motion of the indicator needle swinging from one polarity to the other provides a better indication of the presence of the object than a slowly increasing needle deflection.

In performing these tests, the accuracy of locating the position of the target was also evaluated. The TEMP specifies an accuracy of 1 foot or the depth of burial, whichever is greater. Because the indicator needle swings from one polarity to the other as the midpoint of the object is crossed, the accuracy of locating the target is very good. Based on these tests, the accuracy of locating the target is estimated to be within the TEMP specifications.

Ocean Tests. The objectives of the ocean tests were to verify the operational performance of the system and to identify any safety or human factor deficiencies. These tests were conducted offshore Port Hueneme, California, with dive support provided by the NCEL dive locker.

To verify the operational performance of the system, both the dipping mode and diver-held mode of operation were tested from an inflatable boat. Prior to beginning the test, a 7-foot length of SD List 5 cable and a 6-foot length of 3/4-inch chain were positioned on the ocean floor in approximately 35 feet of water. The chain was stretched out in a line to produce a line source target (as opposed to a point source for a pile of chain). The relative positions of the targets were recorded using visual sightings.

To verify the operational performance of the system in the dipping mode, the system was assembled for operation in the inflatable boat (at the test site) and suspended in the water column while the boat performed a slow speed grid pattern search. The probe was positioned about 3 feet off the seafloor during this search by periodically lowering it to get slack and then reeling in 3 feet of cable. To aid in towing the probe, a 2-pound brass weight was attached to the end of the probe.

While executing this search pattern, both the cable and the chain were located with a sensitivity setting of 10 gammas. In both cases, the meter polarity was observed to change as the probe passed over the target.

To verify the location of the target, the system was converted on site (in the inflatable) to the diver operation mode and used by the divers to pinpoint and provide positive identification of the target. To locate objects on the seafloor, the divers were given about 1/2 hour of instruction prior to the operation. Locating objects in the diver operation mode requires the diver to conduct an iterative procedure of rotating 360 degrees (with the probe extended outward), observing the direction of the largest magnetic signature, and following the direction of the largest magnetic signature until he finds the object or travels 20 to 30 feet. Using this technique, both divers were readily able to find both targets in water with visibility of about 5 feet. In one case, the diver reported that he walked right by the target without seeing it but observed that he passed it by the change in the meter polarity.

After completing the above tests, the operators were asked to complete a human factors evaluation form on the system. In general, the tool qualities were judged to be suitable for use by the UCTs. One of the divers felt the probe end of the telescoping rod was slightly heavy and could use a small amount of buoyancy (less than 2 pounds). This addition would make the tool almost neutrally buoyant in the water and easier to handle and operate.

Two of the divers commented on the need for diver training in the operation of the tool. Neither felt the amount of training required would be excessive, perhaps an hour or so of instruction in its use, restrictions, operating procedure, and search techniques. In addition, many of the operators commented that the audio output turned off at least once when they switched sensitivity settings.

Controls were judged easy to operate and located properly for a hand-held tool. In the 2- to 3-foot visibility, the display could be seen and the individual LEDs were distinguishable. One diver commented that the green color of the display LEDs might be more difficult to see under certain limited visibility conditions than a red display.

None of the divers felt the need to increase the length of the standoff because of interference from ferromagnetic items of their scuba gear. One diver commented that he was able to swim with the tool as he operated it.

High/Low Temperature Testing. To verify the operation and performance of the BP&CL at extreme operating and storage temperatures, both high and low temperature tests were performed. Table 8 shows the TEMP thresholds for temperature. Temperature thresholds as listed in the manufacturer's literature on the commercial Ferex are also listed for comparison. Since the modifications to the commercial unit were limited to the housing and the LED operator display, the manufacturer's temperature values apply only to the sensing probe and the processing electronics.

Table 8. TEMP and Manufacturer Thresholds for Temperature

Characteristic	TEMP Thresholds	Manufacturer
Operational Water Temperature	28 to 85 °F	-22 to 130 °F
Nonoperational (storage) Temperature	-20 to 140 °F	-67 to 158 °F

To verify the cold operating and cold storage temperature thresholds in the TEMP (28°F and -20°F, respectively), the BP&CL was tested in the NCEL Polar Laboratory Facility. These tests were performed in air and in a tank filled with fresh water. The temperature in the fresh water tank was regulated by adjustment of the air temperature in the cold chamber. A thermocouple with digital readout was used to monitor the temperature of the water. Air temperature was monitored using the temperature gages provided in the cold chamber.

To begin the cold tests, the air temperature in the cold chamber was lowered to about -17°F. The BP&CL was then placed in the chamber (going from a temperature of about 63°F to -17°F) over night while the cold air cooled the water in the tank. In the morning, new batteries were placed in the BP&CL and the tool was turned on and used (in air) to find rebar placed in the cold chamber. The BP&CL was then placed in the tank while the water temperature was being lowered. After about 4 hours, the BP&CL was pulled from the tank and operated in air to find the rebars. The water temperature was about 34°F with ice beginning to form at the surface. No operational problems were encountered during these tests.

To verify the high temperature operating and storage thresholds in the TEMP (85°F and 140°F, respectively), tests of the BP&CL were performed with the tool submerged in a tub of warm water after sitting outside (in direct sunlight) while packaged inside its storage container. To monitor the temperature inside the container, both a thermometer and a thermocouple (with digital readout) were placed inside the contain. With the ambient air temperature (in the shade) at approximately 82°F, the temperature inside the box eventually reached 125°F. The BP&CL was then taken from its storage container and placed in a tub of warm water (approximately 90°F) for about 20 minutes. The BP&CL was then turned on inside the tub of water and then pulled out and used in air to locate rebar laid on the ground. No operational problems were encountered during these tests.

USER TESTS

To verify the suitability of the tool for UCT use, user tests of the modified Forster Ferex system were performed offshore Anacapa Island by the NCEL dive locker. Although these tests were originally scheduled with UCT-TWO (and NCTC Delta Company as a backup), fleet scheduling conflicts required using the NCEL dive locker to avoid further schedule delays and additional project costs. Reference 4 authorized NCEL to conduct the user tests with in-house personnel previously stationed with either UCT-ONE or UCT-TWO. These tests were performed in March 1988.

The test consisted of divers using the BP&CL (in the diver-held mode) to find a 10-foot section of 1.5-inch chain placed on the seafloor. The chain was placed about 100 feet away from the dive station (LCM-8 boat) in about 45 feet of water. The sea conditions were considered good, with 10 feet of visibility, no current, and a water temperature of 65 degrees.

Prior to beginning the dive, the operators received a 15-minute instruction on how to use the BP&CL (both divers were unfamiliar with its use). Upon reaching the bottom, the divers determined which course to take by using the audio and visual output of the BP&CL while making a 360-degree turn. This procedure was repeated after traveling a short distance (about 30 to 40 feet) until the chain was found. The total time on the bottom actually searching for the chain was about 5 minutes.

Comments from the divers indicated that the BP&CL meets the operational effectiveness and operational suitability thresholds stated in the TEMP. One problem mentioned was the loss of the audio output signal while adjusting the frequency control. This problem will be solved by substituting the switch with a "make before break" type.

CONCLUSIONS

The EDM test results show that the BP&CL has met or exceeded the TEMP thresholds. Table 9 shows TEMP thresholds and summarizes test results.

The reliability thresholds were met with a confidence factor of 90 percent. There were only two minor incidents observed during this portion of the test and neither would prevent the unit from performing its mission. The test battery life of 43 hours was judged to be in excess of actual operating battery life since the unit was not generating any audio output during the tests. It is estimated that actual battery life will consist of at least 25 hours of operation.

The detection thresholds were met for all items listed in the TEMP. This includes a detection range of: (1) 2-1/2 feet for 5-inch-diameter Simplex pipeline (with a layer of armor), (2) 3 feet for SD list 5 armored cable, (3) 6 feet for 1-1/2-inch chain, and (4) 10 feet for a 6,000-pound anchor.

