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ECOM-2861

USE OF RAILROAD TRACKS FOR CARRIER TELEPHONY AND AS LONG-WIRE ANTENNAS FOR TRANSMISSION OF LONG-WAVE RADIO SIGNALS

By

William Kennebeck
Kurt Ikrath

July 1967

ECOM

UNITED STATES ARMY ELECTRONICS COMMAND · FORT MONMOUTH, N.J.

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RESEARCH AND DEVELOPMENT TECHNICAL REPORT

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William Kennebeck and Kurt Ikrath

July 1967

DA Task No. 1PO-14501-B31A-01-43

U. S. ARMY ELECTRONICS COMMAND
FORT MONMOUTH, NEW JERSEY

ABSTRACT

Investigations have been made of the performance characteristics of man-made structures (i.e., railroad tracks, buried pipes, and sewer lines) for VLF signal transmission. Electromagnetic coupling devices designed for signal transmission are discussed. Signal transmissions over a distance of up to 15 miles were achieved with a consumption of less than 10 watts (nominal 48 kHz) transmitted power. A single ferrite loop was used as a receiver. Impulses picked up along fences and other metal structures denote signal re-radiation by railroad track. Results of these experiments indicate that railroad tracks act as signal ducts, and possibly, long-wave antennas.

FOREWORD

AUTHORIZATION

Research was performed and authorized under DA 0A1743, AMC Code 5011 11 854 01, Project/Task No. 1P0 14501 B31A 01, "Research in Electronics - ECOM".

ACKNOWLEDGMENT

The authors wish to acknowledge the cooperation extended them by personnel of the U. S. Naval Ammunition Depot, Earle, New Jersey, especially Commander G. Rooney, Executive Officer. Appreciation is also accorded Lt. P. Thornton, Public Works Division, and Mr. D. Brundage, Chief Engineer, for their assistance in securing the use of the railroad and pier areas for test purposes.

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INTRODUCTION

Instrumentation and equipment for exploitation of the earth's weathered layer and use as a medium for communications and surveillance are being developed utilizing seismic acoustical and electromagnetic phenomena. Part of this research program is directed toward the development of magnetic couplers for excitation of electrical currents in manmade structures such as buried pipes, railroad tracks, water towers, telephone and power lines and possibly in such physical features of the terrain as creeks, rivers, and the beaches of oceans and lakes.

The technical objectives of this research program are:

(1) Exploitation of structures highly opaque to radio waves and suitable for use as signal ducts. These structures may be located on or underneath the earth's surface.

(2) Utilization of these types of structures to act as secondary radiators and launchers of long-wave radio signals.

(3) Development of the resultant methods and equipments with seismic acoustical counterparts for formation of active seismic electrical feedback and feed-forward systems,[1] for communications and surveillance through solid earth media and along the interfaces between soil and air, and soil and water.

Field experiments during which nominal 48 kHz signals were induced in and picked up from railroad tracks are discussed.

INSTRUMENTATION

1. <u>Transmitter</u>

Figure 1 shows the transmitter setup. An experimental magnetic sheet antenna (coupler) made from iron-powder loaded rubber was used to induce signal currents into the rails of the track. The drive circuit for the coupler consisted of an HP (Hewlett-Packard) Model 200 CD signal generator which fed a Krohn-Hite 50-watt power amplifier. The output of the amplifier was connected by a 4-meter-long RG-17/AU cable to the magnetic coupler via matching coils, an HF ampere meter, and a capacitor. For safety, the coils and meter were mounted in a plastic container.

The coupler was encased in a lucite box and potted in rubber compound. Depending upon local conditions, the coupler may be placed on the rails (as shown in Fig. 1) or under the rails between the ties. In the

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[1] K. Ikrath and W. Schneider: "The Realization of Active Seismic Systems and Their Practical Applications," USAERDL Technical Report No. 2446, April 1964.

