NOLTR 61-76

RADIO DIRECTION FINDING OVER A TROPOSCATTER PATH

PART I: GENERAL DESCRIPTION

N-62-3-6

1 AUGUST 1961

NOL

UNITED STATES NAVAL ORDNANCE LABORATORY, WHITE OAK, MARYLAND

NOLTR 61-76

RADIO DIRECTION FINDING OVER A TROPOSCATTER PATH

PART I: GENERAL DESCRIPTION

Prepared by:

R. S. Hebbert and E. H. Hug

ABSTRACT: Measurements of fluctuations (from the great circle path to a transmitter) in the bearing estimates of a microwave interferometer were made at 910 mcs with the transmitter located beyond the horizon. This report presents a general description of the apparatus and some experimental results. The standard deviations of the bearing estimates were typically of the order of 1/10 degree for averaging times longer than 10 seconds, larger fluctuations being observed on over-land than over-water paths due to asymmetries in the cross-path geometry coupled with humidity differences.

U. S. NAVAL ORDNANCE LABORATORY
WHITE OAK, MARYLAND

NOLTR 61-76 1 August 1961

This is the first of three reports which present the results of a feasibility study of using a trans-horizon microwave interferometer as a direction standard for experimental ship-to-ship sonar devices. It is supported through the Acoustics Division and the Subroc Technical Advisory Group by the Bureau of Naval Weapons Task No. 3E001. This work has, in addition, resulted in the system design of an interferometer bearing standard now on contract to private industry.

W. D. COLEMAN
Captain, USN
Commander

Zaka I Slawsky
Z. I. SLAWSKY
By direction

CONTENTS

ILLUSTRATIONS

RADIO DIRECTION FINDING OVER A TROPOSCATTER PATH

PART I: GENERAL DESCRIPTION

INTRODUCTION

1. Ultra high frequency and microwave interferometers have long been used in satellite trackers and radio telescopes over line-of-sight source to receiver paths. This report describes the program undertaken to evaluate the feasibility of tracking a one kilomegacycle transmitter located beyond the horizon by means of an interferometer. If the study showed the method to be feasible, the program was to result in the system design for an interferometer direction standard intended to provide a reference bearing of a target ship with respect to a buoy equipped with experimental acoustical direction finding devices.

2. Energy is propagated beyond the horizon by scattering from atmospheric inhomogeneities that are constantly shifting; hence the feasibility of tracking a troposcatter transmitter hinges on two questions, namely:

A. How long will it take to achieve a prescribed accuracy in the face of fluctuations in the direction of arrival of the signal?

B. Can semi-permanent (one hour say) errors in the bearing occur due to fronts, storms or other meteorological phenomena?

3. It is also necessary to investigate the factors influencing the choice of interferometer baseline.

4. These questions have been investigated experimentally and sufficient theory developed to permit analysis of the data and guide in apparatus design. The theory is phenomenological but, combined with the results obtained, may be related to more physical theories of atmospheric turbulence and tropospheric propagation. The theory and conclusions concerning the limitations of radio direction finding over a troposcatter path will appear in companion reports. The scope of this report will be the equipment used along with typical data obtained to illustrate its actual operation on troposcattered signals.

SYSTEM DESCRIPTION

5. The function of a radio interferometer is to measure the phase difference of two radio signals and infer the bearing to their source. A system was devised which will plot on a CRT the phase difference and mean amplitude of the signals with approximately one second smoothing. The system is considered in three parts: reception and conversion, phase measurement, and manner of presentation. The complete system is shown in block form in Figure 1.

A. Reception and Conversion

The signals from two four foot parabolic antennas at 910 mcs are converted by separate front ends to an intermediate frequency of 30 mcs (the phase of one being shifted linearly in time), added, and the sum converted to 10 kcs. At this point, the sum signal is a vector quantity, the phase and magnitude corresponding to that of the sum of the two signal vectors (one shifted in phase), as shown in Figure 2. Detection produces a signal corresponding to the magnitude of the sum vector.

