AD-A101 295 ARMY MOBILITY EQUIPMENT RESEARCH AND DEVELOPMENT COMM--ETC F/G 17/9
EVALUATION OF THE GEOPHYSICAL SURVEY SYSTEMS, INC. RADAR FOR TH--ETC(U)
MAR 81 M H FRIEDMAN DAAK70-79-C-0011
UNCLASSIFIED MERADCOM-2322 NL

1 of 1
AD A
101 295

END
DATE
FILMED
8-81
DTIC

AD A101295

LEVEL 4

(12)

AD

Report 2322

EVALUATION OF THE GEOPHYSICAL SURVEY SYSTEMS, INC. RADAR FOR THE DETECTION OF UNEXPLODED ORDNANCE

by

Melvin H. Friedman, Ph.D.

March 1981

Approved for public release; distribution unlimited.

U.S. ARMY MOBILITY EQUIPMENT

RESEARCH AND DEVELOPMENT COMMAND

FORT BELVOIR, VIRGINIA

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER 2322	2. GOVT ACCESSION NO. AD-A101295	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) EVALUATION OF THE GEOPHYSICAL SURVEY SYSTEMS, INC. RADAR FOR THE DETECTION OF UNEXPLODED ORDNANCE		5. TYPE OF REPORT & PERIOD COVERED Final, December 1979-1980
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Melvin H. Friedman, Ph.D.		8. CONTRACT OR GRANT NUMBER(s) DAAK70-79-C-0011
9. PERFORMING ORGANIZATION NAME AND ADDRESS Countermine Lab; Mine Detection Div; DRDME-ND; US Army Mobility Equipment Research and Development Command; Fort Belvoir, Virginia 22060		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS US Army Toxic and Hazardous Materials Agency Aberdeen Proving Ground, Maryland 21010		12. REPORT DATE March 1981
		13. NUMBER OF PAGES 26
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Radar
Unexploded Ordnance
Ground Penetrating
Evaluation

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

MERADCOM was tasked by USATHAMA to administer and monitor a contract with Geophysical Survey Systems, Inc. on the utility of a ground-penetrating radar for the detection of buried unexploded ordnance (UXO). This report documents that evaluation.

Disposition of military installations known or suspected to be contaminated with UXO has become a matter of increasing concern to the Department of the Army. Reutilization of

(Continued)

DD FORM 1473, 1 JAN 73 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

405160

JCB

(Block 20 (Cont'd))

cont DA lands previously utilized as impact areas, demolition ranges, and munition burial sites is significantly restricted. In particular, any such lands declared excess to Army needs are precluded from being turned over to productive civil disposition until determined to be free of hazardous UXO contamination.

In order to define the scope of work required for cleanup and to plan and support actual UXO recovery and disposal operations, an effective UXO detection and location system must be developed to define the extent of any such UXO contamination; i.e., type munitions, quantity, conditions, depth of burial, etc. Final certification of such land as free of UXO contamination could potentially be based on the findings of surveys done with such systems.

The GSSI radar was evaluated and in its present form was found to be unsuitable for the task for two reasons: (1) it detected only a small portion of the buried targets and (2) there were many more false detections than true detections.

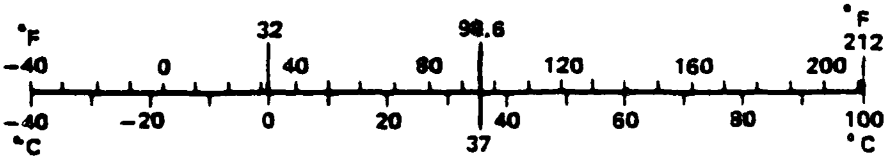
CONTENTS

A

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 (2000 lb)	0.9	metric ton	t
		VOLUME		
tsp	teaspoons	5	milliliters	mL
Tbsp	tablespoons	15	milliliters	mL
in^3	cubic inches	16	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	degrees Fahrenheit	5/9 (after subtracting 32)	degrees Celsius	°C



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	metric ton (1000 kg)	1.1	short tons	
		VOLUME		
mL	milliliters	0.03	fluid ounces	fl oz
mL	milliliters	0.06	cubic inches	in^3
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	degrees Celsius	9/5 (then add 32)	degrees Fahrenheit	°F

EVALUATION OF THE GEOPHYSICAL SURVEY SYSTEMS, INC.

RADAR FOR THE DETECTION OF UNEXPLODED ORDNANCE

I. INTRODUCTION

1. **Scope.** The purpose of this investigation was to determine if a commercially available ground-penetrating radar could be used by the Army for the detection of buried unexploded ordnance (UXO). This investigation was limited to the design and monitoring of a test by MERADCOM personnel of a commercially available radar produced by GSSI. During the course of this test, the radar was to be operated by GSSI personnel.

2. **Background.** The Army has a variety of areas on its many installations that have been used for ordnance testing, material storage, and disposal over a number of years. As the need to use such areas for ordnance testing, storage, and disposal is phased out, the Army would like to release this land for other uses by the Army or by non-military and civilian activities. The preferred goal is to release the land for completely unrestricted use. While magnetometers (and, to a lesser extent, gradiometers) offer performance down to the 5-ft level, the Army would prefer to certify that a given land area is safe to greater depths (15 to 20 ft). It is for this purpose that the Army has evaluated the utility of the GSSI ground-penetrating radar.