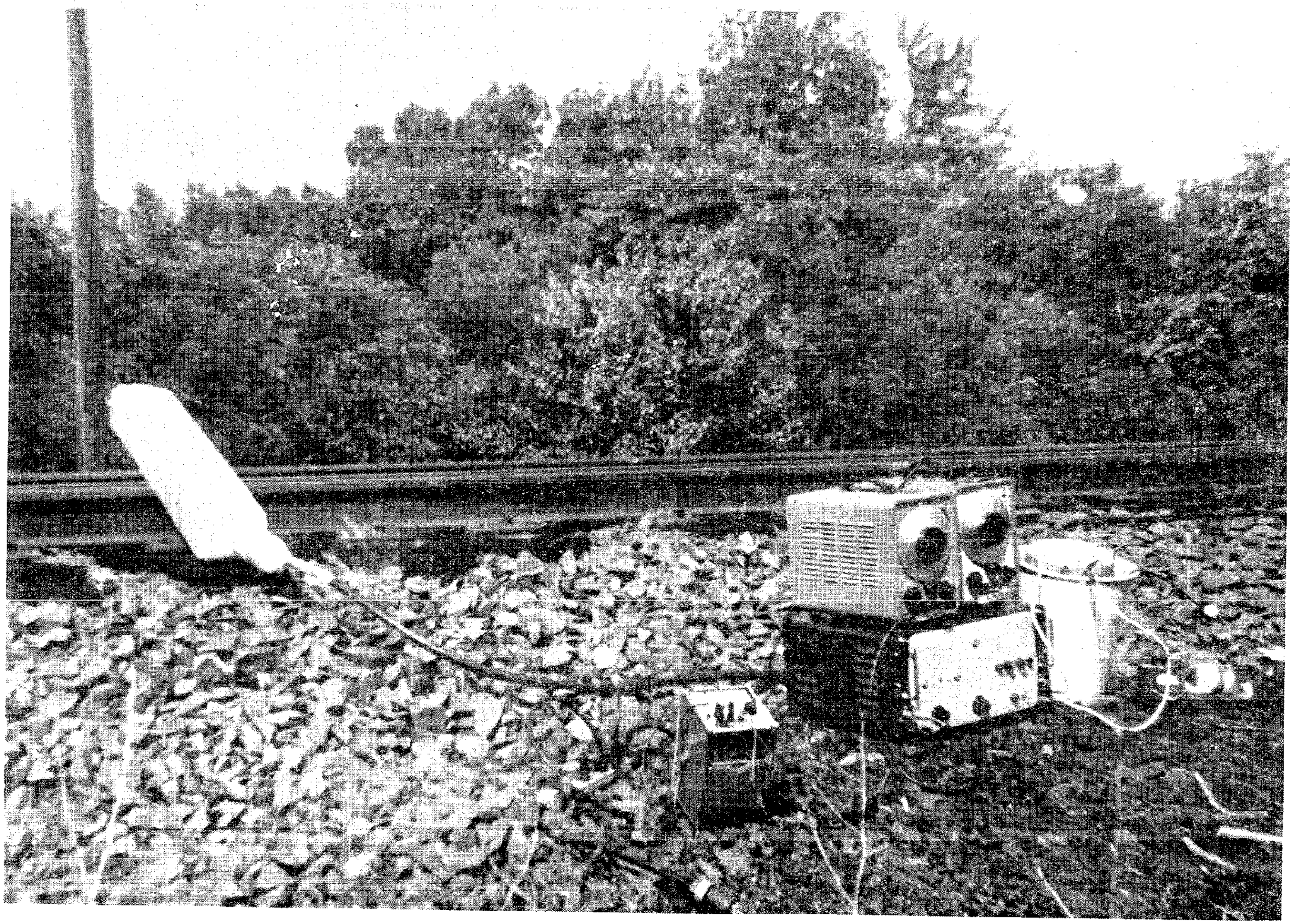


FIG. I TRANSMITTER SET-UP - EARLE-NAVY RAILROAD latter case, some of the ballast gravel or the ashes of the track bed must be removed to make space for the coupler.

2. Receiver

A loop stick made from Type B ferrite and mounted in a small lucite box was used to pick up transmitted signals from the rails and metal structures (usually fences or the steel structures of underpasses and bridges) located in the vicinity of the tracks. Fig. 2 shows this ferrite pickup probe situated on the rails and oriented for maximum signal reception.

The pickup probe was connected via a 7-meter-long RG-58 cable to the input of a HP 203 battery-operated wave analyzer which served as a detector and a meter. The input of this wave analyzer was shunted by a 150 to 1000 pF tuning capacitor. This capacitor was used to tune the pickup probe to the transmitted frequency. Fifty millivolts across this capacitor at resonance corresponds to a current flow of 1 mA RF in the rails.

FIELD EXPERIMENTS ALONG RAILROAD TRACKS

1. Tracks of the Central Railroad Co. of New Jersey

Initial experiments utilizing tracks of the Central Railroad Co. of New Jersey were conducted in the Fort Monmouth area during August 1966. The signals were induced into rails of the railroad siding leading to the warehouse (Bldg. T2506). These tracks are electrically isolated from the main line, being separated therefrom by switches which were open at the time of the experiment.

Railroad maintenance personnel explained the wiring of the signal block system and confirmed that the transmitter site was electrically isolated from the main line. The rails of the loading siding were not electrically bonded and consequently had extremely high contact resistances (4 ohms) at joints between rail sections. This was confirmed by measurements of the galvanic voltage drop across a joint. For this purpose, a loop was made by shorting the rails with braid wire before and after a joint. A one-ampere 48-kHz current was induced into the loop by setting the coupling perpendicular to the ground into the center of the loop. The minima of the signals in rail one and rail two at a distance of 700 feet from the transmitter are tentatively attributed to the shorting of the rails by a flatcar located at that distance. Subsequent equalization of signals at larger distances in both rails tends to confirm this effect (See Fig. 3).

Spot checks of signals received from the transmitter site near Bldg. T2506 were made at:

