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Engineer Research and Development Laboratories, Fort Belvoir, Virginia
AMPLITUDE TYPE SEARCH HEAD INVESTIGATIONS FOR UHF MINE DETECTORS (U) - Manfred Gale

Report No. 1456-RR, 8 Aug 1956, 33 pp, 9 illus, 3 tables.
DA Project 8-07-04-014, Confidential Report

A comprehensive study of the performance characteristics of amplitude type search heads operating at frequencies of 400 mc and 800 mc to obtain antenna design guides which will lend to more reliable detection of land mines, under a variety of operating conditions, than presently achieved with AN/PRS-4.
Conclusions: (a) Field operation of any search head, similar to the models investigated, without an adequate parasitic reflector is completely impractical at operating heights of approximately 6 inches above the ground; (b) Addition of an adequate reflector shield improves the overall search head performance both in terms of increased mine signal identification and reduction in above-ground interferences; (c) Use of an 800-mc operating frequency yielded, at best, no improvement in performance characteristics over similar units at 400 mc, and in most cases caused the performance to deteriorate; and (d) Best mine detection performance was achieved with the search head models A-7 and A-2 which had an operating frequency of 400 mc, parasitic reflector, and dipole spacing of 9 inches and 12 inches, respectively.

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Conclusions: (a) Field operation of any search head, similar to the models investigated, without an adequate parasitic reflector is completely impractical at operating heights of approximately 6 inches above the ground; (b) Addition of an adequate reflector shield improves the overall search head performance both in terms of increased mine signal identification and reduction in above-ground interferences; (c) Use of an 800-mc operating frequency yielded, at best, no improvement in performance characteristics over similar units at 400 mc, and in most cases caused the performance to deteriorate; and (d) Best mine detection performance was achieved with the search head models A-7 and A-2 which had an operating frequency of 400 mc, parasitic reflector, and dipole spacing of 9 inches and 12 inches, respectively.

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Conclusions: (a) Field operation of any search head, similar to the models investigated, without an adequate parasitic reflector is completely impractical at operating heights of approximately 6 inches above the ground; (b) Addition of an adequate reflector shield improves the overall search head performance both in terms of increased mine signal identification and reduction in above-ground interferences; (c) Use of an 800-mc operating frequency yielded, at best, no improvement in performance characteristics over similar units at 400 mc, and in most cases caused the performance to deteriorate; and (d) Best mine detection performance was achieved with the search head models A-7 and A-2 which had an operating frequency of 400 mc, parasitic reflector, and dipole spacing of 9 inches and 12 inches, respectively.

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Conclusions: (a) Field operation of any search head, similar to the models investigated, without an adequate parasitic reflector is completely impractical at operating heights of approximately 6 inches above the ground; (b) Addition of an adequate reflector shield improves the overall search head performance both in terms of increased mine signal identification and reduction in above-ground interferences; (c) Use of an 800-mc operating frequency yielded, at best, no improvement in performance characteristics over similar units at 400 mc, and in most cases caused the performance to deteriorate; and (d) Best mine detection performance was achieved with the search head models A-7 and A-2 which had an operating frequency of 400 mc, parasitic reflector, and dipole spacing of 9 inches and 12 inches, respectively.

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Conclusions: (a) Field operation of any search head, similar to the models investigated, without an adequate parasitic reflector is completely impractical at operating heights of approximately 6 inches above the ground; (b) Addition of an adequate reflector shield improves the overall search head performance both in terms of increased mine signal identification and reduction in above-ground interferences; (c) Use of an 800-mc operating frequency yielded, at best, no improvement in performance characteristics over similar units at 400 mc, and in most cases caused the performance to deteriorate; and (d) Best mine detection performance was achieved with the search head models A-7 and A-2 which had an operating frequency of 400 mc, parasitic reflector, and dipole spacing of 9 inches and 12 inches, respectively.

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ABSTRACT

An experimental program was conducted in order to make a comprehensive study of the performance characteristics of amplitude type search heads operating at frequencies of 400 mc and 800 mc. The purpose of the investigations was to obtain antenna design guides which will lead to more reliable detection of land mines, under a variety of operating conditions, than is presently achieved with the AN/PRS-4, UHF, "Uncle Henry" Standard Non-Metallic Mine Detector.

Twenty-seven search head models were designed, constructed and tested. All models were initially pre-tested, and the appropriate corrections or adjustments applied to assure that the expected operational modes were evidenced. Each laboratory model was subjected to an identical series of six experiments carried out over the loam test lane at the ERDL minefield. A method was derived whereby the degree of desireble search head performance could be calculated for each antenna configuration, and the data were subsequently processed to reflect an overall figure of merit for given system parameters. In order to study the possible cause of false signal indications due to the presence of a potential operator or above ground obstructions, investigations were undertaken to quantize the effect of these interferences vs some antenna properties.

From the measurements and evaluations of amplitude type search head models this report concludes that:

a. The field operation of any search head, similar to the models investigated, without an adequate parasitic reflector is completely impractical at operating heights of approximately 6 inches above the ground.

b. The addition of an adequate reflector shield improves the overall search head performance both in terms of increased mine signal identification and reduction in above-ground interferences.

c. The use of an 800-mc operating frequency yielded, at best, no improvement in performance characteristics over similar units at 400 mc, and in most cases caused the performance to deteriorate.

d. The best mine detection performance was achieved with the search head models A-7 and A-2 which had an operating frequency of 400 mc, parasitic reflector, and dipole spacing of 9 inches and 12 inches respectively. The operational detection characteristics of these models is superior to those of the AN/PRS-4, UHF, "Uncle Henry" Standard Non-Metallic Mine Detector.

It is recommended that:

a. Any present development of portable non-metallic mine detector search heads adapt the basic design of the A-7 or A-2 configurations listed in this report.

b. The research on data analysis techniques be intensified in order to find criteria other than peak amplitude ratios, to achieve a substantially higher probability of mine signal identification.

c. If further research based on optimum mine signal to average anomaly ratio responses is conducted, that these investigations be guided by the theoretical and experimental behavior of the scalar product field distributions associated with the partial fields of the transmitter and receiver.

AMPLITUDE TYPE SEARCH HEAD INVESTIGATIONS FOR UHF MINE DETECTORS (U)

I. INTRODUCTION

1. Subject. This investigation was conducted to establish a basis for advancing and improving the development of non-metallic land mine detectors which depend on amplitude changes in the received signal for target identification. The work was authorized and accomplished under Project 8-07-04-014. The project card is not included so that the report may be graded "Confidential." The specific objective of this research was aimed at determining possible guidelines for the design of ultra high frequency (UHF) search heads which would surpass the operational performance characteristics of the AN/PRS-4, UHF, "Uncle Henry" Standard Non-Metallic Mine Detector. A variety of antenna configurations were designed, constructed and tested over the ERDL mine lane facilities using several representative operating conditions. The received response data were then statistically evaluated to indicate trends associated with specific antenna parameters, and a figure of merit was calculated for each laboratory model search head.

2. Background. ERDL and many commercial organizations under contract to ERDL have previously conducted studies and experiments pertaining to the behavior characteristics of amplitude type UHF mine detector search heads. In general, however, the results of these past investigations have not been capable of reduction to a common basis which would permit an evaluation of the relative merits of the various experimental models. This was largely due to varying test facilities and methods utilized. Hence, it has been nearly impossible to gauge the overall progress which was collectively achieved by the individual investigative efforts. This present work, therefore, was intended to make a systematic and more intensive effort to establish the capabilities of amplitude type search heads in the 400-mc and 800-mc regions.

3. Personnel. This project was planned, the procedures were determined, and the execution of the investigations was directed by Mr. Manfred Gale. Mr. Robert Thonen performed the experimental work of this research and assisted in applying the data evaluation procedure. A small staff assembled by Dr. James H. Taylor, George Washington University, assisted in carrying out the figure of merit calculations.

II. INVESTIGATION

4. General. The entire research program pertaining to the studies and investigations of the feasibility of electromagnetic mine detectors at UHF was based on the observations of performance data gathered at selected test facilities. This experimental approach was not dictated by choice but rather by necessity. Very limited theoretical knowledge existed which could be applied to the design improvement of antenna structures so as to enhance the utility of non-metallic mine detection systems in terms of increasing the probability of responding to wanted targets only. Basically speaking, therefore, a measure of success of any amplitude type mine detector model depends on how much and how reliably the magnitude of any mine response can be increased in relation to the magnitude of the responses of all other electromagnetic disturbances which occur in and above the soil. In the recent past, a theory has been advanced which treats the problem from the point of view of maximizing the signal of a discrete discontinuity (mine) in the presence of other distributed discontinuities (anomalies), and experiments have been initiated to investigate and determine if the theoretical requirements can be approached in a physical sense. However, the underlying principle from the outset of the work reported herein was directed towards obtaining adequate detector search head design information by observing the performance characteristics vs variations, and modifications of the parameters associated with specific antenna structures.

5. Description of Search Heads. Search heads of two general antenna configurations were included in the investigations - the A-type and C-type. The A-type consists of two parallel dipoles which are in phase opposition and center fed from a balanced two-wire transmission line, with the receiving dipole located coplanar, parallel to and symmetrically between the transmit antennas. The C-type unit consists essentially of two balanced and coplanar dipoles crossed at right angles to each other; one dipole is used as the transmitting element while the other dipole is used as the receiver. The units were then modified by the addition of parasitic reflectors, consisting of solid metal shields, which were always larger than the driven curtain and placed less than one quarter wavelength behind it. All laboratory models were powered from an 800 mc and/or a 400 mc oscillator, amplitude modulated at 1000 cycles per second.

Twenty-seven sets of experiments were conducted. Of this total, 16 of the test specimens were designed and constructed at ERDL while 11 models were obtained from Varian Associates under Contract eng-1145. Although some duplication in search head model design was deliberately intended, in general the models differed in one or more of the following parameters: (1) type of configuration; (2) operating frequency; (3) spacing of transmitting dipoles;

(4) application of parasitic reflector; and (5) size of parasitic reflector. Table I lists the pertinent features of the search head models which were investigated.

6. Laboratory Tests. To assure that the operation and performance of the constructed laboratory models was indeed a function of known search head parameters and not dependant on some incidental, parasitic or erratic mode of operation, it was of utmost significance for the purposes of this investigation to carefully examine, pre-test, and correct all units for conformance to required electrical behavior characteristics.

These characteristics refer primarily to the absolute sensitivity and the antenna symmetry properties of a given system. The absolute response is admittedly of secondary importance; however, there exist finite limitations to the amount of available signal power from laboratory oscillators, and it is, therefore, important to achieve sufficiently satisfactory transfer characteristics in order to obtain adequate signal-to-noise ratios. For purposes of this investigation, the required ratio (using square law detection) was approximately 80 db above 1 microvolt for maximum target response.

Symmetry of antenna fields is a practical requirement for the elimination of height effect. In other words, the system must be so balanced that the mutual admittance Y_{12} between transmitter and receiver vanishes, regardless of the height of an antenna above an "ideal" surface. This will occur when

$$\iint_{-\infty}^{\infty} (E_1 \cdot E_2)\, dx\, dy = 0$$

meaning that the scalar product of the partial fields associated with the antennas (transmitter and receiver) must be as often positive as negative in any horizontal plane.

