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THE EFFECT OF SOURCE SPEED ON THE TIME SCALE OF ACOUSTIC FLUCTUATIONS

BY DR. I. J. ROSENBAUM

ORDNANCE SYSTEMS DEVELOPMENT DEPARTMENT

15 SEPTEMBER 1976

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The time scale of acoustic fluctuations has been found to depend on source speed for a shallow receiver-shallow sound source configuration in deep water off the coast of St. Croix, U. S. Virgin Islands. Measurements were made of a cw 135 hz source towed at 4 and 8 knots on a 5-mile tangential track through a point 7.5 miles from the receiving hydrophones. Using the correlation time, the time it takes an autocorrelogram to decay to (1/e) of its maximum value as a norm or standard, the higher source speed

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consistently gave rise to shorter correlation times. As the data integration period was increased from 5 seconds to 100 seconds, the measured correlation times increased as well, covering the range of 4 to 462 seconds for various source speed-receiver depth combinations. As a function of integration time, the difference between the correlation times at the two speeds became greater for a receiver located in the thermal layer than for a receiver beneath the layer.

PREFACE

(U) This report presents the results of a field test that attempted to measure the time scale of acoustic fluctuations. The report should be of interest to those concerned with sonar performance and sonar systems analysis for the case of moving sound sources.

(U) The results reported herein were derived with the support of Task No. WF11121711.

E. C. Whitman

E. C. WHITMAN
By direction

CONTENTS

ILLUSTRATIONS

TABLES

INTRODUCTION

1. Under the most ideal conditions, the measurement of physical quantities will display some variability. Even in the laboratory one expects differences in successive measurements of "identical" phenomena. Indeed this variation determines the precision with which a quantity may be measured. The causes of these differences fall into three basic categories: (1) variations in the physical quantity itself, (2) variations in the measurement system, and (3) variations in the physical environment. There is usually no way a priori to determine which of these factors will be the dominant contributor to the experimental scatter.

2. Once the confines of the laboratory environment are left behind, the major contributor to experimental scatter is often the variability of the physical environment. The measurement of the fluctuations in an acoustic signal transmitted through the ocean is a case in point. Depending on the time scale of the measurements, a variation of 10 or 20 dB is not uncommon. In fact, the lack of fluctuation in a received signal is usually interpreted as an indication that something went wrong with the measurement. The causes of the variability are many. Included in a list of causes would be: the internal tides and waves in the sea and their effect on the temperature structure of the medium, the time variant acoustic scattering properties of the sea surface, and variations in receiver-source geometry.

3. The fluctuations are characterized by both amplitude and temporal distributions. Over short periods of time the motions of the sea surface could be a dominant contributor to the variability whereas the diurnal changes in the temperature structure of the medium often account for long term fluctuations. An experiment is detailed below which attempts to sort out one of the causes of fluctuations from the rest, in a case which is of considerable interest for sonar applications, i.e., the case of relative source-receiver motion.

EXPERIMENT

4. Acoustic energy is often simultaneously transmitted over a large number of paths between source and receiver. The existence of these various paths has been proposed to be one of the prime sources for signal fluctuations in the ocean.[1] In the case of single frequency transmission, the contributions from the various multipaths will interfere with each other both constructively and destructively, producing a fluctuating signal. One can attempt to control the rate at which multipaths interfere with each other by controlling the geometry under which the sound is transmitted and received. Furthermore, one might hope to control the rate of the fluctuations produced by multipath interference by controlling the rate at which geometry is changed, i.e., by changing relative source-receiver velocity.

5. The experimental arrangement used to demonstrate this effect is shown in Figure (1). Sound travelling over the paths marked B and SB will produce interference effects which cause signal fluctuations. (Only two of the many paths are depicted.) If there is no source motion, the signal will fluctuate at a rate which is characterstic of the rate at which the two acoustic path lengths vary with time. For the case of source motion, an additional fluctuation due to the rate of change of source-receiver geometry will be present. The purpose of the experiment was to see if this change in fluctuation rate is a measurable quantity as a function of source speed.

6. The test was conducted off the coast of St. Croix, in the U. S. Virgin Islands. The Navy barge YSN1126 was brought to its deep mooring site at 17°52'7"N and 64°41'1"W for the duration of the test. Three hydrophones were deployed from the barge at depths of 50 feet, 100 feet, and 475 feet. The data from the 100 foot phone is not included in the report due to its similarity with the 50 foot phone. The sound source, in a streamlined body, was towed by the research vessel PAUL LANGEVIN III on an east to west path through the test datum 7.5 miles due north of the barge. The first of two runs was made at 4 knots with the sound source at 500 foot depth. A DECCA navigation system was used to return the towing vessel to the identical path for a second pass at 8 knots. The sound source emitted a CW signal at 135 Hz. The source driving power was monitored and maintained constant aboard the towing vessel. Sea state 3 conditions held for the duration of the test.

7. A sound velocity profile is given in Figure (2). The layer depth was 360 feet. A ray plot diagram for this profile is shown in Figure (3). The ray bundle shown leaves the source between the horizontal ray and 5° above the horizontal at increments of .2°. The region occupied by the hydrophones in ray space is shaded in. The range interval for the test was from 7.5 to 7.9 miles. Little if any direct energy reaches the hydrophones in this shallow source-shallow receiver configuration. Most of the sound will arrive via bottom bounce paths or through scattering mechanisms.

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[1] R. J. Urick, "A Statistical Model for the Fluctuation of Sound Transmission in the Sea," NSWC/WOL/TR 75-18, 1975.

8. In Figure (4) is seen the ray paths which would have existed had the bottom been absolutely flat. The rays shown are between $\pm 30°$ at 2° increments. The bottom bounce mode is the major contributor in this idealized case.

9. The bottom profile was measured along two orthogonal paths through the test datum, and is shown in Figure (5). A north-south track ten miles long and an east-west track five miles long were surveyed. Though the fathometer had an 8 kHz transducer while the test frequency was 135 Hz, it is not unreasonable to assume that the bottom appeared flat at the test frequency as well.

RESULTS AND DISCUSSION

10. The data were converted from analog to digital format and analyzed with a fast Fourier transform spectrum analyzer having 1 Hz resolution. In Figure (6) are displayed 5 second averages for the 4 and 8 knot runs received at the 50 foot hydrophone for 1 Hz window at 135 Hz. In Figure (7) similar data are shown for the 475 foot receiver. The power averages are shown on a relative scale. A cursory review of these figures does not reveal any significant trends with speed or depth.

11. An analysis of these data in the time domain is somewhat more revealing. A convenient way to characterize the fluctuation rate is with the autocorrelation function. The autocorrelation function $c(\ell)$ for a discrete set of data values a_j is defined as

$$c(\ell) = \frac{1}{(N-\ell)} \sum_{j=1}^{n-\ell} a_j a_{j+\ell}$$

12. The correlation time is a convenient measure of the degree of correlation. It is defined as that time which the correlogram takes to fall to (1/e) of its maximum value at $\ell=0$. For the normalized autocorrelation function, this is the time it takes to fall to .368. The correlation time concept has been used by previous investigators[2] and is particularly useful in quantifying the temporal scale of signal fluctuations.

13. In Figures (8) and (9) are shown the autocorrelation function for the 4 and 8 knot runs for the 50 and 475 foot hydrophones. Only the first 5 minutes of the correlograms are shown although the calculations were made for the full 33 and 75 minute data set in each instance. Using the correlation time as a measure of the time scale of the fluctuations, we see that the 8 knot runs have a shorter correlation time than the 4 knot runs at both receiver depths, i.e., the higher speed correlogram decays more rapidly.

[2] R. J. Urick, "The Time-Scale of the Fluctuations of a Bottom Bounce Narrow-Band Signal from a Moving Source in the Sea," NSWC/WOL/TR 75-83.

14. As the data is integrated over longer periods of time, one might expect to see different trends in the time scale of the fluctuations. One would tend to associate the longer term fluctuations with the change in geometry during the runs and the shorter period fluctuations with the sea surface motion although at the low test frequency used there is probably not a large contribution from sea surface motion. In Figures (10) through (17) autocorrelograms are displayed for data integration periods of 25 to 100 seconds in steps of 25 seconds. In every one of these cases the higher speed runs have correlograms which decay to (1/e) more rapidly than the lower speed runs. So despite two diverse causes of fluctuations, the trend for longer correlation times at lower speeds remains.

15. In Table I are listed the correlation times for all integration periods at both speeds and both receiver depths. For each set of data we see an increase of correlation time with increase of integration period. Additionally, we see that the difference in correlation times between the two speeds becomes much more pronounced with increasing integration time at the shallower receiver.

CONCLUSIONS

16. The conclusions of this study may be summmarized as follows:

a. Under controlled experimental conditions, the effect which speed has upon the time scale of acoustic fluctuation is measurable using the correlation time as an indicator.

b. Higher source speed give rise to shorter correlation times for sound transmission in the bottom bounce mode.

c. For a sound source beneath a thermal layer, the effect which source speed has upon correlation time is more pronounced for receivers whithin the layer than beneath the layer as data integration time is increased.

d. Correlation time increases uniformly with data integration periods at fixed source speeds.