a. The Hope Road railroad intersection

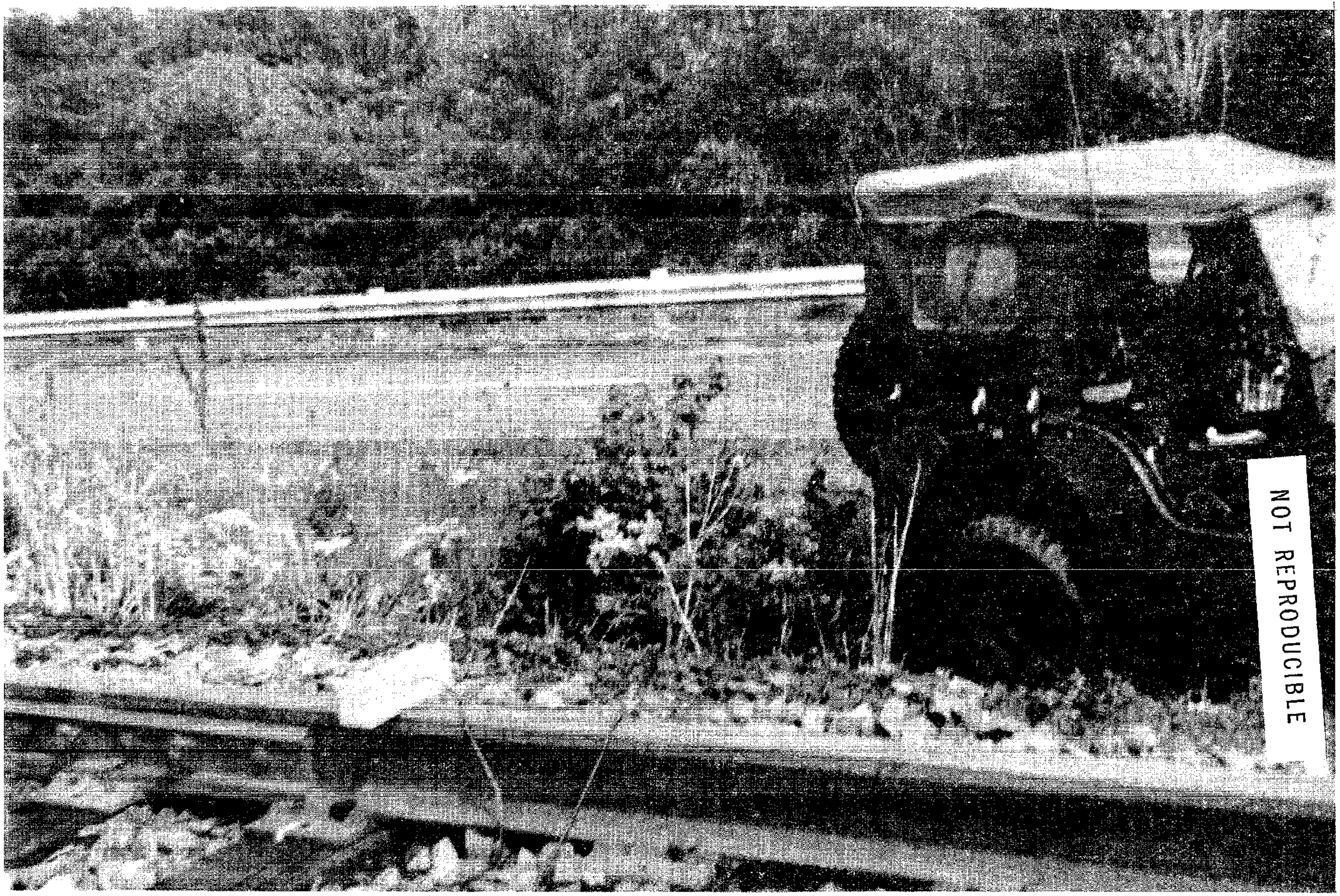
b. The Eatontown Railroad Station

c. The Sycamore Avenue railroad intersection

d. The Stavola asphalt plant railroad intersection

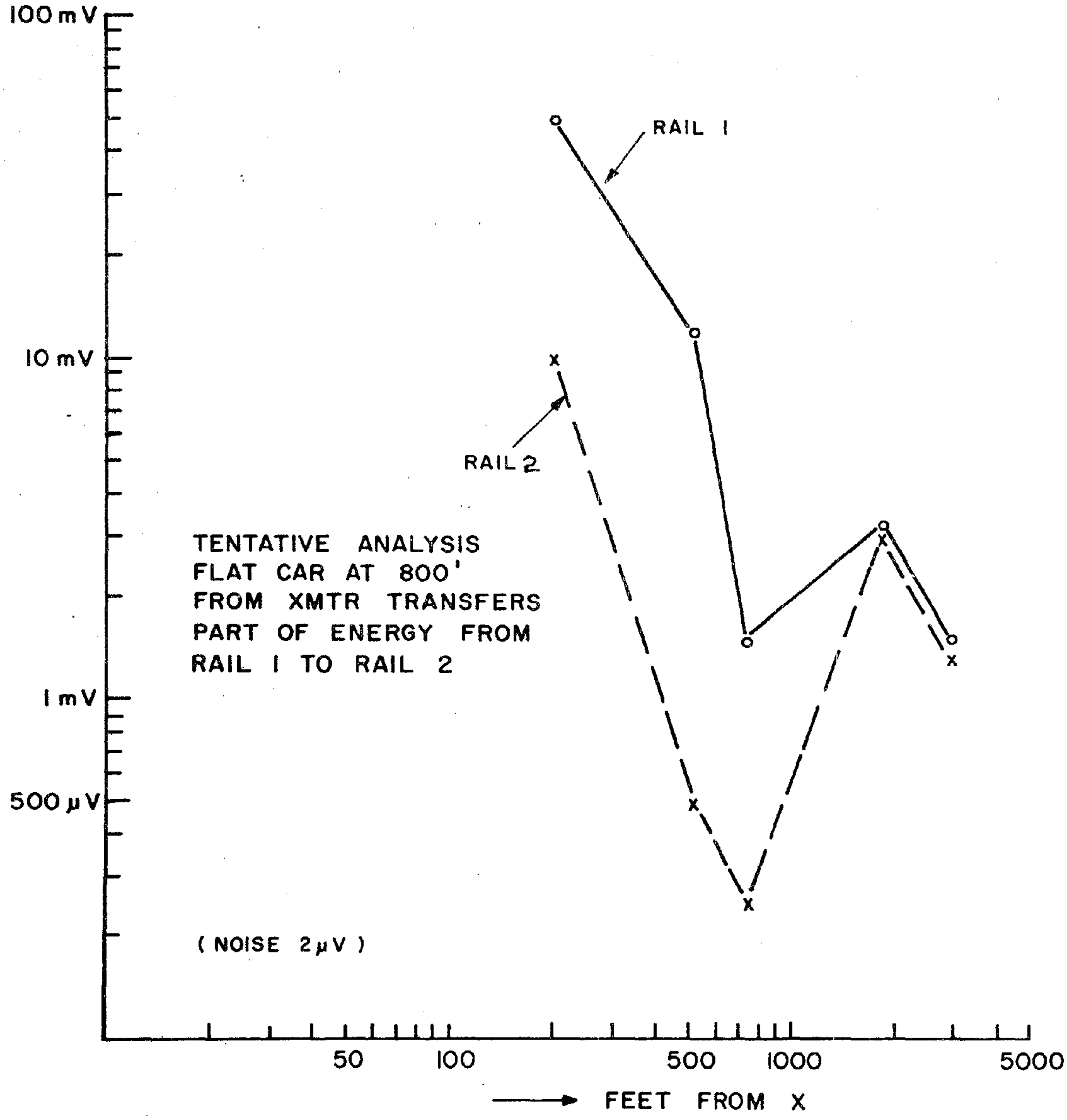
e. Garden State Parkway bridges in the vicinity of Ft. Monmouth.

The signals induced into the rails at Bldg. T2506 were easily detectable at all locations.



RECEIVER SET-UP - EARLE-NAVY RAILROAD

FIG. 2 RECEIVER FERRITE COUPLED RAIL



48 Kc SIGNAL VS DISTANCE ALONG
NJCRR TRACKS
FT. MONMOUTH AREA
(XMTR: LOGISTIC WAREHOUSE BLDG. T 2506)
AUG. 19 1966

FIG. 3

In one case, the probe was laid under a rail on the roadbed so as to observe the effects of a passing freight train on the received signal level. The passing of the freight train produced a slight modulation of the signal apparently caused by mechanical variations in the separations between the rail, the probe, and the rail roadbed due to the weight of the cars. When the pickup probe was placed beneath the rails, received signal levels were slightly less than those obtained with the probe on the rail.

2. Tracks of the Naval Ammunition Depot Railroad, Earle, N. J.

Measurements of signal strength versus distance were made along the NAD Earle railroad (Fig. 4): (a) From Scobeyville to Leonardo (b) at Lincroft, and (c) on the Leonardo Pier.

a. Scobeyville to Leonardo (7 September 1966)

The transmitter was placed near the NAD Earle railroad sentry building, Gate 52 (Milepost 4 of Fig. 4). The magnetic sheet antenna (coupler) was placed perpendicular to the track on the first rail (which is the easterly rail of the two tracks) in a slightly oblique position (Fig. 1). Resonant coupling to the rail was achieved at 48 kHz. A resonant current of 1.8 A was used.

The received signal levels, indicated by the voltage readings of the HP 203A wave analyzer, were obtained with the ferrite loop stick placed perpendicular to the rails (Fig. 2) at various distances of up to 12 miles to the north, almost up to the Leonardo Pier terminal (Fig. 4).

Reception of the 48-kHz CW signal was confirmed at all locations by reporting, via a PRC-9 radio, the on-off state of the 48-kHz transmission to the transmitter site. Beyond the PRC-9 range, reporting was accomplished by telephoning from the sentry building at Gate 53 (Leonardo) to Gate 52 (Scobeyville).