The weight and balance of the tool in the diver-operated mode was judged acceptable by the divers. However, making the probe end of the standoff device neutrally buoyant would add to the tool's effectiveness. In the dipping mode of operation it was noted that the unit can be used effectively from an inflatable boat. The speed of the boat must be kept slow enough to permit the probe to remain perpendicular to the seabed.

RECOMMENDATIONS

Based on the results of the development effort, it is recommended that:

1. The Buried Pipe and Chain Locator be approved for limited production of three systems.

2. The performance of the three systems should be monitored by NCEL during a UCT operation to insure a smooth transition into fleet use.

3. The User Data Package prepared during the EDM effort should be updated with as-built drawings after fabrication of the three production systems.

4. The Buried Pipe and Chain Locator should be included in the NCTC school as part of the training curriculum.

REFERENCES

1. Naval Civil Engineering Laboratory. Memorandum to files on the survey of diver-operated metal detecting systems, by Eastport International, Inc. Port Hueneme, CA, Jul 1985.

2. Naval Explosive Ordnance Disposal Technology Center ltr Ser FL/165 of 19 Sep 1985. Subj: Use of MK-10 magnetometer.

3. M. Oliver, CEC (DV). Personal communication, Naval Civil Engineering Laboratory, Ocean Operations Division, Port Hueneme, CA, Jan 1986.

4. H. Herrman. Telephone conversation, NAVFAC and H. Thomson and S. Black, NCEL, Mar 1988.

Table 9. TEMP Thresholds and Test Results

Characteristics	TEMP Threshold	Manufacturer Specification	Test Results
1. Operational Effectiveness			
Power Supply	Self-contained, rechargeable, or replacable	6 to 12 volt (6 mono-cells each 1.5V)	6 replacable alkaline D cells
Operational life cycle	6 hours	N/A	18 hours
Detection Distance			
Buried chain, 1.5 in. or larger	6 feet	N/A	6.1 feet
Buried pipeline (5-in.-diam Simplex w/armor	2.5 feet	N/A	4.0 feet
Anchors (6,000 lb)	10 feet	N/A	10 feet
Armored cable (SD List 5)	3 feet	N/A	6 feet
Accuracy of Detection Location on Seafloor	Location on seafloor will be 1 foot or the depth of burial, whichever is greater	N/A	<1 foot
Weight (system)			
In air	35 pounds	20.8 pounds	21 pounds (excluding case)
In water	3 pounds +/- 1 pound	N/A	3 pounds
Operational Range	On the beach to 190 feet of water	0 to 300 feet (probe)	Demonstrated 0 to 55 feet
Handling			
Diver-held mode	Carried by one free swimming diver (requires only one hand to carry underwater, but may require two hands to operate)	N/A	One hand to carry, two hands to operate
Boat-towed mode	The sensing probe can be towed at slow speed from an inflatable boat	N/A	Demonstrated towing from inflatable boat
Operational Water Temperature	28 to 85°F	5 to 149°F	Demonstrated 34 to 90°F
Nonoperating Temperature	None	-58 to 176°F (with lithium batteries)	Demonstrated -20 to 125°F
Operating Turbidity	Clear water to zero visibility	N/A	Demonstrated 3- to 10-foot visibility

Table 9. Continued

Characteristics	TEMP Threshold	Manufacturer Specification	Test Results
2. Operational Suitability			
Life	7 years	N/A	
Mean Cycles Between Failure	>20	N/A	>20 based on MTBF of 42 hours
Reliability of a Single Unit	>90%	N/A	>90% at 90% confidence level
Preventative Maintenance Times			
Daily (excluding recharging power source)	1 hour	N/A	<1 hour (limited to wash-off and O-ring lubrication)
End of Project	1.5 hours	N/A	<1 hour (limited to wash-off, O-ring lubrication, and systems check)
Annual	3 hours	N/A	<3 hours (recalibration at Depot level)
MTTR	1 hour	N/A	<1 hour (limited to O-ring replacement)
Skill Level	75% of all divers can operate with 1 hour of instruction on beach	N/A	4 out of 4 divers can operate with 1 hour of instruction on the beach

Appendix A

COMPONENT DESCRIPTION - METAL DETECTING SYSTEM MISSION AND REQUIRED OPERATIONAL CHARACTERISTICS

MISSION: To locate and track underwater metal pipelines, armored cable, and chain.

Characteristic	Threshold
A. Operational Effectiveness	
• Power Supply	Self-contained, rechargeable or replaceable
- Operational life cycle	6 hours
• Detection Distance	
- Buried chain (1-1/2 inches or larger)	6 feet
- Buried pipeline (5-inch diameter Simplex with layer of armor)	2-1/2 feet
- Anchors (6,000 lb)	10 feet
- Armored cable (SD List 5)	3 feet
• Accuracy of Detection	<1 foot or depth of burial
• Weight	
- In air	<35 lb
- In water	3 + 1 lb
• Operational Range	On the beach to 190 feet of water

Characteristic	Threshold
• Handling	
- Diver-held mode	Carried by one free swimming diver (requires only one hand to carry underwater, but may require two hands to operate)
- Boat-towed mode*	The sensing probe can be towed from an inflatable boat
• Operational Water Temperature	28 to 85°F
• Operational Turbidity	Clear water to zero visibility

B. Operational Suitability

• Life (sensor system or component which will likely contact seafloor regularly during operation shall be abrasion resistant (on sand or gravel) or inexpensive and easy to operate)	>7 years
• Mean Cycles Between Failure	>20
• Reliability of Single Unit	>90%
• Redundant Supply or Two or More Units is Acceptable	
• Reliability of Two Units	>99%
• Preventative Maintenance Times	
- Daily (excluding recharging power source)	1.0 hour

Characteristic	Threshold
- End of project	1.5 hour
- Annual	3.0 hours
• MTTR/On-Site Maintainability (limited to replacing O-rings and power pack - all other repairs at depot level)	1.0 hour
• Production Cost (assume order of 5, FY85 dollars)	$20,000/unit
• Skill level	75% of all divers can operate with 1 hour of instruction on the beach

*Revised content.

Appendix B

COMPARISON OF PHYSICAL CHARACTERISTICS

VISUAL OUTPUT

Garrett XL500

POOR. The indication meter is located on the top of the electronics housing, which is either worn around the waist or attached to the top of the sensing wand. Target strength is indicated by an analog meter with scale readings between low and high. In either position, the meter is poorly positioned for viewing. With the housing attached to the sensing wand, the operator must lean forward over the wand and electronics housing to view the meter. With the housing attached to the belt, the operator must twist and bend over at the waist to view the meter. In addition, the meter is not back-lit for viewing in dark or low visibility areas.

White's PI-1000

POOR. There are two light-emitting diodes that are located inside the electronics housing. One diode provides a battery check indicator. The other diode indicates the presence of metallic objects by blinking (the higher the frequency of blinking, the greater the target strength). Although these diodes are positioned well for viewing, this form of indication is somewhat ambiguous since the output is qualitative in nature.

Fisher Pulse 8

FAIR. The target indication meter is located on the sensing wand and is an integral part of the handle. The meter is adequately sized and positioned well for viewing. However, the meter is not back-lit for viewing in dark or low visibility areas.

Forster Ferex

GOOD. Signal strength, battery status, and check indicator for proper operation are all displayed on an analog meter. Although the meter is not submersible, it provides a good indication of target strength and location. This is because the sensitivity of the unit can be adjusted to obtain quantitative readings and the meter swings from one extreme to the other (i.e., positive to negative) when moving over a target.

AUDIO OUTPUT

Garrett XL500

FAIR. The audible output from this unit is an oscillating tone that increases in volume as an object is detected. This method of detection is adequate and allows for a reasonable reaction time. However, the headphones are cumbersome and the sound may become muffled if the headphones are worn over a hood.