II. HOW THE GSSI RADAR WORKS

3. **Principles Involved.** A detailed description of the circuitry employed in making the GSSI radar work is beyond the scope of this report. The purpose of this section is to describe some of the principles which motivated the design of the GSSI radar and to tell enough about how the radar works so that the reader can better appreciate the theoretical capabilities and limitations of the system.

The probe in the GSSI system is a pulse radar which uses a burst of electromagnetic energy to excite echoes from buried objects or sharp electromagnetic boundaries within the earth. As the system traverses the earth's surface, a radar profile of subterranean reflections in two dimensions is displayed. The spatial resolution of pulse radar is a complex function of many factors including pulse length, pulse shape, dispersion of the medium studied, and properties of the targets. Some of the important factors are beyond the control of the radar designer and force realistic compromises to achieve a useful system. The GSSI system is a production radar incorporating such compromises and has been applied extensively to subsurface profiling throughout the country for several years. It has a nominal pulse length of approximately 5 x 10^{-9} s or 5 ns, which GSSI indicates results in a center frequency of about 200 MHz. This pulse length is similar to many other previous radars designed for deep penetration into the earth. GSSI now produces design variants with pulse length from approximately 10 ns to 1 ns and center frequencies from 80 MHz to 900 MHz.

Any radar system designed to "see" targets buried in the ground is forced to trade off two contradictory requirements: a high resolution requirement associated with high frequencies, and a deep penetration requirement associated with low frequencies. Additional important factors are the frequency dependence of target backscatter and soil transmission properties.

Soil attenuation is a strong function of frequency when appreciable moisture is present. Microwave ovens can operate effectively around 900 MHz because water in food absorbs well at this frequency. For nominal soil moisture of about 12 to 14 percent, typical of the temperate zone of the US, the attenuation at a frequency of 100 MHz is on the order of 0.25 decibels per foot and rises rapidly to a value on the order of 10 dB/ft at 1000 MHz. The earth acts as a low pass filter for the broadband energy of a pulse, attenuating the higher frequencies much more rapidly than the lower ones. In addition, the dielectric constant of the earth is a function of frequency, which leads to dispersion. A nicely shaped pulse incident at the surface is stretched out as it traverses the lossy, dispersive soil medium, resulting in a marked and steady decrease of resolving power. If the targets of interest are extended layers, the signal processing techniques developed over many years in geophysics can be used to compensate for these effects. For the point targets of interest to this project, such processing techniques are expected to have limited usefulness. A desire for deep penetration leads to reliance on low frequencies and long pulse lengths resulting in limited range resolution.

The velocity of propagation in free space is on the order of 1 ft/ns. In a dielectric medium, the velocity is inversely proportional to the square root of the relative dielectric constant. In typical earth, the velocity is slowed by a factor of three or four. If we hypothesize a resolution capability on the order of the pulse length, a 5-ns pulse will be compressed in the earth to a length of 1 to 2 ft near the surface. Gradual spreading will occur as the pulse penetrates as well as a marked decrease in peak energy. Neglecting the pulse spreading, target features and multiple targets with 1- or 2-ft spacing or larger should be resolvable as long as the received signal exceeds the noise threshold of the receiver/processor.

Target scattering characteristics also will have an impact on the utility of any such radar. Extended layers or boundaries in the earth reflect energy in a manner relatively independent of frequency. Although only part of the incident energy is reflected, the reflected pulse will closely resemble the incident pulse in shape, length, and spectral content. Of course, the greater the change in electrical properties across a boundary, the larger the fraction of incident power reflected. Point targets, with dimensions on the order of the resolution limit of the pulse, will behave much differently and will reflect energy in a manner highly dependent on target size, target shape, and frequency.

If the amount of backscatter is examined as a function of frequency and target size, a general understanding of the situation can be reached. Ignoring the shape of the target, let us ascribe to it an average physical dimension or diameter, D. The reflected signal should reach a peak value when the incident energy wavelength is on the order of this physical dimension. A 2-ft-diameter target would best respond to a free space wavelength of 6 to 8 ft, allowing for wavelength compression in the earth. Reflections from these targets would be a maximum in the range of 100 to 200 MHz, depending on local soil moisture near the target. The amplitude of the reflected signal will rapidly decrease for longer wavelengths, monotonically approaching zero at a zero frequency. At higher frequencies, or shorter wavelengths, the shape and orientation of the target will result in complex resonances and slowly decreasing amplitude, if soil attenuation is ignored. Target resonances are apt to be severely damped if the local environment is lossy. The backscatter observed from an unexploded ordnance should be a strong function of frequency.

For simplicity of operation, GSSI puts both the transmitting antenna and the receiving antenna in the same module and thus as one surveys the area, only one package needs to be towed. Since the receiver and transmitter are in one package and are nearly coincident, the range r of the object from the transmitter is given by:

$$r = \frac{t\,v}{2}, \tag{1}$$

where t is the time for the pulse to travel from the transmitter to the object and back to the receiver and v is the speed of propagation in the soil (which is about one third the speed of light, c, in vacuum). The range is determined by using a sampling oscilloscope to measure the time difference t between the transmitted and received pulse. The constant $\frac{v}{2}$ which characterizes the soil can be determined in one of two ways, chosen at the convenience of the operator: by measuring t for a target of known range; or by digging two holes a known distance apart and measuring the time to travel from one hole to the other and back again. This is very approximate and ignores substantial variations in moisture content which frequently occur.