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17. The author wishes to thank Mr. R. J. Urick of Tracor, Inc. for his valuable advice and counsel on this project, Mr. G. M. Colvin of NAVSURFWPNCEN and the personnel of Tracor Marine who operate the NAVAIR facility in St. Croix for their able assistance in the data collection, and Mr. R. S. Hebbert of NAVSURFWPNCEN for his help with the data analysis.

TABLE I

CORRELATION TIME

Integration Period (sec)	Correlation Time (sec) Receiver Depth: 50 ft Source Speed		Receiver Depth: 475 ft Source Speed	
	4 kt	8 kt	4 kt	8 kt
5	7	4	11	7
25	23	22	39	19
50	190	42	56	40
75	354	57	85	58
100	462	61	91	74

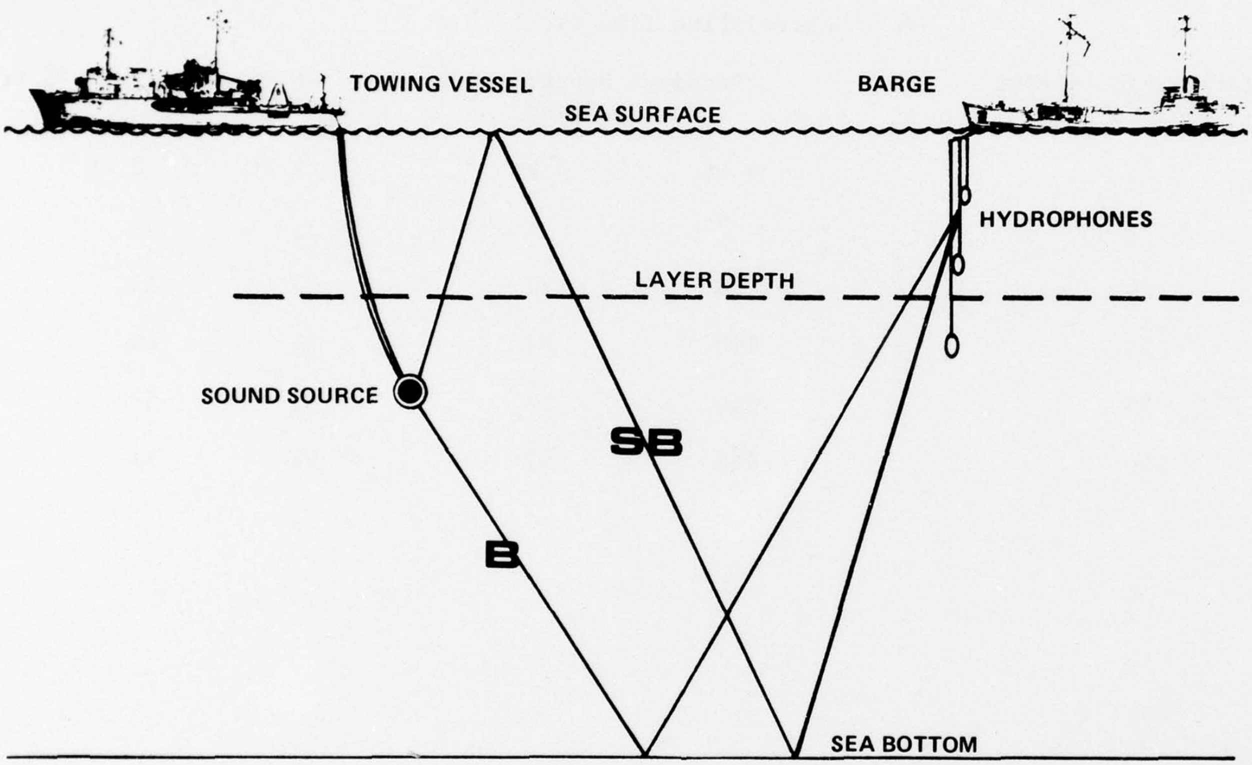


FIG. 1 EXPERIMENTAL ARRANGEMENT

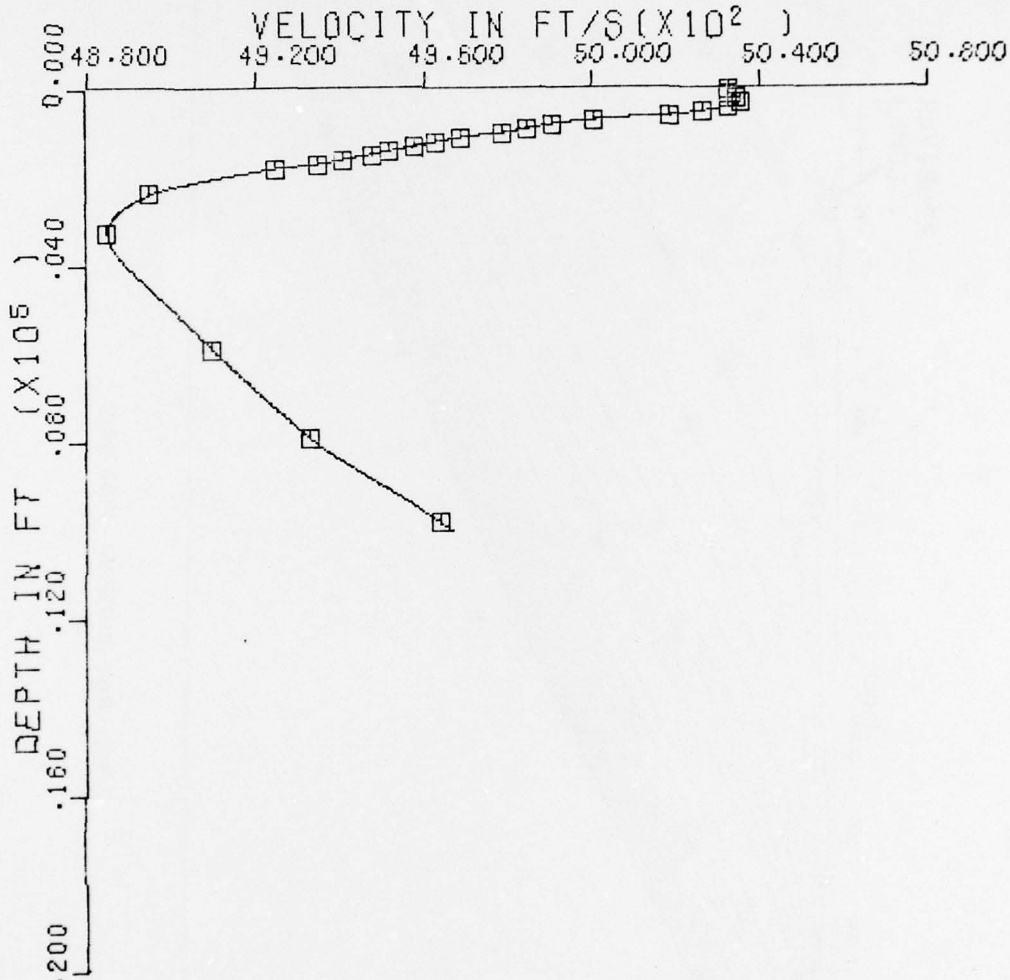


FIG. 2 SOUND VELOCITY PROFILE - St. CROIX - SPRING

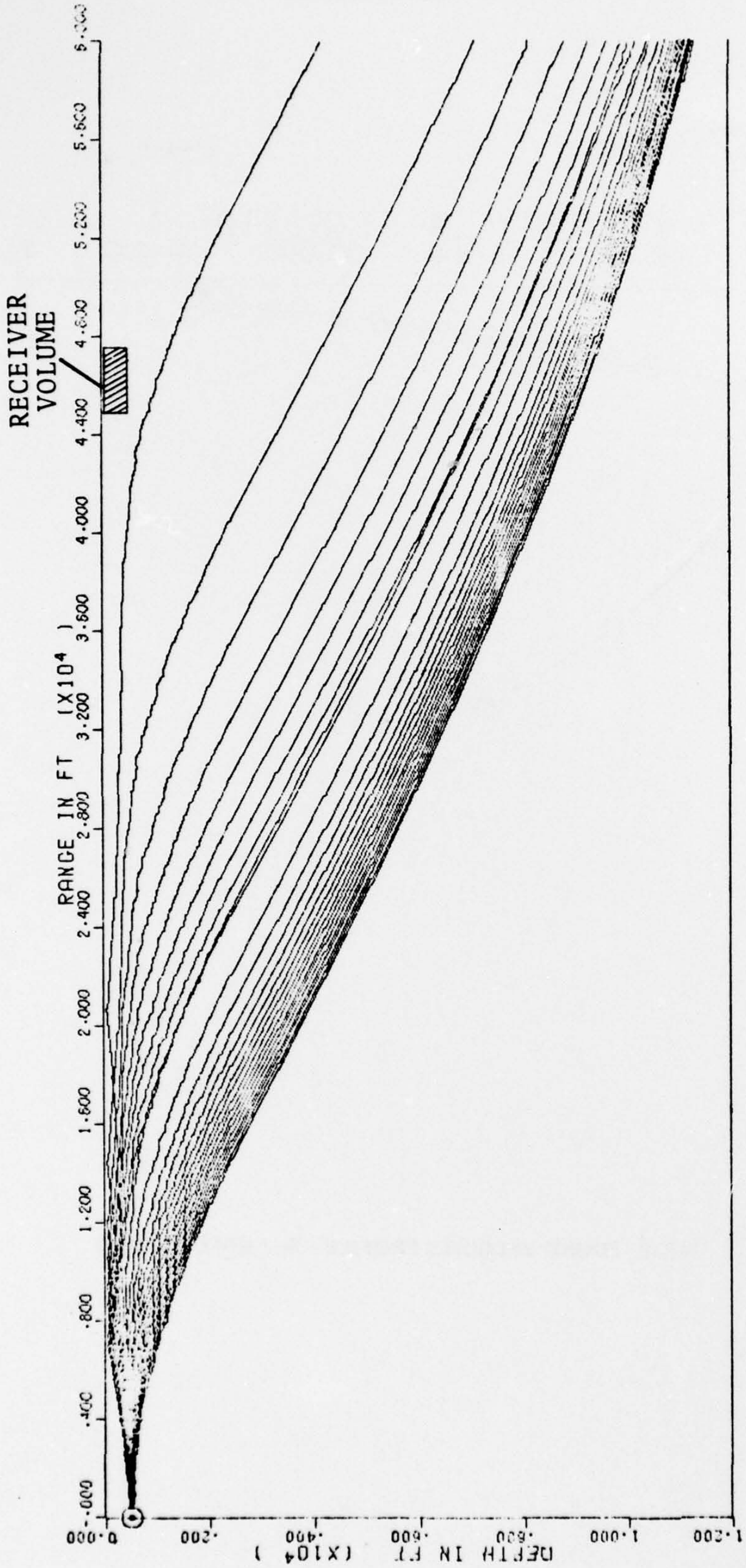


FIG. 3 RAY DIAGRAM – FINE GRID

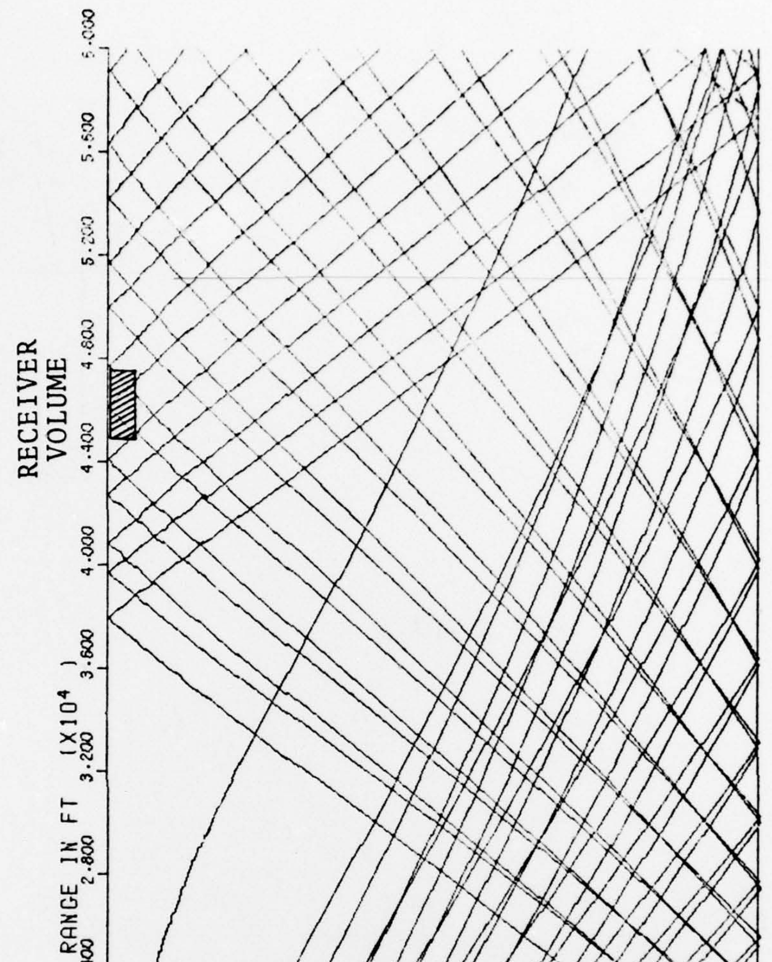
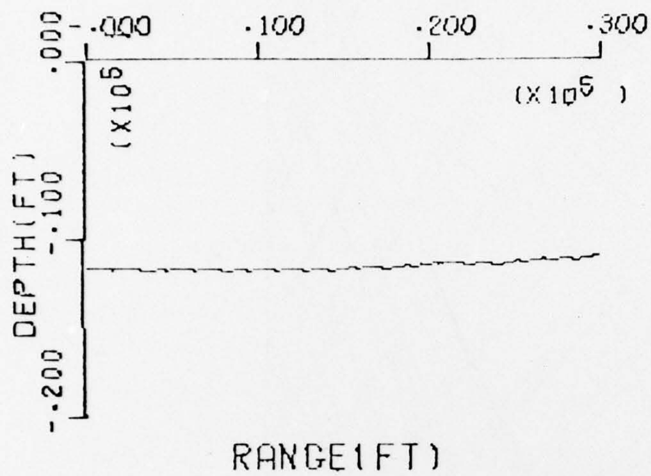
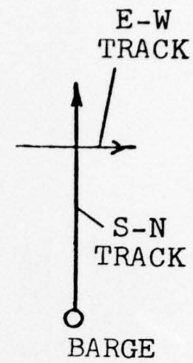
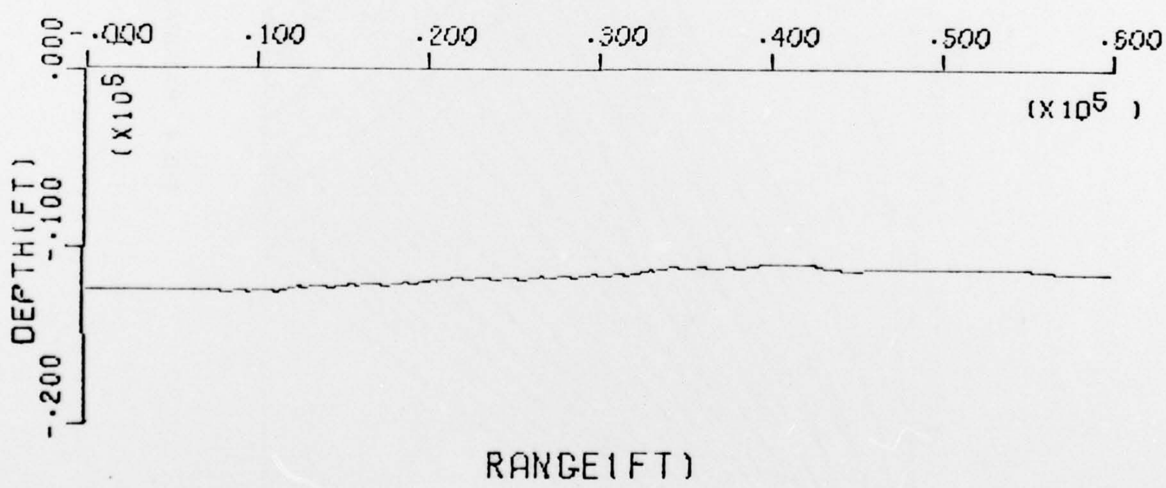