White's PI-1000

FAIR. This unit has a clicking indicator that changes clicking speed as an object is detected. Discernment of the change in clicking rate is fair. However, the headset has only one transducer and is not well balanced. Because of this, the headset is very difficult to keep from sliding off the user's head. The sound may also become muffled if the headset is worn over a hood.

Fisher Pulse 8

GOOD. This unit comes with a diver earphone that may be used inside a diver's hood. The earphone indicates the presence of a target by a change in its output tone (higher frequencies indicate increased target strength).

Forster Ferex

FAIR. This unit has a clicking indicator that changes clicking speed as an object is detected. Discernment of the change in clicking rate is rated as fair.

GENERAL HANDLING

Garrett XL500

FAIR. The handle design and weight distribution is good for supporting this unit. However, the wand length is adjusted by adding either one or two extension rods that are connected together by nuts and bolts. This type of fastening arrangement is not well suited for quick adjustment to wand lengths, particularly in a small boat or by divers in the water. The parts of the fasteners are also likely to become lost.

White's PI-1000

GOOD. The handle design and weight distribution is good for use in handling this unit. In addition, the length of the wand is easily adjusted by means of a telescoping mechanism on the wand. The rod uses compressive pins that lock into holes on the outer tube. Since no tools are required for adjustment, varying the length can be done easily on land, boat, or in the water.

Fisher Pulse 8

POOR. The handle design and weight distribution is poor due to inadequate balancing (the front end is heavy) and lack of a forearm rest. As a result, short duration, limited handling of this unit is likely to fatigue the arm. The mechanism for adjusting the wand length is also rated as poor. Adjusting the wand length is done by unscrewing threaded pieces of PVC pipe and removing or adding sections. The extra sections would have to be taken with the diver for adjustment to be made underwater.

Forster Ferex

NOT APPLICABLE. This system was not designed as a diver tool.

RUGGEDNESS

Garrett XL500

FAIR. The ruggedness of this unit is rated as only fair. Although the electronic housing appears very rugged, the arm rest and sensing coil attachments appear weak and prone to damage. All plastic portions of the wand should be replaced with aluminum tubing.

White's PI-1000

FAIR. The wand and the attachment points for the handle, arm rest, and coil appear to be fairly rugged. However, the overall rating is only fair because the electronics housing appears prone to damage. The housing is a thin-walled plastic enclosure that is positioned on the top of the wand grip. In this position, the housing extends outside the body of the unit and is susceptible to impact or snagging.

Fisher Pulse 8

POOR. This unit is poorly constructed. The wand, fabricated from PVC pipe, is weak and inadequately designed for supporting the components of the system. The attachment points for the coil, handle, and electronics housing are welded PVC and also appear fragile. The electronics housing appears to be the only ruggedly constructed component of this system.

Forster Ferex

GOOD. The components of this system appear very rugged and well constructed. However, only the probe is submersible. The electronics housing and power supply would require redesign to make these components waterproof.

MAINTENANCE

Garrett XL500

GOOD. Maintenance is rated as good since this is limited to recharging the batteries (required after 9 hours of operation), periodic lubrication of O-rings, inspecting for signs of wear or damage, and rinsing the unit with fresh water after use. The batteries are charged by plugging a 12-volt transformer (supplied with the unit) into the earphone connector. All O-rings on the connectors and the electronic housing cover are accessible and easily replaced.

White's PI-1000

GOOD. Maintenance on this item is rated as good since it is limited to replacing the batteries every 12 hours, lubricating O-rings on the cover to the electronics housing, inspecting the unit for wear or damage, and rinsing the unit with fresh water after use. Although the batteries are nonrechargeable (six "AA" batteries) they should be readily available in most locations.

Fisher Pulse 8

FAIR. Maintenance on this unit is minimal (limited to charging the batteries, inspecting the unit for wear or damage, and rinsing the unit with fresh water after use) but is rated as only fair since the batteries require recharging after 4 hours of operation.

Forster Ferex

GOOD. Maintenance on this unit is limited to replacing the batteries, inspecting the unit for wear or damage, and rinsing the probe with fresh water after use.

REPAIR

Repair of all four systems is rated as fair. Repair of these units in the field is limited to replacement of O-rings. All other repairs such as replacement of faulty electrical components or repair of mechanical items (i.e., broken handles, stripped threads, or damaged electrical housing) must be conducted at the Depot level.

MATERIALS OF CONSTRUCTION

Garrett XL500

SENSING WAND:	aluminum tube and plastic
COIL COATING:	plastic
ELECTRONIC HOUSING:	plastic
OUTPUT TRANSDUCER:	plastic earphones

White's PI-1000

SENSING WAND: aluminum
COIL COATING: plastic
ELECTRONIC HOUSING: plastic
OUTPUT TRANSDUCER: plastic coated

Fisher Pulse 8

SENSING WAND: PVC pipe
COIL COATING: plastic and potting compound
ELECTRONIC HOUSING: plastic
OUTPUT TRANSDUCER: plastic coated

Forster Ferex

SENSING PROBE: aluminum
ELECTRONIC HOUSING: aluminum
POWER SUPPLY HOUSING: aluminum

COLOR

Garrett XL500

WAND: white and silver
COIL: white
ELECTRONIC HOUSING: clear with yellow stickers

White's PI-1000

WAND: black
COIL: black
ELECTRONIC HOUSING: orange with clear cover

Fisher Pulse 8

WAND: gray
COIL: black
ELECTRONIC HOUSING: yellow with clear cover

Forster Ferex

PROBE: gray
ELECTRONIC HOUSING: gray
POWER SUPPLY HOUSING: gray

Appendix C

DETECTION THRESHOLDS FOR PULSE-INDUCED SYSTEMS

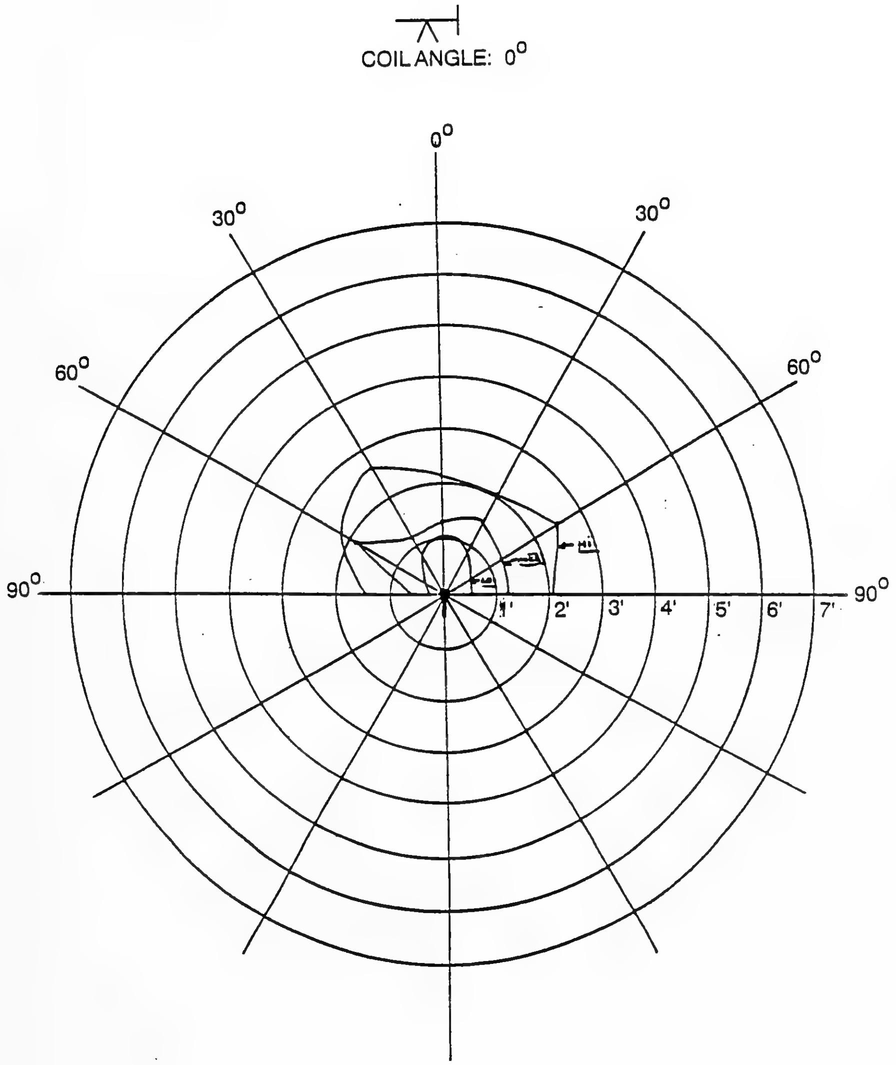


Figure C-1
Detection threshold for the Garrett XL500 (7-inch coil model) at low, medium, and high settings, 0° coil angle.