Radar reflections can take place not only from buried ordnance but from layers within the earth where the characteristic impedance $\sqrt{\frac{\mu}{\epsilon}}$ changes abruptly (in a distance much less than a wavelength).[1] The GSSI radar display is designed to help the interpreter of the returned signal distinguish between reflections from a plane layer and a point object. The principle by which this is done is as follows. Suppose threre is a plane layer parallel to the earth's surface with a discontinuity in the characteristic impedance $\sqrt{\frac{\mu}{\epsilon}}$ some distance d beneath the surface of the earth. Then as one traverses the surface of the earth, the reflection will appear at a constant $t = \frac{2d}{v}$. Suppose, now, that there is a point object (buried ordnance can be approximated in this part of the discussion as a point object since it is assumed that the ordnance is small compared to the separation from the radar antenna) a distance d beneath the surface of the earth. In that case, when one is far away from the point object the measured time t will be much greater than $\frac{2d}{v}$. As one gets closer and closer to the object the time delay of the reflected pulse will get smaller and smaller until when one is directly above the object the time delay of the reflected pulse will be $\frac{2d}{v}$. This, then, is the signature of a point object (buried ordnance) and it is clear that this signature is quite different from a plane layering parallel to the surface of the earth. Similarly, the signatures as one traverses the earth's surface of other plane layerings (those not parallel to the earth's surface) is different from that of a point object and this difference in signature as one traverses the earth's surface can be used to discriminate against plane layerings.

4. **Correlation of Reflections.** From the discussion in the preceeding paragraph, it is clear that it is desirable to be able to correlate the reflections arising from neighboring points on a given traversal. The method for doing this is outlined in this paragraph. Suppose the transmitted signal looked something like that in Figure 1a. Here the horizontal axis corresponds to the magnitude of the $\vec{E}$ vector and the vertical axis

[1] The electrical properties of many media can be completely described using three scalar quantities: a resistivity ρ, a permeability μ, and a permittivity ϵ. The significance of these quantities is as follows: The resistivity ρ is a measure of the resistance of a material to electron flow. The permeability μ is a measure of how much the magnetic field $\vec{B}$ is increased when the material is introduced into a current-carrying coil. The permittivity ϵ is a measure of how much the force between two charges in vacuum is reduced when the charges are embedded and held in place in the media.

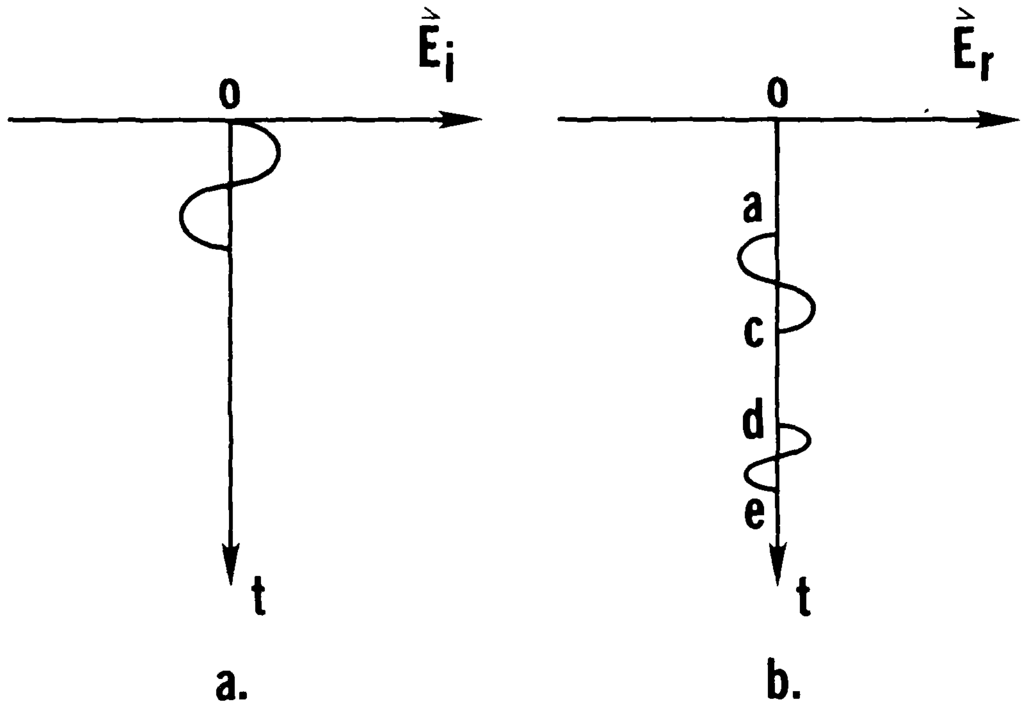


Figure 1. a. Shows schematically what the signal transmitted into the earth's surface looks like as a function of time.
b. Shows schematically what the returned signal (that picked up by the receiver) looks like as a function of time assuming reflections from buried ordnance and a plane layering of the earth beneath.