FIG. 4 RAY DIAGRAM – COARSE GRID





E - W TRACK



S - N TRACK

FIG. 5 BOTTOM PROFILES

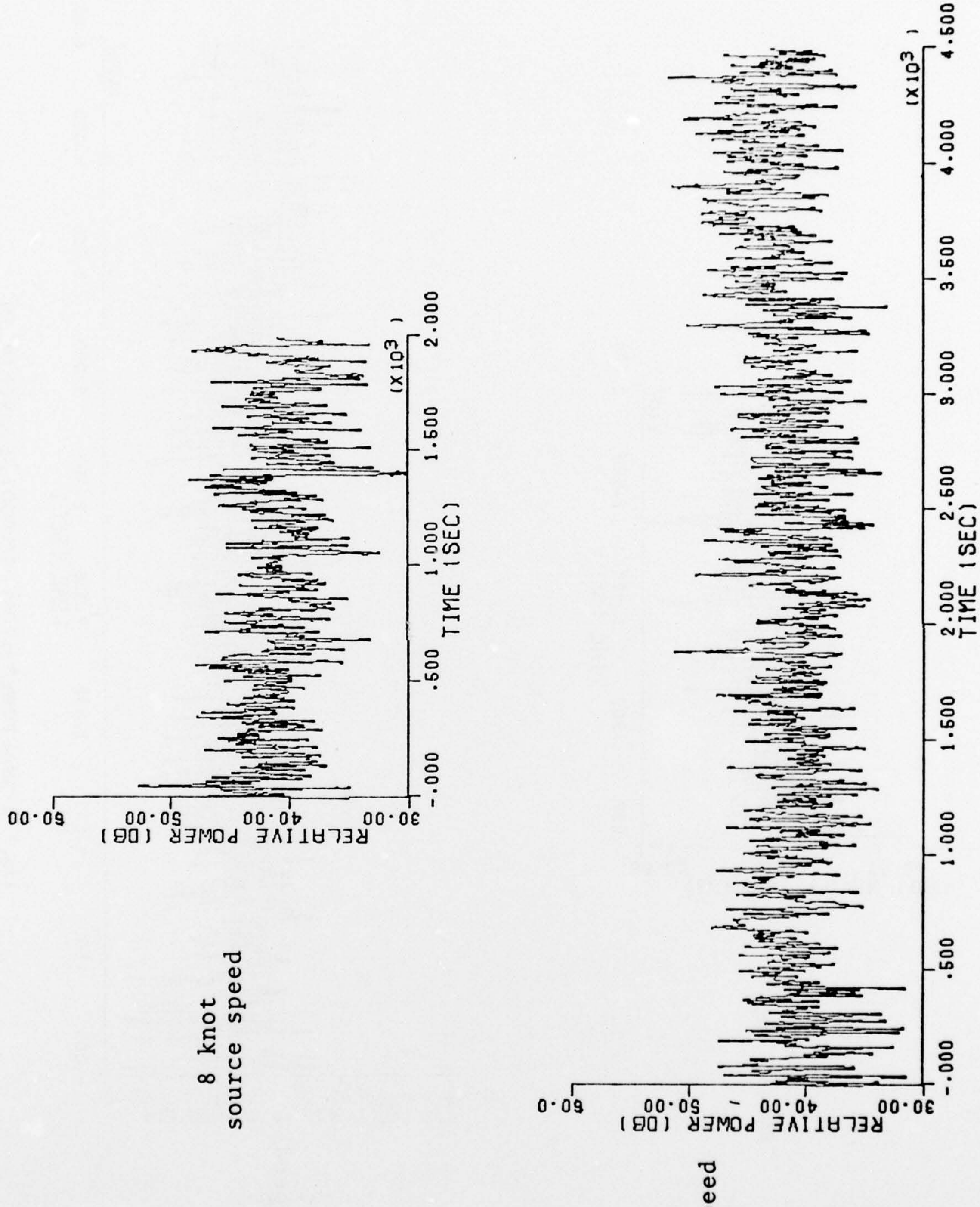


FIG. 6 SIGNAL POWER vs TIME - 50 FOOT RECEIVER DEPTH

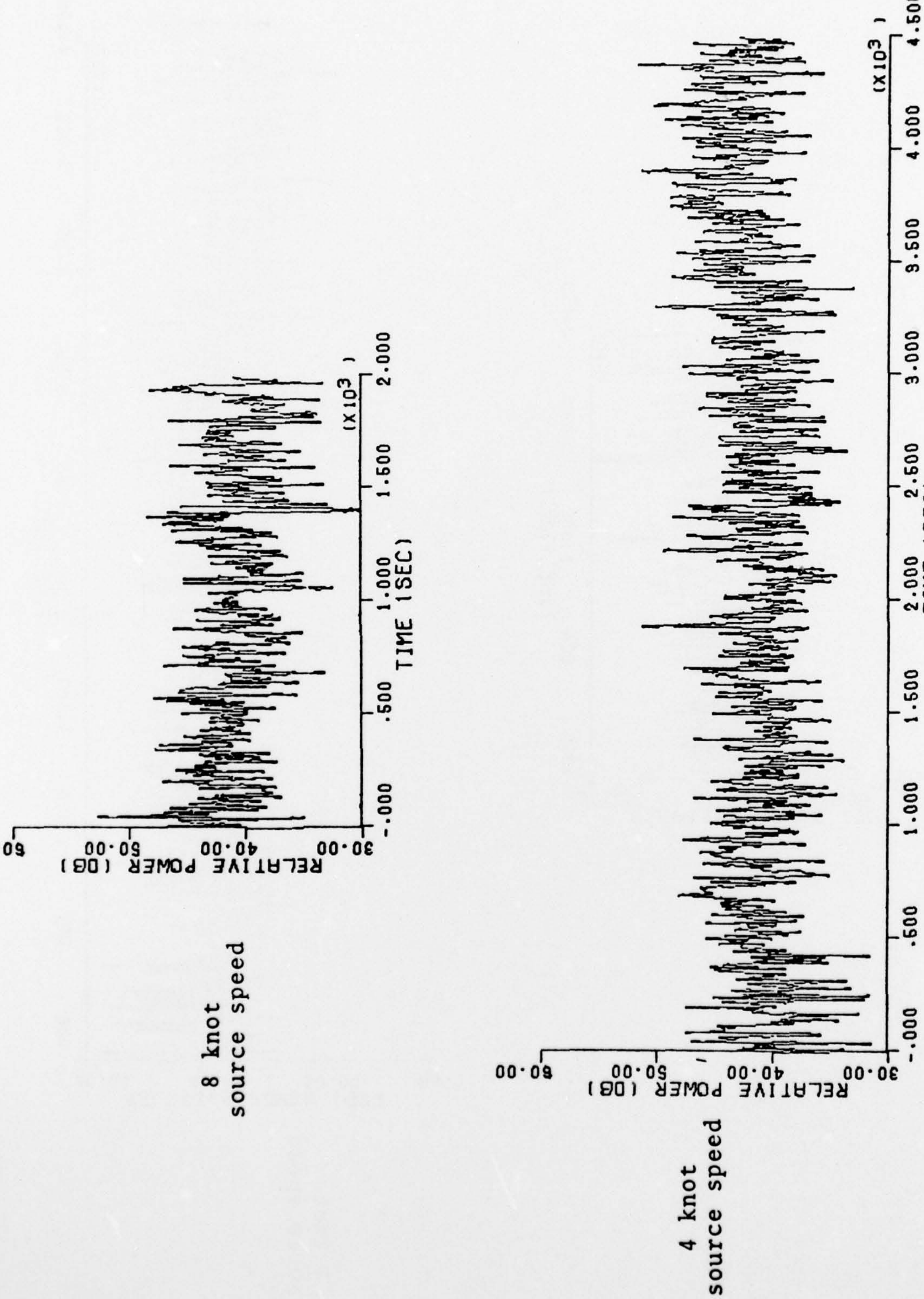


FIG. 7 SIGNAL POWER vs TIME – 475 FOOT RECEIVER DEPTH