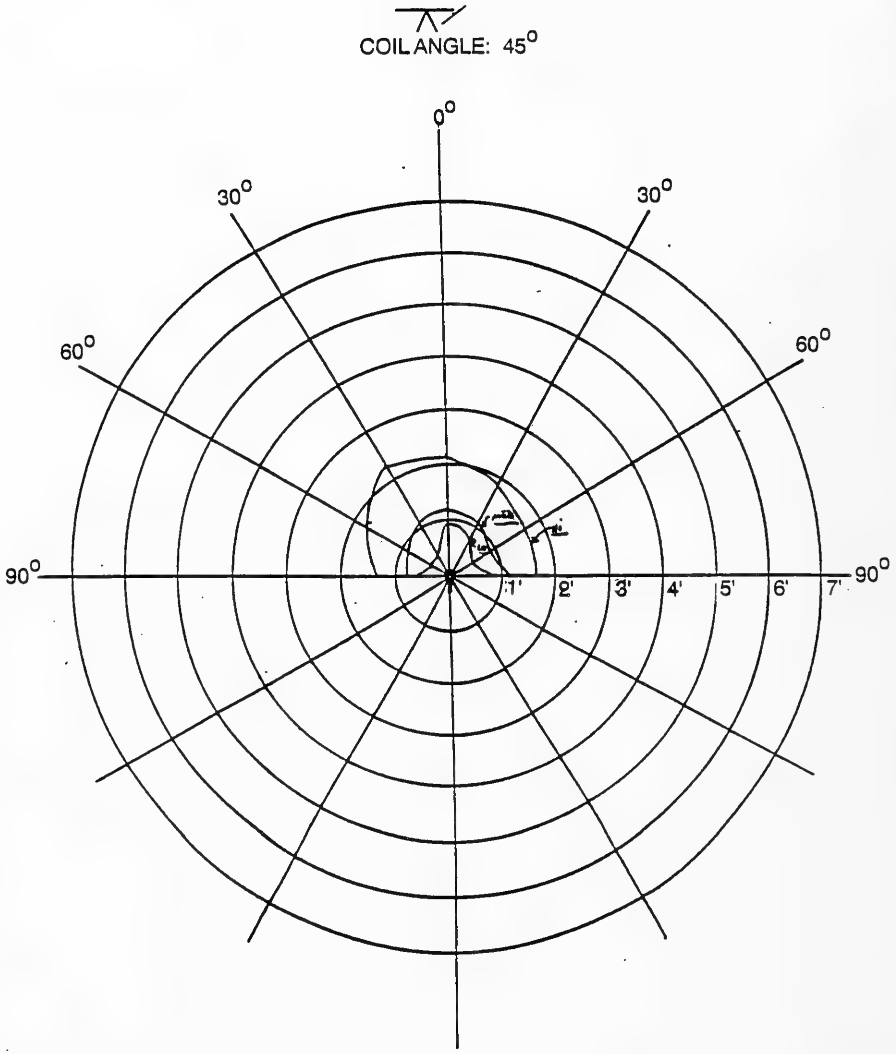


Figure C-2
Detection threshold for the Garrett XL500 (7-inch coil model) at low, medium, and high settings, 45° coil angle.

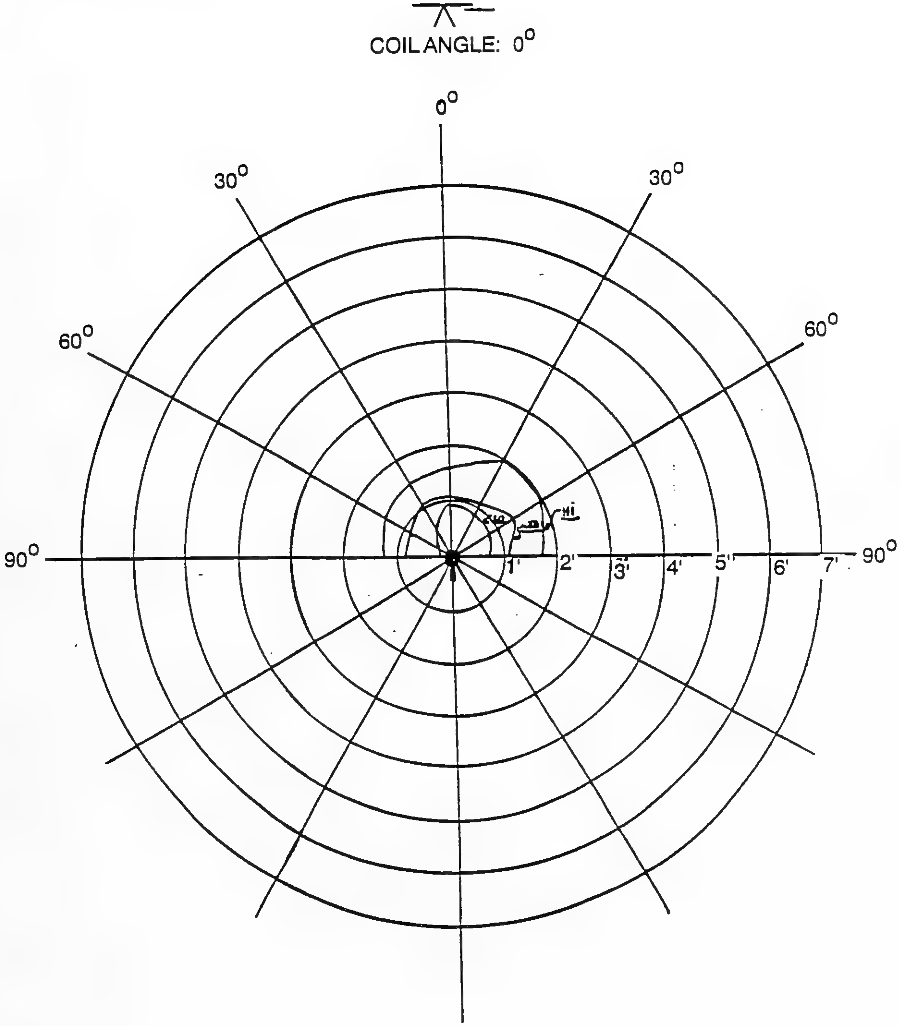


Figure C-3
Detection threshold for the Garrett XL500 (7-inch coil model) at low, medium, and high settings, 90° coil angle.