The methods previously applied to check and correct search head symmetry properties were time consuming, and in many instances resulted in repeated construction of the same unit until a satisfactory pre-test performance could be ascertained. To overcome this cumbersome and intuitive approach, a series of laboratory tests were developed which allowed us to isolate the faulty or damaged search head component, and proceed with the necessary modifications which would restore the search head to its desired design criteria. The details pertaining to the techniques and procedures utilized in achieving the necessary pre-test performance are discussed in Appendix A. The models constructed by Varian Associates had been subjected to the same test procedures by advance agreement. With the search heads now in their proper operating conditions, we were ready to conduct the field performance experiments.

Table I. Description of Search Head Models

Type of Search Head Configuration and Number	Operating Frequency Appr. (mc)	Length of Dipoles Appr. (λ)	Dipole Spacing (In.)	Dipole Spacing (λ)	Was a Parasitic Reflector Attached?	Size of Parasitic Reflector (In.)	Laboratory Developing Model
A-1	400	λ/4	12	0.4	No	-	ERDL
A-2[a]	400	λ/4	12	0.4	Yes	20 x 15	ERDL
A-3	800	λ/2	12	0.8	No	-	ERDL
A-4	800	λ/2	12	0.8	Yes	20 x 15	ERDL
A-5	800	λ/2	11	0.75	Yes	12 x 15	Varian
A-6[b]	400	λ/4	9	0.3	No	-	ERDL
A-7[a]	400	λ/4	9	0.3	Yes	15 x 15	ERDL
A-8	800	λ/2	9	0.6	No	-	ERDL
A-9	800	λ/2	9	0.6	Yes	15 x 15	ERDL
A-10	800	λ/2	8	0.55	Yes	16d	Varian
A-11	800	λ/2	8	0.55	Yes	14d	Varian
A-12	800	λ/2	8	0.55	Yes	12d	Varian
A-13	800	λ/2	8	0.55	Yes	12 x 15	Varian
A-14	400	λ/4	7	0.24	No	-	ERDL
A-15	400	λ/4	7	0.24	Yes	15 x 15	ERDL
A-16	800	λ/2	7	0.48	No	-	ERDL
A-17	800	λ/2	7	0.48	Yes	15 x 15	ERDL
A-18	800	λ/2	6	0.4	Yes	12d	Varian
C-19	400	λ/4	Crossed	Dipole	No	-	ERDL
C-20	400	λ/4	Crossed	Dipole	Yes	18d	ERDL
C-21	800	λ/2	Crossed	Dipole	No	-	ERDL
C-22	800	λ/2	Crossed	Dipole	Yes	18d	ERDL
C-23	800	λ/2	Crossed	Dipole	Yes	16d	Varian
C-24	800	λ/2	Crossed	Dipole	Yes	14d	Varian
C-25	800	λ/2	Crossed	Dipole	Yes	14d	Varian
C-26	800	λ/2	Crossed	Dipole	Yes	14d	Varian
C-27	800	λ/2	Crossed	Dipole	Yes	12d	Varian

(a) Recommended (See Sections 12 and 13).
(b) Laboratory model of AN/PRS-4.

7. Minefield Tests. The laboratory models listed in Table I were tested under controlled and identical field conditions. All performance tests were carried out over the loam test mine lane, located at ERDL. The test lane contained the following targets at the indicated depths below the soil surface: Schu at ½ in; 12 in.-diameter Sulphur Block at surface; M-5 at 4 in; M-5 at 7 in; M-5 at 2 in; Schu at 1 in; and T-20 at ½ in. The relative placement of these targets along the center line of the lane is shown in Fig. 1. The search head and associated equipment, i.e. power oscillators, modulators, amplifiers, filters, recorders etc., were transported by a carriage which assured nearly identical terrain traversing for each experiment. The schematic of the typical circuitry employed in these tests is shown in Fig. 2. A boom, extending approximately 10 ft from the main body of the carriage, was used to hold and locate the search head handle. This extension plus adequate electrical termination of the underside of the boom assured almost complete freedom from interference of the test apparatus with the measured results. The height and orientation of the units under test were adjusted relative to the cement block located at the north end of the loam lane. It was necessary to choose a well-defined surface for these adjustments since the total effect of rail height variations and surface terrain fluctuations account for an overall but repeatable search head height deviation, along the lane, of approximately 1½ inches. Now with the units oriented for maximum detection in the direction of travel and with the geometrical center directly above the center line of the test lane, the following sets of successive adjustments were made, preparatory to their respective test runs:

(a) Height 3 in., Forward Tilt 0°

(b) Height 3 in., Forward Tilt 3°

(c) Height 3 in., Forward Tilt 6°

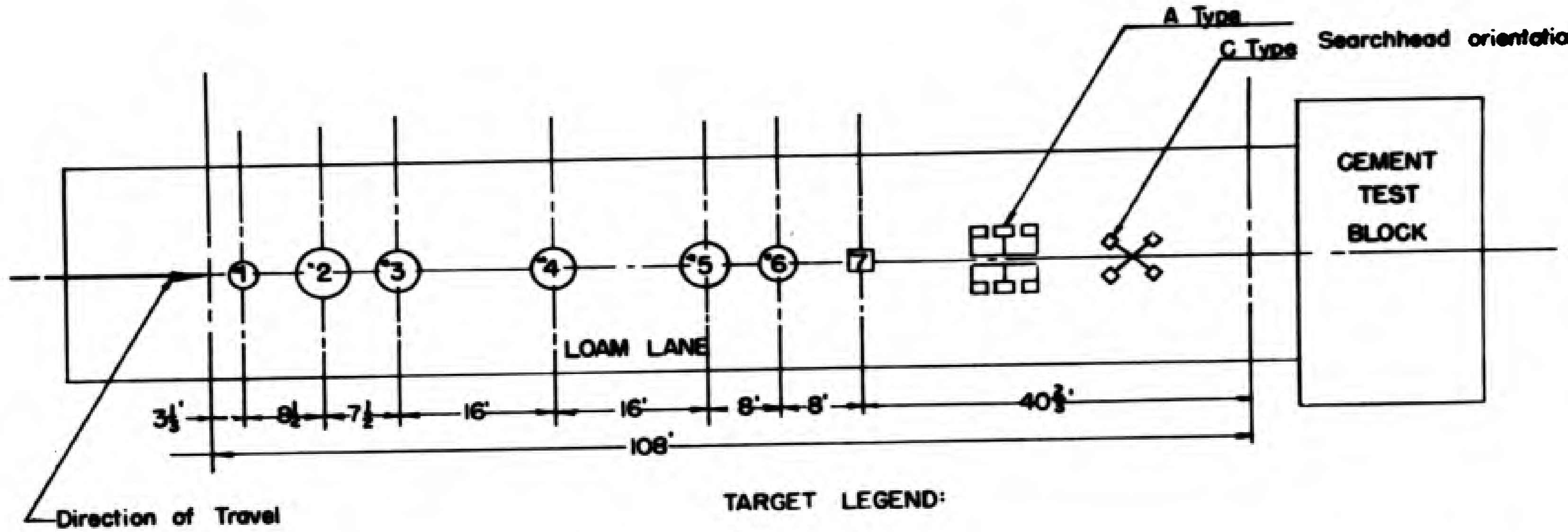
(d) Height 6 in., Forward Tilt 0°

(e) Height 6 in., Forward Tilt 3°

(f) Height 6 in., Forward Tilt 6°

Forward tilt refers to the angular rotation of the search head about an axis coplanar with the search head and perpendicular to the direction travel relative to the plane of the terrain surface. This is the tilt direction which is most likely to be encountered by the radial sweep of an operator in the field.

These 6 test runs were conducted for each of the 27 units listed in Table I, and the complete analogue of the received signals of



TARGET LEGEND:

#1	Schu Mine	Top surface buried 1/2" below soil surface	
#2	Sulphur Block (12"D)	" " "	0" " " "
#3	M-5 Mine	" " "	4" " " "
#4	M-5 Mine	" " "	7" " " "
#5	M-5 Mine	" " "	2" " " "
#6	Schu Mine	" " "	1" " " "
#7	T-20 Mine	" " "	1/2" " " "

Fig. 1. Layout o. ERDL test lane.

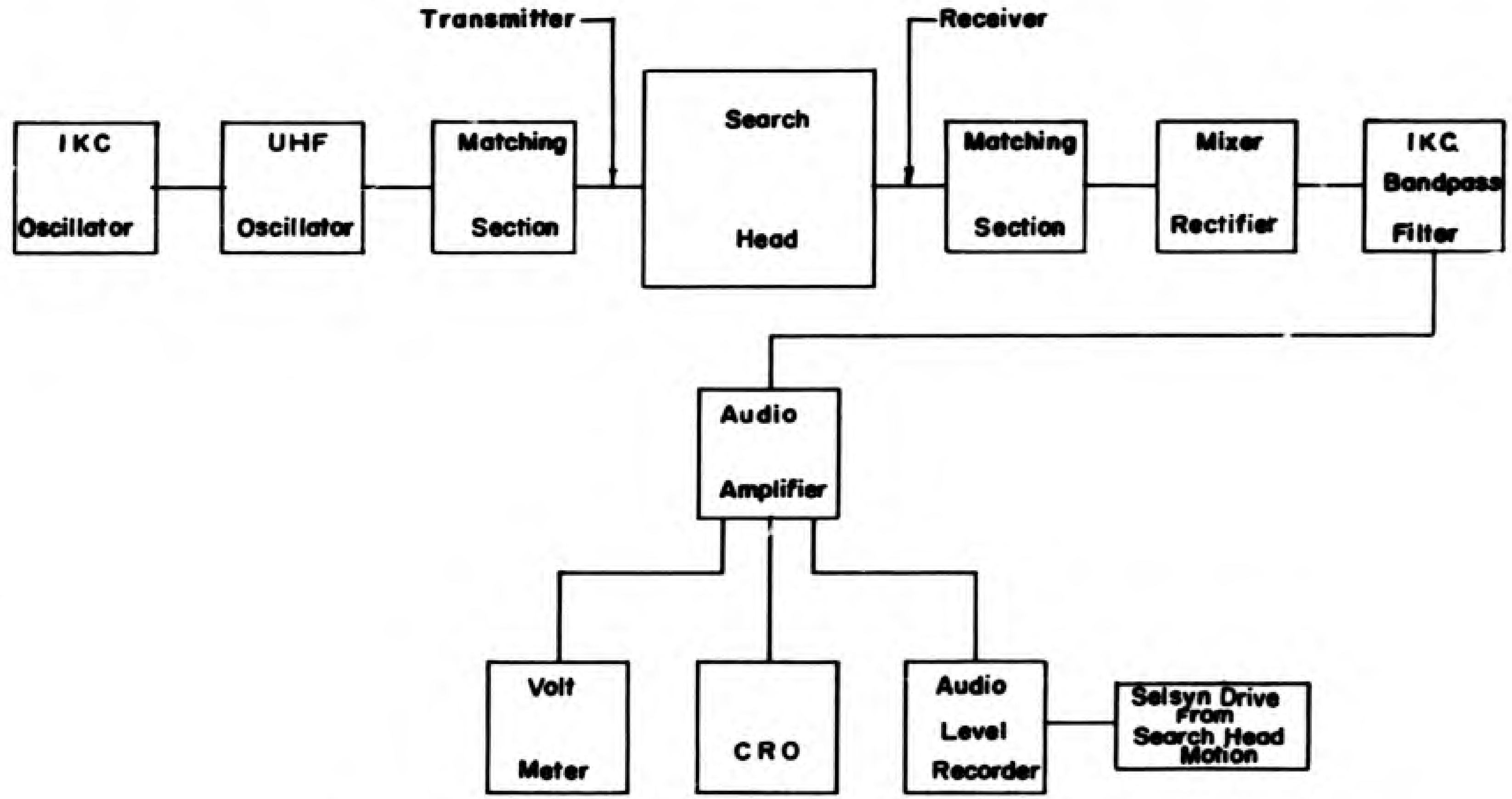


Fig. 2. Block diagram of typical measuring system.

the experiments was permanently recorded on paper charts. The reproductibility of the experiments had been checked both at frequent and extended (3 months) intervals in order to observe any changes that might occur either in the test equipment or the mine lane; however, no perceptible variations in detector output were noted during the course of this investigation.