(in the direction of the arrow) corresponds to increasing time. The reason for this unconventional way of orienting the axis (usually $\vec{E}$ is shown on the vertical axis and t on the horizontal axis) is that increasing time for the reflected pulse to arrive at the receiver corresponds to a more deeply buried target and it is natural to show increasing depth as going further toward the bottom of the figure. Figure 1a is intended to show that the $\vec{E}$ field propagating into the earth has the form of a single bipolar pulse. The fact that it goes positive and negative indicates that it is pointing along a reference direction during the positive part of the cycle and opposite the reference direction during the negative part of the cycle. Not shown in Figure 1a (because it would be off the scale of the figure) is that the transmitted pulse is repeated periodically at a 50-kHz rate.

Figure 1b shows schematically what the received signal might look like and indicates that there are two reflections. In this case, one of the reflections might be from buried UXO and one from a plane discountinuity assumed parallel to the surface of the earth. From the discussion in paragraph II3, the reflection from the plane layer could be readily identified and distinguished from the UXO by traversing the earth's surface and seeing which of the signals is constant in time.

A problem with this approach is that in a given traversal of the earth's surface there are thousands of graphs with the form 1b. What is needed is a method of showing thousands of graphs of the form 1b on a single sheet of paper. The method for doing this is as follows: a gray scale is used in the GSSI apparatus to indicate the absolute value of the reflected signals magnitude. As the absolute value of the reflected signal gets larger, the scale gets darker; places where there is no net signal above noise appear white. Thus the graph shown in Figure 1b, which requires two dimensions for display, can be compressed down to a single vertical line for display by using shades of gray to indicate horizontal deflection. Using this system, the signature of a point object is shown in Figure 2. The advantage of this system is that one can compress three-dimensional information into two dimensions and produce an easily interpreted display of complex reflections.

The disadvantage of this system is that the sign of the reflected signal is lost in the processor and single color display. In a more ideal display, the phase of the received signal would be shown in shades of two colors (for example red and blue), and for any given range, the relative phases could provide additional discrimination.

To summarize the design hurdles of an earth-penetrating radar, we need to generate a well shaped, high-power pulse; radiate this in a preferred direction with minimal spectral modification; penetrate a lossy, dispersive medium; illuminate a very local target; receive the energy returned through the lossy medium; and have sufficient sensitivity to detect signals perhaps 100 dB or more below transmit power.

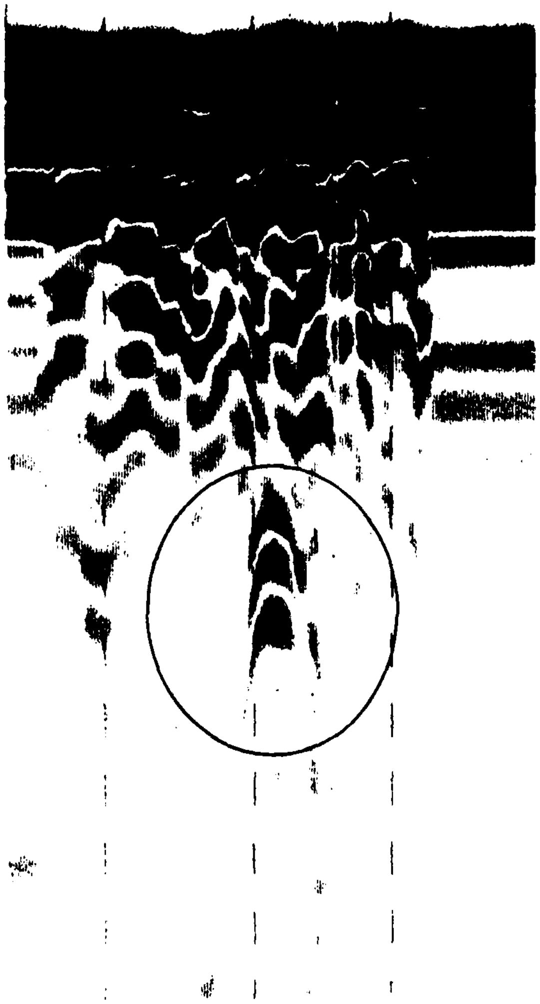


Figure 2. Signature of buried ordnance. Shown above is a graph of the received signal as the transmitter/receiver makes a traversal along the earth's surface. The circled area corresponds to a reflection from a point object. The peak of the curves corresponds to the nearest point of approach to the point object of the transmitter/receiver.

All of this should be achieved in a battery-powered (or small generator-powered), man-portable system which is ruggedized for use in the field as a geophysical probe.