B. Phase Measurement

A phase shift, linearly dependent on the bias voltage supplied by a saw tooth source is added to the phase of one of the two original signals. This additive phase goes through 360 degrees in an interval of 1/7 second and proceeds linearly in time so that the magnitude of the sum vector is periodic at seven cycles/second. A pulse generator determining the rate and phase of the saw tooth bias is now a source of reference phase since the additive phase is always zero just at the time of the pulse as shown in Figure 3. The detected signal, a noisy sinusoid of 7 c/s is filtered by a narrow band mechanical filter to obtain the desired averaging time before presentation.

C. Manner of Presentation

The 7 c/s sinusoid is divided into quadrature components and the two components placed on the horizontal and vertical deflection terminals of a CRT. The diameter of the resulting circular trace is approximately proportional to the mean signal amplitude. The reference pulse train is placed on the Z axis to produce a bright spot along the circumference, its position corresponding to the phase difference at the antennas. Since relative phase drifts in the separate front ends and antenna cables are inevitable, a phase referencing system is required. This is accomplished with three antennas as shown in Figure 4. The angular bearing of the transmitter with respect to the normal to the antennas' baseline is obtained from the phase difference between the center left and center right pairs of antennas.

6. A word of justification is appropriate at this point regarding the choice of the interferometer configuration in these experiments.

7. For a signal in the presence of additive gaussian noise, the optimum detector (in several senses of the word "optimum") is the correlation detector, which, in essence, gives an output which is proportional to the component of a signal vector in the "direction" (in the Hilbert space sense of "direction") of a reference signal vector. In the system under consideration, the signal at one antenna is taken to be the reference signal, and the phase angle to the signal vector determined from the pair of components, one between signal and reference, and the other between the quadrature-to-signal and reference. Elementary calculations would show that this pair of components can be obtained as the products of the stable oscillator (cf. Figure 1) with the pair of outputs of the phase splitter. The method of display used in Figure 1 is equivalent with the advantage of presenting the origin of co-ordinates.

8. In an earlier form of the interferometer, the signals were carried on separate channels to the lowest frequency (10 kc) before combining. Excessive short term system phase fluctuations were encountered due to relative instabilities in the separated amplifier mixer chains. The single channel strategy employed for this report has overcome these fluctuations sufficiently for our measurements.

SOME EXPERIMENTAL RESULTS

9. Experiments were conducted for several months (December, 1960 through mid April, 1961) over a 110 mile path from the vicinity of Onancock, Virginia to the Naval Ordnance Laboratory. From the profile map (cf. Figure 8) this path is seen to be roughly 2/3 over water and 1/3 over land with the rays from the Naval Ordnance Laboratory to the common scatter volume passing close to the ground at several points twenty to thirty miles distant from the Naval Ordnance Laboratory. During early April, a search was made with 14 foot antenna spacing, using automatic recording equipment for possible long term deviations from the mean bearing angle. The deviations observed were typically small, of the order of

0.1 degrees in bearing and hence uncertain but occasional larger deviations were observed in the evenings. On April 3rd, a shift beginning in mid afternoon gradually increased to about 0.4 degrees bearing by 10:00 p.m. and then suddenly disappeared. A possible explanation would be water vapor gradients over hills adjacent to the path where the path is close to the ground. If this explanation is true, such a shift would not be expected on a purely over water path.

10. The photographs of Figure 7 display a characteristic property of the troposcatter medium, the decrease in correlation between the channel signals with increasing antenna separation. Associated with the decrease in correlation is the decrease in the mean distance of the points from the origin and increase in the angular standard deviation to the point where the distribution encloses the origin (cf. Figure 7(c)). These photographs imply a correlation length of some 40'; however, the correlation length varies widely and can be of the order of 15' or less on the same day.

11. From 26 April to 13 May 1961, the interferometer operated on a 75 mile over water path from a field station near Onancock, Virginia (37° 45'N, 75° 47'W; ant. elev. 0') to the Chesapeake Bay Annex of the Naval Research Laboratory (38° 41'N, 76° 32'W; ant. elev. 130'). Two minute photographs of the CRT screen with the referencing scheme of Figure 4 operating (cf. Figure 5 for example) were taken several times an hour. Figure 6 shows the hourly averages during a four day run. Due to a light leak, data was lost during daylight hours. This data revealed no systematic bearing shifts larger than 0.1°.