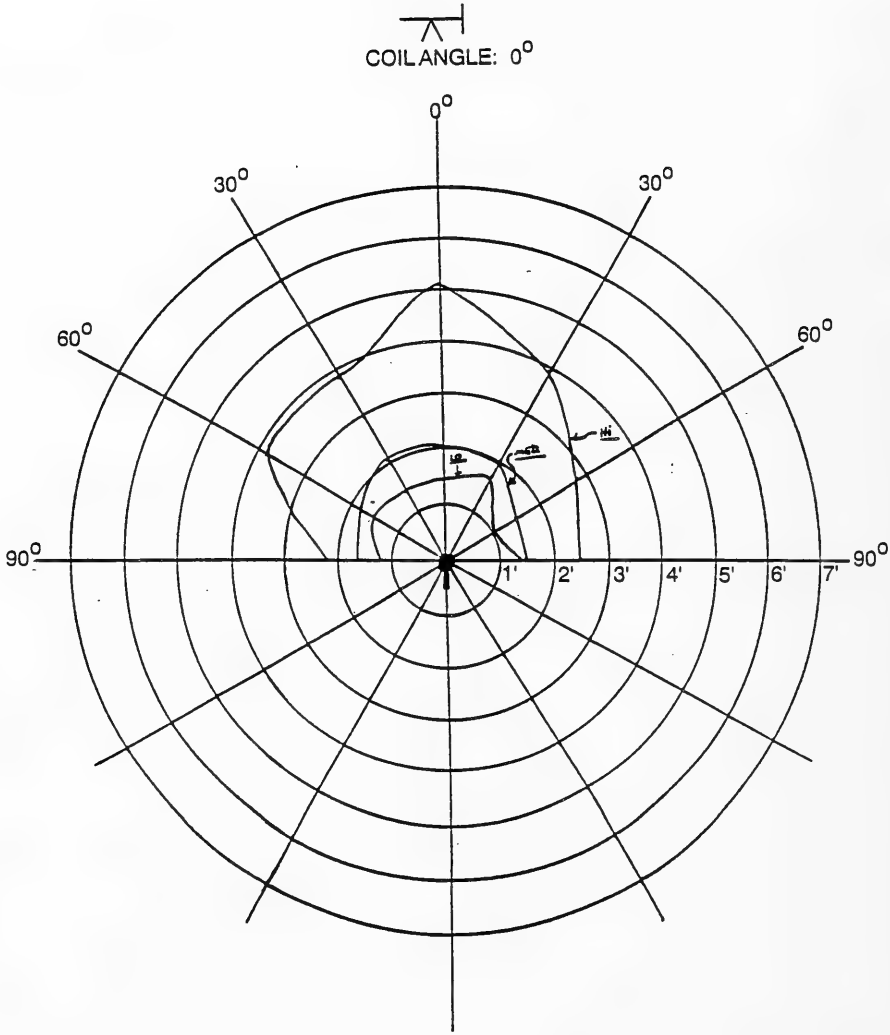


Figure C-4
Detection threshold for the Garrett XL500 (13-inch coil model) at low, medium, and high settings, 0° coil angle.

COIL ANGLE: 45°

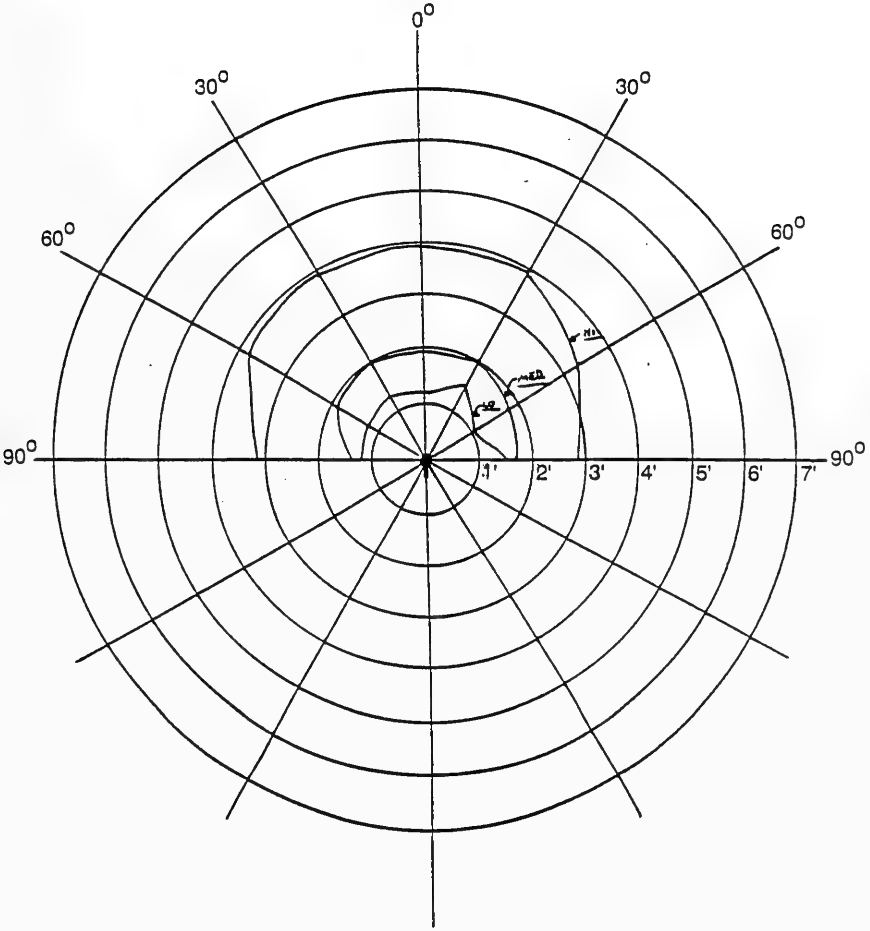


Figure C-5
Detection threshold for the Garrett XL500 (13-inch coil model) at low, medium, and high settings, 45° coil angle.

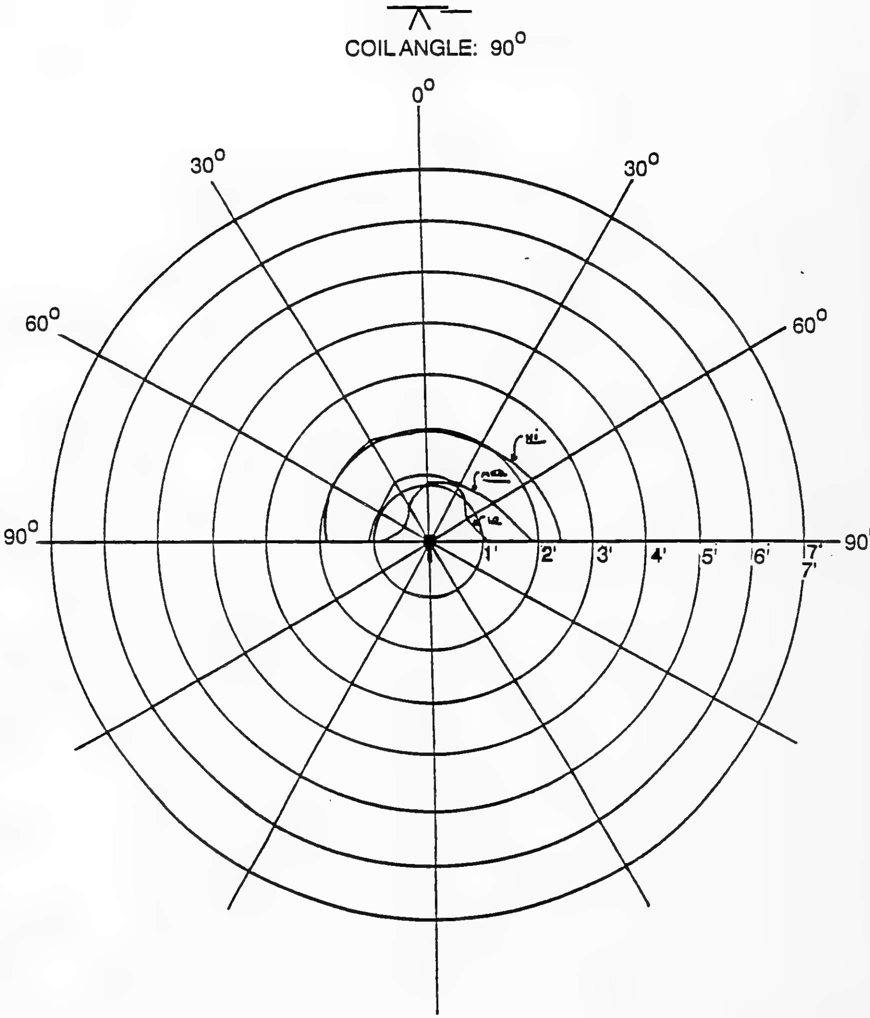


Figure C-6
Detection threshold for the Garrett XL500 (13-inch coil model) at low, medium, and high settings, 90° coil angle.