Resultant measurement data are graphically plotted in Fig. 5. Mileage was derived from the mileage counter of an automobile driven on the road which parallels the railroad tracks. Corresponding mileposts of the railroad are indicated in the plot of Fig. 5.

b. Lincroft (19 September 1966)

The setup and measurement procedures were the same as those used for the 7 September 1966 transmission experiments from Scobeyville to Leonardo. This time the transmitter location was chosen to be roughly halfway between the southern and northern ends of the railroad (0.2 miles north or Milepost 8). This choice was made to determine the extent to which railroad track bends and the location of the transmitter influence the distribution of the maxima and minima of the signal amplitude versus distance curves.

The magnetic rubber-sheet antenna (coupler) was damaged in previous underwater transmission experiments (made between Oceanport and Little Silver at Horseneck Point, on 16 September 1966), when sea water

MAP OF EARLE-N

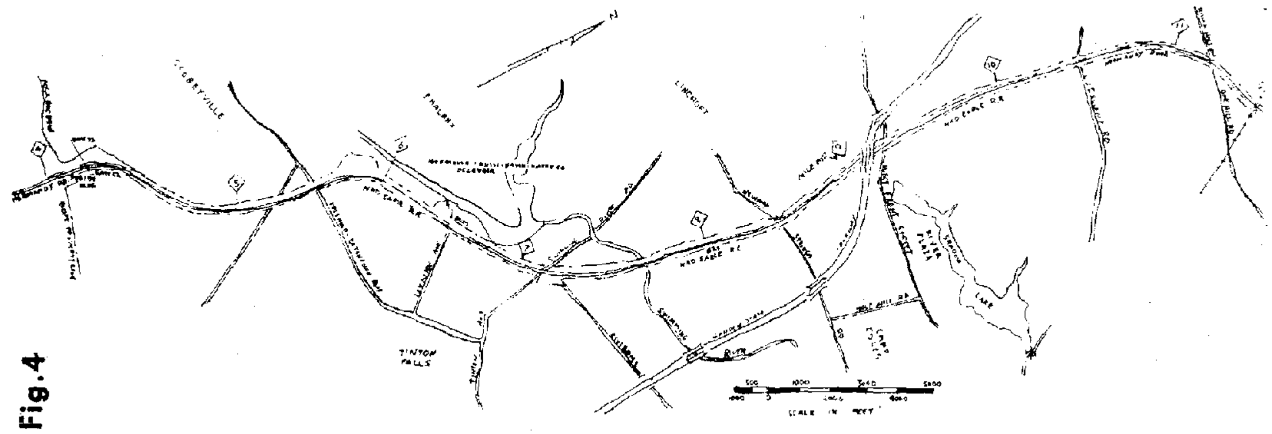
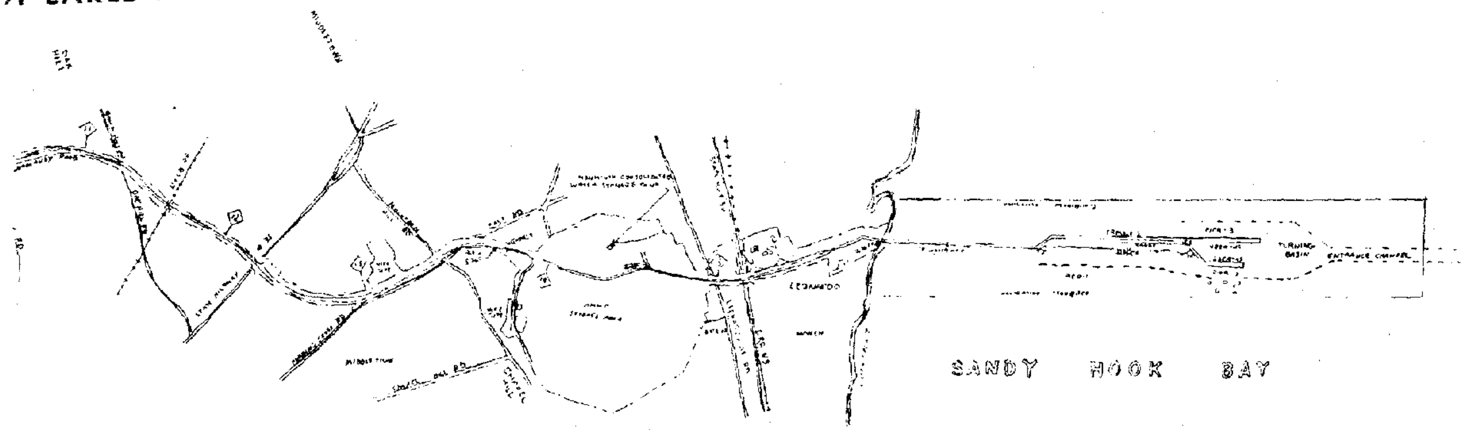