CONCLUSION

12. Equipment has been described and preliminary results presented for a troposcatter radio interferometer. This report will be followed by one on the theory of interferometry with statistical signals, and one compiling data pertaining to the accuracy and limitations of this type of interferometer.

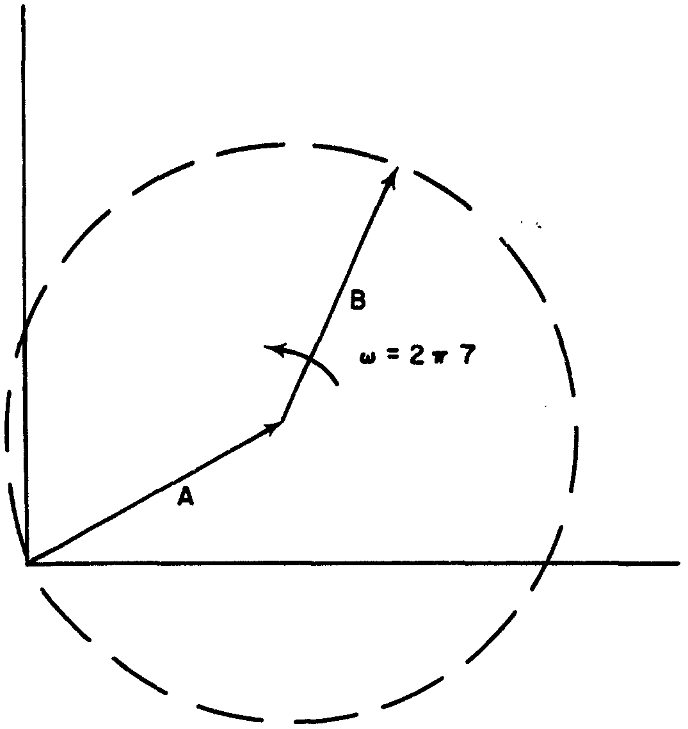