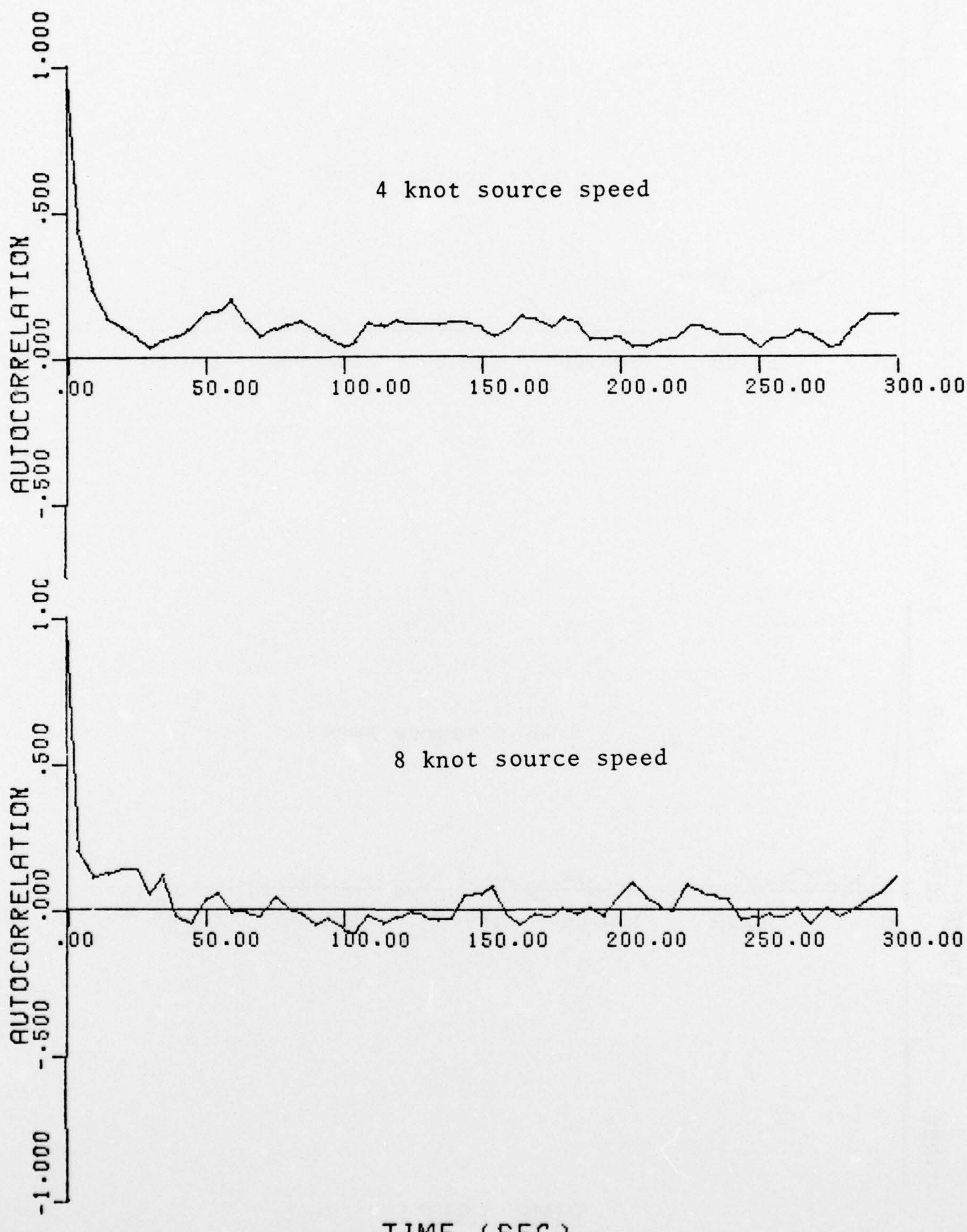


FIG. 8 AUTOCORRELOGRAM - 50 FOOT RECEIVER DEPTH 5 SECOND INTEGRATION PERIOD

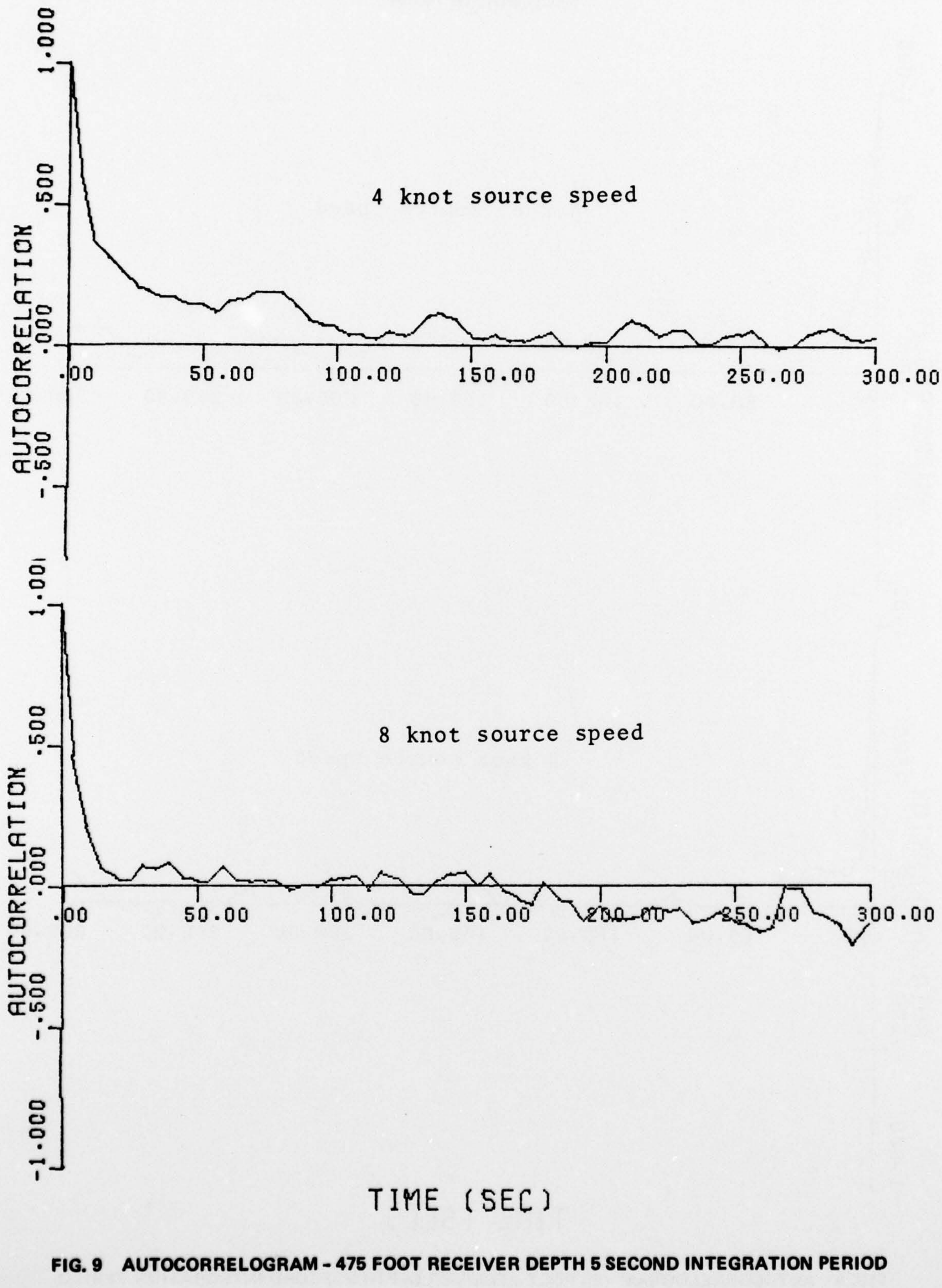


FIG. 9 AUTOCORRELOGRAM - 475 FOOT RECEIVER DEPTH 5 SECOND INTEGRATION PERIOD

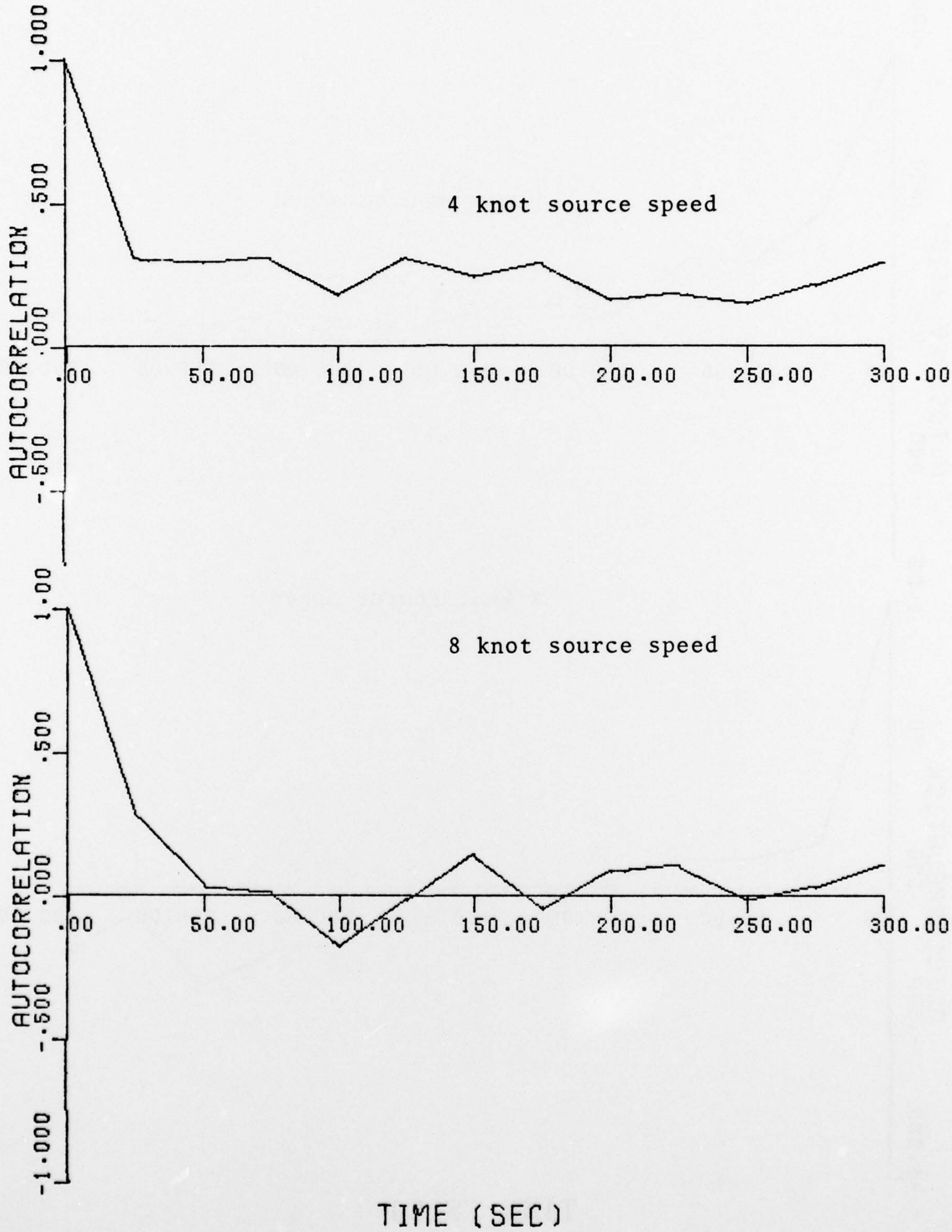