III. LIMITATIONS IN GROUND-PENETRATING RADAR

5. **Physical Principles Which Limit the Utility of Any Ground-Penetrating Radar.** Limitations in the GSSI radar and any ground-penetrating radar include the following:

a. The penetration depth of the radar depends on the moisture content of the soil and the type of soil, and generally these are not known. This is one factor which makes it difficult to certify a depth at which there are no UXO.

b. The magnitude of the reflected signal depends on the length of the object in the direction of the electric field $\vec{E}$. An object long in the direction of the $\vec{E}$ field gives a strong signal, and an object short in the direction gives a smaller signal. Qualitatively, this can be understood in the following way: the oscillating electric field tends to drive the free electrons within the conductor and the acceleration of these electrons gives rise to the radiated wave. In the long direction of the object, many electrons make positive contributions to the wave, and in the short direction, few electrons make positive contributions to the wave. This result has two important consequences for locating buried ordnance: ordnance buried vertically is difficult to see, and ordnance buried horizontally is difficult to see unless the $\vec{E}$ field is polarized along the direction of the long axis of the ordnance. (These last two results are based on the material given in this section and the result from Maxwell's equation that a wave propagating in a homogeneous medium has its $\vec{E}$ field perpendicular to its direction of propagation.) The fact that the magnitude of the reflected signal depends strongly on the orientation of the buried object is a second factor which makes it difficult to verify a depth at which there is no UXO.

c. Most scientists and engineers appreciate the fact that an electromagnetic wave will be reflected from a sharp discontinuity between two surfaces. Perhaps less well appreciated is the fact that a large and sharp discontinuity in the permittivity may fail to give any reflection. Suppose we have a material, 1, characterized by permittivity and permeability ϵ_1 and μ_1 and a second material, 2, characterized by parameters ϵ_2 and μ_2. Then it is known that for the case of a plane infinite wave perpendicularly incident (traveling in medium 1) on such a plane infinite boundary that the ratio of the magnitude of the reflected wave to the incident wave is given by

$$\frac{E_r}{E_i} = \frac{\sqrt{\frac{\mu_2}{\epsilon_2}} - \sqrt{\frac{\mu_1}{\epsilon_1}}}{\sqrt{\frac{\mu_1}{\epsilon_1}} + \sqrt{\frac{\mu_2}{\epsilon_2}}} \quad . \tag{2}$$

Thus, if the properties of the first and second medium are related by

$$\sqrt{\frac{\mu_2}{\epsilon_2}} = \sqrt{\frac{\mu_1}{\epsilon_1}} \quad , \tag{3}$$

then there will be no reflected wave. The quantity $\sqrt{\frac{\mu_i}{\epsilon_i}}$ has the dimensions of ohms and is called the impedance of media i. Equation (3) is analogous to the case of a transmission line being terminated in an impedance which matches the line. Although the proof of this result is based on a plane infinite wave perpendicularly incident on a plane infinite boundary, it is expected to be at least approximately true of finite waves incident on finite objects. From a practical viewpoint, it is unlikely that the properties of media will satisfy equation (3), and so in almost all cases, where media are different, reflections will occur. Still, the fact that there may be no reflected wave, providing the properties of the earth match those of the buried ordnance, is a third factor which makes it difficult to certify a depth at which there are no UXO.

d. In paragraph III 5c, possible difficulties in seeing objects when they are there was discussed. A more serious problem is radar reflections from objects that are not of interest, such as rocks, roots, moisture discontinuities, and discontinuities in the layering of the soil. With the possible exception of signals arising from the layering of the soil, these signals are either indistinguishable from or difficult to distinguish from UXO reflections. This is a fourth factor, perhaps the most important, which makes it difficult to certify a depth at which there are no UXO.

IV. DESIGN OF EXPERIMENTS FOR TESTING THE GSSI RADAR

6. **Ordnance Burial.** Ordnance was buried by using an auger to dig the holes and a bulldozer to fill them in, as shown in the table. The area was surveyed carefully so that in all cases the absolute location of the center of mass of the ordnance was known with an error which did not exceed 6 in. (Almost all of this error is due to uncertainties in the location of center of mass for the larger pieces of ordnance.) The selection of the maximum depths at which the ordnance was buried was based on

Type of Ordnance, Depth Buried, and Orientation of Ordnance Used to Test the Operation of GSSI Radar

Type	Depth (ft)[a]	Orientation
500-lb bomb	15	Vertical
500-lb bomb	15	30° from horizontal
250-lb bomb[b]	5	Horizontal
250-lb bomb[b]	5	30° from horizontal
250-lb bomb	10	Horizontal
250-lb bomb	10	Vertical
250-lb bomb	10	30° from horizontal
155 mm[b]	5	Horizontal
155 mm[b]	5	Vertical
155 mm[b]	10	Horizontal
155 mm[b]	10	Vertical
81 mm[b]	3	Horizontal
81 mm[b]	3	Vertical
81 mm[b]	5	Horizontal
81 mm[b]	5	Vertical
4-in. pipe[b c]	3	Horizontal
4-in. pipe[b c]	3	Vertical
4-in. pipe[b c]	5	Horizontal
4-in. pipe[b c]	5	Vertical

[a] All depths are measured from the location of the center of mass of the object.

[b] This ordnance was in the area actually surveyed by GSSI radar.

[c] The pipe (4 in. long and 1½ in. in diameter) was meant to simulate smaller ordnance which was not readily available for these tests.

experimental data published in the Henegar report.[2] Ordnance was buried shallowly (so that the tested equipment would have some successes) and deeply (but never deeper than the experimental values given in Henegar report) to establish maximum detection capabilities. Thus the equipment performance (as measured by the probability of detection for a given type of ordnance in a given type of soil) could be measured over a depth range that was of interest.