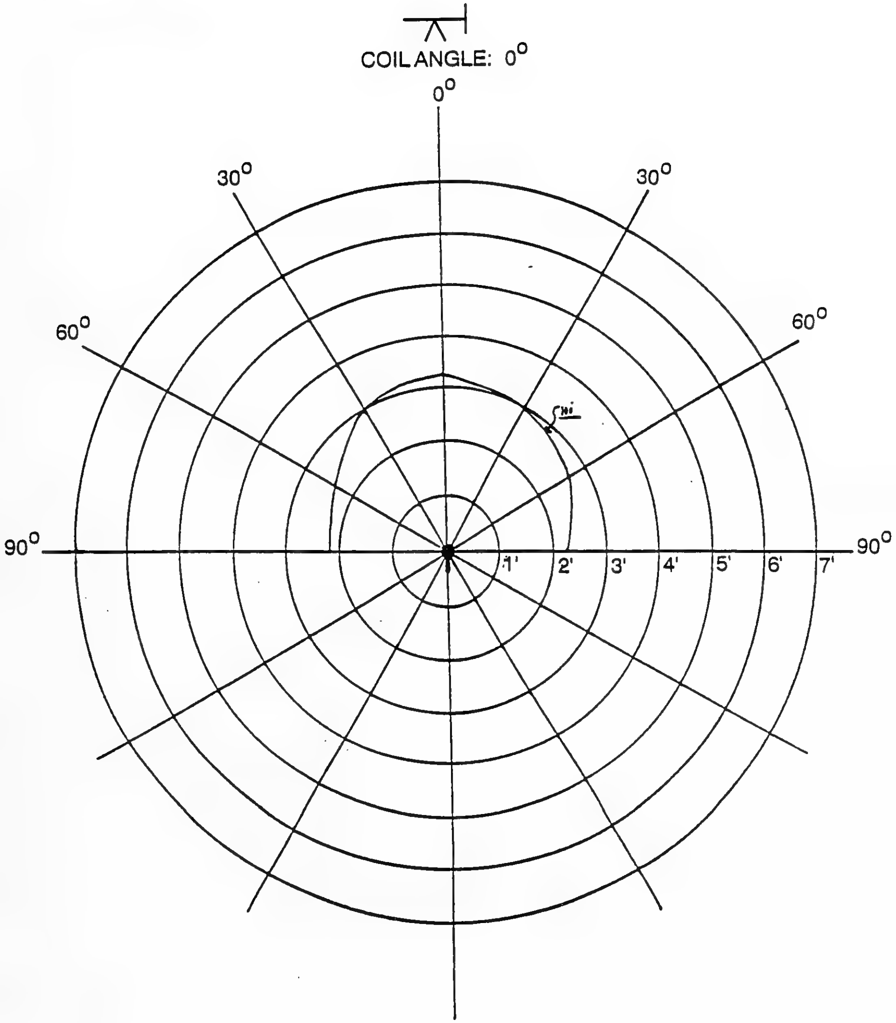


Figure C-7
Detection threshold for the White's PI-1000 at high setting, 0° coil angle.

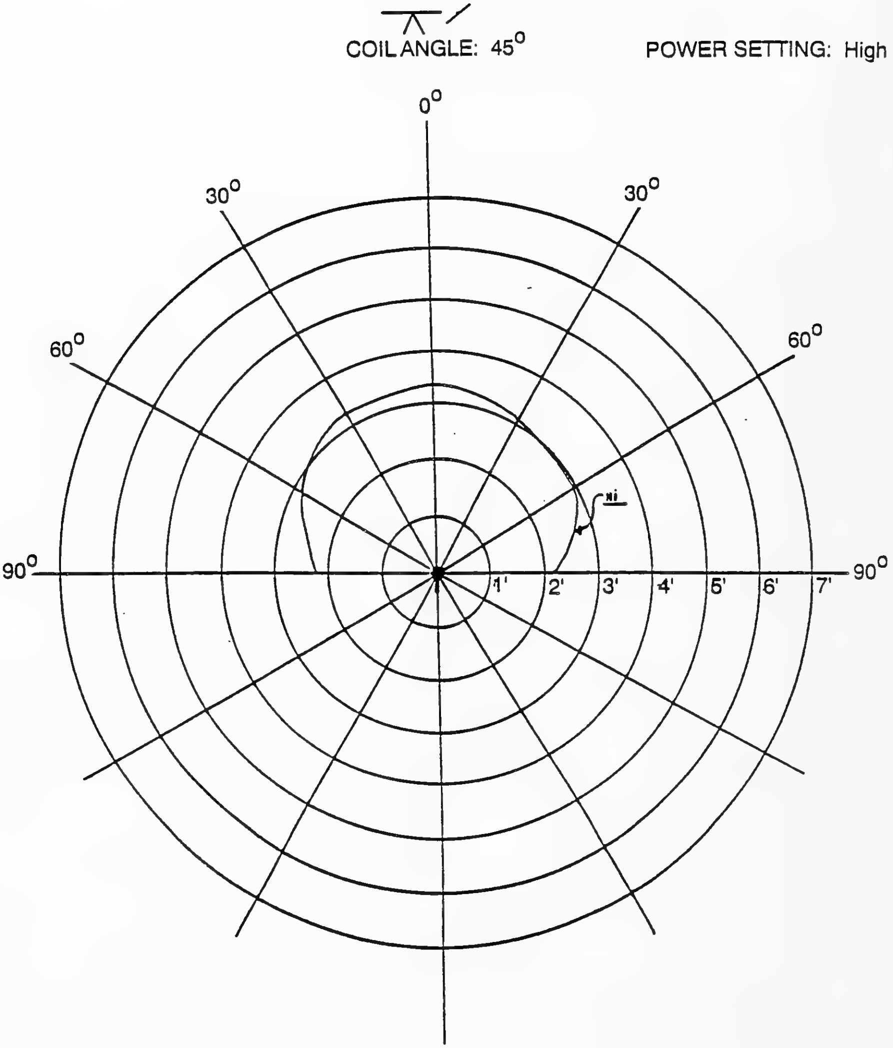


Figure C-8
Detection threshold for the White's PI-1000 at high setting, 45° coil angle.