FIG. 10 AUTOCORRELOGRAM – 50 FOOT RECEIVER DEPTH 25 SECOND INTEGRATION PERIOD

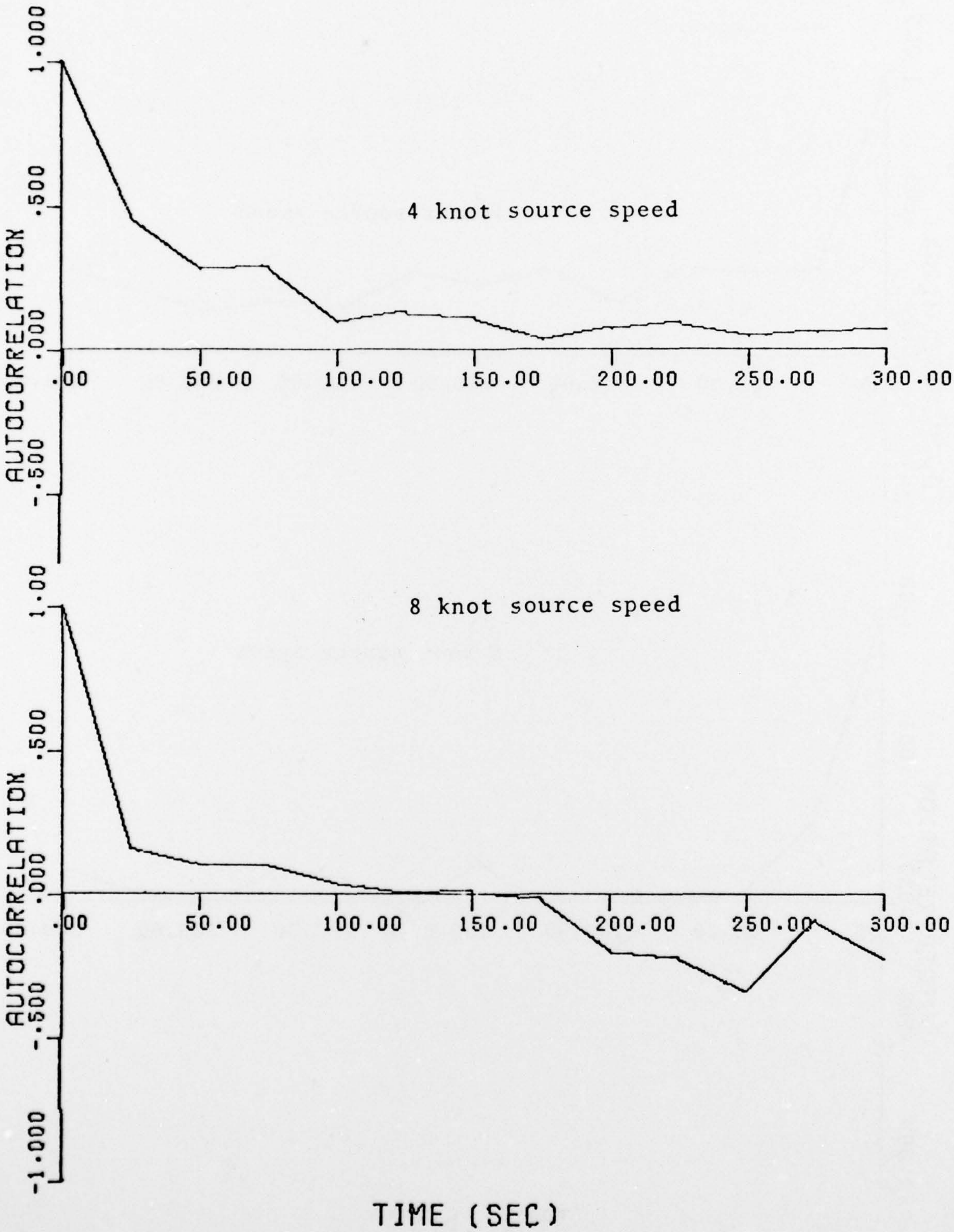


FIG. 11 AUTOCORRELOGRAM – 475 FOOT RECEIVER DEPTH 25 SECOND INTEGRATION PERIOD

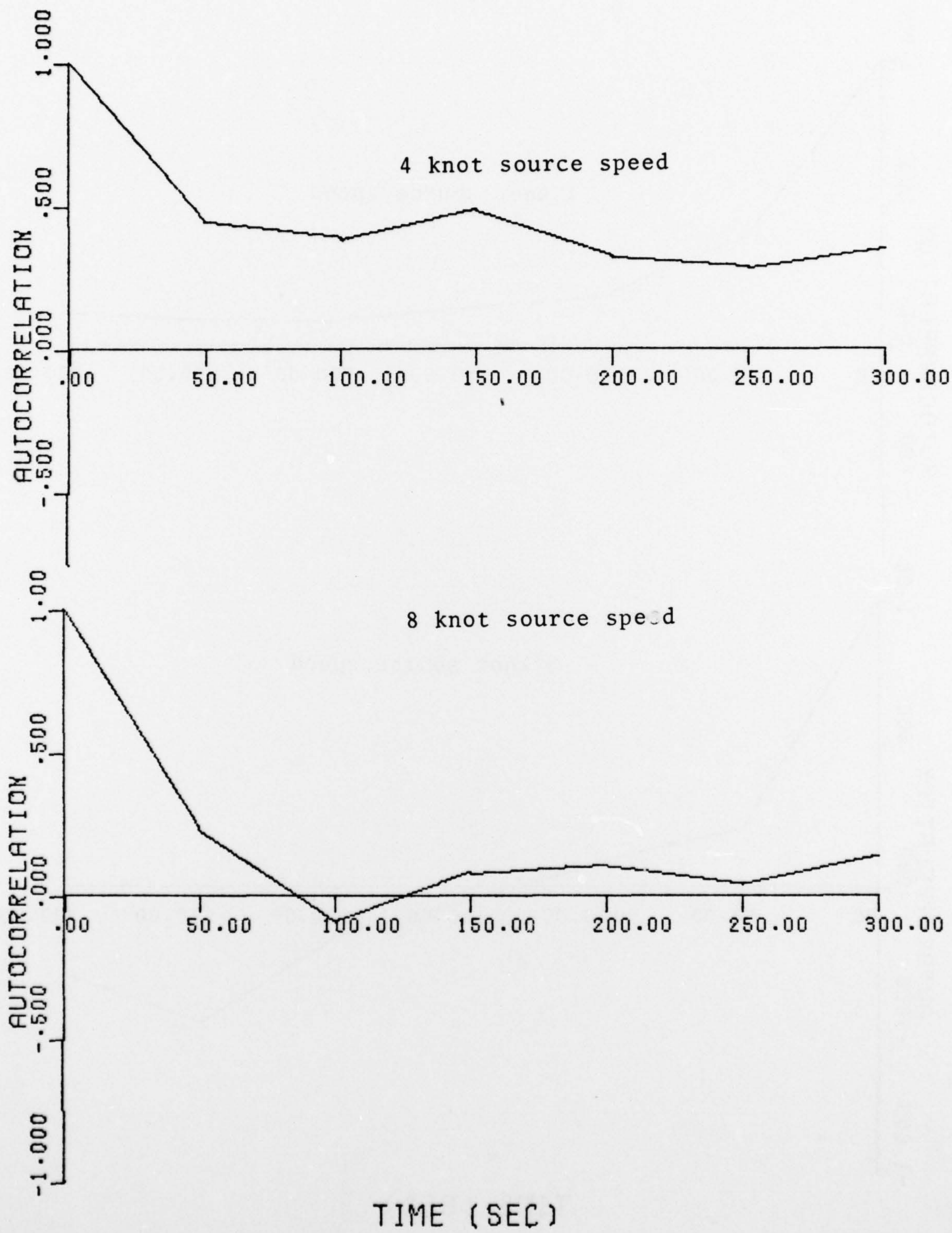


FIG. 12 AUTOCORRELOGRAM – 50 FOOT RECEIVER DEPTH 50 SECOND INTEGRATION PERIOD