FIG. 2 PHASOR DIAGRAM FOR SUM SIGNAL

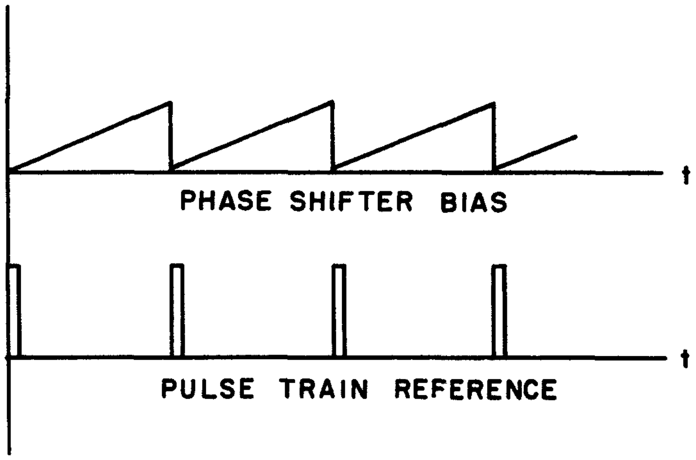


FIG. 3 VOLTAGES RELATING TO PHASE MEASUREMENT

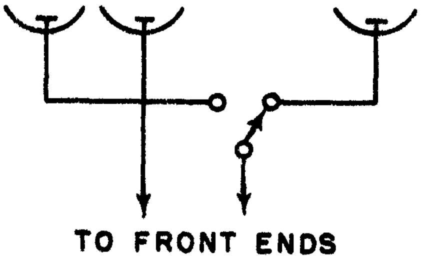


FIG. 4 REFERENCING SCHEMES

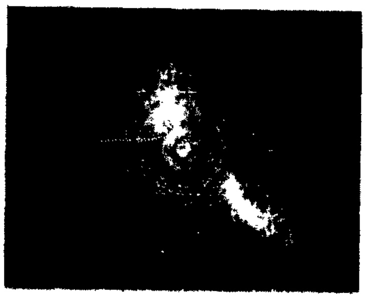
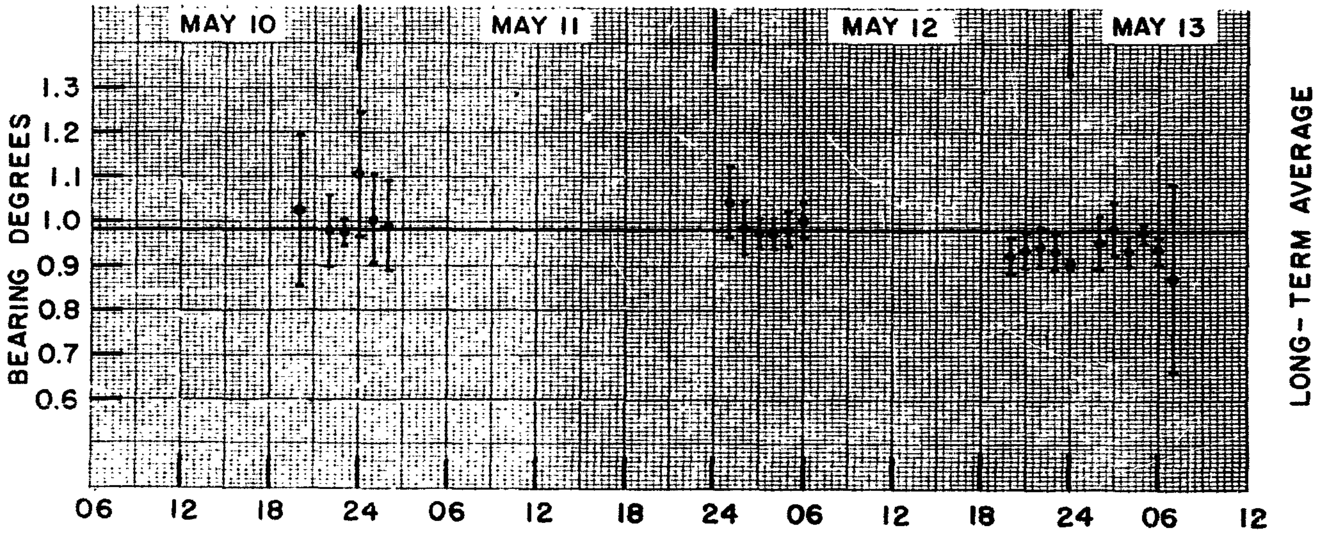
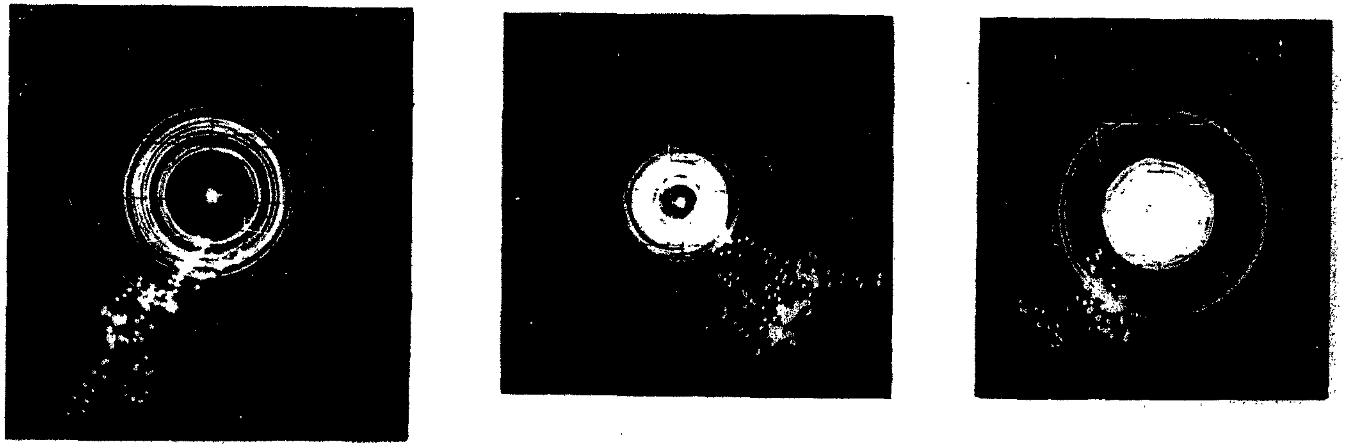