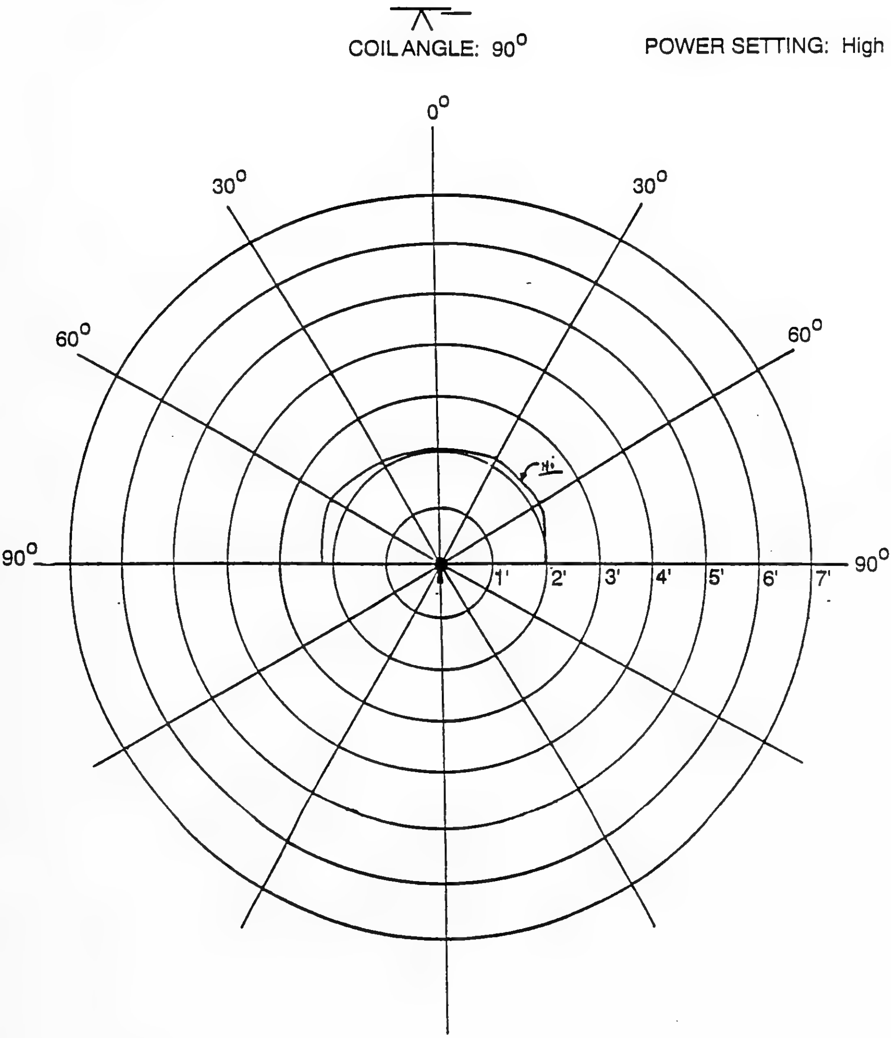


Figure C-9
Detection threshold for the White's PI-1000 at high setting, 90° coil angle.

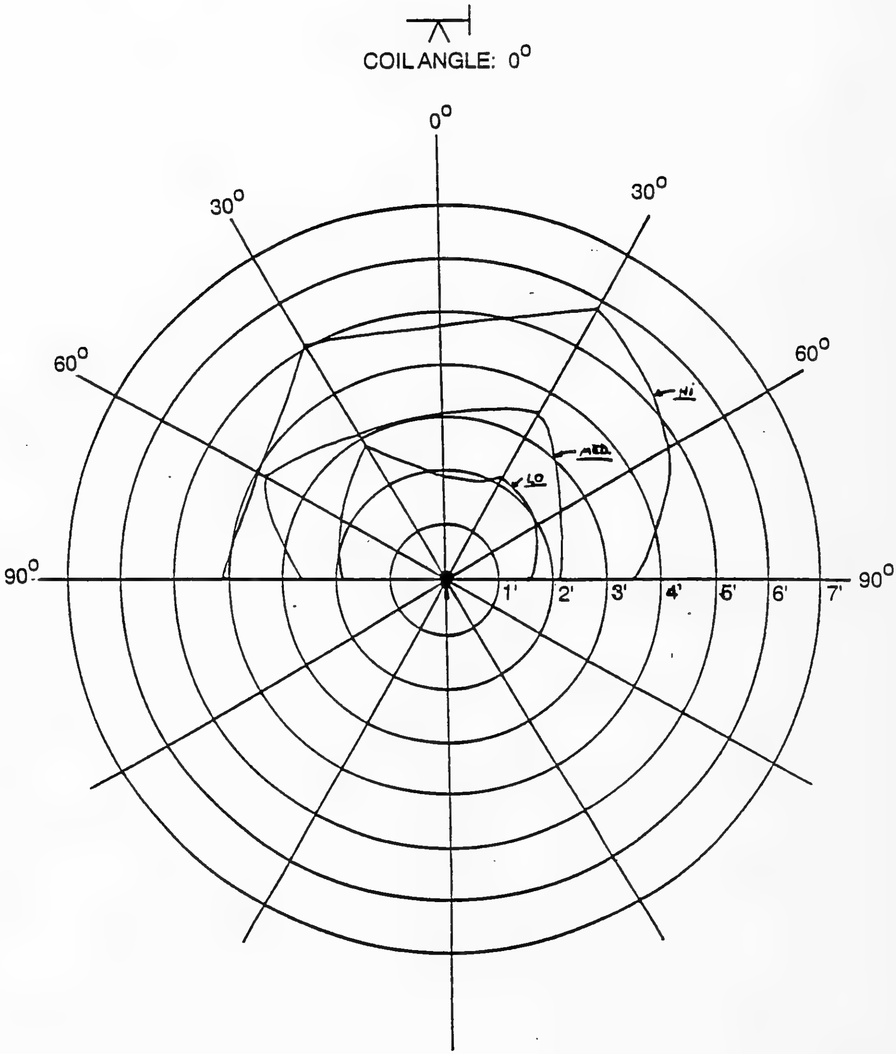


Figure C-10
Detection threshold for the Fisher Pulse 8 at low, medium, and high settings, 0° coil angle.

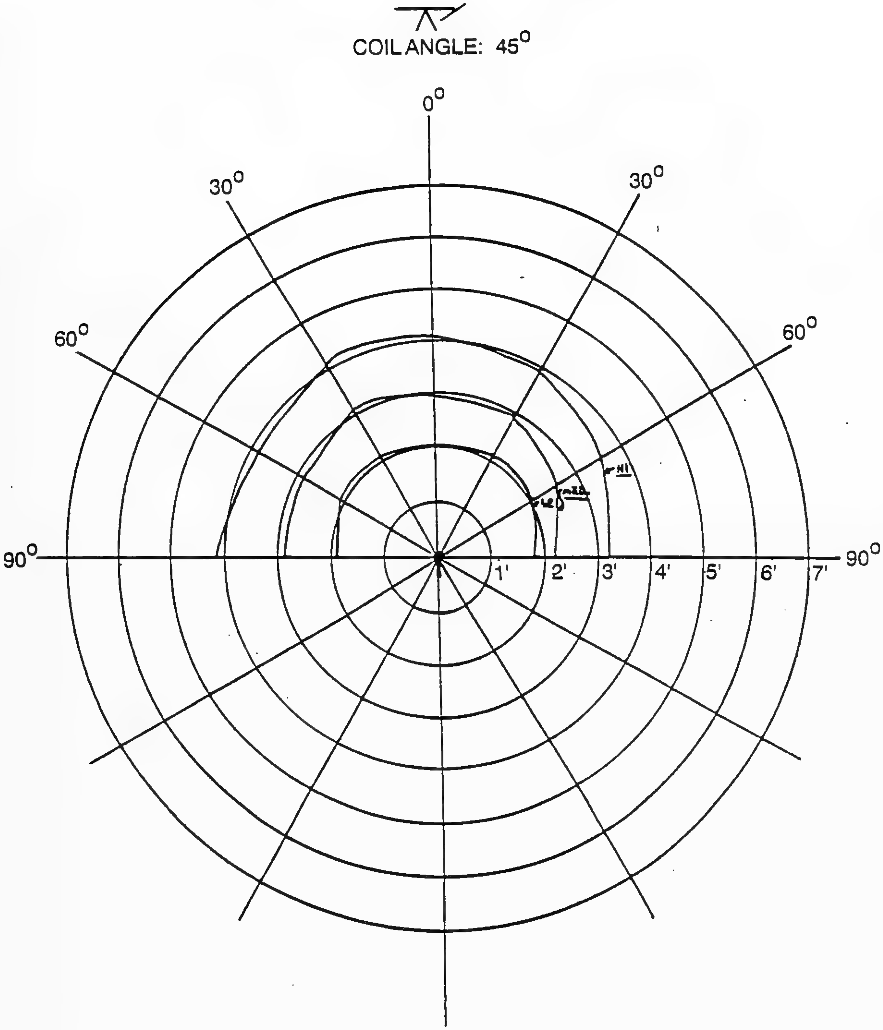


Figure C-11
Detection threshold for the Fisher Pulse 8 at low, medium, and high settings, 45° coil angle.