8. Method of Data Evaluation. Some method had to be devised which would permit a comparison of the merits of the various search head models. The problem to be solved here was not merely a determination as to whether or not a unit "works," but rather an assessment of the degree of performance attained within these extreme limits. The evaluation technique developed, therefore, does not attempt to give a final answer to the ultimate capabilities of a given system which could only be attained by complete analysis of all the information contained in the data, but strives to rank the search head models on a relative scale.

The essential criteria which forms the basis for decision in this evaluation method is the peak mine signal to "average" anomaly signal ratio (S/A) in which the mine signal is represented by the maximum peak amplitude response occuring within the approximated total illuminated area centered about the known mine location; and the anomaly signal refers to the arithmetical average of all background signal amplitudes (mined areas excluded) present during each test run of approximately 108 feet in length. For those units in which the S/A was greater than zero for all mines and under all conditions referred to in paragraph 7, the relative merits of the system were determined by the total number of actual and "equivalent" false signals (more specifically, false signals per 10 ft) which would be received if a system were so devised that the mine with the lowest S/A could be detected by a voltage excursion of 2 db above a predetermined threshold. The "equivalent" false signals were derived by converting the change in average background level to a weighted number of anomalies per 10 ft, so that evidence of any height or tilt effect is evaluated in terms of a probable source of false signals. If the S/A was zero or less for any mine contained in the loamy soil lane and under any of the 6 test conditions referred to in paragraph 7, the unit was automatically ranked infinitely bad. The final evaluation, then, culminates in a figure of merit which is in terms of anomalies per 10 ft. The interpretation of the evaluation is such that the lower the total figure of merit, the less anomaly signals have been encountered, and, therefore, the closer a given detector approaches the ideal performance (100% mine signals, 0% anomaly signals). The detailed evaluation procedure and an example are contained in Appendix B.

Since there was hardly an additional effort involved, a figure of merit was also calculated for those experiments which consisted only of level (0^{o} tilt) performance data. Although this information is available in Table II, it is of no practical significance for ascertaining operational performance characteristics since the variations of tilt as well as height are unavoidable in mine detector use.

9. Above-Ground Interference Signals. Experimental observations and actual field use of UHF mine detector models have qualitatively demonstrated that above-ground objects, including the mine detector handle, the operator, etc., have destructively influenced the response of these units, particularly at higher operating heights. Based on the Sommerfeld Renn theory, calculations for elemental dipoles have been made which indicated that, at least for reasonably large dielectric constants, much of the total energy is absorbed in the ground for very low antenna spacings (approximately $1/20\lambda$ to $1/10\lambda$); in other words, a funneling effect characterizes the relative energy distribution immediately above the ground surface. This behavior is of course not present when the height of the antenna is increased beyond approximately a quarter of a wavelength. The parasitic shields can be expected not only to act as reflectors, i.e. tend to direct the electric field pattern towards the excited elements, and therefore towards the ground, but can also be thought of as reducing the radiation resistance in the backward direction and therefore substantially decreasing the energy above the antenna curtain. A series of tests was conducted to evaluate the effect of operational influences above the ground vs the employment of a parasitic shield on a typical antenna configuration (A-1, A-2, A-3, A-4, see Table I).

A brief description of the influence tests follows: The search head model was alternately located at heights of 3 in. and 6 in. above the cement block test facility. Circles of radii 2, 4, 6 and 8-in., respectively, were marked on the block surface, about the vertically projected center of symmetry of the search head. The antennas were operated both with and without a parasitic reflector at frequencies of 400 mc and 800 mc. Prior to the start of any experiment, the residual noise level, although quite low, was recorded for each test condition in order to ascertain the maximum possible error of any measured signal (Since an interferring signal may add in any phase to the initial voltage, the maximum error plus or minus the residual voltage), Three potential operators, in turn, walked in each of the previously marked circles while the search head output signals were recorded. This was intended to simulate the relative position of an operator to an actual mine detection device when scanning an area with radial sweeps. For each test condition, a normalized interference signal, V_{NI}, was computed as follows:

$$V_{N1} = 1/3 \sum_{n=1}^{3} (V_{I_n})_{MAX} \times \frac{V_N}{V_T}$$

where

V_{I_n} = Maximum observed interference signal for operator n

$\frac{V_N}{V_T}$ = Normalizing Ratio - Comparing the actual response to a standard target (V_T) to a standardized response (V_N).

Thus, all cases have been compared on the basis of a potential interference signal which could exist if the response to a mine had been identical for all conditions, and the relative results are therefore independent of changes in such parameters as oscillator power, matching and gain.

10. Results. The relative merits of the units examined during this investigation are shown in graph form, Fig. 3, where all search head models are arranged in order of increasing figure of merit - decreasing performance characteristics. This figure of merit reflects the composite evaluation of the particular search head for all test conditions (variation of height up to 6 in., variation of tilt up to 6^o). At the right end of Fig. 3 are listed those models which failed to detect one or more targets in the loamy lane and are therefore not considered in the ranking procedures, but are rejected as failures. The test conditions to which the detectors were subjected and the targets which were buried in the loamy lane are well within the tactical specifications under which a portable detector must operate in the field; hence failure to detect any of these targets, regardless of the magnitude of the number of possible false signals, does not qualify these units as feasible prototypes when compared to the remaining 75 percent which did meet these minimum performance standards. It must be noted that the relatively low figures of merit indicated for some of the search heads, which did not use a reflecting shield, were favorably influenced by the carefully controlled test conditions which minimized the disturbances due to above-ground interferences.

An inspection of the last column in Table II reveals the general decrease in detection performance, i.e. increase in figure of merit due to the inclusion of the tilt runs. It means, that with the usual mine searching procedures in the field, where the ground surface or the operator is just as likely to cause a tilt as not, the number of false signals (for the units included in this investigation) could increase between 27 percent and 2020 percent above those existing when the plane of the search head is perfectly parallel to the terrain surface.

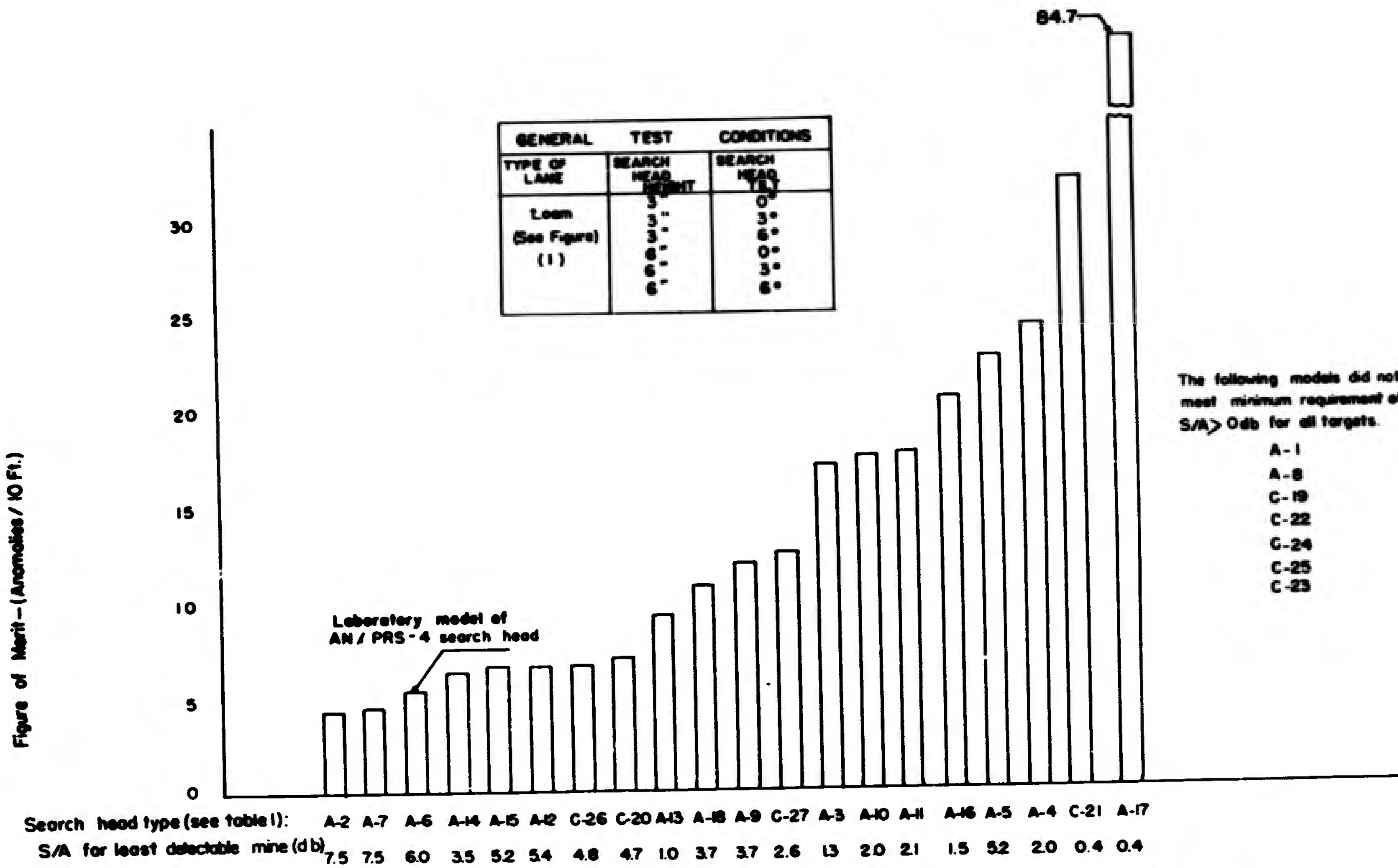


Fig. 3. Composite evaluation of amplitude type search heads.