Fig.4

)F EARLE-NAVY RAILROAD



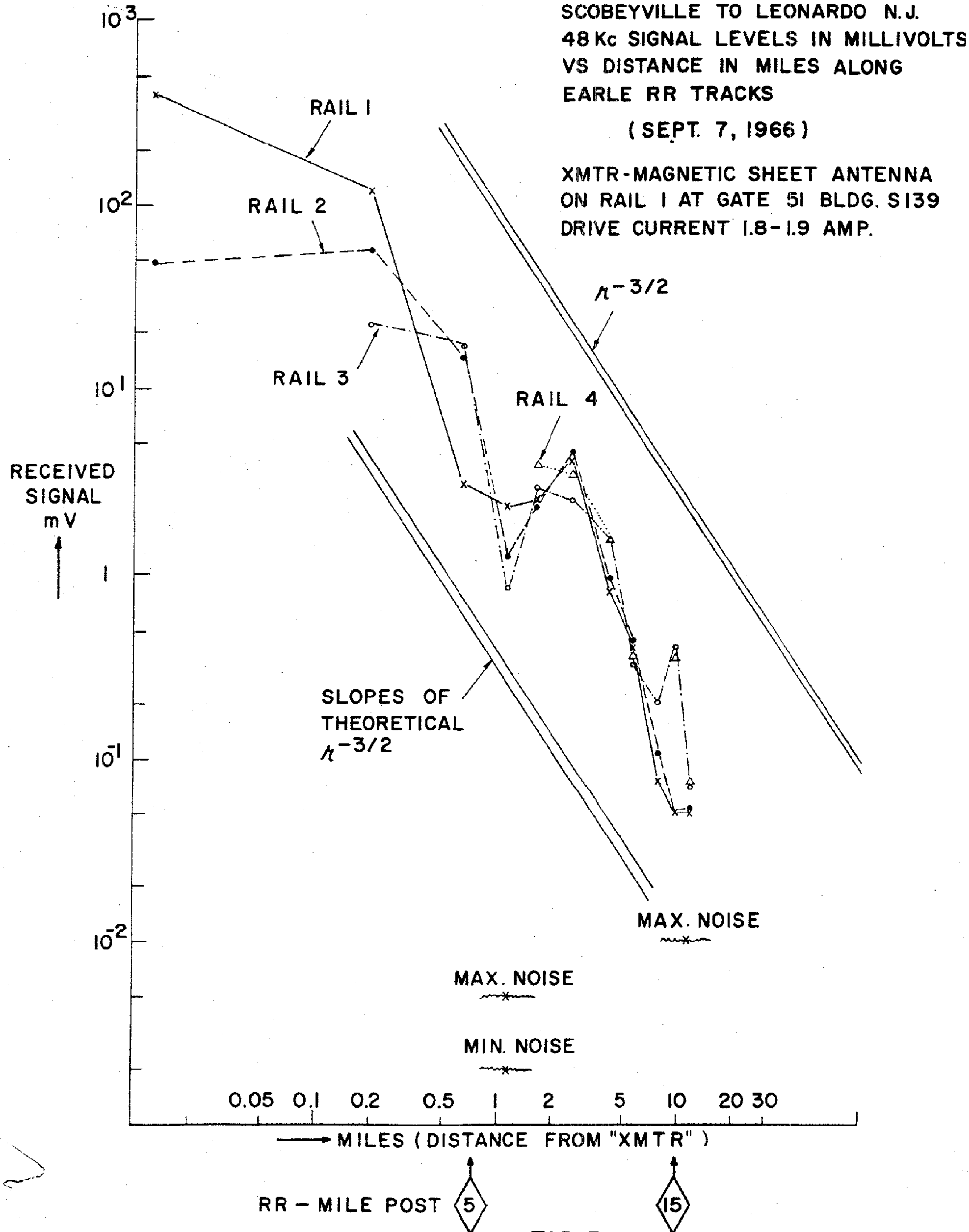

SCOBEYVILLE TO LEONARDO N.J.
48 Kc SIGNAL LEVELS IN MILLIVOLTS
VS DISTANCE IN MILES ALONG
EARLE RR TRACKS
(SEPT. 7, 1966)
XMTR-MAGNETIC SHEET ANTENNA
ON RAIL 1 AT GATE 51 BLDG. S139
DRIVE CURRENT 1.8-1.9 AMP.
RAIL 1
RAIL 2
RAIL 3
RAIL 4
$r^{-3/2}$
SLOPES OF
THEORETICAL
$r^{-3/2}$
RECEIVED
SIGNAL
mV
10^3
10^2
10^1
1
10^{-1}
10^{-2}
MAX. NOISE
MAX. NOISE
MIN. NOISE
0.05 0.1 0.2 0.5 1 2 5 10 20 30
MILES (DISTANCE FROM "XMTR")
RR – MILE POST
5
15

FIG. 5

seeped into the lucite case.* For this reason, the originally used resonant current of 1.8 A could not be attained. Instead, the damaged coupler could tolerate no more than 1 A; hence, signal amplitude versus distance curves were measured at corresponding lower signal levels only, over distances of up to 4 miles to the north and to the south of the transmitter. This transmitter was located between Scobeyville and the Earle pier at the halfway point of the Earle railroad, which is south of the railroad bend at the Newman Springs Road railroad crossing (Fig. 4). Results of these measurements are plotted in Fig. 6. Signal propagation to the north differs from that to the south, indicating the influence of the bend very clearly by the larger attenuation.

Measurements of the signal levels away from the rails were made at a height of 7 to 8' above the tracks at the Garden State Parkway-NAD Earle railroad underpass, 0.9 miles north from the transmitter location. The amplitude of the received signal was about 40 microvolts; the signal to noise voltage ratio was approximately 4 to 1. The signal was also detectable (15 microvolts) by holding the pickup probe close to the metal guard frame mounted over the railroad tracks before the entrance to the Garden State Parkway underpass.

c. Leonardo Pier (7-8 September 1966)

Experiments were conducted on the railroad pier at Leonardo to verify the influence of the underlying medium on the signal propagation along the railroad tracks. On the pier, the "height" of the tracks above the electrical "ground" (the sea water) is well defined by the distance between the pier and the sea water surface. The electrical ground in the case of railroads on soil is an unknown quantity.

Results of an experiment involving magnetic excitation of the tracks at the sea terminal of the pier are shown in Fig. 7. Fig. 8 illustrates results of the excitation of the tracks at the land terminal of the pier. These results also include the attenuation effect of a nearby crossbar rail switch, which tends to short out the signal propagating towards the south.

The shorting effect of the crossbar rail switch was overcome by obliquely mounting the coupler to the water pipe under the pier. This water pipe feeds the fire hydrants on the pier. Results in the form of curves representing signal levels versus distance on pipe, rails, and water surface are plotted in Fig. 9.

RESULTS AND DISCUSSION

Results of the NAD Earle railroad tests were remarkable, not only in regard to the transmission range of over 10 miles obtained with simple instrumentation and methods, but especially with respect to the measured signal versus distance attenuation law as derived from the plot of Fig. 5.

By connecting signal maxima or signal minima with a straightedge (as indicated by the double lines in Fig. 5), it is recognized that the average attenuation is of the $r^{-3/2}$ type (3 decades down on the ordinate, and 2 decades to the right along the abscissa of the log-log plot). A similar trend appears in the plots in Fig. 6.

*It was found later that the rubber potting compound had failed to prevent sea water seepage as the rubber had remained liquid instead of hardening as expected.