FIG. 5 TYPICAL PHOTOGRAPH OF CRT PRESENTATION



LOCAL TIME

FIG. 6 HOURLY AVERAGES OF BEARING ESTIMATES BRACKETED BY STANDARD DEVIATIONS OF 2 MINUTE AVERAGES FOR THE OVER-WATER PATHS



(a) 9 FEET (b) 18 FEET (c) 40 FEET

FIG. 7 TYPICAL DISPLAY FOR 3 ANTENNA SEPARATIONS

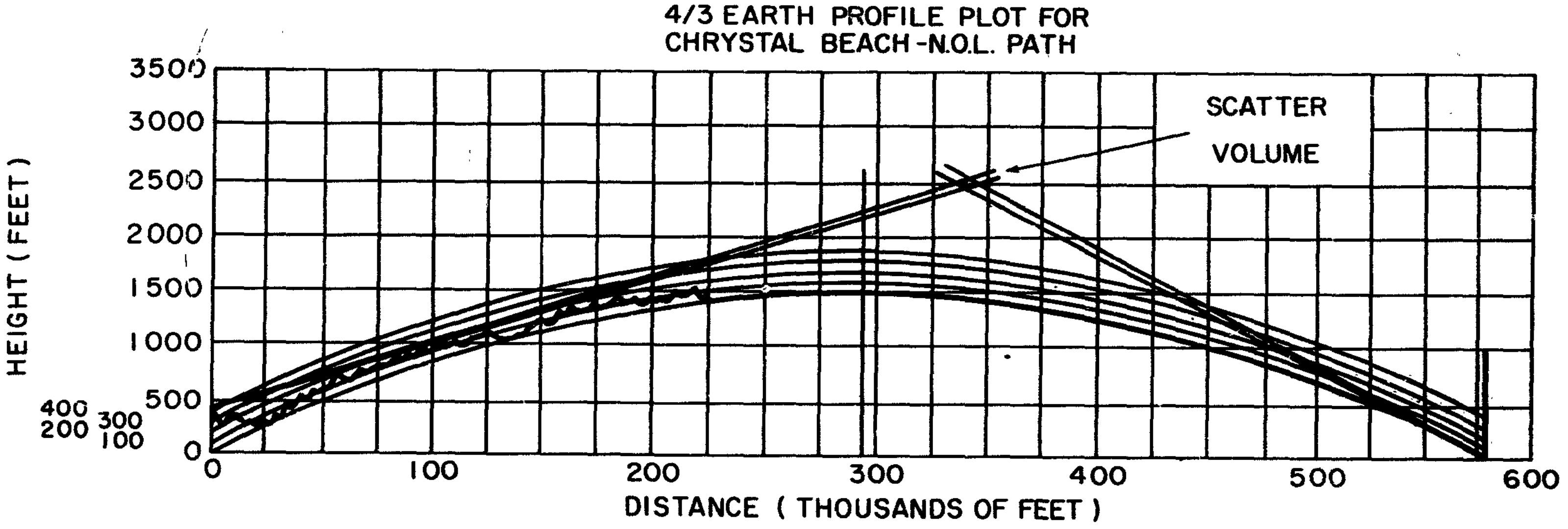


FIG. 8 110-MILE PATH PROFILE FOR ONANCOCK (CHRYSTAL BEACH) -N.O.L. EXPERIMENT (1/3 OVER-LAND; 2/3 OVER-WATER)

Naval Ordnance Laboratory, White Oak, Md.
(NOL technical report 61-76)
RADIO DIRECTION FINDING OVER A TROPOSCATTER PATH. PART I: GENERAL DESCRIPTION (U), by R.S. Hebbert and E.H. Hug. 1 Aug. 1961. 11p. charts, diagrs. Task 3E001. UNCLASSIFIED

Measurements of fluctuations (from the great circle path to a transmitter) in the bearing estimates of a microwave interferometer were made at 910 mcs with the transmitter located beyond the horizon. This report presents a general description of the apparatus and some experimental results. The standard deviations of the bearing estimates were typically of the order of 1/10 degree for averaging times longer than 10 seconds, larger fluctuations being observed on over-land than over-water paths due to asymmetries in the cross-path geometry coupled with humidity differences.