7. **Physical Characteristics of the Site.** GSSI was given three areas to survey with their equipment. One area, called the linear grid, was rectangular in shape with dimensions 30 ft by 85 ft. A second area, called grid A, was 160 ft by 160 ft and had a rectangle 80 ft by 40 ft added to one side. The third area, called grid B, was rectangular with dimensions of 160 ft by 200 ft.

Each site had stakes put in the ground defining a rectangular grid. At places where ordnance was buried with a high density, the stakes were separated by a distance of 40 ft, and at places where ordnance was buried with a lower density, the stakes were separated by a distance of 80 ft. All of the stakes were labeled with x, y coordinates. Direction vectors and help in locating the stakes (sometimes the stakes were hidden by brush) were provided GSSI by connecting the stakes diagonally with twine. In this way GSSI personnel could easily and accurately locate in our coordinate system where ordnance was buried without having to spend time surveying.

The three areas GSSI was asked to survey had the following properties. The soil was mostly clay. The linear site was flat and devoid of vegetation. Grid A was fairly flat but sloped gently and was covered with some brush. Grid B had a flat plateau with light brush for half of its area and the other half sloped slightly and was heavily covered with a grass-like plant that was approximately 3 ft high during tests. Although a person could easily walk through this area, a vehicle might have had trouble traversing such an area. (GSSI never surveyed site B, the most difficult to traverse and survey, because of lack of time.)

8. **Information Provided GSSI at the Outset of the Tests.** The following information was given to GSSI personnel upon their arrival at MERADCOM:

a. All the ordnance was buried at depths greater than 6 in. and less than 15 ft.

b. Some of the ordnance was buried with the long axis perpendicular to the surface of the earth.

---

2 H. H. Henegar, *Detection of Unexploded Ordnance* DOD Explosives Safety Board Report 76-1, US Army Mobility Equipment Research and Development Command April 1976.

c. Some of the ordnance was buried horizontally; this ordnance was oriented either north/south or east/west.

d. Some of the ordnance was tilted up slightly from the horizontal.

The first piece of information was given to GSSI because their equipment can have trouble detecting shallow objects and they needed to know what maximum range to set their equipment. The second piece of information was given to GSSI so that they could confirm (which they did orally) that their equipment was not expected to find vertically buried ordnance. The third piece of information was given to GSSI so that they would have more time to show how well their equipment worked. For them to detect buried ordnance, they need to approach the target so that the long axis of the target is approximately perpendicular to the direction of traversal. Had the information in paragraph IV 8c not been revealed, GSSI would have had to survey the area in four directions (bearings of 0°, 45°, 90°, and 135°). Because this information was provided, they needed only to survey the land in two directions: the north/south direction which corresponds to 0° and the east/west direction which corresponds to 90°. The fourth piece of information was given to GSSI so that they would know that not all of their signatures would come from horizontally buried ordnance.

Information that was not given to GSSI personnel (although they requested it) was the location of the ordnance. The reason for this is that there is a subjective element in interpreting the data from their apparatus and the objectivity of the test could be compromised if this information was revealed.

9. **The Task of GSSI.** Given these four pieces of information and the area boundaries defining where the ordnance was buried, GSSI was tasked to construct a map showing where and how deep the ordnance was buried. They were also allowed to designate with a stake in the ground where the ordnance was buried; this was not convenient for them to do since their equipment requires interpreting data and comparing it with other data before the location of the ordnance can be determined.

GSSI was also told that it was important to do a good job rather than try to cover a large area; i.e., to determine the location and depth of the ordnance as accurately as possible. They were told that their performance would be judged on whether or not they located the ordnance accurately enough to dig up the ordnance, which meant that the detected x, y coordinates had to be within 2 ft of the actual ordnance coordinates. Near the end of the tests, GSSI personnel informed MERADCOM personnel that they did not have time to survey area B because of the difficulty in locating ordnance accurately. This was not caused by surveying difficulties but because many traversals had to be made to accurately locate the ordnance.

10. **Additional Information Requested by GSSI.** GSSI requested and was provided information on the radar propagation speed in the soil and ordnance signature.

a. **Radar Propagation Speed.** To get an accurate depth measurement it is necessary to measure the speed at which the radar travels through the earth. This depends on the soil type, its moisture, and the frequency of the exciting radiation. The method used was to put the transmitter/receiver in one hole and a reflector in the second hole and to measure how long it takes the signal to go from hole 1 to hole 2 and back again. Four holes approximately 1 ft in diameter and 3 ft deep were dug, the metal from a shovel served as a reflector, and the speed of propagation was measured. The measurements could have been made by digging just two holes. The extra holes provided redundancy in the measurement. Because the holes were only 1 ft in diameter, the 900-MHz transmitter/receiver was employed in these speed measurements rather than the 300-MHz system that was actually used in the survey. The reason for this substitution is that the 300-MHz transmitter/receiver antenna was too large (it would have required about a 1-meter-diameter hole) for the holes. It is assumed in this work that the 900-MHz signal travels at the same speed as the 300-MHz signal actually used. Although this assumption can introduce errors in the depth measurement, GSSI personnel did not ask that holes large enough to accommodate the 300-MHz transmitter/receiver be dug.

b. **Ordnance Signature.** To help GSSI personnel recognize their signatures, five pieces of ordnance typical of that found in the table were buried in a trench. The ordnance buried at GSSI's request included a 250-lb bomb, two different types of 155-mm ordnance, 81-mm ordnance, and a mortar round. These were buried at depths of 5, 4, 3, and 2 ft, respectively. All pieces were buried horizontally since this is the only way such ordnance was expected to be seen by the ground-penetrating radar. The separation between adjacent pieces of ordnance in the trench was at least as large as the largest dimension of the two adjacent pieces of ordnance. GSSI personnel felt that with this separation they could spatially resolve the different pieces of ordnance.