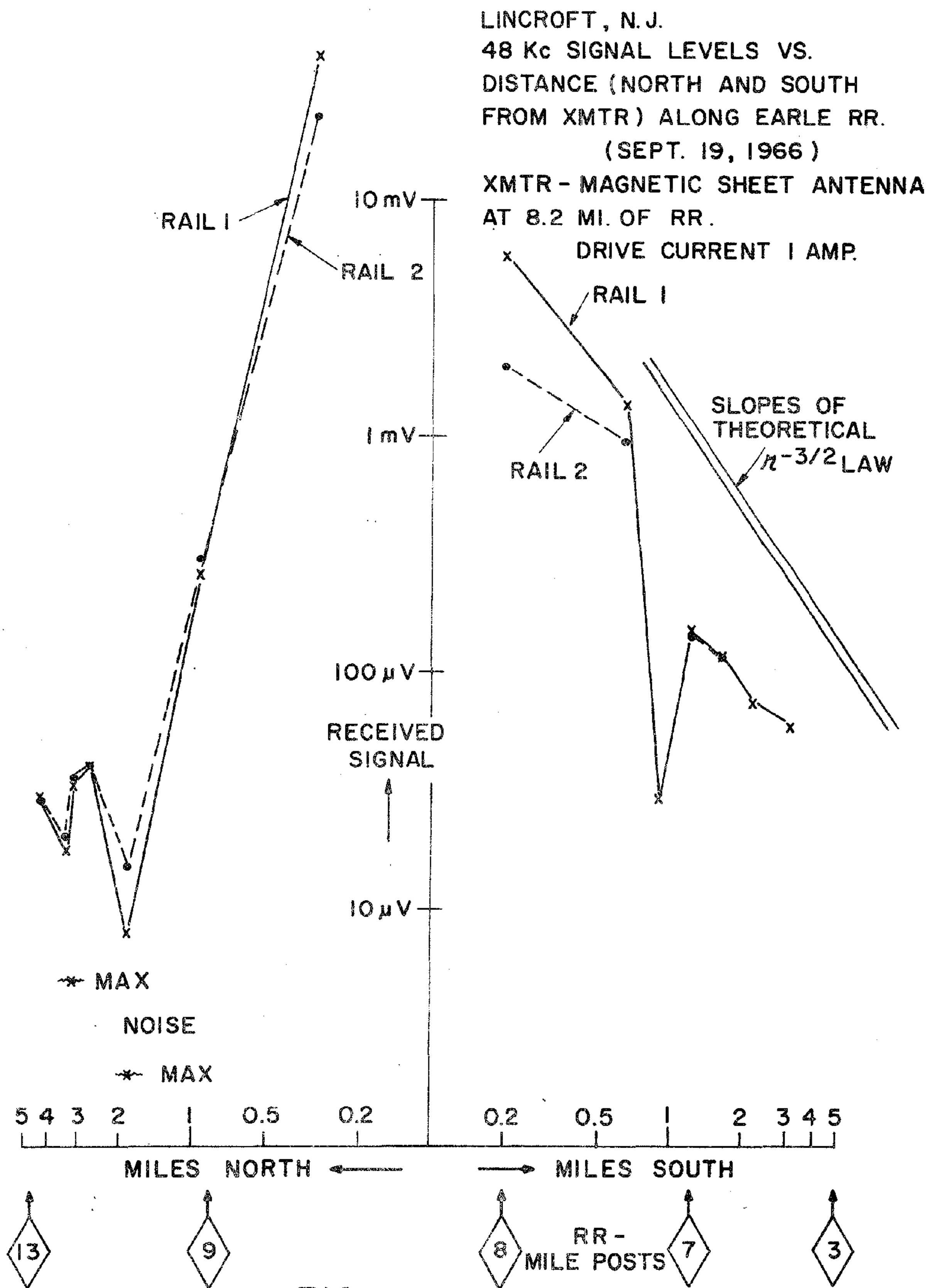

LINCROFT, N. J.
48 Kc SIGNAL LEVELS VS. DISTANCE (NORTH AND SOUTH FROM XMTR) ALONG EARLE RR.
(SEPT. 19, 1966)
XMTR - MAGNETIC SHEET ANTENNA AT 8.2 MI. OF RR.
DRIVE CURRENT 1 AMP.
RAIL 1
RAIL 2
RAIL 1
RAIL 2
SLOPES OF THEORETICAL $r^{-3/2}$ LAW
10 mV
1 mV
100 μV
10 μV
RECEIVED SIGNAL
MAX
NOISE
MAX
5 4 3 2 1 0.5 0.2
0.2 0.5 1 2 3 4 5
MILES NORTH
MILES SOUTH
13
9
8
7
3
RR - MILE POSTS