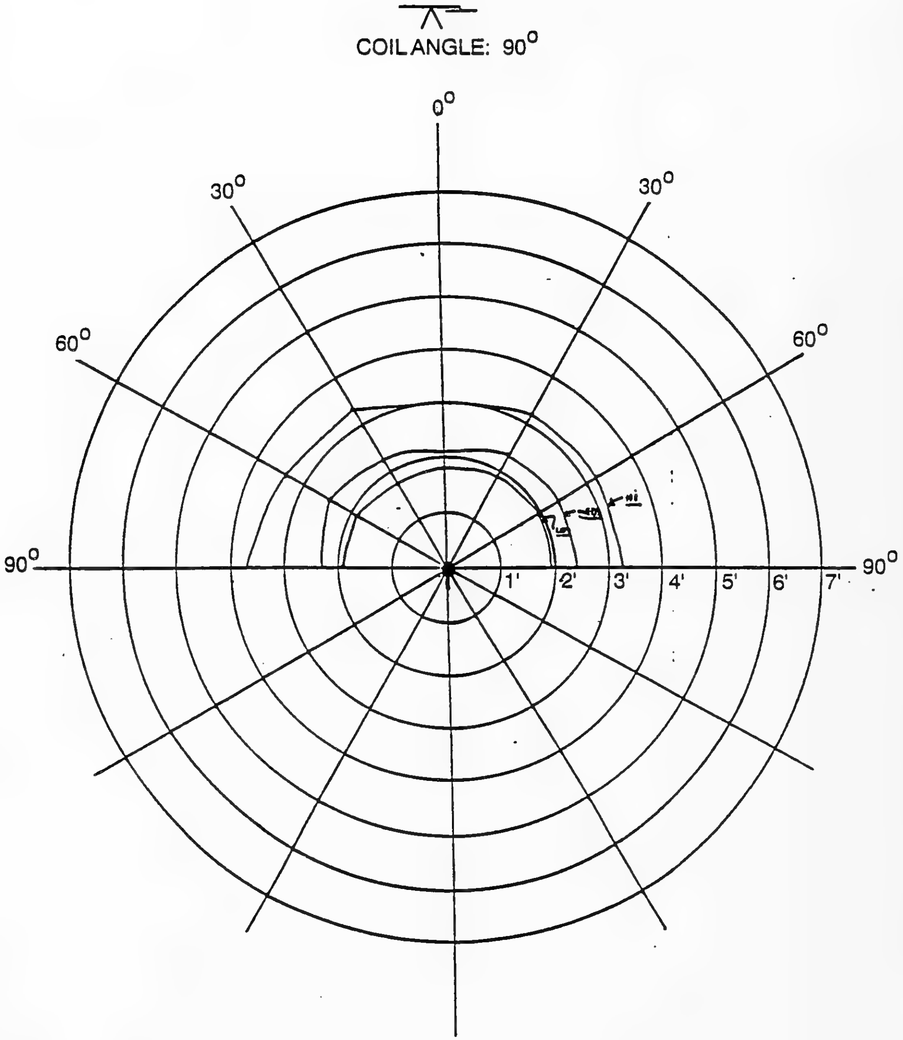
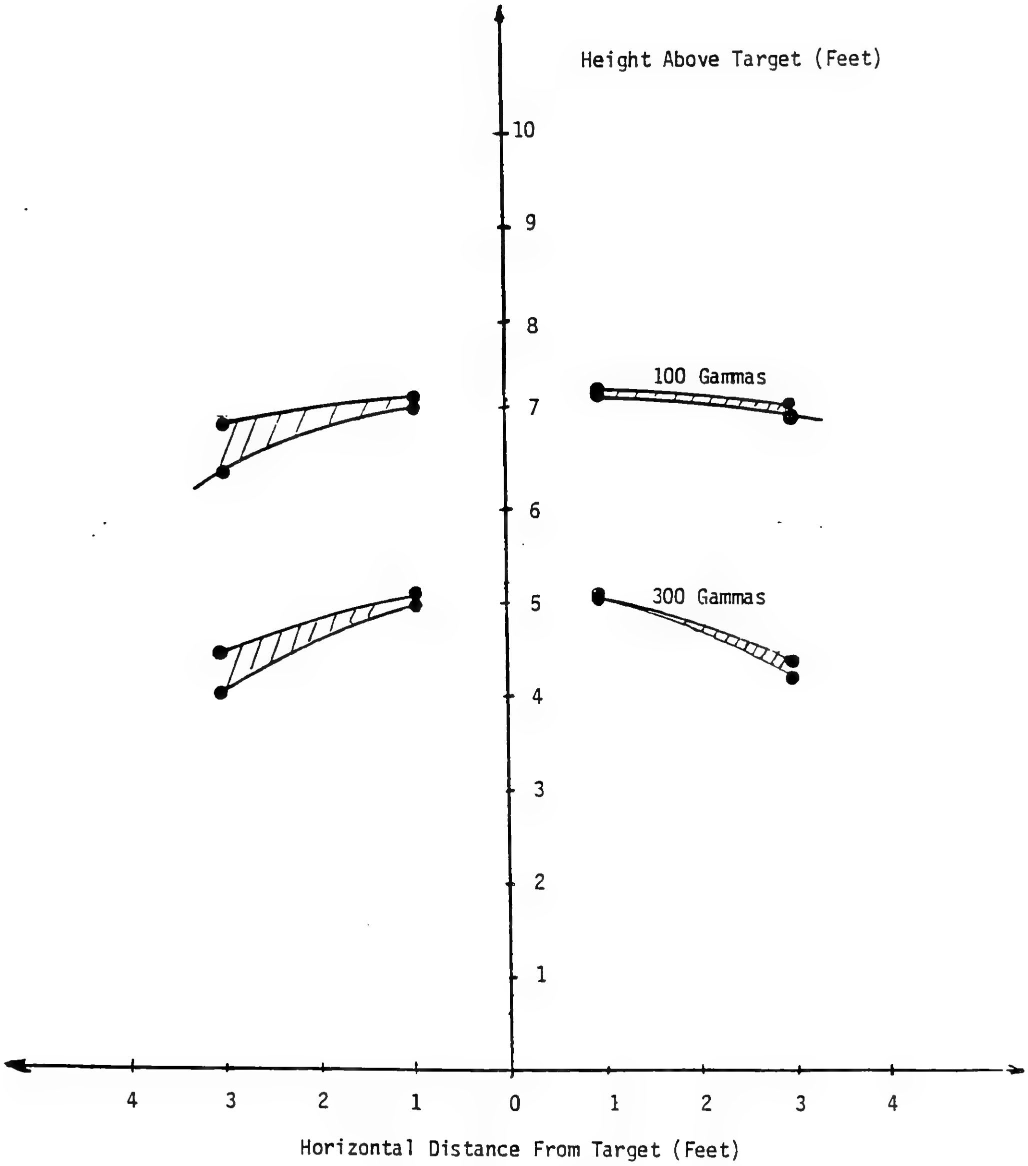


Figure C-12
Detection threshold for the Fisher Pulse 8 at low, medium, and high settings, 90° coil angle.

Appendix D

DETECTION THRESHOLDS FOR FORSTER FEREX

Probe Position Relative to Tartet at Half Scale Reading



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