Table II. Comparison of Performance for Level and General Operation

Search Head[a] Identification	Level Operation Only[b] Pk Signal/AV.AN for least Detectable Mine (db)	Level Operation Only[b] Figure of Merit (AN/10 ft)	General Operation[c] Including Tilt Pk Signal/AV.AN for least Detectable Mine (db)	General Operation[c] Including Tilt Figure of Merit (AN/10 ft)	% Change Due to Operation W/Tilt Angles Pk Signal/AV.AN for least Detectable Mine (% Decrease)	% Change Due to Operation W/Tilt Angles Figure of Merit (% Increase)
A-1	8.5	2.3	-2.3	(d)	127	(d)
A-2[e]	11.0	2.7	7.5	4.4	32	63
A-3	5.0	6.6	1.3	17.0	74	158
A-4	9.2	4.8	2.0	24.1	78	402
A-5	8.5	4.4	1.6	22.3	81	407
A-6[f]	6.0	3.4	6.0	5.4	0	59
A-7[g]	14.5	1.5	7.5	4.5	52	200
A-8	5.2	10.3	0.0	(d)	100	(d)
A-9	10.4	3.8	3.7	11.9	64	213
A-10	4.0	4.5	2.0	17.4	50	287
A-11	6.1	4.3	2.1	17.5	66	307
A-12	11.5	1.5	5.4	6.6	53	340
A-13	3.4	5.3	1.0	9.2	71	74
A-14	4.5	4.2	3.5	6.3	22	50
A-15	5.2	5.2	5.2	6.6	0	27
A-16	2.5	11.9	1.5	20.3	40	71
A-17	7.5	4.0	0.4	84.7	95	2020
A-18	8.5	3.5	3.7	10.9	56	211
C-19	-2.2	(d)	-2.2	(d)	0	(d)
C-20	4.7	5.6	4.7	7.1	0	27
C-21	0.4	13.7	0.4	31.8	0	132
C-22	0.1	72.3	-0.9	(d)	1000	(d)
C-23	0.0	(d)	0.0	(d)	0	(d)
C-24	6.2	2.6	-1.0	(d)	116	(d)
C-25	8.0	2.9	0.0	(d)	100	(d)
C-26	6.1	3.6	4.8	6.7	21	86
C-27	2.8	5.7	2.6	12.3	8	115

(a) For detailed description see Table I.

(b) For the following test conditions:
(1) Operating Ht. 3 in. (no tilt)
(2) Operating Ht. 6 in. (no tilt)

(c) For the following test conditions:
(1) Operating Ht. 3 in. tilt 0°
(2) Operating Ht. 3 in. tilt 3°
(3) Operating Ht. 3 in. tilt 6°
(4) Operating Ht. 6 in. tilt 0°
(5) Operating Ht. 6 in. tilt 3°
(6) Operating Ht. 6 in. tilt 6°

(d) These units had no figure of merit assigned, since they did not meet the minimum performance requirement of a $S/A > 0$db, for the least detectable mine.

(e),(g) Recommended - See Sections 12 and 13.

(f) Laboratory model AN/PRS-4.

The results represented in Fig. 4 are intended to show the statistical effect on the signal-to-anomaly ratio when the following changes are made on search head antennas:

a. Addition of parasitic elements to units operating at 400 mc.

b. Addition of parasitic elements to units operating at 800 mc.

c. Changes in operating frequencies from 400 mc to 800 mc.

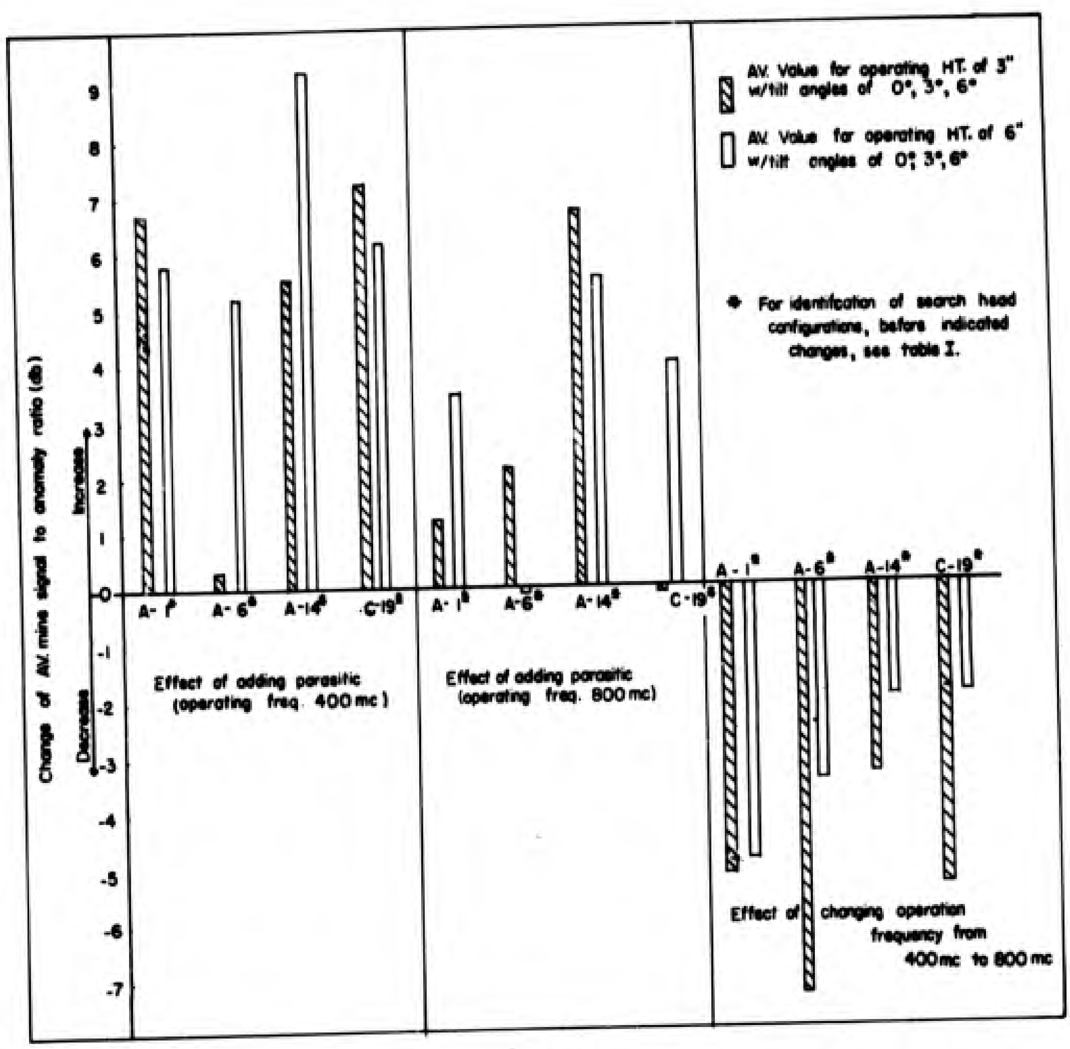


Fig. 4. Variation of $\frac{\text{AV. Mine Signal}}{\text{Anomaly Signal}}$ as a function of some search head parameters.

Note that the information here is presented as an average signal-to-anomaly ratio for all mines and all tilt angles at operating heights of 3 and 6 inches. Furthermore, the following general trends are indicated by the results:

a. Even under ideal operating conditions, the parasitic shield generally increases the signal-to-anomaly ratio at frequencies of 400 mc and 800 mc; however, in some cases very slight deterioration in S/A is evidenced.

b. Changing operating frequency from 400 mc to 800 mc reduced the signal-to-anomaly ratio in all cases.

The information contained in Fig. 5 shows the relative interference signals that could be expected from a typical search head due to the presence of an operator or other above-ground influences. The data is arranged so that adjacent columns refer to identical test conditions with and without a reflecting shield. The results obtained from these investigations show that the interference signal can be reduced 20 to 50 db with the addition of parasitic reflectors.

III. DISCUSSION

11. Explanation and Limitations. It was expected that a large number of carefully planned tests, performed on a group of search heads which possessed certain deliberate differences in their physical and electrical characteristics, would lead to some definite performance trends. The further exploration of the desirable trends, then, would serve as guides in optimizing the design of the system. The degree to which the sequence of this particular approach has been possible to pursue is indicated by the results of the investigation. Some very general trends which will undoubtedly result in performance that is superior to the AN/PRS-4 detector have been observed; namely, the addition of a reflecting shield. Aside from the fact that a somewhat lower figure of merit (better performance) was obtained for the A-2 configuration with shield, compared to a laboratory model equivalent to the AN/PRS-4, it is quite certain that under actual field conditions the AN/PRS-4 performance would deteriorate considerably more than is indicated by its relative assigned rank. This effect has been quantitatively demonstrated by the tests conducted with above-ground influences (see par. 9) and has been qualitatively observed by operating the AN/PRS-4 in the field.

Also, the spacing or shape of the dipoles did not indicate any fixed trends. Since mines of large dimensional variations were used in these experiments, this result is not very surprising. If one had concentrated on detection of anti-vehicular mines or small