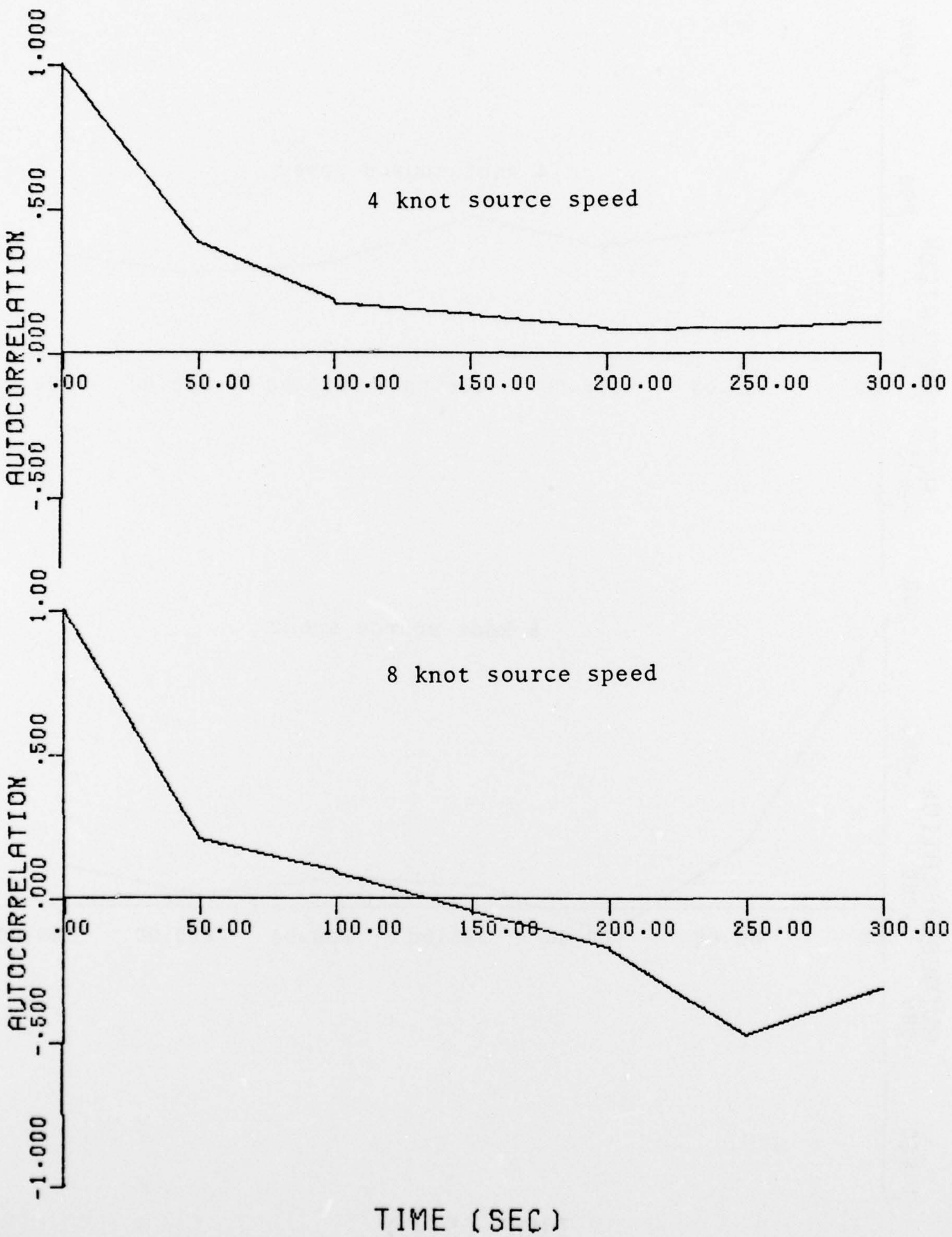


FIG. 13 AUTOCORRELOGRAM -475 FOOT RECEIVER DEPTH 50 SECOND INTEGRATION PERIOD

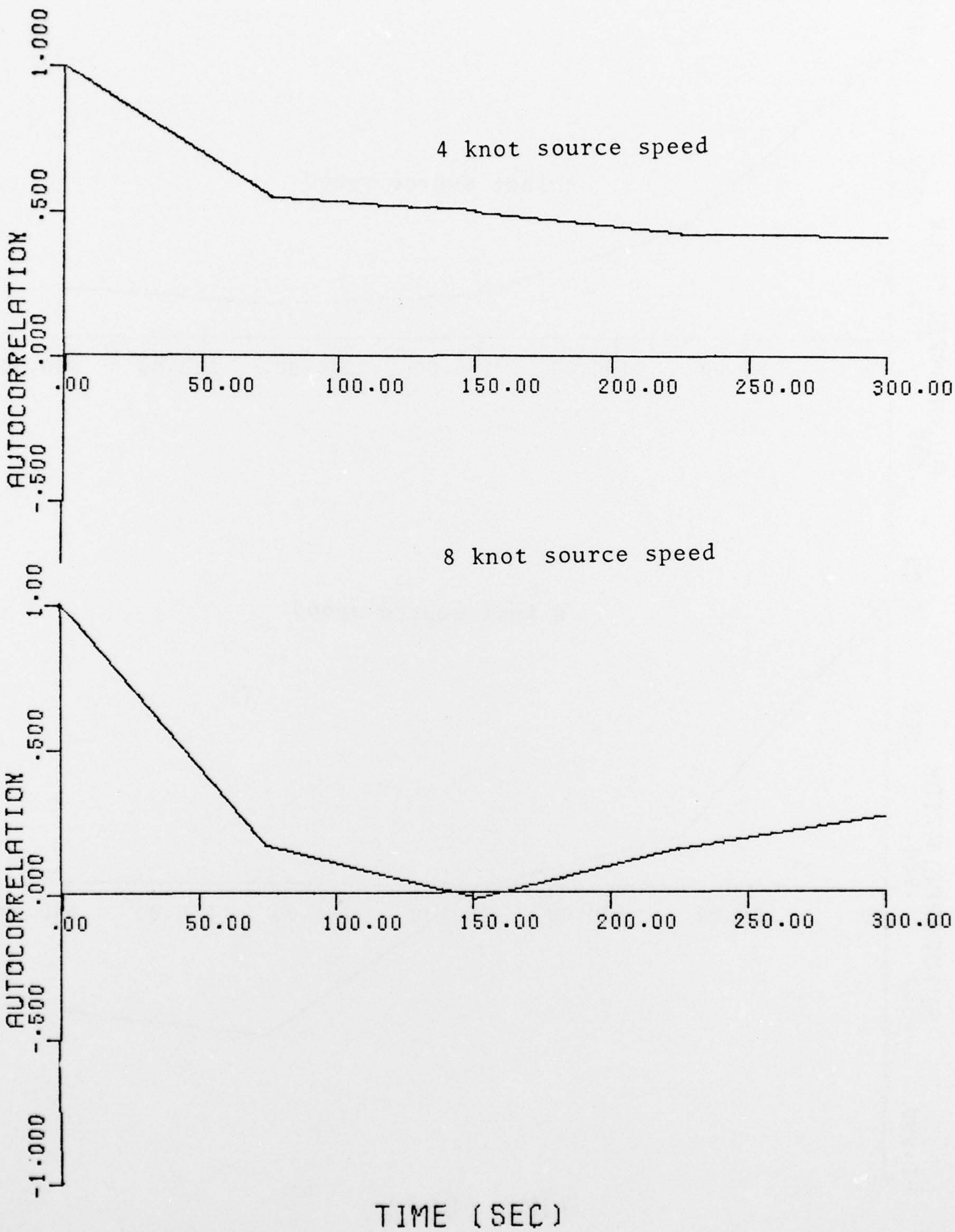


FIG. 14 AUTOCORRELOGRAM – 50 FOOT RECEIVER DEPTH 75 SECOND INTEGRATION PERIOD

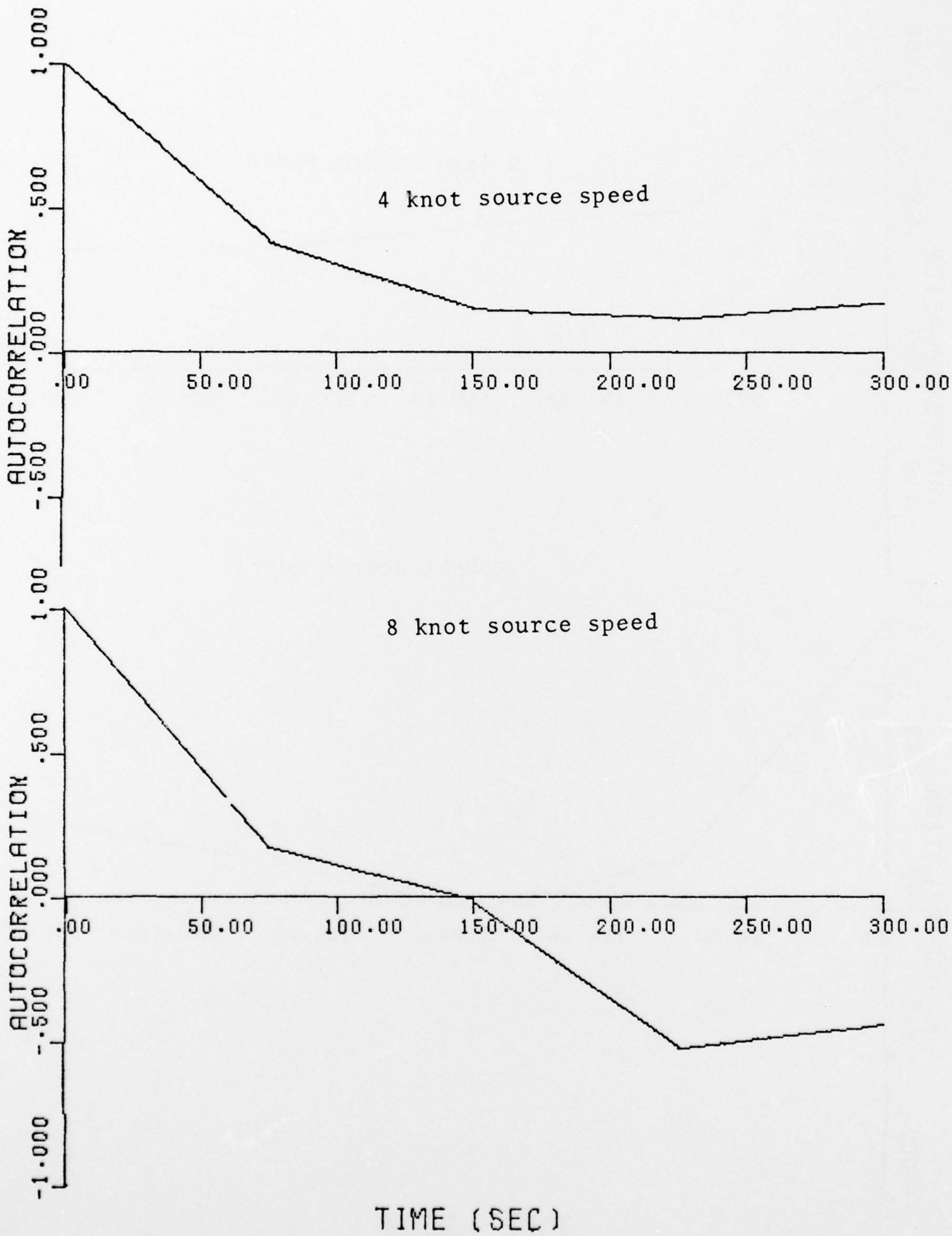