FIG.6

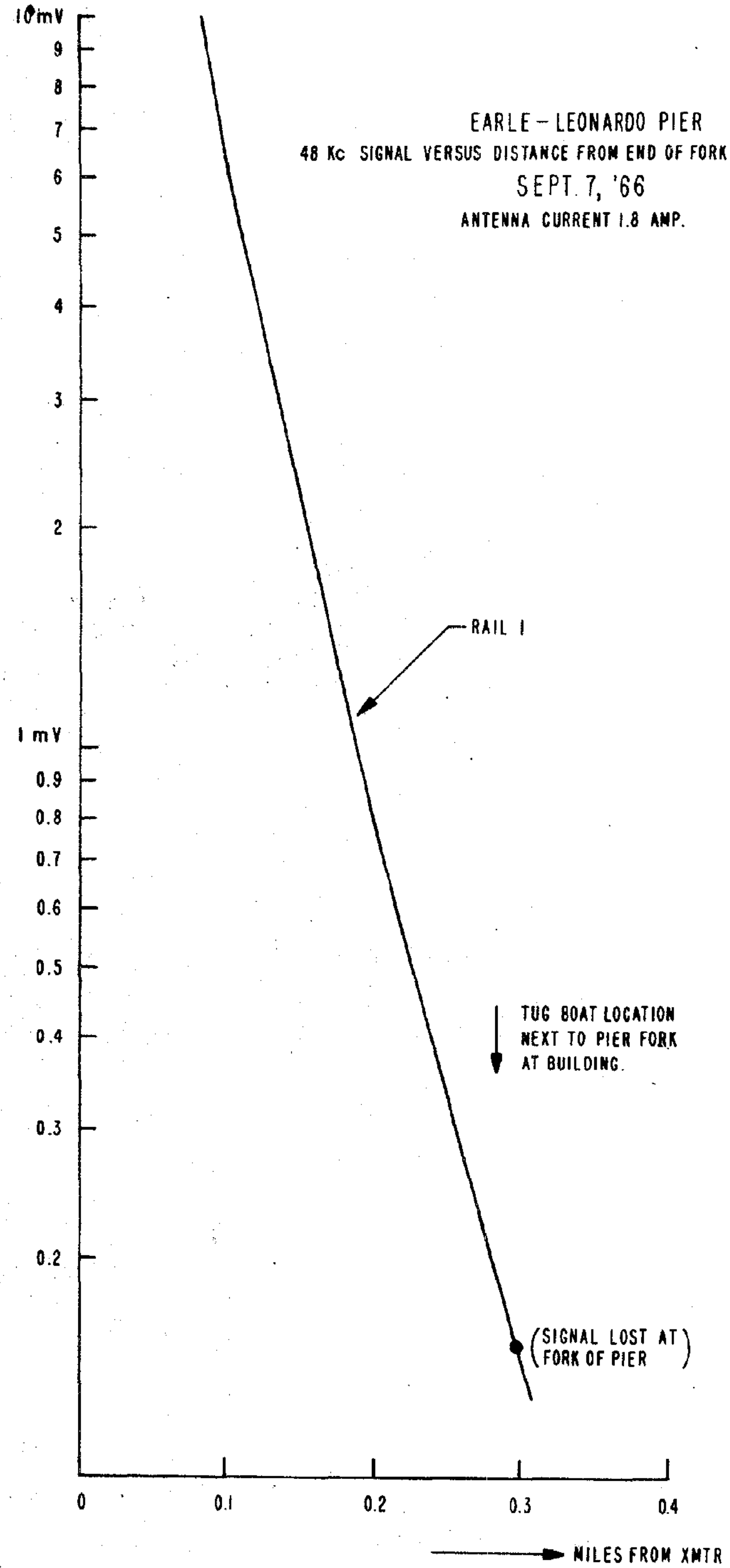

EARLE - LEONARDO PIER
48 Kc SIGNAL VERSUS DISTANCE FROM END OF FORK TOWARD LAND
SEPT. 7, '66
ANTENNA CURRENT 1.8 AMP.
10 mV
9
8
7
6
5
4
3
2
1 mV
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
RAIL 1
TUG BOAT LOCATION NEXT TO PIER FORK AT BUILDING.
(SIGNAL LOST AT FORK OF PIER)
0
0.1
0.2
0.3
0.4
MILES FROM XMTR

FIG. 7

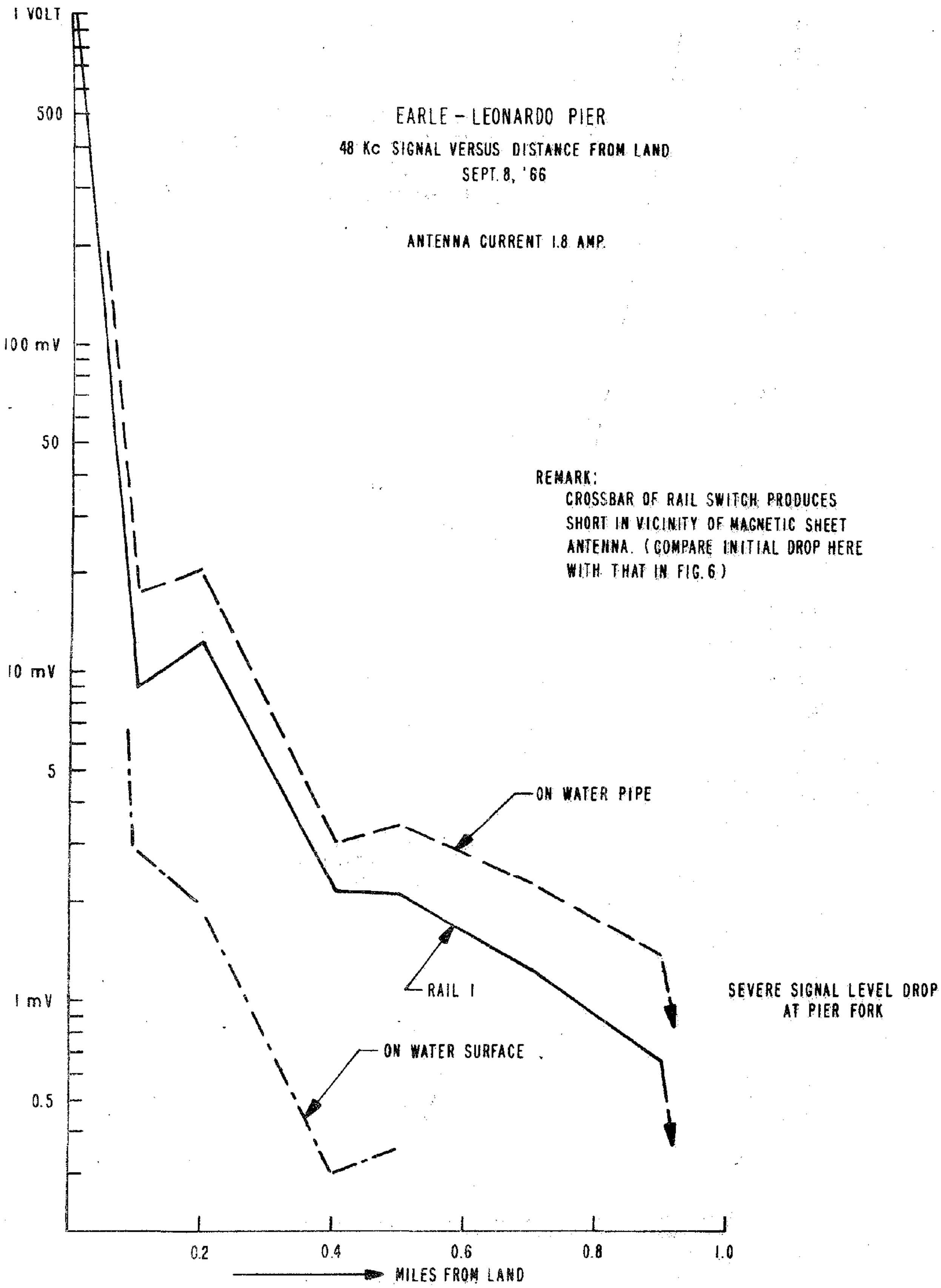

EARLE - LEONARDO PIER
48 Kc SIGNAL VERSUS DISTANCE FROM LAND
SEPT. 8, '66
ANTENNA CURRENT 1.8 AMP.
REMARK:
CROSSBAR OF RAIL SWITCH PRODUCES SHORT IN VICINITY OF MAGNETIC SHEET ANTENNA. (COMPARE INITIAL DROP HERE WITH THAT IN FIG. 6)
1 VOLT
500
100 mV
50
10 mV
5
1 mV
0.5
ON WATER PIPE
RAIL 1
ON WATER SURFACE
SEVERE SIGNAL LEVEL DROP AT PIER FORK
0.2
0.4
0.6
0.8
1.0
MILES FROM LAND