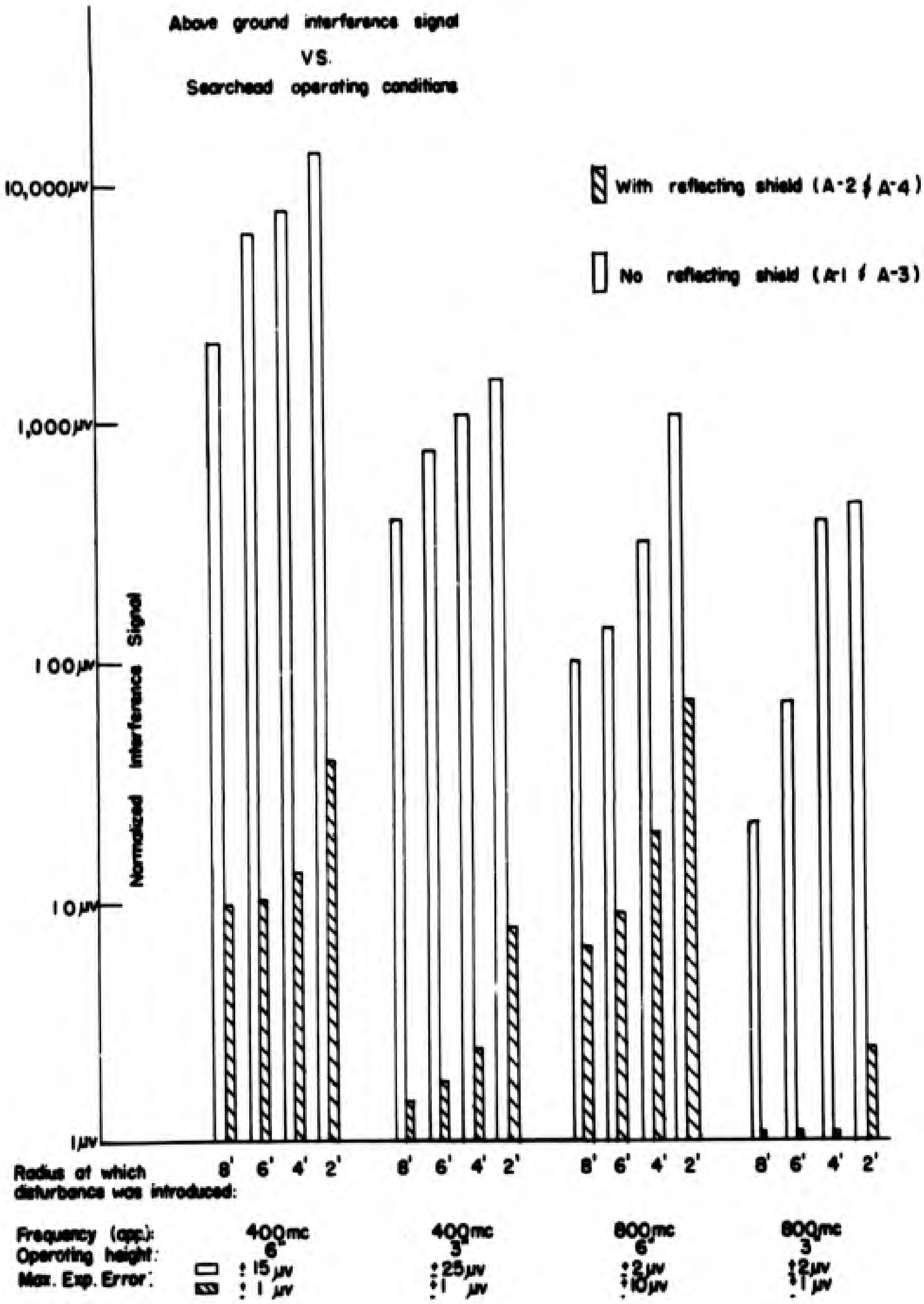


Fig. 5. Typical signal amplitudes due to above-ground disturbances.

anti-personnel mines only, it is quite conceivable that a definite trend in dipole spacing could be associated with the dimension of the size of the discontinuity because the relative size of the illuminated area will be influenced by the dipole spacing.

It is not obvious why the average results at a transmitting frequency of 800 mc are consistently inferior to those at 400 mc. This holds for units on which only the operating frequency was changed as well as for units where reasonable scaling of the antenna location was achieved. One may speculate that a possible explanation is attributable to the condition of the test mine lane which causes a small surface indentation to exist above all buried targets. This particular surface condition might aid in the detection of the mine below under certain circumstances. At 400 mc, for instance, the ground surface is well within a radian distance ($\frac{\lambda}{2\pi}$) or just marginal (depending on the operating height) and hence a relatively strong induction field, which decays at a higher power with distance, exists near the surface causing a relatively high response due to surface variations. This is true to a much lesser degree at 800 mc where the surface is practically always in the transition-field zone, and sensitivity to surface variations is decreased.

It would have been very desirable to conduct these investigations with more representative soil samples than those which were employed, in order to give more credence to the statistical evaluation. At the time of these experiments, however, no adequate soil lanes existed in addition to the loam lane; nevertheless, this lane, with a dielectric constant of approximately 4, represents an average soil condition.

Further experimental research based only on the overall operating performance of A and C type search heads is not likely to lead to any significant improvements over a system similar to the A-2 or A-7 models. Cook Research Laboratory, under ERDL Contract eng-2572, recently conducted similar investigations in an effort to achieve optimum search head performance; however, when their "best" unit was subjected to the identical tests and evaluations discussed in this report, the overall performance was about 25 percent worse than the best obtained at ERDL. This relatively small operational deterioration is of no particular significance by itself, except to verify the limits beyond which an experimental approach does not seem capable of improvements.

The performance deterioration with relatively small tilt angles (up to 6^o), as shown in Table II, is perhaps the severest limitation which is inherently present in any practical UHF mine detector. The investigations of Dr. E. T. Jaynes predicted that it is theoretically possible to design antennas so that at least the first order tilt (where Y_{12} is a linear function of small tilt

Table III. Target Detection Ratios - Peak Mine Signal/Average Anomal

Search Head Identification	Test Condts.: Ht. 3 in., Tilt 0° Target No.[c] 1	2	3	4	5	6	7	Test Condts.: Ht. 6 in., Tilt 0° Target No.[c] 1	2	3	4	5	6	7	Test Condts.: Ht. 3 in., Tilt 3° Target No.[c] 1	2	3	4	5	6	7	Test Condts.: Ht. 6 in., Tilt 3° Target No.[c] 1	2	3	4	5	6	7	Test 1
A-1	13.4	25.4	24.4	16.9	16.9	20.9	19.4	11.5	19.0	16.0	13.5	10.0	8.5	9.5	5.6	23.6	21.1	12.6	15.1	19.1	13.6	10.5	23.5	18.0	13.0	13.0	14.0	13.5	-1.1
A-2[a]	11.2	27.0	29.0	23.0	25.0	25.0	18.0	13.5	27.5	26.5	21.5	13.5	22.5	19.5	8.9	26.9	27.9	20.4	24.4	24.9	25.4	7.9	25.9	24.9	17.4	11.4	21.4	14.4	7.9
A-3	9.0	11.0	9.0	8.0	14.5	5.0	12.0	9.0	6.5	9.0	6.0	11.0	11.0	9.0	11.5	10.5	8.0	8.5	16.0	3.5	15.0	5.8	1.3	6.3	3.8	7.8	5.8	7.8	5.9
A-4	15.5	16.5	12.5	11.5	20.5	16.5	21.0	11.7	15.2	14.2	12.2	21.7	9.2	17.2	12.2	16.2	6.2	7.2	12.2	9.7	12.2	5.7	6.2	4.2	7.2	9.2	6.2	8.2	8.5
A-5	21.3	11.3	20.3	15.3	21.3	17.3	25.3	12.4	19.4	13.4	8.4	17.4	15.4	18.4	19.9	12.9	15.9	13.9	18.9	15.9	21.9	9.8	8.3	6.8	8.8	11.3	8.8	7.8	14.9
A-6[b]	10.3	26.3	26.3	22.3	20.8	18.8	20.8	6.0	12.0	13.0	10.5	10.5	[illegible]	8.5	10.3	25.8	24.8	21.3	20.3	18.3	20.8	11.5	19.5	20.0	15.0	15.0	14.0	15.5	7.7
A-7[a]	16.3	24.3	24.8	23.3	18.8	22.8	22.8	14.5	25.5	24.5	22.0	25.0	21.0	22.0	13.3	22.3	22.3	21.8	18.8	20.3	20.3	11.1	23.6	24.6	21.1	17.1	20.6	19.6	10.5
A-8	14.2	9.2	13.7	10.2	13.2	6.2	14.2	9.7	5.2	14.7	9.7	14.7	9.2	10.7	14.1	11.6	21.1	8.6	15.1	11.6	17.6	7.5	0.5	9.5	11.0	15.0	11.0	13.0	7.0
A-9	22.7	15.7	18.7	14.7	21.7	13.2	25.2	14.9	13.4	14.4	11.4	20.4	10.4	13.9	17.9	13.4	11.9	8.4	7.4	11.4	18.4	9.8	7.3	6.3	7.8	4.8	6.8	3.8	13.3
A-10	28.0	4.0	26.0	20.0	28.0	25.5	32.0	23.3	19.3	21.3	9.3	27.3	12.3	27.3	15.4	5.4	13.4	7.4	18.4	14.4	27.4	10.3	9.3	6.3	7.3	12.8	4.3	7.3	14.9
A-11	23.5	10.0	22.5	12.5	22.5	22.5	27.5	18.1	18.6	19.1	6.1	23.1	12.1	23.1	16.6	8.6	12.1	9.6	20.6	16.6	25.6	11.5	12.5	9.5	9.5	14.5	10.5	11.5	10.3
A-12	28.7	16.2	22.2	18.2	30.2	30.2	30.2	24.3	14.3	17.3	11.3	28.3	16.3	16.8	25.6	14.6	13.6	12.6	25.6	25.6	25.6	15.8	22.3	8.3	14.3	20.8	19.8	11.8	14.4
A-13	29.0	5.0	21.5	17.0	26.0	21.0	32.0	19.4	3.4	12.9	9.4	13.4	12.4	24.4	22.4	7.4	20.4	17.4	23.4	17.4	27.4	15.0	9.0	4.0	8.0	14.0	7.5	22.0	13.5
A-14	11.5	21.5	21.5	11.5	9.5	15.5	20.5	7.5	15.5	12.5	7.5	4.5	6.5	12.5	8.5	18.5	17.5	7.5	8.5	12.5	16.5	3.5	7.5	8.5	5.5	5.5	4.5	9.5	7.5
A-15	17.1	28.1	28.1	22.1	12.1	26.1	26.1	13.2	27.2	26.2	18.2	5.2	19.2	22.2	14.0	21.0	22.0	17.0	8.0	18.0	21.0	8.8	22.8	23.8	14.8	8.8	16.8	20.8	8.4
A-16	8.5	13.5	7.5	2.5	6.5	13.5	16.5	10.0	8.0	4.0	7.0	6.0	5.0	7.0	6.5	12.5	5.5	3.5	4.5	9.5	11.5	5.0	2.0	6.0	6.0	7.0	4.0	6.0	9.5
A-17	29.0	26.0	18.0	9.0	23.0	28.0	28.0	23.5	30.5	7.5	7.5	18.5	19.5	21.5	17.6	22.6	12.6	10.6	15.6	20.6	15.6	11.4	17.4	2.4	5.4	11.4	9.4	4.4	11.8
A-18	26.8	12.8	20.8	10.8	24.3	24.3	27.8	23.8	8.4	14.8	13.8	24.3	12.8	24.8	15.9	12.4	11.4	7.9	12.9	13.4	17.4	11.9	8.4	6.4	6.4	12.4	9.4	14.9	12.4
C-19	17.7	14.7	18.2	9.7	14.7	19.7	25.2	12.3	8.3	7.8	3.8	4.3	-2.2	9.3	17.5	18.0	13.0	10.0	14.5	16.0	25.5	12.1	9.1	8.6	4.1	3.8	-0.4	6.1	19.5
C-20	26.2	21.7	19.7	22.7	18.7	32.7	39.7	4.7	18.2	18.7	13.2	4.7	11.7	15.2	21.8	21.3	21.3	17.8	19.3	25.8	40.8	10.5	11.5	20.5	12.0	12.0	12.5	23.5	17.0
C-21	7.9	7.9	15.4	7.4	12.9	10.9	16.4	0.4	4.4	5.4	2.4	6.9	7.4	4.9	13.7	5.7	16.7	8.7	12.2	14.7	22.2	1.5	3.0	7.0	5.5	8.0	8.5	8.5	9.7
C-22	3.9	13.4	7.4	6.4	19.9	16.9	10.4	2.1	0.1	20.1	3.1	16.1	16.1	15.1	6.2	14.7	7.2	6.7	18.7	19.2	12.2	7.5	6.5	17.0	2.0	11.5	12.0	10.0	5.1
C-23	26.2	32.7	7.2	22.2	12.2	20.7	19.4	10.1	0.0	14.6	6.1	14.6	8.1	9.6	22.4	10.9	15.4	10.4	20.9	22.4	30.4	9.8	1.8	11.8	9.8	8.8	4.3	3.8	21.6
C-24	29.8	15.8	24.8	18.8	28.8	28.8	31.8	19.2	5.7	15.7	6.2	22.7	12.7	17.2	30.5	7.0	22.5	15.5	31.0	21.0	33.5	19.7	5.2	11.2	3.2	9.7	6.2	14.2	23.1
C-25	25.9	14.9	20.9	13.4	25.9	23.9	31.9	12.0	18.0	18.0	8.0	22.0	17.0	14.0	22.9	22.9	19.9	12.9	26.9	28.9	29.9	9.6	20.1	17.1	1.1	18.1	16.1	10.1	18.1
C-26	26.1	6.1	26.1	26.1	26.1	26.1	28.1	10.5	9.0	17.5	14.0	21.5	13.0	16.5	28.9	11.9	24.4	26.9	25.9	28.9	29.9	13.3	6.8	15.3	13.3	11.3	10.3	16.3	18.1
C-27	25.4	19.9	20.0	18.9	26.4	25.9	34.4	15.3	2.8	22.8	13.8	10.3	4.3	3.8	29.3	13.1	20.6	11.6	28.1	29.1	33.1	8.8	5.8	12.3	2.8	18.3	16.8	19.8	19.0

(a) Recommended (See Sections 12 and 13).