It is not clear to this investigator whether the signals which GSSI saw when they traversed the area were mainly due to disturbed earth or to buried ordnance.

V. EVALUATION OF GSSI RADAR

11. **Problems with the GSSI Radar.** There are two problems with the GSSI radar: (1) a low detection probability and (2) a high false alarm rate.

a. **Definitions.** Before evaluating these qualities, some terms need to be defined.

(1) **Detection Probability.** The detection probability is here experimentally defined as the ratio of the number of targets detected by the GSSI apparatus to the number of targets present.

(2) **True (False) Detections.** A true (false) detection is said to occur when the apparatus indicates there is buried ordnance at a particular spot when, in fact, there is (is not) ordnance near the spot. The definition just given for a true or false detection needs to be made more precise because the word "near" is not defined. Here the criterion used is that there is a true detection if the detected x, y coordinates of the ordnance are within 2 ft of the ordnance's actual x, y coordinates and the depth information provided by the GSSI apparatus falls within plus or minus 50 percent of the ordnance's actual depth. With this definition of a true detection, if one used a 4-ft-diameter auger and dug a hole 50 percent deeper than the depth indicated by the GSSI apparatus, one would uncover the buried ordnance. Since an auger with a diameter much greater than 4 ft is not practical, this represents the weakest practical definition that can be used to define "near" for the purpose of finding and digging up buried ordnance. If one defines "near" using tighter limits of, say, 1 ft, then the GSSI apparatus would have made no true detections. Since the wavelength of the transmitted wave is about 1 m, the apparatus would not be expected to locate ordnance with an accuracy of 1 ft. These are some of the considerations which motivate the definition of "near" in the true (false) detection definition.

(3) **False Alarm.** A false detection will hereafter also be referred to as a false alarm.

(4) **False Alarm Rate.** The false alarm rate is here defined as false alarms per acre.

(5) **Distinct Detection.** GSSI personnel traversed all of the areas in two directions: along lines parallel to the North/South direction, and along lines parallel to the East/West direction. They also duplicated some of their traversals. Occasionally, therefore, two detections will nearly coincide and it is necessary to decide if these two detections correspond to the same target or to two separate targets. Here multiple detections which are separated by less than a foot are defined as a single

detection and multiple detections separated by more than a foot are counted as distinct detections.

b. **Evaluation of Detection Probability.** Using the criterion (discussed in V11a) that a target is detected if its x, y coordinates are within 2 ft of the actual location of the buried object and the depth is correct with an error which does not exceed 50 percent, 2 out of the 14 pieces of ordnance in the area surveyed by GSSI were found. This corresponds to a detection probability of 1/7. The two pieces of ordnance found were the 250-lb bomb buried at a depth of 5 ft and the 4-in. piece of pipe buried vertically at a depth of 5 ft. If one were to adopt the weaker criterion that a target is detected if its indicated x, y coordinates are within 4 ft of the buried object and the depth is correct to within 50 percent, then no additional pieces of ordnance would be detected.

c. **Evaluation of False Alarm Rate.** A feel for the magnitude of the false alarm rate can be obtained from the following results.

(1) In one part of Grid A, set aside to test the equipment false-alarm rate, there was no buried ordnance. This was a regularly shaped area of 3,200 ft^2 (0.0735 acre). In this area, which had no buried ordnance, GSSI personnel observed 27 distinct target-like signatures which they identified as targets and this corresponds to 367 false alarms per acre.

(2) In the remaining part of Grid A which was regularly shaped and covered an area of 25,600 ft^2 (0.588 acre), 10 pieces of ordnance were buried. In this area GSSI personnel had 94 distinct target-like signatures of which 1 was valid. Thus, in this area there were 93 false alarms in 0.588 acre which corresponds to 158 false alarms per acre.

(3) In the linear grid which had an area of 2,500 ft^2 (0.0585 acre), 4 pieces of pipe were buried. In this area GSSI personnel had 34 distinct target-like signatures of which 1 was from a valid target. Thus in this area, there were 33 false alarms in 0.0585 acre which corresponds to 564 false alarms per acre.

VI. RESULTS AND DISCUSSION

12. **Discussion of the Results.** The 250-lb bomb buried horizontally at a depth of 5 ft is considered to be one of the easiest targets to detect. The GSSI equipment appears to have legitimately detected this piece of ordnance. The 4-in. piece of pipe buried vertically at a depth of 5 ft is probably one of the most difficult targets to detect. The fact that the equipment failed to detect the pieces of 4-in. pipe buried horizontally and vertically at depths of 3 ft suggests that this detection is not legitimate. One possible interpretation is that GSSI equipment detected a disturbance in the soil made when the pipe was buried.

A difficulty in using the GSSI equipment is that target detection appears to be subjective.