FIG. 15 AUTOCORRELOGRAM - 475 FOOT RECEIVER DEPTH 75 SECOND INTEGRATION PERIOD

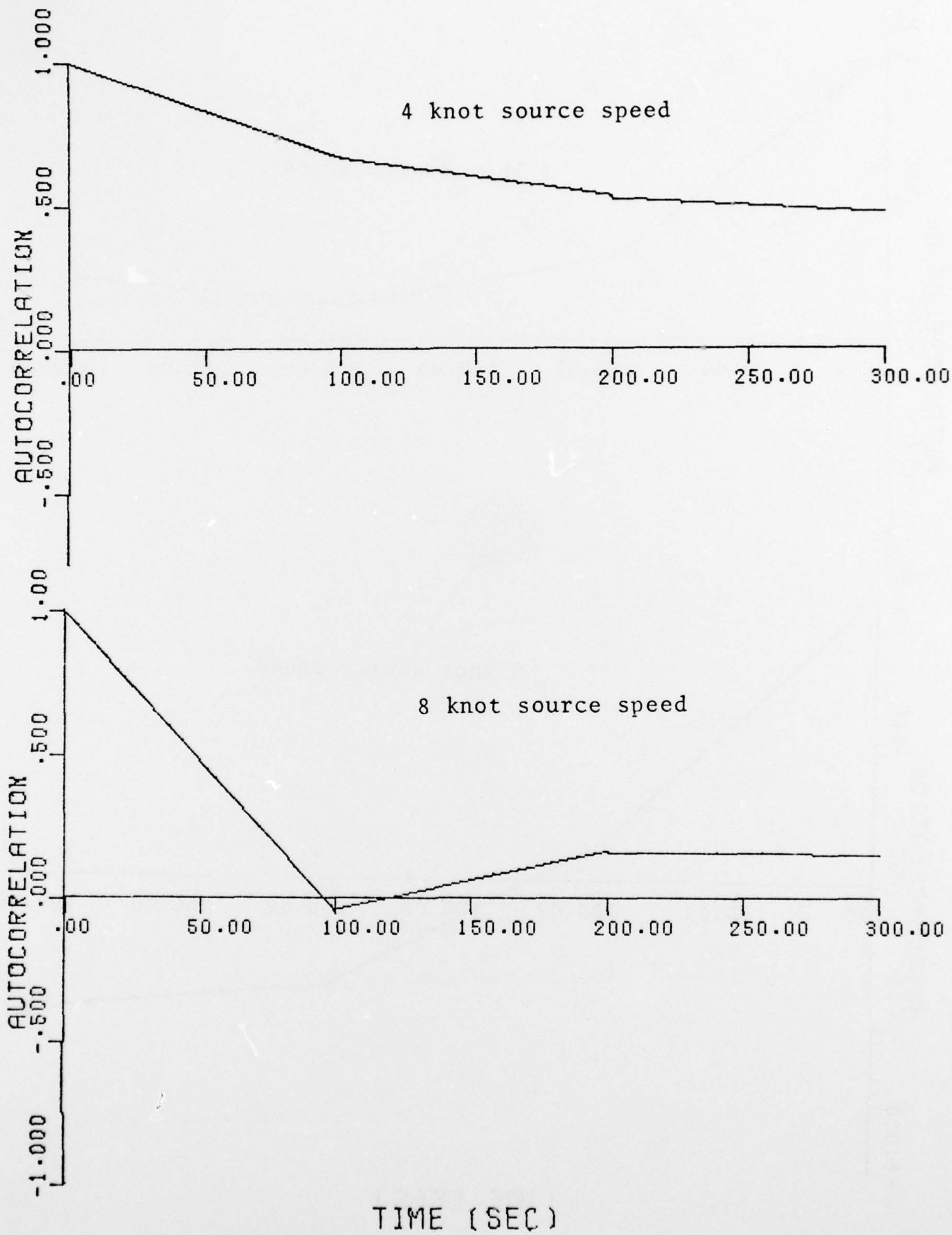


FIG. 16 AUTOCORRELOGRAM – 50 FOOT RECEIVER DEPTH 100 SECOND INTEGRATION PERIOD

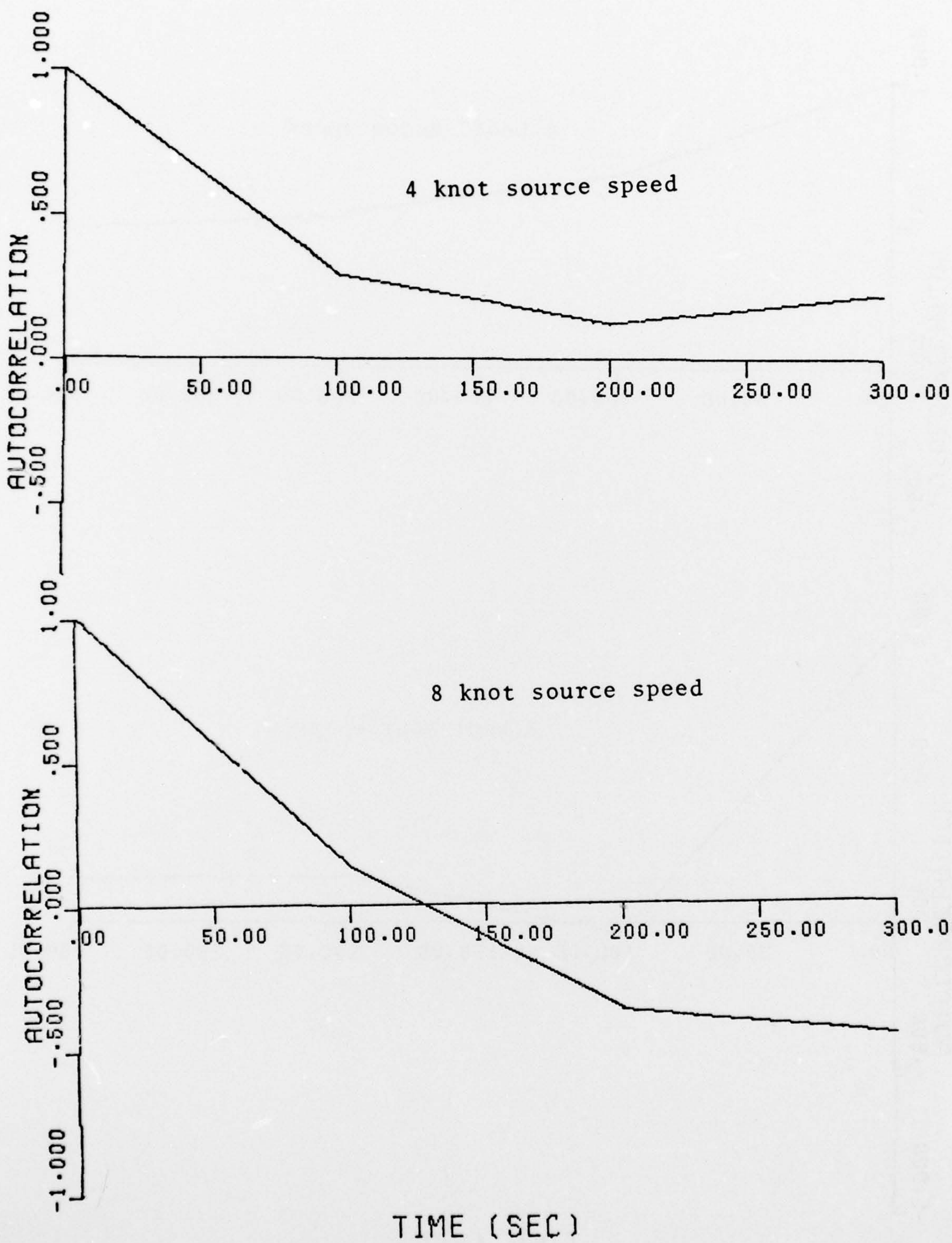


FIG. 17 AUTOCORRELOGRAM - 475 FOOT RECEIVER DEPTH 100 SECOND INTEGRATION PERIOD