(b) Laboratory model AN/PRS-4.

(c) Target Legend:
- No. 1 Schu Mine, top surface buried ½ in. below soil surface.
- No. 2 Sulphur Block (12 in. d.), top surface buried 0 in. below soil surface.
- No. 3 M-5 Mine top surface buried 4 in. below soil surface.
- No. 4 M-5 Mine top surface buried 7 in. below soil surface.
- No. 5 M-5 Mine top surface buried 2 in. below soil surface.
- No. 6 Schu Mine " top surface buried 1 in. below soil surface.
- No. 7 T-20 Mine top surface buried ½ in. below soil surface.

Target Detection Ratios - Peak Mine Signal/Average Anomaly Signal (db)

., Tilt 0°			Test Condts.: Ht. 3 in., Tilt 3° Target No.(c)							Test Condts.: Ht. 6 in., Tilt 3° Target No.(c)							Test Condts.: Ht. 3 in., Tilt 6° Target No.(c)							Test Condts.: Ht. 6 in., Tilt 6° Target No.(c)						
	6	7	1	2	3	4	5	6	7	1	2	3	4	5	6	7	1	2	3	4	5	6	7	1	2	3	4	5	6	7
0	8.5	9.5	5.6	23.6	21.1	12.6	15.1	19.1	13.6	10.5	23.5	18.0	13.0	13.0	14.0	13.5	-1.1	16.4	14.9	9.9	9.9	13.9	8.9	-2.3	10.2	8.2	7.2	6.7	9.2	5.7
5	22.5	19.5	8.9	26.9	27.9	20.4	24.4	24.9	25.4	7.9	25.9	24.9	17.4	11.4	21.4	14.4	7.9	25.4	24.9	17.4	21.9	22.9	22.9	7.5	22.5	20.0	10.0	10.0	18.5	8.0
0	11.0	9.0	11.5	10.5	8.0	8.5	16.0	3.5	15.0	5.8	1.3	6.3	3.8	7.8	5.8	7.8	5.9	9.4	14.9	8.9	14.4	6.9	14.9	4.2	3.7	4.2	3.2	7.2	3.7	7.2
7	9.2	17.2	12.2	16.2	6.2	7.2	12.2	9.7	12.2	5.7	6.2	4.2	7.2	9.2	6.2	8.2	8.5	12.0	2.0	4.0	10.0	7.0	9.0	7.3	8.3	6.3	7.3	11.8	7.8	9.3
4	15.4	18.4	19.9	12.9	15.9	13.9	18.9	15.9	21.9	9.8	8.3	6.8	8.8	11.3	8.8	7.8	14.9	7.9	12.9	10.9	11.9	11.9	20.9	7.1	7.1	4.6	5.6	7.6	1.6	3.6
5	9.5	8.5	10.3	25.8	24.8	21.3	20.3	18.3	20.8	11.5	19.5	20.0	15.0	15.0	14.0	15.5	7.7	21.7	21.2	16.7	15.2	16.2	16.7	8.8	18.8	17.8	13.8	13.3	9.8	13.8
0	21.0	22.0	13.3	22.3	22.3	21.8	18.8	20.3	20.3	11.1	23.6	24.6	21.1	17.1	20.6	19.6	10.5	18.5	18.0	17.5	16.0	15.5	15.5	7.5	18.0	18.5	13.5	8.5	13.5	13.5
7	9.2	10.7	14.1	11.6	21.1	·8.6	15.1	11.6	17.6	7.5	0.5	9.5	11.0	15.0	11.0	13.0	7.0	9.5	7.5	11.5	11.0	8.0	12.0	8.0	0.0	9.0	11.5	14.5	8.0	9.5
4	10.4	13.9	17.9	13.4	11.9	8.4	7.4	11.4	18.4	9.8	7.3	6.3	7.8	4.8	6.8	3.8	13.3	11.3	8.3	7.3	8.8	7.3	13.8	7.2	3.7	4.7	8.2	7.7	5.2	8.2
3	12.3	27.3	15.4	5.4	13.4	7.4	18.4	14.4	27.4	10.3	9.3	6.3	7.3	12.8	4.3	7.3	14.9	2.9	13.4	5.4	14.4	12.4	24.4	10.0	7.5	3.0	5.0	13.0	2.0	4.0
1	12.1	23.1	16.6	8.6	12.1	9.6	20.6	16.6	25.6	11.5	12.5	9.5	9.5	14.5	10.5	11.5	10.3	4.3	9.3	2.8	12.3	9.3	18.3	7.1	6.6	2.6	4.6	8.6	2.1	3.6
3	16.3	16.8	25.6	14.6	13.6	12.6	25.6	25.6	25.6	15.8	22.3	8.3	14.3	20.8	19.8	11.8	14.4	6.4	10.4	8.4	15.4	12.4	14.4	5.9	8.9	5.4	8.4	11.4	5.4	5.4
4	12.4	24.4	22.4	7.4	20.4	17.4	23.4	17.4	27.4	15.0	9.0	4.0	8.0	14.0	7.5	22.0	13.5	6.0	17.5	14.5	18.5	13.0	19.0	11.0	8.0	8.0	11.5	15.0	1.0	15.5
5	6.5	12.5	8.5	18.5	17.5	7.5	8.5	12.5	16.5	3.5	7.5	8.5	5.5	5.5	4.5	9.5	7.5	15.5	15.5	6.5	7.5	10.5	15.5	4.0	7.0	8.0	6.0	5.0	4.0	9.0
2	19.2	22.2	14.0	21.0	22.0	17.0	8.0	18.0	21.0	8.8	22.8	23.8	14.8	8.8	16.8	20.8	8.4	16.4	20.4	16.4	8.4	16.4	18.4	8.3	19.3	21.3	11.3	8.3	13.3	17.3
0	5.0	7.0	6.5	12.5	5.5	3.5	4.5	9.5	11.5	5.0	2.0	6.0	6.0	7.0	4.0	6.0	9.5	18.5	10.5	7.5	9.5	10.5	19.5	1.5	3.5	4.5	4.5	4.5	2.5	4.5
5	19.5	21.5	17.6	22.6	12.6	10.6	15.6	20.6	15.6	11.4	17.4	2.4	5.4	11.4	9.4	4.4	11.8	15.8	8.8	5.8	10.8	12.8	6.8	6.4	12.4	1.4	3.4	6.4	4.4	0.4
3	12.8	24.8	15.9	12.4	11.4	7.9	12.9	13.4	17.4	11.9	8.4	6.4	6.4	12.4	9.4	14.9	12.4	5.4	4.9	6.4	9.9	8.9	15.9	7.2	3.7	4.2	7.2	9.2	6.2	8.2
3	-2.2	9.3	17.5	18.0	13.0	10.0	14.5	16.0	25.5	12.1	9.1	8.6	4.1	3.8	-0.4	8.1	19.5	15.5	13.5	11.0	16.0	16.0	28.0	15.9	14.4	11.4	5.9	6.4	0.4	12.9
7	11.7	15.2	21.8	21.3	21.3	17.8	19.3	25.8	40.8	10.5	11.5	20.5	12.0	12.0	12.5	23.5	17.0	21.0	24.5	15.5	17.0	20.5	40.0	5.7	13.7	19.7	14.7	9.7	10.7	20.2
9	7.4	4.9	13.7	5.7	16.7	8.7	12.2	14.7	22.2	1.5	3.0	7.0	5.5	8.0	8.5	8.5	9.7	0.7	12.2	8.2	9.7	9.7	15.7	3.6	7.1	5.6	6.1	5.6	7.6	6.1
.1	16.1	15.1	6.2	14.7	7.2	6.7	18.7	19.2	12.2	7.5	6.5	17.0	2.0	11.5	12.0	10.0	5.1	16.6	4.1	5.1	18.1	17.6	-0.9	6.6	7.6	16.6	3.6	11.6	9.6	5.6
.6	8.1	9.6	22.4	10.9	15.4	10.4	20.9	22.4	30.4	9.8	1.8	11.8	9.8	8.8	4.3	3.8	21.6	2.6	17.1	4.6	12.6	18.1	28.6	27.1	2.6	2.6	2.1	5.6	5.1	10.1
.7	12.7	17.2	30.5	7.0	22.5	15.5	31.0	21.0	33.5	19.7	5.2	11.2	3.2	9.7	6.2	14.2	23.1	8.1	23.1	13.6	23.1	23.1	27.1	16.0	9.5	9.5	0.5	-1.0	3.5	10.0
.0	17.0	14.0	22.9	22.9	19.9	12.9	26.9	28.9	29.9	9.6	20.1	17.1	1.1	18.1	16.1	10.1	18.1	19.1	21.1	9.6	23.6	20.1	27.1	9.5	14.0	14.0	0.0	13.0	13.0	7.5
.5	13.0	16.5	28.9	11.9	24.4	26.9	25.9	28.9	29.9	13.3	6.8	15.3	13.3	11.3	10.3	16.3	18.1	7.6	14.1	6.1	18.1	18.1	19.1	13.3	4.8	11.3	8.8	9.8	8.8	14.8
.3	4.3	3.8	29.3	13.1	20.6	11.6	28.1	29.1	33.1	8.8	5.8	12.3	2.8	18.3	16.8	19.8	19.0	7.5	12.0	6.0	15.5	20.0	29.5	10.1	2.6	13.6	7.1	12.6	13.1	16.1

buried ½ in. below soil surface.
buried 0 in. below soil surface.
buried 4 in. below soil surface.
buried 7 in. below soil surface.
buried 2 in. below soil surface.
buried 1 in. below soil surface.
buried ½ in. below soil surface.

angles) can be eliminated. The C-type systems have the proper distribution of sensitive areas which this theory demands; however, the contemplated advantages associated with their "tilt" performance have not been experimentally verified during this investigation. In principle, higher symmetry type antennas can be designed which would be of the 2n-upole type, and would tend to discriminate against higher orders of tilt effect. However, even if these theoretical conditions could be met, not only would the practical construction of such a system become extremely difficult to achieve, but also the adjacent lobes of the scalar field product functions would tend to cancel each other and seriously reduce the response to a small target.