A high false alarm rate characterized the GSSI equipment. The probable reason for the high false alarm rate observed in these tests is that reflections can take place from discontinuities other than those due to the buried ordnance. These reflections can be real and reproducible. What is needed is a method to distinguish reflections due to buried ordnance from these unwanted reflections.

Would the GSSI equipment be useful in helping to clear ranges of UXO? It would seem that equipment which detects about 1/10 of the UXO and has approximately 300 false alarms per acre would have limited utility either by itself or in conjunction with other equipment in helping to clear ranges of UXO.

Would these conclusions be changed under different soil conditions? In these tests there are two factors which prevented the equipment from working better: attenuation which prevents the radar from seeing deeply into the earth, and discontinuities which cause false alarms in the equipment as it is presently configured. The soil used was clay which has a high attenuation, but the tests were done during the summer when the average moisture content of the soil was low and this reduces the attenuation. There was an opportunity to view the soil in the hole before the ordnance was buried and it seemed to be homogeneous, which is ideal from the point of view of having a low false alarm rate. The ground itself was fairly level and free from large roots. Apparently there is little evidence which suggests that the equipment would perform significantly better at locations where ordnance is actually buried than it did at the MERADCOM test site.

DISTRIBUTION FOR MERADCOM REPORT 2322

No. Copies	Addressee
	Department of Defense
2	Director of Defense Research and Engineering ATTN: Deputy Dir, Research and Advanced Technology Deputy Dir, Tactical Warfare Systems Washington, DC 20301
1	Director, Tactical Technology Defense Advanced Research Projects Agency 1400 Wilson Blvd Arlington, VA 22209
12	Defense Documentation Center Cameron Station Alexandria, VA 22314
3	Commander US Army Materiel Development and Readiness Command ATTN: DRCDE-DM DRCLDC 5001 Eisenhower Ave Alexandria, VA 22333
7	Commander US Army Training & Doctrine Command ATTN: ATCD-SI ATORI-IT ATCD-CM ATCD-MC ATCD-TM ATCD-TP ATCD-SP-L Fort Monroe, VA 23651
4	HQDA ATTN: DAMA-ZE DAMA-ARZ-A DAMA-CSM DAMA-RQA Washington, DC 20310
2	President US Army Armor and Engineer Board ATTN: ATZK-AE-TD ATZK-AE-EN Fort Knox, KY 40121
1	Commandant US Army Command and General Staff College ATTN: ATSW-RT-L Fort Leavenworth, KS 66027
4	Commander US Army Test and Evaluation Com ATTN: DRSTE-CT-T (3) DRSTE-TO-I Aberdeen Proving Ground, MD 21005
1	Commander Material Test Directorate ATTN: STEAP-MT-I Aberdeen Proving Ground, MD 21005
2	US Army Armaments Research & Development Command ATTN: DRDAR-QAA-Q DRDAR-LCU-E Dover, NJ 07801
1	Director US Army Materiel Systems Analysis Activity ATTN: DRDSY-GB Aberdeen Proving Ground, MD 21005

No. Copies	Addressee
8	Commandant US Army Engineer School ATTN: ATZA-CDT (3) ATZA-CDC ATZA-CDM (3) ATZA-TDC Fort Belvoir, VA 22060
1	Commandant US Army Armor Center ATTN: ATZK-CD-TE Fort Knox, KY 40121
1	Commandant US Army Infantry Center ATTN: ATSH-CD-M Fort Benning, GA 31905
1	Commander US Army Logistics and Evaluation Agency ATTN: DALO-LEI New Cumberland, PA 17070
	MERADCOM
1	Commander, DRDME-Z Technical Director, DRDME-ZT Assoc Tech Dir/R&D, DRDME-ZN Assoc Tech Dir/Engrg & Acq, DRDME-ZE Spec Asst/Matl Asmt, DRDME-ZG Spec Asst/Tech Asmt, DRDME-ZK CIRCULATE
1	C, Engy & Wtr Res Lab, DRDME-G C, Elec Pwr Lab, DRDME-E C, Cam & Topo Lab, DRDME-R C, Mar & Br Lab, DRDME-M C, Mech & Constr Eqpt Lab, DRDME-H C, Ctr Intrus Lab, DRDME-X C, Matl Tech Lab, DRDME-V Director, Product A&T Directorate, DRDME-T CIRCULATE

No. Copies	Addressee
1	Countermine Lab, DRDME-N
20	Mine Det Div, DRDME-ND
1	Systems Office, DRDME-O
2	Tech Library, DRDME-WC
1	Plans, Programs & Ops Ofc, DRDME-U
3	Tech Reports, DRDME-WP
	Department of the Navy
1	Director Naval Research Laboratory ATTN: Code 2627 Washington, DC 20375
1	Commander Naval Weapons Center ATTN: Code 3263 China Lake, CA 93555
1	Commanding General Marine Corps Department and Education Command ATTN: Engineer Branch, Development Center Quantico, VA 22314
3	Technical Director US Army Ballistics Laboratory ATTN: DRDAR-BLV DRDAR-BL DRDAR-BLL-FT Aberdeen Proving Ground, MD 21005
30	US Army Toxic and Hazzardous Materials Agency DRXTH-TH (Cpt Staniec) Aberdeen Proving Ground, MD 21010

1 2 3 - 1,856 — AG — Ft Belvoir