FIG. 8

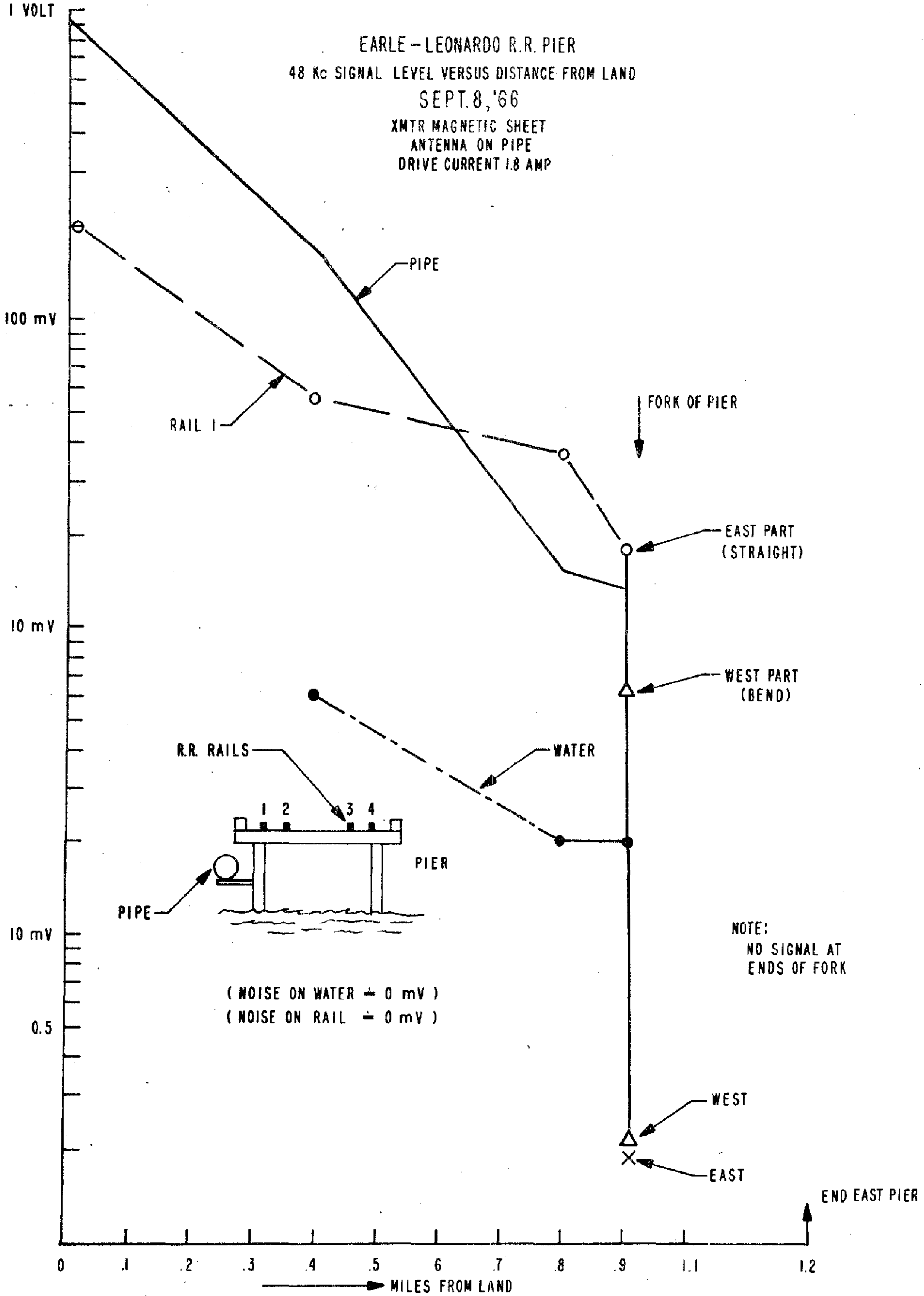

EARLE - LEONARDO R.R. PIER
48 Kc SIGNAL LEVEL VERSUS DISTANCE FROM LAND
SEPT. 8, '66
XMTR MAGNETIC SHEET
ANTENNA ON PIPE
DRIVE CURRENT 1.8 AMP
1 VOLT
100 mV
10 mV
10 mV
0.5
PIPE
RAIL 1
FORK OF PIER
EAST PART
(STRAIGHT)
WEST PART
(BEND)
WATER
R.R. RAILS
1 2 3 4
PIER
PIPE
NOTE:
NO SIGNAL AT
ENDS OF FORK
(NOISE ON WATER ≐ 0 mV)
(NOISE ON RAIL ≐ 0 mV)
WEST
EAST
END EAST PIER
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.1
1.2
MILES FROM LAND

FIG. 9

Upon inspecting the railroad map in Fig. 4 and the curves in Fig. 5, one notices a correlation between bends of the tracks and the minima and maxima of the signal level versus distance curves. This correlation is verified by the signal level versus distance curves given in Fig. 6. Here, the deep minimum at about 1 mile to the south of the transmitter occurred at the sharp bend of the railroad in the vicinity of the Swimming River Reservoir (Milepost 7 of railroad in Fig. 4). Similarly, the minimum at about 2 miles north from the transmitter occurred at the sharp bend of the railroad in the vicinity of Oakhill Road (Milepost 11 of railroad in Fig. 4). High signal levels (maxima), on the other hand, were observed in those regions where straight sections of the track were essentially parallel to those in the transmitter region. The observed correlation of signal minima and maxima with bends of the railroad tracks indicates that radiation is involved.

Results obtained at the Leonardo pier reveal an entirely different attenuation law (Figs. 7, 8, and 9). These semi-log plots show the signal decay as an essentially straight line up to the pier fork where it abruptly vanishes. This is consistent with exponential decay along transmission lines. Hence, there is no doubt that signal propagation along tracks located on the soil involves modes different from those conventionally associated with transmission lines above a highly conductive ground. Further, excitation at the electrically open seaward end of the pier is shown to be extremely inefficient, leading to strong signal decay within a short distance from the magnetic coupler.

CONCLUSIONS

The results of these exploratory experiments and measurements prove that utilization of railroad tracks for ducting and launching of VLF signals is practical.

RECOMMENDATIONS

It is recommended that:

1. Special experimental devices such as transmitter to rail couplers and signal pickup probes be designed and constructed. Particular emphasis must be given to the development of mechanical configurations and features which (a) do not interfere with or obstruct railroad traffic and (b) permit the selection of various operating frequencies for relay transmissions.

2. A concurrent theoretical investigation of the phenomena involved be conducted.

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13. ABSTRACT

Investigations ~~have been~~ were made of the performance characteristics of manmade structures (i.e., railroad tracks, buried pipes, and sewer lines) for VLF signal transmission. Electromagnetic coupling devices designed for signal transmission are discussed. Signal transmissions over a distance of up to 15 miles were achieved with a consumption of less than 10 watts (nominal 48 kHz) transmitted power. A single ferrite loop was used as a receiver. Impulses picked up along fences and other metal structures denote signal re-radiation by railroad track. Results of these experiments indicate that railroad tracks act as signal ducts, and possibly, long-wave antennas.

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