The individual signal-to-anomaly ratios for all targets and all search head models are listed in Table III. This data is useful for extending the study of antenna design trends if specialized operational performance characteristics are to be investigated in the future; i.e. detection of anti-personnel mines only.

The techniques for improving the signal-to-anomaly ratios of amplitude type detectors in any further investigations must be guided by experimental and theoretical exploitation of the scalar product field distributions about the antennas if performance characteristics are to be significantly enhanced over the best models encountered during this research.

IV. CONCLUSIONS AND RECOMMENDATIONS

12. Conclusions. It is concluded that:

a. The field operation of any search head, similar to the models investigated, without an adequate parasitic reflector is completely impractical at operating heights of approximately 6 in. above the ground.

b. The addition of an adequate reflector shield improves the overall search head performance both in terms of increased mine signal identification and reduction in above-ground interferences.

c. The use of an 800 mc operating frequency yielded, at best, no improvement in performance characteristics over similar units at 400 mc, and in most cases caused the performance to deteriorate.

d. The best mine detection performance was achieved with the search head models A-7 and A-2 which had an operating frequency of 400 mc, parasitic reflectors and a dipole spacing of 9 in. and 12 in. respectively. The operational detection characteristics of these models is superior to AN/PRS-4, UHF, "Uncle Henry" Standard Non-Metallic Mine Detector.

13. Recommendations: It is recommended that:

a. Any present development of portable UHF non-metallic mine detector search heads adapt the basic design of the A-7 or A-2 configurations listed in this report.

b. The research on data analysis techniques be intensified in order to find criteria other than peak amplitude ratios to achieve a substantially higher probability of mine signal identification.

c. If further research based on optimum mine signal-to-average anomaly ratio responses is conducted, that these investigations be guided by the theoretical and experimental behavior of the scalar product field distributions associated with the partial fields of the transmitter and receiver.

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APPENDICES

APPENDIX A

PRE-TEST PERFORMANCE DETERMINATION

The following procedure was developed in order to determine: (1) if the antenna structures conform to the symmetry properties which are an essential design criteria; and (2) if the symmetry properties are not met which component of the radiating circuits is causing the unbalanced behavior.

A simplified analysis of a three-element A-Type Search head will serve to illustrate the derivation of the test method. Two basic assumptions are made in this analysis:

(1) There exists no voltage component due to a UHF leakage signal; i.e. the transmitter and receiver circuits are completely decoupled up to the dipole feed points. This assumption is almost always justifiable due to the extreme care taken in achieving complete isolation in the design of the receiver and transmitter coupling networks.

(2) The transmission line is fed in a balanced mode, although unbalanced, grounded oscillators are used as UHF signal sources. There seems to be no risk involved in making this assumption, since our experience indicated excellent results with the use of shielded coupling loops as unbalance-to-balance transformers. Practically none of the unbalanced mode is transmitted by these devices, and Brooklyn Polytechnic Institute under Contract eng-1100 had verified these findings.

Referring to Fig. 6: V_1 = magnitude of voltage at center of transmitter dipole #1

V_2 = magnitude of voltage at center of transmitter dipole #2

i_R = current on receiver dipole

Y_{1R} = mutual admittance between receiver dipole and transmitter dipole #1

Y_{2R} = mutual admittance between receiver dipole and transmitter dipole #2

ϵ_1 = "average" dielectric constant associated with dipole #1

ϵ_2 = "average" dielectric constant associated with dipole #2

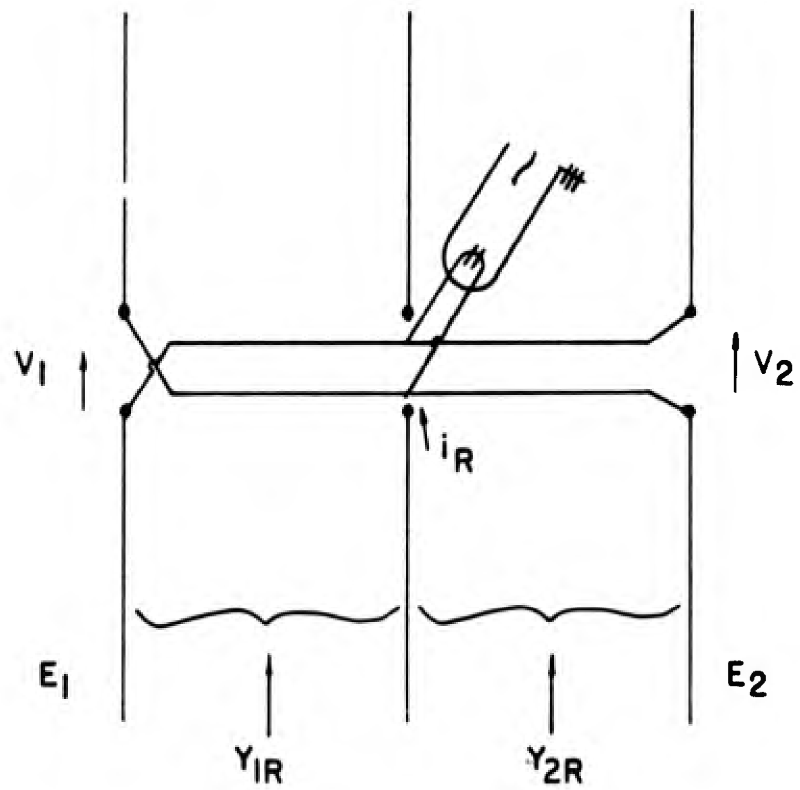


Fig. 6. Simplified A-type schematic.

The total mutual admittance is a function of the mutual admittance in free space (y) and the dielectric constant or

$$Y_{1R} = \epsilon_1 \, y_{1R} \; ; \; Y_{2R} = \epsilon_2 \, y_{2R}$$

$$/i_R/ = /Y_{1R} V_1 - Y_{2R} V_2/ = /\epsilon_1 y_{1R} V_1 - \epsilon_2 y_{2R} V_2/ \qquad (1)$$

We will now examine the behavior of equation 1 under certain experimental conditions. The search head, under test, is run over the cement test block with identical positioning of the plane of the antennas for all pre-test experiments. Let us identify the initial position of the search head as 0° and the reversed position as 180° (leading edge and trailing edge interchanged). Similarily, the original orientation of the transmission line is identified as 0° and the reversed position as 180° (dipole #2 is now fed from transmission line terminals previously applied to dipole #1, etc.).

The following experiments were then performed, and the output data was recorded:

EXPERIMENTS

Experiment No.	Rel. Orientation of Search Head	Rel. Orientation of transmission line	Applicable Form of Equ. #1
1	0°	0°	$/i_{R1}/ = /(\epsilon_1 y_{1R} V_1 - \epsilon_2 y_{2R} V_2)/$
2	180°	0°	$/i_{R2}/ = /(\epsilon_2 y_{1R} V_1 - \epsilon_1 y_{2R} V_2)/$
3	0°	180°	$/i_{R3}/ = /(-\epsilon_1 y_{1R} V_2 + \epsilon_2 y_{2R} V_1)/$
4	180°	180°	$/i_{R2}/ = /(-\epsilon_2 y_{1R} V_2 + \epsilon_1 y_{2R} V_1)/$

Examining and comparing the recorded results, one can arrive at some definite conclusions in the following manner:

If	Than	Because	
a. Run #1 = Run #2	Search head is in balanced condition	$V_1 = V_2$ $y_{1R} = y_{2R}$	(The dipoles are fed with equal voltages and the antenna layout is symmetrical)
b. Run #1 = Run #4	Antenna layout is adequate	$y_{1R} = y_{2R}$	(The free space mutual admittance is a function only of the shape and relative positioning the antennas)
c. Run #1 = Run #3	Balanced two-wire transmission line is adequate	$V_1 = V_2$	(The voltage appearing at the transmitting dipole feed points depend on the transmission line)
d. (a), (b) or (c) do not apply		Check for UHF leakage, and examine shielded loop coupling.	

This procedure was applied very satisfactorily and some detailed results can be found in ERDL notebook #1848. In practice, of course, some experimental errors were unavoidable and "identical" data were defined as those recordings which did not deviate more than 3 db.

It was established during these tests that the transmission line was the most critical component in the antenna structure. Subsequently a balanced two-wire line was developed (Fig. 7) which has exhibited very favorable balance characteristics, and was fairly simple to reproduce.

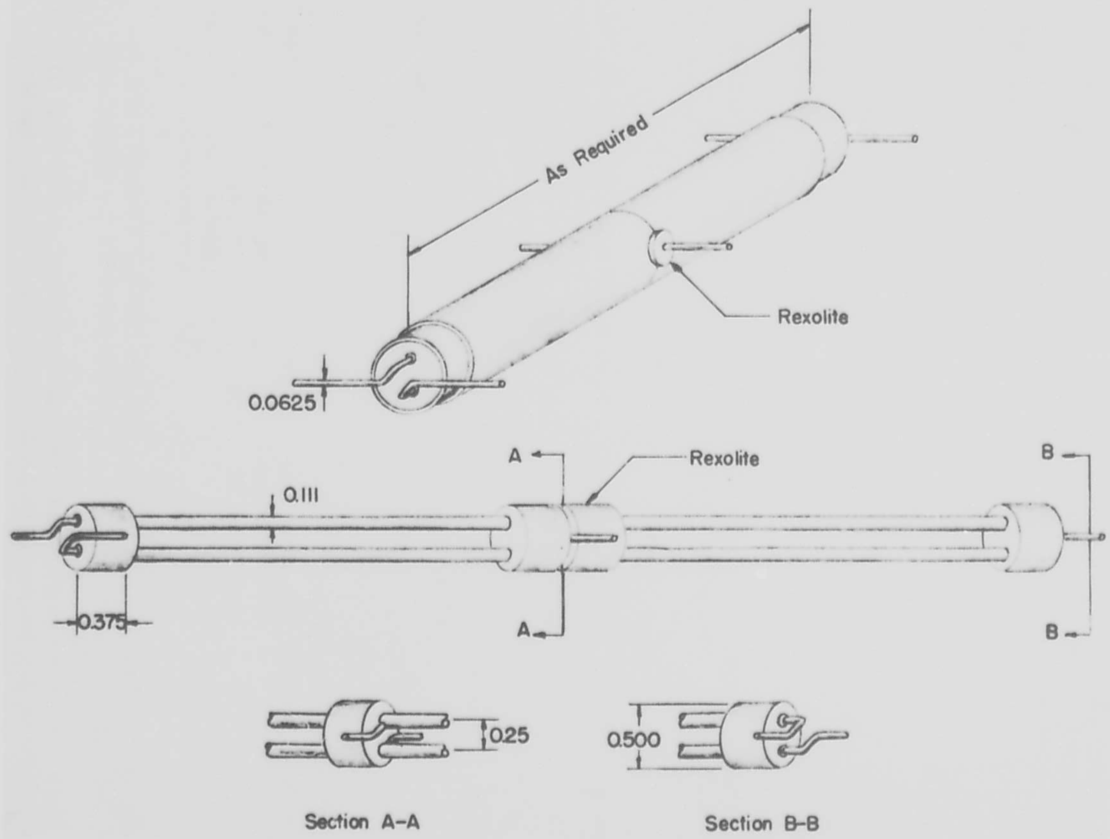


Fig. 7. Balanced two-wire transmission line.