Abstract card is unclassified

1. Interferometers, Microwave
I. Title
II. Hebbert, Ralph S.
III. Hug, Edward H., jt. author
IV. Project

Naval Ordnance Laboratory, White Oak, Md.
(NOL technical report 61-76)
RADIO DIRECTION FINDING OVER A TROPOSCATTER PATH. PART I: GENERAL DESCRIPTION (U), by R.S. Hebbert and E.H. Hug. 1 Aug. 1961. 11p. charts, diagrs. Task 3E001. UNCLASSIFIED

Measurements of fluctuations (from the great circle path to a transmitter) in the bearing estimates of a microwave interferometer were made at 910 mcs with the transmitter located beyond the horizon. This report presents a general description of the apparatus and some experimental results. The standard deviations of the bearing estimates were typically of the order of 1/10 degree for averaging times longer than 10 seconds, larger fluctuations being observed on over-land than over-water paths due to asymmetries in the cross-path geometry coupled with humidity differences.

Abstract card is unclassified

1. Interferometers, Microwave
I. Title
II. Hebbert, Ralph S.
III. Hug, Edward H., jt. author
IV. Project

Naval Ordnance Laboratory, White Oak, Md.
(NOL technical report 61-76)
RADIO DIRECTION FINDING OVER A TROPOSCATTER PATH. PART I: GENERAL DESCRIPTION (U), by R.S. Hebbert and E.H. Hug. 1 Aug. 1961. 11p. charts, diagrs. Task 3E001. UNCLASSIFIED

Measurements of fluctuations (from the great circle path to a transmitter) in the bearing estimates of a microwave interferometer were made at 910 mcs with the transmitter located beyond the horizon. This report presents a general description of the apparatus and some experimental results. The standard deviations of the bearing estimates were typically of the order of 1/10 degree for averaging times longer than 10 seconds, larger fluctuations being observed on over-land than over-water paths due to asymmetries in the cross-path geometry coupled with humidity differences.

Abstract card is unclassified

1. Interferometers, Microwave
I. Title
II. Hebbert, Ralph S.
III. Hug, Edward H., jt. author
IV. Project

Naval Ordnance Laboratory, White Oak, Md.
(NOL technical report 61-76)
RADIO DIRECTION FINDING OVER A TROPOSCATTER PATH. PART I: GENERAL DESCRIPTION (U), by R.S. Hebbert and E.H. Hug. 1 Aug. 1961. 11p. charts, diagrs. Task 3E001. UNCLASSIFIED

Measurements of fluctuations (from the great circle path to a transmitter) in the bearing estimates of a microwave interferometer were made at 910 mcs with the transmitter located beyond the horizon. This report presents a general description of the apparatus and some experimental results. The standard deviations of the bearing estimates were typically of the order of 1/10 degree for averaging times longer than 10 seconds, larger fluctuations being observed on over-land than over-water paths due to asymmetries in the cross-path geometry coupled with humidity differences.

Abstract card is unclassified

1. Interferometers, Microwave
I. Title
II. Hebbert, Ralph S.
III. Hug, Edward H., jt. author
IV. Project

DISTRIBUTION

	Copies
Chief, Bureau of Naval Weapons Attn: Library, DIS 3 Washington 25, D. C.	2
Naval Research Laboratory Chesapeake Bay Annex Randle Cliff, Maryland Attn: Mr. Bramlett	
International Telephone and Telegraph Corporation 500 Washington Avenue Nutley 10, New Jersey Attn: Mr. F. Altman	
Stanford Electronics Laboratory Stanford University Stanford, California Attn: A. T. Waterman	
Armed Services Technical Information Agency Arlington Hall Arlington, Virginia	10