APPENDIX B

SEARCH HEAD AMPLITUDE DATA EVALUATION PROCEDURE

The following instructions, together with the record sheet, Fig. 8 and the minefield sample data, Fig. 9, indicate the systematic procedure used in evaluating all data. The original data recordings and working sheets pertaining to the evaluation are stored in cabinet number 13752, drawer 4, Laboratory #4, Building 362.

INSTRUCTIONS

Col. 1: List search head type, identifying number or symbol, operating frequency and other special features such as reflecting shield size, and spacing.

Col. 2: As listed on test record.

Col. 3: As listed on test record.

Col. 4: Find the total length of the test lane including mined and unmined portions from the beginning of the recorded area up to the vertical line which marks the end of the data to be processed. For ERDL minefield: 1 in. on recorded graph = 20.06 in. on ground.

Col. 5: As listed on test record.

Col. 6: As listed on test record.

Col. 7: As listed on test record.

Col. 8: Make the bottom line of the test record coincide with the bottom of the specially prepared conversion scale; record the equivalent scale reading for every ordinate of the test record at 1/8" intervals for the total length as defined in Col. 4, BUT NOT INCLUDING THE MARKED MINED AREAS. Add all scale readings and record in this column.

Col. 9: List the total number of scale readings made in the preparations of Col. 8.

Col. 10: Divide Col 8 by Col. 9 and record the result.

TEST CONDITIONS							DETERMINATION OF AVERAGE LEVEL					TARGET DETECTION							EVALUATION																
1 Search Head Type, Number & Oper. Freq.	2 Test Lane	3 Test Run Number	4 Total Length of Test Lane	5 Height of Search Head Above Lane	6 Tilt of Search Head in Horiz. Plane	7 Audio Freq. Gain	8 Addition of all Scale Readings	9 Total Number of Scale Readings	10 Calculated Average Level	11 Equivalent Average Level	12 Normalized Equivalent Average Level	13 Ratio of Equival. Av. Level to Largest Mine Signal Peak for Designated Mine Number							14 Evaluation Ratio		15 Evaluation Level		16 Total Number of Anomalies Per Run		17 Total No. of AN/10 ft. Per Run		18 Average Number of Anomalies Per 10 ft.		19 Max. Deviation of Normalized Equivalent Av. Level		20 Equivalent Weighting Factor Due To. Av. Level Variations		21 Figure of Merit	
												#1	#2	#3	#4	#5	#6	#7	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b
			Ft.	In.	Deg.	db	Sc. Units	No.	Sc. Units	db	db	db	db	db	db	db	db	db	db		db		No. of AN		AN/10 ft.		AN/10 ft.		db		AN/10 ft.		AN/10 ft.	
A-2 400 mc	LOAM	100	108	3"	0°	60	19478	436	44.7	33.0	53.0	11.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	18.0	11.0	7.5	42.0	38.5	18	33	1.67	3.06	1.62	2.67	11.5	13.1	1.05	1.75	[illegible]	4.42
		104	108	3"	3°	60	21.004	438	48.0	33.6	53.6	8.9	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	25.0				39.1		33		3.06								
		103	108	3"	6°	60	23.339	433	53.9	34.6	54.6	7.9	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	22.9				40.1		27		2.50								
	LANE	101	108	6"	0°	80	52810	442	119.0	41.5	41.5	13.5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	17.5			30.5	27.0	17	23	1.57	2.13								
		105	108	6"	3°	80	62.910	441	143.0	43.1	43.1	7.9	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	14.4				28.6		32		2.96								
		102	108	6"	6°	80	110.12	439	25.1	48.1	48.1	7.5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	8.0				33.5		25		2.31								

EXAMPLE ONLY

Fig. 8. Evaluation record sheet.

Col. 11: Assigning a value of 1 (0 db) to the bottom line of the test record, compute the average voltage as a db ratio:

$$20 \log \frac{\text{Col. } 10}{1} = \text{Col. } 11$$

Instruction: Draw a red line across the complete test record corresponding to the result of Col. 11, using the following scale: 1 ordinate division of the test record = 2 db.

Col. 12: Normalize Col. 11 to correspond to a gain of 80 db; hence, Col. 11 + (80 db - Col. 7) = Col. 12.

Col. 13: Select the largest peak within each of the areas marked 1 thru 7 on the test record, and list the ratio (db) of these peaks with respect to the equivalent average level, (red line), in the appropriate sub-column. Largest signal peak (db) - Col. 11 = Col. 13.

Col. 14a: Record the lowest ratio as determined in Col. 13 for any mine using test runs of zero degrees tilt only. (Two runs per set of data).

Col. 14b: Record the lowest ratio as determined in Col. 13 for any mine of the complete set of data. (6 test runs)

Instruction: If the number recorded in Col. 14a or 14b is zero or less, enter N.G. in Col. 21a or 21b respectively; and continue the evaluation only for the "a" and/or "b" columns which have values greater than zero in Col. 14.

Col. 15a: Col. 11 + Col. 14a - 2 db = Col. 15a.

Instruction: Draw a blue line across the complete test record corresponding to the result of Col. 15a. (2 runs)

Col. 15b: Col. 11 + Col 14b - 2 db = Col. 15b.

Instruction: Draw a green line across the complete test record corresponding to the results of Col. 15b. (6 runs)

Col. 16a: Count all amplitude peaks for test runs of zero degrees tilt only, (not including the marked mined areas) which exceed the blue line.

Col. 16b: Count all amplitude peaks for each test run of the complete test data, (not including the marked mined areas) which exceed the green line.

Instruction: Five horizontal units on the test record ($1\frac{1}{4}$") shall be considered the maximum width for any peak; hence, each 5 horizontal units or part thereof shall be counted as individual peaks. Also each sudden voltage excursion resulting in a peak of a magnitude at least 2 db above the previous peak shall be counted as an individual peak.

Col. 17a: $\frac{\text{Col. 16a} \times 10}{\text{Col. 4}}$ = Col. 17a

Col. 17b: $\frac{\text{Col. 16b} \times 10}{\text{Col. 4}}$ = Col. 17b

Col. 18a: Add the results in Col. 17a and divide by two.

Col. 18b: Add the results in Col. 17b and divide by six.

Col. 19a: Subtract the higher value from the lower value in Col. 12 for the two 0° tilt runs only, and enter the result.

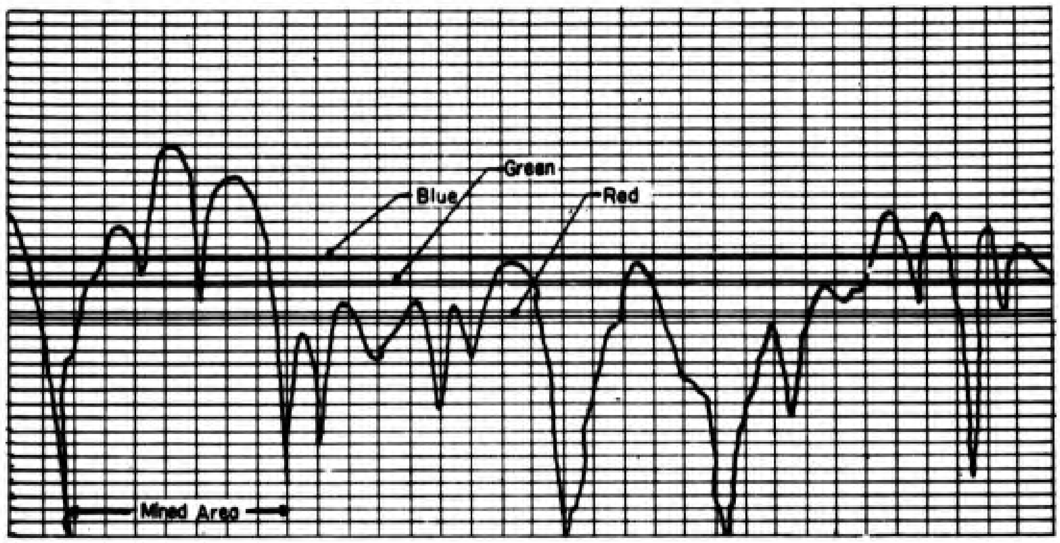
Col. 19b: Find the maximum deviation between any two of the six test runs listed in Col. 12, and enter the result.

Col. 20a: $\frac{\text{Col. 19a}}{\text{Col. 14a}}$ = Col. 20a

Col. 20b: $\frac{\text{Col. 19b}}{\text{Col. 14b}}$ = Col. 20b

Col. 21a: Col. 18a + Col. 20a = Col. 21a.

Col. 21b: Col. 18b + Col. 20b = Col. 21b.



Mine Detection Branch
Mine Field Test Data Sheet

Mine field run no.	100
Preoperation recorder check:	O.K.
Date:	6/6/1955
Detector type:	A-2 400mc (appr.) Scl
Height:	3" - 0° Forward Tilt
Orientation:	Dipoles + to direction of travel
Frequency:	400 mc
A.F. Amplification:	60 db
Recorder input level	(a) U.H.F. and A.F. off: 1.5 µv
Chart scale	(a) Horizontal: 1 in. = 20.06 in on ground (b) Vertical: 1/2 in. = 10 db
Received output impedance:	33 K
Soil type:	Loam test lane

Fig. 9. Sample of field performance data and test record.

APPROVAL OF

Report 1456-RR

AMPLITUDE TYPE SEARCH HEAD INVESTIGATIONS
FOR UHF MINE DETECTORS (U)

8 August 1956

AND

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8-07-04-014

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TO: Chief of Engineers
Department of the Army
Washington 25, D. C.
ENGTN

Report 1456-RR, dated 8 August 1956, and its Proposed Distribution List are submitted for approval.

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SUBJECT: Amplitude Type Search Head Investigation for UHF Mine Detectors

Office of the Chief of Engineers, Department of the Army, Washington 25, D.C.

TO: Commanding General, Engineer Research and Development Laboratories, Fort Belvoir, Virginia

1. Report 1456-RR, subject as above, is approved.

2. The inclosed Distribution List, with changes as noted, is approved.

FOR THE CHIEF OF ENGINEERS:

2 Incls:
1. n/c
2. 4 cys w/d

for H. E. BROWN
Colonel, Corps of Engineers
Chief, Engineer Research and
Development Division

REGRADED Unclassified WHEN SEPARATED FROM CLASSIFIED INCLOSURES

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